MEMORANDUM

TO: INL Work Group
FROM: SC&A, Inc.
DATE: July 14, 2016
SUBJECT: 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

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Executive Summary

In the National Institute for Occupational Safety and Health's (NIOSH's) *SEC Petition Evaluation Report*) – *ANL-W 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 activation product (FAP) and actinide (alpha emitter) intakes using the ratio method. This method requires that radionuclide ratios remain fairly constant for the various functions and locations, and over most of the operating history of the Argonne National Laboratory-West (ANL-W). One of the key cornerstones of the recommended ratio methodology is that the Sr-90/Cs-137 values be centered on unity (i.e., ratio values of 1.0).

As SC&A outlined in a previous report concerning the Idaho National Laboratory (INL), *SC&A's Evaluation of Cs-137/Sr-90 Values and Actinides Using INL Waste Reports in Relationship to Assigning Intakes* (SC&A 2016), SC&A found indications that the Sr-90/Cs-137, FAPs/Cs-137, and actinide/Cs-137 values from the INL data are, in many situations, significantly different than the ratio values recommended in ORAUT-OTIB-0054, *Fission and Activation Product Assignment for Internal Dose-Related Gross Beta and Gross Gamma* Analyses (ORAUT 2015), and ORAUT-TKBS-0007-5, *Idaho National Laboratory and Argonne National Laboratory – West – Occupational Internal Dose* (ORAUT 2010), Tables 5-22 and 5-23. Therefore, in view of this and ANL-W's numerous types of reactors, experimental charter, and the various fuel handling methods, SC&A began a preliminary analysis of some of the available ANL-W air, liquid, solid, soil, and swipe data to obtain an indication of the validity of the ratio values recommended in ORAUT-OTIB-0054 and ORAUT-TKBS-0007-5, Tables 5-22 and 5-23.

SC&A searched the Site Research Database (SRBD), references listed in the National Institute for Occupational Safety and Health's (NIOSH's) evaluation report (ER) for ANL-W, NIOSH's ANL-W ER references on the Advisory Board on Radiation and Worker Health (ABRWH) server and some NIOSH OCAS Claims Tracking System (NOCTS) claims for documents that could provide quantitative radionuclide data. During this search, SC&A located some ANL-W documents that contained quantitative Sr-90 and Cs-137 measurements performed on the same samples (some also contained FAP and actinide analyses in conjunction with the Cs-137 analyses). These samples included air, soil, liquid and solid waste, swipes, reactor water, and particle collection. Several of these documents span a reasonable time period (1958–1993) and were from some of the major operational areas within ANL-W (e.g., Experimental Breeder Reactor-I (EBR-I), EBR-II, Boiling Water Reactor Experiment (BORAX), Hot Fuel Examination Facility (HFEF), and the ANL-W site in general).

Quantitative radionuclide data from these samples at the ANL-W facilities provide an indication of the potential ratio of the radionuclide intake exposures to workers and will help in determining if further investigation is needed. Therefore, these data were analyzed in detail to evaluate if there is a reasonably consistent relationship between the Sr-90/Cs-137 concentrations, and if these indicating radionuclides could be used to assign other radionuclide intakes, such as FAPs, for dose reconstruction (DR) purposes. In addition, quantitative actinide data in relationship to Cs-137 were analyzed when available.

Sr-90/Cs-137
To date, SC&A has found that quantitative radionuclide data for ANL-W are not very plentiful. However, a total of 16 matched pairs of measured Sr-90 and Cs-137 activities were located and analyzed, spanning the period 1972–1989, for EBR-I, BORAX, and the ANL-W site in general. Of these 16 matched pairs, 11 pairs (69%) contained Sr-90/Cs-137 values centered on unity, within a factor of 2 (i.e., Sr-90/Cs-137 = 0.5 to 2.0). The remaining Sr-90/Cs-137 values were outside this interval, with values ranging from 0.04 to 19.

FAP/Cs-137
A total of 14 matched pairs of measured Cs-137 and a FAP (cobalt-60 [Co-60], Cs-134, or cerium-144 [Ce-144]) activity were located and analyzed, spanning the period 1970–1995, for EBR-I, EBR-II, BORAX, and the ANL-W site in general. The measured FAP/Cs-137 values were compared to the FAP/Cs-137 values recommended in Table 7-3 of ORAUT-OTIB-0054 (ORAUT 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 14 matched pairs, 2 pairs (14%) contained FAP/Cs-137 values centered on unity, within a factor of 2 (i.e., FAP/Cs-137 = 0.5 to 2.0). The remaining FAP/Cs-137 values were outside this interval, some ranging orders of magnitude away from unity.

In addition, 98 matched pairs of measured Ce-144 and Cs-137 swipes and particle activity samples for the period 1972–1974 from the HFEF Air Cell and Argon Cell were located and analyzed. The measured Ce-144/Cs-137 values were compared to the Ce-144/Cs-137 values recommended in Table 7-3 of ORAUT-OTIB-0054 (ORAUT 2015), with one-year decay. Of these 98 matched pairs, 1 pair (1%) contained Ce-144/Cs-137 values centered on unity, within a factor of 2 (i.e., FAP/Cs-137 = 0.5 to 2.0). All the remaining Ce-144/Cs-137 values were less than 0.5, with the lowest being 0.004.

Actinides/Cs-137
A total of 17 matched pairs of measured Cs-137 and an actinide (americium-241 [Am-241], plutonium-238 [Pu-238], or Pu-239) activity during the period 1974–1993 were located and analyzed for EBR-I, BORAX, and the ANL-W site in general. The measured actinide/Cs-137 values were compared to the actinide/Cs-137 values recommended in Table 5-23 of ORAUT-TKBS-0007-5 (ORAUT 2010). Of these 17 matched pairs, 3 pairs (18%) contained actinide/Cs-137 values centered on unity, within a factor of 2 (i.e., actinide/Cs-137 = 0.5 to 2.0). The remaining actinide/Cs-137 values were outside this interval; ranging from 0.03 to 89.

Conclusions

These results indicate that while the ANL-W Sr-90/Cs-137 values were more centered around unity (69% of 16 pairs) than those for INL (33% of 251 pairs), the limited number of data points for ANL-W that have been located to date is not sufficient to provide for complete analysis for the time span and varied operations for the numerous facilities at ANL-W. Also, the FAP/Cs-137 values and the actinide/Cs-137 values may not be sufficiently constant (or known) for assigning intakes, even in situations where it can be assumed that the FAP or actinide is tied to an indicating radionuclide, such as Cs-137. These preliminary results are indicative of a potential issue; however, only a very limited number of measured values have been located; additional quantitative data need to be located and analyzed to further evaluate the issue.

Introduction and Background

NIOSH responded to the ANL-W SEC-00224 in an ER of February 18, 2016 (NIOSH 2016). In that ER, and also in the technical basis document (TBD) for ANL-W, ORAUT-TKBS-0007-5, NIOSH's basis for assigning internal intakes/doses for most years and locations at the ANL-W (except those covered by NIOSH's proposed Special Exposure Cohort [SEC], or claimants who had specific radionuclide bioassays) relies on the important assumptions that (1) the Sr-90/Cs-137 values are approximately unity, (2) FAPs are directly tied by a known ratio to Sr-90 or Cs-137 (as per ORAUT-OTIB-0054), and (3) 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).

As SC&A outlined in a previous report concerning INL (SC&A 2016), SC&A found indications that the Sr-90/Cs-137, FAPs/Cs-137, and actinide/Cs-137 values from the INL data are, in many situations, significantly different than the ratio values recommended in ORAUT-OTIB-0054 and ORAUT-TKBS-0007-5, Tables 5-22 and 5-23. Therefore, in view of this and ANL-W's numerous types of reactors, experimental charter, and the various fuel handling methods, SC&A began a preliminary analysis of some of the available ANL-W air, liquid, solid, soil, and swipe data to obtain an indication of the validity of the ratio values recommended in ORAUT-OTIB-0054 and ORAUT-TKBS-0007-5, Tables 5-22 and 5-23. In this evaluation, relatively long-lived (half-life of approximately 1 year or more) radionuclides were selected for analyses, so that the relative ratios would not be significantly dependent upon variations in the time after production to time of exposure.

SC&A searched the SRBD, references listed in NIOSH's ER for ANL-W, NIOSH's ANL-W ER references on the ABRWH server and some NOCTS claims for documents that could provide quantitative radionuclide data. During this search, SC&A located some ANL-W documents that contained quantitative Sr-90 and Cs-137 measurements performed on the same samples (some also contained FAP and actinide analyses in conjunction with the Cs-137 analyses). These samples included air, soil, liquid and solid waste, swipes, reactor water, and particle collection. Several of these documents span a reasonable time period (1958–1993) and were from some of the major operational areas within ANL-W (e.g., EBR-I, EBR-II, BORAX, HFEF, and the ANL-W site in general).

Quantitative radionuclide data from these samples at the ANL-W facilities provide an indication of the potential ratio of the radionuclide intake exposures to workers, and if further investigation

is needed. Therefore, these data were analyzed in detail to evaluate if there is a reasonably consistent relationship between the Sr-90/Cs-137 concentrations, and if these indicating radionuclides could be used to assign other radionuclide intakes, such as FAPs, for DR purposes. In addition, quantitative actinide data in relationship to Cs-137 were analyzed when available. The analyses in this report used Cs-137 as the main indicating radionuclide (i.e., xx/Cs-137 ratios), because there were more matched pairs of data that contained Cs-137 results than Sr-90 results.

Tables containing the source document SRDB reference numbers and the radionuclide data that were used in this evaluation are provided in Attachment A of this memo. The color of the symbols in the figures is correlated with the color of the numerical value of the data in the tables. Analyzes of these data are provided in the following sections.

Sr-90/Cs-137 Values

NIOSH's ER and ORAUT-TKBS-0007-5 (ORAUT 2010) rely heavily on the use of ORAUT-OTIB-0054 (ORAUT 2015) to assign FAP intakes using Sr-90 or Cs-137 as the indicating radionuclide for numerous other FAP radionuclides at ANL-W for most locations and time periods. An example of Table 7-3a from ORAUT-OTIB-0054 is provided here as Figure 1. As can be seen from this table, assignment of FAP intakes is dependent on the Sr-90/Cs-137 value being approximately 1.0.

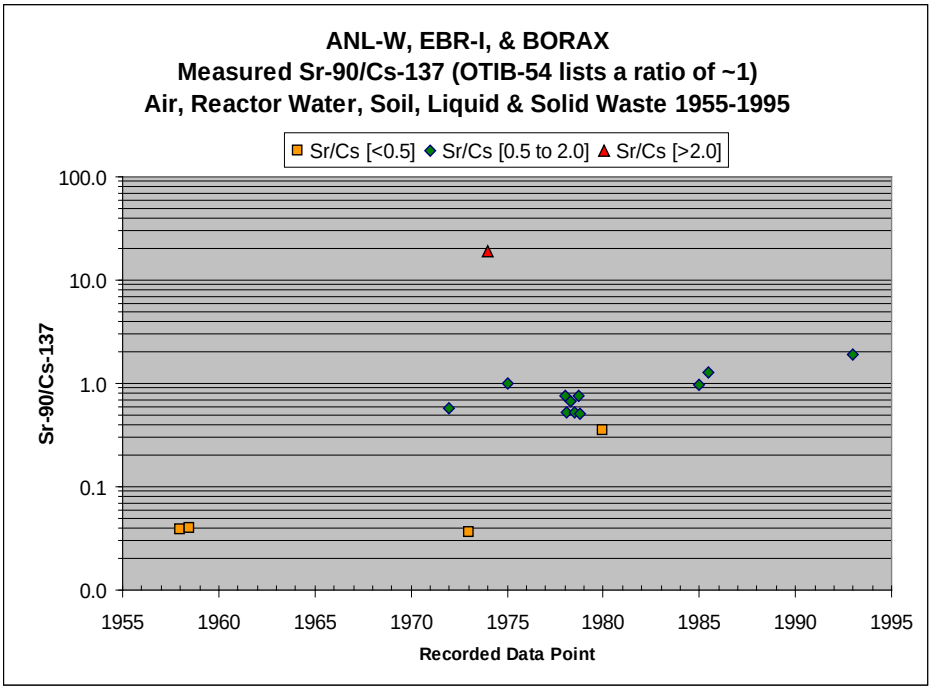
Figure 1. Table 7-3a. FAP-to-Sr-90 or -Cs-137 Ratios for ATR-1 (ORAUT-OTIB-0054)

Table 7-3a. Associated radionuclide activity fractions for assigning intakes: ATR 1.

Table 7-3 values: ATR 1									
	Intake relative to Sr-90					Intake relative to Cs-137			
Nuclide	10 d	40 d	180 d	1 y	Nuclide	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

To date, SC&A has found that quantitative radionuclide data for ANL-W are not very plentiful. However, a total of 16 matched pairs of measured Sr-90 and Cs-137 activities were located and analyzed, spanning the period 1972–1989, for EBR-I, BORAX, and the ANL-W site in general. Of these 16 matched pairs, 11 pairs (69%) contained Sr-90/Cs-137 values centered on unity, within a factor of 2 (i.e., Sr-90/Cs-137 = 0.5 to 2.0). The remaining Sr-90/Cs-137 values were outside this interval, with values ranging from 0.04 to 19. The results of this analysis are summarized in Table A-1 of Attachment A and illustrated here in Figure 2.

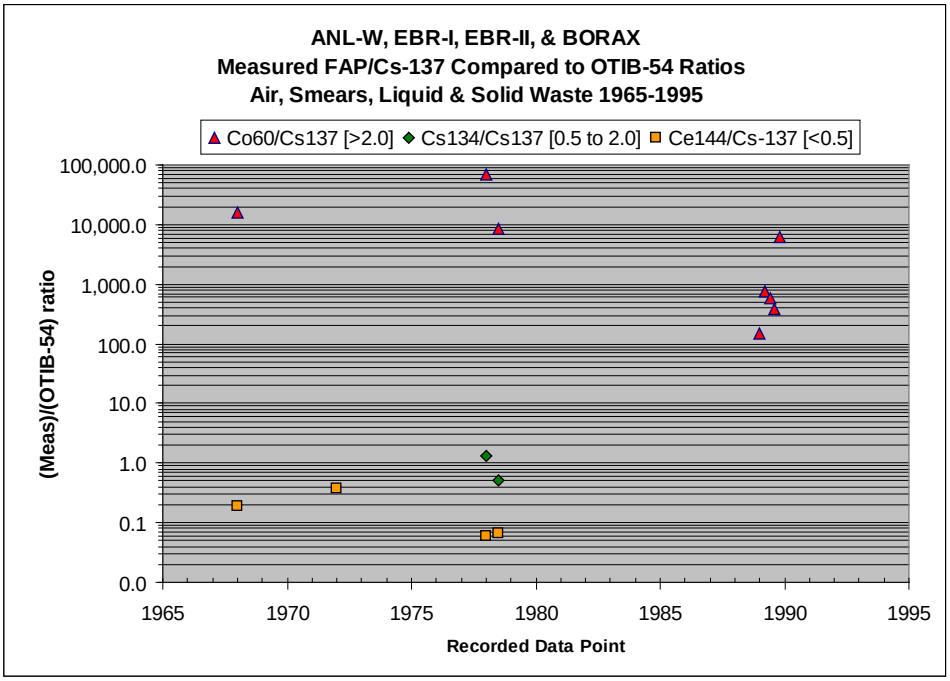
Figure 2. Sr-90/Cs-137 Values for 16 Data Pairs from ANL-W Documents



FAP/Cs-137 Values

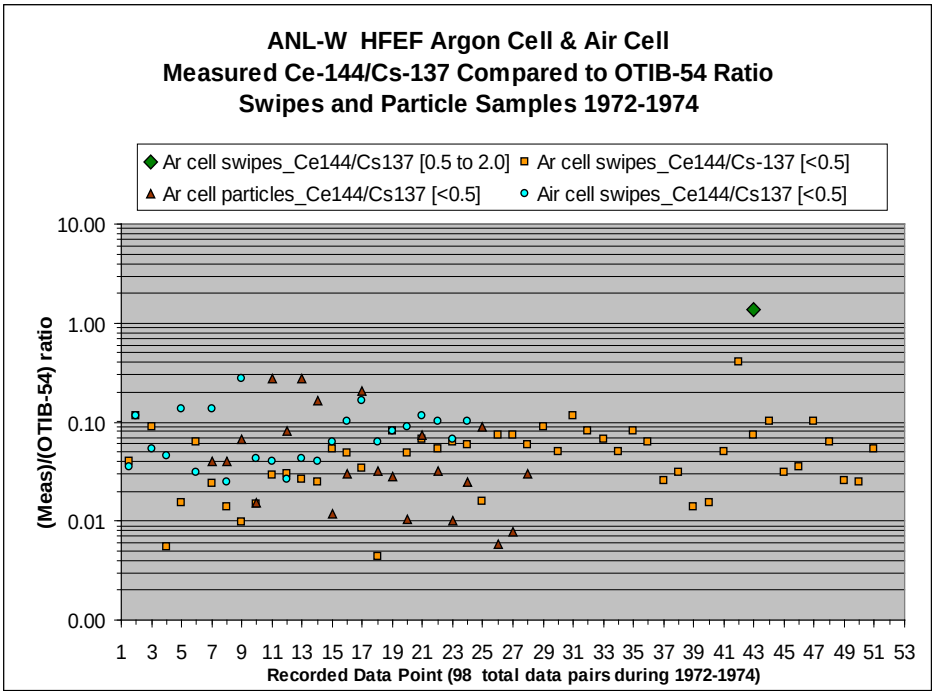
A total of 14 matched pairs of measured Cs-137 and a FAP (Co-60, Cs-134, or Ce-144) activity were located and analyzed; spanning the period 1970–1995 for EBR-I, EBR-II, BORAX, and the ANL-W site in general. The measured FAP/Cs values were compared to the FAP/Cs-137 values recommended in Table 7-3 of ORAUT-OTIB-0054 (ORAUT 2015), with one-year decay, which would likely be representative of the time from production to worker exposure for these samples. 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 dose reconstruction. Of these 14 matched pairs, 2 pairs (14%) contained FAP/Cs-137 values centered on unity, within a factor of 2 (i.e., FAP/Cs-137 = 0.5 to 2.0). The remaining FAP/Cs-137 values were outside this interval, some ranging orders of magnitude away from unity. The results of this analysis are summarized in Tables A-2, A-3, and A-4 of Attachment A and illustrated here in Figure 3.

Figure 3. FAP/Cs-137 Values for 14 Data Pairs from ANL-W Documents



In addition, 98 matched pairs of measured Ce-144 and Cs-137 swipes and particle activity samples for the period 1972–1974 from the HFEF Air Cell and Argon Cell were located and analyzed. The measured Ce-144/Cs-137 values were compared to the Ce-144/Cs-137 values recommended in Table 7-3 of ORAUT-OTIB-0054 (ORAUT 2015), with one-year decay. 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, Ce-144 intake assignments during dose reconstruction. Of these 98 matched pairs, 1 pair (1%) contained Ce-144/Cs-137 values centered on unity, within a factor of 2 (i.e., FAP/Cs-137 = 0.5 to 2.0). All the remaining Ce-144/Cs-137 values were less than 0.5, with the lowest being 0.004. The results of this analysis are summarized in Table A-5 of Attachment A and illustrated here in Figure 4.

Figure 4. Ce-144/Cs-137 Values for 98 Data Pairs from ANL-W HFEF Documents



Actinides/Cs-137 Values

A total of 17 matched pairs of measured Cs-137 and an actinide (Am-241, Pu-238, or Pu-239) activity during the period 1974–1993 were located and analyzed for EBR-I, BORAX, and the ANL-W site in general. The measured actinide/Cs-137 values were compared to the actinide/Cs-137 values recommended in Table 5-23 of ORAUT-TKBS-0007-5 (ORAUT 2010). Table 5-23 is reproduced here as Figure 5.

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

Table 5-23. Actinide-to-Cs-137 ratios.[a]

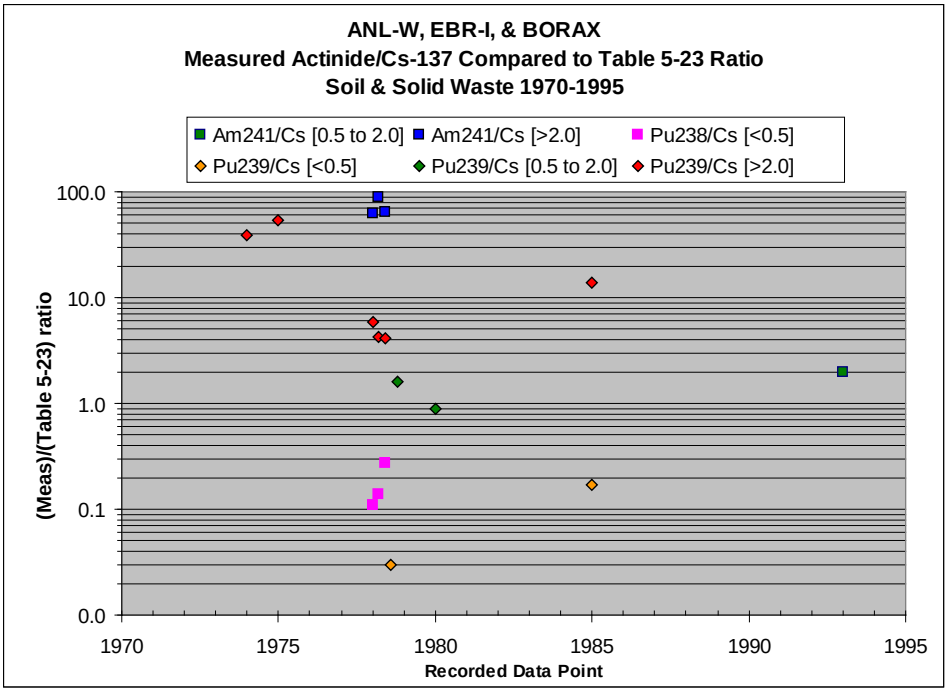
Actinide	Reactor fuel types[b]			
	Al	Zr	SS	Max
Ac	7.6E-12 Ac-227	1.3E-11 Ac-227	2.1E-10 Ac-227	2.1E-10 Ac-227
Th	2.3E-08 Th-228	6.2E-08 Th-228	2.1E-07 Th-228	2.1E-07 Th-228
Pa	1.2E-10 Pa-231	1.1E-10 Pa-231	3.5E-09 Pa-231	3.5E-09 Pa-231
U	5.3E-05 U-234	6.0E-06 U-236	1.3E-03 U-234	1.3E-03 U-234
Np	3.2E-06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

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, actinide intake assignments during dose reconstruction. Of these 17 matched pairs, 3 pairs (18%) contained actinide/Cs-137 values centered on unity, within a factor of 2 (i.e., actinide/Cs-137 = 0.5 to 2.0). The remaining actinide/Cs-137 values were outside this interval, ranging from 0.03 to 89. The results of this analysis are summarized in Tables A-6, A-7, and A-8 of Attachment A and illustrated here in Figure 6.

Figure 6. Actinide/Cs-137 Values for 17 Data Pairs from ANL-W Documents



Summary and Conclusions

This investigation indicates that from the limited measured data points analyzed to date:

- The ANL-W Sr-90/Cs-137 values were more centered around unity (69% of 16 pairs) than those for INL (33% of 251 pairs), but that the limited number of data points for ANL-W that have been located to date are not sufficient to provide for complete analysis for the time span and varied operations for the numerous facilities at ANL-W.

- The FAP/Cs-137 values (as required by ORAUT-OTIB-0054 for assigning FAP intakes) may not be sufficiently constant (or known) for assigning intakes, even in situations where it can be assumed that the FAP is tied to an indicating radionuclide, such as Cs-137.

- The actinide/Cs-137 values (as required by ORAUT-TKBS-0007-5, Table 5-23, for assigning actinide intakes) may not be sufficiently constant (or known) for assigning actinide intakes, even in situations where it can be assumed that the actinide is tied to an indicating radionuclide, such as Cs-137.

These preliminary results are indicative of a potential issue; however, only a very limited number of measured values have been located; additional quantitative radionuclide data need to be located and analyzed to further evaluate the issue.

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

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

ORAUT 2015. *Fission and Activation Product Assignment for Internal Dose-Related Gross Beta and Gross Gamma Analyses*, ORAUT-OTIB-0054, Revision 03, Oak Ridge Associated Universities Team, Cincinnati, Ohio. February 6, 2015.

SC&A 2016. *SC&A's Evaluation of Cs-137/Sr-90 Values and Actinides Using INL Waste Reports in Relationship to Assigning Intakes*, SC&A, Inc., Vienna, Virginia, and Saliant, Inc., Jefferson, Maryland. June 24, 2016.

Attachment A: Documents and Data Used in Evaluation

Table A-1. Summary of Data from SRBD Documents for Sr-90/Cs-137 Values

SRDB Ref. ID	PDF #	Time period	Area	Type of sample	Measured Sr-90 T1/2=29y activity	Measured Cs-137 T1/2=30y activity	Units	(Sr-90/ Cs-137)
140037	89	1973	ANL	liq waste	5.80E-07	1.58E-05	uCi/ml	0.04
140039	118	1974	ANL	solid waste	1.48E+02	7.876	Ci	**18.78**
140040	153	1975	ANL	solid waste	3.98E+01	3.98E+01	Ci	1.00
118841	163	1978	ANL	solid waste	8.84E+01	1.16E+02	Ci	0.76
87191	190	1985	ANL	solid waste	1.84E+01	1.88E+01	Ci	0.98
87191	192	1985	ANL	solid waste	4.4	3.4	Ci	1.29
136493	152	1993	ANL	solid waste	1.188	6.30E-01	Ci	1.88
83153	9	1978	ANL-EBR-I	soil	0.57	1.10	pCi/g	0.52
83153	9	1978	ANL-EBR-I	soil	0.86	1.30	pCi/g	0.66
83153	9	1978	ANL-EBR-I	soil	0.57	1.07	pCi/g	0.53
85427	7	1972	ANL-EBR-I	air	2.00E-15	3.50E-15	uCi/ml	0.57
118841	163	1978	ANL	solid waste	8.84E+01	1.16E+02	Ci	0.762
118841	165	1978	ANL	stored waste	1.00E+02	1.95E+02	Ci	0.513
27049	16	1958	BORAX IV	Rx water	420	1.10E+04	dpm/ml	0.038
27049	16	1958	BORAX IV	Rx water	484	1.20E+04	dpm/ml	0.040
83007	33&34	1980	BORAX I	soil	2.5	7.0	pCi/g	0.357

Table A-2. Summary of Data from SRBD Documents for Co-60/Cs-137 Values

SRDB Ref. ID	PDF #	Time period	Area	Type of sample	Measured Cs-137 activity	Units	Measured Co-60 T1/2=5.3y activity	(Co-60/ Cs-137)	OTIB-54 (Co-60/ Cs-137) ratio	Co-60/ Cs-137 (Meas/ OTIB-54)
87585	18	1968	ANL-EBR-II	liq waste	8.8	% act	25.5	2.90E+00	1.83E-04	**15,835**
118841	163	1978	ANL	solid waste	1.16E+02	Ci	1.47E+03	1.27E+01	1.83E-04	**69,437**
118841	165	1978	ANL-Borax	stored waste	1.95E+02	Ci	2.95E+02	1.51E+00	1.83E-04	**8,271**
83008	7	1989	ANL-Borax	smears	4.59E-04	uCi/sample	1.25E-05	2.72E-02	1.83E-04	**149**
83008	8	1989	ANL-Borax	smears	1.85E-05	uCi/sample	2.62E-06	1.42E-01	1.83E-04	**774**
83008	9	1989	ANL-Borax	smears	6.33E-05	uCi/sample	6.86E-06	1.08E-01	1.83E-04	**592**
83008	10	1989	ANL-Borax	smears	2.71E-04	uCi/sample	1.90E-05	7.00E-02	1.83E-04	**382**
83008	11	1989	ANL-Borax	smears	4.34E-05	uCi/sample	4.95E-05	1.14E+00	1.83E-04	**6,233**

Table A-3. Summary of Data from SRBD Documents for Cs-134/Cs-137 Values

SRDB Ref. ID	PDF #	Time period	Area	Type of sample	Measured Cs-137 activity	Units	Measured Cs-134 T1/2=2.3y activity	(Cs-134/ Cs-137)	OTIB-54 (Cs-134/ Cs-137) ratio	Cs-134/ Cs-137 (Meas/ OTIB-54)
118841	163	1978	ANL	solid waste	1.16E+02	Ci	8.57E+01	7.39E-01	0.546	1.35
118841	165	1978	ANL-Borax	stored waste	1.95E+02	Ci	5.32E+01	2.73E-01	0.546	0.50

Table A-4. Summary of Data from SRBD Documents for Ce-144/Cs-137 Values

SRDB Ref. ID	PDF #	Time period	Area	Type of sample	Measured Ce-144 activity	Units	Measured Ce-144 T1/2=282d activity	(Ce-144/ Cs-137)	OTIB-54 (Ce-144/ Cs-137) ratio	Ce-144/ Cs-137 (Meas/ OTIB-54)
87585	18	1968	ANL-EBR-II	liq waste	8.8	% act	20.0	2.27E+00	12.3	0.18
85427	7	1972	ANL-EBR-I	air	2.00E-15	uCi/ml	1.60E-14	4.57E+00	12.3	0.37
118841	163	1978	ANL	solid waste	1.16E+02	Ci	8.64E+01	7.45E-01	12.3	0.06
118841	165	1978	ANL-Borax	stored waste	1.95E+02	Ci	1.63E+02	8.34E-01	12.3	0.07

Table A-5. Summary of Data from SRBD Documents for HFEF Ce-144/Cs-137 Values

SRDB Ref. ID	PDF #	Time period	Area	Type of sample	Recorded (Cs-137/ Ce-144)	(Ce-144/ Cs-137)	OTIB-54 (Ce-144/ Cs-137) ratio	Ce-144/ Cs-137 (Meas/ OTIB-54)
80575	41	1974	HFEF Ar cell	swipe	0.06	16.67	12.3	1.36
80575	40	1972	HFEF Ar cell	swipe	2.00	0.50	12.3	0.04
80575	40	1972	HFEF Ar cell	swipe	0.70	1.43	12.3	0.12
80575	40	1972	HFEF Ar cell	swipe	0.90	1.11	12.3	0.09
80575	40	1972	HFEF Ar cell	swipe	14.70	0.07	12.3	0.01
80575	40	1972	HFEF Ar cell	swipe	5.30	0.19	12.3	0.02
80575	40	1972	HFEF Ar cell	swipe	1.30	0.77	12.3	0.06
80575	40	1973	HFEF Ar cell	swipe	3.40	0.29	12.3	0.02
80575	40	1973	HFEF Ar cell	swipe	5.90	0.17	12.3	0.01
80575	40	1973	HFEF Ar cell	swipe	8.20	0.12	12.3	0.01
80575	40	1973	HFEF Ar cell	swipe	5.50	0.18	12.3	0.01
80575	40	1973	HFEF Ar cell	swipe	2.80	0.36	12.3	0.03
80575	40	1973	HFEF Ar cell	swipe	2.70	0.37	12.3	0.03
80575	40	1973	HFEF Ar cell	swipe	3.10	0.32	12.3	0.03
80575	40	1973	HFEF Ar cell	swipe	3.30	0.30	12.3	0.02
80575	40	1973	HFEF Ar cell	swipe	1.50	0.67	12.3	0.05
80575	40	1973	HFEF Ar cell	swipe	1.70	0.59	12.3	0.05
80575	40	1973	HFEF Ar cell	swipe	2.40	0.42	12.3	0.03
80575	40	1973	HFEF Ar cell	swipe	18.30	0.05	12.3	0.004
80575	40	1973	HFEF Ar cell	swipe	1.00	1.00	12.3	0.08
80575	40	1973	HFEF Ar cell	swipe	1.70	0.59	12.3	0.05
80575	40	1973	HFEF Ar cell	swipe	1.20	0.83	12.3	0.07
80575	40	1973	HFEF Ar cell	swipe	1.50	0.67	12.3	0.05
80575	40	1973	HFEF Ar cell	swipe	1.30	0.77	12.3	0.06
80575	41	1973	HFEF Ar cell	swipe	1.40	0.71	12.3	0.06
80575	41	1973	HFEF Ar cell	swipe	5.20	0.19	12.3	0.02
80575	41	1973	HFEF Ar cell	swipe	1.10	0.91	12.3	0.07
80575	41	1973	HFEF Ar cell	swipe	1.10	0.91	12.3	0.07
80575	41	1973	HFEF Ar cell	swipe	1.40	0.71	12.3	0.06
80575	41	1973	HFEF Ar cell	swipe	0.90	1.11	12.3	0.09
80575	41	1973	HFEF Ar cell	swipe	1.60	0.63	12.3	0.05
80575	41	1973	HFEF Ar cell	swipe	0.70	1.43	12.3	0.12
80575	41	1973	HFEF Ar cell	swipe	1.00	1.00	12.3	0.08
80575	41	1973	HFEF Ar cell	swipe	1.20	0.83	12.3	0.07
80575	41	1973	HFEF Ar cell	swipe	1.60	0.63	12.3	0.05

SRDB Ref. ID	PDF #	Time period	Area	Type of sample	Recorded (Cs-137/ Ce-144)	(Ce-144/ Cs-137)	OTIB-54 (Ce-144/ Cs-137) ratio	Ce-144/ Cs-137 (Meas/ OTIB-54)
80575	41	1973	HFEF Ar cell	swipe	1.00	1.00	12.3	0.08
80575	41	1973	HFEF Ar cell	swipe	1.30	0.77	12.3	0.06
80575	41	1973	HFEF Ar cell	swipe	3.20	0.31	12.3	0.03
80575	41	1973	HFEF Ar cell	swipe	2.60	0.38	12.3	0.03
80575	41	1973	HFEF Ar cell	swipe	5.90	0.17	12.3	0.01
80575	41	1973	HFEF Ar cell	swipe	5.30	0.19	12.3	0.02
80575	41	1974	HFEF Ar cell	swipe	1.60	0.63	12.3	0.05
80575	41	1974	HFEF Ar cell	swipe	0.20	5.00	12.3	0.41
80575	41	1974	HFEF Ar cell	swipe	1.10	0.91	12.3	0.07
80575	41	1974	HFEF Ar cell	swipe	0.80	1.25	12.3	0.10
80575	41	1974	HFEF Ar cell	swipe	2.60	0.38	12.3	0.03
80575	41	1974	HFEF Ar cell	swipe	2.30	0.43	12.3	0.04
80575	41	1974	HFEF Ar cell	swipe	0.80	1.25	12.3	0.10
80575	41	1974	HFEF Ar cell	swipe	1.30	0.77	12.3	0.06
80575	41	1974	HFEF Ar cell	swipe	3.20	0.31	12.3	0.03
80575	41	1974	HFEF Ar cell	swipe	3.30	0.30	12.3	0.02
80575	41	1974	HFEF Ar cell	swipe	1.50	0.67	12.3	0.05
80575	42	1973	HFEF Ar cell	particle	2.00	0.50	12.3	0.04
80575	42	1973	HFEF Ar cell	particle	2.00	0.50	12.3	0.04
80575	42	1973	HFEF Ar cell	particle	1.20	0.83	12.3	0.07
80575	42	1973	HFEF Ar cell	particle	5.30	0.19	12.3	0.02
80575	42	1973	HFEF Ar cell	particle	0.30	3.33	12.3	0.27
80575	42	1973	HFEF Ar cell	particle	1.00	1.00	12.3	0.08
80575	42	1973	HFEF Ar cell	particle	0.30	3.33	12.3	0.27
80575	42	1973	HFEF Ar cell	particle	0.50	2.00	12.3	0.16
80575	42	1973	HFEF Ar cell	particle	6.80	0.15	12.3	0.01
80575	42	1973	HFEF Ar cell	particle	2.70	0.37	12.3	0.03
80575	42	1973	HFEF Ar cell	particle	0.40	2.50	12.3	0.20
80575	42	1973	HFEF Ar cell	particle	2.50	0.40	12.3	0.03
80575	42	1973	HFEF Ar cell	particle	2.90	0.34	12.3	0.03
80575	42	1973	HFEF Ar cell	particle	7.80	0.13	12.3	0.01
80575	42	1973	HFEF Ar cell	particle	1.10	0.91	12.3	0.07
80575	42	1973	HFEF Ar cell	particle	2.50	0.40	12.3	0.03
80575	42	1973	HFEF Ar cell	particle	8.00	0.13	12.3	0.01
80575	42	1973	HFEF Ar cell	particle	3.30	0.30	12.3	0.02
80575	42	1973	HFEF Ar cell	particle	0.90	1.11	12.3	0.09
80575	42	1973	HFEF Ar cell	particle	13.80	0.07	12.3	0.01
80575	42	1973	HFEF Ar cell	particle	10.30	0.10	12.3	0.01
80575	42	1973	HFEF Ar cell	particle	2.70	0.37	12.3	0.03
80575	42	1972	HFEF Air cell	swipe	2.30	0.43	12.3	0.04
80575	42	1972	HFEF Air cell	swipe	0.70	1.43	12.3	0.12
80575	42	1972	HFEF Air cell	swipe	1.50	0.67	12.3	0.05
80575	42	1972	HFEF Air cell	swipe	1.80	0.56	12.3	0.05
80575	42	1972	HFEF Air cell	swipe	0.60	1.67	12.3	0.14
80575	42	1973	HFEF Air cell	swipe	2.60	0.38	12.3	0.03
80575	42	1973	HFEF Air cell	swipe	0.60	1.67	12.3	0.14
80575	42	1973	HFEF Air cell	swipe	3.30	0.30	12.3	0.02
80575	42	1973	HFEF Air cell	swipe	0.30	3.33	12.3	0.27
80575	42	1973	HFEF Air cell	swipe	1.90	0.53	12.3	0.04

SRDB Ref. ID	PDF #	Time period	Area	Type of sample	Recorded (Cs-137/ Ce-144)	(Ce-144/ Cs-137)	OTIB-54 (Ce-144/ Cs-137) ratio	Ce-144/ Cs-137 (Meas/ OTIB-54)
80575	42	1973	HFEF Air cell	swipe	2.00	0.50	12.3	0.04
80575	42	1973	HFEF Air cell	swipe	3.10	0.32	12.3	0.03
80575	42	1973	HFEF Air cell	swipe	1.90	0.53	12.3	0.04
80575	42	1973	HFEF Air cell	swipe	2.00	0.50	12.3	0.04
80575	42	1973	HFEF Air cell	swipe	1.30	0.77	12.3	0.06
80575	42	1973	HFEF Air cell	swipe	0.80	1.25	12.3	0.10
80575	42	1973	HFEF Air cell	swipe	0.50	2.00	12.3	0.16
80575	42	1973	HFEF Air cell	swipe	1.30	0.77	12.3	0.06
80575	42	1973	HFEF Air cell	swipe	1.00	1.00	12.3	0.08
80575	42	1973	HFEF Air cell	swipe	0.90	1.11	12.3	0.09
80575	42	1973	HFEF Air cell	swipe	0.70	1.43	12.3	0.12
80575	42	1973	HFEF Air cell	swipe	0.80	1.25	12.3	0.10
80575	42	1973	HFEF Air cell	swipe	1.20	0.83	12.3	0.07
80575	42	1973	HFEF Air cell	swipe	0.80	1.25	12.3	0.10

Table A-6. Summary of Data from SRBD Documents for Am-241/Cs-137 Values

SRDB Ref. ID	PDF #	Time period	Area	Type of sample	Measured Cs-137 activity	Units	Measured Am-241 T1/2=433y activity	(Am-241/ Cs-137)	OTIB-54 (Am-241/ Cs-137) ratio	Am-241/ Cs-137 (Meas/ Table 5-23)
136493	152	1993	ANL	solid waste	6.30E-01	Ci	1.63E-04	2.59E-04	1.30E-04	1.99
83153	9	1978	ANL-EBR-I	soil	1.10	pCi/g	0.009	8.18E-03	1.30E-04	**62.9**
83153	9	1978	ANL-EBR-I	soil	1.30	pCi/g	0.015	1.15E-02	1.30E-04	**88.8**
83153	9	1978	ANL-EBR-I	soil	1.07	pCi/g	0.009	8.41E-03	1.30E-04	**64.7**

Table A-7. Summary of Data from SRBD Documents for Pu-238/Cs-137 Values

SRDB Ref. ID	PDF #	Time period	Area	Type of sample	Measured Cs-137 activity	Units	Measured Pu-238 T1/2=88y activity	(Pu-238/ Cs-137)	OTIB-54 (Pu-238/ Cs-137) ratio	Pu-238/ Cs-137 (Meas/ Table 5-23)
83153	9	1978	ANL-EBR-I	soil	1.10	pCi/g	0.0017	1.55E-03	1.40E-02	**0.11**
83153	9	1978	ANL-EBR-I	soil	1.30	pCi/g	0.0025	1.92E-03	1.40E-02	**0.14**
83153	9	1978	ANL-EBR-I	soil	1.07	pCi/g	0.0041	3.83E-03	1.40E-02	**0.27**

Table A-8. Summary of Data from SRBD Documents for Pu-239/Cs-137 Values

SRDB Ref. ID	PDF #	Time period	Area	Type of sample	Measured Cs-137 activity	Units	Measured Pu-239 T1/2=2.4E4y activity	(Pu-239/ Cs-137)	OTIB-54 (Pu-239/ Cs-137) ratio	Pu-239/ Cs-137 (Meas/ Table 5-23)
140039	118	1974	ANL	solid waste	7.876	Ci	1.04E+00	1.32E-01	3.40E-03	**38.84**
140040	153	1975	ANL	solid waste	3.98E+01	Ci	7.34E+00	1.84E-01	3.40E-03	**54.17**
87191	190	1985	ANL	solid waste	1.88E+01	Ci	1.09E-02	5.79E-04	3.40E-03	0.17
87191	192	1985	ANL	solid waste	3.4	Ci	1.61E-01	4.73E-02	3.40E-03	**13.92**
83153	9	1978	ANL-0EBR-I	soil	1.10	pCi/g	0.022	2.00E-02	3.40E-03	**5.88**
83153	9	1978	ANL-EBR-I	soil	1.30	pCi/g	0.019	1.46E-02	3.40E-03	**4.30**
83153	9	1978	ANL-EBR-I	soil	1.07	pCi/g	0.015	1.40E-02	3.40E-03	**4.12**
118841	163	1978	ANL	solid waste	1.16E+02	Ci	1.19E-02	1.02E-04	3.40E-03	0.03
118841	165	1978	ANL	stored waste	1.95E+02	Ci	1.07E+00	5.49E-03	3.40E-03	1.61
83007	34&35	1980	BORAX I	soil	7.0	pCi/g	0.021	3.00E-03	3.40E-03	0.88