
Draft

**ADVISORY BOARD ON
RADIATION AND WORKER HEALTH**

National Institute for Occupational Safety and Health

**SC&A'S EVALUATION OF Cs-137/Sr-90, FISSION AND
ACTIVATION PRODUCT, AND ACTINIDE VALUES USING
ANL-W MONTHLY AND ANNUAL WASTE REPORTS
IN RELATIONSHIP TO ASSIGNING INTAKES**

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ABBREVIATIONS AND ACRONYMS

ABRWH	Advisory Board on Radiation and Worker Health
Al	aluminum
Am	americium
ANL	Argonne National Laboratory (West)
ANL-W	Argonne National Laboratory – West
BORAX	Boiling-Water Reactor Experiment
Ce	cerium
Ci	curie
Co	cobalt
Cs	cesium
DR	dose reconstruction
EBR	Experimental Breeder Reactor
ER	evaluation report
FAP	fission and activation product
Max	maximum
μCi	microcurie
uCi/gm	uCi/gram
uCi/m ³	microcurie per cubic meter
uCi/ml	microcurie per milliliter
NIOSH	National Institute for Occupational Safety and Health
ORAUT	Oak Ridge Associated Universities Team
OTIB	ORAUT technical information bulletin
pCi/g	picocurie per gram
Pu	plutonium

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Ru ruthenium
SEC Special Exposure Cohort
Sr strontium
SS stainless steel
SRDB Site Research Database
TKBS site technical basis document
U uranium
Zr zirconium

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EXECUTIVE SUMMARY

In the National Institute for Occupational Safety and Health's (NIOSH's) evaluation report for the Argonne National Laboratory West (ANL-W) Special Exposure Cohort (SEC) petition SEC-00224 of February 18, 2016 (NIOSH 2016), one of the major assumptions was that a bioassayed indicator radionuclide (strontium-90 [Sr-90] and/or cesium-137 [Cs-137]) can be used to assign dosimetric-significant fission and activation product (FAP) and actinide (alpha emitter) intakes using the ratio method. This method requires that radionuclide ratios remain fairly constant for the many processes and locations, and over most of the operating history of ANL-W. However, SC&A found that apparently most of the radionuclide ratios recommended by NIOSH were generated by computer modeling, and that there was no indication that the computer-generated ratio values had been compared to ratio values derived from physical measurement.

SC&A searched the Site Research Database for documents that could provide quantitative radionuclide data. During this search, SC&A located ANL-W waste reports that contained quantitative Cs-137 and Sr-90 measurements performed on the same samples (some also contained FAP and actinide analyses). These reports spanned a relatively long time period (1958–1993) for a number of areas at ANL-W. Quantitative radionuclide data for waste materials (air, liquid, and solid) at the ANL-W facilities provide a good representation of the potential intake exposures to workers. Therefore, these data were analyzed in detail to evaluate if there is a reasonably consistent relationship between the Cs-137/Sr-90 concentrations, and if these indicating radionuclides could be used to assign other radionuclide intakes such as FAP for dose reconstruction (DR) purposes. In addition, quantitative actinide data in relationship to Sr-90 and Cs-137 were analyzed when available. Data for this report included both monthly and annual radionuclide concentrations. A former SC&A ANL-W progress report analyzed mostly annual radionuclide concentrations (SC&A 2016).

Cs-137/Sr-90

A total of 34 monthly and 16 annual matched pairs of measured Cs-137 and Sr-90 activities were located and analyzed, spanning the period 1958–1993 at the ANL-W site. Of these matched monthly data pairs, approximately 32% contained Cs-137/Sr-90 values centered on unity, within a factor of 2 (i.e., Cs-137/Sr-90 = 0.5 to 2.0), and 56% for annual data pairs. The remaining Cs-137/Sr-90 values were outside this interval, with values ranging from 0.38 to 120. Similar results were obtained for Sr-90/Cs-137 values, with the ratio values being the inverse of the Cs-137/Sr-90 ratio values. Cs-137 activities were generally slightly greater than Sr-90 activities.

Fission and Activation Product Ratios

A total of 35 monthly and 12 annual matched pairs of measured Sr-90 and FAP (cerium-144 [Ce-144], cobalt-60 [Co-60], and ruthenium-106 [Ru-106]) activity were located and analyzed, spanning the period 1958–1993 for the ANL-W site. The measured FAP/Sr values were compared to the FAP/Sr values recommended in Table 7-3a (with a 1-year decay time) of ORAUT-OTIB-0054, *Fission and Activation Product Assignment for Internal Dose-Related Gross Beta and Gross Gamma Analyses*, Revision 03, dated February 6, 2015. A comparison ratio value centered on 1.0 would indicate agreement between the measured and recommended values; however, ratio values not centered on unity would indicate insufficient or excessive FAP intake assignments during DR. Of these matched pairs, measured Ce-144/Sr-90 values generally fell below the recommended ratio of 12.5, measured Co-60/Sr-90 values were greater than the

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recommended value of 1.8E-4, and the relatively few measured Ru-106/Sr-90 values tended to scatter both above and below the recommended ratio of approximately 1. Using annual data to calculate Ce-144/Sr-90 values appeared to provide some smoothing effect compared to using the monthly data. There was no significant difference in using annual versus monthly data for determining the Co-60/Sr-90 values. There were too few Ru-106/Sr-90 data pairs to evaluate annual versus monthly data. Similar results were obtained using FAP/Cs-137 data.

Actinide Ratios

As outlined in SC&A's progress report of July 2016 (SC&A 2016), a total of only 15 matched pairs (monthly plus annual) of ANL-W measured actinide and Cs-137 activity were located for analysis. (SC&A did not locate any additional actinide data pairs during the recent search for monthly and annual data.) The measured actinide/Sr values were compared to the actinide/Sr values recommended in Table 5-23 of ORAUT-TKBS-0007-5, *Idaho National Laboratory and Argonne National Laboratory – West – Occupational Internal Dose*, Revision 03, dated March 2, 2010. In general, the measured actinide/Cs-137 ratio values were greater than those recommended by NIOSH, but some were less. There was considerable scatter in the ratio values, and there were too few data pairs to allow for meaningful statistical analysis. Similar results were obtained using actinide/Sr-90 data.

Conclusions

These results indicate that at ANL-W, the Cs-137/Sr-90 values may not be centered on unity as indicated in ORAUT-OTIB-0054, Revision 03, and some FAP/Sr and FAP/Cs measured values may be greater or less than recommended for assigning FAP intakes. Also, actinide/Sr or actinide/Cs values may not be sufficiently constant (or known) as required by ORAUT-TKBS-0007-5, Revision 03, Tables 5-22 and 5-23, for assigning actinide intakes, even in situations where it can be assumed that the actinides are tied to an indicating radionuclide, such as Sr-90 or Cs-137. Therefore, SC&A finds:

1. Cs-137/Sr-90 values are not sufficiently constant to assume a ratio of unity. Using the results of Cs-137 bioassays versus Sr-90 bioassays may lead to differences in FAP intake assignments for the radionuclides listed in Table 7-3 of ORAUT-OTIB-0054, Revision 03, for DR.
2. Measured Ce-144/Sr-90 or Ce-144/Cs-137 values indicate that the recommended values in Table 7-3 of ORAUT-OTIB-0054, Revision 03, are reasonable for DR purposes.
3. Measured Co-60/Sr-90 or Co-60/Cs-137 values are not in agreement with the recommended values in Table 7-3 of ORAUT-OTIB-0054, Revision 03. Using the recommended ratio values would usually lead to significant underestimation of Co-60 intake for the waste materials analyzed in this report.
4. Measured Ru-106/Sr-90 or Ru-106/Cs-137 values were too few in number to indicate if the recommended values in Table 7-3 of ORAUT-OTIB-0054, Revision 03, are reasonable for DR purposes for ANL-W claimants. For the few data pairs located, there was noticeable scatter in the measured ratio values.

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5. Measured FAP ratio values could only be obtained for relatively long-lived radionuclides (Cs-137, Sr-90, Ce-144, Co-60, and Ru-106). Therefore, the actual ratio values for the short-lived FAPs in Table 7-3 of ORAUT-OTIB-0054, Revision 03, are not known at this time for the material analyzed.
6. Measured actinide/Sr-90 or actinide/Cs-137 values are difficult to obtain because FAPs are generally not analyzed when actinide samples are taken. During the search for monthly and annual FAP data pairs, SC&A did not locate any additional actinide/Sr-90 or actinide/Cs-137 data pairs that were not already analyzed in a previous SC&A progress report for ANL-W (SC&A 2016). In that progress report, the few matched pairs indicated considerable scatter in the ratio values and did not provide statistically significant results.

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1.0 INTRODUCTION AND BACKGROUND

The National Institute for Occupational Safety and Health (NIOSH) responded to the Argonne National Laboratory West (ANL-W) Special Exposure Cohort (SEC)-00224 in an evaluation report (ER) of February 18, 2016 (NIOSH 2016). In that ER, and also in the technical basis document for ANL-W, ORAUT-TKBS-0007-5, Revision 03, *Idaho National Laboratory and Argonne National Laboratory – West – Occupational Internal Dose*, issued March 2010, NIOSH’s basis for assigning internal intakes and doses for most years and locations at ANL-W (except the period covered by NIOSH’s proposed SEC class) relies on the important assumption that the cesium-137/strontium-90 (Cs-137/Sr-90) values are approximately unity, that fission activation products (FAPs) are directly tied by a known ratio to Sr-90 or Cs-137 (as per ORAUT-OTIB-0054, *Fission and Activation Product Assignment for Internal Dose-Related Gross Beta and Gross Gamma Analyses*¹), and that actinides are directly tied by a known ratio to Sr-90 or Cs-137 (as per Tables 5-22 and 5-23 of ORAUT-TKBS-0007-5, Revision 03). However, SC&A found that apparently most of the radionuclide ratios recommended by NIOSH were generated by computer modeling, and that there was no indication that the computer-generated ratio values had been compared to ratio values derived from physical measurement.

SC&A searched the Site Research Database and located ANL-W waste management reports that contained quantitative Sr-90 and Cs-137 measurements performed on the same samples (some also contained FAP and actinide data). These reports span a relatively long time period (1958–1993) and cover a number of operational areas within ANL-W. These data provide a good representation of the materials workers could have been exposed to and the potential intake mixtures. SC&A analyzed annual and one-of-a-kind (i.e., point sample) radionuclide pairs in a progress report issued in July 2016 (SC&A 2016). In response to Work Group tasking at the joint Idaho National Laboratory/ANL-W meeting held in August 2016, SC&A prepared this report in which SC&A analyzed both monthly and corresponding annual data pairs to determine if the measured-to-recommended ratio values were useful for dose reconstruction (DR) purposes, and to determine if there is any difference in resulting ratios using monthly versus annual activity data. A list of the documents that contained useful radionuclide measures and some of the recorded data that were used in this evaluation are provided in this report as Attachment A (for Cs-137 and Sr-90), Attachment B (for FAP), and Attachment C (for actinide). Analyses of these data are provided in the following sections.

2.0 Cs-137/Sr-90 VALUES

NIOSH’s ER and ORAUT-TKBS-0007-5, Revision 03, rely heavily on the use of ORAUT-OTIB-0054 to assign FAP intakes using Sr-90 or Cs-137 as the indicating radionuclide for many other FAP radionuclides at ANL-W for most locations and time periods. An example of Table 7-3a from ORAUT-OTIB-0054, Revision 03, is provided here as Figure 1. As can be seen

¹ NIOSH used ORAUT-OTIB-0054, Revision 02 of March 6, 2014, for the ER, and Revision 00 PC-1 of November 19, 2007, for ORAUT-TKBS-0007-5. For this analysis, SC&A used ORAUT-OTIB-0054, Revision 03 of February 6, 2015.

from this table, assignment of FAP intakes is dependent on the Cs-137/Sr-90 value being approximately 1.

Figure 1. Table 7-3a, FAP-to-Sr-90 or -Cs-137 Ratios for ATR-1 (ORAUT-OTIB-0054)

Table 7-3a. Associated radionuclide activity fractions for assigning intakes: ATR 1.									
Table 7-3 values: ATR 1									
Nuclide	Intake relative to Sr-90				Nuclide	Intake relative to Cs-137			
	10 d	40 d	180 d	1 y		10 d	40 d	180 d	1 y
Co-60	2.05E-04	2.03E-04	1.95E-04	1.85E-04	Co-60	2.03E-04	2.01E-04	1.93E-04	1.83E-04
Sr-89	6.72E+01	4.46E+01	6.61E+00	5.29E-01	Sr-89	6.66E+01	4.42E+01	6.54E+00	5.24E-01
Sr-90	1.00E+00	1.00E+00	1.00E+00	1.00E+00	Sr-90	9.90E-01	9.90E-01	9.89E-01	9.89E-01
Y-90	1.00E+00	1.00E+00	1.00E+00	1.00E+00	Y-90	9.93E-01	9.90E-01	9.90E-01	9.89E-01
Y-91	8.04E+01	5.64E+01	1.09E+01	1.23E+00	Y-91	7.96E+01	5.59E+01	1.07E+01	1.21E+00
Zr-95	8.67E+01	6.28E+01	1.39E+01	1.90E+00	Zr-95	8.59E+01	6.22E+01	1.38E+01	1.88E+00
Nb-95	7.49E+01	7.41E+01	2.66E+01	4.08E+00	Nb-95	7.42E+01	7.34E+01	2.63E+01	4.04E+00
Ru-103	4.50E+01	2.65E+01	2.26E+00	8.73E-02	Ru-103	4.45E+01	2.63E+01	2.24E+00	8.64E-02
Ru-106	1.74E+00	1.65E+00	1.28E+00	9.17E-01	Ru-106	1.72E+00	1.63E+00	1.27E+00	9.07E-01
I-131	1.21E+03	9.13E+01	5.29E-04	6.33E-11	I-131	1.20E+03	9.05E+01	5.23E-04	6.26E-11
Cs-134	7.48E-01	7.29E-01	6.47E-01	5.52E-01	Cs-134	7.41E-01	7.22E-01	6.40E-01	5.46E-01
Cs-137	1.01E+00	1.01E+00	1.01E+00	1.01E+00	Cs-137	1.00E+00	1.00E+00	1.00E+00	1.00E+00
Ce-141	8.62E+01	4.55E+01	2.32E+00	4.54E-02	Ce-141	8.54E+01	4.51E+01	2.30E+00	4.49E-02
Ce-144	2.89E+01	2.69E+01	1.93E+01	1.25E+01	Ce-144	2.86E+01	2.66E+01	1.91E+01	1.23E+01
Pr-143	7.60E+01	1.65E+01	1.30E-02	1.04E-06	Pr-143	7.52E+01	1.63E+01	1.29E-02	1.03E-06
Pm-147	2.81E+00	2.96E+00	2.74E+00	2.42E+00	Pm-147	2.78E+00	2.94E+00	2.71E+00	2.40E+00
Eu-154	2.36E-02	2.35E-02	2.30E-02	2.23E-02	Eu-154	2.34E-02	2.32E-02	2.27E-02	2.21E-02

SC&A located a total of 34 monthly and 16 annual matched pairs of measured Cs-137 and Sr-90 activity in the ANL-W waste reports, spanning the period 1958–1993 for the ANL-W site. SC&A analyzed these data to determine the Cs-137/Sr-90 values for each matched pair for the ANL-W site. Only recorded and paired data points specifically listing Cs-137 and Sr-90 in units of activity (microcurie [μCi], curie [Ci], etc.) on the same material were used in these analyses; this included air, liquid, and solid waste. Figures 2 and 3 contain the results for the 34 monthly (represented by orange squares) and 16 annual (represented by blue diamonds) ANL-W data pairs analyzed.

Figure 2. Cs-137/Sr-90 Values for Monthly and Annual Data Pairs from ANL-W Waste Reports

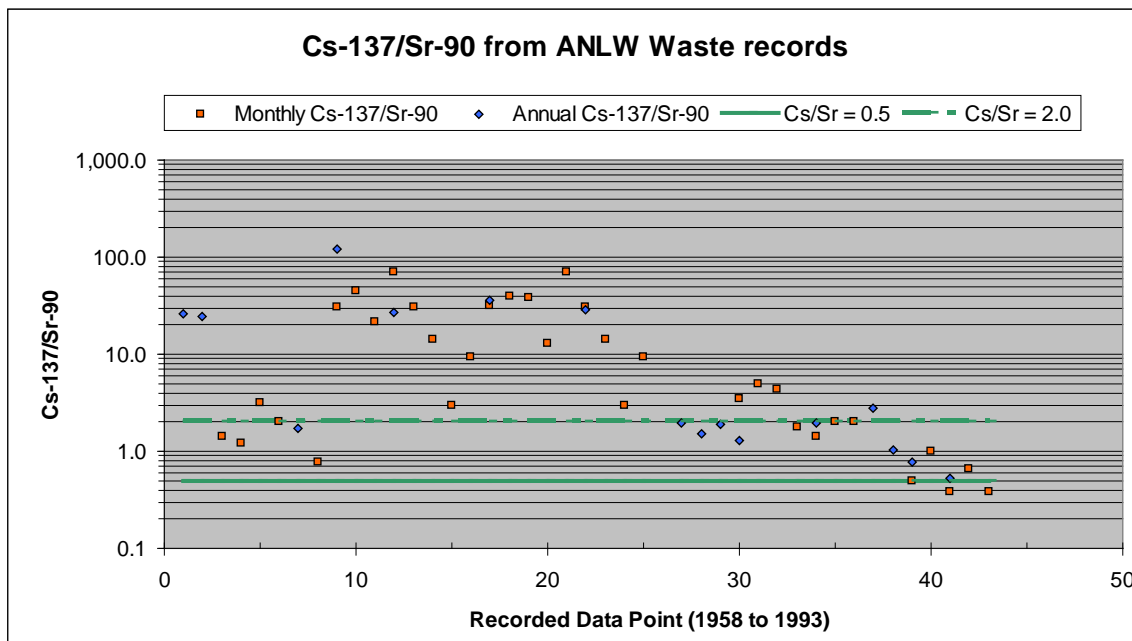
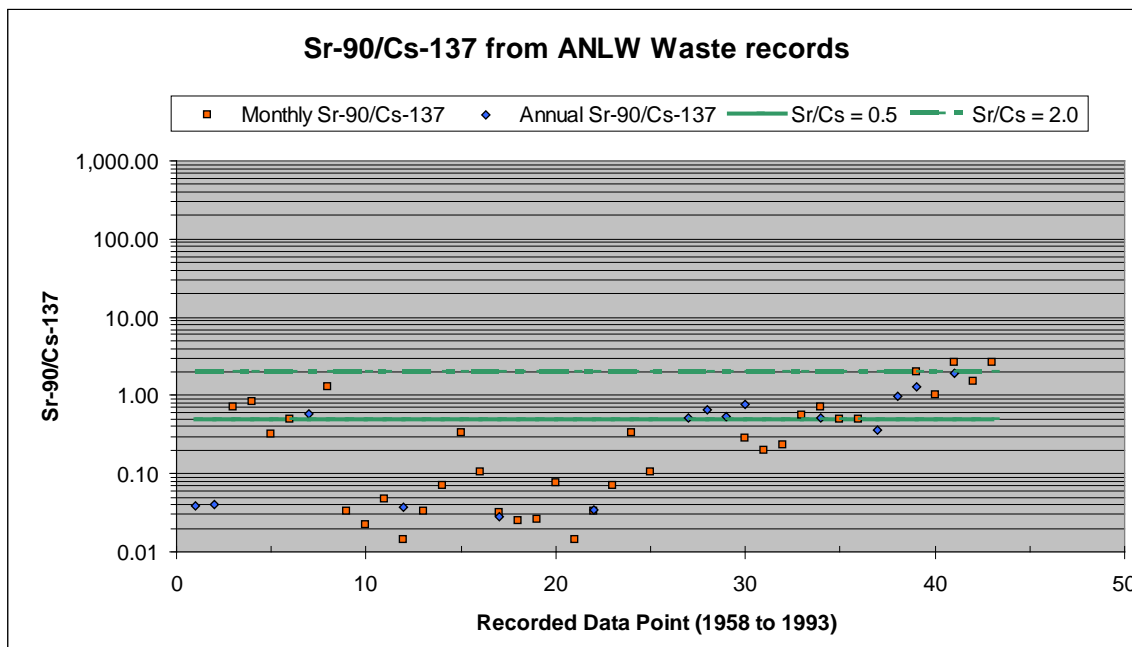


Figure 3. Sr-90/Cs-137 Values for Monthly and Annual Data Pairs from ANL-W Waste Reports



Of the 34 monthly pairs, 32.4% contained Cs-137/Sr-90 or Sr-90/Cs-137 values centered on unity, within a factor of 2 (i.e., ratio = 0.5 to 2.0) of the recommended values; these are represented by the data points between the solid and dashed thick green horizontal lines in Figures 2 and 3. Of the 34 monthly pairs, 44.1% fell within a factor of 3 (i.e., 0.33 to 3.0). The

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remaining Cs-137/Sr-90 values were outside these intervals, with values ranging from 0.38 to 120. Table 1 summarizes the distribution of the ratios that fell below, within, and above the recommended ratio by a factor of 2 (i.e., 0.5 to 2.0), and the corresponding data for a factor of 3 (i.e., 0.33 to 3.0) for both the monthly and annual data.

Table 1. Summary of Measured Cs-137/Sr-90 and Sr-90/Cs-137 Values Compared to Ratio Values Recommended in Table 7-3a of ORAUT-OTIB-0054

Radionuclides*	Number of Pairs	Type of Data	Percent of Pairs with Ratios <0.5	Percent of Pairs with Ratios 0.5–2.0	Percent of Pairs with Ratios >2.0	Percent of Pairs with Ratios <0.33	Percent of Pairs with Ratios 0.33–3.0	Percent of Pairs with Ratios >3.0
Cs-137/Sr-90	34	Monthly	5.9%	32.4%	61.8%	0.0%	44.1%	55.9%
Cs-137/Sr-90	16	Annual	0.0%	56.3%	43.8%	0.0%	62.5%	37.5%
Sr-90/Cs-137	34	Monthly	61.8%	32.4%	5.9%	55.9%	44.1%	0.0%
Sr-90/Cs-137	16	Annual	43.8%	56.3%	0.0%	37.5%	62.5%	0.0%

*NIOSH recommended a ratio value of approximately 1 (ORAUT-OTIB-0054, Revision 03, Table 7-3a, at 1 year).

As can be seen from Table 1, the annual data provided a greater number of the Cs-137/Sr-90 values that fell within a factor of ± 2 (or ± 3) as compared to the monthly data (the annual data tended to average out the individual monthly readings if there was considerable variance in their ratio values). The ratio values derived using annual activity data pairs in these analyses were similar to those obtained using only annual data in the July 2016 progress report (SC&A 2016).

Figures 4 and 5 show the ratio values derived from the measured monthly and annual data compared to NIOSH's recommended ratios. The black bar inside the smaller shaded rectangle (gray) represents a central estimate of the value of the ratio from measured pairs (with the smaller shaded rectangle representing the 95% confidence interval² of the central estimate of the value of the ratio from measured pairs). The center horizontal red line inside the larger shaded rectangle (pink) represents the NIOSH-recommended ratio value of approximately 1. The larger shaded rectangle represents the recommended ratio value, \pm a factor of 3.

² The small rectangle (gray) represents the 95% confidence interval of the center estimate of the ratio value derived from statistical analysis, which is different from the 95% confidence level of the original data in the data pairs.

Figure 4. Comparison of Cs-137/Sr-90 Ratio of 1.0 Recommended by NIOSH with the Central Estimated Ratio and Its Confidence Interval from Measured Pairs

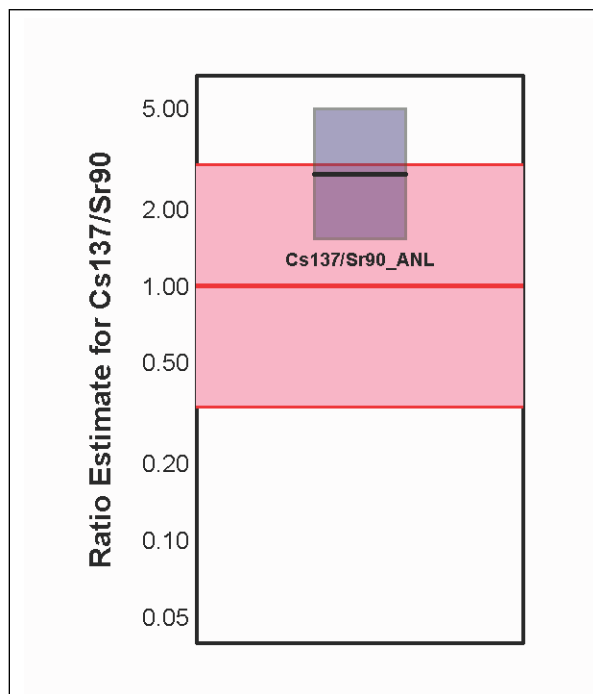
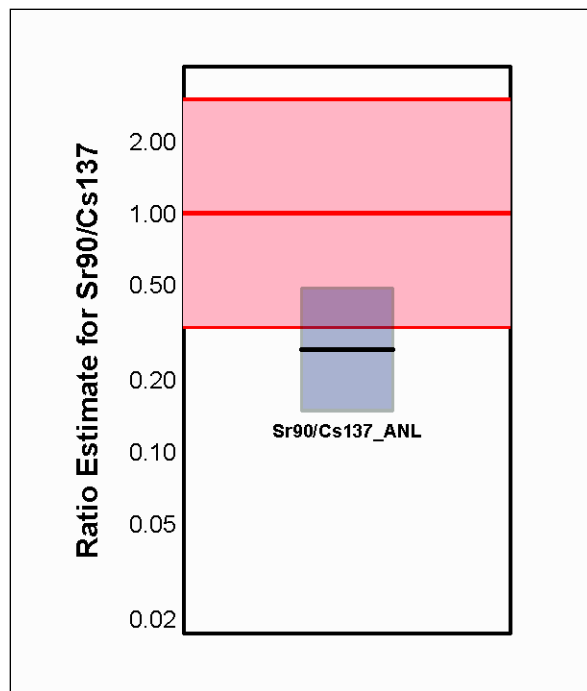


Figure 5. Comparison of Sr-90/Cs-137 Ratio of 1.0 Recommended by NIOSH with the Central Estimated Ratio and Its Confidence Interval from Measured Pairs



Figures 4 and 5 indicate that the central estimate of the ratio from measured pairs for Cs-137/Sr-90 was 2.7 and for Sr-90/Cs-137 was 0.3, and that the associated 95% confidence

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intervals generally fall near the boundaries of a factor of 3 of the recommended ratio. There was considerable scatter of the ratio values over a wide range, as shown in Figures 2 and 3.

3.0 FAP/Sr-90 VALUES

Although a large number of radionuclides are listed in Table 7-3 of ORAUT-OTIB-0054, Revision 03, many have relatively short half-lives (compared to the time from when the radionuclide was created until the time the waste sample was analyzed); therefore, when analyzing the ANL-W waste reports, only those with relatively long half-lives (equal to or greater than approximately 1 year) were selected for analysis. A total of 35 monthly and 12 annual matched pairs of measured Sr-90 and FAP (cerium-144 [Ce-144], cobalt-60 [Co-60], and ruthenium-106 [Ru-106]) activities were located and analyzed, spanning the period 1958–1993 for various facilities at the ANL-W site. The measured FAP/Sr values were compared to the FAP/Sr values recommended in Table 7-3a (with a 1-year decay time) of ORAUT-OTIB-0054, Revision 03. A comparison ratio value centered on 1 would indicate agreement between the measured and recommended values; however, ratio values not centered on unity would indicate insufficient or excessive FAP intake assignments during DR. Figures 6 through 8 contain the results for the monthly (represented by orange squares) and annual (represented by blue diamonds) FAP ANL-W data pairs analyzed.

Figure 6. Ce-144/Sr-90 Values for Monthly and Annual Data Pairs from ANL-W Waste Reports

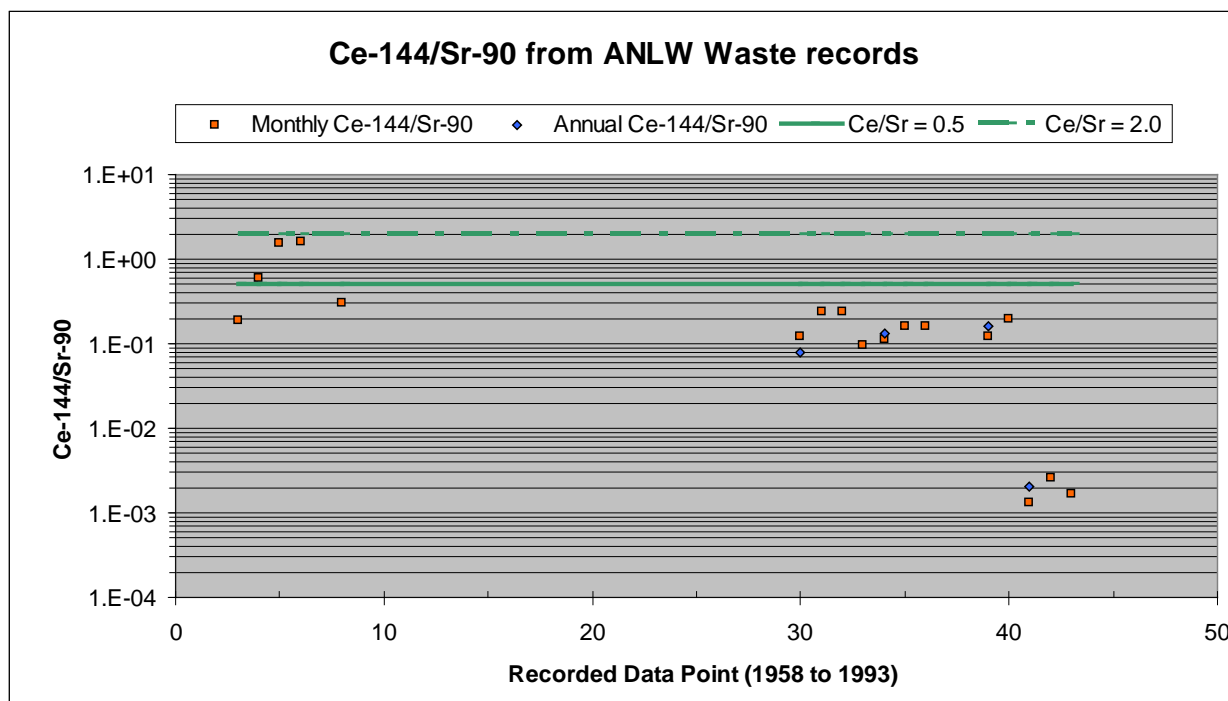


Figure 7. Co-60/Sr-90 Values for Monthly and Annual Data Pairs from ANL-W Waste Reports

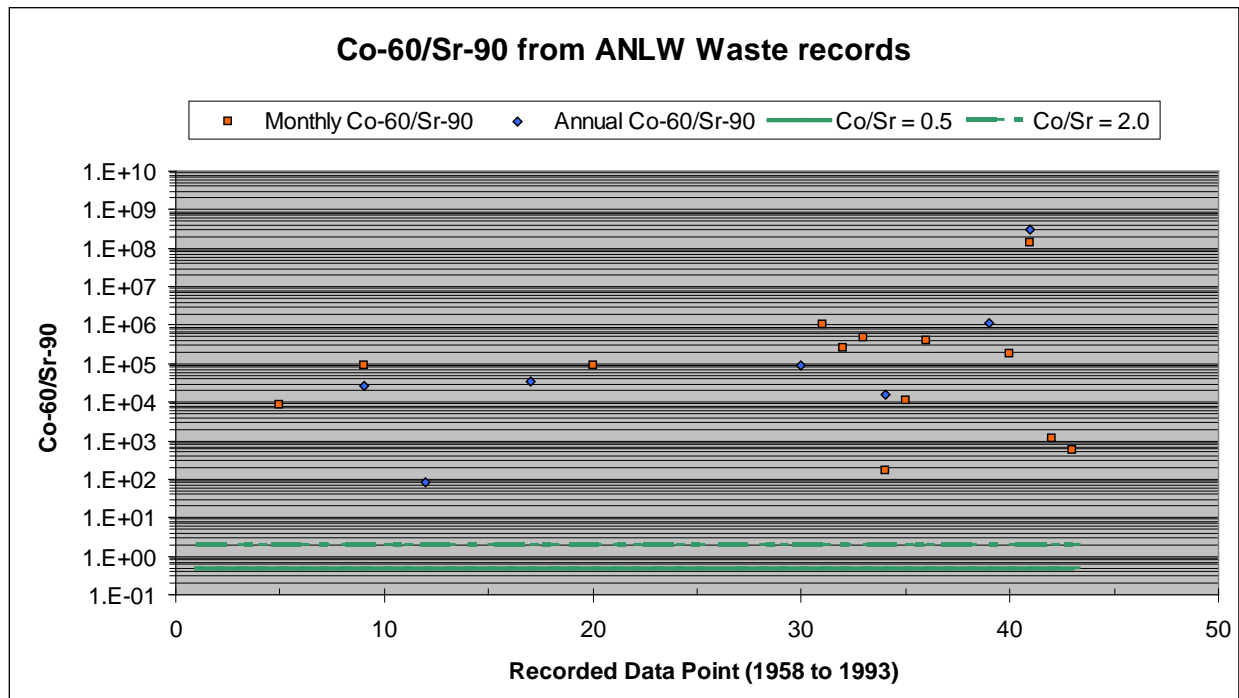
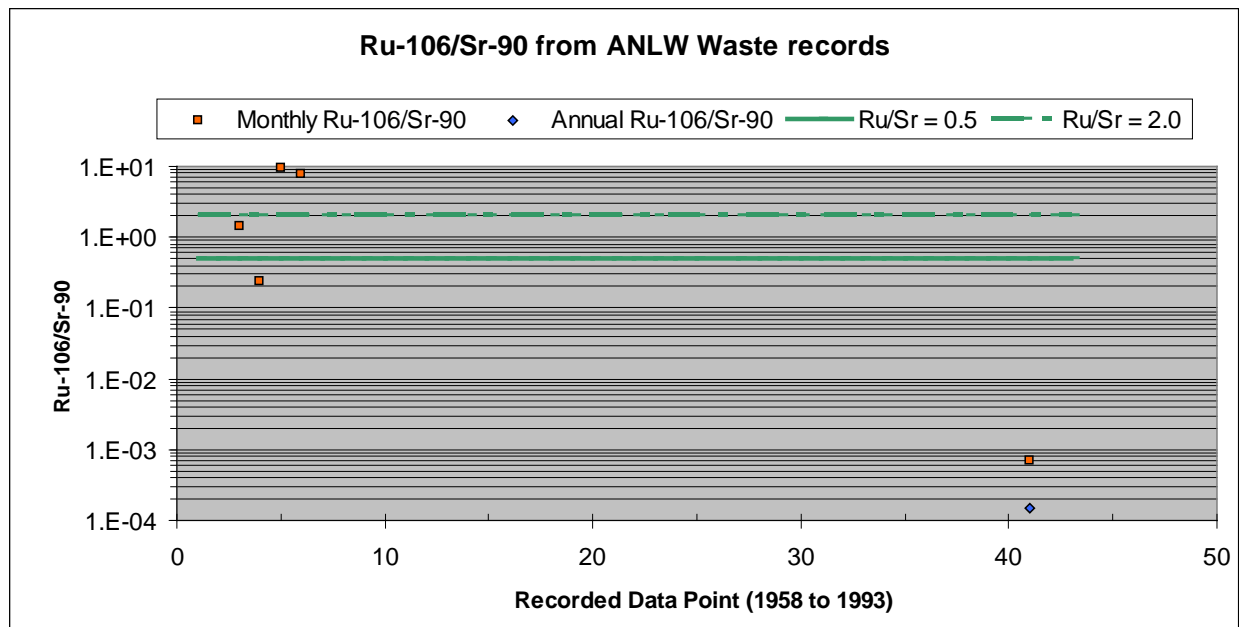


Figure 8. Ru-106/Sr-90 Values for Monthly and Annual Data Pairs from ANL-W Waste Reports



Of the 35 monthly and 12 annual data pairs, some fell within a factor of 2 (i.e., ratio = 0.5 to 2.0) of the recommended value; these are represented by the data points between the solid and dashed thick green horizontal lines in Figures 6 through 8. The remaining ratio values were outside this

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interval. Table 2 summarizes the distribution of the ratios that fell below, within, and above the recommended ratio by a factor of 2 (i.e., 0.5 to 2.0), and the corresponding data for a factor of 3 (i.e., 0.33 to 3.0).

As can be seen from Table 2, in general, the annual data provided a slightly greater number of the Cs-137/Sr-90 values that fell within a factor of ± 2 (or ± 3) as compared to the monthly data (the annual data tended to average out the individual monthly readings if there was considerable variance in their ratio values). Measured Ce-144/Sr-90 values generally fell below the recommended ratio of 12.3, and measured Co-60/Sr-90 values were always greater than the recommended value of $1.8E-4$. There were very few measured Ru-106/Sr-90 pairs, but those that were obtained had ratio values that were scattered both below and above the recommended ratio value of 1. Similar results were obtained for FAP/Cs-137 values.

Table 2. Summary of Measured FAP/Sr-90 and FAP/Cs-137 Values Compared to Ratio Values Recommended in Table 7-3a of ORAUT-OTIB-0054

Radionuclides	*Recommended Ratio	# of Pairs	Type of Data	% of Pairs with Ratios <0.5	% of Pairs with Ratios 0.5–2.0	% of Pairs with Ratios >2.0	% of Pairs with Ratios <0.33	% of Pairs with Ratios 0.33–3.0	% of Pairs with Ratios >3.0
Ce-144/Sr-90	12.5	17	Monthly	82.4%	17.7%	0.0%	82.4%	17.7%	0.0%
Ce-144/Sr-90	12.5	4	Annual	100.0%	0.0%	0.0%	100.0%	0.0%	0.0%
Ce-144/Cs-137	12.3	17	Monthly	47.1%	5.9%	47.1%	47.1%	29.4%	23.5%
Ce-144/Cs-137	12.3	4	Annual	100.0%	0.0%	0.0%	100.0%	0.0%	0.0%
Co-60/Sr-90	1.85E-04	13	Monthly	0.0%	0.0%	100.0%	0.0%	0.0%	100.0%
Co-60/Sr-90	1.85E-04	7	Annual	0.0%	0.0%	100.0%	0.0%	0.0%	100.0%
Co-60/Cs-137	1.83E-04	13	Monthly	0.0%	0.0%	100.0%	0.0%	0.0%	100.0%
Co-60/Cs-137	1.83E-04	7	Annual	0.0%	0.0%	100.0%	0.0%	14.3%	85.7%
Ru-106/Sr-90	1	5	Monthly	40.0%	20.0%	40.0%	40.0%	20.0%	40.0%
Ru-106/Sr-90	1	1	Annual	100.0%	0.0%	0.0%	100.0%	0.0%	0.0%
Ru-106/Cs-137	1	5	Monthly	40.0%	20.0%	40.0%	40.0%	40.0%	20.0%
Ru-106/Cs-137	1	1	Annual	100.0%	0.0%	0.0%	100.0%	0.0%	0.0%

*NIOSH-recommended ratio values (ORAUT-OTIB-0054, Revision 03, Table 7-3a, at 1 year).

Figures 9 and 10 show the ratio values derived from the measured monthly and annual data compared to NIOSH's recommended ratios. The black bar inside the vertical shaded rectangle (gray) represents a central estimate of the value of the ratio from measured pairs (with the vertical shaded rectangle representing the 95% confidence interval of the central estimate of the value of the ratio from measured pairs). The center horizontal red line inside the horizontal shaded rectangle (pink) represents the NIOSH-recommended ratio value. The horizontal shaded rectangle represents the recommended ratio value, \pm a factor of 3.

Figure 9. Comparison of Ce-144/Sr-90 Ratio of 12.5 Recommended by NIOSH with the Central Estimated Ratio and Its Confidence Interval from Measured Pairs

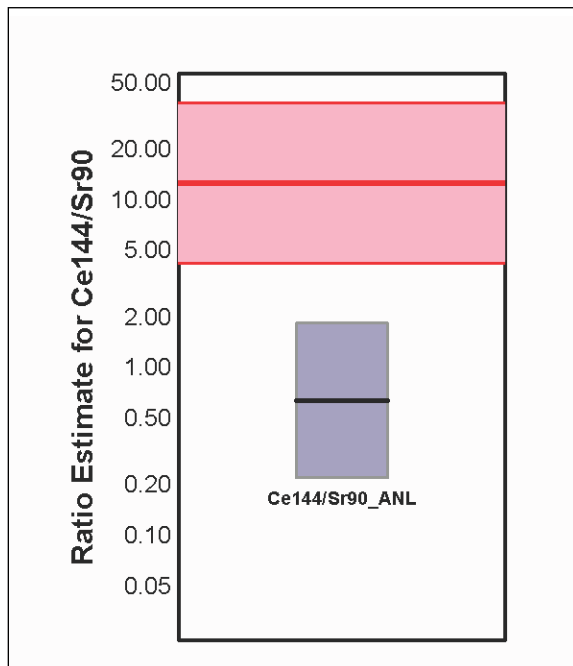


Figure 10. Comparison of Co-60/Sr-90 Ratio of 1.8E-4 Recommended by NIOSH with the Central Estimated Ratio and Its Confidence Interval from Measured Pairs

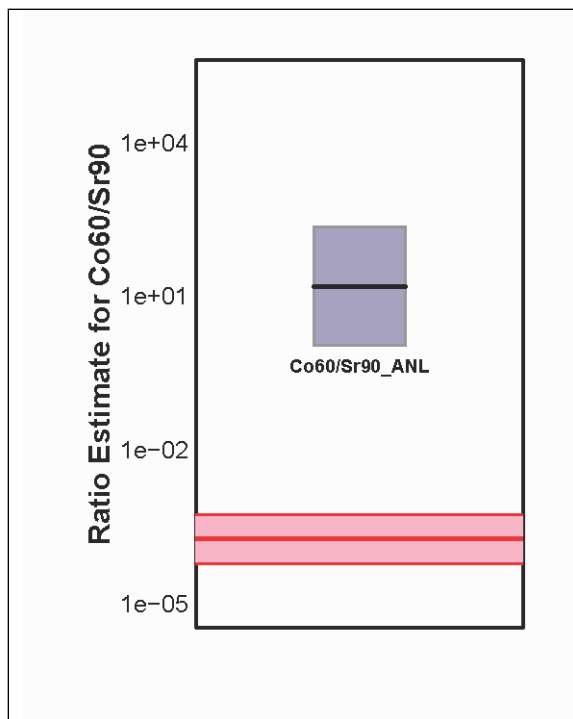


Figure 9 illustrates that the measured center estimated Ce-144/Sr-90 value, as well as the 95% confidence interval area, fell below the recommended Ce-144/Sr-90 value (with a central

estimate of the ratio from measured pairs of 0.63 compared to a recommended ratio of 12.5), with some scatter as shown in Figure 6.

Figure 10 illustrates that the measured center estimated Co-60/Sr-90 value, as well as the entire 95% confidence interval area, were well above the recommended Co-60/Sr-90 value of 1.8E-4, with considerable scatter as shown in Figure 7.

There were too few Ru-106/Sr-90 (or Ru-106/Cs-137) data pairs to allow for meaningful statistical analysis, but those that were obtained had ratio values that were scattered both below and above the recommended ratio value of 1.

Similar results were obtained for FAP/Cs-137 values.

4.0 ACTINIDE/Cs-137 VALUES

According to NIOSH's ER, the basis for assigning actinide intakes, except for special situations, is directly tied (in a constant ratio) to an indicating radionuclide (Sr-90 or Cs-137) using Table 5-22 (Sr-90 ratios) and/or Table 5-23 (Cs-137 ratios) of ORAUT-TKBS-0007-5, Revision 03. These tables are reproduced here as Figures 11 and 12.

Figure 11. Table 5-22, Actinide-to-Sr-90 Ratios (ORAUT-TKBS-0007-5, Revision 03)

Actinide	Reactor fuel types ^b			
	Al	Zr	SS	Max
Ac	8.0E-12 Ac-227	1.3E-11 Ac-227	2.3E-10 Ac-227	2.3E-10 Ac-227
Th	2.4E-08 Th-228	6.4E-08 Th-228	2.3E-07 Th-228	2.3E-07 Th-228
Pa	1.2E-10 Pa-231	1.1E-10 Pa-231	3.8E-09 Pa-231	3.8E-09 Pa-231
U	5.6E-05 U-234	6.2E-06 U-236	1.4E-03 U-234	1.4E-03 U-234
Np	3.4E-06 Np-237	3.7E-06 Np-237	6.8E-07 Np-237	3.7E-06 Np-237
Pu	8.7E-03 Pu-238	1.5E-02 Pu-238	3.7E-03 Pu-239	1.5E-02 Pu-238
Am	1.4E-04 Am-241	3.9E-06 Am-241	9.0E-08 Am-241	1.4E-04 Am-241
Cm	4.9E-05 Cm-244	1.8E-06 Cm-244	1.1E-10 Cm-242	4.9E-05 Cm-244

a. The values in this table were obtained from the MS Excel workbook titled *INEL – Actinide Ratios* (ORAUT 2009a).

b. Al = aluminum; Zr = zirconium; SS = stainless-steel; Max = maximum; The actinide isotopes to use for the dose calculations are provided below each actinide ratio; The actinide isotopes listed are the predominant alpha-emitting actinides in the source term for a given fuel type.

Figure 12. Table 5-23, Actinide-to-Cs-137 Ratios (ORAUT-TKBS-0007-5, Revision 03)

Actinide	Reactor fuel types ^b			
	Al	Zr	SS	Max
Ac	7.6E-12	1.3E-11	2.1E-10	2.1E-10
	Ac-227	Ac-227	Ac-227	Ac-227
Th	2.3E-08	6.2E-08	2.1E-07	2.1E-07
	Th-228	Th-228	Th-228	Th-228
Pa	1.2E-10	1.1E-10	3.5E-09	3.5E-09
	Pa-231	Pa-231	Pa-231	Pa-231
U	5.3E-05	6.0E-06	1.3E-03	1.3E-03
	U-234	U-236	U-234	U-234
Np	3.2E-06	3.5E-06	6.2E-07	3.5E-06
	Np-237	Np-237	Np-237	Np-237
Pu	8.3E-03	1.4E-02	3.4E-03	1.4E-02
	Pu-238	Pu-238	Pu-239	Pu-238
Am	1.3E-04	3.7E-06	8.3E-08	1.3E-04
	Am-241	Am-241	Am-241	Am-241
Cm	4.7E-05	1.7E-06	1.0E-10	4.7E-05
	Cm-244	Cm-244	Cm-242	Cm-244

a. The values in this table were obtained from the MS Excel workbook titled *INEL – Actinide Ratios* (ORAUT 2009a).

b. Al = aluminum; Zr = zirconium; SS = stainless-steel; Max = maximum; The actinide isotopes to use for the dose calculations are provided below each actinide ratio; The actinide isotopes listed are the predominant alpha-emitting actinides in the source term for a given fuel type.

Because this method involves assigning actinide intakes and doses over a long time span and many areas and operations, it results in the majority of the internal alpha dose assignments for ANL-W workers who did not have specific actinide radionuclide bioassays. Therefore, SC&A searched for measured actinide/Sr-90 and actinide/Cs-137 values to determine if the ratio values recommended in Tables 5-22 and 5-23, respectively, are applicable to DR for ANL-W workers. The major dose-contributing radionuclides in these tables are americium-241 (Am-241), plutonium-238 (Pu-238), Pu-239, uranium-234 (U-234), and U-236; therefore, these were the radionuclides searched for in this analysis (with emphases on Pu-238, Am-241, and U-234, the largest of the dose contributors). SC&A found that there were not significant entries for actinides in the waste reports until the late 1970s, and actinides were many times not included in the waste reports even in the 1970s and afterward. During the recent search of FAP monthly and annual data pairs, SC&A did not locate any additional actinide data pairs compared to those presented in the earlier progress report of July 2016 (SC&A 2016), which consisted of a total (monthly plus annual) of 15 matched pairs of measured Cs-137 and an actinide (four pairs for Am-241, three pairs for Pu-238, and eight pairs for Pu-239). These data are illustrated in Figure 13 and summarized in Table 3.

Figure 13. Measured Actinide/Cs-137 Values Compared to Ratio Values in Table 5-23 from ORAUT-TKBS-0007-5, Revision 03

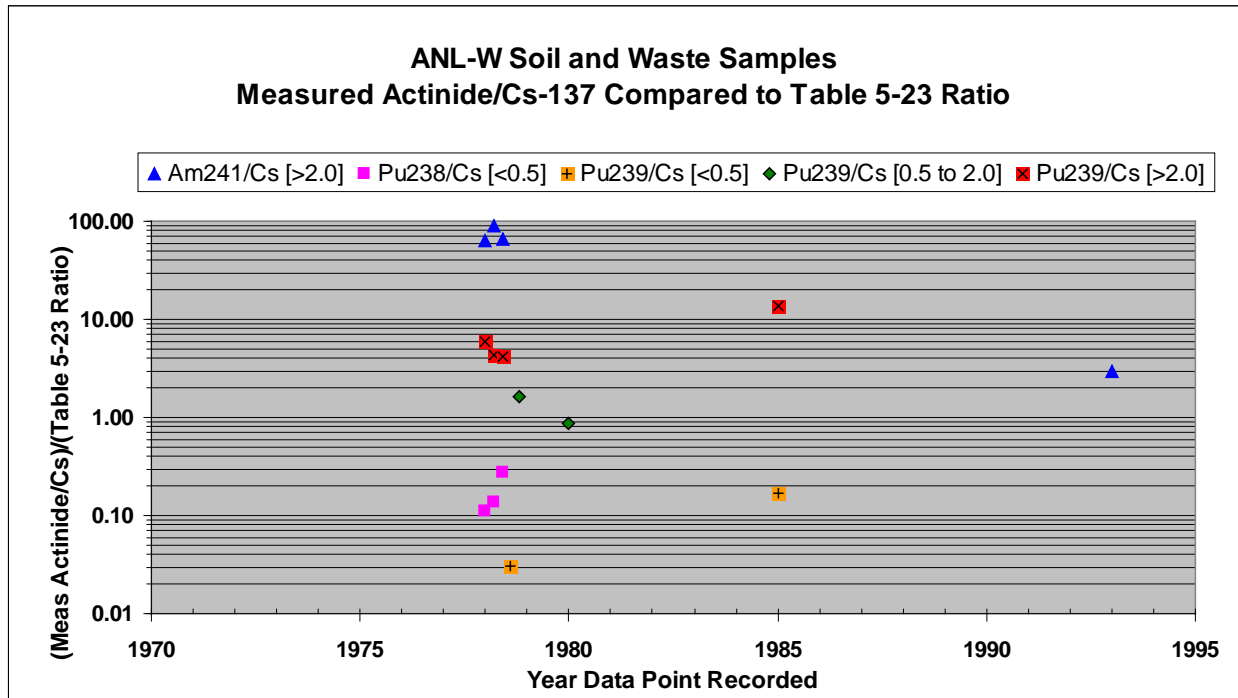


Table 3. Summary of Measured FAP/Cs-137 Values Compared to Ratio Values Recommended in Table 7-3a of ORAUT-OTIB-0054, Revision 03

Radionuclides	Recommended NIOSH Ratio (TKBS-0007-5, Tables 5-22 & 5-23 at Max.)	# of Pairs*	Type of Data (monthly or annual)	% of Pairs with Ratios <0.5	% of Pairs with Ratios 0.5–2.0	% of Pairs with Ratios >2.0	% of Pairs with Ratios <0.33	% of Pairs with Ratios 0.33–3.0	% of Pairs with Ratios >3.0
Am-241/Cs-137	1.30E-04	4	Mixed	0.0%	0.0%	100.0%	0.0%	25.0%	75.0%
Pu-238/ Cs-37	1.40E-02	3	Mixed	100.0%	0.0%	0.0%	100.0%	0.0%	0.0%
Pu-239/ Cs-37	3.40E-03	8	Mixed	25.0%	25.0%	50.0%	25.0%	25.0%	50.0%

*In this analysis, two data pair were removed from the earlier data used in the progress report of July 2016 (SC&A 2016) because recent analyses of detailed monthly data sheets indicated that the recorded Cs-137 and Sr-90 activities were exactly equal (to four significant figures) for each month, which would indicate invalid data.

SC&A did not find sufficient ANL-W quantitative actinide data to provide for meaningful statistical analysis. The data that were obtained indicate that actinide/Sr-90 and actinide/Cs-137 values vary considerably from those recommended in ORAUT-TBKS-007-5, Revision 03, Tables 5-22 and 5-23, respectively.

5.0 SUMMARY AND CONCLUSIONS

The following list summarizes the results based on the measured data points analyzed to date and SC&A's conclusions about those results:

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- **Cs-137/Sr-90** – Many of the Cs-137/Sr-90 values were not centered on unity; 32.4% of 34 monthly data points analyzed for Cs-137/Sr-90 from the 1958–1993 ANL-W waste reports fell within a range of 0.5 to 2.0, and 44.1% fell within a range of 0.33 to 3.0, of the recommended ratio of 1. Some ratio values were a magnitude above or below unity. Somewhat better results were obtained using annual data pairs because they averaged recorded monthly activity values over the year. SC&A finds that the measured Cs-137/Sr-90 values are not sufficiently constant to assume a ratio of unity. Differences in FAP intake assignments during DR for the radionuclides listed in Table 7-3 of ORAUT-OTIB-0054 could occur depending on whether Cs-137 bioassays or Sr-90 bioassays were performed.
- **FAP/Sr-90** – Analysis of a total of 35 monthly and 12 annual measured FAP/Sr-90 and FAP/Cs-137 data pairs provided the following results:
 - Ce-144: All of the measured Ce-144/Sr-90 values were below a factor of 2 of the recommended ratio value of 12.5; Ce-144/Cs-137 results were similar. Therefore, SC&A finds that the use of the recommended Ce-144 ratios is reasonable for DR purposes.
 - Co-60: All of the measured Co-60/Sr-90 and Co-60/Cs-137 values were greater than the recommended value of 1.8E-4, with many values orders of magnitude greater. Therefore, SC&A finds that the use of the recommended ratio of 1.8E-4 would result in significant underestimation of Co-60 intakes for much of the materials analyzed in this report.
 - Ru-106: There were too few Ru-106/Sr-90 (or Ru-106/Cs-137) data pairs to allow for meaningful statistical analysis, but those that were obtained had ratio values that were scattered both well below and above the recommended ratio value of 1.
 - Measured FAP ratio values could only be obtained for relatively long-lived radionuclides (Cs-137, Sr-90, Ce-144, Co-60, and Ru-106). Therefore, the actual ratio values for the shorter-lived FAPs in Table 7-3 are not known at this time for the materials analyzed.
- **Actinide ratios** – SC&A did not locate additional actinide data from those used in SC&A’s progress report of July 2016 (SC&A 2016), in which SC&A did not locate sufficient ANL-W quantitative actinide data to provide for meaningful statistical analysis. The data that were obtained indicate that actinide/Sr-90 and actinide/Cs-137 values vary considerably from those recommended in ORAUT-TBKS-007-5, Revision 03, Tables 5-22 and 5-23, respectively.
- **Use of only Sr-90 or Cs-137** – Evaluation of the data pairs and radionuclide combinations indicates that the sole use of Sr-90 or Cs-137 does not offer an advantage in consistency when assigning FAP or actinide intakes. In addition, many bioassays only analyzed for Cs-137 or Sr-90, not both.

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- **Monthly versus annual data** – Comparing the results obtained from using monthly and annual data in the ANL-W waste reports indicates that the use of annual data compared to using monthly data tends to average out the variations in the monthly recorded activity values. SC&A’s analysis in this report provides similar results as those obtained in the July 2016 progress report (SC&A 2016), which used mostly annual results.

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6.0 REFERENCES

NIOSH 2016. *SEC Petition Evaluation Report – ANL-W Petition SEC-00224 of February 18, 2016*, National Institute for Occupational Safety and Health, Division of Compensation Analysis and Support, Cincinnati, Ohio. February 18, 2016.

ORAUT 2009. *INEL-Actinide Ratios* [Microsoft Excel® workbook], Revision 0, Oak Ridge Associated Universities Team, Oak Ridge, Tennessee. December 18, 2009. [SRDB Ref. ID 77440]

ORAUT-TKBS-0007-5. 2010. *Idaho National Laboratory and Argonne National Laboratory – West – Occupational Internal Dose*, Revision 03, Oak Ridge Associated Universities Team, Cincinnati, Ohio. March 2, 2010.

ORAUT-OTIB-0054. 2007. *Fission and Activation Product Assignment for Internal Dose-Related Gross Beta and Gross Gamma Analyses*, Revision 00 PC-1, Oak Ridge Associated Universities Team, Cincinnati, Ohio. November 19, 2007.

ORAUT-OTIB-0054. 2014. *Fission and Activation Product Assignment for Internal Dose-Related Gross Beta and Gross Gamma Analyses*, Revision 02, Oak Ridge Associated Universities Team, Cincinnati, Ohio. March 6, 2014.

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SC&A 2016. *Progress Report: SC&A's Evaluation of Sr-90/Cs-137, FAP/Cs-137, and Actinides/Cs-137 Ratios Using ANL-W Measured Values in Relationship to Assigning Intakes*, SC&A, Inc., Vienna, Virginia, and Saliant, Inc., Jefferson, Maryland. July 14, 2016.

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ATTACHMENT A. DOCUMENTS AND DATA USED TO EVALUATE Cs-137/Sr-90 VALUES

SRDB Ref #	PDF Page #	Time Period	Area	Type of Waste	Units of Activity	Monthly Measured Cs-137 Activity	Monthly Measured Sr-90 Activity	Monthly Measured [Cs-137/Sr-90]	Annual Measured Cs-137 Activity	Annual Measured Sr-90 Activity	Annual Measured [Cs-137/Sr-90]
27049	16	1958	BORAX IV	Rx water	dpm/ml	No data	No data	No data	1.100E+04	4.200E+02	26.19
27049	16	1958	BORAX IV	Rx water	dpm/ml	No data	No data	No data	1.200E+04	4.840E+02	24.79
118781	2-23	1970	EBR-I	AIR filter-E	uCi/m3	3.000E-04	2.130E-04	1.41	No data	No data	No data
118781	2-23	1970	EBR-I	AIR filter-F	uCi/m3	1.000E-04	8.200E-05	1.22	No data	No data	No data
118781	2-23	1970	EBR-I	AIR filter-G	uCi/m3	1.000E-04	3.140E-05	3.18	No data	No data	No data
118781	2-23	1970	EBR-I	AIR filter-H	uCi/m3	1.000E-05	5.010E-06	2.00	No data	No data	No data
85427	7	1972	ANL_EBR-I	air	uCi/ml	No data	No data	No data	3.500E-15	2.000E-15	1.75
118781	211	1972	ANL	Air filter	uCi/cc	4.600E-15	6.000E-15	0.77	No data	No data	No data
85523	25	1972	ANL	Liquid	Ci	4.346E-04	1.413E-05	30.76	5.892E-03	4.929E-05	119.54
85523	25	1972	ANL	Liquid	Ci	7.575E-04	1.672E-05	45.31	No data	No data	No data
85523	25	1972	ANL	Liquid	Ci	3.951E-04	1.844E-05	21.43	No data	No data	No data
140037	89	1973	ANL	Liquid	Ci	5.311E-04	7.611E-06	69.78	4.360E-03	1.605E-04	27.17
140037	89	1973	ANL	Liquid	Ci	2.060E-04	6.782E-06	30.37	No data	No data	No data
140037	89	1973	ANL	Liquid	Ci	3.073E-04	2.151E-05	14.29	No data	No data	No data
140037	89	1973	ANL	Liquid	Ci	4.477E-05	1.506E-05	2.97	No data	No data	No data
140037	89	1973	ANL	Liquid	Ci	1.211E-04	1.289E-05	9.39	No data	No data	No data
85524	30	1973	ANL	Liquid	Ci	6.916E-04	2.165E-05	31.94	3.681E-03	1.028E-04	35.81
85524	30	1973	ANL	Liquid	Ci	7.685E-04	1.934E-05	39.74	No data	No data	No data
85524	30	1973	ANL	Liquid	Ci	4.884E-04	1.280E-05	38.16	No data	No data	No data
85524	30	1973	ANL	Liquid	Ci	5.342E-04	4.140E-05	12.90	No data	No data	No data
85524	30	1973	ANL	Liquid	Ci	5.310E-04	7.611E-06	69.77	No data	No data	No data
85524	771	1973	ANL	Liquid	Ci	2.060E-04	6.782E-06	30.37	4.600E-03	1.605E-04	28.66
85524	771	1973	ANL	Liquid	Ci	3.073E-04	2.151E-05	14.29	No data	No data	No data
85524	771	1973	ANL	Liquid	Ci	4.477E-05	1.506E-05	2.97	No data	No data	No data
85524	771	1973	ANL	Liquid	Ci	1.211E-04	1.289E-05	9.39	No data	No data	No data
83153	8	1978	ANL_EBR-I	soil	uCi/gm	No data	No data	None	1.100E+00	5.700E-01	1.93
83153	8	1978	ANL_EBR-I	soil	uCi/gm	No data	No data	None	1.300E+00	8.600E-01	1.51
83153	8	1978	ANL_EBR-I	soil	uCi/gm	No data	No data	None	1.070E+00	5.700E-01	1.88
118841	163	1978	ANL	Solid waste	Ci	7.037E+00	2.000E+00	3.52	1.160E+02	8.842E+01	1.31
118841	163	1978	ANL	Solid waste	Ci	5.000E+00	1.000E+00	5.00	No data	No data	No data
118841	163	1978	ANL	Solid waste	Ci	6.500E+00	1.500E+00	4.333	No data	No data	No data
118841	163	1978	ANL	Solid waste	Ci	4.400E+00	2.500E+00	1.76	No data	No data	No data
118841	165	1978	ANL	Solid waste	Ci	8.700E+01	6.200E+01	1.40	1.949E+02	1.000E+02	1.95
118841	165	1978	ANL	Solid waste	Ci	7.000E+01	3.500E+01	2.00	No data	No data	No data
118841	165	1978	ANL	Solid waste	Ci	2.000E+00	1.000E+00	2.00	No data	No data	No data
83007	33&34	1980	BORAX I	soil	pCi/gm	No data	No data	None	7.000E+00	2.500E+00	2.80
87191	190	1985	ANL	solid waste	Ci	No data	No data	None	1.876E+01	1.840E+01	1.02
87191	192	1985	ANL	Solid waste	Ci	1.000E+00	2.000E+00	0.50	3.400E+00	4.400E+00	0.77
87191	192	1985	ANL	Solid waste	Ci	2.400E+00	2.400E+00	1.00	No data	No data	No data
136493	152	1993	ANL	Solid waste	Ci	9.918E-02	2.629E-01	0.38	6.303E-01	1.188E+00	0.53
136493	152	1993	ANL	Solid waste	Ci	4.202E-01	6.361E-01	0.66	No data	No data	No data
136493	152	1993	ANL	Solid waste	Ci	1.108E-01	2.886E-01	0.38	No data	No data	No data

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ATTACHMENT B. DOCUMENTS AND DATA USED TO EVALUATE FAP/Sr-90 AND FAP/Cs-137 VALUES

Table B.1. Documents and Data Used to Evaluate Ce-144/Sr-90 and Ce-144/Cs-137 Values

SRDB Ref #	PDF Page #	Time Period	Area	Type of Waste	Units of Activity	Monthly Measured Cs-137 Activity	Monthly Measured Sr-90 Activity	Annual Measured Cs-137 Activity	Annual Measured Sr-90 Activity	Monthly Measured Ce-144 Activity	Monthly Measured [Ce-144/Sr-90]/12.5	Annual Measured Ce-144 Activity	Annual Measured [Ce-144/Sr-90]/12.5
118781	2-23	1970	EBR-I	AIR filter-E	uCi/m3	3.000E-04	2.130E-04	No data	No data	5.000E-04	0.19	No data	No data
118781	2-23	1970	EBR-I	AIR filter-F	uCi/m3	1.000E-04	8.200E-05	No data	No data	6.000E-04	0.59	No data	No data
118781	2-23	1970	EBR-I	AIR filter-G	uCi/m3	1.000E-04	3.140E-05	No data	No data	6.000E-04	1.53	No data	No data
118781	2-23	1970	EBR-I	AIR filter-H	uCi/m3	1.000E-05	5.010E-06	No data	No data	1.000E-04	1.60	No data	No data
118781	211	1972	ANL	Air filter	uCi/cc	4.600E-15	6.000E-15	No data	No data	2.300E-14	0.31	No data	No data
118841	163	1978	ANL	Solid waste	Ci	7.037E+00	2.000E+00	1.160E+02	8.842E+01	3.000E+00	0.12	8.641E+01	0.0782
118841	163	1978	ANL	Solid waste	Ci	5.000E+00	1.000E+00	No data	No data	3.000E+00	0.24	No data	No data
118841	163	1978	ANL	Solid waste	Ci	6.500E+00	1.500E+00	No data	No data	4.500E+00	0.24	No data	No data
118841	163	1978	ANL	Solid waste	Ci	4.400E+00	2.500E+00	No data	No data	3.000E+00	0.10	No data	No data
118841	165	1978	ANL	Solid waste	Ci	8.700E+01	6.200E+01	1.949E+02	1.000E+02	8.700E+01	0.11	1.625E+02	0.1300
118841	165	1978	ANL	Solid waste	Ci	7.000E+01	3.500E+01	No data	No data	7.000E+01	0.16	No data	No data
118841	165	1978	ANL	Solid waste	Ci	2.000E+00	1.000E+00	No data	No data	2.000E+00	0.16	No data	No data
87191	192	1985	ANL	Solid waste	Ci	1.000E+00	2.000E+00	3.400E+00	4.400E+00	3.000E+00	0.12	9.000E+00	0.1636
87191	192	1985	ANL	Solid waste	Ci	2.400E+00	2.400E+00	No data	No data	6.000E+00	0.20	No data	No data
136493	152	1993	ANL	Solid waste	Ci	9.918E-02	2.629E-01	6.303E-01	1.188E+00	4.328E-03	0.0013	3.087E-02	0.0021
136493	152	1993	ANL	Solid waste	Ci	4.202E-01	6.361E-01	No data	No data	2.047E-02	0.0026	No data	No data
136493	152	1993	ANL	Solid waste	Ci	1.108E-01	2.886E-01	No data	No data	6.077E-03	0.0017	No data	No data

Table B.2. Documents & Data Used to Evaluate Co-60/Sr-90 & Co-60/Cs-137 Values

SRDB Ref #	PDF Page #	Time Period	Area	Type of Waste	Units of Activity	Monthly Measured Cs-137 Activity	Monthly Measured Sr-90 Activity	Annual Measured Cs-137 Activity	Annual Measured Sr-90 Activity	Monthly Measured Co-60 Activity	Monthly Measured [Co-60/Sr-90]/1.85E-4	Annual Measured Co-60 Activity	Annual Measured [Co-60/Sr-90]/1.85E-4
118781	2-23	1970	EBR-I	AIR filter-G	uCi/m3	1.000E-04	3.140E-05	None	None	5.000E-05	8.61E+03	No data	No data
85523	25	1972	ANL	Liquid	Ci	4.346E-04	1.413E-05	5.892E-03	4.929E-05	2.354E-04	9.01E+04	2.354E-04	2.58E+04
140037	89	1973	ANL	Liquid	Ci	5.311E-04	7.611E-06	4.360E-03	1.605E-04	No data	No data	2.412E-06	8.12E-01
85524	30	1973	ANL	Liquid	Ci	6.916E-04	2.165E-05	3.681E-03	1.028E-04	No data	No data	6.678E-04	3.51E+04
85524	30	1973	ANL	Liquid	Ci	5.342E-04	4.140E-05	No data	No data	6.678E-04	8.72E+04	No data	No data
118841	163	1978	ANL	Solid waste	Ci	7.037E+00	2.000E+00	1.160E+02	8.842E+01	No data	No data	1.474E+03	9.01E+04
118841	163	1978	ANL	Solid waste	Ci	5.000E+00	1.000E+00	No data	No data	1.930E+02	1.04E+06	No data	No data
118841	163	1978	ANL	Solid waste	Ci	6.500E+00	1.500E+00	No data	No data	7.000E+01	2.52E+05	No data	No data
118841	163	1978	ANL	Solid waste	Ci	4.400E+00	2.500E+00	No data	No data	2.170E+02	4.69E+05	No data	No data
118841	165	1978	ANL	Solid waste	Ci	8.700E+01	6.200E+01	1.949E+02	1.000E+02	2.000E+00	1.74E+02	2.950E+02	1.59E+04
118841	165	1978	ANL	Solid waste	Ci	7.000E+01	3.500E+01	No data	No data	7.000E+01	1.08E+04	No data	No data
118841	165	1978	ANL	Solid waste	Ci	2.000E+00	1.000E+00	No data	No data	7.600E+01	4.11E+05	No data	No data
87191	192	1985	ANL	Solid waste	Ci	1.000E+00	2.000E+00	3.400E+00	4.400E+00	No data	No data	9.250E+02	1.14E+06
87191	192	1985	ANL	Solid waste	Ci	2.400E+00	2.400E+00	No data	No data	8.300E+01	1.87E+05	No data	No data
136493	152	1993	ANL	Solid waste	Ci	9.918E-02	2.629E-01	6.303E-01	1.188E+00	6.505E+03	1.34E+08	6.557E+04	2.98E+08
136493	152	1993	ANL	Solid waste	Ci	4.202E-01	6.361E-01	No data	No data	1.389E-01	1.18E+03	No data	No data
136493	152	1993	ANL	Solid waste	Ci	1.108E-01	2.886E-01	No data	No data	2.921E-02	5.47E+02	No data	No data

Table B.3. Documents and Data Used to Evaluate Ru-106/Sr-90 and Ru-106/Cs-137 Values

SRDB Ref #	PDF Page #	Time Period	Area	Type of Waste	Units of Activity	Monthly Measured Cs-137 Activity	Monthly Measured Sr-90 Activity	Annual Measured Cs-137 Activity	Annual Measured Sr-90 Activity	Monthly Measured Ru-106 Activity	Monthly Measured [Ru-106/Sr-90]	Annual Measured Ru-106 Activity	Annual Measured [Ru-106/Sr-90]
118781	2-23	1970	EBR-I	AIR filter-E	uCi/m3	3.000E-04	2.130E-04	None	None	3.000E-04	1.408	No data	No data
118781	2-23	1970	EBR-I	AIR filter-F	uCi/m3	1.000E-04	8.200E-05	None	None	2.000E-05	0.244	No data	No data
118781	2-23	1970	EBR-I	AIR filter-G	uCi/m3	1.000E-04	3.140E-05	None	None	3.000E-04	9.554	No data	No data
118781	2-23	1970	EBR-I	AIR filter-H	uCi/m3	1.000E-05	5.010E-06	None	None	4.000E-05	7.984	No data	No data
136493	152	1993	ANL	Solid waste	Ci	9.918E-02	2.629E-01	6.303E-01	1.188E+00	1.793E-04	6.81E-4	1.793E-04	1.51E-4

NOTICE: This report has been reviewed to identify and redact any information that is protected by the Privacy Act 5 U.S.C. § 552a and has been cleared for distribution.

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ATTACHMENT C. DOCUMENTS AND DATA USED TO EVALUATE ACTINIDE/Cs-137 AND ACTINIDE/Sr-90 VALUES

Table C.2. Documents and Data Used to Evaluate Am-241/Cs-137 and Am-241/Sr-90 Values

SRDB Ref #	PDF #	Time Period	Area	Type of Sample	Type of Data	Measured Cs-137 Activity	Units	Measured Am-241 T1/2=433y Activity	(Am-241/Cs-137)	OTIB-54 (Am-241/Cs-137) Ratio	[Meas. Am241/Cs-137/ (1.3E-4)]
83153	8	1978	ANL_EBR-1	soil	One sample	1.10E+00	pCi/g	9.00E-03	8.18E-03	1.30E-04	62.94
83153	8	1978	ANL_EBR-1	soil	One sample	1.30E+00	pCi/g	1.50E-02	1.15E-02	1.30E-04	88.76
136493	152	1993	ANL	solid waste	Monthly	4.20E-01	Ci	1.63E-04	3.88E-04	1.30E-04	2.99
83153	8	1978	ANL_EBR-1	soil	One sample	1.07E+00	pCi/g	9.00E-03	8.41E-03	1.30E-04	64.70

Table C.1. Documents and Data Used to Evaluate Pu-238/Cs-137 and Pu-238/Sr-90 Values

SRDB Ref #	PDF #	Time Period	Area	Type of Sample	Type of Data	Measured Cs-137 Activity	Units	Measured Pu-238 T1/2=88y Activity	(Pu-238/Cs-137)	OTIB-54 (Pu-238/Cs-137) ratio	[Meas. Pu238/Cs-137/(1.4E-2)]
83153	8	1978	ANL_EBR-1	soil	One sample	1.10E+00	pCi/g	1.70E-03	1.55E-03	1.40E-02	0.11
83153	8	1978	ANL_EBR-1	soil	One sample	1.30E+00	pCi/g	2.50E-03	1.92E-03	1.40E-02	0.14
83153	8	1978	ANL_EBR-1	soil	One sample	1.07E+00	pCi/g	4.10E-03	3.83E-03	1.40E-02	0.27

Table C.3. Documents and Data Used to Evaluate Pu-239/Cs-137 and Pu-239/Sr-90 Values

SRDB Ref #	PDF #	Time Period	Area	Type of Sample	Type of Data	Measured Cs-137 Activity	Units	Measured Pu-239 T1/2=2.4E4y Activity	(Pu-239/Cs-137)	OTIB-54 (Pu-239/Cs-137) Ratio	[Meas. Pu239/Cs-137/(3.4E-3)]
87191	190	1985	ANL	solid waste	Annual	1.88E+01	Ci	1.09E-02	5.79E-04	3.40E-03	0.17
87191	192	1985	ANL	solid waste	Annual	3.40E+00	Ci	1.61E-01	4.73E-02	3.40E-03	13.92
83153	8	1978	ANL_EBR-1	soil	One sample	1.10E+00	pCi/g	2.20E-02	2.00E-02	3.40E-03	5.88
83153	8	1978	ANL_EBR-1	soil	One sample	1.30E+00	pCi/g	1.90E-02	1.46E-02	3.40E-03	4.30
83153	8	1978	ANL_EBR-1	soil	One sample	1.07E+00	pCi/g	1.50E-02	1.40E-02	3.40E-03	4.12
118841	163	1978	ANL	solid waste	Annual	1.16E+02	Ci	1.19E-02	1.02E-04	3.40E-03	0.03
118841	165	1978	ANL	solid waste	Annual	1.95E+02	Ci	1.07E+00	5.49E-03	3.40E-03	1.61
83007	34&35	1980	BORAX I	soil	One sample	7.00E+00	pCi/g	2.10E-02	3.00E-03	3.40E-03	0.88