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BACKGROUND RADIATION MEASUREMENTS AT THE
WASTE ISOLATION PILOT PLANT (WIPP) SITE
CARLSBAD, NEW MEXICO

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Background Radiation Measurements at the
Waste Isolation Pilot Plant (WIPP) Site,
Carlsbad, New Mexico

Abstract

A series of background radiation measurements were performed at the Waste Isolation Pilot Plant (WIPP) Site, Carlsbad, New Mexico. The survey consisted of gross gamma and gamma spectral measurements of the radiation fields, soil and salt grab sample gamma analysis, and radon and working level measurements. The survey included locations at the surface and also within the mine itself. Background radiation levels on the surface were measured to average 7.65 microR/hour, and 0.7 microR/hour within the mine. Radon and working levels were at or below detection levels at all locations, and the radon concentration was estimated to be about 0.01 pCi/liter on the surface based on spectral measurements. The spectral measurements were performed using an intrinsic germanium spectrometer, and calculations from the spectra indicated that potassium-40 contributed about 28% to the surface level dose rates, natural uranium daughters contributed about 64%, and cesium-137 from weapons testing fallout contributed about 8%. In the mine potassium-40 was the only identifiable contributor to the dose rate.

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INTRODUCTION

A series of background radiation measurements at the Waste Isolation Pilot Plant (WIPP) Site were made to aid in establishing an introductory baseline for the environmental monitoring program. The background radiation survey involved three discrete measurements that combine to form an overall characterization of the site. The measurements that were performed at the site were:

1. Radiation Field Spectral Studies: The background radiation field was measured both on the surface and in the mine using a high resolution intrinsic germanium gamma spectrometer. This analysis provides a qualitative and quantitative identification of the contributors to the field.
2. Grab Sample Analysis: A series of grab samples were taken at most of the sites at which the field spectral studies were performed. The samples of soil or salt were analyzed for their radioisotope content and compared with the corresponding radiation field analysis.
3. Airborne Radionuclide Analysis: A series of air samples were collected at selected sites and analyzed for radon and radon daughter concentrations in air. The radon gas was analyzed with standard 'Lucas cells' and the daughters were evaluated with standard working level (WL) techniques. These measurements were also compared to the radiation field measurements where appropriate.

This group of measurements provides a basis for establishing the criteria necessary for an effective preoperational monitoring program, and points out areas of concern for further study.

RADIATION FIELD SPECTRAL STUDY

The radiation field spectral study was performed using a high resolution intrinsic germanium detector and a battery powered 2048 channel multichannel analyzer. The spectra were measured over an energy range of 0 to 2 MeV and then recorded on magnetic tape. The tapes were returned to SNLA and transferred to a computer for analysis. Appendix 1

contains plots of the measured spectra. The spectra were analyzed using a standard peak search routine and the count rates for any identified peaks were determined. Using an appropriate efficiency curve, the peak measurements were converted to yield the corresponding uncollided photon flux in air. Finally, this uncollided flux was used with suitable models to provide estimates of radionuclide concentrations in the media of concern, and their corresponding dose rate contributions. As an example of this algorithm, the potassium-40 peak measured in a spectrum is easily converted to an equivalent soil concentration assuming a semi-infinite distribution with the detector near the boundary. The uncollided flux at the boundary is:

$$\phi_u = Qv / (2 * U_s(E)) \quad (\text{eq. 1})$$

where

ϕ_u = uncollided photon flux, (photons/cm²-sec);
 Qv = volumetric source strength (photons/cm³-sec);
 $U_s(E)$ = attenuation coefficient for soil for energy E, (/cm).

Defining the source term as

$$Qv = Sv * b * 0.037 \quad (\text{eq. 2})$$

where

Sv = source concentration (pCi/cm³);
 b = branching ratio of photon of interest; and
 0.037 = conversion from pCi to dps.

The detected uncollided photon flux can be represented by

$$\phi_u = R_p / e(E) \quad (\text{eq. 3})$$

where

R_p = count rate of peak in counts per second;
 $e(E)$ = detector efficiency for energy E in
 cps/(photons/cm²-sec).

These equations are combined to yield

$$Sv = (54.05 * R_p * U_s(E)) / (b * e(E)) \quad (\text{eq. 4}).$$

A density of 1.5 gm/cm³ was used for the conversion to pCi/gm for the soil and 2.17 gm/cm³ was used for the salt.

In the K-40 example, the 1461 keV photon has a branching ratio of 0.11, an efficiency of 1.83 and an attenuation coefficient of 0.078. A count rate of 0.7 cps yields a concentration of 9.6 pCi/gm in soil.

This model can also be used for conditions in the mine, only it is converted to assume an infinite source rather than a semi-infinite source. This results in dropping the factor of 2 in equation 1. The results of these calculations are listed in Table 1 along with the results of the grab samples taken at the same locations.

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GRAB SAMPLE ANALYSIS

Grab samples were taken at several locations above ground and at two locations in the mine. The samples were placed in standard Marinelli beakers and returned to SNLA for analysis. Gamma spectroscopy was run on the samples to determine radioisotopic concentrations for comparison with the radiation field analysis. Analysis is performed using a standard isotope identification program and the calibration is traceable to NBS standards. The results of these analyses are listed in Table 1 along with the results of the radiation field measurements for comparison.

After the concentration of radionuclides in the soil has been determined, either through radiation field estimates as described above, or through the use of grab samples as in this section, it is possible to use the results to estimate the radiation exposure levels at ground level using assumptions similar to those in the field analysis section. Reference 1 contains factors for converting from concentrations in soil to dose equivalent rate in air near ground level for uniformly distributed sources. From this reference it is found that for Ra-226 and daughters in soil the factor is $13.0 \text{ (urem/hr)/(uCi/m}^3\text{)}$, and for Cs-137 (resulting from fallout), the factor is $4.9 \text{ (urem/hr)/(uCi/m}^3\text{)}$. A similar analysis yields a factor for K-40 of $0.138 \text{ (urem/hr)/(uCi/m}^3\text{)}$. Calculating dose equivalent rates for each nuclide and summing them allows one to compare these calculated rates to the measured dose rates, and to evaluate fractional contributions from each nuclide. Table 2 contains this evaluation for the grab sample results, compared with pressurized ion chamber (Reuter-Stokes) measurements taken at the same time, and with long term averages obtained from Sandia's TLD plants at selected WIPP sites (reference 4).

AIRBORNE RADIONUCLIDE ANALYSIS

A series of air samples were collected at several locations in order to evaluate the airborne contribution to the natural background. It should be noted that while the soil contribution to the background should remain fairly static with time, the airborne contribution is very dependent upon time of day, season, and meteorological conditions at the sampling time. This dependency mainly reflects the conditions affecting the diffusion of radon from the soil into the atmosphere.

Two types of samples were taken at each of the sampling locations, radon concentration and working level. The radon concentrations were taken by collecting filtered air samples in vacuum flasks. These samples were then transferred into 'Lucas cells' at the base station, and were counted in an appropriate counter. The 'Lucas Cell' is an alpha scintillation chamber which consists of a glass container coated on the inside with a silver-activated zinc sulfide mixture. This mixture is a phosphor which emits light when excited by alpha particles. The light pulses are then counted through a window in the chamber using a photomultiplier detector, yielding the radon concentration in picocuries per liter (pCi/l). The working level is a measure of the combination of

the alpha activity of the radon daughters in air. The working level is measured by drawing air through an appropriate filter for a set length of time (10 minutes was used in this study), and then counting the alpha activity with an alpha filter counter using defined decay and counting intervals. In this study both the Rolle method and the modified Kusnetz method were used for comparison. Reference 2 details these techniques, along with that used for the radon measurement.

The main difficulty in attempting to make these measurements is that the techniques are not extremely sensitive. They were originally intended for uranium mining and other situations where there would be significant levels of radon and its daughters. As an example of this, for the systems used in this survey, the background in the radon counter was only 0.94 cpm, which corresponds to a critical level at which detection can be assumed of 3.6 pCi/l. Similarly, the background in the alpha filter counter was only 0.1 cpm, which this corresponds to critical level of 0.7 mWL for the Rolle and 1.0 mWL for the Kusnetz method (assuming that the daughters are in equilibrium with the radon these measurements could be used to estimate radon also, at a value of 100 pCi/l/WL, yielding 0.1 pCi/l). These levels are high enough to present difficulties in attempting to make the measurements proposed in this study, as will be seen; however, the equipment necessary to achieve higher sensitivities was not available in the time span necessary to meet the schedule of this study. Reference 3 details the method for determining the critical, determination, and quantitative levels for a counting system.

As an alternative method for estimating the radon concentration, another method was used combining results from both the radiation field study and the grab sample study. The radium concentrations in soil estimated from the radiation field study result from a measurement of the photons from the radium daughters, since the photon directly from radium is normally too weak to observe directly. In reality, these daughter peaks combine contributions from the daughters in the soil and from the daughters in the air. If the soil sample from the grab sampling is assumed to be characteristic of the site (a reasonable assumption since the total variation of all the surface samples is only 20%), then the ratio of the two values at a given location represents the fraction of the signal from the daughters in the air. By inserting this fraction and the appropriate values into equation 4 for air rather than soil, the airborne concentration of the daughters can be estimated. The radon concentration can be estimated by approximating the fractional equilibrium with the daughters, which is probably on the order of 10 - 30% under disturbed atmospheric conditions. Table 3 contains the results of the air sampling survey along with the estimates based upon the radiation field analysis study.

DISCUSSION OF THE RESULTS

Tables 1, 2, and 3 contain the results obtained during this sampling program, and present a detailed description of the site, both on the surface and in the mine. On the surface it was found that radium, and

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hence its parent uranium, occurred in concentrations averaging 0.25 pCi/gm at all locations, with a variation of 20%. This accounts for about 64% of the dose rate on the surface, not including the radon and daughters in the air. The radon concentration in air is estimated to be about 0.01 pCi/l (based on the method described in the previous paragraph, assuming 10% equilibrium with the daughters) and would then contribute only about 0.2% to the dose rate. The potassium-40 in the soil appears quite uniform at about 10.2 pCi/gm (5.6% variation), and contributes about 28% of the dose rate. Cesium-137 from atmospheric weapons testing fallout was observed in about 64% of the soil samples at levels of about 0.13 pCi/gm, with a 31% variation, accounting for about 8% of the dose rate on the average. These totaled out to yield an average calculated dose rate of 7.63 urem/hr, comparing well with the pressurized ion chamber average of 7.65 uR/hr, and the 5.5 year average for the SNLA TLD survey of 8.10 urem/hr.

In the mine, the dose rate appears to be coming entirely from potassium-40, probably from within the salt bed. Unfortunately, the K-40 levels in the salt samples are at about the minimum sensitivity of our detector with its present shielding. The estimated dose rates in the mine are somewhat higher than those measured with the ion chamber (although at those levels a factor of 1.5 - 2 is insignificant for either instrument), however the difference is probably due to deviations in the geometry from the infinite source assumed in equation 4 and uncertainties in equipment calibration at such low levels.

The airborne activity measurements all were found to be at or below the minimum detectable levels for our instruments, undoubtedly due to the low uranium concentration observed in the soil. Only under the worst possible condition, of no ventilation in the south drift of the mine, were radon levels found that even approached the detection limits (with a critical level of 3 pCi/l, the detection limit is 15.5 pCi/l). This is very promising in evaluating the interference of the radon daughters upon the response of the proposed plutonium alpha air monitoring system.

One final comment should be made about the radiation field measurements in the mine. In several of the spectra in the mine, there appeared to be traces of Cobalt-60. Although the levels were very low, this caused some concern as to its origin, since it could be positively identified. It was decided that this was probably coming from the detector itself. Co-60 is a minor impurity in steels due to its use for a tracer in wall linings of blast furnaces; however it was never expected to be observable. The extremely low radiation levels found in the mine, lower than the levels found in most counting shields, apparently allowed us to observe the trace impurities in the steel of the detector's own liquid nitrogen dewar.

CONCLUSIONS

Most of the results found in this study can speak for themselves. They provide a good characterization of the site background radiation levels and radionuclides. Most of the findings will not change significantly

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with time, except for the airborne radionuclide levels. This study then provides a baseline for evaluation of changes in the background due to the influence of the site itself. However, this type of survey is too complex to be repeated except at rare intervals, especially since simpler measurements will provide the necessary indicators for gross changes in the environment due to the site. A reasonable approach would be to maintain a series of TLD stations, similar to the ongoing Sandia National Laboratories TLD survey in progress, and support that with an annual grab sampling program for verification. Only if long term trends in the TLD surveys or unusual findings in the grab sampling identify changes from the baseline should a survey of this type be repeated.

The air monitoring for radon and its daughters should be approached separately from the comments above. There can be significant changes in these levels due to a variety of conditions, and this should be evaluated further to determine its full potential for interfering with the plutonium air monitoring program. Based upon the observations made in this study the radon and radon daughter levels appear to be very low, but under different seasonal or meteorological conditions their levels could vary significantly. It is therefore recommended that the radon and radon daughter concentrations be studied over a longer term (minimum of a year) in order to reach a better understanding of the radon potential at the site. There are techniques and equipment available that are more sensitive than those chosen for this study that would permit reliable measurement of the levels estimated by this study.

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2. IAEA/ILO Publication No. 43, Manual on Radiological Safety in Uranium and Thorium Mines and Mills, 1976.

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 - (d) Rolle, R., Rapid Working Level Monitoring, Health Physics Journal, vol 22-3, 233, 1972.
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 4. Brewer, L. W., and Metcalf, J. H., "Environmental Monitoring at the WIPP Site -- CY 1976", SAND 77-1021; and unpublished data for CY 1977 to present.

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Table 1

Grab Sample vs. Radiation Field Spectra Results

Location	Isotope	Soil Sample (pCi/g)		Radiation Field (pCi/g)
ERDA 6	Bi-212	0.13 (23%)	(notes 1,2)	N.D.
	Tl-208	0.09 (21%)		N.D.
	Pb-214	0.27 (15%)		N.D.
	Bi-214	0.19 (19%)		0.93
	K-40	9.74 (7%)		7.4
AEC 7	Pb-212	0.22 (14%)		N.D.
	Pb-214	0.27 (16%)		N.D.
	Bi-214	0.28 (16%)		N.D.
	K-40	11.3 (6%)		11.1
	Cs-137	0.09 (23%)		N.D.
AEC 8	Pb-212	0.20 (35%)		N.D.
	Tl-208	0.08 (20%)		N.D.
	Pb-214	0.25 (14%)		N.D.
	Bi-214	0.27 (33%)		1.5
	K-40	10.1 (6%)		13.0
ERDA 9	Pb-212	0.21 (12%)		N.D.
	Pb-214	0.20 (19%)		N.D.
	Bi-214	0.30 (32%)		0.93
	K-40	10.0 (6%)		9.93
WIPP 11	Pb-212	0.14 (19%)		N.D.
	Pb-214	0.18 (20%)		N.D.
	Bi-214	0.20 (18)		1.0
	K-40	9.6 (6%)		9.6
	Cs-137	0.19 (14%)		N.D.
Badger	Pb-212	0.14 (18%)		N.D.
	Pb-214	0.24 (14%)		N.D.
	Bi-214	0.27 (36%)		2.0
	K-40	9.4 (6%)		13.5
	Cs-137	0.10 (18%)		N.D.
Met. Stat.	Pb-212	0.26 (11%)		N.D.
	Pb-214	0.25 (18%)		N.D.

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Location	Isotope	Soil Sample (pCi/g)	Radiation Field (pCi/g)
	Bi-214	0.24 (15%)	N.D.
	K-40	10.9 (6%)	N.D.
	Cs-137	0.13 (16%)	N.D.
NW Cor.	Pb-212	0.15 (16%)	---
	Pb-214	0.20 (15%)	---
	Bi-214	0.27 (26%)	---
	K-40	10.0 (6%)	---
	Cs-137	0.08 (21%)	---
SW Cor.	Pb-212	0.17 (14%)	---
	Pb-214	0.17 (23%)	---
	K-40	0.8 (6%)	---
NE Cor.	Pb-212	0.22 (11%)	---
	Tl-208	0.07 (23%)	---
	Pb-214	0.20 (14%)	---
	Bi-214	0.1 (18%)	---
	K-40	10.3 (6%)	---
	Cs-137	0.14 (15%)	---
Vent.	Pb-212	0.21 (14%)	N.D.
	Pb-214	0.39 (10%)	N.D.
	Bi-214	0.32 (14%)	0.81
	K-40	10.5 (6%)	7.3
E140/N780	K-40	<1.0 (8%) (note 3)	---
E140/S3650	K-40	<1.0 (7%) (note 3)	---

NOTES:

1. The uncertainties quoted are one standard deviation and are based on counting statistics and calibration errors summed in quadrature.

2. For the radiation field estimates, no uncertainties have been assigned to the values at the present, since the technique used is still under evaluation. Also, N.D. indicates that the corresponding isotope was not detected in the spectra, and "---" indicates that no spectra was run at that location.

3. The values quoted for K-40 are after subtracting background. However, there is some uncertainty as to the actual background value.

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Table 2

Calculated Dose Rate from Soil Compared to Measured Dose Rate

Location: Mine outlet Shaft

Isotope	Concentration (pCi/g)	Calc. Dose Rate (urem/hr)	Fraction of Total
Ra-226 (1)	0.35	6.8	0.76
K-40	10.5	2.2	0.24
Cs-137	N.D.	-	-

Total Calculated Dose Rate = 9.0 urem/hr

Reuter-Stokes PIC (2) = 7.5 uR/hr

TLD (3) = N.A.

Location: ERDA #9 TLD site

Isotope	Concentration (pCi/g)	Calc. Dose Rate (urem/hr)	Fraction of Total
Ra-226	0.25	4.9	0.70
K-40	10.0	2.1	0.30
Cs-137	N.D.	-	-

Total Calculated Dose Rate = 7.0 urem/hr

Reuter-Stokes PIC = 7.2 uR/hr

TLD = 8.1 urem/hr

Location: WIPP #11 TLD Site

Isotope	Concentration (pCi/g)	Calc. Dose Rate (urem/hr)	Fraction of Total
Ra-226	0.20	3.9	0.53
K-40	9.6	2.0	0.27
Cs-137	0.19	1.4	0.19

Total Calculated Dose Rate = 7.3 urem/hr

Reuter-Stokes PIC = 7.4 uR/hr

TLD = 7.2 urem/hr

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Table 2 (cont.)

Location: AEC #7 TLD Site

Isotope	Concentration (pCi/g)	Calc. Dose Rate (urem/hr)	Fraction of Total
Ra-226	0.30	5.9	0.66
K-40	11.3	2.3	0.26
Cs-137	0.09	0.7	0.08

Total Calculated Dose Rate = 8.9 urem/hr

Reuter-Stokes PIC = 8.5 uR/hr

TLD = 8.8 urem/hr

Location: ERDA #6 TLD Site

Isotope	Concentration (pCi/g)	Calc. Dose Rate (urem/hr)	Fraction of Total
Ra-226	0.25	4.9	0.71
K-40	9.7	2.0	0.29
Cs-137	N.D.	-	-

Total Calculated Dose Rate = 6.9 urem/hr

Reuter-Stokes PIC = 8.5 uR/hr

TLD = 8.3 urem/hr

Location: AEC #8 TLD Site

Isotope	Concentration (pCi/g)	Calc. Dose Rate (urem/hr)	Fraction of Total
Ra-226	0.26	5.1	0.71
K-40	10.1	2.1	0.29
Cs-137	N.D.	-	-

Total Calculated Dose Rate = 7.2 urem/hr

Reuter-Stokes PIC = 8.5 uR/hr

TLD = 8.3 urem/hr

Location: Badger TLD Site

Isotope	Concentration (pCi/g)	Calc. Dose Rate (urem/hr)	Fraction of Total
Ra-226	0.26	5.1	0.65
K-40	9.4	2.0	0.26
Cs-137	0.10	0.7	0.09

Total Calculated Dose Rate = 7.8 urem/hr

Reuter-Stokes PIC = 8.0 uR/hr

TLD = 8.4 urem/hr

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Table 2 (cont.)

Location: Metro Station TLD Site

Isotope	Concentration (pCi/g)	Calc. Dose Rate (urem/hr)	Fraction of Total
Ra-226	0.25	4.9	0.60
K-40	10.9	2.3	0.28
Cs-137	0.13	1.0	0.12

Total Calculated Dose Rate = 8.2 urem/hr

Reuter-Stokes PIC = 7.5 uR/hr

TLD = 7.6 urem/hr

Location: WIPP Site NW corner outside of fenced area

Isotope	Concentration (pCi/g)	Calc. Dose Rate (urem/hr)	Fraction of Total
Ra-226	0.24	4.7	0.64
K-40	10.0	2.1	0.28
Cs-137	0.09	0.6	0.08

Total Calculated Dose Rate = 7.4 urem/hr

Reuter-Stokes PIC = 8.0 uR/hr

TLD = N.A.

Location: WIPP Site NE Corner outside Fenced Area

Isotope	Concentration (pCi/g)	Calc. Dose Rate (urem/hr)	Fraction of Total
Ra-226	0.20	3.9	0.56
K-40	10.3	2.1	0.30
Cs-137	0.14	1.0	0.14

Total Calculated Dose Rate = 7.0 urem/hr

Reuter-Stokes PIC = 8.0 uR/hr

TLD = N.A.

Location: WIPP Site SW Corner outside fenced area

Isotope	Concentration (pCi/g)	Calc. Dose Rate (urem/hr)	Fraction of total
Ra-226	0.20	3.9	0.54
K-40	9.8	2.0	0.28
Cs-137	0.17	1.3	0.18

Total Calculated Dose Rate = 7.2 urem/hr

Reuter-Stokes PIC = 5.0 uR/hr

TLD = N.A.

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Table 2 (cont.)

Location: WIPP Mine at E140'/S3650'

Isotope	Concentration (pCi/g)	Calc. Dose Rate (urem/hr)	Fraction of Total
Ra-226	N.D.	0.0	0.0
K-40 (4)	1.9	0.8	100.0
Cs-137	N.D.	0.0	0.0

Total Calculated Dose Rate = 0.8 urem/hr

Reuter-Stokes PIC = 0.6 uR/hr

TLD = N.A.

Location: WIPP Mine at E140'/S1607'

Isotope	Concentration (pCi/g)	Calc. Dose Rate (urem/hr)	Fraction of total
Ra-226	N.D.	0.0	0.0
K-40	2.9	1.21	100.0
Cs-137	N.D.	0.0	0.0

Total Calculated Dose Rate = 1.21 urem/hr

Reuter-Stokes PIC = 0.7 uR/hr

TLD = N.A.

Location: WIPP Mine at E140'/N140'

Isotope	Concentration (pCi/g)	Calc. Dose Rate (urem/hr)	Fraction of Total
Ra-226	N.D.	0.0	0.0
K-40	2.2	0.92	100.0
Cs-137	N.D.	0.0	0.0

Total Calculated Dose Rate = 0.92 urem/hr

Reuter-Stokes PIC = 0.6 uR/hr

TLD = N.A.

Location: WIPP Mine E140'/N780'

Isotope	Concentration (pCi/g)	Calc. Dose Rate (urem/hr)	Fraction of Total
Ra-226	N.D.	0.0	0.0
K-40	3.5	1.46	100.0
Cs-137	N.D.	0.0	0.0

Total Calculated Dose Rate = 1.46 urem/hr

Reuter-Stokes PIC = 0.7 uR/hr

TLD = N.A.

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Table 2 (cont.)

Location: WIPP Mine at E140°/N1450°

Isotope	Concentration (pCi/g)	Calc. Dose Rate (urem/hr)	Fraction of Total
Ra-226	N.D.	0.0	0.0
K-40	2.2	0.92	100.0
Cs-137	N.D.	0.0	0.0

Total Calculated Dose Rate = 0.92 urem/hr

Reuter-Stokes PIC = 0.7 uR/hr

TLD = N.A.

NOTES:

N.D. = not detected

N.A. = not available

(1) Radium-226 concentration inferred from assuming equilibrium with Pb-214 and Bi-214 daughters.

(2) Reuter-Stokes PIC refers to the Reuter-Stokes pressurized ion chamber measurements taken in this study.

(3) TLD refers to the 5.5 year averages of the SNLA TLD survey program continuing at the site (reference 4).

(4) The potassium-40 values used for the salt concentration in the mine are the estimated values from the radiation field spectra study.

Table 3

Radon and Working Level Results

Location	Radon (pCi/l)		Working Level (mWL)	
	Lucas	Field (1)	Rolle	Kusnetz
Outlet	<MCL	0.0005	<MCL	<MCL
ERDA 9	<MCL	0.0007	<MCL	<MCL
WIPP 11	<MCL	0.0007	1.3	<MCL
AEC 7	<MCL	N.A.	<MCL	<MCL
ERDA 6	<MCL	0.0007	<MCL	<MCL
AEC 8	<MCL	0.001	<MCL	<MCL
Badger	<MCL	0.0014	<MCL	<MCL
Metro	<MCL	N.A.	<MCL	<MCL
Inlet	<MCL	N.A.	<MCL	<MCL
E140'/S3650' (2)	<MCL	N.D.	1.1	<MCL
E140'/S1600' (2)	<MCL	N.D.	1.1	1.1
E140'/S1600' (3)	<MCL	N.D.	<MCL	<MCL
E140'/S1600' (4)	<MCL	N.D.	<MCL	<MCL
E140'/S400'	<MCL	N.A.	<MCL	<MCL
0'/0'	<MCL	N.A.	<MCL	<MCL
<hr/>				
MCL =	3.6	N.A.	0.7	1.0

NOTES:

(1) 'Lucas' represents the 'Lucas' cell methodology, and 'field' represents the estimate from the radiation field spectra.

(2) The booster fans used for circulating air in this shaft were not turned on for these measurements.

(3) One booster fan was turned on, representing normal conditions in this shaft.

(4) Both booster fans were turned on, a condition used with high vehicular activity in this shaft.

APPENDIX 1: Spectral Results

LT= 3000 SECS

METRO STA. 890 GM

LT= 3150 SECS

WIPP NE COR. 965 GM

LT= 3000 SECS

WIPP SW COR. 905 GM

LT= 3000 SECS

WIPP NW COR. 963 GM

LT= 3000 SECS

ERDA 9 SOIL 891 GM

LT= 3000 SECS

BADGER SITE 940 GM

LT= 2000 SECS

BADGER RAD FIELD

LT= 3000 SECS

WIPP 11 SOIL 880 GM

LT= 3000 SECS

WIPP 11 RAD. FIELD

LT= 3000 SECS

AEC 7 SOIL 832 GM

LT= 2500 SECS

AEC 7 RAD. FIELD

LT= 3000 SECS

ERDA 6 SOIL 855 GM

LT= 2500 SECS

ERDA #6 RAD. FIELD

LT= 3000 SECS

AEC 8 SOIL 945 GRAMS

LT= 2500 SECS

AEC #8 RAD. FIELD

LT= 3000 SECS

VENT OUTLET 805 GM

LT= 3000 SECS

MINE OUTLET FIELD

LT= 3000 SECS

WIPP E140/S3650 835G

LT= 3000 SECS

S3650'E140' RAD.FIEL

LT= 4000 SECS

S1607'E140'RAD FIELD

LT= 3000 SECS

E140/N1450 RAD FIELD

LT= 3000 SECS

WIPP E140/N780 880 G

LT= 3000 SECS

E140/N780 RAD FIELD

LT= 3000 SECS

N140'E140' RAD FIELD

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