ATTACHMENT B

Radon Barrier Cover Thickness Design
Calculation 89241.7 - ALB08CA001

TAILING CELL CLOSURE DESIGN REPORT
ENERGY FUELS RESOURCE CORPORATION
PIÑON RIDGE PROJECT

CALCULATION COVER SHEET

Date: 10/14/2009 **Page** 1 **of** 23

Project No.: 89241 **Project Title:** Energy Fuels Uranium Mill Licensing Support

Calculation No.: 89241.7 - ALB08CA001
Calculation Title: Radon Barrier Cover Thickness Design

Design Verification Required: ☒ Yes ☐ No

Calculation Type: ☐ Scoping ☐ Preliminary ☒ Final ☐ Voided
☐ Superseded by Calculation No.: _____

ORIGINAL AND REVISED CALCULATIONS/ANALYSIS APPROVAL

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Originator:	Courtney Vallejo 11/07/08	Courtney Vallejo 10/14/09	
Checked By:	John B. Case 11/07/08	John B. Case 10/14/09	
Approved By:	Alan Kuhn 11/07/08	Alan Kuhn 10/14/09	
Other:			

AFFECTED DOCUMENTS

Document Number	Document Title	Rev. No.	Responsible Project Manager Initials

RECORD OF REVISION

Rev.	Reason for Revision
0	Original Issue
1	Revised references for radium activity through the mill based on information provided by Energy Fuels Resource Corporation.

ATTACHMENTS

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A	RADON Program Listing	11
B	Radon Program Verification	2
C	Radon Output Files	10
D	Analysis of Moisture Content for Radon Barrier Analysis	6
E	Verification of Cell Formulas for Diffusion Coefficient Calculation	3
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Calculation Title:	Radon Barrier Cover Thickness Design		

Originator:	Courtney Vallejo	Courtney Vallejo	10/14/09
	Print Name	Signature	Date
Checker:	John B. Case	John B. Case	10/14/09
	Print Name	Signature	Date

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1.0 Introduction

1.1 Objective

The purpose of this calculation is to determine the radon barrier cover design parameters for the three proposed tailings cells for Energy Fuels Resource Corporation at its Piñion Ridge Uranium Mill site in Montrose County, Colorado. The radon barrier cover will be part of a closure plan for the tailings cells. The material properties and required minimum thickness for the radon barrier required for closure were calculated for various tailings thicknesses based on anticipated soil properties and EPA and NRC radon flux criteria.

1.2 Scope

The scope of this calculation included radon barrier cover thickness design to reduce radon releases from the tailings produced at the Piñion Ridge Uranium Mill. The minimum cover thickness was designed to meet the requirements to adequately reduce radon emanation based on Environmental Protection Agency (EPA) and U.S. Nuclear Regulatory Commission (NRC) regulations (Reference 8). The cover thickness was designed utilizing the RADON computer software developed by the NRC (Reference 7). The RADON software code utilized for calculations was taken from the NRC Regulatory guide (Reference 8) and was unaltered . The RADON code utilized for calculations is documented in Attachment A of this calculation.

2.0 Basis

2.1 Design Inputs

Design inputs included the following design parameters:

- Tailings material properties were obtained from Golder Associates, Inc. project design criteria (Reference 5), and regional mine data provided by Energy Fuels Resource Corporation (Reference 1). Tailings material properties were also estimated based on Reference 10, a geotechnical investigation from a closed tailings cell at the Crescent Junction, Utah, Disposal Site. The material properties were modified based on anticipated site conditions, construction practices and engineering judgment.
- Radon cover material properties were obtained from Golder Associates, Inc. laboratory test data from the Phase II geotechnical exploration (Reference 3), and laboratory test results of native soils provided by Energy Fuels Resource Corporation (Reference 2). Cover material properties were modified based on anticipated site conditions, construction practices and engineering judgment.
- The cover layer thicknesses, specific gravity of solids, and dry densities for the layers used in the analysis are obtained from Table 5-1 of Reference 9.

2.2 Criteria

The radon barrier minimum cover thickness was designed to meet the EPA and NRC requirements. The following requirements for radon flux criteria established by the EPA and the NRC were used for the radon barrier thickness design:

- EPA requirements state that the radon cover must be designed to "produce reasonable assurance that the radon-222 release rate would not exceed 20 pCi m^{-2} s^{-1} for a period of 1000 years to the extent reasonable achievable and in any case for at least 200 years when averaged over the disposal area over at least a one-year period" (Reference 8, page 3.64-1).

- NRC requirements state that the radon cover must be designed so that "the radon-222 release rate must not exceed 20 pCi m^{-2} s^{-1} for active (UMTRCA Title II) sites" (Reference 8, page 3.64-1).

In addition, engineering judgment, along with data identified in section 2.1 above, were used to estimate the engineering properties and design parameters.

2.3 Assumptions

This calculation assumes the following:

- The tailings will be placed in the tailings cells based on the cross sections provided by Golder Associates, Inc. in their design drawings (Reference 4). The tailings thickness will vary based on the tailings cell basin depth and dike slopes.

- The moisture content and thickness of the tailings material will affect the required radon barrier thickness (Reference 8). The thickness of the tailings which requires the largest radon barrier thickness in order to adequately reduce radon flux will be representative of an "infinitely thick" radon source, as any additional tailings material will effectively reduce radon flux (Reference 8).

  The NRC regulatory guide states that a tailings thickness of 500 cm (approximately 16.4 feet) is representative of an "infinitely thick" radon source. A sensitivity analysis was performed in this calculation in order to determine the tailings thickness that will represent an "infinitely thick" radon source. The results of this analysis are presented in Sections 5 and 6.

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Assumptions Continued:

- The radon concentration above the top layer represents the radon concentration of the soil/ air interface (Reference 8). A conservative default value of zero (Reference 8) was used for the radon concentration above the top layer since measured values were not available.

- The tailings are expected to densify over time due to the static loads of the overlying tailings/ cover soils and downward seepage pressures which will result in an overall volume reduction. The dry density of the tailings was increased from the values provided by the Golder Design Criteria (Reference 5) in order to account for anticipated densification. The tailings dry density value used in this calculation was also supplemented by results from the Crescent Junction, Utah disposal site (Reference 10).

- The surface of the tailings will be graded by dozer/ grader to a uniform horizontal surface before the placement of the closure cover.

- The tailings closure cover will consist of a five layer system as presented in the Kleinfelder Calculation "Hydrological and Geotechnical Properties" (Reference 9, Table 5-1) as summarized below:

1) An interim cover of native soil approximately 2.0 feet thick. The interim cover will be placed in 12-inch lifts across the tailings surface and compacted by dozer to an assumed 85% of maximum dry density per ASTM D 698 by tracking with a CAT D6 dozer.

2) A radon barrier of native soil compacted to 95% of maximum dry density per ASTM D-698 overlying the interim cover.

3) A capillary break layer overlying the radon barrier consisting of 1.0 feet of granular material based on recycled base course (No. 2 and No. 6) from reclaimed pads and roads on site (additional material may also be imported). The capillary break will be placed in 6-inch lifts and compacted with at least two passes of a smooth drum roller. The capillary break layer was assumed to have a negligible effect on radon attenuation and was not included in the radon barrier thickness calculations.

4) A 0.5-ft thick filter layer located above the capillary break layer and the erosion barrier designed to limit fine particle migration. Due to the nominal thickness of the filter layer, it was assumed to have a negligible effect on radon attenuation and was not included in the radon barrier thickness calculations.

5) An erosion/vegetative cover consisting of of native soil with native seed mix approximately 2.0 feet thick. The ET cover will be placed in 6 to 8-inch lifts and compacted to 85% standard Proctor dry density per ASTM D-698 based on anticipated vegetation requirements.

- In summary, the radon barrier calculation included the following four layers: the tailings, interim layer, radon barrier, and the erosion/ vegetative cover.

Assumptions Continued:

- The radium-226 activity value of 683 pCi/g used in the RADON model was based on data assembled by EFRC in 2007 – 2008 and is the average of seven samples from six mines in the Uravan Mineral Belt (Reference 12). This value was assumed to be the best available estimate for ores that would supply the Pinon Ridge Mill. Subsequent information collected by EFRC indicates that the ores from likely sources will have an average radium-226 activity of 647 pCi/g based on an average ore grade of 0.23% U_3O_8 (see Section 6.2.3.).

- Volumetric moisture contents of the interim layer and radon barrier was based on the estimated wilting point of the material. The wilting point is moisture content at which soil can no longer supply sufficient water at a rate to maintain plant life (Reference 8). The NUREG 3.64 Regulatory Guide (Reference 8) states that the wilting point is an acceptable estimate for long-term moisture content of a soil.

  The wilting point of the radon barrier and interim layer was estimated for a sandy loam material based on long-term vegetation trends and soil moisture retention characteristics of the native soils as discussed in the Kleinfelder Memo (Reference 11) located in Attachment F. The estimated moisture content of the erosion barrier was increased slightly above the soil wilting point in order to account for exposure to precipitation\ and the presence of vegetation.

- The anticipated radium-226 activity of the interim cover and radon barrier soils was obtained from laboratory test results of native soils provided by Energy Fuels Resource Corporation (Reference 1).

- The long-term tailings gravimetric moisture content was estimated from average moisture content results from the Crescent Junction, Utah disposal site (Reference 10). The long-term gravimetric moisture content of 15 percent was reduced to 12 percent for conservatism in radon barrier design.

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3.0 References

The following references have been peer reviewed. The exact page number, table, or figure will be specified in calculations as they are utilized.

1) Energy Fuels Resource Corporation, "ACZ Laboratories, Inc. Analytical Report", Project ID L68386, April 11, 2008.

2) Energy Fuels Resource Corporation, Email from Mr. Frank Filas, Environmental Manger, titled "Uranium and radiium content of ore and tails at Pinon Ridge", June 3, 2009, 7:19 AM.

3) Golder Associates, Inc., "Phase 2 Geotechnical Field and Laboratory Program, Piñon Ridge Project, Montrose County, Colorado", Project No. 073-81694, March 2008.

4) Golder Associates, Inc., Preliminary Design Drawings:
- File Number 07381694A039, "Tailings Cell A Excavation Grading Plan and Isopach", Drawing 3, Rev. A, dated 03/12/08.
- File Number 07381694A040, "Tailings Cell B Excavation Grading Plan and Isopach", Drawing 4, Rev. A, dated 03/12/08.
- File Number 07381694A042, "Tailings Cell C Excavation Grading Plan and Isopach", Drawing 5, Rev. A, dated 03/12/08.
- File Number 07381694A043, "Tailings Cell Typical Sections", Drawing 6, Rev. A, dated 03/12/08.

5) Golder Associates, Inc., "Project Design Criteria", Revision B, Piñon Ridge Geotechnical Services, Project No. 073-81694, January 15, 2008.

6) Kleinfelder Calculation No. 89241.7 - ALB08CA002, "Volumetrics for Tailings Cell Closure Cover" Rev. 0, Energy Fuels Resource Corporation Piñion Ridge Uranium Mill Project.

7) U.S. Nuclear Regulatory Commission Office of Research, RADON, Version 1.2, May 22, 1989.

8) U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research, "Regulatory Guide 3.64, calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers", June 1989.

9) Kleinfelder Calculation No. 89241.7 - ALB08CA003, "Piñon Ridge Closure Cover Geotechnical and Hydrologic Properties" Rev. 0, Energy Fuels Resource Corporation Piñion Ridge Uranium Mill Project.

References Continued:

10) U.S. Department of Energy, "Final Remedial Action Plan and Site Design for Stabilization of Moab Title I Uranium Mill Tailings at the Crescent Junction, Utah, Disposal Site – Attachment 5: Field and Laboratory Results, Volume I – Appendix A through Appendix K", Office of Environmental Management, MOAB UMTRA Project, February 2008.

11) Kleinfelder Memorandum, "Review of Soil and Vegetation Parameters for Pinon Ridge Closure Cap", Energy Fuels Resource Corporation Piñion Ridge Uranium Mill Project, September 24, 2008.

12) Energy Fuels Resource Corporation, "Energy Laboratories, Inc. Laboratory Analytical Report", March 13 2007, and March 13, 2008.

4.0 Methods

The methods utilized to obtain the applicable design properties are presented in the following subsections.

4.1 General Parameters

The general parameters utilized in the RADON program (Reference 7) for the calculation of the optimized radon barrier thickness are provided in the following sections.

4.1.1 Number of Layers

A total of four layers were utilized for this calculation:

Layer 1 - Tailings	Uranium tailings material from the Piñion Ridge Uranium Mill.
Layer 2 - Interim Cover	The interim cover is utilized as a boundary between the tailings and the radon barrier to provide a stable construction surface for the placement of the radon barrier. It is composed of native soil.
Layer 3 - Radon Barrier	The radon barrier consists of native soil and is placed above the tailings and interim cover to reduce radon release (radon flux) from the surface of the tailings.
Layer 4 - Erosion Barrier/ Vegetative Cover	This is the top most protective layer and consists of native soil with native seed mix.

4.1.2 Radon Flux Limit, J_r

The radon flux limit is the radon-222 release rate at the surface of the radon barrier . This value is regulated by the EPA and the NRC and is averaged over the entire disposal area over a period of at least one year (Reference 8). Based on EPA and NRC regulations, the radon flux should not exceed 20 pCi m^{-2} s^{-1}.

4.1.3 Optimized Layer

The thickness of the radon barrier (Layer 3) was optimized to achieve the required radon flux limit.

4.1.4 Radon Concentration Above Top Layer

The radon concentration at the soil/ air interface above the radon barrier was obtained using the RADON program conservative default value of zero (Reference 8) since measured values were not available.

4.1.5 Lower Boundary Radon Flux

The lower boundary radon flux is the downward radon flux of the soil beneath the tailings material. This value is usually zero for most tailings but the downward flux could reduce the amount of radon available for upward diffusion in a thin tailings layer (Reference 8). The RADON program was utilized to calculate the lower boundary radon flux (assuming and infinitely thick subsoil with no radon source) and adjust the available radon for upward diffusion.

4.1.6 Surface Flux Precision

The surface flux precision is the acceptable level of computation error (determined by the RADON program user) for the radon surface flux calculations. A precision value of 0.001 was utilized for calculations.

4.2 Layer Parameters

The layer parameters utilized in the RADON program (Reference 7) for the calculation of the optimized radon barrier thickness are provided in the following sections. Parameters were calculated for the tailings, interim cover, radon barrier and erosion barrier/ interim cover layers.

4.2.1 Layer Thickness, T

$T_{Tailings}$ = Tailings thickness — Obtained from the design geometry provided by Golder Associates, Inc. (Reference 4). The maximum tailings thickness was reduced by 10% to account for anticipated tailings consolidation.

$T_{Interim}$ = Interim cover thickness — Assumed thickness of approximately 2 feet.

T_{Radon} = Radon barrier thickness — Calculated with the RADON program (Reference 7) to meet EPA and NRC radon flux criteria (Reference 8, page 3.64-1).

$T_{Erosion}$ = Erosion Barrier/ Vegetative Cover Thickness — Assumed thickness of approximately 2 feet.

4.2.2 Specific Gravity, SG

The specific gravity of solids used in the analysis are obtained from Table 5-1 of Reference 9.

4.2.3 Porosity, n

The porosities for the four layers used in the analysis are obtained from Table 5-1 of Reference 9.

The porosity of a layer is given by the following equation:

$$n = 1 - \frac{\gamma_d}{SG\gamma_w}$$

Equation 1 (Reference 8, Page 3.64-7)

where:

SG = specific gravity

γ_d = Dry Density

This relationship was subsequently used to obtain the dry density from the specific gravity of solids and the porosit

4.2.4 Dry Density, γ_d

Equation 1 was used to calculate the dry density of the tailings:

$\gamma_{d\ Tailings} = SG\ (1-n)\ \gamma_w$ **Equation 2 (Reference 8, Page 3.64-7)**

where:

$\gamma_{d\ Tailings}$ = Dry density of tailings

SG = specific gravity of tailings (described in Section 4.2)

n = Porosity of tailings (described in Section 4.3)

γ_w = Density of water

$\gamma_{d\ Interim}$ = Dry density of interim cover — 85% of maximum dry density based on Table 5-1 of Reference 9.

$\gamma_{d\ Radon}$ = Dry density of radon barrier — 95% of maximum dry density based on Table 5-1 of Reference 9.

4.2.5 Tailings Long-Term Gravimetric Moisture Content, m_g

$m_{g\ Tailings}$ = Estimated long-term gravimetric moisture content of tailings — Estimated from average moisture content results from the Crescent Junction, Utah disposal site (Reference 10) and reduced for conservative radon barrier design as stated in Section 2.3.

4.2.6 Long-Term Gravimetric Moisture Content of Interim Layer, Radon Barrier and Erosion Barrier

Calculated from the layer long-term volumetric moisture content and dry density with the following equation:

$$m_{g\ Layer} = \frac{m_{v\ Layer}\ \gamma_w}{\gamma_{d\ Layer}}$$ **Equation 3 (Reference 8, Page 3.64-9)**

where:

$m_{g\ Layer}$ = Long-term gravimetric moisture content of layer

$m_{v\ Layers}$ = Long-term volumetric moisture content of layer

γ_w = Density of water

$m_{g\ Interim}$ = Estimated long-term gravimetric moisture content of interim cover — Based on Equation 3 and a wilting point volumetric moisture content of 13% as discussed in Section 2.3.

$m_{g\ Radon}$ = Estimated long-term gravimetric moisture content of radon barrier — Based on Equation 3 and a wilting point volumetric moisture content of 13% as discussed in Section 2.3.

$m_{g\ Erosion}$ = Estimated long-term gravimetric moisture content of erosion barrier/ vegetative cover — Based on increased value above soil wilting pointas discussed in Section 2.3.

4.2.7 Total Density, γ_t

Calculated by the RADON program (Reference 7) from dry density and the gravimetric moisture content:

$\gamma_t = \gamma_d (1 + m_g)$ **Equation 4**

where:

γ_t = Total (or moist) density

$m_{g\ Layer}$ = Long-term gravimetric moisture content of layer

4.2.8 Moisture Saturation Fraction, m_f

The volumetric fraction of saturation used in the diffusion coefficient calculations presented for the tailings or cover soils is expressed by the moisture saturation fraction:

$$m_f = \frac{\gamma_d m_g}{n \gamma_w}$$ **Equation 5 (Reference 8, Page 3.64-11)**

where:

m_f = Moisture saturation fraction

m_g = Gravimetric moisture content

γ_d = Dry density

γ_w = Density of water

4.2.9 Radon Diffusion Coefficient, D

The radon diffusion coefficient of the tailings and cover soils was calculated using the moisture saturation fraction and porosity (Reference 8) and calculated with the following equation:

$D = 0.07 \exp [-4 * (m_f - m_f * n^2 + m^5)]$ **Equation 5 (Reference 8, Page 3.64-10)**

where:

D = Radon diffusion coefficient (in cm^2/sec)

m_f = Moisture saturation fraction

n = Porosity

4.2.10 Radon Emanation Coefficient, E

The portion of radon that is released from the tailings or cover soil matrix into the pore space is expressed by the radon emanation coefficient (Reference 8). The reference value of 0.35 given in the NRC regulatory guide (Reference 8) was utilized for all materials.

4.2.11 Radium Activity

The uranium tailings activity source term was calculated based on average uranium activities from Reference 12 as discussed in Section 2.3, resulting in an estimated radium-226 activity value of 683 pCi/g. More recent information (Reference 2) indicates that this source term is higher than that estimated from the expected average ore grade of 0.23% U_3O_8 and Reference 8. However, the original value of 683 pCi/g radium-226 was retained in the RADON calculation for conservatism.

5.0 Results and Conclusions

5.1 Radon Barrier Thickness Results

The following sections provide a summary of the calculation results. Detailed calculation inputs and results for each material property scenario are presented in Section 6 and Attachment C through E.

The optimized radon barrier thickness results for the minimum tailings thickness (Scenario 1) and an "infinitely thick" radon source (Scenarios 2 and 3) are presented in Table 5.1 below. Detailed results are presented in Table 5.2 on the following page.

The results presented in Table 5.1 show no difference in optimized radon barrier thickness between the Scenario 2 tailings thickness of 15 feet and the Scenario 3 thickness of 16.4 feet. It was determined that the required radon barrier thickness for a 15 foot tailings section is equivalent to a 16.4 foot section, and that the 15 foot results can represent an infinitely thick radon source.

Table 5.1 - Optimized Radon Barrier Thickness Results

Scenario	Tailings Thickness	Optimized Radon Barrier Thickness
Scenario 1	1 foot	**4.5 feet**
Scenario 2	15 feet	**6.9 feet**
Scenario 3	16.4 feet	**6.9 feet**

Calculation and Analysis Sheet

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Table 5.2 - Detailed Input Parameters and Results *

General Input Parameters					
Number of Layers	Radon Flux Limit (1), pCi m^{-2} s^{-1}	Optimized Layer	Radon Concentration Above Top Layer	Lower Boundary Radon Flux	Surface Flux Precision
4	20	3 (Radon Barier)	0	default (calculated)	0.001

Layer Input Parameters														Results		
Layer #	Material Type	Thickness, cm	Porosity	Dry Density, pcf	Dry Density, g/cc	Radium Activity, R, pCi/ g	Specific Gravity, SG	Volumetric Moisture Content, m_v	Gravimetric Moisture Content, m_g	Total Density (15), g/cc	Moisture Saturation Fraction, m_f (16)	Radon Diffusion Coeff. (cm/sec^2), D (17)	Emanation Coefficient, E (18)			
1	Tailings	30 - 457	0.40 (3)	103 (5)	1.65	683 (7)	2.75 (9)	--	12.0% (12)	1.85	0.50	0.012	default, 0.35	cm	ft	
2	Interim Layer	61	0.39 (4)	100.3 (6)	1.61	0.98 (8)	2.65 (10)	13.0% (11)	8.1% (13)	1.74	0.33	0.022		138.6	4.5	min
3	Radon Barrier	optimized	0.32 (4)	112.1 (6)	1.80	0.98 (8)	2.65 (10)	13.0% (11)	7.2% (13)	1.93	0.41	0.016				
4	Erosion Barrier/ Vegetative Cover	60.96	0.39 (4)	100.3 (6)	1.61	0.98 (8)	2.65 (10)	--	8.0% (14)	1.74	0.33	0.022		209.7	6.9	max

Notes:

* **Table 5.2 References provided on the following page**

= Values input into RADON program

= Values calculated internally by RADON program during radon surface flux calculations.

Table 5.2 References

Ref. #	Explanation	Source
(1)	Radon flux limit	U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research, "Regulatory Guide 3.64, calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers", June 1989 (Reference 8).
(2)	Radon Concentration above top layer: A conservative default value of zero was used since measured values were not available.	U.S. Nuclear Regulatory Commission Office of Research, RADON, Version 1.2, May 22, 1989 (Reference 7).
(3)	Tailings porosity based on Golder Design Criteria.	Golder design criteria (Reference 5).
(4)	Interim layer, radon barrier, and erosion barrier porosity calculated from in-place dry density and a specific gravity of 2.65 as discussed in hydrologic properties calculation.	Kleinfelder Calculation 89241.7 - ALB08CA003 Pinon Closure Cover Geotechnical and Hydrologic Properties (Table 5-1 Reference 9).
(5)	Tailings dry density based on anticipated densification of soils (as discussed in Section 2.3) and site-specific data from Crescent Junction, Utah Disposal Site.	US. DOE. 2008. Final Remedial Action Plan and Site Design for Stabilization of Moab Title 1 Uranium Mill Tailings at the Cresent Junction, Utah, Disposal Site (Reference 10).
(6)	Interim layer, radon barrier, and erosion barrier dry density calculated from in-place dry density and percent compaction as discussed in hydrologic properties calculation.	Kleinfelder Calculation 89241.7 - ALB08CA003 Pinon Closure Cover Geotechnical and Hydrologic Properties (Table 5-1 Reference 9).
(7)	Radium Activity is based upon the average of values for uranium ore from the Slickrock Mine, the Paradox Valley Mine, the Packrat Mine, the Energy Queen Mine, and the Whirlwind Mine. The average value is 683 pCi/g. This value is more conservative than the 647 pCi/g value based on more recently estimated average ore grades (as discussed in Section 4.2.11).	Energy Laboratories, Inc, March 2007 - March 2008. Laboratory Analytical Reports. Energy Fuels Resource Corporation (Reference 12).
(8)	The anticipated radium-226 activity of the interim cover and radon barrier soils was obtained from laboratory test results of native soils provided by Energy Fuels Resource Corporation .	Energy Fuels Resource Corporation. April 11, 2008. "Energy Laboratories, Inc. Laboratory Analytical Report (Reference 1)
(9)	Tailings Specific Gravity based on Golder Design Criteria.	Golder design criteria (Reference 5).
(10)	Interim layer, radon barrier, and erosion barrier specific gravity based typical values for sand as discussed in Reference 9.	Kleinfelder Calculation 89241.7 - ALB08CA003 Pinon Closure Cover Geotechnical and Hydrologic Properties (Table 5-1 Reference 9).
(11)	Volumetric moisture content of interim layer and radon barrier based on wilting point of sandy loam material (wilting point is acceptable estimate for long-term moisture content in NUREG 3.64)	Kleinfelder Memorandum, "Review of Soil and Vegetation Parameters for Pinon Ridge Closure Cap", dated 9/24/08 (Reference 11) and U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research, "Regulatory Guide 3.64, calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers", June 1989 (Reference 8).
(12)	Estimated from average moisture content results from the Crescent Junction, Utah disposal site (Reference 10).	US. DOE. 2008. Final Remedial Action Plan and Site Design for Stabilization of Moab Title 1 Uranium Mill Tailings at the Cresent Junction, Utah, Disposal Site (Reference 10).
(13)	Gravimetric moisture content of interim layer and radon barrier calculated from volumetric moisture content and dry density.	Section 4.2.6 Equation 3
(14)	Gravimetric moisture content of erosion barrier was inreased slightly above wilting point values for native soils.	Kleinfelder Memorandum, "Review of Soil and Vegetation Parameters for Pinon Ridge Closure Cap", dated 9/24/08 (Reference 11).
(15)	Total density calculated from dry density and gravimetric moisture content.	Section 4.2.7 Equation 4
(16)	Moisture saturation fraction calculated from total density, gravimetric moisture content and porosity.	U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research, "Regulatory Guide 3.64, calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers", June 1989 (Reference 8).
(17)	Radon diffusion coefficient calculated from moisture saturation fraction and porosity.	U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research, "Regulatory Guide 3.64, calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers", June 1989 (Reference 8).
(18)	The reference value of given in the NRC regulatory guide was utuilized for the emanation coefficient.	U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research, "Regulatory Guide 3.64, calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers", June 1989 (Reference 8).

6.0 Calculations and Analysis

The calculations for moisture contents used in the Radon program are presented in Attachment D.
The calculations for the diffusion coefficient are presented in Attachment E.

6.1 General Parameters

6.1.1 Number of Layers

Four layers were utilized for this calculation: the tailings layer, interim cover, radon barrier and erosion barrier/ vegetative cover. Note that the erosion barrier/vegetative cover has the same properties as the interim cover.

6.1.2 Radon Flux Limit, J_c

Jc = 20 pCi m^{-2} s^{-1} Based on EPA and NRC regulations (Reference 8).

6.1.3 Optimized Layer

Optimized layer = Radon barrier (Layer 3)

6.1.4 Radon Concentration Above Top Layer

Radon concentration above top layer = 0 Based on EPA and NRC default values (Reference 8) as discussed in section 4.1.4.

6.1.5 Lower Boundary Radon Flux

The lower boundary radon flux was calculated by the RADON program and adjusted the available radon for upward diffusion during radon flux computations.

6.1.6 Surface Flux Precision

Surface flux precision = 0.001 Acceptable level of computation error as discussed in Section 4.1.6.

6.2 Layer Parameters

The calculations for the dry density, the gravimetric moisture content used in the RADON Program, and the moistu fraction for each of the layers are presented in Attachment D: "Analysis of Moisture Contents for Radon Barrier Analysis".

6.2.1 Radon Diffusion Coefficient

The radon diffusion coefficient, D, for each of the layers based upon the porosity and moisture fraction for each layer is presented in Attachment E: "Verification of Cell Formulas for Diffusion Coefficient Calculation".

6.2.2 Radon Emanation Coefficient, E

The reference value given in the NRC regulatory guide (Reference 8) utilized for all materials is 0.35.

6.2.3 Radium Activity Source Term for Uranium Tailings

The following radium activities were obtained for use in the RADON model from Reference 12. These values yield a more conservative average than the 647 pCi/g value based on more recently estimated average ore grades.

Mine	Value (pCi/g)
Slickrock Mine	335
Paradox Valley	274
Packrat Mine	334
Energy Queen Mine	2070
Whirlwind Mine 1	113
Whirl Wind Mine 2	1170
	482
Average	**683**

6.2.4 Radium Activity

Obtained from laboratory test results of native soils provided by Energy Fuels Resource Corporation (Reference 2):

$RA_{Interim}$ & RA_{Radon} = 0.98 pCi/g

6.7 Optimized Radon Barrier Thickness, T_{Radon}

The radon barrier thickness optimized to meet EPA and NRC radon flux criteria (Reference 8, page 3.64-1) was calculated with the RADON program with the input values given in Section 6. The radon barrier thickness optimized to meet EPA and NRC radon flux criteria (Reference 8, page 3.64-1) was:

Scenario 1 T_{Radon} = 138.6 cm = 4.5 ft

Scenario 2 T_{Radon} = 209.7 cm = 6.9 ft

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Checker:	John B. Case	John B. Case	10/14/09
	Print Name	Signature	Date

ATTACHMENT A

RADON Program Listing

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	Print Name	Signature	Date

```
10 KEY OFF : COLOR 15,1,0 : CLS
20 PRINT "                    -----*****! RADON !*****-----" :PRINT
30 PRINT "Version 1 - April 1, 1986 - G.F. Birchard -  tel.# (301) 492-7000"
40 PRINT "U.S. Nuclear Regulatory Commission Office of Research" : PRINT
50 PRINT "          RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS",
60 PRINT "                    ARE CALCULATED FOR MULTIPLE LAYERS"  : PRINT
70 ON ERROR GOTO 90
80 GOTO 120
90  PRINT "CHECK THE PRINTER & PRESS ANY KEY TO CONTINUE"
100  V$=INPUT$(1)
110  RESUME NEXT
120 LPRINT "                    -----*****! RADON !*****-----" : LPRINT
130 LPRINT "Version 1 - April 1, 1986 - G.F. Birchard tel.# (301) 492-7000"
140 LPRINT "U.S. Nuclear Regulatory Commission Office of Research" : LPRINT
150 ON ERROR GOTO 0
160 LPRINT "         RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS",
170 LPRINT "                    ARE CALCULATED FOR MULTIPLE LAYERS" : LPRINT
180 INPUT "TITLE OF THIS DATA SET";TITLE$ : LPRINT :LPRINT TITLE$ :LPRINT
190 DEFDBL A-H,O-Z : DEFINT I-N
200 DIM D(50),DX(50),P(50),Q(50),XM(99) 'INPUT VARIABLES
210 DIM AB(50),AIP1MI(50),ALP(50),RHO(50),X(50),XMS(99) 'COMPUTATION VARIABLES
220 DIM A4(50),DDX(50),RC(50),RF(50) 'OUTPUT VARIABLES
230 DIM A(245),AS(50),B(99),BS(50),BU(99),G(245),R(50),RR(50),T(50),U(50)          'MATRIX
VARIABLES
240 XL=.0000021# : PC=.26# : SG=2.65#    'CONSTANTS
250 PRINT "TYPE Y TO INPUT INTERACTIVELY OR N TO READ INPUT FROM DRIVE A:"
260 W$=INPUT$(1)
270 IF W$="y" OR W$="Y" GOTO 290
280 IF W$="N" OR W$="n" GOTO 1750 ELSE 250
290 LPRINT :LPRINT " ","CONSTANTS" :LPRINT
300 PRINT :PRINT " ","CONSTANTS" :PRINT
310 LPRINT "RADON DECAY CONSTANT"," ",XL,"1/s"
320 PRINT "RADON DECAY CONSTANT",      " ",XL,"1/s"
330 LPRINT "RADON WATER/AIR PARTITION COEFFICIENT",PC
340 PRINT "RADON WATER/AIR PARTITION COEFFICIENT",PC
350 LPRINT "SPECIFIC GRAVITY OF COVER & TAILINGS",SG,"g/cm^3" :LPRINT
360 PRINT "SPECIFIC GRAVITY OF COVER & TAILINGS",SG,"g/cm^3" :PRINT
370 PRINT " ","GENERAL INPUT PARAMETERS" : PRINT
380 LPRINT : LPRINT " ","GENERAL INPUT PARAMETERS" : LPRINT
390 PRINT "ENTER -1 TO USE DEFAULT VALUES WHICH ARE SPECIFIED IF THEY EXIST."
```

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Checker:	John B. Case	John B. Case	10/14/09

```
400 INPUT "NUMBER OF LAYERS COVER AND TAILINGS";N
410 IF N<2 GOTO 420 ELSE IF N>99 GOTO 430 ELSE 440
420 PRINT "TWO LAYERS MINIMUM PLEASE" : GOTO 400
430 PRINT "NINETY-NINE LAYERS MAXIMUM PLEASE" : GOTO 400
440 LPRINT "LAYERS OF COVER AND TAILINGS",N : GOTO 460
450 PRINT "THE LAYER THICKNESS CANNOT BE OPTIMIZED WITHOUT A FLUX LIMIT"
460 INPUT "RADON FLUX LIMIT (pCi*m^-2/s) default=20, enter 0 for no limit";CRITJ
470 IF CRITJ<0# THEN CRITJ=20# : PRINT "DEFAULT FLUX LIMIT ASSIGNED"
480 IF CRITJ=0 THEN LPRINT "NO LIMIT ON RADON FLUX" : GOTO 510
490 LPRINT "DESIRED RADON FLUX LIMIT"," ",CRITJ,"pCi*m^-2/s" :GOTO 510
500 PRINT "THE LAYER NUMBER CANNOT EXCEED THE NUMBER OF LAYERS.
510 INPUT "THE LAYER NUMBER FOR THICKNESS OPIMIZATION 0=no optimization";ICOST
520 IF CRITJ=0 AND ICOST>0 GOTO 450
530 IF ICOST=0 THEN LPRINT "LAYER THICKNESS NOT OPTIMIZED" :GOTO 570
540 IF ICOST<=1 THEN PRINT "THE LOWEST LAYER CANNOT BE OPTIMIZED" :GOTO 510
550 IF ICOST>N GOTO 500
560 LPRINT "NO. OF THE LAYER TO BE OPTIMIZED",ICOST
570 INPUT "RADON CONCENTRATION ABOVE TOP LAYER (pCi/l) default=0";CN1
580 IF CN1<0 THEN CN1=0
590 IF CN1=0 THEN LPRINT "DEFAULT SURFACE RADON CONCENTRATION",CN1,"pCi/l"
600 IF CN1>0 THEN LPRINT "MEASURED SURFACE RADON CONCENTRATION",CN1,"pCi/l"
610 INPUT "LOWER BOUNDARY RADON FLUX (pCi*m^-2/s) default=calculation";F01
620 IF F01=-1 GOTO 630 ELSE 650
630 PRINT "LOWER BOUNDARY FLUX TO BE CALCULATED ASSUMING AN INFINITE SUBSOIL
640 GOTO 660
650 LPRINT "RADON FLUX INTO LAYER 1"," ",F01,"pCi*m^-2/s"
660 INPUT "SURFACE FLUX PRECISION (pCi*m^-2/s)  This number is the acceptable          level of
computation error.";ACC
670 IF 1<ACC OR ACC<0 GOTO 680  ELSE 700
680 PRINT "THE SURFACE FLUX PRECISION SHOULD BE BETWEEN 0 AND 1"
690 GOTO 660
700 LPRINT "SURFACE FLUX PRECISION"," ",ACC,"pCi*m^-2/s"
710 PRINT : PRINT " ","LAYER INPUT PARAMETERS" : PRINT
720 LPRINT : LPRINT : LPRINT " ","LAYER INPUT PARAMETERS" :LPRINT
730 FOR I=1 TO N
740  PRINT USING "LAYER #";I : PRINT :PRINT
750  LPRINT USING "LAYER #";I : LPRINT :LPRINT
760  INPUT "LAYER THICKNESS (cm)";DX(I)
770  IF DX(I)<0 THEN PRINT "THE THICKNESS CANNOT BE NEGATIVE" : GOTO 760
780  LPRINT "LAYER THICKNESS"," ",DX(I),"cm"
```

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	Print Name	Signature	Date

```
790  INPUT "LAYER POROSITY  default =.40. Enter a value >1 to calculate porosity     ";P(I)
800  IF P(I)>1 GOTO 820 ELSE IF P(I)=-1 GOTO 880 ELSE IF P(I)<0 GOTO 890
810  GOTO 910
820  INPUT "LAYER DENSITY";RHO(I)
830  IF RHO(I)<1 OR RHO(I)>3 GOTO 840 ELSE 860
840  PRINT "ACCEPTABLE DENSITY VALUES ARE BETWEEN 1 AND 3. PLEASE REENTER"
850  GOTO 820
860  P(I)=1-RHO(I)/SG
870  LPRINT "CALCULATED LAYER POROSITY "," ",P(I) :GOTO 980
880  P(I)=.4# : LPRINT "DEFAULT LAYER POROSITY"," ",P(I) : GOTO 920
890  PRINT "THE POROSITY VALUE CANNOT BE NEGATIVE. PLEASE REENTER."
900  GOTO 800
910  LPRINT "LAYER POROSITY "," ",P(I)
920  INPUT "LAYER DENSITY default=calculated";RHO(I)
930  IF RHO(I)=-1 GOTO 940 ELSE IF RHO(I)<1 OR RHO(I)>3 GOTO 960 ELSE 980
940  RHO(I)=SG*(1-P(I))
950  LPRINT "CALCULATED LAYER DENSITY"," ",RHO(I),"g/cm^3" : GOTO 990
960  PRINT "ACCEPTABLE DENSITY VALUES ARE BETWEEN 1 AND 3. PLEASE REENTER"
970  GOTO 920
980  LPRINT "MEASURED LAYER DENSITY"," ",RHO(I),"g/cm^3"
990  PRINT "CHOOSE TO ENTER EITHER THE RADON SOURCE TERM CONCENTRATION ,
THE ORE GRADE % OR RADIUM ACTIVITY"
1000  PRINT "TYPE S FOR SOURCE TERM G FOR ORE GRADE OR R FOR RADIUM ACTIVITY"
1010  QQ$=INPUT$(1)
1020  IF QQ$="S" GOTO 1230 ELSE IF QQ$="s" GOTO 1230
1030  IF QQ$="G" GOTO 1060 ELSE IF QQ$="g" GOTO 1060
1040  IF QQ$="R" GOTO 1100 ELSE IF QQ$="r" GOTO 1100 ELSE 1000
1050  PRINT "THE ORE GRADE % MUST BE BETWEEN 0 AND 100. PLEASE REENTER"
1060  INPUT "ORE GRADE PERCENTAGE";OG :IF OG<0 OR OG>100 GOTO 1050
1070  LPRINT "ORE GRADE PERCENTAGE"," ",OG,"%"
1080  RA=OG*2812#
1090  LPRINT "CALCULATED RADIUM ACTIVITY"," ",RA,"pCi/g" :GOTO 1130
1100  INPUT "RADIUM ACTIVITY (pCi/g)";RA
1110  IF RA<0 THEN PRINT "THE RADIUM ACTIVITY CANNOT BE NEGATIVE" :GOTO 1100
1120  LPRINT "MEASURED RADIUM ACTIVITY"," ",RA,"pCi/g"
1130  INPUT "LAYER EMANATION COEFFICIENT default=.35";E
1140  IF E=-1 GOTO 1150 ELSE IF E<0 OR E>1 GOTO 1160 ELSE 1180
1150  E=.35# : LPRINT "DEFAULT LAYER EMANATION COEFFICIENT",E : GOTO 1190
1160  PRINT "THE EMANATION COEFFICIENT MUST BE BETWEEN 0 AND 1."
1170  GOTO 1130
```

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	Print Name	Signature	Date

```
1180  LPRINT "MEASURED LAYER EMANATION COEFFICIENT",E
1190  Q(I)=XL*RA*E*RHO(I)/P(I)
1200  PRINT "CALCULATED LAYER SOURCE TERM",Q(I)
1210  LPRINT "CALCULATED LAYER SOURCE TERM",
1220  LPRINT USING "##.###^^^^    ";Q(I), :LPRINT "pCi*cm^-3/s" :GOTO 1270
1230  INPUT "SOURCE TERM (pCi*cm^-3/s)";Q(I)
1240  IF Q(I)<0 GOTO 1250 ELSE 1260
1250  PRINT "THE SOURCE TERM CANNOT BE NEGATIVE." :GOTO 1230
1260  LPRINT "MEASURED LAYER SOURCE TERM"," ",Q(I),"pCi*cm^-3/s"
1270  INPUT "LAYER WEIGHT % MOISTURE";XM(I)
1280  IF XM(I)<0 OR XM(I)>100 GOTO 1290 ELSE 1310
1290  PRINT "THE WEIGHT % MOISTURE MUST BE BETWEEN 0 AND 100. "
1300  GOTO 1270
1310  LPRINT "LAYER WEIGHT % MOISTURE"," ", XM(I), "%"
1320  XMS(I)=.01*XM(I)*RHO(I)/P(I)
1330  LPRINT "MOISTURE SATURATION FRACTION", :LPRINT USING " .###";XMS(I)
1340  IF XMS(I)>1! GOTO 1350 ELSE 1370
1350  PRINT "THE MOISTURE CONTENT IS >100% SATURATION. PLEASE REENTER."
1360  LPRINT "MOISTURE SATURATION >100%. NEW VALUE REQUESTED." :GOTO 1270
1370  INPUT "LAYER DIFFUSION COEFFICIENT default=calculated ";D(I)
1380  IF D(I)=-1 GOTO 1410  ELSE IF D(I)<0 OR D(I)>1 GOTO 1390 ELSE 1440
1390  PRINT "REENTER DIFFUSION COEFFICIENT VALUES BETWEEN 0 AND 1.
1400  GOTO 1370
1410  D(I)=.07*EXP(-4*(XMS(I)-XMS(I)*P(I)*P(I)+XMS(I)^5))
1420  LPRINT "CALCULATED LAYER DIFFUSION COEFFICIENT",
1430  LPRINT USING "##.###^^^^    ";D(I), :LPRINT "cm^2/s" :GOTO 1450
1440  LPRINT "MEASURED LAYER DIFFUSION COEFFICIENT",D(I),"cm^2/s"
1450  PRINT : PRINT : LPRINT : LPRINT
1460  IF I=2 OR I=5 AND N=5 OR I=6 OR I>8 THEN LPRINT CHR$(12)
1470 NEXT I
1480 ON ERROR GOTO 1500
1490 GOTO 1510
1500  IF ERR=53 GOTO 1540
1510 PRINT "THE BACKUP FILE RNDATA.BAK WILL BE REPLACED IF IT EXISTS UNLESS N IS
TYPED. TYPE ANY OTHER KEY TO CONTINUE. IF N IS TYPED THE INPUT DATA          WILL NOT
BE SAVED."
1520 V$=INPUT$(1)
1530 IF V$="N" OR V$="n" GOTO 1980 ELSE GOTO 1550
1540 RESUME NEXT
1550 KILL "A:RNDATA.BAK"
```

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Checker:	John B. Case	John B. Case	10/14/09
	Print Name	Signature	Date

```
1560 ON ERROR GOTO 1580
1570 GOTO 1600
1580  IF ERR=53 THEN PRINT "BACKING UP RNDATA"
1590  RESUME NEXT
1600 NAME "A:RNDATA" AS "A:RNDATA.BAK"
1610 ON ERROR GOTO 0
1620 OPEN "A:RNDATA" FOR OUTPUT AS #2
1630 PRINT #2,USING " ##.# ";N;
1640 PRINT #2,USING " ##.###^^^^";F01;CN1;
1650 PRINT #2,USING " ##.# ";ICOST;
1660 PRINT #2,USING " ##.###^^^^";CRITJ;ACC
1670 FOR I=1 TO N
1680  PRINT #2,USING " ##.###^^^^";DX(I);D(I);P(I);Q(I);XMS(I);RHO(I)
1690 NEXT I
1700 CLOSE #2
1710 LPRINT :LPRINT :LPRINT
1720 LPRINT " ","DATA SENT TO THE FILE `RNDATA' ON DRIVE A:" :LPRINT
1730 GOSUB 1850
1740 GOTO 1980
1750 OPEN "A:RNDATA" FOR INPUT AS #3
1760 INPUT #3,N,F01,CN1,ICOST,CRITJ,ACC
1770 FOR I=1 TO N
1780  INPUT #3,DX(I),D(I),P(I),Q(I),XMS(I),RHO(I)
1790 NEXT I
1800 CLOSE #3
1810 LPRINT :LPRINT :LPRINT
1820 LPRINT " ","DATA INPUT TO DIFFUSION CALCULATIONS" : LPRINT
1830 GOSUB 1850
1840 GOTO 1980
1850  ' PRINT SUBROUTINE
1860  LPRINT "  N       F01       CN1       ICOST      CRITJ       ACC"
1870  LPRINT USING "###  ";N; :  LPRINT USING " ##.###^^^^";F01;CN1;
1880  LPRINT USING "    ###    ";ICOST;
1890  LPRINT USING " ##.###^^^^";CRITJ;ACC : LPRINT
1900  LPRINT "LAYER      DX         D          P          Q         XMS      RHO      "
1910  FOR I=1 TO N
1920   LPRINT USING "###  ";I;
1930   LPRINT USING " ##.###^^^^";DX(I);D(I);P(I);Q(I);XMS(I);
1940   LPRINT USING "###.###";RHO(I)
1950  NEXT I
```

```
1960  LPRINT : IF N=4 OR N=8 OR N>11 THEN LPRINT CHR$(12)
1970 RETURN  'END PRINT SUBROUTINE
1980   ' END DATA INPUT MODULE BEGIN RAECOM MODULE
1990 NO3=0
2000 IF ICOST>0 THEN NO3=ICOST : ICOST=1
2010 ITHK=0
2020 NO2=NO3-1 : NO1=NO2-1 : NO4=NO3+1
2030 NM1=N-1 : NM2=N-2 : JTST=1
2040 F0=F01/10000
2050 CN=CN1/1000
2060 CRITJ=CRITJ/10000
2070 FOR I=1 TO N
2080  A4(I)=1-.74*XMS(I)
2090 NEXT I
2100 AB=SQR(XL/D(1))
2110 V=AB*DX(1)
2120 GOSUB 4000
2130 RF(1)=(Q(1)*P(1)/AB)*FNTANH(V)
2140 IF F01=-1 GOTO 2150 ELSE 2170
2150 RF(1)=RF(1)/(1+(.5*FNTANH(V))/.5/(EXP(V)+EXP(-V)))
2160 F0 =-.5*RF(1)*FNTANH(V)
2170 DDX(1)=DX(1)
2180 RC(1)=CN/A4(1)
2190 J0#=RF(1)*10000
2200 PRINT : LPRINT
2210 PRINT USING "BARE SOURCE FLUX FROM LAYER 1:   ##.###^^^^ pCi*cm^-3/s";J0#
2220 LPRINT USING "BARE SOURCE FLUX FROM LAYER 1:   ##.###^^^^ pCi*cm^-3/s";J0#
2230 PRINT "calculation in progress"
2240 FOR I=1 TO N
2250  Q(I)=Q(I)*P(I)
2260  P(I)=P(I)*A4(I)
2270  D(I)=D(I)*P(I)
2280 NEXT I
2290 DDX(1)=DX(1)
2300 ALP(1)=SQR(XL*P(1)/D(1))
2310 FOR I=2 TO N 'THICKNESS OPTIMIZATION FEEDS BACK HERE
2320  DDX(I)=DX(I)
2330 NEXT I
2340 ' MODIFY PARAMETERS FOR PROGRAM LIMITS
2350 SUMX=0 : SUMA=0 : SUMAX=0 : XRED=0 : XCHG=0 : X(1)=0 : X0=0
```

```
2360 SUMMAX=ALP(1)*DX(1)
2370 IF SUMMAX>4.61 THEN XRED=4.61/ALP(1) ELSE GOTO 2400
2380 F0=F0*EXP(4.61-SUMMAX)
2390 SUMMAX=ALP(1)*(DX(1)-XRED)
2400 IF XRED>0 THEN XCHG=DX(1)-XRED
2410 FOR I=1 TO N
2420  ALPI=SQR(XL*P(I)/D(I))
2430  SUMX=SUMX+DX(I)
2440  X(I+1)=SUMX-XCHG
2450  SUMA=SUMA+ALPI
2460  ALSUM=ALPI*X(I+1)
2470  IF ALSUM>SUMMAX THEN SUMMAX=ALSUM
2480  SUMAX=SUMAX+ALSUM
2490  ALP(I)=ALPI
2500 NEXT I
2510 IF SUMMAX>174 GOTO 2520 ELSE 2540
2520 LPRINT "THE LAYER THICKNESS OR DIFFUSION COEFFICIENT EXCEEDS LIMITS"
2530 LPRINT
2540 IF SUMMAX>87 THEN X0=SUMAX/SUMA : ELSE GOTO 2580
2550 FOR I=0 TO N
2560  X(I+1)=X(I+1)-X0
2570 NEXT I
2580 ' CALCULATE PARAMETERS FOR MATRIX
2590 FOR I=1 TO NM1
2600  RDUM=SQR(P(I+1)*D(I+1)/(P(I)*D(I)))
2610  R(I)=-.5*(1-RDUM)
2620  RR(I)=-.5*(1+RDUM)
2630  QP=(Q(I+1)/P(I+1)-Q(I)/P(I))/XL
2640  T(I)=QP*EXP(-ALP(I)*X(I+1))
2650  U(I)=QP*.5*EXP(ALP(I)*X(I+1))
2660  AIP1MI(I)=SQR(XL)*(SQR(P(I+1)/D(I+1))-SQR(P(I)/D(I)))
2670 NEXT I
2680 ALP(N)=SQR(XL*P(N)/D(N))
2690 'SPECIFY MATRIX ELEMENTS AND SOLVE
2700 FOR I=1 TO NM1
2710  J=5*I-4
2720  K=2*I-1
2730  A(J)=EXP(-2*ALP(I)*X(I+1))
2740  A(J+1)=-EXP(AIP1MI(I)*X(I+1))
2750  A(J+2)=-EXP(-(ALP(I+1)+ALP(I))*X(I+1))
```

```
2760  A(J+3)=R(I)*EXP((ALP(I+1)+ALP(I))*X(I+1))
2770  A(J+4)=RR(I)*EXP(-AIP1MI(I)*X(I+1))
2780  B(K)=T(I)
2790  B(K+1)=U(I)
2800 NEXT I
2810 N5M4=5*N-4
2820 A(N5M4)=EXP(-2*ALP(N)*X(N+1))
2830 N2M1=2*N-1
2840 B(N2M1)=(CN-Q(N)/(P(N)*XL))*EXP(-ALP(N)*X(N+1))
2850 'UPPER TRIANGULARIZE MATRIX
2860 G(1)=A(1)+EXP(-2*ALP(1)*X(1))
2870 G(2)=A(2)/G(1)
2880 G(3)=A(3)/G(1)
2890 BU(1)=(B(1)+F0*EXP(-ALP(1)*X(1))/(D(1)*ALP(1)))/G(1)
2900 FOR I=1 TO NM2
2910  J=5*I-1
2920  K=2*I
2930  G(J)=A(J)-G(J-2)
2940  G(J+1)=(A(J+1)-G(J-1))/G(J)
2950  BU(K)=(B(K)-BU(K-1))/G(J)
2960  G(J+2)=A(J+2)-G(J+1)
2970  G(J+3)=A(J+3)/G(J+2)
2980  G(J+4)=A(J+4)/G(J+2)
2990  BU(K+1)=(B(K+1)-BU(K))/G(J+2)
3000 NEXT I
3010 N5M6=5*N-6
3020 G(N5M6)=A(N5M6)-G(N5M6-2)
3030 G(N5M6+1)=(A(N5M6+1)-G(N5M6-1))/G(N5M6)
3040 N2M2=2*N-2
3050 BU(N2M2)=(B(N2M2)-BU(N2M2-1))/G(N5M6)
3060 G(N5M6+2)=A(N5M6+2)-G(N5M6+1)
3070 BS(N)=(B(N2M1)-BU(N2M1-1))/G(N5M6+2)
3080 AS(N)=BU(N2M1-1)-G(N5M6+1)*BS(N)
3090 FOR I=1 TO NM2
3100  J=5*(N-I)-3
3110  K=2*(N-I)-1
3120  L=N-I
3130  BS(L)=BU(K)-G(J)*AS(L+1)-G(J+1)*BS(L+1)
3140  AS(L)=BU(K-1)-G(J-2)*BS(L)
3150 NEXT I
```

Project No.: 89241 **Page** A-10 **of** A-12

Calculation No.: 89241.7 - ALB08CA001 **Rev.:** 1

Calculation Title: Radon Barrier Cover Thickness Design

Originator:	Courtney Vallejo	Courtney Vallejo	10/14/09
	Print Name	Signature	Date
Checker:	John B. Case	John B. Case	10/14/09
	Print Name	Signature	Date

```
3160 BS(1)=BU(1)-G(2)*AS(2)-G(3)*BS(2)
3170 AS(1)=(BS(1)*EXP(-ALP(1)*X(1))-F0/(ALP(1)*D(1)))*EXP(-ALP(1)*X(1))
3180 'COMPLETE MATRIX SOLUTION
3190 FOR I=1 TO N
3200  ALPI=ALP(I)*X(I+1)
3210  ASI=AS(I)*EXP(ALPI)
3220  BSI=BS(I)*EXP(-ALPI)
3230  RC(I)=ASI+BSI+Q(I)/(P(I)*XL)
3240  RF(I)=-D(I)*ALP(I)*(ASI-BSI)
3250 NEXT I
3260 RC(N)=CN
3270 IF ICOST=0 GOTO 3650
3280 F0P=F0
3290 IF F0<1 THEN F0P=1
3300 IF RF(1)<0 OR RF(1)=0 THEN RF(1)=1
3310  'BEGIN COVER THICKNESS OPTIMIZATION
3320 IF JTST=0 OR CRITJ>99 OR NOT CRITJ>0 GOTO 3650
3330 T7=(RF(N)-CRITJ)/CRITJ
3340 ABT7=ABS(T7)
3350 IF ABT7<ACC GOTO 3650
3360 NTST=NO3
3370 IIJ=NO2
3380 IF NTST=NSAVE GOTO 3410
3390 DXMAX=0 : DXMIN=0 : RFMAX=0 : RFMIN=0
3400 NSAVE=NTST
3410 'SET LIMITS AND SEARCH FOR DX
3420 IF T7=0 GOTO 3650
3430 IF T7<0 THEN DXMAX=DX(NTST) ELSE 3450
3440 RFMIN=RF(N) : GOTO 3460
3450 DXMIN=DX(NTST) : RFMAX=RF(N)
3460 IF DXMAX=0 GOTO 3470 ELSE 3480
3470 DX(NTST)=DX(NTST)*(1+.5*T7) : GOTO 3490
3480 DX(NTST)=DXMIN+(DXMAX-DXMIN)*(RFMAX-CRITJ)/(RFMAX-RFMIN)
3490 IF RFMAX=0 THEN DX(NTST)=.5*DXMAX
3500 IF NOT DX(NTST)>1 THEN DX(NTST)=0 AND JTST=0
3510 IF ITHK=0 GOTO 2310
3520 T2T=0
3530 IF NO4>N GOTO 3570
3540 FOR IJ=NO4 TO N
3550  T2T=T2T+DX(IJ)
```

```
3560 NEXT IJ
3570 IF NO1<2 GOTO 3610
3580 FOR IJ=2 TO NO1
3590 T2T=T2T+DX(IJ)
3600 NEXT IJ
3610 T23=DX(NTST)
3620 T2T=T2T+DX(NTST)
3630 IF NOT DX(NTST)=T23 THEN CRITJ=-1
3640 GOTO 2310
3650 'PRINT RESULTS
3660 PRINT : PRINT "    RESULTS OF RADON DIFFUSION CALCULATIONS" : PRINT
3670 PRINT "  LAYER    THICKNESS    EXIT FLUX    EXIT CONC.",
3680 PRINT "             (cm)     (pCi/m^2/s)    (pCi/l) " : LPRINT
3690 FOR I=1 TO N
3700 RXYZ=RF(I)*10000
3710 CXYZ=RC(I)*1000*A4(I)
3720  PRINT USING "  ###  ";I;
3730  PRINT USING "   ##.###^^^^";DDX(I);RXYZ;CXYZ
3740 NEXT I
3750 LPRINT :LPRINT
3760 LPRINT " ","RESULTS OF THE RADON DIFFUSION CALCULATIONS"
3770 LPRINT :LPRINT
3780 LPRINT " ","LAYER    THICKNESS    EXIT FLUX    EXIT CONC."
3790 LPRINT " ","           (cm)     (pCi/m^2/s)    (pCi/l) "
3800 LPRINT
3810 FOR I=1 TO N
3820  RXYZ=RF(I)*10000
3830  CXYZ=RC(I)*1000*A4(I)
3840  LPRINT " ", : LPRINT USING "###  ";I;
3850  LPRINT USING "   ##.###^^^^";DDX(I);RXYZ;CXYZ
3860 NEXT I
3870 LPRINT CHR$(12)
3880 END
4000 IF V<-9.01 GOTO 4120 'THIS SUBROUTINE CALCULATES TANH
4010 IF V<-.7 THEN GOTO 4100
4020 IF ABS(V)<=2^-12 THEN GOTO 4060
4030 IF ABS(V)<=.7 THEN GOTO 4070
4040 IF V<=9.01 THEN GOTO 4080
4050 IF V>9.01 THEN GOTO 4090
4060 DEF FNTANH(V)=V :RETURN
```

CALCULATION AND ANALYSIS SHEET

Project No.: 89241 **Page** A-12 **of** A-12

Calculation No.: 89241.7 - ALB08CA001 **Rev.:** 1

Calculation Title: Radon Barrier Cover Thickness Design

Originator:	Courtney Vallejo	Courtney Vallejo	10/14/09
	Print Name	Signature	Date
Checker:	John B. Case	John B. Case	10/14/09
	Print Name	Signature	Date

```
4070 DEF FNTANH(V)=V*(1-V^2*(.0037828+.8145651/(V^2+2.471749))) :RETURN
4080 DEF FNTANH(V)=1-2/(EXP(V)*EXP(V)+1) :RETURN
4090 DEF FNTANH(V)=1 :RETURN
4100 V=-V
4110 DEF FNTANH(V)=-(1-2/(EXP(V)*EXP(V)+1)):RETURN
4120 V=-V
4130 DEF FNTANH(V)=-1 :RETURN  'END OF SUBROUTINE TANH
```

Project No.: 89241 **Page** B-1 **of** B-2

Calculation No.: 89241.7 - ALB08CA001 **Rev.:** 1

Calculation Title: Radon Barrier Cover Thickness Design

Originator:	Courtney Vallejo	Courtney Vallejo	10/14/09
	Print Name	Signature	Date
Checker:	John B. Case	John B. Case	10/14/09
	Print Name	Signature	Date

ATTACHMENT B

Verification of RADON Code

Project No.:	89241	**Page** B-2	**of** B-2
Calculation No.:	89241.7 - ALB08CA001	**Rev.:**	1
Calculation Title:	Radon Barrier Cover Thickness Design		

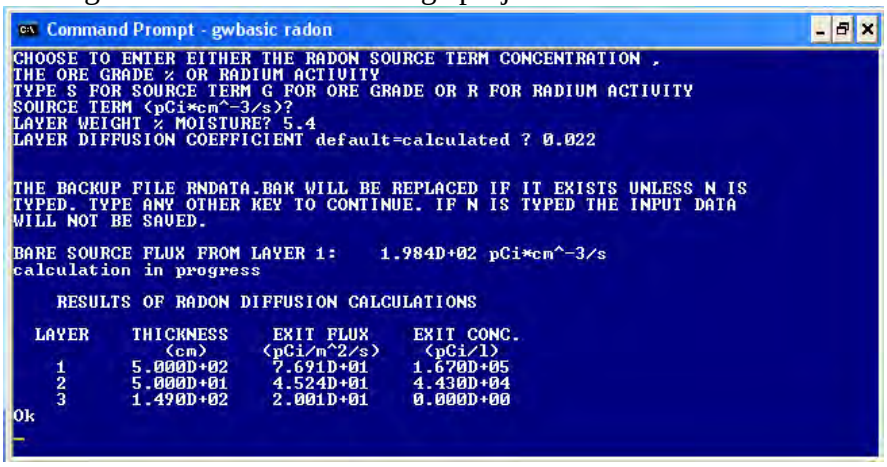
Originator:	Courtney Vallejo	Courtney Vallejo	10/14/09
	Print Name	Signature	Date
Checker:	John B. Case	John B. Case	10/14/09
	Print Name	Signature	Date

Verification of RADON CODE

The Radon Computer code is a basic program that calculates radon flux attenuation for earthen uranium mill tailings covers. The source listing for this code is documented in TABLE 1B RADON Program LISTING (Attachment A) in NRC REGULATORY GUIDE 3.64 entitled "Calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers" dated June 1989 (Reference 8). The regulatory guide presents information on the determination of fundamental input parameters and cover thickness calculations. Table 2B of Reference 8 presents a sample problem for a three layer system that is used for verification and validation of the software.

The program runs in the COMMAND prompt in Windows XP [Version 5.1.2600]. The program listing is presented in the file RADON.BAS. The program is run interactively in the command prompt by using the GWBASIC interpreter with the command GWBASIC RADON. The program executes with the presentation of a menu screen in which fundamental parameters for the RADON calculation are input. Note that several of the parameters have default values.

The program was executed at the COMMAND prompt with inputs from Table 2B. The results of the analysis are captured in the command prompt window below. The results of the analysis are in agreement with the results in Table 2B of Reference 8, and the program is verified for its intended use of sizing covers for the Piñon Ridge project.



```
Command Prompt - gwbasic radon
CHOOSE TO ENTER EITHER THE RADON SOURCE TERM CONCENTRATION ,
THE ORE GRADE % OR RADIUM ACTIVITY
TYPE S FOR SOURCE TERM G FOR ORE GRADE OR R FOR RADIUM ACTIVITY
SOURCE TERM (pCi*cm^-3/s)?
LAYER WEIGHT % MOISTURE? 5.4
LAYER DIFFUSION COEFFICIENT default=calculated ? 0.022


THE BACKUP FILE RNDATA.BAK WILL BE REPLACED IF IT EXISTS UNLESS N IS
TYPED. TYPE ANY OTHER KEY TO CONTINUE. IF N IS TYPED THE INPUT DATA
WILL NOT BE SAVED.

BARE SOURCE FLUX FROM LAYER 1:    1.984D+02 pCi*cm^-3/s
calculation in progress

    RESULTS OF RADON DIFFUSION CALCULATIONS

  LAYER    THICKNESS     EXIT FLUX     EXIT CONC.
             (cm)      (pCi/m^2/s)     (pCi/l)
    1      5.000D+02    7.691D+01    1.670D+05
    2      5.000D+01    4.524D+01    4.430D+04
    3      1.490D+02    2.001D+01    0.000D+00
Ok
_
```

Project No.: 89241 **Page** C-1 **of** C-10

Calculation No.: 89241.7 - ALB08CA001 **Rev.:** 1

Calculation Title: Radon Barrier Cover Thickness Design

	Print Name	Signature	Date
Originator:	Courtney Vallejo	Courtney Vallejo	10/14/09
Checker:	John B. Case	John B. Case	10/14/09

ATTACHMENT C

RADON Output Files

Project No.: 89241 **Page** C-2 **of** C-10

Calculation No.: 89241.7 - ALB08CA001 **Rev.:** 1

Calculation Title: Radon Barrier Cover Thickness Design

Originator:	Courtney Vallejo	Courtney Vallejo	10/14/09
	Print Name	Signature	Date
Checker:	John B. Case	John B. Case	10/14/09
	Print Name	Signature	Date

RUN NAME: Radon Barrier Scenario 1 – One Foot Tailings, Radium Activity Source 683

```
-----*****! RADON !*****-----

Version 1 - April 1, 1986 - G.F. Birchard -  tel.# (301) 492-7000
U.S. Nuclear Regulatory Commission Office of Research

        RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS
              ARE CALCULATED FOR MULTIPLE LAYERS

CHECK THE PRINTER & PRESS ANY KEY TO CONTINUE
TITLE OF THIS DATA SET? Scenario One One Foot Layer of Tailings
TYPE Y TO INPUT INTERACTIVELY OR N TO READ INPUT FROM DRIVE A:

        CONSTANTS

RADON DECAY CONSTANT                .0000021    1/s
RADON WATER/AIR PARTITION COEFFICIENT     .26
SPECIFIC GRAVITY OF COVER & TAILINGS      2.65        g/cm^3

        GENERAL INPUT PARAMETERS


RADON DECAY CONSTANT                .0000021    1/s
RADON WATER/AIR PARTITION COEFFICIENT     .26
SPECIFIC GRAVITY OF COVER & TAILINGS      2.65        g/cm^3

        GENERAL INPUT PARAMETERS

ENTER -1 TO USE DEFAULT VALUES WHICH ARE SPECIFIED IF THEY EXIST.
NUMBER OF LAYERS COVER AND TAILINGS? 4
RADON FLUX LIMIT (pCi*m^-2/s) default=20, enter 0 for no limit? -1
DEFAULT FLUX LIMIT ASSIGNED
THE LAYER NUMBER FOR THICKNESS OPIMIZATION 0=no optimization? 3
RADON CONCENTRATION ABOVE TOP LAYER (pCi/l) default=0? -1
LOWER BOUNDARY RADON FLUX (pCi*m^-2/s) default=calculation? -1
LOWER BOUNDARY FLUX TO BE CALCULATED ASSUMING AN INFINITE SUBSOIL
SURFACE FLUX PRECISION (pCi*m^-2/s)  This number is the acceptable
level of computation error.? .001
```

Project No.: 89241 **Page** C-3 **of** C-10

Calculation No.: 89241.7 - ALB08CA001 **Rev.:** 1

Calculation Title: Radon Barrier Cover Thickness Design

Originator:	Courtney Vallejo	Courtney Vallejo	10/14/09
	Print Name	Signature	Date
Checker:	John B. Case	John B. Case	10/14/09
	Print Name	Signature	Date

LAYER INPUT PARAMETERS

LAYER 1

LAYER THICKNESS (cm)? 30.48
LAYER POROSITY default =.40. Enter a value >1 to calculate porosity ? 0.40
LAYER DENSITY default=calculated? 1.65
CHOOSE TO ENTER EITHER THE RADON SOURCE TERM CONCENTRATION ,
THE ORE GRADE % OR RADIUM ACTIVITY
TYPE S FOR SOURCE TERM G FOR ORE GRADE OR R FOR RADIUM ACTIVITY
RADIUM ACTIVITY (pCi/g)? 683
LAYER EMANATION COEFFICIENT default=.35? -1
CALCULATED LAYER SOURCE TERM .002070770625
LAYER WEIGHT % MOISTURE? 12.0
LAYER DIFFUSION COEFFICIENT default=calculated ? -1

LAYER 2

LAYER THICKNESS (cm)? 61
LAYER POROSITY default =.40. Enter a value >1 to calculate porosity ? 0.39
LAYER DENSITY default=calculated? 1.61
CHOOSE TO ENTER EITHER THE RADON SOURCE TERM CONCENTRATION ,
THE ORE GRADE % OR RADIUM ACTIVITY
TYPE S FOR SOURCE TERM G FOR ORE GRADE OR R FOR RADIUM ACTIVITY
RADIUM ACTIVITY (pCi/g)? 0.98
LAYER EMANATION COEFFICIENT default=.35? -1
CALCULATED LAYER SOURCE TERM 2.973546153846154D-06
LAYER WEIGHT % MOISTURE? 8.03
LAYER DIFFUSION COEFFICIENT default=calculated ? -1

LAYER 3

LAYER THICKNESS (cm)? 182
LAYER POROSITY default =.40. Enter a value >1 to calculate porosity ? 0.32
LAYER DENSITY default=calculated? 1.80
CHOOSE TO ENTER EITHER THE RADON SOURCE TERM CONCENTRATION ,
THE ORE GRADE % OR RADIUM ACTIVITY
TYPE S FOR SOURCE TERM G FOR ORE GRADE OR R FOR RADIUM ACTIVITY
RADIUM ACTIVITY (pCi/g)? 0.98
LAYER EMANATION COEFFICIENT default=.35? -1

CALCULATED LAYER SOURCE TERM .0000040516875
LAYER WEIGHT % MOISTURE? 7.2
LAYER DIFFUSION COEFFICIENT default=calculated ? -1

Layer 4

LAYER THICKNESS (cm)? 60.96
LAYER POROSITY default =.40. Enter a value >1 to calculate porosity ? 0.39
LAYER DENSITY default=calculated? 1.61
CHOOSE TO ENTER EITHER THE RADON SOURCE TERM CONCENTRATION ,
THE ORE GRADE % OR RADIUM ACTIVITY
TYPE S FOR SOURCE TERM G FOR ORE GRADE OR R FOR RADIUM ACTIVITY
RADIUM ACTIVITY (pCi/g)? 0.98
LAYER EMANATION COEFFICIENT default=.35? -1
CALCULATED LAYER SOURCE TERM 2.973546153846154D-06
LAYER WEIGHT % MOISTURE? 8.0
LAYER DIFFUSION COEFFICIENT default=calculated ? -1

THE BACKUP FILE RNDATA.BAK WILL BE REPLACED IF IT EXISTS UNLESS N IS
TYPED. TYPE ANY OTHER KEY TO CONTINUE. IF N IS TYPED THE INPUT DATA
WILL NOT BE SAVED.

BARE SOURCE FLUX FROM LAYER 1: 2.032D+02 pCi*cm^-3/s
calculation in progress

RESULTS OF RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi/m^2/s)	EXIT CONC. (pCi/l)
1	3.048D+01	1.594D+02	1.805D+05
2	6.100D+01	7.502D+01	1.354D+05
3	1.386D+02	2.281D+01	1.340D+04
4	6.096D+01	1.999D+01	0.000D+00

Ok

END OF RUN: Radon Barrier Scenario 1 – One Foot Tailings, Radium Activity Source 683

CALCULATION AND ANALYSIS SHEET

Project No.: 89241 **Page** C-5 **of** C-10

Calculation No.: 89241.7 - ALB08CA001 **Rev.:** 1

Calculation Title: Radon Barrier Cover Thickness Design

Originator:	Courtney Vallejo	Courtney Vallejo	10/14/09
	Print Name	Signature	Date
Checker:	John B. Case	John B. Case	10/14/09
	Print Name	Signature	Date

RUN NAME: Radon Barrier Scenario 2 – 15 Feet Tailings, Radium Activity Source 683

```
-----*****! RADON !*****-----

Version 1 - April 1, 1986 - G.F. Birchard -  tel.# (301) 492-7000
U.S. Nuclear Regulatory Commission Office of Research

        RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS
              ARE CALCULATED FOR MULTIPLE LAYERS

CHECK THE PRINTER & PRESS ANY KEY TO CONTINUE
TITLE OF THIS DATA SET? Scenario 2 15 Foot Tailings
TYPE Y TO INPUT INTERACTIVELY OR N TO READ INPUT FROM DRIVE A:

          CONSTANTS

RADON DECAY CONSTANT                    .0000021     1/s
RADON WATER/AIR PARTITION COEFFICIENT      .26
SPECIFIC GRAVITY OF COVER & TAILINGS       2.65        g/cm^3


          GENERAL INPUT PARAMETERS

ENTER -1 TO USE DEFAULT VALUES WHICH ARE SPECIFIED IF THEY EXIST.
NUMBER OF LAYERS COVER AND TAILINGS? 4
RADON FLUX LIMIT (pCi*m^-2/s) default=20, enter 0 for no limit? -1
DEFAULT FLUX LIMIT ASSIGNED
THE LAYER NUMBER FOR THICKNESS OPIMIZATION 0=no optimization? 3
RADON CONCENTRATION ABOVE TOP LAYER (pCi/l) default=0? -1
LOWER BOUNDARY RADON FLUX (pCi*m^-2/s) default=calculation? -1
LOWER BOUNDARY FLUX TO BE CALCULATED ASSUMING AN INFINITE SUBSOIL
SURFACE FLUX PRECISION (pCi*m^-2/s)  This number is the acceptable
level of computation error.? .001
```

LAYER INPUT PARAMETERS

LAYER 1

LAYER THICKNESS (cm)? 457
LAYER POROSITY default =.40. Enter a value >1 to calculate porosity ? 0.40
LAYER DENSITY default=calculated? 1.65
CHOOSE TO ENTER EITHER THE RADON SOURCE TERM CONCENTRATION ,
THE ORE GRADE % OR RADIUM ACTIVITY
TYPE S FOR SOURCE TERM G FOR ORE GRADE OR R FOR RADIUM ACTIVITY
RADIUM ACTIVITY (pCi/g)? 683
LAYER EMANATION COEFFICIENT default=.35? -1
CALCULATED LAYER SOURCE TERM .002070770625
LAYER WEIGHT % MOISTURE? 12.0
LAYER DIFFUSION COEFFICIENT default=calculated ? -1

LAYER 2

LAYER THICKNESS (cm)? 61
LAYER POROSITY default =.40. Enter a value >1 to calculate porosity ? 0.39
LAYER DENSITY default=calculated? 1.61
CHOOSE TO ENTER EITHER THE RADON SOURCE TERM CONCENTRATION ,
THE ORE GRADE % OR RADIUM ACTIVITY
TYPE S FOR SOURCE TERM G FOR ORE GRADE OR R FOR RADIUM ACTIVITY
RADIUM ACTIVITY (pCi/g)? 0.98
LAYER EMANATION COEFFICIENT default=.35? -1
CALCULATED LAYER SOURCE TERM 2.973546153846154D-06
LAYER WEIGHT % MOISTURE? 8.0
LAYER DIFFUSION COEFFICIENT default=calculated ? -1

LAYER 3

LAYER THICKNESS (cm)? 250
LAYER POROSITY default =.40. Enter a value >1 to calculate porosity ? 0.32
LAYER DENSITY default=calculated? 1.80
CHOOSE TO ENTER EITHER THE RADON SOURCE TERM CONCENTRATION ,
THE ORE GRADE % OR RADIUM ACTIVITY
TYPE S FOR SOURCE TERM G FOR ORE GRADE OR R FOR RADIUM ACTIVITY
RADIUM ACTIVITY (pCi/g)? 0.98
LAYER EMANATION COEFFICIENT default=.35? -1

Project No.: 89241 **Page** C-7 **of** C-10

Calculation No.: 89241.7 - ALB08CA001 **Rev.:** 1

Calculation Title: Radon Barrier Cover Thickness Design

Originator:	Courtney Vallejo	Courtney Vallejo	10/14/09
	Print Name	Signature	Date
Checker:	John B. Case	John B. Case	10/14/09
	Print Name	Signature	Date

```
CALCULATED LAYER SOURCE TERM              .0000040516875
LAYER WEIGHT % MOISTURE? 7.2
LAYER DIFFUSION COEFFICIENT default=calculated ? -1

LAYER 4

LAYER THICKNESS (cm)? 60.96
LAYER POROSITY  default =.40. Enter a value >1 to calculate porosity     ? 0.39
LAYER DENSITY default=calculated? 1.61
CHOOSE TO ENTER EITHER THE RADON SOURCE TERM CONCENTRATION ,
THE ORE GRADE % OR RADIUM ACTIVITY
TYPE S FOR SOURCE TERM G FOR ORE GRADE OR R FOR RADIUM ACTIVITY
RADIUM ACTIVITY (pCi/g)? 0.98
LAYER EMANATION COEFFICIENT default=.35? -1
CALCULATED LAYER SOURCE TERM              2.973546153846154D-06
LAYER WEIGHT % MOISTURE? 8.0
LAYER DIFFUSION COEFFICIENT default=calculated ? -1

THE BACKUP FILE RNDATA.BAK WILL BE REPLACED IF IT EXISTS UNLESS N IS
TYPED. TYPE ANY OTHER KEY TO CONTINUE. IF N IS TYPED THE INPUT DATA
WILL NOT BE SAVED.

BARE SOURCE FLUX FROM LAYER 1:    6.190D+02 pCi*cm^-3/s
calculation in progress

   RESULTS OF RADON DIFFUSION CALCULATIONS

 LAYER    THICKNESS    EXIT FLUX    EXIT CONC.
           (cm)     (pCi/m^2/s)    (pCi/l)
   1      4.570D+02    3.616D+02    4.112D+05
   2      6.100D+01    1.677D+02    3.113D+05
   3      2.097D+02    2.280D+01    1.340D+04
   4      6.096D+01    1.998D+01    0.000D+00
Ok
```

END OF RUN: Radon Barrier Scenario 2 – 15 Feet Tailings, Radium Activity Source 683

Project No.: 89241 **Page** C-8 **of** C-10

Calculation No.: 89241.7 - ALB08CA001 **Rev.:** 1

Calculation Title: Radon Barrier Cover Thickness Design

Originator:	Courtney Vallejo	Courtney Vallejo	10/14/09
	Print Name	Signature	Date
Checker:	John B. Case	John B. Case	10/14/09
	Print Name	Signature	Date

RUN NAME: Radon Barrier, 16.4 ft (500 cm) Tailings

```
     -----*****! RADON !*****-----

Version 1 - April 1, 1986 - G.F. Birchard -  tel.# (301) 492-7000
U.S. Nuclear Regulatory Commission Office of Research

RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS
            ARE CALCULATED FOR MULTIPLE LAYERS

TITLE OF THIS DATA SET? 500 cm thick tailings
TYPE Y TO INPUT INTERACTIVELY OR N TO READ INPUT FROM DRIVE A:

     CONSTANTS

RADON DECAY CONSTANT                .0000021    1/s
RADON WATER/AIR PARTITION COEFFICIENT     .26
SPECIFIC GRAVITY OF COVER & TAILINGS      2.65        g/cm^3

     GENERAL INPUT PARAMETERS

ENTER -1 TO USE DEFAULT VALUES WHICH ARE SPECIFIED IF THEY EXIST.
NUMBER OF LAYERS COVER AND TAILINGS? 4
RADON FLUX LIMIT (pCi*m^-2/s) default=20, enter 0 for no limit? -1
DEFAULT FLUX LIMIT ASSIGNED
THE LAYER NUMBER FOR THICKNESS OPIMIZATION 0=no optimization? 3
RADON CONCENTRATION ABOVE TOP LAYER (pCi/l) default=0? -1
LOWER BOUNDARY RADON FLUX (pCi*m^-2/s) default=calculation? -1
LOWER BOUNDARY FLUX TO BE CALCULATED ASSUMING AN INFINITE SUBSOIL
SURFACE FLUX PRECISION (pCi*m^-2/s)  This number is the acceptable
level of computation error.? .001
```

LAYER INPUT PARAMETERS

LAYER 1

LAYER THICKNESS (cm)? 500
LAYER POROSITY default =.40. Enter a value >1 to calculate porosity ? .40
LAYER DENSITY default=calculated? 1.65
CHOOSE TO ENTER EITHER THE RADON SOURCE TERM CONCENTRATION ,
THE ORE GRADE % OR RADIUM ACTIVITY
TYPE S FOR SOURCE TERM G FOR ORE GRADE OR R FOR RADIUM ACTIVITY
RADIUM ACTIVITY (pCi/g)? 683
LAYER EMANATION COEFFICIENT default=.35? -1
CALCULATED LAYER SOURCE TERM .002070770625
LAYER WEIGHT % MOISTURE? 12
LAYER DIFFUSION COEFFICIENT default=calculated ? -1

LAYER 2

LAYER THICKNESS (cm)? 61
LAYER POROSITY default =.40. Enter a value >1 to calculate porosity ? .39
LAYER DENSITY default=calculated? 1.61
CHOOSE TO ENTER EITHER THE RADON SOURCE TERM CONCENTRATION ,
THE ORE GRADE % OR RADIUM ACTIVITY
TYPE S FOR SOURCE TERM G FOR ORE GRADE OR R FOR RADIUM ACTIVITY
RADIUM ACTIVITY (pCi/g)? .98
LAYER EMANATION COEFFICIENT default=.35? -1
CALCULATED LAYER SOURCE TERM 2.973546153846154D-06
LAYER WEIGHT % MOISTURE? 8.03
LAYER DIFFUSION COEFFICIENT default=calculated ? -1

LAYER 3

LAYER THICKNESS (cm)? 182
LAYER POROSITY default =.40. Enter a value >1 to calculate porosity ? .32
LAYER DENSITY default=calculated? 1.8
CHOOSE TO ENTER EITHER THE RADON SOURCE TERM CONCENTRATION ,
THE ORE GRADE % OR RADIUM ACTIVITY
TYPE S FOR SOURCE TERM G FOR ORE GRADE OR R FOR RADIUM ACTIVITY
RADIUM ACTIVITY (pCi/g)? .98
LAYER EMANATION COEFFICIENT default=.35? -1

CALCULATED LAYER SOURCE TERM .0000040516875
LAYER WEIGHT % MOISTURE? 7.2
LAYER DIFFUSION COEFFICIENT default=calculated ? -1

LAYER 4

LAYER THICKNESS (cm)? 60.96
LAYER POROSITY default =.40. Enter a value >1 to calculate porosity ? .39
LAYER DENSITY default=calculated? 1.61
CHOOSE TO ENTER EITHER THE RADON SOURCE TERM CONCENTRATION ,
THE ORE GRADE % OR RADIUM ACTIVITY
TYPE S FOR SOURCE TERM G FOR ORE GRADE OR R FOR RADIUM ACTIVITY
RADIUM ACTIVITY (pCi/g)? .98
LAYER EMANATION COEFFICIENT default=.35? -1
CALCULATED LAYER SOURCE TERM 2.973546153846154D-06
LAYER WEIGHT % MOISTURE? 8
LAYER DIFFUSION COEFFICIENT default=calculated ? -1

THE BACKUP FILE RNDATA.BAK WILL BE REPLACED IF IT EXISTS UNLESS N IS TYPED. TYPE ANY OTHER KEY TO CONTINUE. IF N IS TYPED THE INPUT DATA WILL NOT BE SAVED.

BARE SOURCE FLUX FROM LAYER 1: 6.196D+02 pCi*cm^-3/s
calculation in progress

RESULTS OF RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi/m^2/s)	EXIT CONC. (pCi/l)
1	5.000D+02	3.613D+02	4.117D+05
2	6.100D+01	1.676D+02	3.107D+05
3	2.095D+02	2.282D+01	1.341D+04
4	6.096D+01	2.000D+01	0.000D+00

Ok

END OF RUN: Radon Barrier, 16.4 ft (500 cm) Tailings

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	Print Name	Signature	Date
Originator:	Courtney Vallejo	Courtney Vallejo	10/14/09
Checker:	John B. Case	John B. Case	10/14/09

ATTACHMENT D

Analysis of Moisture Content for Radon Barrier Analysis

CALCULATION AND ANALYSIS SHEET

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	Print Name	Signature	Date
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	Print Name	Signature	Date

PROBLEM STATEMENT:

Develop the properties for use in the radon barrier calculation. The properties include the dry density expressed in gm/cc, the gravimetric moisture content, and the percent saturation of the voids.

DOCUMENTS CITED

Kleinfelder Calculation 89241.7 - ALB08CA003 Piñon Ridge Closure Cover Geotechnical and Hydrologic Properties (Reference 9).

U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research, "Regulatory Guide 3.64 (Reference 8).

US. DOE. 2008. Final Remedial Action Plan and Site Design for Stabilization of Moab Title 1 Uranium Mill Tailings at the Cresent Junction, Utah, Disposal Site (Reference 10).

URANIUM TAILINGS

From **Kleinfelder 2008 Pinon Ridge Closure Cover Geotechnical and Hydrologic Properties, Table 5-1**:

$pcf := \frac{lbf}{ft^3}$ $\gamma_w := 1.0 \cdot \frac{gm}{cm^3}$ 62.4 pcf

$n := 0.40$ $\gamma_d := 103 \cdot pcf$ $\gamma_d = 1.65\ g/cm^3$

From **US DOE 2008**, the gravimetric moisture content was estimated to be 12%.

$$m_g := 0.12$$

Use the porosity, the dry density, and the gravimetric moisture content for input tc the Radon program presented in Attachment C.

Calculate the total unit weight from Equation 4 of the main calculation:

$$\gamma_t := \gamma_d \cdot (1 + m_g)$$

$\gamma_d = 1.848$ g/cm^3

Calculate the moisture saturation fraction from Equation 5 of the main calculation:

$$m_f := \frac{\frac{\gamma_d}{g} \cdot m_g}{n \cdot \gamma_w}$$

$$m_f = 0.495$$

Eq. 8, Reference 8 Page 3.64-11

Use this moisture saturation and porosity for calculation of the diffusion coefficient presented in Attachments E and summarized in Table 5-2.

INTERIM COVER AND EROSION BARRIER

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From Kleinfelder 2008 Pinon Ridge Closure Cover Geotechnical and Hydrologic Properties, Table 5-1:

$pcf := \frac{lbf}{ft^3}$ $\gamma_w := 1.0 \cdot \frac{gm}{cm^3}$ 62.4 pcf

$n := 0.39$ $\gamma_d := 100.3 \cdot pcf$ $\gamma_d = 1.607\ g/cm^3$

From Attachment D, the volumetric moisture content is

$m_v := 0.13$

From Equation 3 of the main calculation:

$$m_g := \frac{m_v \cdot \gamma_w}{1.607 \cdot \frac{gm}{cm^3}}$$

$m_g = 0.081$

Eq. 6, Reference 8 p. 3.64-9

Use the porosity, the dry density, and the gravimetric moisture content for input tc the Radon program presented in Attachment C.

Calculate the total unit weight from Equation 4 of the main calculation:

$\gamma_t := \gamma_d \cdot (1 + m_g)$ $\gamma_t = 1.737\ g/cm^3$

Calculate the moisture saturation fraction from Equation 5 of the main calculation:

$$m_f := \frac{\frac{\gamma_d}{g} \cdot m_g}{n \cdot \gamma_w}$$

$m_f = 0.333$

Eq. 8, Reference 8 Page 3.64-11

Use this moisture saturation and porosity for calculation of the diffusion coefficient presented in Attachments E and summarized in Table 5-2.

RADON BARRIER

From Kleinfelder 2008 Pinon Ridge Closure Cover Geotechnical and Hydrologic Properties, Table 5-1:

$pcf := \frac{lbf}{ft^3}$ $\gamma_w := 1.0 \cdot \frac{gm}{cm^3}$ 62.4 pcf

$n := 0.32$ $\gamma_d := 112.1 \cdot pcf$ $\gamma_d = 1.796\ gm/cm^3$

From Attachment D, the volumetric moisture content is

$m_v := 0.13$

From Equation 3 of the main calculation:

$$m_g := \frac{m_v \cdot \gamma_w}{1.796 \cdot \frac{gm}{cm^3}}$$

$m_g = 0.072$

Eq. 6, Reference 8 p. 3.64-9

Use the porosity, the dry density, and the gravimetric moisture content for input tc the Radon program presented in Attachment C.

Calculate the total unit weight from Equation 4 of the main calculation:

$$\gamma_t := \gamma_d \cdot (1 + m_g)$$

$\gamma_t = 1.926\ gm/cm^3$

Calculate the moisture saturation fraction from Equation 5 of the main calculation:

$$m_f := \frac{1.796 \cdot \frac{gm}{cm^3} \cdot m_g}{n \cdot \gamma_w}$$

$m_f = 0.406$

Eq. 8, Reference 8 Page 3.64-11

Use this moisture saturation and porosity for calculation of the diffusion coefficient presented in Attachments E and summarized in Table 5-2.

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Checker:	John B. Case	John B. Case	10/14/09
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ATTACHMENT E

Verification of Cell Formulas for Diffusion Coefficient Calculation

CALCULATION AND ANALYSIS SHEET

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Checker:	John B. Case	John B. Case	10/14/09
	Print Name	Signature	Date

Problem Statement:
Verify the cell formula calculations for determining the diffusion coefficient as presented in Table 5-2 of the main calculation.

Documents Cited
U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research, "'93Regulatory Guide 3.64 (Reference 8).

Input the porosity, and moisture saturation fraction from the four layers in **Attachment D**

Array :=

Parameter	n	m_f
Tailings	0.4	0.495
Interim Layer	0.39	0.33
Radon Barrier	0.32	0.41
Erosion Barrier	0.39	0.33

$$Array = \begin{pmatrix} 0.4 & 0.495 \\ 0.39 & 0.33 \\ 0.32 & 0.41 \\ 0.39 & 0.33 \end{pmatrix}$$

From REG Guide 3.64 based upon Equation 6 in the main calculation

$$D(m_f, n) := 0.07 \cdot exp\left[-4 \cdot \left(m_f - m_f \cdot n^2 + m_f^5\right)\right]$$

Equation 6 Reference 8, Page 3.64-10

CALCULATION AND ANALYSIS SHEET

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$$n := Array^{\langle 1 \rangle} \qquad m_f := Array^{\langle 2 \rangle} \qquad n = \begin{pmatrix} 0.4 \\ 0.39 \\ 0.32 \\ 0.39 \end{pmatrix} \qquad m_f = \begin{pmatrix} 0.495 \\ 0.33 \\ 0.41 \\ 0.33 \end{pmatrix}$$

$$\overrightarrow{D(m_f, n)} = \begin{pmatrix} 0.012 \\ 0.023 \\ 0.015 \\ 0.023 \end{pmatrix}$$

Note the units are in the cgs system.
cm/sec^2

CONCLUSION: The results are in agreement with the cell formulas for in Column S of the EXCEL workbook (Table 5-2) and the cell formulas are verified.

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ATTACHMENT F

Kleinfelder Memorandum:
Review of Soil and Vegetation Parameters for the Piñon Ridge Closure Cap

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	Print Name	Signature	Date
Originator:	Courtney Vallejo	Courtney Vallejo	10/14/09
Checker:	John B. Case	John B. Case	10/14/09

MEMORANDUM

TO: Alan Kuhn

FROM: Stephen Caruana

DATE: 9/24/08

SUBJECT: Review of Soil and Vegetation Parameters for Piñon Ridge Closure Cap

CC: R. McKinney, C. Vallejo, J. Case, and L. Bridges

This memo is a summation of my findings regarding the long-term vegetation trends and soil moisture retention characteristics of Piñon Ridge Closure Cap. This analysis was conducted utilizing a number of sources. A literature search of AGRICOLA and University of Oregon Library Catalog was performed incorporating the keywords: Colorado native vegetation, arid and semi-arid evapotranspiration, long-term vegetational dynamics, and southwest rangeland trends. Also consulted was the USDA Soil Survey for San Miguel Area, Colorado, Parts of Dolores, Montrose, and San Miguel Counties, 2003; and the literature database of the Jornada Experimental Range.

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Checker:	John B. Case	John B. Case	10/14/09
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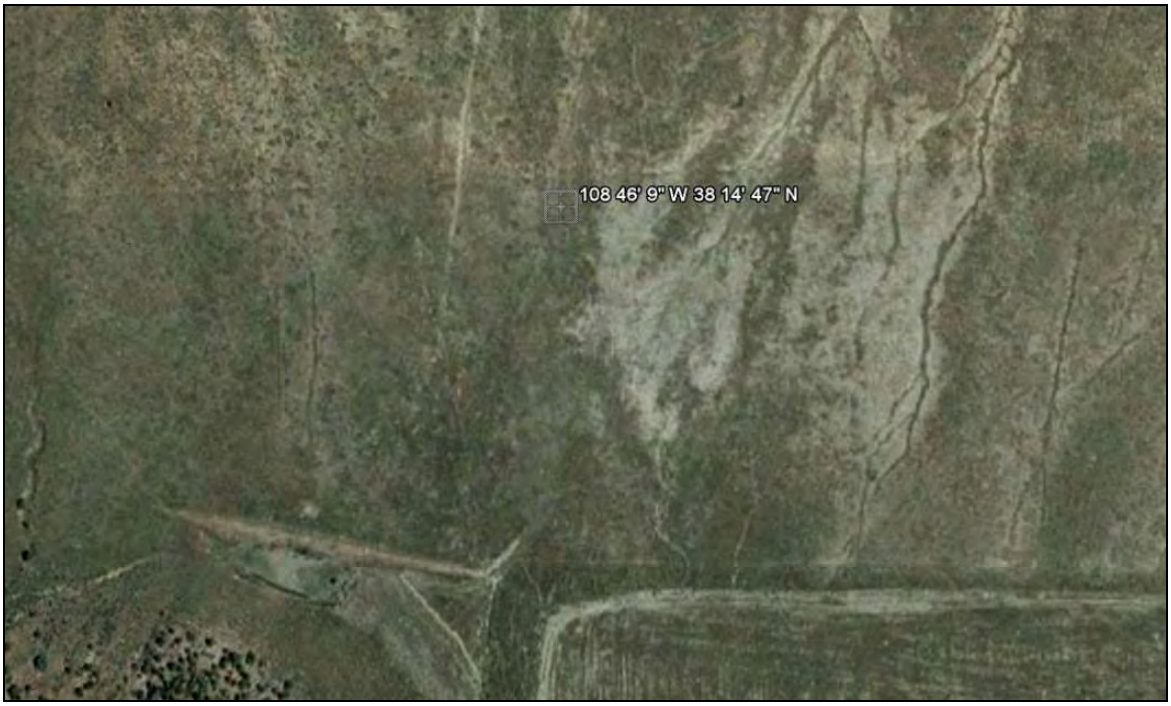

Site Location: 38º 14' 47" North Latitude, 108º 46' 9" West Longitude

Long-term Vegetation Trends

Predicting the response of a rangeland grass planting over a long time period is dependent upon several factors, notably the success of the initial planting, weed control and competition during the establishment period, inherent soil fertility, use by wild and domesticated herbivores, and climatic flux. Rangelands of the American Southwest have been influenced by both large scale climatic events and human influence through the introduction on non-native herbivores (primarily sheep, cattle, and horses).

In order to understand the possible trends that the grass plantings of the Piñon Ridge Closure may experience over time, the literature was consulted for rangeland areas of the Southwest that were studied over relatively long periods. One such area is the Jornada Experimental Range in New Mexico. Although the Jornada is located approximately 380 miles southeast of Piñon Ridge and is part of the northern Chihuahuan Desert and not the Colorado Plateau; rainfall is similar at approximately 10 inches per year and with similar sandy loam soils. The

harsher conditions at the Jornada may better represent possible future conditions under climate change.

Grasslands of the Jornada have been studied since 1858. Various ecological sites of the Jornada have been dominated by black and blue grama, tobosa, burrograss, and poverty threeawn. Basal area of these dominant grasses exhibit sharp decreases during severe drought periods and partial recovery during more favorable periods (Gibbens and Beck, 1988). Over the past 150 years the long term trend has been for the basal area of perennial grasses to decline and for non-native weeds and woody brush to increase. The basal area of the perennial grasses on the Jornada Range is somewhat associated with the antecedent moisture of the previous 3 to 4 years. Drought years had a tremendous impact on perennial grass basal area whereas grazing appears not to have had as significant an impact. Different perennial grasses respond differently and have different recovery rates when subjected to drought stress. Even with a conservative grazing management scheme, unpalatable shrubs have become widespread across the Jornada Range.

Long term observations on the Jornada (Buffington and Herbel, 1965) have recorded a decline since 1858 of over 90% of the range covered in good grass to less than 25% in 1963. The main invasive was mesquite on sandy soils. Grass cover on this range was reduced by grazing pressure and periodic droughts.

There are significant implications for the establishment of the Piñon Ridge Closure Cap from the above research. Initial establishment of a vigorous, healthy stand is essential. If at all possible the seedings should be planted following several years of above normal rainfall. If the sites are irrigated this becomes less critical. The mix of initially planted species is likely to simplify over time, especially shorter lived perennial grasses.

The area of the proposed closure cap is classified as a Semidesert Loam and Semidesert Sandy Loam ecological site. Current dry-weight production on this site is 600 to 850 lbs/ac in a normal year. A normal year's precipitation for these sites is 9 to 12 inches, with a mean annual air temperature of 46 to 48º F, and an average frost-free period of 90 to 120 days. The characteristic vegetation for these sites (under excellent, climax conditions) is:

Semidesert Sandy Loam:

- Galleta 20%
- Wyoming big sagebrush 15%
- Needleandthread 10%
- Indian ricegrass 10%
- Bottlebrush squirreltail 5%
- Blue grama 5%
- Sand dropseed 5%

Semidesert loam:

- Wyoming big sagebrush 15%
- Needleandthread 15%
- Galleta 15%
- Indian ricegrass 5%
- Bottlebrush squirreltail 5%

The following is the proposed seeding mix for the closure cap (percentages as reported):

- Needleandthread 20%
- Indian ricegrass 20%
- Thickspike wheatgrass 20%
- Sandberg bluegrass 10%
- Bottlebrush squirreltail 10%
- Blue grama 10%
- Galleta 10%

Grass Basal Area Coverage

Studies were conducted by Ambos et al. (2000) on Dutchwoman Butte, an isolated, ungrazed butte located in the transition zone between the Colorado Plateau and the Basin and Range province. Elevation at the site is approximately 5,000 feet, and the estimated annual rainfall at is 17 inches, slightly more than the Piñon Ridge site. The vegetation of the site is a semidesert grassland with widely scattered juniper. Grasses consist primarily of grama grasses and plains lovegrass. Soils are gravelly and stony loams. Grass species diversity is high at the site.

Grass canopy cover is 35 to 45%, grass basal area is 8% and grass litter is 25%, thus giving an effective vegetative cover of 35%. Bare soil and rock fragments were approximately 65%. This site represents the extreme cool/moist end of the semi-desert grassland gradient and as such would likely represent the best possible conditions that could be expected at the Piñon Ridge site.

Grass basal area on the Jornada range exhibited similar characteristics in basal area trends. Maximum rates of basal area coverage for perennial grasses were 30% on the heavy soils in low lying areas that received supplemental runoff water. Basal area coverage at these rates occurred during the wet cycles over the past century. Perennial grasses located on the sandy loam soils approached 15% basal area coverage during the wet periods.

Cryptobiotic Crusts

Healthy, living soils of the American deserts are characterized by cryptobiotic crusts. These crusts are composed of cyanobacteria, soil lichens, mosses, green algae, microfungi, and bacteria. Cryptobiotic crusts perform important soil ecosystem functions including soil aggregation and binding, nitrogen fixation, water storage, and contributions to organic matter nutrient flow. Cryptobiotic crusts provide essential resistance to wind and water erosion (NPS, 2008).

A stable soil surface with an intact cryptobiotic can make stabilize the area between the perennial grass plants. Once disturbed it may take up to 50 to 100 years for a fully functioning, stable soil crust to form. Further research may be necessary to identify procedures for promoting the growth of a cryptobiotic crust on the Piñon Ridge Closure Cap, however every effort should be made to keep the site free from any disturbance that may limit the establishment of a soil crust.

Soil Moisture Retention Characteristics

Soil Survey: The Piñon Ridge Closure Cap proposes to utilize locally available, native soil material. The area proposed for the tailings cap is mapped as part of the USDA Soil Survey of San Miguel Area, Colorado, Parts of Dolores, Montrose, and San Miguel Counties. 2003. The area of the proposed cap is mapped with two separate soil series – 18 Begay fine sandy loam and 56 Mikim loam. Both soils are deep, with reported depths of 60 inches.

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Begay fine sandy loam soil hydraulic properties:

- Moist bulk density (g/cc) 1.40 – 1.50
- Saturated Hydraulic Conductivity (micro m/sec) 14.11 – 42.34
- Available water capacity (in/in) 0.09 – 0.18
- Total Available Water (24 inches of soil) 7.74 inches
- Organic Matter 0.0 – 3.0
- Water Content, 15 Bar 6.9%
- Water Content, 0.33 Bar 16.2%

Mikim Loam

- Moist bulk density (g/cc) 1.30 – 1.50
- Saturated Hydraulic Conductivity (micro m/sec) 4.23 – 14.11
- Available water capacity (in/in) 0.07 – 0.18
- Total Available Water (24 inches of soil) 8.30 inches
- Organic Matter 0.5 – 3.0
- Water Content, 15 Bar 13.4%
- Water Content, 0.33 Bar 27.1%

Note: Water content, one-third bar, is the amount of soil water retained at a tension of 1/3 bar, expressed as a percentage of the oven-dry weight of soil material that is less than 2 mm in diameter. Water retained at 1/3 bar is significant in the determination of soil water-retention difference, which is used as the initial estimation of available water capacity for some soils. Water retained at 1/3 bar is the value commonly used to estimate the content of water at field capacity for most soils.

Water content, 15 bar, is the amount of soil water retained at a tension of 15 bars, expressed as a percentage of the oven-dry weight of soil material that is less than 2 mm in diameter. Water retained at 15 bars is significant in the determination of soil water-retention difference, which is used as the initial estimation of available water capacity for some soils. Water retained at 15 bars is an estimation of the wilting point (USDA, 2003).

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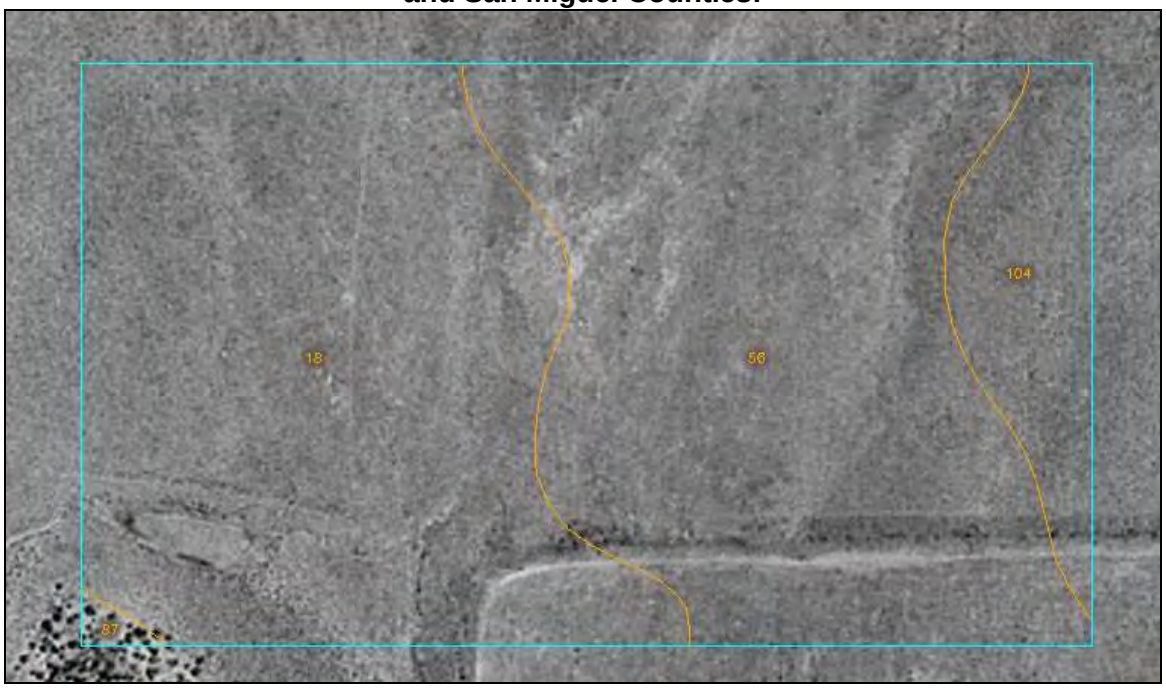
USDA Soil Survey Soil Survey for San Miguel Area, Colorado, Parts of Dolores, Montrose, and San Miguel Counties:



Soil Hydraulic Properties:

The attached spreadsheet developed by Saxton and Rawls (2006) will compute a variety of soil moisture percentages. The prediction equations were derived for soil moisture tensions of 0, 33, and 1500 kPa and air-entry based on commonly available variables of soil texture and organic matter.

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Evapotranspiration Values

Studies conducted at the Amargosa Desert Research Site in Nye County near Beatty, Nevada (Johnson et al., 2007) report the following evapotranspiration values:

Amargosa Desert Research Site Evapotranspiration Rates		
Year	**Annual Precipitation (mm/yr)**	**Annual Evapotranspiration (mm/yr)**
2001	164.8	-
2002	3.5	48.0
2003	131.8	148.0
2004	173.6	198.0
2005	177.7	233.0
Average	130.3	
Long Term Average (25 yrs)	112.0	-

Various authors have reported the following Penman-Monteith values:

Kc = Dimensionless Crop Coefficient (Burman and Pochop, 1994)				
Dry, with light to moderate winds	**Kc**	**Grass Hay**	**Clover/Grass/Legumes**	**Pasture**
	Mean	0.90	1.05	1.00
	Peak	1.10	1.15	1.10
	Low	0.55	0.55	0.50

Stage 1 and 2 Evaporation Values of Constants U and Cs (Burman and Pochop, 1994)		
Soil Texture	**Cs (mm/day/**	**U (mm)**
Loam	4.50	10.60
Clay loam	6.67	11.38
Sand	3.32	5.70

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	Print Name	Signature	Date

Leaf Area Index for Growing Season Fractions (Burman and Pochop, 1994)	
Fraction of Growing Season	**Excellent Grass**
0.0	0.00
0.1	1.84
0.2	3.00
0.3	3.00
0.4	3.00
0.5	3.00
0.6	3.00
0.7	2.70
0.8	1.96
0.9	0.96
1.0	0.50

Reporting on maximum evapotranspiration at eight arid sites across the western United States Evans et al. (1981) that evapotranspiration rates ranged 2 mm/d to 10 mm/d as influenced by vegetation, water availability and climate. During extended periods of no precipitation rates of evapotranspiration were less than 1 mm/d.

In studies of Great Basin sagebrush communities (Prater and DeLucia, 2006) evapotranspiration is observed to increase in a linear manner correlated with soil moisture (top 20 cm). However, they did note that the evapotranspiration was very closely tied to the top (<5 cm) soil moisture in the New Mexico arid grass and shrublands. The authors in independent studies found that perennial bunchgrasses had higher morning evapotranspiration rates than sagebrush. They note that in sagebrush ecosystems annual evapotranspiration typically exceeds precipitation, whereas evapotranspiration from grass stands in similar environments may equal annual precipitation.

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Checker:	John B. Case	John B. Case	10/14/09
	Print Name	Signature	Date

References

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Buffington, L.C and C.H. Herbel. 1965. Vegetational changes on a semideseret grassland range. Ecological Monographs. 35(2): 139-164.

Burman, R. and L.O. Pochop. 1994. Evaporation, Evapotranspiration and Climatic Data. Elsevier, New York.

Evans, D.D., T.W. Sammis, and D.R. Cable. 1981. Actual Evapotranspiration under Desert Conditions. In Water in Desert Ecosystems. Ed. D.D. Evans and J.L. Thames (eds.), pp 195-218. Dowden, Hutchinson and Ross, Inc. Stroudsburg, Pennsylvania.

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