QA: QA

Model Administrative Change Notice

Complete only applicable items.

1. Document Number:	MDL-MGR-HS-000001	2. Revision:	00	3. ACN:	01
4. Title:	Irrigation Recycling Model				
5. No. of Pages Attached	~~1~~ 16 BJ 1-10-08				

6. Approvals:

	Print name and sign	Date
Preparer:	Elena Kalinina [signature]	01-10-08
Checker:	Al Eddebbarh Bruce A. Robinson for Al Eddebbarh	01/10/2008
QCS/Lead Lab QA Reviewer:	Peter Persoff [signature]	01/10/2008
Independent Technical Reviewer:	Ming Zhu [signature]	1/10/08
Responsible Manager:	Kathryn Knowles [signature]	1/10/08

7. Affected Pages	8. Description of Change:
1-1	First paragraph, second sentence: Deleted unnecessary "the". Second paragraph, sixth bulleted item: Deleted two unnecessary instances of "the". Third paragraph, last sentence: Deleted unnecessary "the".
4-3	Last paragraph, first sentence: Deleted unnecessary "the" in front of "Amargosa Valley".
4-5	First paragraph, first sentence: Deleted unnecessary "The" and "the appearance of".
6-45	First paragraph, last sentence: Deleted unnecessary "is". Last paragraph, first sentence: Changed "914.5" to "914.6".
6-59	First paragraph in Section 6.7: Added explanation following first sentence to point out that the version of the TSPA model used is not the final one, but the latest available at the time of modeling; added sentence to say that it is expected that using an earlier version of the TSPA model will have no impact on the sensitivity analysis results.
6-60	First paragraph under "Seismic-Ground Motion Scenario (GM)" sub-heading: In third sentence, changed "peak dose" to "maximum dose within the period of geologic stability", changed "15% difference" to "13% difference" to correct typo, and added explanation about average difference over 10,000 year period of simulation; in fifth sentence, changed "nonsorbing" to "non-sorbing".
6-62	First paragraph under "Igneous Scenario" sub-heading: In third sentence, changed "peak dose" to "maximum dose within the period of geologic stability" and added explanation about average difference over 10,000 year period of simulation; in fifth sentence, changed "nonsorbing" to "non-sorbing"; in next-to-last sentence, added missing comma; in last sentence, added missing comma and "a" before "moderately-sorbing species".
6-63	First paragraph, third sentence: Changed "nonsorbing" to "non-sorbing".

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7-7	Paragraph above Section 7.3, first sentence: Changed "nonsorbing" to "non-sorbing"; changed "nondecaying" to non-decaying". Section 7.3, second paragraph, second sentence: changed "nondecaying" to "non-decaying".
7-8	First paragraph, third and fifth sentences: Changed "nonsorbing" to "non-sorbing". First paragraph, fifth sentence: Changed "nondecaying" to non-decaying".
8-1	First paragraph: Added sentence at the end of the paragraph explaining that the decision concerning the inclusion or exclusion of the irrigation recycling FEP will be documented in DIRS 183041.
8-2	Second paragraph, second sentence: Changed "nonsorbing" to "non-sorbing". Last paragraph: After second sentence, added new sentence explaining that the version of the TSPA model used is not the final one, but the latest available at the time of modeling, and another new sentence explaining that using an earlier version of the TSPA model is expected to have no impact on the sensitivity analysis results; changed "peak dose" to "maximum dose within the period of geologic stability" in fifth and sixth sentences; reworded the sixth sentence and added the average difference over 10,000 year period; capitalized "s" in "seismic-GM scenario" in three places where it occurred in this paragraph.
8-3	First paragraph under Section 8.2.1: Changed "DTN: SN0709SENANL.001" to "DTN: SN0709IRSENANL.001". Last paragraph under Section 8.2.1: Changed "DTN: SN0709SENANL.001" to "DTN: SN0709IRSENANL.001" in underlined paragraph heading; capitalized "Ground Motion" in "Seismic ground motion" in second sentence; added sentence at end of paragraph explaining that the version of the TSPA model used is not the final one, but the latest available at the time of modeling.
9-3	Added DIRS 183041 to the list of references in Section 9.1. Listing for DIRS 181326: Changed "EPS" to "EPA" in document identifier for reference.

1. PURPOSE

The overall objective of this work is to provide technical support to the evaluation of the feature, event, and process (FEP) 1.4.07.03.0A, "Recycling of Accumulated Radionuclides from Soils to Groundwater." This support will include development of a consequence irrigation recycling model that will be used to estimate radionuclide concentrations in groundwater, including recycling of accumulated radionuclides from soil (irrigation with contaminated water) and the unsaturated zone (residential septic systems). This model will be used in a total system performance assessment (TSPA) sensitivity analysis to evaluate the impact of the irrigation recycling model to mean dose results. This task also includes developing irrigation recycling modeling parameters and assessing uncertainties.

The irrigation recycling model report documents the development of the following:

- A conceptual model of irrigation recycling
- Mathematical representation of the conceptual model using GoldSim 9.60 (STN: 10344-9.60-00 [DIRS 180224])
- An interface between the irrigation recycling model and the saturated zone flow and transport abstraction model
- An interface between the irrigation recycling model and the biosphere process model
- The irrigation recycling modeling parameters and parameter uncertainty analysis
- An estimate of the effects of irrigation recycling on radionuclide concentrations in groundwater
- An estimate of the impacts of irrigation recycling to mean dose results based on the TSPA sensitivity analysis
- Validation of the irrigation recycling model.

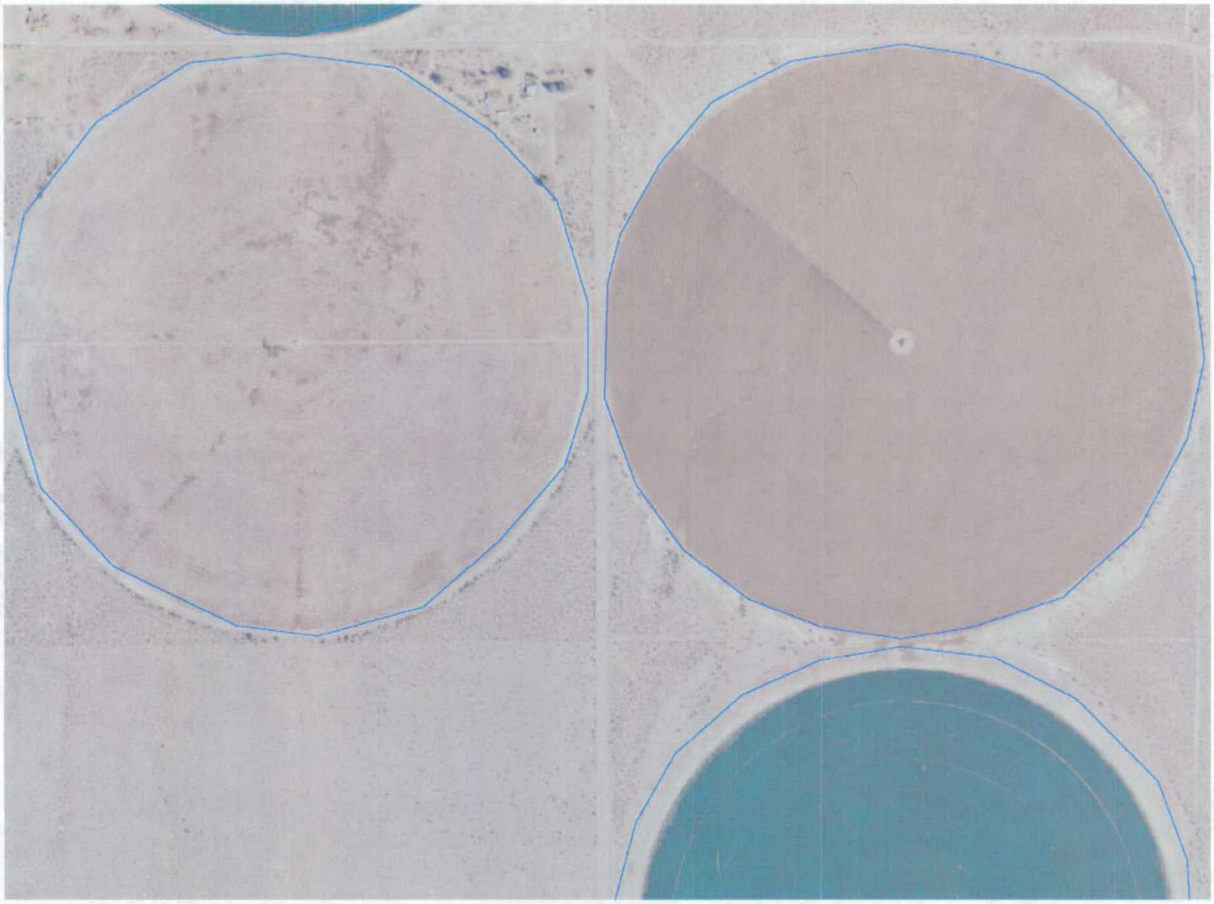
The irrigation recycling model is based on a number of assumptions described in Section 5 of this report. Use of the model is limited by the conditions imposed by these assumptions. The limitations also apply to the irrigation recycling modeling parameters. Limitations in the knowledge of these parameters are addressed in the parameter uncertainty analysis (Section 6.5).

This model report is governed by the Office of Civilian Radioactive Waste Management Lead Laboratory *Technical Work Plan for: Evaluation of the FEP 1.4.07.03.0A - Recycling of Accumulated Radionuclides from Soils to Groundwater* (SNL 2007 [DIRS 181342]), which was developed in accordance with SCI-PRO-002, *Planning for Science Activities*. The work is performed in accordance with SCI-PRO-006, *Models*.

- The unqualified DTN: MO0706FD30MQMA.000 [DIRS 181355], Four Digital 30 Minute Quad Mosaics of Part of the Amargosa Valley Area consists of black and white aerial photography in a mosaic pattern as 30-minute quads. These images are part of a large set covering most of Nevada and are available from the website of the Keck Library map collection at the University of Nevada Reno. The original source imagery was the United States Geological Survey (USGS) Digital Orthophoto Quarter Quads. These data are in universal transverse mercator (UTM) zone 11 coordinates, NAD83, GRS80. The resolution or pixel size is 1 meter. The quadrangles are East of Echo Canyon, Franklin Well, Leeland, and South of Amargosa Valley. These mosaics were produced by personnel from the Nevada Department of Transportation.

- The unqualified DTN: MO0706NAIPDQI9.000 [DIRS 181356] Nine National Agriculture Imagery Program (NAIP) digital quarter quad (3.75-minute) images of part of the Amargosa Valley area, consists of natural color aerial photography in 3.75-minute quarter quads. These images are part of a large set covering much of Nevada available from the website of the Keck Library map collection at the University of Nevada Reno. The imagery is from the NAIP. The data are in the UTM zone 11 coordinate, NAD83. The resolution or pixel size is 1 meter. Portions of the East of Echo Canyon, Franklin Well, Leeland, and South of Amargosa Valley quadrangles are included.

These data are used to delineate agricultural areas within the area of interest and specifically to assign a single centroid location to each agricultural area in Amargosa Valley. Agricultural areas of interest approximate a quarter mile (or larger) center pivot. Acceptance criteria for the qualification of these data using corroboration will consist of visual inspection of the agricultural areas defined from one DTN set compared to the second data set. Both data sets are in the same coordinate/projection system, and no transformations are required. Georeferencing files are included with each data set, minimizing or essentially eliminating the need for interaction in viewing the data sets. Figures 4.1-1 and 4.1-2 show several of the defined areas on the 30 minute mosaics and on the NAIP photographs.



Source: DTN: MO0706NAIPDQI9.000 [DIRS 181356].

Figure 4.1-2. Digital Quarter Quad (3.75-minute) Image of the Amargosa Valley Agricultural Area Shown in Figure 4.1-1

Visual inspection shows the defined areas to be essentially identical with respect to the underlying photography. The extent and quality of the visual match can be easily verified throughout the area of interest. The fact that the same polygon appears in the same place on both images is evidence that they do corroborate each other. The polygonal outline that is visible in both figures is not part of the original image but was used for the purpose of delineating irrigated areas.

In addition to the essentially identical corroboration of the two data sets by visual inspection, other factors may be considered in this qualification process. Both data sets originated with separate federal organizations with long histories of aerial photography and mensuration using photography. Based on the factors considered above, both of the data sets, DTNs: MO0706FD30MQMA.000 [DIRS 181355] and MO0706NAIPDQI9.000 [DIRS 181356] are adequately and appropriately justified for use as direct input to this report.

6.5.3.7 Depth to Water Table

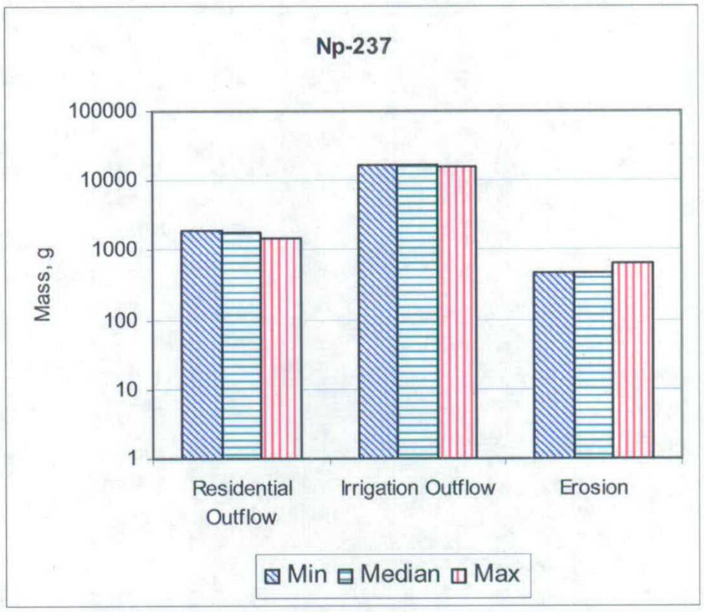
The depth to the water table beneath the irrigated fields defines the distance over which the radionuclides are transported in the unsaturated zone. The current depth to the water table beneath well NC-EWDP-19D is 107.0 m (Table 6.5-1). The depth to the water table beneath the upgradient well NC-EWDP-22S is 143.6 m (Table 6.5-1). The depth to the water table will change due to the rise in water table during the monsoon and glacial transition climates. As discussed in Section 6.3, the depth to the water table is assumed to be equal to the depth corresponding to the glacial transition climate for the entire period of simulation. This is a reasonable assumption (Section 6.3) because the shorter the distance traveled in the unsaturated zone, the faster the recycling time is through the system (the time when equilibrium concentrations establish).

The estimates of the rise in water table during the glacial transition climate are available from *Simulated Effects of Climate Change on the Death Valley Regional Ground-Water Flow System, Nevada and California* (D'Agnese et al. 1999 [DIRS 120425]). These data are qualified for use in this model report in Section 4.1.1.2. According to these estimates, the water table would rise 120 m beneath the repository (D'Agnese et al. 1999 [DIRS 120425], Figure 13). The water table rises to the surface at a number of discharge points. The closest discharge point located on the flow path from the repository downgradient from the well NC-EWDP-19D and north from the Amargosa Valley area shown by D'Agnese et al. (1999 [DIRS 120425], Figure 16) has UTM northing of 4052000 m and UTM easting of 546152 m. The predicted water table rise beneath wells NC-EWDP-19D and NC-EWDP-22S was estimated using these data as described below.

First, the average flow path from the repository was obtained using the data in DTN: SN0704T0510106.008 [DIRS 181283] (file *sz06-100.sptr2*) and EARTHVISION V. 5.1 (STN: 10174-5.1-00 [DIRS 167994]) These data represent the coordinates of 1,000 particle tracks that are generated by the site-scale flow model as described in *Saturated Zone Site-Scale Flow Model* (SNL 2007 [DIRS 177391]). For each 100-m interval in the north-south direction, the average easting and elevation were calculated to determine a single average flow path. The resulting flow path is shown in Figure 6.5-15. This average flow path originates from UTM northing of 4081400 m and UTM easting of 548877 m.

Using the x and y coordinates of the average flow path, the surface elevations of the points located on the flow path were determined using topographic data from DTN: MO0010COV00124.001 [DIRS 153783]. Similarly the present day water table elevations were determined using water level data from DTN: MO0611SCALEFLW.000 [DIRS 178483] (file *wt_HFM2006_X.dat*). Both the water table elevations and the surface elevations were queried along the average flow path and the data placed into *Depth_to_WT.xls* (DTN: SN0703PASZIRMA.001, directory *Parameters*).

The predicted water table elevation beneath the repository during the glacial transition climate was set equal to 914.6 m (the current elevation of 794.6 m + 120 m water table rise). Note that the average flow path (Figure 6.5-15) starts at the northern part of the repository where the water table elevation is higher than the water table elevation beneath most of the repository, which is about 730 m. The predicted water table elevation at the discharge point during the glacial transition climate was set equal to the surface elevation at this point (759.8 m). The predicted



Source: Output DTN: SN0703PASZIRMA.001 (*\Results\ Modeling_Results.xls*).

Figure 6.6-7. Total Mass Removed from Recycling

The other modeling parameters not considered in the sensitivity runs above are as follows:

- Depth to water table
- Saturation
- Residual uncertainty fraction
- Leach field thickness
- Leach field application rate.

These parameters do not affect the equilibrium concentrations of the long-lived radionuclides. They only affect the time when the equilibrium concentrations are established.

6.7 IMPACTS OF THE IRRIGATION RECYCLING MODEL TO MEAN DOSE RESULTS

The impacts of the irrigation recycling model to mean dose results were evaluated as a part of the TSPA sensitivity analysis. Note that the version of the TSPA model used is the latest version available at the time of modeling, but not the final version because the TSPA model at that time was still under refinement. This is expected to have no impacts on the sensitivity analysis conclusions. In this analysis the irrigation recycling model (GoldSim file *Irrigation_Recycling_Model.gsm*, output DTN: SN0703PASZIRMA.001, directory *Model*) was implemented in the TSPA-LA compliance model. The implementation was executed by incorporating the standalone irrigation recycling model into Version 5.0 of the TSPA-LA model implemented with GoldSim v. 9.60.100 (STN: 10344-9.60-01 [DIRS 181903]). Slight modifications were made to the irrigation recycling model to reflect the structure of the TSPA-LA model. All parameters sampled using stochastic GoldSim elements were put in the

TSPA-LA model *Epistemic_Params* submodel container: *\Input_Params_Epistemic\ Epistemic_Params_SZ_Transport\Recycling_Model_Uncert_Inputs*. In addition, the remaining elements found in the container, *\TSPA_Model\SZ_Transport\Model_Inputs_SZ_Transport\ Input_Params_SZ_Transport\Irrigation_Recycling_Model\Recycling_Parameters*, of the standalone irrigation recycling model were divided into two containers, one for the input parameters and one for calculated parameters.

After implementation of the stand-alone irrigation recycling model into Version 5.0 of the TSPA-LA model, the compliance model 1,000,000-year Seismic-Ground Motion (GM) and igneous scenarios were run with the irrigation recycling model included. The results of these runs were saved as text files using GoldSim export function. These files are included in output DTN: SN0703PASZIRMA.001 (directory *Results\TSPA Runs*). The results of these runs were compared to the results of the compliance model. The results of the compliance model are also saved as text files and included in the output DTN: SN0703PASZIRMA.001 (directory *Results\TSPA Runs*). The data from these text files were imported into an Excel file *TSPA_Results.xls* (output DTN: SN0703PASZIRMA.001, directory *Results\TSPA Runs*) to do data comparison and plotting. The GoldSim 9.60.100 (STN: 10344-9.60-01 [DIRS 181903]) compliance model that includes irrigation recycling was submitted in output DTN: SN0709IRSENANL.001. The following two GoldSim files included in this DTN implement igneous and seismic scenarios with the irrigation recycling:

- v5.000_GS_9.60.100_SZ_Recycle_Prototype_Igneous_1Myr.gsm – Igneous scenario with irrigation recycling
- v5.000_GS_9.60.100_SZ_Recycle_Seismic_1Myr.gsm – Seismic scenario with irrigation recycling.

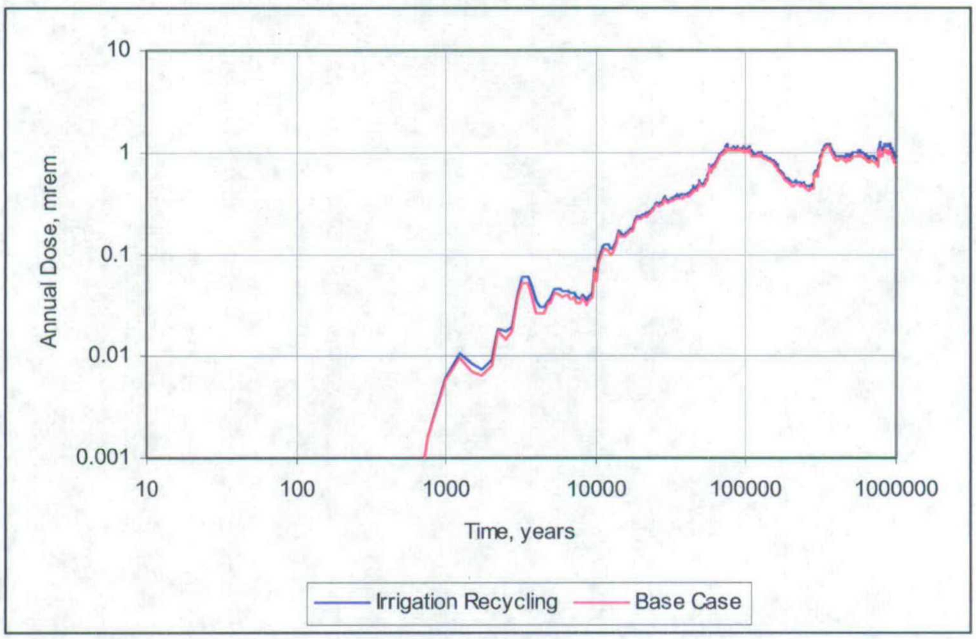
In these runs, the partition coefficient of ^{240}Pu on irreversible colloids in soil was greater than 0. This should not have any impacts on the following comparisons because ^{240}Pu is insignificant.

Seismic-Ground Motion (GM) Scenario

The Seismic-GM scenario results are shown in Figures 6.7-1 and 6.7-2. Figure 6.7-1 depicts the Seismic-GM scenario probability weighted mean annual total doses for the compliance model (denoted as Base Case) and the model that includes irrigation recycling (denoted as Irrigation Recycling). There is about 11% increase in simulated dose at the time of maximum dose within the period of geologic stability, about 13% as an average over the 1 million-year simulation period, and about 11% as an average over the 10,000 year simulation period due to including irrigation recycling. Figure 6.7-2 depicts the individual radionuclide mean annual doses for the model that includes irrigation recycling. The non-sorbing radionuclides such as ^{14}C, ^{99}Tc, and ^{129}I are the dominant contributors to the total dose results (Figure 6.7-1). ^{14}C is a major contributor during the first 10,000 years and ^{99}Tc and ^{129}I are the major contributors during all the period of simulation.

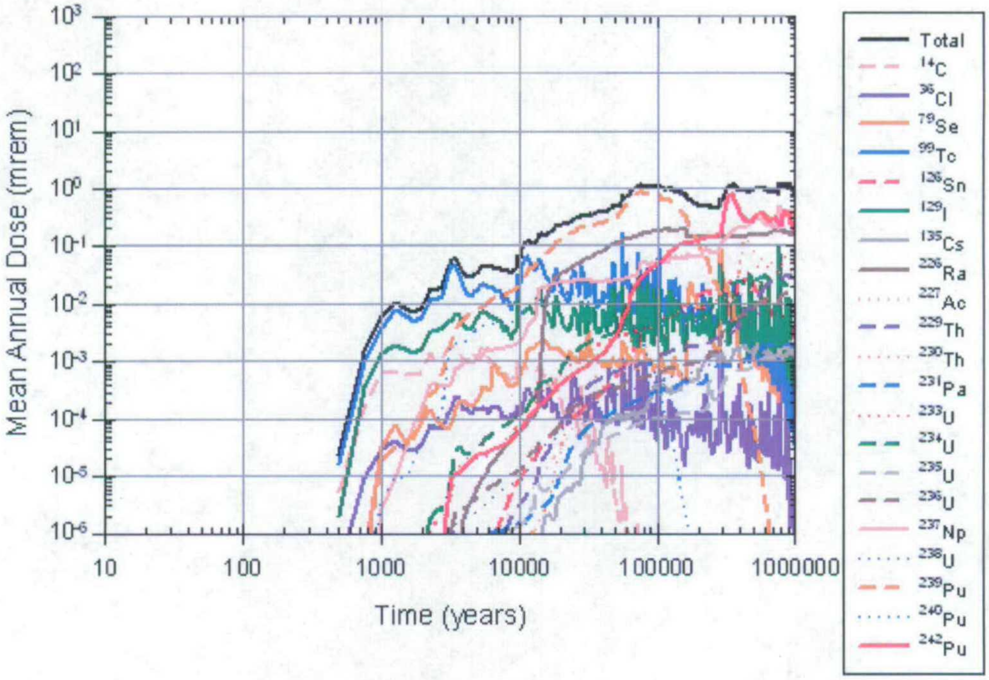
Igneous Scenario

The Igneous scenario results are shown in Figures 6.7-3 and 6.7-4. Figure 6.7-3 depicts the Igneous scenario probability weighted mean annual total doses for the Compliance Model (denoted as Base Case) and the model that includes irrigation recycling (denoted as Irrigation Recycling). There is about 7% increase in simulated dose at the time of maximum dose within the period of geologic stability, about 8% as an average over the 1 million year simulation period, and about 11% as an average over the 10,000 year simulation period due to including irrigation recycling. Figure 6.7-4 depicts the individual radionuclide mean annual doses for the model that includes irrigation recycling. The times where the greatest degree of increase took place are times where non-sorbing radionuclides such as ^{99}Tc and slightly-sorbing radionuclides such as ^{237}Np dominate the total dose results. Note that ^{99}Tc, ^{129}I, and ^{239}Pu are the most dominant contributors to dose early in the simulation and ^{237}Np and ^{242}Pu are the two most dominant contributors to dose at the end of the simulation. During the time span where little difference in results is exhibited, ^{239}Pu, which is mainly a reversible colloid highly influenced by sorption in the rock matrix, is the dominant contributor to dose. ^{226}Ra, which is a moderately-sorbing species, is the next most important contributor to dose during this time span.



Source: Output DTN: SN0703PASZIRMA.001 (*Results*\TSPA Runs*TSPA_Results.xls*).

Figure 6.7-3. Probability Weighted Mean Annual Total Dose, Igneous Scenario



Source: Output DTN: SN0703PASZIRMA.001 (*\Results\TSPA Runs*, file: *v5.000_SZ_Recycle_Igneous_1Myr_RN_Dose_WT.txt*)

Figure 6.7-4. Individual Radionuclide Mean Annual Doses, Igneous Scenario with the Irrigation Recycling Model

The differences between the model with irrigation recycling and the base case are greater for the Seismic-GM scenario than for Igneous scenario. This can be explained based on the major contributors to the total dose. As it was discussed above, the major contributors to the mean annual total dose in the Seismic-GM scenario are non-sorbing radionuclides during all the period of simulation. Removal of these radionuclides from the irrigation recycling system due to soil erosion is very limited because of the short residence time in the soil compartment. As the result, the impacts of the irrigation recycling are more noticeable. The major contributors to the total mean annual dose in the Igneous scenario during later times are moderately sorbing and strongly sorbing radionuclides. Removal of these radionuclides from the irrigation recycling system due to soil erosion is significant and the irrigation recycling impacts are less noticeable than in Seismic-GM scenario.

The deep percolation rates, calculated using the chloride mass balance method, were 16.4 in the west field and 81.6 cm/yr in the east field. The corresponding transport velocities shown in Table 7.2-2 are 0.89 and 4.4 m/yr, respectively.

The deep percolation rates calculated using the chloride mass balance method were 15.0 cm/yr at the west field and 38.0 cm/yr at the east field. The corresponding transport velocities shown in Table 7.2-2 are 0.81 and 2.1 m/yr, respectively.

Table 7.2-2. Estimated Transport Velocities in the Unsaturated Zone Beneath the Irrigated Fields in the Roswell Area

Study Area	Transport Velocity (m/yr)	Method Used
West field	0.89	Water budget
	1.2	Volumetric moisture
	0.81	Chloride mass balance
East field	4.4	Water budget
	1.7	Volumetric moisture
	2.1	Chloride mass balance

Source: Roark and Healy 1998 [DIRS 165864].

The overall range of transport velocities is from 0.81 to 4.4 m/yr. The transport velocity ranges are similar to that observed beneath the irrigated fields in the Amargosa Farms area and that obtained from the irrigation recycling model.

Based on the comparison between the modeling results and available field data, it can be concluded that the range of uncertainty in transport velocity obtained for a non-sorbing, non-decaying species in the irrigation recycling model falls within the range in measured values of transport velocity. Consequently, the validation criterion described in the TWP (SNL 2007 [DIRS 181342]) is satisfied.

7.3 VALIDATION SUMMARY

The irrigation recycling model was validated to Level II as classified in Attachment 3 of SCI-PRO-002 in accordance with the TWP (SNL 2007 [DIRS 181342], Section 2.3). The first and the third methods as defined in SCI-PRO-006, Section 6.3.2 were used in validation.

The third method included the comparison of the irrigation recycling modeling results with the mathematical analytical solution of equilibrium concentration for open-system behavior with recycling derived in *Features, Events, and Processes in SZ Flow and Transport* (BSC 2005 [DIRS 174190], Appendix B). The difference between the equilibrium concentration of a non-decaying species obtained from the irrigation recycling model and calculated by an analytical solution using the same parameters F_c (well recapture fraction) and F_i (fraction of water used for irrigation) is less than 0.1%. The same conclusion applies to the concentration increase due to the recycling (ratio of equilibrium concentration with recycling and without recycling). Consequently, the validation criteria set in the TWP (SNL 2007 [DIRS 181342]) with regard to this comparison (10% difference was specified) are satisfied.

The first method included corroboration of the modeling results with the available field data. The available field data considered included the estimates of the transport velocity in the unsaturated zone beneath the irrigated fields in the Amargosa Farms area (Stonestrom et al. 2003 [DIRS 165862]) and at a similar site located in Roswell, New Mexico (Roark and Healy 1998 [DIRS 165864]). The irrigation recycling model was used to simulate the transport of a non-sorbing species through the unsaturated zone. The uncertainty in the saturation within the unsaturated zone and overwatering rate was used in these simulations to produce the range in the calculated transport times. Based on the comparison between the modeling results and available field data, it was concluded that the range of uncertainty in transport velocity obtained for a non-sorbing, non-decaying species in the irrigation recycling model falls within the range in measured values of transport velocity. Consequently, the validation criteria set in the TWP (SNL 2007 [DIRS 181342]) are satisfied.

8. CONCLUSIONS

8.1 SUMMARY OF MODELING ACTIVITIES

The stand-alone irrigation recycling model was developed to provide technical support to the evaluation of the FEP "Recycling of Accumulated Radionuclides from Soils to Groundwater 1.4.07.03.0A." This model was used in a sensitivity analysis to evaluate the impact of the irrigation recycling model to mean dose results. The model was developed using GoldSim 9.60 (STN: 10344-9.60-00 [DIRS 180224]). The results obtained in this report will be considered in determining whether this FEP is to be included or excluded, which will be documented in the FEPs report (SNL 2008 [DIRS 183041]).

The stand-alone irrigation recycling model calculates radionuclide concentrations in the groundwater based on (1) radionuclide mass fluxes exiting the saturated zone flow and the transport abstraction model and (2) radionuclide mass fluxes due to recycling of accumulated radionuclides from soil (irrigation with contaminated water) and the unsaturated zone (residential septic systems). These concentrations are passed to the TSPA. The stand-alone irrigation recycling model is incorporated into the TSPA model in order to calculate doses for sensitivity analysis.

The irrigation recycling model implicitly includes a stand-alone one-dimensional saturated zone flow and transport abstraction model (DTN: SN0702PASZFTMA.002 [DIRS 183471]). This model calculates the radionuclide fluxes at the boundary of the accessible environment given a radionuclide mass, which represents the input for calculating concentrations in the groundwater. The same parameters and parameter distributions as defined in the saturated zone flow and transport abstraction model are used in the irrigation recycling model. The same realization of a parameter is used in the saturated zone flow and transport abstraction model and the irrigation recycling model to synchronize the calculations.

The irrigation recycling model does not implicitly include the biosphere process model. The biosphere modeling parameters are copied into the irrigation recycling model. The same realization of a parameter is used in the biosphere model and irrigation recycling model to synchronize the calculations. This synchronization takes place when the irrigation recycling model is incorporated into the TSPA model.

The constant values or probability distributions were developed for the irrigation recycling model specific input parameters that had not been defined elsewhere. These parameters are:

- Fraction of water used for irrigation (constant), Section 6.5.3.1
- Fraction of water representing residual uncertainty in water use (distribution), Section 6.5.3.1
- Fraction of residential water used indoors (distribution), Section 6.5.3.5.2
- Fraction of residential water used within the well capture zone (distribution), Section 6.5.3.5.1

- Fraction of irrigation water recaptured by the well (distribution), Section 6.5.3.4.3
- Depth to water table (constant), Section 6.5.3.7
- Alluvium saturation in the unsaturated zone beneath the irrigated fields (distribution), Section 6.5.3.8
- Septic leach field application rate and thickness (constant), Section 6.5.3.9.

Well-recapture fraction and fraction of residential water used within the well capture zone (residential fraction) are the irrigation recycling modeling parameters that have the greatest impact on the radionuclide concentrations in groundwater. The probability distributions were developed for these fractions based on the analysis of the distances to the irrigated fields and residences within the hypothetical community and an analysis of the capture zone from a hypothetical well. The well recapture fraction is estimated from the number of irrigated fields that fall inside the well capture zone. The residential fraction is estimated from the number of residences that fall inside the well capture zone. Uncertainties in the potential locations of the irrigated fields and residences, uncertainties in the parameters affecting the capture zone dimensions (such as the aquifer thickness and specific discharge), and uncertainties in indoor water uses were considered when developing these probability distributions.

The irrigation recycling modeling runs were performed to demonstrate the potential impacts of the well recapture fraction and indoor residential fraction on the radionuclide concentrations in the groundwater (Section 6.6). The maximum, minimum, and most likely impacts were estimated in terms of increase in concentrations due to recycling for non-sorbing, moderately sorbing, and highly sorbing radionuclides. It was shown that the most significant impacts on groundwater concentration are from recycling of contaminated irrigation water. The impacts due to recycling of the contaminated residential water are about order of magnitude smaller.

The other irrigation recycling modeling parameters do not affect the equilibrium radionuclide concentrations. These parameters affect the time when equilibrium is established. The probability distribution was developed for the saturation in the unsaturated zone beneath the irrigated fields. The bounding constant values were developed for the depth to water table and septic leach field parameters (thickness and application rate). Using bounding values results in faster recycling which, in turn, results in an earlier equilibrium.

The impacts of the irrigation recycling model to mean dose results were evaluated as a part of the TSPA sensitivity analysis (Section 6.7). In this analysis the stand-alone irrigation recycling model was implemented in the TSPA-LA compliance model. The version of the TSPA model used is the latest version available at the time of modeling, but not the final version because the TSPA model at that time was still under refinement. This is expected to have no impacts on the sensitivity analysis conclusions. The compliance model 1,000,000-year Seismic-Ground Motion (GM) and igneous scenarios were run with the irrigation recycling model included and the results were compared to the base case results. The increase in maximum dose due to irrigation recycling within the period of geologic stability was about 11% for the Seismic-GM scenario and about 7% for the Igneous scenario. The average increases in the total doses over the 1 million year and 10,000 year simulation periods due to irrigation recycling were comparable to the ones calculated for the time of maximum dose within the period of geologic stability. When TSPA simulated dose is dominated by non-sorbing radionuclides (as in Seismic-GM scenario) the impact of irrigation recycling is greater and when the simulated dose is dominated by moderately to strongly sorbing radionuclides (as in Igneous scenario) the impact of irrigation recycling is less due to removal of the radionuclides by soil erosion.

The irrigation recycling model is validated, and the results of the validation are documented in this report (Section 7). The irrigation recycling model calculates the same equilibrium concentrations as the analytical solution derived for a simplified recycling (BSC 2005 [DIRS 174190], Appendix B). The transport velocities in the unsaturated zone calculated by the irrigation recycling model fall within the range observed in similar conditions beneath the irrigated fields.

8.2 MODEL OUTPUTS

8.2.1 Developed Output

The technical output from this modeling report is provided in output DTN: SN0703PASZIRMA.001 and output DTN: SN0709IRSENANL.001.

Output DTN: SN0703PASZIRMA.001

The directory *Model* in this DTN contains the irrigation recycling model and all files required to run this model as a stand-alone GoldSim 9.60 (STN: 10344-9.60-00 [DIRS 180224]) application.

The directory *Parameters* in this DTN contains the files with the calculations performed to develop the irrigation recycling modeling parameters.

The directory *Results* in this DTN contains the results of the modeling runs (Section 6.6), including the validation runs (Section 7). Subdirectory *TSPA_Runs* includes the outputs from the TSPA Compliance model with irrigation recycling used in the TSPA sensitivity analysis (Section 6.7).

Output DTN: SN0709IRSENANL.001

This DTN contains two GoldSim files representing Version 5.0 of the TSPA-LA model implemented in GoldSim v. 9.60.100 (STN: 10344-9.60-01 [DIRS 181903]) and modified to include irrigation recycling model. One file implements Igneous scenario and another file implements Seismic Ground Motion scenario. The results of the TSPA runs for these scenarios are saved in the form of the text files and are included in the DTN. Note that the version of the TSPA model used is the latest version available at the time of modeling, but not the final version because the TSPA model at that time was still under refinement.

8.2.2 Output Uncertainties and Limitations

Both uncertainties in the modeling parameters and model output were considered in this modeling report. The probability distributions were developed to address the uncertainties in the irrigation recycling model parameters. The probability distributions for these parameters are provided in output DTN: SN0703PASZIRMA.001 (directory *Parameters*) and incorporated in the irrigation recycling model provided in output DTN: SN0703PASZIRMA.001 (directory *Model,* file: *Irrigation_Recycling_Model.gsm*). Bounding parameter values were used in a few cases in which there were no data to develop probability distributions. The distributions for the other model parameters were taken from the stand-alone saturated zone flow and transport abstraction model (DTN: SN0702PASZFTMA.002 [DIRS 183471]) and from the biosphere process model (DTN: MO0705GOLDSIMB.000 [DIRS 181281]), file

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9.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES

180319 10 CFR 63. 2007. Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada. Internet Accessible.

155216 66 FR 32074. 40 CFR Part 197, Public Health and Environmental Radiation Protection Standards for Yucca Mountain, NV; Final Rule. ACC: MOL.20050418.0113.

IM-PRO-002, *Control of the Electronic Management of Information.*

IM-PRO-003, *Software Management.*

PM-PRO-001, *Procurement Documents.*

SCI-PRO-002, *Planning for Science Activities.*

SCI-PRO-003, *Document Review.*

SCI-PRO-004, *Managing Technical Product Inputs.*