A CHANGE IN ENVIROCARE'S DISPOSAL CELL DESIGN

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ABSTRACT

Envirocare of Utah, Inc. operates a Low Level Radioactive Waste (LLRW) and 11e.(2) disposal facility in the Utah west dessert. Envirocare disposes of LLRW in above ground cells. A seven-foot excavation lined with two feet of clay comprises the cell floor. Approximately 22 feet of waste is then placed in the cell in one-foot thick compacted lifts. The cover system consists of a nine-foot clay radon barrier and three-foot rock erosion barrier. This is required to prevent radon emissions at the surface of the radon barrier from exceeding 20 pCi/m^2s, the radon release standard in Criterion 6 of 10 CFR 40, Appendix A.

The required thickness of the current clay radon barrier cover was based on the original radon flux model used to evaluate the safety of Envirocare's proposed LLRW and 11e.(2) license operations. Because of the lack of actual measurements, universally conservative values were used for the long-term moisture content and the radon diffusion coefficients of the waste and radon barrier material. Since receiving its license, Envirocare has collected a number of samples from the radon barrier and waste material to determine their actual radon attenuation characteristics, including the long-term moisture content and the associated radon diffusion coefficient. In addition, radon flux measurements have been performed to compare the model calculations with the calculated results. The results from these analyses indicate that the initial modeling input parameters, specifically the long-term moisture content and the radon diffusion coefficient, are more conservative than that needed to ensure compliance with the applicable regulatory requirements.

Envirocare has updated the surface radon flux calculations, using the RADON code. The radon flux for the disposal cells was calculated using the actual measured radon diffusion and emanation coefficients, density, and long-term moisture content. The results from these analyses indicate that Envirocare could safely reduce the radon barrier thickness to three feet and the radon flux would be less than 4 pCi/m^2s, well below 20 pCi/m^2s at the surface of the cover.

The most significant parameter limiting the thickness of the clay radon barrier required to meet the EPA radon flux criterion is the radon diffusion coefficient of the cover. In turn, the value of the radon diffusion coefficient is very sensitive to the moisture content of the material. The parameter that introduces the greatest uncertainty into the calculation of the radon flux is the moisture content of the cover. The NRC has identified several methods for determining an acceptable long-term moisture content. From the methods listed, Envirocare opted to measure the actual long-term moisture content in the radon barrier borrow area.

To determine the long-term moisture content, Envirocare contracted with Applied Geotechnical Engineering Consultants, Inc. to take samples in the borrow pit walls 152 to 183 cm below the ground surface. The outer six inches of the wall was first removed and then the samples were collected of the underlying material. The analytical results show that the natural weight percent moisture of the material that makes up the radon barrier varies from 41.4 percent to 25.6 percent. The most conservative value, 25.6 weight percent moisture, was selected as the long-term moisture value for the radon model. The long-term moisture content used in the initial modeling was 13 weight percent.

Envirocare has performed additional measurements and modeling to demonstrate that it would be impossible for the long-term moisture content of the radon barrier to be below the value (25.6 %) selected and used in the radon attenuation model. Several moisture content analyses are performed during the placement of radon barrier. Analytical results for year 1999 and 2000 in-situ moisture content and density measurements which were performed on the radon barrier clay material indicate that the average dry density and moisture content is 1.54g/cm^3 and 26 %, respectively.

As part of the fate and transport modeling, moisture content modeling was performed for the cover and embankment system using the UNSAT-H model. This modeling establishes that steady-state moisture content for the clay layers of the cover remain constant.

There are no credible evaporative mechanisms to dry out the radon barrier, regardless of the length or severity of drought conditions. The moisture content of the radon barrier will remain constant for the life of the embankment based on the following three aspects of the cover design:

1. Moisture that enters the system is designed to run off the cell cover at the interface between the lower filter zone and the surface of the radon barrier. Runoff at this interface provides a re-wetting mechanism for radon barrier clays, should they fall below optimum moisture content.
2. The field capacity of the lower filter zone is over an order of magnitude less than that of the radon barrier. Accordingly, moisture in the system will preferentially migrate to the radon barrier clay. The difference in field capacity confirms the effectiveness of the lower filter zone as a capillary break, as the lower filter zone will not be able to pull moisture from the radon barrier clay for transport to the surface of the cover.
3. The evaporative zone depth (EZD) for the cover system was modeled at 18 inches for the site. EZD is defined as the depth to which evaporation and transpiration from the soil or rock can occur. An EZD of 18 inches equals the thickness of the rock erosion barrier only; accordingly, lower layers of the cover system are not impacted by evaporation.

The current design of the cell cover includes two layers of rock placed on the clay cover consisting of 12 inches of filter rock and 18 inches of rip-rap rock. The EZD would only go down to the 12 inches of filter rock. Therefore, there is no viable mechanism by which the radon barrier clay could lose moisture. In fact, the model results indicate that the moisture of the clay could increase over time.

The amount of moisture in a soil can have a great effect on the diffusion properties of a soil or clay. The value used to quantify the attenuation of a radon flux through a substance is known as the diffusion coefficient. The larger the diffusion coefficient the greater the radon flux. In general, the diffusion coefficient decreases exponentially with moisture content. The diffusion coefficient values can be estimated using the material's moisture content and porosity but direct measurements are preferred. The calculated diffusion coefficient for the identified long-term moisture value of 25.6 weight percent was 6.37E-4 cm^2/s, which is approximately one order of magnitude lower than the value used in the initial modeling.

Over the years, a number of radon barrier samples have been collected for measurement of diffusion coefficients. Each sample was measured at several different moisture contents. A trend line was developed to relate the moisture content to the measured radon diffusion coefficients. From the trend line, 25.6 percent moisture corresponds to a diffusion coefficient of 3.20E-4 cm^2/s. For comparison, the sample closest to the identified long-term moisture had 25.3 weight percent moisture and a diffusion coefficient value of 4.4 E-4 cm^2/s. Since the calculated value of 6.37E-4 cm^2/s is more conservative, it was selected for the radon flux model.

Potential external gamma exposure rates at the top of waste and radon barrier were evaluated. The results indicated that the reduction in radon barrier thickness will still provide enough shielding to reduce gamma exposure rates to background levels. Using the Ra-226 concentration to exposure rate relationship cited in Section 6.5 of Section 6 in the 11e.(2) license application, the potential exposure rates above the waste column was calculated to be 10,000 rem/hr, conservatively assuming that all waste contained 4,000 pCi/g of Ra-226, Envirocare's license limit. The tenth value layer of the compacted clay and rock barrier was assumed to be the same as concrete and sand (23.4 cm) and 5 feet of cover is equivalent to approximately 6.5 tenth value layers. The calculated exposure rate at the surface of the cover is 3E-3 rem/hr, indistinguishable from background.

The estimated design frost depth is 27.5 inches, based on the required 1,000 year requirement. On the side slopes of the embankment the filter zones and riprap total 30 inches and therefore there would be no frost penetration into the radon barrier. On the top portion the riprap and filter zones are 24 inches. Therefore the frost would penetrate 3.5 inches into the clay layer. For this purpose, the top layer will consist of 3.5 feet of radon barrier clay. However, a uniform thickness of 3 feet will be used in the RADON model for conservatism.

The RADON computer code was used to calculate the radon flux at the surface of the cover. The input parameters remained the same as the initial NRC modeling except for the long-term moisture content and the corresponding radon diffusion coefficient as identified previously. The results from the various RADON computer calculations indicates that with 3 feet of clay cover, the radon flux at the surface is still well below the EPA radon flux standard. To help validate the RADON results, actual radon flux measurements were performed on cell areas with clay cover of 2 to 8 feet. The results from these analyses are extremely close to the RADON codes results when the lower diffusion coefficient is used.

INTRODUCTION

Envirocare's current cell design includes an 8 to 9-foot clay radon barrier cover. This is required to prevent radon emissions at the surface of the radon barrier from exceeding 20 pCi/m^{2}s, the radon release standard in Criterion 6 of 10 CFR 40, Appendix A.

The required thickness of the current clay radon barrier cover was based on the original radon flux model used to evaluate the safety of Envirocare's proposed 11e.(2) license operations. Because of the lack of actual measurements, universally conservative values were used for the long-term moisture content and the radon diffusion coefficients of the waste and radon barrier material. Since receiving its license, Envirocare has collected a number of samples from the radon barrier and waste material to determine their actual radon attenuation characteristics, including the long-term moisture content and the associated radon diffusion coefficient. In addition, radon flux measurements have been performed to compare the model calculations with the calculated results. The results from these analyses indicate that the initial modeling input parameters, specifically the long-term moisture content and the radon diffusion coefficient, are more conservative than that needed to ensure compliance with the applicable regulatory requirements.

Envirocare has updated the surface radon flux calculations, using the RADON code (NRC, 1989). The radon flux for the disposal cells was calculated using the actual measured radon diffusion and emanation coefficients, density, and long-term moisture content. The results from these analyses indicate that Envirocare could safely reduce the radon barrier thickness to three feet and the radon flux would be less than 4 pCi/m^{2}s, well below 20 pCi/m^{2}s at the surface of the cover.

LONG-TERM MOISTURE CONTENT

The radon diffusion coefficient is the most significant parameter in modeling radon attenuation. Because the radon diffusion coefficient value is very sensitive to moisture content, the NRC has identified several methods for determining an acceptable long-term moisture content of cover materials. In October 1998, Envirocare contracted with Applied Geotechnical Engineering Consultants, Inc. to take samples in the borrow pit walls 152 to 183 cm below the ground surface as prescribed in the NRC Guidance. The outer six inches of the wall was first removed and then the samples were collected from the underlying material. The analytical results from these samples, which are listed in Table I, demonstrate that the clay has a natural moisture content varies from 25.6 to 41.4 percent by weight.

Table I. Borrow Pit Sample Data

Description	Sample #	Date	Wt. % Moisture	Soil Type*
Borrow Pit North of 11e(2) Cell	1	10/20/98	35.2	Grey Lean Clay
	2	10/20/98	40.5	Grey Lean Clay
	3	10/20/98	35.4	Grey Lean Clay
	4	10/20/98	38.2	Grey Lean Clay
	5	10/20/98	40.4	White Lean Clay
	6	10/20/98	41.0	White Lean Clay
	7	10/20/98	41.4	White Lean Clay
Borrow Pit North-west of Mixed Waste	8	10/20/98	29.5	Grey Lean Clay
	9	10/20/98	27.2	Grey Lean Clay
	10	10/20/98	29.4	Grey Lean Clay
	11	10/20/98	28.8	Grey Lean Clay
	12	10/20/98	25.6	White Lean Clay
	13	10/20/98	28.6	White Lean Clay
	14	10/20/98	26.7	White Lean Clay
Borrow Pit inside 11e.(2) Area	15	10/20/98	37.3	Grey Lean Clay
	16	10/20/98	37.6	Grey Lean Clay
	17	10/20/98	37.3	Grey Lean Clay
	18	10/20/98	37.4	White Lean Clay
	19	10/20/98	36.7	White Lean Clay
	20	10/20/98	37.0	White Lean Clay

*Soil types were identified by visual appearance.

Envirocare has performed additional measurements and modeling to demonstrate that it would be impossible for the long-term moisture content of the radon barrier to be below the value (25.6 %) selected and used in the radon attenuation model. Several moisture content analyses are performed during the placement of radon barrier. The average dry density and moisture content for 1999, 2000 and 2001 was 1.54g/cm^3 and 26 %, respectively.

As part of the fate and transport modeling conducted for the Utah Division of Radiation Control (UDRC), moisture content modeling was performed for the cover and embankment system using the UNSAT-H model. This modeling establishes that steady-state moisture content for the clay layers of the cover remain constant.

There are no credible evaporative mechanisms to dry out the radon barrier, regardless of the length or severity of drought conditions. The moisture content of the radon barrier will remain constant for the life of the embankment based on the following three aspects of the cover design:

4. Moisture that enters the system is designed to run off the cell cover at the interface between the lower filter zone and the surface of the radon barrier. Runoff at this interface provides a re-wetting mechanism for radon barrier clays, should they fall below optimum moisture content.
5. The field capacity of the lower filter zone is over an order of magnitude less than that of the radon barrier. Accordingly, moisture in the system will preferentially migrate to the radon barrier clay. The difference in field capacity confirms the effectiveness of the lower filter zone as a capillary break, as the lower filter zone will not be able to pull moisture from the radon barrier clay for transport to the surface of the cover.
6. The evaporative zone depth (EZD) for the cover system was modeled at 18 inches for the site. EZD is defined as the depth to which evaporation and transpiration from the soil or rock can occur. An EZD of 18 inches equals the thickness of the rock erosion barrier only; accordingly, lower layers of the cover system are not impacted by evaporation.

The current design of the cell cover includes two layers of rock placed on the clay cover consisting of 12 inches of filter rock and 18 inches of rip-rap rock. The EZD would only go down to the 12 inches of filter rock. Therefore, there is no viable mechanism by which the radon barrier clay could lose moisture. In fact, the model results indicate that the moisture of the clay could increase over time.

Envirocare's position based on the above information is that a 25.6 percent long-term moisture content provides a conservative evaluation of radon attenuation. Therefore, a weight percent of 25.6 was selected as the long-term moisture value for the radon attenuation model. The moisture content value used for the waste material was consistent with the value used in the initial NRC modeling.

POROSITY AND DRY BULK MASS DENSITY

Porosity and dry bulk mass density values are related (Equation 1) and do not vary significantly for a specific soil type. The NRC permits conservative values of 0.35 and 1.6 respectively for these parameters (NRC, 1989). Based upon actual analytical results, from 11e.(2) radon barrier and waste samples, more conservative values of 1.5 g/cm^3 and 0.444 were used for mass density and the porosity of the radon barrier and 1.65 g/cm^3 and 0.384 for the mass density and porosity of the waste material. The relationship between the mass density and porosity is defined in Equation 1.

$$n_c = 1 - \frac{\rho_c}{G_c \rho_w} \qquad \text{(Eq. 1)}$$

where:

n_c = Porosity of the cover.
ρ_c = Mass density of the cover, (g/cc).
G_c = Specific Gravity of Cover (2.7)
ρ_w = Mass density of water, (g/cc). $\rho_w = 1$.

RADON DIFFUSION COEFFICIENT

The amount of moisture in a soil can have a great effect on the radon diffusion properties of a soil or clay. The value used to quantify the attenuation of a radon flux through a substance is known as the radon diffusion coefficient. The larger the radon diffusion coefficient the greater the radon flux. In general, the radon diffusion coefficient decreases exponentially with moisture content. The diffusion coefficient values can be estimated using the material's moisture content and porosity (Equations 2 and 3 from NRC, 1989) but direct measurements are preferred. The calculated diffusion coefficient for the long-term moisture value of 25.6 weight percent was 6.37E-4 cm^2/s as shown below:

$$m_c = \frac{10^{-2} \rho_c w_c}{n_c \rho_w} \qquad \text{(Eq. 2)}$$

where

m_c = Moisture saturation fraction of the cover
ρ_c = Mass density of the cover, (g/cc).
w_c = Long-term average dry weight percent moisture.
n_c = Porosity of the cover
ρ_w = Mass density of water, (g/cc), ($\rho_w = 1$).

$$D = 0.07e^{\left[-4\left(m - mn^2 + m^5\right)\right]} \qquad \text{(Eq. 3)}$$

where:

D = Diffusion coefficient for the cover.
m = Moisture saturation fraction.
n = Porosity.

$$\frac{10^{-2}(1.5)(25.6)}{0.4444(1)} = m_c = 0.864 \qquad \text{(Eq. 4)}$$

$$0.07e^{\left[-4\left(0.864-0.864\left(0.4444^2\right)+0.864^5\right)\right]} = D = 6.37\times10^{-4}\,\frac{cm^2}{\sec}$$

Over the years, a number of radon barrier samples have been collected for measurement of diffusion coefficients. Each sample was measured at several different moisture contents. A trend line was developed to relate the moisture content to the measured radon diffusion coefficients (Figure 1). From the trend line, 25.6 percent moisture corresponds to a diffusion coefficient of 3.20E-4 cm^2/s. For comparison, the sample closest to the identified long-term moisture had 25.3 weight percent moisture and a diffusion coefficient value of 4.4 E-4 cm^2/s. Since the calculated value of 6.37E-4 cm^2/s is more conservative, it was selected for the radon flux model. The radon diffusion coefficient value used for the waste material was consistent with the values used in the initial NRC modeling.

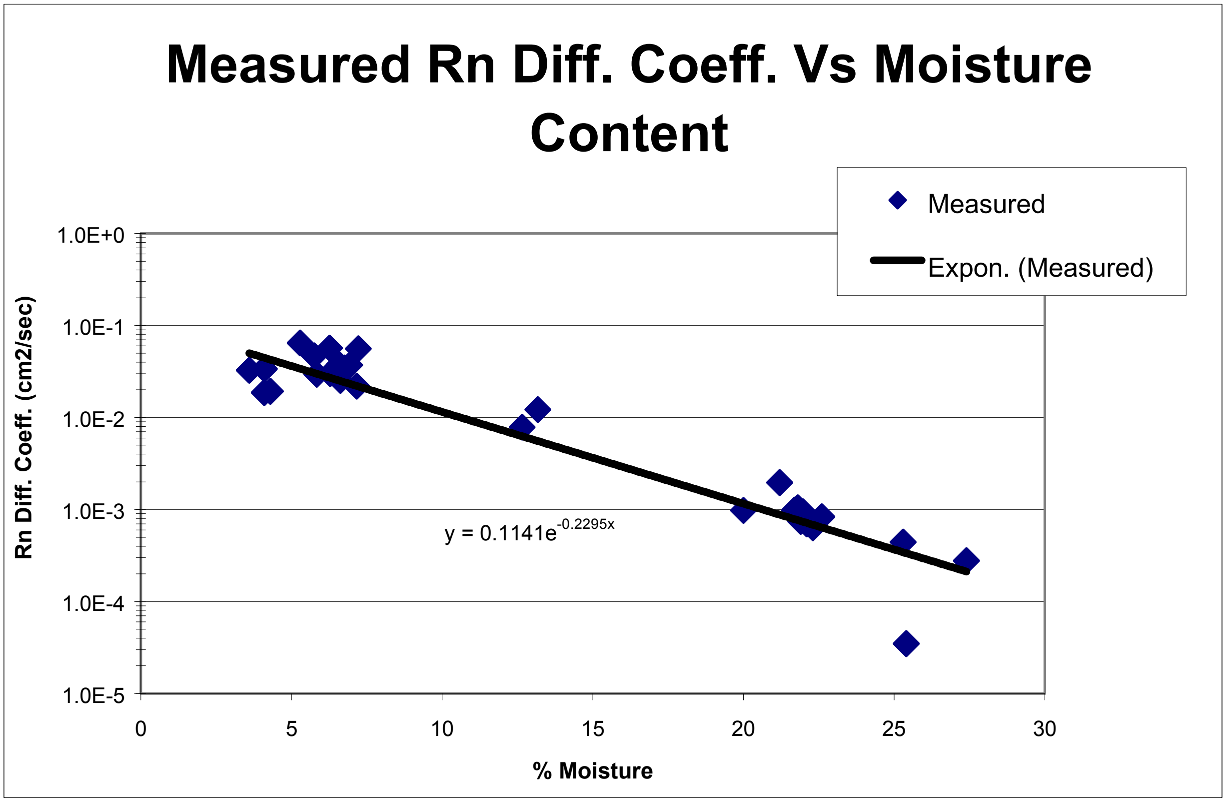

Fig. 1. Measured Diffusion Coefficients

Radon Flux Contribution of the Cover

The radon flux contribution from the Ra-226 present in the radon barrier also contributes to the total radon flux. A general rule of thumb is that there is about one pCi/m^2s radon flux for each pCi/g concentration of Ra-226 in soil. The Ra-226 concentration was assumed to be that of natural background (1.5 pCi/g). Because no analytical information was available for the emanation fraction the NRC default value of 0.35 was assumed (NRC, 1989).

RADIUM-226 AND TH-230 CONCENTRATIONS IN WASTE

A review of Envirocare's disposal history was also considered when determining the Ra-226 value used in the model. Th-230 concentrations were included to help calculate the contribution of Ra-226 from the decay of Th-230. Since the commencement of waste placement into the 11e.(2) cell in 1994, average Ra-226 and Th-230 concentrations that have been disposed in the embankment each year has been less than 150 and 700 pCi/g, respectively. Ra-226 concentrations in the projected waste streams are decreasing. Additionally, Envirocare commits in their Radioactive Materials License Application that the average Ra-226 concentration in the cell will remain less than 500 pCi/g. However, a conservative Ra-226 concentration value of 4,000 pCi/g, Envirocare's license limit, was used in the radon flux calculations.

DIRECT GAMMA LEVELS

Potential external gamma exposure rates at the top of waste and radon barrier were evaluated. The results indicated that the reduction in radon barrier thickness will still provide enough shielding to reduce gamma exposure rates to background levels. The potential exposure rates above the waste column was calculated to be 10,000 µrem/hr, conservatively assuming that all waste contained 4,000 pCi/g of Ra-226, Envirocare's license limit. The tenth value layer of the compacted clay and rock barrier was assumed to be the same as concrete and sand (23.4 cm) and 5 feet of cover is equivalent to approximately 6.5 tenth value layers. The calculated exposure rate at the surface of the cover is 3E-3 µrem/hr, indistinguishable from background.

FROST PROTECTION

The estimated design frost depth is 27.5 inches, based on the required 1,000 year requirement. On the side slopes of the embankment the filter zones and riprap total 30 inches and therefore there would be no frost penetration into the radon barrier. On the top portion the riprap and filter zones are 24 inches. Therefore the frost would penetrate 3.5 inches into the clay layer. For this purpose, the top layer will consist of 3.5 feet of radon barrier clay. However, a uniform thickness of 3 feet will be used in the RADON model for conservatism.

RADON MODEL RESULTS

The RADON computer code was used to calculate the radon flux at the surface of the cover for five scenarios. The calculation of Scenario 1 was performed to provide the radon flux at the surface of the cover at the proposed radon barrier thickness assuming that the uniform Ra-226 concentration in the disposal cell was 4,000 pCi/g, Envirocare's license limit. The input parameters for this calculation remained the same as the initial NRC modeling except for the density, long-term moisture content, and the corresponding radon diffusion coefficient of the radon barrier clay material as identified previously. Scenarios 2-5 compare the radon flux at the surface of the cover for various Ra-226 concentrations and clay thickness using both the initial NRC diffusion coefficients and the proposed diffusion coefficient as explained previously. In addition, actual radon flux measurements were made on the cell at clay thicknesses equivalent to those entered in Scenarios 2-5 in order to demonstrate the accuracy of the proposed radon diffusion coefficient. Table II provides the input parameters for the 5 scenarios. The results from these measurements are provided in Table III.

Table II . RADON Input Parameters

	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**		**Scenario 5**	
Input Parameter	**Upper Waste**	**Radon Barrier**	**Upper Waste**	**Radon Barrier**	**Upper Waste**	**Radon Barrier**	**Upper Waste**	**Radon Barrier**	**Upper Waste**	**Radon Barrier**
Radium-226 (pCi/g)	4000	1.5	200	1.5	200	1.5	160	1.5	160	1.5
Emanation (fraction)	0.25	0.35	0.25	0.35	0.25	0.35	0.25	0.35	0.25	0.35
Bulk Dry Density (g/cm^3)	1.65	1.50	1.50	1.50	1.65	1.50	1.50	1.50	1.65	1.50
Specific Gravity	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
Porosity	0.38	0.44	0.44	0.44	0.38	0.44	0.44	0.44	0.38	0.44
Thickness (cm)	762	91.4	762	244	762	244	762	61	762	61
Rn Diffusion Coefficient (cm^2/s)	0.03100	0.00064	0.03100	0.00800	0.03100	0.00064	0.03100	0.00800	0.03100	0.00064
Moisture (% dry weight)	6.0	25.6	6	10	6	25.6	6	10	6	25.6

Table III. RADON and Measured Results

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**
RADON Calculated Rn Flux (pCi/m^{2}s)	3.32	3.89	0.29	37.8	0.79
Measured Rn Flux (pCi/m^{2}s)		0.32	0.32	0.73	0.73
% Difference		1,200 %	10 %	5,200 %	8 %

The results for scenario 1 indicate that the radon flux at the surface of the cover is less than 4 pCi/m^{2}s, well below the EPA radon flux standard even with the increase in Ra-226 concentration. As shown in Table III, the actual measured radon flux values correlated much closer to the calculated radon flux using Envirocare's proposed radon diffusion coefficient than that used in the initial NRC calculation. Radon flux was calculated in both Scenario 2 and 3 at a radon barrier thickness of eight feet. The calculated radon flux using Envirocare's radon diffusion coefficient was less than 11 % different from the measured value while the radon flux value calculated using initial the NRC radon diffusion coefficient was 1,200 % different, greater than twelve times the measured radon flux value. There was an even greater disparity when comparing Scenarios 4 and 5; at a two foot radon barrier thickness, the percent difference between the calculated radon flux value using the original NRC radon diffusion coefficient was 5,200 %, greater than 64 times the measured value. The same comparison using the radon diffusion coefficient that Envirocare proposes yielded a percent difference of 8 %. Analysis of this data reveals that the radon diffusion coefficient proposed by Envirocare is many times more accurate when compared to actual conditions.

Another scenario, not listed above, was also performed to provide a calculated radon flux at the actual projected average Ra-226 concentrations in the cell. As stated previously, the actual average Ra-226 concentration in the cell is currently, and is projected to be, less than 150 pCi/g, 27 times lower than the value used in Scenario 1. This extreme conservatism provides a significant margin of safety which negates the effects of any possible minor discrepancies between Envirocare and the NRC concerning the long-term moisture content and the associated radon diffusion coefficient. The results from Scenario 6 indicate that the radon flux would be much less than 1 pCi/m^{2}s. In fact, using the actual Ra-226 concentration and the proposed radon barrier thickness, the long-term moisture content in the clay could be much less and still the radon flux would be less than the EPA standard.

One last Scenario was calculated to identify the minimum moisture concentration in the radon barrier sufficient to prevent the radon flux from exceeding 20 pCi/m^2/sec and demonstrate the radon flux at the actual Ra-226 concentrations with the propose radon barrier thickness. Because the moisture concentration affects the radon diffusion coefficient a diffusion coefficient was calculated for was calculated for a series of moisture concentrations using the relationship identified in Figure 1. The RADON code was iterated several times with decreasing moisture concentrations values and the corresponding radon diffusion coefficient until the corresponding radon flux was approximately 20 pCi/m^{2}s. The radon diffusion coefficient that would allow the radon flux at the surface of the cover to reach the EPA radon flux standard was determined to be 8.15E-3 cm^2/s, which corresponds to a moisture content of 11.5 percent. This value is 14 percent below the 25.6 long-term moisture content used in the radon flux calculation.

In aid in the evaluation of the reduction of radon barrier thickness, Envirocare reviewed other facilities which dispose/store materials containing Ra-226. The material from UMTRA projects contain significantly higher Ra-226 concentrations and are only required to place 3 to 4 feet of radon barrier on the tailings. These projects are held to the same radon flux standards as Envirocare is and sets precedence for the amount of radon barrier required. Since Envirocare disposes of material with much less concentrations of Ra-226 than UMTRA projects, 3 feet of radon barrier provides a significant safety factor.

CONCLUSION

The radon attenuation characteristics of the radon barrier are significantly more conservative than the values that were used in the RADON model that was used to establish the required radon barrier thickness in radioactive materials license application. Because the moisture present in the soil can change the diffusion coefficient value of a material by several orders of magnitude, the long-term moisture concentration used in the model has a large impact on the calculated radon flux value. A study of the long-term moisture content in the radon barrier borrow area was done according to the guidance provided in NRC guidance. The lowest moisture concentration found in the radon barrier borrow area had a 25.6 weight percent moisture concentration. Based on this sampling, Envirocare submits that 25.6 weight percent is a conservative value for the long-term moisture concentration. A corresponding radon diffusion coefficient of 6.37E-4 cm^2/s was calculated using an algorithm provided by the NRC. The proposed diffusion coefficient value of 6.37E-4 cm^2/s used in this report was determined to be conservative when compared with the diffusion coefficients measured in actual radon barrier samples. In addition, when using Envirocare's proposed radon diffusion coefficient, the calculated radon flux at different radon barrier thicknesses had a much higher degree of correlation with actual measured radon flux values. The results from these analyses indicate that Envirocare could safely reduce the radon barrier thickness to three feet and the radon flux would be less than 4 pCi/m^2s, well below 20 pCi/m^2s at the surface of the cover. This conclusion is drawn assuming a conservative uniform 4,000 pCi/g Ra-226 concentration in the cell, when in reality the average Ra-226 concentration in the cell is less than 150 pCi/g.

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