APPENDIX D
RADON EMANATION MODELING

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LIST OF ATTACHMENTS

Attachment D.1 RADON Model Output

1.0 BACKGROUND

This appendix presents the results of modeling of the emanation of radon-222 from the top surface of the proposed cover over the Primary and Secondary tailings impoundments. These results were previously presented as a portion of the update to radon emanation modeling presented in MFG (2005). This update is based on the current proposed cover system. The physical and radiological properties of tailings and cover materials that were used in the model are discussed in Appendix B of MFG (2005).

A borrow source investigation and evaluation of in-place interim cover and random fill is currently being conducted. Laboratory testing on collected samples will be used to update values used for radon modeling for radium activity, density, porosity, and long-term moisture content for the final cover material, as well as the in-place interim cover on the Secondary Impoundment and in-place random fill on the Primary Impoundment. Laboratory testing results, in addition to radon measurements from the Secondary Impoundment interim cover surface, will be used to estimate diffusion coefficients for the in-place interim cover. The updated radon analyses will be presented in a future submittal of this appendix.

The cover system evaluated in this appendix consists of a four-foot thick homogeneous material profile to enhance evapotranspiration. This cover thickness incorporates the anticipated frost depth in the area of approximately 27 inches (Fremont Board of County Commissioners, 2008). Random fill or contaminated site soils will form a platform, or base for construction, directly beneath the cover system. For the radon emanation modeling, the topsoil layer (0.5 feet thick) was not included.

The modeling results presented in this appendix show that the planned cover system reduces the rate of radon emanation to values below the NRC and CDPHE limit of 20 picocuries per square meter per second (pCi/m^2-sec) averaged over the entire impoundment area. The radon emanation modeling was conducted for conditions in the Primary Impoundment, due to the higher radium-226 activity concentrations of the tailings in the Primary Impoundment. The emanation results conservatively apply to the cover system over the Secondary Impoundment, since the excavated Old Pond materials in the Secondary Impoundment have a lower average radium-226 activity concentration.

2.0 DESCRIPTION OF MODEL AND INPUT VALUES

Radon emanation calculations from the cover system were made with the RADON model (Rogers and others 1984; NRC, 1989), a one-dimensional model that calculates radon flux from decay of a radium-226 source (such as the tailings). The key input parameters to the model include the radium-226 activity concentration, the coefficient of diffusion of radon through the cover materials, and the density and moisture content values for the cover materials that affect the diffusion of radon. The input parameters and values used in the model are outlined below.

2.1 Radium Activity Concentration

The radium-226 activity concentration values used in the model are outlined below.

Tailings. The radium-226 activity concentration values for the tailings in the primary impoundment were based on measurements presented in WWL (1990) and results from testing in 1999. The 1999 testing results were presented in Appendix A and discussed in Appendix B of MFG (2005). For the coarse fraction of tailings (classified as sand or sand-slime tailings), the

calculated average of radium-226 activity was 555 pCi/g, with a median value of 420 pCi/g. Adjusting to represent the proportion of tailings sand and slimes in the upper zones of tailings, an average value of 500 pCi/g was used in the modeling.

For the fine fraction of tailings (classified in Appendix A of MFG (2005) as tailings slimes), a value of 1,800 pCi/g was used in the modeling. Although the calculated tailings radium-226 activity concentration based on uranium ore grade is roughly 1,400 pCi/g, the average and median value for tailings slimes samples (from Appendix B of MFG (2005)) are approximately 1,800 pCi/g.

The radium-226 values for tailings under current conditions were used to represent the most conservative radium-226 activity concentrations in the modeling. Calculations of radium-226 ingrowth from decay of thorium-230 are summarized in Appendix B of MFG (2005), and show that the current values of radium-226 are the highest values over a 20,000-year time frame.

Random Fill. For random fill, a radium-226 activity concentration value of 40 pCi/g was used. This value was based on the average radium-226 activity concentration from interim cover samples of 12.3 pCi/g and the average thorium-230 activity concentration of 26.8 pCi/g (from Appendix B of MFG (2005)). Based on ingrowth of radium-226 from decay of thorium-230, the highest radium-226 value from ingrowth is 24 pCi/g at 10,000 years (Appendix B of MFG (2005)). This value was conservatively increased to 40 pCi/g.

A conservative random fill case was also run with a radium-226 activity concentration of 400 pCi/g. This value was based on the highest activity concentration from the interim cover samples of 40 pCi/g radium-226 and 240 pCi/g thorium-230. Based on ingrowth of radium-226 from decay of thorium-230, the highest radium-226 value from ingrowth is 217 pCi/g at 10,000 years (Appendix B of MFG (2005)). This value was conservatively increased to 400 pCi/g to allow for random fill soils with relatively high radium-226 or thorium-230 values.

Cover materials. For cover materials to be excavated from the Northwest Borrow area, a radium-226 activity concentration value of zero pCi/g was used. According to guidance in Regulatory Guide 3.64 (NRC 1989), the radium activity in cover soils may be neglected for cover design purposes if the cover soils are obtained from background materials. Testing is currently being performed on the cover material. The radium activity will be measured and verified to be at or below background concentrations prior to a future submittal of this appendix.

2.2 Radon Emanation Coefficient

For all of the tailings, random fill, and cover materials, a radon emanation coefficient of 0.35 was used. This is the conservative default value used in the RADON model.

2.3 Density and Porosity

The density of the tailings and cover materials is represented in the model by porosity. The porosity of the tailings used in model was 0.54 for sand-slimes and 0.62 for slimes (based on measured values in Appendix B of MFG (2005)). A tailings porosity of 0.54 was used in ESCI (1995). The porosity of 0.54 is equivalent to a unit weight of 77.4 pcf at a specific gravity of 2.70. The porosity of 0.62 is equivalent to a unit weight of 64.3 pcf at a specific gravity of 2.70. The RADON model employs a constant specific gravity in the calculations, so that a value of 2.70 was used for tailings and cover materials (although there is some variation between these materials, as shown in Appendix B of MFG (2005)).

The porosity of the cover material used in model was 0.34 for Northwest Borrow area sand (based on measured values in Appendix B of MFG (2005)). This value will be reviewed based on the results of the borrow area testing that is currently in progress.

2.4 Long-Term Moisture Content

Long-term moisture content values used in the model for tailings were 15 percent for sand-slimes and 20 percent for slimes (based on measured values in Appendix B of MFG (2005)).

The long-term moisture content of the cover material used in model was 14 percent for Northwest Borrow area sand, based on measured values in Appendix B of MFG (2005).

2.5 Radon Diffusion Coefficient

The radon diffusion coefficient used in the RADON model can either be calculated within the model (based on an empirical relationship with degree of saturation) or input directly in the model using values measured from laboratory testing. For this evaluation, both calculated and measured values (from Appendix B of MFG (2005)) were used in the RADON model runs. The values that were used are summarized in the table below. The lower the diffusion coefficient value, the lower the resulting rate of radon emanation.

Table D.1. Summary of Radon Diffusion Coefficient Values used in RADON Model

Radon Diffusion Coefficient Case Layer	Measured Coefficient (cm^2/sec)	Calculated Coefficient (cm^2/sec)
Tailings sand-slime	0.030	0.026
Tailings slime	0.0070	0.030
Northwest Borrow sand	0.0010	0.0022

3.0 DISCUSSION OF RESULTS

The radon emanation modeling consisted of two scenarios: (1) the cover system constructed directly on the tailings, and (2) the cover system constructed on random fill.

3.1 Cover Directly on Tailings

Four cases were analyzed for the cover directly on the tailings scenario, as listed below.

1. Cover system directly on tailings sand-slimes, with calculated radon diffusion coefficient values.
2. Cover system directly on tailings sand-slimes, with measured radon diffusion coefficient values.
3. Cover system directly on tailings slimes, with calculated radon diffusion coefficient values.
4. Cover system directly on tailings slimes, with measured radon diffusion coefficient values.

The input values and results from these four cases are summarized in Tables D.2 and D.3, with the RADON model output for each of these cases included in Attachment D.1.

Table D.2. Cover Directly on Tailings Sand-Slimes

Layer Material		1 Tailings Sand-slime	2 NW Borrow Sand
Layer thickness	(cm) (ft)	500 16.4	122 4.0
Porosity		0.54	0.34
Radium-226 activity conc.	(pCi/g)	500	0
Moisture content	(%)	15	14
Degree of saturation	(%)	34	74
Calculated radon diffusion coefficient	(cm^2/sec)	0.026	0.0022
Radon flux from top of Layer 2	(pCi/m^2-sec)	-----	**2.34**
Measured radon diffusion coefficient	(cm^2/sec)	0.030	0.0010
Radon flux from top of Layer 2	(pCi/m^2-sec)	-----	**0.26**

Table D.3. Cover Directly on Tailings Slimes

Layer Material		1 Tailings Slimes	2 NW Borrow Sand
Layer thickness	(cm) (ft)	500 16.4	122 4.0
Porosity		0.54	0.34
Radium-226 activity conc.	(pCi/g)	1800	0
Moisture content	(%)	20	14
Degree of saturation	(%)	46	74
Calculated radon diffusion coefficient	(cm^2/sec)	0.030	0.0022
Radon flux from top of Layer 2	(pCi/m^2-sec)	-----	**9.45**
Measured radon diffusion coefficient	(cm^2/sec)	0.0070	0.0010
Radon flux from top of Layer 2	(pCi/m^2-sec)	-----	**0.99**

The radon emanation model results presented in Tables D.2 and D.3 above show that the cover system reduces the rate of radon-222 emanation to less than 20 pCi/m^2-sec for the four cases of cover directly on tailings.

3.2 Cover on Random Fill

For the scenario of the cover on random fill (and above the tailings), two cases were analyzed, as listed below.

1. Cover system directly on random fill, which is over tailings slimes, with calculated radon diffusion coefficient values. Random fill modeled with radium-226 value.
2. Cover system directly on random fill, which is over tailings slimes, with measured radon diffusion coefficient values. Random fill modeled with radium-226 value.

The input values and results from these two cases are summarized in Table D.4 with RADON model output included in Attachment D.1.

Table D.4. Cover on Random Fill, High Radium-226 Value

Layer Material		1 Tailings Slime	2 Random Fill	3 NW Borrow Sand
Layer thickness	(cm) (ft)	500 16.4	122 4.0	122 4.0
Porosity		0.54	0.34	0.34
Radium-226 activity conc.	(pCi/g)	1800	400	0
Moisture content	(%)	15	14	14
Degree of saturation	(%)	34	74	74
Calculated radon diffusion coefficient	(cm^2/sec)	0.026	0.0022	0.0022
Radon flux from top of Layer 3	(pCi/m^2-sec)	-----	-----	**3.98**
Measured radon diffusion coefficient	(cm^2/sec)	0.030	0.0010	0.0010
Radon flux from top of Layer 3	(pCi/m^2-sec)	-----	-----	**0.43**

The results in Table D.3 above show that the cover system reduces the rate of radon-222 emanation to less than 20 pCi/m^2-sec for the four cases of cover on random fill.

4.0 REFERENCES

Earth Science Consultants, Inc. (ESCI), 1995. "Decommissioning and Reclamation, Chapter 9," prepared for Cotter Corporation and included in the Cotter Corporation Application for Amendment to Radioactive Materials License 369-01, December.

Fremont Board of County Commissioners, 2008. “Resolution No. 40, Series of 2008: A Resolution Adopting the International Building Code, International Residential Code, and International Energy Conservation Code, 2006 Editions as the Building Code of Fremont County, Effective July 1, 2008.

MFG, Inc. (MFG) 2005. “2005 Update of the Mill Decommissioning and Tailings Reclamation Plan for the Cotter Corporation Canon City Milling Facility, prepared for Cotter Corporation, August.

Nuclear Regulatory Commission, 1989. “Calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers”, Regulatory Guide 3.64.

Rogers, V.C., K.K. Nielson, and D.R. Kalkwarf, 1984. "Radon Attenuation Handbook for Uranium Mill Tailings Cover Design," NUREG/CR-3533, prepared for U.S. Nuclear Regulatory Commission, April.

Water, Waste and Land, Inc. (WWL), 1990. "Canon City Tailings Basin Reclamation Plan," prepared for Cotter Corporation, January.

ATTACHMENT D.1

RADON Model Output

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

Version 1.2 - MAY 22, 1989 - G.F. Birchard tel.# (301)492-7000
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RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS ARE CALCULATED FOR MULTIPLE LAYERS

OUTPUT FILE: P:\100277\RADON\April-04\acov1
DESCRIPTION: Alternative Cover Directly on Tailings Sand-Slimes

CONSTANTS

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

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS	2	
RADON FLUX LIMIT	20	pCi m^-2 s^-1
LAYER THICKNESS NOT OPTIMIZED		
DEFAULT SURFACE RADON CONCENTRATION	0	pCi l^-1
RADON FLUX INTO LAYER 1	0	pCi m^-2 s^-1
SURFACE FLUX PRECISION	.1	pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings Sand-Slimes

THICKNESS	500	cm
POROSITY	.54	
MEASURED MASS DENSITY	1.24	g cm^-3
MEASURED RADIUM ACTIVITY	500	pCi/g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	8.439D-04	pCi cm^-3 s^-1
WEIGHT % MOISTURE	15	%
MOISTURE SATURATION FRACTION	.344	
MEASURED DIFFUSION COEFFICIENT	.026	cm^2 s^-1

LAYER 2 NW Borrow Sand

THICKNESS	122	cm
POROSITY	.34	
MEASURED MASS DENSITY	1.8	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi/g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	0.000D+00	pCi cm^-3 s^-1
WEIGHT % MOISTURE	14	%
MOISTURE SATURATION FRACTION	.741	
MEASURED DIFFUSION COEFFICIENT	.0022	cm^2 s^-1

DATA SENT TO THE FILE `RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
2	0.000D+00	0.000D+00	0	2.000D+01	1.000D-01

LAYER	DX	D	P	Q	XMS	RHO
1	5.000D+02	2.600D-02	5.400D-01	8.439D-04	3.444D-01	1.240
2	1.220D+02	2.200D-03	3.400D-01	0.000D+00	7.412D-01	1.800

BARE SOURCE FLUX FROM LAYER 1: 5.069D+02 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	5.000D+02	5.070D+01	3.617D+05
2	1.220D+02	2.338D+00	0.000D+00

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

OUTPUT FILE: P:\100277\RADON\ACov1m
DESCRIPTION: Alternative Cover Directly on Tailings Sand-Slimes

CONSTANTS

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

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS	2	
RADON FLUX LIMIT	20	pCi m^-2 s^-1
LAYER THICKNESS NOT OPTIMIZED		
DEFAULT SURFACE RADON CONCENTRATION	0	pCi l^-1
RADON FLUX INTO LAYER 1	0	pCi m^-2 s^-1
SURFACE FLUX PRECISION	.1	pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings Sand-Slimes

THICKNESS	500	cm
POROSITY	.54	
MEASURED MASS DENSITY	1.24	g cm^-3
MEASURED RADIUM ACTIVITY	500	pCi/g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	8.439D-04	pCi cm^-3 s^-1
WEIGHT % MOISTURE	15	%
MOISTURE SATURATION FRACTION	.344	
MEASURED DIFFUSION COEFFICIENT	.03	cm^2 s^-1

LAYER 2 NW Borrow Sand

THICKNESS	122	cm
POROSITY	.34	
MEASURED MASS DENSITY	1.8	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi/g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	0.000D+00	pCi cm^-3 s^-1
WEIGHT % MOISTURE	14	%
MOISTURE SATURATION FRACTION	.741	
MEASURED DIFFUSION COEFFICIENT	.001	cm^2 s^-1

DATA SENT TO THE FILE `RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
2	0.000D+00	0.000D+00	0	2.000D+01	1.000D-01

LAYER	DX	D	P	Q	XMS	RHO
1	5.000D+02	3.000D-02	5.400D-01	8.439D-04	3.444D-01	1.240
2	1.220D+02	1.000D-03	3.400D-01	0.000D+00	7.412D-01	1.800

BARE SOURCE FLUX FROM LAYER 1: 5.444D+02 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	5.000D+02	3.547D+01	3.757D+05
2	1.220D+02	2.648D-01	0.000D+00

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

OUTPUT FILE: P:\100277\RADON\April-04\acov2
DESCRIPTION: Alternative Cover Directly on Tailings Slimes

CONSTANTS

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

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS	2	
RADON FLUX LIMIT	20	pCi m^-2 s^-1
LAYER THICKNESS NOT OPTIMIZED		
DEFAULT SURFACE RADON CONCENTRATION	0	pCi l^-1
RADON FLUX INTO LAYER 1	0	pCi m^-2 s^-1
SURFACE FLUX PRECISION	.1	pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings Slimes

THICKNESS	500	cm
POROSITY	.54	
MEASURED MASS DENSITY	1.24	g cm^-3
MEASURED RADIUM ACTIVITY	1800	pCi/g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	3.038D-03	pCi cm^-3 s^-1
WEIGHT % MOISTURE	20	%
MOISTURE SATURATION FRACTION	.459	
MEASURED DIFFUSION COEFFICIENT	.03	cm^2 s^-1

LAYER 2 NW Borrow Sand

THICKNESS	122	cm
POROSITY	.34	
MEASURED MASS DENSITY	1.8	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi/g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	0.000D+00	pCi cm^-3 s^-1
WEIGHT % MOISTURE	14	%
MOISTURE SATURATION FRACTION	.741	
MEASURED DIFFUSION COEFFICIENT	.0022	cm^2 s^-1

DATA SENT TO THE FILE `RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
2	0.000D+00	0.000D+00	0	2.000D+01	1.000D-01

LAYER	DX	D	P	Q	XMS	RHO
1	5.000D+02	3.000D-02	5.400D-01	3.038D-03	4.593D-01	1.240
2	1.220D+02	2.200D-03	3.400D-01	0.000D+00	7.412D-01	1.800

BARE SOURCE FLUX FROM LAYER 1: 1.960D+03 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	5.000D+02	2.050D+02	1.295D+06
2	1.220D+02	9.452D+00	0.000D+00

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

OUTPUT FILE: P:\100277\RADON\April-04\Acov2m
DESCRIPTION: Cover Directly on Tailings Slimes

CONSTANTS

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

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS	2	
RADON FLUX LIMIT	20	pCi m^-2 s^-1
LAYER THICKNESS NOT OPTIMIZED		
DEFAULT SURFACE RADON CONCENTRATION	0	pCi l^-1
RADON FLUX INTO LAYER 1	0	pCi m^-2 s^-1
SURFACE FLUX PRECISION	.1	pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings Slimes

THICKNESS	500	cm
POROSITY	.54	
MEASURED MASS DENSITY	1.24	g cm^-3
MEASURED RADIUM ACTIVITY	1800	pCi/g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	3.038D-03	pCi cm^-3 s^-1
WEIGHT % MOISTURE	20	%
MOISTURE SATURATION FRACTION	.459	
MEASURED DIFFUSION COEFFICIENT	.007	cm^2 s^-1

LAYER 2 NW Borrow Sand

THICKNESS	122	cm
POROSITY	.34	
MEASURED MASS DENSITY	1.8	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi/g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	0.000D+00	pCi cm^-3 s^-1
WEIGHT % MOISTURE	14	%
MOISTURE SATURATION FRACTION	.741	
MEASURED DIFFUSION COEFFICIENT	.001	cm^2 s^-1

DATA SENT TO THE FILE `RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
2	0.000D+00	0.000D+00	0	2.000D+01	1.000D-01

LAYER	DX	D	P	Q	XMS	RHO
1	5.000D+02	7.000D-03	5.400D-01	3.038D-03	4.593D-01	1.240
2	1.220D+02	1.000D-03	3.400D-01	0.000D+00	7.412D-01	1.800

BARE SOURCE FLUX FROM LAYER 1: 9.472D+02 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	5.000D+02	1.326D+02	1.244D+06
2	1.220D+02	9.897D-01	0.000D+00

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

OUTPUT FILE: P:\100277\RADON\April-04\Acov3
DESCRIPTION: Alternative Cover on Random Fill

CONSTANTS

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

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS	3	
RADON FLUX LIMIT	20	pCi m^-2 s^-1
LAYER THICKNESS NOT OPTIMIZED		
DEFAULT SURFACE RADON CONCENTRATION	0	pCi l^-1
RADON FLUX INTO LAYER 1	0	pCi m^-2 s^-1
SURFACE FLUX PRECISION	.1	pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings Slimes

THICKNESS	500	cm
POROSITY	.54	
MEASURED MASS DENSITY	1.24	g cm^-3
MEASURED RADIUM ACTIVITY	1800	pCi/g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	3.038D-03	pCi cm^-3 s^-1
WEIGHT % MOISTURE	15	%
MOISTURE SATURATION FRACTION	.344	
MEASURED DIFFUSION COEFFICIENT	.026	cm^2 s^-1

LAYER 2 Random Fill

THICKNESS	122	cm
POROSITY	.34	
MEASURED MASS DENSITY	1.8	g cm^-3
MEASURED RADIUM ACTIVITY	400	pCi/g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	1.556D-03	pCi cm^-3 s^-1
WEIGHT % MOISTURE	14	%
MOISTURE SATURATION FRACTION	.741	
MEASURED DIFFUSION COEFFICIENT	.0022	cm^2 s^-1

LAYER 3 NW Borrow Sand

THICKNESS	122	cm
POROSITY	.34	
MEASURED MASS DENSITY	1.8	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi/g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	0.000D+00	pCi cm^-3 s^-1
WEIGHT % MOISTURE	14	%
MOISTURE SATURATION FRACTION	.741	
MEASURED DIFFUSION COEFFICIENT	.0022	cm^2 s^-1

DATA SENT TO THE FILE `RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
3	0.000D+00	0.000D+00	0	2.000D+01	1.000D-01

LAYER	DX	D	P	Q	XMS	RHO
1	5.000D+02	2.600D-02	5.400D-01	3.038D-03	3.444D-01	1.240
2	1.220D+02	2.200D-03	3.400D-01	1.556D-03	7.412D-01	1.800
3	1.220D+02	2.200D-03	3.400D-01	0.000D+00	7.412D-01	1.800

BARE SOURCE FLUX FROM LAYER 1: 1.825D+03 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	5.000D+02	3.174D+01	1.422D+06
2	1.220D+02	8.638D+01	3.734D+05
3	1.220D+02	3.983D+00	0.000D+00

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

Version 1.2 - MAY 22, 1989 - 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

OUTPUT FILE: P:\100277\RADON\April-04\acov3m
DESCRIPTION: Alternative Cover on Random Fill

CONSTANTS

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

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS	3	
RADON FLUX LIMIT	20	pCi m^-2 s^-1
LAYER THICKNESS NOT OPTIMIZED		
MEASURED SURFACE RADON CONCENTRATION	20	pCi l^-1
RADON FLUX INTO LAYER 1	0	pCi m^-2 s^-1
SURFACE FLUX PRECISION	.1	pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings Slimes

THICKNESS	500	cm
POROSITY	.54	
MEASURED MASS DENSITY	1.24	g cm^-3
MEASURED RADIUM ACTIVITY	1800	pCi/g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	3.038D-03	pCi cm^-3 s^-1
WEIGHT % MOISTURE	15	%
MOISTURE SATURATION FRACTION	.344	
MEASURED DIFFUSION COEFFICIENT	.03	cm^2 s^-1

LAYER 2 Random Fill

THICKNESS	122	cm
POROSITY	.34	
MEASURED MASS DENSITY	1.8	g cm^-3
MEASURED RADIUM ACTIVITY	400	pCi/g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	1.556D-03	pCi cm^-3 s^-1
WEIGHT % MOISTURE	14	%
MOISTURE SATURATION FRACTION	.741	
MEASURED DIFFUSION COEFFICIENT	.001	cm^2 s^-1

LAYER 3 NW Borrow Sand

THICKNESS	122	cm
POROSITY	.34	
MEASURED MASS DENSITY	1.8	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi/g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	0.000D+00	pCi cm^-3 s^-1
WEIGHT % MOISTURE	14	%
MOISTURE SATURATION FRACTION	.741	
MEASURED DIFFUSION COEFFICIENT	.001	cm^2 s^-1

DATA SENT TO THE FILE `RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
3	0.000D+00	2.000D+01	0	2.000D+01	1.000D-01

LAYER	DX	D	P	Q	XMS	RHO
1	5.000D+02	3.000D-02	5.400D-01	3.038D-03	3.444D-01	1.240
2	1.220D+02	1.000D-03	3.400D-01	1.556D-03	7.412D-01	1.800
3	1.220D+02	1.000D-03	3.400D-01	0.000D+00	7.412D-01	1.800

BARE SOURCE FLUX FROM LAYER 1: 1.960D+03 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	5.000D+02	2.014D+01	1.432D+06
2	1.220D+02	5.782D+01	3.711D+05
3	1.220D+02	4.302D-01	9.031D+00