WBS: 1.2.5.4
QA: L

Civilian Radioactive Waste Management System
Management & Operating Contractor

Chapter 9
Total System Performance Assessment-Viability Assessment (TSPA-VA) Analyses Technical Basis Document

Biosphere

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August 14, 1998

Prepared for:

U.S. Department of Energy
Yucca Mountain Site Characterization Office
P.O. Box 30307
North Las Vegas, Nevada 89036-0307

Prepared by:

TRW Environmental Safety Systems Inc.
1261 Town Center Drive
Las Vegas, Nevada 89134

Under Contract Number
DE-AC08-91RW00134

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Biosphere

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ACRONYMS

ADI	average daily intake
BDCFs	biosphere dose conversion factor
BIOMOVS	Biosphere Model Validation Study
BMIDF	biosphere modeling input data file
$^{14}CO_2$	gaseous carbon dioxide
CADI	contingent average daily intake
CATI	Computer Assisted Telephone Interviewing
DCF	Dose Conversion Factor
DOE	U.S. Department of Energy
DOF	degree of freedom
EBS	engineered barrier system
EPA	Environmental Protection Agency
ESTSC	Energy Science and Technology Software Center
ET	evapotranspiration
FEP	features, events, and processes
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
I	irrigation rate
M&O	Management and Operating
NAS	National Academy of Science
NIST	National Institute of Standards and Technology
NRC	National Research Council
RSICC	Radiation Safety Information Computational Center

SIIP	Scientific Investigation Implementation Package
SZ	saturated zone
TEDE	total effective dose equivalent
TSPA-VA	Total System Performance Assessment-Viability Assessment
UNLV	University of Nevada Las Vegas
USGS	United States Geological Survey
USNRC	United States Nuclear Regulatory Commission

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9. BIOSPHERE

9.1 INTRODUCTION

9.1.1 Overview of Biosphere Modeling for TSPA-VA

The Total System Performance Assessment (TSPA) process integrates a set of individual process models to assess the long-term behavior of the potential repository at Yucca Mountain. To evaluate the efficacy of the site, a measure of performance is required. In line with the operating and decommissioning requirements placed on the nuclear industry, the project has adopted an all pathways radiation dose to humans as the principal measure of repository performance.

Previous sections of this report have discussed the potential release and transport of the radioactive elements through the engineered barrier system (EBS) and the geosphere. The final steps in the TSPA-Viability Assessment (VA) evaluation process are to model the movement of the radionuclides from the geosphere into and throughout the biosphere, the region in which flora and fauna are present, and to assess dose to humans. If radionuclides are introduced into the biosphere, they are subjected to various physical, chemical, and biological processes, some of which can result in radiation exposures to humans.

Yucca Mountain lies in an arid, sparsely populated region between the Great Basin and Mojave deserts in southern Nevada. The local vegetation is primarily desert scrub and grasses. The annual precipitation in the area is between 100–150 mm (4-6 in.) per year and the mean annual temperature is about 18°C. The nearest community in the direction of flow of groundwater is Amargosa Valley (Figure 9-1), an area of approximately 500 mi^2 defined as a tax district by the Nye County commissioners in the early 1980s. Within this district the closest inhabitants to Yucca Mountain are approximately 20 km (15 mi) south at the intersection of US 95 and Nevada State Road 373, in the community of Lathrop Wells. There are about eight inhabitants at this location. The closest agricultural area and where the majority of the people live is the Amargosa Farms area located approximately 30 km (20 mi) to the south of Yucca Mountain. The Amargosa Farms area is a triangle of land bounded by the Amargosa Farm Road to the north, Nevada State Road 373 to the east, and the California border running from the northwest to the southeast. The next community in the direction of groundwater flow is across the California state line in Inyo County. The community known as Death Valley Junction is about 60 km (40 mi) south of Yucca Mountain and has a permanent population of fewer than 10. Evaluation of water flow and wind patterns suggests that any contamination from a repository at Yucca Mountain could spread south and east into this region.

The Amargosa Valley region is primarily rural agrarian in nature. Annual precipitation is approximately 120 mm (4.8 in.) per year. Agriculture is mainly directed toward growing livestock feed, for example, alfalfa; however, gardening and animal husbandry are common. Water for household uses, agriculture, horticulture, and animal husbandry is primarily acquired from local wells. Although sparsely populated, the Amargosa Valley region does support a population of about 1,300 in approximately 450 households (CRWMS M&O 1997a). Commercial agriculture in the Amargosa Valley farming triangle includes a relatively large dairy that operates with approximately 4,500 milk cows, a garlic farm producing about 2,000 lbs of garlic per year, and a catfish farm that sustains approximately 15,000 catfish. The dairy employs approximately 50 people. The area contains approximately 1,800 acres planted in alfalfa, 30 acres in oats, 80 acres in pistachios, and 10 acres in grapes. There is a general store, community center, senior center, library, medical clinic, elementary school, restaurant, hotel-casino, and a motel.

The biosphere exposure scenario adopted for the base case of the TSPA-VA evaluation occurs as a result of contaminated groundwater use for both domestic and agricultural purposes. Such usage is the current practice in Amargosa Valley. This area is hydraulically down gradient from the proposed repository site (Luckey et al. 1996, p. 14). A second biosphere exposure scenario being investigated, appropriate to the Amargosa Valley community, occurs as a result of the distribution within the environment of radionuclides in ash.

Three receptors were considered as part of the farming scenario. The first was the group of people who were members of the existing community in Amargosa Valley as defined by a regional survey conducted in the vicinity of Yucca Mountain in 1997. As this receptor is based on the existing population, it is considered to be representative of the critical population group. Throughout this chapter parameters defined for this group are referred to as being applicable to the average Amargosa Valley community resident. To allow a sensitivity study of his/her lifestyle, two other receptors (subsistence farmer and resident farmer) were defined. For the subsistence farmer, all foodstuffs consumed were assumed to be raised locally using contaminated groundwater for irrigation, while for the resident farmer, only half the food was assumed to be grown locally. In each case, food and water intakes were based on data generated by the regional survey. For all three receptor groups, the characteristics (lifestyles) required to define the groups were based on present day data. No attempt was made to anticipate changes over time of social, economic, and agricultural factors that may influence predicted exposures.

The product of the primary biosphere modeling effort was a set of "biosphere dose conversion factors" (BDCFs) for use in the integrated TSPA predictive code "RIP" (Golder 1998). For a defined scenario, a BDCFs for a given radionuclide is the scalar multiplier that converts the concentration of that radionuclide as defined in TSPA into an annual total dose (total effective dose equivalent—see discussion on dose below). The BDCFs multiplier has to include all the significant routes or pathways for the radionuclide to move from the radionuclide source in the biosphere to the receptor of interest. In the base case for the TSPA-VA, the source of radionuclides is the groundwater used by the receptor for domestic and agricultural purposes. Examples of the pathways considered for this scenario include: (1) drinking the contaminated water; (2) consumption of crops grown using groundwater irrigation; (3) consumption of meat and dairy products from animals given the contaminated groundwater and fed with fodder produced with the contaminated water; and (4) exposure to ionizing radiation from the decay of radionuclides accumulated in soil by irrigation. A more comprehensive set of pathways is given and further discussed in Section 9.2.1.

The units of the BDCFs are dependent on the scenario under consideration. The radionuclide concentration for contaminated groundwater is expressed in picocuries per liter and the BDCFs has dimensions of millirem/year per picocurie/liter (see Section 9.1.2). For the farming scenario on volcanic ash (see Section 9.5.5), the radionuclide concentration on the ground is expressed as picocuries per square meter and the units for the BDCFs are millirem/year per picocurie/square meter. Multiplication of the radionuclide concentrations described for the above two scenarios with their respective BDCFs yields the annual dose to the receptor (that is, radionuclide concentration × BDCFs = dose in millirem/per year).

This chapter discusses this migration of radionuclides through the various biosphere pathways to the receptor and identifies how values for the BDCFs were determined.

A BDCFs was calculated for each radionuclide for each combination of receptor and precipitation rate. The BDCFs were generated using a set of biosphere pathways considered appropriate to the region (CRWMS M&O 1996, p. 5). All BDCFs were calculated for a unit concentration of the specific radionuclide present in the groundwater (picocuries per liter). The parametric values required to define the biosphere pathways were either estimated from the regional survey or taken from existing literature. Where appropriate, parameters were represented by a distribution over a range of values rather than being assigned a fixed unique value. The BDCFs were generated by performing multiple evaluations of the biosphere model and are therefore statistical distributions. Statistical testing indicated that there was no reason to reject the hypothesis that these distributions were lognormal. This was expected from the central limit theorem as the BDCFs are formed by the product of several factors each sampled from appropriate distributions. This knowledge, coupled with the calculated first two moments (mean and standard deviation) of these BDCFs distributions, allowed the RIP code to statistically sample the BDCFs during the stochastic evaluation of repository performance under various assumptions.

Over the period of interest for the repository assessment, it is anticipated that the climate will change appreciably. One result of this change will be an increase in precipitation with an increase in infiltration at the repository site, thereby affecting waste isolation (Atkins et al. 1995, p. 9-23). To allow for consistency with the other process models in the TSPA-VA, the BDCFs were generated for three rates of annual precipitation. For the TSPA-VA, the values for the precipitation rate correspond to the present day average, and twice and three times this rate.

9.1.2 Radiation Dose Concepts and Terminology

The terms and concepts relating to exposure dose used in the TSPA-VA follow the recommendations of the International Commission on Radiological Protection (ICRP 1977). Human exposure to radiation is quantified in terms of the amount of radiation absorbed, which is referred to as dose. Technically, dose is defined as the amount of energy (in the form of ionizing radiation) absorbed by the body and has units of energy per unit mass. In this document, as in many radiological assessments, the term dose is used to express effective dose equivalent (EDE). The use of EDE provides a means for expressing radiation doses when such radiation exposure is due to a variety of radionuclides through several exposure pathways.

Effective dose equivalent is most easily understood when broken down into its constituent parts. Dose equivalent refers to the radiation dose absorbed by a tissue or organ, multiplied by a quality factor that accounts for the different biological impacts of different types of radiation (that is, gamma rays, beta, and alpha particles). Effectiveness accounts for the nonuniform or partial body exposures that often occur following an intake of radioactive material and the different sensitivities of tissues to radiation. For example, the alpha particles emitted by plutonium cannot penetrate the skin; however, should plutonium be ingested or inhaled, the alpha particles can damage internal body tissues. Accounting for the effectiveness of radiation is accomplished by defining a system of tissue weighting factors (Eckerman et al. 1988 p.6, such that the sum of the products of the dose equivalent to each organ and its associated tissue weighting factor yields an effective dose equivalent. Use of tissue weighting factors allows nonuniform exposures to be treated as if they were whole body exposures. A common unit for the dose equivalent is the rem (Roentgen equivalent man) or mrem (millirem).

In this study, two types of radiation exposures were considered when determining the dose to a receptor: internal and external exposures. Internal exposures result from ingestion or inhalation of radioactive materials, such that the individual is exposed to radiation internally (for example, from the lungs or some other organ). External exposures result from an individual's proximity to a radiation source present outside of the body (for example, contaminated soil).

Internal doses are expressed in terms of the committed effective dose equivalent (CEDE). Radionuclides that have half-lives greater than several months and are retained in the body, and have biological elimination half-lives greater than several months, will continue to irradiate the body after the time of ingestion. Under these circumstances, the receptor is committed to receiving the dose over an extended period. The factors used to calculate CEDE integrate the dose that will be received by an individual during the 50-year period following ingestion.

In the TSPA-VA calculations, the results are presented in terms of annual doses (mrem/yr). A dose resulting from an external exposure to radiation can readily be expressed as the total dose the receptor would receive in a given year (that is, annual effective dose equivalent). In contrast, internal doses are expressed as committed doses, such that the receptor might not incur this entire dose during the year of exposure. Consequently, interpretation of a CEDE in terms of an annual dose limit requires additional consideration. The following two hypothetical examples illustrate this concept.

1. Consider that the entire committed dose for a given year of exposure (for example, 5 mrem) was due to ingestion of tritiated water (hydrogen-3). It would be appropriate to report this as an annual dose of 5 mrem/yr because the tritiated water has a biological half-life of approximately 10 days, and the tritium would, therefore, deliver its entire CEDE within the year of exposure.

2. In contrast, consider that all of the committed dose for a given year of exposure (again, 5 mrem) was due to plutonium-239. Plutonium-239 has long biological (>40 yr) and radiological (24,000 yr) half-lives. The 5 mrem CEDE would actually be spread out over the 50-yr period for which the CEDE is calculated (that is, an average dose of 0.1 mrem/yr for 50 years).

Consequently, the most appropriate way to interpret the "annual doses" is to think of them as "doses associated with a single year of exposure." That is, an "annual dose" of 5 mrem/yr means that for every year that the receptor is exposed, he/she will receive a dose of 5 mrem (which for some radionuclides may actually be spread out over a number of years subsequent to the year of exposure). Under this premise, doses from internal and external exposures can be appropriately combined. This "combined" dose is referred to as total effective dose equivalent (TEDE). In the TSPA-VA, all results are presented as annual doses in terms of the TEDE .

9.1.3 Biosphere in Previous TSPA Evaluations

Since the time when the U.S. Congress identified Yucca Mountain as the site to be evaluated for the proposed HLW geologic repository, the U.S. Department of Energy (DOE) has commissioned several TSPA studies as part of the ongoing evaluation process. The first such evaluation, known as TSPA-91, was performed by Pacific Northwest Laboratory and reported in 1993 (Eslinger et al. 1993). This was followed by two subsequent iterations conducted by the current Management and Operating Contractor (M&O). These were issued as TSPA-93 (Andrews et al. 1994; Wilson et al. 1994) and TSPA-95 (Atkins et al. 1995).

From the perspective of the biosphere scenarios evaluated, the first of these assessments (Eslinger et al. 1993, Section 10.3) was the most comprehensive. The scenarios evaluated included:

- Farmer scenario—where a self-sufficient farmer exclusively uses contaminated groundwater for all purposes. (The contamination in the groundwater was assumed to result from the degradation and failure of the waste packages, or the injection of repository wastes into the aquifer by drilling activities.)

- Drinking water only scenario—based on the assumed consumption of drinking two liters of water per day.

- Drill operator scenario—in which a worker, operating a drill, breaches a waste package and is exposed to dust and external contamination.

- Garden exposure scenario—at the location of the event described in the drilling scenario, where fruit and vegetables are grown on exhumed wastes.

- External exposure scenario—at the site discussed in the drilling scenario, where a resident is exposed only to contaminated soil.

- Gaseous carbon dioxide ($^{14}CO_2$) release scenario to the atmosphere—with dispersion and subsequent incorporation into vegetation which subsequently serves as food.

The findings of the TSPA-91 effort were that the pathways from inadvertent intrusion produced the highest annual doses (Eslinger et al. 1993, Chapter 10). The $^{14}CO_2$ release was predicted to give the lowest annual dose.

Building on this initial assessment, the two subsequent TSPA evaluations focused on the process models believed to be major contributors to the uncertainties in the overall TSPA results. The processes evaluated were limited to the geosphere; they did not include the biosphere. For these later TSPAs, dose consequences were assessed using the assumption of ingesting two liters of contaminated water per day. Using this elementary surrogate for the biosphere model allowed the use of deterministic dose conversion factors taken from Federal Guidance Report Number 11 (Eckerman et al. 1988, Tables 2-1, 2-2). Although elementary in nature, the model was readily incorporated into the TSPA capability and permitted the assessment of the relative importance of various ingested radionuclides as a function of time.

9.1.4 Advances in Present Modeling

For the TSPA-VA the M&O was provided the opportunity to model the biosphere in a substantially improved manner. The modeling approach selected had to provide the BDCFs distribution data that could be used for input to the RIP code. This required a stochastic sampling approach. Following this approach, the uncertainties in the parameters defining the details of the numerical model could be incorporated for each of the radionuclide specific BDCFs and propagated into the integrated TSPA-VA evaluation.

The biosphere study was performed to provide the TSPA-VA with the capability to predict dose consequences to individuals using contaminated groundwater or exposed to contaminated ash from a volcanic event. These two were the only mechanisms introducing radionuclides into the biosphere that were considered in the TSPA-VA modeling effort. As no consideration was given in the other TSPA-VA process models to the prediction of gaseous radionuclide release from the repository, the biosphere modeling effort did not consider the development of a dose prediction capability for gaseous pathways. Furthermore, the requirement placed on the biosphere effort was for a capability to predict dose to individuals, and thus, population dose predictions were not considered. As the biosphere model provided a capability to predict the dose to an individual for an arbitrary concentration of radionuclides in groundwater, a simple extension of the integrated TSPA-VA model (RIP) would enable population dose to be calculated for the groundwater pathway.

The process followed in modeling the biosphere is given in detail in the Scientific Investigation Implementation Package (SIIP) for Developing Biosphere Dose Conversion Factors (CRWMO M&O 1996). A brief summary of the approach is given here. It was decided to use an existing computer code rather than develop a new code or modify an existing one. To help focus the effort, an interaction matrix methodology was selected to identify the major physical characteristics of the biosphere (features) and the mechanisms (events and processes) by which radionuclides move from one feature to another. The identification of the relevant features, events, and processes (FEPs) focused on the area of southern Nevada, specifically the area around the Amargosa Valley community (Section 9.2).

The exact nature of the critical group could not be defined because of uncertainties in the geosphere transport model and the need to extrapolate into the future. However, for purposes of the Viability Assessment, the critical group was assumed to be located in the existing community of Amargosa Valley. As previously indicated, this is the nearest populated area hydraulically down gradient from Yucca Mountain. Initial pathway sensitivity analyses conducted in support of this effort indicated that the ingestion pathway was the major contributor to dose for those pathways identified as relevant for the Yucca Mountain area.

Although sparsely populated, the Amargosa Valley community supports approximately 450 households (CRWMS M&O 1997a, p. 18). To permit an accurate representation of this population, a survey was conducted to determine their eating and drinking habits. This survey was focused on the community of Amargosa Valley but for statistical sampling reasons extended to a distance of 84 km (approximately 50 mi) and included the community of Pahrump.

In modeling the biosphere, appropriate site-specific data were used to generate the BDCFs. Many of the site-specific data were based on local conditions (agricultural and climatic) and on the survey of the residents of the Amargosa Valley and nearby communities. It should be mentioned that code input parameters based on these data are likely to provide good estimates for the parameters throughout the Yucca Mountain groundwater flow region in those areas where conditions are suitable for habitation and farming. Thus, the BDCFs presented in this chapter can be used to predict individual doses arising from groundwater outside the survey area (closer than 20 km and farther than 30 km from the repository).

9.1.5 Outline of the Biosphere Chapter

This chapter discusses the details and issues of the biosphere modeling. The following section (Section 9.2) presents an overview of the model used for estimating the BDCFs. Addressed here is the conceptual model of the biosphere that was developed to identify pathways of concern for the site-specific model. This is followed by a review of the available and accepted software packages that were evaluated for use. The section closes with a discussion and presentation of the various parameters needed to adequately describe the movement of radionuclides in groundwater obtained from a well through the subsequent multiple pathways leading to human exposure.

In Section 9.3, a summary of the findings of the biosphere workshop held in June, 1997 is presented. This section contains the suggested work plans for the issues regarded as key by the workshop participants. Other issues that were not recommended for immediate action are identified along with a brief discussion of the implications for the TSPA-VA.

One of the assumed advantages of locating the potential repository at Yucca Mountain is the sparsity of the local population. This low population density suggests that the details of their habits have not been adequately captured in previous surveys conducted over much larger regions including large centers of population. In an attempt to minimize these deficiencies and to establish some of the characteristics of the local population, a regional survey was conducted. The details of this survey and the results are discussed in the subsections of Section 9.4.

The biosphere abstraction process is discussed in Section 9.5. Topics covered include the receptors used for calculating the BDCFs along with the precipitation levels assumed to be representative for the climate changes envisioned over the TSPA-VA assessment period. This section also addresses the fitting of the individual stochastic data from the BDCFs modeling to statistical distributions needed for RIP. This is followed by a brief discussion of the volcanic dispersion of radionuclides and the biosphere modeling appropriate to this type of disruptive event.

In Section 9.6, the BDCFs for the base case TSPA-VA calculation are discussed. The resulting BDCFs are presented along with an evaluation of their statistical parameters.

Sensitivity studies are discussed in Section 9.7. Attention is focused on the sensitivity of the BDCFs to the various defined receptors and the assumed rates of precipitation. Although these studies are ongoing, some detail is presented on the sensitivity of the results to various input parameters. These analyses are limited to those radionuclides that have been shown to be important to the final dose predictions of the TSPA-VA.

Section 9.8 is a synopsis of the biosphere modeling effort to date and concludes with a summary and discussion of this iteration of the biosphere modeling. This includes both the base case scenario of exposures resulting from the use of contaminated well water and from environmental contamination due to volcanic dispersion of the waste. The final section, Section 9.9, provides details of the reference material cited in the body of the document.

9.2 PROCESS MODEL DESCRIPTION

9.2.1 Conceptual Model for Farming Scenarios

The biosphere pathway analyses performed for the TSPA-VA are consistent with similar activities being pursued by the international scientific community. Specifically, assessment of radionuclide transfer and accumulation in the biosphere resulting from the long-term disposal of radioactive waste followed the guidelines and recommendations of the BIOMOVS II international study group (BIOMOVS II [Reference Biosphere Working Group] 1996). An international FEPs list developed by the BIOMOVS II participants was used as a guide in developing the biosphere model.

The reference case for the biosphere modeling is based on the anticipated long-term deterioration and failure of the EBS, and subsequent mobilization and transport of radionuclides in groundwater to a well used by a resident in the Amargosa Valley community. As previously indicated, this well is assumed to provide the receptor with water for domestic and agricultural purposes. Radiation dose to a person occurs via exposure "pathways" that describe the manner the radiation enters the body. As illustrated in Figure 9-2, exposure pathways in the biosphere fall in three principal categories: (1) ingestion dose, (2) inhalation dose, and (3) external dose.

There are many possible ingestion pathways. The ingestion pathway includes drinking of contaminated water, consumption of locally produced crops that have been irrigated with contaminated groundwater, consumption of meat and dairy products taken from livestock that have been sustained on contaminated stock-tank water, and ingestion of contaminated soil. The biosphere model allows for the assumption that livestock and poultry are sustained with some quantity of locally grown feed (e.g., pasture and seasonally harvested alfalfa). Thus, these animals are exposed to the groundwater-derived radionuclides by consuming the radionuclides present in or on the plant tissues. Alfalfa is the predominant crop produced by the Amargosa Valley community and alfalfa and forage grasses comprise a major proportion of Nye County agricultural land (LaPlante and Poor 1997, p. 2-6). Another component of the ingestion dose is the inadvertent ingestion of soil. For most scenarios, soil ingestion tends to be a minor contributor to exposure compared to the food ingestion pathway. However, it could be important for young children who, during play, tend to ingest much greater quantities of contaminated soil than the remainder of the population.

The inhalation dose pathways include breathing of re-suspended soil/dust during outdoor activities such as farming and recreation. Uncertainty in these parameters results from difficulties establishing quantities of radionuclides associated with the suspended soil/dust particles as well as the quantities of material inhaled by residents in the community of Amargosa Valley. Some of the factors that determine the degree of exposure through dust re-suspension are the prevailing meteorological conditions (dry/wet and calm/windy), size and mineralogical composition of the soil particles, their ability to sorb radionuclides, and the time spent outdoors by residents.

The external dose pathway is the exposure to a radiation source that is external to the body. This pathway is also called "ground shine" when the source of the radiation is on the ground or "submersion" when airborne. The radiation dose can come directly from the radionuclides in the soil, dust, crops, building materials, fuel such as wood, etc. The dose can also come from swimming or bathing in contaminated waters ("immersion"). Here again, there is uncertainty in quantifying the exposure from this pathway. The uncertainties arise from our ability to predict source strengths, the times of exposure (usually time spent outdoors), distance to the source, etc.

To bound the exposure of a potential critical group, three receptors were defined:

- The group of adults who are present day residents in the Amargosa Valley community whose dietary fractions of locally grown foods were based on the survey data. In this chapter this receptor is referred to as the average Amargosa Valley resident.

- Resident farmer who was assumed to grow half of the required food using irrigation from the well. (All domestic water was assumed to come from the well.

- Subsistence farmer who grows all his/her own food but otherwise has the same habits as the resident farmer.

The subsistence farmer is in all probability the maximally exposed individual of the critical group at any time, now or in the future. It is important to note that no one interviewed in the survey (either in the community of Amargosa Valley or beyond) fit the criteria of such a farmer. The resident farmer is more likely to be the average member of the critical group. From the perspective of those people who presently reside in the region, the average individual provides the best estimate of future exposures.

In the conceptual model used for the base case, domestic use of the well water can result in radiation exposure primarily through ingestion. The agricultural use of contaminated groundwater can result in internal exposures via the consumption of locally grown food stuffs (e.g., vegetables, poultry, fruit, and meat). Sensitivity analyses indicated that of the two pathways, consumption of contaminated locally grown foodstuffs would result in a higher dose than drinking contaminated water. Although these two are considered to be the most significant pathways for the scenarios addressed in the TSPA-VA, other potential pathways are present. Figure 9-3 presents an illustrative but not exhaustive flow chart for the pathways considered. Use of contaminated water for irrigation of crops can result in the build-up of radionuclides in the soils. These radionuclides can then produce an external dose and/or may result in additional internal doses because of inhalation of re-suspended soil particles or by ingestion of contaminated soil.

A convenient way to show the compartments within the environment, that contain radioactive contaminants and the pathways between these compartments is through the use of interaction matrix methodology. This is similar to the Rock Engineering System matrix used by the Electric Power Research Institute (Smith et al. 1996, Section 2.4). The matrix showing those compartments and the coupling routes thought to be of concern to the populated area of Amargosa Valley is given in Table 9-1. The elements in the leading diagonal of the matrix (printed in bold faced type) define the individual compartments or features. The off-diagonal entries indicate the mechanisms of transport between the two linked diagonal entries. Under the accepted convention, radionuclides in one compartment (row *i*, column *i*) can be transported to another compartment (*j*, *j*) by the mechanism in matrix element *i*, *j*. For example, the mechanism by which radionuclides in the "atmosphere" can be transferred to "surface water" is through "deposition." The mechanism through which radionuclides in "sediment" can be transferred to "soil" is through "erosion" and "dredging."

From the inception of this biosphere modeling effort, the goal has been to use existing software and not to develop a new modeling capability for the TSPA-VA. Although the interaction matrix could be useful in starting a new modeling effort, its application on this project was solely to assist in evaluating the suitability of available software. This aspect is discussed in further detail in Section 9.2.2.1. A major benefit of the discussions leading up to the definition of the matrix was the insight they provided into some of the questions that should be included in the survey of the inhabitants of the Amargosa Valley and adjacent regions. One example was to ask if evaporative (swamp) coolers are used during periods of hot weather. The use of contaminated groundwater in such a cooling unit could disperse fine particles containing radionuclides into the air within a dwelling during the warmer periods of the year. This could lead to additional exposure via inhalation. Another example was to ask about the availability and use of swimming/paddling pools. This pathway has the potential for causing exposure through immersion.

The majority of the pathways identified in Table 9-1 are those that have been included in the dose consequence evaluation codes. A prerequisite for using these codes is a detailed knowledge of the farming and living habits of the receptor group. The survey questions were structured to provide this knowledge. Information requested included what proportion of food consumed was grown locally (i.e., irrigated with the potentially contaminated groundwater), and details of what food types were eaten on a regular basis.

9.2.2 TSPA-VA Biosphere Model

The post-closure biosphere modeling effort for the TSPA-VA will assess the radiation dose to a member of a critical population from radionuclides released from the repository some time after permanent closure. Under this scenario, radionuclides in the repository eventually break through the engineered (e.g., waste package and engineered structures) and natural (e.g., host rocks) barriers and are transported into the accessible environment. Subsequently, the radionuclides may be further transported through various pathways and cause radiation exposures to humans by inhalation, ingestion, or direct exposure. Figure 9-3 shows the various radionuclide reservoirs and pathways, and interactions among these, considered in the biosphere model to produce the BDCFs. Under the assumptions of SIIP for Developing Biosphere Dose Conversion Factors (CRWMS M&O 1996, p. 13), the primary source of radionuclides is assumed to be a well through which groundwater is withdrawn for human use during the post-closure time period. Consequently, a numerical model was needed to evaluate all the important pathways that could lead to radiation exposures to a reference individual.

9.2.2.1 Biosphere Model Requirements and Code Selection Criteria

Code selection for the calculation of BDCFs to support the TSPA-VA was based on the guidelines and requirements outlined in the SIPP and the accompanying Site-specific Assessment Context (CRWMS 1996, p. 13). The SIIP stipulated that the computer code employed for the biosphere modeling be an existing code that (1) satisfies regulatory requirements, (2) meets the fundamental modeling assumptions outlined in the SIIP, (3) is capable of addressing the FEPs defined in the Site-specific Assessment Context, and 4) is accepted by the scientific community. The SIIP also specified that use of the code must be approved by the DOE prior to use in the biosphere modeling.

The GENII-S code (Leigh et al. 1993), coupled system of computer codes, was selected as the model for the BDCFs calculations because it met all of the above criteria. The first version of the code (GENII) was developed by the Pacific Northwest Laboratory (Napier et al. 1988). The code was designed to incorporate the internal dosimetry models recommended by the International Commission on Radiological Protection (ICRP), into an updated version of the environmental analysis models used at Hanford. GENII is capable of analyzing environmental contamination from either acute or chronic radionuclide releases to air, water, or soil. The code was subsequently augmented to handle probabilistic parameter distributions for biosphere pathway parameters, such as radionuclide uptake by plants under defined irrigation conditions, and subsequent uptake of plants by humans and animals in the human food chain. Also included are procedures to account for human exposures based on time spent outdoors, amount of dust inhaled, radionuclide build-up in soils, etc. The GENII-S code has a proven track record of successful application in environmental dose assessment and acceptance by the DOE and Environment Protection Agency (EPA) through its use in the Waste Isolation Pilot Plant Project's performance assessment (DOE 1996, p. 8-8 and Appendix GENII) and a previous performance assessment for the repository disposal of spent nuclear fuel and high level waste (Rechard 1995). The NRC and its contractors also use the GENII-S code.

9.2.2.2 Methodology Employed for Modeling Code Selection

Extensive studies of the methods for environmental radiological assessments have been conducted and numerous computer codes have been developed for use in this area. The primary sources of information on such computer codes are the scientific literature and two scientific software databases, the Energy Science and Technology Software Center (ESTSC) and the Radiation Safety Information Computational Center (RSICC). The ESTSC serves as a library for, and source of, software developed under the sponsorship of the DOE and/or the Nuclear Regulatory Commission (USNRC). The ESTSC also houses software obtained from the Nuclear Energy Agency of the Organization for Economic Cooperation and Development. Scientific software available from this source includes codes developed for radiological safety and accident analysis. The RSICC, formerly known as RSIC, is a similar library authorized by the Specialized Information Analysis Center to collect, analyze, maintain, and distribute computer software and data sets in the areas of radiation transport and safety. RSICC follows the policy and procedure directives set by the DOE for scientific and technical information management. Personal communication with members of the various scientific communities can be another effective way to identify existing computer codes.

Relevant computer codes for consideration in the Yucca Mountain Project were identified through in-depth reviews of these libraries and consultation with technical experts. The functionality of each code selected for evaluation was compared against the model selection criteria. Once a code that appeared to be applicable was identified, it was subjected to the following additional reviews and evaluations. Specifically, it was deemed necessary that any code to be used in the biosphere modeling should have the capability to:

- Assess chronic release scenarios
- Perform stochastic modeling for uncertainty analyses
- Incorporate atmospheric releases as source-term input for pre-closure assessment
- Incorporate radionuclide concentrations in groundwater as source-term input for post-closure assessment
- Stipulate food and water consumption patterns to reflect the characteristics of a particular receptor
- Simulate complex terrain atmospheric dispersion, or incorporate dispersion coefficients pre-calculated by a complex terrain model.

Gaining the confidence and acceptance of the regulatory agencies for a newly developed computer code, or an existing code that has not been previously employed in the U.S. regulatory environment for dose assessment purposes, is a lengthy process—one that could not be accomplished within the TSPA-VA modeling schedule (CRWMS 1996, Section 2.3). Therefore, the evaluation process was limited to those codes that have been used in the U.S. regulatory environment for dose assessment purposes.

Following this procedure, seven computer codes were ultimately compared against the established selection criteria. Information on each of these codes is summarized in Table 9-2. CAP-88PC and AIRDOS-PC use a straight-line Gaussian plume model to calculate radiation dose resulting from chronic atmospheric releases. Neither of these codes, however, can assess groundwater release scenarios. RASCAL was developed for use in accidental release situations and the code can only calculate doses from airborne radionuclides. Although RESRAD is an excellent computer code for environmental dose assessment, it is restricted to dose calculation from residual radioactive materials in soil. As such, the code is not suitable for assessing groundwater and atmospheric releases. MEPAS is another multi-pathway environmental pollutant assessment code that is capable of evaluating both chemical and radioactive contaminants. The assessment end-point of this code, however, is focused on health risk; MEPAS is not capable of calculating organ doses. Both GENII and GENII-S (stochastic version of GENII) are capable of assessing radiation doses to humans from groundwater, as well as atmospheric releases, based on user-defined parameters and pathways.

9.2.2.3 Justification for GENII-S

As shown in Table 9-2, with the exception of GENII-S, no other code satisfied all of the established selection criteria. GENII and GENII-S were found the most comprehensive codes available for use in the biosphere modeling. These two codes are generally flexible enough to address most of the FEPs applicable to the Amargosa Valley area of Nevada. Moreover, as previously mentioned (Section 9.2.2.1), these two codes have been successfully used by DOE for environmental dose assessment and have gained acceptance by regulatory agencies. Given the stochastic modeling approach employed by the other components of the TSPA-VA (e.g., waste form and waste package degradation, saturated and unsaturated flow, etc.), GENII-S was selected as the modeling tool for calculating the BDCFs for input into the TSPA-VA. To provide timely support to the TSPA-VA, the GENII-S code was used to generate the necessary BDCFs in parallel with being qualified under the project's quality assurance program. The code is now in the final documentation stages of being qualified. Thus the BDCFs provided in this report are not QA data. The GENII-S (Environmental Radiation Dosimetry Software) code used had a version number 1.485. It was run on a Pentium Pro platform (Gateway 2000 Model G6-200) with M&O tag number 111210. The code was run in a DOS window within the Microsoft Windows NT 4.0 operating system. The input data required to run the specific calculations performed to support the TSAPA-VA biosphere effort are discussed in Sections 9.2, 9.4, and 9.5 and are presented in Table 9-3.

9.2.3 Parameters Used in GENII-S

Input data that can be used in GENII-S include parameters that can be specified by statistical distributions. During a model run, the user assigns the value range and distribution nature for each variable, and statistical sampling is performed through the use of the Latin Hypercube Sampling (Iman et al. 1985, pp. 1-2) or Monte Carlo sampling. The types of data distributions that can be handled by the GENII-S code include fixed, normal, lognormal, triangular, uniform, loguniform, and empirical (Leigh et al. 1993, p. 5-33). The fixed distribution requires that one parameter value be entered into the code for these variables, while variables with normal, lognormal, and loguniform distributions require the input of two values (distribution parameters). For the normal and lognormal distributions these values are the 0.1 and 99.9 percentiles of the variable distributions. The two required input parameters for variables with uniform and log uniform distributions are the minimum and maximum values of the distributions. Variables with triangular distributions require three parameter input values: minimum, most probable, and maximum values. It should be noted that for the triangular distribution the most probable value is not the mean for the distribution. The final distribution employed is the loguniform. Use of the loguniform distribution requires that the user define the lower and upper limit of the distribution. Because of the logarithmic nature of this distribution the lower limit cannot be set to zero. However an arbitrary low value can be set for the lower limit. The lower limit used is generally selected such that the mean of the approximating loguniform distribution has the same value as the actual mean value, as determined from sampling or experiment.

For the purpose of the TSPA-VA, the input parameters were grouped into major pathway categories, as shown in Table 9-3. The minimum, maximum and best estimate values for input parameters, and where appropriate, the distribution of values for each parameter are also listed in Table 9-3. The references/comments column includes a cross-reference to the project's biosphere modeling input data file (BMIDF) or other data source reference, as appropriate. The BMIDF is an assemblage of all parametric data used for the biosphere component of the TSPA-VA. This file is a records package containing parameter values and supplementary information including data sources in Data Tracking Number MO9806MWDGENII.000 and all data is non-Q (i.e., data were not collected in accordance with quality affecting procedures). Although the majority of the input parameters were derived from site-specific data obtained through the Yucca Mountain regional survey (Section 9.4) and meteorological data, some input parameters were taken from other published sources (LaPlante and Poor 1997; IAEA 1994). For some of the parameters, additional cross-reference notes and pertinent information are included.

Inhalation exposure is influenced by two factors: the mass concentration of particles of such size that they can enter and be retained by the lungs and the duration of the exposure. Thus the exposure is based on the amount of time the reference person spends outdoors. The external/inhalation exposure mass load is the amount of material, dust for example, in a given volume of outside air.

9.2.3.1 Irrigation

Irrigation rates (I) for each biosphere plant group (leafy vegetables, root vegetables, fruit, cereal, grain, hay and forage, turf grasses) are based on estimates of crop water requirements or evapotranspiration (ET) rates for representative plants within each plant group grown in southern Nye County. Reference ETs were calculated from two alfalfa-based ET equations (Jensen-Haise and Kimberly-Modified Penman equations, Martin et al. 1991, Appendix II) using local weather data from the communities of Amargosa Valley and Pahrump. Crop coefficients, average planting dates (specific to southern Nye County), and growing periods (specific to the western United States) were used to convert alfalfa water requirements into specific plant water requirements. Following the calculation of ET values for specific plants, the irrigation rates were estimated from the relationship:

$$I = ET - P + DP \quad (9\text{-}1)$$

where:

I	=	irrigation rate
ET	=	evapotranspiration rate
P	=	precipitation rate
DP	=	deep percolation rate.

The average precipitation rate, 11.7 cm per year, was obtained from a weather station in Amargosa Valley (NCDC 1995, Station: Amargosa Farms Garey). Site specific values for the deep percolation rates (water percolating below the root zone) appropriate to local irrigation rates were not available, therefore, a conservative value of 6.0 inches per year was assumed for DP.

Irrigation rates for specific plants were combined to provide an estimate of I for each plant group. Details on how the best estimate and range of I for each plant group were determined are provided in the BMIDFs. Data on irrigation rates provided by local farmers from southern Nye

County were less than the calculated rates based on Equation 9-1 for a few plants (grapes, wheat, and alfalfa). For the plant groups considered in GENII-S (fruit, cereal, grain, hay and forage), the lower bound of the distribution of potential irrigation rates was set equal to those values reported by local farmers. The home irrigation rate is the water application rate to lawns. Irrigation rates change with the different climates modeled and decrease with increasing precipitation.

9.2.3.2 Basic Soil Data

Soil and plant relationships are site specific and depend on soil types, climate, irrigation rate, and plant species. There is uncertainty in the quantities of radionuclides taken from the soil by the various plants and the amounts subsequently consumed by animals. A recently completed study of the soils in the community of Amargosa Valley and the area north extending to the Yucca Mountain repository reported alkaline soils (pH > 7.0) (CRWMS M&O 1997b). The study documented soil pHs ranging from 7.7 in surface horizons to 9.6 in subsurface horizons (CRWMS M&O 1997b, p. 8, Table 2). The solubility and bioavailability of most metals in soils are highly dependent on the pH of the soil. Generally, soils with naturally high pHs, including many of the calcareous soils of the western United States, are associated with deficiencies of high valence metallic cations including iron, manganese, zinc, and copper for agronomic and agricultural production (Brady 1998, Section 11.4, p. 371). The high pH soils in the vicinity of Yucca Mountain may limit the bioavailability of metal contaminants, including radionuclides, because of the low solubility of the common metal oxide forms in pH conditions above 7.0. For each unit increase in pH there can be an order of magnitude decrease in the solubility of many metals (Tisdale et al. 1985, Chapter 9). Above pH 7.0, both calcium and magnesium carbonates are generally abundant and metals will be complexed as carbonate mineral phases or become trace inclusions in calcium carbonate precipitates. An abundance of calcium and magnesium carbonates in the alkaline soils in the vicinity of the community of Amargosa Valley may further ensure that radionuclides will be rendered unavailable for plant uptake. Given that many of the radionuclides of concern in the TSPA-VA are metallic cations, the naturally occurring high pH soils in the vicinity of Yucca Mountain may greatly limit their transfer from the soil to the plants.

There are few published data on soil properties specific to Nye County and the Yucca Mountain region. Consequently, values for five basic soil parameters (surface soil depth, surface soil density, deep soil density, fraction of roots in upper soil, and fraction of roots in deep soil) were taken from LaPlante and Poor 1997 (Table B-1, p. B-1). Surface soil depth has been defined as a fixed parameter equivalent to the common soil plow layer depth of 15 cm (6 in.). The surface soil density parameter was calculated as a function of soil density and surface soil depth [surface soil density parameter (kg/m^2) = soil density (kg/m^3) $\times$ soil depth (m)]. Because surface soil density is not a sensitive input parameter, the parameter has been assigned a fixed value (225 kg/m^3) for the BDCFs calculations.

9.2.3.3 Crop Interception Fraction and Crop Re-suspension Factor

The crop interception fraction is the fraction of radionuclide contamination from rainfall, irrigation, or aerosol deposition that is intercepted by and adheres to the plant surface. The adsorbed radionuclides are then available for ingestion by foraging livestock and poultry, etc., or for direct ingestion by the human receptor. Alfalfa is the predominant crop produced in the farming community of Amargosa Valley, and alfalfa and forage grasses comprise a major proportion of the crops grown on Nye County agricultural land (LaPlante and Poor 1997). The crop interception fraction is an important and sensitive input parameter for dose calculations and was assigned as a variable input parameter. The values used in the GENII-S calculations were taken from LaPlante and Poor 1997 (p. 2-25). The crop resuspension factor input parameter was taken from LaPlante and Poor (1997, p. B2); as recommended applicable to the Nevada Test Site, it was reported to have a lognormal distributed re-suspension factor (10^{-5} m^{-1}) with a geometric standard deviation (2.5). Crop interception varies with plant type and thus should be based on crops produced in the vicinity of Yucca Mountain. The parameter distribution was assumed to be triangular, with a best estimate value of 0.4 and lower and upper bounds of 0.06 and 1.0, respectively.

9.2.3.4 Food Transfer, Soil/Plant, and Animal Uptake Factors

Two types of food transfer factors are considered in GENII-S: (1) a soil-to-plant transfer factor and (2) a feed-to-animal products transfer factor (animal food transfer coefficient). The soil-to-plant transfer factor represents the activity concentration (Ci/kg, dry weight) ratios between the soil and the edible parts of plants grown in that soil. This factor, which is dimensionless, determines the amount of radioactive material accumulated in plants from soil. The animal feed-to-animal product transfer coefficient is the ratio of the daily radionuclide intake rate (Ci/day) to the radionuclide concentration in animal products (Ci/kg). The coefficient, expressed in units of day/kg (or day/l for milk), is used to determine the amount of radioactive material in edible animal products that results from the ingestion of contaminated feed.

Four types of soil-to-plant transfer factors (soil to leafy vegetables, other vegetables, fruit, and grain) and four types of animal food transfer coefficients (contaminated feed to beef, milk, poultry, and egg products), are considered as the ingestion pathways in GENII-S. Unfortunately, data on transfer factors appropriate to local food types are limited. Therefore, generic food transfer factors were examined and selected. The most recent available information on food transfer factors is from a handbook published by the International Atomic Energy Agency (IAEA 1994, Chapter 6). Thus, the data published by the IAEA were used.

The soil-to-plant uptake parameter values used in the biosphere modeling are not based on soil properties specific to the area surrounding Yucca Mountain, but rather on more generalized temperate soil conditions (IAEA 1994). The soil/plant transfer and animal uptake factors are designed in GENII-S to allow for stochastic runs that will encompass a wide range of soil-to-plant transfer factors and animal food transfer coefficients assigned as fixed values. According to LaPlante and Poor 1997 (p. 212 and Table B-1), these transfer factors/coefficients exhibit lognormal distributions with a geometric deviation of two. For lognormal distributions, GENII–S requires 0.1 and 99.9 percentile values (Leigh et al. 1993, p 5-33), corresponding to a "z" value of 3.09 in a cumulative distribution function F(z). Thus, the lower and upper boundaries calculated for the parameter distributions are $2^{-3.09}$ and $2^{3.09}$, that is, 0.117 and 8.51. This wide range should conservatively cover the uncertainties of soil-to-plant and plant-to-animal food transfer coefficients.

To fit the GENII-S requirements, some transfer factors for the food types included in the IAEA handbook were combined and a geometric mean was calculated with the number of sample data used as a weighting factor. For example, since the transfer factors for leafy vegetables in GENII-S are used for both human food and animal fresh forage, the leafy vegetables consumed by both humans (cabbage, lettuce, and spinach) and as animal fresh forage (alfalfa, clover, and grass) were condensed into one category. The "other vegetables" category includes beans, carrots, radishes, potatoes, and peas. The IAEA handbook does not contain many fruit transfer factors, thus transfer factors recommended by IAEA for "other vegetables" were used for fruits not included in the handbook. The "grain" category includes wheat, barley, and cereals.

Food transfer factors and coefficients can be directly used as variable input parameters for stochastic analysis where they were sampled independently. However, two variable input parameters, the soil-to-plant factor and animal uptake factor, were used for each of four broad categories of food. The parameter value ranges for these two factors are discussed above.

9.2.3.5 Other Input Parameters

The GENII-S code requires several additional parameters (see Table 9-3). Some of these are user defined, while others can be defined or taken from code default values. This section provides a brief discussion of these parameters.

The contaminated water fraction in this effort was defined to be unity, and the parameter defining the total quantity of water ingested was defined to be the quantity of contaminated water. The need for two parameters illustrates a capability (the use of both contaminated and clean water) of the code that was not exercised in this effort.

The stored feed fraction parameters allow the user to define the fraction of stored feed given to farm animals. The remaining fraction is assumed by the code to come from fresh feed. In the modeling reported here the stored feed fraction was defined to be unity for poultry and egg production and zero for beef and milk. Both stored and fresh feed were assumed to be grown locally using contaminated groundwater. The feed requirement for hens (poultry and egg production) was defined as 0.12 wet kg/day of feed and 0.3 liter/day of contaminated water. For bovines, beef producers consumed 68.0 wet kg/day of feed and 50.0 liter of contaminated water; for milk producers the values were 55.0 wet kg/day and 60.0 liters/day.

Fish consumption is a pathway that is incorporated in GENII-S. In generating the BDCFs for TSPA-VA, this option was not used because of the small number of persons who reported eating locally grown fish. In the total survey area, the average fish consumption contributed about 0.2 percent of the mass of food eaten, and only a single respondent in the subsistence category admitted to using this food source.

9.3 ISSUES ASSOCIATED WITH THE BIOSPHERE

9.3.1 Workshop Overview

To support the TSPA-VA effort across the spectrum of process modeling, a series of ten workshops were held in FY-97. Each workshop was devoted to one of the process models used in the TSPA-VA process. The workshop objectives were to identify, discuss, and prioritize through expert consensus the potential technical problems (issues) in each process model. None of the workshops were mandated by any procedure or process. The workshops was conducted to provide a broad based identification and evaluation of relevant and potentially important FEPs in each of the TSPA process models. The outcomes from the workshops were non-Q.

The biosphere workshop was held in Las Vegas in June of 1997. For further details on the brief subject matter discussed below, the reader is referred to draft report of the workshop and its findings (CRWMS M&O 1997c). The workshop was attended by 24 participants. The majority (19) were drawn from TSPA personnel within the M&O and United States Geologic Survey (USGS). However, invitations were also extended to some external Performance Assessment (PA)/Biosphere experts. Additional organizations supporting the workshop were Jason Associates (and their subcontractors), the independent contractor for the Environmental Impact Statement, the Whiteshell Laboratories of the AECL, and the Electric Power Research Institute. In addition, other interested parties were invited to send observers to the meeting. These parties included the DOE, the USNRC, the EPA, the Nuclear Waste Technical Review Board, the TSPA Peer Review Panel, and interested groups in the M&O.

9.3.2 Definition and Prioritization of Issues

Three technical sessions were held in a serial manner to define, discuss, and evaluate the biosphere issues. These pertained to

- Critical group definition
- Biosphere pathways
- The geosphere-biosphere interface.

At the beginning of each session, the importance of the relevant issues was described, and this was followed by invited speakers who presented details of the predefined issues. An open forum concluded the discussion phase in which all participants were given the opportunity to voice their thoughts about any additional, but unidentified, issue or to present further discussion on issues already identified.

For the issues sessions, the participants were segregated into four working groups. In each session, all groups independently ranked the issues using three evaluation criteria. The criteria were defined in terms of the question: "*To what extent does the issue affect: (a) the individual dose, (b) the population dose, and (c) the range or uncertainty in BDCFs as generated by the biosphere model?*" The participants had to assign each issue one of three possible scores. A score of five was to be given if the issue was judged to be of high importance, three if considered of intermediate importance, and one if assessed to be of minor importance. The reported score of the group was the sum of the scores assigned by the individual group members.

9.3.2.1 Critical Group Definition

In the sessions on critical group definition, the workshop participants identified and ranked nine issues. These rankings are shown in Table 9-4. The group scores are included in the table as an indication of ranking consistency among the groups.

The following issues were carried forward for further discussion

- Extrapolation of present habits to the future (Issue 1.3)
- Location of the critical group (Issue 1.4)
- Habits of the critical group that are major contributors to dose (Issue 1.2)
- Effects of climate change on establishing a definition of the critical group (Issue 1.5).

The critical group issue (Issue 1.7) ranked of highest concern in Table 9-4 was already proposed for evaluation as part of the biosphere effort. For this reason, it was not considered for further study by the working group. The issue concerning the effects of climate change on defining the critical group (Issue 1.5) was combined with the climate change topic in the biosphere pathways group. This is discussed in the Section 9.3.2.2.

9.3.2.2 Biosphere Pathways

Ten issues of potential significance were identified and discussed in the biosphere pathways session. These are listed in Table 9-5 in order of importance, as judged by the workshop participants.

Of these issues, three high ranking issues were selected for further study for the TSPA-VA:

- Defining the radionuclides that are of prime importance (Issue 2.06)

- Radionuclide accumulation in the soil from continuous irrigation (Issue 2.01)

- Effects of climate change on habits of critical group (Issue 2.10).

Workshop participants noted that climate change effects (Item 3) were also applicable to the geosphere-biosphere interface definition session of the workshop, as climate change could increase the water table level and give rise to new seeps and springs.

9.3.2.3 Geosphere—Biosphere Interface

The third and final biosphere session focused attention on the potential issues concerning the interface between the geosphere and the biosphere (Table 9-6). Some issues involved the saturated zone (SZ), while others pertained to non-aqueous release mechanisms such as volcanism, human intrusion, and gaseous (primarily $^{14}CO_2$) releases.

Of the seven issues identified, only two were carried forward for further study. Both of these were related to pathway variability: 1) the location and definition of the biosphere-geosphere interface (Issue 3.7) and 2) identification of important radionuclides transferred by disruptive events (Issue 3.2).

9.3.3 Development of Biosphere Analysis Plans

In the case of the biosphere workshop, the participants were assigned to one of three groups. In undertaking this task an attempt was made to ensure that members in each group represented a "typical" cross-section of expertise. Each group had the responsibility to formulate an analysis and abstraction plan to address one of the three categories of issues as shown in Table 9-7.

These plans generally formed the basis for the biosphere effort that was pursued in support of the TSPA-VA.

9.3.3.1 Development of Critical Group Definition

The two objectives defined for this task were to define the membership of the critical group and to provide estimates of the parameters required for calculating the BDCFs for the important radionuclides.

The outline of the plan generated by the group was consistent with the biosphere effort. As noted earlier, a pilot study to determine the consumption rate of locally produced foods had been conducted in the community of Amargosa Valley and the surrounding region. The goal was to identify and quantify the locally produced food consumption habits of the residents. The results were used to generate the statistical distribution of the many parameters defined for use in stochastic modeling of the biosphere to calculate the BDCFs distributions for the TSPA-VA receptors.

A majority of the current Amargosa Valley residents live at least 20 km from the potential repository site. A recommendation was made to review available data to determine whether any agri-economic factors limiting exploitation of unused land closer to Yucca Mountain existed. In the absence of such data, it was thought that it might be necessary to initiate an investigative program to measure any such limitations.

As discussed in Section 9.1.1, annual dose to a receptor in the community of Amargosa Valley and nearby areas was to be the measure of repository performance the TSPA-VA. A spectrum of receptors can be defined. In the absence of regulatory guidance, three receptors were considered in the TSPA-VA effort. The first receptor defined was the group of individuals living in the Amargosa Valley community. The habits of these individuals were based on current day information. To bound other groups within the population, two additional receptors were defined. BDCFs were calculated for the following three groups:

- The average present day Amargosa Valley resident (used as base case for the TSPA-VA)
- A subsistence farmer
- A partially self-sufficient farmer (resident farmer).

The habits (locally grown food and water consumption) of the first group were determined from the survey data. The subsistence farmer was assumed to exclusively consume locally produced food and well water. The habits of the last group were based on a modification of those adopted for the subsistence farmer. The use of these receptors as critical groups for the TSPA-VA is discussed later in Section 9.4.5.2.

9.3.3.2 Establishment of Biosphere Pathways

The objective of this planning activity was to provide input on how to address the issues considered significant on the topic of pathways. This plan was to aid in the ongoing biosphere effort to develop a credible all pathways model of the community of Amargosa Valley and nearby regions.

The issues addressed were

- Identification of the radionuclides of importance to dose calculation (Issue 2.06 Table 9-5)

- Incorporation, where applicable, of the build-up of radionuclides in soils subjected to prolonged irrigation (Issue 2.01, Table 9-5)

- Incorporation of change in habits of critical group (due to climate change) the modeling effort (Issue 2.10, Table 9-5 see Section 9.5.3).

The review group began by constructing a plan to identify the radionuclides of importance. Before this work package was finished, it became apparent that the selected code (GENII-S) could readily generate the BDCFs for all 39 radionuclides considered in the other sub-models in the TSPA-VA. Subsequently, the BDCFs were generated for all radionuclides considered in the TSPA-VA.

Evaluation of the process of radionuclide accumulation in soil irrigated with contaminated groundwater is an ongoing effort. This will lead to a more detailed modeling capability for this mechanism, but not in time to support the TSPA-VA. For the TSPA-VA, the existing capability in the GENII-S code for modeling this process will be used.

9.3.3.3 Defining the Geosphere and Biosphere Interface

The objectives of this effort were to provide consistency between the radionuclide concentration in the SZ and the radionuclide concentrations assumed to be released to the biosphere, infiltration of precipitation into Yucca Mountain, natural outflows to the accessible environment, and water use by inhabitants.

The issues covered were

- Location and definition of the geosphere and biosphere interface (Issue 3.7, Table 9-6)

- Effect of climate change on the interface (through changes in habits of critical group) (this is an extension of Issue 2.10, Table 9-5)

- Interaction effects of multiple discharge locations and mechanisms (Issue 3.3, Table 9-6).

- Issue 3.2 (Table 9-6) concerning the identification of radionuclides important to disruptive events was discussed. The issue ceased to be of concern when it was decided that the appropriate BDCFs would be generated for all (39) radionuclides considered in the TSPA-VA.

All three receptors defined for the TSPA-VA are local residents withdrawing their water from a local well. There is large uncertainty as to where these residences and wells will be located over the next many millennia. To avoid this problem, it is assumed that at any prescribed distance from Yucca Mountain water is taken at the point of maximum radionuclide concentration, as calculated by the TSPA-VA SZ model. This assumption defines the primary interface between the geosphere and the biosphere.

The effects of increased precipitation and infiltration are modeled by the hydrological sections of the TSPA (Unsaturated Zone Transport - Chapter 2 and Saturated Zone Flow and Transport - Chapter 8). Thus, changes in groundwater velocity and depth to the water table are inherently accounted for within the TSPA code.

The third issue, regarding the interaction of multiple discharges, is a problem associated with the SZ and not the biosphere. This issue is being addressed in Chapter 8, Saturated Zone Flow and Transport.

Finally, another release scenario under consideration is that arising from volcanic activity. Such events are being treated independently of the groundwater pathway.

9.3.3.4 Discussion of Issues Not Addressed in Detail

The workshop process had identified 26 issues most in need of discussion and debate in the arena of the biosphere. It was acknowledged that not all issues could be addressed in time to support the TSPA-VA effort. Thus, it was necessary to identify those issues considered to have sufficient importance to require resolution as part of the biosphere modeling work plan. It should be noted that annual dose to individuals was to be used to evaluate performance in the TSPA-VA; evaluations of risk and population dose were specifically excluded from the analyses. For completeness, it should be pointed out that Volcanism (Issue 3.4, Table 9-6) is discussed in Section 9.5.5 and in Chapter 10, Disruptive Events.

For this reason, the plans presented in Sections 9.3.3.1, 9.3.3.2, and 9.3.3.3 address only the most important issues in each of the three identified categories: "Critical Group," "Biosphere Pathways," and "Geosphere-Biosphere Interface" as given in Table 9-7. As discussed earlier, exclusion of an issue from immediate study does not imply that the issue is inconsequential. The prioritized ranking allowed attention and effort to be focused on those issues thought by a reasonable cross-section of knowledgeable experts, to warrant consideration for the TSPA-VA effort.

The recommendations of the workshop participants for each of the issues not carried forward for inclusion in the detailed study plans are summarized below. Included is a review of the implications of each issue to the TSPA process, as well as how each was treated in the VA analysis.

Issue 1.7—The range of uncertainty and variability in parameters for the critical group. This issue had already been included in the plans for biosphere modeling. The regional survey, for example, has generated the information needed to accommodate, in a statistically sound manner, the range of parameter uncertainties and variabilities for the three possible critical groups.

Issue 1.5—The effect of climate change on critical group definition. There was agreement among participants that several factors could change the definition of the critical group over time. The workshop participants were of the opinion that it would be speculative to attempt to quantify the effect of the technological and societal advances or declines over the next many thousand years. However, to address the climate influence on the critical group, a comparatively small survey has been conducted in Lincoln County, Nevada. This area was selected as a surrogate for the survey since the climatic conditions there are similar to those cooler and wetter conditions predicted by the climate change models for the Amargosa Valley area. The results from this survey are being analyzed and will be presented in a later report.

Issue 1.9—Variation of dominant biosphere pathway with time. It was understood by the participants that the dominant pathway for dose is radionuclide dependent. As the concentrations of each radionuclide in groundwater will vary as a function time (to be predicted by the improved modeling in the TSPA-VA), any change in the dominant pathway will be captured by the model. The impact of this issue on the definition of the critical group was considered by all workshop participants to be minor. During development of the biosphere modeling work package (CRWMS M&O 1996) it was stated that for the TSPA-VA the biosphere model would be based on present day conditions. Thus this issue was not pursued further.

Issue 1.1—Unknown performance criteria. The absence of any mandated standard for the long-term performance of the potential repository was considered a major inconvenience to model development. However, this situation is beyond the control of the program staff and as such cannot be resolved by either the workshop participants or the TSPA team. This issue was not considered further. At the time of the biosphere workshop annual dose to a defined receptor(s) was used as a measure of performance for the purpose of the TSPA-VA.

Issue 1.8—Special cases. During the workshop, the term, "special cases," was coined to capture special groups at potential risk (such as mining or drill operators), who could receive high doses if they encountered the waste. However, it was the conclusion of the group that, although dose estimates for these special cases may have to be derived, existing capabilities will be adequate. The uncertainties in the scenarios will exceed those in the input parameters for the analytical model. As a result, the decision was made not to expend any special development effort on this topic for the TSPA-VA.

Issue 1.6—Effect of group composition (age, gender, etc.). Compliance with existing USNRC and EPA regulations is to be demonstrated using dose conversion factors (DCFs) based on reference man (ICRP 26, 1977) and using ICRP 30 methodology. This approach was adopted by the work reported in Federal Guidance Report 11 (Eckerman et al. 1988, Table 2-1 and 2-2). As a result, they do not specifically consider the age and/or gender of the receptor.

Issue 2.08—Preserving correlation between parameters within the biosphere. Where the correlation between biosphere parameters is known, the intent is to consider this to the extent permitted by the selected software. The workshop participants judged the impact of any such correlation to be a small correction to the contribution to the dose from that relevant pathway. However, it was noted that a positive correlation between input parameters could increase the values of the prediction and their range. The issue was considered not to be of prime concern for the TSPA-VA.

Issue 2.02—Atmospheric dispersion. The concern identified in this issue is the dispersion of contaminated (from irrigation) surface soil by the wind over significant distances. The local effect of soil re-suspension (but not the ensuing transport) and inhalation is incorporated in the biosphere model. The majority of the workshop participants considered the dose arising from soil dispersion over long distances to be relatively insignificant compared to that which might be received by people living near the proposed repository. In case of a future large urban development in or near the present community of Amargosa Valley, this pathway may become important in terms of the population (collective) dose.

Issue 2.07—Preserving correlation between variables across the interface of biosphere and geosphere. This issue is concerned with the effects of increased precipitation on both the geosphere and the biosphere. In particular, it relates to the delay between the time of the anticipated increase in radionuclide releases from the repository (due to increased infiltration) and the resulting increase in the quantities of radionuclides reaching the accessible environment. Subsequent analyses showed that the values of the BDCFs are only weakly dependent on precipitation (for example, doubling the rate of precipitation changes the BDCFs values by about 2 percent). Thus, any change in dose estimates due to this correlation would be small. As a result, the participants decided not to devote more detailed study to this issue.

Issue 2.09—Determination of sensitive model parameters. In the plan developed for the biosphere effort, those parameters of importance, will be identified in an iterative manner. Once identified such parameters will be the focus of more detailed study and data collection.

Issue 2.03—Non-SZ pathways (gas, intrusion) and **Issue 3.6**-Gaseous releases. These issues were judged by the workshop participants not to be of concern. Gaseous pathways were assessed as being of low consequence in terms of the TSPA-VA. If necessary, the intrusion scenarios could be evaluated with the code used for the SZ based releases. There are, however, no plans in the TSPA-VA to consider either of these pathways in the geosphere component.

Issue 2.04—Selection of appropriate DCFs and **Issue 2.05**-Determination and incorporation of uncertainty into DCFs. This has already been touched upon in the comments on Issue 1.6 above. Since current USNRC and EPA regulations generally require the use of Federal Guidance Reports (FGRs) Nos 11 (Eckerman et al. 1988) and 12 (Eckerman and Ryman 1993) for DCFs, it was considered that using DCFs derived from using other methodologies would obscure the issue of regulatory compliance. Because DCFs derived from methodologies based on reference man (ICRP 26 1977) and ICRP 30 (ICRP 30 1979) as given in the FGR are single-valued parameters, it was considered that any attempt to estimate the uncertainty in these (or other) DCFs would require extensive effort without providing any additional insight into the behavior of the facility. The DCFs values presented the FGR are designed for use in radiological protection calculation and are therefore considered conservative.

Issue 3.3—Interaction effects of multiple discharges, locations, and mechanisms. The concern here was that, within the biosphere region of interest, adjacent wells and springs could be coupled, with the flow in one location affecting the radionuclide concentration available from the other. For this reason, this effect is not considered in the biosphere analyses for the TSPA-VA. In the RIP code it is always assumed that the water in the SZ that is used for dose calculations at a specified distance from the repository is taken from the region of maximum radionuclide concentration in the plume at that distance. This approach eliminates the need to define well locations with respect to concentration profiles in the plume.

Issue 3.5—Inadvertent intrusion. At the time of the workshop, it was thought that this scenario would not be addressed for the TSPA-VA. However, one such scenario will be analyzed. The details of this scenario are discussed Chapter 10 – Disruptive Events.

Issue 3.1—Effect of draw-down on dilution. Estimates have been made (and were presented to the workshop audience (CRWMS M&O 1997d, p. 3-11) for the degree of dilution as a function of well usage. These data show that for a typical subsistence farmer, the annual volume of water used would produce little, if any, significant change in radionuclide concentration. For this reason, no credit is to be taken for this effect. Such an omission will result in a small but conservative, error in the BDCFs generated.

9.4 REGIONAL DEMOGRAPHICS AND FOOD/WATER CONSUMPTION SURVEY

9.4.1 Survey Overview

Site-specific or locally-focused information on demographics and food and water consumption are necessary to model, in a realistic manner, the biosphere processes that affect the potential doses from the use of contaminated groundwater in the vicinity of the proposed Yucca Mountain repository. In terms of assessing the performance of the potential repository, the characteristics of future human activities cannot be accurately predicted. Data from national food consumption surveys are not adequate because these databases are not site-specific and, in fact, lack even state-level specificity (U.S. GAO 1994, Table 1, footnote c). The GENII-S model (Leigh et al. 1993, Table 5.7) can use input parameters derived from local or site-specific data on environmental factors (climate, soils, groundwater, etc.) and quantities of food and water consumed by the reference person potentially exposed to contamination. Therefore, the strategy for the TSPA-VA is to base human demographic and living habits (kinds and quantities of foods and water consumed, time spent outdoors, hobbies (e.g., gardening), occupations (e.g., animal husbandry), etc. on actual data where possible. A regional survey was conducted to obtain site-specific, localized data on food and water consumption habits of people living near Yucca Mountain. Because the receptor of interest for this assessment is based on the physical and biokinetic characteristics of a reference adult, the survey focused on adults.

The TSPA-VA base case modeling considers a reference adult person living 20 km from the proposed repository. A component of this reference biosphere comprises the population near the site. This population, referred to as the "critical group," has been defined as

> "...a partially self-sustaining rural, agrarian, desert community where humans either produce portions of their own food or gather it from the natural environment.... (It) will be identified based on the lifestyles and dietary patterns of a local population located to be consistent with locations specified in applicable regulatory standards" (CRWMS M&O 1996, p. 3).

Although the regional survey had several secondary objectives, including providing additional data for the Yucca Mountain project's radiological monitoring and environmental justice programs, its main purpose was to provide site-specific data for use as, or establishment of, input parameters for the GENII-S code.

The survey included two primary components. The first was to determine the frequency of consumption of locally produced food (in 11 categories) and tap water by adults residing in the survey area; this was done to establish site specific parameters for input to GENII-S. Demographic measurements (gender, occupations, etc.) of adults residing in the 84-km radius survey area centered around Yucca Mountain were included. The survey also attempted to capture ancillary information that may be needed for GENII-S input (e.g., swamp cooler use) and to provide estimates of precision (sampling error) for data obtained through the survey. The second component was to estimate the quantities (kg per year) of locally produced food and well water consumed. This data would be input to GENII-S by combining frequency of consumption data (obtained from the first component) with estimates of contingent average daily (CADI) intake for the western United States (USDA 1993, pp. 18-29)

The survey area covered the communities of Amargosa Valley, Beatty, Indian Springs, and Pahrump. Data were collected in such a manner that would allow for linking of consumption, demographics, and geography for subsets of the adult population (e.g., resident adult, resident adult - partial subsistence, resident adult subsistence), one or more of whom may serve as an empirically-based "critical group" for the purposes of biosphere modeling with GENII-S. Maintaining respondent confidentiality was paramount in the data collection process. All data either collected during the survey or subsequently generated were non-Q.

An initial pilot survey was conducted in January and February 1997 to define a more comprehensive survey. The Cannon Center For Survey Research, University of Nevada Las Vegas (UNLV), conducted the pilot survey using Computer Assisted Telephone Interviewing (CATI). The preliminary investigation represented the first empirical information gathering on the consumption of locally-produced food in the vicinity of Yucca Mountain. The pilot survey identified the consumption levels of locally-grown food and identified a suitable sample frame (a source from which all or nearly all members of the population of interest could be contacted). In this case a set of telephone numbers was selected for a more comprehensive survey of the area within a radius of 84 km of Yucca Mountain. Using information gained from the pilot survey, questionnaire design and interviewing procedures were established to minimize non-sampling error. A full-scale sample survey was then approved by the U.S. Office of Management and Budget (OMB) (Control #1910-1400) in April 1997. The full survey was subsequently conducted using the CATI system at UNLV. The data generated by both the pilot and full survey were non-Q.

Nearly 13,000 adults are estimated to live in the total survey area, with 900 (7 percent) of them residing in the community of Amargosa Valley. The needs of the survey (obtaining localized or site-specific data) suggested a higher proportion of households should be sampled in the areas closer to the potential repository. The full survey, completed in June 1997, consisted of an inverse gradient sample design for more comprehensive survey representation of the inhabitants closer to Yucca Mountain, thus, approximately 67 percent of the estimated 450 households in the community of Amargosa Valley were targeted for the survey (Figure 9-4).

Climate effects on critical group habits will be evaluated by comparing the results of this survey with similar survey results from Lincoln County, Nevada. Lincoln County is located approximately 200 km northeast of the potential repository site. This county is generally higher in elevation and is characterized by cooler temperatures and higher precipitation (2 to 3 times greater mean annual rainfall, depending upon elevation) than the Yucca Mountain survey area. The data gathered in the Lincoln County survey will be used in conjunction with the double (2×) and triple (3×) increased rainfall climate change scenarios being modeled in the TSPA-VA.

9.4.2 Reliability, Validity, and Accuracy of the Survey Results

Two important criteria must be satisfied in a questionnaire designed to provide empirical measurements: reliability and validity. In gathering information to characterize a population, the major objectives are to maximize accuracy, while minimizing costs and time (Swanson et al. 1996). The desired outcome is to compile a data set with high utility. Therefore, the methodological goals of the survey were to produce maximally accurate estimates using a reliable and valid questionnaire, while conforming to budget and timing constraints. These goals needed to be accomplished within the context of the federal guidelines on minimizing respondent burden (United States Code Service 1997, Section 3506).

Reliability refers to the extent that a measurement procedure yields the same results when repeated, [i.e., the extent to which measurement techniques produce a consistent answer (Carmines and Zeller 1979, p. 11)]. Validity refers to the extent that a given indicator represents an underlying, often abstract, concept and represents the relationship between the underlying concept and its indicator (Carmines and Zeller 1979, p. 12). It is impossible to provide direct evidence of the reliability and validity of <u>all</u> the information collected in a survey. However, for the food consumption items considered in this survey, the TSPA-VA Biosphere staff had recourse to indirect evidence of their reliability and validity. For purposes of comparison, subsistence consumption levels from the survey were aggregated across broader categories of food types to make them conceptually similar to information from other sources (CRWMS M&O 1997d, p. 17, Table 2.3.7). These comparisons indicated that food consumption levels in the survey area compared favorably with levels reported elsewhere. However, a difference in water consumption was notable; adults in the survey area consume about 2.0 liters of drinking water per day (see Tables 9-15 to 9-20), while rates reported in an USNRC guide (USNRC 1977, Table E-4) would suggest only about 1.0 liter per day. The 2.0 liters per day reported as a result of the survey, however, compare favorably with ICRP estimates as presented in their Publication 23 (1974). In terms of accuracy, a major goal in any survey is to control total error, which results from two sources: sampling error and non-sampling error (Andersen et al. 1979, pp. 1-14).

Special steps were taken to ensure the reliability and validity of the survey results. As was the case for the pilot survey, the comprehensive survey questionnaire design followed principles developed by the U.S. Office of Management and Budget (DeMaio 1983, p. 13; U.S. OMB 1983). Underlying the entire project were Dillman's (1978) "Total Design Method" principles and interviewing standards promulgated by the Institute for Social Research, University of Michigan (Guenzel et al. 1983), to maintain high response rates and accuracy.

The survey included Spanish language interviews to accommodate those respondents who spoke only Spanish, or whose primary spoken language was Spanish. In addition, the survey included a special "difficult to interview" population sample (n=33) to determine if "non-response bias" was present and if special weighting (adjusting the value or influence of the "difficult to interview" population) or other adjustments were required to account for this bias.

9.4.3 Data Gathering

Along with information about the needs of the GENII-S Model (Leigh et al. 1993, Chapter 5) employed for the biosphere modeling, the *Scientific Investigation Implementation Package for Developing Biosphere Dose Conversion Factors* (CRWMS M&O 1996, p. 13) formed the conceptual basis for the survey questionnaire. The actual design work for the survey was initiated in the fall of 1996 with a series of internal meetings designed to identify specific research objectives, timing requirements, and the resources required to conduct a survey that would provide adequate information on food consumption for biosphere modeling.

The population in the survey area, particularly that residing in the community of Amargosa Valley, has been the subject of many studies over the past decade related to the proposed Yucca Mountain repository. Thus, a conscious effort was made to minimize intrusiveness and cost wherever possible when conducting the survey. From the pilot survey, it was known that the consumption of locally produced food was not a "rare event" and a series of questions on demographic characteristics of respondents and their households would be needed to satisfy the survey goals and objectives. Therefore, a decision was made to use the first available adult household resident as a respondent, thus avoiding the time-consuming screening procedures and callbacks associated with other respondent selection techniques (Bryant 1975, pp. 130-131; Troldahl et al. 1964, p. 75).

The effort to measure the incidence of a "rare event" (i.e., population never consumes locally produced food products) would have required other respondent selection procedures (Bergsten and Pierson 1982, p. 145). Because it was not known in advance if significant differences would be found between men and women, and females tend to answer the telephone about two-thirds of the time (Dillman 1978, p. 248), the demographic information was used to "post-stratify" the survey data, thereby compensating for any gender bias that may arise due to the respondent selection method employed in the survey (Banks 1979, pp.104-112; Kish 1965, p. 519). When values within a stratum are similar, but values in some strata differ substantially from those in other strata, stratified sampling can help ensure a representative sample. Post-stratification of the survey data by gender corrected for the above cited tendency of women to be over-represented in telephone-based surveys (CRWMS M&O 1997d, p. 29, Table 3.5.2).

Given what was learned from the pilot survey about the likely average interview length (approximately 10 to 12 minutes) and the survey goals and objectives, it appeared that the available resources would support an upper limit of about 1,200 completed interviews. Because of its proximity to Yucca Mountain, the needs of the survey suggested that a higher proportion of households would be sampled in Amargosa Valley community than elsewhere. An attempt to interview approximately 67 percent (circa 300) of the estimated 450 households in the community of Amargosa Valley was made. The target household sample sizes for Beatty, Indian Springs, and Pahrump were 300 (40 percent), 50 (9 percent) and 500 (10 percent), respectively. Thus in light of constraints and needs, the target sample interview size for the entire survey area was determined to be around 1,150. The pilot survey results suggested that a list of telephone numbers provided by Survey Sampling Inc., a major vendor of randomly-generated telephone numbers, would be adequate as a sample frame.

Because of the importance of Amargosa Valley community, the survey respondents from this community were mapped into the "grid cells" in which they resided. These cells are subsets of the radiological monitoring grid (CRWMS M&O 1997a, pp. 2-3, Figure 2.2). The grid cell mapping was accomplished by matching the telephone number of each completed interview against the telephone number found in the records maintained by the Valley Electric Association and using the geographic information system to allocate matched numbers into their corresponding grid cells. For the reasons cited, caution was exercised to preserve confidentiality of respondent records during this process. For example, the telephone numbers were deleted from the respondent information records and only the grid cell geographic identifier was ultimately left on the respondent data record. Given statistical uncertainty and the restrictions associated with small sample sizes, very precise inferences for any given inhabited grid cell would not be attainable. To achieve any level of statistical precision on inferences drawn from the grid cell data, information would have to be aggregated across grid cells.

All of the interviewees contacted corresponded with one of the following household telephone prefixes: 372—the communities of Amargosa Valley, including Lathrop Wells, Ash Meadows and Crystal (Pahrump Valley Times 1995, rural telephone book); 553—Beatty, including Oasis Valley and Scotty's Junction; 879—Indian Springs; and 727 and 751—Pahrump. The interviews were initiated in mid-May and completed in early June 1997. During this period, no known peripheral events occurred that affected the results of the survey. All interviewing was done by a supervised staff of well-trained and experienced interviewers at the Center between 12:00 (noon) and 7:00 p.m.

The CATI system employed in the survey is one in which an electronic copy of the questionnaire appears on the computer monitor screen. The interviewer communicates with a respondent over the telephone by means of a telephone headset and reads the survey questions directly from the screen. The responses given to the interviewer are then key-punched directly onto the questionnaire as the interview proceeds. This direct data entry process eliminated the potential errors that could result from the transfer of information from one medium to another (e.g., from paper to a computer file). In addition, instantaneous checks for valid entries and correct sequencing of questions were conducted. Upon the completion of an interview, the questionnaire and its data became a case in the record data file and were immediately ready for the next step of the editing and quality control process.

As stated previously, the approximate target number of completed interviews was 1,150. The actual number of interviews completed was 1,079, with 2,395 attempts and 373 refusals. The disposition of each of the 2,395 attempts is shown in Table 9-8. From these data, the cooperation rate was calculated to be 74 percent, [(1,079 completes)/(1,079 completes + 373 refusals) ×100] while the Working Number Completion Rate was found to be 51.4 percent [1,079/(2,395-296) ×100]. Although not indicated in Table 9-8, the automatic time logs of the CATI system revealed that the average time consumed in each of the 1,079 completed interviews was 12.5 minutes.

9.4.4 Calculations and Statistical Analyses

All calculations and analysis were made using the NCSS 6.0 statistical software system (Hintze 1995). This system is built on a Microsoft Excel platform. The computational precision of the system was tested before the survey using the reference data sets provided by the National Institute of Standards and Technology (NIST 1997).

9.4.4.1 Weighting of Survey Data

In many sample surveys, the proportion of respondents with a given characteristic does not match the same proportion found in the entire survey population of interest. Under these circumstances, "weighting" is used to ensure that the survey results are consistent with what one would expect for the entire population (Kish 1965, p. 519). Weighting corrects or adjusts the importance or influence of a survey object or subject from a given subset population by proportionally increasing or decreasing its value based upon its importance or significance to the entire population. In this survey, "weighting" was required for two reasons: (1) each community's share of the total survey sample was not proportional to its share of total households and (2) the previously cited over-representation of females in the survey sample.

Total household numbers surveyed in the various communities are shown in Table 9-9, and the number and frequency of adult females surveyed by community are shown in Table 9-10. Gender, area, and total weighting coefficients that were developed for the survey and the formulae used in developing these data are presented in Table 9-11. As an example of the application of weighting coefficients in the analyses of the survey data, consider the "total" survey weighting for males from the communities Amargosa Valley and Indian Springs. Upon examining results for the entire survey (Table 9-11), the Amargosa Valley and Indian Spring's male survey weighting coefficients are 0.487 and 1.898, respectively. That is, every 10 males in the Amargosa Valley community represent approximately five males (4.87) and 10 males in community of Indian Springs comprise approximately 19 males (18.98) in the context of survey interpretations for the total survey area.

Note that in examining and interpreting the results for a specific community, only the gender weighting is required (Table 9-11). Again, using the Amargosa Valley community as an example, the weighting coefficient for females and males are 0.80 and 1.320, respectively. That is, every ten females represent eight females and every 10 males represent approximately 13 males (13.2) in the context of the total survey for the Amargosa Valley. Also, note that if there had been response homogeneity by area - no difference in food consumption habits, for example - and if males and females had the same average daily intake of food, then weighting would not have been necessary. However, as revealed in the survey data presented in subsequent discussions (Sections 9.4.4.2 and 9.4.5.1), responses for this survey were not homogenous, either by gender or area; furthermore, males and females do not have the same average daily intake of food (Table 9-12).

Statistical tests were also conducted to ascertain if response patterns for key questions differed between the "difficult to interview" group and the "not difficult to interview" group. This was necessary to determine if special weighting or adjustment was needed for the "non-response" group. The tests were conducted across all food groups and five socio-economic characteristics. The tests were structured in the standard manner, with a "null" hypothesis that there was no difference between a parameter of interest (i.e., the percent consuming locally produced food) and an alternative hypothesis that there was a difference in this parameter, with the probability of rejecting a true null hypothesis set at 0.05.

In all but one of the tests, it was found that the null hypothesis could not be rejected. The only case in which a difference was found was gender: men were more likely to refuse being interviewed than women. Thus an additional 15 tests were conducted comparing females to males to see if these two groups differed in their habits and assess whether having lower representation of males in the survey might impact the survey results. The tests showed that females and males differed in only three areas: Females were more likely than men to consume locally produced poultry and locally produced eggs, and less likely to consume locally produced game. The overall conclusion was that there was no compelling evidence to indicate that non-respondents, on average, were systematically and substantially different from respondents. Furthermore, gender-based weighting already in place would account for the three areas (poultry, egg, and game consumption) where differences may exist due to gender.

Table 9-13 provides an example of one of these tests. The test concerns question three in the survey: "Have you eaten locally produced food in the past year?" While there are differences between the difficult to interview sample and the other respondents, 65.6 percent of the difficult to interview, versus 60.4 percent of the others, reported that they had consumed such food during the indicated time period. However, the difference is not statistically significant. The chi-square statistic is 0.35, with a probability of 0.55. This exceeds the alpha level of 0.05 and is therefore not statistically significant. In other words, because of sample variability, one could expect differences as large as this between respondents and non-respondents in 55 percent of the samples of this size drawn from a population in which there was no difference between the frequency of respondents and non-respondents eating locally produced food.

9.4.4.2 Food Intake Calculations

The GENII-S biosphere modeling program requires estimates of annual consumption of selected foods in terms of mass (Leigh et al. 1993, Tables 5.7–5.10), but it was not feasible to collect this type of information directly through the CATI-based survey. It was, however, feasible to collect "frequency" information on food consumption. Data from USDA surveys on food intake in the United States were combined with information from the survey to produce estimates of annual quantities (kg) of the various food groups consumed.

Eleven food groups and a "residual" group (included primarily so the interviewers could administer the questionnaire easily) were included in the survey. The survey questionnaire included a four-part question for each food group.

For the respondent who answered "yes" to whether he/she consumed a particular food group, he/she was then asked how many months of the year that food was eaten. The questionnaire response categories were 1–3 months, 4–6 months, 7–9 months, and 10–12 months. Because the survey focused on the consumption of "locally produced" food, there may be a larger seasonal effect than found with the consumption of food in general, such as those products purchased at the market and meals eaten away from home. The midpoints of each of the response categories were used (i.e., 2, 5, 8, and 11 months) for calculating the amount of the food consumed.

The third part of the question asked how many days per week the respondent consumed the food in question: less than 1 day per week, 1–2 days per week, 3–4, 5–6, or 7 days per week. The mid-points of each of the response categories were again used for those reporting consumption one or more days per week: 1–2 days = 1.5; 3–4 days = 3.5; 5–6 days = 5.5; and 7 days = 7. The "less than one day per week" response category was for those who only rarely ate the food in question (e.g., only once in a two month period). Interviewers were instructed to probe when this response was given so that a coefficient appropriate to the response could be assigned. When evaluated during the data editing phase, the coefficients were clustered around 0.5 (i.e., once every 2 weeks), thus this value was used universally for those responding "less than 1 day per week."

Finally, the fourth part of the food consumption question asked the respondent how much of the food in question was locally produced: all, most, some, or very little. For calculating the amount consumed, the response categories were converted as follows: all = 1; most = 0.75; some = 0.5; and very little = 0.25.

Supplemental quantitative information was then required to convert the frequency information on the consumption of the various food categories to annual, per-capita intakes (kg) for input to the GENII-S model. The USDA has produced relevant information over the years from a regular survey series. A recent report (USDA 1993, pp. 18-29) provides estimates for 1987–1988 of average daily intake (ADI) and the fraction of people that consume a given food group per day (FPC). The ADI for a food group is simply the total amount of that food group consumed over a reference interval divided by the total population surveyed. The agency conducted similar surveys over the periods 1989–1991 and 1994–1996. Final reports of the 1987–1988 (USDA 1993) and 1989–1991 surveys have been published, but only preliminary results are available for the 1994–1996 survey.

From the USDA surveys, the contingent average daily intake (CADI) of a particular food group, can be estimated. CADI is the average amount of food from each group that is consumed by individuals on the days that they consumed some of that food group. It is important to distinguish CADI from ADI because the calculation for the latter includes in its denominator those who do not consume the food in question on a given day. The contingent ADI for food group i can be estimated from the ADI for food group i and the fraction of people consuming from food group i each day as

$$(\mathrm{CADI}_i) = (\mathrm{ADI}_i)/(\mathrm{FPC}_i)$$

Note that finding a CADI value for a given food type is equivalent to dividing the total amount consumed by only those consuming the food in question. In using CADI for purposes of estimating food consumption quantities in the survey area, the assumption was made that during the months when respondent j ate locally produced food from group i, respondent j ate at least some locally produced food from group i on every day that j ate any food from group i. With this assumption, the annual amount of locally produced food from group i that respondent j consumed (AAC_{ij}) is given by the number of days per year that j ate the food (DPY_j) times the average amount of the food that j ate on the days that he or she ate some of the food in question (CADI_i) times the fraction of locally produced food eaten over the period (Q_{ij}). That is,

$$\mathrm{AAC}_{ij} = (\mathrm{DPY}_j)(\mathrm{CADI}_i)(\mathrm{Q}_{ij}) = (\mathrm{DPY}_j)(\mathrm{Q}_{ij})(\mathrm{ADI}_i)/(\mathrm{FPC}_i).$$

where

AAC_{ij} = annual amount of locally produced food from group i consumed by individual j

$CADI_I$ = contingent average daily intake of food from group i (USDA survey)

Q_{ij} = locally produced fraction of total consumption during the months in which respondent $_j$ consumed locally produced food from group i: 1, 0.75, 0.5, or 0.25 as translated from "all," "most," "some," and "very little" (Biosphere Survey)

and

ADI_i = average daily intake of food from group i (USDA survey)

FPC_i = fraction of people consuming food from group i per day (USDA survey)

DPY_{ij} = number of days per year that j consumed locally produced food from group i (Biosphere Survey) = $DPW_{ij} \times WPY_{ij}$

where

DPW_{ij} = (Days Per Week) = j's response to third part of food question i

WPY_{ij} = (Weeks Per Year) = $MPY_{ij} \times (4.33)$

and

MPY_{ij} = (Months Per Year) = j's response to second part of food question I

4.33 = average number of weeks per month over a year.

Estimates of contingent ADI for the United States and the western United States were extracted from the 1987–1988 survey (Table 9-12). Although differences between the United States as a whole and the western United States are mostly only a few percent one way or the other, values for the western United States were used in the calculations.

The following example calculation illustrates how food consumption quantities were estimated. Suppose that a female respondent ate locally produced fruit 3–4 days per week over 4–6 months during the past year. Over the 4–6 months, "some" of the fruit she ate was locally produced. Her annual amount consumed (AAC) was calculated as:

$$AAC = (CADI_i)(Q_{ij})(DPY_j)$$

$$\approx (293\ g)\ (0.5)\ (3.5\ day/week \times 5\ month/yr \times 4.33\ week/month)$$
$$\approx 11{,}000\ grams,\ or\ 11\ kilograms\ per\ year.$$

In summary, while the survey data are subject to error from a number of sources, the extensive tests done in regard to non-response bias and gender, as well as the validity and reliability checks, all suggest that the survey data are valid and reliable. Given this testing and the fact that statistical precision is high for the survey overall and also measurable for subsets derived from the overall survey, it can be concluded that the data are generally adequate for biosphere modeling purposes.

9.4.5 Survey Inferences for TSPA-VA Biosphere Modeling

As previously mentioned, the most likely scenario for radionuclide release from the repository to the biosphere is through groundwater transport, and the community of Amargosa Valley is hydrologically down-gradient from Yucca Mountain (Luckey et al. 1996, p. 14). Thus, given their proximity to the potential Yucca Mountain repository and their rural, agrarian characteristics, the residents of the Amargosa Valley community are the most likely to be exposed to groundwater-borne radionuclides released from the repository.

9.4.5.1 Survey Inferences for Amargosa Valley

Table 9-14 shows the percent of the survey respondents consuming tap water and locally produced food by type for the community of Amargosa Valley, the remainder of the survey area, and the total survey area, including the Amargosa Valley community. In general, locally produced food is consumed by a higher percent of the residents in the Amargosa Valley community than in the remainder of the survey area. Perhaps more importantly, tap water is consumed by a substantially higher percentage of Amargosa Valley community residents than the other two survey area categories; nearly 88 percent reported consuming tap water in the Amargosa Valley, while only 79 percent did so in the remainder of the survey area. Nearly 80 percent of the survey respondents reported consuming locally produced food of some type (any food type) over the past year in the Amargosa Valley community, while only about 57 percent did so in the remainder of the survey area. With the exception of grain, a higher percent of adults in the Amargosa Valley community consume locally produced food across all food types than elsewhere in the survey area.

Using the data presented in Tables 9-15 and 9-18, the consumption averages across food types were summed to obtain an indication of the average consumption of locally produced food for the total population set in comparison to the Amargosa Valley community only (CRWMS M&O 1997d, Section 3.6). Excluding milk, the average consumption in the total survey area per resident adult was 15.1 kg per year, while in the Amargosa Valley group the average was 28.4 kg per year. The annual consumption of locally produced milk is slightly lower in the Amargosa Valley settlement (4.4 liters) than for the total survey area (4.8 liters). However, the annual quantity of tap water consumption is higher for the Amargosa Valley resident (684 liters) than in the total survey area (646 liters). These findings further support the premise that Amargosa Valley residents exhibit more of the life-style habits stated in the definition of the "critical group" (Section 9.4.1) than the residents in the remainder of the survey area.

The quantities of locally produced food and local tap water consumed by an individual will have a significant impact on the radiation dose if contaminated groundwater is used for irrigation and drinking water as modeled in the TSPA-VA. The survey data can be analyzed to consider and contrast three subsets of respondents to evaluate differences in the consumption of locally-produced food and tap water: (1) total population, (2) partial subsistence, and (3) subsistence farmer. The "subsistence" subset comprises those for whom all of what they eat of a given food is locally produced. The "partial subsistence" subset includes the subsistence set plus every adult who eats at least some locally produced food type in question. The "total population" data subset, includes the first two subsets plus those who reported no consumption of the locally produced food type in question. Tables 9-15 through 9-17 and Tables 9-18 through 9-20 show these differences for the entire survey area and for a subset of Amargosa Valley residents only, respectively. As would be expected, for both the entire survey area data set and the Amargosa Valley subset, the average consumption level of locally produced foods and tap water increases dramatically as one moves from the total population survey data set to the partial subsistence subset and on to the subsistence subset.

9.4.5.2 Receptor Groups for the Biosphere Modeling

For the purposes of the TSPA-VA biosphere modeling, three receptor groups (subsistence farmer, resident farmer, and an average Amargosa Valley resident) were established in an attempt bound the upper and lower limits of the various input parameters (e.g., consumption of locally produced food and tap water, etc.) to capture the probable range of future habits of a reference individual as given in Table 9-21. The subsistence farmer is defined as an individual who eats only locally-produced food, drinks only local water (obtained from a well), and spends a substantial amount of his/her time outdoors engaged in activities needed to maintain existence (i.e., gardening and animal husbandry). The subsistence farmer receptor represents the upper limit of dose through the established biosphere exposure pathways. The resident farmer receptor is defined as an individual who produces some of his/her food locally, but does not depend entirely on this source for his/her subsistence. Through the various pathways modeled in the TSPA-VA, the resident farmer is subjected to approximately half of the exposure as the subsistence farmer. The average Amargosa Valley resident is used in the TSPA-VA to provide an estimate of the expected exposure.

No one interviewed in the survey area (Amargosa Valley community or beyond) completely met the criteria established for the subsistence farmer receptor. The resident farmer is more likely to be the average member of the critical farmer group. However, from the perspective of those people who presently reside in the region, the average individual provides the best estimate for future exposures.

The "total population" resident adult data subset of the Amargosa Valley data set (n = 195) was sufficiently large to provide good statistical representation for the development of the various input parameters for the average Amargosa Valley resident receptor. However, with the exception of water consumption data, the survey "subsistence" resident adult data subset for the Amargosa Valley community (Table 9-20) contained too small of a population to provide a statistically meaningful representation of the subsistence farmer receptor. Consequently, the total survey area "subsistence" resident adult subset was selected to emulate the subsistence farmer receptor for purposes of biosphere modeling.

9.4.6 Survey in Lincoln County

The analyzed data from the Lincoln County survey were not available for incorporation into the TSPA-PA. These data will be used in future TSPA efforts.

9.4.7 Summary of Survey Results

The results of the regional survey on demographics and food and water consumption support the possibility that the "critical group" for use in the TSPA-VA biosphere modeling effort is most likely to reside in the community of Amargosa Valley than elsewhere in the 84 km radius surrounding the potential Yucca Mountain repository. Estimates of the quantities of locally produced foods and water consumed within the survey area suggest that Amargosa Valley adult residents consume higher proportions of locally produced food products and tap water than those in other portions of the survey area (Figure 9-5).

Six survey data subsets ("total population" resident adults for total survey, "partial subsistence" resident adults for total survey, "subsistence" resident adult for total survey, Amargosa Valley "total population" resident adults, Amargosa Valley "partial subsistence" resident adults, and Amargosa "subsistence" resident adults) were evaluated for their appropriateness to represent the three target receptors established for the biosphere modeling (subsistence farmer, resident farmer, and average Amargosa Valley resident, see Table 9-21). The Amargosa Valley "total population" adult resident data subset was selected to represent the average Amargosa Valley resident. Although the Amargosa Valley "subsistence" resident adult subset would likely correlate best with the subsistence farmer receptor, this data subset population was deemed too small to provide a statistically meaningful representation of the survey parameters. Consequently, the total survey area "subsistence" adult resident was chosen to represent the subsistence farmer receptor for development of the required input parameters for the GENII-S model biosphere dose calculations.

9.5 ABSTRACTION PROCESS FOR BIOSPHERE

9.5.1 Evaluation of BDCFs for TSPA-VA

The TSPA-VA predictive capability considers the mobilization, transport and radioactive decay of 39 radionuclides. The anticipated standard against which the potential repository will be judged will require the calculation of annual dose through a multiple pathways methodology. The mode of introducing the radionuclides into the accessible environment is assumed to be a well supplying contaminated groundwater for both domestic and agricultural purposes. To complete their predictive capability, the TSPA coding group needed an abstraction of an all-pathways dose model for a member of the Amargosa Valley population who fits this exposure scenario.

Two requirements were placed on the biosphere abstraction process to generate the BDCFs. Three receptors had to be considered. The choice of receptors is discussed in Section 9.5.2. Because of anticipated climate change over the periods to be modeled, three climatic conditions had to be evaluated. These conditions are discussed in Section 9.5.3.

The regional survey data (Section 9.4) were used to formulate the food consumption and agricultural practices appropriate to the three receptors. Additional parameters required by the code to evaluate the annual dose arising from a given radionuclide were obtained from published literature. Where available, data appropriate to the region (desert SW) were used. In the absence of any site or regional data, generic data were used.

A major reason for selecting the GENII-S code was that this code provided the capability to perform multiple evaluations with input parameters being sampled from defined distributions. Some of the parameters used in the abstraction process were represented by such distributions. The parameters and the details of the assumed distributions are further discussed in Section 9.6.2.

For each radionuclide, for each receptor, and for each precipitation level, the GENII-S code was run using Latin Hypercube Sampling from all defined parameter distributions. As the radionuclide content in the groundwater was defined as being of unit concentration, the output from the GENII-S code provided the required BDCFs. The multiple samples provided an approximation to the statistical distribution of the BDCFs.

9.5.2 Receptors to be Used for BDCFs

Three receptors were defined for generating the BDCFs. All three were based on present day habits as determined by the survey. No attempt was made to forecast changes in receptor habits over the period of the performance assessment. The participants at the biosphere workshop believed that any such projections would be speculative and would add no benefit to the understanding of the behavior of the potential repository. In selecting the receptor groups, consideration was given to existing regulatory standards and the recommendations of the National Academy of Sciences Committee on Technical Bases for Yucca Mountain Standards (NAS 1995, pp. 95-104). Following the recommendations of the participants at biosphere workshop reported in Section 9.3.2.1, no consideration was given in the TSPA-VA to various age groups. It was acknowledged that for some of these special groups the doses and risks might be higher than for adult groups. However, it was considered that for the purpose of radiological safety the DCFs based on the methodology presented in Federal Guidance Report No. 11 (Eckerman et al. 1988, Tables 2.1 and 2.2) are adequately protective of such groups. The assessment of the effect of age on the exposure consequences is being addressed independently of the TSPA-VA.

The GENII-S code generates the DCFs required to calculate the BDCFs. The approach used in the code is that employed by Eckerman et al. 1988. This approach was adopted to allow the code developers to incorporate any improvement in metabolic and dosimetric modeling. Examples of such parameters are the gastrointestinal absorption fractions for the various compounds of the radionuclides, the lung clearance classes of compounds, lung retention as a function of particle size, and organ weighting factors. The ingestion DCFs for four radionuclides, as generated by GENII-S, are presented in Table 9-22, where they are compared to values from Federal Guidance Report No. 11 (Eckerman et al. 1988, Table 2.2). As expected, there are differences between the two sets of derived data. However, the differences are thought to be minor and serve to validate the acceptance GENII-S has received from the dosimetric and regulatory communities.

One of the receptor groups was taken to be the present day residents of the Amargosa Valley community. This group was used for the base case evaluations in the TSPA-VA and is referred to in this chapter as the Average Resident of Amagosa Valley, where in effect, the average member of the critical group was defined as the average member of the population currently living in the area.

The limiting critical group was identified by the NAS Committee (NAS 1995, Appendix D) as a subsistence farmer. Such a farmer is assumed to use groundwater for all domestic and agricultural purposes. This water is also used for growing all required food. For this receptor, eating and drinking habits were estimated from the regional survey and all food was locally produced. It is important to note that the survey did not identify any resident of the area who had these characteristics.

An intermediate group, the resident farmer, was defined as the third receptor. This farmer is assumed to produce only 50 percent of his/her dietary needs using contaminated groundwater, with the remainder of the food being imported into the region. This imported food is assumed free of radionuclides. As with the subsistence farmer, this resident farmer uses groundwater to meet all his/her drinking water needs.

9.5.3 Consideration of Climatic Changes

An external factor that has to be considered in the TSPA-VA is the anticipated climate change over the period for which the repository performance has to be evaluated. The TSPA-VA analysis incorporates cyclical changes in climate over the next million years. The prevailing change is postulated to be towards a cooler and wetter environment at Yucca Mountain and adjacent regions (including the site of the Amargosa Valley community). The resulting higher precipitation on Yucca Mountain will give rise to increased infiltration. This increased water flow will eventually intercept the repository and affect the rate of waste package degradation. If one or more waste packages are breached, any increased water flux will increase the dissolution of the waste form and transport of the released radionuclides. Eventually, after the appropriate transit time, changes in the concentrations of radionuclides will be seen at the accessible environment.

However, a climate change will also have a direct effect on the habits of the critical group. An increase in precipitation will reduce the quantity of groundwater that has to be pumped for irrigation. Associated with the rainfall increase will be an expected decrease in temperatures. Such reductions are expected to have an effect on the type of crops raised, the eating and drinking habits of the inhabitants, and the duration of the growing seasons. An additional effect of precipitation increase will be a rise in the elevation of the water table. This process may result in new natural outflows (springs and seeps). Such a change could impact the location of future habitation and agriculture. However, as the BDCFs developed under this effort are based on unit concentration in the groundwater, they could be used to predict exposure dose in a farming scenario using natural outflows.

As both radionuclide transport and the biosphere are functions of climate, then to be consistent with the geosphere process models, the BDCFs generated for the biosphere should reflect the effects of changes in climatic conditions. This climatic dependence was addressed on two fronts. First was the incorporation, into the GENII code, of the effect of a reduction of Is because of increased precipitation. The average annual rainfall for the region of interest (the community of Amargosa Valley) is approximately 12.0 cm per year (based on 24 years of data). At the biosphere workshop, representatives of the USGS provided their initial thinking that approximate values to assume for future precipitation levels would be three times and five times the current annual average. Additional discussion between the TSPA team and the USGS led to revising these projected levels to twice and three times present annual rates. These rates were used to generate the BDCFs, taking into account the fact that the increase in precipitation would lead to a reduction in Is.

As previously mentioned, a present day surrogate having precipitation rates about three times that in the Amargosa Valley community (Lincoln County, Nevada) has been selected to estimate the effect of climate change in the habits of the receptors of interest. This data, not presented here, will be used in any future TSPA.

Future changes in the level of the water table are acknowledged to have a potential impact on the biosphere model and dose predictions. However, these effects have not been addressed in this iteration of the biosphere modeling.

9.5.4 Discussion of BDCFs Statistics

The TSPA-VA is based on a stochastic modeling approach. Rather than predict a single deterministic value of performance, a probability distribution for the expected result is generated. This is achieved by assigning an appropriate distribution to those parameters that cannot be accurately described by a single value. The same approach was adopted for the biosphere modeling. The specific representations of the GENII-S input parameters are provided with discussion in Section 9.6.2. Of the approximately 91 parameters required to model the contaminated well scenario for the biosphere, some 46 were represented by variables. The expected distributions of the BDCFs were generated by randomly sampling these distributions (using a Latin Hypercube approach to improve computational efficiency) and running multiple realizations of the code.

For each combination of the 39 radionuclides, 3 receptors, and 3 precipitation rates, 130 realizations were executed. The BDCFs data generated by these realizations provided the information needed to specify the required distributions. The mean value and standard deviation were calculated for each distribution along with the 5, 50, and 95 percentiles of the distribution. These reduced data are presented in Section 9.6.2. It is acknowledged that if any significant correlations exist between input parameters for a particular radionuclide, the actual BDCFs distribution could be modified from those presented in Section 9.6.2

The RIP code allows the user to define a mathematical distribution with attendant parameters to specify a variable[1]. To ensure the use of an appropriate statistical distribution, a chi-square goodness of fit test was made for several of the more common continuous probability distributions. This analysis and the results are provided in Section 9.6.2. Of the available distributions, the lognormal provided the best fit to the GENII-S predicted distribution. The lognormal distribution was used for sampling of the BDCFs within the RIP predictive code. Figure 9-6 shows the comparison between the GENII-S generated data and the fitted lognormal distribution. When sampling the appropriate BDCFs distributions in the RIP code, it was

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[1] The available distributions in RIP are: - normal, lognormal, uniform, loguniform, triangular, logtriangular, poisson, beta, gamma, weibull, binomial, boolean, cumulative, and discrete.

assumed that the BDCFs had a correlation of unity. That is a single random variable was used to select all of the required radionuclide BDCFs from their appropriate lognormal distribution.

9.5.5 Discussion of Volcanic Biosphere Pathways

The event under consideration is an ash release that settles on a farming area. The two scenarios considered include inhalation and submersion during the ash fall followed by ongoing farming activity on soil containing the contaminated volcanic ash.

The following pathways are considered within these two scenarios:

- During the passage of the ash cloud
  - Inhalation of airborne ash
  - External exposure to radionuclides in the cloud

- Subsequent to passage of the ash cloud
  - Ingestion of contaminated food and animal products
  - Ingestion of contaminated soil
  - Inhalation of resuspended soil.

To assess the radiological impact of a volcanic disruptive event occurring at Yucca Mountain, it was necessary to define a receptor of interest. For the purpose of this preliminary assessment, this receptor was assumed to be the average Amargosa Valley resident adult. This individual has the lifestyle characteristics identified in Section 9.4.5.2.

In the first scenario, an individual is assumed to remain outdoors during the passage of an ash cloud containing the radionuclides. The BDCFs were calculated for unit concentration of the radionuclides in air and for one hour of exposure. To determine the dose, the quantity of radionuclides expelled by the event is calculated, then the radionuclides are distributed in an appropriate volume of air. Exposure time (in hours) is estimated. The dose is then determined by the product of the radionuclide concentration, the BDCFs for inhalation and submersion, and the assumed time of exposure.

The BDCFs for inhalation during the passage of the cloud were calculated using the U.S. Environmental Protection Agency's (EPA) Dose Conversion Factors (Eckerman et al. 1988, Table 2-1) for the assumed exposure length and radionuclide concentration in air (see Chapter 10). The lung clearance class resulting in the highest value of dose conversion factor for a given radionuclide was selected for conservatism. An acute breathing rate of 330 cm^3 per second was assumed for radionuclide intake calculation. Similarly, BDCFs for submersion in contaminated air were calculated using the EPA's dose conversion factors for the assumed exposure duration and unit air concentration of radionuclides (Eckerman and Ryman 1993, Table III.1). The BDCFs for the two exposure pathways, inhalation and submersion, associated with the first scenario are shown in Table 9-23.

The second scenario considers the exposure dose associated with the residential and agricultural use of land upon which the contaminated ash has been deposited. The assumption was made that the contaminated land is farmed and used to grow food for local consumption. It is assumed that the ash from the eruption comprises the entire upper 15 cm (6 in.) of the ground surface because this depth encompasses the root zone of most agronomic and agricultural plants. For these calculations, the groundwater is assumed not to be contaminated; radionuclides in groundwater have already been taken into account in the base case BDCFs factor calculations and including them again in the volcanic scenario BDCFs would result in erroneous duplication of this factor when dose calculations are subsequently executed. As with the base case, the dominant pathway is the ingestion of contaminated foods. To generate BDCFs for this scenario, a unit surface activity (1 picocurie per square meter) from the ash fall is assumed. The BDCFs generated for the TEDE (ingestion of contaminated food and animal products, ingestion of soil, submersion, and inhalation of resuspended soil) for a 1–year exposure associated with the second scenario are shown in Table 9-24.

The results of this assessment were provided to the Performance Assessment Group investigating the radiological consequences of disruptive events and have been incorporated into the assessment of igneous activity (volcanic eruption).

9.6 PROCESS BASE CASE

9.6.1 Model Description

The receptor in the base case for the TSPA-VA was the average current-day resident in the Amargosa Valley. The characteristics of this average resident were discussed in detail in Section 9.4. The parameters of importance for the individual include the amount of well water and the amount of locally grown foods consumed. To allow for exposures from other potentially significant pathways, such as inhalation of resuspended radionuclides and direct radiation, it was also necessary to define the length of time spent outdoors.

As discussed in Section 9.5.4, the BDCFs had to be generated for three defined rates of precipitation. The primary change in the input into the GENII-S code was to reduce the amount of irrigation water required. In the absence of the analysis of the data from the Lincoln County survey, the total (i.e., precipitation plus irrigation) water volume per unit area of irrigated land was assumed to be the same as now required in the Amargosa Valley community.

9.6.2 Analyses

The GENII-S code parameter input was constructed using data representative of the average resident for the region, as determined by the regional survey. As noted above, the I (this parameter was itself a distribution) was tied into the precipitation rate. Latin Hypercube stochastic sampling was used to optimize computational efficiency. The code was directed to execute 130 multiple realizations to generate the distribution of the BDCFs for each radionuclide of concern to the TSPA-VA.

The output data for each realization were saved for subsequent analyses. The process was repeated for each of the 39 radionuclides (shown in Table 9-25). After generating the required raw data for one precipitation rate, the process was repeated for the other defined rates. The BDCFs data were then used in the RIP studies for the TSPA-VA base case.

The arithmetic mean and standard deviation of the BDCFs were generated for each data set. These values are shown in Tables 9-25, 9-26 and 9-27 for the three precipitation rates. Also provided in the tables are the 5, 50, and 95 percentile points of the BDCFs distributions. As may be noted, the median values are systematically lower than the mean values. Furthermore, the 5 percentile and 95 percentile points are not symmetrically distributed about the mean. The ratio of the 5 percentile value to the mean is approximately equal to the ratio of the mean value to the 95 percentile value. These observations are consistent with the distribution being closer to a lognormal rather than normal distribution.

The Excel spreadsheet program was used to optimally fit several continuous distributions to the BDCFs data sets. For supporting the TSPA-VA, the chi-square goodness of fit was used to quantify the adequacy of each distribution in representing the data. The 130 realizations for the BDCFs generated by the GENII-S code were sorted into 10 BDCFs bins. The lower and upper limits of the bins were selected so that each bin contained approximately the same number of observations. This ensured that the criterion set by the chi-square test of having not less than 5 predicted observations in any bin would be met for all reasonable approximating distributions. The Excel "solve" capability was used to determine the optimum parameters for each distribution to mimic the GENII-S data. To use the chi-square test, the number of degrees of freedom (DOF) has to be established. The DOF is the number of bins into which the data have been sorted less the number of parameters that have to be specified for the distribution under test. Most distributions tested had two parametric variables. A notable exception was the beta distribution with four adjustable parameters. In this case the accept/reject chi-square criterion is lower that that for the other distributions. The results of this distribution fitting are summarized in Table 9-28 for ^{237}Np. For this example, the accept/reject limit indicates that only the lognormal and gamma distributions provide acceptable fits to the data. The lognormal distribution was used in RIP.

9.6.3 Discussion of Results

The use of a finite number of realizations to generate each BDCFs, implies that the average BDCFs value reported here is only an approximation to the true BDCFs mean value. Statistical sampling theory allows the development of an estimate for the range within which the actual mean of the BDCFs will fall. For a measured mean $:_m$ derived from a sample of n observations drawn from a distribution with a given standard deviation (Φ), an estimate of the 95 percent confidence interval for the true mean is given by $:_m \pm 1.96\ \Phi/n^2$. The factor of 1.96 arises in the expression for the upper and lower limits of the true mean because the limits so defined for the approximating Gaussian (or normal) distribution then contain 95 percent of the expected population. For the BDCFs this indicates that the possible variability of the reported versus the actual BDCFS mean is about 6 percent. The width (or range) of the BDCFs distribution can be estimated from the calculated 5 percentile to 95 percentile points. For the average resident in Amargosa Valley, the ratios between the 95 percentile value to the mean value and the mean value to the 5 percentile value are both about a factor of three. For the resident and subsistence farmer receptors, these ratios are lower and have a value of approximately two. Thus, the use of a limited sampling size of 130 realizations did not introduce any significant error over and above the inherent range in the distribution.

The values of the 5 percentile and 95 percentile points on the BDCFs distributions provide an indication of the uncertainties introduced into the TSPA-VA dose predictions from the biosphere modeling. Thus, in terms of the expected value of dose to a receptor, the biosphere uncertainty can change the predicted dose values by a factor of between two and three.

9.7 SENSITIVITY STUDIES

9.7.1 Approach to Sensitivity Studies

In addition to the average resident base case, two other receptors were evaluated: the subsistence farmer and resident farmer. For the former, all food intake was assumed to be locally grown, while for the latter only half of the food intake was assumed to be locally grown. Both used local groundwater for drinking. Each receptor scenario was evaluated for the three prescribed precipitation rates. The nine BDCFs cases for each radionuclide provided a matrix of results that allowed some parametric sensitivity to be evaluated.

In stochastic evaluations of multiple parameter models, it is possible to estimate the sensitivity of an output measure to variations in input parameter values. The GENII-S code has this capability. This capability was exercised to identify (for selected radionuclides) the parameter(s) that have the more significant impact on the modeling results. This process is discussed in more depth in Section 9.7.2.

9.7.2 Sensitivity Analyses

Sensitivity analysis is the study of the variation in model output with respect to changes in the input parameters. The objectives of this analysis are to develop understanding of the overall model performance, to identify which input parameters have more influence on the model output, and to provide direction and focus for data collection and modeling activities. The GENII-S code has the capability to perform sensitivity and uncertainty studies. Details of the sensitivity capability in the code can be found in Leigh et al. 1993. A brief overview for the benefit of the reader is presented in the remainder of this section.

To perform the sensitivity analysis, a set of parameters used in the modeling must be identified. These parameters define the modeling scenario under consideration, for example, an average individual in the community of Amargosa Valley living in current climatic conditions. Each of these parameters is described by a statistical distribution obtained from either the regional survey or scientific literature (Table 9-3). The computer code, GENII-S, samples from each of these input parameters using a stratified Monte Carlo (Latin Hypercube) sampling technique and produces the individual realizations of the BDCFs. These data are those referred to in Section 9.6.2.

Regression is employed to assess the relationship between the model inputs and output. The strength of the linear relationship between the inputs and output can be measured by the correlation coefficient, or square of the correlation coefficient, R^2. However, each of the model inputs (independent variables) and the model output (dependent variable) may have different underlining statistical distributions and are unlikely to be linearly related. Under these circumstances, the correlation coefficient calculated from numerical values of the input and output parameters will have reduced significance.

A more robust approach is to use rank correlation. In this technique, the correlation coefficient is calculated using the parameters' rank instead of actual parametric values. Rank values are determined by arranging the actual values in ascending order and replacing the values with their rankings. For example, the lowest actual value will have a rank of one, the next lowest value a rank of two, and so on. Correlation coefficients calculated based on rank are more robust even for variables with different distributions.

9.7.3 Results of Sensitivity Studies

9.7.3.1 Alternative Receptors

The BDCFs calculated for the resident farmer and the subsistence receptors are listed in Tables 9-29 through 9-34. As anticipated, the magnitude of the BDCFs for a given radionuclide is commensurate with the consumption of locally grown food with the resident farmer and subsistence farmer progressively having higher BDCFs. This dependency is illustrated in Figure 9-7.

9.7.3.2 Parametric Sensitivity

Forty-six variables were evaluated in the parametric sensitivity study. Depending on the radionuclides, typically it was found that less than 10 independent variables (i.e., model-input parameters) accounted for more than 90 percent of the variance of the model output. This finding represents valuable information, which can be used to base decisions on the allocation of modeling resources to those input parameters contributing most to modeling uncertainty. The finding also identifies the factors driving certainty in the model output.

As an example of the parameter sensitivity analyses, Table 9-35 summarizes the results of sensitivity analysis for ^{99}Tc, ^{129}I, ^{237}Np, which are considered among the more important for the base case modeling scenario.

A further example from the sensitivity study is a comparative assessment of the relative importance of individual pathways to total exposure. The fractional contributions to the expected BDCFs for ^{99}Tc, ^{129}I, and ^{237}Np are shown in Table 9-36 for the current average resident of Amargosa Valley. The data presented allow the important pathways to be identified and the contribution of the remaining to be put into perspective. Direct consumption of groundwater contributes approximately 50 percent of the expected annual dose for the average Amargosa Valley resident.

9.7.4 Interpretation of Sensitivity Studies

The calculated BDCFs for the nine case studies (three receptors at three precipitation levels) show the rate of precipitation, as modeled by the change in irrigation levels, has very little effect on the BDCFs. For each unit of increase in rainfall (a unit is the present day annual precipitation), the values of the BDCFs are reduced by about 2 percent. These changes are inconsequential in comparison to the predicted range of the BDCFs distributions. This is anticipated because irrigation rate is affected only minimally by precipitation levels.

In contrast, the definition of the receptor had a significant influence on the BDCFs. The annual dose to the resident farmer from a particular radionuclide is increased over the annual dose to the current average resident by a factor of between 2.5 to 3.5 (the actual factor is radionuclide dependent). For the subsistence farmer the increase in annual dose over the same base case annual dose is a factor of between 4 to 7 (radionuclide dependent). The BDCFs values for ^{237}Np as a function of receptor and precipitation rate are shown in Figure 9-7. Similar patterns are present for all other radionuclides.

For the receptor based on a present day average resident of the Amargosa Valley community, the dominant pathway for the radionuclides studied in detail is drinking water. For these radionuclides three pathways (drinking water, leafy vegetables, and meat) contribute more than 90 percent of the total BDCFs.

The stochastic biosphere modeling shows that for a given radionuclide the BDCFs can vary by about a factor of three above and below the mean value. Thus, the range of the BDCFs spans approximately one order of magnitude (Figure 9-6 and Tables 9-25 through 9-27 and Tables 9-29 through 9-34). Because of this variation, it is useful to understand which input parameters are dominant in causing this variance in the output. Rank regression is a technique employed to assess the relationship between the model input and the output. The simple and partial correlation coefficients are measures of how much the calculated biosphere dose conversion factor is correlated with a given sampled parameter. In the case of the simple correlation coefficient, the statistical variations due to the stochastic sampling of all other parameters are ignored. In partial correlation, statistical methods are used to factor out the random (non-correlated) effects for the parametric stochastic sampling. Consequently, the partial correlation coefficients provide better estimates for the true correlation between input parameters and BDCFs output. Forty-six variables were evaluated in the parametric sensitivity study. Depending on which radionuclides were considered, typically less than 10 independent variables accounted for more than 90 percent of the variance of the model output. Table 9-35 summarizes the results of sensitivity analysis for ^{99}Tc, ^{129}I, and ^{237}Np. Only the parameters with partial correlation coefficients greater than 0.2 are included in the table. A correlation coefficient of 0.2 is approximately the level of significance in the analysis. The final BDCFs results of the biosphere modeling are less sensitive to other parameters, such as the inhalation and external exposure parameters.

Of the uncertain or variable parameters that most affect the calculation of the BDCFs, the leafy-vegetable and drinking water consumption rates are the most important. That is, changes in these two parameters typically produce the largest changes in the BDCFs. That these two parameters are identified by the analysis is not unexpected, because the probability distributions used to define them (Table 9-3) have relatively large variances. In addition, the drinking water and leafy-vegetable pathways were identified as the major contributors to the dose rate (above). ^{129}I differs somewhat from ^{99}Tc and ^{237}Np in that iodine is more easily concentrated in animals and, thus, the beef consumption rate, and to a certain extent the milk consumption rate, are important to its biosphere dose conversion factor.

Parameters that are identified as the next in importance are the crop-interception fraction and the crop resuspension factor. The crop-interception fraction is the fraction of contamination in rainfall, irrigation, or aerosols that is intercepted by and adheres to the plant surface. The crop resuspension factor describes the amount of contaminated dust that settles on the plant surface. The adsorbed contaminants are then available for ingestion by foraging livestock and poultry, or direct ingestion by humans. Processes that contribute to these parameters are wind and overhead irrigation. This mode of irrigation is common in the region.

The least important parameters given in the table are the root-vegetable consumption rate, the eggs yield, the grain irrigation rate, and the animal-uptake scale factor. Although the partial correlation coefficients for these parameters are relatively insignificant, it is important to note that they still rank highly among the 46 parameters defined with probability distributions. The results of this sensitivity analysis can be used to identify the factors driving uncertainty of the model output and determine where attention should be focused in the future.

9.8 SUMMARY AND DISCUSSION OF BIOSPHERE MODELING

The BDCFs, as requested for the TSPA-VA, have been calculated for incorporation into the RIP code. A multiple pathway model of the biosphere was used. Relevant computer codes readily available to the Yucca Mountain Project were evaluated for their use in the TSPA-VA biosphere modeling. The functionality of each code selected for evaluation was compared against the project's established model selection criteria. Although no single code satisfied all of the established selection criteria, GENII and GENII-S were found to be the most comprehensive codes available for the biosphere modeling. These two codes are generally flexible enough to address most of the FEPs applicable to the proposed high-level waste repository at Yucca Mountain, Nevada. Given the stochastic modeling approach employed by all the other components of the TSPA-VA, GENII-S was selected as the modeling tool for calculating the BDCFs.

The incorporation of a site specific model of the biosphere for this iteration of TSPA is a significant improvement over previous M&O models. Site-specific or locally-focused information on demographics and food and water consumption were collected through a survey of the area extending to a radius of 80 km around Yucca Mountain. The survey information filled a data need to support parameter development for the GENII-S modeling effort by providing food and water consumption data for the local population in the vicinity of Yucca Mountain. The modeling process incorporated, when available, parameters appropriate to the community of Amargosa Valley. Three predefined receptor groups (e.g., average Amargosa Valley resident adult, resident farmer, and subsistence farmer) were evaluated in an attempt to bound the upper and lower limits of the various input parameters (e.g., consumption of locally produced food and tap water), thereby effectively capturing the range of future habits of a reference critical group individual. Three precipitation rates (current annual average precipitation in Amargosa Valley, and twice and three times the current rate) were modeled to assess the effects of potential future climate change.

The goals of the regional food and water consumption survey were to produce optimally accurate estimates using a reliable and valid questionnaire, while conforming to budget and time constraints. Special steps were taken to ensure the reliability and validity of the survey results.

To assess the validity of the survey data, specific food group consumption levels obtained from the survey were aggregated across broader categories of food types to make them conceptually similar to information from other sources for the purposes of comparison. These comparisons showed that food consumption levels in the survey area compared favorably with data reported elsewhere. However, water consumption by adults in the survey area was found to be about twice as much as reported elsewhere.

No one interviewed in the survey area (Amargosa Valley or beyond) completely met the criteria established for the subsistence farmer receptor. The resident farmer is more likely to be the average member of the critical group. However, from the perspective of those people who presently reside in the region, the average Amargosa Valley resident provides the best estimate of future potential exposures. From six survey data subsets (Section 9.4.5.1, Tables 9-15 through 9-20), the Amargosa Valley "total population" adult resident data subset (Table 9-18) was selected to represent the average Amargosa Valley resident receptor and the total survey area "subsistence" adult resident subset (Table 9-17) was chosen to represent the subsistence farmer receptor. Survey data were not used directly to develop the parameter input values for the resident farmer receptor. Rather, the resident farmer receptor was defined as consuming half the quantity of locally produced food (but the same quantity of water) as the subsistence farmer; that is, exposure from contaminated food is assumed to be half that of the subsistence farmer receptor (Table 9-21).

The stochastic biosphere modeling showed that for a given radionuclide, the BDCFs can vary (as measured by the 5 and 95 percentile points) by about a factor of three above and below the median value. Of the statistical distributions available to users of the RIP code, the best approximation to the predicted BDCFs distribution was shown to be lognormal. Changes induced in the BDCFs values from increases in precipitation rates modeled to represent changes in climatic conditions are small and of no statistical significance. However, which particular receptor was modeled did have a significant influence on the BDCFs. For most radionuclides the BDCFs for the subsistence farmer receptor are a factor of about 4.5 higher than those for the average Amargosa Valley resident receptor. In the case of ^{129}I, where the meat and milk pathways are more significant than for most other radionuclides, the ratio is higher with a value of approximately 12.

The 1997 biosphere workshop identified many issues of concern to the biosphere modeling effort. However, due to acknowledged constraints, some of these issues could not be addressed and incorporated into the work reported here. The ranking of issues by the workshop participants formed the basis for the selection of issues that were addressed. The data presented in this draft report are preliminary and thus subject to modification. In particular, the survey data from Lincoln County were not available to model the eating and farming habits of the cooler and wetter environment anticipated in future periods. The impact of this effect will be addressed as a sensitivity study when the analyses of these data have been completed.

9.9 REFERENCES

Andersen, R.; Kasper, J.; and Frankel, M.R., Editors. 1979. "A Model of Survey Error." Total Survey Error: Applications to Improve Health Surveys. 1-14. San Francisco, California: Jossey-Bass Publishers. TIC Catalog Number: 236464.

Andrews, R.W.; Dale, T.F.; and McNeish, J.A. 1994. Total System Performance Assessment - 1993: An Evaluation of the Potential Yucca Mountain Repository. B00000000-01717-2200-00099-Rev. 01. Las Vegas, Nevada: Intera, Inc. NNA.19940406.0158. TIC Catalog Number: 222076.

Atkins, J.E.; Lee, J.H.; Lingineni, S.; Mishra, S.; McNeish, J.A.; Sassani, D.C.; Sevougian, S.D.; Andrews, R.W.; and Younker, J.L. 1995. Total System Performance Assessment - 1995: An Evaluation of the Potential Yucca Mountain Repository. B00000000-01717-2200-00136, Rev. 01. Las Vegas, Nevada: TRW Environmental Safety Systems. MOL.19960724.0188. TIC Catalog Number: 224028.

Banks, M. 1979. "Weighting the Data." Total Survey Error: Applications to Improve Health Surveys. Andersen, R.; Kasper, J.; and Frankel, M.R.; Editors. 104-112. San Francisco, California: Jossey-Bass Publishers. TIC Catalog Number: 236465.

Bergsten, J. and Pierson, S. 1982. "Telephone Screening for Rare Characteristics Using Multiplicity Counting Rules." American Statistical Association, Proceedings of the Survey Research Methods Section, pp. 145-150. Alexandria, Virginia: American Statistical Association. ON ORDER FOR TIC.

BIOMOVS II [Reference Biosphere Working Group] Development of a reference Biosphere Methodology for Radioactive Waste Disposal. Technical Report No. 6. September 1996. Stockholm, Sweeden: Swedish Radiation Protection Institute.

Brady, N. C. 1984. The Nature and Properties of Soils. Ninth Edition. Macmillan Publishing Company, New York, New York.

Bryant. B.E. 1975. "Respondent Selection in a Time of Changing Household Composition." Journal of Marketing Research, 12 (2),129-135. Chicago, Illinois: American Marketing Association. TIC Catalog Number: 236440.

Carmines, E.G. and Zeller, R.A. 1979. Reliability and Validity Assessment. Beverly Hills, California: Sage Publications. TIC Catalog Number: 237111.

CRWMS M&O. 1996. Scientific Investigation Implementation Package for Developing Biosphere Dose Conversion Factors. Report B00000000-01717-4600-00073 REV 00. Las Vegas, Nevada: TRW Environmental Safety Systems Inc. MOL.19970616.0412. TIC Catalog Number: 226814.

CRWMS M&O. 1997a. Yucca Mountain Site Characterization Project: Summary of Socioeconomic Data Analyses Conducted in Support of the Radiological Monitoring Program, First Quarter 1996 to First Quarter 1997, June 1, 1997. Las Vegas, Nevada: TRW Environmental Safety Systems Inc. MOL.19971117.0460

CRWMS M&O. 1997b. Suitability of Amargosa Valley Soils for Farming. B00000000-01717-5705-00084 REV 00 DRAFT A. September 30, 1997. Report prepared for the U.S. Department of Energy, Yucca Mountain Site Characterization Office, Las Vegas, NV. MOL 19980105.0149.

CRWMS M&O. 1997c. Biosphere Abstraction/Testing Workshop Results. B00000000-01717-2200-00192. Las Vegas, Nevada: TRW Environmental Safety Systems Inc. MOL.19980427.0190.

CRWMS M&O. 1997d. The 1997 "Biosphere" Food Consumption Survey - Summary Findings and Technical Documentation, November 1997. Las Vegas, Nevada: TRW Environmental Safety Systems Inc. MOL.19980202.0239.

DeMaio, T.J., Editor. 1983. Approaches To Developing Questionnaires. Statistical Policy Working Paper No. 10. Washington, D.C.: Statistical Policy Office, Office of Information and Regulatory Affairs, Office of Management and Budget. (Full text available at http://www.bts.gov/smart/cat/WP10.html. Accessed: May 8, 1998. TIC Catalog Number: 237085.

Dillman, D.A. 1978. Mail and Telephone Surveys: The Total Design Method. New York, New York: Wiley-Interscience. TIC Catalog Number: 236961.

Eckerman, K.F. and Ryman, J.C. 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. EPA 402-R-93-081. Oak Ridge, Tennessee: Oak Ridge National Laboratory; Washington, D.C.: U.S. Environmental Protection Agency, Office of Radiation and Indoor Air. TIC Catalog Number: 225472.

Eckerman, K.F.; Wolbarst, A.B.; and Richardson, A.C.B. 1988. Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion. Federal Guidance Report No. 11. EPA 520/1-88-020. Oak Ridge, Tennessee: Oak Ridge National Laboratory; Washington, D.C.: U.S. Environmental Protection Agency, Office of Radiation Programs. TIC Catalog Number: 203350.

Eslinger, P.W.; Doremus, L.A.; Engel, D.W.; Miley, T.B.; Murphy, M.T.; Nichols, W.E.; White, M.D.; Langford, D.W.; and Ouderkirk, S.J. 1993. Preliminary Total-System Analysis of a Potential High-Level Nuclear Waste Repository at Yucca Mountain. PNL-8444. Richland, Washington: Pacific Northwest Laboratory. TIC Catalog Number: 205581.

Golder. 1998. RIP Repository Performance Assessment and Strategy Evaluation Model: Theory Manual and User's Guide. Golder Associates Inc. Redmond, Washington: MOL.19960422.0211.

Guenzel, P.J.; Berckmans, T.R.; and Cannell, C.F. 1983. General Interviewing Techniques: A Self-Instructional Workbook For Telephone and Personal Interviewer Training. Ann Arbor, Michigan: ISR, Survey Research Center, Institute for Social Research, University of Michigan. ON ORDER (TIC).

Hintze, J. 1995. NCSS 6.0 User's Guide. Kaysville, Utah: NCSS, Inc. Telephone: 908/788-5550. ON ORDER (TIC). Sandia unable to verify for pp reviewers. Found company homepage and telephone number. No email connected to homepage. Not in TICweb or RIS 6/16/98.

IAEA. 1994. Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments. IAEA-TECDOC-364. Vienna, Austria: International Atomic Energy Agency. TIC Catalog Number: 232035.

ICRP [International Commission on Radiological Protection]. 1975. Report of the Task Group on Reference Man. ICRP No. 23. New York, New York: Pergamon Press. Not in TICweb 6/16/98. Available at the University of New Mexico as QP34.5 I57 1975.

ICRP. 1977. Recommendations of the International Commission on Radiological Protection. ICRP Publication 26. New York, New York: Pergamon Press.

ICRP. 1978. Limits for Intakes of Radionuclides by Workers. ICRP No. 30. New York, New York: Pergamon Press. TIC Catalog Number: 221575.

Iman, R.L.; Shortencarrier, M.J.; and Johnson, J.D. 1985. A FORTRAN 77 Program and User's Guide for the Calculation of Partial Correlation and Standardized Regression Coefficients. NUREG/CR-4122; SAND-0044. Albuquerque, New Mexico: Sandia National Laboratories. (Available from the National Technical Information Service, Springfield, VA as NUREG/CR-4122.) Not in TICweb or RIS 6/16/98.

Kish, L. 1965. Survey Sampling. New York, New York: John Wiley & Sons. TIC Catalog Number: 236609.

LaPlante, P.A. and Poor, K. 1997. Information and Analyses to Support Selection of Critical Groups and Reference Biospheres for Yucca Mountain Exposure Scenarios. CNWRA 97-009. San Antonio, Texas: CNWRA, The Center for Nuclear Waste Regulatory Analyses. TIC Catalog Number: 236454.

Leigh, C.D.; Thompson, B.M.; Campbell, J.E.; Longsine, D.E.; Kennedy, R.A.; and Napier, B.A. 1993. User's Guide for GENII-S: A Code for Statistical and Deterministic Simulations of Radiation Doses to Humans from Radionuclides in the Environment. SAND91-0561. Albuquerque, New Mexico: Sandia National Laboratories. TIC Catalog Number: 231133.

Luckey, R.R.; Tucci, P.; Faunt, C.C.; Ervin, E.M.; Steinkampf, W.C.; D'Agnese, F.A.; and Patterson, G.L. 1996. Status of Understanding of the Saturated-Zone Ground-Water Flow System at Yucca Mountain, Nevada, as of 1995. USGS-WRI Report 96-4077, p. 14. Denver, Colorado: United States Geological Survey. MOL.19970513.0209. TIC Catalog Number: 227084.

Martin, D.L.; Gilley, J.R.; and Skaggs, R.W. 1991. "Appendix II Evapotranspiration Equations." Managing Nitrogen for Groundwater Quality and Farm Profitability, Proceedings of a Symposium, Anaheim, California, 1988. Editors: Follett, R.F.; Keeney, D.R.; and Cruse, R.M. 333-338. Madison, Wisconsin: Soil Science Society of America, Inc.

Napier, B.A.; Peloquin, R.A.; Strenge, D.L.; and Ramsdell, J.V. 1988a. GENII - The Hanford Environmental Radiation Dosimetry Software System. Volume I: Conceptual Representation. PNL-6584, Vol. 1. Richland, Washington: Pacific Northwest Laboratory, Hanford Environmental Dosimetry Upgrade Project. NNA.19920626.0034. TIC Catalog Number: 206898.

Napier, B.A.; Peloquin, R.A.; Strenge, D.L.; and Ramsdell, J.V. 1988b. GENII - The Hanford Environmental Radiation Dosimetry Software System. Volume 2: User's Manual. PNL-6584, Vol. 2. Richland, Washington: Pacific Northwest Laboratory, Hanford Environmental Dosimetry Upgrade Project. NNA.19920626.0036. TIC Catalog Number: 206898.

Napier, B.A.; Peloquin, R.A.; Strenge, D.L.; and Ramsdell, J.V. 1988c. GENII - The Hanford Environmental Radiation Dosimetry Software System. Volume 3: Code Maintenance. PNL-6584, Vol. 3. Richland, Washington: Pacific Northwest Laboratory, Hanford Environmental Dosimetry Upgrade Project. NNA.19920626.0041. TIC Catalog Number: 206898.

NAS/NRC [National Academy of Sciences/National Research Council]. 1995. Technical Bases for Yucca Mountain Standards. Committee on Technical Bases for Yucca Mountain Standards, Board on Radioactive Waste Management. Washington, D.C.: National Academy Press. 205 p. TIC Catalog Number: 104273.

NCDC, 1995. National Climatic Data Center, Climate Data. 151 Patton Avenue, Ashville, North Carolina 28801-5001. Station: Amargosa Farms Garey; PO Code: NV; Station ID: 150; County: Nye.

NIST. 1997. Univariate Summary Statistics Datasets. Boulder, Colorado: National Institute of Standards and Technology. Full text available at http://www.itl.nist.gov/div898/strd/ univ/ home page.html. Accessed: May 10, 1998.

Otis, M.D. 1983. Sensitivity and Uncertainty Analysis of the PATHWAY Radionuclide Transport Model. Ph.D. Dissertation. Fort Collins, Colorado: Colorado State University. Dissertations Abstracts Order Number: AAD83-27986. ON ORDER FOR TIC.

Pahrump Valley Times. 1995. Rural Phone Book. Pahrump, Nevada: Pahrump Valley Times. ON ORDER BY TIC. Copy needs to be supplied. Not in TICweb 6/16/98.

Rechard, R.P., Editor. 1995. Performance Assessment of the Direct Disposal in Unsaturated Tuff of Spent Nuclear Fuel and High-Level Waste Owned by U.S. Department of Energy. Volume 2: Methodology and Results. SAND94-2563/2. Albuquerque, New Mexico: Sandia National Laboratories. TIC Catalog Number: 231491.

Smith, G.M.; Watkins, B.M.; Little, R.H.; Jones, H.M.; and Mortimer, A.M. 1996. Biosphere Modeling and Dose Assessment for Yucca Mountain. TR-107190. Prepared by QuantiSci Ltd, Henley on Thames, Oxon, United Kingdom. Palo Alto, California: Electrical Power Research Institute. TIC Catalog Number: 231592.

Swanson, D.A.; Burch, T.K.; and Tedrow, L.M. 1996. "What Is Applied Demography?" Population Research and Policy Review, 15 (5-6), 403-418. Netherlands: Kluwer Academic Publishers. TIC Catalog Number: 236466.

Tisdale, S. L.; Nelson, W. L.; and Beaton, J. D. 1985. Soil Fertility and Fertilizers—Fourth Edition. Macmillan Publishing Co., New York, NY 754 p.

Troldahl, V.C. and Carter, R.E., Jr. 1964. "Random Selection of Respondents Within Households in Phone Surveys." Journal of Marketing Research, 5, 71-76. Chicago, Illinois: American Marketing Association. TIC Catalog Number: 236452.

United States Code Service. 1997. "Title 44 Public Printing and Documents. Chapter 35. Coordination of Federal Information Policy. 3506 Federal Agency Responsibilities." United States Code Service 44 USCS @ 3506 (1996). On-line: Lawyers Cooperative Publishing. TIC Catalog Number: 237087.

USDA [U.S. Department of Agriculture]. 1993. Food and Nutrient Intakes by Individuals in the United States, 1 Day, 1987-88. Nationwide Food Consumption Survey, 1987-88. Report No. 87-I-1. Washington, D.C.: U.S. Department of Agriculture, Human Nutrition Information Service. TIC Catalog Number: 236493.

U.S. DOE [Department of Energy]. 1996. Title 40 CFR Part 191 Compliance Certification Application for the Waste Isolation Pilot Plant. DOE/CAO-1996-2184. Carlsbad, New Mexico: United States Department of Energy, Waste Isolation Pilot Plant, Carlsbad Area Office. Not in TICweb 6/16/98.

U.S. EPA [Environmental Protection Agency]. Date? Code of Federal Regulations: 40 CFR 141.16 Maximum Contaminant Levels for Beta Particle and Photon Radioactivity from Man-made Radionuclides in Community Water Systems. Washington, D.C.: Superintendent of Documents, U.S. Government Printing Office.

U.S. GAO [General Accounting Office]. 1994. Nutrition Monitoring: Progress in Developing a Coordinated Program. Report to the Chairman, Committee on Science, Space, and Technology, House of Representatives. GAO/PEMD-94-23. Washington, D.C.: General Accounting Office; Gaithersburg, Maryland: Distributed by the Office. TIC Catalog Number: 237084.

U.S. NRC [Nuclear Regulatory Commission]. 1977. Regulatory Guide 1.109 Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I. Rev. 1. REG/G-1.109, Rev. 1. Washington, D.C.: U.S. Nuclear Regulatory Commission, Office of Standards Development. NNA.19870806.0032.

U.S. OMB [Office of Management and Budget]. 1983. Contracting for Surveys. Statistical Policy Working Paper No. 9. Washington, D.C.: Statistical Policy Office, Office of Information and Regulatory Affairs, Office of Management and Budget. (Full text available at http://www.bts.gov/ntl/docs/images/SW9.html. Accessed: May 8, 1998.) TIC Catalog Number: 237086.

Wilson, M.L.; Gauthier, J.H.; Barnard, R.W.; Barr, G.E.; Dockery, H.A.; Dunn, E.; Eaton, R.R.; Guerin, D.C.; Lu, N.; Martinez, M.J.; Nilson, R.; Rautman, C.A.; Robey, T.H.; Ross, B.; Ryder, E.E.; Schenker, A.R.; Shannon, S.A.; Skinner, L.H.; Halsey, W.G.; Gansemer, J.D.; Lewis, L.C.; Lamont, A.D.; Triay, I.R.; Meijer, A.; and Morris, D.E. 1994. Total-System Performance Assessment for Yucca Mountain - SNL Second Iteration (TSPA-1993). SAND93-2675. Albuquerque, New Mexico. Sandia National Laboratories. NNA.19940112.0123. TIC Catalog Number: 102773.

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Chapter 9
Figures

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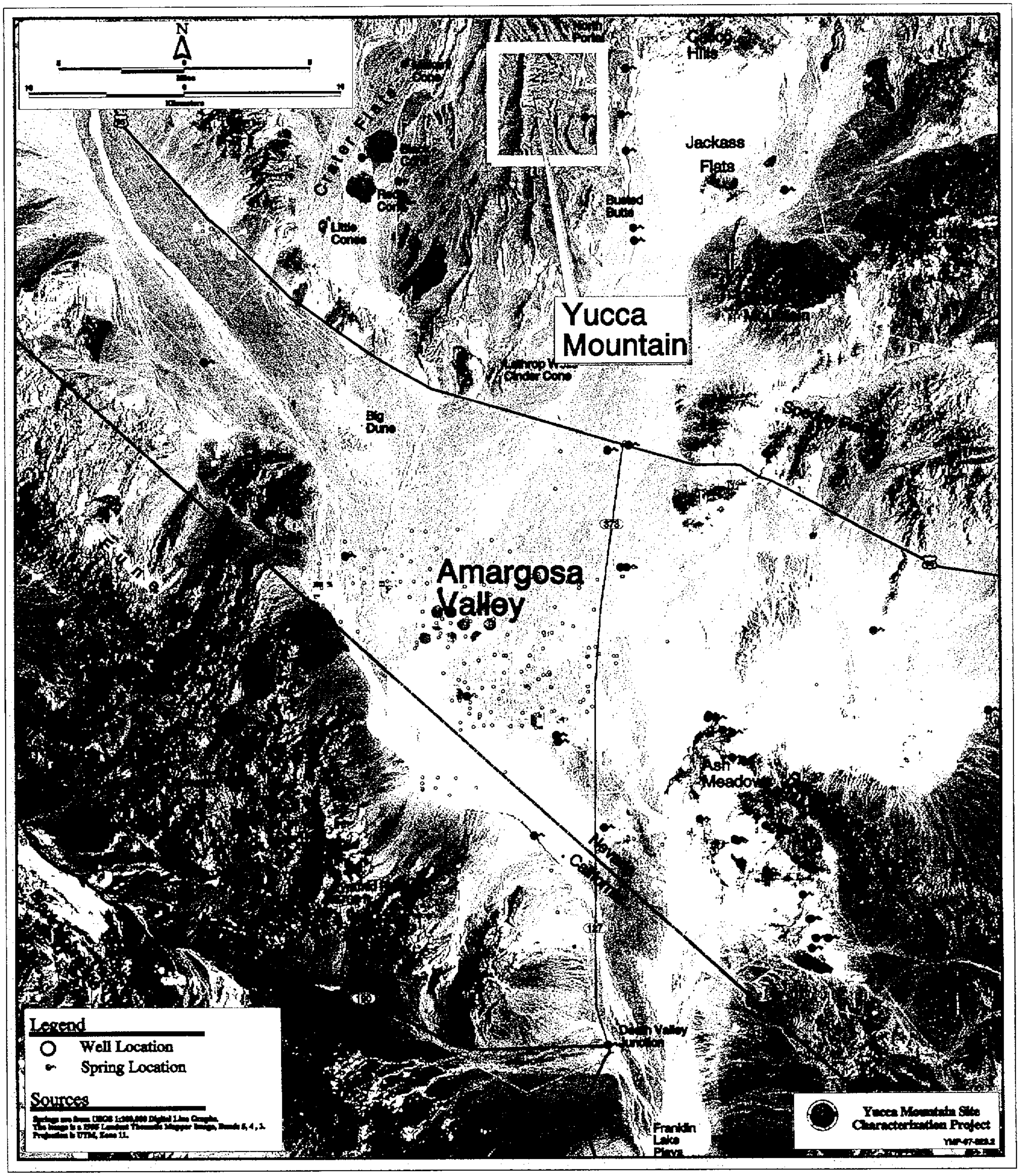

Figure 9-1. This color enhanced satellite image shows the Yucca Mountain and Amargosa Valley area. The agricultural area can be identified by the green coloration of the vegetation. The Amargosa Valley is the nearest populated area to Yucca Mountain in the direction of groundwater flow.

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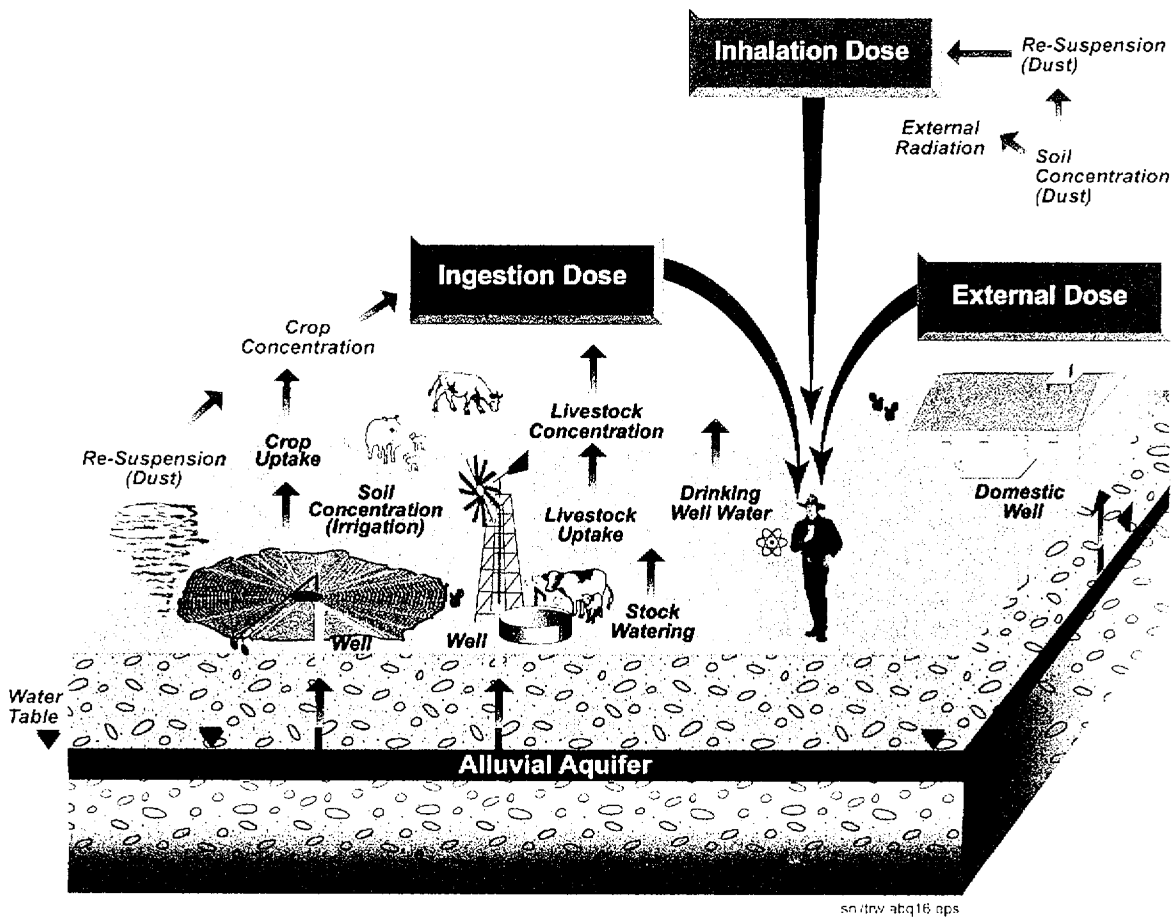

Figure 9-2. The biosphere modeling components comprise pathways contributing to three major dose categories to humans arising from ingestion of contaminated food and water, and exposure resulting from inhalation and direct exposure to contaminated soil.

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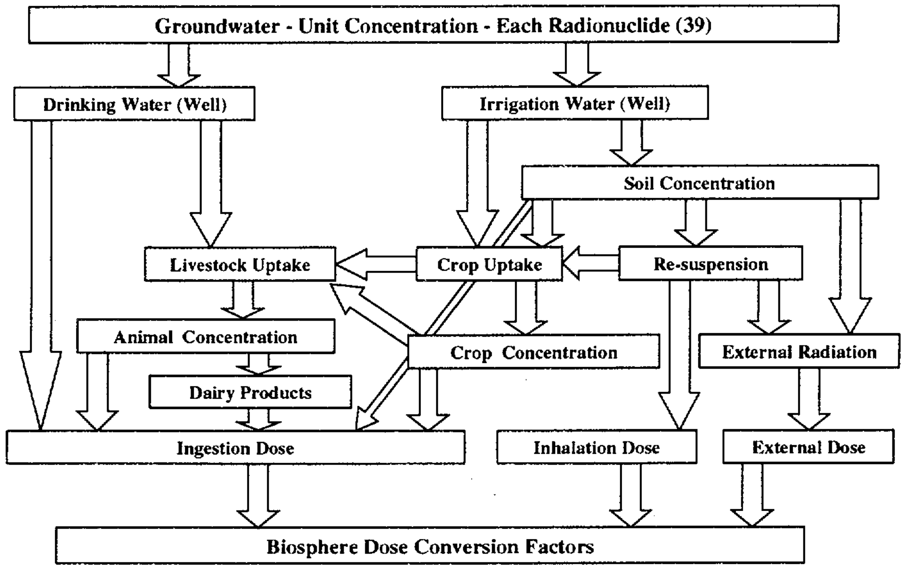

Figure 9-3. Pathways and reservoirs considered in the biosphere model. Radionuclides in groundwater can lead to exposure to humans through consumption of contaminated well water and food produced with this water, inhalation of dust-bounded radionuclides (resuspended soil), and external radiation from contaminated soil.

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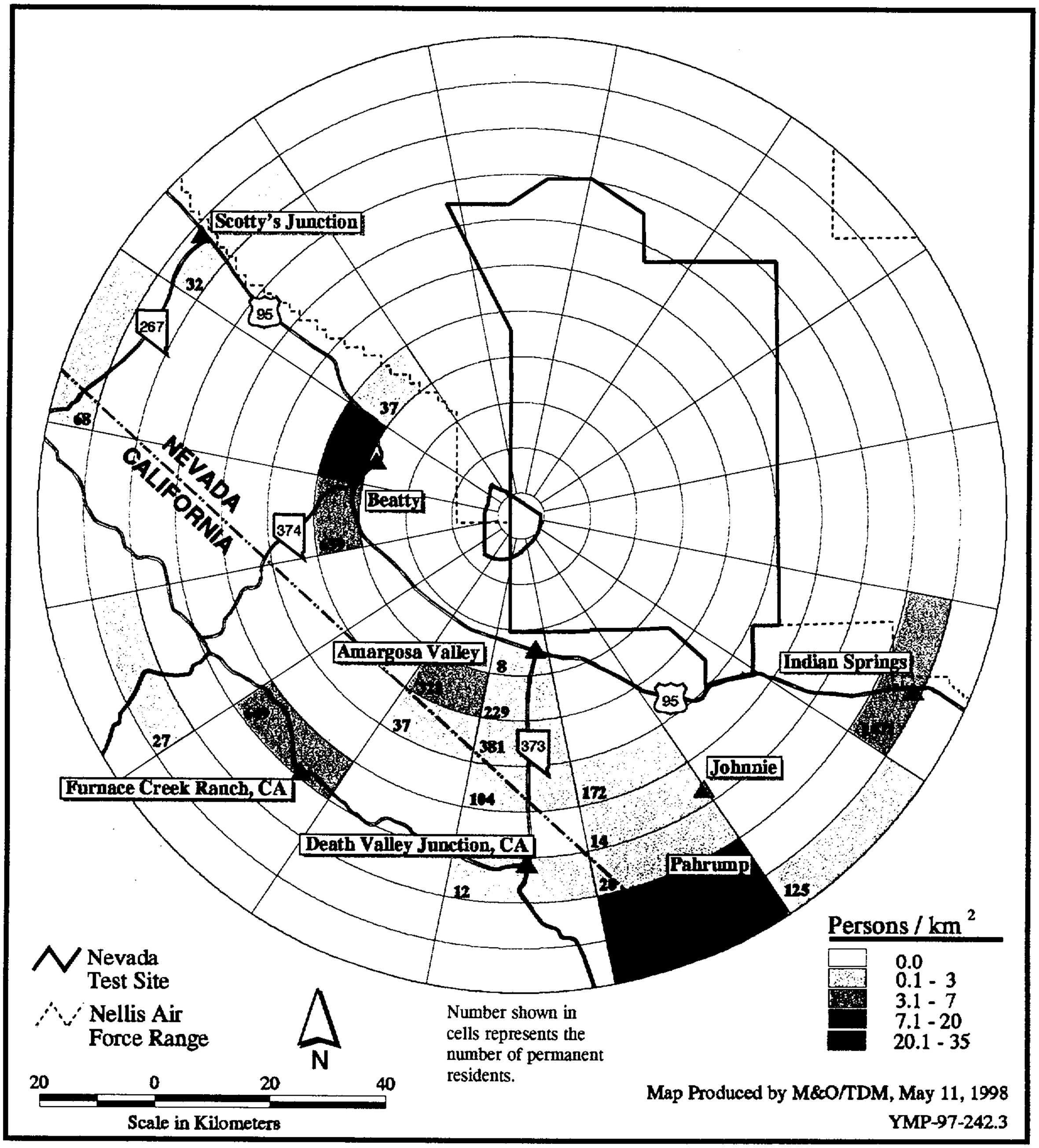

Figure 9-4. This map shows the total population (adults and children) and population density around Yucca Mountain. The grid is comprised of 16 sectors. The radii shown start at 4 km from the mountain and are then equally spaced at a distance of 8 km. Also shown are the boundaries of the Nevada Test Site and the Nellis Air Force Range, and the major highways in the area.

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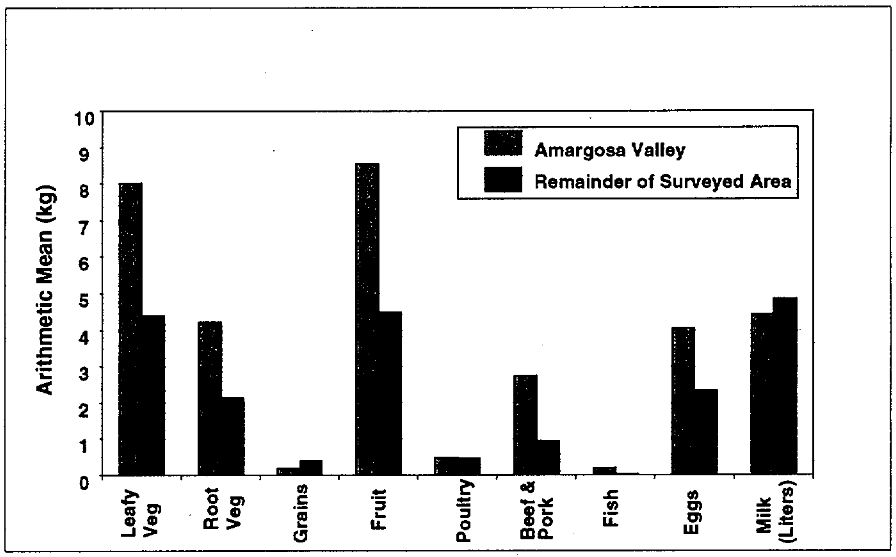

Well Water: Amagosa Valley residents consumed 684 liters per year
Remainder of residents surveyed consumed 646 liters per year

Figure 9.5. Survey data show that Amargosa Valley residents annually consume substantially greater quantities (kg) of locally produced food and well water than the residents in the remainder of the survey area.

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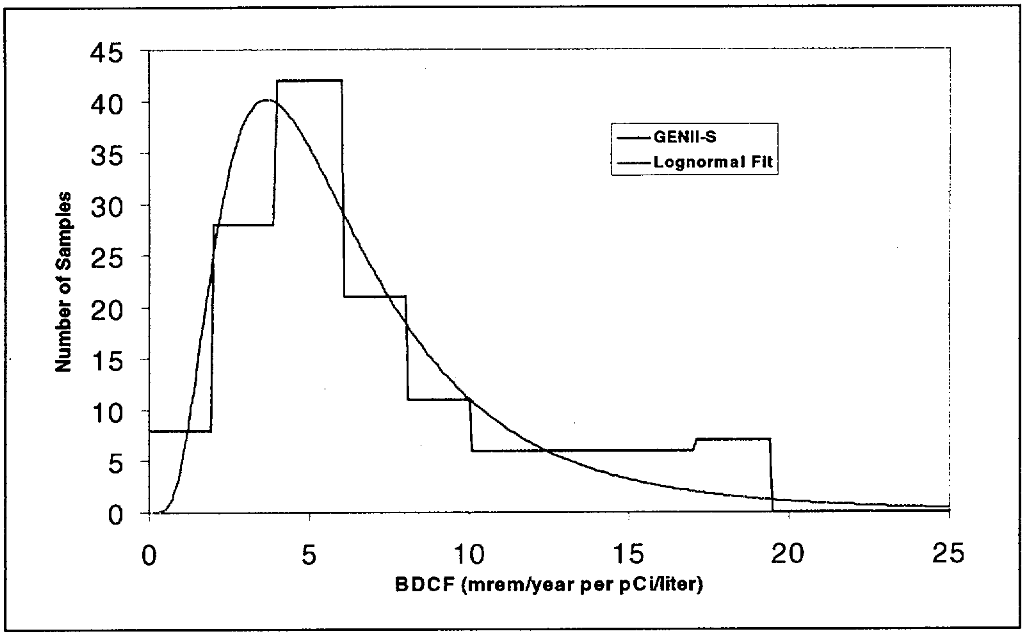

Figure 9-6. Histogram of the biosphere dose conversion factor (BDCF) for ^{237}Np on the average resident of the Amagosa Valley community with the fitted lognormal distribution.

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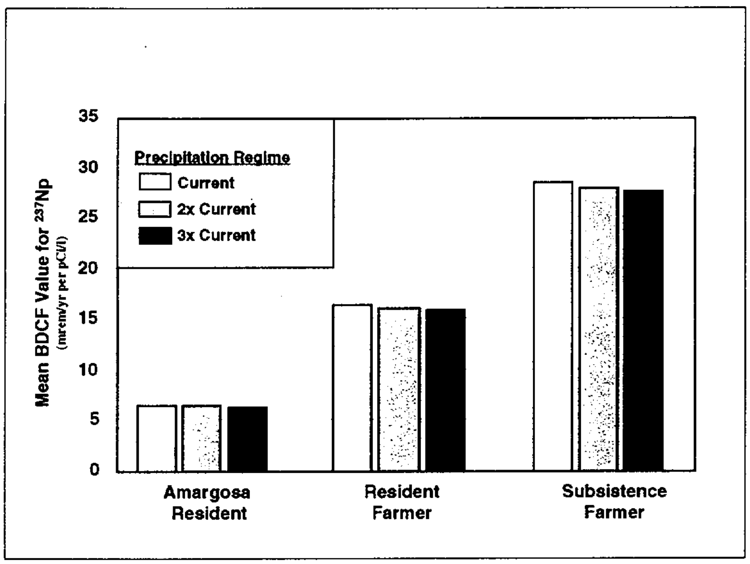

Figure 9-7. Comparison of biosphere dose conversion factors (BDCFs) for ^{237}Np as a function of receptor and precipitation regime. The BDCFs generated for the subsistence farmer are approximately 5–6 times greater than those calculated for the current average Amargosa Valley resident. However, the BDCFs do not vary notably among the three precipitation regimes modeled.

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Table 9-1. Interaction Matrix Considered for Model Development.

Source (well water)	**Aerosol**	**Pumping**	**X**	**Irrigation**	**Irrigation**	**Ingestion**	**Ingestion Submersion**
X	**ATMOSPHERE**	Deposition	X	Deposition	Deposition Gas Exchange	Inhalation	Inhalation Submersion
X	Aerosol Degassing Evaporation	**SURFAC E WATER**	Sedimentation	Flood Irrigation Erosion	Irrigation	Ingestion	Ingestion Submersion
X	X	X	**SEDIMENT**	Erosion Dredging	Uptake Contact	Ingestion	Ingestion Exposure
X	Re-suspension	Erosion Leaching	X	**SOIL**	Uptake Contact	Ingestion	Ingestion Exposure
X	Evapotranspiration Burning	Decay	Decay	Decay	**FLORA**	Ingestion	Ingestion
X	X	X	Bioturbation	Bioturbation	X	**FAUNA**	Ingestion
X	X	X	X	X	X	X	**RECEPTOR OF INTEREST**

X indicates that the pathway was not considered significant.

Table 9-2. Summary of Computer Code Evaluation for TSPA-VA Biosphere Modeling.

Computer Codes	Category	Description and Primary Application	Evaluation Criteria* 1	2	3	4	5	6	7	8	9
CAP-88PC	Radiation dose	Calculates maximum individual and population dose from chronic air releases of radionuclides	X	X	X		X		X		X
AIRDOS-PC	Radiation dose	Calculates maximum individual and population dose from chronic air releases of radionuclides		X	X	X		X		X	
RASCAL	Radiation dose	Calculates dose from a radiological accident		X	X	X				X	
RESRAD	Radiation dose	Calculates site-specific residual radiation contamination guidelines	X	X	X		X				X
MEPAS	Health risk	Calculates health risks from radionuclides and chemicals via air and water pathways	X	X	X	X	X		X	X	X
GENII	Radiation dose	Calculates dose from air and water releases of radionuclides via various pathways	X	X	X	X	X		X	X	X
GENII-S	Radiation dose	GENII with stochastic analysis capability	X	X	X	X	X	X	X	X	X

*Criteria Description

1 Off-the-shelf
2 Accepted by the regulatory agencies for intended use
3 Using ICRP-30 methodology for dose calculation
4 Addressing the significant FEPs defined in the SIIP
5 Capability to model chronic release scenario
6 Capability to perform stochastic modeling for uncertainty analysis
7 Using atmospheric release as source-term for pre-closure assessment
8 Using radionuclide concentrations in groundwater as source-term for post-closure assessment
9 Flexible to define food and water consumption patterns to model a subsistence or resident farmer

Table 9-3. GENII-S Input Parameters for the Biosphere Modeling Component of the TSPA-VA Base Case. (Source data is found in DTN MO9806MWDGENII.000 and is non-Q).

Parameter	Min. value	Mode or best estimate	Max. value	Distribution	References/Comments
Population/Soil/Scenario Data					
Population Scale Factor (number of people used for population dose calculations)		1		Fixed	Dose to individual (not population) required.
Dose Commitment Period (yr)		50		Fixed	Based on standard regulatory period.
Soil/Plant Transfer Scale Factor	0.117	(1)[1]	8.51	Lognormal	LaPlante and Poor, 1997, Section 2.3.2.82, but changed to 0.1% ~ 99.9% as required by GENII-S, see Section 9.2.3.1
Animal Uptake Scale Factor	0.117	(1)	8.51	Lognormal	LaPlante and Poor, 1997, Section 2.3.2.8, but changed to 0.1% ~ 99.9% as required by GENII-S, see Section 9.2.3.1
Human Dose Scale Factor		1		Fixed	Best estimate of dose required
Surface Soil Depth (cm)		15		Fixed	LaPlante and Poor, 1997, Section 2.3.4.2, see Section 9.2.3.1
Surface Soil Density (kg/m^2)		225		Fixed	LaPlante and Poor, 1997, Section 2.3.4.3, see Section 9.2.3.1
Deep Soil Density (kg/m^3)		1500		Fixed	LaPlante and Poor, 1997, Section 2.3.4.3, see Section 9.2.3.1
Roots in Upper Soil (Fraction)		1		Fixed	LaPlante and Poor, 1997, Section 2.3.4.3, see Section 9..2.3.1
Roots in Deep Soil (Fraction)		0		Fixed	LaPlante and Poor, 1997, Section 2.3.4.3, see Section 9.2.3.1
External/Inhalation Exposure					
Inhalation Exposure (hr/yr)					Biosphere Modeling Input Data File (BMIDF, see Section 9.2.3) Inhalation exposure.
Subsistence farmer[2]	5563	6192	6969	Triangular	
Resident farmer[3]	3248	3869	4217	Triangular	
Amargosa Valley population[4]	3248	3869	4217	Triangular	
Mass Load (g/m^3)	2.40E-6	(1.93E-5)	1.54E-4	Lognormal	BMIDF: Mass loading factor.

Table 9-3. (continued).

Parameter	Min. value	Mode or best estimate	Max. value	Distribution	References/Comments
Soil Exposure Time (hr)					BMIDF: Individual annual exposure time to soil contamination. Fixed value used for postclosure
Subsistence farmer		3624		Fixed	
Resident farmer		1578		Fixed	
Amargosa Valley population		1578		Fixed	
Home Irrigation Water source		Groundwater			Self explanatory
Home Irrigation Water Contamination		Yes			
Home Irrigation Rate (in/yr):					BMIDF: External ground exposure irrigation rate and irrigation duration, and Irrigation rate for precipitation equal to 2 x3 times current level.Fixed value used for postclosure
Current precipitation	46	(71)	96	Uniform	
×2 precipitation[5]	41	(66)	91	Uniform	
×3 precipitation	36	(61.5)	87	Uniform	
Home Irrigation Duration (mo/yr)		12		Fixed	BMIDF: External ground exposure irrigation rate and irrigation duration.
Ingestion Exposure					
Crop Re-suspension Factor (m^{-1})	5.89E-7	(1E-5)	1.70E-4	Lognormal	LaPlante and Poor, 1997, Section 2.3.5.2, but change to 0.1 ~ 99.9% as required by GENII-S, see Section 9.2.3.2
Crop Deposition Velocity (m/s)		0.001		Fixed	GENII-S default value (Leigh et al., 1993)
Crop Interception Fraction	0.06	0.4	1.0	Triangular	LaPlante and Poor, 1997, Section 2.3.5.3, see Section 9.2.3.2
Soil Ingestion Rate (mg/day)		410		Fixed	GENII-S default value (Leigh et al., 1992)
Drinking Water Contaminated Fraction		1		Fixed	BMIDF: Fraction of drinking water that is contaminated.
Drinking Water Treatment		No			Groundwater used directly (no treatment)
Drinking Water Holdup Time (days)		0		Fixed	BMIDF: Holdup/transit time for drinking water.
Drinking Water Consumption (l/yr):					BMIDF: Annual "Partial Subsistence" consumption level of tap water for adults residing in the fifty-mile grid.
Subsistence farmer	82.6	867.7	1487.5	Triangular	
Residentl farmer	82.6	867.7	1487.5	Triangular	
Amargosa Valley population	0	683.8	1487.5	Triangular	

Table 9-3. (continued).

Parameter	Min. value	Mode or best estimate	Max. value	Distribution	References/Comments
Terrestrial Food Ingestion					
Terrestrial Food Irrigation Water Source		Groundwater			By definition
Terrestrial Food Irrigation Water Contamination		Yes			By definition
Leafy Vegetables Grow Time (days)	45	67	75	Triangular	BMIDF: Growing period for leafy vegetables.
Root Vegetables Grow Time (days)	70	(84)	98	Uniform	BMIDF: Growing period for root vegetables.
Fruit Grow Time (days)	88	(119)	150	Uniform	BMIDF: Fruit irrigation rate, irrigation duration, growing period, yield.
Grain Grow Time (days)	75	(132.5)	190	Uniform	BMIDF: Irrigation duration, growing period for cereal and grain.
Leafy Vegetables Irrigation Rate (in/yr):					BMIDF: Irrigation rate for leafy vegetables, and Irrigation rate for precipitation equal to 2 times current level.
Current precipitation	25	36	66	Triangular	
×2 precipitation	24	36	65	Triangular	
×3 precipitation	24	35	64	Triangular	
Other Vegetables Irrigation Rate (in/yr):					BMIDF: Irrigation rate for root vegetables, and Irrigation rate for precipitation equal to 2 times current level.
Current precipitation	39	(41)	43	Uniform	
×2 precipitation	38	(40)	42	Uniform	
×3 precipitation	37	(39)	41	Uniform	
Fruit Irrigation Rate (in/yr):					BMIDF: Fruit irrigation rate, irrigation duration, growing period, yield, and Irrigation rate for precipitation equal to 2x3times current level.
Current precipitation	33	(36)	39	Uniform	
×2 precipitation	31	(35)	39	Uniform	
×3 precipitation	28	(33)	38	Uniform	

Table 9-3. (continued).

Parameter	Min. value	Mode or best estimate	Max. value	Distribution	References/Comments
Grain Irrigation Rate (in/yr):					BMIDF: Irrigation rate for cereal and grain, and Irrigation rate for precipitation equal to 2x3times current level.
Current precipitation	36	(51)	66	Uniform	
×2 precipitation	33	(49)	65	Uniform	
×3 precipitation	31	(47.5)	64	Uniform	
Leafy Vegetables Irrigation Time (months/yr)	2	3	4.9	Triangular	BMIDF: Annual irrigation duration for leafy vegetables.
Other Vegetables Irrigation Time (months/yr)	3.2	(3.9)	4.6	Uniform	BMIDF: Annual irrigation duration for root vegetables.
Fruit Irrigation Time (mo/yr)	3.0	(4.0)	5.0	Uniform	BMIDF: Fruit irrigation rate, irrigation duration, growing period, yield.
Grain Irrigation Time (mo/yr)	4.9	(5.55)	6.2	Uniform	BMIDF: Irrigation duration, growing period for cereal and grain.
Leafy Vegetables Yield (kg/m^2)	1.8	(2.2)	2.6	Uniform	BMIDF: Effective yield for leafy vegetables in the 84-km circle.
Other Vegetables Yield (kg/m^2)	1.7	3.8	5.9	Triangular	BMIDF: Effective yield for root vegetables in the 84-km circle.
Fruit Yield (kg/m^2)	1.6	(1.9)	2.2	Uniform	BMIDF: Fruit irrigation rate, irrigation duration, growing period, yield.
Grain Yield (kg/m^2)	0.34	0.62	1.3	Triangular	BMIDF: Effective yield for grain for human and animal consumption.
Leafy Vegetables Holdup (days)		1		Fixed	BMIDF: Holdup times between harvest or slaughter and human consumption.
Other Vegetables Holdup (days)		14		Fixed	BMIDF: Holdup times between harvest or slaughter and human consumption.
Fruit Vegetables Holdup (days)		14		Fixed	BMIDF: Holdup times between harvest or slaughter and human consumption.
Grain Vegetables Holdup (days)		14		Fixed	BMIDF: Holdup times between harvest or slaughter and human consumption.

Table 9-3. (continued).

Parameter	Min. value	Mode or best estimate	Max. value	Distribution	References/Comments
Leafy Vegetables Consumption Rate (kg/yr):					BMIDF: Annual "Subsistence" consumption level of locally produced leafy vegetables for adults residing in the fifty-mile grid, and for Amargosa Valley population.
Subsistence farmer	21.43	63.55	89.54	Triangular	
Resident farmer	10.72	31.78	44.77	Triangular	
Amargosa Valley population	0.035	(8.01)	59.68	Log Uniform	
Other Vegetables Consumption Rate (kg/yr):					BMIDF: Annual "Subsistence" consumption level of locally produced other vegetables for adults residing in the fifty-mile grid, and for Amargosa Valley population.
Subsistence farmer	8.14	28.86	50.01	Triangular	
Resident farmer	4.07	14.43	25.01	Triangular	
Amargosa Valley population	0.0045	(4.20)	38.01	Log Uniform	
Fruit Consumption Rate (kg/yr):					BMIDF: Annual "Subsistence" consumption level of locally produced fruit for adults residing in the fifty-mile grid, and for Amargosa Valley population.
Subsistence farmer	20.93	59.32	106.02	Triangular	
Resident farmer	10.47	29.66	53.01	Triangular	
Amargosa Valley population	0.001	(8.53)	97.69	Log Uniform	
Grain Consumption Rate (kg/yr):					BMIDF: Annual "Subsistence" consumption level of cereal and bread made locally produced grain for adults residing in the fifty-mile grid, and for Amargosa Valley population.
Subsistence farmer	56.85	60.64	72.35	Triangular	
Resident farmer	28.43	30.32	36.18	Triangular	
Amargosa Valley population	1E-31	(0.17)	12.33	Log Uniform	
Animal Product Consumption					
Beef Consumption Rate (kg/yr):					BMIDF: Annual "Subsistence" consumption level of locally produced meat (beef + pork) for adults residing in the fifty-mile grid, and for Amargosa Valley population.
Subsistence farmer	27.01	38.97	53.96	Triangular	
Resident farmer	13.51	19.49	26.98	Triangular	
Amargosa Valley population	2E-7	(2.75)	53.11	Log Uniform	
Poultry Consumption Rate (kg/yr):					BMIDF: Annual "Subsistence" consumption level of locally produced poultry for adults residing in the fifty-mile grid, and for Amargosa Valley population.
Subsistence farmer	7.36	15.74	34.34	Triangular	
Resident farmer	3.68	7.87	17.17	Triangular	
Amargosa Valley population	5E-9	(0.49)	10.50	Log Uniform	

Table 9-3. (continued).

Parameter	Min. value	Mode or best estimate	Max. value	Distribution	References/Comments
Milk Consumption Rate (l/yr):					BMIDF: Annual "Subsistence" consumption level of locally produced milk for adults residing in the fifty-mile grid, and for Amargosa Valley population.
Subsistence farmer	21.5	136.0	136.03	Triangular	
Resident farmer	10.75	68.0	68.01	Triangular	
Amargosa Valley population	5E-12	(4.42)	136.03	Log Uniform	
Eggs Consumption Rate (kg/yr):					BMIDF: Annual "Subsistence" consumption level of locally produced eggs for adults residing in the fifty-mile grid, and for Amargosa Valley population.
Subsistence farmer	1.69	16.67	33.34	Triangular	
Resident farmer	0.85	8.34	16.67	Triangular	
Amargosa Valley population	0.009	(4.03)	33.34	Log Uniform	
Beef Holdup (days)		20		Fixed	BMIDF: Holdup times between harvest or slaughter and human consumption.
Poultry Holdup (days)		1		Fixed	BMIDF: Holdup times between harvest or slaughter and human consumption.
Milk Holdup (days)		1		Fixed	BMIDF: Holdup times between harvest or slaughter and human consumption.
Eggs Holdup (days)		1		Fixed	BMIDF: Holdup times between harvest or slaughter and human consumption.
Beef Contaminated Water (Fraction)		1		Fixed	BMIDF: Fractions of drinking water that is contaminated.
Poultry Contaminated Water (Fraction)		1		Fixed	BMIDF: Fractions of drinking water that is contaminated.
Milk Contaminated Water (Fraction)		1		Fixed	BMIDF: Fractions of drinking water that is contaminated.
Eggs Contaminated Water (Fraction)		1		Fixed	BMIDF: Fractions of drinking water that is contaminated.
Stored Feed Data					
Beef – Dietary Fraction		0		Fixed	BMIDF: Fraction of livestock diets consisting of fresh forage and locally produced stored feed.
Poultry – Dietary Fraction		1		Fixed	BMIDF: Fraction of livestock diets consisting of fresh forage and locally produced stored feed.

Table 9-3. (continued).

Parameter	Min. value	Mode or best estimate	Max. value	Distribution	References/Comments
Milk – Dietary Fraction		0		Fixed	BMIDF: Fraction of livestock diets consisting of fresh forage and locally produced stored feed.
Eggs – Dietary Fraction		1		Fixed	BMIDF: Fraction of livestock diets consisting of fresh forage and locally produced stored feed.
Stored Feed Irrigation Water Source		Groundwater			Self explanatory
Stored Feed Irrigation Water Contamination		Yes			Self explanatory
Poultry – Grow Time (days)	60	(75)	90	Uniform	BMIDF: Irrigation duration and growing times for grain (poultry and laying hen consumption).
Eggs – Grow Time (days)	60	(75)	90	Uniform	BMIDF: Irrigation duration and growing times for grain (poultry and laying hen consumption).
Poultry – Irrigation Rate (in/yr):					BMIDF: Irrigation rates for grain (poultry and laying hen consumption).
Current precipitation	60	(66)	72	Uniform	
×2 precipitation	59	(65)	71	Uniform	
×3 precipitation	58	(64)	70	Uniform	
Eggs – Irrigation Rate (in/yr):					BMIDF: Irrigation rates for grain (poultry and laying hen consumption).
Current precipitation	60	(66)	72	Uniform	
×2 precipitation	59	(65)	71	Uniform	
×3 precipitation	58	(64)	70	Uniform	
Poultry – Irrigation Time (mo/yr)	3.9	(4.9)	5.9	Uniform	BMIDF: Irrigation duration and growing times for grain (poultry and laying hen consumption).
Eggs – Irrigation Time (mo/yr)	3.9	(4.9)	5.9	Uniform	BMIDF: Irrigation duration and growing times for grain (poultry and laying hen consumption).
Poultry – Yield (kg/m^2)	0.34	0.62	1.3	Triangular	BMIDF: Effective yield for grain for human and animal consumption.
Eggs – Yield (kg/m^2)	0.34	0.62	1.3	Triangular	BMIDF: Effective yield for grain for human and animal consumption.

Table 9-3. (continued).

Parameter	Min. value	Mode or best estimate	Max. value	Distribution	References/Comments
Poultry – Feed Storage Time (days)		14		Fixed	BMIDF: Storage times for hay and grain for consumption by livestock.
Eggs – Feed Storage Time (days)		14		Fixed	BMIDF: Storage times for hay and grain for consumption by livestock.
Fresh Forage Data					
Beef – Dietary Fraction		1		Fixed	BMIDF: Fraction of livestock diets consisting of fresh forage and locally produced stored feed.
Milk – Dietary Fraction		1		Fixed	BMIDF: Fraction of livestock diets consisting of fresh forage and locally produced stored feed.
Fresh Feed Irrigation Water Source		Groundwater			Self explanatory
Fresh Feed Irrigation Water Contamination		Yes			Self explanatory
Beef – Grow Time (days)	36	(57.5)	79	Uniform	BMIDF: Irrigation rates, irrigation duration, and growing period for hay and forage.
Milk – Grow Time (days)	36	(57.5)	79	Uniform	BMIDF: Irrigation rates, irrigation duration, and growing period for hay and forage.
Beef – Irrigation Rate (in/yr)					BMIDF: Irrigation rates, irrigation duration, and growing period for hay and forage, and irrigation rate for annual precipitation assumed to be twice and three times current level.
Current precipitation	60	(73.5)	87	Uniform	
×2 precipitation	56	(69.5)	83	Uniform	
×3 precipitation	53	(66.5)	80	Uniform	
Milk – Irrigation Rate (in/yr)					BMIDF: Irrigation rates, irrigation duration, and growing period for hay and forage, and irrigation rate for annual precipitation assumed to be twice and three times current level.
Current precipitation	60	(73.5)	87	Uniform	
×2 precipitation	56	(69.5)	83	Uniform	
×3 precipitation	53	(66.5)	80	Uniform	
Beef – Irrigation Time (mo/yr)		10.5		Fixed	BMIDF: Irrigation rates, irrigation duration, and growing period for hay and forage.
Milk – Irrigation Time (mo/yr)		10.5		Fixed	BMIDF: Irrigation rates, irrigation duration, and growing period for hay and forage.

Table 9-3. (continued).

Parameter	Min. value	Mode or best estimate	Max. value	Distribution	References/Comments
Beef – Yield (kg/m^2)	0.26	0.93	1.1	Triangular	BMIDF: Effective yield for hay and forage for Cattle and milk cows in the 84-km circle.
Milk – Yield (kg/m^2)	0.26	0.93	1.1	Triangular	BMIDF: Effective yield for hay and forage for Cattle and milk cows in the 84-km circle.
Beef – Feed Storage Time (days)		0		Fixed	BMIDF: Meat – storage time for hay.
Milk – Feed Storage Time (days)		0		Fixed	BMIDF: Milk – storage time for hay.

[1] Best estimate value is not needed by GENII-S to define lognormal,, normal, and uniform distributions; parentheses imply that the number is not needed as input to GENII-S.

[2] Data was taken from the total survey "subsistence" resident adult subset to represent this receptor (see Table 9-21, Section 9.4.5.2).

[3] By definition, this receptor consumes half the quantity of locally-produced food (but the same amount of water) as the subsistence farmer (see Table 9-21, Section 9.4.5.2).

[4] Data were taken from the Amargosa Valley "total population" survey subset to represent this receptor (see Table 9-21, Section 9.4.5.2).

[5] Precipitation regimes: ×2 implies twice current annual precipitation, ×3 implies three time current annual precipitation.

Table 9-4. Issues Associated with the Definition of the Critical Group.

		Group Score				
Issue #	Issue	1	2	3	4	Mean
1.7	Range of uncertainties and variabilities in parameters for critical group	13	13	13	13	13
1.3	Extrapolation of present habits to the future	15	7	9	15	11.5
1.4	Location of critical group	13	11	11	11	11.5
1.5	Effect of climate change on critical group definition	15	7	13	7	10.5
1.2	Habits of critical group	11	9	9	11	10.0
1.9	Variation of dominant pathway with time	11	7	9	13	10.0
1.1	Unknown performance criteria (No regulatory standard)	7	3	7	15	8.0
1.8	Special cases (miners, drill operators etc.)	13	3	3	13	8.0
1.6	Effect of group composition (age, gender, etc.)	11	3	5	5	6.0

Table 9-5. Biosphere Pathways.

		Group Score				
Issue #	**Issue**	**1**	**2**	**3**	**4**	**Mean**
2.06	Important radionuclides	15	15	15	15	15.0
2.01	Radionuclide build-up in soil	15	13	15	13	14.0
2.10	Habits of critical group	15	11	11	15	13.0
2.08	Preserving correlation within the biosphere	15	9	11	9	11.0
2.02	Atmospheric dispersion	13	13	7	7	10.0
2.07	Preserving correlation among biosphere and geosphere parameters	9	9	11	9	9.5
2.09	Determination of sensitive model parameters	9	7	5	9	7.5
2.03	Non-SZ pathways (gas, intrusion, etc.)	3	9	5	11	7.0
2.04	Selection of appropriate DCFs	3	3	3	3	3.0
2.05	Determination and incorporation of uncertainties into DCFs	3	3	3	3	3.0

Table 9-6. Geosphere Pathways Session.

		Group Score				
Issue #	Issue	1	2	3	4	Mean
3.7	Location and definition of the biosphere-geosphere interface	15	15	11	11	13.0
3.2	Identification of Important radionuclides transferred by disruptive events	11	3	15	15	11.0
3.3	Interaction effects of multiple discharge locations and mechanisms	11	13	5	7	9.0
3.5	Inadvertent intrusion	13	5	7	11	9.0
3.4	Volcanism	13	7	5	7	8.0
3.6	Gaseous releases	7	7	9	7	7.5
3.1.	Effect of draw-down on dilution	11	3	5	5	6.0

Table 9-7. Biosphere Issues Identified as Key to the Modeling Process.

Category	Issue #	Issue (Score)
Critical Group Definition	1.3	Extrapolation to future (11.5)
	1.4	Location of critical group (11.5)
	1.2	Habits of critical group (10)
Biosphere Pathways	2.06	Which radionuclides (15)
	2.01	Radionuclide build up in soil (14)
	2.10	Climate change effects (13)
Geo-Biosphere Interface	3.7	Location and definition of bio/geosphere interface (13)
	3.2	Important radionuclides transferred by disruptive events (11)

Table 9-8. Disposition of Attempted Interviews During the Comprehensive Survey.

Disposition	Frequency	Percent
Completed Interview	1,079	45.05
Refusal	373	15.57
Not In Service	296	12.36
No Answer	168	7.02
Answering Machine	160	6.68
Not Eligible	47	1.96
All Other Dispositions[1]	272	11.36
Total Attempts	2,395	100.00

[1] "All Other Dispositions" include:

(a) business or fax;

(b) respondent termination of interview once it had begun; and

(c) respondent unable to communicate in English or Spanish.

Table 9-9. Sample and total household numbers by community.

Community	Number of Households Surveyed (n_h)[1]	Total Number of Households (N_h)	Percent of Households in Survey
Amargosa Valley	195	452	43.0
Beatty	250	751	33.0
Indian Springs	65	529	12.0
Pahrump	569	4,993	11.0
Total	1,079	6,725	16.0

[1] The sample is randomly drawn from households within each community

Table 9-10. Number and Frequency of Adult Females Surveyed by Community.

Community	Number of Females Sampled [1] (p_{hf})	Proportion of Females in the Sample[1] (p_{hf}/p_h)	Proportion of Females in the Population (P_{hf}/P_h)
Amargosa Valley	120	.615	.490
Beatty	152	.608	.435
Indian Springs	42	.646	.490
Pahrump	373	.656	.502

[1] The sample is randomly drawn from households within each community.

Table 9-11. Gender, Area, and Total Weighting Coefficients for the Various Communities in the Survey Area.

Community	Gender	Gender Weight[1]	Area Weight[2]	Total Weight[3]
Amargosa Valley	Male	1.320	.369	.487
	Female	.800	.369	.295
Beatty	Male	1.424	.484	.689
	Female	.715	.484	.349
Indian Springs	Male	1.435	1.306	1.874
	Female	.762	1.306	0.995
Pahrump	Male	1.444	1.406	2.030
	Female	.761	1.406	1.078

[1] Female Weighting Coefficient = $(p_h \times P_{hf}/P_h)/(p_{hf})$

Male Weighting Coefficient = $(p_h \times P_{hm}/P_h)/(p_{hm})$

[2] Area Weighting Coefficient = $(1{,}079 \times N_h/N)/n_h$

[3] Total Weight = (gender weight) × (area weight)

Table 9-12. Contingent Average Daily Intakes for the U.S. and the Western U.S. (USDA, 1993).

Food Group	Contingent Average Daily Intake for the US and the West from the 1987-88 USDA Survey (grams)[1]					
	males, age 20 & over			Females, age 20 & over		
	US	West	% diff.	US	West	% diff.
Tomatoes	102	114	12	89	97	9
Leafy Vegetables other than Tomatoes (Deep Green, Other, & Legumes)	171	179	5	127	136	7
Root Vegetables (White Potatoes & Deep Yellow Vegetables)	163	150	-8	119	114	-4
Grains	285	308	8	218	217	0
Fruit	286	318	11	266	293	10
Poultry	153	147	-4	111	103	-7
Beef	151	134	-11	114	104	-9
Pork	78	72	-8	63	58	-8
Lamb, Veal, & Game	154	143	-7	91	67	-26
Fish	138	105	-24	110	116	5
Milk & Milk Products (Ca Equivalent)	439	408	-7	325	301	-7
Eggs	99	100	1	75	71	-5

[1] All values are given in grams. For purposes of calculating the annual consumption of milk in the survey area, grams were converted to liters: 1,000 grams = 1 liter.

Table 9-13. Chi-Square Test: Consumption of :Locally Produced Food*.

Interview Type	Yes, Consumed Locally Produced Food	No, Did Not Consume Locally Produced Food	TOTAL
Not Difficult To Interview	60.4% (612)	39.6% (401)	100.0% (1,013)
Difficult to Interview	65.6% (21)	34.4% (11)	100.0% (32)
TOTAL	60.6% (633)	39.4% (412)	100.0% (1,045)

*These results are based on the sample weighted for both gender and area. The percentages shown are based on the row totals.

Chi-square statistic = 0.35 (df=1), $p = 0.55$, do not reject the null hypothesis that the difficult to interview are similar to the other respondents in terms of the propensity to consume locally produced food.

Conclusion: The consumption pattern of non-respondents is not different from respondents in regard to consuming locally produced food.

Table 9-14. Percent of Resident Adults Consuming Locally Produced Food and Tap Water, by Food Type and Survey Area.

Food Type	Amargosa Valley[1]	Remainder of Survey Area[2]	Total Survey Area[3]
Leafy Veg.	64.7	42.5	46.5
Root Veg.	58.2	30.4	35.4
Grains	2.7	3.6	3.4
Fruit	62.2	40.9	44.1
Poultry	15.8	6.8	8.3
Meat[4]	34.2	7.7	12.5
Fish[5]	15.3	2.8	5.0
Eggs	55.1	29.7	33.9
Milk	10.9	7.4	8.0
Any Food type	78.5	56.6	60.1
Tap Water[6]	87.5	79.4	80.8

[1] Although the total sample was 195 in the Amargosa Valley, some respondents either could not or would not provide specific information (i.e., they responded "don't know" or otherwise declined) to a given question. The percentages shown do not reflect weighting.

[2] Although the total sample was 884 in the remainder of the survey area, some respondents either could not or would not provide specific information (i.e., they responded "don't know" or otherwise declined) to a given question. The percentages shown do not reflect weighting.

[3] Although the total sample was 1,079, some respondents either could not or would not provide specific information (i.e., they responded "don't know" or otherwise declined) to a given question. The percentages shown do not reflect weighting.

[4] "Meat" is comprised of beef and pork.

[5] The only known source of "locally produced" fish in the entire survey area is the catfish farm in the Amargosa Valley. Thus, the values provided are specific to the consumption of fish from this location.

[6] This refers to water from a local ground source. It excludes any bottled water purchased from a commercial vendor.

Table 9-15. Annual Consumption of Locally Produced Food and Tap Water by "Total Population" Resident Adults in the Total Survey Area.

Food Type	Number Responding[1]	Arithmetic Mean[2]	Standard Deviation	Standard Error[3]	95 Percent Confidence Interval[4]
Leafy Veg.	1,035	4.39	10.30	0.320	3.76 to 5.02
Root Veg.	1,022	2.13	5.83	0.182	1.77 to 2.49
Grains	1,021	0.40	4.37	0.137	0.13 to 0.67
Fruit	1,037	4.47	11.54	0.358	3.77 to 5.17
Poultry	1,026	0.45	2.27	0.071	0.31 to 0.59
Meat[5]	1,025	0.92	4.97	0.155	0.62 to 1.22
Fish[6]	1,041	0.04	0.50	0.015	0.01 to 0.07
Eggs	1,021	2.32	5.51	0.172	1.98 to 2.66
Milk	996	4.84	19.94	0.632	3.60 to 6.08
Tap Water[7]	1,068	646.2	475.02	14.535	617.7 to 674.7

[1] Although the total sample was 1,079, some respondents either could not or would not provide specific information (i.e., they responded "don't know" or otherwise declined) to a given question. The "number responding" is the number who provided information for the food type in question. The values shown reflect weighting by gender and area.

[2] The values shown for food are in kilograms; for milk and tap water they are in liters. The arithmetic mean is calculated by summing the annual consumption amount of locally produced food reported by those who responded and dividing this number by the total responding. Keep in mind that many of the respondents reported that they consumed no locally produced food of the type in question. The conceptual denominator of this mean is the total resident adult population of the survey area, not just those who reported consuming locally produced food (or tap water) of the type in question.

[3] The standard error is calculated by dividing the standard deviation by the square root of the number responding. It is an estimate of sampling variation.

[4] For a given food type, it is 95 percent certain that the "true" average consumption level for the entire resident adult population is within the range shown. The lower limit of the 95 percent confidence interval is calculated by multiplying 1.96 by the standard error and then subtracting this value from the sample mean; the upper limit is found by adding the product of 1.96 and the standard error to the sample mean. This is known as the normal approximation. It is appropriate when the sample size is 30 or more. Where sample size is substantially less than 30 (designated by ****), no interval was calculated using the normal approximation.

[5] "Meat" is comprised of beef and pork.

[6] The only known source of "locally produced" fish in the entire survey area is the catfish farm in the Amargosa Valley. Thus, the values provided are specific to the consumption of fish from this location.

[7] This refers to water from a local ground source. It excludes any bottled water purchased from a commercial vendor.

Table 9-16. Annual Consumption of Locally Produced Food and Tap Water by "Partial Subsistence" Resident Adults in the Total Survey Area.

Food Type	Number Responding[1]	Arithmetic Mean[2]	Standard Deviation	Standard Error[3]	95 Percent Confidence Interval[4]
Leafy Veg.	468	9.70	13.47	0.623	8.48 to 10.92
Root Veg.	342	6.37	8.57	0.463	5.46 to 7.28
Grains	37	11.01	19.24	3.163	4.81 to 17.21
Fruit	441	10.54	15.41	0.734	9.10 to 11.98
Poultry	94	4.88	6.33	0.653	3.60 to 6.16
Meat[5]	109	8.66	13.04	1.249	6.21 to 11.11
Fish[6]	36	1.05	2.33	0.388	0.29 to 1.81
Eggs	327	7.28	7.79	1.377	4.58 to 9.98
Milk	80	60.50	49.59	5.544	49.63 to 71.37
Tap Water[7]	896	769.70	402.15	13.435	743.4 to 796.0

[1] Although the total sample was 1,079, this subset excludes those who reported that none of the food in question (that they consumed) was locally produced. Those who reported "don't know" or otherwise declined to respond are also excluded. Thus, this subset includes only those who report that "all," "most," "some," or "very little" of the food type in question (that they consumed) was locally produced. The values shown reflect weighting by gender and area.

[2] The values shown for food are in kilograms; for milk and tap water they are in liters. The arithmetic mean for the "partial subsistence" group by food type is calculated by summing the annual consumption amount of locally produced food reported by those who responded that "very little," "some," "most," or "all" of the food in question (they consumed) was locally produced and dividing this sum by the number responding that "very little," "some,", "most," or "all" of the food in question (they consumed) was locally produced. The conceptual denominator of this mean includes only resident adults that consume locally produced food of the type in question; it excludes those resident adults who reported that none of the food in question (they consumed) was locally produced.

[3] The standard error is calculated by dividing the standard deviation by the square root of the number responding. It is an estimate of sampling variation.

[4] For a given food type, we are 95 percent certain that the "true" average consumption level for the entire resident adult population is within the range shown. The lower limit of the 95 percent confidence interval is calculated by multiplying 1.96 by the standard error and then subtracting this value from the sample mean; the upper limit is found by adding the product of 1.96 and the standard error to the sample mean. This is known as the normal approximation. This statistical application is appropriate when the sample size is 30 or more. Where sample size is substantially less than 30 (designated by ****), no interval was calculated using the normal approximation.

[5] "Meat" is comprised of beef and pork.

[6] The only known source of "locally produced" fish in the entire survey area is the catfish farm in the Amargosa Valley. Thus, the values provided are specific to the consumption of fish from this location.

[7] This refers to water from a local ground source. It excludes any bottled water purchased from a commercial vendor.

Table 9-17. Annual Consumption Levels of Locally Produced Food and Tap Water by "Subsistence" Resident Adults in the Total Survey Area.

Food Type	Number Responding[1]	Arithmetic Mean[2]	Standard Deviation	Standard Error[3]	95 Percent Confidence Interval[4]
Leafy Veg.	7	63.55	22.46	8.489	*****
Root Veg.	17	28.86	12.57	3.049	*****
Grains*	1	60.64	18.82	18.820	*****
Fruit	9	59.32	30.81	10.270	*****
Poultry	14	15.74	8.94	2.389	*****
Meat[5]	63	38.97	10.07	1.269	36.48 to 41.46
Fish[6]	1	7.50	*****	*****	*****
Eggs	93	15.78	7.58	0.786	14.24 to 17.32
Milk	28	119.39	26.27	4.965	109.66 to 129.12
Tap Water[7]	896	769.70	402.15	13.435	743.4 to 796.0

* In the case of "grains," there are actually three respondents but when weighted, the number of respondents sums to approximately one.

[1] Although the total sample was 1,079, this subset excludes those who report that either (a) nothing they consume is locally produced; or (b) that only "most," "some," or "very little" of the food type in question (that they consumed) was locally produced. Those who responded "don't know" or otherwise declined to answer are also excluded. Thus, this subset includes ONLY those who reported that ALL of the food in question (that they consumed) was locally-produced. The "number responding" is the number who provided information. The values shown reflect weighting by gender and area.

[2] The values shown for food are in kilograms; for milk and tap water they are in liters. The arithmetic mean is calculated by summing the annual amount consumed reported by those who responded that ALL of the food in question (they consumed) was locally produced and dividing this sum by the number responding that ALL of the food in question (they consumed) was locally produced. The conceptual denominator of this mean includes only those resident adults in the survey area for whom ALL of the food in question (they consumed) was locally produced; it excludes all others.

[3] The standard error is calculated by dividing the standard deviation by the square root of the number responding. It is an estimate of sampling variation.

[4] For a given food type, we are 95 percent certain that the "true" average consumption level for the entire resident adult population is within the range shown. The lower limit of the 95 percent confidence interval is calculated by multiplying 1.96 by the standard error and then subtracting this value from the sample mean; the upper limit is found by adding the product of 1.96 and the standard error to the sample mean. This is known as the normal approximation. This statistical application is appropriate when the sample size is 30 or more. Where sample size is substantially less than 30 (designated by ****), no interval was calculated using the normal approximation.

[5] "Meat" is comprised of beef and pork.

[6] The only known source of "locally produced" fish in the entire survey area is the catfish farm in the Amargosa Valley. Thus, the values provided are specific to the consumption of fish from this location.

[7] This refers to water from a local ground source. It excludes any bottled water purchased from a commercial vendor. The manner in which the question on water consumption was phrased precludes identifying those for whom all of the water they consumed was from a local ground source.

Table 9-18. Annual Consumption Levels of Locally Produced Food and Tap Water by "Total Population" Resident Adults in the Amargosa Valley.

Food Type	Number Responding[1]	Arithmetic Mean[2]	Standard Deviation	Standard Error[3]	95 Percent Confidence Interval[4]
Leafy Veg.	190	8.01	12.75	0.925	6.20 to 9.82
Root Veg.	90	4.20	6.83	0.496	3.23 to 5.17
Grains	190	0.17	1.44	0.104	0.00 to 0.37
Fruit	190	8.53	14.67	1.064	6.45 to 10.62
Poultry	190	0.49	1.60	0.116	0.26 to 0.72
Meat[5]	190	2.75	7.96	0.577	1.62 to 3.89
Fish[6]	190	0.19	1.03	0.075	0.04 to 0.34
Eggs	190	4.03	6.77	0.491	3.07 to 4.99
Milk	190	4.42	19.37	1.405	1.67 to 7.17
Tap Water[7]	190	683.84	475.07	34.46	616.3 to 751.4

[1] Although the total sample was 195 for the Amargosa Valley, some respondents either could not or would not provide specific information (i.e., they responded "don't know" or otherwise declined) to a given question. The "number responding" is the number who provided information. The values shown reflect weighting by gender.

[2] The values shown for food are in kilograms; for milk and tap water they are in liters. The arithmetic mean is calculated by summing the annual consumption amount of locally produced food reported by those who responded and dividing this sum by the number responding. Keep in mind that many of the respondents reported that they consumed no locally produced food of the type in question. The conceptual denominator of this mean is the total resident adult population of the Amargosa Valley, not just those who reported consuming locally produced food (or tap water) of the type in question.

[3] The standard error is calculated by dividing the standard deviation by the square root of the number responding. It is an estimate of sampling variation.

[4] For a given food type, we are 95 percent certain that the "true" average consumption level for the entire resident adult population is within the range shown. The lower limit of the 95 percent confidence interval is calculated by multiplying 1.96 by the standard error and then subtracting this value from the sample mean; the upper limit is found by adding the product of 1.96 and the standard error to the sample mean. This is known as the normal approximation. This statistical application is appropriate when the sample size is 30 or more. Where sample size is substantially less than 30 (designated by ****), no interval was calculated using the normal approximation.

[5] "Meat" is comprised of beef and pork.

[6] The only known source of "locally produced" fish in the entire survey area is the catfish farm in the Amargosa Valley. Thus, the values provided are specific to the consumption of fish from this location.

[7] This refers to water from a local ground source. It excludes any bottled water purchased from a commercial vendor.

Table 9-19. Annual Consumption Levels of Locally Produced Food and Tap Water by "Partial Subsistence" Resident Adults in the Amargosa Valley.

Food Type	Number Responding[1]	Arithmetic Mean[2]	Standard Deviation	Standard Error[3]	95 Percent Confidence Interval[4]
Leafy Veg.	111	13.78	14.35	1.362	11.11 to 16.45
Root Veg.	101	7.90	7.78	0.774	6.38 to 9.42
Grains	4	8.06	5.00	2.500	*****
Fruit	104	15.66	16.76	1.643	12.44 to 18.88
Poultry	27	3.48	3.10	0.597	2.31 to 4.65
Meat[5]	54	9.65	12.75	1.735	6.25 to 13.05
Fish[6]	15	2.40	2.87	0.741	*****
Eggs	92	8.00	7.58	0.790	6.45 to 9.55
Milk	15	56.62	49.10	12.678	*****
Tap Water[7]	167	777.44	423.74	32.790	713.20 to 841.70

[1] Although the total sample was 195 in the Amargosa Valley, this "partial subsistence" subset excludes those who reported that none of the food in question (that they consumed) was locally produced. Those who reported "don't know" or otherwise declined to respond are also excluded. Thus, this subset includes only those who report that "all," "most," "some," or "very little" of the food type in question (that they consumed) was locally produced. The values shown reflect weighting by gender.

[2] The values shown for food are in kilograms; for milk and tap water they are in liters. The arithmetic mean for the "partial subsistence" group by food type is calculated by summing the annual consumption amount of locally produced food reported by those who responded that "very little," "some,", "most," or "all" of the food in question (they consumed) was locally produced and dividing this sum by the number responding that "very little," "some,", "most," or "all" of the food in question (they consumed) was locally produced. The conceptual denominator of this mean includes only adults residing in the Amargosa Valley that consume locally produced food of the type in question; it excludes those adults residing in the Valley who reported that none of the food in question (they consumed) was locally produced.

[3] The standard error is calculated by dividing the standard deviation by the square root of the number responding. It is an estimate of sampling variation.

[4] For a given food type, we are 95 percent certain that the "true" average consumption level for the entire resident adult population is within the range shown. The lower limit of the 95 percent confidence interval is calculated by multiplying 1.96 by the standard error and then subtracting this value from the sample mean; the upper limit is found by adding the product of 1.96 and the standard error to the sample mean. This is known as the normal approximation. This statistical application is appropriate when the sample size is 30 or more. Where sample size is substantially less than 30 (designated by ****), no interval was calculated using the normal approximation.

[5] "Meat" is comprised of beef and pork.

[6] The only known source of "locally produced" fish in the entire survey area is the catfish farm in the Amargosa Valley. Thus, the values provided are specific to the consumption of fish from this location.

[7] This refers to water from a local ground source. It excludes any bottled water purchased from a commercial vendor.

Table 9-20. Annual Consumption Levels of Locally Produced Food and Tap Water by "Subsistence" Resident Adults in the Amargosa Valley.

Food Type	Number Responding[1]	Arithmetic Mean[2]	Standard Deviation	Standard Error[3]	95 Percent Confidence Interval[4]
Leafy Veg.	1	21.43	****	****	****
Root Veg.	5	23.35	11.07	4.95	*****
Grains	0	****	****	****	****
Fruit	3	64.11	27.80	16.050	*****
Poultry	2	9.32	2.16	1.527	*****
Meat[5]	0	****	****	****	****
Fish[6]	1	7.50	****	****	****
Eggs	26	14.52	8.03	1.575	11.43 to 17.61
Milk	4	122.57	20.41	10.205	*****
Tap Water[7]	167	777.44	423.74	32.790	713.2 to 841.7

[1] Athough the total sample was 195 for the Amargosa Valley, this "subsistence" subset excludes those who report that either (a) nothing they consume is locally produced; or (b) that only "most," "some," or "very little" of the food type in question (that they consumed) was locally produced. Those who responded "don't know" or otherwise declined to answer are also excluded. Thus, this subset includes ONLY those who reported that ALL of the food in question (that they consumed) was locally-produced. The "number responding" is the number who provided information. The values shown reflect weighting by gender.

[2] The values shown for food are in kilograms; for milk and tap water they are in liters. The arithmetic mean is calculated by summing the annual amount consumed reported by those who responded that ALL of the food in question (they consumed) was locally produced and dividing this sum by the number responding that ALL of the food in question (they consumed) was locally produced. The conceptual denominator of this mean includes only those resident adults in the Amargosa Valley for whom ALL of the food in question (they consumed) was locally produced; it excludes all others.

[3] The standard error is calculated by dividing the standard deviation by the square root of the number responding. It is an estimate of sampling variation.

[4] For a given food type, we are 95 percent certain that the "true" average consumption level for the entire resident adult population is within the range shown. The lower limit of the 95 percent confidence interval is calculated by multiplying 1.96 by the standard error and then subtracting this value from the sample mean; the upper limit is found by adding the product of 1.96 and the standard error to the sample mean. This is known as the normal approximation. This application is appropriate when the sample size is 30 or more. Where sample size is substantially less than 30 (designated by ****), no interval was calculated using the normal approximation.

[5] "Meat" is comprised of beef and pork.

[6] The only known source of "locally produced" fish in the entire survey area is the catfish farm in the Amargosa Valley. Thus, the values provided are specific to the consumption of fish from this location.

[7] This refers to water from a local ground source. It excludes any bottled water purchased from a commercial vendor. The manner in which the question on water consumption was phrased precludes identifying those for whom all of the water they consumed was from a local ground source.

Table 9-21. Correlation Between Biosphere Modeling Receptor Groups and the Survey Data Subsets.

Biosphere Modeling Receptor	Regional Survey Data Subset Correlate	Comments
Subsistence Farmer: Consumes only locally-produced food and tap water. Adult spends large amount of time (15 hrs/day) outdoors engaged in activities required to maintain subsistence. [Represents upper limit of exposure]	Total survey "subsistence" resident adult (Table 9-17)	Survey data set for Amargosa Valley "subsistence" resident adult was deemed too small of a population to yield statistically meaningful interpretations for parameter development.
Resident Farmer: Relative to the subsistence farmer, this receptor consumes half the quantity of locally-produced food (but the same quantity of water) and spends half as much time engaged in outdoor activities. Exposure through the food pathway is assumed to be half that of the subsistence farmer receptor; i.e., most parameter values are one-half the established subsistence farmer levels.	None	This receptor is intended to represent the "median" level of exposure risk relative to the subsistence farmer and the average Amargosa Valley resident.
Average Amargosa Valley Resident: Adult living the "average" lifestyle of an Amargosa Valley resident. Consumes some locally produced food, but not as much tap water as the other two receptors. [Represents lower limit of exposure]	Amargosa Valley "total population" resident adult (Table 9-18)	Survey data set for Amargosa Valley "total population" resident adult was sufficiently large to yield statistically meaningful interpretations for parameter development. Because of its proximity to the proposed repository this data subset was deemed more appropriate than the total survey area "total population" resident adult data set (Table 9-15).

Table 9-22. The DCFs for Ingestion for Four Important Radionuclides as Calculated and Used by GENII and those Published in Federal Guidance Report #11. The ratios of the two values are also given.

RADIONUCLIDE	GENII-S (Rem/Ci)	FGR #11 (Rem/Ci)	RATIO (GENII-S/FGR)
^{99}Tc	2.21E+00	1.46E+00	1.51
^{129}I	2.51E+02	2.76E+02	0.91
^{237}Np	5.23E+03	4.44E+03	1.18
^{242}Pu	3.29E+03	3.36E+03	0.98

Table 9-23. Biosphere Dose Conversion Factors for the Two Exposure Pathways Associated with Exposure to Contaminated Ash Fallout During a Volcanic Event at Yucca Mountain (scenario 1).

	BDCF, rem h^{-1} per pCi m^{-3}	
Radionuclide	Inhalation	Submersion
Ac-227	7.96E-03	7.75E-14
Am-241	5.28E-04	1.09E-11
Am-242m	5.06E-04	4.22E-13
Am-243	5.23E-04	2.90E-11
C-14	2.80E-11	2.98E-15
Cl-36	2.61E-08	2.97E-13
Cm-244	2.95E-04	6.54E-14
Cm-245	5.41E-04	5.27E-11
Cm-246	5.36E-04	5.94E-14
Cs-135	5.41E-09	7.53E-15
I-129	2.06E-07	5.06E-12
Nb-93m	3.47E-08	5.91E-14
Nb-94	4.92E-07	1.03E-09
Ni-59	1.57E-09	0.00E+00
Ni-63	3.69E-09	0.00E+00
Np-237	6.42E-04	1.37E-11
Pa-231	1.53E-03	2.29E-11
Pb-210	1.61E-05	7.51E-13
Pd-107	1.52E-08	0.00E+00
Pu-238	4.66E-04	6.50E-14
Pu-239	5.10E-04	5.65E-14
Pu-240	5.10E-04	6.33E-14
Pu-241	9.80E-06	9.66E-16
Pu-242	4.88E-04	5.34E-14
Ra-226	1.02E-05	4.20E-12
Ra-228	5.67E-06	0.00E+00
Se-79	1.17E-08	4.04E-15
Sm-151	3.56E-08	4.81E-16
Sn-126	1.18E-07	2.81E-11
Tc-99	9.89E-09	2.16E-14
Th-229	2.55E-03	5.10E-11
Th-230	3.87E-04	2.32E-13
Th-232	1.95E-03	1.16E-13
U-233	1.61E-04	2.17E-13
U-234	1.57E-04	1.02E-13
U-235	1.46E-04	9.59E-11
U-236	1.49E-04	6.67E-14
U-238	1.41E-04	4.54E-14
Zr-93	3.81E-07	0.00E+00

Table 9-24. Biosphere Dose Conversion Factors for the Total Effective Dose Equivalent for a One Year Exposure Associated with the Residential and Agricultural Use of Contaminated Volcanic Ash Following an Eruption at Yucca Mountain (scenario 2).

	BDCF, rems from year exposure per pCi m^{-2}				
Radionuclide	**Mean**	**SD**	**5%**	**50%**	**95%**
Ac-227	8.49E-07	2.11E-06	1.88E-08	2.29E-07	2.53E-06
Am-241	2.14E-07	5.41E-07	4.08E-09	5.21E-08	6.48E-07
Am-242m	2.06E-07	5.19E-07	3.87E-09	5.00E-08	6.22E-07
Am-243	2.14E-07	5.40E-07	4.16E-09	5.21E-08	6.47E-07
C-14	1.40E-12	2.75E-15	1.39E-12	1.40E-12	1.40E-12
Cl-36	4.53E-09	6.68E-09	4.55E-11	2.03E-09	1.62E-08
Cm-244	1.18E-07	3.00E-07	2.24E-09	2.88E-08	3.59E-07
Cm-245	2.18E-07	5.52E-07	4.42E-09	5.33E-08	6.62E-07
Cm-246	2.20E-07	5.57E-07	4.15E-09	5.35E-08	6.68E-07
Cs-135	1.21E-09	2.62E-09	1.44E-11	2.61E-10	4.36E-09
I-129	3.94E-08	8.12E-08	4.82E-10	8.67E-09	1.29E-07
Nb-93m	3.00E-11	7.52E-11	6.44E-13	7.81E-12	9.02E-11
Nb-94	6.04E-09	1.98E-09	3.14E-09	6.04E-09	8.20E-09
Ni-59	2.10E-11	4.25E-11	2.75E-13	6.27E-12	8.02E-11
Ni-63	5.79E-11	1.17E-10	7.59E-13	1.73E-11	2.21E-10
Np-237	3.20E-07	7.84E-07	6.15E-09	1.07E-07	9.37E-07
Pa-231	7.42E-07	1.63E-06	1.45E-08	2.77E-07	2.66E-06
Pb-210	3.33E-07	8.18E-07	5.96E-09	9.92E-08	9.89E-07
Pd-107	1.15E-11	2.33E-11	2.01E-13	4.20E-12	3.88E-11
Pu-238	1.89E-07	4.79E-07	3.57E-09	4.60E-08	5.73E-07
Pu-239	2.10E-07	5.31E-07	3.96E-09	5.11E-08	6.37E-07
Pu-240	2.10E-07	5.31E-07	3.96E-09	5.10E-08	6.35E-07
Pu-241	4.03E-09	1.02E-08	7.57E-11	9.83E-10	1.22E-08
Pu-242	1.95E-07	4.94E-07	3.68E-09	4.75E-08	5.92E-07
Ra-226	6.12E-08	1.44E-07	1.10E-09	1.96E-08	1.74E-07
Ra-228	5.41E-08	1.28E-07	9.59E-10	1.73E-08	1.54E-07
Se-79	8.58E-10	1.56E-09	1.55E-11	2.92E-10	2.62E-09
Sm-151	2.66E-11	5.91E-11	5.09E-13	9.39E-12	9.68E-11
Sn-126	1.77E-09	3.35E-09	1.34E-10	7.22E-10	5.55E-09
Tc-99	5.85E-10	9.64E-10	1.25E-11	2.01E-10	2.08E-09
Th-229	2.17E-07	5.45E-07	5.24E-09	5.41E-08	6.55E-07
Th-230	3.18E-08	8.02E-08	7.52E-10	7.81E-09	9.61E-08
Th-232	1.62E-07	4.09E-07	3.84E-09	3.98E-08	4.90E-07
U-233	1.78E-08	4.33E-08	4.01E-10	5.83E-09	5.23E-08
U-234	1.75E-08	4.25E-08	3.94E-10	5.72E-09	5.14E-08
U-235	1.69E-08	4.01E-08	9.27E-10	5.74E-09	4.87E-08
U-236	1.66E-08	4.03E-08	3.73E-10	5.42E-09	4.87E-08
U-238	1.62E-08	3.93E-08	3.60E-10	5.31E-09	4.75E-08
Zr-93	9.64E-11	2.44E-10	1.89E-12	2.35E-11	2.92E-10

Table 9-25. BDCFs for the Average Amargosa Valley Resident, Current Precipitation.

		[(mrem/yr)/(pCi/l)]		Percentiles		
No.	Radionuclide	Mean	Standard Deviation	5%	50%	95%
1	Ac-227	1.75E+01	1.21E+01	4.99E+00	1.40E+01	4.43E+01
2	Am-241	4.50E+00	3.13E+00	1.28E+00	3.57E+00	1.14E+01
3	Am-242m	4.30E+00	3.00E+00	1.23E+00	3.42E+00	1.09E+01
4	Am-243	4.48E+00	3.12E+00	1.28E+00	3.56E+00	1.14E+01
5	C-14	2.81E-03	1.29E-03	1.15E-03	2.62E-03	4.82E-03
6	Cl-36	8.31E-03	7.55E-03	1.81E-03	5.93E-03	2.67E-02
7	Cm-244	2.48E+00	1.72E+00	7.11E-01	1.97E+00	6.31E+00
8	Cm-245	4.58E+00	3.19E+00	1.31E+00	3.64E+00	1.16E+01
9	Cm-246	4.62E+00	3.22E+00	1.32E+00	3.67E+00	1.17E+01
10	Cs-135	1.48E-02	1.85E-02	3.40E-03	8.42E-03	4.29E-02
11	I-129	4.79E-01	4.75E-01	1.24E-01	3.13E-01	1.30E+00
12	Nb-93m	6.24E-04	4.32E-04	1.79E-04	4.95E-04	1.58E-03
13	Nb-94	2.04E-02	6.73E-03	1.34E-02	1.88E-02	3.48E-02
14	Ni-59	3.14E-04	2.39E-04	1.00E-04	2.25E-04	7.34E-04
15	Ni-63	8.65E-04	6.58E-04	2.77E-04	6.19E-04	2.02E-03
16	Np-237	6.57E+00	4.52E+00	1.89E+00	5.24E+00	1.65E+01
17	Pa-231	1.40E+01	9.55E+00	4.24E+00	1.11E+01	3.48E+01
18	Pb-210	6.85E+00	4.75E+00	1.93E+00	5.45E+00	1.73E+01
19	Pd-107	1.99E-04	1.31E-04	6.19E-05	1.58E-04	4.74E-04
20	Pu-238	3.97E+00	2.77E+00	1.14E+00	3.15E+00	1.01E+01
21	Pu-239	4.41E+00	3.07E+00	1.26E+00	3.50E+00	1.12E+01
22	Pu-240	4.41E+00	3.07E+00	1.26E+00	3.50E+00	1.12E+01
23	Pu-241	8.40E-02	5.82E-02	2.41E-02	6.67E-02	2.14E-01
24	Pu-242	4.10E+00	2.86E+00	1.17E+00	3.25E+00	1.04E+01
25	Ra-226	1.23E+00	8.31E-01	3.79E-01	9.83E-01	3.05E+00
26	Ra-228	1.08E+00	7.27E-01	3.31E-01	8.63E-01	2.66E+00
27	Se-79	1.36E-02	9.76E-03	4.14E-03	1.02E-02	3.02E-02
28	Sm-151	5.10E-04	3.47E-04	1.54E-04	4.03E-04	1.27E-03
29	Sn-126	4.22E-02	2.04E-02	2.19E-02	3.56E-02	8.50E-02
30	Tc-99	3.14E-03	2.41E-03	8.27E-04	2.37E-03	8.56E-03
31	Th-229	4.45E+00	3.15E+00	1.25E+00	3.51E+00	1.14E+01
32	Th-230	6.66E-01	4.64E-01	1.90E-01	5.28E-01	1.69E+00
33	Th-232	3.39E+00	2.36E+00	9.69E-01	2.69E+00	8.60E+00
34	U-233	3.65E-01	2.50E-01	1.05E-01	2.91E-01	9.29E-01
35	U-234	3.58E-01	2.45E-01	1.03E-01	2.85E-01	9.12E-01
36	U-235	3.37E-01	2.30E-01	9.75E-02	2.68E-01	8.56E-01
37	U-236	3.40E-01	2.33E-01	9.76E-02	2.71E-01	8.65E-01
38	U-238	3.28E-01	2.27E-01	9.38E-02	2.60E-01	8.41E-01
39	Zr-93	2.02E-03	1.41E-03	5.78E-04	1.60E-03	5.13E-03

Table 9-26. BDCFs for the Average Amargosa Valley Resident, 2× Current Precipitation.

		[(mrem/yr)/(pCi/l)]		Percentiles		
No.	Radionuclide	Mean	Standard Deviation	5%	50%	95%
1	Ac-227	1.74E+01	1.20E+01	4.98E+00	1.39E+01	4.35E+01
2	Am-241	4.47E+00	3.09E+00	1.28E+00	3.54E+00	1.12E+01
3	Am-242m	4.28E+00	2.96E+00	1.23E+00	3.39E+00	1.07E+01
4	Am-243	4.45E+00	3.08E+00	1.28E+00	3.54E+00	1.12E+01
5	C-14	2.77E-03	1.26E-03	1.13E-03	2.61E-03	4.77E-03
6	Cl-36	8.09E-03	7.25E-03	1.81E-03	5.83E-03	2.54E-02
7	Cm-244	2.46E+00	1.69E+00	7.10E-01	1.96E+00	6.19E+00
8	Cm-245	4.55E+00	3.15E+00	1.31E+00	3.61E+00	1.14E+01
9	Cm-246	4.59E+00	3.18E+00	1.32E+00	3.64E+00	1.15E+01
10	Cs-135	1.44E-02	1.79E-02	3.38E-03	8.42E-03	4.09E-02
11	I-129	4.67E-01	4.52E-01	1.24E-01	3.11E-01	1.23E+00
12	Nb-93m	6.19E-04	4.26E-04	1.78E-04	4.91E-04	1.56E-03
13	Nb-94	1.96E-02	6.64E-03	1.24E-02	1.80E-02	3.40E-02
14	Ni-59	3.09E-04	2.30E-04	1.00E-04	2.24E-04	7.19E-04
15	Ni-63	8.51E-04	6.35E-04	2.76E-04	6.19E-04	1.98E-03
16	Np-237	6.52E+00	4.46E+00	1.87E+00	5.21E+00	1.62E+01
17	Pa-231	1.39E+01	9.41E+00	4.24E+00	1.09E+01	3.43E+01
18	Pb-210	6.80E+00	4.70E+00	1.92E+00	5.41E+00	1.70E+01
19	Pd-107	1.97E-04	1.29E-04	6.10E-05	1.57E-04	4.65E-04
20	Pu-238	3.95E+00	2.73E+00	1.13E+00	3.13E+00	9.90E+00
21	Pu-239	4.38E+00	3.03E+00	1.26E+00	3.47E+00	1.10E+01
22	Pu-240	4.38E+00	3.03E+00	1.26E+00	3.47E+00	1.10E+01
23	Pu-241	8.34E-02	5.74E-02	2.40E-02	6.63E-02	2.10E-01
24	Pu-242	4.07E+00	2.82E+00	1.17E+00	3.23E+00	1.02E+01
25	Ra-226	1.22E+00	8.20E-01	3.72E-01	9.80E-01	3.00E+00
26	Ra-228	1.07E+00	7.17E-01	3.25E-01	8.60E-01	2.65E+00
27	Se-79	1.34E-02	9.45E-03	4.14E-03	1.01E-02	2.99E-02
28	Sm-151	5.05E-04	3.42E-04	1.54E-04	3.96E-04	1.25E-03
29	Sn-126	4.09E-02	2.00E-02	2.09E-02	3.46E-02	8.28E-02
30	Tc-99	3.12E-03	2.37E-03	8.24E-04	2.37E-03	8.41E-03
31	Th-229	4.42E+00	3.11E+00	1.25E+00	3.48E+00	1.12E+01
32	Th-230	6.62E-01	4.58E-01	1.90E-01	5.24E-01	1.66E+00
33	Th-232	3.37E+00	2.33E+00	9.67E-01	2.67E+00	8.44E+00
34	U-233	3.62E-01	2.47E-01	1.05E-01	2.89E-01	9.14E-01
35	U-234	3.56E-01	2.42E-01	1.03E-01	2.84E-01	8.97E-01
36	U-235	3.34E-01	2.27E-01	9.72E-02	2.66E-01	8.42E-01
37	U-236	3.37E-01	2.29E-01	9.75E-02	2.69E-01	8.50E-01
38	U-238	3.26E-01	2.24E-01	9.36E-02	2.59E-01	8.27E-01
39	Zr-93	2.01E-03	1.39E-03	5.77E-04	1.59E-03	5.04E-03

Table9-27. BDCFs for the Average Amargosa Valley Resident, 3× Current Precipitation.

		[(mrem/yr)/(pCi/l)]		Percentiles		
No.	**Radionuclide**	**Mean**	**Standard Deviation**	**5%**	**50%**	**95%**
1	Ac-227	1.73E+01	1.17E+01	4.97E+00	1.39E+01	4.28E+01
2	Am-241	4.43E+00	3.03E+00	1.28E+00	3.53E+00	1.10E+01
3	Am-242m	4.24E+00	2.90E+00	1.22E+00	3.38E+00	1.06E+01
4	Am-243	4.42E+00	3.02E+00	1.28E+00	3.53E+00	1.10E+01
5	C-14	2.74E-03	1.23E-03	1.10E-03	2.59E-03	4.72E-03
6	Cl-36	7.87E-03	6.90E-03	1.78E-03	5.68E-03	2.45E-02
7	Cm-244	2.45E+00	1.67E+00	7.08E-01	1.94E+00	6.10E+00
8	Cm-245	4.51E+00	3.09E+00	1.30E+00	3.60E+00	1.12E+01
9	Cm-246	4.55E+00	3.11E+00	1.32E+00	3.63E+00	1.13E+01
10	Cs-135	1.41E-02	1.70E-02	3.35E-03	8.38E-03	3.98E-02
11	I-129	4.58E-01	4.40E-01	1.23E-01	3.08E-01	1.20E+00
12	Nb-93m	6.15E-04	4.21E-04	1.78E-04	4.88E-04	1.53E-03
13	Nb-94	1.88E-02	6.53E-03	1.17E-02	1.72E-02	3.26E-02
14	Ni-59	3.04E-04	2.22E-04	9.95E-05	2.24E-04	6.95E-04
15	Ni-63	8.37E-04	6.11E-04	2.74E-04	6.18E-04	1.92E-03
16	Np-237	6.47E+00	4.38E+00	1.86E+00	5.20E+00	1.60E+01
17	Pa-231	1.38E+01	9.19E+00	4.23E+00	1.08E+01	3.37E+01
18	Pb-210	6.74E+00	4.62E+00	1.92E+00	5.38E+00	1.67E+01
19	Pd-107	1.95E-04	1.26E-04	6.08E-05	1.55E-04	4.58E-04
20	Pu-238	3.91E+00	2.68E+00	1.13E+00	3.12E+00	9.75E+00
21	Pu-239	4.35E+00	2.97E+00	1.26E+00	3.46E+00	1.08E+01
22	Pu-240	4.34E+00	2.97E+00	1.25E+00	3.46E+00	1.08E+01
23	Pu-241	8.29E-02	5.67E-02	2.40E-02	6.58E-02	2.07E-01
24	Pu-242	4.04E+00	2.76E+00	1.17E+00	3.22E+00	1.01E+01
25	Ra-226	1.21E+00	8.04E-01	3.66E-01	9.76E-01	2.95E+00
26	Ra-228	1.06E+00	7.06E-01	3.20E-01	8.56E-01	2.57E+00
27	Se-79	1.32E-02	9.19E-03	4.11E-03	1.01E-02	2.93E-02
28	Sm-151	5.00E-04	3.34E-04	1.54E-04	3.93E-04	1.23E-03
29	Sn-126	3.97E-02	1.95E-02	2.00E-02	3.36E-02	7.99E-02
30	Tc-99	3.09E-03	2.33E-03	8.22E-04	2.36E-03	8.34E-03
31	Th-229	4.38E+00	3.05E+00	1.25E+00	3.47E+00	1.10E+01
32	Th-230	6.56E-01	4.49E-01	1.90E-01	5.23E-01	1.63E+00
33	Th-232	3.34E+00	2.28E+00	9.65E-01	2.66E+00	8.31E+00
34	U-233	3.59E-01	2.42E-01	1.04E-01	2.89E-01	8.97E-01
35	U-234	3.53E-01	2.37E-01	1.02E-01	2.83E-01	8.81E-01
36	U-235	3.31E-01	2.22E-01	9.69E-02	2.66E-01	8.27E-01
37	U-236	3.34E-01	2.25E-01	9.72E-02	2.69E-01	8.35E-01
38	U-238	3.23E-01	2.20E-01	9.33E-02	2.58E-01	8.12E-01
39	Zr-93	1.99E-03	1.36E-03	5.76E-04	1.59E-03	4.96E-03

Table 9-28. The χ^2 Goodness of Fit Values for Various Statistical Distribution on ^{237}Np BDCF Data 130 Data Points in 10 Data Bins for the Average Amagosa Valley Resident at Current Day Precipitation Levels.

Distribution	Value of χ^2	Degrees of freedom	Accept/Reject 5% limit
Lognormal	6.0	8	15.5
Beta	14.3	6	12.6
Gamma	14.5	8	15.5
Weibull	23.3	8	15.5
Normal	55.	8	15.5
Exponential	59.	9	16.9
Uniform	>100	8	15.5

Table 9-29. BDCFs for the Resident Farmer with Current Precipitation.

		[(mrem/yr)/(pCi/l)]		Percentiles		
No.	Radionuclide	Mean	Standard Deviation	5%	50%	95%
1	Ac-227	4.32E+01	1.52E+01	1.97E+01	4.14E+01	7.15E+01
2	Am-241	1.10E+01	3.86E+00	5.03E+00	1.04E+01	1.83E+01
3	Am-242m	1.05E+01	3.70E+00	4.82E+00	9.98E+00	1.75E+01
4	Am-243	1.09E+01	3.85E+00	5.02E+00	1.04E+01	1.82E+01
5	C-14	1.19E-02	1.25E-03	9.96E-03	1.19E-02	1.41E-02
6	Cl-36	5.09E-02	3.65E-02	1.72E-02	4.00E-02	1.20E-01
7	Cm-244	6.04E+00	2.13E+00	2.77E+00	5.74E+00	1.01E+01
8	Cm-245	1.12E+01	3.94E+00	5.13E+00	1.06E+01	1.86E+01
9	Cm-246	1.13E+01	3.97E+00	5.18E+00	1.07E+01	1.88E+01
10	Cs-135	7.69E-02	5.41E-02	2.86E-02	5.84E-02	1.62E-01
11	I-129	2.34E+00	1.53E+00	9.30E-01	1.82E+00	5.10E+00
12	Nb-93m	1.51E-03	5.33E-04	6.96E-04	1.44E-03	2.54E-03
13	Nb-94	3.33E-02	8.10E-03	2.08E-02	3.27E-02	4.86E-02
14	Ni-59	1.36E-03	7.82E-04	5.07E-04	1.12E-03	2.73E-03
15	Ni-63	3.75E-03	2.16E-03	1.40E-03	3.10E-03	7.53E-03
16	Np-237	1.65E+01	5.79E+00	7.41E+00	1.59E+01	2.71E+01
17	Pa-231	3.90E+01	1.46E+01	1.72E+01	3.77E+01	6.99E+01
18	Pb-210	1.75E+01	6.24E+00	7.85E+00	1.69E+01	2.91E+01
19	Pd-107	6.15E-04	2.48E-04	2.76E-04	5.80E-04	1.04E-03
20	Pu-238	9.67E+00	3.41E+00	4.45E+00	9.19E+00	1.62E+01
21	Pu-239	1.07E+01	3.79E+00	4.94E+00	1.02E+01	1.79E+01
22	Pu-240	1.07E+01	3.78E+00	4.93E+00	1.02E+01	1.79E+01
23	Pu-241	2.04E-01	7.19E-02	9.39E-02	1.94E-01	3.42E-01
24	Pu-242	9.99E+00	3.52E+00	4.59E+00	9.49E+00	1.67E+01
25	Ra-226	3.28E+00	1.17E+00	1.45E+00	3.20E+00	5.57E+00
26	Ra-228	2.86E+00	1.02E+00	1.27E+00	2.77E+00	4.87E+00
27	Se-79	5.11E-02	2.72E-02	2.08E-02	4.37E-02	1.01E-01
28	Sm-151	1.42E-03	5.31E-04	6.23E-04	1.37E-03	2.53E-03
29	Sn-126	1.05E-01	4.04E-02	5.47E-02	9.79E-02	1.86E-01
30	Tc-99	8.16E-03	2.70E-03	4.16E-03	7.96E-03	1.29E-02
31	Th-229	1.10E+01	3.92E+00	5.02E+00	1.05E+01	1.85E+01
32	Th-230	1.62E+00	5.72E-01	7.46E-01	1.54E+00	2.71E+00
33	Th-232	8.25E+00	2.91E+00	3.79E+00	7.84E+00	1.38E+01
34	U-233	9.20E-01	3.22E-01	4.13E-01	8.90E-01	1.51E+00
35	U-234	9.03E-01	3.17E-01	4.06E-01	8.74E-01	1.49E+00
36	U-235	8.47E-01	2.97E-01	3.81E-01	8.20E-01	1.39E+00
37	U-236	8.56E-01	3.00E-01	3.85E-01	8.28E-01	1.41E+00
38	U-238	8.34E-01	2.93E-01	3.75E-01	8.06E-01	1.37E+00
39	Zr-93	4.92E-03	1.74E-03	2.26E-03	4.68E-03	8.22E-03

Table 9-30. BDCFs for Resident Farmer with 2x Current Precipitation.

		[(mrem/yr)/(pCi/l)]		Percentiles		
No.	Radionuclide	Mean	Standard Deviation	5%	50%	95%
1	Ac-227	4.25E+01	1.49E+01	1.93E+01	4.08E+01	7.03E+01
2	Am-241	1.08E+01	3.80E+00	4.95E+00	1.03E+01	1.80E+01
3	Am-242m	1.03E+01	3.64E+00	4.73E+00	9.88E+00	1.72E+01
4	Am-243	1.08E+01	3.79E+00	4.93E+00	1.03E+01	1.80E+01
5	C-14	1.16E-02	1.24E-03	9.66E-03	1.15E-02	1.37E-02
6	Cl-36	4.88E-02	3.49E-02	1.67E-02	3.82E-02	1.14E-01
7	Cm-244	5.94E+00	2.10E+00	2.72E+00	5.59E+00	9.95E+00
8	Cm-245	1.10E+01	3.87E+00	5.04E+00	1.05E+01	1.83E+01
9	Cm-246	1.11E+01	3.91E+00	5.09E+00	1.06E+01	1.85E+01
10	Cs-135	7.38E-02	5.14E-02	2.77E-02	5.62E-02	1.57E-01
11	I-129	2.25E+00	1.45E+00	8.90E-01	1.76E+00	4.84E+00
12	Nb-93m	1.49E-03	5.26E-04	6.84E-04	1.40E-03	2.50E-03
13	Nb-94	3.22E-02	7.97E-03	1.97E-02	3.18E-02	4.75E-02
14	Ni-59	1.31E-03	7.38E-04	4.90E-04	1.08E-03	2.59E-03
15	Ni-63	3.61E-03	2.03E-03	1.35E-03	2.98E-03	7.12E-03
16	Np-237	1.62E+01	5.68E+00	7.29E+00	1.55E+01	2.68E+01
17	Pa-231	3.81E+01	1.42E+01	1.68E+01	3.68E+01	6.77E+01
18	Pb-210	1.72E+01	6.12E+00	7.72E+00	1.64E+01	2.86E+01
19	Pd-107	5.99E-04	2.39E-04	2.68E-04	5.68E-04	1.00E-03
20	Pu-238	9.51E+00	3.36E+00	4.37E+00	9.01E+00	1.59E+01
21	Pu-239	1.06E+01	3.73E+00	4.85E+00	1.01E+01	1.77E+01
22	Pu-240	1.06E+01	3.72E+00	4.85E+00	1.01E+01	1.76E+01
23	Pu-241	2.01E-01	7.10E-02	9.22E-02	1.89E-01	3.37E-01
24	Pu-242	9.83E+00	3.46E+00	4.51E+00	9.40E+00	1.64E+01
25	Ra-226	3.21E+00	1.14E+00	1.43E+00	3.10E+00	5.49E+00
26	Ra-228	2.81E+00	9.99E-01	1.25E+00	2.70E+00	4.79E+00
27	Se-79	4.95E-02	2.61E-02	2.01E-02	4.26E-02	9.68E-02
28	Sm-151	1.39E-03	5.19E-04	6.09E-04	1.33E-03	2.47E-03
29	Sn-126	1.02E-01	3.88E-02	5.27E-02	9.52E-02	1.78E-01
30	Tc-99	8.04E-03	2.66E-03	4.10E-03	7.87E-03	1.27E-02
31	Th-229	1.09E+01	3.85E+00	4.94E+00	1.04E+01	1.82E+01
32	Th-230	1.60E+00	5.62E-01	7.33E-01	1.53E+00	2.67E+00
33	Th-232	8.12E+00	2.86E+00	3.73E+00	7.77E+00	1.36E+01
34	U-233	9.04E-01	3.17E-01	4.05E-01	8.63E-01	1.50E+00
35	U-234	8.88E-01	3.11E-01	3.98E-01	8.48E-01	1.47E+00
36	U-235	8.33E-01	2.91E-01	3.74E-01	7.95E-01	1.38E+00
37	U-236	8.42E-01	2.95E-01	3.77E-01	8.04E-01	1.39E+00
38	U-238	8.20E-01	2.88E-01	3.67E-01	7.89E-01	1.36E+00
39	Zr-93	4.84E-03	1.71E-03	2.22E-03	4.63E-03	8.09E-03

Table 9-31. BDCFs for the Resident Farmer with 3x Current Precipitation.

		[(mrem/yr)/(pCi/l)]		Percentiles		
No.	Radionuclide	Mean	Standard Deviation	5%	50%	95%
1	Ac-227	4.18E+01	1.47E+01	1.92E+01	4.03E+01	6.93E+01
2	Am-241	1.06E+01	3.73E+00	4.91E+00	1.01E+01	1.77E+01
3	Am-242m	1.02E+01	3.57E+00	4.70E+00	9.63E+00	1.70E+01
4	Am-243	1.06E+01	3.72E+00	4.90E+00	1.00E+01	1.77E+01
5	C-14	1.13E-02	1.26E-03	9.29E-03	1.12E-02	1.33E-02
6	Cl-36	4.69E-02	3.31E-02	1.61E-02	3.66E-02	1.11E-01
7	Cm-244	5.86E+00	2.05E+00	2.70E+00	5.54E+00	9.80E+00
8	Cm-245	1.08E+01	3.80E+00	5.01E+00	1.02E+01	1.80E+01
9	Cm-246	1.09E+01	3.84E+00	5.05E+00	1.03E+01	1.82E+01
10	Cs-135	7.10E-02	4.93E-02	2.63E-02	5.36E-02	1.48E-01
11	I-129	2.17E+00	1.39E+00	8.56E-01	1.71E+00	4.71E+00
12	Nb-93m	1.47E-03	5.15E-04	6.77E-04	1.39E-03	2.46E-03
13	Nb-94	3.11E-02	7.84E-03	1.89E-02	3.06E-02	4.60E-02
14	Ni-59	1.27E-03	7.21E-04	4.78E-04	1.05E-03	2.49E-03
15	Ni-63	3.51E-03	1.99E-03	1.31E-03	2.90E-03	6.85E-03
16	Np-237	1.59E+01	5.58E+00	7.23E+00	1.53E+01	2.60E+01
17	Pa-231	3.73E+01	1.38E+01	1.66E+01	3.59E+01	6.57E+01
18	Pb-210	1.69E+01	6.00E+00	7.62E+00	1.61E+01	2.80E+01
19	Pd-107	5.86E-04	2.32E-04	2.64E-04	5.56E-04	9.80E-04
20	Pu-238	9.37E+00	3.30E+00	4.34E+00	8.88E+00	1.56E+01
21	Pu-239	1.04E+01	3.66E+00	4.82E+00	9.86E+00	1.74E+01
22	Pu-240	1.04E+01	3.65E+00	4.81E+00	9.85E+00	1.73E+01
23	Pu-241	1.98E-01	6.94E-02	9.13E-02	1.88E-01	3.32E-01
24	Pu-242	9.68E+00	3.40E+00	4.48E+00	9.17E+00	1.62E+01
25	Ra-226	3.15E+00	1.12E+00	1.41E+00	3.03E+00	5.39E+00
26	Ra-228	2.76E+00	9.79E-01	1.23E+00	2.65E+00	4.75E+00
27	Se-79	4.82E-02	2.53E-02	1.96E-02	4.14E-02	9.41E-02
28	Sm-151	1.36E-03	5.04E-04	6.04E-04	1.31E-03	2.39E-03
29	Sn-126	9.86E-02	3.76E-02	5.10E-02	9.13E-02	1.73E-01
30	Tc-99	7.92E-03	2.61E-03	4.03E-03	7.77E-03	1.25E-02
31	Th-229	1.07E+01	3.78E+00	4.90E+00	1.01E+01	1.78E+01
32	Th-230	1.57E+00	5.52E-01	7.28E-01	1.49E+00	2.62E+00
33	Th-232	8.00E+00	2.81E+00	3.70E+00	7.58E+00	1.33E+01
34	U-233	8.89E-01	3.10E-01	4.01E-01	8.51E-01	1.46E+00
35	U-234	8.73E-01	3.05E-01	3.94E-01	8.35E-01	1.43E+00
36	U-235	8.19E-01	2.86E-01	3.70E-01	7.84E-01	1.34E+00
37	U-236	8.28E-01	2.89E-01	3.74E-01	7.92E-01	1.35E+00
38	U-238	8.06E-01	2.82E-01	3.63E-01	7.72E-01	1.32E+00
39	Zr-93	4.77E-03	1.68E-03	2.21E-03	4.52E-03	7.96E-03

Table 9-32. BDCFs for the Subsistence Farmer with Current Precipitation.

		[(mrem/yr)/(pCi/l)]		Percentiles		
No.	Radionuclide	Mean	Standard Deviation	5%	50%	95%
1	Ac-227	7.49E+01	2.97E+01	3.34E+01	7.10E+01	1.31E+02
2	Am-241	1.89E+01	7.54E+00	8.46E+00	1.79E+01	3.35E+01
3	Am-242m	1.81E+01	7.21E+00	8.10E+00	1.71E+01	3.20E+01
4	Am-243	1.89E+01	7.52E+00	8.44E+00	1.78E+01	3.34E+01
5	C-14	2.22E-02	2.25E-03	1.85E-02	2.20E-02	2.58E-02
6	Cl-36	9.96E-02	7.33E-02	3.14E-02	7.79E-02	2.40E-01
7	Cm-244	1.04E+01	4.14E+00	4.68E+00	9.87E+00	1.83E+01
8	Cm-245	1.93E+01	7.68E+00	8.62E+00	1.82E+01	3.41E+01
9	Cm-246	1.95E+01	7.75E+00	8.70E+00	1.84E+01	3.44E+01
10	Cs-135	1.48E-01	1.08E-01	5.02E-02	1.11E-01	3.23E-01
11	I-129	4.48E+00	3.04E+00	1.66E+00	3.46E+00	9.93E+00
12	Nb-93m	2.62E-03	1.04E-03	1.17E-03	2.48E-03	4.60E-03
13	Nb-94	6.40E-02	1.60E-02	4.03E-02	6.20E-02	9.58E-02
14	Ni-59	2.56E-03	1.56E-03	9.36E-04	2.10E-03	5.31E-03
15	Ni-63	7.05E-03	4.30E-03	2.58E-03	5.78E-03	1.46E-02
16	Np-237	2.86E+01	1.13E+01	1.26E+01	2.75E+01	5.00E+01
17	Pa-231	6.92E+01	2.87E+01	2.80E+01	6.50E+01	1.31E+02
18	Pb-210	3.07E+01	1.22E+01	1.35E+01	2.93E+01	5.36E+01
19	Pd-107	1.11E-03	4.92E-04	4.64E-04	1.01E-03	1.98E-03
20	Pu-238	1.67E+01	6.65E+00	7.47E+00	1.58E+01	2.96E+01
21	Pu-239	1.86E+01	7.39E+00	8.30E+00	1.75E+01	3.28E+01
22	Pu-240	1.85E+01	7.38E+00	8.28E+00	1.75E+01	3.28E+01
23	Pu-241	3.53E-01	1.40E-01	1.58E-01	3.34E-01	6.19E-01
24	Pu-242	1.73E+01	6.87E+00	7.71E+00	1.63E+01	3.05E+01
25	Ra-226	5.78E+00	2.30E+00	2.45E+00	5.61E+00	1.04E+01
26	Ra-228	5.04E+00	2.00E+00	2.10E+00	4.91E+00	9.04E+00
27	Se-79	9.53E-02	5.42E-02	3.86E-02	8.19E-02	1.92E-01
28	Sm-151	2.52E-03	1.05E-03	1.02E-03	2.37E-03	4.78E-03
29	Sn-126	1.99E-01	8.05E-02	1.00E-01	1.83E-01	3.56E-01
30	Tc-99	1.45E-02	5.33E-03	6.99E-03	1.41E-02	2.40E-02
31	Th-229	1.92E+01	7.67E+00	8.56E+00	1.81E+01	3.39E+01
32	Th-230	2.80E+00	1.12E+00	1.25E+00	2.64E+00	4.96E+00
33	Th-232	1.43E+01	5.68E+00	6.37E+00	1.35E+01	2.52E+01
34	U-233	1.60E+00	6.30E-01	7.04E-01	1.54E+00	2.84E+00
35	U-234	1.57E+00	6.18E-01	6.91E-01	1.51E+00	2.79E+00
36	U-235	1.48E+00	5.80E-01	6.49E-01	1.42E+00	2.61E+00
37	U-236	1.49E+00	5.86E-01	6.55E-01	1.43E+00	2.64E+00
38	U-238	1.46E+00	5.74E-01	6.38E-01	1.40E+00	2.58E+00
39	Zr-93	8.51E-03	3.39E-03	3.80E-03	8.03E-03	1.50E-02

Table 9-33. BDCFs for the Subsistence Farmer with 2x Current Precipitation.

		[(mrem/yr)/(pCi/l)]		Percentiles		
No.	Radionuclide	Mean	Standard Deviation	5%	50%	95%
1	Ac-227	7.35E+01	2.91E+01	3.28E+01	6.97E+01	1.28E+02
2	Am-241	1.86E+01	7.40E+00	8.34E+00	1.76E+01	3.28E+01
3	Am-242m	1.78E+01	7.08E+00	7.98E+00	1.68E+01	3.14E+01
4	Am-243	1.86E+01	7.38E+00	8.32E+00	1.75E+01	3.27E+01
5	C-14	2.15E-02	2.30E-03	1.79E-02	2.12E-02	2.51E-02
6	Cl-36	9.49E-02	6.93E-02	3.04E-02	7.55E-02	2.27E-01
7	Cm-244	1.03E+01	4.09E+00	4.60E+00	9.72E+00	1.80E+01
8	Cm-245	1.90E+01	7.53E+00	8.49E+00	1.79E+01	3.34E+01
9	Cm-246	1.91E+01	7.60E+00	8.57E+00	1.81E+01	3.37E+01
10	Cs-135	1.42E-01	1.02E-01	4.87E-02	1.06E-01	3.05E-01
11	I-129	4.28E+00	2.88E+00	1.60E+00	3.32E+00	9.40E+00
12	Nb-93m	2.57E-03	1.02E-03	1.16E-03	2.44E-03	4.52E-03
13	Nb-94	6.15E-02	1.58E-02	3.76E-02	5.93E-02	9.23E-02
14	Ni-59	2.46E-03	1.48E-03	9.01E-04	2.02E-03	5.02E-03
15	Ni-63	6.76E-03	4.08E-03	2.49E-03	5.57E-03	1.38E-02
16	Np-237	2.81E+01	1.11E+01	1.24E+01	2.67E+01	4.90E+01
17	Pa-231	6.75E+01	2.78E+01	2.73E+01	6.38E+01	1.26E+02
18	Pb-210	3.01E+01	1.20E+01	1.31E+01	2.87E+01	5.26E+01
19	Pd-107	1.07E-03	4.72E-04	4.48E-04	9.87E-04	1.91E-03
20	Pu-238	1.64E+01	6.53E+00	7.36E+00	1.55E+01	2.90E+01
21	Pu-239	1.82E+01	7.25E+00	8.18E+00	1.72E+01	3.22E+01
22	Pu-240	1.82E+01	7.24E+00	8.16E+00	1.72E+01	3.21E+01
23	Pu-241	3.47E-01	1.38E-01	1.56E-01	3.29E-01	6.10E-01
24	Pu-242	1.70E+01	6.74E+00	7.60E+00	1.60E+01	2.99E+01
25	Ra-226	5.65E+00	2.24E+00	2.37E+00	5.47E+00	1.01E+01
26	Ra-228	4.94E+00	1.96E+00	2.07E+00	4.78E+00	8.82E+00
27	Se-79	9.22E-02	5.20E-02	3.74E-02	7.89E-02	1.85E-01
28	Sm-151	2.46E-03	1.01E-03	9.88E-04	2.32E-03	4.60E-03
29	Sn-126	1.91E-01	7.71E-02	9.57E-02	1.75E-01	3.42E-01
30	Tc-99	1.43E-02	5.19E-03	6.84E-03	1.39E-02	2.35E-02
31	Th-229	1.88E+01	7.52E+00	8.37E+00	1.78E+01	3.32E+01
32	Th-230	2.75E+00	1.09E+00	1.23E+00	2.60E+00	4.85E+00
33	Th-232	1.40E+01	5.57E+00	6.28E+00	1.32E+01	2.47E+01
34	U-233	1.57E+00	6.17E-01	6.87E-01	1.51E+00	2.78E+00
35	U-234	1.54E+00	6.06E-01	6.75E-01	1.48E+00	2.73E+00
36	U-235	1.45E+00	5.68E-01	6.34E-01	1.39E+00	2.56E+00
37	U-236	1.46E+00	5.74E-01	6.40E-01	1.40E+00	2.59E+00
38	U-238	1.43E+00	5.62E-01	6.21E-01	1.37E+00	2.53E+00
39	Zr-93	8.36E-03	3.32E-03	3.75E-03	7.90E-03	1.47E-02

Table 9-34. BDCFs for the Subsistence Farmer with 3x Current Precipitation.

		[(mrem/yr)/(pCi/l)]		Percentiles		
No.	Radionuclide	Mean	Standard Deviation	5%	50%	95%
1	Ac-227	7.23E+01	2.86E+01	3.24E+01	6.86E+01	1.26E+02
2	Am-241	1.83E+01	7.27E+00	8.25E+00	1.72E+01	3.21E+01
3	Am-242m	1.75E+01	6.96E+00	7.90E+00	1.65E+01	3.07E+01
4	Am-243	1.83E+01	7.25E+00	8.23E+00	1.72E+01	3.20E+01
5	C-14	2.09E-02	2.29E-03	1.74E-02	2.06E-02	2.45E-02
6	Cl-36	9.14E-02	6.64E-02	2.97E-02	7.18E-02	2.19E-01
7	Cm-244	1.01E+01	4.00E+00	4.56E+00	9.51E+00	1.76E+01
8	Cm-245	1.87E+01	7.41E+00	8.40E+00	1.76E+01	3.27E+01
9	Cm-246	1.88E+01	7.48E+00	8.48E+00	1.77E+01	3.30E+01
10	Cs-135	1.37E-01	9.86E-02	4.73E-02	1.02E-01	2.91E-01
11	I-129	4.14E+00	2.78E+00	1.55E+00	3.25E+00	9.04E+00
12	Nb-93m	2.53E-03	1.00E-03	1.15E-03	2.39E-03	4.43E-03
13	Nb-94	5.93E-02	1.56E-02	3.57E-02	5.74E-02	8.96E-02
14	Ni-59	2.38E-03	1.42E-03	8.80E-04	1.97E-03	4.77E-03
15	Ni-63	6.55E-03	3.91E-03	2.43E-03	5.42E-03	1.32E-02
16	Np-237	2.76E+01	1.09E+01	1.23E+01	2.63E+01	4.77E+01
17	Pa-231	6.61E+01	2.72E+01	2.68E+01	6.25E+01	1.24E+02
18	Pb-210	2.95E+01	1.17E+01	1.30E+01	2.82E+01	5.18E+01
19	Pd-107	1.05E-03	4.60E-04	4.40E-04	9.58E-04	1.86E-03
20	Pu-238	1.62E+01	6.42E+00	7.29E+00	1.52E+01	2.84E+01
21	Pu-239	1.80E+01	7.13E+00	8.09E+00	1.69E+01	3.15E+01
22	Pu-240	1.79E+01	7.12E+00	8.08E+00	1.69E+01	3.14E+01
23	Pu-241	3.41E-01	1.36E-01	1.51E-01	3.22E-01	5.97E-01
24	Pu-242	1.67E+01	6.63E+00	7.52E+00	1.57E+01	2.93E+01
25	Ra-226	5.54E+00	2.20E+00	2.33E+00	5.33E+00	9.88E+00
26	Ra-228	4.83E+00	1.91E+00	2.04E+00	4.68E+00	8.61E+00
27	Se-79	8.96E-02	5.04E-02	3.70E-02	7.71E-02	1.79E-01
28	Sm-151	2.40E-03	9.90E-04	9.72E-04	2.27E-03	4.51E-03
29	Sn-126	1.85E-01	7.48E-02	9.26E-02	1.71E-01	3.33E-01
30	Tc-99	1.40E-02	5.11E-03	6.78E-03	1.37E-02	2.31E-02
31	Th-229	1.85E+01	7.39E+00	8.28E+00	1.74E+01	3.25E+01
32	Th-230	2.71E+00	1.08E+00	1.22E+00	2.55E+00	4.75E+00
33	Th-232	1.38E+01	5.48E+00	6.22E+00	1.30E+01	2.42E+01
34	U-233	1.55E+00	6.06E-01	6.79E-01	1.49E+00	2.71E+00
35	U-234	1.52E+00	5.95E-01	6.67E-01	1.46E+00	2.66E+00
36	U-235	1.42E+00	5.58E-01	6.26E-01	1.37E+00	2.50E+00
37	U-236	1.44E+00	5.64E-01	6.32E-01	1.38E+00	2.53E+00
38	U-238	1.41E+00	5.52E-01	6.13E-01	1.35E+00	2.47E+00
39	Zr-93	8.22E-03	3.27E-03	3.71E-03	7.75E-03	1.44E-02

Table 9-35. Preliminary Parametric Sensitivity Study Results for the Average Amargosa Valley Resident at Current Day Precipitation Levels.

Radionuclide	Parameter (only major contributors with partial coefficient > 0.2 given)	Rank Correlation Coefficient	
		Partial	Simple
^{99}Tc	Leaf Veg. Consumption Rate	0.87	0.73
	Drinking Water Consumption	0.77	0.51
	Crop Interception Fraction	0.29	0.12
	Root Veg. Consumption Rate	0.26	0.09
	Eggs Yield	0.20	0.10
^{129}I	Leaf Veg. Consumption Rate	0.62	0.51
	Beef Consumption Rate	0.52	0.37
	Drinking Water Consumption	0.46	0.33
	Milk Consumption Rate	0.26	0.17
	Crop Resuspension Factor	0.25	0.18
	Grain irrigation Rate	0.22	0.14
	Animal Uptake Scale Factor	0.20	0.15
^{237}Np	Leaf Veg. Consumption Rate	0.84	0.69
	Drinking Water Consumption	0.77	0.54
	Crop Interception Fraction	0.31	0.14
	Root Veg. Consumption Rate	0.23	0.08
	Eggs Yield	0.22	0.11

Table 9-36. Fractional Contribution to the predicted BDCFs by GENII-S Pathways for Some Important Radionuclides for the Average Amargosa Valley Resident.

	Radionuclide		
Pathway	**Tc-99**	**I-129**	**Np-237**
Drinking Water	5.7E-01	4.4E-01	6.4E-01
Leafy Vegetables	3.7E-01	2.1E-01	3.1E-01
Meat	1.7E-03	2.6E-01	1.0E-02
Fruit	2.1E-02	1.3E-02	2.0E-02
Cow's Milk	2.5E-03	6.0E-02	4.9E-05
Other Vegetables	1.8E-02	1.1E-02	1.7E-02
Eggs	1.8E-02	1.3E-02	1.3E-05
Cereals	1.3E-03	9.2E-04	1.4E-03
Soil Ingestion	7.0E-04	5.3E-04	1.1E-03
External Exposure	1.4E-06	3.0E-05	2.3E-04
Dirt Inhalation	1.3E-06	1.5E-07	6.6E-05