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Westinghouse Hanford Company**

**Statistical Analyses of In-Situ
and Soil-Sample Measurements
for Radionuclides in Surface
Soil Near the 116-K-2 Trench**

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September 1988

**Prepared for the U.S. Department of Energy
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STATISTICAL ANALYSES OF IN-SITU AND SOIL-
SAMPLE MEASUREMENTS FOR RADIONUCLIDES IN
SURFACE SOIL NEAR THE 116-K-2 TRENCH

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SUMMARY

Radiation detection surveys are used at the U.S. Department of Energy's Hanford Reservation near Richland, Washington to determine areas that need posting as radiation zones or to measure dose rates in the field. The relationship between measurements made by Sodium Iodide (NaI) detectors mounted on the mobile Road Monitor vehicle and those made by hand-held GM P-11 probes and Micro-R meters are of particular interest because the Road Monitor can survey large land areas in much less time than hand-held detectors.

Statistical regression methods are used here to develop simple equations to predict GM P-11 probe gross gamma count-per-minute (cpm) and Micro-R-Meter $\mu\text{R/h}$ measurements on the basis of NaI gross gamma count-per-second (cps) measurements obtained using the Road Monitor. These equations were estimated using data collected near the 116-K-2 Trench in the 100-K area on the Hanford Reservation. Equations are also obtained for estimating upper and lower limits within which the GM P-11 or Micro-R-Meter measurement corresponding to a given NaI Road Monitor measurement at a new location is expected to fall with high probability. An equation and limits for predicting GM P-11 measurements on the basis of Micro-R-Meter measurements is also estimated. Also, we estimate an equation that may be useful for approximating the ^{90}Sr measurement of a surface soil sample on the basis of a spectroscopy measurement for ^{137}Cs on that sample.

The estimates of in-situ radiation levels and ^{90}Sr surface-soil measurements obtained using the equations developed here are not without error. The magnitude of the error due to random scatter in the data is estimated and used to obtain the upper and lower limits mentioned above. Also, the prediction equations and limits reported here were estimated from data that were obtained under specific operating protocols in the field that specified, e.g., the distance of the detectors from the ground surface, and the speed at which the Road Monitor moved while NaI-detector measurements were being taken. Hence, the equations given here may be biased if applied to other operating procedures that may be used in the future.

Comparisons are also made here between thermoluminescent dosimeter (TLD) measurements at off-Hanford-site locations with those taken on a grid pattern

at 34 locations at the 116-K-2 Trench study site. TLD measurements made at the 34 locations indicate that a small fraction of the study area ($< 0.5\%$ of the 92-acre area) may have mrem/30-day dose rates about 5 to 7 times larger than Spokane, Washington and about 10 to 15 times larger than Seattle, Washington, or communities nearer to the Hanford Reservation. However, dose rates over the remainder ($> 99.5\%$) of the 116-K-2 Trench study area appeared to be lower than the mrem/30-day dose rates at Seattle, Spokane, and other Washington communities.

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CONTENTS

SUMMARY	iii
ACKNOWLEDGMENTS	v
1.0 INTRODUCTION	1.1
2.0 FIELD DESIGN AND METHODS FOR IN-SITU DATA	2.1
3.0 BACKGROUND GROSS-GAMMA READINGS	3.1
4.0 REGRESSION EQUATIONS	4.1
4.1 GM P-11 PROBE VERSUS NaI ROAD MONITOR MEASUREMENTS	4.1
4.1.1 Interpretation of ~10,000 Road Monitor Measurements Recorded at the 116-K-2 Trench Study Site	4.7
4.2 MICRO-R-METER VERSUS NaI ROAD MONITOR MEASUREMENTS	4.9
4.3 GM P-11 PROBE VERSUS MICRO-R-METER MEASUREMENTS	4.9
5.0 ⁹⁰ Sr VERSUS ¹³⁷ Cs MEASUREMENTS IN SURFACE SOIL SAMPLES	5.1
6.0 THERMOLUMINESCENT DOSIMETER (TLD) MEASUREMENTS	6.1
7.0 REFERENCES	7.1

FIGURES

1.1	The 116-K-2 Trench Study Area Divided into 256 Sectors. The Black Areas had Gross Gamma NaI-Detector Readings Above Local Background Levels of About 800 cps	1.2
4.1	Scatter Plot of GM P-11 Probe Gross Gamma cpm Measurements Versus Road Monitor NaI-Detector Gross Gamma Measurements. See Text for Definition of Plotting Symbols	4.2
4.2	Estimated Linear Regression and 95% Confidence Intervals for Predicting GM P-11-Probe Gross Gamma Measurements From Road Monitor NaI Gross Gamma Measurements Obtained While the Road Monitor is Stationary	4.2
4.3	Estimated Linear Regression and 95% Confidence Intervals for Predicting GM P-11-Probe Gross Gamma Measurements From Road Monitor NaI Gross Gamma Measurements Obtained While the Road Monitor is Moving	4.3
4.4	Scatter Plot of Micro-R-Meter $\mu\text{R/h}$ Measurements Versus Road Monitor NaI Gross Gamma Measurements. See Text for Definition of Plotting Symbols	4.10
4.5	Estimated Linear Regression and 95% Confidence Intervals for Predicting Micro-R-Meter Measurements from Road Monitor Gross Gamma Measurements Obtained While the Road Monitor is Stationary	4.10
4.6	Estimated Linear Regression and 95% Confidence Intervals for Predicting Micro-R-Meter Measurements from Road Monitor NaI Gross Gamma Measurements While the Road Monitor is Moving	4.11
4.7	Estimated Linear Regression and 95% Confidence Intervals for Predicting GM P-11 Probe Gross Gamma Measurements from Micro- R-Meter Measurements. See Text for Definition of Plotting Symbols	4.11
5.1	Estimated Linear Regression and 95% Confidence Intervals for Predicting ^{90}Sr Measurements from ^{137}Cs Measurements	5.3
6.1	Locations Where Capsules Containing Three Thermoluminescent Dosimeters (TLDs) were Placed at the 116-K-2 Trench Study Area	6.4
6.2	Comparison of Average Thermoluminescent Dosimeter (TLD) Measurements for October and November at 32 Locations Outside the more Contaminated Northwest Corner of the 116-K-2 Trench Study Area	6.5

TABLES

2.1	In-situ-detector Measurements Taken in the 116-K-2 Trench Study Area (Figure 1.1) Between the 116-K-2 Trench and the Columbia River	2.2
3.1	Summary of NaI Gross-Gamma Measurements (cps) Made in the Morning and Afternoon at Background Locations at Both Ends of the 116-K-2 Trench	3.1
4.1	Equations for Computing Estimated Upper and Lower 95% Confidence Intervals on a Predicted In-Situ Measurement in Logarithmic Scale	4.5
5.1	Measurements (pCi/g) of ^{90}Sr and ^{137}Cs in Surface Soil Samples Collected Near the 116-K-2 Trench	5.2
6.1	TLD Data (mrem/30-day Period) for Locations in Figure 6.1	6.2

1.0 INTRODUCTION

This report describes the statistical analyses conducted by the Pacific Northwest Laboratory (PNL) in support of the radiological characterization of surface soil that has recently been conducted by UNC Nuclear Industries (now Westinghouse Hanford Company) near the 116-K-2 Trench on the Hanford Reservation. This survey was conducted in part to more accurately determine the size and location of areas of elevated radionuclide concentrations in the 37 hectare (92 acre) study area between the trench and the Columbia River (Figure 1.1). In addition, data were needed to develop a better understanding of the relationships between the various types of in-situ-detector measurements made at Hanford to determine areas that need posting as a radiation zone or to measure radiation dose in the field. A quantitative assessment of these relationships is provided in this report. This information is needed to develop more thorough and cost effective radiological ground surveys of large land areas.

Information on radionuclide concentrations in surface soil at the 116-K-2 trench study area were obtained using radiation detectors, surface soil samples, and thermoluminescent dosimeters (TLDs). Three types of in-situ detectors were used: (1) NaI detectors (four of them) mounted on a mobile tracker called the "Road Monitor", (2) hand-held GM P-11 probes, and (3) hand-held Micro-R meters. In this study, all three detectors measured gross gamma radiation. The TLDs measured radiation dose in units of millirem (mrem) per 30-day period.

In Section 2.0 the field design and radiation survey methods are discussed. In Section 3.0, some preliminary information on background gross-gamma radiation levels near the 116-K-2 trench is provided. In Section 4.0, regression equations are estimated that relate the different types of in-situ measurements to one another. In Section 4.1.1 we use the estimated regression equation for GM P-11 probe and Road Monitor measurements to interpret the ~ 10,000 recorded Road Monitor readings taken throughout the study area. In Section 5.0, equations are estimated for converting ^{137}Cs gamma-spectroscopy measurements of surface soil samples into estimates and bounds for ^{90}Sr

FIGURE 1.1. The 116-K-2 Trench Study Area Divided into 256 Sectors. The Black Areas had Gross NaI-Detector Readings Above Local Background Levels of About 800 cps.

measurements in those samples. In Section 6.0, the TLD measurements made at locations on a grid throughout the study site are compared with TLD measurements made at off-site locations near Hanford and in Seattle and Spokane.

2.0 FIELD DESIGN AND METHODS FOR IN-SITU DATA

The study area was divided into a grid of square 38-m by 38-m (125-ft by 125-ft) sectors that were numbered from 1 to 256, as shown in Figure 1.1. Three types of detectors were used for in-situ measurements over this region of sectors. The Road Monitor moved back and forth across the study area making 6- to 7-ft wide passes traveling at a rate of 1 to 2 mph. Gross gamma readings (sum of the four detector readings) were taken continuously and recorded at approximately 20-second (~12 m (40-ft)) intervals. The measurements were taken with the NaI detectors at a nominal height of 46 cm (18 inches). A total of about 10,000 measurements were taken in this way. As the Road Monitor moved along, the gross gamma reading would occasionally exceed by 20% or more the nominal background readings being recorded. When this occurred, a wood stake was placed on the ground to mark the spot. About 450 locations were marked in this way. Figure 1.1 shows the small areas found by the Road Monitor that were above background. At 88 of the 450 locations, a GM P-11 probe measurement and a Micro-R-Meter measurement were made. These measurements were made while both detectors were held at ground level. About 5% of the study area could not be surveyed by the Road Monitor because of rough terrain. These rough regions were systematically surveyed by personnel using the GM P-11 probe.

Table 2.1 gives the measurements obtained at the 88 locations using the GM P-11 probe, the Micro-R meter, and the NaI detectors. The sector within which each measurement was obtained is also given. Each NaI-detector measurement in Table 2.1 is the sum of the cps measurements for the four detectors at the location. Table 2.1 also gives the natural logarithms of the measurements. The regression equations in Sections 4.1, 4.2, and 4.3 below were estimated using these transformed data.

The 88 locations were purposely selected from among the ~450 stake locations to provide a wide range of measurements so that the estimated regression equations would be valid over a wide range of activity levels. Also, an effort was made to chose locations from different portions of the study area. As the 88 locations were not chosen at random from the ~450 stake locations where above-background Road Monitor measurements were recorded, the

TABLE 2.1. In-situ-detector Measurements Taken in the 116-K-2 Trench Study Area (Figure 1.1) Between the 116-K-2 Trench and the Columbia River.

Row	Sector	GM P-11 Probe		Road Monitor NaI Detector ^(a)		Micro-R-Meter	
		Gross cpm	Gamma Ln cpm ^(b)	Gross cps	Gamma Ln cps ^(b)	$\mu\text{R/h}$	Ln $\mu\text{R/h}$ ^(b)
1	8	400	5.991	2500	7.824	(c)	(c)
2	8	400	5.991	2000	7.601	(c)	(c)
3	17	300	5.704	2000	7.601	(c)	(c)
4	17	300	5.704	1500	7.313	(c)	(c)
5	37	80	4.382	1000	6.908	(c)	(c)
6	126	250	5.521	4000	8.294	60	4.094
7	127	250	5.521	3000	8.006	55	4.007
8	127	250	5.521	3000	8.006	70	4.248
9	127	400	5.991	5000	8.517	100	4.605
10	127	200	5.298	2000	7.601	55	4.007
11	128	300	5.704	4000	8.294	90	4.500
12	128	300	5.704	5000	8.517	70	4.248
13	129	500	6.215	3000	8.006	70	4.248
14	131	600	6.397	3000	8.006	80	4.382
15	131	900	6.802	5000	8.517	(c)	(c)
16	131	500	6.215	(c)	(c)	(c)	(c)
17	132	1000	6.908	4000	8.294	100	4.605
18	132	2500	7.824	7500	8.923	200	5.298
19	132	1000	6.908	2000	7.601	200	5.298
20	132	2500	7.824	>10,000	(c)	200	5.298
21	132	900	6.802	2500	7.824	90	4.500
22	132	1000	6.908	8000	8.987	90	4.500
23	132	500	6.215	(c)	(c)	80	4.382
24	132	600	6.397	4000	8.294	70	4.248
25	132	500	6.215	3000	8.006	40	3.689
26	132	7000	8.854	8000	8.987	600	6.397
27	132	1000	6.908	8000	8.987	140	4.942
28	132	500	6.215	>10,000	(c)	50	3.912
29	132	500	6.215	6500	8.780	70	4.248
30	132	4000	8.294	9000	9.105	600	6.397
31	132	5000	8.517	>10,000	(c)	600	6.397
32	132	1000	6.908	4000	8.294	150	5.011
33	132	1500	7.313	4000	8.294	90	4.500
34	132	800	6.685	4500	8.412	110	4.700
35	132	1000	6.908	(c)	(c)	150	5.011
36	132	4500	8.412	>10,000	(c)	400	5.991
37	159	300	5.704	2500	7.824	75	4.317
38	159	250	5.521	2000	7.601	70	4.248
39	159	200	5.298	2000	7.601	50	3.912
40	194	500	6.215	4000	8.294	70	4.248

TABLE 2.1. (Continued)

Row	Sector	GM P-11 Probe		Road Monitor NaI Detector ^(a)		Micro-R-Meter	
		Gross cpm	Gamma Ln cpm ^(b)	Gross cps	Gamma Ln cps ^(b)	μ R/h	Ln μ R/h ^(b)
41	194	600	6.397	2000	7.601	70	4.248
42	194	4000	8.294	>10,000	(c)	320	5.768
43	194	500	6.215	(c)	(c)	50	3.912
44	7	150	5.011	(c)	(c)	18	2.890
45	7	50	3.912	3000	8.006	16	2.773
46	16	100	4.605	(c)	(c)	6	1.792
47	17	50	3.912	900	6.802	10	2.303
48	17	100	4.605	6000	8.700	30	3.401
49	17	150	5.011	2000	7.601	14	2.639
50	17	150	5.011	1000	6.908	8	2.079
51	17	150	5.011	2500	7.824	16	2.773
52	17	150	5.011	1500	7.313	12	2.485
53	17	100	4.605	900	6.802	8	2.079
54	37	80	4.382	(c)	(c)	17	2.833
55	37	50	3.912	2000	7.601	12	2.485
56	49	50	3.912	(c)	(c)	10	2.303
57	49	50	3.912	1000	6.908	12	2.485
58	49	100	4.605	1000	6.908	10	2.303
59	49	100	4.605	1000	6.908	8	2.079
60	85	200	5.298	3000	8.006	16	2.773
61	99	80	4.382	2000	7.601	20	2.996
62	117	100	4.605	900	6.802	8	2.079
63	126	180	5.193	5000	8.517	50	3.912
64	127	250	5.521	3500	8.161	20	2.996
65	127	150	5.011	3000	8.006	12	2.485
66	127	100	4.605	2500	7.824	18	2.890
67	127	100	4.605	3000	8.006	14	2.639
68	128	100	4.605	3000	8.006	20	2.996
69	128	100	4.605	1000	6.908	16	2.773
70	129	400	5.991	3500	8.161	40	3.689
71	129	250	5.521	4000	8.294	24	3.178
72	131	400	5.991	5500	8.613	60	4.094
73	131	300	5.704	5000	8.517	25	3.219
74	133	400	5.991	2200	7.696	20	2.996
75	133	150	5.011	3000	8.006	16	2.773
76	157	150	5.011	(c)	(c)	10	2.303
77	157	50	3.912	1200	7.090	10	2.303
78	158	50	3.912	1000	6.908	12	2.485
79	158	100	4.605	6000	8.700	20	2.996
80	158	100	4.605	1000	6.908	8	2.079
81	159	100	4.605	1000	6.908	8	2.079
82	159	100	4.605	1000	6.908	8	2.079
83	160	200	5.298	(c)	(c)	15	2.708

TABLE 2.1. (Continued)

Row	Sector	GM P-11 Probe		Road Monitor NaI Detector ^(a)		Micro-R-Meter	
		Gross cpm	Gamma Ln cpm ^(b)	Gross cps	Gamma Ln cps ^(b)	μ R/h	Ln μ R/h ^(b)
84	160	50	3.912	800	6.685	10	2.303
85	160	100	4.605	2000	7.601	12	2.485
86	164	3200	8.071	8000	8.987	40	3.689
87	727	70	4.248	727	6.589	14	2.639
88	735	60	4.094	591	6.382	14	2.639

(a) Each cps datum is the sum of the cps readings of the four NaI detectors at that location. NaI measurements in rows 1 through 43 were taken while the Road Monitor was moving. Measurements in rows 44 through 88 were made when the Road Monitor was stationary. See Section 2.0 for discussion.

(b) Natural logarithms

(c) Measurement not taken.

data in Table 2.1 are not suitable for estimating the average radiation levels at above-background locations.

For the first 43 rows of data in Table 2.1, the NaI measurements are those that were taken as the Road Monitor was moving. For rows 44 through 88, the Road Monitor measurements are those taken when the Road Monitor returned at a later time to the stake location and made a measurement while the vehicle was stationary. A regression equation was estimated for each of the two data sets to determine the extent that the response of the NaI detectors depended on whether the Road Monitor was stationary or moving.

On occasion, while the Road Monitor was surveying the study area, a NaI measurement greater than the largest value on the detector meter scale (10,000 cps) was observed. When this happened the measurement was recorded as > 10,000 cps. This occurred at several of the 88 stake locations used in this study (see Table 2.1). These locations could not be used when estimating the regression equations because of the lack of a quantitative cps datum.

3.0 BACKGROUND GROSS-GAMMA READINGS

Partial information about background gross-gamma radiation levels for the study area is provided by NaI (Road Monitor) gross-gamma measurements taken at both ends of the 116-K-2 Trench in the morning and afternoon on 22 days between September 15, 1986 and November 23, 1986, when the Road-Monitor survey of the study area was being conducted. These measurements were taken daily as a partial check that the NaI detectors were working properly, and to measure changes in gross gamma levels over time, both within and between days. The data are summarized in Table 3.1. As these data were taken at only two locations, they are not sufficient to characterize average background gross-gamma radiation levels for the entire study site. These data are used here only as an approximate baseline for comparison with the gross-gamma measurements at stake locations.

In Table 3.1 we see that the mean gross gamma morning and afternoon measurements at the upriver location are similar in value (550 cps versus 590 cps). This also occurred for the downriver location (657 cps versus 687 cps).

TABLE 3.1. Summary of NaI Gross-Gamma Measurements (cps) Made in the Morning and Afternoon at Background Locations at Both Ends of the 116-K-2 Trench.

	<u>Upriver Location</u>			<u>Downriver Location</u> ^(a)		
	<u>Morning</u>	<u>Afternoon</u>	<u>Average</u>	<u>Morning</u>	<u>Afternoon</u>	<u>Average</u>
n	20	11	31	21	11	32
Maximum	647	679	679	820	756	820
Minimum	435	538	435	495	566	495
Mean ($\bar{x}$)	550	590	565	657	687	667
SD ^(b)	58	48	57	88	49	78

(a) End of trench closest to the N reactor.

(b) SD = Standard Deviation = $[(n - 1)^{-1} \sum_{i=1}^n (x_i - \bar{x})^2]^{1/2}$.

The mean gross gamma measurement for morning and afternoon combined was 565 ± 57 (mean $\pm$ standard deviation) cps at the upriver location and 667 ± 78 at the downriver location. The difference in these two averages is 99 ± 12 cps, which is significantly greater than zero ($P < 0.001$; paired t test, Snedecor and Cochran 1980, p. 85). This difference may reflect the fact that the downriver location is closer to the N reactor than the upriver location.

4.0 REGRESSION EQUATIONS

4.1 GM P-11 PROBE VERSUS NaI ROAD MONITOR MEASUREMENTS

Figure 4.1 is a scatter plot of the natural logarithms of GM P-11 probe measurements versus the natural logarithms of NaI (Road Monitor) measurements. The data points associated with NaI measurements obtained while the Road Monitor was stationary are indicated with the symbols S or * . Data points associated with NaI measurements obtained while the Road Monitor was moving are indicated with the symbols M or + . The S and * data are also plotted in Figure 4.2, and the M and + data are plotted in Figure 4.3. The + and * points denote measurements that were taken in one of the following sectors: 129, 131, 132, 133, 164 or 194. These sectors are in a portion of the study site (see Figure 1.1) that has somewhat higher gross gamma levels than other sectors.

Figure 4.1 indicates that the points associated with stationary Road Monitor measurements (S and * points) tend to cluster below the points for mobile Road Monitor measurements (M and + points). This clustering is believed to occur because the NaI measurements taken while the Road Monitor is moving tend to be lower than those taken when the Road Monitor is stationary. The present data are not ideal for testing this hypothesis since the stationary and moving Road Monitor NaI measurements were taken at different locations. However, an experiment was conducted wherein three line gamma-ray sources were placed on the ground surface and the Road Monitor took measurements while stationary and again while moving. The stationary readings were approximately 30% larger than the moving readings.

The linear regression (calibration) lines in Figure 4.2 and 4.3 were obtained using ordinary least-squares linear regression techniques using the plotted data points (see, e.g., Snedecor and Cochran 1980, Chapter 9). These equations may be used to approximately convert a NaI Road Monitor gross gamma cps measurement (sum of four detector measurements) into a GM P-11 gross gamma cpm measurement when the Road Monitor is stationary (Figure 4.2) or moving (Figure 4.3).

FIGURE 4.1. Scatter Plot of GM P-11 Probe Gross Gamma cpm Measurements Versus Road Monitor NaI-Detector Gross Gamma Measurements. See Text for Definition of Plotting Symbols.

FIGURE 4.2. Estimated Linear Regression and 95% Confidence Intervals for Predicting GM P-11-Probe Gross Gamma Measurements From Road Monitor NaI Gross Gamma Measurements Obtained While The Road Monitor is Stationary.

FIGURE 4.3. Estimated Linear Regression and 95% Confidence Intervals for Predicting GM P-11-Probe Gross Gamma Measurements From Road Monitor NaI Gross Gamma Measurements Obtained While The Road Monitor is Moving.

Example 1

To illustrate the use of the equation in Figure 4.3, suppose a new NaI measurement of 1300 cps (sum of the four detectors) is observed while the Road Monitor is moving. Using $\ln 1300 (= 7.170)$ in the equation gives

$$\ln(\text{GM}) = -3.34 + 1.19(7.170) = 5.19,$$

which gives $\exp(5.19) = 180$ cpm as the predicted GM P-11 gross-gamma measurement at that location.

Since there is considerable scatter in the data points about the estimated regression lines in Figures 4.2 and 4.3, conversions using these equations are not exact. That is, if an actual GM P-11 cpm measurement were made at a location where a NaI Road Monitor cps measurement had been made, the NaI measurement may be greater or less than predicted by the equation. The correlation, r between the two types of measurements, was only 0.63 in Figure 4.2 and 0.71 in Figure 4.3. For these reasons, Figures 4.2 and 4.3 also show

curves that give an interval within which we can be 95% confident that the actual GM P-11 measurement, if it were made, would fall. That is, given that a new NaI cps measurement has been obtained, we can be 95% confident that if a GM P-11 measurement were taken at that location, it would fall between the upper and lower limit. We can also say that the probability is only 0.025 (25 chances out of one thousand) that the GM P-11 measurement, if it were taken, would exceed the upper limit. Similarly, the probability is only 0.025 that the GM P-11 measurement would be below the lower limit.

In practice, the limit lines plotted in the figures can be used graphically to obtain preliminary estimates of these limits for any new NaI datum. When more computationally accurate limits are needed, Equations 1 and 2 in Table 4.1 may be used. Equations 1 and 2 are used when the Road Monitor is stationary and moving, respectively. These equations are of the standard form used in linear-regression calculations to estimate upper and lower limits between which individual values are expected to fall (see, e.g., Snedecor and Cochran 1980, p. 166).

To use Equations 1 and 2 in Table 4.1, the only information needed is the natural logarithm of the new NaI cps measurement (denoted by x_0 in these equations). The equation gives the upper limit (UL) and the lower limit (LL) in natural logarithms. The upper and lower limits in the original (untransformed) scale are obtained by computing $\exp(\text{UL})$ and $\exp(\text{LL})$, respectively.

Example 2

To illustrate the equations in Table 4.1, suppose as in Example 1 above, that a NaI measurement of 1300 cps is observed while the Road Monitor is moving. Then using $\ln 1300 = 7.170$ in Equation 2 in Table 4.1 gives

$$[-3.34 + 1.19(7.170)] \pm 2.04(0.65)[1 + 1/34 + (7.170 - 8.14)^2/9.40]^{1/2},$$

or, $\text{UL} = 5.19 + 1.41 = 6.60$, and $\text{LL} = 5.19 - 1.41 = 3.78$. Hence, in the original (untransformed scale), the 95% confidence limits are $\exp(6.60) = 735$ cpm and $\exp(3.78) = 44$ cpm, respectively. The probability is only 0.05 (5 chances out of 100) that an actual GM P-11 gross-gamma measurement at

TABLE 4.1. Equations for Computing Estimated Upper and Lower 95% Confidence Intervals on a Predicted In-Situ Measurement in Logarithmic Scale(a)

Prediction	Road Monitor Status	Equation Number	Upper and Lower Limits in Ln Scale ^(b)
Predicting a GM P-11 gross gamma cpm measurement using a Road Monitor gross gamma cps measurement (sum of four detector measurements)	Stationary	1	$(-0.565 + 0.712x_{\ell}) \pm 2.03(0.63)[1 + 1/39 + (x_{\ell} - 7.57)^2/19.12]^{1/2}$
	Moving	2	$(-3.34 + 1.19x_{\ell}) \pm 2.04(0.65)[1 + 1/34 + (x_{\ell} - 8.14)^2/9.40]^{1/2}$
Predicting a Micro-R-Meter ($\mu R/h$) Measurement using a Road Monitor gross gamma cps measurement (sum of four detector measurements)	Stationary	3	$(-1.82 + 0.60x_{\ell}) \pm 2.02(0.31)[1 + 1/39 + (x_{\ell} - 7.57)^2/19.12]^{1/2}$
	Moving	4	$(-1.98 + 0.792x_{\ell}) \pm 2.06(0.53)[1 + 1/28 + (x_{\ell} - 8.25)^2/6.04]^{1/2}$
Predicting a GM P-11 gross gamma cpm Measurement using a Micro-R-Meter ($\mu R/h$) Measurement	Not Applicable	5	$(2.17 + 0.965x_m) \pm 1.99(0.56)[1 + 1/81 + (x_m - 3.57)^2/109.77]^{1/2}$

(a) Denoting UL and LL to be the upper and lower limits computed using an equation in this table, then the upper and lower limits in the original (untransformed) scale are computed as $\exp(UL)$ and $\exp(LL)$, respectively. See text for discussion.

(b) x_{ℓ} = natural logarithm of the Road Monitor gross gamma cps measurement (sum of four detector measurements).

x_m = natural logarithm of the Micro-R-Meter $\mu R/h$ measurement.

the NaI measurement location would fall outside the interval from 44 cpm to 735 cpm. Also, the probability is only 0.025 that the GM P-11 measurement would exceed the upper limit of 735 cpm.

The confidence statements illustrated in Example 2 are correct only if (1) the deviations about the logarithmic-scale regression line are normally distributed, (2) the data set used to estimate the parameters in Equations 2 and 3 in Table 4.1 are representative of other data sets that might have been collected at the study site using the same procedures, and (3) new NaI gross-gamma measurements are taken in the same way as the NaI measurements used to estimate the equations.

If several new NaI measurements are taken, the probability that all of the predicted GM P-11 measurements will be between the limits given by Equations 1 and 2 in Table 4.1 is substantially less than 0.95. That is, the 95% confidence statement is correct only for a single new NaI measurement. The case of multiple predictions can be handled by moving the confidence limit lines farther away from the linear regression line so that the probability statements apply to the entire group of new predictions. Several statistical techniques for doing so are available, one of which is given by Snedecor and Cochran (1980, p. 166).

The reader may wonder why we have plotted the data (Figures 4.1, 4.2, and 4.3) and estimated the regression lines and confidence limit lines using the natural logarithms of the data rather than the original-scale (untransformed) measurements. The reason is that the data cover a wide range of values, a few of which are substantially larger than the others (see Table 2.1). In this situation, it is more likely that the data for each type of detector are distributed lognormally rather than normally. This situation in turn implies that the logarithms are normally distributed, which implies that regression estimates and confidence limits should be computed in logarithmic scale, and these limits then transformed back (exponentiated) to get estimates in the original scale.

A consequence of this approach is that in the original scale, the final predicted value will not be midway between the estimated upper and lower limits. To illustrate, in Examples 1 and 2 above, the best estimate of the GM P-11 measurement (180 cpm) is not midway between the estimated upper and

lower limits (44 cpm and 735 cpm). This happened because the regressions and limits were first calculated in logarithmic scale and then exponentiated.

4.1.1 Interpretation of ~10,000 Road Monitor Measurements Recorded at the 116-K-2 Trench Study Site

As noted above, about 10,000 measurements made by the Road Monitor NaI detectors were recorded as the Road Monitor moved back and forth across the 116-K-2 study area. All but about 450 of these measurements were below nominal background readings of about 800 cps. The small areas found to be above background are shown in Figure 1.1. The total size of these above-background areas is about 6000 ft^2 ($\sim 560 \text{ m}^2$), or about 0.15% of the $4,000,000 \text{ ft}^2$ ($\sim 370,000 \text{ m}^2$) study area. Most of the 10,000 readings were between about 800 and 1400 cps. Using the equation in Figure 4.3 we find that the estimated GM P-11 probe readings corresponding to these two Road Monitor readings are 100 cpm and 194 cpm, respectively. Of course, as is evident from the scatter of data points about the equation in Figure 4.3, the actual GM P-11 reading may be different from that predicted using the equation. For example, in Table 2.1 we see that the GM P-11 readings ranged from 200 cpm to 1000 cpm at seven locations where the moving Road Monitor reading was a constant 2000 cps. The seven GM P-11 readings were 200, 200, 250, 300, 400, 600, and 1000 cpm. This variability in the GM P-11 readings at locations where the Road Monitor reading was the same may have been caused in part by the fact that the Road Monitor reading applies to the area scanned by all four NaI detectors, whereas a GM P-11 reading applies to a smaller portion of that area. The GM P-11 readings are more sensitive to small "point" sources of surface-soil radioactivity because they apply to a smaller area.

It was because of this variability in GM P-11 readings for a given Road Monitor reading that the 95% confidence-limit lines were estimated for the regression line. These limit lines provide guidance on GM P-11 probe measurements that are unlikely to occur for any given Road Monitor reading. It should be noted that other percentage confidence-limit lines could have been constructed. In this report we choose to compute 95% confidence limits primarily because of their common use in research applications. It could be argued that a smaller percentage limit, perhaps 90%, 80%, or even smaller is more appropriate for making decisions at the 116-K-2 Trench. Use of these

smaller percentage limits will result in the limit lines lying closer to the fitted equation line.

To illustrate, in 12 background sectors at the 116-K-2 Trench study site, 250 background Road Monitor readings of 800 cps were recorded. The equation in Figure 4.3 predicts that the GM P-11 reading at these 250 locations would be ~100 cpm. Using Equation 2 in Table 4.1, we find that the upper 95% limit on the GM P-11 reading is ~450 cpm when the Road Monitor reads 800 cps. Hence, we would expect that 2.5% (~6 locations) of the 250 locations would have GM P-11 readings greater than ~450 cpm and 97.5% (~244 locations) of the 250 locations would have GM readings less than ~450 cpm. Now suppose we compute 80% confidence limits. Then the factor of 2.04 in Equation 2 (Table 4.1) would change to 1.31 (see Table A.4 in Snedecor and Cochran, 1980). Then, recomputing Equation 2, we find the upper 80% limit for the GM P-11 reading is ~260 cpm when the Road Monitor reads 800 cps. That is, we would expect that 10% (25 locations) of the 250 locations would have GM P-11 readings greater than ~260 cpm, and 90% (225 locations) of the 250 locations would have GM readings less than ~260 cpm. If we compute 50% limits, the factor of 2.04 in Equation 2 of (Table 4.1) changes to 0.683. Then, recomputing Equation 2, we find the upper 50% limit for the GM P-11 reading is ~170 cpm when the Road Monitor reads 800 cps. That is, we would expect that 25% (~62 locations) of the 250 locations would have GM P-11 readings greater than ~170 cpm, and 75% (~188 locations) of the 250 locations would have GM readings less than ~170 cpm.

To summarize, upper limits for individual GM P-11 probe readings provide information on the proportion of GM P-11 readings that are expected to exceed the computed upper limit value for a given Road Monitor reading. The upper limit value depends on the percentage confidence limit that is chosen as being appropriate for the situation. Also, as pointed out above, the computed upper limits are valid only when the distribution (variability or scatter) of GM P-11 readings for any given Road Monitor reading is Gaussian (the "normal" distribution), and when this variability about the fitted regression line does not change for different Road Monitor readings. The need to fulfill this latter assumption was the reason we fit equations to the log-transformed data.

4.2. MICRO-R-METER VERSUS NaI ROAD-MONITOR MEASUREMENTS

Figures 4.4, 4.5, and 4.6 display the natural logarithms of the Micro-R-Meter $\mu\text{R/h}$ measurements plotted versus the natural logarithms of the NaI gross-gamma cps measurements. The symbols S, M, +, and * used in the plots have the same meaning as described above for Figures 4.1, 4.2, and 4.3. Also, the same statistical methods were used to obtain the regression equations and the confidence limits.

For these data we also see that the points associated with stationary Road Monitor measurements (S and * points) tend to cluster above the points for mobile Road Monitor measurements (M and + points). Hence, Figures 4.5 and 4.6 are provided and should be used for the stationary and moving cases, respectively. The correlation between the Road Monitor and Micro-R-Meter measurements was 0.81 in Figure 4.5 and 0.58 in Figure 4.6. The linear equations in these two figures may be used to approximately convert a NaI Road Monitor gross-gamma cps measurement (sum of the four detector measurements) into a Micro-R-Meter $\mu\text{R/h}$ measurement. This is done using the same approach that was illustrated in Section 4.1 for GM P-11-probe measurements. Equations 3 and 4 in Table 4.1 may be used to compute upper and lower limits between which the Micro-R-Meter measurement, if it were to be made, would fall with 95% confidence. The procedure for doing so is the same as illustrated in Section 4.1.

4.3. GM P-11 PROBE VERSUS MICRO-R-METER MEASUREMENTS

In Figure 4.7 are plotted the natural logarithms of GM P-11-probe gross-gamma measurements versus the natural logarithms of Micro-R-Meter $\mu\text{R/h}$ measurements. The correlation between GM P-11 probe measurements and Micro-R-Meter measurements was 0.90. Also shown is the estimated linear regression line which may be used to convert a Micro-R-Meter $\mu\text{R/h}$ measurement into a GM P-11-probe gross-gamma cpm measurement. In addition, the 95% confidence-limit lines are shown. Equation 5 in Table 4.1 may be used to compute the 95% limits for a predicted GM P-11 probe measurement in the same manner as described in Section 4.1. In Table 4.1, Equation 5, x_m denotes the natural logarithm of the Micro-R-Meter $\mu\text{R/h}$ measurement for which the corresponding GM P-11 measurement is desired.

FIGURE 4.4. Scatter Plot of Micro-R-Meter $\mu R/h$ Measurements Versus Road Monitor NaI Gross Gamma Measurements. See Text for Definition of Plotting Symbols.

FIGURE 4.5. Estimated Linear Regression and 95% Confidence Intervals for Predicting Micro-R-Meter Measurements from Road Monitor Gross Gamma Measurements Obtained While the Road Monitor is Stationary.

FIGURE 4.6. Estimated Linear Regression and 95% Confidence Intervals for Predicting Micro-R-Meter Measurements from Road Monitor NaI Gross Gamma Measurements While the Road Monitor is Moving.

FIGURE 4.7. Estimated Linear Regression and 95% Confidence Intervals for Predicting GM P-11 Probe Gross Gamma Measurements from Micro-R-Meter Measurements. See Text for Definition of Plotting Symbols.

5.0 ⁹⁰Sr VERSUS ¹³⁷Cs MEASUREMENTS IN SURFACE SOIL SAMPLES

Measurements of ⁹⁰Sr concentrations in soil must be obtained using radiochemical techniques, whereas ¹³⁷Cs concentrations are measured using less expensive gamma spectroscopy. In this section, a linear regression equation is estimated that may be used to approximately convert a ¹³⁷Cs gamma spectroscopy measurement of a surface soil sample into a ⁹⁰Sr measurement on that sample. Also provided is an equation for estimating the limits within which we can be 95% confident that the actual ⁹⁰Sr measurement would fall.

The statistical methods used to estimate these equations are the same as used in Sections 4.1, 4.2, and 4.3 above. The ⁹⁰Sr and ¹³⁷Cs data that were used to estimate the equations are given in Table 5.1. The first seven of these samples were collected in sectors identified by GM P-11 and Micro-R-Meter detectors as having above-background contamination levels. Samples 8 through 14 in Table 5.1 were surface soil samples collected in 1975 (Dorian and Richards 1978, Table 2.7-38, p. 2-88). We note that measurements of subsurface soil samples were not included when estimating the regression line or limit lines because ⁹⁰Sr may be more mobile in the soil column than ¹³⁷Cs. If ⁹⁰Sr is more mobile, then the regression relationship between ⁹⁰Sr and ¹³⁷Cs would depend on the depth at which soil was collected. Accordingly, the linear regression line and limit lines obtained in this section should be used only for surface soil.

Figure 5.1 is a plot of the natural logarithms of the ⁹⁰Sr data versus the natural logarithms of the ¹³⁷Cs measurements (both in units of ln pCi/g). Also shown is the estimated linear regression line and the 95% confidence-interval lines. The natural logarithm of the ¹³⁷Cs measurement is used in the equation to compute the predicted natural logarithm of the ⁹⁰Sr measurement. Then this value is exponentiated to obtain the predicted ⁹⁰Sr measurement in the original, untransformed, scale. The correlation between the logarithms of the ⁹⁰Sr and ¹³⁷Cs measurements was 0.92.

The 95% confidence limits in logarithmic scale are computed for a new ¹³⁷Cs measurement by computing

$$(-0.986 + 0.613x_2) \pm 2.18(0.69)[1 + 1/14 + (x_2 - 1.54)^2/83.34]^{1/2}, \quad (1)$$

TABLE 5.1. Measurements (pCi/g) of ^{90}Sr and ^{137}Cs in Surface Soil Samples Collected Near the 116-K-2 Trench

Sample Number	Sample Identification	Sector Number	^{90}Sr (pCi/g)	^{137}Cs (pCi/g)
1	86-202	129	1.22	12.7
2	86-213	132	22.6	157
3	86-258	137	0.503	5.50
4	86-279	158	0.506	4.93
5	86-277	17	0.768	5.36
6	86-207	194	39.6	895
7	86-257	7	0.484	1.6
8	Q-0(a)	N/A(b)	0.31	0.880
9	U-0(a)	N/A	0.097	0.069
10	V-0-1(a)	N/A	2.00	2.80
11	V-0-2(a)	N/A	2.20	97.0
12	Y-0(a)	N/A	0.21	0.54
13	Z-0(a)	N/A	0.70	0.65
14	DD-0(a)	N/A	0.27	0.93

(a) These data are from Table 2.7-38 in Dorian and Richards (1978, p. 2-88)

(b) N/A = Not Applicable

where x_2 denotes the natural logarithm of the new ^{137}Cs measurement. Then the confidence-interval limits in the original scale on the ^{90}Sr measurement are obtained by exponentiating these logarithmic limits. These computational procedures are the same as were used in previous sections.

Example 3

Suppose a new surface soil sample is collected at the 116-K-2 study site and that the gamma-spectroscopy analysis on that sample gave a ^{137}Cs measurement of 20 pCi/g. Using $\ln 20 (= 3.00)$ in the linear equation given in Figure 5.1 we obtain

$$\ln (^{90}\text{Sr}) = -0.986 + 0.613(3.00) = 0.853 ,$$

which gives $\exp(0.853) = 2.3$ pCi/g as the predicted ^{90}Sr measurement for that surface soil sample.

FIGURE 5.1. Estimated Linear Regression and 95% Confidence Intervals for Predicting ^{90}Sr Measurements from ^{137}Cs Measurements.

To estimate the 95% confidence interval we insert 3.00 in Equation 1 above to obtain

$$[-0.986 + 0.613(3.00)] \pm 2.18(0.69)[1 + 1/14 + (3.00 - 1.54)^2/83.34]^{1/2}$$

or, 0.853 ± 1.58 , or -0.73 and 2.43 , which are the limits in logarithmic scale. In the original (untransformed) scale, the upper and lower limits defining the confidence interval are $\exp(-0.73) = 0.48$ pCi/g and $\exp(2.43) = 11.4$ pCi/g, respectively. Hence, the best estimate of the ^{90}Sr measurement is 2.3 pCi/g, and we are 95% confident that the ^{90}Sr measurement, if it were made, would fall between 0.48 pCi/g and 11.4 pCi/g. We are also 97.5% confident that the ^{90}Sr measurement would not exceed 11.4 pCi/g.

We note that only 14 data pairs were available for estimating the regression line and limits. It would be desirable to obtain additional data so that more accurate predictions could be made. A minimum of 25 data pairs is recommended.

6.0 THERMOLUMINESCENT DOSIMETER (TLD) MEASUREMENTS

Thermoluminescent dosimeters were used to measure dose rates in millirem (mrem) per 30-day period at 34 locations on a grid pattern (Figure 6.1) over the study area during October and November of 1986. This was done to estimate the spatial variability of dose-rate measurements over the study area and to compare those rates with those at communities relatively close to Hanford and at Spokane and Seattle.

At each location, three TLD chips were encased in a plastic capsule that was placed 0.15 m (six inches) from the ground surface in a horizontal attitude. At two of the locations a capsule was also placed at 1-m height. These capsules were numbered 33 and 35. The capsules placed at 0.15-m height were numbered 1 through 32 and 34 and 36. The 36 TLD capsules remained in the field for 30 days during October 1986. Following their removal from the field, a new set of 36 TLD capsules were placed at the same locations and remained for 30 days during November. The October TLD capsules were inadvertently left unshielded for 10 days after their removal from the field, whereas the November TLD capsules were promptly shielded.

Table 6.1 gives the measured dose rate in units of mrem/30day for each of the three TLD chips at each location. We see from Table 6.1 that the average dose rates (average of the three chips at each location) for the 0.15-m height TLDs ranged from 8.2 to 10.4 (average of 8.98) in October and from 6.3 to 8.7 (average of 7.61) in November for capsules other than 34 and 36. These latter two capsules were located in the northwest corner of the study area (Section 132 and 194; see Figures 1.1 and 6.1) where the NaI (Road Monitor) data indicated higher radiation levels were present. The dose rate for capsule 34 was 326 in October and 365 in November. The dose rates for capsule 36 were 190 and 205 for October and November, respectively.

Figure 6.2 plots the October and November dose rates for capsules 1 through 32 to show graphically the spatial variability in the rates between capsules over the study site. The capsules with the lowest rates (capsules 4, 5, 6, 7, 8, 16, 24, and 25) were in areas that had been covered with rock. For each location the October rate was larger than the November rate. This

TABLE 6.1. TLD Data (mrem/30day Period) for Locations in Figure 6.1.

<u>Location</u>	<u>October</u>	<u>November</u>	<u>Location</u>	<u>October</u>	<u>November</u>
1	8.22	7.10	17	8.59	8.47
1	8.66	7.47	17	9.60	8.56
1	8.47	7.76	17	9.53	8.73
2	9.28	7.69	18	7.97	6.60
2	8.70	7.91	18	8.66	7.38
2	9.69	7.86	18	8.31	7.45
3	9.28	7.27	19	8.34	8.23
3	9.10	7.88	19	9.19	8.36
3	9.26	7.64	19	8.73	8.19
4	8.08	6.62	20	8.75	7.84
4	8.45	7.01	20	7.88	7.64
4	8.24	6.95	20	9.35	7.91
5	7.07	5.83	21	8.89	6.25
5	7.76	6.20	21	9.14	8.06
5	8.77	7.01	21	9.07	8.54
6	8.93	6.66	22	8.98	6.60
6	9.43	6.84	22	9.44	8.30
6	7.51	6.66	22	9.60	7.23
7	7.00	6.57	23	10.5	8.49
7	8.18	7.21	23	9.44	7.95
7	8.24	6.51	23	10.1	8.36
8	8.36	6.99	24	7.83	6.03
8	8.73	6.99	24	8.54	7.19
8	9.07	6.84	24	8.08	6.07
9	9.60	8.17	25	7.76	6.25
9	8.84	7.34	25	8.31	6.68
9	9.22	8.12	25	8.87	6.64
10	9.51	6.31	26	9.39	6.68
10	9.86	8.63	26	9.28	8.32
10	10.6	8.08	26	9.10	7.69
11	9.19	8.23	27	8.50	7.84
11	8.68	8.06	27	9.79	7.86
11	9.16	7.73	27	9.10	7.71
12	9.65	7.86	28	8.22	7.40
12	8.93	8.12	28	8.98	7.67
12	10.0	8.12	28	9.56	8.32
13	9.44	7.36	29	10.0	7.67
13	9.21	8.25	29	10.6	7.97
13	9.67	7.84	29	10.43	8.25
14	9.37	8.34	30	8.43	8.93
14	9.37	8.73	30	9.46	8.04
14	10.6	8.01	30	10.5	8.89
15	9.92	7.93	31	8.27	7.53
15	9.53	8.06	31	8.08	8.56
15	10.0	8.52	31	8.82	7.97
16	6.79	6.12	32	10.6	9.13
16	7.74	7.01	32	9.76	8.17
16	7.30	6.53	32	10.2	8.93

TABLE 6.1. (Continued)

<u>Location</u>	<u>October</u>	<u>November</u>
33	69.5	69.2
33	71.6	79.2
33	80.2	77.8
34	306	334
34	350	369
34	320	393
35	36.3	32.0
35	40.8	33.0
35	38.1	34.0
36	172	208
36	201	203
36	197	206

FIGURE 6.1. Locations Where Capsules Containing Three Thermoluminescent Dosimeters (TLDs) were Placed at the 116-K-2 Trench Study Area.

FIGURE 6.2. Comparison of Average Thermoluminescent Dosimeter (TLD) Measurements for October and November at 32 Locations Outside the more Contaminated Northwest Corner of the 116-K-2 Trench Study Area.

systematic difference is believed to be due to the fact that the October TLDs were left unshielded for several days after their removal from the field.

A rough comparison of the 116-K-2 Trench study-site TLD dose rates with those obtained offsite for capsules placed at 1-m height was obtained as follows. The dose rates for the 116-K-2 Trench TLD capsules that were placed at 1-m height (those numbered 33 and 35) were 74 and 38, respectively, in October, and 75 and 33, respectively, in November. Dividing each of these rates by the corresponding rate obtained for the TLD capsule placed at 0.15-m height at the same location (capsules numbered 34 and 36) gives $74/326 = 0.227$, $38/190 = 0.20$, $75/365 = 0.205$, and $33/205 = 0.161$. The arithmetic average of these four ratios is 0.20 ± 0.0275 ($\pm$ standard deviation). Hence, at the 116-K-2 trench study site in the higher radiation area, TLD capsules placed at 1-m height gave mrem/30day measurements that were on the average about one-fifth as large as when the capsules was placed at 0.15-m height. Multiplying 0.20 by the average TLD dose rate at 0.15-m height over the study site for October gives $0.20(8.983) = 1.80$ mrem/30day. Similarly, for November

we obtain $0.20(7.609) = 1.52$ mrem/30day. That is, 1.80 and 1.52 are the estimated TLD mrem/30day rates that would have been measured if the TLDs had been placed at 1-m height. (This conversion assumes the factor 0.20, which was estimated in the higher radiation zone, is valid for the lower radiation zone at the study site).

Now, the annual Hanford environmental monitoring report for 1986 (Hanford, 1987) reported (p. 3.51) that the TLD dose rates for Seattle and Spokane for 1985, which were taken at 1-m height, were 56 mrem/yr (4.7 mrem/30day) and 88 mrem/yr (7.3 mrem/30day), respectively. That document also reported that the average of the 1-m-height mrem/yr TLD dose rate for Walla Walla, McNary, Sunnyside, Moses Lake, Washtucna, and Yakima was 60 mrem/yr (5 mrem/30day). These offsite rates are from 3 to 5 times larger than the rates of 1.80 and 1.52 for October and November computed above for the lower-radiation-level portion of the 116-K-2 Trench study site. However, that portion of the 116-K-2 Trench study site that has higher radiation levels (the Northwest portion) had 1-m-height mrem/30day rates about 10 to 15 times larger than Seattle and the communities nearer to Hanford, and rates about 5 to 7 times larger than Spokane. Table A.54 in Hanford (1987, p. A.57) gives additional TLD data for other offsite locations.

We emphasize that these dose-rate calculations are preliminary and approximate because TLD capsules were placed at only two locations in the higher radiation zone at the 116-K-2 Trench study site, and the measured dose rates at these locations differed by a factor of 2.

7.0 REFERENCES

- Dorian, J. J. and R. Richards. 1978. Radiological Characterization of the Retired 100 Areas. UNI-946, UNC Nuclear Industries, Inc., Richland, Washington.
- Hanford. 1987. Environmental Monitoring at Hanford for 1986. PNL-6120, Pacific Northwest Laboratory, Richland, Washington.
- Snedecor, G. W. and W. G. Cochran. 1980. Statistical Methods. 7th Edition Iowa State University Press, Ames.

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