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**OAK RIDGE
NATIONAL
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MARTIN MARIETTA

**Active Sites Environmental
Monitoring Program:
Action Levels**

J. S. Ashwood
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Environmental Sciences Division
Publication No. 3741

MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
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Environmental Sciences Division

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ACTION LEVELS**

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ACRONYMS

ASEMP	Active Sites Environmental Monitoring Program
DOE	U.S. Department of Energy
FY	Fiscal Year
HDTF	Hillcut Disposal Test Facility
IWMF	Interim Waste Management Facility
LLW	Low-Level Radioactive Waste
ORNL	Oak Ridge National Laboratory
SWSA	Solid Waste Storage Area
TRU	Transuranic

EXECUTIVE SUMMARY

The Active Sites Environmental Monitoring Program (ASEMP) was established at Oak Ridge National Laboratory to provide for early leak detection and to monitor performance of the active low-level waste disposal facilities in Solid Waste Storage Area (SWSA) 6 and the transuranic waste storage areas in SWSA 5 North. Early leak detection is accomplished by sampling runoff, groundwater, and perched water in burial trenches. Sample results are compared to action levels that represent background contamination by naturally occurring and fallout-derived radionuclides.

The function of action levels is to screen samples to identify data that exceed the normal background levels of radioactivity. Such anomalous data are then investigated further to determine whether a leak has occurred from one of the monitored facilities. Ideally, action levels should represent the upper limit of the background population of a specific analyte in a specific hydrologic setting.

Prior to this study, action levels had only been established for gross alpha and gross beta concentrations and were based on measurements of rainwater flowing off one facility in SWSA 6. Because rainwater does not necessarily represent groundwater or perched water in trenches and because action levels are needed for gamma-emitting radionuclides, this investigation was initiated to review the action levels for gross alpha and gross beta as well as to recommend other action levels where possible.

ASEMP monitoring results from groundwater wells in SWSA 5 North and intratrench wells in SWSA 6 were used for this investigation. Two data problems arose during the statistical analysis: negative values and results reported as less than detection limits. Both of these types of data cause difficulty when trying to obtain an accurate description of the data and, when coupled with the lack of normally distributed data (even after transformation), lead to the need for a nonparametric method of determining an action level.

The method chosen for establishing action levels for the analytes involves the use of confidence intervals for quantiles. This method relies on the sample size as well as a quantile and a confidence level. The quantile and confidence level must be chosen carefully so as to minimize false positives or false negatives. False positives lead to expenditure of time and money looking for a leak that is not present. False negatives mean a leak will not be detected when it first occurs because the action level is too high.

We have proposed action levels that generally include 90% to 95% of the background population (with 90% confidence). For gross alpha, we recommend retaining the existing 1 Bq/L action level. In SWSA 5 North, the gross beta, ^{60}Co , and ^{137}Cs action levels should be 2 Bq/L, 1.5 Bq/L, and 1 Bq/L, respectively. The recommended action levels in SWSA 6 are 5 Bq/L, 1.5 Bq/L, and 2.5 Bq/L for gross beta, ^{60}Co , and ^{137}Cs , respectively.

1. INTRODUCTION

1.1 BACKGROUND

Oak Ridge National Laboratory (ORNL) operates solid low-level radioactive waste (LLW) disposal facilities in Solid Waste Storage Area (SWSA) 6 (Fig. 1). These facilities consist of concrete silos in subsurface trenches, steel-lined auger holes, and tumulus-type facilities (concrete vaults on a concrete pad). ORNL also maintains transuranic (TRU) waste storage areas in SWSA 5 North (Fig. 2).

Management of radioactive waste facilities is controlled by U.S. Department of Energy (DOE) Order 5820.2A (DOE 1988). The Active Sites Environmental Monitoring Program (ASEMP) was established in FY 1990 to comply with monitoring provisions of this order. The primary objectives of ASEMP are (1) to provide for early detection of releases from TRU waste storage areas and solid LLW disposal facilities and (2) to monitor the performance of these facilities (Ashwood et al. 1990a).

1.2 SUBSURFACE HYDROLOGY AROUND WASTE AREAS

In order to accomplish its objectives, ASEMP includes monitoring of all components of the hydrologic system in SWSA 6 and the shallow aquifer beneath SWSA 5 North. A clear understanding of the hydrology of these areas is essential to understand the rationale for this study. Material in this section is based on Sect. 2.1 in ASEMP program plan (Ashwood et al. 1990a).

1.2.1 Storm Flow and Bathtubbing Trenches

In many areas around ORNL, an important component of the groundwater flow occurs laterally in a storm flow zone from the ground surface to a depth of 1–2 m (Moore 1988, 1989). This zone typically has a hydraulic conductivity much greater than deeper zones and is active when infiltrating precipitation exceeds the soil moisture deficit. Water in the storm flow zone moves rapidly to surface water drainages.

Trenches, like those containing high and low activity silos in SWSA 6 (Fig. 3), intercept shallow storm flow. Because the disturbed soil in waste trenches has a higher porosity and hydraulic conductivity than the surrounding media, water infiltrates into the trenches faster than it can flow out again. Trenches may thus have standing water for some time following storms. Solomon et al. (1988) summarized water level data collected from 1975 to 1988 from unlined waste trenches in SWSA 6. They estimated that 85% of the trenches had standing water during some part of that period.

1.2.2 Monitoring Approach

Davis et al. (1989) demonstrated that some of the silos in SWSA 6 leak. In order to determine whether water from leaking silos may be contaminated, wells have been installed in the silo trenches (Fig. 3) and sampled. Auger holes, fissile wells, and asbestos silos are not in trenches but are surrounded by a small volume of backfilled soil and are probably subject to the same bathtubbing effect as the silo trenches. Accordingly, monitoring wells have been installed where possible in the backfill around fissile wells, asbestos silos, and some high activity auger holes that were active during or after September 1988.

Fig. 1. Capped and active low-level waste facilities in SWSA 6, including low and high activity silos, auger holes, asbestos silos, fissile wells, tumulus pads, interim waste management facility (IWMF), and hillcut disposal test facility (HDTF).

Fig. 2. Transuranic waste storage and handling areas and monitoring wells in SWSA 5 North.

Fig. 3. Cross section of a typical silo trench in SWSA 6 with major hydrologic zones, silos, and intratrench well.

The monitoring program for Tumulus I and II is designed to sample pad runoff and storm flow that runs on or under the concrete pads. In addition, this program includes sampling monitoring wells around the sites to identify any contamination of the shallow aquifer.

No data are available on the existence of bathtubbing trenches or a storm flow zone in SWSA 5 North. However, storm-driven contaminant transport is an important transport mechanism for radionuclides in the remainder of SWSA 5 (Solomon et al. 1991). Monitoring in SWSA 5 North utilizes existing wells in the shallow aquifer surrounding the TRU waste storage areas (Fig. 2).

All samples from SWSA 5 North and SWSA 6 are screened for alpha and beta activity and for gamma-emitting radionuclides to determine whether contaminants have leaked from the monitored facilities. All natural waters contain background levels of alpha, beta, and gamma radioactivity from naturally-occurring (e.g., ^{40}K , Ra, Rn, Th, and U) and fallout-derived (e.g., ^3H , ^{90}Sr , and ^{137}Cs) radionuclides. The ASEMP screening approach is based on action levels that are set at the upper end of the background range. If radionuclide concentrations exceed the action levels, additional investigations are conducted to determine the source of the elevated activity.

1.3 OBJECTIVE OF THIS STUDY

To date, ASEMP monitoring has been based on action levels (1 Bq/L for gross alpha and 5 Bq/L for gross beta) that were established by measuring rain water that had fallen on Tumulus I (Fig. 1) prior to installation of any LLW vaults (Garland 1988). However, rain water is not representative of the groundwater beneath SWSA 5 North nor of the water that bathtubs in the silo trenches in SWSA 6. Moreover, no action levels have been established for tritium or gamma-emitting radioisotopes (e.g., ^{60}Co and ^{137}Cs). Therefore, the objectives of this study are (1) to determine the upper level of background radioactivity in SWSA 5 North groundwater and SWSA 6 silo trenches by statistically evaluating samples drawn from various wells in SWSA 5 North and from the intratrench wells in SWSA 6, and (2) to recommend action levels based on the analysis of background radioactivity.

2. APPROACH

2.1 DATA ACQUISITION

2.1.1 Data Sources

Data for the analytes of interest were obtained from ASEMP annual and semi-annual reports (Wickliff et al. 1991a,b; Ashwood et al. 1991). These reports include all monitoring results for the groundwater wells in SWSA 5 North and the intratrench wells in SWSA 6 from October 1990 through March 1991.

2.1.2 Data Problems

The data contained a large number of negative values (Table 1). Although a negative value for radioactivity has no physical meaning, such values frequently occur as artifacts of the analytical process when samples containing only trace levels are analyzed.

Negative values interfered with the log transformation needed to normalize the data, so a constant was added to all values to eliminate negatives during the transformation process.

Most of the ^{60}Co and ^{137}Cs measurements were reported to be below analytical detection limits. Censored data sets (i.e., "less than" values) are difficult to analyze. Options for dealing with the censored data typically include (1) ignoring the missing values, (2) substituting zero for the missing values, or (3) substituting the detection limit (or one-half of the limit) for "less than" values. However, when a large proportion of the data are censored, such treatments result in biased estimates. This was the case for the ^{60}Co and ^{137}Cs data.

Table 1. Sample size and number of negative and less-than values for each analyte in SWSA 5 North and SWSA 6

Site	Analyte	Sample size ^a	Number of negative values	Number of less-than values
SWSA 5 North	gross alpha	66	12	0
	gross beta	64	2	0
	^{137}Cs	57	10	24
	^{60}Co	57	12	24
SWSA 6	gross alpha	109	23	0
	gross beta	108	4	0
	^{137}Cs	118	9	89
	^{60}Co	62	3	43

^a Number of observations in dataset.

2.2 STATISTICAL ANALYSES

2.2.1 Tolerance Limits

2.2.1.1 Application to action level

The first idea as to how to set an action level was to set an upper tolerance limit. Setting a tolerance limit in this case would mean that we could say with a certain level of confidence that a certain proportion of the data would fall below a given level. If the data is normally distributed with a mean of m and a standard deviation of s , then the upper limit could be written as:

$$\text{limit} = m + ks, \quad (1)$$

where k equals a constant dependent upon the sample size, the specified confidence level, and the proportion (Hines and Montgomery 1980: Chap. 15).

Tolerance limits differ from confidence limits in that confidence limits are used to determine a plausible range of values for parameters of a population, while tolerance limits

set the boundaries for a certain proportion of the population. The upper limit is the important one for this study. With a given degree of confidence (e.g., 95%) the conclusion could be reached that a proportion of the population (e.g., 90%) would be less than the upper tolerance limit derived from the Eq. 1.

2.2.1.2 Kolomogorov statistic as a test for normality

In order to use tolerance limits to establish an action level, the data is assumed to be normally distributed. The SAS¹ UNIVARIATE PROCEDURE, with the normal and plot options, was used to determine the necessary statistics to test for normality. The output from that procedure included the Kolomogorov statistic used to test for normality as well as a corresponding p-value for the statistic. These two values were used to determine whether the data are normally distributed.

2.2.2 Confidence Interval for a Quantile

A nonparametric confidence interval for the p^* th quantile can be determined without having to assume the data are normally distributed. If sample size = n , p^* is specified between 0 and 1 and $100(1-\alpha)\%$ is the confidence level, then Eq. 2 can be used to determine an upper confidence limit, r^* on the p^* th quantile (Conover 1980: Chapter 3):

$$r^* = np^* + w_\alpha (np^*(1-p^*))^{1/2} \quad (2)$$

where w_α is the $(1-\alpha)$ th quatnile for the standard normal distribution. The result of this equation should be rounded up to the next highest integer (e.g., 74.013 would be rounded to 75). That integer will equal the observation number in the data set whose corresponding value will be the upper $100(1-\alpha)\%$ confidence limit on the p^* th quantile. (Note: The data must be sorted in ascending order.)

This method also solves the problems of negative and less-than values. Because the confidence limit is based on a proportion rather than a mean, the sample size is more important than the actual values.

3. RESULTS AND DISCUSSION

Data from the annual and semi-annual ASEMP reports is included in the Appendix. Data from well 516 in SWSA 5 North and intratrench well 19 in SWSA 6 were not included in the statistical analysis because these wells are known to be contaminated by leaching of buried waste (Ashwood et al. 1990b, Wickliff et al. 1991a,b); therefore, data from these wells are not part of the background population. Sufficient data were not available to perform a meaningful analysis of background tritium concentrations in SWSA 5 North groundwater. Tritium is not one of the usual analytes in samples from SWSA 6 intratrench wells.

Gross beta concentrations from both SWSAs were found to be distributed log-normally (Table 2). Gross alpha concentrations in both SWSAs were not normally

¹ SAS release 6.03 (a computer program for statistical analysis) created by SAS institute Inc., Cary, NC, 1988.

distributed and could not be transformed to a normal distribution using the log transformation (Table 2). The ^{60}Co and ^{137}Cs data contained such high proportions of negative and less-than values (Table 1), that the samples were not normally distributed and transformation was not feasible. For these reasons, the tolerance limit approach was not appropriate to determine the action levels for gross alpha, ^{60}Co , or ^{137}Cs . Tolerance limits could have been used for evaluating the gross beta measurements, but, for consistency, the quantile method was used for all analytes.

Table 2. Results of test for normal distribution of analytical data from SWSA 5 North and SWSA 6

Site	Analyte		Kolomogorov statistic	p-value
SWSA 5	gross alpha	untransformed	0.515	<0.01
		transformed	0.341	<0.01
	gross beta	untransformed	0.629	<0.01
		transformed	0.989	0.92
SWSA 6	gross alpha	untransformed	0.656	<0.01
		transformed	0.502	<0.01
	gross beta	untransformed	0.629	<0.01
		transformed	0.989	0.92

Six combinations of quantiles ($100p^*$) and confidence levels $100(1-\alpha)$ were entered into Eq. 2 along with the sample sizes (n) to determine the observation number (r^*) for each combination (Table 3). The observation number was compared to the ordered datasets (Appendix) to derive the analyte concentration that corresponds to each quantile/confidence level combination. For example, in SWSA 5 North, the 62nd gross beta observation (with a concentration of 0.87 Bq/L) represents the upper confidence limit on the 90% quantile at a confidence level of 90%. In other words, one can be 90% confident that 90% of the shallow aquifer in SWSA 5 North contains gross beta concentrations <0.87 Bq/L.

Table 3. Quantile and confidence level combinations with corresponding concentrations for each analyte in SWSA 5 North and SWSA 6

Area	Analyte	Sample Size (n) ^a	Quantile (p^*) ^a	Confidence Level ($100(1-\alpha)$) ^a	Upper confidence limit	
					Observation No. (r^*) ^a	Concentration (Bq/L)
SWSA 5 North	gross beta	64	90	90	61	0.8
			90	95	62	0.87
			95	90	64	1.9
			95	95	64	1.9
			99	90	65	≥1.9
			99	95	65	≥1.9

Table 3 (continued)

Area	Analyte	Sample Size (n) ^a	Quantile (p*) ^a	Confidence Level (100(1-α)) ^a	Upper confidence limit	
					Observation No. (r*) ^a	Concentration (Bq/L)
SWSA 5 North	¹³⁷ Cs	57	90	90	55	0.31
			90	95	56	0.9
			95	90	57	1.1
			95	95	57	1.1
			99	90	58	≥1.1
			99	95	58	≥1.1
SWSA 5 North	⁶⁰ Co	57	90	90	55	0.4
			90	95	56	0.4
			95	90	57	1.4
			95	95	57	1.4
			99	90	58	≥1.4
			99	95	58	≥1.4
SWSA 6	gross alpha	109	90	90	103	0.29
			90	95	104	0.35
			95	90	107	0.7
			95	95	108	1.4
			99	90	110	≥1.4
			99	95	110	≥1.4
SWSA 6	gross beta	108	90	90	102	2.23
			90	95	103	2.4
			95	90	106	2.7
			95	95	107	4.5
			99	90	109	≥9.3
			99	95	109	≥9.3
SWSA 6	¹³⁷ Cs	118	90	90	111	1.1
			90	95	112	1.4
			95	90	116	2.4
			95	95	116	2.4
			99	90	119	≥2.5
			99	95	119	≥2.5
SWSA 6	⁶⁰ Co	70	90	90	67	0.4
			90	95	68	0.8
			95	90	69	1.2
			95	95	70	1.6
			99	90	71	≥1.6
			99	95	71	≥1.6

^a See Eq. 2.

4. PROPOSED ACTION LEVELS

An action level is necessarily a trade-off. If the action level is set too low, then false positives will occur more frequently, resulting in the expenditure of time and money to investigate nonexistent leaks. On the other hand, if the action level is set too high, then the risk of missing a real leak is increased. The objective of ASEMP is to provide early detection of leaks. Therefore, it is more important to identify possible leaks than to minimize the costs of additional investigations.

Recognizing that the waste characteristics in SWSA 5 North differ from those in SWSA 6 and that the potential for contamination in the shallow aquifer below SWSA 5 North may be different than that for bathtubting trenches in SWSA 6, it is appropriate to have different action levels for the two areas. We propose the action levels in Table 4 based on the statistical analyses summarized in Table 3.

Table 4. Recommended action levels for SWSA 5 North groundwater samples and samples from SWSA 6 low-level waste disposal facilities

Area	Analyte	Action Level (Bq/L)
SWSA 5 North	Gross beta	2.0
	^{60}Co	1.5
	^{137}Cs	1.0
SWSA 6 ^a	Gross Alpha	1.0
	Gross beta	5.0
	^{60}Co	1.5
	^{137}Cs	2.5

^a Includes intratrench wells, tumulus facilities, interim waste management facility, and hillcut disposal test facility.

No action level is proposed for gross alpha in SWSA 5 North because ASEMP is moving away from gross alpha as a screening measurement in this area. The analyses for specific transuranics (i.e., ^{241}Am and ^{244}Cm) are more sensitive than the gross alpha analysis and can quantify the presence of transuranics at levels that would be undetectable by the gross alpha screen (Ashwood et al. 1991: Sect. 3).

Monitoring data from SWSA 5 North indicate that the current action level for gross beta (5 Bq/L) exceeds the highest sample concentrations by more than a factor of 2 (Table 3). At a 95% confidence level, 99% of the background population has a gross beta concentration of <1.9 Bq/L. Therefore we have recommended an action level of 2.0 Bq/L.

The recommended action levels for ^{137}Cs and ^{60}Co in SWSA 5 North encompass 99% of the background population with 95% confidence (Table 4). However, given the presence of counting errors, we have rounded the data from Table 3 to the nearest 0.5 Bq/L.

For the SWSA 6 intratrench wells, the gross alpha monitoring results support the existing 1 Bq/L action level. The two gross alpha values that exceed 1 Bq/L are not

sufficient justification to raise the action level because they represent <2% of the data. Similarly, the 1 gross beta result that exceeds the current action level (5 Bq/L) does not justify raising the action level for gross beta concentrations in SWSA 6 intratrench wells.

Cobalt-60 results for SWSA 6 are similar to those for SWSA 5 North, yielding the same recommended action level (Table 4). We have recommended a ^{137}Cs action level in SWSA 6 that includes 99% of the background population (with a 95% confidence level).

Action levels for both ^{137}Cs and gross beta are higher in SWSA 6 than in SWSA 5 North, reflecting a higher background for both analytes in SWSA 6. Because ^{137}Cs is a beta-gamma emitter, the presence of higher ^{137}Cs activity would be expected to cause a corresponding increase in gross beta activity. The difference appears to be real, not a statistical artifact. In SWSA 5 North, one sample out of 57 contained $^{137}\text{Cs} > 1 \text{ Bq/L}$ (1.1 Bq/L; Table A-8); whereas in SWSA 6, nine ^{137}Cs values (out of 118) exceeded 1 Bq/L, ranging as high as 2.5 Bq/L (Table A-4). This higher background may reflect contamination within the storm flow zone in SWSA 6, or the difference may be due to differences in the sample preparation steps for the two areas.

The action levels for SWSA 6 include all active SWSA 6 facilities. The gross alpha and gross beta action levels are identical to those already established for tumulus pad runoff, and we have no better data on which to base action levels for the other components of the tumulus monitoring program or the monitoring programs for the interim waste management facility and hillcut disposal test facility.

We strongly recommend that these action levels be reviewed annually as more background data are obtained. Also, as additional data become available, it may be possible to establish an action level for tritium.

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APPENDIX

**RADIONUCLIDE MONITORING DATA FROM SOLID WASTE
STORAGE AREAS 5 NORTH AND 6**

Table A-1. Gross alpha concentrations in intratrench wells in SWSA 6

Observation No. ^a	Date	Gross alpha (Bq/L)	Transformed gross alpha ^b
1	2-7-91	-0.840	-1.22185
2	12-12-90	-0.73	-0.76955
3	9-20-90	-0.33	-0.24413
4	2-7-91	-0.11	-0.10237
5	2-7-91	-0.10	-0.09691
6	2-7-91	-0.088	-0.09044
7	2-7-91	-0.08	-0.08619
8	2-7-91	-0.08	-0.08619
9	2-22-91	-0.06	-0.07572
10	2-7-91	-0.06	-0.07572
11	2-7-91	-0.05	-0.07058
12	6-11-90	-0.038	-0.06449
13	2-7-91	-0.02	-0.05552
14	2-22-91	-0.02	-0.05552
15	12-12-90	-0.02	-0.05552
16	2-7-91	-0.02	-0.05552
17	2-7-91	-0.02	-0.05552
18	2-7-91	-0.01	-0.05061
19	1-25-90	-0.01	-0.05061
20	2-12-90	-0.01	-0.05061
21	12-12-90	-0.01	-0.05061
22	7-26-90	-0.006	-0.04866
23	7-26-90	-0.001	-0.04624
24	2-22-91	0.0	-0.04576
25	7-25-90	0.000	-0.04576
26	7-26-90	0.000	-0.04576
27	2-7-91	0.0	-0.04576
28	6-11-90	0.001	-0.04528
29	7-25-90	0.002	-0.04479
30	7-26-90	0.002	-0.04479
31	7-25-90	0.004	-0.04383
32	6-11-90	0.005	-0.04335
33	6-11-90	0.007	-0.04239
34	2-22-91	0.01	-0.04096
35	1-16-90	0.01	-0.04096
36	12-12-90	0.01	-0.04096
37	12-12-90	0.01	-0.04096
38	6-11-90	0.011	-0.04048
39	9-19-90	0.015	-0.03858
40	8-3-90	0.018	-0.03716

Table A-1 (continued)

Observation No. ^a	Date	Gross alpha (Bq/L)	Transformed gross alpha ^b
41	8-3-90	0.019	-0.03668
42	2-12-90	0.02	-0.03621
43	9-20-90	0.02	-0.03621
44	8-3-90	0.021	-0.03574
45	9-20-90	0.027	-0.03292
46	9-20-90	0.029	-0.03198
47	2-12-90	0.03	-0.03152
48	1-25-90	0.03	-0.03152
49	2-12-90	0.03	-0.03152
50	7-26-90	0.032	-0.03058
51	2-7-91	0.04	-0.02687
52	6-11-90	0.040	-0.02687
53	1-25-90	0.04	-0.02687
54	2-7-91	0.04	-0.02687
55	12-8-90	0.04	-0.02687
56	2-22-91	0.04	-0.02687
57	9-20-90	0.041	-0.02641
58	6-11-90	0.045	-0.02457
59	9-20-90	0.049	-0.02273
60	2-12-90	0.05	-0.02228
61	2-7-91	0.05	-0.02228
62	9-20-90	0.052	-0.02136
63	6-11-90	0.054	-0.02045
64	9-20-90	0.057	-0.01909
65	7-25-90	0.057	-0.01909
66	12-12-90	0.06	-0.01773
67	2-22-91	0.06	-0.01773
68	2-12-90	0.06	-0.01773
69	12-8-90	0.06	-0.01773
70	2-7-91	0.06	-0.01773
71	12-12-90	0.06	-0.01773
72	2-7-91	0.07	-0.01323
73	9-20-90	0.073	-0.01189
74	2-12-90	0.08	-0.00877
75	2-7-91	0.08	-0.00877
76	2-7-91	0.08	-0.00877
77	9-20-90	0.08	-0.00877
78	12-12-90	0.09	-0.00436
79	2-12-90	0.09	-0.00436
80	9-20-90	0.091	-0.00393

Table A-1 (continued)

Observation No. ^a	Date	Gross alpha (Bq/L)	Transformed gross alpha ^b
81	2-7-91	0.10	0
82	12-12-90	0.10	0
83	2-7-91	0.10	0
84	2-7-91	0.10	0
85	9-20-90	0.11	0.004321
86	2-7-91	0.11	0.004321
87	2-7-91	0.12	0.0086
88	6-11-90	0.122	0.009451
89	12-8-90	0.13	0.012837
90	1-16-90	0.13	0.012837
91	2-22-91	0.15	0.011189
92	9-20-90	0.16	0.025306
93	2-7-91	0.16	0.025306
94	12-12-90	0.16	0.025306
95	2-7-91	0.17	0.029384
96	12-12-90	0.18	0.033424
97	12-12-90	0.21	0.045323
98	12-8-90	0.24	0.056905
99	12-12-90	0.25	0.060698
100	2-7-91	0.26	0.064458
101	2-7-91	0.28	0.071882
102	2-7-91	0.28	0.071882
103	12-12-90	0.29	0.075547
104	2-7-91	0.35	0.09691
105	9-19-90	0.49	0.143015
106	9-20-90	0.49	0.143015
107	9-20-90	0.7	0.20412
108	2-7-91	1.4	0.361728
109	9-20-90	1.4	0.361728

^a Observations are listed in order of ascending gross alpha values.

^b Gross alpha results were transformed by adding 0.85 and taking the logarithm to the base 10.

Table A-2. Gross beta concentrations in intratrench wells in SWSA 6

Observation No. ^a	Date	Gross beta (Bq/L)	Transformed gross beta ^b
1	9-20-90	-0.2	-1
2	2-7-91	-0.11	-0.72125
3	2-22-91	-0.05	-0.60206
4	2-7-91	-0.03	-0.56864
5	2-7-91	0.01	-0.50864
6	7-25-90	0.06	-0.4437
7	2-22-91	0.07	-0.4318
8	6-11-90	0.07	-0.4318
9	12-12-90	0.09	-0.40894
10	8-3-90	0.10	-0.39794
11	2-7-91	0.11	-0.38722
12	2-7-91	0.14	-0.35655
13	2-22-91	0.16	-0.33724
14	2-12-90	0.16	-0.33724
15	12-12-90	0.17	-0.3279
16	8-3-90	0.18	-0.31876
17	7-25-90	0.20	-0.30103
18	2-7-91	0.20	-0.30103
19	12-7-90	0.22	-0.284
20	9-20-90	0.23	-0.27572
21	7-26-90	0.23	-0.27572
22	2-7-91	0.24	-0.26761
23	6-11-90	0.25	-0.25964
24	12-12-90	0.26	-0.25181
25	7-26-90	0.27	-0.24413
26	7-25-90	0.28	-0.23657
27	12-12-90	0.28	-0.23657
28	8-3-90	0.28	-0.23657
29	6-11-90	0.29	-0.22915
30	9-20-90	0.29	-0.22915
31	2-7-91	0.32	-0.20761
32	6-11-90	0.32	-0.20761
33	6-11-90	0.32	-0.20761
34	1-25-90	0.32	-0.20761
35	6-11-90	0.33	-0.20066
36	2-22-91	0.35	-0.18709
37	7-26-90	0.37	-0.17393
38	7-26-90	0.38	-0.16749
39	9-20-90	0.38	-0.16749
40	2-7-91	0.39	-0.16115

Table A-2 (continued)

Observation No. ^a	Date	Gross beta (Bq/L)	Transformed gross beta ^b
41	7-25-90	0.40	-0.1549
42	2-7-91	0.40	-0.1549
43	2-7-91	0.40	-0.1549
44	2-7-91	0.46	-0.11919
45	2-22-91	0.47	-0.11351
46	9-20-90	0.47	-0.11351
47	2-22-91	0.49	-0.10237
48	9-20-90	0.5	-0.09691
49	2-22-91	0.50	-0.09691
50	9-20-90	0.51	-0.09151
51	12-12-90	0.51	-0.09151
52	9-19-90	0.54	-0.07572
53	2-7-91	0.55	-0.07058
54	2-7-91	0.57	-0.06048
55	9-20-90	0.59	-0.05061
56	2-7-91	0.61	-0.04096
57	2-12-90	0.62	-0.03621
58	9-20-90	0.63	-0.03152
59	2-7-91	0.64	-0.02687
60	12-7-90	0.66	-0.01773
61	2-7-91	0.67	-0.01323
62	2-7-91	0.68	-0.00877
63	12-12-90	0.69	-0.00436
64	2-12-90	0.69	-0.00436
65	9-20-90	0.69	-0.00436
66	2-22-91	0.73	0.012837
67	9-20-90	0.73	0.012837
68	2-7-91	0.75	0.021189
69	1-16-90	0.76	0.025306
70	2-7-91	0.76	0.025306
71	2-7-91	0.77	0.029384
72	2-12-90	0.78	0.033424
73	12-12-90	0.80	0.041393
74	2-7-91	0.80	0.041393
75	9-20-90	0.8	0.041393
76	12-12-90	0.80	0.041393
77	6-11-90	0.82	0.049218
78	2-7-91	0.86	0.064458
79	2-7-91	0.89	0.075547
80	9-20-90	0.89	0.075547

Table A-2 (continued)

Observation No. ^a	Date	Gross beta (Bq/L)	Transformed gross beta ^b
81	12-7-90	0.90	0.079181
82	2-12-90	0.97	0.103804
83	2-22-91	1.0	0.113943
84	12-12-90	1.1	0.146128
85	2-12-90	1.17	0.167317
86	12-12-90	1.2	0.176091
87	6-11-90	1.27	0.1959
88	12-7-90	1.3	0.20412
89	12-12-90	1.4	0.230449
90	1-25-90	1.41	0.232996
91	12-12-90	1.5	0.255273
92	6-11-90	1.54	0.264818
93	1-25-90	1.58	0.274158
94	2-22-91	1.6	0.278754
95	1-16-90	1.82	0.326336
96	2-12-90	1.88	0.338456
97	12-12-90	1.9	0.342423
98	2-7-91	2.0	0.361728
99	2-7-91	2.1	0.380211
100	12-12-90	2.1	0.380211
101	9-20-90	2.2	0.39794
102	2-12-90	2.23	0.403121
103	9-19-90	2.4	0.431364
104	2-7-91	2.5	0.447158
105	2-22-91	2.6	0.462398
106	2-7-91	2.7	0.477121
107	9-20-90	4.5	0.681241
108	9-20-90	9.3	0.982271

^a Observations are listed in order of ascending gross beta values.

^b Gross beta values were transformed by adding 0.3 and taking the logarithm to the base 10.

Table A-3. ^{60}Co concentrations in intratrench wells in SWSA 6

Observation No. ^a	Well No.	Date	^{60}Co (Bq/L)
63	C 520	12-12-90	-0.4
64	3	12-12-90	-0.3
65	32	12-12-90	-0.2
66	8	12-7-90	0.1
67	C 595	12-12-90	0.4
68	42	12-12-90	0.8
69	28	12-12-90	1.2
70	FIS 102	12-12-90	1.6

^a Observations are listed in order of ascending ^{60}Co values. The first 62 observations were reported as below detection limit, so no value was available. Because there were only eight results above detection limit, no transformation was performed on the data.

Table A-4. ^{137}Cs concentrations in intratrench wells in SWSA 6

Observation No. ^a	Well No.	^{137}Cs (Bq/L)
90	13	-2.3
91	6	-1.2
92	25	-0.8
93	520 C	-0.34
94	12	-0.3
95	8	-0.2
96	595 C	-0.1
97	28	-0.1
98	3	-0.01
99	35	0.2
100	102 FIS	0.3
101	30	0.3
102	36	0.3
103	42	0.3
104	10	0.4
105	7	0.6
106	8	0.6
107	32	0.7
108	15	0.8
109	5	0.9
110	12	1.1
111	42	1.1
112	23	1.4
113	11	1.8
114	27	2.0
115	28	2.0
116	11	2.4
117	36	2.4
118	45	2.5

^a Observations are listed in order of ascending ^{137}Cs values. The first 89 observations were reported as below detection limit, so no value was available and no transformation could be made.

**Table A-5. Gross alpha concentrations in groundwater wells in
SWSA 5 North**

Observation No. ^a	Well No.	Gross alpha (Bq/L)	Transformed gross alpha ^b
1	525	-0.9	-1
2	517	-0.21	-0.10237
3	521	-0.15	-0.07058
4	523	-0.14	-0.0655
5	513	-0.12	-0.05552
6	519	-0.011	-0.0048
7	522	-0.01	-0.00436
8	524	-0.01	-0.00436
9	524	-0.01	-0.00436
10	517	-0.002	-0.00087
11	525	-0.002	-0.00087
12	517	-0.001	-0.00043
13	521	0.0	0
14	524	0.001	0.000434
15	518	0.004	0.001734
16	521	0.004	0.001734
17	514	0.005	0.002166
18	520	0.007	0.003029
19	522	0.007	0.003029
20	523	0.008	0.003461
21	514	0.01	0.004321
22	519	0.01	0.004321
23	519	0.01	0.004321
24	520	0.01	0.004321
25	521	0.010	0.004321
26	522	0.01	0.004321
27	523	0.01	0.004321
28	524	0.01	0.004321
29	708	0.01	0.004321
30	513	0.012	0.005181
31	518	0.013	0.005609
32	519	0.013	0.005609
33	521	0.014	0.006038
34	524	0.014	0.006038
35	525	0.015	0.006466
36	519	0.016	0.006894
37	525	0.018	0.007748
38	513	0.02	0.0086
39	514	0.02	0.0086
40	519	0.02	0.0086

Table A-5 (continued)

Observation No. ^a	Well No.	Gross alpha (Bq/L)	Transformed gross alpha ^b
41	520	0.02	0.0086
42	522	0.02	0.0086
43	524	0.02	0.0086
44	517	0.023	0.009876
45	517	0.023	0.009876
46	715	0.026	0.011147
47	518	0.028	0.011993
48	518	0.03	0.012837
49	715	0.03	0.012837
50	514	0.035	0.01494
51	514	0.035	0.01494
52	716	0.04	0.017033
53	513	0.05	0.021189
54	520	0.05	0.021189
55	520	0.05	0.021189
56	525	0.05	0.021189
57	525	0.05	0.021189
58	514	0.053	0.022428
59	513	0.068	0.028571
60	523	0.083	0.034628
61	517	0.09	0.037426
62	518	0.14	0.056905
63	523	0.15	0.060698
64	523	0.15	0.060698
65	520	0.32	0.120574
66	982	1.1	0.322219

^a Observations are listed in order of ascending gross alpha values

^b Gross alpha results were transformed by adding 1 and taking the logarithm to the base 10

**Table A-6. Gross beta concentrations in groundwater wells in
SWSA 5 North**

Observation No. ^a	Well No.	Gross beta (Bq/L)	Transformed gross beta ^b
1	522	-1.4	-1
2	525	-0.9	-0.22185
3	513	0.01	0.178977
4	514	0.04	0.187521
5	514	0.04	0.187521
6	520	0.05	0.190332
7	519	0.06	0.193125
8	519	0.078	0.198107
9	518	0.08	0.198657
10	519	0.08	0.198657
11	520	0.08	0.198657
12	520	0.08	0.198657
13	520	0.08	0.198657
14	513	0.09	0.201397
15	517	0.09	0.201397
16	518	0.09	0.201397
17	513	0.1	0.20412
18	517	0.1	0.20412
19	520	0.10	0.20412
20	708	0.10	0.20412
21	518	0.11	0.206826
22	525	0.11	0.206826
23	514	0.12	0.209515
24	521	0.12	0.209515
25	518	0.13	0.212188
26	521	0.13	0.212188
27	513	0.14	0.214844
28	523	0.16	0.220108
29	519	0.17	0.222716
30	525	0.17	0.222716
31	525	0.17	0.222716
32	513	0.19	0.227887
33	525	0.19	0.227887
34	514	0.20	0.230449
35	524	0.2	0.230449
36	521	0.21	0.232996
37	517	0.22	0.235528
38	523	0.22	0.235528
39	523	0.22	0.235528
40	524	0.22	0.235528

Table A-6 (continued)

Observation No. ^a	Well No.	Gross beta (Bq/L)	Transformed gross beta ^b
41	522	0.23	0.238046
42	514	0.26	0.245513
43	716	0.27	0.247973
44	517	0.28	0.25042
45	517	0.28	0.25042
46	522	0.28	0.25042
47	523	0.28	0.25042
48	519	0.3	0.255273
49	519	0.3	0.255273
50	518	0.32	0.260071
51	525	0.32	0.260071
52	524	0.35	0.267172
53	524	0.35	0.267172
54	522	0.39	0.276462
55	514	0.4	0.278754
56	524	0.54	0.30963
57	523	0.6	0.322219
58	715	0.6	0.322219
59	715	0.6	0.322219
60	521	0.64	0.330414
61	520	0.8	0.361728
62	524	0.87	0.374748
63	521	1.2	0.431364
64	523	1.9	0.531479

^a Observations are listed in order of ascending gross beta values

^b Gross beta results were transformed by adding 1.5 and taking the logarithm to the base 10

Table A-7. ^{60}Co concentrations in groundwater wells in SWSA 5 North

Observation No. ^a	Well No.	^{60}Co (Bq/L)
25	517	-1.1
26	519	-0.4
27	517	-0.11
28	517	-0.11
29	715	-0.09
30	715	-0.09
31	513	-0.08
32	525	-0.06
33	525	-0.06
34	522	-0.03
35	524	-0.02
36	524	-0.02
37	521	0.04
38	519	0.05
39	519	0.05
40	525	0.05
41	514	0.06
42	514	0.06
43	708	0.07
44	518	0.08
45	520	0.08
46	521	0.08
47	519	0.09
48	523	0.10
49	523	0.1
50	524	0.1
51	716	0.11
52	520	0.12
53	520	0.12
54	513	0.4
55	522	0.4
56	523	0.4
57	518	1.4

^a Observations are listed in order of ascending ^{60}Co values. The first 24 observations were reported as below the detection limit so no value was available.

Table A-8. ^{137}Cs concentrations in groundwater wells in SWSA 5 North

Observation No. ^a	Well No.	^{137}Cs (Bq/L)
25	514	-1.4
26	518	-1.2
27	519	-0.9
28	513	-0.7
29	513	-0.08
30	521	-0.04
31	523	-0.04
32	523	-0.04
33	715	-0.03
34	715	-0.03
35	520	0.01
36	520	0.02
37	520	0.02
38	522	0.04
39	524	0.04
40	524	0.04
41	517	0.05
42	517	0.05
43	518	0.05
44	525	0.08
45	524	0.09
46	716	0.09
47	525	0.11
48	525	0.11
49	514	0.12
50	514	0.12
51	708	0.15
52	519	0.18
53	519	0.18
54	521	0.2
55	983	0.31
56	517	0.9
57	523	1.1

^a Observations are listed in order of ascending ^{137}Cs value. The first 24 observations were reported as below detection limits, so no value was available.

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