CNWRA 97-009

INFORMATION AND ANALYSES TO SUPPORT SELECTION OF CRITICAL GROUPS AND REFERENCE BIOSPHERES FOR YUCCA MOUNTAIN EXPOSURE SCENARIOS

Prepared for

Nuclear Regulatory Commission
Contract NRC-02-93-005

Prepared by

Center for Nuclear Waste Regulatory Analyses
San Antonio, Texas

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ABSTRACT

The Nuclear Regulatory Commission (NRC) is conducting total system performance assessments (TSPAs) for the proposed high-level radioactive waste (HLW) repository at the Yucca Mountain (YM) site in Nevada. Because the future U.S. Environmental Protection Agency (EPA) standard applicable to HLW disposal is expected to require a dose or risk limit, this study was conducted to enhance the NRC capability to estimate radiologic risks from HLW disposal at YM. This report is prepared to: (i) providing updated dose conversion factors for use in TSPA studies of the YM site, (ii) summarize and document the site-specific characteristics and parameters used in modeling the environmental pathways, and (iii) present the results of a sensitivity analysis to identify the model parameters that have the greatest effect on the dose calculations.

Dose conversion factors are computed for two assumed receptor groups: (i) an individual of an Amargosa Valley resident farmer group located 20 km or further south from the proposed repository and (ii) an individual of a non-farmer group located less than 20 km from the repository. For each of these receptor groups, dose conversion factors are developed for two reference biospheres; present arid climate and a pluvial climate. The dose conversion factors, which are computed using the GENII-S computer code, are tabulated for use in the NRC Total-system Performance Assessment (TPA) Version 3.1 computer code.

Site characteristics and environmental parameters (such as irrigation rates, soil characteristics, agricultural pathway, resuspension, and crop interception parameters) appropriate to the YM site are acquired through a search of various databases and the open technical literature. In addition, information is developed to provide characteristics of a pluvial biosphere (resulting from anticipated climate changes near the proposed YM site). The numerical values and technical bases for pathway parameters are documented in detail.

A Monte Carlo-based sensitivity analysis is used to identify model parameters having the greatest impact on the dose calculations. In this sensitivity analysis, the GENII-S code was is to generate individual annual Total Effective Dose Equivalents (TEDEs) for 41 radionuclides and 43 sampled parameters based on unit groundwater concentrations. Scatter plots and multiple linear regression statistical techniques are used for the sensitivity analysis. Results confirm past findings that the crop interception fraction, food product consumption rates, and irrigation parameters are important dose parameters for many radionuclides. Influential parameter groups correspond to expected pathway behavior of specific radionuclides. Results for radionuclides that transfer more readily to plants, such as ^{99}Tc, indicate crop ingestion pathway parameters are most highly correlated with total effective dose equivalent (TEDE), and those that transfer to milk, such as ^{59}Ni, or beef (e.g., ^{79}Se, ^{129}I, ^{135}Cs, and ^{137}Cs) show predominant correlations with animal ingestion pathway parameters.

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ACRONYMS

CNWRA	Center for Nuclear Waste Regulatory Analyses
DCF	Dose Conversion Factor
DITTY	Dose In Ten Thousand Years
DCAGW	Dose Conversion Analysis for Groundwater Pathway
DCAGS	Dose Conversion Analysis for Ground Surface Pathway
DOE	U.S. Department of Energy
DWM	Division of Waste Management
EDE	Effective Dose Equivalent
EPA	U.S. Environmental Protection Agency
FDA	U.S. Food and Drug Administration
GEMS	Graphical Exposure Modeling System
GIS	Geographic Information System
HLW	High-level radioactive waste
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IPA	Iterative Performance Assessment
IUR	International Union of Radioecologists
KTU	Key Technical Uncertainty
LHS	Latin Hypercube Sampling
LLW	Low-level radioactive waste
NAS	National Academy of Sciences
NCDC	National Climatic Data Center
NMSS	Office of Nuclear Material Safety and Safeguards
NOAA	National Oceanographic and Atmospheric Administration
NRC	Nuclear Regulatory Commission
NRCS	Natural Resources Conservation Service
NTS	Nevada Test Site
NTIS	National Technical Information Service
ORNL	Oak Ridge National Laboratory
PA	Performance Assessment
PRCC	Partial rank correlation coefficient
PRESS	Predicted Error Sum of Squares
SCS	Soil Conservation Service
SNL	Sandia National Laboratories
SRC	Standardized Regression Coefficient
SUNS	Sensitivity and Uncertainty Analysis Shell
TEDE	Total effective dose equivalent
TGEMS	Test Graphical Exposure Modeling System
TPA	Total-system Performance Assessment
TSPA	Total System Performance Assessment
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WIPP	Waste Isolation Pilot Plant
YM	Yucca Mountain

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The authors would like to thank C. McKenney and N. Coleman at the NRC for their valuable assistance to this project. They would also like to thank M. Jarzemba, J. Weldy, and R. Baca for their technical reviews, B. Sagar for his programmatic review, C. Grey and A. Woods for their editorial reviews, and C. Garcia for secretarial support.

QUALITY OF DATA, ANALYSES, AND CODE DEVELOPMENT

DATA: CNWRA-generated original data contained in this report meet quality assurance requirements described in the CNWRA Quality Assurance Manual. Sources for other data should be consulted for determining the level of quality for those data.

ANALYSES AND CODES: The GENII-S computer code (Leigh et al., 1993; Napier et al., 1988) and STEPWISE (Iman et al, 1980) were used for analyses contained in this report. These computer codes are controlled under the CNWRA Software Configuration Procedures.

1 INTRODUCTION

1.1 BACKGROUND

The Energy Policy Act of 1992 (U.S. Congress, 1992) directed a National Academy of Sciences (NAS) committee to review certain aspects of the U.S. Environmental Protection Agency (EPA) standards applicable to licensing the proposed high-level radioactive waste (HLW) repository at the Yucca Mountain (YM) site in Nevada. In their recommendations to the EPA, the NAS committee proposed a risk standard that requires calculation of dose to an "average member of a maximally exposed critical group" (National Research Council, 1995). At present, the EPA has not published an environmental standard applicable to the proposed repository at YM. In order to continue the prelicensing reviews of the U.S. Department of Energy (DOE) studies of the YM site, the Nuclear Regulatory Commission (NRC) and Center for Nuclear Waste Regulatory Analyses (CNWRA) have proceeded with the expectation that total-system performance assessments (TSPAs) will require calculation of peak doses and associated risks to potentially affected individuals in receptor groups that exist in reference biospheres (i.e., environmental setting that the receptor groups reside in).

The International Commission on Radiation Protection (ICRP) (International Commission on Radiation Protection, 1977 and 1985) defines the critical group as a group of people whose location and habits represent those individuals expected to receive the highest dose, based on cautious but reasonable assumptions. Although there is no formal regulatory definition of receptor group(s) for the proposed YM site at this time, this study considers individuals assumed to represent the average members of two receptor groups:

- An Amargosa Valley resident farmer receptor group located 20 km or further south of the proposed site.

- A nonfarmer receptor group located between 5 km and 20 km south of the proposed repository.

The distance defining the two receptor groups is primarily based on considerations of depth to groundwater (i.e., pumping from depths of 100 m or less is assumed to be economically feasible for farming) at the YM site. In addition, two reference biospheres are assumed, one based on the present climatic conditions in the Amargosa Valley area and a second based on a future pluvial climate, i.e., cooler and wetter climate. These assumptions for critical groups and reference biospheres have been adopted in order to permit an initial representation of the environmental pathways and exposure scenarios that will be modeled in future TSPAs. With regards to time period of concern, it is assumed that the TSPA will estimate the doses and risks for a period following repository closure of 10,000 yrs or greater.

The primary purposes of this report are threefold: (i) provide updated pathway dose conversion factors (DCFs) (and their technical bases) for use in the NRC/CNWRA TSPA studies of the YM site, (ii) summarize and document the site-specific and generic information used in modeling the environmental pathways of the YM site, and (iii) present the results of sensitivity analysis that identify the dose model parameters that most influence the calculation of the DCFs. The work presented in this report builds on the earlier study presented in LaPlante et al. (1995) and includes additional information about lifestyle characteristics of the Amargosa Valley population, as well as refined estimates of pathway model parameters such as consumption rates, inadvertent soil ingestion, resuspension parameters, leaching parameters, and exposure times for internal and external dosimetry. In addition, more detailed and comprehensive documentation has been provided on the technical basis for parameter estimates and assumptions. Pathway model parameters with the greatest influence on the dose calculations were determined through a regression analysis of probabilistic calculations performed using the GENII-S computer code (Leigh et al., 1993; Napier et al., 1988).

1.2 DOSE MODELING FOR TOTAL-SYSTEM PERFORMANCE ASSESSMENT

As part of their performance assessment (PA) activities, the NRC and the CNWRA are currently developing the Total-system Performance Assessment (TPA) Version 3.1 computer code. This computer code simulates the performance of the engineered and natural barriers of the geologic repository, taking into account the impact of disruptive events and processes, and quantifies isolation performance in terms of peak dose and other performance exposures. The organization of the TPA Version 3.1 code is outlined in the flow chart shown in figure 1-1. As illustrated in this figure, the TPA Version 3.1 code is a combination of an executive driver, consequence modules, and utility modules (not shown). The executive driver controls the probabilistic sampling of input parameters, the flow of data between consequence modules, and the dose modules Dose Conversion Analysis for Groundwater pathway (DCAGW) and Dose Conversion Analysis for Ground Surface pathways (DCAGS). The latter two modules convert the radionuclide concentrations in groundwater, or surface soil into dose rates. Peak doses for individual and combined pathways are determined by the TPA code by scanning the computed dose histories.

For each TPA realization (i.e. probabilistic simulation), the DCAGW module calculates the individual annual total effective dose equivalent (TEDE) from the 20 radionuclide concentrations in the groundwater. This list of radionuclides was previously identified as important to this pathway (Nuclear Regulatory Commission, 1995a). The DCAGW uses two lookup tables containing DCFs for the two aforementioned receptor groups. For the non-farmer receptor group, it is assumed that the dose received by the average individual is due to consumption of 2 ℓ of water per day pumped from the contaminated groundwater, and inhalation of contaminated air. For the resident farmer receptor group, the exposure is due to consumption of contaminated groundwater, contaminated crops, animal products, as well as direct exposure and inhalation. The resident farmer is assumed to grow alfalfa for beef and milk cow feed, and vegetables, fruits, and grain for personal consumption. The output of this module is the annual TEDE for the groundwater pathway.

The DCAGS module calculates dose to humans from exposure to radionuclides in the surface soil. For each TPA realization, the DCAGS module computes the annual TEDE for 41 radionuclides. Like the DCAGW module, the DCAGS module uses lookup tables containing DCFs for the two previously defined receptor groups. The DCFs in this module take into account the same pathways as DCAGW (minus those unique to a groundwater source of contamination). Parameters for the DCF's are updated to reflect those exposure processes unique to ash blankets. The module uses the radionuclide concentrations in the soil (resulting from a postulated volcanic event) calculated by the ASHPLUME (and adjusted by the ASHREMOVE) module and appropriate DCFs for each radionuclide to obtain an estimate of the TEDE for the ground surface pathway.

The DCFs in both the DCAGS and DCAGW modules were computed using the GENII-S code. The GENII-S code was selected for these dose calculations because of its compatibility with anticipated EPA HLW disposal regulations (i.e., annual individual TEDE), applicability to a variety of scenarios

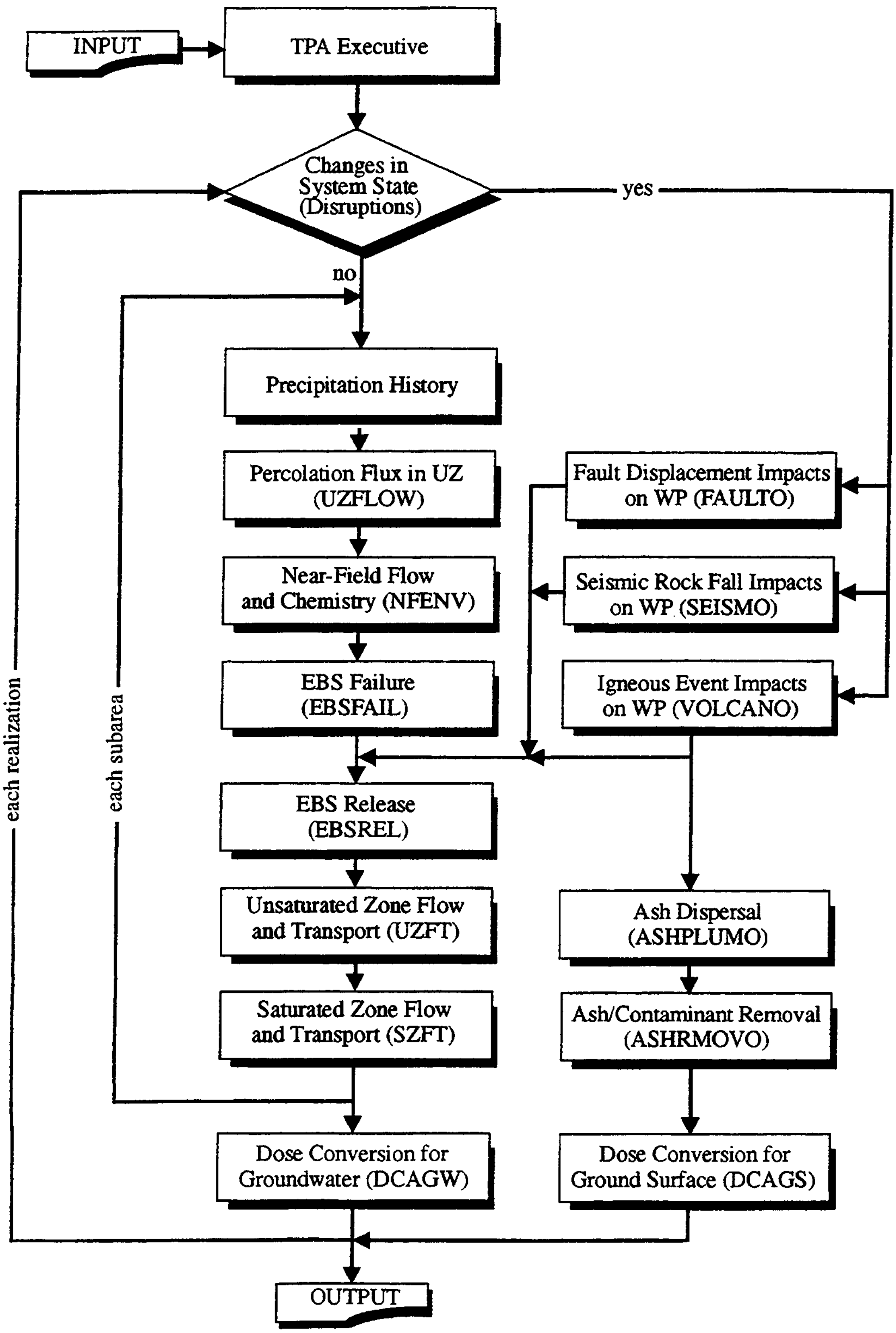

Figure 1-1. Total-system Performance Assessment Code Version 3.1 structure

relevant to HLW disposal, availability of software, extensive documentation, established reputation, and inherent capabilities for stochastic calculations using Latin Hypercube Sampling (LHS). A primary advantage of GENII-S is the capability to calculate an annual individual TEDE. Furthermore, GENII-S includes the Sensitivity and Uncertainty Analysis Shell statistical analysis software with capabilities for processing data for sampling.

The authors acknowledge that radiological assessment is a diverse and changing field that offers a variety of techniques and methodologies. An equally diverse body of opinion exists regarding which approaches are best suited for a particular use. It is noted that the NRC has not made formal decisions about which dose assessment methodologies are best suited to YM PAs. Therefore, this report contains methods that appear to have general acceptance in the field and assumptions and speculative judgments are clearly identified. In many cases, parameter distributions are estimated and the methods and rationale are documented. Methods for selecting the parameter distribution types are generally consistent with methods identified in recent dose reconstruction work at Hanford, Washington (Snyder et al., 1994). In addition, parameters where no site-specific information could be obtained are noted in the text of the report. Where information is limited, generic parameter values from current NRC sources (Nuclear Regulatory Commission, 1994; Kennedy and Strenge, 1992) are used. Use of generic parameters is not a favored approach, but is considered a reasonable compromise for these analyses.

1.3 REPORT ORGANIZATION AND CONTENT

This report is organized into four major technical sections. The first of these, section 2.0, addresses the environmental and biosphere parameters that were compiled for the YM site. Estimates for these parameters were acquired from a variety of databases and available technical literature. The technical bases and sources for these site characteristics and parameters are described in detail. In section 3.0, the multiple regression techniques that were used to assess the importance of individual model parameters to dose are described. The final importance ranking of parameters obtained by these techniques is presented for each radionuclide. In section 4.0, the DCFs computed using the GENII-S code for the two receptor groups and reference biospheres are presented. The final technical section summarizes the principal findings of this study. Appendices at the end of the report contain information on the automated literature search, tabulated values of GENII-S input parameters used in the dose calculations, selected scatterplots from the sensitivity analysis, log probability plots for each radionuclide, and tables of the revised DCFs.

2 SITE-SPECIFIC CHARACTERISTICS AND PARAMETER VALUES

2.1 INTRODUCTION

Recommendations from the Iterative Performance Assessment (IPA) Phase 2 effort stressed the importance of additional work to confirm existing site-specific data and gather more information. The initial literature search obtained information on site-specific parameters relevant to existing conditions in areas south of the proposed repository site (e.g., Amargosa Valley). Since completion of that report (LaPlante et al., 1995), more information about local conditions has become available and some parameters have been identified that need improved documentation or justification. Furthermore, because of the need to consider biosphere parameters relevant to anticipated pluvial conditions resulting from a future glacial period, collection of additional information was required. Therefore, the following sections provide an updated summary of current information that was collected to support parameter values used in the IPA dose calculations.

An iterative approach is used for defining parameters and calculating doses. Because the stochastic calculations are based on a previous iteration of parameter definitions, (LaPlante et al., 1995) the following sections describe the information base and rationales for those parameters, as well as any changes for the revised DCF calculations. The stochastic calculation results are only used for the sensitivity and uncertainty analyses.

2.2 METHODS

While there are many general similarities in dose assessment codes, specific parameter data needs for a given analysis are determined by the dose assessment code. A detailed review of available risk assessment codes is not within the scope of the present task. However, the authors are familiar with many of the available codes, and there are few off-the-shelf programs that model all the relevant exposure pathways for an arid agricultural exposure scenario involving air and water contaminated with radioactive materials. While not the ideal, the GENII-S code allows modeling of most of the applicable exposure pathways under consideration for a farming scenario in areas south of the potential repository site. Thus, it is considered by the authors of this report to be a reasonable and cost effective choice for the current IPA dose work.

Prior to conducting the initial literature search, a list of input parameters for GENII-S was reviewed to identify parameters likely to be influenced by site-specific conditions. General information categories were determined, and a list of keywords developed (see appendix A) to conduct automated searches of major scientific literature databases. These databases include: NTIS (U.S. Government Abstracts: 1964-94), INSPEC (Science Abstracts: 1970-94), EI COMPENDEX-PLUS (Engineering Index: 1970-94), ENERGY SCITECH (Energy and Science Abstracts: 1974-94), POLLUTION ABS (Pollution Abstracts: 1970-94), and AGRICOLA (Agricultural Abstracts: 1979-94). Searches were further limited to 1989-94 to restrict the number of abstracts to a manageable number of recent articles (approximately 350). Abstracts were reviewed and relevant references were obtained for further review. Following this, an additional database search was conducted on well-known authors involved in environmental research at the Nevada Test Site (NTS). This search yielded 100 additional abstracts that were also reviewed. Additional contacts were made with local and federal government offices and individual researchers to gain additional information and insight into local conditions. A visit to the region south of YM including the Amargosa Farms area of Amargosa Valley provided a first-hand look at local agricultural and residential conditions. Section 2.3 provides the results of relevant information gathered to date.

2.3 RESULTS OF LITERATURE SEARCH

2.3.1 Population

While the EPA is likely to require calculation of an individual dose for compliance demonstration in future HLW regulations, it is still important to understand the population characteristics of the region. Spatial population density information can be informative in understanding what characteristics of the local areas attract human settlements, or conversely, lead to the absence of human settlements. Therefore, population information is presented in this report as a reference, but is not used directly in the individual dose calculations discussed in section 3 and 4. A population dose was calculated in IPA Phase 2 (Nuclear Regulatory Commission, 1995a) dose analyses and parameters were determined using the reference biosphere assumption (i.e., current estimates of biosphere parameters were assumed for long-term calculations since it has problematic to predict future states and human activity).

The population information used in IPA Phase 2 (Nuclear Regulatory Commission, 1995a) was adopted from Logan et al. (1982). The original grid was updated with additional population counts for some of the major towns within the 100-km radius of the site (U.S. Department of Energy, 1988a). Logan determined the population by allocating counts of major population centers (such as the towns of Mercury, Beatty, Amargosa Farms, and Indian Springs) to the appropriate sectors of the grid. In addition, a 0.1 person/km^2 density was added to these populations to account for commuters, visitors on recreational activities, and ranchers. The population of areas between the population centers was determined by allocating average population densities to the number of acres per sector. This is a conservative estimate of the local population since it is likely that sectors exist that have no residents. Comparison of the total population in the IPA Phase 2 (Nuclear Regulatory Commission, 1995a) grid (22,421 residents) with 1990 census figures for Nye and Lincoln Counties combined (21,556 residents) (U.S. Department of Commerce, 1990) shows the conservatism of the prior estimates of population size.

To determine more precise population figures for the area around YM, a new grid was developed from 1990 census population statistics at the census block level (see figure 2-1). The values used in IPA Phase 2 analyses (Nuclear Regulatory Commission, 1995a) are shown in parentheses for comparison. An EPA Geographic Information System (GIS) population database and the information retrieval system known as Graphical Exposure Modeling System (GEMS) (Hunt et al., 1989) are used to generate the new grid. To obtain access to 1990 census data, it was necessary to use the test version of GEMS Test Graphical Exposure Modeling System (TGEMS) that is a version of GEMS in which new features are made available after they have been tested, but before all aspects are fully operational. The TGEMS code generates circular population grids by comparing grid coordinates with geographic population information to determine the number of population centroids that fall within each grid sector. A population centroid is the geographic center of a census block to which the population total is associated. TGEMS sums the population totals for each centroid within a grid sector to determine a sector population total. Thus, the TGEMS grid provides results that are geographically representative of the actual population at the census block level—the lowest level of stratification—at which the census collects population data for Nye County (U.S. Department of Commerce, 1990). When compared to the grid used in IPA Phase 2 (Nuclear Regulatory Commission, 1995a) dose assessments (22,421 residents), the total population estimate for the same area (14,441 residents) is lower in the TGEMS grid, as expected.

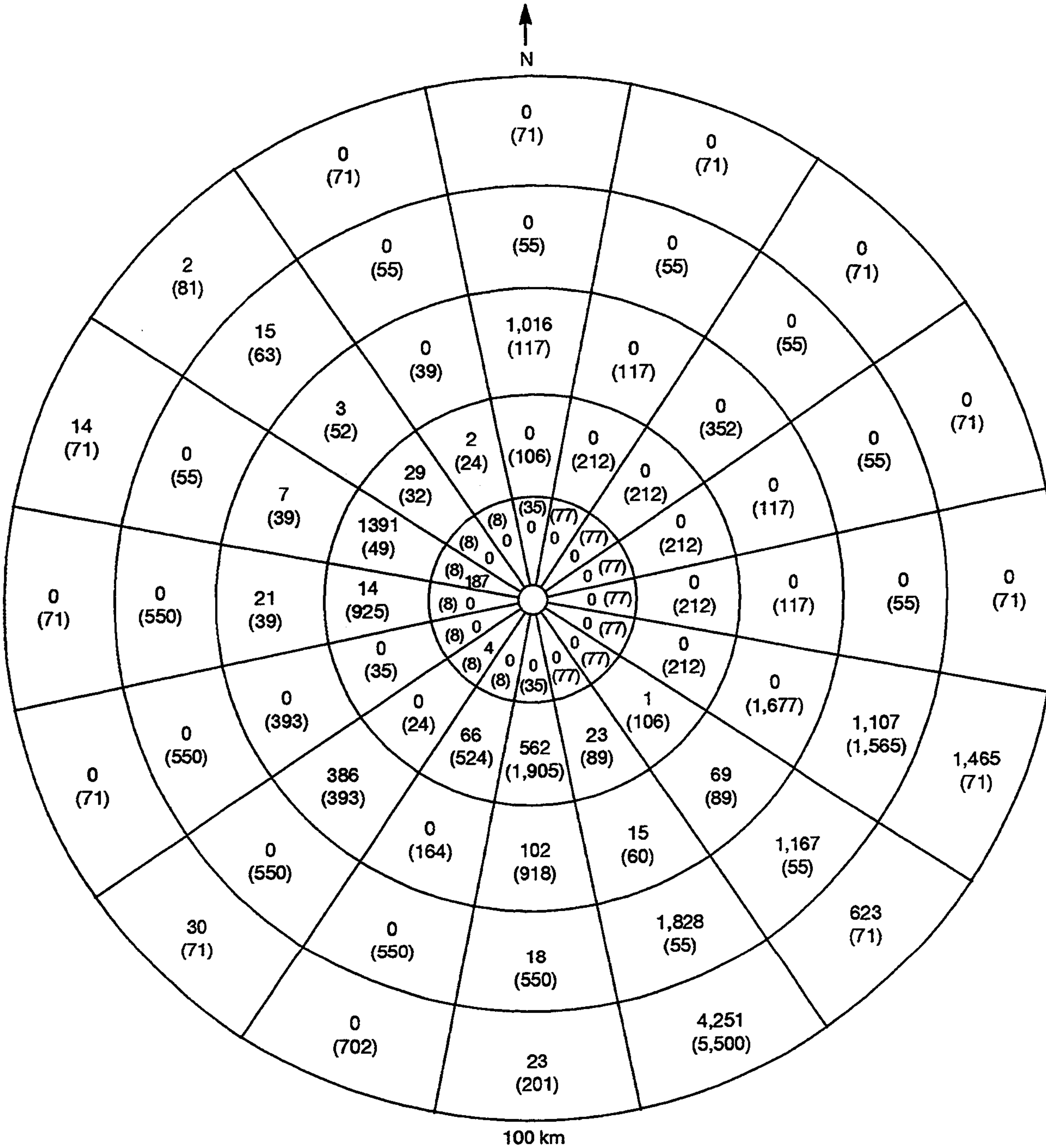

Figure 2-1. Population counts for Yucca Mountain region from 1990 census data and estimates from Iterative Performance Assessment Phase 2 dose assessment (in parentheses). The center of the map is at Yucca Mountain.

The population estimates used in IPA Phase 2 allocate population to all grid areas when in reality some areas are not populated. It is also true that the centroid-based census methods in GEMS tend to aggregate dispersed population to a central location within the block. Nonetheless, the census data are based upon actual counts for each block rather than weighted estimates and are therefore expected to be more representative of the actual geographic population distribution in 1990.

The 100-km-radius grid covers four counties in Nevada (Nye, 61-percent coverage; Clark, 0.4-percent coverage; Esmerelda, 0.01-percent coverage; and Lincoln, 2.46-percent coverage) and one county in California (Inyo, 2.52-percent coverage). The center of the grid is the YM site, which is interpreted from available maps to be at the coordinates of 36° 50′ 00" latitude and 116° 30′ 00" longitude. Areas of population concentration (i.e., cities or towns) which are included in the grid are Death Valley and Shoshone, California; and Indian Springs, Beatty, Lathrop Wells, Mercury, and Pahrump, Nevada. There are 30 census blocks included in the grid and each sector with a population value above zero contain one census block centroid. It is notable that in the southerly direction of current groundwater flow, the first populated areas are shown to occur within the 20- to 40-km band, which includes the communities of Lathrop Wells and Amargosa Valley. Figure 2-2 is a rendering from satellite data that clearly shows the potential repository site area, an anticipated groundwater transport zone, and the populated areas that, under assumed conditions of release and transport, would be expected to receive the highest groundwater-based exposures due to their close proximity to the potential repository site, relative to other populated areas which are further to the south. This information provides a reasonable basis for focusing on Amargosa Valley as a location for a potential critical group.

2.3.2 Agriculture Information

2.3.2.1 Agriculture in Southwestern Nevada

IPA Phase 2 work (Nuclear Regulatory Commission, 1995a) obtained some local information on agricultural parameters, and these sources still prove to be useful. These sources include the U.S. Census Bureau (U.S. Department of Commerce, 1989), and the Nevada Department of Agriculture in cooperation with the U.S. Department of Agriculture and the University of Nevada (Nevada Agricultural Statistics Service, 1988). Nye County is much larger than the area of interest south of YM and therefore county-level information can only provide a general understanding of regional activities. Additional detailed information on agricultural practices in local communities has been collected since the initial study, thus additional census reports (last updated 1992) are not reviewed due to their general (county) focus.

The 1987 census indicates predominant livestock in Nye County are cattle and calves, with 79 farms (58 percent of the total) reporting cattle/calf ownership, and 73 farms (53 percent of the total) raising an average of 163 head for sale per farm in 1987 (U.S. Department of Commerce, 1989). Of the total farms, 51 percent raise an average of 191 beef cows per farm, and 11 percent raise an average of 2 milk cows per farm. Hogs and pigs are grown for sale on 9 farms (6 percent of the total) with an average of 27 animals per farm sold in 1987. Chickens were raised on 22 farms (16 percent of total farms) with an average of 35 chickens per farm, but no poultry meat was sold on the open market. This may be an indication that the chickens were used for egg production.

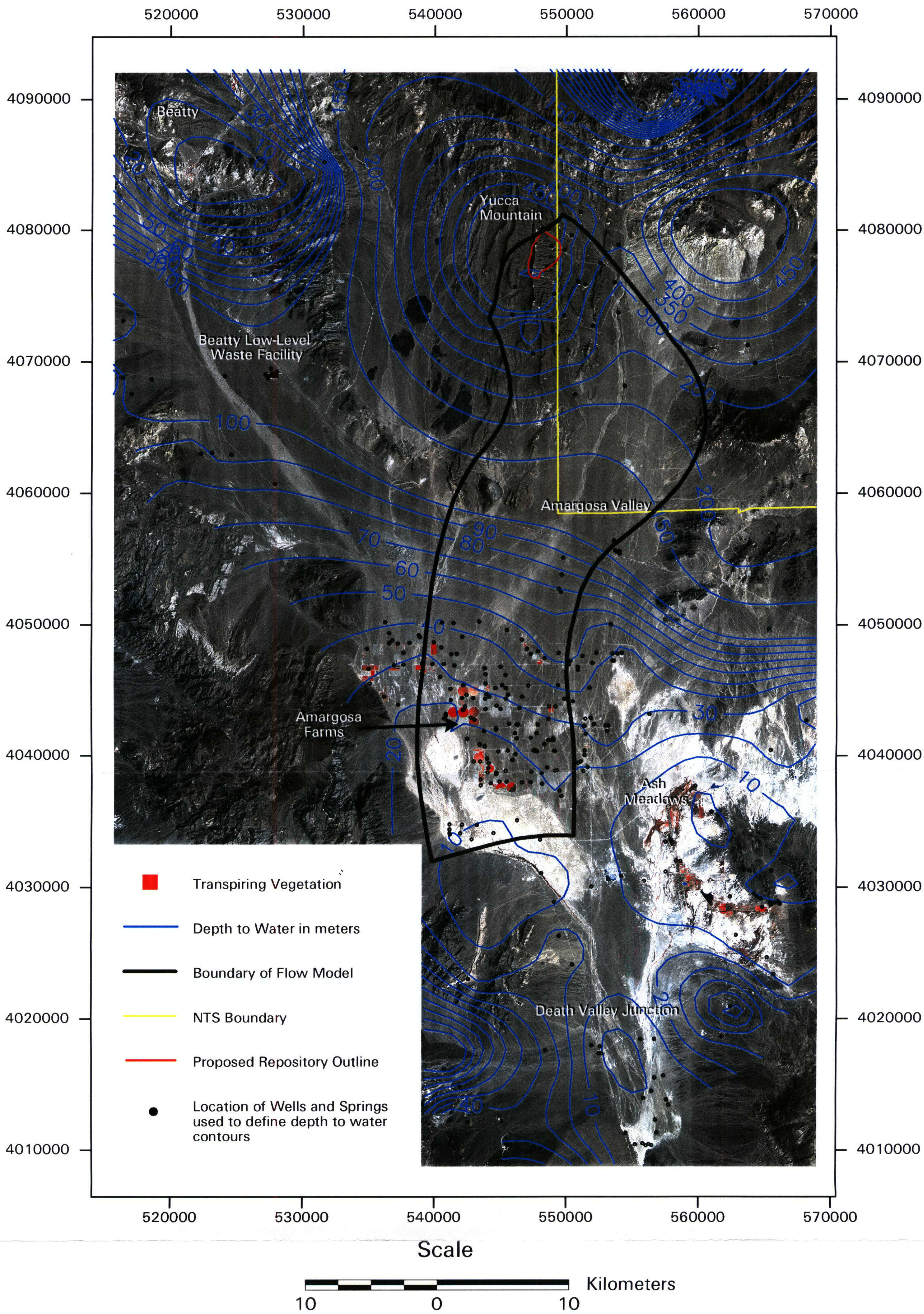

Figure 2-2. False-color image of proposed Yucca Mountain site and communities to the south based on thematic mapper data.

Practices in Amargosa Valley are similar to those identified in the county-level census information. Livestock in Amargosa Valley are predominantly cows (5,000 head) for dairy farming, although much lower numbers of beef cattle (about 100 head) and pigs, goats, sheep, chickens, and rabbits are known to exist in local commercial operations (Eisenberg, 1996). Almost all of these rely to some extent on locally grown alfalfa for feed, however, the commercial dairy is known to import a majority of their feed from areas outside the county which produce higher nutrient content crops.

The 1987 census indicates that crops in Nye County were harvested on 94 farms (69 percent of the total) with an average area of 123 acres/farm. Hay production, including alfalfa, small grain, grass silage, and green chop accounted for 88 percent of the harvested cropland, while wheat and barley for grain sale represented only 3 percent (the remaining 9 percent of harvested cropland is not accounted for in the census statistics). Thus, alfalfa is the dominant crop in Nye County. Pasture and grazing occurred on farms that also grew crops (46 percent of cropland). Total pastureland in Nye County accounted for 347,433 acres in 1987 on 75 farms (an average of 4,632 acres per farm). Vegetable production for market included 1 farm (1 percent of harvested land is vegetables, sweet corn, and melons) and 1 farm for fruits, nuts, and berries. Thus, vegetable production for market is negligible in Nye County.

Local data sources indicate the area of southern Nevada that surrounds the proposed YM site, located in Nye County, does not have farms that sell food crops for export[1], but does have farms that grow feed crops for livestock sold on the open market. The principal agricultural crop in Amargosa Valley is alfalfa that is predominantly sold to export markets (Eisenberg, 1996). Other crops include grain, barley, oats, hay, and hayfine in lesser quantities.

Despite low levels of vegetable production, local gardeners can grow a variety of vegetables. The local agricultural extension office in Nye County no longer has any agricultural production staff, but does have staff that focus on horticulture, which may indicate a higher demand or priority for such information. The extension office provides guidelines for desert gardening (Mills, 1993) that were used in IPA Phase 2 analyses (Nuclear Regulatory Commission, 1995a) to determine home gardening related parameter values and are also used in this study. Eisenberg (1996) describes an interview with a local resident who indicated many residents (approximately 50 percent) of Amargosa Valley maintain gardens that provide fruits and vegetables. Local residents are known to share, barter, and sell their garden crops among themselves.

The preceding summary of local agricultural practices indicates that crop and animal product ingestion are potential human exposure pathways that should be considered in exposure assessments for YM. Therefore, a farming scenario that is generally similar to that used in IPA Phase 2 (Nuclear Regulatory Commission, 1995a) is used in this study. This scenario includes a farmer who grows alfalfa for livestock feed, and vegetables and grains for personal consumption. Egg consumption was added to the revised DCF calculations (see Chapter 4) due to an understanding gained from a recent visit to the area that some eggs are produced for local consumption. Section 2.3.2.2 discusses individual site-specific agricultural and other parameters in greater detail.

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[1] Las Vegas Agricultural Extension Office, Nevada, 1995, Personal communication.

2.3.2.2 Terrestrial Crop Growing Duration

The growing duration for specific crops is used in GENII-S to calculate the concentration of radionuclides in crops for the ingestion pathway dose calculation. Growing duration represents the amount of time an edible crop is exposed to deposition (and decay) of radionuclides from resuspended soil and contaminated irrigation water. The growing duration is dependent on plant species and also varies within plant species depending on genetic and environmental growing conditions. NUREG/CR-5512, Residual Radioactive Contamination from Decommissioning - Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent (Kennedy and Strenge, 1992) provides generic minimum growing duration values for broad categories of crops, however, these point estimates were not useful for the stochastic analysis where uncertainty had to be characterized. Ranges of growing durations from planting to harvest for a variety of vegetables were found in a comprehensive gardening manual written by professional botanical gardeners (Chambers and Mays, 1994). This reference focuses on growing vegetables in a variety of climates found in the United States (including desert gardening) and the ranges for growing period are expected to reflect a variety of growing conditions.

To determine growing durations for the stochastic calculations, crops likely to be grown in local vegetable gardens were selected from Mills (1993) and cross referenced to the growing period information in Chambers and Mays (1994). Crops were then grouped into the three relevant categories (leafy vegetable, fruit, and other vegetable) used in the GENII-S and DITTY codes. The minimum and maximum growing durations for any vegetable in each crop category were considered to characterize the full range of variation in growing periods for all the vegetables in a category. A uniform distribution is assumed for these ranges. Growing duration ranges for selected individual garden crops are also considered, as well as information from Kennedy and Strenge (1992) on minimum growing durations for each crop category. The information is summarized in table 2-1.

The minimum growing durations from Kennedy and Strenge (1992) generally fall within the upper part of the range determined from the information in Chambers and Mays (1994). The wide ranges in growing durations are a result of aggregating the information from a variety of crops to account for the uncertainty in knowing which crops a hypothetical vegetable gardener would choose to grow. To limit this variation, specific representative crops (e.g., corn, onions, beans, and garlic) could be chosen rather than using the full range of possibilities. Note that cantaloupe was the only fruit plant mentioned in the desert gardening tips in Mills (1993), however, water-use information from the Nevada Department of Resource Conservation suggests some permitted water users grow fruit trees (Nevada Division of Water Resources, 1995a). For the revised DCF calculations, the midpoints of the distribution from the stochastic calculation were used. The sensitivity analysis results (see section 3.4) suggest that the estimated variation in growing duration does not have a significant effect on the variation in dose results.

2.3.2.3 Terrestrial Crop Yield

Terrestrial crop yields are used in GENII-S to determine the concentration of radioactive contaminants on crops from irrigation or aerosol deposition. The crop yield specifies the plant weight per square meter of soil that (along with other parameters) allows conversion of the deposition rate of radionuclides ($Ci/m^2/sec$) to a crop concentration in units of Ci/kg of plant.

Discussions with local staff at the Nevada Agricultural Extension office indicated the Nevada Agricultural Statistics Service (1988) was the only known source of local yield information. Terrestrial crop information included state yields for wheat, barley, potatoes, garlic, and onions. While none of these

Table 2-1. Comparison of growing period ranges with Kennedy and Strenge (1992) point estimates

Crop Group (one crop)	Growing Period Range (days)*	NUREG/CR-5512 (minimum days)
Leafy vegetables (corn)	40–120 70–100	45
Root vegetables (onions)	25–120 90–120	90
Grain	60–90	90
Fruit (cantaloupe)	65–95	90
*Source: Chambers and Mays, 1994		

crops were grown in Nye County for market (U.S. Department of Commerce, 1989), it is possible they could be grown in small personal gardens and, therefore, are still considered relevant to an exposure assessment for YM. The information is provided in table 2-2. The local vegetable yields are different than the Kennedy and Strenge (1992) values, however, the latter source provides summary yields for groups of individual crops (i.e., vegetables) that have considerable variabilities in mass (i.e., garlic versus onion), thus wide variability in yields should be expected when compared with specific crops.

For the stochastic calculations, a locally determined range for wheat with a uniform distribution is assumed because local variation data are available, and wheat is not aggregated with other crops, as are the vegetables. The uniform distribution for wheat is arbitrarily assigned due to lack of more detailed data to characterize the actual distribution. Local point estimates for specific vegetables are not used because the values in Kennedy and Strenge (1992) are based upon a wider variety of vegetables and are provided for crop categories used in GENII-S (i.e., leafy vegetables, fruit vegetables). The point estimates of yield for leafy and other vegetables are 2 and 4 kg/m^2, respectively (Kennedy and Strenge, 1992). As no distribution information is provided in Kennedy and Strenge (1992), the yields are assumed to be distributed lognormally as reported in Hoffman et al. (1982) for the stochastic analysis. The point estimates for vegetables from Kennedy and Strenge (1992) are used for the revised DCF calculations. The ranges for the yields used in the stochastic runs presented in table 2-3 are for a 95-percent confidence interval. For the purpose of this report, the 95-percent confidence interval for a probability distribution is the interval about the mean which is expected to contain 95 percent of the possible values for the parameter (see chapter 3.3).

As indicated in table 2-2, local agricultural statistics sources for Nye County and Nevada were reviewed and did not contain yield information for fruit. This is probably due to the low level of fruit production in the region. The 1987 Agricultural Census indicated only one farm sold products in the fruits, nuts, and berries category (U.S. Department of Commerce, 1989). Water-permit data (discussed in

Table 2-2. Comparison of crop-specific yields from Nevada with general values from Kennedy and Strenge (1992)

Crop	Minimum Yield from NUREG/CR-5512 (kg/m^2)	Yield Reported for Nevada (kg/m^2)*
Wheat	1.0 (grains)	0.47–0.60
Potatoes	4.0 (other vegetables)	3.80
Onions	4.0 (other vegetables)	5.59
Garlic	4.0 (other vegetables)	1.57
Fruit	2.0	None
*Source: Nevada Agricultural Statistics Service, 1988		

Table 2-3. Vegetable yields from Kennedy and Strenge (1992) with assumed geometric standard deviation

Food	Yield (kg/m^2)	Geometric Standard Deviation	Range
Leafy vegetables	2.0	1.82	0.62–6.5
Other vegetables	4.0	2.32	0.77–21.0
Source: Hoffman et al., 1982			

section 2.3.3) indicated at least three properties with fruit trees in the Amargosa Valley area. Possibly, fruit trees are used for domestic consumption rather than for market. Despite the low overall production, the existence of the practice locally suggested it was reasonable to be included in dose calculations for YM. Snyder et al. (1994) reported a maximum fruit tree yield estimate from analysis of agricultural survey data from Yakima, Washington. Snyder determined the data are consistent with a triangular distribution and a range of 0.3 to 2.0 kg/m^2, with a mean of 0.54 kg/m^2 (dry wt.).

For the revised DCF calculations, the means of the distributions used in the stochastic analysis are used. The value of 0.54 kg/m^2 for fruit is converted to wet weight (3.0 kg/m^2) using the 0.18 conversion factor in table B-1 to be consistent with code input requirements. Sensitivity analysis results (see section 3.4) indicate crop yields are not influential parameters among the group of 43 parameters that are sampled and analyzed for sensitivity to dose.

Table 2-4. Consumption rates for major food groups from Kennedy and Strenge (1992) and lognormal distribution information from Hoffman et al. (1982)

Food	Consumption Rate	Geometric Standard Deviation	Range
Leafy vegetables	11 kg/yr	1.6	4.3–28
Other vegetables	51 kg/yr	2.2	11–230
Fruit	46 kg/yr	2.2	10–210
Grain	69 kg/yr	2.2	15–310
Beef	59 kg/yr	1.6	22–160
Milk	100 ℓ/yr	2.2	21–480

2.3.2.4 Terrestrial Crop and Animal Product Consumption Rates

Terrestrial crop consumption rates are used in GENII-S to determine the amount of contaminated food products that are ingested by the exposed individual. In the search for information, no sources were identified for current local consumption rates. In the near future, information should be available from local socioeconomic studies sponsored by the DOE. In the absence of more relevant information, general consumption rates in Kennedy and Strenge (1992) for U.S. consumption of leafy vegetables, other vegetables, fruit, grain, beef, and milk are used. To determine sampling distributions for the stochastic calculations, the consumption rates are assumed to be distributed lognormally, with geometric standard deviations applicable to consumption rates in Hoffman et al. (1982). The range for the consumption rates is calculated using a 95-percent confidence interval. Table 2-4 shows the resulting ranges for various consumption rates.

Results from the sensitivity analysis (see section 3.4) show consumption rates are important parameters for the dose calculation. Further consideration of additional information on local practices (Eisenberg, 1996) indicate it is unlikely an individual in the Amargosa Valley derives all food from local sources. Therefore, the assumption is considered excessively conservative. Results from ongoing DOE socioeconomic studies should help to resolve this issue. For the current revision of DCFs, consistent with NRC Policy Guidance Document PG8-08, (Nuclear Regulatory Commission, 1994), the consumption rates for all foods except milk are halved to conform to an assumption of 50-percent-local food consumption and 100-percent-local milk consumption. It is expected that the actual consumption will probably be less than these figures and, thus, this reduced level of conservatism is considered reasonable until more specific information is available.

2.3.2.5 Forage Growing Duration

The forage pathway is another route of potential exposure to air and waterborne contamination. The growing duration for a forage crop is used to determine the amount of material that can be deposited on forage crops from air or irrigation sources prior to consumption. Growing duration varies with forage crop type and, therefore, information on the types of forage crops grown in the vicinity of YM is essential to determining a meaningful growing duration (see general discussion of agricultural crops in section 2.3.2.1). Alfalfa production has been associated with southern Nevada agriculture by various sources including Federal and State census data (U.S. Department of Commerce, 1989; Nevada Agricultural Statistics Service, 1988), communications with agricultural extension agents, water-use data for the Amargosa Valley (Nevada Division of Water Resources, 1995a), and dose assessment for NTS (Breshears et al., 1989). Therefore, alfalfa is considered a primary forage crop.

State and local agricultural extension offices were contacted to find information on alfalfa growing parameters. A local extension agent indicated the growing season is May through October and three to four cuttings occur during that time. This information is compared with that used by Breshears et al. (1989) who report a season from June to mid-December with three to five cuttings. Eisenberg (1996) indicated the season in Amargosa Valley can last approximately 200 days. Thus, it appears the growing season for alfalfa is approximately 6 mo.

For the stochastic calculations, the growing duration is assumed to be the time between cuttings so a range from 37 to 62 days is determined from a 6 mo. season and three to five cuttings. A different source, (Stichler, 1991) indicated variation in time of cutting due to variations in climate and management practice. Cutting was reported as occurring after bloom (30+ days). This value is consistent with the generic beef/dairy forage minimum growing duration provided by Kennedy and Strenge (1992). Thus, a reasonable lower bound for alfalfa growing duration is assumed at 30 days and a reasonable upper bound is fixed at 62 days. This range was used for the stochastic calculations. Since there is insufficient data to determine the type of distribution, a uniform distribution is assumed.

For revised DCF calculations, the midpoint of the distribution is used. The sensitivity analysis results indicated that forage growing duration is not an important parameter of the 43 parameters that were analyzed (see section 3.4).

2.3.2.6 Forage Yield

Forage crop yield is used in GENII-S to determine the radionuclide concentration in forage crops from surficial deposition from air and irrigation water. Yields for alfalfa hay and other hay in Nye County for 1986 were 1.23 and 0.34 kg/m^2 (dry weight), respectively (Nevada Agricultural Statistics Service, 1988). In 1987, these same yields were 1.21 and 0.36 kg/m^2, respectively. No other local data on yields were identified. Therefore, the range of possible yields for hay in the stochastic calculations is set from 0.34 to 1.23 kg/m^2. No information on the distribution was obtained, thus it is assumed to be uniform. The sensitivity analysis results indicates crop yields are not important parameters for any of the radionuclides considered. The local yield for alfalfa (1.23 kg/m^2) is used for the revised DCF calculations because alfalfa was assumed to be the primary forage crop.

2.3.2.7 Forage Diet Fraction

The fresh forage diet fraction in GENII-S is the fraction of livestock diet consumed fresh from the field. Locally applicable forage information from an NTS study of food pathways (Breshears et al., 1992) is used as a primary source of information. The study focuses on southwestern Nevada agricultural pathways and included information on alfalfa and grain forage, production, and storage. The fresh forage diet fraction is reported as normally distributed with mean and standard deviation of 0.55 and of 0.13, respectively, and a range of 0.30 to 0.82 at the 95-percent level. This distribution is used for the stochastic calculations. Forage diet fraction is included in the final regression models for those radionuclides where animal uptake is an important pathway (see section 3.4) but ranked low within those models. The mean value is used in the revised DCF calculations.

2.3.2.8 Food Transfer Factors

Food transfer factors determine the amount of radioactive material transferred to food and forage plants from soil (concentration ratios) and to animal products from contaminated water and feed (transfer coefficients). Concentration ratios are influenced by site-specific conditions such as soil and plant type. A potential source of site-specific food transfer research are studies on the NTS. A number of risk assessments and related documents applicable to the NTS were reviewed and an expert[2] with experience conducting risk assessments of the NTS was contacted.

Many prior dose assessments of the NTS modeled the effects of atomic bomb test fallout and early screening studies determined that the groundwater/ingestion pathway was not a major contributor to dose (Daniels, 1993). Therefore, subsequent studies and research that were reviewed did not consider the soil to-food-pathway or the feed-to-livestock pathway. Similarly, since the test site encompasses a large area restricted from civilian uses (e.g., farming), and fallout contamination is restricted to a small group of radionuclides, research interest in the development of site-specific transfer and uptake factors appeared low. One early risk assessment did consider ingestion and included forage and beef cattle pathways. Tabulated parameter values for this study are not referenced to a source, and the origin of parameter values cannot be determined from the text (Kercher and Anspaugh, 1984). Overall, NTS studies are not considered to be a major source of transfer factor information for the large number of elements considered herein, so international sources for summary values were consulted to obtain values.

Food transfer factors were obtained from the most recent publication of such information from the International Atomic Energy Agency (IAEA) (1994). This source was published as a collaboration between the IAEA and the International Union of Radioecologists (IUR). The IUR was previously the primary source of transfer factors in Kennedy and Strenge (1992). The IAEA report is used in this study because it represents the most recent literature summary of available information. For some elements, concentration ratios are provided for numerous crops, but no summary values are provided for the other vegetable category. In this instance, the geometric mean of the available values is calculated. The geometric mean is considered appropriate since some of the values range over an order of magnitude. Some elements do not have values for fruit, and thus the values for other vegetables are used. For elements not covered by IAEA, food transfer factors are obtained from Baes et al. (1982), a primary source for IPA Phase 2 transfer factors, and Kennedy and Strenge (1992). The resulting factors are provided in table 2-5.

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[2] M.D. Otis, Science Applications International, Corporation, 1995, Personal communication

Table 2-5. Concentration ratios and transfer coefficients by element

Element	Concentration Ratios				Transfer Coefficients		
	Leafy Vegetable	Other Vegetable	Fruit	Grain	Beef	Milk	Egg
AC	3.5E−03	3.5E−03	3.5E−03	3.5E−03	2.5E−05	2.0E−05	2.0E−03
AM	1.2E−03	4.7E-04	4.7E−04	2.2E−05	4E−05	1.5E−06	4E−03
CS	1.1E−01	7.2E−02	7.2E−02	1.0E−02	5E−02	7.9E−03	4E−01
CM	1.1E−03	5.8E−04	5.8E−04	2.1E−05	3.5E−06	2.0E−05	2.0E−03
I	3.4E−03	2.0E−02	2.0E−02	2.0E−02	4E−02	1.0E−02	3E+00
PB	1.1E−03	6.4E−03	6.4E−03	4.7E−03	4E−04	2.5E−04	8.0E−01
MO	8.0E−01	8.0E−01	8.0E−01	8.0E−01	1E−03	2.0E−03	9E−01
NP	6.9E−02	2.7E−02	2.7E−02	2.7E−03	1E−03	5.0E−06	2.0E−03
NI	1.8E−01	3.0E−02	3.0E−02	3.0E−02	5E−03	1.6E−02	1.0E−01
NB	5.0E−02	1.7E−02	1.7E−02	1.7E−02	3E−07	4.1E−07	1E−03
PD	1.5E−01	1.5E−01	1.5E−01	1.5E−01	4.0E−03	1.0E−02	4.0E−03
P	4.0E−00	4.0E−00	4.0E−00	4.0E−00	5.0E−02	1.5E−02	1.0E+01
PU	3.4E−04	2.3E−04	2.3E−04	8.6E−06	1E−05	1.1E−06	5E−04
PO	1.0E−02	1.0E−02	1.0E−02	1.0E−03	4E−03	1.2E−04	7.0E+00
PA	2.5E−03	2.5E−03	2.5E−03	2.5E−03	1.0E−05	5.0E−06	2.0E−03
RA	8.0E−02	1.3E−02	1.3E−02	1.2E−03	9E−04	1.3E−03	2.0E−05
SM	1.0E−02	1.0E−02	1.0E−02	1.0E−02	5.0E−03	2.0E−05	7.0E−03
AG	2.7E−04	1.3E−03	8.0E−04	1.5E−01	3E−03	5.0E−05	5.0E−01
SE	2.5E−02	2.5E−02	2.5E−02	2.5E−02	1.5E−02	4.0E−03	9E+00
SR	1.1E+00	8.6E−01	2.0E−01	1.2E−01	8E−03	3.0E−03	2E−01
TC	7.6E+01	1.1E+01	1.1E+01	7.3E−01	1E−04	1.4E−04	3E+00
TH	1.1E−02	3.1E−04	3.1E−04	3.4E−05	6.0E−06	5.0E−06	2.0E−03
SN	3.0E−02	3.0E−02	3.0E−02	3.0E−02	8.0E−02	1.0E−03	8.0E−01
U	2.3E−02	1.1E−02	1.1E−02	1.3E−03	3E−04	4.0E−04	1E+00
ZR	1.0E−03	1.0E−03	1.0E−03	1.0E−03	1E−06	6.0E−07	2E−04

Four types of concentration ratios and four types of transfer coefficients are used in GENII-S. The poultry transfer factor is not used for this analysis due to a lack of evidence of local poultry meat farming in Amargosa Valley and indications that egg production is more likely (see section 2.3.2.1). Transfer factors cannot be sampled directly for stochastic analyses in GENII-S without code modifications. Variation in these parameters is modeled using the soil/plant scale factor and the animal uptake scale factor. These scale factors are derived from uncertainty factors for concentration ratios provided by the IUR in their 1989 report (International Union of Radioecologists, 1989). The uncertainty factors from IUR are favored over the IAEA values since IUR obtained broader coverage of the data by deriving their values as the mean of a sample of transfer factors (more than 3 point estimates per sample) while the IAEA (1994) factors were based on point estimates. The uncertainty factors determine the bounds of a 95% confidence interval about the expected values (i.e., geometric means) of the transfer factors. The lower limit of the confidence interval is determined when the expected value of the transfer factor is divided by the uncertainty factor and the upper limit is determined by multiplying the expected value and uncertainty factor. The form of the transfer factor distribution is not discussed in the source documents, however, a lognormal distribution is consistent with the general statistical approach used by IUR (International Union of Radioecologists, 1989). Thus, a lognormal distribution for the transfer scale factor is assumed.

To determine the range of the scale factor sampling distribution, the IUR uncertainty factors were reviewed for the radionuclides and crops relevant to this study and a value of four is selected as a reasonable upper bound that encompasses the majority of uncertainty factors for relevant crops and elements. Using Eqs. (3-4) and (3-5) (see section 3.3), the selected uncertainty factor translates to a geometric standard deviation of 2.0 for a lognormal distribution. A 95-percent confidence interval was calculated from this geometric standard deviation to determine the ranges for the GENII-S scale factors that are provided in table B-1 in appendix B. A nominal geometric mean scale factor of 1.0 is used so that the expected value of the transfer factor provided by IAEA is taken to be the geometric mean of the distribution of transfer factors that results from applying the scale factor. An equally comprehensive list of uncertainty factors is not available for the transfer coefficients for animal products. The point estimates for uncertainty factors in International Atomic Energy Agency (1994) are far more variable than the concentration ratio factors and values are not available for many elements. Thus, the uncertainty scale factor determined for the concentration ratios is also used for the GENII-S animal uptake scale factor because it is considered to encompass the range of uncertainty in these factors as well as any other single factor that could be chosen. The next revision to the IAEA report is expected to include more complete information on the uncertainty factors.

The sensitivity analysis results rank the soil-to-plant transfer factors as highly important for those radionuclides that are known to be particularly mobile in the environment (see section 3.4). Animal uptake factors are also found to be highly important for those radionuclides that concentrate relatively well in animal systems. This raised the level of scrutiny of these parameters for the revised DCFs. Following review, the values used for the transfer factors are considered to be the best available information; however, the application of a single uncertainty factor for all elements is crude and is remedied by conducting a deterministic calculation of the DCFs using the expected values for the transfer factors. If future stochastic analyses are done, it may be more appropriate to apply the available element-specific scale factors for each radionuclide.

2.3.3 Water Use in Nevada

Irrigation water from underground wells is a potentially important pathway for exposure to radioactive contaminants. The DOE has reported general groundwater flow as moving south and southeast from the site (U.S. Department of Energy, 1988a). Thus, any potential releases to groundwater present a possible risk to populations south and southeast of the site that rely on groundwater to meet their commercial and residential needs. Dose assessments involving the groundwater pathway should focus on these populations when considering potential critical groups. The Amargosa Valley area is the nearest agricultural area south of YM (approximately 35 km). This community uses groundwater for agricultural irrigation and drinking water consumption and is considered a reasonable focal point for defining a site-specific exposure scenario.

Primary routes of exposure from water pathways that are considered in the present study include internal exposure from drinking water, consumption of crops or animal products that have been directly or indirectly contaminated by irrigation and feedwater, and exposure to external radiation and inhalation of resuspended material from soils contaminated from irrigation. Bathing in contaminated water is a potential route of exposure that is not included in the analyses; however, it could be modeled in GENII-S by using the swimming exposure model. The exposure from bathing is expected to be a small fraction of that from the other routes of exposure considered in this study (e.g., consumption of contaminated plant and animal products). A discussion of parameters that describe water use characteristics in the communities south of the YM site follows.

2.3.3.1 Home Irrigation Rate

The home irrigation rate is used in GENII-S to determine the amount of contamination deposited on soils for the purpose of calculating external exposure. Due to the arid climate in the southwestern Nevada region, it is likely that home irrigation would be greater than in more moderate climates. Lawns in the Amargosa Valley are uncommon, however, some residents do have them[3] and, therefore, it is reasonable to include lawn watering in an exposure scenario for the most highly exposed group. Mills (1993) provides estimates of the water required to grow a lawn in Nye County. These estimates are 1 in./wk during the cooler winter months and 4 in./wk during the hot summer months. Mills also indicates that some residents may only care for a lawn in the winter months. For the stochastic calculations, a minimum irrigation rate is calculated as 26 in./yr assuming a 6-mo cool season lawn. A maximum value is reported in LaPlante et al., (1995) assuming a year-round lawn with 3 mo of summer watering at 4 in./wk and the remaining 9 mo at 1 in./wk to equal 84 in./yr. This maximum includes a small amount of error from rounding time to 4 wk/mo. A uniform distribution is assumed since there was no information to support a more precise distribution type. For the revised DCF calculations, the rounding error in the upper bound is corrected (91 in./yr) and the midpoint of the distribution is used.

2.3.3.2 Home Irrigation Duration

Irrigation duration is used in GENII-S to calculate the soil concentration resulting from residential water uses such as lawn watering. A resident is assumed to grow a lawn for 6 mo to 1 yr, thus the irrigation duration range is assumed to be 6 mo to 1 yr for the stochastic calculations. A uniform distribution is assumed since no information is available to determine a more precise distribution type. For

[3] P. LaPlante, May 97, CNWRA, Personal observation.

the revised DCF calculations, the midpoint of the distribution is used. The sensitivity analysis concludes that the home irrigation duration is not an important parameter in this calculation.

2.3.3.3 Terrestrial Crop Irrigation Rate

The Nevada Division of Water Resources issues permits and regulates water for domestic and agricultural use. No local agencies systematically collect or summarize information on the irrigation rates for various crops, however, an upper bound for water usage is indicated on permits. All large-quantity users (not including individual homeowners with only one house on the property who do not intend to pump more than 800 ft^3 per day) are required to have permits. Thus, local farms are represented in the permit data.

Permits are categorized by end use, so it is possible to determine the permitted rates for agricultural uses, but not for specific crops. IPA Phase 2 analyses (Nuclear Regulatory Commission, 1995a) used a maximum permitted amount of 60 in./yr (stated as 127 $\ell/m^2/mo$) for the irrigation rate. Unpublished information from the Nevada Division of Water Resources (Nevada Division of Water Resources, 1995b) shows the number of permits and the permitted amount for all large users in Amargosa Valley. The information is not thoroughly checked for errors and is marked as preliminary, but is the best currently available. Figure 2-3 shows the cumulative distribution of estimated water withdrawals in the Amargosa Valley basin based upon permitted water rights (includes 140 permits). Zero estimates are for sites that have water rights, but no anticipated use, such as abandoned cropland. For a small number of permits there is additional information on the type of crops grown on farms. This provides some confirmation of the amount of water permitted for different agricultural uses. From this information, two approaches to determine irrigation rates are considered.

The approach used for the stochastic calculations relies on the permit information to establish the maximum permitted irrigation rates for specific crops. While the available data are not inclusive of all farms, all seven alfalfa farms, all three grain farms, one of four vegetable gardens, and one of four fruit tree orchards reported had a 60 in./yr permitted withdrawal. Therefore, an irrigation rate of 60 in./yr for all crop types is assumed. For the stochastic calculations, an empirical distribution of irrigation rates is derived.

To determine the distribution, rainfall predictions from a recent formal expert elicitation for YM during the next 10,000 yr (DeWispelare et al., 1993) are considered. In the elicitation, five experts made four estimates of possible future annual rainfall rates: 5, 6, 8.3, and 11.8 in./yr. Each of these estimates is assumed normally distributed with standard deviations equal to the product of 0.829 (Sandia WIPP Project, 1992) and the estimated annual rainfall rates. This resulted in standard deviations of 4.15, 4.97, 6.88, and 9.78, respectively. Each mean annual rainfall is then subtracted from the irrigation rate which resulted in four irrigation-minus-rainfall adjusted estimates (55.0, 54.0, 51.7, and 48.2 in/yr respectively).

Normal distributions are then estimated about these adjusted estimates using the aforementioned rainfall standard deviations. Each distribution is sampled to create an empirical distribution using GENII-S. Sampling probabilities for each distribution are determined as follows. Probabilities associated with predicted changes in average annual rainfall are determined by multiplying the estimated chance of a change in climate (64.4 percent) by the proportion of the elicitation experts who favored a given rainfall estimate. The probability of a change in climate is determined by subtracting the chance of no climate change (Nuclear Regulatory Commission, 1995a) from 1.0. The 6 in./yr point estimate represents current conditions and thus the sampling probability is set equal to the chance of no climate change (0.36). The resulting probabilities were 0.13, 0.36, 0.38, and 0.13 for the normal distributions relevant to rainfall rates

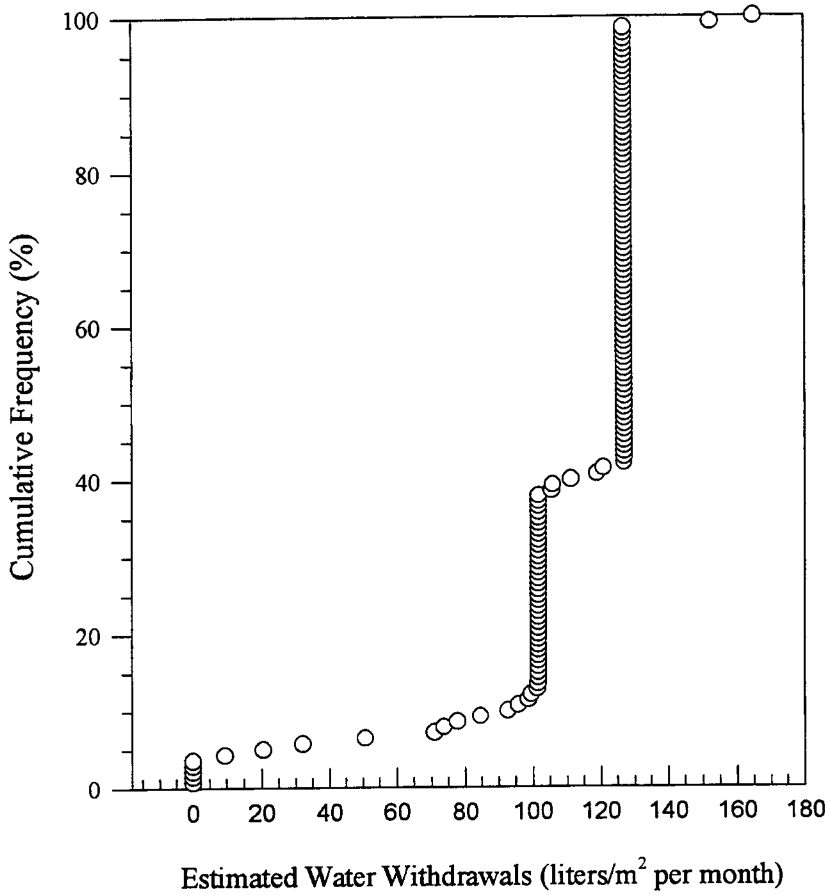


Figure 2-3. Cumulative distribution of estimated water withdrawals in the Amargosa Valley basin (Data source: Nevada Division of Water Resources, 1995b)

of 5, 6, 8.3, and 11.8 in./yr, respectively. Sampling to create the empirical distribution is limited to 100 values in GENII-S. Therefore, the sampling probabilities are used to determine the number of values to sample from each of the normal distributions. Thus, 13 values are sampled from the irrigation minus 5 in./yr rainfall distribution, 36 values are selected from the irrigation minus 6 in./yr rainfall distribution, and so forth. The resulting distribution is then sampled by GENII-S for the stochastic code runs.

The results of the sensitivity analysis indicates that the terrestrial crop irrigation rates are not important parameters relative to the others that were included in the analysis. This is because of the small amount of variation considered in the empirical distribution. The irrigation rate directly affects the amount of contamination introduced into the agricultural system and, therefore, is a key parameter for calculating dose. For the revised DCFs, the fixed value of the permitted maximum is used for all current biosphere crop irrigation rates. These rates are adjusted accordingly for the pluvial biosphere (see section 2.3.6).

2.3.3.4 Terrestrial Crop Irrigation Duration

The terrestrial crop irrigation duration is the number of months per year in which irrigation occurs. In the GENII-S model, the annual irrigation rate is divided by the irrigation duration to calculate a deposition rate (Ci/m^2-sec), which is then used to determine deposition onto soil and crops. The irrigation duration is specified for four crop groups: leafy vegetables, root vegetables, fruit, and grain.

The irrigation duration is assumed to be similar to the growing period; however, crops such as wheat require a drying out period prior to harvest, that reduces the irrigation duration. The U.S. Department of Agriculture (USDA) and local agricultural extension agents in Nevada do not have duration information readily available, so other sources were consulted.

Vegetables and fruit are watered until harvest and, therefore, values for irrigation duration are assumed to be the same as the growing period. Irrigation durations for various crops are calculated by multiplying the growing duration per planting season by the number of plantings per year. The irrigation duration period for wheat is assumed equal to the growing duration minus 1 mo for drying multiplied by the number of plantings. Growing seasons for each crop group except grain are interpreted from a planting guide provided in Mills (1993). The planting guide shows the months of the year when various vegetable and fruit crops should be planted. The irrigation field study by English and Nakamura (1989) is used to estimate growing duration for wheat. This study was conducted in an arid environment approximately 50 miles south of Hanford, Washington. Wheat was grown over a period of 4 mo using high fertilizer applications. These experimental conditions were optimal for growth and thus a wider range of 4 to 5 mo is assumed for wheat under more variable conditions. Table 2-6 shows information used for determining the irrigation period for various crops.

The sensitivity analysis results indicate that irrigation durations for leafy vegetables and other vegetables have a sufficient influence on the calculated dose to be selected for the final regression models, but are ranked low compared to other parameters in the same models. Since these parameters are based on the length of the growing season and that information is derived from local sources (Mills, 1993), there is no need to update the information source. For the revised DCFs, the growing seasons for individual crops are reviewed, and the fixed values closest to the actual recommendations for the individual crops in each group are chosen. The results are shown in table B-1 in appendix B. For the leafy vegetable category, the value chosen is slightly less than the midpoint of the distribution used in the stochastic calculation because the upper limit of that distribution is very conservatively estimated. The value for fruit MAT is at the top of the range used for the stochastic calculations because this value is common in the source information and therefore more representative of actual conditions is used than the midpoint of the range.

2.3.3.5 Consumption Rate for Water

Water consumption in hot, dry regions, such as southwestern Nevada, may be above national average values due to the climate. Nonetheless, local information sources with drinking water consumption rates could not be identified. As a result, information from Roseberry and Burmaster (1992) is used for the stochastic calculation because the information appears broadly representative of the general U.S. population and includes probability distribution information. This study is a reanalysis of data from a nationwide Food and Drug Administration (FDA) food consumption survey conducted in 1977–78 to determine distributions of water intake. Their analysis indicates distributions of water intake are lognormally distributed. The average consumption rate for tap water is reported as 349 ℓ/yr with a geometric standard deviation of 1.78. The distribution is calculated based on a 95-percent confidence interval. As with other consumption information, these data are old and may not be representative of current tap water consumption rates, which can change over time due to trends in consumption of non-tap water beverages. Nonetheless, more recent data were not identified when the stochastic calculations were conducted.

Table 2-6. Factors used to determine irrigation duration for various crops

Crop Type	Number of Plantings per year	Growing Time per Planting (mo/yr)	Total Irrigation Time (mo/yr)
Leafy vegetables	2	1.5–4	3–8
Other vegetables	2	1–4	2–8
Fruit	1	1–1.5	2–3
Grain	2	4–5	6–8

The sensitivity analysis results (see section 3.4) show that the drinking water consumption rate is sufficiently important to include in the regression models for a number of radionuclides, but is ranked relatively low compared to most of the other parameters in these models. A reassessment of the consumption rate for the revised DCF calculations concludes that the mean of 349 ℓ/yr is too low for a very hot, arid, location such as Amargosa Valley. The paucity of information on local consumption rates led to a decision to use the commonly accepted default value of 2ℓ/day (730ℓ/yr) which has been used by the NRC for exposure assessment (Nuclear Regulatory commission, 1995a) and by EPA in their regulations (40 CFR 140). It is anticipated that in the future, the DOE may obtain local estimates from their socioeconomic studies of the local areas.

2.3.4 Soil Characteristics for Southwestern Nevada

Soil characteristics in the GENII code are used to calculate transfer of radionuclides from irrigation water and air deposition to soil and subsequently to crops and feed, where it enters the livestock and human food supply. Because soils vary with geography, site-specific soil classification information can help avoid the problems associated with use of generic parameters that may lack relevance to local conditions.

2.3.4.1 Soil Plow Depth

Soil plow depth in GENII-S is used to determine the areal density of the upper layer of soil and also defines the two compartments for the soil model. Such specific information on farming techniques is not provided in the primary sources of agricultural data (Nevada Agricultural Statistics Service, 1988; U.S. Department of Commerce, 1989) and, therefore, a GENII-S default value of 15 cm is used in our analysis. No information to characterize the variation has been found and, thus, the parameter is not sampled. This value is also used in the deterministic calculations of updated DCFs.

2.3.4.2 Soil Exposure Duration

The soil exposure duration is used in GENII-S to calculate the amount of time an individual would be exposed to external radiation from contaminated soils. No information has been identified for outdoor activity of farmers, which could be used to determine the soil exposure duration. For the stochastic calculations, an assumption is made that a farmer is likely to be in close proximity to irrigated (i.e., contaminated) land working out-of-doors. As a result, the soil exposure duration for a farmer was initially assumed to be equivalent to the outdoor activity duration (section 2.3.5.1) with a minimum of 6.5 hr/day and a maximum of 15 hr/day. In the previous report (LaPlante et al., 1995), it was acknowledged that these values were very conservative and speculative.

The sensitivity analysis results indicated soil exposure duration is not important for most radionuclides and is included in the regression model for only 1 radionuclide (^{94}Nb). After visiting an alfalfa farm in Amargosa Valley it became evident that these operations were not as labor intensive as previously thought. Thus, for the revised DCFs the outdoor exposure duration from Kennedy and Strenge (1992) (1,800 hr/yr) is used. This value can be compared with EPA's recommendation of 730 hr/yr (U.S. Environmental Protection Agency, 1997) for general outdoor activities in the United States. It is expected a farmer would still spend more time outdoors than an average U.S. citizen.

2.3.4.3 Areal Soil Density

The GENII-S code uses a two-compartment soil model developed by Anspaugh (Leigh et al., 1993; Napier et al., 1988). The model accounts for differences in densities between the tilled layer of soil and the more dense lower layer beneath the tilled zone. The fraction of roots contacting either zone is set by the user. If a single-compartment model is desired, the root fraction for the tilled layer is set to 1.0 as is done for the calculations in this report. An important note is that alfalfa utilizes a tap root that can grow to a depth of 20 ft (Stichler, 1991) while other crops such as carrots would be completely within the tilled zone. Therefore, the single-compartment assumption is conservative for some crops and more realistic for others.

The areal soil density (kg/m^2) is the weight of a block of soil with 1 m^2 of surface area and a thickness equal to the plow layer. The deposition of radionuclides (Ci/m^2) (i.e., irrigation water) is divided by the soil density to determine the areal soil concentration (Ci/kg of soil). The soil concentration is then multiplied by the plant/soil concentration ratio to determine the concentration in forage, feed, and crops. These calculations, therefore, define an inverse relationship between areal soil density and dose.

The U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) collects and maintains information resources on the nation's soils. A major soil survey of the Amargosa Valley region of Southern Nevada has been completed and, while unpublished, the information is available upon request. Soil characterization information for agricultural sites in the Amargosa Valley region was obtained from the local Soil Conservation Service (SCS) office in Topopah, Nevada. This information consists of aerial photographs of Amargosa Valley region farms with major soil classification regions identified. Supplementary information provides classifications of the soils associated with the regions outlined on the map, that included the farms. Bulk density measurements on these soils were not conducted for this survey so other sources were consulted.

Taxonomies for the farming soils includes gravelly sandy loam and fine sandy loam. Krynine and Judd (1957) reported an average dry density of a sandy soil as 1.76g/cm^3. An agricultural study of an arid region approximately 50 miles south of Hanford, Washington, reported a range of 1.20 to 1.80 g/cm^3 for a loamy fine sand soil (English and Nakamura, 1989). A soil analyst at the national office of the SCS indicated this range should include any sandy soil. Additional information for each soil type relevant to Amargosa Valley farms is available from the SCS Soil Interpretation Record database which contains estimates of soil densities. Table 2-7 summarizes the information. Each map unit number area

Table 2-7. Primary soil compositions and bulk densities for the soils of four farming areas in Amargosa Valley, Nevada

Map Unit Number	Primary Soil Composition	Percent of Soil	Bulk Density Range (g/cm^3)
2054	Yermo very gravelly sandy loam	55	1.50–1.60
2054	Arizo very gravelly sandy loam	30	1.40–1.55
2054	Arizo very gravelly loamy sand	5	1.45–1.65
2152	Arizo very gravelly sandy loam	85	1.40–1.55
2152	Arizo very gravelly loamy sand	5	1.45–1.65
2153	Arizo very gravelly sandy loam	35	1.40–1.55
2153	Corbilt gravelly fine sandy loam	25	1.35–1.50
2153	Commski very gravelly fine sandy loam	25	Data not available
2070	Shamock gravelly fine sandy loam	93	1.50–1.70
NOTE: The map unit number defines an area in the Amargosa Valley where the U.S. Soil Conservation Service has characterized soil types.			

in table 2-7 represents a unique soil classification area that contains one or more farms. This information is applicable to an area of southwestern Nevada near the Amargosa Desert. The area is bounded by coordinates 116° 37′ 30" to 116° 30′ longitude and 36° 30′ to 36° 35′ latitude.

For the stochastic calculations, a range of 1.35 to 1.70 effectively characterizes the uncertainty in the values considered. This range is less uncertain than the values reported by English and Nakamura (1989) (i.e., 1.20 to 1.80 g/cm^3), and the upper bound is close to the value of 1.75 g/cm^3 reported in Krynine and Judd (1957). To obtain the areal bulk density required by the GENII-S code, the soil density is multiplied by the plow depth of 15 cm and the units are converted to kg/m^2 resulting in a range of 180 to 270. A uniform distribution is assumed since no information was identified to determine a more precise distribution type.

The sensitivity analysis results indicates that surface soil areal density is not important for most radionuclides. There is one relatively moderate ranking for one radionuclide (^{14}C) where the parameter is included in the final regression model. For the revised DCF calculations, the midpoint of the uniform distribution is used.

2.3.4.4 Soil Leaching Factors

The soil leaching factors are used in GENII-S as element-specific loss terms that account for removal of contamination from surface soils through leaching into deeper layers. The model used in GENII-S is based upon an equation by Baes and Sharp (1981).

$$\lambda_{wi} = \frac{P + I - E}{d(1 + \rho/\theta * Kd_{di})} \qquad (2\text{-}1)$$

where

λ_{wi} = leaching factor (yr^{-1})
P = total precipitation (cm/yr)
I = total irrigation (cm/yr)
E = total evapotranspiration (cm/yr)
d = depth of the rooting zone (cm)
ρ = soil bulk density (g/cm^3)
θ = soil volumetric water content (ml/cm^3)
Kd_{di} = distribution coefficient for isotope i (ml/g)

The stochastic dose calculations use the default leach factors in the GENII-S code. The parameters used to generate the default values were not explicitly referenced in the user manual, therefore, for revised DCF calculations, the leach factors are updated using site-specific (or site-relevant) information for total annual precipitation, total annual irrigation, total evapotranspiration, soil bulk density, soil volumetric water content, and Kd values. Kd values for a sandy soil are obtained from Sheppard and Thibuilt (1990). See appendix B for specific values for the above parameters.

2.3.5 Meteorology and Air Dispersion Parameters

The air dispersion model is not emphasized in the literature review due to the conclusion from the IPA Phase 2 dose work indicating this pathway was much less important to the calculated dose relative to the groundwater pathway. Nonetheless, the resuspension pathway is included in exposure scenarios, therefore some parameters are considered.

2.3.5.1 Inhalation and External Plume Exposure Duration

The inhalation exposure duration is used in calculating the dose from inhalation of aerosolized radioactive material and is based upon the time spent indoors and outdoors. The chronic plume exposure is involved in the calculation of external exposure from resuspended material and is also based upon fractions of time spent indoors and outdoors. The stochastic analysis uses the same values for both of the parameters.

For a groundwater exposure scenario, the inhalation exposure component is due to resuspended material deposited from irrigation of soils. In a recent risk assessment of the NTS (Daniels, 1993), human outdoor activity fractions for indoor and outdoor activities are reported from birth to 70 yr. The original source of this information is Wiley et al. (1991) and is based on activity patterns of California residents.

The outdoor activity duration for farmers, however, is much higher than that applicable to average residents who are likely to be involved in indoor occupations. Anspaugh (Daniels, 1993) affirms this view when reporting difficulty in finding activity data for individuals living on farms—"a population likely to spend much more time outdoors."

IPA Phase 2 analyses assumed 73 percent of farming time is spent indoors (Nuclear Regulatory Commission, 1995a). A 0.5 indoor exposure factor was used (Nuclear Regulatory Commission, 1994) to account for the reduced inhalation exposure indoors. This resulted in a value of 5,548 hr/yr for the inhalation exposure duration. If the primary occupation is farming, it was initially thought that more time would be spent out-of-doors than assumed in the Phase 2 analyses. Without further information, other than anecdotal information from an individual with a farming background, a maximum value for the stochastic calculations was assumed to be equivalent to a 15-hr day, 7 days/wk, which results in 7,117 hr/yr when the 0.5 indoor exposure factor is used. A triangular distribution was assumed sloping to the minimum of 5,548 hr/yr from the maximum value under the assumption that the farmer was likely to spend much of the day outdoors.

The sensitivity analysis results indicate that inhalation exposure and chronic plume exposure are not included as important parameters in any of the regression models. Despite the lack of importance, the excessive conservatism of the values used for the stochastic analysis necessitated revision for the updated DCF calculations. Recommended activity values from Kennedy and Strenge (1992) are used for this calculation. The 0.5 indoor exposure factor is again used to adjust indoor inhalation exposures. A 0.33 shielding factor is used for the chronic plume exposure time. The resulting effective inhalation exposure duration is 4,200 hr/yr for a farmer. This duration is based on 4,800 hr/yr indoors, 1,700 hr/yr outdoors, and 100 hr/yr gardening. Forty hr/wk are assumed to be spent offsite for work and other activities. Similar times are assumed for the plume exposure which results in 3,384 hr/yr after consideration of the shielding factor. For the resident scenario, it is assumed that the individual works away from the home and spends about 1 hr/day outdoors and 10 hr/day indoors. This results in an effective exposure time of 2,184 hr/yr.

2.3.5.2 Resuspension and Mass Load Factors

The resuspension factor is used to calculate the resuspension rate constant—the amount of the radioactive material initially deposited to soil by contaminated air or water which is resuspended by wind or other disturbance. The resuspended material is then available for inhalation, external exposure, or redeposition to crops. The resuspension rate constant is the product of the resuspension factor and the deposition velocity. The GENII-S code separates the calculation of resuspension for the inhalation and crop deposition pathways and has an input parameter for each of these pathways. The input parameter applicable to the inhalation pathway can be either a mass loading factor or selection of a model developed by Anspaugh which calculates a time-dependent resuspension factor. For the crop deposition pathway, a resuspension factor is the only option. For the stochastic calculations, a mass loading factor that accounts for agricultural activities that cause resuspension of material (Maheras et al., 1994) is used for inhalation, and a resuspension factor described in the following paragraph is used for the crop deposition pathway.

A number of resuspension models exist which are applicable to NTS conditions (Anspaugh et al., 1975; Sehmel, 1980; Eckhart and Chen, 1993). Resuspension is an uncertain process due to the number of variables which contribute to the amount of material resuspended at a given site. Eckhart and Chen (1993) illustrate these factors in a resuspension model for soils following site restoration of an arid site. They include soil particle size, surface wind, surface roughness, surface cover, time following disturbance, soil adhesion, and saltation flux. Their model results in a range from approximately 10^{-5} to

10^{-9} m^{-1}. Anspaugh, widely known for his work on resuspension and other risk assessment research, reports values ranging from 10^{-3} to 10^{-7} m^{-1} (Anspaugh et al., 1975), however, the values below 10^{-4} m^{-1} are due to artificial disturbances not considered applicable to a farming analysis (Breshears, et. al 1989). Otis (1983) reports a lognormally distributed resuspension factor (10^{-5} m^{-1}) and geometric standard deviation (2.5) applicable to the NTS that incorporates the uncertainty associated with both the deposition velocity and the resuspension factor. The deposition velocity and resuspension factor are multiplied together to determine the resuspension rate; therefore, it is possible to assign the uncertainty in both parameters to one of the two. The value by Otis (1983) is used because it is applicable to southwestern Nevada (i.e., developed for dose assessments of NTS), is less uncertain than the other reported factors, and has a standard deviation by which a probability distribution can be determined. The resulting range for a 95-percent interval is 6.03×10^{-5} m^{-1} to 1.66×10^{-6} m^{-1}. The default values from GENII-S for deposition velocity are used as fixed parameters because the variation is accounted for in the resuspension factor. Note that the aforementioned resuspension factors apply to times immediately after contamination is deposited, and these factors decrease exponentially with time.

The sensitivity analysis results shows that the resuspension factor is sufficiently important to be included in most of the radionuclide-specific final regression models, but is ranked lower than many of the other parameters included in these models. Subsequent further review of the resuspension parameters and models led to an adjustment to the modeling approach.

For the revised DCF calculation, because the mass loading model is favored for the farming scenario, the equation in the GENII-S code to determine an equivalent resuspension factor from the mass load factor is used to ensure consistency between the modeling of inhalation and crop deposition pathways. The equation determines the resuspension factor (m^{-1}) by dividing the mass loading factor (g/m^3) by the surface soil areal density (g/m^2) (Napier et al., 1988). In reviewing the existing information, the mass loading factor for inhalation (5.0E−5 g/m^3) is found to be lower than that recommended in Kennedy and Strenge (1992) for a residential scenario (1.0E−4 g/m^3). The Kennedy and Strenge (1992) value is selected for the revised DCF calculations since it is based upon review of studies involving actual field measurements and is more conservative than the value used in the stochastic calculation. The resulting equivalent resuspension factor for the current biosphere is 4.4E−10 m^{-1}.

For the volcanism exposure scenario, the resuspension model is considered more applicable than the mass load model due to the characteristics of the modeled ash deposition (i.e., thin layer of contamination on ground surface). For this calculation, no specific resuspension information is found for volcanic ash. Therefore, a reasonable, generally applicable initial (i.e., for immediately after the volcanic event) resuspension factor equivalent to 1.0E−6 m^{-1} (International Atomic Energy Agency, 1982 and 1986) is used. An average annual resuspension factor is then calculated from that value using the Anspaugh equation provided in the GENII manual (Napier et al., 1988). Because resuspension modeled using a resuspension factor is a time-dependent process (decreases exponentially with time), resuspension factors for each day of the first year following deposition are averaged over the year to avoid calculation of DCFs based on the unrealistic assumption that the peak resuspension (i.e., 1.0E−6 m^{-1}) occurs at all times after an event to which the DCF will be applied. This average is determined to be 2.0E−7 m^{-1}. There are numerous uncertainties involved in the determination of resuspension factors and, in the absence of site-specific measurements, this admittedly limited approach is the best that could be done for this report.

2.3.5.3 Crop Interception Fraction

The crop interception fraction is the fraction of contamination from rainfall, irrigation, or aerosol deposition which is intercepted by and adheres to the plant surface. Plant surface contamination is then available for ingestion by foraging livestock or the human receptor. The interception fraction varies with plant type and therefore should be based on crops grown near YM.

Anspaugh (1987) summarizes results of 22 laboratory and field studies conducted on a variety of crops in different geographic locations, including the NTS. Approximately half of these studies used artificial sprays while the other half were conducted under natural conditions. Many of the studies focus on the elements Cs and Sr, however a few studies include Pb, I, Ce, Mn, as well. Crops considered include pasture grasses and alfalfa (primarily), but also rye, wheat, barley, corn (and corn silage), beans, cabbage, and potatoes. Anspaugh (1987) summarizes data for grass and alfalfa to determine an interception fraction for forage crops in general. He further mentions that values for other crops are not much different than the forage crop values.

The forage crop value is relevant to YM since alfalfa and grasses represent a major proportion of Nye County cropland and alfalfa is predominant in Amargosa Valley. A recommended range for retention is 0.4 to 0.5, but Anspaugh (1987) mentions a value of 1.0 is not unreasonable for a conservative analysis—particularly in high-density vegetation situations. The lowest value reported is 0.06. Therefore, without additional information about the distribution type other than a range and central value, a triangular distribution is used in the stochastic calculations with a best estimate of 0.40 and a range from 0.06 to 1.0.

Chambers and Mays (1994) discuss home desert gardening and suggest some home gardeners in arid regions cover their vegetable gardens with a sun screening cloth (propped up over the bed about 3 ft) to avoid overexposure to sunlight and quick drying of soil. Such a screen would likely affect the amount of airborne material that can settle onto crops. This is an example of a potential site-specific practice that may influence dose modeling calculations. However, since the screen would have the effect of lowering estimated dose, failure to account for this practice would be conservative and serve to overestimate actual exposures.

The results of the sensitivity analysis (see section 3.4) show the crop interception fraction is the most important parameter in a majority of the radionuclide-specific regression models. The wide input distribution range likely contributes to this result. The data for this parameter are considered very applicable to farming conditions in Amargosa Valley and thus do not need to be revised. The value used for the revised DCF calculations is the midpoint of the distribution used for the stochastic calculations (0.4).

2.3.6 Definition of Parameters for a Pluvial Period Biosphere

Providing the capability to evaluate the effects of potential climate changes on repository performance is a goal for TPA code development in phase 3. In their report on technical bases for YM standards (National Research Council, 1995), the NAS committee note that a glacial climate is probable within the next 10,000 yr and virtually certain over a million-year period. A glacial period is expected to produce conditions at YM that are cooler and wetter than the current climate in the area. Information from climate studies related to YM provide a basis for an initial effort to define a pluvial biosphere for TPA dose calculations. It is expected that this biosphere definition will be further refined in future IPA work.

The NRC provides a comprehensive summary of existing technical information related to anticipated climate change in an issue resolution status report on methods to evaluate climate change and associated effects at YM (Stablien, 1997). That report includes discussion of multiple sources of data that are used to predict climate including: paleodischarge sites, packrat middens, pollen studies, paleolake levels and sediments, groundwater isotopic data, soil properties, tree rings, and erosion studies. A glacial period is expected to result in pluvial conditions in the YM vicinity which are characterized by increases in precipitation, surface water, and decreases in temperature. Emphasis is on changes in precipitation and temperature since these variables largely define climatic conditions. Such changes have the potential to affect the types of human activities that reasonably can be expected to occur in the region and change exposure pathways related to these activities. These changes in exposure pathways can be due to both the nature of the activities and changes in the biosphere conditions.

The initial effort to define a pluvial biosphere for TPA dose calculations uses results of climate predictions and expected temperature and rainfall estimates for YM pluvial conditions (Stablien, 1997) to select a geographic location in the western United States which has conditions similar to the expected YM pluvial. Once a reasonable analogue site was selected, information was collected on agricultural practices to determine the extent of expected activities in a YM pluvial biosphere. While activities other than agriculture can change with climate, agriculture is expected to include many exposure pathways and is, therefore, a key activity on which to focus the initial biosphere definition effort. The analysis is limited to those characteristics of the biosphere and related human activities that can be described with existing data and available information. The effort is further limited in scope by consideration of those processes and pathways that can be modeled by the GENII-S code that is currently being used for the calculation of DCFs for the TPA code. Purely speculative judgements on potential human behaviors are kept to a minimum to limit the scope to reasonably defensible possibilities.

Expected pluvial rainfall conditions are defined by recent estimates and interpretations of changes in mean annual precipitation by Forrester, et al. (1996); Forrester (1996); and Spaulding (1995) which indicate a doubling of current rainfall is expected. A range of estimates from different authors is provided in Stablien (1997), however, the aforementioned authors appear to represent the central tendency of the various estimates. The current rainfall is 6 in. (152 mm) per yr (Dewispelare et al., 1993) resulting in a pluvial rainfall of 12 in. (304 mm) per year. Expected pluvial mean annual temperature (MAT) is determined for YM in recent work by Forrester et al. (1996) to range from 5 to 10 °C (9 to 18 °F). This range is applied to adjust current monthly temperature profiles for extreme southern Nevada, found in Dewispelare et al. (1993) to create expected pluvial monthly temperature ranges for an annual period.

To focus the search for a YM pluvial analogue location, a United States Geological Survey (USGS) geological atlas of the United States (U.S. Department of the Interior, 1970) was first consulted for regional climate and ecology information. Spaulding's (1985) investigation of mummified plant fossils from local packrat middens concludes that the climate (indicated by plant life) at the Nevada test site during the last glacial period (45 kyr ago) was similar to that of present-day northern Nevada (i.e., Steppe shrubs and Juniper woodland were common). The USGS atlas terrestrial vegetation maps confirm that a predominant natural vegetation for northern Nevada is Sagebrush Steppe and Great Basin Sagebrush with smaller pockets of Juniper-pinion forest. The USGS atlas also shows Steppe vegetation extending northward to large sections of eastern Oregon, eastern Washington, and southern Idaho. Since the presence of similar plant ecology is assumed to be an indication of similar climatic conditions, these locations are considered to be generally similar in climate to the estimated Wisconsin glacial period and Northern Nevada and therefore potential candidate areas for a YM pluvial analogue. Rainfall data from the National Weather Service and state registries were then analyzed for selected locations in each of these general areas to find a close match to a mean annual precipitation (MAP) of 12 in. (304 mm) per yr and on MAT that is in the expected pluvial range (45 to 54 °F). A subset of the locations considered is provided in table 2-8.

Table 2-8 shows Idaho has conditions that are closest to the pluvial conditions for both temperature and precipitation at YM. Pendleton, Oregon, also has very similar conditions. Time and resources limited the amount of information that could be gathered on each of these sites, however, a soil survey for Blackfoot, Idaho (U.S. Department of Agriculture, 1973) describes the types of crops grown on soils that are of similar taxonomy as the Amargosa Valley farming soils discussed in LaPlante et al., (1995). While this area is slightly drier than the desired precipitation selection criterion, the difference is small. Due to the availability of relevant information on agricultural crops and soil type, and mean annual climate conditions that are similar to the expected pluvial, Blackfoot is used as a basis for defining agricultural parameters for the pluvial biosphere for this iteration of the DCF calculations. Figure 2-4 shows a comparison of monthly temperature profiles for the expected pluvial versus selected candidate areas. This indicates the Blackfoot area to be very similar to the expected pluvial temperature profile range. Future analyses may be able to gather additional information on the other areas that also have conditions close to the selection criteria.

With a general understanding of climate changes and a pluvial analogue site located, the extent of the changes from the present biosphere to the pluvial biosphere that are likely to impact the exposure scenario are assessed. Parameterization of the pluvial biosphere-based exposure scenario can now be conducted.

Information collected to date indicates that a farming exposure scenario is still applicable to a pluvial biosphere. Other types of human activities are likely to provide less contact with exposure pathways. Residential development is also likely to continue, if not expand, in a wetter and cooler biosphere. The current study includes these two exposure scenarios (farmer and resident) with an emphasis on defining the characteristics of the exposed groups rather than determining the potential locations of their activities. The characteristics that define the group behaviors are general enough to apply to various locations where it is later determined that such activities can exist. Future investigation into variables such as water table rise and soil quality can help to further refine the current understanding of potential locations for farming and residential settlement.

Many of the parameters used in the calculation of dose to a farmer are either not influenced by climate change or have an information base that does not allow such adjustments with precision. These parameters include consumption rates, transfer and uptake factors, crop interception, and soil density. Those that appear likely to be affected by a change to a wetter and cooler biosphere that can be adjusted using available information include: tolerant crop and livestock types, irrigation rates, soil leach factors, the duration of the growing season, precipitation, and evapotranspiration.

The types of crops that might be expected to be grown in a pluvial biosphere are determined from information obtained on crops grown in Blackfoot, Idaho. A soil survey was conducted by the SCS (U.S. Department of Agriculture, 1973) for the 1,388 square miles of Bingham county where Blackfoot is located. Soils in the area are found to be similar in type to soils of Amargosa Valley farms (sandy alluvium and gravelly loams). Agricultural activities on these soils include grazing, and farming of potatoes, alfalfa, small grain, and sugar beets. These uses are similar to current agriculture in Amargosa Valley except potatoes and sugar beets are not known to be grown commercially (however they have been recommended for desert vegetable gardens and were included in previous IPA dose calculations). This

Table 2-8. A subset of candidate pluvial analogue sites based on vegetation, annual precipitation, and temperature

Location	Common Natural Vegetation	Mean Annual Precipitation (in./yr)	Mean Annual Temperature (°F)
Boise, ID	Sagebrush-Steppe	12.11	50.9
Blackfoot, ID	Sagebrush-Steppe	10.81	45.9
Pocatello, ID	Sagebrush-Steppe	12.14	46.4
Elko, NV	Sagebrush-Great Basin	9.93	46.8
Ely, NV	Juniper-pinion Woodland	10.13	44.6
Burns, OR	Sagebrush-Steppe	9.96	44.1
Pendelton, OR	Sagebrush-Steppe	12.02	52.3
Yakima, WA	Sagebrush-Steppe	7.97	49.8
Est. Pluvial YM	Sagebrush-Steppe	12	45–54

indicates that, for the purpose of calculating individual exposures, agricultural practices could remain much the same as today when considering only climate-induced changes to a pluvial biosphere.

In the previous study (LaPlante et al., 1995), and for current biosphere conditions in the present study, irrigation rates are assumed to be near the maximum pumping limit allowed for Amargosa Valley due to the lack of site-specific measurements of irrigation usage. For the stochastic calculation, variation was induced by subtracting various estimates of rainfall from the irrigation limit. For the present study of the pluvial biosphere, crop-specific (alfalfa) irrigation rates from the latest agricultural census (U.S. Department of Commerce, 1994) are considered for Nevada and Idaho. The average irrigation rate for alfalfa in Nevada was 31.2 in./yr (79.2 cm/yr) which is about half of the maximum pumping limit for Amargosa Valley. This is an indication that the irrigation rates used for modeling current conditions based upon pumping limits may be overestimated; however, the extreme south of Nevada is warmer and dryer than the rest of the state, so higher rates would be expected. The irrigation rate for alfalfa in Idaho is 23 in./yr (58 cm/yr). Thus, the average alfalfa irrigation rate in Idaho is 74 percent of the average rate in Nevada. Similar comparisons for vegetables and hay resulted in 62 and 76 percent differences, respectively. The average of the three categories was 71 percent. This difference was applied to the present pumping limit in Amargosa Valley to determine the expected pluvial irrigation of 43 in./yr (109 cm/yr). While there are many uncertainties involved with the determination of this value, it is considered to be more relevant than simply adjusting the current irrigation rates by the expected pluvial rainfall increase, which would not take into account important factors such as temperature and evapotranspiration effects.

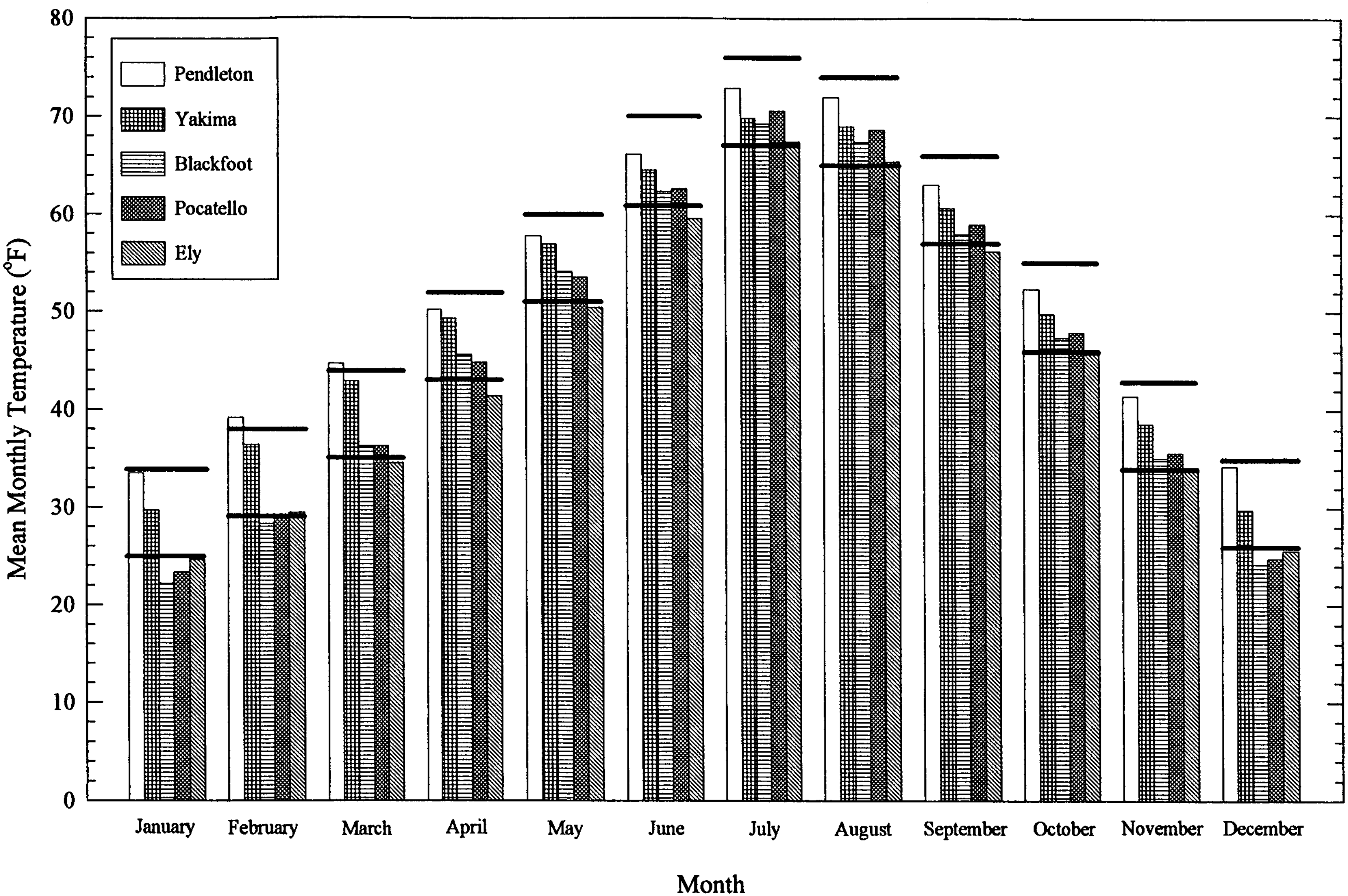


Figure 2-4. Comparison of monthly mean temperatures for selected locations with estimated pluvial biosphere temperature range (dark lines)

The duration of the growing season for crops is used to determine the total duration of irrigation on a plot of land. Changes to duration of the growing season are investigated by first reviewing the estimated pluvial monthly temperature profile (see figure 2-4) to determine the number of months that are likely to be frost-free. The temperature profiles for both the pluvial and current conditions are then compared with current growing season duration information for Nevada desert gardens (Mills, 1993) to gain additional insight into relationships between temperature and growing season. Mills indicates that vegetables begin to show heat stress above 90 °F (32 °C). Between the temperature extremes, plant growth is likely to be controlled by the availability of light. Periods that are currently off-season for most crops include November, December, January (probably due to frost and light conditions), and July (heat), for a total of 4 mo off-season. For the expected pluvial temperature profile, the months of November, December, and January are considered to be off-season due to both temperature and (probably) light conditions. Additional off-season months are assumed to be February and March due to expected below-freezing temperatures, for a total of 5 mo of off-season. This represents a slight reduction in the available growing season for all crops over the entire year. The reduction in extremely hot days, however, should serve to expand the growing season for many vegetable crops that can now only grow during about 3 mo each year due to summer heat and winter cold extremes. The temperature decrease in the pluvial biosphere is expected to provide tolerable conditions for summer crops and thus 3 mo are added to the revised current growing season for fruits and vegetables, and the forage growing season is increased to 7 mo per yr (see table B1). The growing season for grain is not changed since the estimated pluvial growing season would not accommodate more than 2 plantings per season. The amount of time it takes a plant to grow to maturity is not expected to change with expected pluvial conditions.

Precipitation estimates for the pluvial biosphere have already been discussed. The pluvial analogue site in Idaho is chosen based on an expected doubling of rainfall. Upon release of the NRC issue resolution status report on climate change at YM (Stablien, 1997) and further consideration of the information presented in that report, it is noted that Forester (among others) predicted a doubling, but when the standard deviation is taken into consideration, the range spans double to triple the current estimates. Therefore, for the revised DCF and other TPA calculations, the midpoint of this range is used to determine the expected rainfall (2.5 × current). The same DCF calculations have been conducted for a subset of radionuclides using the 2 × rainfall assumption and the results compare well with the results based upon the 2.5 × assumption (no difference for most results, none greater than 3 percent). Therefore, the noted inconsistency in the underlying predicted rainfall assumptions does not significantly change the results.

Current estimates of evapotranspiration for YM from Hevesi and Flint (1994) and from Boulder City, NV (Farnsworth and Thompson, 1982) are reduced by 60 percent to account for the differences in measured pan evapotranspiration from south to north-central Nevada (assumed to be closer to expected pluvial conditions as stated in the preceding paragraphs). Specifically, this represents the percent difference between average May–Oct pan evapotranspiration from the Boulder City station (35° 59', 114° 51') to the Ruby Lake station (40° 12', 115° 30'). The expected pluvial precipitation and evapotranspiration are included in the calculation of a pluvial soil leach factor (loss term for leaching away from root zone due to overwatering soil) using the method described in section 2.3.4.3.

3 SENSITIVITY AND UNCERTAINTY ANALYSIS

3.1 INTRODUCTION

Understanding the effects of parameter uncertainty on calculated doses and determination of which parameters have the most influence on these exposures is an important aspect of IPA work. This information can be used in subsequent iterations to make important modeling decisions and help focus resources on key issues. An uncertainty analysis shows the range of variation in calculated doses that result from sampling input parameters from known or estimated probability distributions. A sensitivity analysis provides insights into which parameters have the greatest influence on dose. While quantification of the parameter uncertainties is the ultimate responsibility of the DOE, use of generally conservative parameter distributions established from reviewing site-specific information provide reasonable initial estimates of parameter uncertainties for the present analysis. This analysis is conducted using a Monte Carlo approach with LHS parameter sampling. Scatterplot analysis and partial raw and rank correlations were calculated for a set of 20 radionuclides in prior work (LaPlante et al., 1995, 1996). For the present study, additional radionuclides are included, and more advanced statistical analysis techniques are used for the sensitivity analysis.

3.2 METHODS

A number of methods are available for conducting uncertainty and sensitivity analysis for radiological dose assessments. These methods have been summarized by Helton et al. (1991) and Iman and Conover (1982). Since the scope for this activity is limited in nature, it is important to choose methods that could be applied efficiently to provide useful insights into the data using available tools. Thus, a scatterplot and multiple regression analysis approach is chosen. The analyses are conducted only on the groundwater concentration-based dose calculations. It is expected that the sensitivities for the soil concentration-based calculations will include a similar set of key parameters since the exposure pathways are very similar, other than the absence of irrigation as a source. A Monte Carlo analysis is favored because (i) parameter uncertainty information is obtained directly from code outputs without use of time consuming or complex analysis procedures, (ii) sampling is conducted on the full range of input distributions allowing the entire range of results to be analyzed, and (iii) results are generated in the proper format for analysis using scatterplot and multiple regression statistical methods.

Scatterplots visually depict the slope and provide some insight into the strength of a correlation between an individual parameter and the output (dose) distribution. When sampling from a number of uncertain parameters, a highly correlated parameter has an association with the calculated dose that is greater than the totality of output variation in the plot contributed by variation of the other input parameters that have relatively lower correlations (i.e., the linear association stands out from the *noise* created by less important parameters). Therefore, scatterplot results provide insight into the relative sensitivity of parameters on the calculated result. This measure of sensitivity can be influenced by many factors (input parameter ranges, code algorithms, the number of important pathways in the calculation), and the scatterplot analysis cannot discern the influence of each. For the present study, scatterplots of input parameter distributions and the calculated TEDE distribution for individual radionuclides are provided. To limit the number of plots, only those parameters determined to have the greatest influence on dose are plotted (see appendix C).

Multiple regression is used for the sensitivity analysis because it provides a best fit (least squares) model which contains those parameters that best explain the variation in the calculated dose distribution. For the present study, standardized regression coefficients (SRC) are calculated for each parameter in the model to show the magnitude by which the calculated dose changes per unit change in an input parameter. Standardization of the coefficient removes the effect of parameter units on the regression results. The SRCs are used to rank parameter importance.

For the sensitivity analysis, stepwise multiple linear regression of the dose output (dependent variable) on all 43 sampled parameter distributions (independent variables) for each radionuclide and 125 vectors are conducted using the STEPWISE code (Iman et al., 1980). The t-tests for inclusion and removal of parameters into the models are conducted using $\alpha = 0.05$ and $\alpha = 0.10$ significance levels, respectively. Plotted residuals for each model are analyzed to check deviations from regression model assumptions. Predicted regression error sum of squares (PRESS) values for each model in the stepwise selection process are plotted and analyzed to select the model with the fewest parameters that explained the most variation in the dose distributions.

Because the PRESS statistic is a measure of the prediction error of each model (Neter et al., 1990) fitted to the dose distribution, it is often desirable to select the model with the lowest PRESS value. Nonetheless, as parameters of low predictive capability are added to the model to explain a small amount of residual variation in the last few models of the stepwise process, the amount of reduction in residual error decreases considerably, even though the fitted parameters meet the statistical significance criteria for inclusion in the model. Thus, to obtain models that only contain parameters that explain the greatest amount of variation in the output (i.e., "key" parameters), models were selected that correspond to the point where the slope of the PRESS curve begins to approach zero (see figure 3-1).

To avoid the undesirable effects of multi-colinearity, it is best to ensure parameters that are independent in nature (i.e., the sampled value of x_1 does not influence the sampled value of x_2) are independent in the modeling analysis. This is largely taken care of by the LHS sampling. Furthermore, for best results, parameters that are correlated in nature should be modeled in a way that accounts for these correlations. While GENII-S allows specification of such parameter correlations, and some correlations were likely to exist, the actual values of these correlations are unknown and were, therefore, not included in this study. Inclusion of simple correlations between very closely related parameters (such as all irrigation rates) is recommended for any future stochastic analyses.

3.2.1 Sampling Methods and Sample Size

The LHS method is used to ensure full stratification across the range of each variable. A sample size of 125 is chosen because tests indicated this is the maximum size the GENII-S code would process using available hardware. With 43 sampled parameters, the chosen sample size was well above the minimum sample estimated by Eq. (3-1) provided by the developers of GENII-S (Leigh, 1992). The sample size is also within 2 to 3 times the number of variables (86 to 129) which has been recommended by Iman and Conover (1982) for best results using LHS for correlation analyses.

$$N = 4/3(n) \tag{3-1}$$

where N is the estimated minimum sample size, and n is the number of sampled parameters.

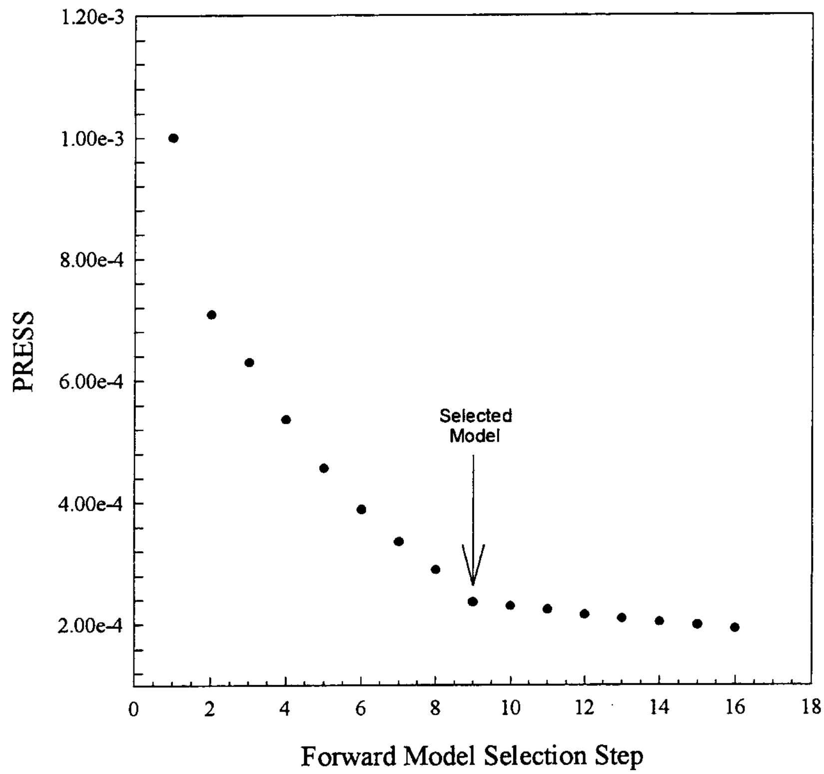


Figure 3-1. PRESS plot used for selection of the best regression model for sensitivity analysis

3.2.2 Dose Assessment Scenario and Assumptions

3.2.2.1 Determination of the Appropriate Dose Endpoint

To determine an appropriate scenario for conducting the uncertainty and sensitivity analysis calculations it is necessary to speculate on the type of standards which are likely to be developed by the EPA for the HLW program. Recent standards promulgated by the EPA that are relevant to radioactive waste disposal are in 40 CFR 191 (U.S. Environmental Protection Agency, 1994) as they apply to the WIPP site in New Mexico. The individual protection requirements in §191.15 require a disposal system be designed to:

> ". . .provide a reasonable expectation that, for 10,000 yr after disposal, undisturbed performance of the disposal system shall not cause the annual committed effective dose, received through all potential pathways from the disposal system, to any member of the public in the accessible environment, to exceed 15 millirems."

By specifying the dose to any individual, the dose is applicable to a maximally exposed individual. Therefore, the endpoint of interest for the stochastic analysis was assumed to be the annual TEDE to an individual using conservative modeling assumptions. The TEDE is defined by the NRC as the sum of external deep dose for 1 yr plus the 50-yr committed effective dose equivalent from 1 yr of intake (Nuclear Regulatory Commission, 1995b). Currently available exposure-to-dose conversion factors are used in calculations for this report. Recently developed Federal guidance on external dose factors (Eckerman and Ryman, 1993) is used to update code defaults. These factors were not available for use in either IPA Phase 2 or 10 CFR Part 20. Default values (in GENII-S) for internal dose and inhalation factors are not changed. These factors are consistent with factors in U.S. Department of Energy (1988b) and are similar to factors in Federal Guidance 11 (Eckerman et al., 1988) used in 10 CFR Part 20.

After the stochastic parameter distributions were determined, the NAS published their recommendations for HLW dose standards. They recommended calculating a dose to the average member of a critical group. This endpoint is less conservative than the maximally exposed individual and, therefore, for revised DCF calculations the risk assessment philosophy and some parameters had to be adjusted accordingly (see chapter 4).

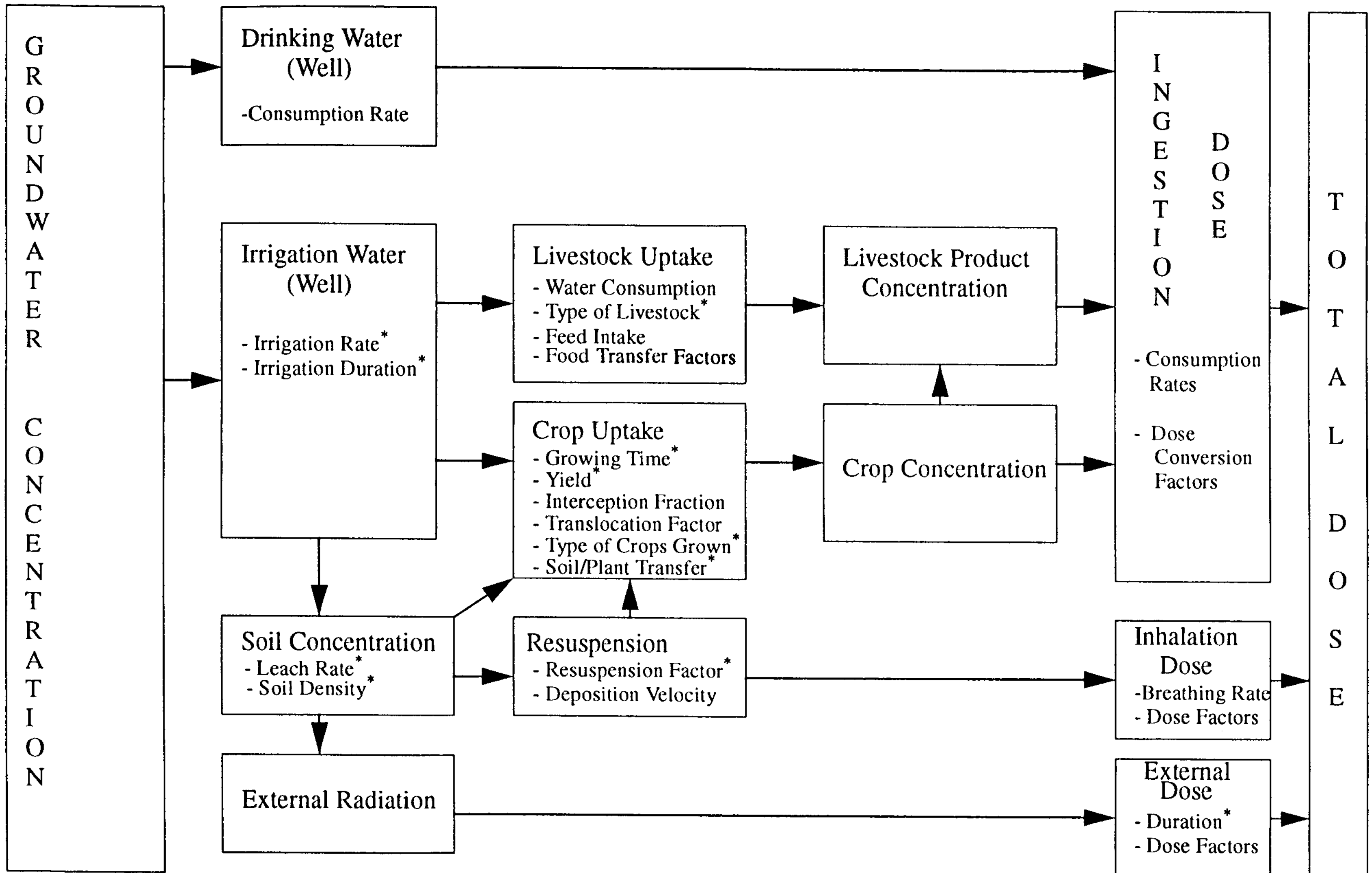
3.2.2.2 Target Individual: The Resident Farmer

The scenario developed for the stochastic calculations consists of a farmer living south of the proposed YM site. The scenario is similar to that used in IPA Phase 2 (Nuclear Regulatory Commission, 1995a). The southern location is chosen because groundwater flows in a south and southeasterly direction from YM (U.S. Department of Energy, 1988b). A potential release of radionuclides is assumed to follow the groundwater flowpath. The farmer is assumed to grow alfalfa, which is used for beef and milk cow feed. A garden plot is used to grow vegetables, fruits, and grain for personal consumption. While available information from Mills (1993) and local water permit records supports the assumption that the farmer grows fruits and vegetables, there is less support for the assumption that grain is grown. Nonetheless, because agricultural statistics indicate a small amount of grain farming in Nye County (section 2.3.2.1), it is assumed possible for the purpose of exploring the importance of that potential exposure pathway. All food from the categories included in the model (i.e., grain, vegetables, fruits, milk, and beef) is assumed grown by the farmer for personal consumption. Drinking and irrigation water was assumed to be pumped from a groundwater well at the farmer's residence. Specific parameter values are discussed in section 2 and are summarized in table B-1 in appendix B. The pathways modeled for the groundwater source scenario are provided in figure 3-2. Applicable pathways for the soil concentration-based scenario (for volcanism) are the same as in figure 3-2 with the groundwater and irrigation water components removed. Adjustments to any of the above assumptions for the revised DCF calculations are provided in chapter 4, and in the parameter discussions in chapter 2.

3.2.2.3 Selection of Radionuclides for the Analysis

The choice of radionuclides for analysis is determined by reviewing other relevant PAs (Sandia WIPP Project, 1992; Eslinger et al., 1993; Duguid et al., 1993; Sandia National Laboratories, 1994; Nuclear Regulatory Commission, 1995a) to achieve a consensus among sources on which radionuclides are important for release and transport at YM. Radionuclide lists vary due to different underlying assumptions for release and transport analyses (for example, accounting for the effects of retardation). Such issues are key technical uncertainties and work continues to reduce these uncertainties to improve modeling assumptions. With such uncertainties, it remains difficult to determine with confidence the predominant radionuclides in release and transport scenarios.

The initial report (LaPlante et al., 1995) focused on 20 radionuclides. For the present study, to fully support dose calculations in the NRC/CNWRA TPA code, the list is increased to include all the radionuclides in DOE's TSPA-93 (Wilson et al., 1994). This is necessary to provide NRC confirmatory review capabilities for all radionuclides under consideration by the DOE. Two of the radionuclides on the



*Examples of Site Specific Parameters

Figure 3-2. Human exposure pathways and parameters applicable to a groundwater release scenario

TSPA-93 list, ^{108m}Ag and ^{238}Pu are not included in the present dose calculations because they are not in the GENII-S radionuclide library. The code could not be modified to include them; however, the DCFs are expected to be similar to ^{110m}Ag and ^{239}Pu, which are included in the analyses.

3.3 PROPAGATION OF PARAMETER UNCERTAINTY ESTIMATES

GENII-S runs were completed and descriptive statistics were calculated for the annual individual TEDE distributions for each radionuclide and source type (see tables 3-1 and 3-2). Cumulative log probability plots of TEDE distributions (in appendix D) suggest most approach a lognormal distribution as is characteristic of results of multiplicative models (Hoffman and Hammonds, 1992). Curve fitting analyses are not conducted on these distributions, but would improve accuracy of predictions based on these data. Additional plots are not provided for the expanded list of radionuclides because most of the initial plots are similar. Both the arithmetic and geometric means and corresponding standard deviations are provided in tables 3-1 and 3-2 as a reference for future analyses. Equations for the geometric mean (x_g) [Eq. (3-2)] and geometric standard deviation (s_g) [Eq. (3-3)] are found in NUREG/CR-3332 (Till and Meyer, 1983):

$$x_g = \text{antilog}\left(\frac{\sum \log x_i}{n}\right) \tag{3-2}$$

$$s_g = \text{antilog}\sqrt{\frac{\sum (\log x_i - \mu)^2}{n}} \tag{3-3}$$

where

μ = the mean of log-transformed TEDE values for a given radionuclide

n = the number of TEDE values for a given radionuclide (i.e., realizations)

x_i = a single TEDE value for a given radionuclide

The range of annual individual TEDEs resulting from the 125 realizations of sampled runs per radionuclide are shown as box plots for each radionuclide in figures 3-3 and 3-4. These plots represent results of propagating input parameter uncertainty estimates to generate the TEDE ranges for each radionuclide and indicate the relative variability in magnitudes of TEDEs across radionuclides. The 25th and 75th percentiles are bounded by the box, and the error bars extend to 10th and 90th percentiles. Circles represent outliers beyond the error bars. A log plot is used because the variation in TEDE among all radionuclides spans many orders of magnitude.

Table 3-1. Arithmetic and geometric means and standard deviations for total effective dose equivalent distributions (rem) calculated using a groundwater concentration of 1 pCi/ℓ

Radionuclide	Arithmetic Mean	Standard Deviation	Geometric Mean	Standard Deviation
Ac-227	3.1E−02	1.2E−02	2.9E−02	1.5E+00
Ag-110m	2.6E−04	6.1E−05	2.5E−04	1.3E+00
Am-241	7.9E−03	2.9E−03	7.4E−03	1.4E+00
Ac-242m	7.6E−03	2.8E−03	7.1E−03	1.4E+00
Ac-243	7.9E−03	2.9E−03	7.4E−03	1.4E+00
C-14	1.9E−05	5.1E−06	1.8E−05	1.3E+00
Cl-36	8.7E−05	4.8E−05	7.8E−05	1.6E+00
Cm-243	5.4E−03	2.0E−03	5.1E−03	1.4E+00
Cm-244	4.3E−03	1.6E−03	4.1E−03	1.5E+00
Cm-245	8.0E−03	3.0E−03	7.5E−03	1.4E+00
Cm-246	8.1E−03	3.0E−03	7.6E−03	1.5E+00
Cs-135	1.0E−04	6.1E−05	8.5E−05	1.8E+00
Cs-137	7.6E−04	4.2E−04	6.6E−04	1.7E+00
I-129	3.1E−03	1.9E−03	2.7E−03	1.8E+00
Mo-93	4.4E−06	1.4E−06	4.2E−06	1.4E+00
Ni-63	3.8E−06	2.3E−06	3.3E−06	1.7E+00
Nb-94	2.0E−04	5.8E−05	1.9E−04	1.4E+00
Ni-59	1.4E−06	8.2E−07	1.2E−06	1.7E+00
Np-237	1.3E−02	4.6E−03	1.2E−02	1.4E+00
Pa-231	2.3E−02	8.7E−03	2.2E−02	1.4E+00
Pb-210	1.3E−02	4.8E−03	1.2E−02	1.4E+00
Pd-107	8.1E−07	4.1E−07	7.2E−07	1.6E+00
Pu-239	1.1E−04	4.0E−05	1.0E−04	1.4E+00
Pu-240	1.1E−04	4.0E−05	1.0E−04	1.4E+00
Pu-241	3.2E−06	1.2E−06	3.0E−06	1.5E+00
Pu-242	1.0E−04	3.8E−05	9.6E−05	1.4E+00
Ra-226	2.8E−03	9.3E−04	2.6E−03	1.4E+00
Se-79	5.2E−05	2.6E−05	4.7E−05	1.6E+00
Sm-151	1.2E−06	4.8E−07	1.1E−06	1.5E+00
Sn-121m	4.3E−05	2.8E−05	3.6E−05	1.9E+00
Sn-126	6.3E-04	2.7E−04	5.8E−04	1.5E+00
Sr-90	6.1E−04	2.6E−04	5.6E−04	1.6E+00
Tc-99	8.4E−06	2.9E−06	7.9E−06	1.4E+00
Th-229	8.1E−03	3.0E−03	7.6E−03	1.4E+00
Th-230	1.2E−03	4.3E−04	1.1E−03	1.5E+00
U-232	2.4E−04	7.5E−05	2.2E−04	1.4E+00
U-233	6.1E−05	2.2E−05	5.8E−05	1.4E+00
U-234	6.1E−05	2.2E−05	5.7E−05	1.4E+00
U-235	8.4E−05	2.4E−05	8.1E−05	1.3E+00
U-236	5.7E−05	2.1E−05	5.3E−05	1.4E+00
U-238	7.2E−05	2.6E−05	6.8E−05	1.4E+00
Zr-93	3.5E−06	1.3E−06	3.3E−06	1.4E+00

Table 3-2. Arithmetic and geometric means and standard deviations for TEDE distributions (rem) calculated using a soil concentration of 1 Ci/m²

Radionuclide	Arithmetic Mean	Standard Deviation	Geometric Mean	Standard Deviation
Ac-227	2.7E+06	1.8E+06	2.3E+06	1.8E+00
Ag-110m	2.3E+05	1.3E+04	2.3E+05	1.1E+00
Am-241	7.0E+05	4.6E+05	5.9E+05	1.8E+00
Am-242m	6.7E+05	4.4E+05	5.6E+05	1.8E+00
Am-243	7.0E+05	4.6E+05	5.9E+05	1.8E+00
C-14	1.4E+00	7.9E−02	1.4E+00	1.1E+00
Cl-36	6.9E+04	4.7E+04	5.9E+04	1.7E+00
Cm-243	4.9E+05	3.2E+05	4.1E+05	1.8E+00
Cm-244	3.9E+05	2.5E+05	3.2E+05	1.8E+00
Cm-245	7.2E+05	4.7E+05	6.0E+05	1.8E+00
Cm-246	7.2E+05	4.7E+05	6.0E+05	1.8E+00
Cs-135	1.0E+04	7.7E+03	7.8E+03	2.1E+00
Cs-137	1.2E+05	5.4E+04	1.1E+05	1.5E+00
I-129	3.3E+05	2.5E+05	2.5E+05	2.1E+00
Mo-93	1.1E+03	2.9E+02	1.0E+03	1.3E+00
Ni-63	4.2E+02	3.6E+02	3.2E+02	2.1E+00
Nb-94	1.3E+05	7.5E+03	1.3E+05	1.1E+00
Ni-59	1.5E+02	1.3E+02	1.2E+02	2.1E+00
Np-237	1.1E+06	7.2E+05	9.6E+05	1.8E+00
Pa-231	2.1E+06	1.3E+06	1.7E+06	1.8E+00
Pb-210	1.2E+06	7.5E+05	9.7E+05	1.8E+00
Pd-107	8.9E+01	6.8E+01	7.1E+01	1.9E+00
Pu-239	1.0E+04	6.3E+03	8.6E+03	1.8E+00
Pu-240	1.0E+04	6.3E+03	8.6E+03	1.8E+00
Pu-241	2.4E+02	1.5E+02	2.0E+02	1.8E+00
Pu-242	9.5E+03	5.9E+03	8.1E+03	1.8E+00
Ra-226	2.4E+05	1.5E+05	2.0E+05	1.8E+00
Se-79	5.2E+03	3.7E+03	4.1E+03	2.0E+00
Sm-151	1.1E+02	7.3E+01	9.4E+01	1.8E+00
Sn-121m	4.6E+03	3.3E+03	3.7E+03	1.9E+00
Sn-126	4.3E+04	3.1E+04	3.5E+04	1.9E+00
Sr-90	7.3E+04	4.3E+04	6.3E+04	1.7E+00
Tc-99	4.6E+03	2.4E+03	4.1E+03	1.6E+00
Th-229	7.3E+05	4.7E+05	6.1E+05	1.8E+00
Th-230	1.0E+05	6.8E+04	8.6E+04	1.8E+00
U-232	1.8E+04	1.1E+04	1.6E+04	1.7E+00
U-233	5.8E+03	3.6E+03	4.9E+03	1.8E+00
U-234	5.7E+03	3.5E+03	4.9E+03	1.8E+00
U-235	1.9E+04	3.8E+03	1.9E+04	1.2E+00
U-236	5.4E+03	3.3E+03	4.6E+03	1.8E+00
U-238	6.6E+03	4.1E+03	5.6E+03	1.8E+00
Zr-93	3.1E+02	2.1E+02	2.6E+02	1.8E+00

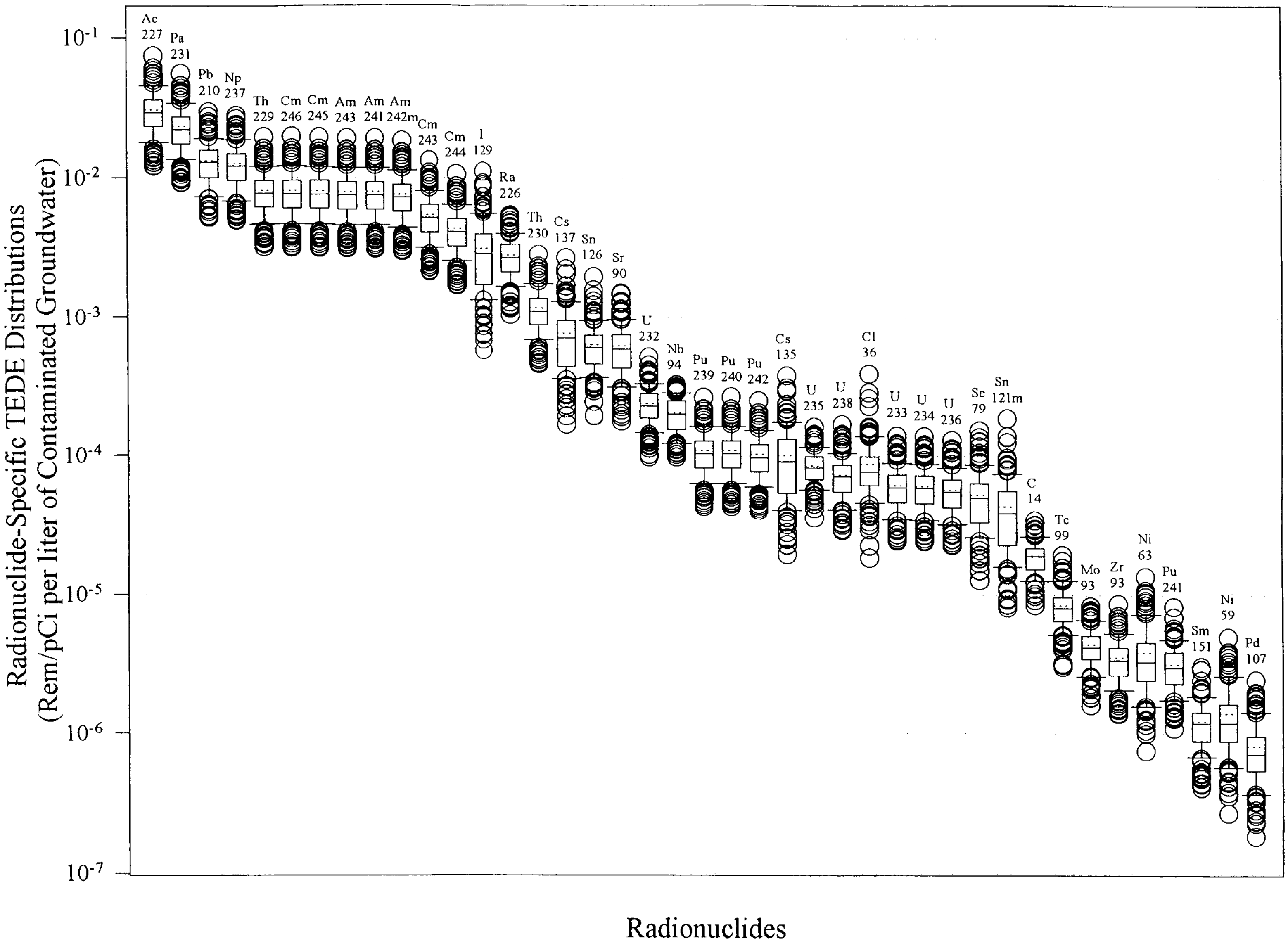


Figure 3-3. Annual individual total effective dose equivalent distributions for each radionuclide for groundwater scenario

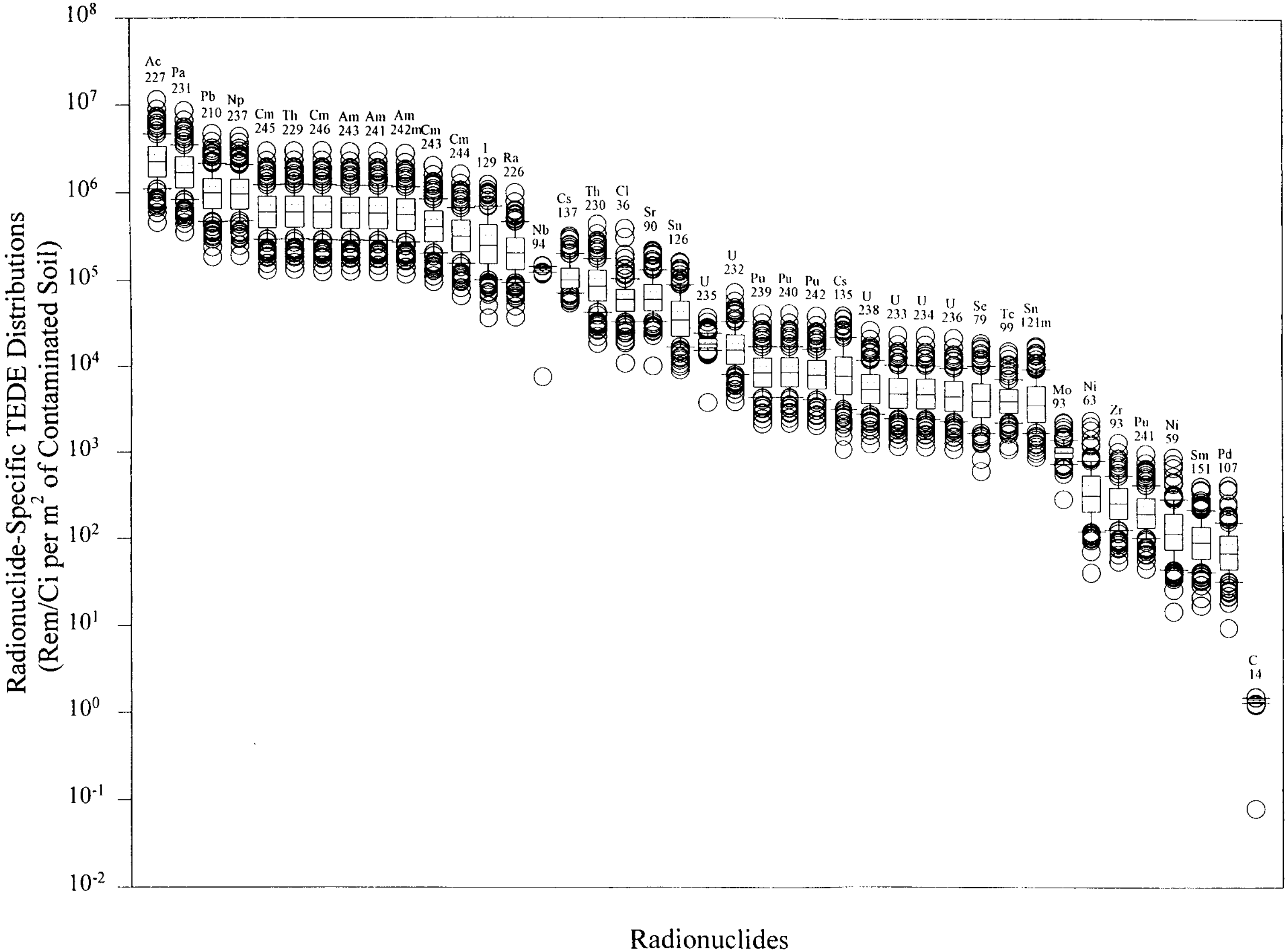


Figure 3-4. Annual individual total effective dose equivalent distributions for each radionuclide for soil contamination scenario

The estimated total TEDE uncertainty range for most radionuclides is approximately 1 order of magnitude or less for the groundwater-based TEDEs and slightly larger than 1 order of magnitude for the soil concentration-based TEDEs. This, however, describes all values in the calculated distribution and includes the few extreme values in the tails. A 95-percent confidence interval provides more useful information on the variation of most points (i.e., 95 percent) about the mean. To illustrate this, an uncertainty factor which bounds the limits of such an interval for most of the distributions in table 3-1 is calculated by selecting a representative geometric standard deviation from the table that bounds most of the values listed and applying Eqs. 3-4 and 3-5. Assuming the TEDE distributions are log normally distributed as indicated by the plots in appendix D, and selecting a representative geometric standard deviation of 1.6 for the groundwater concentration based TEDE distributions, the upper 95-percent limit of the distribution is determined by applying a factor of 2.5 times the geometric mean and the lower 95-percent limit is 0.4 times the geometric mean. A similar calculation done for table 3-2 soil concentration-based TEDE distributions results in an upper 95-percent limit of 3.9 times the geometric mean and a lower limit of 0.26 times the mean. Thus, the variation is less when the extreme tails of the distribution are not considered. A similar effect can be seen graphically by comparing the range represented by the t-bars (10th and 90th percentiles) in the box plots (figures 3-3 and 3-4) with that created by including the outlying circles (full distribution).

The variation among all radionuclides is about 5 orders of magnitude for the groundwater TEDEs and about 7 orders of magnitude for the soil concentration-based TEDEs. The relatively larger uncertainty range for radionuclides of Cs, I, Cl, Ni, Sn, and Pd can be explained by the relatively high transfer rates of these radioelements into the beef and milk food products and the large uncertainties in parameters related to these pathways. The consumption rates for both beef and milk vary widely and increase the variation in TEDEs for those radioelements that readily transfer to animal products. This interpretation is supported by regression results (section 3.4) by showing beef and milk consumption rates to be particularly important in the models for these radioelements.

Figures 3-3 and 3-4 provide insight into which radionuclides have relatively high dose potential for the same level of concentration. This does not mean that radionuclides with relatively low TEDE distributions will not contribute to potentially significant doses nor those that are high will contribute to high doses because the results in the figures are relative, and actual expected TEDE distributions are dependent on the magnitude of the initial radionuclide concentrations in the groundwater at the accessible environment. Nonetheless, the figure does provide insight into how the totality of health physics and environmental characteristics of each radionuclide affect the magnitude of calculated dose.

When reliable initial concentration estimates are available, the TEDEs can be used as factors for conversion of initial concentrations in groundwater and soil to annual individual TEDEs. A review of GENII-S calculations indicates the initial concentration parameter occurs only in linear calculations. Therefore, mean TEDEs in tables 3-1 and 3-2 (which are reported on a per pCi/ℓ of initial concentration basis) can be multiplied by values of radionuclide-specific initial concentration estimates to determine the mean dose for the new initial concentration levels. The standard deviations can be used to determine the distributions for these point estimates. Refer to the latter part of this section for a discussion of estimating total (all-radionuclide) doses using similar methods.

For radionuclide-specific doses that are lognormally distributed (see probability plots in appendix D), the geometric mean TEDE can be multiplied by the new concentration value to determine a new mean TEDE and the geometric standard deviation can be used to estimate the distribution of values about this new mean TEDE. For example, to determine a 95-percent confidence interval for the new geometric mean TEDE, use the following equations:

Upper 95-percent limit:

$$x_{gi} \cdot s_{gi}^{1.96} \tag{3-4}$$

Lower 95-percent limit:

$$x_{gi} / s_{gi}^{1.96} \tag{3-5}$$

where x_{gi} is the geometric mean and s_{gi} is the geometric standard deviation for radionuclide i.

For those TEDEs that approximate normal distributions, both the arithmetic mean and arithmetic standard deviation (separately) are multiplied by the new concentration value and the following equation is used to determine a 95-percent confidence interval about the new arithmetic mean:

$$x_i \pm (1.96) s_i \tag{3-6}$$

where x_i is the arithmetic mean and s_i is the arithmetic standard deviation for radionuclide i.

To verify these techniques, code runs for ^{241}A are repeated with 2, 3, and 10 pCi/ℓ initial concentration values. The resulting arithmetic and geometric mean and standard deviations are shown in table 3-3. Proportional increases in the arithmetic mean and standard deviation result from increases in initial concentration. Proportional increases also result in the geometric mean, however, the geometric standard deviation is unchanged.

The aforementioned method of estimating TEDE distributions for new radionuclide concentrations can be used in place of code runs to determine radionuclide-specific doses for groundwater concentration estimates. Such an approach can be applied to calculating total doses, however, generating the distribution about the mean becomes more complex.

To determine the total TEDE distribution from all radionuclides combined, each unit TEDE distribution must be adjusted by its respective initial concentration value, and these adjusted distributions for all radionuclides must be properly summed to derive a new total TEDE distribution. To ensure the summation is done for doses based upon the same sampled parameter vectors, it is necessary to calculate the adjusted TEDEs and sum results within the same vector across all radionuclides, then sum the vector totals across all vectors to obtain a distribution of total TEDEs. Summary statistics can then be calculated on the resulting distribution.

An attempt was made to incorporate a similar calculational routine into the TPA code; however, the number of calculations required was prohibitive for efficient operation, and there were also some limitations of not integrating the sampling that generated the TEDE's with the internal TPA sampling. The current implementation of TPA, therefore, is based on a deterministic calculation that uses mean TEDEs for DCFs. A deterministic approach for the dose module is reasonable since the variation in the biosphere part of the dose calculation (see figures 3-3 and 3-4) is much less than the variation expected in the geosphere pathways. Updates to these mean DCFs based on a deterministic calculation, using information in this report, are discussed in chapter 4 and included in appendix E. This current approach does not preclude development and use of stochastic methods for dose conversion in future iterations of the TPA code.

Table 3-3. Effect of increases in groundwater concentrations of ^{241}Am on total effective dose equivalent means and standard deviations

Radionuclide Concentration (pCi/ℓ)	Annual TEDE (rem) Arithmetic		Annual TEDE (rem) Geometric	
	Mean	Standard Deviation	Mean	Standard Deviation
1	7.9×10^{-3}	2.9×10^{-3}	7.38×10^{-3}	1.45
2	1.6×10^{-2}	5.9×10^{-3}	1.48×10^{-2}	1.45
3	2.4×10^{-2}	8.9×10^{-3}	2.22×10^{-2}	1.45
10	7.9×10^{-2}	2.9×10^{-2}	7.38×10^{-2}	1.45

3.4 SENSITIVITY ANALYSIS RESULTS

Results of the stepwise multiple regression analysis are summarized in table 3-4. The discussion of results emphasizes those parameters that have been included in final regression models. These regression models (table 3-4) contain the group of parameters that explains most of the variation in a given TEDE distribution. The coefficient of determination (R^2) is a measure of the fraction of total variation in the TEDE distribution that is explained by the regression model. R^2 ranges from 0 to 1 with the higher values indicating a close fit of the model to the data. Due to the large number of regression models run (one for each radionuclide), the resulting models are initially analyzed for similarities in results among radionuclides. Regression models with the same SRCs are placed into the groups that are shown in table 3-4. These groups share many similarities to the groups that were determined in the initial scatterplot and correlation analysis (LaPlante et al., 1995), but a greater number of radionuclides was included in the present analysis. The regression model results are analyzed to determine which parameters are important among most of the models and more specifically to determine which radionuclides are associated with specific exposure pathways.

When all regression models are considered together, some general trends in the results are identified. For this analysis, the inclusion of a parameter in a regression model, by itself, denotes a level of importance above all those parameters that are not included. The selected parameters explain, in the majority of models, about 90 percent of the variation in the respective TEDE distributions. Within each model, the SRCs denote the ranking of importance, and parameters are tabulated by importance in table 3-4. Considering these results, the crop interception fraction is consistently included in a majority of the models and consistently ranked highest in most of these models. The consumption rates for crops are also consistently included in a majority of models along with irrigation duration for vegetables. Drinking water consumption is also selected for most models but is ranked fairly low in most of them. Some parameters are not included in any models. These include home irrigation duration, vegetable and grain growing times, animal product and crop yields, and forage growing durations.

Table 3-4. Summary of radionuclides-specific results showing parameters ranked by SRCs from regression of TEDE distribution on 43 sampled input parameters

^{14}C		^{36}Cl		^{59}Ni, ^{63}Ni	
Grain Cons. Rate	0.79	Soil/Plant Transfer	0.59	Animal Uptake Factor	0.56
Surface Soil Density	−0.38	Animal Uptake Factor	0.49	Milk Cons. Rate	0.50
Fruit Cons. Rate	0.33	Milk Cons. Rate	0.32	Crop Interception Frac.	0.48
Other Veg. Cons. Rate	0.21	Crop Interception Frac.	0.19	Milk Forage Frac.	0.15
Beef Cons. Rate	0.17	Surface Soil Density	−0.13	Milk Feed Irrig. Dur.	−0.14
Milk Cons. Rate	0.16	Beef Cons. Rate	0.12	Milk Feed Irrig. Rate	0.12
Root Irrig. Dur.	−0.16	Other Veg. Cons. Rate	0.11		
Beef Irrig. Dur.	−0.15	Milk Forage Frac.	0.11		
Grain Irrig. Rate	0.14				
Grain Irrig. Dur.	−0.12				
Beef Forage Frac.	0.10				
$R^2 = 0.92$		$R^2 = 0.88$		$R^2 = 0.88$	

^{79}Se		^{90}Sr		^{93}Zr	
Crop Interception Frac.	0.63	Crop Interception Frac.	0.70	Crop Interception Frac.	0.78
Animal Uptake Factor	0.57	Animal Uptake Factor	0.52	Other Veg. Cons. Rate	0.78
Beef Cons. Rate	0.29	Beef Cons. Rate	0.24	Grain Cons. Rate	0.39
Beef Irrig. Dur.	−0.18	Milk Cons. Rate	0.17	Leaf Veg. Cons. Rate	0.22
Milk Cons. Rate	0.14	Beef Irrig. Dur.	−0.15	Fruit Cons. Rate	0.20
Beef Forage Frac.	0.13	Crop Resuspension Factor	0.14	Crop Resuspension Factor	0.18
Crop Resuspension Factor	0.13	Grain Cons. Rate	0.12	Drinking Water Cons.	0.16
Beef Feed Irrig. Rate	0.09	Beef Forage Frac.	0.12	Leafy Veg. Irrig. Dur.	−0.15
		Milk Feed Forage Frac.	0.08	Other Veg. Irrig. Dur.	−0.14
$R^2 = 0.88$		$R^2 = 0.89$		$R^2 = 0.92$	

^{94}Nb		^{93}Mo		^{99}Tc	
Home Irrig. Rate	0.98	Crop Interception Frac.	0.79	Soil/Plant Transfer	0.61
Soil Exposure Dur.	0.18	Grain Cons. Rate	0.28	Crop Interception Frac.	0.49
Crop Interception Frac.	0.08	Animal Uptake Factor	0.26	Other Veg. Cons. Rate	0.36
		Milk Cons. Rate	0.25	Fruit Cons. Rate	0.30
		Leaf Veg. Cons. Rate	0.17	Grain Cons. Rate	0.25
		Fruit Cons. Rate	0.16	Leafy Veg. Cons. Rate	0.20
		Other Veg. Cons. Rate	0.14		
		Drinking Water Cons.	0.14		
		Crop Resuspension Factor	0.12		
		Leaf Veg. Irrig. Dur.	−0.12		
		Other Veg. Irrig. Dur.	−0.11		
$R^2 = 0.99$		$R^2 = 0.91$		$R^2 = 0.87$	

Table 3-4. Summary of radionuclides-specific results showing parameters ranked by SRCs from regression of TEDE distribution on 43 sampled input parameters (cont'd)

^{107}Pd	
Crop Interception Frac.	0.56
Animal Uptake Factor	0.53
Milk Cons. Rate	0.46
Beef Forage Fraction	0.14
Milk Feed Irrig. Dur.	−0.12
Crop Resuspension Factor	0.12
Milk Feed Irrig. Rate	0.11
$R^2 = 0.88$	

^{135}Cs, ^{137}Cs, ^{129}I, ^{121}Sn, ^{126}Sn	
Animal Uptake Factor	0.58
Crop Interception Frac.	0.53
Beef Cons. Rate	0.36
Beef Feed Irrig. Dur.	0.23
Beef Forage Frac.	0.15
$R^2 = 0.84$	

^{151}Sm	
Crop Interception Frac.	0.78
Animal Uptake Factor	0.33
Beef Cons. Rate	0.24
Grain Cons. Rate	0.24
Crop Resuspension Factor	0.17
Beef Feed Irrig. Dur.	−0.14
Fruit Cons. Rate	0.12
Drinking Water Cons.	0.12
Beef Forage Frac.	0.12
Leafy Veg. Cons. Rate	0.11
$R^2 = 0.90$	

^{226}Ra	
Crop Interception Frac.	0.81
Grain Cons. Rate	0.31
Crop Resuspension Factor	0.20
Leafy Veg. Cons.	0.19
Animal Uptake Factor	0.19
Milk Cons. Rate	0.18
Fruit Cons. Rate	0.17
Other Veg. Cons. Rate	0.15
Drinking Water Cons.	0.14
Leafy Veg. Irrig. Dur.	−0.13
Other Veg. Irrig. Dur.	−0.11
$R^2 = 0.93$	

^{227}Ac, ^{110m}Ag, $^{241-243}$Am, $^{243-246}$Cm, ^{237}Np, ^{231}Pa, ^{210}Pb, $^{239-242}$Pu, ^{229}Th, ^{230}Th	
Crop Interception Frac.	0.79
Grain Cons. Rate	0.39
Leaf Cons. Rate	0.21
Fruit Cons. Rate	0.20
Other Veg. Cons. Rate	0.18
Crop Resuspension Factor	0.17
Drinking Water Cons.	0.16
Leafy Veg. Irrig. Dur.	−0.15
Other Veg. Irrig. Dur.	−0.13
$R^2 = 0.92$	

^{232}U, ^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U	
Crop Interception Frac.	0.78
Grain Cons. Rate	0.38
Crop Resuspension Factor	0.17
Leafy Veg. Cons. Rate	0.21
Fruit Cons. Rate	0.20
Other Veg. Cons. Rate	0.18
Drinking Water Cons.	0.13
Leafy Veg. Irrig. Dur.	−0.14
Root Veg. Irrig. Dur.	−0.13
$R^2 = 0.91$	

Scatterplots in appendix C are reviewed in conjunction with the regression analysis results to gain familiarity with the relationships in the data and assess the validity of the linear assumption in the regression analysis. The top four parameters ranked by SRCs are selected for plotting because plots of comparisons with SRCs below the fourth ranked parameter in any group are uncertain and unlikely to provide meaningful information. The scatterplots indicate that most of the top-ranked parameters from the regression modeling exhibit a linear or nearly linear association with the respective TEDE distribution. Scatterplots of parameters ranked below the top exhibit more variation about the simple linear regression line included on the plots. This is expected given that other parameters of similar influence are concurrently being independently sampled and used in the same calculation, causing a noticeable level of background noise variation in the plots. The converse of this effect is evident when pathways are inherently limited and variation from most other parameters is not propagated to the dose distribution. This is shown in the plot of home irrigation rate for ^{94}Nb, which is so limited in its relevant exposure pathways (external exposure to irrigated ground), and so dominated by the importance of the parameter that the variation about the regression line is minimal. From table 3-4, it is apparent that for all the regression models, the amount of total variation in the dose that is explained by the model is very high (about 90 percent) as indicated by the coefficient of determination (R^2) for each model. This indicates a good fit of the model to the data.

The logarithmic distributions of some parameters such as consumption rates and uptake factors, result in sampling of a few values from the extreme high end of the distribution leading to outliers in the plots. These outliers can pull a regression line (or surface) away from the central tendency in the data as can be seen in some of the scatter plots. The outliers were not deleted, however, since they were calculated from the existing parameter distributions and represent rare but possible outcomes. The existence of these outliers can explain why the residual error terms for many of the regression models are somewhat skewed toward negative values when ideally the residuals should contain equal numbers of positive and negative values. This does not compromise the fit of the model to the data to any great degree because the residuals are a small fraction of the magnitude of the predicted and observed (i.e., TEDE) values. Thus, for the purpose of this analysis, the linear regression model provides good fit to the data.

When the radionuclides in table 3-4 are considered together with the ordered parameters, some biologically relevant relationships are apparent. These relationships indicate the importance analysis results are consistent with known properties of radionuclides (enhancing validity of results) and provide insights into important exposure pathways for specific radionuclides.

The largest group (e.g., Np, Pu, Am, Cm) and the uranium group include many alpha emitters that do not readily transfer from the soil to plants relative to the other radionuclides. Alpha particles cannot penetrate the skin and, therefore, must be ingested or inhaled to produce a dose. The parameters included in the regression model, such as the crop interception fraction, resuspension factor, grain, vegetable and fruit consumption rates, and crop irrigation durations indicate the key pathways are surficial deposition of radioactive material from resuspension and irrigation onto crops and subsequent human ingestion of these contaminated crops.

The ^{129}I group, in contrast, show much different results. This difference might be expected since these radionuclides transport through the food chain more readily than those of the aforementioned group. Considering the transfer coefficients in table 2-5, I, Cs, and Se show relatively high transfer factors to beef; and I, in particular, has relatively high transfer to milk. The parameters selected for the regression model (animal uptake, crop interception, beef consumption rate, beef feed irrigation duration, and forage fraction) suggest key pathways are surficial deposition to feed crops, with animal ingestion leading to high relative uptake to meat, and subsequent human consumption. Whicker et al. (1990) in a NTS study showed the crop interception fraction to be highly correlated with calculated doses (around 0.70). This result is consistent with the results of the present study that finds the crop interception fraction to be the most highly ranked parameter for the most radionuclides.

^{14}C is unique among the radionuclides as it is readily incorporated into human and biological systems as carbon dioxide gas or carbohydrates. As such, a separate specific activity model in GENII-S is used for ^{14}C dose analysis. All inhaled or ingested ^{14}C is assumed to be absorbed immediately by the lungs and gastrointestinal tract. The code developers recognized that plants acquire most of their carbon by air but the model assumes the specific activity of ^{14}C (i.e., curies of radionuclide per kg of soluble element) of the environmental media (plants, animals) is equivalent to that of the contaminating medium (air or water) and adds a correction factor for the water/plant transfer. The correlated parameter results, unlike those for the other groups, do not include transfer mechanism related parameters, rather, the ^{14}C is readily incorporated into plants and animal tissues causing the consumption rates and irrigation to have the primary influence on dose for this radionuclide. The appearance of soil density is due to its use in the denominator of the equation to calculate plant ^{14}C concentration (thus the negative correlation).

^{99}Tc is a beta-emitting radionuclide that transports readily through the food chain, however, unlike the ^{129}I group, has very high concentration ratios for soil-to-plant transfer for all plants considered. As a beta emitter, ^{99}Tc must be ingested to obtain a dose. Parameters in this model (plant transfer, crop interception, and all crop consumption rates) suggest key pathways for ^{99}Tc include both external deposition and soil uptake to crops that are then consumed by the resident farmer.

Ni is readily transferred to milk as indicated by its high transfer factor. The regression model for ^{59}Ni and ^{63}Ni include animal uptake, milk consumption, crop interception fraction, and milk forage parameters. This suggests key pathways involving deposition of contamination to soil for uptake by milk cow feed (alfalfa) and direct deposition to crop surface from irrigation water and subsequent human consumption of the contaminated milk.

^{94}Nb is a gamma emitter that does not transfer readily into animal products (it has the lowest milk and beef transfer coefficient of the elements considered). Therefore, external gamma dose is likely to predominate here compared with the other radionuclide groups. The results show a top ranking for home irrigation rate and soil exposure duration at a much more reduced level. These parameters are relevant to the dose calculation for external exposure from air and water deposition of radionuclides to soil. An analysis of dose results for ^{94}Nb indicates external dose is 91.5 percent of the TEDE, thus ^{94}Nb is the only radionuclide of the 20 radionuclides considered where external exposure predominates. The remainder of the radionuclides can be reviewed in a similar manner as those above to identify potential key exposure pathways. These relationships can be helpful when focusing attention to relevant biosphere pathways for specific radionuclides that are expected to be key contributors to source activity at the geosphere/biosphere interface.

4 REVISED DOSE CONVERSION FACTORS

The results of the importance analysis are used to focus attention on key parameters for the next revision of deterministic dose conversion factors for the TPA code. Revisions to DCFs in the TPA code are necessary to account for changes since the last DCFs were calculated (LaPlante et al., 1995), including changes in anticipated standards for a HLW repository that result in a less conservative calculation. Revised DCFs are also necessary to improve documentation of parameter selections. Parameters used for the updated calculations are provided in appendix B and discussed in the relevant sections of chapter 2. Parameters which are ranked important in the sensitivity analysis are given extra scrutiny in the review to ensure their applicability to expected or known conditions in the Amargosa Valley and surrounding areas. Similarly, the sensitivity analysis results allow less attention to be placed on those parameters that are not included in the regression models and therefore determined to be of less importance to the dose results. In cases where site-specific information is not available, an attempt is made to ensure that parameters from generally relevant sources are adequately documented.

4.1 DOSE ASSESSMENT CONTEXT FOR REVISED DOSE CONVERSION FACTORS

An assessment philosophy for compliance determination with applicable standards is assumed to be eventually defined by the standard setting agencies. Until that time, it is reasonable to assume a dose assessment context based upon the general recommendations of the NAS committee (National Research Council, 1995).

For the revised DCF calculations, a reasonable approximation to an average individual in a maximally exposed critical group is assumed to be an Amargosa Valley resident farmer who grows alfalfa for forage, grows half of fruits and vegetables that are consumed, and raises livestock for beef and milk (see description in section 3.2.4.2). Local egg production and consumption (at 30 percent of the rate in Kennedy and Strenge, 1992) was added in the revised calculation due to some preliminary indications that such activities exist in Amargosa Valley. Consumption rates for all local food products except milk and eggs were reduced by 50 percent to accommodate the assumption that 50 percent of these products are locally produced (Nuclear Regulatory Commission, 1994). It is expected that DOE surveys of local consumption habits will provide additional detailed information on all local consumption habits when study results are published. Inadvertent soil ingestion was also included in the revised DCF calculations. This pathway was not included in prior dose calculations. A soil ingestion value of 50 mg/day was used. This value is based on a comprehensive review of the literature and subsequent recommendation by the EPA (U.S. Environmental Protection Agency, 1997).

To gain additional insights into what type of group in the vicinity of YM is most exposed, a need exists to consider a variety of possible groups. Therefore, a non-farming resident individual is also considered. This individual is not limited to locating in areas where farming is possible and thus may exist in closer proximity to the site and receive greater exposures from potential releases. Primary exposure pathways considered for the resident individual include drinking water for a groundwater contamination-based scenario and external and inhalation exposure for a volcanic event/ash-deposition scenario.

All of the lifestyle activities considered for the exposure scenarios have been found to occur in Amargosa Valley, or in Nye County, although not necessarily all by the same individual. Therefore, the farmer scenario is conservative in that there is not likely to exist a group that would be expected to receive higher exposures, but perhaps not excessively so in that all activities are site-specific. Since the critical group is defined by (International Commission on Radiological Protection, 1985) for maximum exposure relative to other potential critical groups, the parameters that describe the magnitude of the group's activities are set to average values to approximate the average member of the most highly exposed critical group. This approach is a shortcut compared to the computationally intensive methods described by the NAS that cannot be efficiently accommodated in IPA computation.

4.2 METHODS

To meet the calculational needs of the TPA code, revised DCFs are calculated for individual pathways for both groundwater and soil (i.e., assumed deposited volcanic ash) unit concentrations and for both today's environment and the expected conditions of a pluvial period biosphere (see section 2.3.6). The deterministic calculation capabilities of GENII-S are used for these calculations. The input parameters for these calculations are listed in table B-1, appendix B. The parameters are those under the Revised Dose Conversion Factor Best Estimate column.

4.3 RESULTS

The results of the revised DCF calculations are provided in appendix E.

5 CONCLUSIONS

5.1 SENSITIVITY ANALYSIS

Results of the scatterplot and multiple regression analysis indicate that a small subset of parameters explain a majority of the variation in radionuclide-specific TEDE distributions. It is not uncommon for dose modeling sensitivity analyses to determine that a relatively small group of important parameters exist among many less important ones. The parameters that are found to be important include the following:

- The crop interception fraction is consistently included in regression models for a majority of radionuclides and consistently ranked highest in most of the regression models
- The crop resuspension factor is moderately important for many radionuclides
- The consumption rates for crops are consistently ranked important for a number of radionuclides
- Animal and plant uptake factors (transfer coefficients and concentration ratios) are important for a select group of biologically mobile elements
- Irrigation duration for vegetable crops are of moderate to low importance, but are sufficiently important to be included in the regression models for calculated dose
- Drinking water consumption is also included in most regression models, but ranked low in most of them

Some parameters that were not considered important to dose for any radionuclides include:

- Home irrigation duration (i.e., lawn watering)
- Vegetable, grain, and forage crop growing durations
- Animal forage and crop yields

The parameter importance results are also assessed to determine predominant pathways and processes that can be inferred from the important parameters associated with specific radionuclides. These predominant pathways and processes are consistent with past analyses conducted using rank and raw correlation techniques on a subset of radionuclides (LaPlante et al., 1995, 1996).

General trends for predominant pathways and processes include surficial deposition from irrigation water and soil resuspension to crop surfaces for most radionuclides and subsequent human consumption of crops. Beef uptake and subsequent human consumption of animal products appears to be important for the ^{129}I, ^{135}Cs, ^{137}Cs, and ^{79}Se group; soil uptake to crops for ^{99}Tc; milk uptake for ^{59}Ni; and external gamma radiation exposure for ^{94}Nb (see Section 3.4). This analysis included a large number of radionuclides, and regression results for additional individual radionuclides are provided for further reference and analysis.

The results of the sensitivity analysis are also used to assess if sufficient information has been gathered on those parameters that are found to be important in the dose calculation. This helps to identify key topics for direction of future resources to improve the bases for parameters that are found to have the greatest impact on dose.

One of the highest ranked parameters in the sensitivity analysis was the crop interception fraction. The literature search (section 2.3.5.3) produced a range of values from a considerable body of field research that is applicable to conditions at YM. Some of this research was conducted at the NTS using alfalfa, a predominant forage/feed crop grown locally in Amargosa Valley. These results, however, range from 0.06 to 1.0, which is practically the entire range of possible values. Future dose modeling efforts should continue to check for new research in this area.

The resuspension factor (section 2.3.5.2) ranks moderate to low in many of the regression models, however, its inclusion indicates some level of importance in relation to the other parameters not included in the models. This parameter varies considerably in nature, is dependent upon local environmental conditions, and is highly uncertain due to lack of site-specific information. For the present study, a generally applicable value is used for the revised DCF calculations and future efforts to further investigate the applicability of this value to local conditions may be helpful in reducing some of the uncertainty in this parameter.

The home irrigation rate (section 2.3.3.1) is a parameter ranked high in the sensitivity analysis, however, for only one radionuclide-specific dose. This association is thought to be related to the lack of food chain mobility of ^{94}Nb, which thereby removes the uncertainty associated with the food pathway parameters. The value for this parameter is also based on site-specific information, although this information is limited to water requirements for growing a lawn in Nye County. The uncertainty associated with this parameter is difficult to reduce due to the likely variabilities in home water use. This and similar local parameter information would ideally be collected by the DOE in household surveys to obtain the most accurate information. A recent visit to the Amargosa Valley provided confirmation that some households currently have green lawns.

The consumption rates (section 2.3.2.4) are also found to be important parameters for many radionuclides in the dose calculation. Consumption rates are highly variable as indicated by the values used from Hoffman et al. (1982) for milk consumption that range from 20.8 to 482 kg/yr. Based upon review of the literature, it does not appear likely that better values currently can be obtained. Due to the local variabilities in eating habits and dieting, and the ever changing suite of popular foods, it is important to have local information on consumption patterns. The DOE has conducted a survey of local demographic characteristics that will include food production and consumption patterns in the areas south of YM. This information will be useful for reducing the uncertainties associated with the currently available consumption rate information.

Animal and plant uptake factors (i.e., transfer coefficients and concentration ratios) (section 2.3.2.8) are found to be important for elements which are biologically mobile (e.g., Tc, Ni, Cl). The information used for these transfer factors is from the IAEA and is considered to be the best available source. If additional stochastic calculations are conducted in the future, it may be prudent to consider incorporating any updates to the uncertainty factors to improve quantification of the range of variation about the expected values of these factors.

Irrigation parameters are also found to be important to dose. New information from the agriculture census suggests that the present rates used for dose assessment may be high. Nonetheless, the irrigation rates based upon the pumping limit in Amargosa Valley are site specific and the census values are averaged over the entire state. The pumping limit values are likely to also include uses other than irrigation. In future work, it may be possible to obtain better information on specific irrigation rates for relevant crops in areas that are similar in climate to Amargosa Valley but have the resources and infrastructure to collect more detailed information on water use.

5.2 UNCERTAINTY ANALYSIS

Uncertainty in individual parameter values is estimated by reviewing available data and selecting ranges conservatively with the intent of determining crude estimates of the true parameter uncertainty. Propagation of the uncertainty of each sampled parameter in the model generates TEDE distributions which reflect the total uncertainty contributed to the output from the sampled input parameters. Results indicate most of the uncertainty that can be expected from the biosphere in dose assessment calculations is less than an order of magnitude. The upper 95-percent limits for most radionuclide specific TEDE distributions are explained by calculated uncertainty factors of 2.5 times and 3.9 times the geometric means for groundwater and soil concentration-based TEDEs, respectively. While the current results are limited by the ability to fully characterize all true parameter uncertainties, the analysis is an improvement over IPA Phase 2 dose assessment analyses that did not propagate any variation in dose assessment input parameters. The present study also builds on the previous CNWRA work (LaPlante et al., 1995, 1996) by adding 21 more radionuclides.

The amount of variation in TEDE distributions is associated with uncertainties in key parameters identified in the importance analysis. Thus, wider variation in TEDEs for ^{107}Pd, ^{59}Ni, ^{63}NI, ^{36}Cl is explained by the high importance of the milk consumption rate, that has a very wide distribution range compared to other radionuclides. Furthermore, for the soil concentration based TEDEs, the relatively large variation in Cs, I, Sn TEDEs that is seen in the groundwater concentration based TEDEs is not evident. This is likely due to the importance of the crop interception fraction for these radionuclides that traps contamination from irrigation water—a process that is absent from the soil-based TEDEs. Conversely, the limited variation shown for ^{94}Nb is likely the result of limited input parameter uncertainty from few relevant pathways due to low biologic mobility. Additional conclusions include the following:

- Figures 3-3 and 3-4 can be used to gain insights into estimated uncertainties within, and variation among, radionuclide-specific TEDE distributions and to understand the combined effects of radionuclide-specific properties (independent of initial concentration) that increase or decrease TEDE results.

- Most TEDE distributions are approximately lognormally distributed as expected for a multiplicative type of model (Hoffman and Hammonds, 1992), as shown in the nearly linear log probability charts in appendix D. Curve fitting techniques can be applied to the data to more accurately model the distributions.

- Available arithmetic and geometric means and standard deviations can be used to efficiently calculate new TEDE distributions when estimates of initial radionuclide concentrations are available. This can be accomplished without additional code runs and processing of raw data. Results of such calculations can be used to rank results by magnitude of TEDE (or recreate figures 3-3) to determine the relative importance of specific radionuclides to the TEDE. Other potential applications include efficient determination of individual dose estimates and distributions for comparison with EPA standards.

- TEDE means and standard deviations are provided for potential future work that may require propagation of uncertainties for dose estimates. Revised deterministic DCFs based on parameter review following the sensitivity analysis and consideration of new HLW standards are provided for current TPA use to improve the technical basis and relevance of the TPA dose calculations to the HLW program.

5.3 SUMMARY

The objectives of this report are to (i) provide pathway DCFs (and their technical bases) for use in the NRC/CNWRA TSPA studies of the YM site, (ii) summarize and document the site-specific and generic information used in modeling the environmental pathways of the YM site, and (iii) present the results of an importance analysis identifying the dose parameters that most influenced the calculation of DCFs. In this regard, tables of revised site-specific DCFs by radionuclide, exposure scenario, exposure pathways, and biosphere type are provided in appendix E. These revised DCFs build on prior dose assessment work, incorporate new information that has been collected since the last iteration of DCFs, and address current expectations for revised dose standards for YM. Parameter information for these DCFs has been updated and expanded to provide a more transparent and comprehensive reference of all parameters values and assumptions used in the DCF modeling. This includes documentation of information used to define a pluvial biosphere. Results from past stochastic analyses are analyzed using more advanced statistical techniques to determine important parameters. Results from the importance analysis help focus attention and resources on key parameters for the revised DCF calculations and provide insights into predominant radionuclide-specific pathways and processes relevant to human exposure assessments at YM. The improvements to the information base and TPA dose assessment capabilities will help the NRC and CNWRA conduct future technical reviews of DOE dose assessment activities and improve the staff's knowledge base for future work in the HLW program.

5.4 RECOMMENDATIONS

- Improved estimates of groundwater concentration at the accessible environment and at locations where water is currently being pumped would be useful for determining the dose-based importance of specific radionuclides. Results from this study can also be used to supplement future efforts to determine important radionuclides for IPA.

- Dose standards must be promulgated with proper guidance to reduce uncertainties in the types of dose assessment calculations and the exposure assessment philosophy that will be necessary to implement standards.

- Interactions with the DOE to discuss their dose assessment parameter information would be helpful to: (i) obtain additional information on dose parameters that was not obtained in the present task, and (ii) gain a better understanding of the DOE progress to date and current insights into dose assessment parameters and techniques to be applied to YM IPA. No attempt was made in the current study to obtain unpublished data from the DOE or to discuss at length any recent studies that may have been conducted by the DOE for the HLW program. Greater interaction with DOE dose assessment staff and review of currently available information in the DOE databases should be conducted to ensure the best available information is being used in TPA dose calculations.

- Information in this report, in conjunction with knowledgeable judgments and future results of reviews of DOE dose assessment activities, can be used to determine if additional site-specific dose parameter research is necessary to reduce uncertainties in important parameters and validate dose assessment assumptions.

- The information in this report should support any NRC efforts to define reference biosphere(s) and potential critical groups to improve NRC IPA dose assessment capabilities for YM. Such information can also help the NRC in their efforts to review the final dose parameters determined by the DOE for their TSPA dose assessments.

6 REFERENCES

Anspaugh, L.R. 1987. *Retention by Vegetation of Radionuclides Deposited in Rainfall—A Literature Summary*. UCRL-53810. Livermore, CA: Lawrence Livermore National Laboratory.

Anspaugh, L.R., J.H. Shinn, P.L. Phelps, and N.C. Kennedy. 1975. Resuspension and redistribution of plutonium in soils. *Health Physics* 29: 571-582.

Baes, C.F., III, and R.D. Sharp. 1981. Predicting radionuclide leaching from root zone soil from assessment applications. *Proceedings of the American Nuclear Society*. CONF-81606. Oak Ridge, TN: Oak Ridge National Laboratory.

Baes, C.F., III, R.D. Sharp, A.L. Sjoreen, and R.W. Shor. 1982. *A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides Through Agriculture*. ORNL-5786. Oak Ridge, TN: Oak Ridge National Laboratory.

Breshears, D.D., T.B. Kirchner, M.D. Otis, and F.W. Whicker. 1989. Uncertainty in predictions of fallout radionuclides in foods and of subsequent ingestion. *Health Physics* 57(6): 943–953.

Breshears, D.D., T.B. Kirchner, and F.W. Whicker. 1992. Contaminant transport through agroecosystems: Assessing relative importance of environmental, physiological, and management factors. *Ecological Applications* 2(3): 285–297.

Chambers, D., and L. Mays, eds. 1994. *The American Garden Guides: Vegetable Gardening*. New York, NY: Pantheon Books.

Daniels, J.I., ed. 1993. *Pilot Study Risk Assessment for Selected Problems at the Nevada Test Site (NTS)*. UCRL-LR-113891. Livermore, CA: Lawrence Livermore National Laboratory.

DeWispelare, A.R., L.T. Herren, M.P. Miklas, and R.T. Clemen. 1993. *Expert Elicitation of Future Climate in YM Vicinity: Iterative Performance Assessment, Phase 2.5*. CNWRA 93-016. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

Duguid, J.O., R.W. Andrews, E. Brandsetter, T.F. Dale, and M. Reeves. 1993. *Total System Performance Assessment—1993: An Evaluation of the Potential Yucca Mountain Repository*. B00000000-01717-2200-00099-Rev. 01. Las Vegas, NV: Intera, Inc.

Eckerman, K.F., and J.C. Ryman. 1993. *External Exposure to Radionuclides in Air, Water, and Soil: Exposure-to-Dose Coefficients for General Application, Based on the 1987 Federal Radiation Protection Guidance*. Federal Guidance Report No. 12. Oak Ridge, TN: Oak Ridge National Laboratory.

Eckerman, K.F., A.B. Wolbarst, and A.C.B. Richardson. 1988. *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*. Federal Guidance Report No. 11. Oak Ridge, TN: Oak Ridge National Laboratory.

Eckhart, R., and H. Chen. 1993. Dust resuspension from soil in a semi-arid environment at the Nevada test site. *Transactions of the American Nuclear Society* 69: 46–49.

Eisenberg, N.A. 1996. *Staff Visit to Amargosa Valley: Trip Report*. Memorandum to M. Federline, Acting Director, Division of Waste Management, Nuclear Regulatory Commission, dated May 14, 1996. Washington, DC: Nuclear Regulatory Commission.

English, M., and B. Nakamura. 1989. Effects of deficit irrigation and irrigation frequency on wheat yields. *Journal of Irrigation and Drainage Engineering* 115(2): 173–184.

Eslinger, P.W., L.A. Doremus, D.W. Engel, T.B. Miley, M.T. Murphy et al. 1993. *Preliminary Total-System Analysis of a Potential High-Level Nuclear Waste Repository at Yucca Mountain*. PNL-8444. Richland, WA: Pacific Northwest Laboratory.

Farnsworth, R.K., and E.S. Thompson. 1982. *Mean Monthly, Seasonal, and Annual Pan Evaporation for the United States*. NOAA Technical Report NWS 34. Washington, DC: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service, Office of Hydrology.

Forrester, R.M. 1996. *Paleoclimate Records — Implications for Future Climate Change*. Presentation to U.S. Nuclear Waste Technical Review Board. July 9–10, 1996 Denver, CO. Washington DC: U.S. Nuclear Waste Technical Review Board.

Forrester, R.M., J.P. Bradbury, C. Carter, A.B. Elvidge, M.L. Hemphill, S.C. Lundstrom, S.A. Mahan, B.D. Marshall, L.A. Neymark, J.B. Paces, S.E. Sharpe, J.F. Whelan, and P.E. Wigand. 1996. *Synthesis of Quaternary Response of the Yucca Mountain Unsaturated and Saturated Zone Hydrology to Climate Change*. Milestone Report 3GCA102M. Denver, CO: U.S. Geological Survey, Yucca Mountain Project Branch.

Helton, J.C., J.W. Garner, R.D. McCurley, and D.K. Rudeen. 1991. *Sensitivity Analysis Techniques and Results for Performance Assessment at the Waste Isolation Pilot Plant*. SAND90-7103. Albuquerque, NM: Sandia National Laboratories.

Hevesi, J.A. and A.L. Flint. 1994. The influence of seasonal climatic variability on shallow infiltration at Yucca Mountain. *Proceedings of the Annual International High-Level Radioactive Waste Management*. La Grange Park, IL: American Nuclear Society: 122–131.

Hoffman, F.O., and J.S. Hammonds. 1992. *An Introductory Guide to Uncertainty Analysis in Environmental and Health Risk Assessment*. ES/ER/TM-35. Oak Ridge, TN: Oak Ridge National Laboratory.

Hoffman, F.O., R.H. Gardner, and K.F. Eckerman. 1982. *Variability in Dose Estimates Associated with the Food Chain Transport and Ingestion of Selected Radionuclides*. NUREG/CR-2612. Washington, DC: Nuclear Regulatory Commission.

Hunt, H., D. Ward, and J. Chen, 1989. *USEPA/Office of Toxic Substances Graphical Exposure Modeling System: GEMS User Guide*. GSC-TR-32-88-018. Laurel, MD: General Sciences Corporation.

Iman, R.L., and W.J. Conover. 1982. *Sensitivity Analysis Techniques: Self-Teaching Curriculum*. NUREG/CR-2350. Washington, DC: Nuclear Regulatory Commission.

Iman, R.L., J.M. Davenport, E.L. Frost, and M.J. Shortencarrier. 1980. *Stepwise Regression With PRESS and Rank Regression (Program User Guide)*. SAND79-1472. Albuquerque, NM: Sandia National Laboratories.

International Atomic Energy Agency. 1982. *General Models and Parameters for Assessing the Environmental Transfer of Radionuclides from Routine Releases*. Safety Series No. 57. Vienna: International Atomic Energy Agency.

International Atomic Energy Agency. 1986. *Derived Intervention Levels for Application in Controlling Radiation Doses to the Public in the Event of a Nuclear Accident or Radiological Emergency*. Safety Series No. 81. Vienna: International Atomic Energy Agency.

International Atomic Energy Agency. 1994. *Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments*. Technical Report Series No 364. Vienna, Austria: International Atomic Energy Agency.

International Commission on Radiological Protection. 1977. *Recommendations of the International Commission on Radiological Protection*. ICRP Publication 26. Annals of the ICRP 1(3). Oxford, UK: Pergammon Press.

International Commission on Radiological Protection. 1985. *Radiation Protection Principles for the Disposal of Solid Radioactive Waste*. ICRP Publication 46. Annals of the ICRP, Vol. 15, No. 4. Oxford, UK: Pergamon Press.

International Union of Radioecologists. 1989. *Sixth Report of the Working Group on Soil-to-Plant Transfer Factors*. Biltoven, The Netherlands: RIVM.

Kennedy, W.E., and D.L. Strenge. 1992. *Residual Radioactive Contamination From Decommissioning: Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent*. NUREG/CR-5512, Vol. 1. Washington, DC: Nuclear Regulatory Commission.

Kercher, J.R., and L.R. Anspaugh. 1984. *Analysis of the NAEG Model of Transuranic Radionuclide Transport and Dose*. UCRL-91781. Livermore, CA: Lawrence Livermore National Laboratory.

Krynine, D.P., and W.R. Judd. 1957. *Principles of Engineering Geology and Geotechnics: Geology, Soil and Rock Mechanics, and Other Earth Sciences as Used in Civil Engineering*. New York, NY: McGraw-Hill Book Company.

LaPlante, P.A., S.J. Maheras, and M.S. Jarzemba. 1995. *Initial Analysis of Selected Site-Specific Dose Assessment Parameters and Exposure Pathways Applicable to a Groundwater Release Scenario at Yucca Mountain*. CNWRA 95-018. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

LaPlante, P.A., S.J. Maheras, and M.S. Jarzemba. 1996. Preliminary analysis of important site-specific dose assessment parameters and exposure pathways applicable to a groundwater release scenario at Yucca Mountain. *Scientific Basis for Nuclear Waste Management XIX, Materials Research Society Symposium Proceedings, vol. 412*. Murphy W.M. and D.A. Knecht, eds. Pittsburgh, PA: Materials Research Society.

Leigh, C.D. 1992. *GENII-S Product Demonstration Workshop Notebook. October 28-29, 1992, Seattle, Washington*. Albuquerque, NM: Sandia National Laboratories.

Leigh, C.D., B.M. Thompson, J.E. Campbell, D.E. Longsine, R.A. Kennedy, B.A. Napier et al. 1993. *User's Guide for GENII-S: A Code for Statistical and Deterministic Simulation of Radiation Doses to Humans from Radionuclides in the Environment*. SAND 91-0561. Albuquerque, NM: Sandia National Laboratories.

Logan, S.E., R.L. Link, H.S. Ng, F.A. Rockenbach, and K.J. Hong. 1982. *Parametric Studies of Radiological Consequences of Basaltic Volcanism*. SAND 81-2375. Albuquerque, NM: Sandia National Laboratories.

Maheras, S.J., A.S. Rood, S.O. Magnuson, M.E. Sussman, and R.N. Bhatt. 1994. *Radioactive Waste Management Complex Low-Level Waste Radiological Performance Assessment*. EGG-WM-8773. Idaho Falls, ID: Idaho National Engineering Laboratory.

Mills, L. 1993. *Beginning Desert Gardening*. Reno, NV: University of Nevada Cooperative Extension.

National Research Council. 1995. *Technical Bases for Yucca Mountain Standards*. Washington, DC: National Research Council: Committee on Technical Bases for Yucca Mountain Standards.

Napier, B.A., R.A. Peloquin, D.L. Strenge, and J.V. Ramsdell. 1988. *GENII: The Hanford Environmental Radiation Dosimetry Software System, Volumes 1, 2, and 3: Conceptual Representation, Users Manual, Code Maintenance Manual*. PNL-6584, Volumes 1, 2, and 3. Richland, WA: Pacific Northwest Laboratory.

Neter J., W. Wasserman, and M.H. Kutner, eds. 1990. *Applied Linear Statistical Models, Third Edition*. Richard D. Irwin, Inc. Burr Ridge, IL.

Nevada Agricultural Statistics Service. 1988. *Nevada Agricultural Statistics: 1, 1987-88*. Reno, NV: Nevada Agricultural Statistics Service.

Nevada Division of Water Resources. 1995a. *Preliminary Summary of Ground Water Pumpage Inventory for Amargosa Valley Basin No. 230 from 1989 through 1993*. Carson City, NV: Nevada Division of Water Resources. (Unpublished).

Nevada Division of Water Resources. 1995b. *Preliminary Special Hydrographic Abstract for Valley Basin No. 230 from the Nevada Division of Water Resources Water Rights Database*. Carson City, NV: Nevada Division of Water Resources. (Unpublished).

Nuclear Regulatory Commission. 1994. *Policy and Guidance Directive PG-8-08: Scenarios for Assessing Potential Doses Associated with Residual Radioactivity*. Washington, DC: Nuclear Regulatory Commission: Division of Waste Management.

Nuclear Regulatory Commission. 1995a. *NRC Iterative Performance Assessment Phase 2: Development of Capabilities for Review of a Performance Assessment for a High-Level Waste Repository*. R.G. Wescott, M.P. Lee, T.J. McCartin, N.A. Eisenberg, R.G. Baca. eds. NUREG-1464. Washington, DC: Nuclear Regulatory Commission.

Nuclear Regulatory Commission. 1995b. *Standards for Protection Against Radiation*. Title 10, Energy, Part 20 (10 CFR Part 20). Washington, DC: U.S. Government Printing Office.

Otis, M.D. 1983. *Sensitivity and Uncertainty Analysis of the PATHWAY Radionuclide Transport Model*. Ph.D. Dissertation. Fort Collins, CO: Colorado State University.

Roseberry, A.M., and D.E. Burmaster. 1992. Lognormal distributions for water intake by children. *Risk Analysis* 12: 99–104.

Sandia WIPP Project. 1992. *Preliminary Performance Assessment for the Waste Isolation Pilot Plant, Volume 3*. SAND92-0700/3. Albuquerque, NM: Sandia National Laboratories: Waste Isolation Pilot Plant Performance Assessment Department.

Sandia National Laboratories. 1994. *Total-System Performance Assessment for Yucca Mountain—SNL Second Iteration (TSPA-1993)*. SAND93-2675. Albuquerque, NM: Sandia National Laboratories.

Sehmel, G.A. 1980. Particle resuspension: A review. *Environmental International* 4: 107–127.

Sheppard, M.I., and D.H. Thibault. 1990. Default soil solid/liquid partition coefficients, K_ds, for four major soil types: A compendium. *Health Physics*, 59: 471–482.

Snyder, S.F, T.A. Ikenberry, W.T. Farris, R.O Gilbert, and B.A. Napier. 1994. *Parameters Used in the Environmental Pathways and Radiological Dose Modules (DESCARTES, CIDER, AND CRD Codes) of the Hanford Environmental Dose Reconstruction Integrated Codes (HEDRIC)*. PNWD-2023 HEDR, Revision 1. Richland, WA: Pacific Northwest Laboratory.

Spaulding, W.J. 1985. *Vegetation and Climates of the Last 45,000 Years in the Vicinity of the Nevada Test Site, South-Central Nevada*. Professional Paper 1329. Washington DC: U.S. Geological Survey.

Spaulding, W.G. 1995. *Climate Change and Groundwater Conditions in the Vicinity of Yucca Mountain — General Conditions*. Las Vegas, NV: Dames and Moore.

Stablien, N.K. 1997. *Issue Resolution Status Report on Methods to Evaluate Climate Change and Associated Effects at Yucca Mountain (Key Technical Issue: Unsaturated and Saturated Flow Under Isothermal Conditions)*. Letter to S. Broccoum, Assistant Manager for Licensing, U.S. Department of Energy, dated June 30, 1997. Washington, D.C.: Nuclear Regulatory Commission.

Stichler, C. 1991. *Texas Alfalfa Production*. B-5017. College Station, TX: Texas Agricultural Extension Service.

Tanner, A.B. 1991. Methods of characterization of ground for assessment of indoor radon potential at a site. *Field Studies of Radon in Rock, Soils and Water, Part 1*. L.C.S. Gundersen and R.B. Wanty, eds. USGS Bulletin 1971. Reston, VA: U.S. Geological Survey.

Till, J.E., and H.R. Meyer. 1983. *Radiological Assessment: A Textbook on Environmental Dose Analysis*. NUREG/CR-3332. Washington, DC: Nuclear Regulatory Commission: Office of Nuclear Reactor Regulation.

U.S. Congress. 1992. *Energy Policy Act of 1992*. Public Law No 102-486. Washington, DC: U.S. Congress.

U.S. Department of Agriculture. 1973. *Soil Survey of Bingham Area, Idaho*. Washington DC: U.S. Department of Agriculture, Soil Conservation Service in Cooperation with the University of Idaho, Idaho Agricultural Experiment Station.

U.S. Department of Commerce. 1989. *Census of Agriculture, Volume 1: Geographic Area Series, Part 28: Nevada State and County Data*. AC87-A-28. Washington, DC: U.S. Department of Commerce.

U.S. Department of Commerce. 1990. *Census of Population: State Reports and Census of Population 2—General Population, Tape 3A*. Washington, DC: U.S. Department of Commerce.

U.S. Department of Commerce. 1994. *Census of Agriculture: Farm and Ranch Irrigation Survey*. Washington, DC: U.S. Department of Commerce.

U.S. Department of Energy. 1988a. *Site Characterization Plan: Yucca Mountain Site, Nevada Research and Development Area, Nevada, Volume II*. DOE/RW-0199. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1988b. *Internal Dose Conversion Factors for Calculation of Dose to the Public*. DOE/EH-0071. Washington, DC: U.S. Department of Energy: Assistant Secretary for Environment, Safety, and Health.

U.S. Department of the Interior. 1970. *The National Atlas of the United States of America*. Washington DC: U.S. Department of the Interior, U.S. Geological Survey.

U.S. Environmental Protection Agency. 1994. *Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*. Title 40, Protection of Environment, Part 191 (40 CFR Part 191). Washington, DC: U.S. Government Printing Office.

U.S. Environmental Protection Agency. 1997. *Exposure Factors Handbook*. Washington, DC: U.S. Environmental Protection Agency.

Whicker, W.F., T.B. Kirchner, D.D. Breshears, and M.D. Otis. 1990. Estimation of radionuclide ingestion: The "pathway" food-chain model. *Health Physics* 59(5): 645–657.

Wiley, J.A., J.P. Robinson, T. Piazza, K. Garrett, K. Cirksena, Y.T. Cheng, and K.G. Martin. 1991. *Activity Patterns of California Residents*. Sacramento, CA: California Air Resources Board: Research Division.

Wilson, M.L., J.H. Gauthier, R.W. Barnard, G.E. Barr, H.A. Dockery, E. Dunn, R.R. Eaton, D.C. Guerin, N. Lu, M.J. Martinez, R. Nielson, C.A. Rautman, T.H. Robey, B. Ross, E.E. Ryder, A.R. Scheneker, S.A. Shannor, L.H. Skinner, W.G. Halsey, J.d. Gansemer, L.C. Lewis, A.D. Lamont, I.R. Triay, A. Meijer, and D.E. Morris. 1994. *Total System Performance Assessment for Yucca Mountain-SNL Second Iteration (TSPA-1993)*. Volume 2. SAND93-2675. Albuquerque, NM: Sandia National Laboratories.

APPENDIX A

AUTOMATED LITERATURE SEARCH CRITERIA

Logon file001 05nov94 09:58:00

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File   2:INSPEC  1969-1994/Oct W5
File   8:Ei Compendex*Plus(TM)  1970-1994/Dec W1
File   6:NTIS  1964-1994/Dec B2
File 103:Energy SciTec  1974-1994/Oct B2
File  41:Pollution Abs  1970-1994/Oct
File  10:AGRICOLA  1979-1994/Sep
   Set  Items  Description
   ---  -----  -----------
   EXS SD036/1-31
   SELECT response set to SHORT.
   S1   10344  NEVADA()TEST()SITE OR YUCCA()MOUNTAIN
   S2   53625  DOSE()ASSESSMENT OR RISK()ASSESSMENT
   S3 1071019  PARAMETER? ?
   S4   44162  PATHWAY? ?
   S5   40784  ENVIRONMENTAL()TRANSPORT
   S6   11641  RADIOACTIVE AND (FALLOUT OR DISPERSION)
   S7      95  S1ANDS2AND(S3ORS4ORS5ORS6)
   S8   18920  RADIOACTIVE AND CONTAMINATION
   S9   20770  PLANT? ? AND UPTAKE
  S10   34595  VEGETABLE? ?
  S11   11318  ALFALFA
  S12     118  FEED()CROP? ?
  S13   16298  FORAGE
  S14   44367  FRUIT? ?
  S15  195815  GRAIN? ?
  S16   18965  BEEF
  S17   20026  POULTRY
  S18   41769  MILK
  S19   23823  EGG OR EGGS
  S20     396  SOIL()LEACH?
  S22      48  SOIL()UPTAKE
  S23      64  DESERT()AGRICULTURE
  S24     882  MUNICIPAL()WATER AND (DETECT? OR TREAT? OR REMOVAL)
  S25    1364  S8AND(S9ORS10ORS11ORS12ORS13ORS14ORS15ORS16ORS17ORS18ORS-
               19ORS20ORS22ORS23ORS24)
  S26       5  (GENII OR DITTY) AND (PARAMETER? ? OR SENSITIVITY)
  S27    1462  S7ORS25ORS26
  S28    1188  S27/ENG
  S29     449  S28/1989:1994
  S30     956  RD S28 (unique items)

  S31     352  S30/1989:1994  [Off-line prints ordered]

  S32     604  30NOT31
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APPENDIX B

INPUT PARAMETER VALUES

Table B-1. Input parameter information

Parameter	Inputs for Stochastic Calculation				Revised Dose Conversion Factor Best Estimate	Comments
	Minimum	Best Estimate	Maximum	Distribution		
Population/Soil/Scenario Data						
Population Scale Factor		1.0		Fixed	1.0	
Soil/Plant Transfer Scale Factor	0.26		3.9	Log Normal	N/A	Section 2.3.2.8
Animal Uptake Scale Factor	0.26		3.9	Log Normal	N/A	Section 2.3.2.8
Human Dose Factor Scale Factor		1.0		Fixed	N/A	
Surface Soil Plow Depth (cm)		15		Fixed	15	Section 2.3.4.1
Surface Areal Soil Density (kg/m^2)	180	225	270	Uniform	225	Section 2.3.4.3
Deep Areal Soil Density (kg/m^3)		1,500		Fixed	1,500	N/A due to 0% Deep Soil Root Fraction Assumed
Roots in Upper Soil (Fraction)		1.0		Fixed	1.0	Conservative Assumption—All roots in upper soil
Roots in Deep Soil (Fraction)		0.0		Fixed	0.0	Conservative Assumption—No roots in deep soil
External/Inhalation Exposure						
Chronic Plume Exposure (hr)	5,548	7,116	7,117	Triangular	3,384 (farmer) 2,184 (resident)	Section 2.3.5.1
Inhalation Exposure (hr/yr)	5,548	7,116	7,117	Triangular	4,200 (farmer) 2,184 (resident)	Section 2.3.5.1
Mass Load (g/m^3)		5.0E-5		Fixed	4.6E-2 (ash) 1.0E-4 (soil)	Mass loading model used but value was adjusted to match resuspension factors used for crop deposition model
Soil Exposure Duration (hr)	5,548	7,116	7,117	Triangular	1,800 (farmer) 364 (resident)	Section 2.3.4.2

Table B-1. Input parameter information (cont'd)

Parameter	Inputs for Stochastic Calculation: Minimum	Best Estimate	Maximum	Distribution	Revised Dose Conversion Factor Best Estimate	Comments
Home Irrigation Rate (in./yr)	26	55	84	Uniform	58 (current) 41 (pluvial)	Section 2.3.3.1, upper end of range was corrected as 91 and midpoint 58.
Home Irrigation Duration (mo/yr)	6	9	12	Uniform	9 (current) 12 (pluvial)	Section 2.3.3.2, 2.3.6
Ingestion Exposure						
Crop Resuspension Factor (m^{-1})	1.66E-6	1.0E-5	6.03E-5	Log Normal	2.0E-7 (ash) 4.4E-10 (soil)	Section 2.3.5.2
Crop Deposition Velocity (m/s)		0.001		Fixed	0.001	Section 2.3.5.2
Crop Interception Fraction	0.06	0.40	1.0	Triangular	0.40	Section 2.3.5.3
Soil Ingestion Rate (mg/day)				Fixed	50	Section 4.1 Replaced Default Data with current EPA Recommended Value
Drink Water Holdup Duration (days)		0		Fixed	0	No municipal system—well water used
Drink Water Consumption (ℓ/yr)	113		1,081	Log Normal	730	Section 2.3.3.5—EPA and NRC recommended 2ℓ/day.
Terrestrial Food Ingestion						
Leaf Vegetable—Grow Duration (days)	40	80	120	Uniform	80	Section 2.3.2.2
Other Vegetable—Grow Duration (days)	25	85	120	Uniform	85	Section 2.3.2.2
Fruit—Grow Duration (days)	65	80	95	Uniform	80	Section 2.3.2.2
Grain—Grow Duration (days)	60	75	90	Uniform	75	Section 2.3.2.2
Leaf Vegetable—Irrigation Rate (in./yr)	50	54	56	Empirical	60 (current) 43 (pluvial)	Section 2.3.3.3 Section 2.3.6
Other Vegetable-Irrigation Rate (in./yr)	50	54	56	Empirical	60 (current) 43 (pluvial)	Section 2.3.3.3 Section 2.3.6

Table B-1. Input parameter information (cont'd)

Parameter	Inputs for Stochastic Calculation				Revised Dose Conversion Factor Best Estimate	Comments
	Minimum	Best Estimate	Maximum	Distribution		
Fruit—Irrigation Rate (in./yr)	50	54	56	Empirical	60 (current) 43 (pluvial)	Section 2.3.3.3 Section 2.3.6
Grain—Irrigation Rate (in./yr)	50	54	56	Empirical	60 (current) 43 (pluvial)	Section 2.3.3.3 Section 2.3.6
Leaf Vegetable—Irrigation Duration (mo/yr)	3	5.5	8	Uniform	3.0 (current) 6.0 (pluvial)	Section 2.3.3.4 Section 2.3.6
Other Vegetable—Irrigation Duration (mo/yr)	2	5	8	Uniform	5.0 (current) 6.0 (pluvial)	Section 2.3.3.4 Section 2.3.6
Fruit—Irrigation Duration (mo/yr)	2	2.5	3	Uniform	2.5 (current) 6.0 (pluvial)	Section 2.3.3.4 Section 2.3.6
Grain—Irrigation Duration (mo/yr)	6	7	8	Uniform	5 (current) 5 (pluvial)	Section 2.3.3.4, 2.3.6. Changed to be consistent with grow time for 2 plantings per season
Leaf Vegetable—Yield (kg/m^2)	0.618	2	6.47	Log Normal	2	Section 2.3.2.3
Other Vegetable—Yield (kg/m^2)	0.769	4	20.8	Log Normal	4	Section 2.3.2.3
Fruit—Yield (kg/m^2)	.3	0.54	2.0	Triangular	3	Section 2.3.2.3—Original midpoint (0.54) converted to wet wt
Grain—Yield (kg/m^2)	0.471	0.54	0.605	Uniform	0.54	Section 2.3.2.3
Leaf Vegetable—Holdup (days)		1		Fixed	1	Kennedy and Strenge (1992)
Other Vegetable—Holdup (days)		14		Fixed	14	Kennedy and Strenge (1992)
Fruit—Holdup (days)		14		Fixed	14	Kennedy and Strenge (1992)
Grain—Holdup (days)		14		Fixed	14	Kennedy and Strenge (1992)

Table B-1. Input parameter information (cont'd)

Parameter	Inputs for Stochastic Calculation				Revised Dose Conversion Factor Best Estimate	Comments
	Minimum	Best Estimate	Maximum	Distribution		
Leaf Vegetable—Consumption Rate (kg/yr)	4.27	11	28.3	Log Normal	6	Section 2.3.2.4—Original values halved to account for 50% of food produced locally
Other Vegetable—Consumption Rate (kg/yr)	11.3	51	231	Log Normal	26	Section 2.3.2.4—Original values halved to account for 50 percent of food produced locally
Fruit—Consumption Rate (kg/yr)	10.2	46	208	Log Normal	23	Section 2.3.2.4—Original values halved to account for 50 percent of food produced locally
Grain—Consumption Rate (kg/yr)	15.3	69	312	Log Normal	34	Section 2.3.2.4—Original values halved to account for 50 percent of food produced locally
Animal Product Consumption						
Beef—Consumption Rate (kg/yr)	22.1	59	157	Log Normal	29.5	Section 2.3.2.4—Original values halved to account for 50 percent of food produced locally
Poultry—Consumption Rate (kg/yr)		0		Fixed	0	N/A
Milk—Consumption Rate (kg/yr)	20.8	100	482	Log Normal	0	Section 2.3.2.4
Eggs—Consumption Rate (kg/yr)		0		Fixed	3	Section 4.1—Eggs added based on information that Amargosa residents consume local eggs. 30 percent of eggs assumed local.

Table B-1. Input parameter information (cont'd)

Parameter	Inputs for Stochastic Calculation				Revised Dose Conversion Factor Best Estimate	Comments
	Minimum	Best Estimate	Maximum	Distribution		
Beef—Holdup (days)		20		Fixed	20	Kennedy and Strenge (1992)
Poultry—Holdup (days)		0		Fixed	0	N/A
Milk—Holdup (days)		1		Fixed	1	Kennedy and Strenge (1992)
Eggs—Holdup (days)		0		Fixed	1	
Beef—Contaminated Water (Fraction)		1		Fixed	1	Assumption—all water from same well
Poultry—Contaminated Water (Fraction)		0		Fixed	0	N/A
Milk—Contaminated Water (Fraction)		1		Fixed	1	Assumption—all water from same well
Eggs—Contaminated Water (Fraction)		0		Fixed	1	Egg pathway added, all water assumed from same well
Fresh Forage Data						
Beef Forage—Dietary Fraction	0.3		0.82	Normal	0.56	Section 2.3.2.6
Milk Cow Forage—Dietary Fraction	0.3		0.82	Normal	0.56	Section 2.3.2.6
Beef Forage—Grow Duration (days)	30	46	62	Uniform	46	Section 2.3.2.5
Milk Forage—Grow Duration (days)	30	46	62	Uniform	46	Section 2.3.2.5
Beef Forage—Irrigation Rate (in./yr)		54		Empirical	60 (current) 43 (pluvial)	Section 2.3.3.3—Maximum permitted amount for Amargosa (adjusted for pluvial—Section 2.3.6)

Table B-1. Input parameter information (cont'd)

Parameter	Inputs for Stochastic Calculation				Revised Dose Conversion Factor Best Estimate	Comments
	Minimum	Best Estimate	Maximum	Distribution		
Milk Forage—Irrigation Rate (in./yr)		54		Empirical	60 (current) 43 (pluvial)	Section 2.3.3.3—Maximum permitted amount for Amargosa (adjusted for pluvial—Section 2.3.6)
Beef Forage—Irrigation Duration (mo/yr)	3	5.5	8	Uniform	5.5 (current) 7 (pluvial)	Section 2.3.3.4 Section 2.3.6
Milk Forage—Irrigation Duration (mo/yr)	3	5.5	8	Uniform	5.5 (current) 7 (pluvial)	Section 2.3.3.4 Section 2.3.6
Beef Forage—Yield (kg/m^3)	0.34	0.78	1.23	Uniform	1.23	Section 2.3.2.6—Used Nye County value for alfalfa, which was the previous upper end value for the distribution.
Milk Forage—Yield (kg/m^3)	0.34	0.78	1.23	Uniform	1.23	Section 2.3.2.6—Used Nye County value for alfalfa, which was the previous upper end value for the distribution.
Beef Forage—Storage Duration (days)				Fixed	20	Kennedy and Strenge (1992)
Milk Forage—Storage Duration (days)				Fixed	1	Kennedy and Strenge (1992)
Stored Feed Data						
Hen—Drinking Water Dietary Fraction					1	Assumed all water from well
Hen—Fraction of Contaminated Feed					1	Assumed all feed was from grain harvest

Table B-1. Input parameter information (cont'd)

Parameter	Inputs for Stochastic Calculation: Minimum	Best Estimate	Maximum	Distribution	Revised Dose Conversion Factor Best Estimate	Comments
Hen—Drinking Water Source					Contaminated Groundwater	
Hen Feed—Storage Duration (days)					14	Kennedy and Strenge (1992) (for Grain)
Hen Feed—Grow Duration (days)					75	Section 2.3.2.2.— Hen feed is Grain
Hen Feed—Irrigation Rate (in./yr)					60 (current) 43 (pluvial)	Section 2.3.3.3 Section 2.3.6
Hen Feed—Irrigation Duration (mo/yr)					5	Section 2.3.3.4
Hen Feed—Yield (kg/m^2)					0.54	Section 2.3.2.3
Miscellaneous Default Parameters						
Absolute Humidity (kg/m^3)		0.008			0.008	GENII-S Default
Leaf Surface Resuspension Factor (m^{-1})		1.0E-9			1.0E-9	GENII-S Default
Biomass (wet kg/m^2)						
Leafy Vegetables		2			2	GENII-S Default
Other Vegetables		2			2	
Fruits		3			3	
Grain		0.8			0.8	
Beef Feed—Stored		0.8			0.8	
Poultry Feed—Stored		0.8			0.8	
Milk Feed—Stored		1			1	
Laying Hen Feed—Stored		0.8			0.8	
Beef Forage—Fresh		1			1	
Milk Forage—Fresh		1.5			1.5	
Weathering Half Time (da)		14			14	GENII-S Default

Table B-1. Input parameter information (cont'd)

Parameter	Inputs for Stochastic Calculation				Revised Dose Conversion Factor Best Estimate	Comments
	Minimum	Best Estimate	Maximum	Distribution		
Translocation Fractions						GENII-S Defaults from Reg. Guide 1.109
Leafy Vegetables		1.0			1.0	
Other Vegetables		0.1			0.1	
Fruit		0.1			0.1	
Grain		0.1			0.1	
Translocation—Animal						GENII-S Defaults from Reg. Guide 1.109
Beef Feed—Stored		0.1			0.1	
Poultry Feed—Stored		0.1			0.1	
Milk Feed—Stored		0.1			0.1	
Laying Hen Feed—Stored		0.1			0.1	
Beef Forage—Fresh		1.0			1.0	
Milk Forage—Fresh		1.0			1.0	
Animal Water Consumption Rates (kg/day)						GENII-S Defaults updated using International Atomic Energy Agency (1994)
Beef Cow		50			60	
Poultry		0.3			0.3	
Milk Cow		60			100	
Laying Hen (eggs)		0.3			0.3	
Animal Consumption Rates (wet—kg/day)						GENII-S Defaults updated using International Atomic Energy Agency (1994)
Beef Feed—Stored		68			33	
Poultry Feed—Stored		0.12			0.08	
Milk Feed—Stored		55			73	
Laying Hen Feed—Stored		0.12			.11	
Beef Forage—Fresh		68			33	
Milk Forage—Fresh		55			73	
Chronic Breathing Rate (cm^3/sec)		270			270	GENII-S Default
Acute Breathing Rate (cm^3/sec)		330			330	GENII-S Default and 10 CFR 20, Appendix B value

Table B-1. Input parameter information (cont'd)

Parameter	Inputs for Stochastic Calculation				Revised Dose Conversion Factor Best Estimate	Comments
	Minimum	Best Estimate	Maximum	Distribution		
Dry/Wet Ratio						GENII-S defaults updated to conform to conversions used in Kennedy and Strenge (1992)
Leafy Vegetables		0.1			0.20	
Other Vegetables		0.25			0.25	
Fruit		0.18			0.18	
Grain		0.18			0.91	
Beef—Stored Feed		0.18			0.22	
Poultry—Stored Feed		0.18			0.22	
Milk Cow—Stored Feed		0.18			0.22	
Hen (Eggs)—Stored Feed		0.18			0.91	
Beef Cattle—Fresh Forage		0.20			0.22	
Milk Cow—Fresh Forage		0.20			0.22	
Organ Weighting Factors		See 10 CFR 20.1003			See 10 CFR 20.1003	
Leaching Factor Parameters						Sections 2.3.4.4, 2.3.6 (pluvial)
Total Annual Precipitation (cm/yr)		Unknown Default			15 (current) 37.5 (pluvial)	
Total Annual Irrigation Rate (cm/yr)		Unknown Default			152 (current) 108 (pluvial)	Maximum Permissible Pumping Limit for Properties in Amargosa (Nuclear Regulatory Commission, 1995a). Adjusted for pluvial.
Total Annual Evapotranspiration (cm/yr)		Unknown Default			80 (current) 48 (pluvial)	NOAA NV pan evaporation data (Farnsworth and Thompson, 1982) and Hevesi and Flint (1994)

Table B-1. Input parameter information (cont'd)

Parameter	Inputs for Stochastic Calculation				Revised Dose Conversion Factor Best Estimate	Comments
	Minimum	Best Estimate	Maximum	Distribution		
Soil Volumetric Water Content (ml/cm^3)		Unknown Default			0.35	Total porosity of gravelly sandy loam soil type from Tanner (1991). Soil type is similar to farming soils in Amargosa Valley.
Soil Partition Coefficients (Kd) (ℓ/kg)		Unknown Defaults			Various	Source: Sheppard (1990) Kd values for many radionuclides for sandy soils

APPENDIX C

SELECTED SCATTERPLOTS OF PARAMETER VERSUS TOTAL EFFECTIVE DOSE EQUIVALENT DISTRIBUTIONS

^{14}C

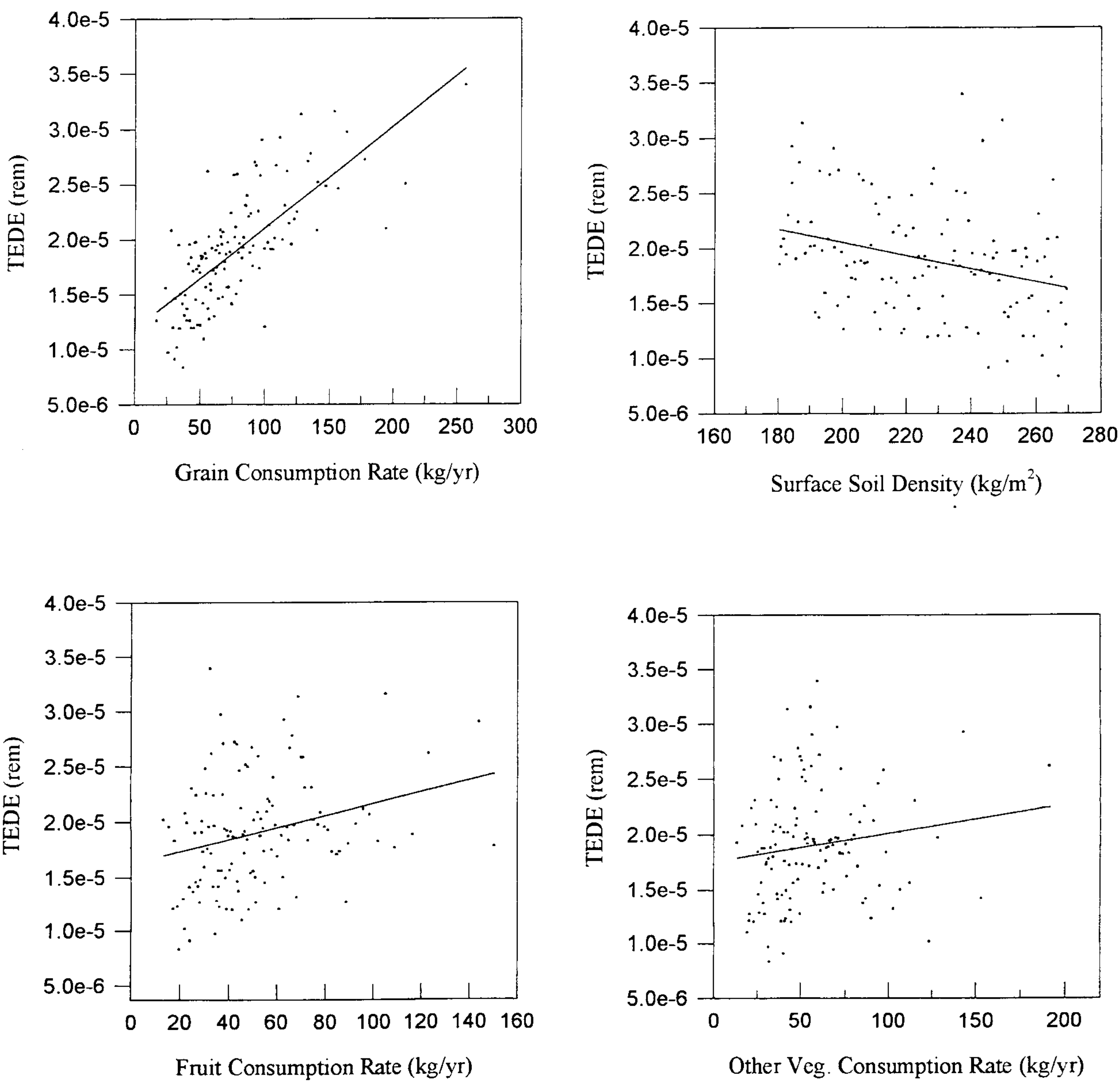

Figure C-1. Scatterplots of input parameters versus ^{14}C total effective dose equivalent distribution for the top four important parameters

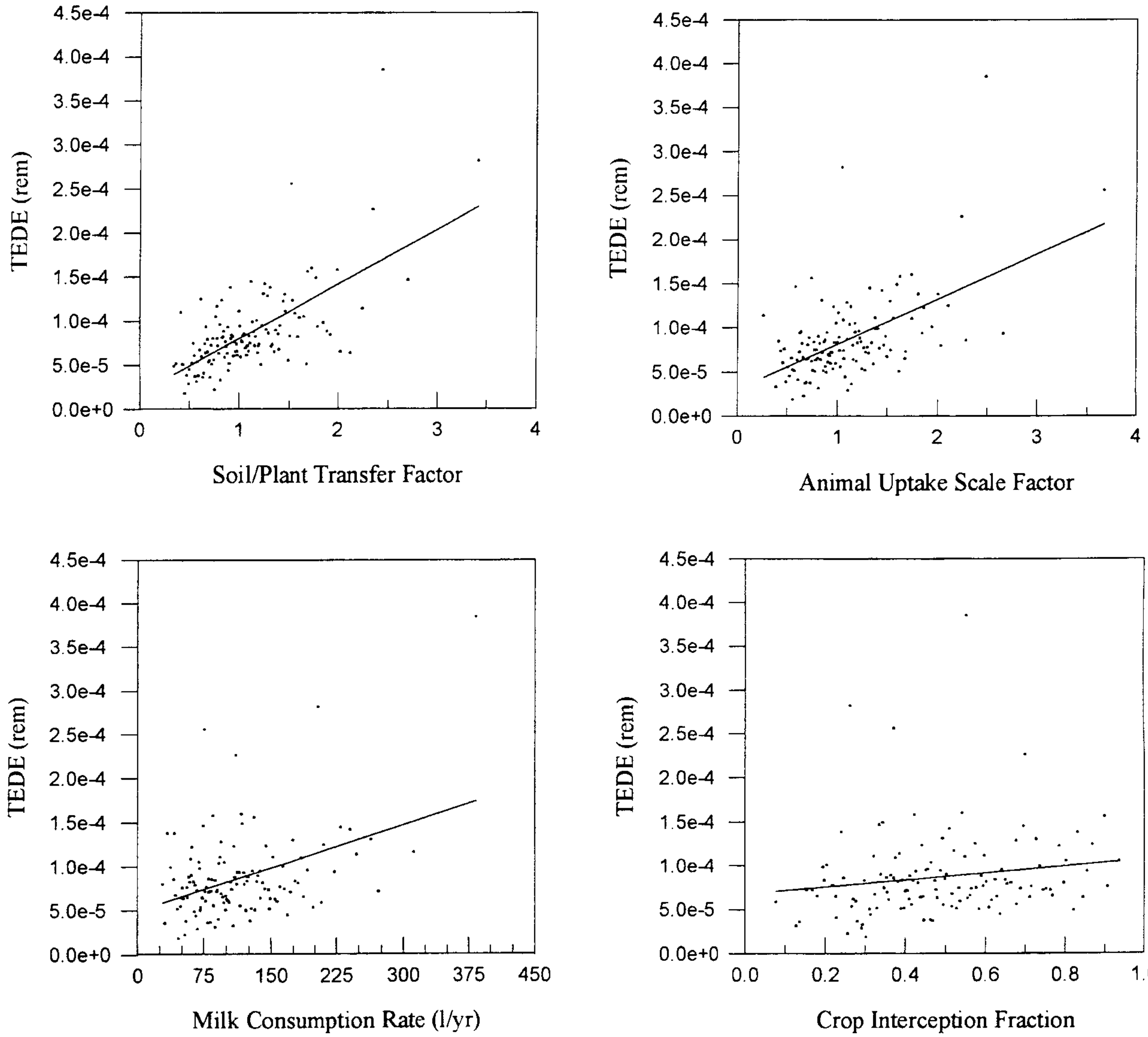

Figure C-2. Scatterplots of input parameters versus ^{36}CL total effective dose equivalent distribution for the top four important parameters

^{59}Ni

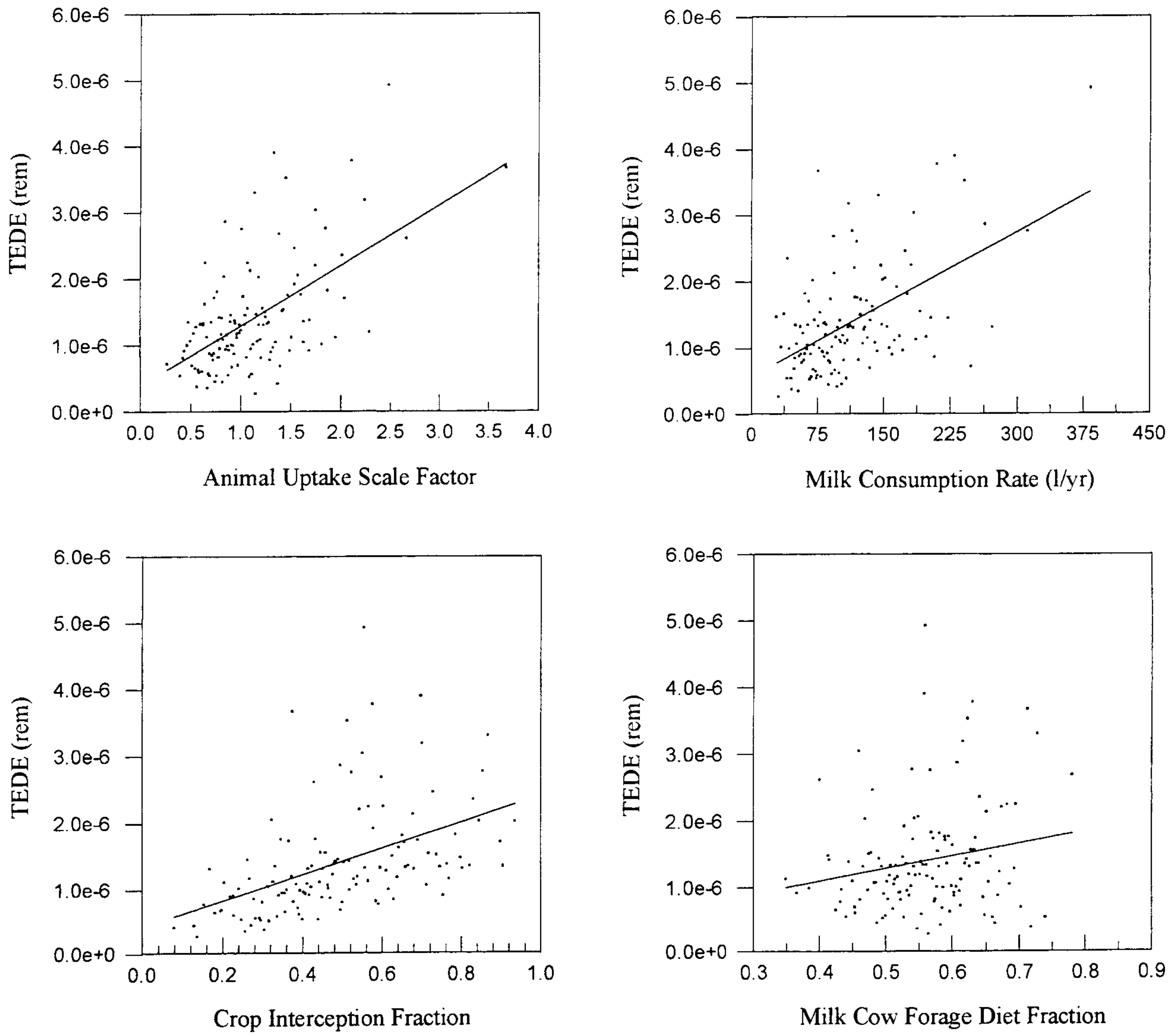

Figure C-3. Scatterplots of input parameters versus ^{59}Ni total effective dose equivalent distribution for the top four important parameters

^{79}Se

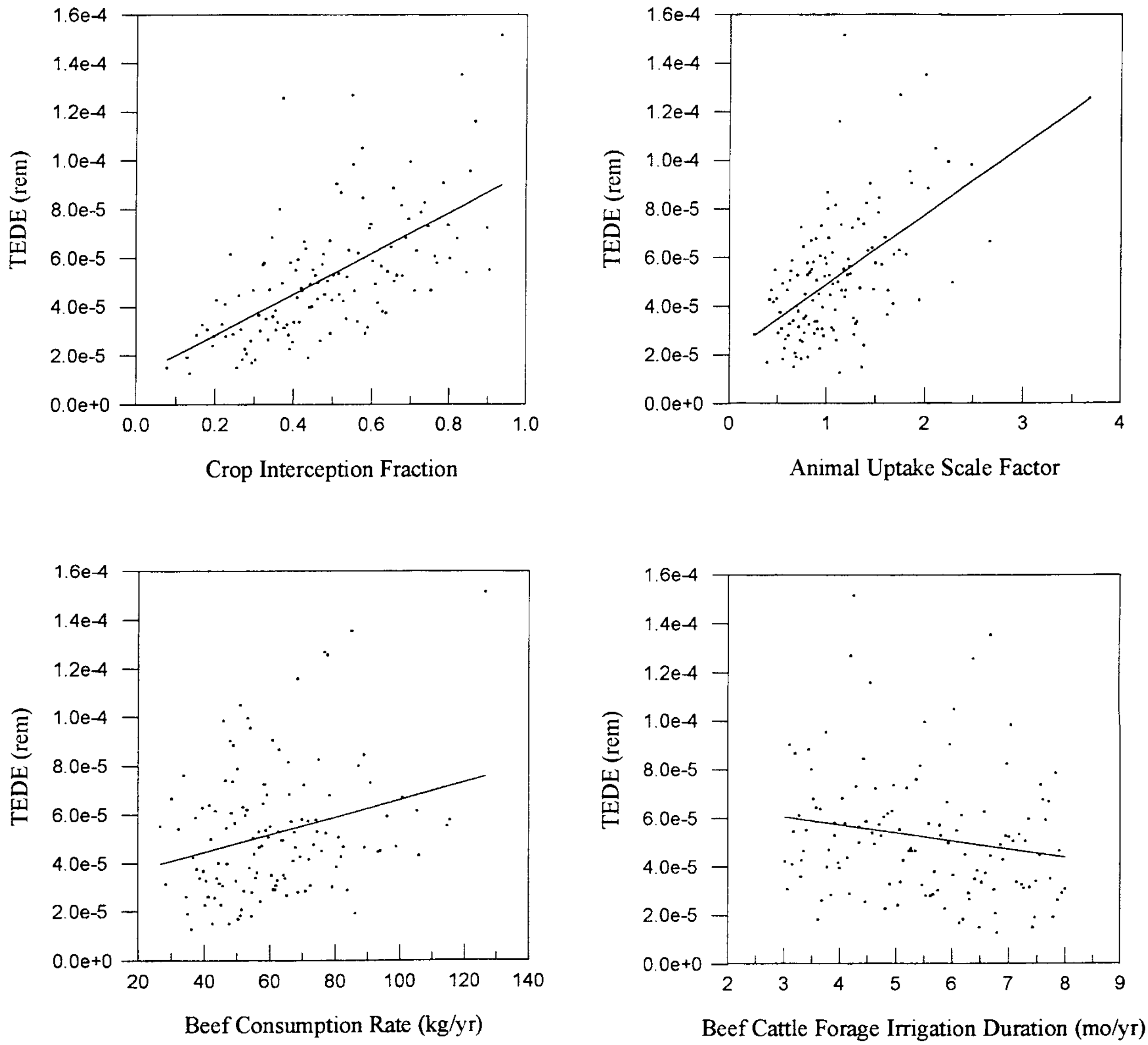

Figure C-4. Scatterplots of input parameters versus ^{79}Se total effective dose equivalent distribution for the top four important parameters

^{90}Sr

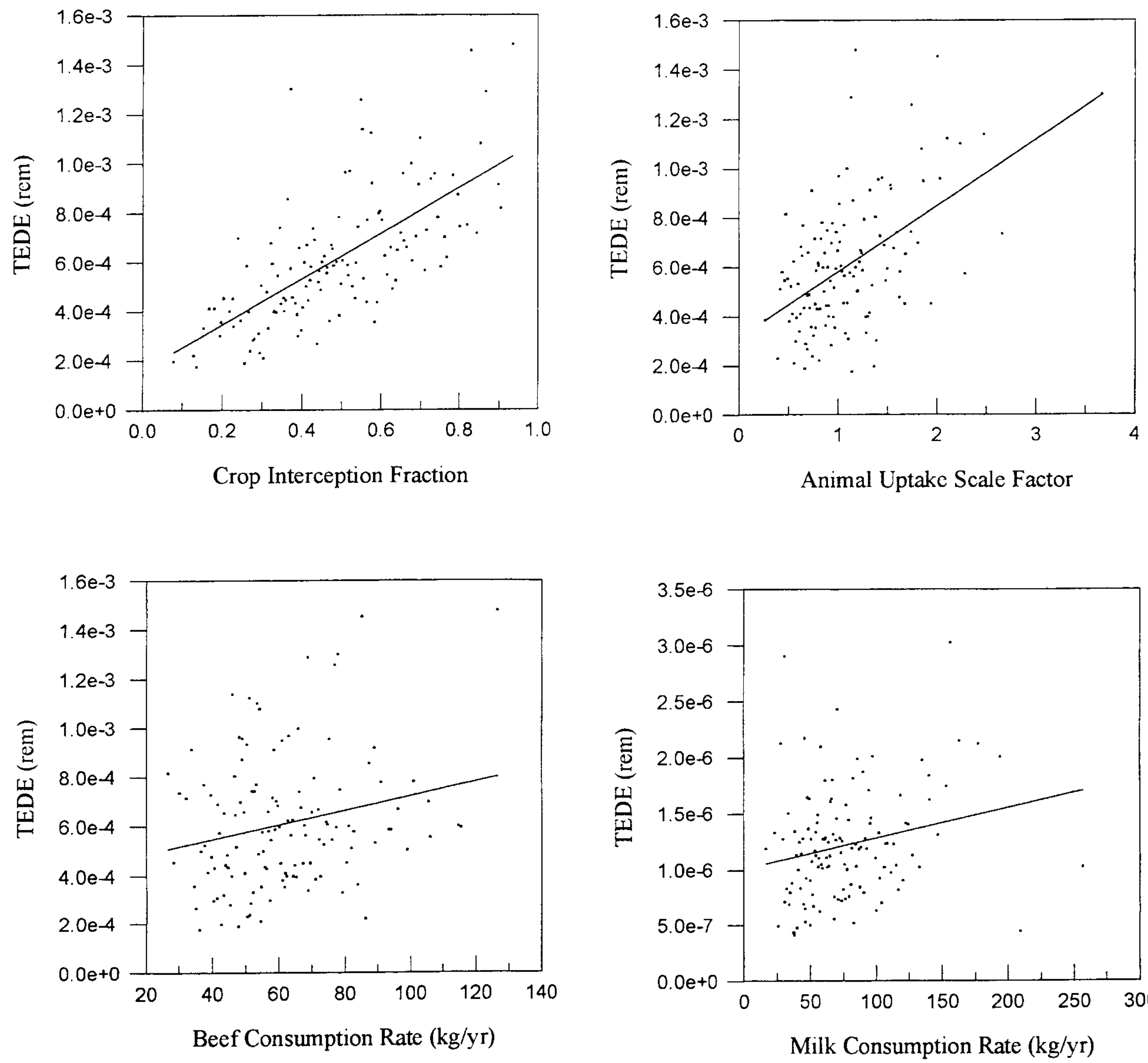

Figure C-5. Scatterplots of input parameters versus ^{90}Sr total effective dose equivalent distribution for the top four important parameters

^{93}Mo

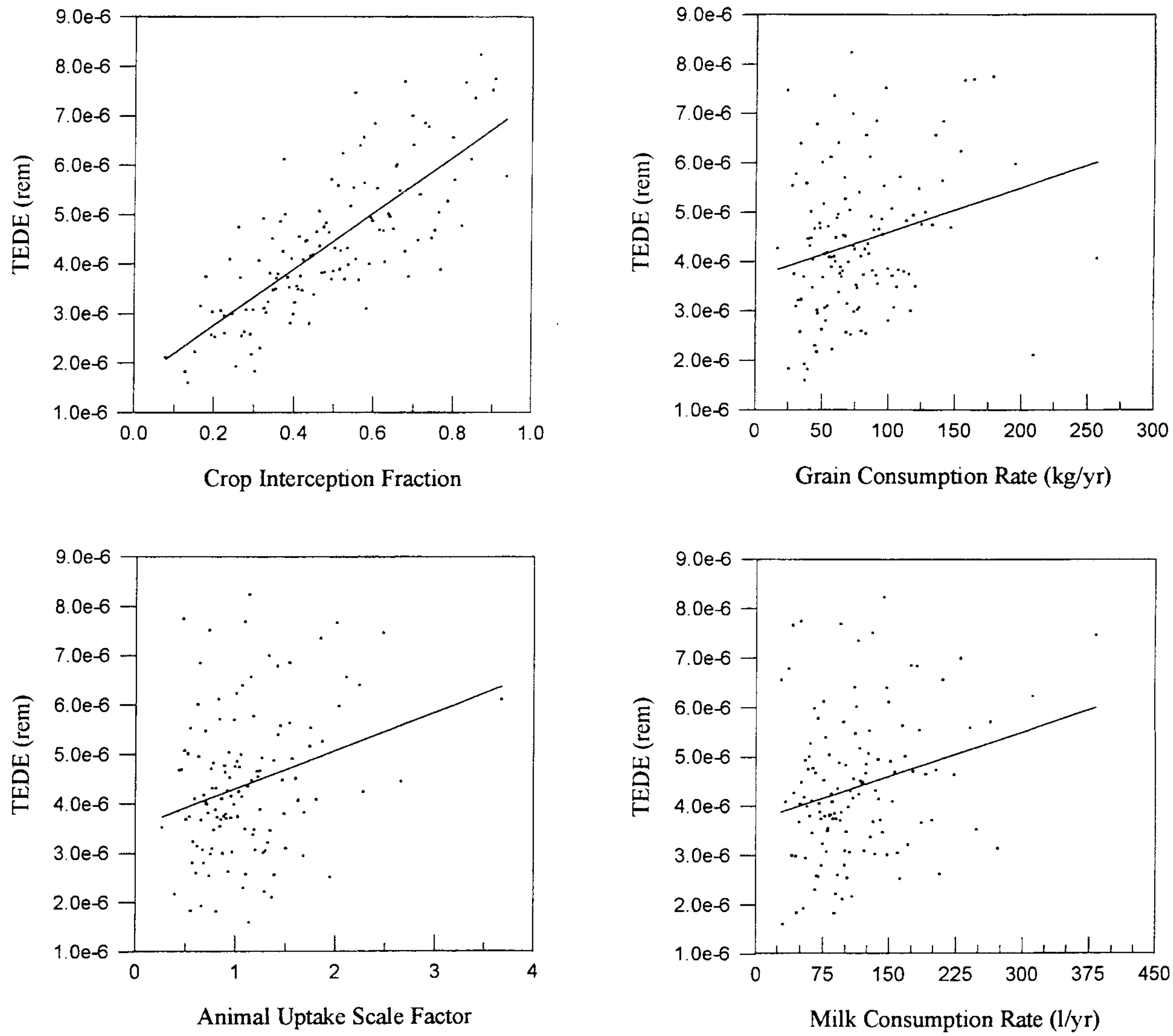

Figure C-6. Scatterplots of input parameters versus ^{93}Mo total effective dose equivalent distribution for the top four important parameters

^{93}Zr

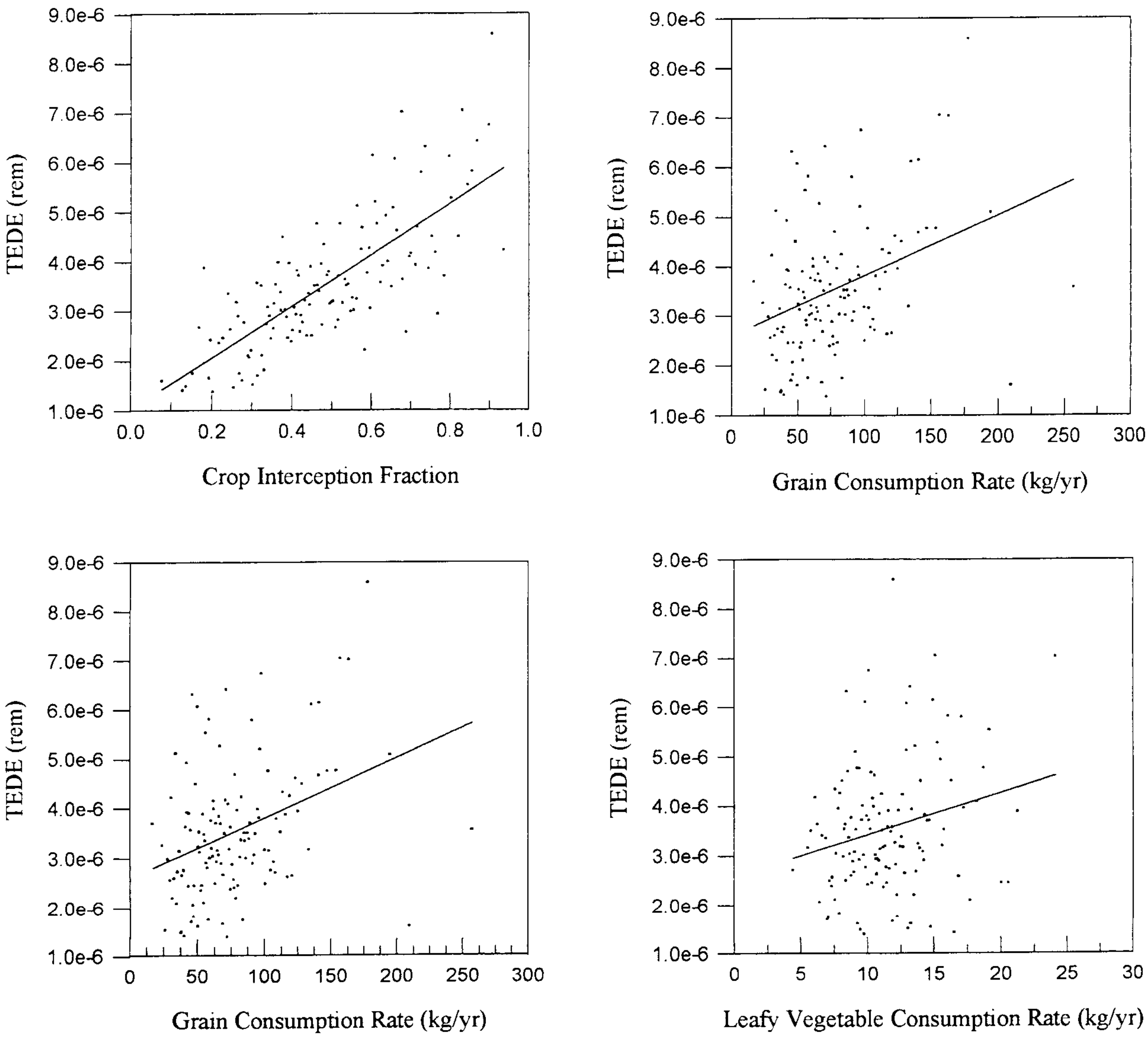

Figure C-7. Scatterplots of input parameters versus ^{93}Zr total effective dose equivalent distribution for the top four important parameters

^{94}Nb

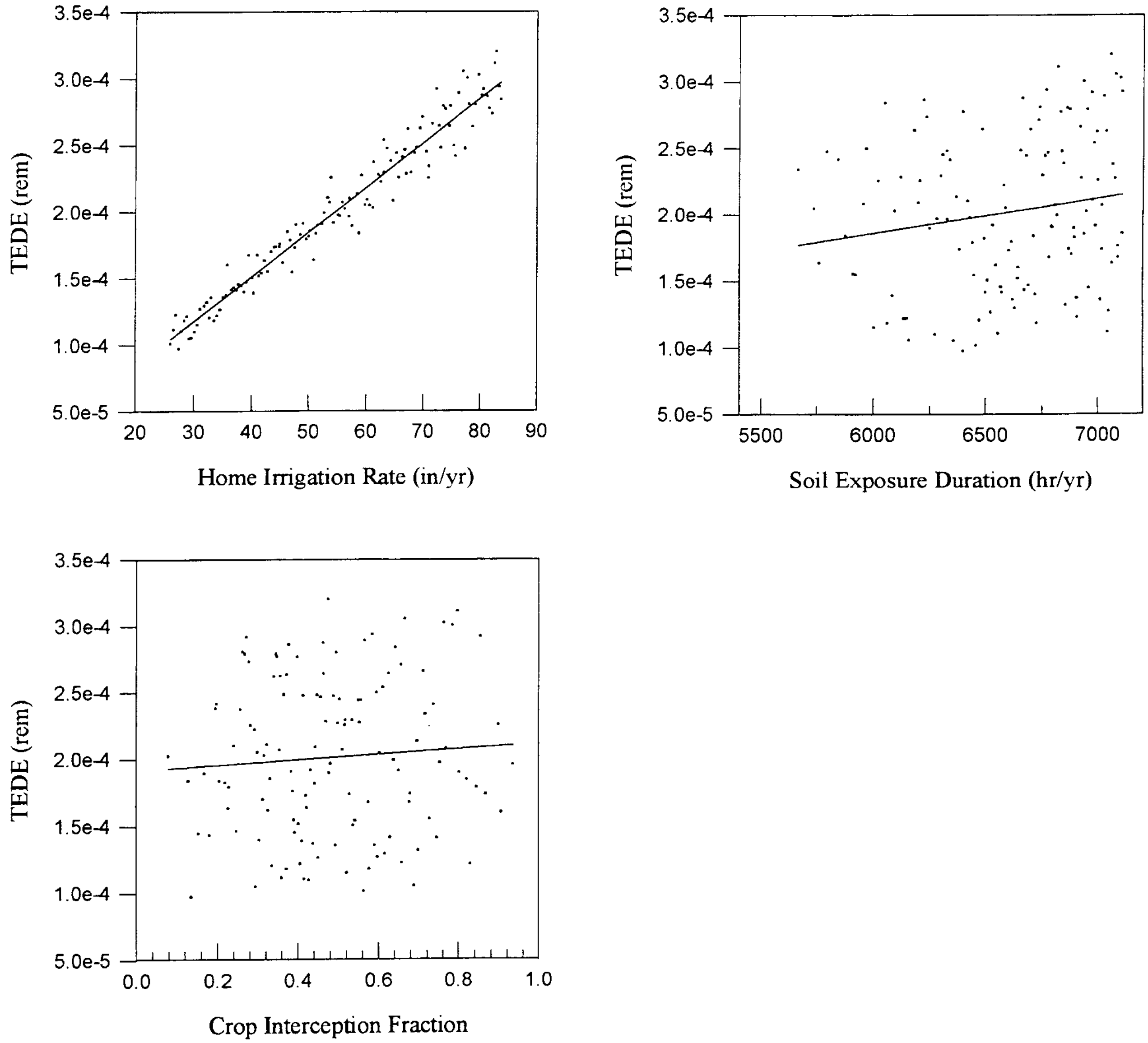

Figure C-8. Scatterplots of input parameters versus ^{94}Nb total effective dose equivalent distribution for the top four important parameters

^{99}Tc

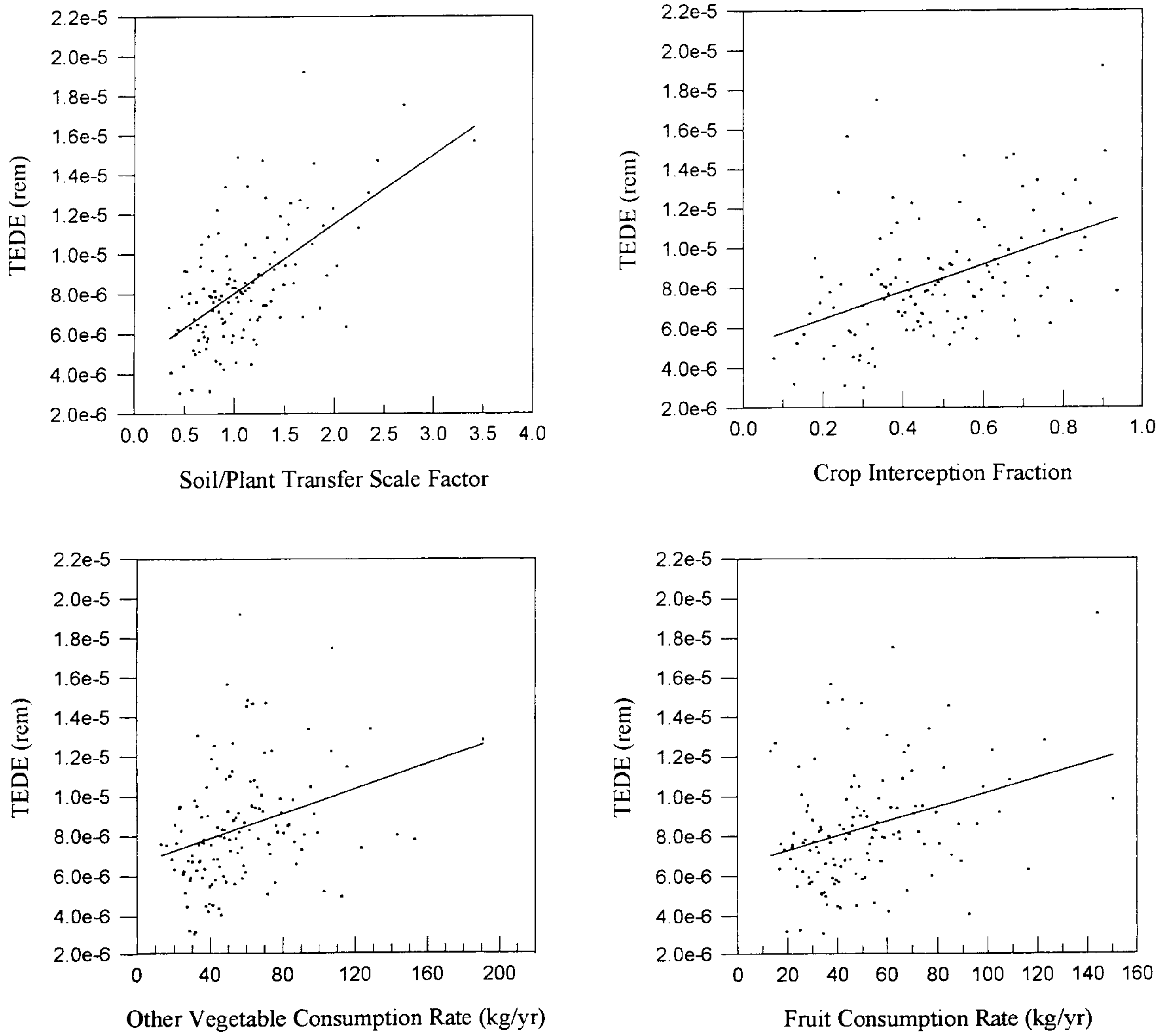

Figure C-9. Scatterplots of input parameters versus ^{99}Tc total effective dose equivalent distribution for the top four important parameters

^{107}Pd

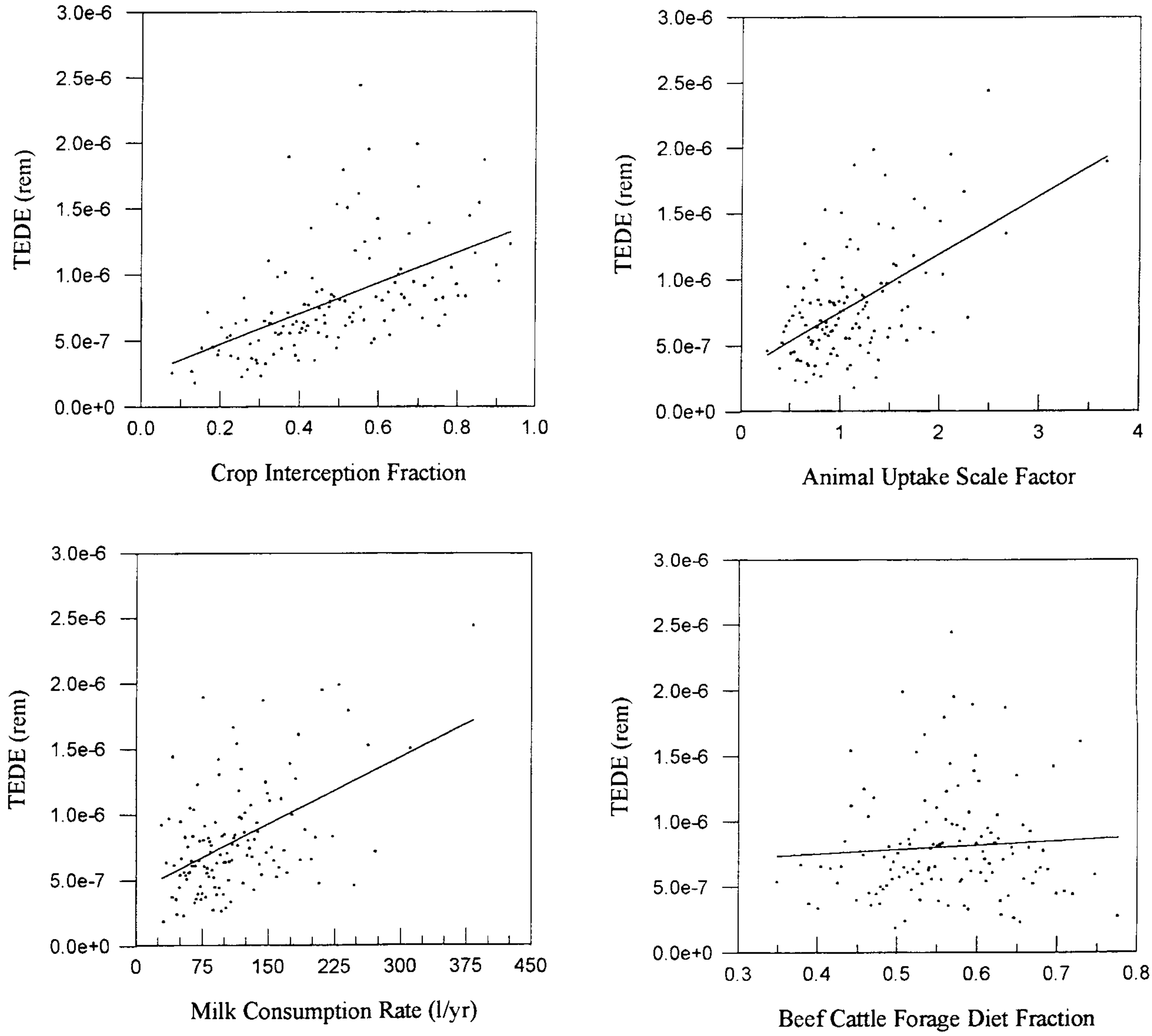

Figure C-10. Scatterplots of input parameters versus ^{107}Pd total effective dose equivalent distribution for the top four important parameters

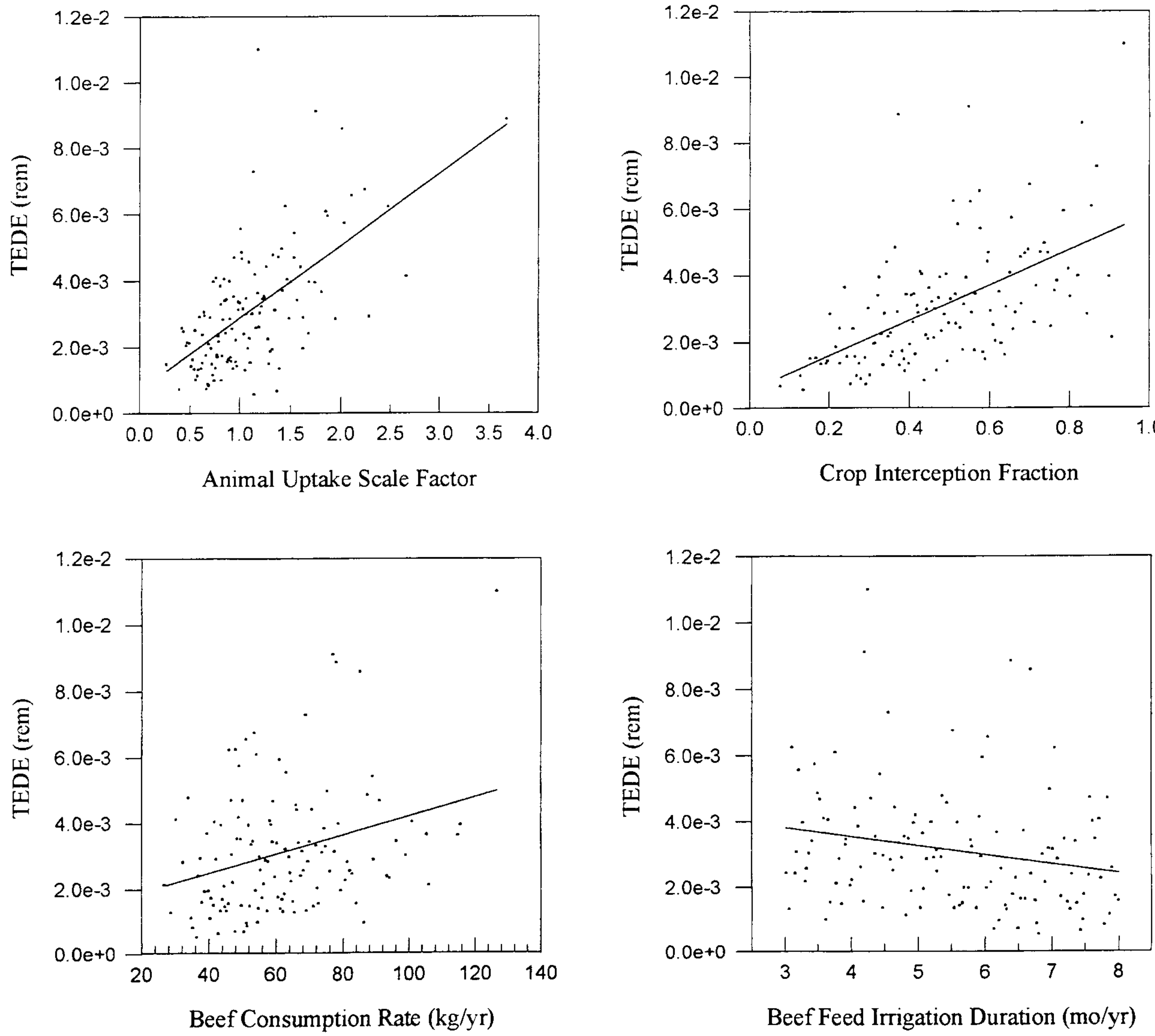

Figure C-11. Scatterplots of input parameters versus ^{129}I total effective dose equivalent distribution for the top four important parameters

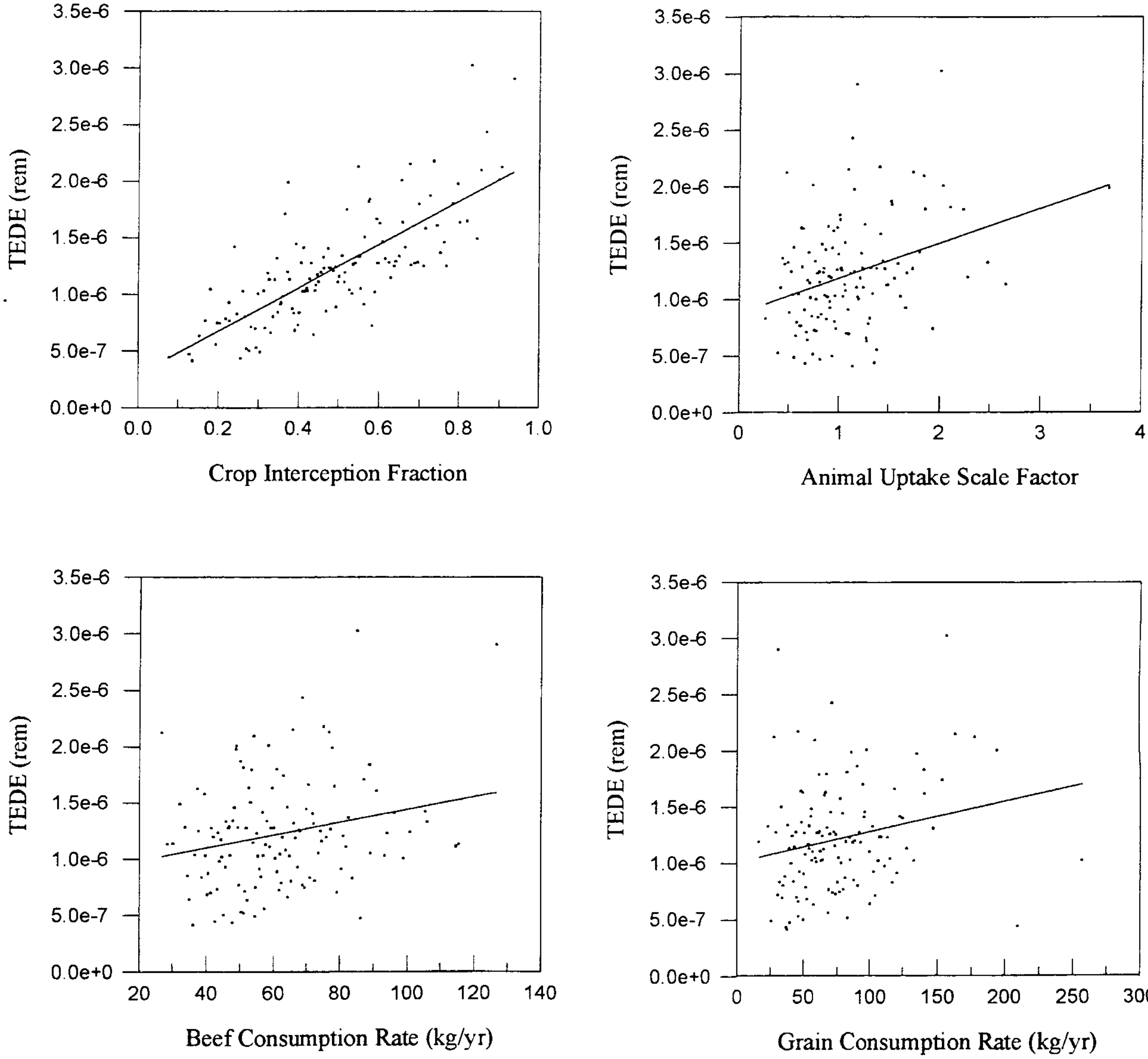

Figure C-12. Scatterplots of input parameters versus ^{151}Sm total effective dose equivalent distribution for the top four important parameters

^{226}Ra

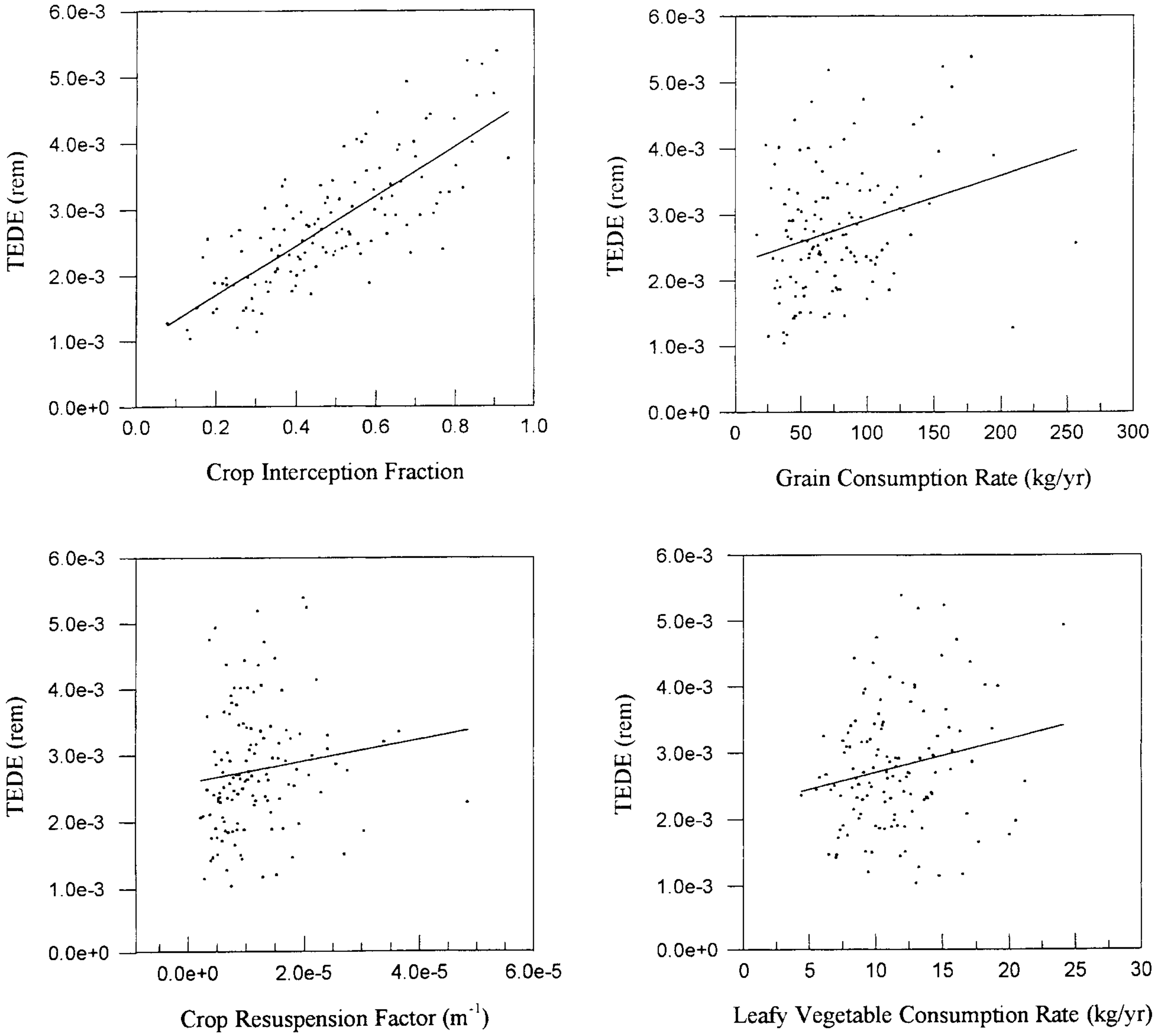

Figure C-13. Scatterplots of input parameters versus ^{226}Ra total effective dose equivalent distribution for the top four important parameters

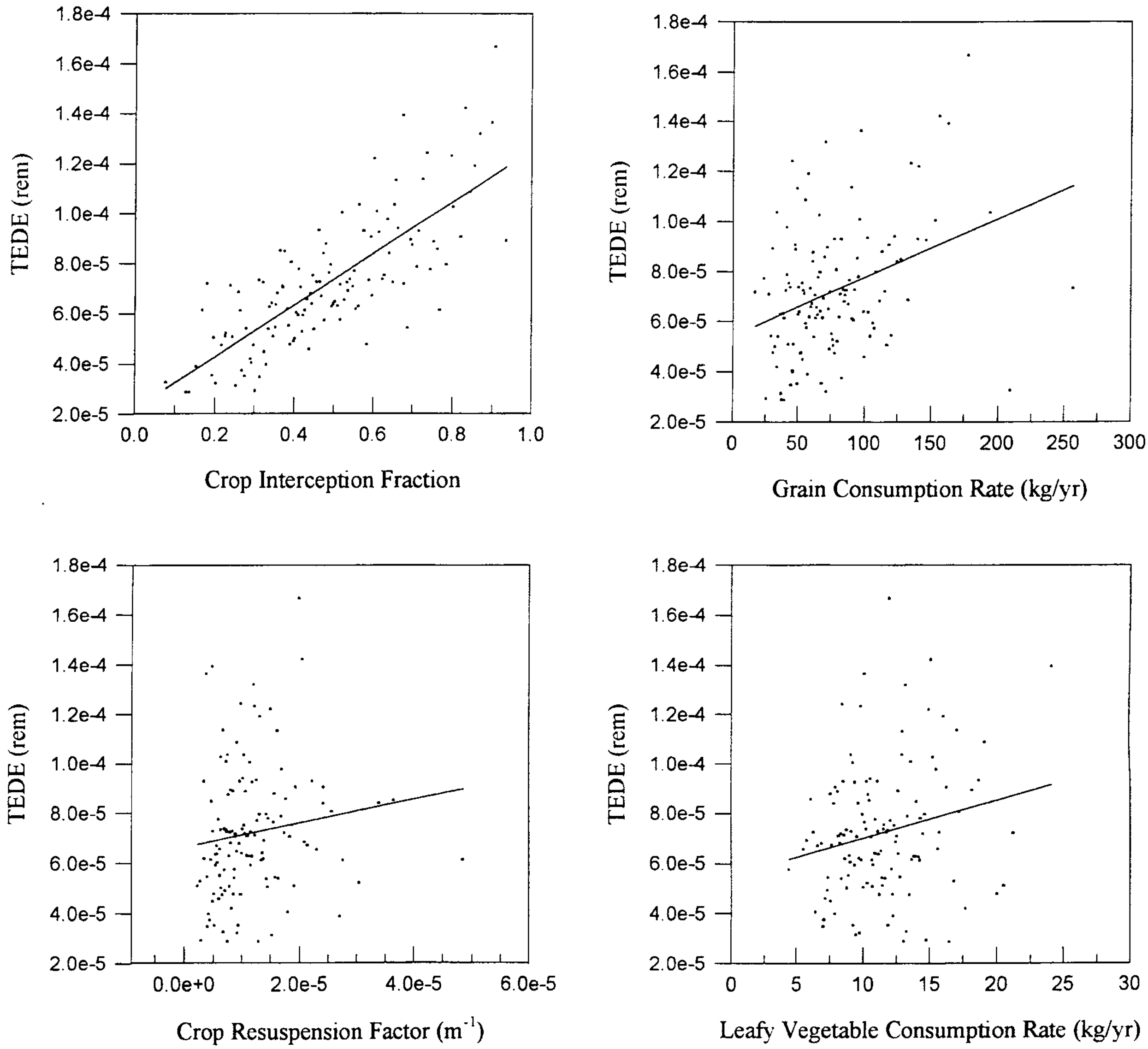

Figure C-14. Scatterplots of input parameters versus ^{238}U total effective dose equivalent distribution for the top four important parameters

^{243}Am

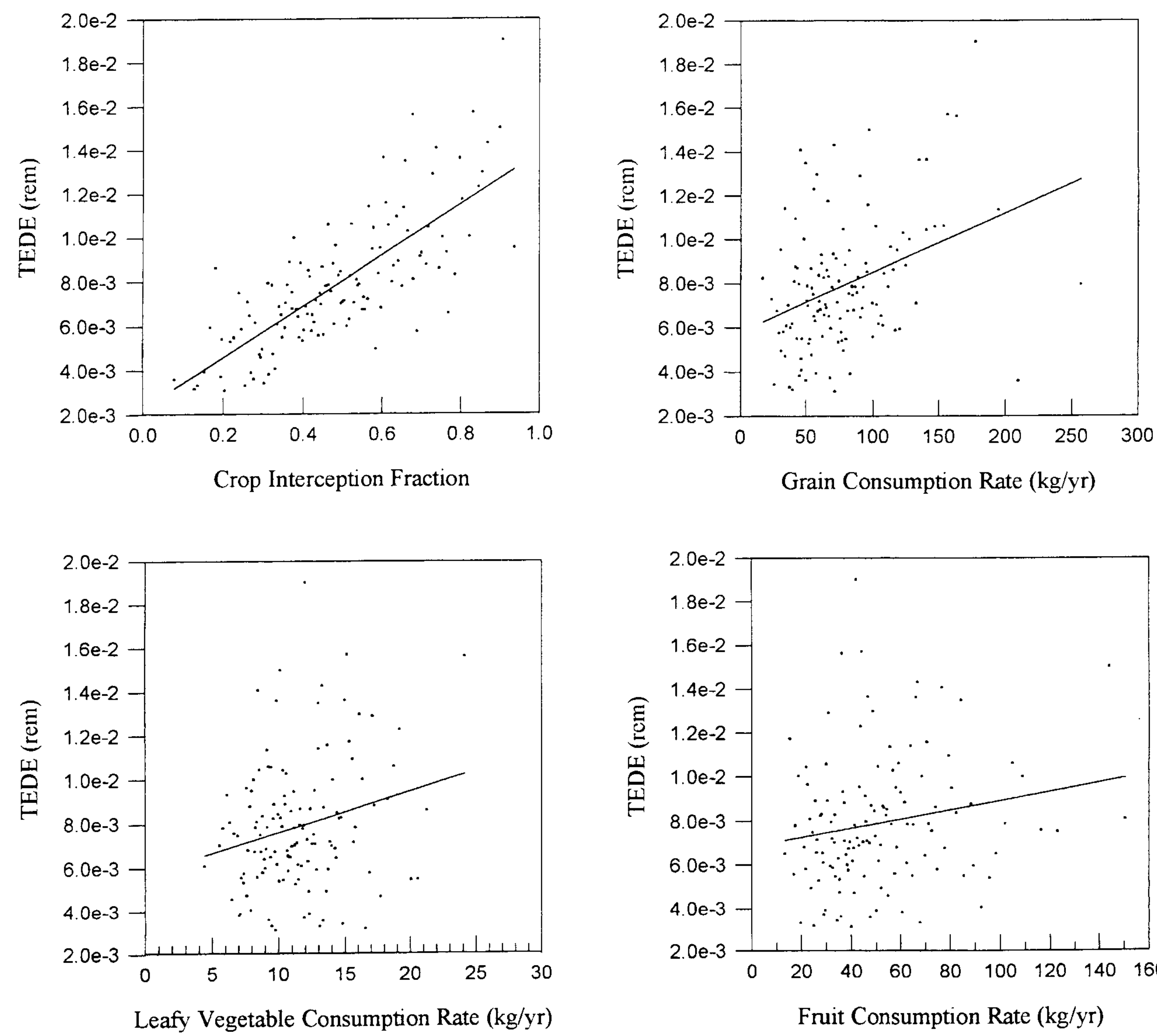

Figure C-15. Scatterplots of input parameters versus ^{243}Am total effective dose equivalent distribution for the top four important parameters

APPENDIX D

LOG PROBABILITY PLOTS OF EACH RADIONUCLIDE-SPECIFIC TOTAL EFFECTIVE DOSE EQUIVALENT DISTRIBUTION

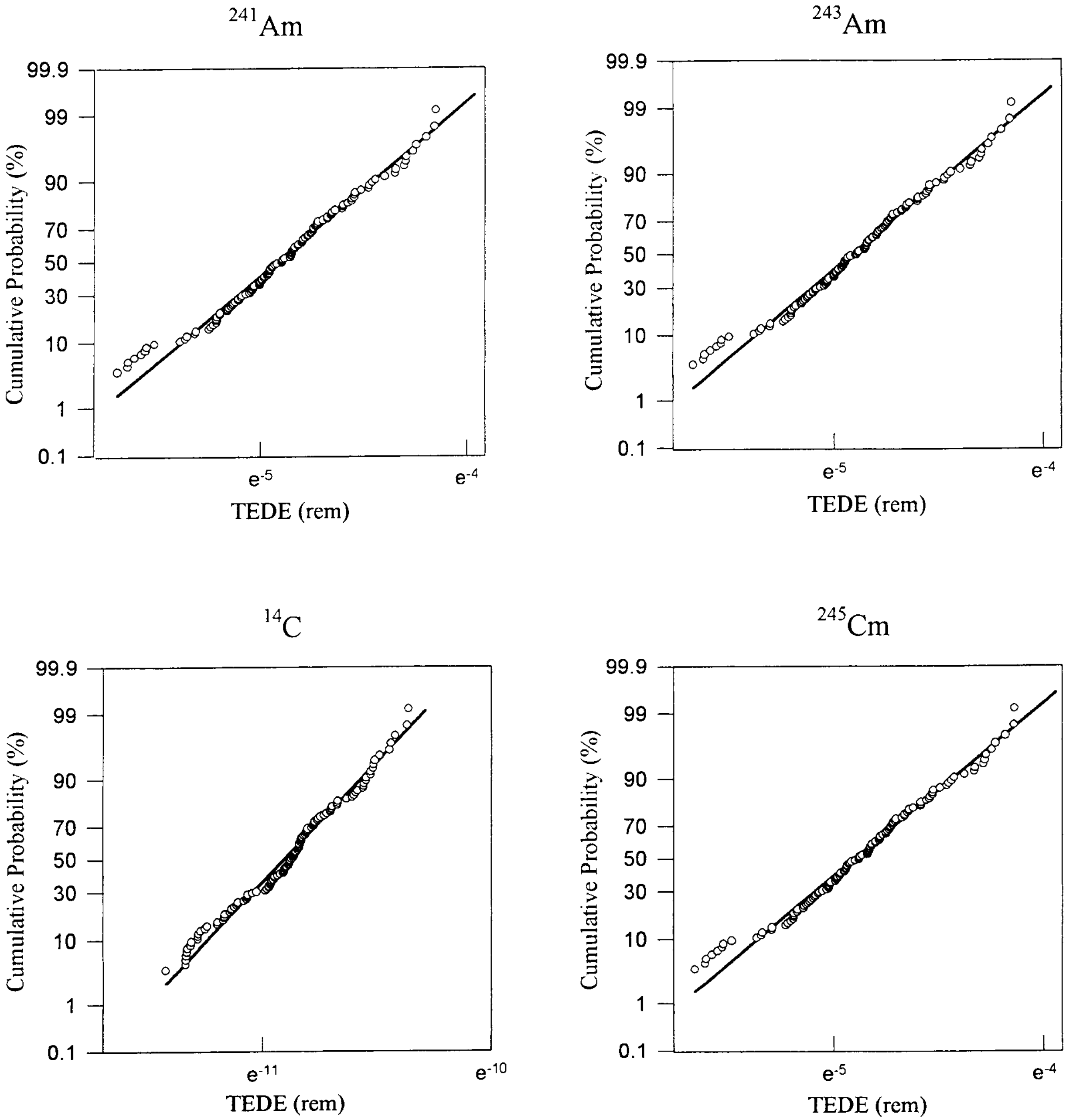

Figure D-1. Log probability plots of radionuclide-specific total effective dose equivalents for ^{241}Am, ^{243}Am, ^{14}C, and ^{245}Cm

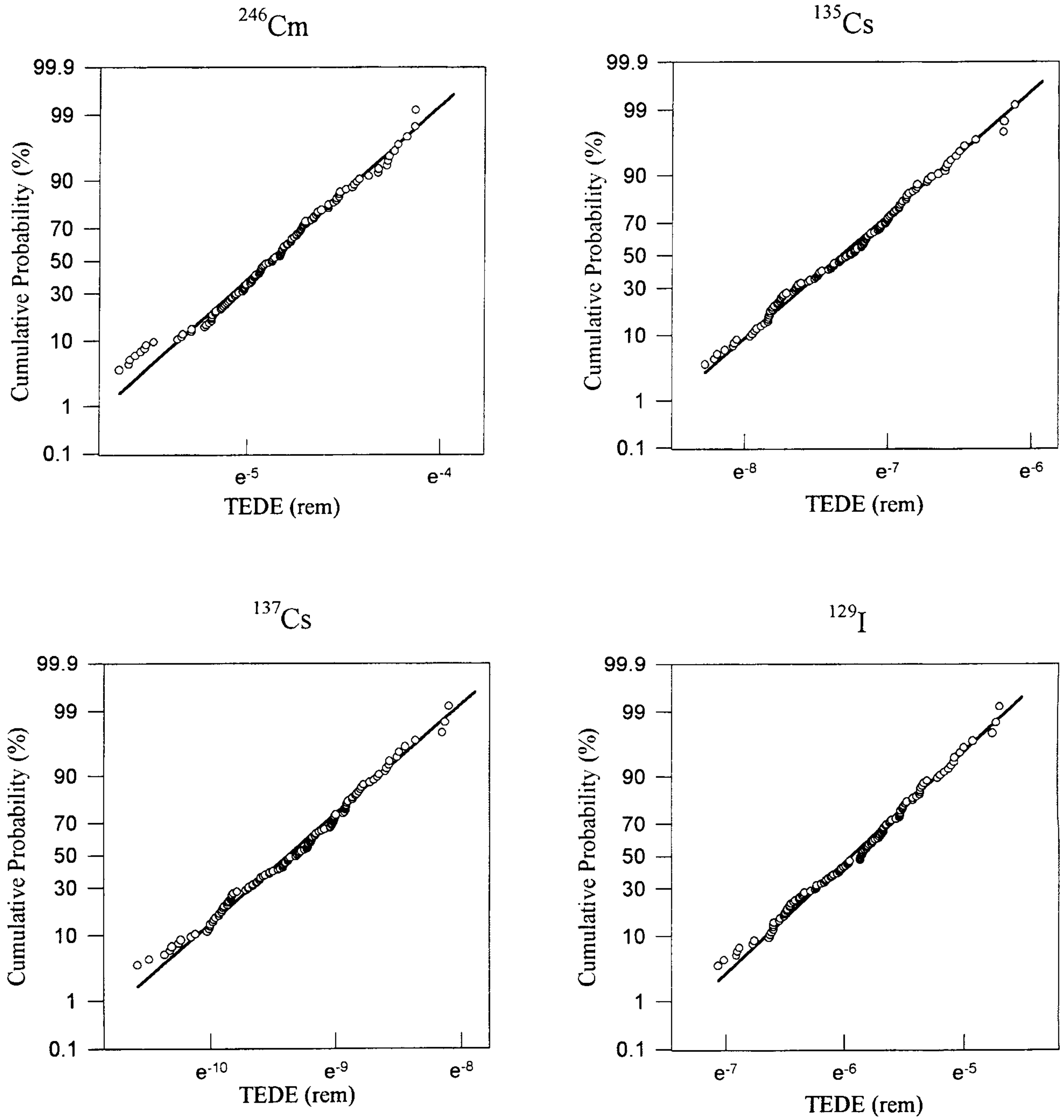

Figure D-2. Log probability plots of radionuclide-specific total effective dose equivalents for ^{246}Cm, ^{135}Cs, ^{137}Cs, and ^{129}I

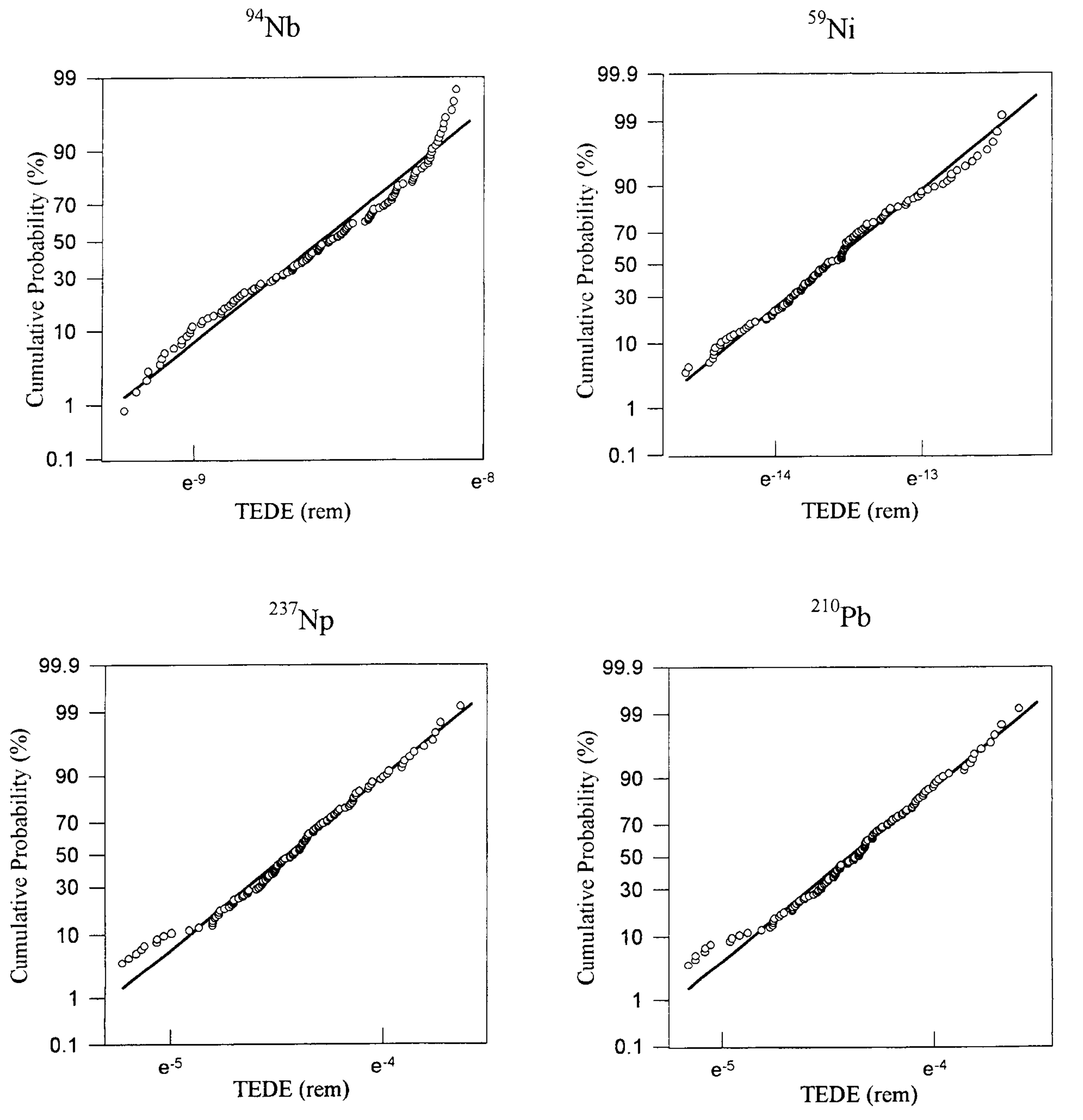

Figure D-3. Log probability plots of radionuclide-specific total effective dose equivalents for ^{94}Nb, ^{59}Np, ^{237}Np, and ^{210}Pb

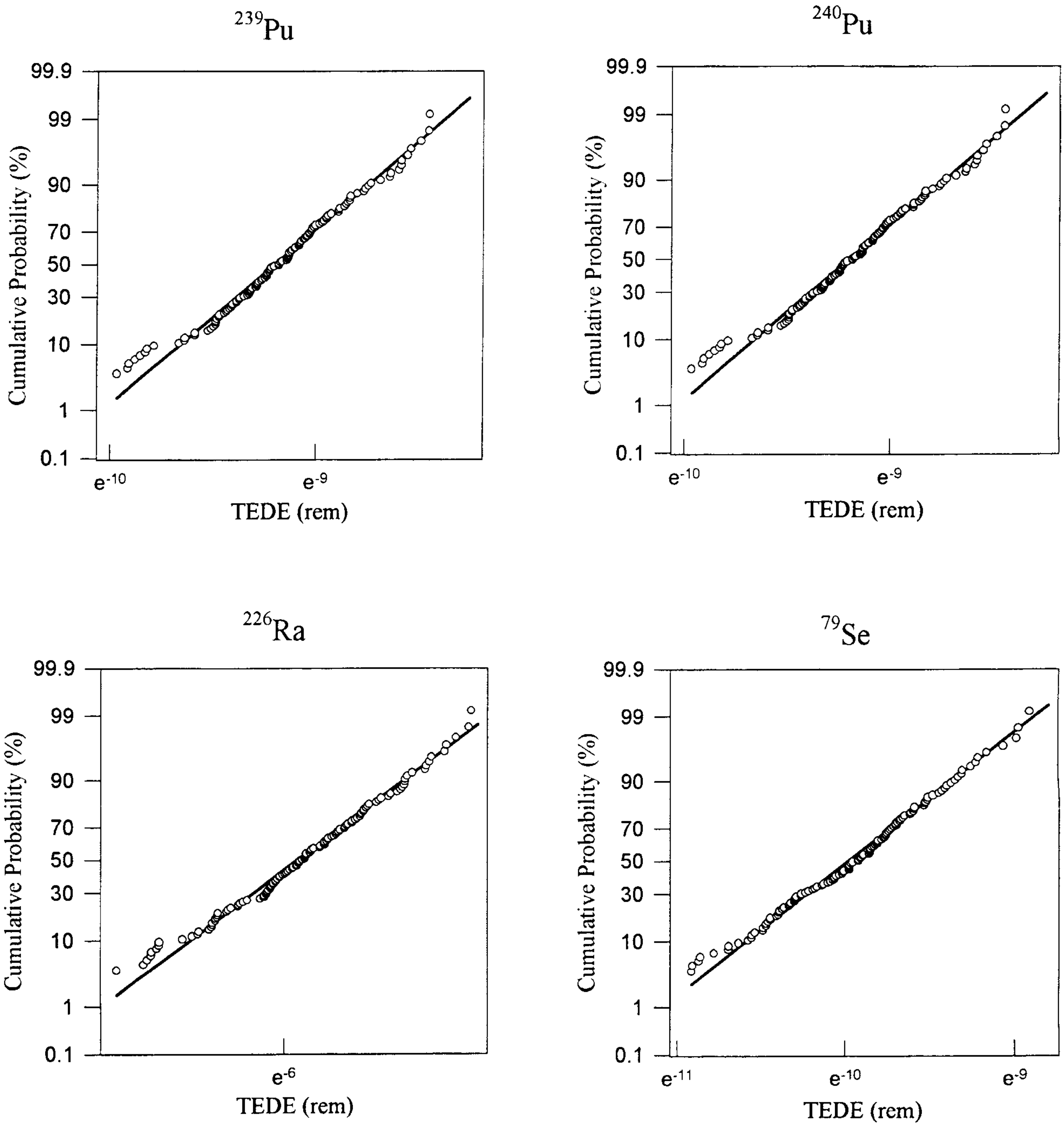

Figure D-4. Log probability plots of radionuclide-specific total effective dose equivalents for ^{239}Pu, ^{240}Pu, ^{226}Ra, and ^{79}Se

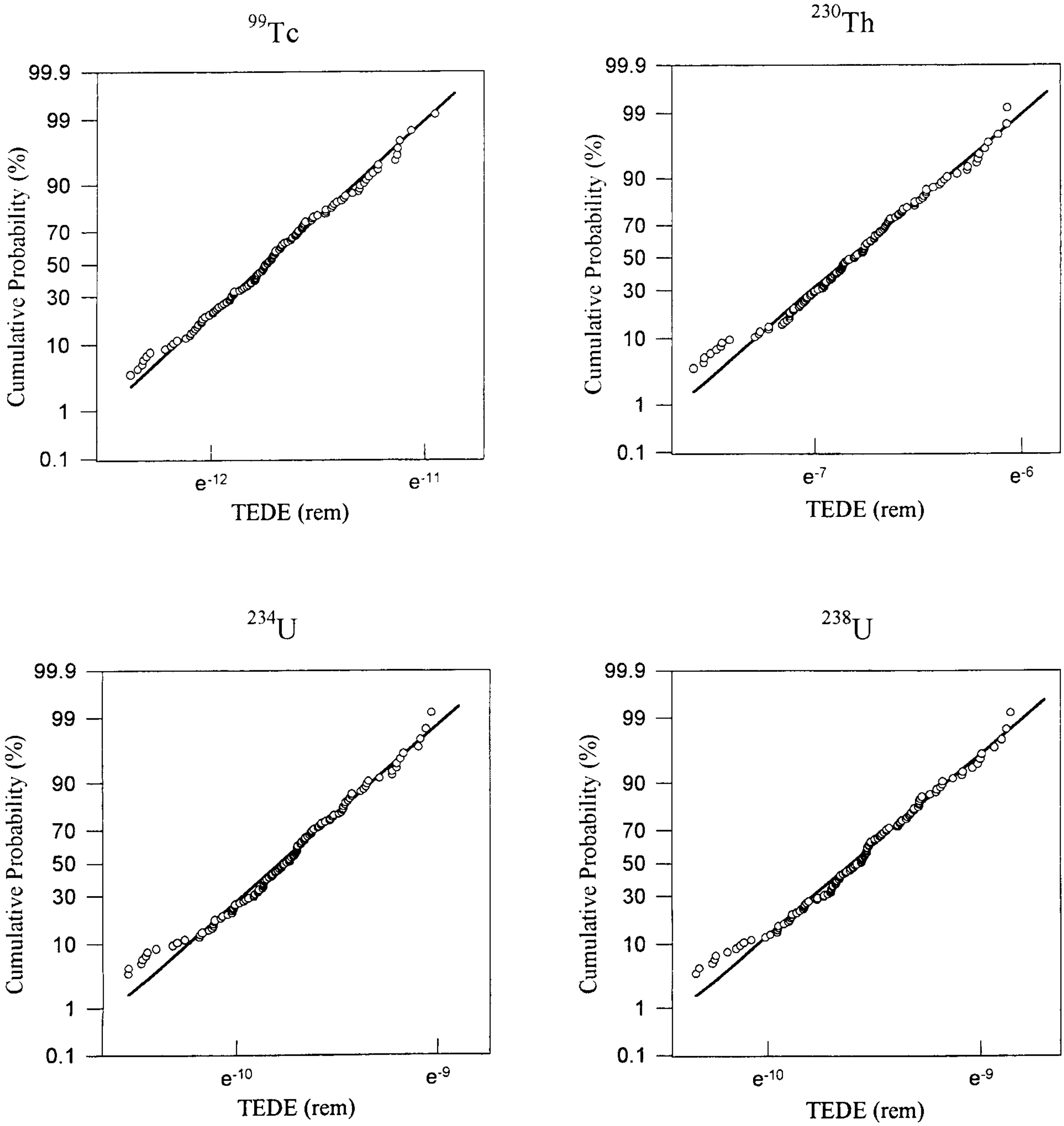

Figure D-5. Log probability plots of radionuclide-specific total effective dose equivalents for ^{99}Tc, ^{230}Th, ^{234}U, and ^{238}U

APPENDIX E

REVISED DOSE CONVERSION FACTORS

Table E-1. Dose conversion factors for a resident farmer in current biosphere by exposure pathway and radionuclide for groundwater source (rem per pCi/ℓ in groundwater)

Radionuclide	Animal Product Ingestion	Drinking Water Ingestion	External Plume and Groundshine	Inhalation	Terrestrial Crop Ingestion	Total EDE
C 14	3.2E−06	1.5E−06	0.0E−00	0.0E−00	8.9E−06	1.4E−05
CL 36	2.0E−05	2.2E−06	7.9E−09	1.9E−12	2.3E−05	4.5E−05
NI 59	6.6E−07	1.5E−07	0.0E−00	2.4E−12	2.0E−07	1.0E−06
NI 63	1.8E−06	4.0E−07	0.0E−00	6.0E−12	5.3E−07	2.8E−06
SE 79	1.1E−05	6.1E−06	7.3E−10	2.6E−11	8.0E−06	2.5E−05
SR 90	1.2E−04	8.8E−05	9.3E−09	5.3E−10	1.4E−04	3.4E−04
ZR 93	3.2E−10	1.2E−06	1.6E−09	2.2E−10	1.6E−06	2.8E−06
NB 94	6.7E−10	5.3E−06	5.3E−05	1.0E−09	7.0E−06	6.6E−05
MO 93	5.9E−07	1.0E−06	1.7E−07	2.5E−12	1.6E−06	3.4E−06
TC 99	1.4E−07	1.6E−06	6.8E−10	5.6E−12	3.0E−06	4.8E−06
PD 107	3.1E−07	1.1E−07	0.0E−00	3.3E−11	1.5E−07	5.7E−07
AG 110M	3.7E−06	2.4E−05	5.6E−05	1.5E−10	3.0E−05	1.1E−04
SN 121M	6.9E−06	1.1E−06	1.7E−07	3.0E−11	2.1E−06	1.0E−05
SN 126	6.4E−05	1.4E−05	6.7E−05	2.5E−10	2.0E−05	1.6E−04
I 129	8.5E−04	1.8E−04	5.3E−07	2.4E−10	2.4E−04	1.3E−03
CS 135	2.3E−05	5.0E−06	1.2E−09	1.2E−11	6.6E−06	3.5E−05
CS 137	1.6E−04	3.5E−05	1.9E−05	7.8E−11	4.6E−05	2.6E−04
SM 151	7.3E−08	2.8E−07	1.8E−10	7.8E−11	3.6E−07	7.1E−07
PB 210	4.0E−04	3.9E−03	1.3E−07	4.8E−08	5.3E−03	9.6E−03
RA 226	2.7E−04	7.0E−04	5.6E−05	2.2E−08	9.2E−04	2.0E−03
AC 227	7.9E−05	1.0E−02	1.3E−05	3.6E−06	1.4E−02	2.4E−02
TH 229	2.9E−05	2.6E−03	1.1E−05	4.6E−06	3.6E−03	6.1E−03
TH 230	6.4E−07	3.9E−04	2.6E−08	7.0E−07	5.2E−04	9.1E−04
PA 231	1.4E−05	7.8E−03	1.4E−06	2.3E−06	1.0E−02	1.8E−02
U 232	6.8E−06	5.0E−05	7.3E−06	1.8E−06	7.9E−05	1.4E−04
U 233	2.4E−06	1.9E−05	2.5E−08	3.5E−07	2.5E−05	4.7E−05
U 234	2.4E−06	1.9E−05	2.6E−08	3.5E−07	2.5E−05	4.6E−05
U 235	2.5E−06	1.9E−05	5.8E−06	3.2E−07	2.6E−05	5.4E−05
U 236	2.2E−06	1.8E−05	2.3E−08	3.3E−07	2.3E−05	4.4E−05
U 238	2.3E−06	1.7E−05	8.4E−07	3.1E−07	2.9E−05	4.9E−05
NP 237	2.0E−04	3.8E−03	6.3E−06	1.5E−06	5.0E−03	9.1E−03
PU 239	2.9E−08	3.6E−05	1.3E−08	8.2E−07	4.8E−05	8.5E−05
PU 240	3.0E−08	3.6E−05	2.8E−08	8.2E−07	4.8E−05	8.5E−05
PU 242	2.8E−08	3.4E−05	1.1E−07	7.9E−07	4.5E−05	8.0E−05
AM 241	6.6E−06	2.7E−03	9.6E−07	1.2E−06	3.5E−03	6.1E−03
AM 242M	6.3E−06	2.5E−03	7.0E−07	1.1E−06	3.3E−03	5.9E−03
AM 243	6.5E−06	2.6E−03	7.5E−06	1.2E−06	3.5E−03	6.1E−03
CM 243	9.9E−06	1.8E−03	4.4E−06	8.0E−07	2.4E−03	4.3E−03
CM 244	7.9E−06	1.5E−03	3.1E−08	6.4E−07	1.9E−03	3.4E−03
CM 245	1.5E−05	2.7E−03	3.0E−06	1.2E−06	3.6E−03	6.3E−03
CM 246	1.5E−05	2.7E−03	2.7E−08	1.2E−06	3.6E−03	6.3E−03

Table E-2. Dose conversion factors for a resident farmer in pluvial biosphere by exposure pathway and radionuclide for groundwater source (rem per pCi/ℓ in groundwater)

Radionuclide	Animal Product Ingestion	Drinking Water Ingestion	External Plume and Groundshine	Inhalation	Terrestrial Crop Ingestion	Total EDE
C 14	1.8E−06	1.5E−06	0.0E−00	0.0E−00	5.4E−06	8.7E−06
CL 36	1.3E−05	2.2E−06	5.2E−09	1.3E−12	1.5E−05	2.9E−05
NI 59	3.8E−07	1.5E−07	0.0E−00	1.7E−12	9.9E−08	6.3E−07
NI 63	1.1E−06	4.0E−07	0.0E−00	4.2E−12	2.7E−07	1.7E−06
SE 79	6.7E−06	6.1E−06	5.1E−10	1.8E−11	4.0E−06	1.7E−05
SR 90	6.7E−05	8.8E−05	6.4E−09	3.9E−10	7.1E−05	2.3E−04
ZR 93	2.0E−10	1.2E−06	1.1E−09	1.5E−10	7.8E−07	2.0E−06
NB 94	4.0E−10	5.3E−06	3.7E−05	7.2E−10	3.5E−06	4.6E−05
MO 93	3.5E−07	1.0E−06	1.2E−07	1.8E−12	8.7E−07	2.3E−06
TC 99	8.7E−08	1.6E−06	4.3E−10	3.5E−12	1.6E−06	3.3E−06
PD 107	1.8E−07	1.1E−07	0.0E−00	2.4E−11	7.6E−08	3.6E−07
AG 110M	2.2E−06	2.4E−05	3.8E−05	1.0E−10	1.5E−05	8.0E−05
SN 121M	4.2E−06	1.1E−06	1.2E−07	2.2E−11	1.1E−06	6.4E−06
SN 126	3.9E−05	1.4E−05	4.7E−05	1.9E−10	1.0E−05	1.1E−04
I 129	5.0E−04	1.8E−04	3.6E−07	1.7E−10	1.2E−04	8.0E−04
CS 135	1.4E−05	5.0E−06	8.3E−10	8.5E−12	3.3E−06	2.2E−05
CS 137	9.4E−05	3.5E−05	1.3E−05	5.7E−11	2.3E−05	1.6E−04
SM 151	4.2E−08	2.8E−07	1.2E−10	5.7E−11	1.8E−07	5.0E−07
PB 210	2.4E−04	3.9E−03	8.8E−08	3.5E−08	2.7E−03	6.8E−03
RA 226	1.6E−04	7.0E−04	4.0E−05	1.5E−08	4.6E−04	1.3E−03
AC 227	4.6E−05	1.0E−02	9.0E−06	2.5E−06	6.8E−03	1.7E−02
TH 229	1.7E−05	2.6E−03	7.6E−06	3.3E−06	1.8E−03	4.4E−03
TH 230	3.7E−07	3.9E−04	1.8E−08	4.9E−07	2.6E−04	6.5E−04
PA 231	8.4E−06	7.8E−03	9.8E−07	1.6E−06	5.1E−03	1.3E−02
U 232	4.0E−06	5.0E−05	5.3E−06	1.3E−06	4.0E−05	1.0E−04
U 233	1.4E−06	1.9E−05	1.8E−08	2.4E−07	1.3E−05	3.3E−05
U 234	1.4E−06	1.9E−05	1.8E−08	2.4E−07	1.2E−05	3.3E−05
U 235	1.4E−06	1.9E−05	4.0E−06	2.2E−07	1.4E−05	3.8E−05
U 236	1.3E−06	1.8E−05	1.6E−08	2.3E−07	1.2E−05	3.1E−05
U 238	1.4E−06	1.7E−05	6.0E−07	2.1E−07	1.4E−05	3.4E−05
NP 237	1.2E−04	3.8E−03	4.6E−06	1.0E−06	2.5E−03	6.5E−03
PU 239	1.7E−08	3.6E−05	8.8E−09	5.8E−07	2.4E−05	6.1E−05
PU 240	1.7E−08	3.6E−05	2.0E−08	5.8E−07	2.4E−05	6.1E−05
PU 242	1.6E−08	3.4E−05	7.6E−08	5.5E−07	2.2E−05	5.7E−05
AM 241	3.9E−06	2.7E−03	6.7E−07	8.4E−07	1.7E−03	4.4E−03
AM 242M	3.7E−06	2.5E−03	4.9E−07	8.1E−07	1.7E−03	4.2E−03
AM 243	3.9E−06	2.6E−03	5.3E−06	8.4E−07	1.7E−03	4.4E−03
CM 243	5.7E−06	1.8E−03	3.1E−06	5.8E−07	1.2E−03	3.0E−03
CM 244	4.6E−06	1.5E−03	2.2E−08	4.5E−07	9.6E−04	2.4E−03
CM 245	8.5E−06	2.7E−03	2.1E−06	8.6E−07	1.8E−03	4.5E−03
CM 246	8.5E−06	2.7E−03	1.9E−08	8.6E−07	1.8E−03	4.5E−03

Table E-3. Dose conversion factors for a resident farmer in current and pluvial biosphere by exposure pathway and radionuclide for soil source (rem per pCi/m^2 in soil)

Radionuclide	Animal Product Ingestion	External Plume and Groundshine	Inhalation	Terrestrial Crop Ingestion	Total EDE
C 14	0.0E−00	3.9E−13	1.7E−12	1.7E−13	2.3E−12
CL 36	1.7E−08	1.7E−11	1.8E−12	3.9E−08	5.6E−08
NI 59	4.2E−12	0.0E−00	7.3E−13	1.8E−12	6.8E−12
NI 63	1.2E−11	0.0E−00	1.8E−12	5.1E−12	1.8E−11
SE 79	3.6E−11	5.1E−13	7.9E−12	6.2E−11	1.1E−10
SR 90	2.6E−09	6.7E−12	1.7E−10	7.0E−09	9.7E−09
ZR 93	1.9E−15	0.0E−00	6.8E−11	4.7E−12	7.2E−11
NB 94	2.7E−15	3.7E−08	3.1E−10	4.4E−11	3.8E−08
MO 93	1.2E−11	1.3E−10	8.3E−13	2.1E−10	3.5E−10
TC 99	1.1E−10	1.9E−12	7.1E−12	2.3E−09	2.4E−09
PD 107	1.7E−12	0.0E−00	1.1E−11	4.7E−12	1.7E−11
AG 110M	1.1E−11	6.2E−08	7.1E−11	7.4E−10	6.3E−08
SN 121M	1.8E−11	1.2E−10	9.4E−12	1.8E−11	1.6E−10
SN 126	1.7E−10	1.3E−09	8.1E−11	1.7E−10	1.7E−09
I 129	2.2E−09	6.2E−10	1.3E−10	1.6E−09	4.5E−09
CS 135	1.0E−10	8.3E−13	3.7E−12	5.5E−11	1.6E−10
CS 137	6.9E−10	1.3E−08	2.5E−11	3.8E−10	1.5E−08
SM 151	1.7E−13	1.2E−13	2.5E−11	1.7E−12	2.7E−11
PB 210	1.1E−09	6.2E−11	1.1E−08	2.0E−08	3.2E−08
RA 226	1.2E−09	1.6E−10	6.7E−09	3.6E−09	1.2E−08
AC 227	2.1E−10	3.8E−12	1.1E−06	4.7E−08	1.1E−06
TH 229	8.5E−11	2.1E−09	1.4E−06	1.0E−08	1.4E−06
TH 230	1.8E−12	1.8E−11	2.1E−07	1.5E−09	2.2E−07
PA 231	3.8E−11	9.8E−10	7.2E−07	3.3E−08	7.5E−07
U 232	2.2E−11	2.5E−11	5.5E−07	2.7E−10	5.5E−07
U 233	7.7E−12	1.8E−11	1.1E−07	9.0E−11	1.1E−07
U 234	7.6E−12	1.8E−11	1.1E−07	8.9E−11	1.1E−07
U 235	7.9E−12	3.6E−09	1.0E−07	9.4E−11	1.1E−07
U 236	7.1E−12	1.6E−11	1.0E−07	8.3E−11	1.0E−07
U 238	7.2E−12	1.3E−11	9.8E−08	1.0E−10	9.8E−08
NP 237	6.5E−10	7.3E−10	5.3E−07	2.5E−08	5.5E−07
PU 239	7.0E−14	8.8E−12	2.5E−07	1.3E−10	2.5E−07
PU 240	7.0E−14	2.0E−11	2.5E−07	1.3E−10	2.5E−07
PU 242	6.5E−14	1.7E−11	2.4E−07	1.3E−10	2.4E−07
AM 241	1.5E−11	6.7E−10	3.7E−07	9.8E−09	3.8E−07
AM 242M	1.4E−11	7.3E−11	3.5E−07	9.4E−09	3.6E−07
AM 243	1.5E−11	1.3E−09	3.7E−07	9.8E−09	3.8E−07
CM 243	2.8E−11	3.1E−09	2.6E−07	6.8E−09	2.6E−07
CM 244	2.3E−11	2.2E−11	2.1E−07	5.4E−09	2.1E−07
CM 245	4.2E−11	2.1E−09	3.7E−07	1.0E−08	3.9E−07
CM 246	4.2E−11	1.9E−11	3.8E−07	1.0E−08	3.9E−07

Table E−4. Dose conversion factors for a non−farming resident in current or pluvial biosphere by exposure pathway and radionuclide for groundwater (rem per pCi/ℓ in groundwater) or soil (rem per pCi/m^2 in soil) source

Radionuclide	Drinking Water from Groundwater Source	External Plume and Groundshine from Soil Source
C 14	1.5E−06	7.7E−14
CL 36	2.2E−06	3.2E−12
NI 59	1.5E−07	0.0E−00
NI 63	4.0E−07	0.0E−00
SE 79	6.1E−06	9.9E−14
SR 90	8.8E−05	1.3E−12
ZR 93	1.2E−06	0.0E−00
NB 94	5.3E−06	7.3E−09
MO 93	1.0E−06	2.5E−11
TC 99	1.6E−06	3.7E−13
PD 107	1.1E−07	0.0E−00
AG 110M	2.4E−05	1.2E−08
SN 121M	1.1E−06	2.3E−11
SN 126	1.4E−05	2.6E−10
I 129	1.8E−04	1.2E−10
CS 135	5.0E−06	1.6E−13
CS 137	3.5E−05	2.6E−09
SM 151	2.8E−07	2.4E−14
PB 210	3.9E−03	1.2E−11
RA 226	7.0E−04	3.0E−11
AC 227	1.0E−02	7.5E−13
TH 229	2.6E−03	4.0E−10
TH 230	3.9E−04	3.5E−12
PA 231	7.8E−03	1.9E−10
U 232	5.0E−05	4.9E−12
U 233	1.9E−05	3.4E−12
U 234	1.9E−05	3.5E−12
U 235	1.9E−05	7.1E−10
U 236	1.8E−05	3.1E−12
U 238	1.7E−05	2.6E−12
NP 237	3.8E−03	1.4E−10
PU 239	3.6E−05	1.7E−12
PU 240	3.6E−05	3.8E−12
PU 242	3.4E−05	3.2E−12
AM 241	2.7E−03	1.3E−10
AM 242M	2.5E−03	1.4E−11
AM 243	2.6E−03	2.5E−10
CM 243	1.8E−03	6.0E−10
CM 244	1.5E−03	4.2E−12
CM 245	2.7E−03	4.1E−10
CM 246	2.7E−03	3.7E−12