II-G-40:Summary of the EPA-Mandated Performance Assessment Verification Test Results for Individual Protection Requirements: Estimated Doses to Internal Organs and Total Body from Groundwater Ingestion and to the Total Body from Beef Consumption, Vegetable Consumption and Inhalation of Soil - 22 September, 1997

WPO # 47309

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1.0 INTRODUCTION

Two prior reports (WPO # 46674 and WPO # 46702) describe the results obtained from the U.S. Environmental Protection Agency (EPA)-Mandated Performance

Assessment Verification Test (PAVT) of the U.S. Department of Energy's Performance Assessment Analyses supporting the Waste Isolation Pilot Plant (WIPP) Compliance Certification Application (CCA). A third report (WPO # 47258) describes the PAVT results for individual and groundwater protection requirements. This report presents additional results for individual protection requirements and provides a summary comparison of PAVT and CCA estimated doses to: (1) internal organs and total body due to beta particle and photon radioactivity from man-made radionuclides in drinking water (as required in 40 CFR § 141.16(a)); and (2) an individual due to cattle consumption in a cattle rancher scenario and vegetable consumption and soil inhalation in a farm family scenario (as required in 40 CFR § 194.51, 40 CFR § 194.52, and 40 CFR § 191.15(a). Additional supporting information and descriptions of calculations are provided in Appendix A (Doses to Organs and Whole Body) and Appendix B (Beef, Vegetable, and Inhalation Pathways).

1.1 Summary of Differences Between the PAVT and CCA Calculations For Individual Protection Requirements

In both the PAVT and CCA calculations presented herein, a very conservative bounding-analysis approach is used to estimate potential doses. Using this approach, the calculated maximum potential dose (millirems) to any internal organ due to beta particle and photon radioactivity from man-made radionuclides in drinking water is 2.9E-04 in the PAVT and 4.2E-03 for the CCA. Further, the annual effective dose equivalent to the total body due to beta particle and photon radioactivity is 1.5E-05 in the CCA and 2.3E-04 for the CCA. All of these values are well below the acceptable standard of 4 millirems per year as specified in 40 CFR § 141.16(a). Finally, the calculated maximum potential doses (millirems) to an individual due to meat consumption, vegetable consumption, and inhalation of resuspended irrigated soil are 2.7×10^{-7}, 0.031, and 2.1×10^{-5}, respectively, in the PAVT and 3.3×10^{-8}, 0.46, 3.1×10^{-4}, respectively, in the CCA. All of these values are well below the individual protection standard, an annual committed effective dose of 15 millirems as specified in 40 CFR § 191.15(a).

2.0 MODELING RESULTS

In both the PAVT and CCA, contaminant transport to the accessible environment boundary (subsurface land withdrawal boundary (LWB)) in the undisturbed repository scenario occurred only in Marker Bed 139 (MB139) to the south of the repository. In the PAVT, fifteen of the 300 realizations show concentrations at the accessible environment boundary greater that 10^{-18} curies per liter in MB139 at the accessible environment boundary compared to nine realizations in the CCA. Values less than 10^{-18} curies per liter are considered to be negligible. As in the CCA, maximum doses occur at 10,000 years and are dominated by ^{239}Pu. Table 1 shows the concentrations of radionuclides at the LWB in MB139 at 10,000 years that were calculated in the PAVT. Table 2 shows the corresponding concentrations for the nine nonzero release CCA realizations (WPO #42959). As shown, ^{239}Pu concentrations tend to be lower in the PAVT than in the CCA. This behavior is primarily due to lower Salado ^{239}Pu solubilities in the PAVT; this issue is discussed in detail in a prior report (WPO # 46674).

It is emphasized that the concentrations presented in Tables 1 and 2(2) greatly overestimate potential concentrations at the LWB because of numerical dispersion in the NUTS transport calculations (WPO # 40515). Numerical dispersion is caused by the coarse lateral gridding between the repository and LWB, and large time steps in the transport calculations. This conclusion is further supported by the fact that the maximum amount of brine volume flowing across the LWB in MB139 in the PAVT is 2250 m^3 (WPO # 46674) and 128 m^3 in the CCA (WPO #40514). Both of these values are much smaller than the pore volume of MB139 between the repository and LWB, which is approximately 155,000 m^3 (WPO #40514). Therefore, the predicted brine volumes crossing the LWB during the 10,000 year regulatory period likely do not originate in the repository, instead these brine volumes are initially present in the marker beds. However, in order to have a quantitative bounding estimate to compare to the standards, the following calculations are presented even though estimated concentrations only represent numerical dispersion effects and, therefore, greatly overestimate concentrations at the accessible environment boundary.

3.0 ANNUAL DOSE EQUIVALENT TO INTERNAL ORGANS FROM THE AVERAGE ANNUAL CONCENTRATION OF BETA PARTICLE AND PHOTON RADIOACTIVITY FROM MAN-MADE RADIONUCLIDES

The maximum annual committed effective dose (millirems) to an individual was previously estimated to be 0.032 in the PAVT and 0.47 in the CCA (see WPO # 47258). These values include alpha, as well as beta particle and photon radioactivity. These values are well below the regulatory standard of 4 millirem annual dose equivalent specified in 40 CFR § 141.16(a). It is important to note that the regulatory standard in 40 CFR § 141.16(a) is for beta particle and photon radioactivity only. Since the radionuclides of concern emit predominately alpha radiation, the maximum annual committed effective doses noted above and in WPO # 47258 are very conservative. In this report, alpha contributions to annual committed effective doses are excluded from the dose calculations (see Appendix A and WPO # 47308). Again, it is emphasized that concentrations in Tables 1 and 2 include alpha particle radioactivity; radioactivity contributions due to beta particle and photon radioactivity are determined as described in Appendix A and are used to calculate committed dose equivalent to internal organs as required in 40 CFR § 141.16(a). The resulting maximum annual committed dose equivalents to each internal organ from beta particle and photon radiation are shown in Table 3 for the PAVT and Table 4 for the CCA. These doses are calculated using concentrations from vector 38 of replicate 1 (Table 1) in the PAVT and vector 64 of replicate 3 (Table 2) in the CCA; all other realizations yield lower maximum organ and whole body doses. As shown in Table 3, the maximum dose (millirems) to any organ is 2.9E-04 in the PAVT and 4.2E-03 in the CCA. Both of these values are well below the acceptable standard of 4 millirems per year as specified in 40 CFR § 141.16(a). In addition, the annual effective dose equivalent (millirems) to the whole body due to beta particle and photon radioactivity are 1.5E-05 in the PAVT (Table 3) and 2.3E-04 (Table 4) in the CCA. Again, both of these values are well below the acceptable standard of 4 millirems per year.

4.0 INDIVIDUAL PROTECTION STANDARD

As in the CCA (WPO # 43298), three pathways are considered: (1) Consumption of beef by a cattle rancher; (2) Consumption of vegetables by a farmer; and (3) Inhalation of resuspended irrigated soil by a farmer. The maximum doses determined from concentrations shown in Tables 1 and 2 are presented in Table 5 for the PAVT and CCA. The maximum doses are from vegetable consumption and result from vector 38 of replicate 1 in the PAVT and vector 64 of replicate 3 in the CCA. As shown in Table 3, the calculated doses for the PAVT are much smaller than the CCA values with a maximum PAVT value of 0.031 millirems versus a maximum 0.46 millirems in the CCA. This trend is consistent with the lower ^{239}Pu solubilities and concentrations noted previously. Both maximum doses occur to farm family vegetable ingestion. These values are well below the 40 CFR 191.15(a) individual protection standard of 15 millirems.

5.0 REFERENCES

Summary of EPA-Mandated Performance Assessment Verification Test (Replicate 1) and Comparison With the Compliance Certification Application Calculations, WPO # 46674

Supplemental Summary of EPA-Mandated Performance Assessment Verification Test (All Replicates) and Comparison With the Compliance Certification Application Calculations, WPO # 46702.

Summary of EPA-Mandated Performance Assessment Verification Test Results For the Individual and Groundwater Protection Requirements, WPO # 47258.

Analysis Report for Estimating Dose From Cattle, Vegetable Consumption and Inhalation Pathways Utilizing Contaminated Water From the Top of the Salado, Culebra, and Selected Marker Beds for an Undisturbed Case Supporting Review Compliance Certification Application, WPO # 43298.

Analysis Report For Estimating Dose Due to Drinking Water For Undisturbed Performance at the Top of the Salado, Culebra, and Selected Marker Beds

Supporting the Compliance Certification Application, WPO # 42959.

Analysis Report of an Evaluation of the Dose Contributions From Beta, Electron, and Photon Emissions to Critical Organs Related to Drinking Water Consumed for the Undisturbed Performance Supporting the Compliance Certification Application, WPO # 47308**.**

Analysis Package for the Salado Flow Calculations (Task 1) of the Performance Assessment Analysis Supporting the Compliance Certification Application, WPO # 40514.

Analysis Package for the Salado Transport Calculations (Task 2) of the Performance Assessment Analysis Supporting the Compliance Certification Application, WPO # 40515.

Table 1. Concentrations of Radionuclides Within Salado Marker Bed 139 (South) at the Subsurface Land Withdrawal Boundary (PAVT)

Concentration (curies/liter)						
Realization	Vector No.	^{241}Am	^{239}Pu	^{238}Pu	^{234}U	^{230}Th
1	Replicate 1 Vector 26	N1(3)	5.96E-17	N	N	N
2	Replicate 1 Vector 38	1.04E-15	3.75E-13	N	3.21E-14	4.09E-15
3	Replicate 1 Vector 58	N	3.21E-16	N	2.41E-18	N
4	Replicate 1 Vector 93	N	1.61E-18	N	N	N
5	Replicate 2 Vector 23	N	5.23E-18	N	1.73E-18	N
6	Replicate 2 Vector 47	N	9.29E-18	N	N	N

Concentration (curies/liter)						
Realization	Vector No.	^{241}Am	^{239}Pu	^{238}Pu	^{234}U	^{230}Th
7	Replicate 2 Vector 49	N	9.90E-16	N	N	N
8	Replicate 2 Vector 64	7.65E-17	1.61E-13	N	1.36E-14	7.81E-16
9	Replicate 2 Vector 65	N	3.40E-16	N	4.14E-17	3.53E-18
10	Replicate 2 Vector 92	N	7.66E-18	N	N	N
11	Replicate 3 Vector 11	N	9.64E-16	N	1.16E-17	N
12	Replicate 3 Vector 52	N	9.21E-16	N	N	N
13	Replicate 3 Vector 53	2.51E-18	2.61E-15	N	2.61E-18	5.82E-18
14	Replicate 3 Vector 76	N	4.07E-18	N	N	N
15	Replicate 3 Vector 77	9.37E-18	4.72E-14	N	7.07E-16	6.78E-17
16-300	-	N	N	N	N	N

Table 2. Concentrations of Radionuclides Within Salado Marker Bed 139 (South) at the Subsurface Land Withdrawal Boundary (CCA)

Concentration (curies/liter)						
RealizationNo.	Vector No.	^{241}Am	^{239}Pu	^{238}Pu	^{234}U	^{230}Th

Concentration (curies/liter)						
RealizationNo.	Vector No.	^{241}Am	^{239}Pu	^{238}Pu	^{234}U	^{230}Th
1	Replicate 1 Vector 46	1.36E-17	4.33E-12	N[1(4)]	5.82E-13	2.10E-14
2	Replicate 2 Vector 16	N	5.13E-14	N	6.77E-15	1.89E-17
3	Replicate 2 Vector 25	N	1.35E-15	N	1.65E-16	7.00E-18
4	Replicate 2 Vector 33	1.32E-17	7.18E-14	N	9.76E-15	9.36E-16
5	Replicate 2 Vector 81	N	6.23E-18	N	N	N
6	Replicate 2 Vector 90	N	5.20E-16	N	7.40E-17	N
7	Replicate 3 Vector 3	3.50E-18	3.08E-13	N	4.32E-14	1.07E-16
8	Replicate 3 Vector 60	5.98E-17	7.41E-14	N	9.09E-15	2.30E-15
9	Replicate 3 Vector 64	5.42E-17	5.85E-12	N	7.61E-13	4.68E-15
10-300	-	N	N	N	N	N

Table 3. Committed Dose Equivalent, Weighted Dose Equivalent, and Effective Dose Equivalent Due to Beta Particle, Electron, and Photon Radioactivity (PAVT)

Table 3. Committed Dose Equivalent, Weighted Dose Equivalent, and Effective Dose Equivalent Due to Beta Particle, Electron, and Photon Radioactivity (PAVT)

Organ	Committed Dose Equivalent (millirems)	Organ and Tissue Weighting Factors	Weighted Dose Equivalent (millirems)
Gonads	3.9E-06	2.5E-01	9.8E-07
Breast	5.0E-09	1.5E-01	7.5E-10
Red Marrow	2.2E-05	1.2E-01	2.6E-06
Lung	5.0E-09	1.2E-01	6.0E-10
Thyroid	5.0E-09	3.0E-02	1.5E-10
Bone Surface	2.9E-04	3.0E-02	8.7E-06
Liver	4.8E-05	6.0E-02	2.9E-06
Lower Large Int.	9.1E-07	6.0E-02	5.5E-08
Kidneys	9.1E-07	6.0E-02	5.5E-08
Upper Large Int.	3.0E-07	6.0E-02	1.8E-08
Small Int.	5.7E-08	6.0E-02	3.4E-09
Internal Effective Dose Equivalent			1.5E-05
External Dose			0.0E+00
Annual Effective Whole Body Dose Equivalent Due to Beta Particle, Electron, and Photon Radioactivity			1.5E-05

Table 4. Committed Dose Equivalent, Weighted Dose Equivalent, and Effective Dose Equivalent Due to Beta Particle, Electron, and Photon Radioactivity (CCA)

Table 4. Committed Dose Equivalent, Weighted Dose Equivalent, and Effective Dose Equivalent Due to Beta Particle, Electron, and Photon Radioactivity (CCA)

Organ	Committed Dose Equivalent (millirems)	Organ and Tissue Weighting Factors	Weighted Dose Equivalent (millirems)
Gonads	5.8E-05	2.5E-01	1.5E-05
Breast	1.1E-07	1.5E-01	1.7E-08
Red Marrow	3.3E-04	1.2E-01	4.0E-05
Lung	1.1E-07	1.2E-01	1.3E-08
Thyroid	1.1E-07	3.0E-02	3.3E-09
Bone Surface	4.2E-03	3.0E-02	1.3E-04
Liver	7.2E-04	6.0E-02	4.3E-05
Lower Large Int.	1.4E-05	6.0E-02	8.4E-07
Kidneys	2.1E-05	6.0E-02	1.3E-06
Upper Large Int.	4.7E-06	6.0E-02	2.8E-07
Small Int.	9.0E-07	6.0E-02	5.4E-08
Internal Effective Dose Equivalent			2.3E-04
External Dose			0.0E+00
Annual Effective Whole Body Dose Equivalent Due to Beta Particle, Electron, and Photon Radioactivity			2.3E-04

Table 5. Calculated Annual Committed Effective Doses at 10,000 yrs. after Closure For the PAVT and CCA

Scenario	Annual Committed Effective Dose (millirems)	
	PAVT	CCA
Farm Family Inhalation	2.1×10^{-5}	3.1×10^{-4}
Farm Family Ingestion	3.1×10^{-2}	4.6×10^{-1}
Cattle Rancher	2.7×10^{-7}	3.3×10^{-5}

For comparison, the maximum dose reported in the CCA for the drinking water pathway is 4.7×10^{-1} millirem/yr, (Table 8-2 of the CCA).

Appendix A Evaluation of the Dose Contributions From Beta, Electron, and Photon Emissions to Critical Organs Related to Drinking Water Consumed for Undisturbed Repository Performance in the PAVT

A.1 INTRODUCTION

This appendix presents the PAVT calculations performed to determine the contributions of the electron and photon emissions to the critical organs from drinking water consumed for the undisturbed performance supporting the Compliance Certification Application. This analysis is identical to the one performed for the CCA and reported in WPO # 47308. To be consistent with regulation CFR § 141.16(a), we refer to emissions as beta particle and photon emissions. However, there are no beta emissions associated with radionuclides Am-241, Pu-239, Pu-238, U-234 and Th-230. These nuclides are alpha, electron, and photon emitters only. Although CFR § 141.16(a)does not require inclusion of emission electron energy contributions to dose, they are included in the doses presented here. That is, doses presented here include contributions from both electron and photon emissions only.

A.2 METHOD OF ANALYSIS

The procedure involved a determination of the effective energies related to these emission particles through weighting by probability of emission. A list of the radionuclides with associated emission and probability data was obtained from the **RadDecay Version 4.02, Grove Engineering, Inc. Rockville Maryland** (Available from the Radiation Safety Information Computational Center-RSICC of the Oak Ridge National Laboratory as **RSIC DATA LIBRARY DLC-13)** are presented in Section A.5.

To obtain the dose contribution from a selected radionuclide to a specific organ, a parameter known as the "quality or radiation weighting factor" is introduced. This factor represents the rate of energy transfer per unit distance along a ionizing particle track. The value for alpha particles is taken as 20.0, and that for electrons and photon radiation is taken as 1.0. The appropriate radiation weighting factors used in the equations presented in Section A.4 were obtained from **ICRP Publication 60, "Recommendations of the International Commission on Radiological Protection" November 1990, Table S-1 Pg. 68.** The organ and tissue weighting factors (see Table A-1) are given in 40 CFR § 191, Appendix B, Table B.2.

Output related to dose contribution from each radionuclide to a selected critical organ was obtained from the GENII-A dose code used in the CCA analysis. This information was multiplied by a normalizing incorporating the energies of the alpha, electron and photon radiation in addition to the appropriate quality factors for the selected radionuclide. This factor normalized the contribution of the alpha particles by dividing by the radiation weighting or quality factor and therefore represented only the electron and photon emission contributions to the organs. When multiplied by the organ dose from GENII-A for the representative radionuclide , the result represents the contribution of the electron and photon radiation to that specific organ. This procedure was followed for each radionuclide and organ. The total dose to a particular organ was obtained by summing the contribution of each radionuclide to that organ. This procedure was repeated for each of the selected organs which included the following; Gonads, Breast, Red Marrow, Lung, Thyroid, Bone Surface, Liver, Kidneys, Lower Large (LL)

Intestine, Upper Large (UL) Intestine, and Small (S) Intestine.

The equations used for this analysis are presented in section A.4.

A.3 RESULTS OF ANALYSIS

The doses due to beta particle and photon radioactivity are shown in Table A.1. The results indicate that these doses are small and well below the regulatory standard of 4 millirems per year as specified in CFR § 141.16(a).

Table A.1. Committed Dose Equivalent, Weighted Dose Equivalent, and Effective Dose Equivalent Due to Beta Particle, Electron, and Photon Radioactivity

Organ	Committed Dose Equivalent(millirems)	Organ and Tissue Weighting Factors	Weighted DoseEquivalent (millirems)
Gonads	3.9E-06	2.5E-01	9.8E-07
Breast	5.0E-09	1.5E-01	7.5E-10
Red Marrow	2.2E-05	1.2E-01	2.6E-06
Lung	5.0E-09	1.2E-01	6.0E-10
Thyroid	5.0E-09	3.0E-02	1.5E-10
Bone Surface	2.9E-04	3.0E-02	8.7E-06
Liver	4.8E-05	6.0E-02	2.9E-06
Lower Large Int.	9.1E-07	6.0E-02	5.5E-08
Kidneys	9.1E-07	6.0E-02	5.5E-08
Upper Large Int.	3.0E-07	6.0E-02	1.8E-08
Small Int.	5.7E-08	6.0E-02	3.4E-09
Internal Effective Dose Equivalent			1.5E-05

Organ	Committed Dose Equivalent(millirems)	Organ and Tissue Weighting Factors	Weighted DoseEquivalent (millirems)
External Dose			0.0E+00
Annual Effective Whole Body Dose Equivalent Due to Beta Particle, Electron, and Photon Radioactivity			1.5E-05

A.4 EQUATIONS USED IN THE ANALYSIS: ENERGY AND PROBABILITY PER DECAY FOR SELECTED NUCLIDES

A.4.1 Average Energies for Each Radionuclide:

Am-241:

$E(\alpha)$ = 0.014 (5.38) + 0.128 (5.44) + 0.852 (5.49) + 0.002 (5.51) + 0.003 (5.54) + 0.00033 (5.31) = 5.47 Mev (Alpha Particles)

$E([e^-])$ = 9.69E-05 Mev (Photoelectrons)

$E(\gamma)$ = 2.81E-02 Mev (Gamma Radiation)

Pu-239:

$E(\alpha)$ = 5.14799 Mev (Alpha Particles)

$E([e^-])$ = 4.879E-02 Mev (Photoelectrons)

$E(\gamma)$ = 6.541E-04 Mev (Gamma Radiation)

Pu-238:

$E(\alpha)$ = 5.487 Mev (Alpha Particles)

$E([e^-])$ = 8.26E-03 Mev (Photoelectrons)

$E(\gamma)$ = 1.60E-03 Mev (Gamma Radiation)

U-234:

$E(\alpha)$ = 4.763 Mev (Alpha Particles)

$E([e^-])$ = 1.090E-02 Mev (Photoelectrons)

$E(\gamma)$ = 5.579E-02 Mev (Gamma Radiation)

Th-230:

$E(\alpha)$ = 4.6768 Mev (Alpha Particles)

$E([e^-])$ = 1.288E-02 Mev (Photoelectrons)

$E(\gamma)$ = 1.41E-03 Mev (Gamma Radiation)

The average energies listed above are tabulated for each radionuclide in Table A-2.

Table A-2. Average Energies For Each Radionuclide

Radionuclide	$E(\alpha)$ (Mev)	$E([e^-])$ (Mev)	$E(\gamma)$ (Mev)
Am-241	5.47	9.69E-05	2.81E-02
Pu-239	5.15	4.88E-02	6.54E-04
Pu-238	5.49	8.26E-03	1.60E-03
U-234	4.76	1.09E-02	5.58E-02
Th-230	4.68	1.29E-02	1.41E-03

A.4.2 Electron and Photon Energy Dose Contributions For Each Organ For Each Selected Radionuclide

Bone Surface:

Am-241:

[(E(e-)QF(e)+ E(γ)QF(γ))/E(α)QF(α)] x D = [(2.81E-02 + 9.69E-05)/5.47/20.0] x 1.6E-06 rem = 2.58E-04 x 1.6E-06 rem = 4.13E-10 rem

In the above equation, QF(e) = QF(γ) = 1 are the quality factors for electrons and gamma radiation, QF(α) = 20 is the quality factor for alpha particles, and D is the radionuclide specific committed dose equivalent due to total energy. D is computed for vector 38, replicate 1 of the PAVT using GENII-A (see WPO # 47258).

Pu-239:

[(E(e-)QF(e)+ E(γ)QF(γ))/E(α)QF(α)] x D = [(6.54E-04 = 4.88E-02)/5.15/20.0] x 5.9E-04 rem = 4.80E-04 x 5.9E-04 rem = 2.83E-07 rem

Pu-238:

[(E(e-)QF(e)+ E(γ)QF(γ))/E(α)QF(α)] x D = [(8.26E-03 + 1.60E-03)/5.49/20.0] x 7.7E-18 rem = 8.98E-05 x 7.7E-18 rem = 6.91E-22 rem

U-234:

[(E(e-)QF(e)+ E(γ)QF(γ))/E(α)QF(α)] x D = [(1.09E-12 + 5.58E-02)/4.76/20.0] x 3.0E-06 rem = 7.01E-04 x 3.0E-06 rem = 2.10E-09 rem

Th-239:

[(E(e-)QF(e)+ E(γ)QF(γ))/E(α)QF(α)] x D = [(1.29E-02 + 1.41E-03)/4.68/20.0] x 1.20E-06 rem = 1.53E-04 x 1.20E-06 rem = 1.84E-10 rem

Total = 2.86E-07 rem

Liver:

Am-241: [2.58E-04] x 2.8E-07 = 7.22E-11

Pu-239: [4.80E-04] x 1.0E-04 = 4.8E-08

Pu-238: [8.98E-05] x 1.4E-18 = 1.26E-22

U-234: [7.01E-04] x 0.0 = 0.0

Th-230: [1.53E-04] x 2.1E-09 = 3.21E-13

Total = 4.80E-08 rem

Lung:

Am-241: [2.58E-04] x 3.1E-12 = 7.99E-16

Pu-239: [4.80E-04] x 2.5E-10 = 1.20E-13

Pu-238: [8.98E-05] x 4.1E-24 = 3.68E-28

U-234: [7.01E-04] x 6.9E-09 = 4.84E-12

Th-230: [1.53E-04] x 2.5E-10 = 3.83E-14

Total = 4.99E-12 rem

Gonads:

Am-241: [2.58E-04] x 2.2E-08 = 5.68E-12

Pu-239: [4.80E-04] x 8.1E-06 = 3.89E-09

Pu-238: [8.98E-05] x 1.1E-19 = 9.88E-24

U-234: [7.01E-04] x 6.9E-09 = 4.84E-12

Th-230: [1.53E-04] x 2.5E-10 = 3.83E-14

Total = 3.90E-09 rem

Breast:

Am-241: [2.58E-04] x 2.5E-12 = 6.45E-16

Pu-239: [4.80E-04] x 2.5E-10 = 1.20E-13

Pu-238: [8.98E-05] x 4.1E-24 = 3.68E-28

U-234: [7.01E-04] x 6.9E-09 = 4.84E-12

Th-230: [1.53E-04] x 2.5E-10 = 3.83E-14

Total = 4.96E-12 rem

Red Marrow:

Am-241: [2.58E-04] x 1.2E-07 = 3.10E-11

Pu-239: [4.80E-04] x 4.5E-05 = 2.16E-08

Pu-238: [8.98E-05] x 6.2E-19 = 5.57E-23

U-234: [7.01E-04] x 1.9E-07 = 1.33E-10

Th-230: [1.53E-04] x 1.0E-07 = 1.53E-11

Total = 2.18E-08 rem

Thyroid:

Am-241: [2.58E-04] x 1.2E-12 = 3.10E-16

Pu-239: [4.80E-04] x 2.4E-10 = 1.15E-13

Pu-238: [8.98E-05] x 3.8E-24 = 3.41E-28

U-234: [7.01E-04] x 6.9E-09 = 4.84E-12

Th-230: [1.53E-04] x 2.5E-10 = 3.83E-14

Total = 4.99E-12 rem

Kidneys:

Am-241: [2.58E-04] x 0.0 = 0.0

Pu-239: [4.80E-04] x 0.0 = 0.0

Pu-238: [8.98E-05] x 0.0 = 0.0

U-234: [7.01E-04] x 1.3E-06 = 9.11E-10

Th-230: [1.53E-04] x 0.0 = 0.0

Total = 9.11E-10 rem

LL Int:

Am-241: [2.58E-04] x 4.9E-09 = 1.26E-12

Pu-239: [4.80E-04] x 1.7E-06 = 8.16E-10

Pu-238: [8.98E-05] x 2.7E-20 = 2.42E-24

U-234: [7.01E-04] x 1.3E-07 = 9.11E-11

Th-230: [1.53E-04] x 1.7E-08 = 2.60E-12

Total = 9.11E-10 rem

UL Int:

Am-241: [2.58E-04] x 1.6E-09 = 4.13E-13

Pu-239: [4.80E-04] x 5.5E-07 = 2.64E-10

Pu-238: [8.98E-05] x 9.1E-21 = 8.17E-25

U-234: [7.01E-04] x 4.8E-08 = 3.36E-11

Th-230: [1.53E-04] x 5.7E-09 = 8.72E-13

Total = 2.99E-10 rem

S Int:

Am-241: [2.58E-04] x 2.8E-10 = 7.22E-14

Pu-239: [4.80E-04] x 9.8E-08 = 4.70E-11

Pu-238: [8.98E-05] x 1.5E-21 = 1.35E-25

U-234: [7.01E-04] x 1.4E-08 = 9.81E-12

Th-230: [1.53E-04] x 1.2E-09 = 1.84E-13

Total = 5.71E-11 rem

A.5 Emission and Probability Data for Each Radionuclide

Emission and probability data for each radionuclide are provided in the following Tables.

Appendix B Estimating Dose From Beef Consumption, Vegetable Consumption, and Soil Inhalation

B.1 Introduction

This analysis report summarizes the background, analysis procedure and results for the Waste Isolation Pilot Plant (WIPP) Repository PAVT dose calculation resulting from (1) consumption of beef cattle drinking water from a stockpond utilizing a contaminated ground-water source by a rancher residing at the location of the well; (2) consumption of crops irrigated from a contaminated ground-water source by a farm family residing at the location of the well; and (3) inhalation of resuspended irrigated soil. The requirements and standards which form the guidance for this calculation are set forth in the following paragraphs. This analysis represents a continuation of the drinking water pathway calculation, reported in **[PAVT -1]**.

B.1.1 Purpose of this Analysis and Background Information

The purpose of this analysis is to provide quantitative analysis of pathways for human exposure to radionuclides which potentially may be released through MB 139 (and MBs 138, A & B) at the site boundary during 10,000 years of undisturbed performance. This analysis uses the same conservative and bounding assumptions used in **[CCA-2]** to examine alternative exposure pathways. Specifically, this analysis presents dose calculations for ingestion pathways for beef and irrigated crops, and for the inhalation of resuspended particles of irrigated soil.

The undiluted sources for this analysis appear in Table A-1. A dilution factor of 32.4 was used for the purpose of achieving a potable water supply. This was based on a recommendation of 10,000 ppm (mg/L) TDS for potential drinking water sources contained in 40 CFR 191 (1993) . However, in the NALCO Water Handbook (**[NA-1])** a value of 500 ppm (mg/L) TDS is indicated as the level for

potable water.

Three hundred realizations of the modeling system were generated during the PAVT analyses for the containment requirements. These same realizations were also used for individual and groundwater protection requirements (**[PAVT-1]**). These 300 realizations are comprised of three sets (or replicates) of one hundred realizations each, generated using the Latin Hypercube sampling technique. Of the 300 realizations, none show any radionuclides reaching the top of the Salado through the sealed shafts.

Fifteen of the 300 realizations show concentrations of radionuclides greater than zero reaching the accessible environment through the anhydrite interbeds. All of the remaining 285 realizations show that no radionuclides reach the accessible environment during the regulatory time frame of 10,000 years after repository closure through the anhydrite interbeds. A receptor in the accessible environment could not come in contact with the anhydrite interbeds located at a depth greater than 2000 feet. Table B-1 shows the maximum concentrations of radionuclides calculated by the modeling evaluation as reaching the accessible environment in the nine non-zero realizations. These concentrations were obtained from data file **[NU-1]**. The full range of estimated values for radionuclide concentrations is from zero to the values shown in Table B-1. The maximum concentration values shown in Table B-1 occur 10,000 years after closure. These are the same values used in **[PAVT-1]**.

For the purposes of this analysis, the maximum concentration set, Replicate 1 Vector 38, was used to determine doses for the cattle, vegetable consumption, and inhalation pathways since this represents the largest concentration and gave the largest dose from drinking water as reported in **[PAVT-1]**.

40 CFR Part 194.51 states that doses must be estimated for an individual who resides at the location in the accessible environment where that individual would be expected to receive the highest exposure from radionuclide releases from the disposal system. All potential pathways for exposure associated with the undisturbed performance of the repository must be assessed (40 CFR §194.52).

Table B-1. Maximum PAVT Concentrations of Radionuclides (Undiluted) Within the Salado Interbeds at the Disposal System Boundary Occuring at 10,000 yrs. after

Closure [see PAVT-1]

Concentration (curies/liter)						
Realization	Vector No.	^{241}Am	^{239}Pu	^{238}Pu	^{234}U	^{230}Th
1	Replicate 1 Vector 26	N1(5)	5.96E-17	N	N	N
2	Replicate 1 Vector 38	1.04E-15	3.75E-13	N	3.21E-14	4.09E-15
3	Replicate 1 Vector 58	N	3.21E-16	N	2.41E-18	N
4	Replicate 1 Vector 93	N	1.61E-18	N	N	N
5	Replicate 2 Vector 23	N	5.23E-18	N	1.73E-18	N
6	Replicate 2 Vector 47	N	9.29E-18	N	N	N
7	Replicate 2 Vector 49	N	9.90E-16	N	N	N
8	Replicate 2 Vector 64	7.65E-17	1.61E-13	N	1.36E-14	7.81E-16

Concentration (curies/liter)						
Realization	Vector No.	^{241}Am	^{239}Pu	^{238}Pu	^{234}U	^{230}Th
9	Replicate 2 Vector 65	N	3.40E-16	N	4.14E-17	3.53E-18
10	Replicate 2 Vector 92	N	7.66E-18	N	N	N
11	Replicate 3 Vector 11	N	9.64E-16	N	1.16E-17	N
12	Replicate 3 Vector 52	N	9.21E-16	N	N	N
13	Replicate 3 Vector 53	2.51E-18	2.61E-15	N	2.61E-18	5.82E-18
14	Replicate 3 Vector 76	N	4.07E-18	N	N	N
15	Replicate 3 Vector 77	9.37E-18	4.72E-14	N	7.07E-16	6.78E-17
16-300	-	N	N	N	N	N

B.1.2 Bounding Analysis

Uncertainty in the calculation of radionuclide concentrations in the anhydrite interbeds is described in Section 6.1.2 (**[CCA-1]**) . Additional uncertainty is

involved in the calculation of doses resulting from the specified exposure pathways. Given this uncertainty, the DOE has elected to perform a bounding analysis using assumptions that do not represent reality, but that would result instead in a bounding estimate that is much greater than any reasonably expected dose to a receptor. If this unrealistic bounding analysis results in calculated doses to the receptor that are below the regulatory limit, compliance with the standard can be demonstrated.

The bounding analysis used for this assessment is based on the following factors and assumptions:

1. No specific transport mechanism is postulated. Instead, all of the contaminants reaching the accessible environment within the anhydrite interbeds during the year of maximum releases (10,000 years after closure) within the 10,000 year period, are assumed to be available to a receptor.

2. Brine derived from the anhydrite interbeds has total dissolved solids (TDS) concentrations of about 324,000 parts per million (**[BR-1]**); this represents a concentration that is too high to be consumed by humans. For the bounding analysis, the calculation includes the dilution of this brine by a factor of 32.4 to a TDS concentration of 10,000 parts per million.

3. The resulting annual committed effective dose is calculated based on a 50-year dose commitment. Calculations were performed using the GENII-A dose code (Appendix GENII, CCA). A 50-year dose commitment is selected because this period is specified in Appendix B of 40 CFR Part 191.

4. The parameters associated with the individual receptors for each scenario appear in Tables B-2, B-3, and B-4. Data related to food pathways, irrigation and inhalation were selected as representative values typical of the associated activities (**[NRC-1]**, **[DOE-1]**) except where noted.

Table B-2. GENII-A Input Parameters for Farm Family Scenario- Terrestrial Food Consumption Utilizing Irrigation from Ground Water Source.

Food Type	Grow Time Days	Irrigation Rate (cm/yr)	Time months	Yield kg/m^2	Consumption Holdup (days)	Consumption Rate (kg/yr)
Leaf	90	100	6	1.5	14	15
Root	90	100	6	4.0	14	140
Fruit	90	100	6	2.0	14	64
Grain	90	100	6	0.8	180	72

Table B-3 GENII-A Input Parameters for Cattle Rancher Scenario.

Food Type	Consumption Rate (kg/yr)	Consumption Holdup (days)	Drinking Water Contamination Fraction	Diet Fraction	Grow Time days	Stored Feed Irrigation Rate (cm/yr)	St Fe (r
Beef	70	34	1	1	90	100	

Table B-4 GENII-A Input Parameters for Farm Family Inhalation Pathway

Breathing Rate	270 cm^3/sec. (Chronic)
Inhalation Period	8760 hours/yr.
Mass Loading Factor	1.0E-04 gm/m^3

The mass loading factor is based on data representative of regional resuspension data for the 1991 to 1996 time period (**[AIRS-1]**). Section 194.51 states that DOE shall assume that an individual resides at the single geographic point where that individual would receive the highest dose. With the bounding analysis, the DOE complies with the intent of this criterion, but the specific location of the receptor is not identified because all of the contaminants reaching the accessible environment

within the anhydrite interbeds during the year of maximum releases are assumed to be directly available to the receptor, regardless of the location of the receptor. The well from which the receptor drinks is assumed to be located such that the contaminants reaching the anhydrite interbeds are delivered directly to the well. This well is the source of the stockpond from which the cattle drink and from which irrigation for feed and vegetable crops is obtained. Additionally, an inhalation calculation for the farm family represents a pathway by which dried irrigated soil is resuspended above the farm area and inhaled by the farm inhabitants. The data used in this analysis appear in Tables B-2, B-3, and B-4. Data related to food pathways, irrigation, and inhalation were selected as representative values typical of the associated activities (**[NRC-1]**, **[DOE-1]**), except where noted .

The bounding analysis dose calculation was performed using the GENII-A code, Version 2.10 (**[GEN-1]**). This program runs on the DEC Alpha System. Appendix GENII of the CCA (**[CCA-1]**) describes the modeling method. GENII-A incorporates dose-calculation guidance provided in Appendix B of 40 CFR Part 191.

B.1.3 Dose Calculation Results

The maximum doses calculated to result from the releases listed in Table A-1 after applying the factors and assumptions listed above, are shown in Table A-5. Because of the conservative and unrealistic assumptions underlying the analysis, the bounding doses are greater than any realistic doses that could be delivered to a receptor. The calculated bounding doses are well below the regulatory standard, which is an annual committed effective dose of 15 millirem. The full range of estimated radiation doses is from zero to some value less than the bounding values shown in A 1-5

Table B-5. Calculated Annual Committed Effective Doses at 10,000 yrs. after Closure

Scenario .	Annual Committed Effective Dose (millirem)
Farm Family Inhalation	2.1×10^{-5}

Farm Family Ingestion	3.1×10^{-2}
Cattle Rancher	2.7×10^{-7}

For comparison, the maximum dose reported in the CCA for the drinking water pathway is 4.7×10^{-1} millirem/yr, (Table 8-2 of the CCA).

B.2 Summary of Compliance with the Individual Protection Standard

In performing the compliance assessment, the DOE applied a bounding-analysis approach using unrealistic assumptions that result in the over-estimation of potential doses and contaminant concentrations. This conservative approach assumes that all contaminants reaching the accessible environment are directly available to a receptor. Using this very conservative approach, the calculated maximum potential dose to an individual would be about one-thirtieth of the individual protection standard.

B.3 Software Used for Analysis

GENII-A , **Version 2.10 [GEN-1], [GEN-2], [GEN-3]**
This program runs on the DEC Alpha System under VMS Operating system.
This analysis was performed by Leo J. Rahal, the code sponsor.

B.3.1 Point of Contact

Code Sponsor: **GENII-A** Leo J. Rahal , Org. 6849, Geo-Centers Inc. (505)-766-9629

Radionuclide source data were obtained from the **NUTS [NU-1]** output through the **Compliance Assessment Methodology Controller** (CAMCON**)** library data access process. All calculations were performed within the **Configuration Management System** (CMS) environment to ensure QA procedures are followed.

B.4 Input and Output Files and Calculation Procedure

Input and Output Files for Dose Calculations (1(6))

INPUT FILE	OUTPUT FILE	DESCRIPTION
1. gi2_calc911.inp	gi2_calc911_trn.out	r3s1v064 10,000 yrs. MB139s (Farm Family- Food Ingestion)
2. gi2_calc912.inp	gi2_calc912_trn.out	r3s1v064 10,000 yrs. MB139s (Cattle Rancher)
3 gi2_calc912.inp	gi2_calc912_trn.out	r3s1v064 10,000 yrs. MB139s (Farm Family-Inhalatio

Legend:

r3 replicate 3 of NUTS OUTPUT [NU-1]
s1 undisturbed case
v vector number

B.5 References

[AIRS-1] U.S. Environmental Protection Agency. 1992. National Air Data Branch, **Aerometric Information Retrieval System**. Total suspended particulate information for LEA County.

[BR-1] Data taken from BRAGFLO output file relating to brine inventory at 10,000 years after closure for Replicate 1 , Scenario 1 (Undisturbed Case), Vector 46. The file from which these data were taken is as follows: **DISK$TINA_CCA, 19963:[BF.JDMILLE.CCA, 1996.POSTALG.R1S1]OSTALG_CCA, 1996_R1_S1_V046.CDB**

[CCA-1] Compliance Certification Application for the Waste Isolation Pilot Plant, United States Department of Energy Waste Isolation Pilot Plant, Carlsbad Area Office, Carlsbad, New Mexico, October 29, 1996.

[DOE-1] Performance Assessment Task Team Progress Report . Radioactive

Waste Technical Support Program, May 1994. DOE/LLW-157 Revision 1.

[GEN-1] WIPP PA User's Manual for GENII-A, Version 2.10. Document Version 1.00, WPO # 27751. November 13, 1995.

[GEN-2] Napier, B.A., R.A. Peloquin, D.L. Strenge and J.V. Ramsdell. 1988. GENII- *The Hanford Environmental Radiation Dosimetry Software System. Vol. 1: Conceptual Representation.* PNL-6584, Vol. 1. Richland, WA: Pacific Northwest Laboratory.

[GEN-3] Napier, B.A., R.A. Peloquin, D.L. Strenge and J.V. Ramsdell. 1988. GENII- *The Hanford Environmental Radiation Dosimetry Software System Vol. 2: User's Manual. PNL-6584, Vol. 1. Richland, WA: Pacific Northwest Laboratory.*

[NA-1] The NALCO Water Handbook, Frank N. Kemmer, Nalco Chemical Company. McGraw-Hill Book Company. 1987. Pg. 35.2 Table 35.1A.

[NRC-1] U.S. Nuclear Regulatory Commission, "Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I, " Regulatory Guide 1.109 (1997).

[NU-1] Data obtained from NUTS output data file

DISK$TINA_CCA3:[BF.JDMILLE.C97.PA_NUTS.CONC]
PA_NUTS_C97_ISO_R1S1_CONC_V038.CDB

[PAVT-1] Summary of EPA-Mandated Performance Assessment Verification Test Results For the Individual and Groundwater Protection Requirements, WPO # 47258.

Endnotes

1 (Popup - Popup)

1 See Memorandum from Susan Y. Pickering to Margaret S.Y. Chu dated 25 July 1997, "Quality Assurance requirements for the performance assessment verification."

2 (Popup - Popup)

Table 1

Table 2

3 (Popup - Popup)

1 Values less than 10^{-18} curies per liter are considered to be negligible.

4 (Popup - Popup)

1 Values less than 10^{-18} curies per liter are considered to be negligible.

5 (Popup - Popup)

1. Values less than 10^{-18} curies per liter are considered to be negligible (N) relative to the other values and are not reported.

6 (Popup - Popup)

Footnote 1:
To run these data files type the following command: run_gi2 100 where 100 is the number associated with the data file gi2_calc100.inp, for example.
An output file gi2_calc100_trn.out, will be generated.
The edit command EDT filename was used to open and edit input and output files.