

CHAPTER 4

Occurrence of Radionuclides in Residents of the Carlsbad, New Mexico Area

INTRODUCTION

Citizen volunteers from the Carlsbad, New Mexico area were monitored for internally deposited radionuclides through a project entitled "Lie Down and Be Counted" (LDBC). This project is provided as an outreach service to the public and to support education about naturally occurring and man-made radioactivity present in people, especially those who live in the vicinity of the WIPP. The data collected prior to the opening of the WIPP facility (26 March 1999) serve as a baseline for comparisons with periodic follow-up measurements that are slated to continue throughout the approximate 35-year operational phase of the WIPP. It is important to note that these data represent an interim summary (through 31 December 2007) of an ongoing study.

Participating in the LDBC consists of having a lung and whole body count. Volunteers are recruited through presentations to local community groups and businesses. The entire measurement process takes approximately one hour. A detailed description of the measurement protocol, analysis and instrument detection limits is provided in the CEMRC 1998 Report. In addition, the status of the project and results are available on the CEMRC website (<http://www.cemrc.org>).

BIOASSAY RESULTS

As of 31 December 2007, 810 individuals had participated in the LDBC project. At

the time the WIPP opened, 366¹ individuals had been measured using the *in vivo* protocol. This group of 366 measurements constitutes the pre-operational baseline to which subsequent results are compared. Counts performed after the opening of the WIPP are considered to be a part of the operational monitoring phase of the WIPP EM. Recounts began in July 1999, and 254 recount bioassays had been performed through 31 December 2007. In addition, 239 new volunteers have participated in the program since 1 October 2002.

While not part of the LDBC program, CEMRC has also counted over 3,000 rad-trained workers in the region from WIPP, WCS, and NEF.

Demographic characteristics (Table 4-1) of the current LDBC cohort are statistically² unchanged from those reported in previous CEMRC reports, and are generally consistent with those reported in the 2000 census for citizens living in Carlsbad. The largest deviation between the LDBC cohort and 2000 census is under-sampling of Hispanics. In addition, it is important to note that if the presence of a radionuclide is dependent on a subclass of interest (gender, ethnicity,

¹ This number was previously reported at 367 but that number included one test that was not part of the subject population.

² The statistics reported for the bioassay program assume that the individuals participating are a random sample of the population. Given that the bioassay program relies on voluntary participation, randomness of the sample cannot be assured and, as is discussed later, sampling appears to be biased by ethnicity.

etc.), valid population estimates can still be made by correcting for the proportion of under- or over-sampling for the particular subclass.

Baseline monitoring includes only the initial count of individuals made prior to 26 March 1999. Seven people were recounted during the baseline interval but these data are not reported in order to remain consistent with previous reports. Operational monitoring includes the counting of new individuals and the recounting of previously measured participants. Based on the data reported herein, there is no evidence of an increase in the frequency of detection of internally deposited radionuclides for citizens living within the vicinity of the WIPP since the WIPP began receipt of radioactive waste.

As discussed in detail in the CEMRC 1998 Report and elsewhere (Webb and Kirchner, 2000), the criterion, L_C , was used to evaluate whether a result exceeds background, and the use of this criterion will result in a statistically inherent 5% false-positive error rate per pair-wise comparison (5% of all measurements will be determined to be positive when there is no activity present in the person). The radionuclides being investigated and their minimum detectable activities are listed in Table 4-2 for 2006/2007 and 2007/2008. For the baseline measurements ($N = 366$), the percentage of results greater than L_C were consistent with a 5% random false-positive error rate, at the 95% confidence level (1 to 9%), for all radionuclides except ^{232}Th via the decay of ^{212}Pb , $^{235}\text{U}/^{226}\text{Ra}$, ^{60}Co , ^{137}Cs , ^{40}K , ^{54}Mn , and ^{232}Th via the decay of ^{228}Ac (Table 4-2). As discussed in detail in the 1998 report, five of these [^{232}Th via ^{212}Pb , ^{60}Co , ^{40}K , ^{54}Mn (^{228}Ac interference) and ^{232}Th (via ^{228}Ac)] are part of the shield-room background and positive detection is

expected at low frequency. ^{40}K is a naturally occurring isotope of an essential biological element, so detection in all individuals is expected. ^{137}Cs and $^{235}\text{U} / ^{226}\text{Ra}$ are not components of the shielded room background and were observed at frequencies greater than the 95% confidence interval for the false positive error rate (discussed in more detail below).

For the operational monitoring counts (Table 4-3, $N = 690$), the percentage of results greater than L_C were consistent with baseline at a 95% confidence level (margin of error), except for ^{60}Co and ^{232}Th (via ^{228}Ac). For these radionuclides, the percentage of results greater than L_C decreased relative to the baseline. This would be expected for ^{60}Co , since the radionuclide has a relatively short half life (5.2 years), and the content within the shield has decreased via decay by approximately 59% since the baseline phase of monitoring. The differences in ^{232}Th (via ^{228}Ac) results between the baseline and operational monitoring phase were also observed in 2001 and 2002 and are likely due to the replacement of aluminum (tends to contain Th and U) in some of the detector cryostat components with those manufactured from low radiation background steel.

^{40}K results were positive for all participants through December 2007 and ranged from 792 to 5558 Bq per person with an overall mean (\pm SE) of 2526 (\pm 26) Bq per person. Such results are expected since K is an essential biological element contained primarily in muscle, and a theoretical constant fraction of all naturally occurring K is the radioactive isotope ^{40}K . The mean ^{40}K value for males (\pm SE), was 3104 (\pm 30) Bq per person, which was significantly greater ($p < 0.0001$) than that of females, which was 1900 (\pm 22) Bq per person. This result

was expected since, in general, males tend to have larger body sizes and greater muscle content than females.

Detectable ^{137}Cs is present in $23 \pm 3\%$ (95% confidence level, baseline and operational monitoring counts) of citizens living in the Carlsbad area. These results are consistent with findings previously reported in CEMRC reports and elsewhere (Webb and Kirchner, 2000). Detectable ^{137}Cs body burdens ranged from 4.9 to 77.5 Bq per person with an overall mean (\pm SE) of $10.6 (\pm 0.6)$ Bq per person. The mean ^{137}Cs body burden for males (\pm SE), was $11.5 (\pm 0.8)$ Bq per person, which was significantly greater ($p = 0.002$) than that of females, which was $8.7 (\pm 0.3)$ Bq per person. As previously reported (CEMRC Reports; Webb and Kirchner, 2000) the presence of ^{137}Cs was independent of ethnicity, age, radiation work history, consumption of wild game, nuclear medical treatments and European travel. However, the occurrence of detectable ^{137}Cs was associated with gender where males had higher prevalence of ^{137}Cs relative to females. Furthermore, the presence of ^{137}Cs was associated with smoking. Smokers had a higher prevalence of detectable ^{137}Cs (29.7 %) as compared

to non-smokers (24.1 %). It is likely that the association with gender is related to the tendency for larger muscle mass in males than in females, as supported by the ^{40}K results. The association of ^{137}Cs with smoking could be related to the presence of fallout ^{137}Cs in tobacco, decreased pulmonary clearing capability in smokers, or other as yet unidentified factors.

These results, particularly the absence of detectable levels of plutonium, suggest that there have been no significant releases from WIPP.

As reported in previous CEMRC reports, the percentage of results greater than L_C for $^{235}\text{U}/^{226}\text{Ra}$ (11 %) are significantly higher than the distribution-free confidence interval for a 5 % random false-positive error rate. These data are not nearly as compelling as those for ^{137}Cs , but the large sample size of the current cohort tends to support the observed pattern. Although ^{235}U and ^{226}Ra cannot be differentiated via gamma spectroscopy, it is likely the signal is the result of ^{226}Ra because the natural abundance of ^{226}Ra is much greater than that of ^{235}U .

Table 4-1: Demographic Characteristics of the "Lie Down and Be Counted" Population Sample through December 31, 2007

Characteristic		2006 Sample Group ^a (margin of error)	^b Census, 2000
Gender	Male	49.9% (46.9 to 53.8%)	48.2 %
	Female	49.6% (46.2 to 53.1%)	51.8 %
Ethnicity	Hispanic	15.2% (12.7 to 17.7%)	36.7 %
	Non-hispanic	83.7% (82.3 to 87.3%)	63.3 %
Age 60 or older		26.6% (24.0 to 29.2%)	24.5 %
Currently or previously classified as a radiation worker		7.7% (6.1 to 9.3%)	^c NA
Consumption of wild game within 3 months prior to count		21.5% (19.1 to 24.0%)	NA
Medical treatment other than x-rays using radionuclides		7.7% (6.1 to 9.3%)	NA
European travel within 2 years prior to the count		5.4% (4.1 to 6.8%)	NA
Current smoker		13.4% (11.4 to 15.5%)	NA

^a The margin of error represents the 95% confidence interval of the observed proportion.; under complete replication of this experiment, one would expect the confidence interval to include the true population proportion 95% of the time if the sample was representative of the true population.

^b <http://quickfacts.census.gov>. United States Department of Commerce, Economics and Statistics Administration, Bureau of the Census.

^c NA = not available

Table 4-2: Minimum Detectable Activities**2006-2007 Calibration****Radionuclides Deposited in the Lungs**

Radionuclide	Energy (keV)	CWT = 1.6 MDA (nCi)	CWT = 2.22 MDA (nCi)	CWT = 3.01 MDA (nCi)	CWT = 3.33 MDA (nCi)	CWT = 4.18 MDA (nCi)	CWT = 5.10 MDA (nCi)	CWT = 6.0 MDA (nCi)
Am-241	59.50	0.18	0.23	0.29	0.33	0.44	0.60	0.81
Ce-144	133.50	0.47	0.56	0.69	0.76	0.95	1.23	1.57
Cf-252	19.20	16.41	32.73	78.83	112.79	290.17	808.62	2199.46
Cm-244	18.10	15.35	32.95	87.42	129.26	368.87	1145.73	3476.70
Eu-155	105.30	0.28	0.34	0.43	0.47	0.61	0.80	1.06
Np-237	86.50	0.50	0.61	0.78	0.86	1.13	1.52	2.02
Pu-238	17.10	16.38	38.20	112.73	174.23	555.50	1952.28	6685.42
Pu-239	17.10	40.75	95.05	280.49	433.48	1382.11	4857.35	16633.59
Pu-240	17.10	16.01	37.34	110.19	170.30	542.97	1908.24	6534.63
Pu-242	17.10	19.31	45.05	132.93	205.44	655.02	2302.01	7883.04
Ra-226	186.10	1.68	1.95	2.35	2.54	3.11	3.88	4.82
Th-232 Via Pb-212	238.60	0.16	0.18	0.22	0.24	0.30	0.37	0.46
Th-232	59.00	33.96	41.87	54.88	61.17	81.63	111.39	151.30
Th-232 via Th-228)	84.30	5.04	6.16	7.93	8.78	11.52	15.46	20.59
U-233	440.30	0.66	0.76	0.91	0.98	1.19	1.48	1.81
U-235	185.70	0.10	0.12	0.15	0.16	0.19	0.24	0.30
Nat U via Th-234	63.30	1.59	2.13	2.54	2.83	3.76	5.12	6.92

Radionuclides Deposited in the Whole Body

Radionuclide	Energy (keV)	MDA (nCi)
Ba-133	356	0.76
Ba-140	537	1.45
Ce-141	145	1.70
Co-58	811	0.34
Co-60	1333	0.37
Cr-51	320	4.34
Cs-134	604	0.33
Cs-137	662	0.43
Eu-152	344	1.52
Eu-154	1275	0.92
Eu-155	105	4.00
Fe-59	1099	0.63
I-131	365	0.46
I-133	530	0.41
Ir-192	317	0.56
Mn-54	835	0.45
Ru-103	497	0.38
Ru-106	622	3.19
Sb-125	428	1.29
Th-232 via Ac-228	911	1.15
Y-88	898	0.35
Zn-65	1116	1.08
Zr-95	757	0.57

**Table 4-2: Minimum Detectable Activities
(Continued)**

2007-2008 Calibration

Radionuclides Deposited in the Lungs

Radionuclide	Energy (keV)	CWT = 1.6 MDA (nCi)	CWT = 2.22 MDA (nCi)	CWT = 3.01 MDA (nCi)	CWT = 3.33 MDA (nCi)	CWT = 4.18 MDA (nCi)	CWT = 5.10 MDA (nCi)	CWT = 6.0 MDA (nCi)
AM-241	59.50	0.16	0.21	0.29	0.32	0.45	0.64	0.90
CE-144	133.50	0.47	0.55	0.70	0.78	1.01	1.34	1.76
CF-252	19.20	18.63	33.57	76.77	107.19	261.50	686.54	1761.58
CM-244	18.10	16.37	32.80	83.42	121.22	330.83	982.02	2831.38
EU-155	105.30	0.26	0.33	0.44	0.49	0.66	0.91	1.25
NP-237	86.50	0.44	0.58	0.78	0.88	1.22	1.73	2.42
Pu-238	17.10	16.27	37.02	106.40	162.23	502.57	1706.71	5650.94
Pu-239	17.10	40.48	92.12	264.73	403.64	1250.42	4246.37	14059.75
Pu-240	17.10	15.90	36.19	104.00	158.57	491.24	1668.22	5523.47
Pu-242	17.10	19.18	43.66	125.46	191.29	592.60	2012.45	6663.24
Ra-226	186.10	1.75	1.94	2.37	2.57	3.20	4.04	5.08
Th-232 Via Pb-212	238.60	0.15	0.18	0.22	0.24	0.31	0.40	0.51
Th-232	59.00	32.50	42.46	57.54	65.08	90.16	128.42	181.56
Th-232 via Th-228)	84.30	4.57	6.01	8.07	9.15	12.66	17.97	25.32
U-233	440.30	0.61	0.72	0.89	0.97	1.21	1.55	1.96
U-235	185.70	0.11	0.12	0.15	0.16	0.20	0.25	0.31
Nat U via Th-234	63.30	1.45	1.92	2.59	2.94	4.08	5.81	8.23

Radionuclides Deposited in the Whole Body

Radionuclide	Energy (keV)	MDA (nCi)
Ba-133	356	0.75
Ba-140	537	1.46
Ce-141	145	1.67
Co-58	811	0.34
Co-60	1333	0.35
Cr-51	320	4.28
Cs-134	604	0.32
Cs-137	662	0.42
Eu-152	344	1.51
Eu-154	1275	0.90
Eu-155	105	4.06
Fe-59	1099	0.64
I-131	365	0.45
I-133	530	0.41
Ir-192	317	0.56
Mn-54	835	0.43
Ru-103	497	0.36
Ru-106	622	3.16
Sb-125	428	1.30
Th-232 via Ac-228	911	1.16
Y-88	898	0.37
Zn-65	1116	1.06
Zr-95	757	0.56

Table 4-3: "Lie Down and Be Counted" Results through December 31, 2007

Radionuclide	In Vivo Count Type	Baseline Counts ^c (margin of error) (data prior to 27 March 1999) ^a N = 366	Operational Monitoring Counts (margin of error) (27 March 1999 – 31 December 2007) N = 690
		% of Results \geq ^b L _C	% of Results \geq L _C
²⁴¹ Am	Lung	5.2 (4.0 to 6.4)	3.9 (3.2 to 4.6)
¹⁴⁴ Ce	Lung	4.6 (3.5 to 5.7)	3.5 (2.8 to 4.2)
²⁵² Cf	Lung	4.1 (3.1 to 5.1)	5.8 (5.0 to 6.7)
²⁴⁴ Cm	Lung	5.7 (4.5 to 7.0)	4.7 (3.9 to 5.5)
¹⁵⁸ Eu	Lung	7.1 (5.8 to 8.4)	4.9 (4.1 to 5.7)
²³⁷ Np	Lung	3.6 (2.6 to 4.5)	4.0 (3.3 to 4.8)
²¹⁰ Pb	Lung	4.4 (3.3 to 5.4)	5.9 (5.0 to 6.7)
Plutonium Isotope	Lung	5.7 (4.5 to 7.0)	5.6 (4.7 to 6.4)
^d ²³² Th via ²¹² Pb	Lung	34.2 (31.7 to 36.6)	33.8 (32.0 to 35.5)
²³² Th	Lung	4.9 (3.8 to 6.0)	5.3 (4.5 to 6.1)
²³² Th via ²²⁸ Th	Lung	4.1 (3.1 to 5.1)	5.0 (4.2 to 5.8)
²³³ U	Lung	5.7 (4.5 to 7.0)	9.5 (8.4 to 10.5)
²³⁵ U/ ²²⁶ Ra	Lung	10.7 (9.0 to 12.3)	11.3 (10.1 to 12.4)
Natural Uranium via ²³⁴ Th	Lung	5.2 (4.0 to 6.4)	6.3 (5.4 to 7.2)
¹³³ Ba	Whole Body	3.6 (2.6 to 4.5)	2.9 (2.3 to 3.6)
¹⁴⁰ Ba	Whole Body	5.2 (4.0 to 6.4)	3.9 (3.2 to 4.6)
¹⁴¹ Ce	Whole Body	3.6 (2.6 to 4.5)	4.7 (3.9 to 5.5)
⁵⁸ Co	Whole Body	4.4 (3.3 to 5.4)	2.4 (1.8 to 2.9)
^d ⁶⁰ Co	Whole Body	54.6 (52.0 to 57.2)	28.3 (26.6 to 30.0)
⁵¹ Cr	Whole Body	5.7 (4.5 to 7.0)	4.0 (3.3 to 4.8)
¹³⁴ Cs	Whole Body	1.6 (1.0 to 2.3)	2.5 (1.9 to 3.1)
¹³⁷ Cs	Whole Body	28.4 (26.1 to 30.8)	21.4 (19.9 to 23.0)
¹⁵² Eu	Whole Body	7.4 (6.0 to 8.7)	6.3 (5.4 to 7.2)
¹⁵⁴ Eu	Whole Body	3.8 (2.8 to 4.8)	2.6 (2.0 to 3.2)
¹⁵⁸ Eu	Whole Body	3.8 (2.8 to 4.8)	3.6 (2.9 to 4.3)
⁵⁹ Fe	Whole Body	3.8 (2.8 to 4.8)	6.0 (5.1 to 6.9)
¹³¹ I	Whole Body	5.2 (4.0 to 6.4)	4.0 (3.3 to 4.8)
¹³³ I	Whole Body	3.3 (2.3 to 4.2)	3.9 (3.2 to 4.6)
¹⁹³ Ir	Whole Body	4.1 (3.1 to 5.1)	4.1 (3.3 to 4.8)
⁴⁰ K	Whole Body	100.0 (100.0 to 100.0)	100.0 (100.0 to 100.0)
^d ⁵⁴ Mn	Whole Body	12.3 (10.6 to 14.0)	11.8 (10.6 to 13.0)
¹⁰³ Ru	Whole Body	2.2 (1.4 to 3.0)	1.5 (1.1 to 2.0)
¹⁰⁶ Ru	Whole Body	4.4 (3.3 to 5.4)	3.8 (3.1 to 4.5)
¹²⁵ Sb	Whole Body	5.2 (4.0 to 6.4)	3.6 (2.9 to 4.3)
²³² Th via ²²⁸ Ac	Whole Body	34.7 (32.2 to 37.2)	25.7 (24.1 to 27.3)
⁸⁸ Y	Whole Body	7.7 (6.3 to 9.0)	6.3 (5.4 to 7.2)
⁹⁵ Zr	Whole Body	6.6 (5.3 to 7.9)	4.0 (3.3 to 4.8)

^a N = number of individuals. **Baseline counts include only the initial counts during this baseline period.**

^b To determine whether or not activity has been detected in a particular person, the parameter L_C is used; the L_C represents the 95th percentile of a null distribution that results from the differences of repeated, pair-wise background measurements; an individual result is assumed to be statistically greater than background if it is greater than L_C

^c The margin of error represents the 95% confidence interval of the observed percentage; under replication of this experiment, one would expect 95 % of the confidence intervals to include the true population if the sample was representative of the true population.

^d These radionuclides are present in the shield background, so they are expected to be detected periodically