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1. PURPOSE

The purpose of this Analysis and Model Report (AMR) is to select and justify values for ingestion exposure pathway parameters used by the computer code GENII-S (SNL 1993). The GENII-S code is being used to estimate radionuclide-specific biosphere dose conversion factors. The Civilian Radioactive Waste Management System Management and Operating Contractor (CRWMS M&O) Performance Assessment Organization will use the biosphere dose conversion factors to calculate potential radiation dose to a hypothetical human receptor group as part of the post-closure Total System Performance Assessment.

The parameters evaluated in this analysis were selected in accordance with the Technical Product Development Plan (CRWMS M&O 1999a). The parameters are:

- Water source for terrestrial food, fresh feed, and stored feed.
- Drinking water treatment and drinking water holdup time (days of elapsed time between production and consumption).
- Crop interception fraction (fraction of deposited radioactive material that is retained on the plant).
- Fraction of the drinking water that is contaminated.
- Fraction of the water for animal consumption that is contaminated (for both beef and milk cows and for both poultry and laying hens).
- Fraction of the water that is contaminated for irrigating terrestrial food (vegetables, fruit, and grain for human consumption) and for fresh and stored feed (grain, hay, and forage for animal consumption).
- Irrigation time (number of months per year that irrigation is applied for a crop type) for leafy vegetables, other (root) vegetables, fruit, grain, poultry and laying hen feed, and beef and milk cow feed.
- Irrigation rate (annual number of inches of irrigation water applied for a crop type) for leafy vegetables, other (root) vegetables, fruit, grain, poultry and laying hen feed, and beef and milk cow feed.
- Aquatic food consideration (source of aquatic food).
- Yield for leafy vegetables, other (root) vegetables, fruit, grain, poultry and laying hen feed, and beef and milk cow feed.
- Growing time (number of days from planting to harvest per growing season for a crop type) for leafy vegetables, other (root) vegetables, fruit, grain, poultry and laying hen feed, and beef and milk cow feed.
- Holdup time (days of elapsed time between harvest and consumption for a crop or product type) for leafy vegetables, other (root) vegetables, fruit, grain, poultry, eggs, beef, and milk.
- Feed storage time for beef cows, milk cows, poultry, and laying hens.
- Dietary fraction (proportion of diet from locally produced feed) for beef cows, milk cows, poultry, and laying hens.

Two estimates for each parameter, where applicable, were developed in this analysis. First, a reasonable estimate of the distribution of each parameter was developed. Reasonable is defined as being reasonably expected to occur based on the guidance from the U.S. Department of

Energy (DOE) on the use of the proposed Nuclear Regulatory Commission (NRC) regulations (Dyer 1999, p. 1 of enclosure). "Reasonable" is operationally defined as a parameter value that would represent the greatest exposure to radioactive materials released from the repository that a hypothetical group of individuals could be reasonably expected to have. The second estimate for each parameter represents a single, high bounding value that could occur based on extreme behaviors or conditions that would result in a higher biosphere dose conversion factor. For those parameters with fixed distributions there is only one estimate.

This analysis was conducted according to AP-3.10Q (Revision 1), *Analyses and Models*, and an approved development plan (CRWMS M&O 1999a). The only constraints, caveats, or limitations common to the entire analysis are those described above for the reasonable set and the high bounding values.

All references cited in this AMR and listed in Section 8, other than those identified as inputs in Section 4.1, were included only to support or corroborate the assumptions, methods, and conclusions of the analysis.

2. QUALITY ASSURANCE

The analyses in this AMR have been determined to be Quality Affecting in accordance with CRWMS M&O procedure QAP-2-0, *Conduct of Activities*, because the information will be used to support Performance Assessment and other quality-affecting activities. Therefore, this AMR is subject to the requirements of the *Quality Assurance Requirements and Description* (QARD) document (DOE 1998).

Personnel performing work on this analysis were trained and qualified according to Office of Civilian Radioactive Waste Management (OCRWM) procedures AP-2.1Q, *Indoctrination and Training of Personnel*, and AP-2.2Q, *Establishment and Verification of Required Education and Experience of Personnel*. Preparation of this analysis did not require the classification of items in accordance with CRWMS M&O procedure QAP-2-3, *Classification of Permanent Items*. This analysis is not a field activity. Therefore, a *Determination of Importance Evaluation* in accordance with CRWMS M&O procedure NLP-2-0 was not required. The governing procedure for preparation of this AMR is OCRWM procedure AP-3.10Q, *Analyses and Models*.

3. COMPUTER SOFTWARE AND MODEL USAGE

No models were used or developed in this analysis. The only software used was an industry standard spreadsheet (Microsoft Excel). This spreadsheet was used as an aid in calculations; no routines, macros, or other applications were developed and used. Use of this software in this manner is exempt from the requirements in AP-SI.1Q, *Software Management*.

4. INPUTS

4.1 DATA

Data for each of the three inputs listed below are taken from CRWMS M&O (1999b), for which the DTN is MOL9903CLIMATOL.001.

1. **Average Monthly Temperature (°F)** (CRWMS M&O 1999b, parameter 595). Calculated from five years (1993–1997) of data collected at Yucca Mountain Site Characterization Project (YMP) Site 9. This site is at an elevation of 838 m (2,750 feet) (CRWMS M&O 1999c, Table 1-1 on p. 6), near the southwest corner of the Nevada Test Site and 3.1 km north of the proposed location of the critical group at the intersection of U.S. Route 95 and Nevada Route 373 (Dyer 1999, p. 19 of enclosure).

   These data were selected because they represent the best available data. They were collected under a YMP program that met the requirements of the QARD (DOE 1998) from a weather station in the vicinity of Yucca Mountain and the Amargosa Valley. The data are presented in CRWMS M&O (1999c, Table A-9 on p. A-10). For use in the Jensen-Haise equation (see Appendix A), temperatures were converted from the measured units of degrees celsius (°C) to degrees fahrenheit (°F) using the equation °F = (9/5 °C) + 32.

2. **Average Daily Incoming Solar Radiation Per Month (langleys/day)** (CRWMS M&O 1999b, parameter 594). Calculated from five years of data collected at YMP Site 9. These are the best available data. They were collected under a YMP program that met the requirements of the QARD (DOE 1998) and the weather station is in the vicinity of Yucca Mountain and the Amargosa Valley (Dyer 1999, p. 19 of enclosure). The data are presented in CRWMS M&O (1999c, Table A-9 on p. A-10). For the calculation of evapotranspiration (ET), the data were converted from the measured units of megajoules/m^2/day to langleys/day using the equation langleys/day = 23.89 (megajoules/m^2/day).

3. **Average Monthly Precipitation** (CRWMS M&O 1999b, parameter 553). Calculated from five years of data collected at YMP Site 9. These are the best available data. They were collected under a YMP program that met the requirements of the QARD (DOE 1998) and the weather station is in the vicinity of Yucca Mountain and the Amargosa Valley (Dyer 1999, p. 19 of enclosure). The data are presented in CRWMS M&O (1999c, Table A-9 on p. A-10).

4.2 CRITERIA

For this AMR, assumptions about the characteristics of the reference biosphere and the critical group were based on interim guidance from the DOE (Dyer 1999, p. 19 of enclosure) regarding interpretation of the proposed NRC regulations.

4.3 CODES AND STANDARDS

None.

5. ASSUMPTIONS

1. Groundwater is the only source of water for irrigation and for human and animal consumption. In accordance with DOE guidance (Dyer 1999), this assumption is based on firsthand observation of current climate conditions, irrigation infrastructure, and agricultural practices in the vicinity of Yucca Mountain, particularly in the Amargosa Valley. This is a reasonable, although conservative assumption, which does not need further confirmation.

2. Deep percolation equals 6 inches. Deep percolation is the amount of water that passes below the root zone. In mesic regions, deep percolation can result from precipitation or irrigation in excess of evapotranspiration that percolates beyond the root zone. In arid agricultural systems, deep percolation occurs intentionally during irrigation to leach salts (i.e., flush them below the root zone) that are deposited in the soil from irrigation water and that would decrease plant production. The most accurate way to measure deep percolation is to install underground lysimeters, which measure the amount of water that moves below the root zone (e.g., Devitt et al. 1992, pp. 717 through 723). Review of published literature and discussions with University of Nevada Cooperative Extension personnel indicated that no lysimeter measurements have been performed in the agricultural areas surrounding Yucca Mountain.

   In the absence of site specific data, a value of six inches was assumed for this analysis. This is a reasonable value, selected to be compatible with portions of the GENII-S code dealing with the depth of the rooting zone, the depth to which water would have to percolate to flush salts (Napier et al. 1988a, p. 4.58). The validity of this value for 12 crops was checked using the equation of Donahue et al. (1977, pp. 271 through 273), as shown in Appendix B. This equation uses information on salt content of irrigation water and salt tolerance of plants to determine the amount of water required to leach salts. Deep percolation requirements ranged form 1.32 to 6.47 inches/year and averaged 3.29 inches/year. Because 6 inches/year is within the range required by these crops, a deep percolation value of 6 inches is a reasonable assumption and does not require further confirmation.

3. Crop growing seasons for most crops are as defined in Mills et al. (n.d., pp. 7 and 8) and Hogan (1988, pp. 194 through 197). Mills et al. (n.d., pp. 7 and 8) report ranges of planting dates suggested by the University of Nevada, Reno, Cooperative Extension for fruits and vegetables in southern Nye County. This information was selected because it is specific to the area surrounding Yucca Mountain. For this analysis, the midpoint of the range was selected as the planting date (Table 1). Crops with two growing seasons (Mills et al. n.d., pp. 7 and 8) were assumed to be grown during both seasons. No site-specific information on length of growing season are available for most fruits and vegetables; therefore, information from a gardening guide for the Western United States (Hogan 1988, pp. 194 through 197) was used. This guide presents a range of days from planting to harvest. The midpoint of the range was used for this analysis (Table 1). Although the maximum length of growing season would result in more greater exposure, the midpoint was chosen because crops in southern Nevada are likely to grow and mature faster than in cooler regions of the western U.S. also considered in this guide. No site-specific, published information was available on growing season of barley and wheat, so a long season was selected for this cool-season crop (Table 1), based on a information provided by a Pahrump rancher (Hafen 1997). Although alfalfa may

not be irrigated in Amargosa while dormant during mid-November through mid-February (Hafen 1997, p. 1), it was assumed to grow and require water all year for this analysis. Because this assumption is based on the best available information that is specific to the site or region, no further confirmation is required. Growing season for grapes is as defined in Assumption 5.

4. Crop coefficients and growth stages are as defined in Doorenbos and Pruitt (1977, pp. 35 through 45). Crop coefficient is an expression of the evapotranspiration of a plant species relative to the potential evapotranspiration of a reference species. Crop coefficients are commonly used in calculations of evapotranspiration because field measurements of potential evapotranspiration for an area only are needed for one reference crop (Martin et al. 1991a, p. 201). Based on conversations with personnel from the University of Nevada Cooperative Extension, region-specific values for crop coefficients are not available. Therefore, values from Doorenbos and Pruitt (1977), which is an internationally accepted source of crop coefficients published by the Food and Agricultural Organization of the United Nations, were selected (Table 1). This document presents crop coefficients for a range of agricultural conditions, including arid conditions similar to those found at Yucca Mountain. A crop coefficient was not needed for alfalfa because the Jensen-Haise equation used to calculate reference evapotranspiration uses alfalfa as the reference crop.

   To calculate evapotranspiration from crop coefficients, the growing season of crops is divided into four periods (Doorenbos and Pruitt 1977, Figure 7 on p. 39). The first period is from planting until the crop has obtained about 10 percent ground cover. Based on Figure 6 of Doorenbos and Pruitt (1977, p. 38), a coefficient of 1.0 (i.e., equal to that of the reference crop) was chosen for this stage for all crops. This is reasonable, although conservative. The second stage is the crop development stage, when ground cover increases from about 10 percent to 70–80 percent. Crop coefficients are not given for this stage, but are calculated based on an assumption that there is a linear increase in water needs from the end of stage 1 until the beginning of stage 3 (Doorenbos and Pruitt 1977, p. 39). For this analysis, the midpoint between the value for stage 1 (1.0 for all crops) and the value for the beginning of stage 3 (Doorenbos and Pruitt 1977, Table 21 on pp. 40-41) was used. Stage 3 is the mid-season growth period, from attainment of effective ground cover to the onset of maturity. Coefficients for this stage were obtained from the column of Table 21 of Doorenbos and Pruitt (1977, pp. 40-41) for conditions of humidity less than 20 percent and winds of 5-8 m/second, which best match the conditions at Yucca Mountain and generally have the highest coefficients. Values for stage four (from late season to harvest) were calculated as the midpoint between stage 3 coefficients and the values at harvest in Doorenbos and Pruitt (1977, Table 21 on pp. 40-41). The crop coefficients used in this analysis are shown in Table 1.

   To calculate evapotranspiration, crop coefficients must be multiplied by the length of each stage and the reference evapotranspiration for that stage. Stage lengths (in days) for each crop were taken from Doorenbos and Pruitt (1997, Table 22 on pp. 42 to 44). Because the sum of these stage lengths did not always match the growing season length reported in Hogan (1988, pp. 194 through 197), the stage lengths were converted by calculating the proportion of the entire growing season represented by each stage (calculated as the value for a stage divided by sum of all four stages) and multiplying that by the length of growing season reported in Hogan (1988). For example, if Doorenbos and Pruitt (1977) reported 20, 20, 20, and 20 days for each stage, and Hogan (1988) reported a growing season of 40 days, the converted stage lengths were 10, 10, 10, and 10 days. Table 1 displays stage lengths from Doorenbos and Pruitt (1977) and the converted values used in this analysis.

The crop coefficients in Doorenbos and Pruitt (1977) were developed using a reference crop of cool-season grass, whereas the Jensen-Haise evapotranspiration equation used in this analysis is for a reference crop of alfalfa. Doorenbos and Pruitt (1977, Table 23 on p. 45) present data indicating that crop-coefficient values for alfalfa and grass are very similar and the University of California Cooperative Extension (UCCE) (1987, p. 6) stated that "Several agencies and researchers have recommended using ET_o [i.e., from grass] directly as a method to estimate alfalfa ET_c [i.e., crop coefficient for alfalfa]." Conversely, Martin et al. (1991a, p. 202) state that grass usually uses 10-15 percent less water than alfalfa; thus, using a grass-based coefficient with an alfalfa-based estimate of evapotranspiration may result in an 10-15 percent overestimate of water requirements. Therefore, these are reasonable values for this analysis.

5. Because there is no published information on the local growing season, crop coefficients, or irrigation requirements of grapes, an assumption was developed based on information provided by a farmer in Pahrump that grows grapes (Sanders 1997). Grapes bloom from late March to early April and are harvested at the end of August or early September. Most of the irrigation occurs during the period from bloom until harvest. For the purposes of this analysis, it is assumed that grapes are irrigated for the six month period from March 15 to September 15. Annual irrigation requirements are 2.5-acre-feet of water per year (30 inches per year). The yield of grapes in the region is 7 to 10 tons per acre. Because this assumption is based on a reasonable, yet conservative, interpretation of site-specific information, confirmation is not required.

6. Alfalfa is harvested six times per year, with the first cut on April 15 and the last cut on December 1. It is not harvested while dormant from December 2 through April 14. Based on this information, the length of time between harvests periods varied from a minimum of 46 days (number of days from April 15 to December 1 [230] divided by 5) and a maximum of 135 days (number of days from December 2 to April 15). This assumption is based on information provided from a rancher in Pahrump, who stated that alfalfa is harvested 6-7 times from about April 20 though mid-to-late November (Hafen 1997). The minimum number of cuttings suggested and a longer harvesting season were selected to ensure this assumption is reasonable. Because this assumption is a bounded, conservative interpretation of site-specific information, confirmation is not required.

Table 1. Planting Date, Crop Type, Growing Season Length, Crop Coefficients, and Stage Length of Selected Crops

Crop	Planting Date[a]	Growing Season Length[b]		Crop Coefficient[c]	Stage Length (days)	
		Days	Months		Original[d]	Converted[e]
Spinach, spring	16-Mar	45	1.5	1.0/1.025/1.05/1.025	20/20/15/5	15/15/11/4
Spinach, fall	15-Sep	45	1.5	1.0/1.025/1.05/1.025	20/30/40/10	9/14/18/5
Tomato	5-May	73	2.4	1.0/1.125/1.25/0.95	30/40/45/30	15/20/23/15
Cucumber	31-May	60	2.0	1.0/1.0/1.0/0.9	20/30/40/15	11/17/23/9
Peppers	5-May	70	2.3	1.0/1.05/1.1/1.0	30/35/40/20	17/20/22/11
Lettuce, spring	6-Mar	68	2.2	1.0/1.025/1.05/1.025	35/50/45/10	17/24/22/5
Lettuce, fall	30-Aug	68	2.2	1.0/.1.025/1.05/1.025	25/35/30/10	17/24/20/7
Beans, Snap	15-Apr	60	2.0	1.0/1.025/1.05/0.975	20/30/30/10	13/20/20/7
Peas, spring	6-Mar	65	2.1	1.0/1.1/1.2/1.15	20/25/35/15	14/17/24/10
Peas, fall	30-Aug	65	2.1	1.0/1.1/1.2/1.15	25/30/30/15	16/20/20/10
Corn, spring	30-Apr	75	2.5	1.0/1.1/1.2/1.15	20/30/30/10	17/25/25/8
Corn, summer	5-Jul	75	2.5	1.0/1.1/1.2/1.15	20/30/30/10	17/25/25/8
Carrots, spring	16-Mar	70	2.3	1.0/1.075/1.15/1.0	20/30/30/20	14/21/21/14
Carrots, fall	26-Aug	70	2.3	1.0/1.075/1.15/1.0	20/30/80/20	9/14/37/9
Potatoes	26-Mar	98	3.2	1.0/1.1/1.2/0.975	25/30/45/30	19/23/34/23
Melons	15-May	88	2.9	1.0/1.025/1.05/0.9	30/45/65/20	17/25/36/11
Grapes[f]	15-Mar	184	6.0	N/A	N/A	N/A
Alfalfa[g]	1-Feb	365	12.0	N/A	N/A	N/A
Wheat and Barley	15-Oct	244	8.0	1.0/1.1/1.2/0.7	15/25/50/30	31/51/102/61

NOTES: [a]Midpoint of range presented in Mills et al. (n.d., pp. 7–8).
[b]Midpoint of range in Hogan (1988, pp. 194-197). Number of months calculated as days divided by 30.5.
[c]Crop coefficient for four growth stages, from Doorenbos and Pruit (1977, pp. 35 through 45). See text for details of calculations.
[d]Length of four growth stages from Doorenbos and Pruitt (1977, Table 22 on pp. 42 to 44).
[e]Length of four growth stages, converted (and rounded) to match growing season length.
[f]Information on growing season of grapes from Sanders (1997). See Assumption 5.
[g]Evapotranspiration of alfalfa is equal to reference evapotranspiration.

6. ANALYSIS

6.1 IRRIGATION WATER SOURCE

Groundwater is the only source of irrigation water for the local production of terrestrial food, fresh feed, and stored feed. This is the case for all food crops produced in the vicinity of Yucca Mountain, including leafy vegetables, other (root) vegetables, fruit, and grain. It also is true for the locally produced fresh feed and stored feed crops (grain, hay, and forage) that would be consumed by beef and milk cows and the grain that would be consumed by poultry and laying hens.

The estimates for these parameters are based on firsthand observation of current climate, irrigation infrastructure, and agricultural practices in the vicinity of Yucca Mountain, particularly in the Amargosa Valley. Furthermore, they represent reasonable values for these parameters.

6.2 DRINKING WATER TREATMENT AND HOLDUP TIME

There is no treatment of local drinking water. While parts of the communities of Beatty and Pahrump have centralized water systems, most of the area surrounding Yucca Mountain is served only by private, individual wells, particularly in the Amargosa Valley. The dependence on individual wells and the lack of water storage and treatment facilities, also indicates that there is no holdup time for drinking water (i.e., it is assumed that there is no delay between pumping and consumption of the water and that domestic well water is not treated). These estimates represent reasonable values for these parameters.

6.3 FRACTION OF THE WATER THAT IS CONTAMINATED

Based on the guidance from DOE on the use of the proposed NRC regulations regarding the definition of the critical group (Dyer 1999, p. 19 of enclosure), it is assumed that 100 percent of the local groundwater available in the farming community in which the critical group resides is contaminated. Thus, for each of the following parameters, it is assumed that the fraction of the water that is contaminated is 1.0:

- Drinking water for human consumption
- Water for beef cow and milk cow consumption
- Water for poultry and laying hen consumption
- Irrigation water for terrestrial food (leafy and root vegetables, fruit, and grain for human consumption)
- Irrigation water for production of fresh and stored feed (grain, hay, and forage for consumption by beef and milk cows, poultry, and laying hens)

This assumption results in reasonable, yet conservative, estimates for the fractions of water for human and animal consumption and crop and feed production that are contaminated.

6.4 IRRIGATION TIME

Annual irrigation time is the number of months per year that irrigation is applied for a crop type. Annual irrigation time of each crop was calculated as the growing season length for the crop (determined as described in Assumption 2 of Section 5 and displayed in Table 1) multiplied by the number of growing seasons for that crop (Table 1). Annual irrigation time for each crop is listed in Table 2.

Table 2. Annual Evapotranspiration (ET), Precipitation During the Crop Growing Season(s), and Annual Irrigation of Selected Crops[a]

Crop	Crop Type	Growing Time (days)[b]	Irrigation Time (months)[c]	Annual ET (inches)[d]	Precipitation (inches)[e]	Annual Irrigation (inches)[f]
Spinach	Leafy Vegetable	45	3.0	22.92	0.75	28.17
Tomato	Leafy Vegetable	73	2.4	35.25	0.50	40.75
Cucumber	Leafy Vegetable	60	2.0	27.66	0.33	33.34
Peppers	Leafy Vegetable	70	2.3	31.74	0.50	37.24
Lettuce	Leafy Vegetable	68	4.5	38.52	1.22	43.29
Snap Beans	Leafy Vegetable	60	2.0	23.19	0.42	28.77
Peas	Leafy Vegetable	65	4.3	40.11	1.18	44.93
Corn	Leafy Vegetable; Cereal/Grain	75	4.9	75.15	0.78	80.37
Carrots	Root Vegetable	70	4.6	46.72	1.14	51.58
Potatoes	Root Vegetable	98	3.2	42.07	0.73	47.34
Melons	Fruit	88	2.9	39.82	0.44	45.37
Grapes[g]	Fruit	184	6.0	N/A	N/A	30.00
Alfalfa	Hay & Forage	46–135	12.0	92.69	4.03	94.66
Wheat/Barley	Cereal/Grain	244	8.0	53.25	3.40	55.85

NOTES: [a] Values are rounded to the nearest decimal indicated, but are calculated using more precise values from the original data sources.
[b]From growing season length in Table 1, except alfalfa, which is from Assumption 6.
[c]Calculated as growing season length in days (Table 1) X number of growing seasons (Table 1) divided by 30.5 days per month.
[d]From Table 3.
[e]Calculated as the sum of the proportion of days per month the crop was growing (Table 4) by the average precipitation that month (Table 3).
[f]Calculated as evapotranspiration minus precipitation plus 6 inches of deep percolation.
[g]Irrigation requirements of grapes from Sanders (1997). See Assumption 5.

Irrigation time was calculated for eight leafy vegetables (Table 2). Because more than two estimates were available, a triangular distribution was considered for this crop type. The minimum value is 2.0 months, the shortest irrigation time for this crop type (cucumbers and snap beans). The maximum value is 4.9 months, the longest irrigation time for this crop type (corn). A reasonable value is provided by the average of the eight crops, 3.2 months.

Because irrigation time could be calculated for only two crops for the crop types root vegetables (potatoes [3.2 months] and carrots [4.6 months]), fruits (melons [2.9 months]and grapes [6.0 months], and grain (corn [4.9 months] and wheat/barley [8.0 months]), the distribution for these crop types was considered to be uniform with a minimum value equal to the lower irrigation time for the two crops and the maximum equal to the higher irrigation time for the two crops.

Only one crop each was calculated for grain for poultry and laying hen feed and hay and forage for cattle, and the distribution of these types is therefore considered to be fixed. The grain for poultry and laying hen consumption is assumed to be corn and the poultry and eggs irrigation times are 4.9 months. Hay and forage for cattle is assumed to be alfalfa and the beef and milk irrigation times are 12.0 months.

6.5 IRRIGATION RATE

Irrigation rates were calculated for 13 fruits or vegetables representing 5 crop types (Table 2). In addition, irrigation rate for grapes was assumed to be 30 inches per year, based on information provided by a farmer in Pahrump (Sanders 1997 - see Assumption 5). Irrigation rate (IR, inches/year) was calculated using the equation:

$$IR = \sum_{m=1}^{12} ET_m - P + DP$$

where m = month, ET_m = total monthly evapotranspiration, P = annual precipitation, and DP = annual deep percolation. This equation is a reduction of the soil water balance equation in Martin et al. (1991a, p. 200), based on a steady-state condition (i.e., soil water at the beginning of the year equals that at the end of the year). This equation accounts for the water needs of the plant being irrigated (transpiration) and the major site-specific inputs (precipitation and deep percolation) and outputs (evaporation) of water.

Evapotranspiration for a plant species typically is calculated based on the evapotranspiration for a reference crop (i.e., reference evapotranspiration) at the location of interest multiplied by a coefficient specific to the species being considered (Martin et al. 1991a, pp. 201 through 204; UCCE 1987, pp. 1 through 12). For this analysis, reference evapotranspiration was calculated using the Jensen-Haise equation (Martin et al. 1991b, p. 334), as described and justified in Appendix A and summarized in Table 3. Total evapotranspiration for the reference crop of alfalfa was 92.69 inches per year. Barley and wheat have the same planting season and crop coefficients; therefore, they are shown together in all tables.

The start and end dates of the four growth stages (defined in Assumption 3) were calculated based on the planting dates and stage lengths in Table 1, and are shown in Table 4.

Crop evapotranspiration was calculated for each growth stage (ET_{GS}) using the equation:

$$ET_{GS} = Days \times ET_r \times K_C$$

where Days is the number of days in the growth stage for the crop (Table 1), ET_r is the daily reference evapotranspiration during the stage (Table 3), and K_c is the crop coefficient for that period for the crop (Table 1). For stages that occurred in more than one month, the highest monthly value was used unless fewer than 15 percent of the stage occurred during that month. Table 5 shows the values used to calculate evapotranspiration per growth stage for each of the thirteen crops.

Table 3. Average Monthly Precipitation, Temperature, and Solar Radiation at YMP Site 9, and Monthly Reference Evapotranspiration (ET_r) for a Reference Crop of Alfalfa[a]

Month	Average Monthly Precipitation (inches)[b]	Average Monthly Temperature		Average Daily Solar Radiation		ET_r (inches)[e]	
		°C[b]	°F[c]	$mj/m^2/day$[b]	langleys/day[d]	month	day[f]
January	0.92	7.1	44.8	9.5	227.0	2.04	0.066
February	0.67	9.6	49.3	13.9	332.1	3.09	0.110
March	0.46	13.6	56.5	19.4	463.5	5.73	0.185
April	0.12	16.7	62.1	24.6	587.7	7.95	0.265
May	0.22	22.1	71.8	27.5	657.0	11.02	0.356
June	0.30	27.4	81.3	29.9	714.3	13.49	0.450
July	0.02	31.0	87.8	29.4	702.4	15.02	0.485
August	0.01	30.5	86.9	27.0	645.0	13.63	0.440
September	0.36	25.4	77.7	22.6	539.9	9.66	0.322
October	0.21	17.7	63.9	17.4	415.7	6.03	0.194
November	0.28	10.6	51.1	11.9	284.3	2.98	0.099
December	0.46	6.9	44.4	9.6	229.3	2.04	0.066
Annual						**92.69**	

NOTES: [a]Values are rounded to the nearest decimal indicated, but are calculated using more precise values from the original data sources.
[b]CRWMS M&O 1999b.
[c] Converted as (9/5)°C+32.
[d] Converted as langleys/day = 23.89($megajoules/m^2/day$).
[e] See Appendix A for details about the calculation of reference evapotranspiration.
[f]Calculated as monthly evapotranspiration divided by number of days per month.

Total annual evapotranspiration was calculated by summing growth-stage evapotranspiration, and for crops with two planting seasons, by also summing evapotranspiration per season (Table 5).

The calculation used to determine irrigation rate requires information on precipitation during the growing season. This was calculated by summing the products of the proportion of each month during which a crop was growing (i.e., days per month crop was growing, from Table 4, divided by total days per month) by the average precipitation for that month (Table 1). Total precipitation during the growing season of each crop is shown in Table 2.

Table 4. First Day of Four Growth Stages of Selected Crops[a]

Crop	Planting Date	Begin Stage 2	Begin Stage 3	Begin Stage 4	Harvest
Spinach, spring	16-Mar	31-Mar	15-Apr	26-Apr	30-Apr
Spinach, fall	15-Sep	24-Sep	07-Oct	25-Oct	30-Oct
Tomato	05-May	20-May	09-Jun	02-Jul	17-Jul
Cucumber	31-May	11-Jun	28-Jun	21-Jul	30-Jul
Peppers	05-May	21-May	10-Jun	02-Jul	14-Jul
Lettuce, spring	06-Mar	23-Mar	16-Apr	08-May	13-May
Lettuce, fall	30-Aug	16-Sep	09-Oct	30-Oct	06-Nov
Snap Beans	15-Apr	28-Apr	18-May	07-Jun	14-Jun
Peas, spring	06-Mar	19-Mar	05-Apr	29-Apr	10-May
Peas, fall	30-Aug	15-Sep	04-Oct	24-Oct	03-Nov
Corn, spring	30-Apr	16-May	10-Jun	05-Jul	14-Jul
Corn, summer	05-Jul	22-Jul	16-Aug	10-Sep	18-Sep
Carrots, spring	16-Mar	30-Mar	20-Apr	11-May	25-May
Carrots, fall	26-Aug	04-Sep	18-Sep	25-Oct	04-Nov
Potatoes	26-Mar	13-Apr	06-May	09-Jun	02-Jul
Melons	15-May	01-Jun	25-Jun	31-Jul	11-Aug
Wheat and Barley	15-Oct	14-Nov	04-Jan	15-Apr	15-Jun

NOTE: [a] See Table 1 for information on stage lengths.

Irrigation rate (inches per year) for each crop was calculated as annual evapotranspiration minus precipitation plus deep percolation (Table 2). Deep percolation was assumed to be 6 inches for all crops.

Irrigation rate was calculated for eight leafy vegetables (Table 2). Because more than two estimates were available, a triangular distribution was considered for this crop type. The minimum value is 28.17 inches/year, the shortest irrigation time for this crop type (spinach). The maximum value is 80.37 inches/year, the longest irrigation time for this crop type (corn). A reasonable value is provided by the average of the eight crops, 42.11 inches/year.

Because irrigation rate could be calculated for only two crops for the crop types root vegetables (potatoes [47.34 inches/year] and carrots [51.58 inches/year]), fruits (grapes [30.0 inches/year] and melons [45.37 inches/year]), and grain (wheat/barley [55.85 inches/year] and corn [80.37 inches/year]), the distribution for these crop types was considered to be uniform with a minimum value equal to the lower irrigation time for the two crops and the maximum equal to the higher irrigation time for the two crops.

Only one crop each was calculated for grain for poultry and laying hen feed and hay and forage for cattle, and the distribution of these types is, therefore, considered to be fixed. The grain for poultry and laying hen consumption is assumed to be corn and the poultry and eggs irrigation rate is 80.37 inches/year. Hay and forage for beef and milk cows is assumed to be alfalfa and the beef and milk irrigation rate is 94.66 inches/year.

Table 5. Evapotranspiration per Growth Stage (ET_{GS}, inches) and Total Evapotranspiration (ET_c, inches) for Selected Crops[a]

	Stage 1				Stage 2				Stage 3				Stage 4				
Crop	Days[b]	ET_r[c]	K_c[d]	ET_c[e]	Days	ET_r	K_c	ET_c	Days	ET_r	K_c	ET_c	Days	ET_r	K_c	ET_c	Total ET[f]
Spinach, spring	15	0.185	1	2.77	15	0.265	1.025	4.07	11	0.265	1.05	3.13	4	0.265	1.025	1.02	11.00
Spinach, fall	9	0.322	1	2.90	14	0.322	1.025	4.45	18	0.194	1.05	3.67	5	0.194	1.025	0.90	11.92
Spinach, total																	**22.92**
Tomato	15	0.356	1	5.37	20	0.450	1.125	10.19	23	0.450	1.25	12.74	15	0.485	0.95	6.95	**35.25**
Cucumber	11	0.450	1	5.14	17	0.450	1	7.71	23	0.485	1	11.07	9	0.485	0.9	3.74	**27.66**
Peppers	17	0.356	1	5.97	20	0.450	1.05	9.26	22	0.450	1.1	11.08	11	0.485	1	5.43	**31.74**
Lettuce, spring	17	0.185	1	3.14	24	0.265	1.025	6.60	22	0.356	1.05	8.16	5	0.356	1.025	1.77	19.67
Lettuce, fall	17	0.322	1	5.47	24	0.322	1.025	7.85	20	0.194	1.05	4.16	7	0.194	1.025	1.35	18.85
Lettuce, total																	**38.52**
Snap Beans	13	0.265	1	3.53	20	0.356	1.025	7.29	20	0.450	1.05	9.45	7	0.450	0.975	2.92	**23.19**
Peas, spring	14	0.185	1	2.53	17	0.265	1.1	4.99	24	0.265	1.2	7.62	10	0.356	1.15	4.20	19.33
Peas, fall	16	0.440	1	7.14	20	0.322	1.1	6.91	20	0.194	1.2	4.55	10	0.194	1.15	2.18	20.78
Peas, total																	**40.11**
Corn, spring	17	0.356	1	5.93	25	0.450	1.1	12.37	25	0.485	1.2	14.54	8	0.485	1.15	4.64	37.47
Corn, summer	17	0.485	1	8.08	25	0.485	1.1	13.32	25	0.440	1.2	13.19	8	0.322	1.15	3.09	37.67
Corn, total																	**75.15**
Carrots, spring	14	0.185	1	2.59	21	0.265	1.075	5.98	21	0.356	1.15	8.59	14	0.356	1	4.98	22.14
Carrots, fall	9	0.440	1	4.10	14	0.322	1.075	4.85	37	0.322	1.15	13.82	9	0.194	1	1.81	24.58
Carrots, total																	**46.72**
Potatoes	19	0.265	1	4.99	23	0.356	1.1	8.84	34	0.450	1.2	18.31	23	0.450	0.975	9.92	**42.07**
Melons	17	0.356	1	5.87	25	0.450	1.025	11.41	36	0.485	1.05	18.19	11	0.440	0.9	4.35	**39.82**
Wheat/Barley	31	0.194	1	5.93	51	0.099	1.1	5.55	102	0.185	1.2	22.57	61	0.450	0.7	19.21	**53.25**

NOTES: [a]Values are rounded to the nearest decimal indicated, but are calculated using more precise values from the original data sources.
[b]Days per growth stage (Table 1, unrounded converted stage length column).
[c]Daily reference evapotranspiration (inches) per growth stage (Table 3). For stages occurring in more than one month (see Table 4), the month with the highest value was selected, unless less than 15 percent of the stage occurred during that month.
[d]Crop coefficient per stage (Table 1).
[e]Crop evapotranspiration per stage (inches), calculated as unrounded Days x ET_r x K_c.
[f]Total evapotranspiration (inches) for a crop during a growing season, calculated as the sum of evapotranspiration per stage.

6.6 AQUATIC FOOD CONSIDERATION

The average member of the critical group is assumed to ingest locally produced aquatic food of freshwater origin only. The farming community in which the critical group resides is located in the desert far from the nearest ocean. A freshwater fish pond is assumed to be located close to the critical group because one is located in the Amargosa Valley (TRW 1998, pp. 1-2 and 3-14), the area where it is assumed that the critical group will be located (Dyer 1999, p. 19 of enclosure).

6.7 YIELD

To the extent possible, estimates of crop yields were based on local, site-specific information (for Nye County or southern Nevada). Such information was not available for home garden crops such as peas, tomatoes, and beans. Therefore, rather than use commercial production figures from other states, the estimated yields for leafy vegetables and some root vegetables provided by the Park Seed Company (1997) as shown in Table 6 were used.

The effective yield estimate for leafy vegetables is based on home-garden production because production of leafy vegetables within the 80 km circle is assumed to be entirely home-scale or small-commercial-scale production. The leafy vegetable yield estimate is based on the minimum yield shown in Table 6 (0.59 kg/m^2 for peas and corn), the maximum yield shown (4.11 kg/m^2 for tomatoes), and the average yield (1.82 kg/m^2) of the eight leafy vegetables considered, with pole beans and bush beans considered as a single crop to avoid unnecessarily influencing the average.

The estimated effective yield for other (root) vegetables is based on Nevada commercial yields of garlic, onions, potatoes, and potential home-garden yields of carrots, beets, and turnips. Much of the production of root vegetables within the 80-km circle may be in home gardens, for which we know little about crop mix and production. The yields of the two important commercial root crops (onions and garlic) span a wide range, which encompasses the yields of many other crops. Because there are few commercial producers, the mix of commercial crops (and therefore the effective yield) could change greatly if new producers enter the market or existing ones add or drop crops. Under such a dynamic situation, in which we are uncertain about the effective yield, establishing a range by the minimum and maximum yields is a reasonable expedient.

Garlic currently is produced commercially within the vicinity of Yucca Mountain (TRW 1998, p. 3-14). Other root vegetables such as onions, carrots, beets, potatoes, and turnips are assumed to be produced in home gardens. The estimated effective yield for root crops is derived from the range in estimated yields for three commercial crops; garlic with a yield of 1.73 kg/m^2, onions 5.17 kg/m^2, and potatoes 4.10 kg/m^2. For these commercial crops, published 1995 Nevada yields, which are typical of yields in Nevada for recent years, were used (NASS 1996, p. 25). Carrots, beets, and turnips also were considered as representative home-garden root crops as shown in Table 6. The lowest yield of any crop listed (garlic at 1.73 kg/m^2) and the highest yield of any crop listed (beets at 5.87 kg/m^2) establish the minimum and maximum estimated yields. A reasonable value (4.33 kg/m^2) is provided by the arithmetic average of the six root vegetables considered.

Table 6. Crop Yield[a] for Selected Crops and Crop Types[d]

Crop	Crop Type	Yield (pounds per 25 foot row)	Space Between Rows (inches)	Minimum Yield (kg/m^2)	Maximum Yield (kg/m^2)	Average Yield (kg/m^2)
Spinach	Leafy Vegetable	14	15	2.19	2.19	2.19
Tomato	Leafy Vegetable	37 to 63	36	2.41	4.11	3.26
Cucumber	Leafy Vegetable	30	48	1.47	1.47	1.47
Peppers	Leafy Vegetable	15	24	1.47	1.47	1.47
Lettuce	Leafy Vegetable	12	12	2.35	2.35	2.35
Pole Beans[b]	Leafy Vegetable	30 to 40	36	1.96	2.61	2.28
Bush Beans[b]	Leafy Vegetable	20 to 30	24	1.96	2.94	2.45
Peas	Leafy Vegetable	6 to 10	24	0.59	0.98	0.78
Corn[c]	Leafy Vegetable; Cereal/Grain	7.5 to 10	30	0.59	0.78	0.68
Carrots	Root Vegetable	20 to 25	12	3.91	4.89	4.40
Beets	Root Vegetable	25 to 30	12	4.89	5.87	5.38
Turnips	Root Vegetable	25 to 28	12	4.89	5.48	5.19

NOTES: [a]Values for crop yields and space between rows are from the Park Seed Company (1997).
[b]The yields for pole beans and bush beans were averaged to produce one value for the leafy vegetable yield calculation.
[c]The reported yield for corn is 30 to 40 ears per 25 foot row, which was converted to 7.5 to 10 pounds assuming 4 ounces of edible corn per ear.
[d]Pounds per acre of yield were converted to kilograms per square meter (kg/m^2) using 2.20 pounds per kilogram and 4,047 square meters per acre. Values are rounded to the nearest decimal indicated, but are calculated using more precise values from the original data sources.

Two fruits known to grow in southern Nevada are melons and grapes. The yield for melons, 1.89 kg/m^2 (8.4 tons/acre), was obtained from the Bureau of the Census (1990, p. 664). The yield for grapes was estimated by an orchard owner (Sanders 1997) to be from 7 to 10 tons per acre (1.57 to 2.25 kg/m^2). The estimated yield for grapes establishes a range that encompasses the estimate for melons. Therefore, the range of yield estimate for grapes were taken as the minimum and maximum input values.

The estimated effective yields for grain for human and animal consumption are based primarily on commercial wheat and barley yields in southern Nevada and on the yield for corn. The effective yield for grain is based on barley and spring wheat production in southern Nevada in 1993-1994 (bulk density of barley is assumed to be the same as for wheat, 27 kg per bushel [Bureau of the Census 1990, p. 662]) and on the yield for corn shown in Table 6. The estimates of spring wheat and barley yields for the two year period range from 50 to 100 bushels per acre (NASS 1995, pp. 17 and 18), which is converted to 0.33 to 0.67 kg/m^2. Therefore, the minimum estimated yield for grain is spring wheat at 0.33 kg/m^2 and the maximum estimated yield is for corn at 0.78 kg/m^2. The minimum and maximum values establish the range for the uniform distribution.

The feed for consumption by poultry and laying hens is assumed to be corn. The estimated effective yield for corn is shown in Table 6 with a minimum of 0.59 kg/m^2 and a maximum of 0.78 kg/m^2. The minimum and maximum values establish the range for the uniform distribution.

The estimated effective yield for hay and forage for beef cattle and milk cows is based on alfalfa and "other hay" production and acreage in Nye County from 1993-1995. Annual alfalfa production in Nye County ranged from 4.4 to 5.1 tons per acre (0.99 to 1.15 kg/m^2) during that three year period (NASS 1995, p. 20 and NASS 1996, p. 22). During the same period production of other hay ranged from 1.1 to 1.5 tons per acre (0.25 to 0.34 kg/m^2) (NASS 1995, p. 20 and NASS 1996, p. 22). The minimum (0.25 kg/m^2) and maximum (1.15 kg/m^2) estimated yields for alfalfa and other hay establish the range for the uniform distribution.

6.8 GROWING TIME

Growing time is the number of days from planting to harvest per growing season. Growing time for most crops was determined as described in Assumption 2 of Section 5 and is displayed in Table 1 as growing season length. Growing time for alfalfa was determined based on Assumption 6.

Growing time was determined for eight leafy vegetables (Table 1). Because more than two estimates were available, a triangular distribution was considered for this crop type. The minimum value is 45 days, the shortest growing season length for this crop type (spinach). The maximum value is 75 days, the longest growing season length for this crop type (corn). A reasonable value is provided by the average of the eight crops, 64.5 days.

Because growing time (Table 1) could be calculated for only two crops for the crop types root vegetables (carrots [70 days] and potatoes [98 days]), fruits (melons [88 days] and grapes [184 days], and grain (corn [75 days] and wheat/barley [244 days]), the distribution for these crop types was considered to be uniform with a minimum value equal to the lower growing season length for the two crops and the maximum equal to the higher growing season length for the two crops. The grain for poultry and laying hen consumption is assumed to be corn and the poultry and eggs growing times is considered to be a fixed value of 75 days.

Hay and forage for cattle is assumed to be alfalfa. A triangular distribution best matches the cutting schedule defined in Assumption 6 (5 cuttings an average of 46 days apart and one cutting after a 135-day winter dormancy period). The beef and milk irrigation times therefore have a triangular distribution with a minimum of 46 days, a maximum of 135 days, and a reasonable estimate of 47 days (1 day more than the minimum is needed to accommodate a triangular distribution).

6.9 HOLDUP TIME

Holdup times represent the number of days between the harvest of a particular crop or product and its consumption by humans. The holdup times reported here are values taken from NUREG/CR-5512 (PNL 1992, pp. 6.21 and 6.23). The holdup time for leafy vegetables, poultry, eggs, and milk is 1 day. The holdup time for other (root) vegetables, fruit, and grain (for human consumption) is 14 days. The holdup time for beef is 20 days.

These estimates represent fixed distributions. Holdup times between harvest and consumption allow for radioactive decay to reduce the dose to the consumer. Because the source of radioactive contamination from a potential repository is aged spent nuclear fuel and aged reprocessing wastes, the decay half-lives are very long compared to the holdup times. Therefore, holdup times are not critical for the present analysis and fixed generic values are appropriate.

6.10 FEED STORAGE TIME

Feed storage times represent the number of days between harvest of a particular crop and its consumption by animals. The storage times reported here are values taken from NRC Regulatory Guide 1.109 (NRC 1976, pp. 32 and 69) and represent fixed distributions. The storage time for stored feed for consumption by poultry and laying hens is 14 days and is based on the recommended value for grain for human consumption, which was generalized to include grain for consumption by animals. The storage time for stored feed for beef and milk cows is 90 days, the recommended value for "ingestion of forage by animals."

Feed storage times between harvest and consumption allow for radioactive decay to reduce the dose to the animal consuming the feed. Because the source of radioactive contamination from a potential repository is aged spent nuclear fuel and aged reprocessing wastes, the decay half-lives are very long compared to the feed storage times. Therefore, feed storage times are not critical for the present analysis and fixed generic values are appropriate.

6.11 DIETARY FRACTION

The dietary fraction for poultry and laying hens is the proportion of stored feed that is locally produced (versus imported feed). For this analysis it is assumed that the diet for poultry and laying hens consists entirely of locally produced stored feed. These estimates represent reasonable values for these parameters.

The dietary fraction for beef and milk cows represents the proportions of fresh forage, locally produced stored feed, and imported stored feed. For this analysis it is assumed that the diet for beef and milk cows consists entirely of fresh forage. These estimates represent locally relevant, reasonable values for the parameters. Milk cows at the dairy in Amargosa Valley are fed locally produced and imported stored feed (Horak and Carns 1997, p. 12). Local production of stored feed (mainly alfalfa) serves the commercial dairy, which provides a ready market for the product (Horak and Carns 1997, p. 12). If large-scale production is ignored because the milk is not consumed locally, what remains are family milk cows. It is assumed that, like beef cattle, the diet for milk cows consists entirely of fresh forage, which is a reasonable, although conservative assumption.

6.12 CROP INTERCEPTION FRACTION

The crop interception fraction (r) is the fraction of deposited radioactive material, either by dry or wet deposition processes, that is retained on the plant, with the remainder reaching the ground. In the vicinity of Yucca Mountain, irrigation is the only applicable deposition process. The value of r was estimated using an experimentally determined equation (Hoffman et al. 1989, p. 26):

$$r = K_1 Y^{K2} P^{K3} I^{K4}$$

which relates r to crop yield (Y), depth of irrigation (P), and irrigation intensity (I). The constants in the equation (for Beryllium) are as follows: $K_1 = 2.29$, $K_2 = 0.695$, $K_3 = -0.29$, $K_4 = -0.341$. Similar constants in the equation for Iodine are: $K_1 = 1.54$, $K_2 = 0.697$, $K_3 = -0.909$, $K_4 = -0.049$. Site specific values of Y, P, and I were used to calculate the crop interception fraction. The fraction of the total deposition that resides on vegetation is the interception fraction, r, such that $0<r<1.0$. The mean, minimum, and midpoint values of each parameter (crop yield, depth of irrigation, and irrigation intensity) in the equation for r were determined from site specific values for both forage crops and leafy vegetables. The minimum and maximum for each variable were assumed to represent the lower and upper limits of 90% confidence interval of a normal distribution. A detailed explanation of the method used to estimate crop interception fraction is shown in Appendix C.

(1) Crop Type

In both the GENII-S model (SNL 1993, pp. I and 1-1) and its precursor, GENII (Napier et al. 1988a, 1988b), when the interception fraction is used to calculate the concentration of radionuclides in the plant at the time of consumption, the value of r is multiplied by the translocation factor (Napier et al. 1988a, p. 4.67). The translocation factor is the fraction of activity deposited on plant surfaces that reaches the edible parts of the plant. In GENII-S, the translocation factor is set equal to 1 for leafy vegetables and forage crops (Napier et al. 1988a, p. 4.67). For all other vegetation, such as root crops, fruits, cereal, and grain, the translocation is set equal to 0.1 (Napier et al. 1988a, p. 4.67). Therefore the estimate of r focused on leafy vegetables and forage crops and did not consider other vegetation types.

(2) Crop Yield (dry kg/m^2)

The more plant material above ground, the higher the crop interception fraction. For application to the interception fraction calculation, the dry yield for leafy vegetables was calculated using the two plants for which most of the plant is edible, spinach and lettuce. The wet yield is estimated to be 2.192 kg/m^2 for spinach and 2.348 kg/m^2 for lettuce (see Table 6). The dry yield is assumed to be 8.0 percent of the wet yield (IAEA 1994, p. 15) or 0.175 kg/m^2 for spinach and 0.188 kg/m^2 for lettuce. Therefore, for leafy vegetables the minimum yield is 0.175 kg/m^2 , the maximum yield is 0.188 kg/m^2 , and the midpoint is 0.182 kg/m^2.

For forage crops, the estimated effective yield for hay and forage for beef cattle and milk cows is based on alfalfa and other-hay production and acreage in Nye County from 1993-1995. Annual alfalfa production in Nye County ranged from 4.4 to 5.1 tons per acre (0.988 to 1.146 kg/m^2) during that three year period (NASS 1995, p. 20 and NASS 1996, p. 22). During the same period production of other hay ranged from 1.1 to 1.5 tons per acre (0.247 to 0.337 kg/m^2) (NASS 1995, p. 20 and NASS 1996, p. 22). For the interception fraction calculation, it is assumed that the average weight of tons per acre of alfalfa and other hay (NASS 1995, 1996) is dry weight. Also, it is assumed that alfalfa is cut six times a year and that other hay is cut only once per year (Hafen 1997). The interception fraction calculation for alfalfa needs to be based on a single cutting rather than a yearly yield. The low and high average yield per year for alfalfa divided by six results in an estimated range of 0.165 to 0.191 kg/m^2 per cutting. Therefore, for forage crops the minimum yield is 0.165 kg/m^2 (alfalfa), the maximum yield is 0.337 kg/m^2 (other hay), and the midpoint is 0.251 kg/m^2.

These yields represent the quantity of plant mass per area at harvest time. Earlier in the growing season there would be less plant mass per area. Using the plant mass per area at harvest time, rather than an average value over the growing season results in a reasonable, although conservative estimate.

(3) Irrigation Depth at Each Application

If a very light misting of water is applied to plants, it is conceivable that all of the water, hence all of the radionuclides in the water, would adhere to the plants and r would equal 1. But in the case of the biosphere modeling, light misting is not expected, since all of the water that contains radionuclides will come during irrigation.

The minimum depth of irrigation at each application is estimated by assuming that the plants are irrigated once every day during the entire growing period. The maximum depth of irrigation is estimated by assuming irrigation occurs once every three days or three times the minimum. The growing periods are found in Table 1 and annual irrigation is found in Table 2. For leafy vegetables the minimum depth is 8.03 mm, the maximum depth is 24.49 mm, and the midpoint is 16.26 mm (see Appendix C). For forage crops the minimum depth is 6.65 mm, the maximum depth is 19.95 mm, and the midpoint is 13.30 mm (see Appendix C).

(4) Irrigation Intensity

The irrigation application rate must be less than or equal to the intake rate of the soil to prevent runoff. Sandy loam soil has an average intake rate of 2.5 cm/hr, with a range of 1.5 to 7.5 cm/hr (Doorenbos and Pruitt 1977, p. 91). The application rates of common sprinkler sizes range from 0.4 to 1.4 cm/hr (Doorenbos and Pruitt, 1977,p. 94). Combining the above information, the irrigation intensity was estimated to range from 0.4 to 7.5 cm/hr, with a midpoint of 3.95 cm/hr.

(5) Radionuclides Present

Values of interception ratio are likely to be higher for cations (positive ions) than anions, which is consistent with a negative charge of leaf surfaces (Hoffman et al. 1989, p. 60). Cations accumulate on leaf surfaces; whereas, the quantity of anion deposition is limited by the plant's water holding capacity (Hoffman et al. 1992, p. 3321).

(6) Irrigation Method

In drip, furrow, or flood irrigation, the crop interception fraction would be zero because the water is applied directly to the ground, with very little of the water intercepted by the leaves of the plants. The maximum value of crop interception fraction would occur if all of the irrigation water is applied through sprinklers. To be reasonable, yet conservative, all water was assumed to be applied by sprinklers. Using the site specific values for crop yield, irrigation depth, and irrigation intensity for both forage crops and leafy vegetables, the crop interception fractions for iodine and beryllium were calculated.

In developing crop interception fractions under the sprinkler method of irrigation, Hoffman et al. (1989, p. 26) develop such fractions for beryllium and iodine on forage crops. Appendix C shows the results of this analysis and extends it. The estimated crop interception value for iodine on forage crops is 0.052 and the value for beryllium is 0.259 (see Appendix C). The value of crop interception fraction for forage crops rather than leafy vegetables and for beryllium rather than iodine is preferred since it is the highest and represents a reasonable, yet conservative, estimate. Therefore, a reasonable estimate of the crop interception fraction is 0.259 and, assuming a normal distribution, the minimum value is 0.044 and the maximum value is 0.474 (see Appendix C).

7. CONCLUSIONS

Both sets of parameters, the reasonable set and the high bounding set are found in Table 7. In this table, the "Reasonable Estimate" provides the reasonable set, while the "Maximum" provides the high bounding set for all pathways except irrigation times and yields, for which the "minimum" provides the high bounding set. For many parameters the "reasonable estimate" can be considered to be an arithmetic average. These parameters include: irrigation time (average number of months per year), irrigation rate (average number of inches per year), yield (kilograms per square meter), growing time (average number of days), holdup (average number of days), storage time (average number of days), and dietary fraction (average fraction that is local). It is recommended that the high bounding parameters be considered as fixed values.

Table 7. Ingestion Exposure Pathway Parameters

Parameter	Distribution	Reasonable Estimate	Minimum	Maximum	Other
Terrestrial Food Irrigation Water Source	n/a	n/a	n/a	n/a	Local
Fresh Feed Irrigation Water Source	n/a	n/a	n/a	n/a	Local
Stored Feed Irrigation Water Source	n/a	n/a	n/a	n/a	Local
Drinking Water Treatment	n/a	n/a	n/a	n/a	None
Drinking Water Holdup Time	n/a	n/a	n/a	n/a	None
Crop Interception Fraction	Normal	0.259	0.044	0.474	n/a
Drinking Water Contaminated (Fraction)	Fixed	1.0	1.0	1.0	n/a
Beef Water Contaminated (Fraction)	Fixed	1.0	1.0	1.0	n/a
Poultry Water Contaminated (Fraction)	Fixed	1.0	1.0	1.0	n/a
Milk Water Contaminated (Fraction)	Fixed	1.0	1.0	1.0	n/a
Eggs Water Contaminated (Fraction)	Fixed	1.0	1.0	1.0	n/a
Terrestrial Food Irrigation Water Contamination (Fraction)	Fixed	1.0	1.0	1.0	n/a
Fresh Feed Irrigation Water Contamination (Fraction)	Fixed	1.0	1.0	1.0	n/a
Stored Feed Irrigation Water Contamination (Fraction)	Fixed	1.0	1.0	1.0	n/a
Leafy Vegetables Irrigation Time	Triangular	3.2 Mo	2.0 Mo	4.9 Mo	n/a
Other (Root) Vegetables Irrigation Time	Uniform	n/a	3.2 Mo	4.6 Mo	n/a
Fruit Irrigation Time	Uniform	n/a	2.9 Mo	6.0 Mo	n/a
Grain Irrigation Time	Uniform	n/a	4.9 Mo	8.0 Mo	n/a
Poultry (corn) Irrigation Time	Fixed	4.9 Mo	4.9 Mo	4.9 Mo	n/a
Eggs (corn) Irrigation Time	Fixed	4.9 Mo	4.9 Mo	4.9 Mo	n/a
Beef (alfalfa) Irrigation Time	Fixed	12.0 Mo	12.0 Mo	12.0 Mo	n/a
Milk (alfalfa) Irrigation Time	Fixed	12.0 Mo	12.0 Mo	12.0 Mo	n/a
Leafy Vegetables Irrigation Rate	Triangular	42.11 In	28.17 In	80.37 In	n/a
Other (Root)Vegetables Irrigation Rate	Uniform	n/a	47.34 In	51.58 In	n/a
Fruit Irrigation Rate	Uniform	n/a	30.00 In	45.37 In	n/a
Grain Irrigation Rate	Uniform	n/a	55.85 In	80.37 In	n/a
Poultry (corn) Irrigation Rate	Fixed	80.37 In	80.37 In	80.37 In	n/a
Eggs (corn) Irrigation Rate	Fixed	80.37 In	80.37 In	80.37 In	n/a
Beef (alfalfa) Irrigation Rate	Fixed	94.66 In	94.66 In	94.66 In	n/a

Parameter	Distribution	Reasonable Estimate	Minimum	Maximum	Other
Milk (alfalfa) Irrigation Rate	Fixed	94.66 In	94.66 In	94.66 In	n/a
Aquatic Food Consideration	n/a	n/a	n/a	n/a	Yes
Leafy Vegetables Yield	Triangular	1.82 kg/m^2	0.59 kg/m^2	4.11 kg/m^2	n/a
Other (Root) Vegetables Yield	Triangular	4.33 kg/m^2	1.73 kg/m^2	5.87 kg/m^2	n/a
Fruit Yield	Uniform	n/a	1.57 kg/m^2	2.25 kg/m^2	n/a
Grain Yield	Uniform	n/a	0.33 kg/m^2	0.78 kg/m^2	n/a
Poultry (corn) Yield	Uniform	n/a	0.59 kg/m^2	0.78 kg/m^2	n/a
Eggs (corn) Yield	Uniform	n/a	0.59 kg/m^2	0.78 kg/m^2	n/a
Beef (alfalfa and other hay) Yield	Uniform	n/a	0.25 kg/m^2	1.15 kg/m^2	n/a
Milk (alfalfa and other hay) Yield	Uniform	n/a	0.25 kg/m^2	1.15 kg/m^2	n/a
Leafy Vegetables Grow Time	Triangular	64.5 Days	45 Days	75 Days	n/a
Other (Root) Vegetables Grow Time	Uniform	n/a	70 Days	98 Days	n/a
Fruit Grow Time	Uniform	n/a	88 Days	184 Days	n/a
Grain Grow Time	Uniform	n/a	75 Days	244 Days	n/a
Poultry (corn) Grow Time	Fixed	75 Days	75 Days	75 Days	n/a
Eggs (corn) Grow Time	Fixed	75 Days	75 Days	75 Days	n/a
Beef (alfalfa) Grow Time	Triangular	47 Days	46 Days	135 Days	n/a
Milk (alfalfa) Grow Time	Triangular	47 Days	46 Days	135 Days	n/a
Leafy Vegetables Holdup	Fixed	1 Day	1 Day	1 Day	n/a
Other (Root) Vegetables Holdup	Fixed	14 Days	14 Days	14 Days	n/a
Fruit Holdup	Fixed	14 Days	14 Days	14 Days	n/a
Grain Holdup	Fixed	14 Days	14 Days	14 Days	n/a
Poultry Holdup	Fixed	1 Day	1 Day	1 Day	n/a
Eggs Holdup	Fixed	1 Day	1 Day	1 Day	n/a
Beef Holdup	Fixed	20 Days	20 Days	20 Days	n/a
Milk Holdup	Fixed	1 Day	1 Day	1 Day	n/a
Poultry - Feed Storage Time	Fixed	14 Days	14 Days	14 Days	n/a
Eggs - Feed Storage Time	Fixed	14 Days	14 Days	14 Days	n/a
Beef - Feed Storage Time	Fixed	90 Days	90 Days	90 Days	n/a
Milk - Feed Storage Time	Fixed	90 Days	90 Days	90 Days	n/a
Poultry - Dietary Fraction	Fixed	1	1	1	Stored
Eggs - Dietary Fraction	Fixed	1	1	1	Stored
Beef - Dietary Fraction	Fixed	1	1	1	Fresh
Milk - Dietary Fraction	Fixed	1	1	1	Fresh

n/a = not applicable

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APPENDIX A

CALCULATION OF REFERENCE EVAPOTRANSPIRATION (ET_R) AND JUSTIFICATION OF THE SELECTED EQUATION

APPENDIX A. CALCULATION OF REFERENCE EVAPOTRANSPIRATION (ET_R) AND JUSTIFICATION OF THE SELECTED EQUATION

Calculation

Monthly reference evapotranspiration was calculated using the Jensen-Haise equation (Martin et al. 1991b, p. 334):

$$ET_r = \frac{C_T(T - T_x)R_s}{1486} \text{days}$$

where:

$C_T = 1/(C_1 + C_2C_H) = 1/\{58.10 + 13(1.11)\} = 0.014$

$C_1 = 68 - 3.6$ (elevation in feet)/1,000 $= 68 - 3.6(2{,}750)/1{,}000 = 58.10$

$C_2 = 13$, °F (a constant)

$C_H = 50/(e_2 - e_1)$, mbars $= 50/(70.74 - 25.63) = 1.11$

$T_x = 27.5 - 0.25(e_2 - e_1) -$ elevation/1,000 $= 27.5 - 0.25(70.74 - 25.63) - 2{,}750/1{,}000 = 13.47$

e_2 = saturated vapor pressure (mbars) at the mean maximum air temperature for the hottest month (39.2°C; CRWMS M&O 1999b; CRWMS M&O 1999c, Table A-9 on p. A-10). Calculated using the following equation from Buck (1981, p. 1532):

$$e_s = 6.1121\left\{\exp\left(\frac{17.502(°C)}{(240.97 + °C)}\right)\right\} = 6.1121\{\exp(2.45)\} = 70.74$$

e_1 = Saturated vapor pressure (mbars) at the mean minimum air temperature for the hottest month (21.5°C; CRWMS M&O 1999b; CRWMS M&O 1999c, Table A-9 on p. A-10). Calculated using the following equation from Buck (1981, p. 1532):

$$e_s = 6.1121\left\{\exp\left(\frac{17.502(°C)}{(240.97 + °C)}\right)\right\} = 6.1121\{\exp(1.43)\} = 25.63$$

R_s = Incoming solar radiation, langleys/day (see Table 3)

T = Average monthly air temperature, °F (see Table 3)

days = number of days per month

Example: (average monthly temperature and solar radiation, see Table 3)

January ET_r (inches) =

$$ET_r = \frac{0.014(44.8 - 13.47)227}{1486} 31 = 2.04.$$

Justification of Jensen-Haise Equation:

The Jensen-Haise equation was chosen for the calculation of reference evapotranspiration because it is relatively simple to use and is generally reliable for calculating evapotranspiration over long periods (e.g., weekly) in arid climates using the type of climate data available for the Amargosa Valley region (Martin et al. 1991b, p. 334). This equation accounts for local temperature and solar radiation. However, it does not incorporate the effects of wind, as do more complicated methods such as the modified Penman equation (Martin et al. 1991b, pp. 334 through 336).

To ensure that the Jensen-Haise equation did not underestimate reference evapotranspiration, the results calculated for this analysis were compared to two unpublished estimates of evapotranspiration for southern Nevada that used the modified-Penman equation (Figure A-1). The first was calculated from nine years (1986–1994) of climate data from Pahrump, Nevada (McCurdy 1998). The second was based on four years of data (1988, 1990–1992) from Las Vegas (Morris 1997). High and low estimates were considered for Las Vegas.

The Jensen-Haise equation resulted in values that were about 1 inch lower that the modified-Penman estimates during November–January, but as much as 4 inches higher during June–August (Figure A-1). Annual reference evapotranspiration calculated for the proposed location of the critical group (92.7 inches) was higher than that calculated for Pahrump (84.8 inches) and near the high end of the range of values calculated for Las Vegas (84.1–96.7 inches). It is expected that evapotranspiration for the proposed location of the critical group would be slightly lower than the maximum for Las Vegas because the weather data used to calculate evapotranspiration at that site (838 m; CRWMS M&O 1999c, Table 1-1 on p. 6) came from a site about 180 m higher than the elevation in Las Vegas (659 m; Devitt et al. 1995, Table 1 on p. 68). The monthly evapotranspiration values calculated for the proposed location of the critical group using the Jensen-Haise equation also are within the range or higher than those reported for other locations in the southwestern U.S. (Devitt et al. 1992, Table 2 on p. 719; UCCE 1987, Figure 1 on p. 3; Devitt et al. 1995, Figure 3 on p. 77). Therefore, the results of the Jensen-Haise equation used in this analysis are reasonable, although conservative, estimates of monthly reference evapotranspiration.

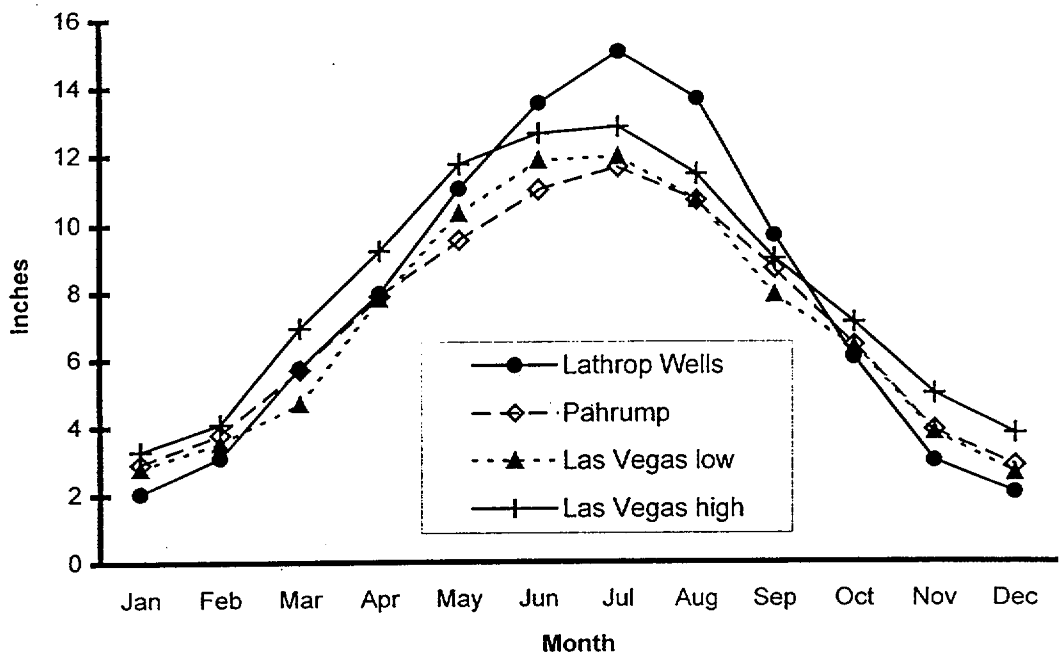

Figure A-1. Reference Evapotranspiration (in inches) Estimated at the Proposed Location of the Critical Group (Labelled as "Lathrop Wells") and Measured in Pahrump (McCurdy 1998) and Las Vegas (Morris 1997).

APPENDIX B

CONFIRMATION OF A DEEP PERCOLATION VALUE

APPENDIX B. CONFIRMATION OF A DEEP PERCOLATION VALUE

The equation of Donahue et al. (1977, pp. 271 through 273) was used to confirm the validity of a deep percolation value of 6 inches. That equation calculates the leaching requirement, which is the minimum fraction of the total applied water that must pass through the root zone to prevent a reduction in crop yield caused by salt accumulation. The equation of Donahue et al. (1977, pp. 271 through 273) is based on the amount of water needed for leaching salts that is in addition to that needed to wet the root zone. For this equation to be used with the data available, one must assume that irrigation is sufficiently applied so that the entire root zone is wetted. Although this assumption may not always be met, completely wetting the root zone is the most efficient method for irrigating; thus, it is valid to assume that this assumption usually will be met.

This equation requires two known values.

EC_i = Electrical conductivity of irrigation water = 0.51 dS/m. Calculated as the average conductivity of water from 31 irrigation or domestic wells (Table B-1) located in Amargosa Valley (formerly Lathrop Wells) or west of State Route 373 and south of Highway 95 in Amargosa Valley (McKinley et al. 1991, pp. 9 through 17). These data are skewed somewhat toward low values; only 9 of the 31 measurements are above the mean. These nine wells are at least 9 km from the intersection of State Route 373 and U.S. Highway 95 and the eight most saline wells are more than 16 km south or southwest of that intersection. These most saline wells are located near the Nevada-California border where the water table is much shallower. Thus, the mean of 0.51dS/m is a reasonable, although high, estimate of salinity expected within the region being evaluated for the reference group.

EC_{dw} = Electrical conductivity causing a 50 percent decrease in yield. Calculated as yield reduction threshold + (50% yield reduction per unit of salinity increase). Yield reduction values were obtained from Table 10-10 of Martin et al. (1991a, p. 223) and are shown in Table B-2.

"Leaching requirement" is calculated as EC_i divided by EC_{dw}. To determine the minimum amount of water required for deep percolation, leaching requirement is multiplied by the irrigation rate necessary to meet the needs of the crop (i.e., evapotranspiration minus precipitation) (Table B-2).

Minimum deep percolation values were calculated for 12 crops using this method (Table B-2). Estimates of yield reduction threshold and yield reduction per unit of salinity were not available for melons or peas. Average deep percolation requirements of the 12 crops was 3.29 inches/year. Nine of the crops had requirements of less than 4 inches/year. The highest deep percolation requirement, 6.47 inches/year for corn, was only slightly above the assumed value of 6 inches/year. Thus, 6 inches is a reasonable assumption for this analysis.

Table B-1. Electrical Conductivity of 31 Wells in Amargosa Valley[a,b]

Site Number	Distance (km)[c]	Electrical Conductivity (dS/m)[d]
37	0.09	0.49
34	3.59	0.34
35	4.33	0.33
36	4.87	0.34
63	9.01	0.65
57	9.13	0.30
60	9.73	0.43
58	9.79	0.31
61	9.84	0.37
59	10.18	0.32
65	12.95	0.30
66	13.36	0.31
53	13.86	0.32
54	15.10	0.33
44	15.44	0.34
43	15.96	0.37
51	16.04	0.35
55	16.33	0.34
77	16.77	0.80
76	17.17	0.38
73	17.87	0.31
56	18.03	0.83
47	18.54	1.07
75	18.73	0.29
42	18.74	0.95
78	18.88	0.28
74	18.90	0.35
39	20.04	0.98
72	20.27	1.29
40	20.71	0.96
89	25.60	0.70
Average		0.51

NOTES: [a]From McKinley et al. (1991, pp. 9 through 17).
[b]All wells are within Amargosa Valley (formerly Lathrop Wells) or south and west of the intersection of U.S. Highway 95 and State Route 373 .
[c]Distance from the intersection of U.S. Highway 95 and State Route 373 to the well.
[d]Converted from μS/cm (units used by McKinley et al. 1991, pp. 14 through 17) to dS/m using the equation dS/m = 0.001(μS/cm).

Table B-2. Leaching and Deep Percolation Requirements of 12 Crops[a]

Crop	Yield Reduction (dS/m)[b] Threshold	Yield Reduction (dS/m)[b] Per unit Salinity	EC_{dw}[c]	Leaching Requirement[d]	ET[e]	Precipitation[f]	Deep Percolation[g]
Spinach	2.0	7.6	8.58	0.06	22.92	0.75	1.32
Tomato	2.5	9.9	7.55	0.07	35.25	0.50	2.35
Cucumber	2.5	13.0	6.35	0.08	27.66	0.33	2.20
Peppers	1.5	14.0	5.07	0.10	31.74	0.50	3.14
Lettuce	1.3	13.0	5.15	0.10	38.52	1.22	3.70
Snap Beans	1.0	19.0	3.63	0.14	23.19	0.42	3.20
Corn	1.7	12.0	5.87	0.09	75.15	0.78	6.47
Carrots	1.0	14.0	4.57	0.11	46.72	1.14	5.08
Potatoes	1.7	12.0	5.87	0.09	42.07	0.73	3.59
Alfalfa	2.0	7.3	8.85	0.06	92.69	4.03	5.11
Wheat	6.0	7.1	13.04	0.04	53.25	3.40	1.95
Barley	8.0	5.0	18.00	0.03	53.25	3.40	1.41

NOTES: [a]Calculated as described in Donahue et al. (1977, pp. 271 through 273).
[b]From Martin et al. (1991a, Table 10-10 on p. 223).
[c]Electrical conductivity (dSm/m) causing a 50 percent decrease in yield, calculated as yield reduction threshold (50/yield reduction per unit of salinity increase.
[d]Calculated as electrical conductivity of groundwater (0.51 dS/m, see Table B-1) divided by EC_{dw}.
[e]Evapotranspiration (inches), from Table 2.
[f]Inches, from Table 2
[g]Inches/year, calculated as leaching requirement x (evapotranspiration – precipitation).

APPENDIX C

CALCULATION OF CROP INTERCEPTION FRACTION

APPENDIX C. CALCULATION OF CROP INTERCEPTION FRACTION

Introduction

The interception fraction is the fraction of deposited radioactive material, either by dry or wet deposition processes, that is retained on the plant, with the remainder reaching the ground. In the vicinity of Yucca Mountain, irrigation is the only applicable deposition process. The fraction of the total deposition that resides on vegetation is the interception fraction, r, such that $0<r<1.0$.

Background

The majority of the literature concerning crop interception fraction with wet deposition focuses on radioactive material in rainfall, not irrigation water. Anspaugh (1987), reviewed studies that applied rain in a controlled manner with artificial sprays. All of the studies applied very small amounts of water at a time, ranging from 0.007 mm to 1.2 mm (Anspaugh 1987). Anspaugh (1987, p. 22) recommended an average value for r of 0.4 or 0.5 with a value of 1.0 being reasonable in some cases.

Anspaugh's (1987, p. 22) upper range of r=1.0 may be applicable during a light rainfall when all of the water can be retained on the leaves of a plant. But in the case of irrigation, when a centimeter or more of water would be applied at each irrigation, the values presented by Anspaugh 1987) appear to be overly conservative.

Method

Hoffman et al. (1989) conducted a study in which the crop interception fraction of beryllium (valence = +2) and iodine (valence = −1) was measured for clover, fescue, and mixed grasses under varying field conditions. For both beryllium and iodine and for each plant type, Hoffman et al. (1989, p. 26) fit the experimental data to an equation in which the crop interception fraction (r) is a function of the yield (Y); the water applied (P), and the irrigation intensity (I):

$$r = K_1\, Y^{K2}\, P^{K3}\, I^{K4}$$

where K_1, K_2, K_3, and K_4 vary with compound and vegetation type. The values of the constants for clover are as follows:

Iodine	Beryllium
$K_1 = 1.54$	$K_1 = 2.29$
$K_2 = 0.697$	$K_2 = 0.695$
$K_3 = -0.909$	$K_3 = -0.29$
$K_4 = -0.049$	$K_4 = -0.341$

An estimate of the standard deviation S_r of the crop interception fraction r is given by:

$$S_r = \sqrt{(K_1 K_2 Y^{(K_2-1)} P^{K_3} I^{K_4} S_Y)^2 + (K_1 K_3 Y^{K_2} P^{(K_3-1)} I^{K_4} S_P)^2 + (K_1 K_4 Y^{K_2} P^{K_3} I^{(K_4-1)} S_I)^2}$$

where S_Y, S_P and S_I are estimated standard deviations of the distributions for yield, irrigation depth, and irrigation intensity. The formula for S_r. was derived by applying a general propagation-of-error formula (Young 1962, Eq. 13.8, p. 98) to the formula for r above. The derivation assumed that the uncertainty in the crop interception fraction (as represented by S_r) is due primarily to the uncertainty in the input variables Y, P, and I and that the uncertainty in the parameters K_1 through K_4 contributes a negligible amount to the uncertainty in the crop interception fraction. This assumption is difficult to justify definitively because Hoffman, et al (1989) did not report t-statistics or confidence intervals for the estimated parameters. Nevertheless, the propagation-of-error formula provides a systematic means of propagating the uncertainty from the input variables Y, P, and I to the crop interception fraction in Table C-2.

The mean, minimum, and midpoint values of each parameter (crop yield, depth of irrigation, and irrigation intensity) in the equation for r were determined from site specific values for both forage crops and leafy vegetables. The minimum and maximum for each variable were assumed to represent the lower and upper limits of 90 percent confidence interval of a normal distribution[1]. The parameters in the equation and the effects of crop type, irrigation method, and the radionuclides present are discussed below.

(1) Crop Type

In the GENII-S model (SNL 1993, pp. I and 1-1), the value of r is multiplied by the translocation factor when the interception fraction is used to calculate the concentration of radionuclides in the plant at the time of consumption (Napier et al. 1988a, equation 4.7.6, p. 4.67). The translocation factor is the fraction of activity deposited on plant surfaces that reaches the edible parts of the plant. In GENII-S, the translocation factor is set equal to 1 for leafy vegetables and forage crops (Napier 1988a, p. 4.67). For all other vegetation, such as root crops, fruits, cereal, and grain, the translocation is set equal to 0.1 (Napier et al. 1988a, p. 4.67). Therefore the estimate of r focused on leafy vegetables and forage crops and did not consider other vegetation types.

[1] The range of experimental values used by Hoffman (1989) to develop the correlation for r were 0.02 to 0.42 kg/m^2 for yield, 1 to 30 mm for irrigation depth, and 1.4 to 12.2 cm/hr for irrigation intensity.

(2) Crop Yield (kg dry/m^2)

The more plant material above the ground, the higher the crop interception fraction. For application to the interception fraction calculation, the dry yield for leafy vegetables was calculated using the two plants for which most of the plant is edible, spinach and lettuce (see Table 6). The wet yield is assumed to be 2.192 kg/m^2 for spinach and 2.348 kg/m^2 for lettuce (see Table 6). The dry yield is assumed to be 8.0 percent of the wet yield (IAEA 1994, p. 15), or 0.175 kg/m^2 for spinach and 0.188 kg/m^2 for lettuce. Therefore, for leafy vegetables the minimum yield is 0.175 kg/m^2 , the maximum yield is 0.188 kg/m^2, and the midpoint is 0.182 kg/m^2.

For forage crops, the estimated effective yield for hay and forage for beef cattle and milk cows is based on alfalfa and other-hay production and acreage in Nye County from 1993-1995. Annual alfalfa production in Nye County ranged from 4.4 to 5.1 tons per acre (0.988 to 1.146 kg/m^2) during that three year period (NASS 1995, p. 20 and NASS 1996, p. 22). During the same period, annual production of other hay ranged from 1.1 to 1.5 tons per acre (0.247 to 0.337 kg/m^2) (NASS 1995, p. 20 and NASS 1996, p. 22). For the interception fraction calculation, it is assumed that the average weight of tons per acre of alfalfa and other hay (NASS 1995, 1996) is dry weight. Also, it is assumed that alfalfa is cut six times a year and that the other hay is cut one time per year (Hafen 1997). The interception fraction calculation for alfalfa needs to be based on a single cutting rather than a yearly yield. The low and high average yield per year for alfalfa divided by six results in an estimated range of 0.165 to 0.191 kg/m^2 per cutting. Therefore, for forage crops the minimum yield is 0.165 kg/m^2 (alfalfa), the maximum yield is 0.337 kg/m^2 (other hay), and the midpoint yield is 0.251 kg/m^2.

These yields represent the quantity of plant mass per area at harvest time. Earlier in the growing season there would be less plant mass per area. Using the plant mass per area at harvest time, rather than an average value over the growing season results in a reasonable, although conservative, estimate.

(3) Irrigation Depth at Each Application

If a very light misting of water is applied to plants, it is conceivable that all of the water, hence all of the radionuclides in the water, would adhere to the plants and *r* would equal 1. But in the case of the biosphere modeling, light misting is not expected, since all of the water that contains radionuclides will come during irrigation.

The minimum depth of irrigation at each application is estimated by assuming that the plants are irrigated once every day during the entire growing period. The maximum depth of irrigation is estimated by assuming irrigation occurs once every three days or three times the minimum. For leafy vegetables the minimum depth is 8.03 mm, the maximum is 24.49 mm, and the midpoint is 16.26 mm. For forage crops the minimum is 6.65 mm, the maximum is 19.95 mm, and the midpoint is 13.30 mm (Table C-1).

Table C-1. Estimated Irrigation Depth for Leafy Vegetables and Forage Crops

Crop	Annual Irrigation (inches)	Annual Growing (days)	Irrigation Depth (inches) Daily Minimum	Daily X3 Maximum	Irrigation Depth (mm) Daily Minimum	Daily X3 Maximum	Midpoint
Leafy Vegetables:							
Spinach	28.17	90	0.313	0.939	8.03	24.08	
Lettuce	43.29	136	0.318	0.955	8.16	24.49	
Midpoint Leafy Vegetables							16.26
Forage Crop: Alfalfa	94.66	365	0.259	0.778	6.65	19.95	13.30

NOTE: Spinach and lettuce are assumed to have two crops per year. Annual growing days is taken from Table 1 and annual irrigation is taken from Table 2.

Higher values of irrigation depth are possible, especially for forage crops. A higher value of irrigation depth, however, results in a lower crop interception fraction and would therefore be less conservative.

(4) Irrigation Intensity

The irrigation application rate must be less than or equal to the intake rate of the soil to prevent runoff. Sandy loam soil has an average intake rate of 2.5 cm/hr, with a range of 1.5 to 7.5 cm/hr (Doorenbos and Pruitt, 1977, p. 91). The application rates of common sprinkler sizes range from 0.4 to 1.4 cm/hr (Doorenbos and Pruitt, 1977, p. 94). Combining the above information, the irrigation intensity was estimated to range from 0.4 to 7.5 cm/hr, with a midpoint of 3.95 cm/hr.

(5) Radionuclides Present

Values of interception ratio are higher for cations (positive ions) than anions, due to the mainly negative charge of leaf surfaces (Hoffman et al. 1989, p.60; Hoffman et al. 1992, p.3321; Hoffman et al. 1995, pp. 1771-1775; and Kinnersley et al. 1997, p. 1137-1145). Cations accumulate on leaf surfaces; whereas, the quantity of anion deposition is limited by the plant's water holding capacity (Hoffman et al. 1992, p. 3321).

(6) Irrigation Method

In drip, furrow, or flood irrigation, the crop interception fraction would be zero because the water is applied directly to the ground, with very little of the water intercepted by the leaves of the plants. The maximum value of crop interception fraction would occur if all of the irrigation water is applied through sprinklers. To be reasonable, yet conservative, all water was assumed to be applied by sprinklers.

Results and Discussion

Using the site specific values for crop yield, irrigation depth, and irrigation intensity for both forage crops and leafy vegetables, the crop interception fraction for iodine and beryllium were calculated in Table C-2. The values of r for beryllium are higher than the values of r for iodine; but for each ion, the values of r for forage crops are higher than r for leafy vegetables. GENII-S requires the lower and upper limits of the 99.9% confidence interval as inputs. These are provided in Table C-2.

Table C-2. Crop Interception Fractions and Input Variables for Leafy Vegetables and Forage Crops

Description	Yield, Y (kg/m^2)	Irrigation Depth, P (mm)	Irrigation Intensity, I (cm/hr)	Iodine Interception Fraction[f], r	Beryllium Interception Fraction[f], r
Leafy Vegetables (Spinach & Lettuce):					
Lower bound of 90% confidence interval[a]	0.175	8.030	0.400	--	--
Upper bound of 90% confidence interval	0.188	24.490	7.500	--	--
Midpoint[b]	0.182	16.260	3.950	0.035	0.195
Standard Deviation[c]	0.004	5.003	2.158	0.010	0.040
Lower bound of 99.9% confidence interval[d]	--	--	--	0.003	0.062
Upper bound of 99.9% confidence interval	--	--	--	0.067	0.328
Forage Crops (Alfalfa & Oats):					
Lower bound of 90% confidence interval	0.165	6.650	0.400	--	--
Upper bound of 90% confidence interval	0.337	19.950	7.500	--	--
Midpoint	0.251	13.300	3.950	0.052	0.259
Standard Deviation	0.052	4.043	2.158	0.016	0.065
Lower bound of 99.9% confidence interval	--[e]	--	--	-0.002	0.044
Upper bound of 99.9% confidence interval	--	--	--	0.106	0.474

NOTES:
- [a] The maxima and minima of the yield, irrigation depth, and irrigation intensity are assumed to represent the upper and lower bounds of 90% confidence intervals of normal distributions for those input variables.
- [b] As a result of the assumption in Note a, the midpoints between the minima and maxima for the input variables are implicitly assumed to be the means of the distributions. The midpoint of the interception-fraction distribution is calculated from the formula for the interception fraction, r, (which is presented in the text) and the midpoint values shown for the input variables.
- [c] For a normal distribution, the 90% confidence interval is located between ±1.645 standard deviations from the mean. The standard deviations of the input variables are calculated as (upper bound- lower bound)/2/1.645. The standard deviation of the interception-fraction distribution is estimated by the propagation-of-error formula for S_r (which is presented in the text).
- [d] For a normal distribution, the 99.9% confidence interval is located between ±3.291 standard deviations from the mean. Therefore, the maximum and minimum of the 99.9% confidence interval for the interception fraction are estimated as the mean plus $3.291S_r$ for the maximum and mean minus $3.291S_r$ for the minimum.
- [e] "--" indicates that the value is not required.
- [f] Intermediate results (e.g., midpoints and standard deviations of the input variables) appear rounded in the table, but more precise values were used for the calculations.

- The results for iodine presented in Table C-2 are assumed to be applicable to the radionuclides I-129, Tc-99, and Np-237 for the following reasons. In aerobic conditions, the most stable form of technetium is the highly soluble pertechnetate anion (TcO_4^-) (Bostick et al. 1995, p. 2). The behavior of technetium is considered similar to that of iodine. "The nonsorbing Tc-99 can be thought of as a surrogate for other conservative radionuclides such as Cl-36, C-14, and I-129." (CRWMS M&O 1997, p. 10-4).

In water compositions expected at Yucca Mountain, neptunium is expected to be present primarily as NpO_2^+ and $NpO_2(CO_3)^-$ (Triay et al. 1996; p. III.3-43). The portion of neptunium appearing as an anion could be expected to have a similar crop interception fraction as iodine. The portion of neptunium occurring as a cation would be expected to have a higher crop interception fraction, possibly similar to the beryllium.

Without any experiments to measure crop interception of neptunium, one approach is to use the results from beryllium on forage crops developed by Hoffman et al. (1989, p. 26) to represent neptunium crop interception fraction and to use the iodine results on forage crops to represent iodine and technetium. The value of *r* for forage crops rather than leafy vegetables would be preferred since it is higher and therefore reasonable, although more conservative. If a separate distribution of values cannot be used for iodine and technetium, then the most conservative approach would be to use the results from the beryllium on forage crops.

ATTACHMENTS

I DOCUMENT INPUT REFERENCE SHEET

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT
DOCUMENT INPUT REFERENCE SHEET

1. Document Identifier No./Rev.:	Change:	Title:
ANL-MGR-MD-000006 REV 00	0	The Critical Group's Ingestion Pathway Parameters

Input Document							8. TBV Due To		
2a	2. Technical Product Input Source Title and Identifier(s) with Version	3. Section	4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	Unqual.	From Uncontrolled Source	Un-confirmed
1	Anspaugh, L. R. 1987. Retention by Vegetation of Radionuclides Deposited In Rainfall--A Literature Summary, UCRL-53810. Livermore, California: Lawrence Livermore National Laboratory, University of California. TIC: 237907	p. 22		p. 44					
2	Bostick, W. et al. 1995. "Treatment of Aqueous Solutions Contaminated with Technetium-99 Originating from Uranium Enrichment Activities, Final Report K/TCD-1120. Oak Ridge, TN: Martin Marietta Energy Systems, Inc. TIC: 243451	p. 2	N/A	p. 49	Technetium stability				
3	Buck, A. 1981. "New Equations for Computing Vapor Pressure and Enhancement Factor." Journal of Applied Meteorology, 20, 1527-1532. Boston, Massachusetts: American Meteorological Society. TIC: 239065			p. 36					
4	Bureau of the Census 1990. "Statistical Abstract of the United States." 110th Edition. Washington, D.C. TIC: 243371.			p. 22					
5	CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor) 1997. The Site-Scale Unsaturated Zone Transport Model of Yucca Mountain, Revision 1, Milestone SP25BM3. Las Vegas, NV: CRWMS M&O. ACC: MOL.19980224.0314			p. 49					

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6	CRWMS M&O 1999a. "Technical Product Development Plan for Identification of Ingestion Exposure Parameters, Rev. 0," TDP-MGR-MD-000004. Las Vegas, Nevada: CRWMS/M&O. ACC: MOL.19990806.0058.			p. 7					
7	CRWMS M&O 1999b. Climatalogical Tables from 1986-1997 Meteorological Data From Site 1 through Site 9 EFPD Meteorological Sites. Las Vegas, Nevada: CRWMS/M&O. DTN: MO9903CLIMATOL.001.	Parameters 553, 594, 595		pp. 10, 18, 36					
8	CRWMS M&O 1999c. Environmental Baseline File: Meteorology and Air Quality. B00000000-01717-5705-00126, Rev. 00. Las Vegas, Nevada: CRWMS/M&O. ACC: MOL.19990302.0186.	p. 6, A-10		pp. 10, 35, 36					
9	Devitt, D. A. et al. 1992. "Evapotranspration, Crop Coefficients, and Leaching Fractions of Irrigated Desert Turfgrass Systems." Agronomy Journal 84 (2): 717-723. Madison, WI: American Society of Agronomy Inc. TIC: 244677.	pp. 717-723		pp. 11, 37					
10	Devitt, D. A., et al. 1995. "Climatic Assessment of the Arid Southwestern United States for Use in Predicting Evapotranspiration of Turfgrass." Journal of Turfgrass Management 1 (2): 65-81. Binghamton, NY: Haworth Press, Inc. TIC: 245203	pp. 75-81		p. 37					
11	DOE (U.S. Department of Energy) 1998. "Quality Assurance Requirewments and Description for the Civilian Radioactive Waste ManagementProgram. DOE/RW-0333P REV. 8. Washington, D.C. U.S. Department of Energy. ACC: MOL.19980601.0022.			pp. 8, 10					

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	2. Technical Product Input Source Title and Identifier(s) with Version	3. Section					Unqual.	From Uncontrolled Source	Un-confirmed
12	Donahue, R. L.; Miller, R. W.; and Shickluna, J. C. 1977. Soils: An Introduction to Soils and Plant Growth. Fourth Edition. Englewood Cliffs, New Jersey: Prentice Hall, Inc. TIC: 242506.	pp.271-273		pp. 11, 40, 42					
13	Doorenbos, J. and Pruitt, W. O., 1977. Guidelines for Predicting Crop Water Requirements, FAO Irrigation and Drainage Paper 24. Rome: Food and Agriculture Organization of the United Nations. TIC: 245199.	Guidelines s, pp. 35-45, 91, 94	N/A	pp. 12, 13, 14, 26, 47	Crop Water Requirements				
14	Dyer, J. R. 1999. "Interim Guidance Pending Issuance of New U.S. Nuclear Regulatory Commission (NRC) Regulations for Yucca Mountain." Letter from J. R. Dyer (DOE/YMSCO) to D. R. Wilkins (CRWMS/M&O). OL&RC:AVG:1435, June 18, 1999, with enclosure. ACC: MOL.19990623.0026; MOL.19990623.0027.	Letter, p. 19 of enclosure	N/A	pp. 7, 10, 11, 15, 21	Guidance on using proposed 10 CFR 63				
15	Hafen, Tim 1997. Crop Management Practices in Pahrump. Personal communication with Susan LeStrange (CRWMS M&O) Rancher, Pahrump, Nevada, July 28. ACC: MOL.19990323.0176.	Notes p. 1	N/A	pp. 12, 13, 26, 46	Information on agricultural practices in southern Nevada				
16	Hoffman, F. O., Frank, M. L.; Blaylock, B. G.; von Bermuth, R. D.; Deming, E. J.; Graham, R. V.; Mohrbacher, D. A.; and Waters, A. E. 1989. Pasture Grass Interception and Retention of 131I, 7Be, and Insoluble Microspheres Deposited in Rain. ORNL--6542, Oak Ridge National Laboratory, Oak Ridge, Tennessee. TIC: 237241	Paper, pp. xv, 26, 122-124	N/A	pp. 25, 26, 27, 44, 45, 47, 49	Crop interception fractions				

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	2. Technical Product Input Source Title and Identifier(s) with Version	3. Section	4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	Unqual.	From Uncontrolled Source	Un-confirmed
17	Hoffman, F. O., Thiessen, K. M.; Frank, M. L.; and Blaylock, B. G. 1992. "Qualification of the Interception and Initial Retention of Radioactive Contaminants Deposited on Pasture Grass by Simulated Rain," Atmospheric Environment 26A (18): 3313-3321. Great Britain: Pergamon Press Ltd. TIC: 243594.			p. 47					
18	Hoffman, F. O;, Thiessen, K. M.; and Rael, R. M. 1995. Comparison of Interception and Initial Retention of Wet-Deposited Contaminants on Leaves of Different Vegetation Types, Atmospheric Environment 29 (15): 1771-1775. Great Britain: Pergamon Press Ltd. TIC: 243593.			p. 47					
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