TIM-68-2

TECHNICAL INFORMATION MEMORANDUM

SUBJECT: REVIEW OF PACIFIC NORTHWEST LABORATORY REPORT, NUREG/CR-3457 "VALIDATION OF METHODS FOR EVALUATING RADON-FLUX ATTENUATION THROUGH EARTHEN COVERS"

BY: V.C. Rogers
K.K. Nielson

FOR: Jacobs-Weston Team
5301 Central Ave., N.E., Suite 1700
Albuquerque, NM 87108

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Rogers & Associates Engineering Corporation

RAE

1. INTRODUCTION

At the request of the Technical Assistance Contractor to the DOE-UMTRAP, Rogers and Associates Engineering Corporation (RAE) has reviewed the report entitled "Validation of Methods for Evaluating Radon-Flux Attenuation Through Earthen Covers" (Ref. 1) as well as the comments to Reference 1 given by the DOE-UMTRAP Remedial Action Contractor.(2) In general, we support the conclusion stated in Reference 2 that "the methods (given in Reference 3-the Handbook) are not validated by the data presented." RAE has concluded from its evaluation that Reference 1 neither validates nor invalidates the methods given in the Handbook because the validation project contains a poorly-conceived and executed field and laboratory measurement program as well as an erroneous and incomplete application of the Handbook methodology. While the general concept of a validation of the Handbook is desirable, it is important that the validation be planned and performed so that measured parameter values and calculated values are compared in a consistent and correct manner.

This memorandum is organized as follows: general comments on the work reported in Reference 1 are given in Section 2, followed by specific comments on each section of Reference 1, except for the Conclusions section, which is addressed in Section 4. Finally, Section 5 contains RAE analyses of the CMS-NW site, correctly using the methodology, and our final conclusions.

2. GENERAL COMMENTS

The main concerns about Reference 1 are organized into five general comments.

1. Simplistic and incorrect representation of specific site data. For example, using only three layers to represent a specific site with as many as 22 different layers gives rise to calculational errors in the surface flux that are greater than the flux differences presented in the report. This step alone caused errors large enough to render the flux comparisons worthless and misleading.

2. Erroneous measured values of key parameters. For example, the measured values of the density of the tailings leads to the preposterous conclusion that the tailings have expanded by 45 percent in two years. That results in an increase in the pile height of up to 27 feet. Yet the density measurement is never questioned in Ref. 1.

3. Poorly conceived and executed field and laboratory measurement program. Examples are: total neglect of measuring R and E of the cover materials, neglecting to correct the measured fluxes for background, performing most flux measurements only during the daytime, and making obviously erroneous diffusion coefficient measurements for the uncompacted cover material.

4. Total lack of RAECOM calculations. The simple, accurate and quick-running RAECOM code is the main tool given in the Handbook methodology. This code was

completely ignored. As shown in Section 5, it can also be used as a valuable part of validating the approximate analytical equations.

5. Lack of internal review. The many questionable statements, faulty data values, omissions and typographical errors indicates insufficient internal review of the document before publication. The importance of the topic and the general, broad conclusions contained in Reference 1 should have received the careful, detailed, internal scrutiny normally accorded such reports in review and clearance procedures.

3. SPECIFIC COMMENTS

This section contains a sequential listing of specific comments on, and errors found in, the PNL validation report.

Item	Page	Comment
1.	4	Radon fluxes were measured only over three days (five days for two locations), and predominantly during daytime hours. Given the large variations (diurnal, seasonal, etc.) that have been observed, including those by PNL, the present flux data are highly selective and subject to significant bias. The long-term flux data mentioned on this page should be incorporated, or at least included by comparison.
2.	4	Since the objective was to validate a model for long-term radon emissions, only the 24 hour flux samples seem valid. Hopefully, the four-hour samples are equivalent; however, such comparison of methods is outside the scope of this report, and no data is given or cited to support their equivalence.
3.	4, A-5	The charcoal flux measurements with open and closed-end samplers again suggest poor procedural QA or a comparison of methods that does not support the purpose of the study. What was the purpose and interpretation of this?
4.	4-7	No radium or emanation measurements were made on any of the cover materials. With fluxes in the 0-5 pCi $m^{-2}s^{-1}$ range, radon originating in the cover is significant, and for the Mancos Shale cover,

Item	Page	Comment
		is dominant. These fluxes were known prior to the validation (Ref. 4), but were neglected by not defining the cover radon sources that can dominate at such low levels
5.	6	Specific gravity measurements are inexpensive and easy to conduct. Due to their strong impact on pososity and moisture saturation estimates, they should be measured and not assumed.
6.	8	Equations 5 and 8 are not valid for application to radon transport through layered systems. Gross errors result from such averaging over layers of different moisture and density, as shown in Section 5 of this memorandum. Analogy is suggested to averaging of parallel electrical resistances.
7.	8	Reference year typo: (Nielson et al., 1982)
8.	8	Weighted averaging of radium and emanation values is incorrect for reasons similar to those in item 6 above.
9.	10	Table 3 - what was the range of the two measurements from "this study"?
10.	9	Table 1. Dry weight percent moistures are reported to four significant figures. This seems excessive given the apparent precisions of the other soil and tailings data.
11.	9	Table 1. Tailings densities as low as 0.75 g/cm^3 and saturations of only 0.21 (CMS-NW-tailings) indicate volumetric compositions of 28 percent tailings, 15 percent water, and 57 percent air existing under the load of a three meter earthen cover. This is inconceivable.
12.	10	Table 2. Radon diffusion coefficients as low as 0.005 cm^2/s for uncompacted adobe clay are unlikely even at seven to nine percent moisture, as are the trends of higher diffusion coefficients

Item	Page	Comment
		in the more moist, highly-compacted second layers. Although Table 3 suggests accuracy for dry diffusion tests, the measured results with compacted, moist soils are mostly questionable.
13.	11	The conclusion that there was an "underground expansion" of the tailings by a factor of 1.82 is incredible. From their 10-m tailings depth (p.13), this suggests that the elevation of the tailings surface has risen by 26.9 feet between 1981 and 1983, assuming it did not expand sideways beyond the property fences. Surely the neighbors would have noticed! The density sampling and measurement procedures need examination.
14.	12	The value of 0.15 assumed for porosity is <u>not</u> suggested by the Handbook. The Handbook suggests 0.35.
15.	12	The Silker and Kalkwarf 1983 reference is missing in the reference list.
16.	12	Three-layer representation of the 22-layer systems described in Appendix A causes flux errors of several orders of magnitude, (see item 6).
17.	13	Extrapolated D s in Table 7 have the same erroneous trends as the measured D's (see item 12).
18.	15	The 0.2m original cover, also illustrated in Fig. 1, is not accounted for in the detailed logging in the appendix. Where did it go?
19.	15	The cover thickness, X_2, used in the calculations, is not given. Is it as in Figure 1, or as in the Appendix?
20.	16	There is a 44.-cm discrepancy in the Mancos Shale thicknesses (CMS-NW) between Figure 1 and the Appendix. Which is correct? This could cause nearly 50 percent error in the radon flux calculation.

Item	Page	Comment
21.	17	In Table 9, the 95 percent Confidence Interval for a single measurement is not appropriate to represent the sets of multiple field measurements. The simple mean and standard deviation (or even range) is more appropriate.
22.	17	The last column in Table 9 has no meaning or application to the Handbook validation.
23.	17	Although certain soil properties may be "too costly or inconvenient to measure" for initial licensing and its related conceptual designs, such measurements are vital and very inexpensive in designing detailed final reclamation plans.
24.	18	In Table 10, the measured radon flux mean and S.D. should be reported and corrected for radon generated by radium in the cover.
25.	18	The comparisons in Table 10 are not valid due to the representation of 22 layers (i.e., for CMS-NW) by three layers. Instead of using the approximate equations for this calculation, the RAECOM program, which is the main basis of the Handbook, should have been used. Calculated fluxes employing all 22 layers (CMS-NW) and measured parameters were less than 1 pCi $m^{-2}s^{-1}$, neglecting cover radium, comparing favorably with the measured fluxes. A three layer RAECOM calculation to represent the same case yielded a flux of 15.6 pCi $m^{-2}s^{-1}$ due to averaging of layer characteristics. Assuming E=0.2, as in Table 10, a complete RAECOM analysis again gives a flux of less than 1 pCi $m^{-2}s^{-1}$, while a three layer corresponding RAECOM calculation gives a flux of 9.46 pCi $m^{-2}s^{-1}$. The intent of the equations 10-12 is

Item	Page	Comment
		to compute an approximate cover thickness to satisfy a given radon flux. With this application, the approximate equations give a top cover thickness of 222 cm to achieve a flux of 9.46 pCi $m^{-2}s^{-1}$, compared to the RAECOM calculated value of 224 cm. The factor of 31 excess and similar values for other sites in Table 10 have no basis.
26.	19	Equations 13 and 14 are both incorrect. In equation 13, the sum should be normalized to $\frac{1}{5}$, not 1/i. In equation 14, the first A_h should be multiplied by 3.
27.	21	The first paragraph's conclusion is incorrect, as shown by IECO's comment (Ref. 2). Other conclusions are also incorrect as discussed in sections 4 and 5 of this review.
28.	21	Botton of page - relation between flux and cover thickness is readily determined using Handbook equations and the RAECOM code.
29.	22	The derivation of equation 19 is simplistic because it is based on exponential flux attenuation (eq. 15). The approximate equations in the Handbook superseded this approach.
30.	24	Hartley et al., 1983 (should be 1981 Field Test)
31.	A1	Moisture gradients in adjacent holes are inconsistent and need explanation.
32.	A4	Depth increments and radiological data for CAC-C and CAC-5E are inconsistent with the data on page 10 and page A3.
33.	A5	Explanation is needed for large variations and trends in side-by-side flux measurements for CMS-C and CAC-C.
34.	7, 25	References (Silker and Kalkwarf 1983) and (Oster and Mayer 1982) are both missing from the Reference List.

4. COMMENTS ON THE CONCLUSIONS SECTION

RAE comments in Sections 2 and 3 support the fact that none of the ten conclusive statements in the first four paragraphes on page four have a valid basis as a result of the validation project. The obvious conclusive statement in paragraph five concerning cover thickness being less sensitive than surface flux, is supported by the report, and the qualitative statements about cover defect effects in the last paragraph is also supported by the report, even though there are errors in both equations used in the relevant analysis.

The broad conclusion that "the radon fluxes predicted by the Handbook equations were always equal to or larger than the fluxes measured at field locations in this study" is not even supported by the report data as demonstrated by the following comparison from reference 2:

Site	Measured Flux From Cover (Avg.) (pCi/m2/S)	Predicted Flux From Cover (pCi/m^2/S)	Ratio of Predicted to Measured
CMS-NW	0.76	3	3.9
CMS-C	1.08	10	9.3
CMS-SE	5.05	1	0.2
CAC-NW	5.62	0.3	0.05
CAC-C	4.78	5	1.05
CAC-SE	21.52	3	0.14

The difference in predicted-to-measured flux ratios ranges from an order of magnitude less than unity to an order of magnitude greater than unity. This variation of two orders of magnitude arises from shortcomings in the validation project, not from errors in the Handbook methodology.

Furthermore, the inconsistency of measured diffusion coefficients for uncompacted adobe clay that are less than or equal to D's for compacted

Mancos Shale and compacted adobe clay should be cause for concern for the diffusion measurements, and not be the basis for the statement that "this Handbook equation generally overestimates values for the radon diffusion coefficient." This issue should have been researched more thoroughly considering the vast quantity of diffusion coefficient data that are in general agreement with the Handbook equations.

5. DISCUSSION AND CONCLUSIONS

Several comparative calculations were performed using the RAECOM computer program, since this program is based on accepted physical principals of gaseous transport, and since it was presented in the Handbook as the primary basis on which radon barrier cover designs should be based. The first field measurement example (CMS-NW, pages A.1 and A.4) was used in the calculations to determine whether the measured radon fluxes, when correctly compared with the measured radon source data, indeed present significant discrepancies.

The first example calculation, using all 22 layers of measured data from the Appendix (p. A.1 and A.4), is shown in Figure 1. As illustrated, the radon flux computed using measured radon emanation coefficients for the tailings, empirically predicted diffusion coefficients, and ignoring the radon that may originate in the cover, is nearly zero (8.6×10^{-4} pCi $m^{-2}s^{-1}$). Hence, the measured radon fluxes in Appendix 3 for this case (0.76 ± 0.33 pCi $m^{-2}s^{-1}$) exceed the radon from the tailings that could reach the surface, and must be dominated by background levels of radium in the cover materials. Figure 2 illustrates the same calculation with background levels (1 pCi/g radium, E = 0.2) of radium assumed for the cover instead of zero radium as in the first calculation. As shown in Figure 2, the 1 pCi/g levels of radium in the cover completely account for the observed radon flux, yielding a computed radon flux of 0.77 pCi $m^{-2}s^{-1}$ (compared to the 0.76 pCi $m^{-2}s^{-1}$ measured mean).

A third RAECOM calculation was conducted using the same measured radium and emanation data as in Figure 1, but averaged into only three layers as done in the PNL Validation Report.[1] This calculation is shown in Figure 3, and yielded a radon flux of 15.6 pCi $m^{-2}s^{-1}$ instead of the near-zero flux of the

CMS - NW EXACT E'S

AAAAAAAAAA I N P U T P A R A M E T E R S AAAAAAAAAA

NUMBER OF LAYERS : 22
RADON FLUX INTO LAYER 1 : 0.000 pCi/m2/sec
SURFACE RADON CONCENTRATION : 0.000 pCi/liter

LAYER 5 EXCEEDS SATURATION. MOISTURE CHANGED FROM 0.101 TO 0.096

BARE SOURCE FLUX (Jo) FROM LAYER 1 : 456.5 pCi/m2/sec

LAYER	THICKNESS (cm)	DIFF COEFF (cm2/sec)	POROSITY	SOURCE (pCi/cm3/sec)	MOISTURE (dry wt. percent)
1	23.	4.2495E-02	0.6810	2.9400E-03	18.30
2	34.	5.7866E-02	0.7300	5.5300E-04	10.20
3	23.	5.2974E-02	0.8070	6.6800E-04	30.80
4	23.	3.1105E-02	0.6740	1.6140E-03	27.60
5	28.	3.5233E-05	0.2070	0.0000E-01	9.57
6	13.	1.6788E-02	0.3930	0.0000E-01	9.80
7	11.	7.3671E-03	0.3850	0.0000E-01	13.50
8	8.	2.0760E-02	0.4590	0.0000E-01	11.80
9	15.	1.2963E-02	0.4070	0.0000E-01	12.10
10	10.	1.7597E-02	0.4070	0.0000E-01	10.20
11	9.	1.7385E-02	0.4330	0.0000E-01	11.70
12	15.	1.7708E-02	0.3850	0.0000E-01	9.10
13	10.	2.4664E-02	0.4850	0.0000E-01	11.70
14	23.	2.5916E-02	0.4070	0.0000E-01	7.50
15	23.	1.3897E-02	0.3630	0.0000E-01	9.40
16	23.	3.8096E-02	0.4700	0.0000E-01	6.40
17	23.	4.9600E-02	0.4630	0.0000E-01	3.50
18	23.	2.7940E-02	0.4220	0.0000E-01	7.50
19	29.	2.4495E-02	0.4590	0.0000E-01	10.30
20	23.	2.2645E-02	0.4190	0.0000E-01	9.00
21	23.	2.3558E-02	0.4300	0.0000E-01	9.20
22	34.	4.1619E-02	0.5110	0.0000E-01	6.80

AAAAA R E S U L T S O F R A D O N D I F F U S I O N C A L C U L A T I O N AAAAA

LAYER	THICKNESS (cm)	EXIT FLUX (pCi/m2/sec)	EXIT CONC. (pCi/liter)	MIC
1	23.	2.5745E+02	6.1049E+05	0.8287
2	34.	4.3573E+01	6.6906E+05	0.9246
3	23.	-7.2928E+01	6.1790E+05	0.8528
4	23.	3.4743E+00	5.3508E+05	0.7333
5	28.	7.3909E-03	4.2355E+00	0.3674
6	13.	6.2795E-03	9.7049E+00	0.6976
7	11.	5.6799E-03	5.6055E+00	0.5691
8	8.	5.1452E-03	6.6579E+00	0.7221
9	15.	4.4730E-03	4.6087E+00	0.6478
10	10.	4.0713E-03	4.4063E+00	0.7031
11	9.	3.7348E-03	3.8825E+00	0.6939
12	15.	3.3011E-03	3.1979E+00	0.7096
13	10.	2.9696E-03	3.1263E+00	0.7518
14	23.	2.3899E-03	2.6683E+00	0.7817
15	23.	2.0794E-03	1.2764E+00	0.6704
16	23.	1.7381E-03	1.3848E+00	0.8558
17	23.	1.4239E-03	1.3288E+00	0.9189
18	23.	1.2164E-03	8.9265E-01	0.7948
19	29.	1.0199E-03	5.6405E-01	0.7574
20	23.	9.3095E-04	3.2351E-01	0.7507
21	23.	8.8476E-04	1.2063E-01	0.7563
22	34.	8.5957E-04	0.0000E-01	0.8700

Figure 1. RAECOM Calculation from Detailed Field Data, with no Radon Source in Cove

CMS-NW, MEASURED E'S, 1 PCI/GRAM RA-226 ASSUMED IN COVER

********** I N P U T   P A R A M E T E R S **********

NUMBER OF LAYERS : 22
RADON FLUX INTO LAYER 1 : 0.000 pCi/m2/sec
SURFACE RADON CONCENTRATION : 0.000 pCi/liter

LAYER 5 EXCEEDS SATURATION. MOISTURE CHANGED FROM 0.101 TO 0.096

BARE SOURCE FLUX (Jo) FROM LAYER 1 : 456.5 pCi/m2/sec

LAYER	THICKNESS (cm)	DIFF COEFF (cm2/sec)	POROSITY	SOURCE (pCi/cm3/sec)	MOISTURE (dry wt. percent)
1	23.	4.2495E-02	0.6810	2.9400E-03	18.30
2	34.	5.7866E-02	0.7300	5.5300E-04	10.20
3	23.	5.2974E-02	0.8070	6.6800E-04	30.80
4	23.	3.1105E-02	0.6740	1.6140E-03	27.60
5	28.	3.5233E-05	0.2070	4.3400E-06	9.57
6	13.	1.6788E-02	0.3930	1.7500E-06	9.80
7	11.	7.3671E-03	0.3850	1.8100E-06	13.50
8	8.	2.0760E-02	0.4590	1.3400E-06	11.80
9	15.	1.2963E-02	0.4070	1.6500E-06	12.10
10	10.	1.7597E-02	0.4070	1.6500E-06	10.20
11	9.	1.7385E-02	0.4330	1.4800E-06	11.70
12	15.	1.7708E-02	0.3850	1.8100E-06	9.10
13	10.	2.4664E-02	0.4850	1.2000E-06	11.70
14	23.	2.5916E-02	0.4070	1.6500E-06	7.50
15	23.	1.3897E-02	0.3630	1.9900E-06	9.40
16	23.	3.8096E-02	0.4700	1.2800E-06	6.40
17	23.	4.9600E-02	0.4630	1.3100E-06	3.50
18	23.	2.7940E-02	0.4220	1.5500E-06	7.50
19	29.	2.4495E-02	0.4590	1.3400E-06	10.30
20	23.	2.2645E-02	0.4190	1.5700E-06	9.00
21	23.	2.3558E-02	0.4300	1.5000E-06	9.20
22	34.	4.1619E-02	0.5110	1.0800E-06	6.80

***** R E S U L T S   O F   R A D O N   D I F F U S I O N   C A L C U L A T I O N *****

LAYER	THICKNESS (cm)	EXIT FLUX (pCi/m2/sec)	EXIT CONC. (pCi/liter)	MIC
1	23.	2.5744E+02	6.1051E+05	0.8287
2	34.	4.3553E+01	6.6909E+05	0.9246
3	23.	-7.2957E+01	6.1792E+05	0.8528
4	23.	3.4377E+00	5.3511E+05	0.7333
5	28.	3.9226E-02	2.7855E+02	0.2674
6	13.	5.1127E-02	7.1777E+02	0.6976
7	11.	7.6725E-02	5.6089E+02	0.5691
8	8.	7.1295E-02	7.0544E+02	0.7221
9	15.	9.2322E-02	6.0962E+02	0.6478
10	10.	1.0350E-01	6.4801E+02	0.7031
11	9.	1.0935E-01	6.2684E+02	0.6939
12	15.	1.3772E-01	6.1388E+02	0.7096
13	10.	1.3025E-01	6.3920E+02	0.7518
14	23.	1.5703E-01	6.3341E+02	0.7817
15	23.	2.3519E-01	4.5444E+02	0.6704
16	23.	2.4534E-01	5.4931E+02	0.8558
17	23.	2.5572E-01	5.6476E+02	0.9189
18	23.	3.1204E-01	4.3327E+02	0.7948
19	29.	3.8706E-01	3.2331E+02	0.7574
20	23.	4.8376E-01	2.1529E+02	0.7507
21	23.	5.9932E-01	9.4445E+01	0.7563
22	34.	7.6633E-01	0.0000E-01	0.8700

Figure 2. RAECOM Calculations from Detailed Field Data with 1pCi/g Radium in Cover

CMS - NW, EXACT E'S

********** I N P U T   P A R A M E T E R S **********

NUMBER OF LAYERS :	3	
RADON FLUX INTO LAYER 1 :	0.000	pCi/m2/sec
SURFACE RADON CONCENTRATION :	0.000	pCi/liter
BARE SOURCE FLUX (Jo) FROM LAYER 1 :	793.0	pCi/m2/sec

LAYER	THICKNESS (cm)	DIFF COEFF (cm2/sec)	POROSITY	SOURCE (pCi/cm3/sec)	MOISTURE (dry wt. percent)
1	103.	4.6164E-02	0.7200	1.2360E-03	20.49
2	119.	1.0960E-02	0.3700	0.0000E-01	10.89
3	224.	2.9458E-02	0.4400	0.0000E-01	7.76

***** R E S U L T S   O F   R A D O N   D I F F U S I O N   C A L C U L A T I O N *****

LAYER	THICKNESS (cm).	EXIT FLUX (pCi/m2/sec)	EXIT CONC. (pCi/liter)	MIC
1	103.	1.9333E+02	4.4508E+05	0.8408
2	119.	5.2917E+01	3.6235E+04	0.6295
3	224.	1.5613E+01	0.0000E-01	0.8027

Figure 3. RAECOM Calculation for the PNL 3-Layer Representation with Measured Emanation Coefficients

corresponding detailed calculation. It is thus suggested that the high, "generally conservative" radon fluxes ascribed to the Handbook by the validation report[1] are not, in fact, characteristic of the methodology in the Handbook. Instead, they resulted from a simplistic interpretation of the field data that was neither suggested nor justified by the Handbook.

A fourth RAECOM calculation was conducted similar to that in Figure 1, but assuming the emanation coefficients to all be 0.2, hence corresponding to the case represented in Table 10, column (b) of the validation report.[1] As illustrated, in Figure 4, the radon flux was again computed to be nearly

CMS - NW, E=0.2

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NUMBER OF LAYERS : 22
RADON FLUX INTO LAYER 1 : 0.000 pCi/m2/sec
SURFACE RADON CONCENTRATION : 0.000 pCi/liter

LAYER 5 EXCEEDS SATURATION. MOISTURE CHANGED FROM 0.101 TO 0.096

BARE SOURCE FLUX (Jo) FROM LAYER 1 : 350.9 pCi/m2/sec

LAYER	THICKNESS (cm)	DIFF COEFF (cm2/sec)	POROSITY	SOURCE (pCi/cm3/sec)	MOISTURE (dry wt. percent)
1	23.	4.2495E-02	0.6010	2.2600E-03	18.30
2	34.	5.7866E-02	0.7300	4.1000E-04	10.20
3	23.	5.2974E-02	0.8070	4.1700E-04	30.80
4	23.	3.1105E-02	0.6740	6.8700E-04	27.60
5	28.	3.5233E-05	0.2070	0.0000E-01	9.57
6	13.	1.6788E-02	0.3930	0.0000E-01	9.80
7	11.	7.3671E-03	0.3850	0.0000E-01	13.50
8	8.	2.0760E-02	0.4590	0.0000E-01	11.80
9	15.	1.2963E-02	0.4070	0.0000E-01	12.10
10	10.	1.7597E-02	0.4070	0.0000E-01	10.20
11	9.	1.7385E-02	0.4330	0.0000E-01	11.70
12	15.	1.7708E-02	0.3850	0.0000E-01	9.10
13	10.	2.4664E-02	0.4850	0.0000E-01	11.70
14	23.	2.5916E-02	0.4070	0.0000E-01	7.50
15	23.	1.3897E-02	0.3630	0.0000E-01	9.40
16	23.	3.8096E-02	0.4700	0.0000E-01	6.40
17	23.	4.9600E-02	0.4630	0.0000E-01	3.50
18	23.	2.7940E-02	0.4220	0.0000E-01	7.50
19	29.	2.4495E-02	0.4590	0.0000E-01	10.30
20	23.	2.2645E-02	0.4190	0.0000E-01	9.00
21	23.	2.3558E-02	0.4300	0.0000E-01	9.20
22	34.	4.1619E-02	0.5110	0.0000E-01	6.80

AAAAA R E S U L T S   O F   R A D O N   D I F F U S I O N   C A L C U L A T I O N AAAAA

LAYER	THICKNESS (cm)	EXIT FLUX (pCi/m2/sec)	EXIT CONC. (pCi/liter)	MIC
1	23.	2.1878E+02	4.0526E+05	0.8287
2	34.	8.8537E+01	4.3983E+05	0.9246
3	23.	8.4574E+00	4.0307E+05	0.8528
4	23.	2.2465E+00	3.4599E+05	0.7333
5	28.	4.7790E-03	2.7387E+00	0.2674
6	13.	4.0603E-03	6.2752E+00	0.6976
7	11.	3.6726E-03	3.6246E+00	0.5691
8	8.	3.3295E-03	4.3051E+00	0.7221
9	15.	2.8923E-03	2.9800E+00	0.6478
10	10.	2.6325E-03	2.8491E+00	0.7031
11	9.	2.4149E-03	2.5105E+00	0.6939
12	15.	2.1345E-03	2.0678E+00	0.7096
13	10.	1.9201E-03	3.0215E+00	0.7518
14	23.	1.5453E-03	1.7254E+00	0.7817
15	23.	1.3446E-03	8.3536E-01	0.6704
16	23.	1.1239E-03	8.9542E-01	0.8558
17	23.	9.2068E-04	8.5924E-01	0.9189
18	23.	7.8656E-04	5.7719E-01	0.7948
19	29.	6.5946E-04	3.6472E-01	0.7574
20	23.	6.0196E-04	2.0918E-01	0.7507
21	23.	5.7209E-04	7.8001E-02	0.7563
22	34.	5.5580E-04	0.0000E-01	0.8700

Figure 4. RAECOM Calculation from Detailed Field Data with no Radon Source in Cover and E=0.2 for Tailings

zero. A fifth RAECOM calculation, for the E - 0.2 case using the PNL three-layer simplification, is shown in Figure 5 and yielded a radon flux of 9.5 pCi $m^{-2}s^{-1}$. Using the approximate equations in the Handbook to do this calculation manually, we obtained a radon flux of 9.3 pCi$m^{-2}s^{-1}$, nearly identical to the value from the RAECOM calculation. The higher value of 13 pCi m^{-2} s^{-1} reported in the validation report (Table 10, column b) apparently utilized the nominal 1.8 m thickness for the top cover layer that they reported in Figure 1,[1] instead of the actual measured thickness of that layer, 2.24 m, as reported in the Appendix (p. A.1), to obtain the higher flux. It also included 20-cm of "original overburden" that was apparently not observed in the field measurements and logging, based on Appendix A.

CMD - NW, E=0.2

********** I N P U T   P A R A M E T E R S **********

NUMBER OF LAYERS :	3	
RADON FLUX INTO LAYER 1 :	0.000	pCi/■2/sec
SURFACE RADON CONCENTRATION :	0.000	pCi/liter
BARE SOURCE FLUX (Jo) FROM LAYER 1 :	480.5	pCi/■2/sec

LAYER	THICKNESS (c■)	DIFF COEFF (c■2/sec)	POROSITY	SOURCE (pCi/c■3/sec)	MOISTURE (dry wt. percent)
1	103.	4.6164E-02	0.7200	7.4900E-04	20.49
2	119.	1.0960E-02	0.3700	0.0000E-01	10.89
3	224.	2.9458E-02	0.4400	0.0000E-01	7.76

***** R E S U L T S   O F   R A D O N   D I F F U S I O N   C A L C U L A T I O N *****

LAYER	THICKNESS (c■)	EXIT FLUX (pCi/■2/sec)	EXIT CONC. (pCi/liter)	KIC
1	103.	1.1716E+03	2.6971E+05	0.8408
2	119.	3.2067E+01	2.1950E+04	0.6295
3	224.	9.4610E+00	0.0000E-01	0.8027

Figure 5. RAECOM Calculation for the PNL 3-Layer Representation with E=0.2

In summary, we conclude that the Validation Study and Report[1] neither validate nor invalidate the Handbook methodology because of their misapplication of the Handbook methodology, their failure to collect adequate field data from which to make direct, quantitative comparisons, and their use of erroneous laboratory and field data. While we agree with the concept and value of comparing the Handbook methodology with additional empirical data, we feel that this goal was not accomplished. The Handbook was not shown to either overestimate or underestimate required cover thicknesses because valid comparisons were not made. If correct interpretations were made of the measured field and laboratory data, perhaps some value could be derived from this study. However, the value will be extremely limited unless explanations or corrections can be found for many of the doubtful but dominant measured parameters such as tailings densities, tailings and cover diffusion coefficients and moisture contents, and cover layer thicknesses. Radon source data for the cover materials is also necessary for quantitative comparisons with measured fluxes, even though it would not ordinarily be required for cover design calculations.

LITERATURE REFERENCES

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

4. J.N. Hartley, G.W. Gee. E.G. Baker and H.D. Freeman, "1981 Radon Barrier Field Test at Grand Junction Uranium Mill Tailings Pile," U.S. Department of Energy Report DOE/UMT-0213, 1983.