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Westinghouse Hanford Company

1990 YEARLY CALIBRATION OF PACIFIC NORTHWEST LABORATORY'S GROSS-GAMMA BOREHOLE GEOPHYSICAL LOGGING SYSTEM

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SUMMARY

This report describes the 1990 yearly calibration of a gross-gamma geophysical pulse logging system owned by the U.S. Department of Energy (DOE) and operated by Pacific Northwest Laboratory (PNL). The calibration was conducted to permit the continued use of this system for geologic and hydrologic studies associated with remedial investigation at the Hanford Site.

Primary calibrations to equivalent uranium units were conducted in borehole model standards that were recently moved to the Hanford Site from the DOE field calibration facility in Spokane, Washington. The calibrations were performed in borehole models SBL/SBH and SBA/SBB, which contain low equivalent-uranium concentrations.

The integrity of the system throughout the previous year for gamma-ray monitoring was demonstrated using the before- and after-logging field calibration readings with the field source in calibration Positions 1 and 2. Most of the Position 1 readings are within an 8% limit that is set by the governing PNL technical reference procedure as a critical value above which the instrument is considered suspect. Many of the Position 2 readings exceed the 8% limit; however, the fluctuation was traced to field-source geometry variability that affected Position 1 count rates by up to 6% and Position 2 count rates by as much as 16%.

Correlations were established based on two similar approaches for relating observed count rate in before- and after-logging field calibrations to equivalent uranium concentrations.

The temperature drift of the gamma-ray probe was documented and amounts to less than 0.1%/°C within the temperature range 0°C to 42°C.

The low-energy cutoff for the gross gamma-ray probe was determined to be between 46.5 and 59.5 keV.

ACKNOWLEDGMENTS

Contributions made by V. L. McGhan made it possible to produce this report. Mr. McGhan's extensive knowledge and interpretative skills were used throughout the calibration process.

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INTRODUCTION

This report describes the yearly calibration of a gross-gamma geophysical pulse logging system owned by the U. S. Department of Energy (DOE) and operated by Pacific Northwest Laboratory (PNL).[a] The initial base calibration of the system is described in a previous report (Brodeur and Koizumi 1989), from which one can obtain a more thorough understanding of the system.

The purpose of the yearly base calibration is to ensure the quality of data obtained in the field. The system calibration summarized in this report includes: 1) a check of basic instrumentation calibration, i.e., rate meters, strip chart recorder, and signal generator; 2) a rigorous determination of the system dead time; 3) two primary calibrations using both the SBL/SBH and the SBA/SBB borehole models; 4) documentation of the probe response to the portable field calibration source throughout the course of calendar year 1989; 5) a determination of the temperature drift of the recorded response as the system warms up; and 6) an estimate of the probe energy cutoff level.

The DOE field calibration borehole model standards, used to establish the primary calibrations, were moved from the Spokane facility to the Hanford Site, so all calibrations were performed on site.

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INSTRUMENTATION CALIBRATION

The critical instrumentation for the geophysical pulse logging system includes: 1) a gamma-ray probe for detecting radiation and transmitting information uphole; 2) a pulse generator for establishing scale integrity; 3) a rate meter to collect signals coming uphole, average statistical fluctuations, and create an analog voltage output; and 4) a chart recorder to provide a hard-copy record of detected probe activity. A detailed description of the logging system can be found in the Gearhart-Owen instruction manual for pulse logging systems (Gearhart-Owen Industries, not dated).

The system instrumentation was not recalibrated at the Westinghouse Hanford Standards Laboratory because field calibrations indicated that no deviation from the base calibration had occurred over the course of a year of data collection.

GAMMA-RAY PROBE (DETECTOR)

A brief experiment was performed using various x-ray and gamma-ray sources to estimate the low-energy cutoff of the gamma-ray probe. The following sources were held against the probe and then moved a few inches away every 15 s to confirm a response to the source: 1) ^{55}Fe with 5.90-keV x-rays, 2) ^{109}Cd with 22-keV and 25-keV x-rays and an 88-keV gamma ray, 3) ^{210}Pb with 46.5-keV gamma rays, and 4) ^{241}Am with 59.5-keV gamma rays. The gamma-ray probe did not responded to the ^{55}Fe (5.90 keV) or ^{210}Pb (46.5 keV) sources, but the probe did respond to the ^{109}Cd (88 keV) and ^{241}Am (59.5 keV) sources, indicating that the energy cutoff is set between 46.5 keV and 59.5 keV. The chart-recorder output for this experiment is contained in Appendix A.

PULSE GENERATOR

The pulse generator was not recalibrated at the Westinghouse Hanford Standards Laboratory since no expiration date had been assigned to the previous calibration. However, the pulse generator was checked against a digital counting system by counting the output pulses at several rate settings. The pulse generator appeared to be accurate, even at higher output rates.

RATE METERS

The original base calibration report verified the linearity of two rate meters (Brodeur and Koizumi 1989, pp. 6-7). A similar set of measurements was again made, the results of which are shown in Tables 1 and 2. The results verify that the linear response of both rate meters has not changed during the past year: the measured linearity for RMM208, Serial No. 185, is 0.001968 ± 0.22% as compared to 0.001968 ± 0.40% previously, while the linearity for RMM208, Serial No. 182, is 0.001794 ± 0.28% compared to 0.001791 ± 0.63%.

The absolute value of the rate-meter output should not be a concern since the "zero" and "scale" dials on the chart recorder should correct for any zero offset or scaling in the output voltage. However, when the rate-meter outputs for known rates from the pulse generator were recorded, the results indicated that the recorder was not properly set to respond to a full-scale setting; nor was a true zero response being obtained since a positive chart recording was consistently obtained when small or zero input signals were applied.

The internal rate-meter potentiometers (R32, R34, R36, R38, R48, R52, and R60 on the RMM208 wiring schematic) were adjusted to give baseline recorder response to a zero signal and a full-scale recorder response to full-scale signal. The potentiometer (R54) controlling the faceplate meter was also adjusted accordingly. In the case of RMM208, Serial No. 182, a 15K resistor was attached in parallel with the 7.5K resistor (R53) to get the faceplate meter to attain a proper full-scale setting.

The resulting recorder output voltage from the adjusted rate meters was measured with a digital voltmeter and is presented in Tables 3 and 4. The data show slightly less variation than data presented in the base calibration report (Brodeur and Koizumi 1989). The linearity constant is the same for

TABLE 1. Recorder Output Voltage from Rate Meter RMM208 Serial No. 185 Before Internal Potentiometer Adjustments

Time Const. (s)	Full-scale Input (Hz)	Voltage output as % of full-scale input 10%	20%	50%	100%	Linearity Constant (x 10^3)	Zero (x 10^3)
1	50		0.0355		0.1930	0.19688	-0.00388
1	100	0.0158		0.0946	0.1930	0.19689	-0.00387
1	500		0.0355		0.1931	0.19700	-0.00390
1	1,000	0.0158			0.1927	0.19656	-0.00386
1	50,000	0.0158			0.1929	0.19678	-0.00388
Average		0.0158	0.0355	0.0946	0.19294	0.19682	-0.00388
Maximum Deviation		0.0	0.0	0.0	0.00040	0.00044	0.00004
Maximum Deviation (%)		0.0	0.0	0.0	0.21%	0.22%	1.0%

TABLE 2. Recorder Output Voltage from Rate Meter RMM208 Serial No. 182 Before Internal Potentiometer Adjustments

Time Const. (s)	Full-scale Input (Hz)	Voltage output as % of full-scale input 10%	20%	50%	100%	Linearity Constant (x 10^3)	Zero (x 10^3)
1	50		0.0400		0.1840	0.18000	0.00400
1	100	0.0220		0.0936	0.1830	0.17889	0.00413
1	500		0.0399		0.1830	0.17888	0.00413
1	1,000	0.0220			0.1830	0.17889	0.00411
1	50,000	0.0220			0.1830	0.17889	0.00411
Average		0.0220	0.03995	0.0936	0.1832	0.17911	0.00410
Maximum Deviation		0.0	0.00010	0.0	0.0010	0.00112	0.00013
Maximum Deviation (%)		0.0	0.25%	0.0	0.55%	0.63%	3.2%

TABLE 3. Recorder Output Voltage from Rate Meter RMM208 Serial No. 185 After Internal Potentiometer Adjustments

Time Const. (s)	Full-scale Input (Hz)	Voltage output as % of full-scale input: 10%	20%	50%	100%	Linearity Constant (x 10^3)	Zero (x 10^3)
1	50		0.0360		0.1790	0.17875	-0.00025
1	100	0.0180		0.0890	0.1790	0.17893	-0.00010
1	500		0.0360		0.1790	0.17875	-0.00025
1	1,000	0.0180		0.0900	0.1790	0.17885	0.00028
1	5,000	0.0180	0.0360		0.1790	0.17885	0.00028
1	10,000	0.0180		0.0900	0.1790	0.17885	0.00028
1	50,000	0.0180	0.0360		0.1790	0.17884	0.00017
Average		0.018	0.036	0.0897	0.179	0.17883	0.00004
Maximum Deviation		0.0	0.0	0.0010	0.0	0.00009	0.00053
Maximum Deviation (%)		0.0	0.0	1.1%	0.0	0.050%	>100%

TABLE 4. Recorder Output Voltage from Rate Meter RMM208 Serial No. 182 After Internal Potentiometer Adjustments

Time Const. (s)	Full-scale Input (Hz)	Voltage output as % of full-scale input: 10%	20%	50%	100%	Linearity Constant (x 10^3)	Zero (x 10^3)
1	50		0.0360		0.1790	0.17875	-0.00025
1	100	0.0180		0.0890	0.1790	0.17893	-0.00010
1	500		0.0360		0.1790	0.17875	-0.00025
1	1,000	0.0180		0.0900	0.1790	0.17885	0.00028
1	5,000	0.0180	0.0360		0.1790	0.17885	0.00028
1	10,000	0.0180		0.0900	0.1790	0.17885	0.00028
1	50,000	0.0180	0.0360		0.1790	0.17884	0.00017
Average		0.018	0.036	0.0897	0.179	0.17883	0.00004
Maximum Deviation		0.0	0.0	0.0010	0.0	0.00009	0.00053
Maximum Deviation (%)		0.0	0.0	1.1%	0.0	0.050%	>100%

both rate meters, and the zero is now truly zero. The use of the "zero" and "scale" dials on the chart recorder is less critical than before.

CHART RECORDER

Some hysteresis was noticed in the chart recorder when the output from the pulse generator was recorded: the particular value asymptotically approached by the recorder pen depended on whether the previous value was lower or higher, and amounted to a 0.5% difference at full scale and a 5% difference at a tenth of full scale.

In normal operation, the time constant is set such that there is sufficient statistical fluctuation in the output that the recorded count rate brackets the true count rate. There are some situations, however, when the recorded count rate might be consistently lower or higher than the true count rate, due to recorder hysteresis. One such situation is the primary calibration using the SBL/SBH borehole model. Figure 1 shows the same scan of the SBL section taken on two different scales. The scan taken on the 10K scale (dry well, no casing) shows some statistical fluctuation at the maximum, whereas the scan taken on the 50K scale asymptotically approaches a maximum, and is potentially low by 2.5% [300 counts per second (cps)], although the non-linearity in chart recorder response offsets the reading in the opposite direction so that the two values agree closely (10,045 cps at 10K versus 10,190 cps at 50K). The low points on either side of the peak illustrate the effect more accurately: the reading on the 50K scale is consistently higher than the corresponding reading on the 10K scale, which is tracking the actual value more precisely.

Once the potentiometers had been reset in the rate meters, the recorder read zero on the strip chart for no input and full scale for full input, but read 55% for input which was half of full scale. Because of the strict linearity for the rate meters (as indicated in Tables 1 through 4), it was concluded that the chart recorder had a non-linear response in the mid-region.

It is possible that the "span" of the chart recorder might be set using the internal oscillator within the rate meter itself. Examination revealed that the oscillator is not based on a crystal, and, therefore, is subject to

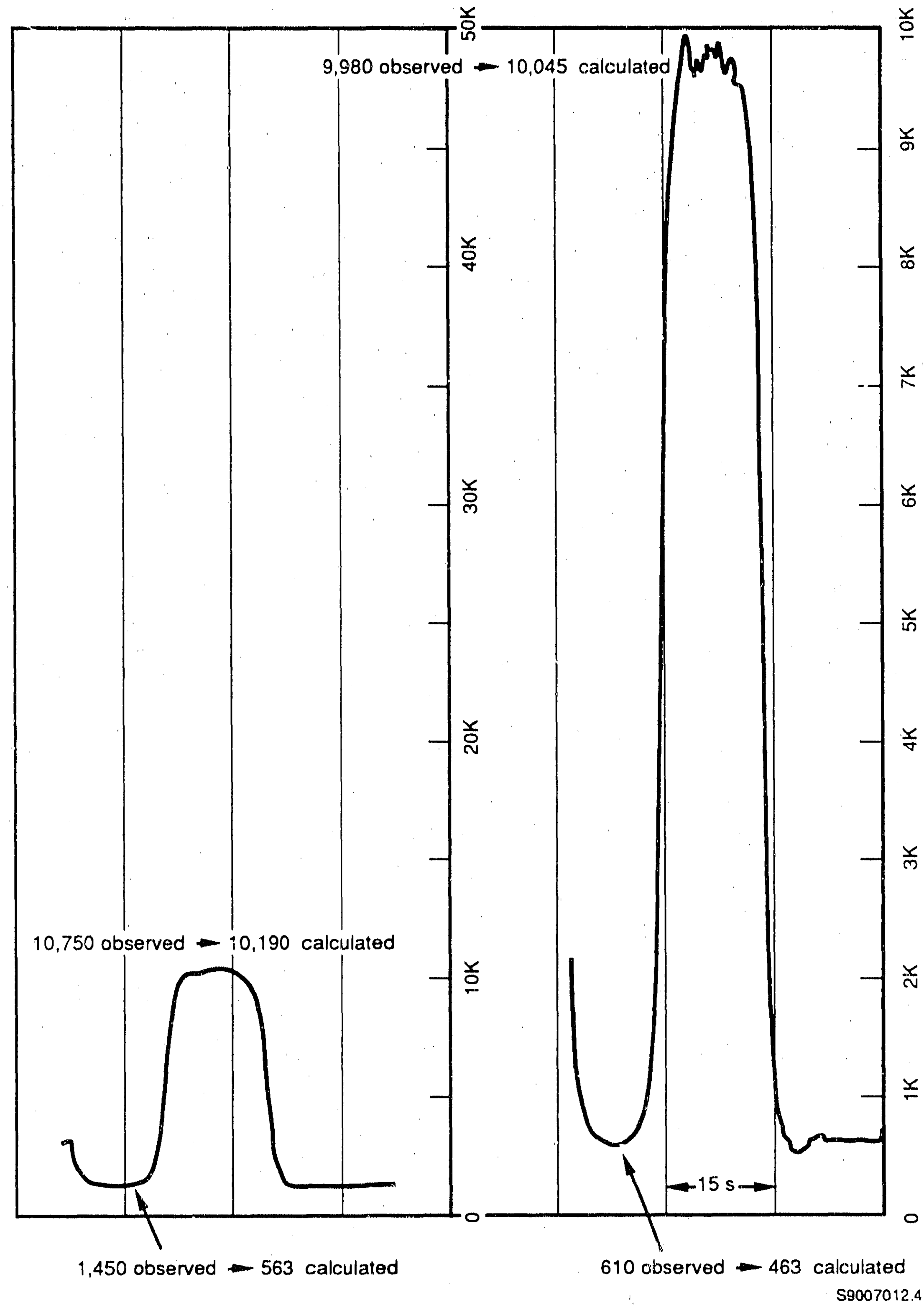

FIGURE 1. Scan of the SBL Section of the DOE SBL/SBH Borehole Model Taken on the 10K and 50K Scales (Dry Well, No Casing)

variability. In fact, the oscillator was off by a few percent, so its potentiometer was adjusted slightly to bring it in line with the pulse generator values.

DEAD-TIME DETERMINATION

REANALYSIS OF PREVIOUS DATA

The dead-time correction value was recomputed, in light of the scale and zero miscalibrations on the chart recorder, from the data given in Table 5 as taken from the base calibration document (Brodeur and Koizumi 1989). The recomputed dead-time correction was 17.0 ± 2.5 microseconds. The uncertainties associated with the dead-time values are based on accepted practices described in various texts dealing with nuclear statistics (Evans 1955; Bevington 1969; Knoll 1979; Krugers 1973).

CURRENT MEASURED VALUE

The data used to compute a more rigorous value for the dead-time correction are compiled in Table 6 from recordings contained in Appendix B. The experimental setup for the measurements, which were made on the dock of the south-east corner of the 329 Building, is shown in Figure 2. The two-source method described in the base calibration document (Scott 1980) was used for the experiment. However, data were taken by placing the two sources at several measured distances to give rate recordings on several different ratemeter scales. As an additional precaution, the scale was not changed during any one run for the series of measurements (source 1 only, both sources, source 2 only, and background).

The method used two ^{137}Cs standard sources placed at measured distances such that each source gave nearly an equal reading on the chart recorder when counted individually, which met the one simplifying assumption used in the

TABLE 5. Reanalysis of Dead-time Correction Values Based on Corrected Chart Recorder Values

Value Type	Scale Used	Rate (Observed)	Rate (Correction)
Background	500 cps	77	69.3
N_1	10K cps	6,750	6,742.0
N_2	10K cps	6,400	6,384.4
N_{12}	50K cps	12,500	11,877.0

TABLE 6. Data Used for Recalibration of Dead-time Correction Values

Value Type	Scale Used	Rate (Observed)	Rate (Correction)
Background	50K cps	1,000	37.9
N_1	50K cps	8,200	7,436.7
N_2	50K cps	5,850	5,021.9
N_{12}	50K cps	12,000	11,341.7
Background	50K cps	1,000	37.9
N_1	50K cps	6,000	5,176.0
N_2	50K cps	6,100	5,278.8
N_{12}	50K cps	10,400	9,697.5
Background	10K cps	285	68.4
N_1	10K cps	4,915	4,832.3
N_2	10K cps	4,805	4,719.1
N_{12}	10K cps	8,700	8,726.7
Background	5K cps	180	86.3
N_1	5K cps	2,270	2,239.1
N_2	5K cps	2,415	2,388.4
N_{12}	5K cps	4,280	4,309.4
Background	1K cps	99.5	81.0
N_1	1K cps	486	478.9
N_2	1K cps	479.5	472.2
N_{12}	1K cps	860	864.0

"two-source" method described by Scott (1980). First, the measured distances were established for the two sources. Then, source 1 was placed on one side of the detector at the appropriate measured distance and a 1.5- to 2.0-min count rate was recorded. Then, source 2 was placed at the corresponding measured distance on the opposite side, and another 2-min count of the combined rates was recorded. Next, source 1 was removed, and the count rate was recorded with only source 2 in place. Finally, source 2 was removed, and a background count rate was recorded on the same scale.

The equations used below to calculate dead time are from Scott (1980) because they give an inherently more accurate value than other published approaches, some of which contain typographical errors (IAEA 1982). The approximate dead-time correction for the system was calculated as

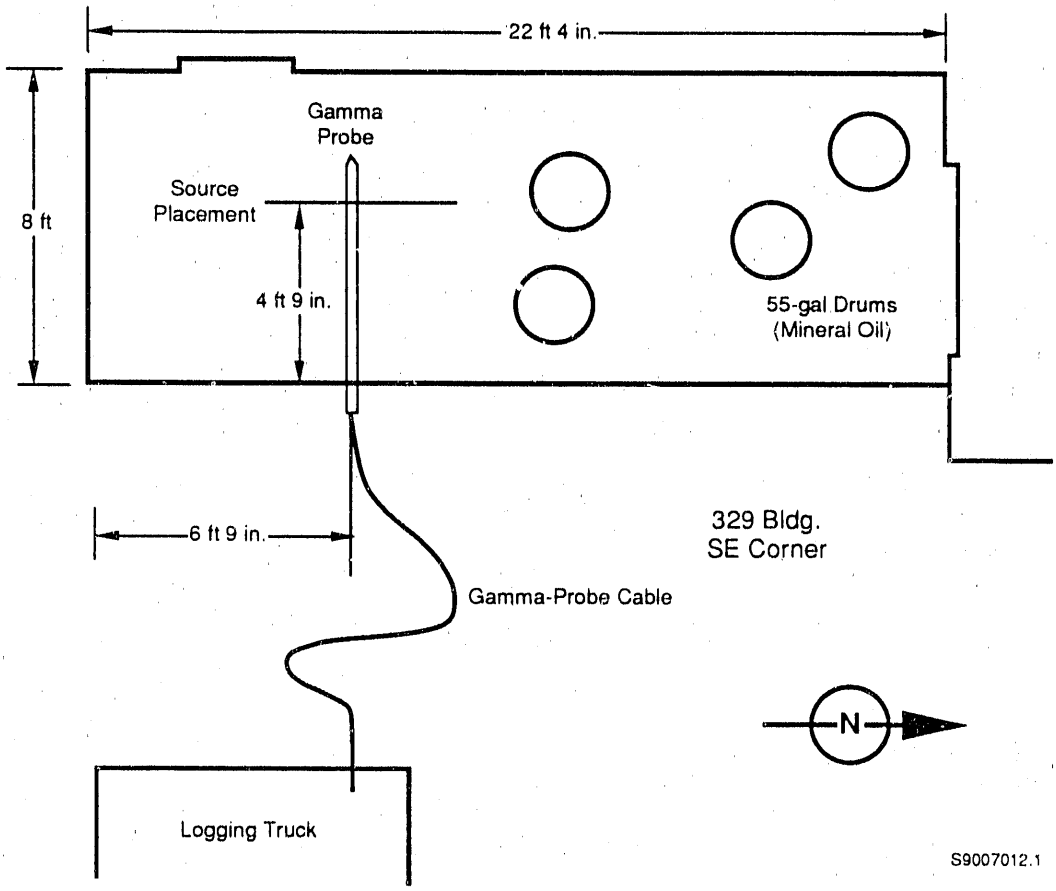

FIGURE 2. Experimental Setup for Dead-Time Measurements

$$t_{approx.} = \frac{2(N_1 + N_2 - N_{12})}{(N_1 + N_2) \cdot N_{12}} \qquad (1)$$

where N_1 = Background-corrected count rate with only source 1

N_2 = Background-corrected count rate with only source 2

N_{12} = Background-corrected count rate with both sources.

The exact dead-time correction is then obtained using

$$t_{exact} = \frac{1 - (1 - 2 \cdot N_{12} \cdot t_{approx.})^{1/2}}{N_{12}} \qquad (2)$$

The values and scale settings used to compute the dead-time correction are given in Table 6. The resulting dead-time correction value of 17.8 microseconds was obtained by averaging the resulting values as shown in Table 7.

TABLE 7. Summary of Measured Dead-time Correction Values

Scale Used	$t_{approx.}$ (microseconds)	t_{exact} (microseconds)
50K	15.42 ± 2.14	17.06 ± 2.72
50K	14.35 ± 2.70	15.51 ± 3.25
10K	18.56 ± 3.06	20.35 ± 3.82
5K	24.64 ± 7.34	26.08 ± 8.47
1K	19.75 ± 9.70	19.90 ± 9.93
		17.78 ± 3.94[a]
Results from the reanalysis of the base calibration study:		
10K, 50K	15.32 ± 1.95	17.03 ± 2.51

(a) The average was arrived at using a maximum likelihood approach involving weighted averages as described in Bevington (1969, pp. 130-131 and pp. 187-189).

PRIMARY CALIBRATION

The primary calibration was performed just outside the 200-West Area of the Hanford Site. The calibration was performed on two separate occasions using the SBL/SBH and the SBA/SBB standard borehole models. Complete descriptions of the models and the radioelement assays are provided in Steele and George (1986). The pertinent equivalent concentrations of uranium are given in Table 8.

SBL/SBH BOREHOLE MODEL CALIBRATION

The first calibration was performed on December 14, 1989, on the SBL/SBH model. Only the SBL zone gave useful recordings for both the 10K and 50K scales; within the SBH zone, the instrument recording saturated at an apparent count rate of 15,000 cps. Initially, the two valid SBL recordings appeared to differ by 8%; however, when the recorder misadjustment between scales was taken into account, the two values agreed quite well.

The field calibration source readings following the primary calibration runs revealed that the probe had an excess of counts, indicating some mild external contamination (150 cps instead of the expected 80 cps background). The source of the contamination was later shown to be radon adhering to the cold (-2°C) surface of the probe.

SBA/SBB BOREHOLE MODEL CALIBRATION

The second calibration was performed on December 18, 1989, using the SBA/SBB borehole model. Two valid readings were obtained on the 5K-cps scale

TABLE 8. Radioelement Assay Data for SBL and SBA Zones in the DOE SBL/SBH and SBA/SBB Standard Borehole Models

Zone	^{226}Ra (pCi/g)	Concentration (ppm)	Thickness (ft)
SBL	324 ± 9	971 ± 27	4.00
SBA	61.2 ± 1.7	183 ± 5	4.01

and one valid reading on the 50K-cps scale. The probe was encased in a polyethylene bag for this calibration run, and no radon contamination of the probe was detected.

LINEARITY DETERMINATION

Two methods are available for computing the primary calibration of the logging system. The first method was proposed in the base calibration document (Brodeur and Koizumi 1989, p.15) once it was found that the high-activity zones of the borehole models could not be measured. This method assumes that the system's response is linear over the measurable equivalent uranium concentration range. The probe constant of proportionality for direct conversion from measured counts per second to equivalent uranium concentration in parts per million is given by:

$$P = \frac{\text{(equivalent uranium concentration in model)}}{(RM)} \quad (3)$$

where P = probe constant of proportionality

RM = dead-time corrected count rate in the model.

The values for the probe constant determined from each of the two borehole models are presented in Table 9. The probe constant, based on data from the base calibration document (Brodeur and Koizumi 1989, p. 15), was recomputed and is also presented in Table 9. It agrees well with the current calibration value.

The second method for determining the probe constant of proportionality uses both measured equivalent uranium values:

$$P' = \frac{\text{(equivalent uranium in model A} - \text{equivalent uranium in model B)}}{(RA - RB)} \quad (4)$$

where P′ = probe constant of proportionality

RA, RB = dead-time corrected count rate in models A and B, respectively.

TABLE 9. Probe Constant of Proportionality for SBL and SBA Zones Using Base Calibration Method

Zone	Apparent Count Rate (c/s)	Dead-time Corr. Count Rate (c/s)	Probe Constant (eU ppm/c/s)
SBL	10,117 ± 103	12,337 ± 609	0.0787 ± 0.0045
SBA	2,258 ± 15	2,352 ± 23	0.0778 ± 0.0023
Recomputation of previous (base calibration) data			
SBL	10,500 ± 103	12,910 ± 665	0.0752 ± 0.0044

The value for the probe constant determined from using the two separate borehole models is presented in Table 10.

TABLE 10. Probe Constant of Proportionality Using Original (Intended) Calibration Method

Zone	Equivalent Uranium Concentration (ppm)	Dead-time Corr. Count Rate (c/s)
SBL	971. ± 27.	12,337 ± 609
SBA	61.2 ± 1.7	2,352 ± 23
Probe Constant (eU ppm/c/s) =		0.0789 ± 0.0056
Linear Intercept Constant (eU ppm) = -2.4 ± 88.4		

FIELD SOURCE CORRELATION

Recommended values, as given in the base calibration document (Brodeur and Koizumi 1989, p. 20) for the Position 1 and 2 base activity values, were 3810 c/s or 325 equivalent uranium (eU) ppm and 1140 c/s or 97 eU ppm. These data, however, are based on measurements performed with the probe lying on the bumper of the logging truck. The method currently being used, as described in PNL Technical Procedure GL-7A, places the gamma-ray probe in a pipe clamp such that the probe is a minimum of 2 ft away from any solid matter to minimize any excess count rate due to variable amounts of backscatter. The base activity to be used in the future should be set once a method for fixing the source-to-detector variable geometry has been determined.

STATISTICAL PROCESS CONTROL METHODS

Statistical process control (SPC) methods are a long-established way to monitor and evaluate the quality of a given process (Tikkanen and Wilson 1989). Basically, such a statistical control approach uses the results of a series of measurements to estimate precision and accuracy, expressed as a standard deviation and an arithmetic mean, respectively. Quality control is evaluated by plotting the statistical quantities on control charts developed from similar statistics taken while the process was under properly controlled operation. The control chart consists of a central line, such as the expected or average value, with control limits positioned at a distance of 2 or 3 standard deviations from the central line, within which 95% or 99.7%, respectively, of the values should lie.

POSITION 1 AND POSITION 2 CONTROL CHARTS

Figure 3 and Table 11 show the control chart and the data used to generate the control chart for Position 1 and 2 measurements performed between April 18, 1989, and November 17, 1989. Six control measurements are shown in Figure 3, each separated by a thick line. The first control measurement, labeled "POS1-PRE," is for Position 1 measurements performed prior to insertion of the probe within a test well (see Figure 3). The central solid line

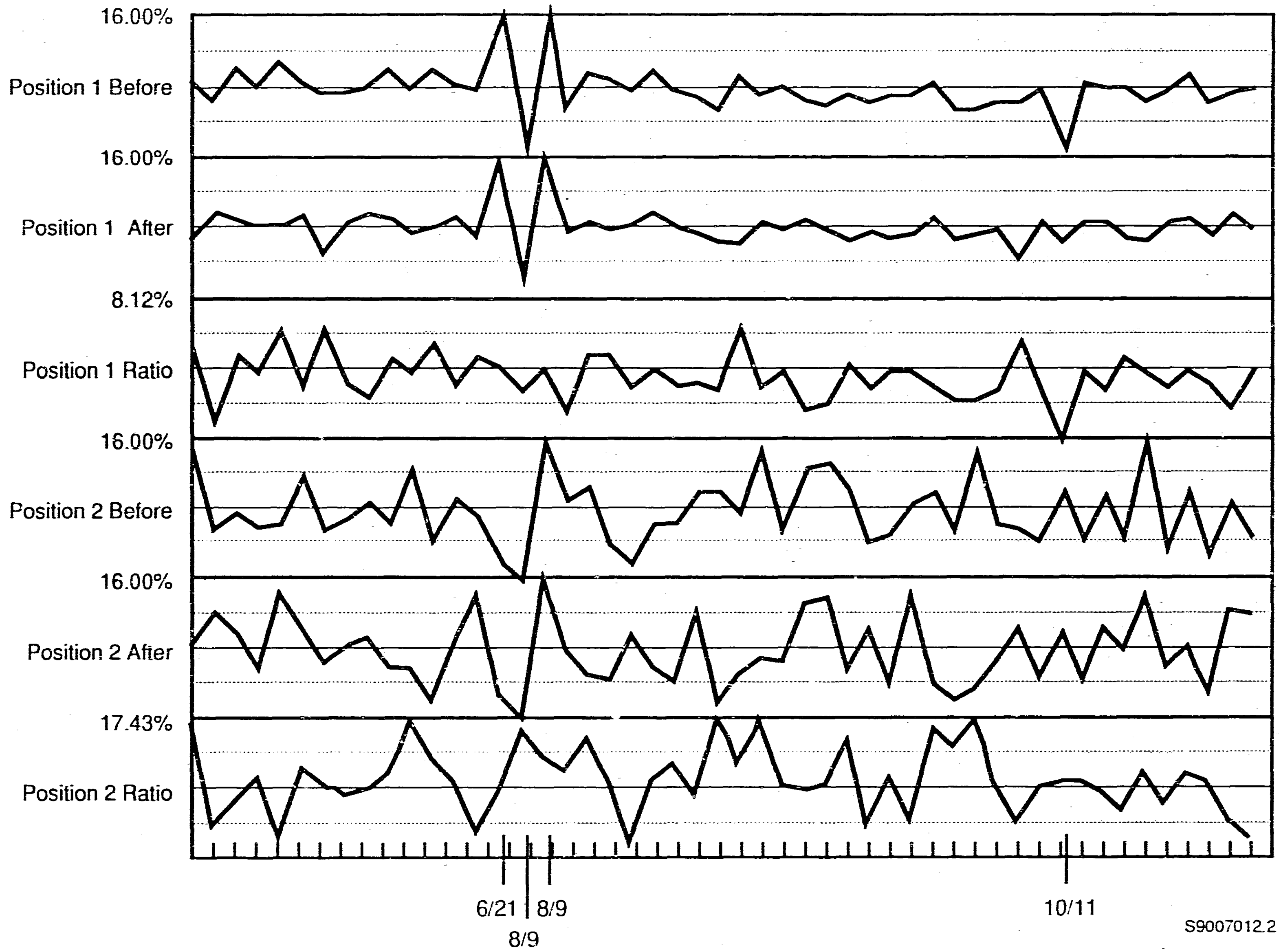

FIGURE 3. Control Charts Generated from the Results of Calendar Year 1989 Field Calibrations

TABLE 11. Data Collected from Field Calibrations Performed During Calendar Year 1989 and Used to Generate Control Charts

Detector Reliability Study
Probe I.D. CG27A97

Corrected Counts per Second

Date	POS1-PRE	POS1-AFT	POS1-RAT	POS2-PRE	POS2-AFT	POS2-RAT	Well I.D.
18-APR-89	3385.	3285.	1.0304	795.	685.	1.1605	6-43-41E
18-APR-89	3290.	3490.	0.9426	660.	740.	0.8918	6-43-41F
25-APR-89	3495.	3440.	1.0159	680.	710.	0.9577	6-40-39
28-APR-89	3390.	3390.	1.0000	660.	655.	1.0076	6-43-41F
18-MAY-89	3540.	3390.	1.0442	665.	770.	0.8636	6-44-43B
23-MAY-89	3385.	3440.	0.9840	735.	710.	1.0352	6-41-40
6-JUN-89	3335.	3185.	1.0470	655.	660.	0.9924	6-43-45
8-JUN-89	3340.	3390.	0.9852	670.	690.	0.9710	6-41-40
27-JUN-89	3390.	3490.	0.9713	690.	700.	0.9857	6-40-39
28-JUN-89	3495.	3445.	1.0145	670.	655.	1.0229	2-E25-37
5-JUL-89	3340.	3340.	1.0000	750.	650.	1.1538	2-E25-38
12-JUL-89	3490.	3385.	1.0310	640.	605.	1.0578	2-E27-11
14-JUL-89	3395.	3445.	0.9854	695.	700.	0.9928	2-E25-37
21-JUL-89	3375.	3325.	1.0150	675.	765.	0.8823	2-E27-11
21-JUL-89	3890.	3885.	1.0012	610.	615.	0.9918	2-E33-32
9-AUG-89	2960.	3020.	0.9801	360.	320.	1.1250	2-E33-32
9-AUG-89	4095.	4095.	1.0000	1595.	1495.	1.0668	2-E33-31
9-AUG-89	3235.	3385.	0.9556	705.	685.	1.0291	2-E33-33
15-AUG-89	3480.	3415.	1.0190	720.	645.	1.1162	2-E25-40
15-AUG-89	3425.	3375.	1.0148	635.	635.	1.0000	2-E25-41
17-AUG-89	3350.	3405.	0.9838	600.	705.	0.8510	2-E24-19
21-AUG-89	3485.	3485.	1.0000	660.	655.	1.0076	2-W15-19
22-AUG-89	3335.	3385.	0.9852	665.	635.	1.0472	2-E34-7
24-AUG-89	3295.	3340.	0.9865	715.	740.	0.9662	2-25-40
24-AUG-89	3215.	3280.	0.9801	715.	600.	1.1916	2-E24-19
24-AUG-89	3430.	3275.	1.0473	680.	645.	1.0542	2-E25-41
29-AUG-89	3345.	3400.	0.9838	775.	670.	1.1567	2-E34-8
29-AUG-89	3360.	3365.	0.9985	660.	665.	0.9924	2-E24-19
5-SEP-89	3290.	3440.	0.9563	750.	760.	0.9868	2-W15-19
6-SEP-89	3250.	3365.	0.9658	760.	765.	0.9934	2-E27-12
6-SEP-89	3330.	3305.	1.0075	720.	655.	1.0992	2-E27-15
18-SEP-89	3290.	3345.	0.9835	640.	715.	0.8951	2-E27-13
18-SEP-89	3310.	3310.	1.0000	650.	640.	1.0156	2-E27-12
18-SEP-89	3325.	3335.	0.9970	695.	765.	0.9084	2-E27-15
22-SEP-89	3415.	3470.	0.9841	715.	630.	1.1349	2-W10-16
27-SEP-89	3200.	3305.	0.9682	660.	605.	1.0909	2-W18-26
27-SEP-89	3225.	3325.	0.9699	775.	625.	1.2400	2-E27-14
28-SEP-89	3290.	3345.	0.9835	665.	670.	0.9925	2-E27-13
29-SEP-89	3275.	3170.	1.0331	655.	720.	0.9097	2-W15-21
2-OCT-89	3365.	3425.	0.9824	640.	645.	0.9922	2-W10-15
11-OCT-89	2935.	3290.	0.8920	715.	710.	1.0070	2-E27-14

TABLE 11. (contd)

Date	POS1-PRE	POS1-AFT	POS1-RAT	POS2-PRE	POS2-AFT	POS2-RAT	Well I.D.
11-OCT-89	3420.	3420.	1.0000	645.	640.	1.0078	2-W10-16
12-OCT-89	3380.	3435.	0.9839	705.	720.	0.9791	2-W15-21
16-OCT-89	3370.	3320.	1.0150	650.	690.	0.9420	2-W10-15
19-OCT-89	3295.	3295.	1.0000	795.	770.	1.0324	2-E32-5
6-NOV-89	3370.	3420.	0.9853	630.	660.	0.9545	2-W19-28
6-NOV-89	3480.	3480.	1.0000	710.	690.	1.0289	2-W19-29
10-NOV-89	3285.	3330.	0.9864	625.	620.	1.0080	2-W7-9
17-NOV-89	3340.	3490.	0.9570	690.	750.	0.9200	2-W7-8
17-NOV-89	3390.	3395.	0.9985	650.	745.	0.8724	2-W7-7
	3366.2	3366.2	1.0006	685.9	685.9	0.9889	

is the average of all Position 1 values (taken before and after logging) which did not exceed a limit of 8% of the standard deviation for the combined values. The central value, uncorrected for dead time, was 3366 c/s which corresponds to an equivalent uranium concentration of approximately 280 ppm. The dotted lines above and below the central line represent a control limit of 8% of the average value. Any value which exceeds the dotted line would generally indicate that the values from the instrument are suspect and that repair of the instrument is warranted.

The second control measurement shown in Figure 3, labeled "POS1-AFT," corresponds to Position 1 measurements performed after well logging. The central value is identical to the value used in the "POS1-PRE" control so that trend comparisons are valid. The dotted line, once again, represents a control limit of 8% of the central value.

The third control measurement shown in Figure 3, labeled "POS1-RAT," is the ratio of "PRE" versus "AFT" Position 1 measurements. The dotted line in this case merely serves as a reference line for assessing any trends present in the data.

The next three sets of similar control charts are for the Position 2 control values, which ran with an average count rate of 685.9 c/s (uncorrected for dead time), corresponding to 54 eU ppm.

CONTROL OBSERVATIONS AND RESULTS

As indicated in the control charts, the 8% limit was exceeded for the Position 1 measurement on a number of occasions. The controls run at the 2-E33-32 well on July 21, 1989, and on August 9, 1989 and at the 2-E33-31 well on August 9, 1989, have a high background since the wells are adjacent to the BY tank farm. The high and low nature of the resulting calibration counts, however, has not been satisfactorily explained. The low value taken at the 2-E27-14 well on October 11, 1989, is also not understood, especially since the calibration run following well logging checks out normal.

The Position 2 measurements exceeded the 8% limit several times, but this is mostly due to the variable source-detector geometry. The control ran reasonably well at the 2-E33-32 well on July 21, 1989, but was definitely off at the same well on August 9, 1989, and at the 2-E33-31 well, as was the Position 1 calibration.

The ratio comparisons indicate no significant trend in the pre- versus post-logging calibration values. The loose source would have given rise to such a random fluctuation unless the operator had developed a habitual way of attaching the source to the probe.

The net apparent values (corrected for background but uncorrected for dead time) that should be used for Position 1 and 2 control purposes on data collected until May 4, 1990, should be 3366 c/s and 685.9 c/s, respectively. A new set of values was determined from data collected subsequent to that date since the cause of the source-to-detector geometry variability had been discovered and dealt with. The data used to determine the new values are compiled in Table 12.

The new net apparent values for Position 1 and 2 are 3466 c/s and 608 c/s, respectively, and should range between 3189 c/s to 3744 c/s or 559 c/s to 657 c/s to meet the 8% control criterion.

As shown in Table 12, these values correspond to dead-time corrected, background subtracted values for Position 1 and 2 of 3702.5 c/s and 616.0 c/s, respectively, corresponding to 291.4 eU ppm and 48.5 eU ppm when a probe factor of 0.0787 eU ppm/c/s is applied.

TABLE 12. Data Used to Compute New Values for Before and After Logging Field Source Verification

Well Identification	Date	Gross Count Rate (c/s)			Count Rate, Deadtime and Background Corrected	
		Pos'n 1	Pos'n 2	Bkgd.	Pos'n 1	Pos'n 2
299-E26-9	08/01/90	3547	675	65	3720.7	618.1
		3547	675	65	3720.7	618.1
299-E26-10	08/01/90	3595	665	55	3785.4	617.9
		3595	665	55	3785.4	617.9
299-E26-9	07/25/90	3604	685	75	3775.7	618.3
		3604	685	75	3775.7	618.3
699-52-54	05/23/90	3547	675	65	3720.7	618.1
		3547	675	65	3720.7	618.1
299-W26-8	05/29/90	3605	675	65	3786.8	618.1
		3605	675	65	3786.8	618.1
299-E35-2	07/05/90	3549	665	55	3733.0	617.9
		3549	665	55	3733.0	617.9
299-E26-11	07/11/90	3547	675	65	3720.7	618.1
		3547	675	65	3720.7	618.1
299-E26-11	06/28/90	3448	670	60	3613.1	618.0
		3448	670	60	3613.1	618.0
299-W26-11	05/29/90	3448	670	60	3613.1	618.0
		3448	670	60	3613.1	618.0
			Average		3702.5	616.0
			Std. Deviation		+/- 67.7	+/- 6.2
			8% Limit Value		+/- 296.2	+/- 49.3
			8% Lower Limit		3406.3	566.7
			8% Upper Limit		3998.7	665.3

ENVIRONMENTAL CONSIDERATIONS

USE OF A BOW SPRING

On April 28, 1989, a gross-gamma geophysical log was performed twice on Hanford well 399-5-2: once with a bow spring attached to the probe and once without a bow spring. Although the count rate was low, some features present on the log confirmed that both logs were identical within allowed statistical uncertainties.

REANALYSIS OF CASING CORRECTIONS

The table of casing corrections contained in the base calibration document (Brodeur and Koizumi 1989, Table 5, p. 21) was recomputed in light of the new dead-time value and the zero/scale misadjustment. The resulting data are presented in Table 13.

PROBE STABILITY VERSUS TEMPERATURE

The temperature response of the probe was evaluated by placing the gamma-ray probe in a 3-in.-diameter aluminum tube containing water initially at 42.3°C. The background count rate was then monitored as the water within

TABLE 13. Recomputed Summary of Environmental Corrections for a 4.5-in. Borehole

	Standard Condition	Cased Hole	Water Filled	Water and Casing
Static Counts Per Second	10,500	7,700	8,900	7,000
Corrected Static Counts Per Second	9,829	7,713	8,939	6,998
Dead-Time Corrected Counts Per Second	11,910	8,939	10,628	7,992
% Reduction of Standard	--	25%	11%	33%
Correction Factor	--	1.322	1.121	1.490

the tube cooled to 24.0°C. The count rate varied from 43 c/s to 40 c/s for a probe temperature drift rate of -0.38%/°C.

SYSTEM STABILITY VERSUS TEMPERATURE

A check of the system response was made with the probe temperature held constant as the instrumentation warmed up. Figure 4 shows the temperature observed within the instrument cabinet as a function of time. The count rate varied from 725 c/s to 712 c/s over a period of 77 min, while the temperature varied from 2°C to 14°C, corresponding to a system temperature drift rate of -0.15%/°C.

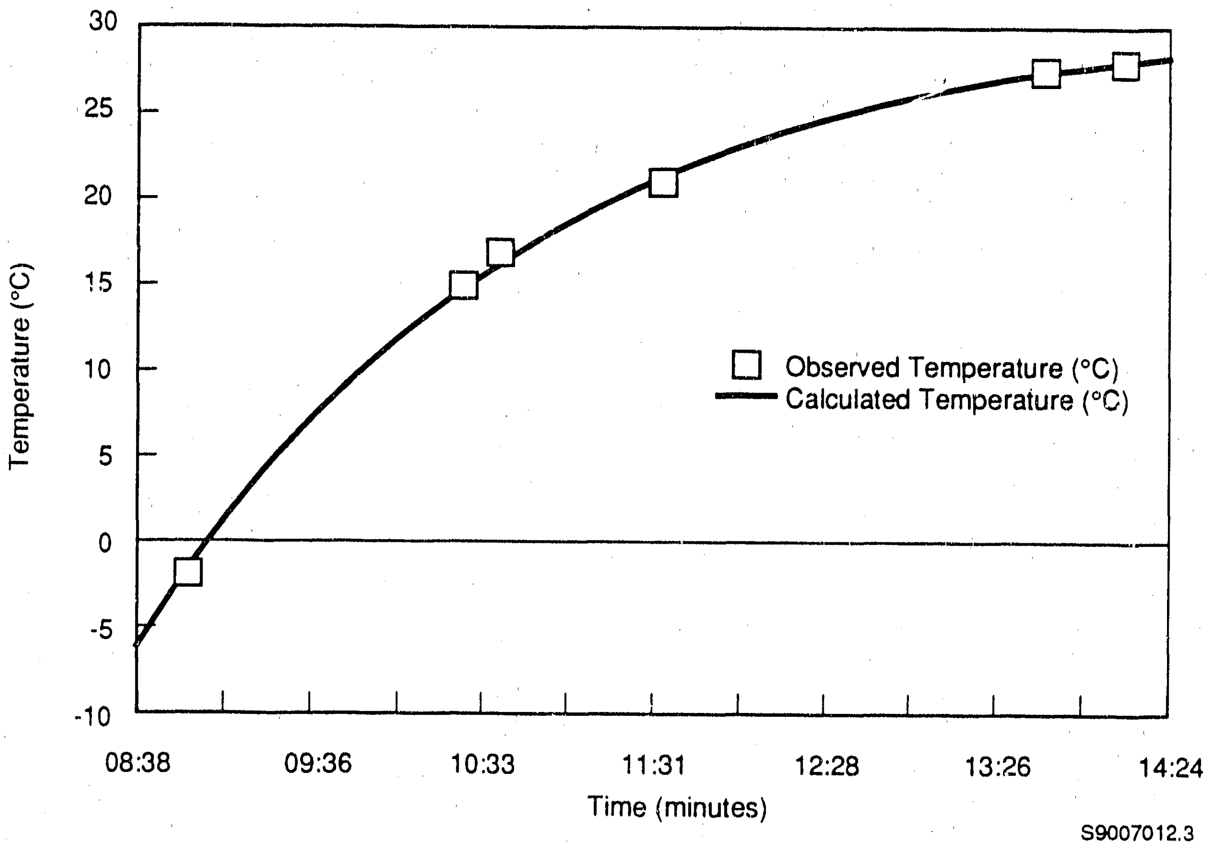

FIGURE 4. Instrument Cabinet Temperature During Warm-up

CONCLUSIONS

The scales on the previous chart-recorder output did not appear to give correct zero and full-scale recordings. The zero and scale were off by approximately 1.8% and 2.3%, respectively. The original dead-time correction was incorrectly calculated as 7.4 microseconds when the actual value was 17.0 microseconds because of a scale change in the middle of a run and as a result of the scale and zero misadjustment. This corresponds to the actual count rates being understated by 0.50% at 500 cps, 1.0% at 1000 cps, and 2.0% at 2000 cps. Since most logs taken with this system are obtained on the 500-cps scale, the count-rate understatement is not significant (less than 0.5%). The new recommended value for system dead time is 17.8 microseconds.

The experimentally determined dead time is consistent with the Gearhart-Owen Instruction Manual (Gearhart-Owen Industries, Inc., Not Dated), which states that "a 1500-ft length of cable permits gross counting rates of over 70,000 counts per second" (corresponding to a dead time of 14.3 microseconds). A discrepancy does exist, however, in that the dead time alone does not explain the saturation of the system at a maximum count rate of 14,500 cps when logging high gamma-ray fields. A maximum of almost 60,000 cps is predicted when dead time is the sole source of the system saturation. The current operating cable length of 5600 ft does not appear to be a limiting factor.

The dead time can be decreased by a small amount with a resistor modification within the rate meter, but cable resistance and capacitance have a greater influence over the dead time.

The raw primary calibration data have not significantly changed since they were determined a year ago; however, the calibration value <u>is</u> 8% different due to the non-linear operation of the chart recorder which was not accounted for in the previous calibration. The new recommended probe constant based on the SBL calibration is 0.0787 ± 0.0045 eU ppm/c/s.

The difference in the before and after survey field calibration was due to the ^{226}Ra source being loose in the portable field calibration source, so that the geometry was not exactly reproduced each time a field calibration was run. New values were determined for before and after logging field source verification. The net apparent values (corrected for background but not for dead time) for Position 1 and 2 collected after May 4, 1990, are 3466 c/s and 608 c/s, respectively. These values may range between 3189 c/s to 3744 c/s or 559 c/s to 657 c/s and still meet the 8% control criterion. These values correspond to dead-time corrected, background subtracted values for Position 1 and 2 of 3702.5 c/s and 616.0 c/s, respectively, corresponding to 291.4 eU ppm and 48.5 eU ppm when a probe constant of 0.0787 eU ppm/c/s is applied.

Microphonics are not a problem in the detector assembly. Some noise is visible on oscilloscope tracing due to dirty slip rings, but the noise was not apparent on the chart recording.

RECOMMENDATIONS

The following actions are recommended as a result of the 1990 calibration of the gross-gamma geophysical pulse logging system:

- Examine the effects on count-rate saturation of modifying the rate meters to allow for lower dead times. Decide if a permanent modification is warranted.
- Modify portable field calibration source to immobilize the source within the holder. In the interim, make sure that the portable field calibration source is tilted in a pre-determined direction prior to mounting it on the probe.
- Clean the slip rings to prevent noise from entering into the system electronics at some later date.
- Calibrate an additional gamma-ray probe and/or system as a backup.
- Adopt the value of 17.8 microseconds as the system dead time.
- Adopt the value of 0.0787 eU ppm/c/s as the calibrated probe constant.
- Adopt the values for before- and after-survey field calibration for Position 1 and 2 as 3702.5 c/s (3466 c/s, net apparent) and 616.0 c/s (608 c/s, net apparent), respectively, which correspond to 291.4 eU and 48.5 eU when the recommended probe constant is applied.

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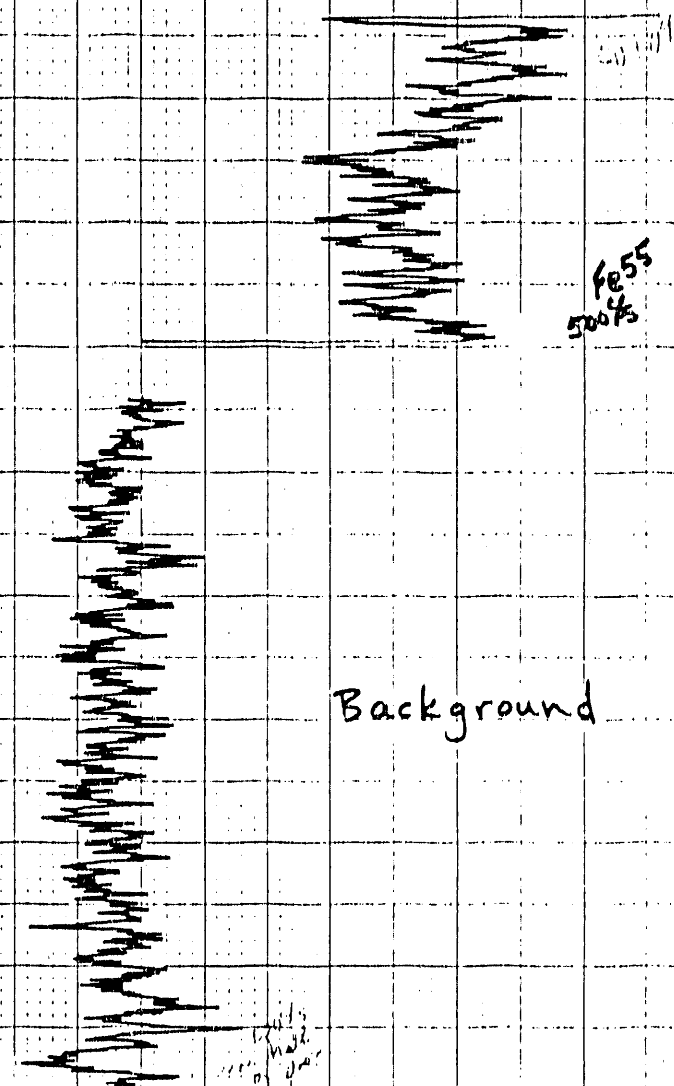
APPENDIX A

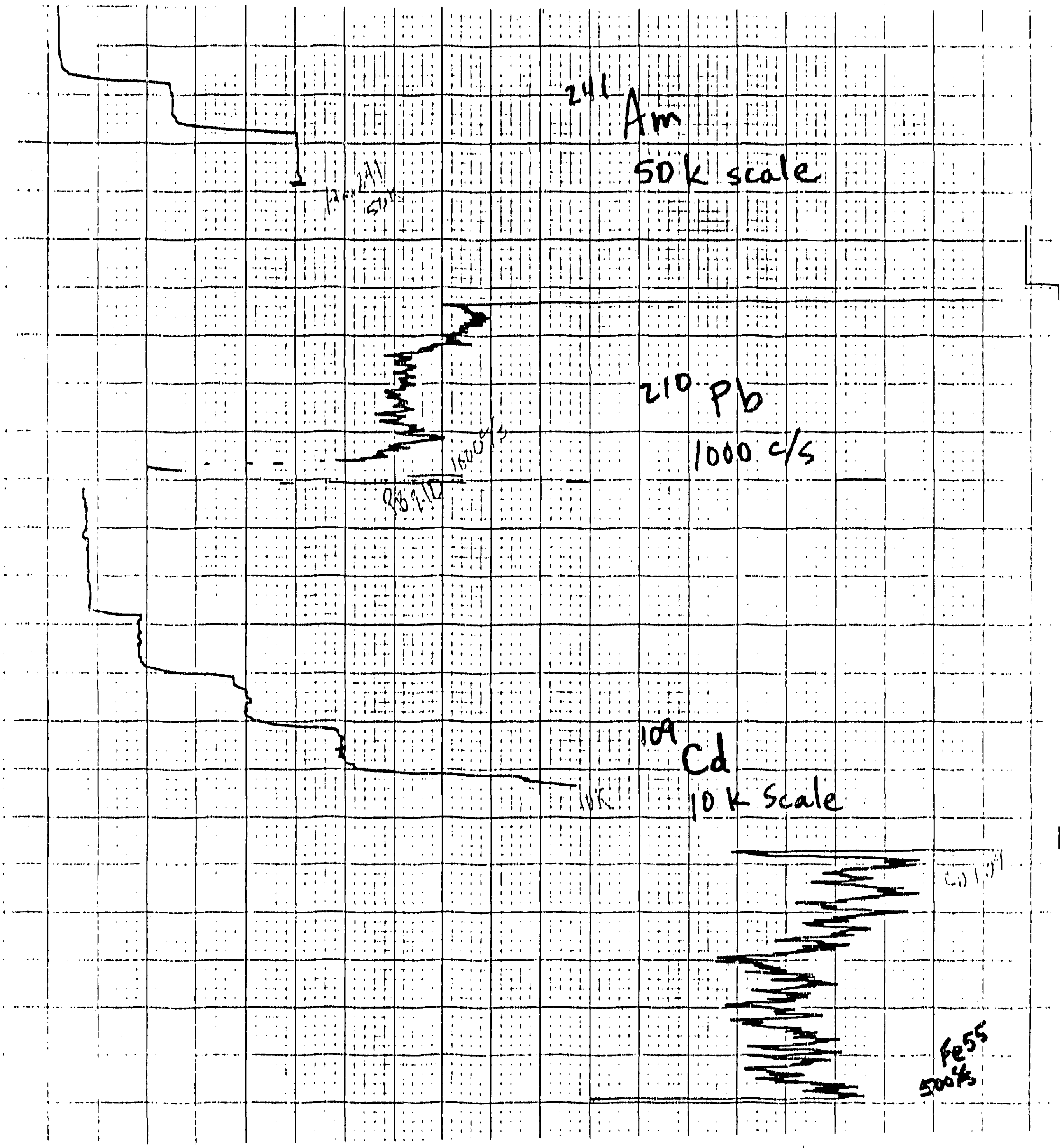
PROBE LOW-ENERGY CUTOFF MEASUREMENTS



4-26-90 Energy-cutoff value for gamma-ray probe was approximated using various low-energy gamma-ray sources

^{55}Fe, ^{109}Cd, ^{210}Pb, ^{241}Am

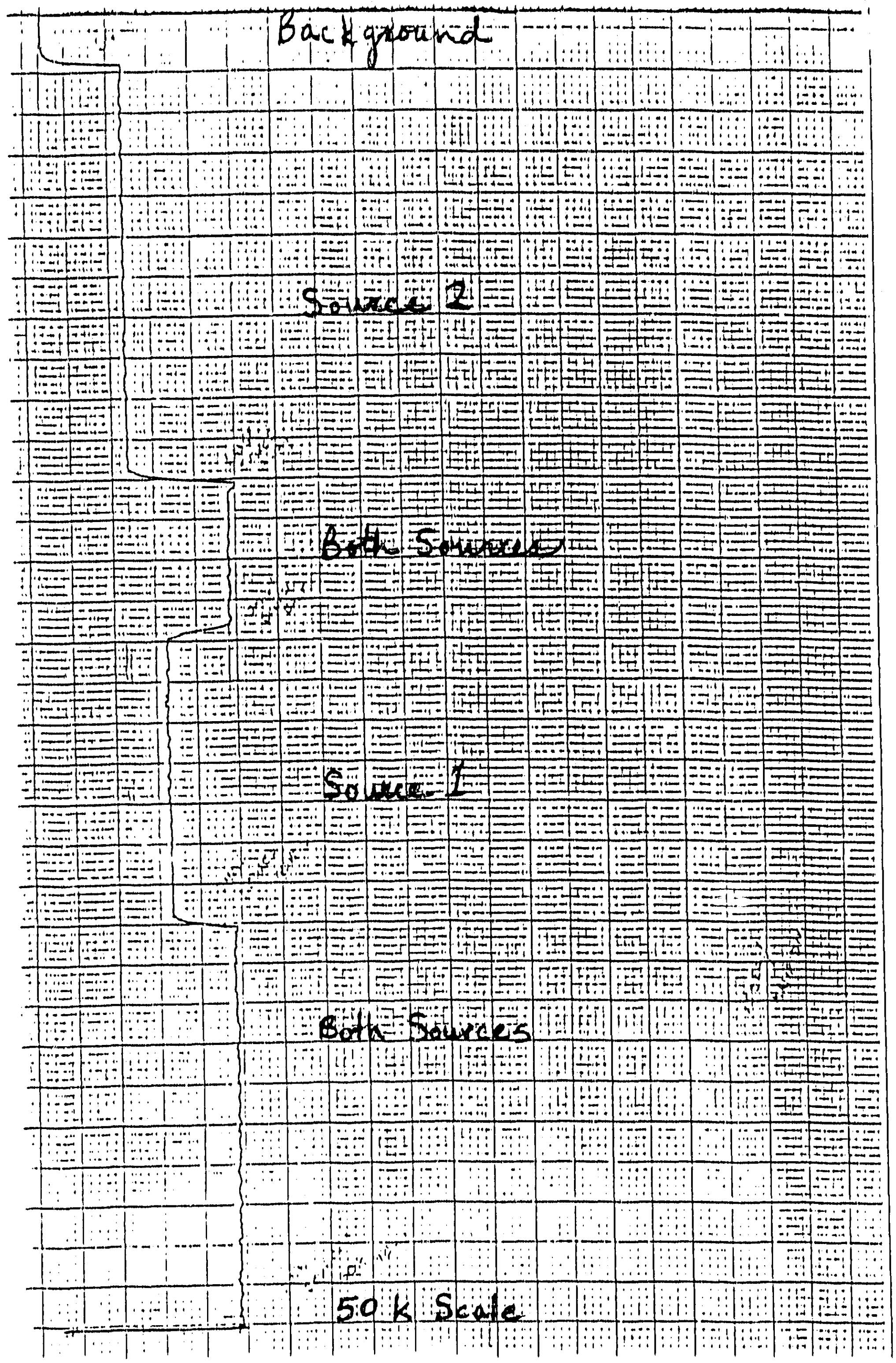
6.4 keV 25 keV 46.5 keV 59.5 keV

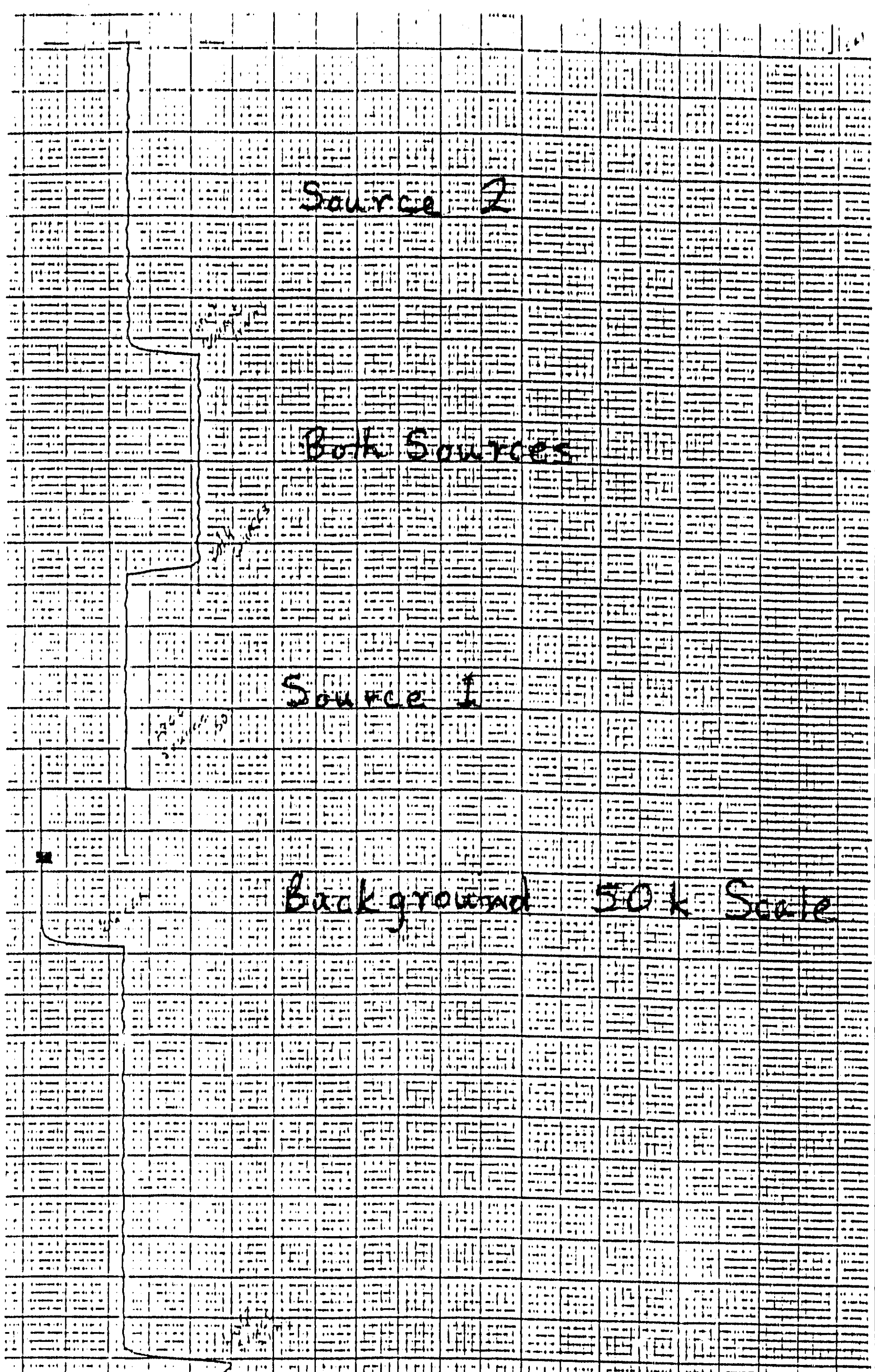


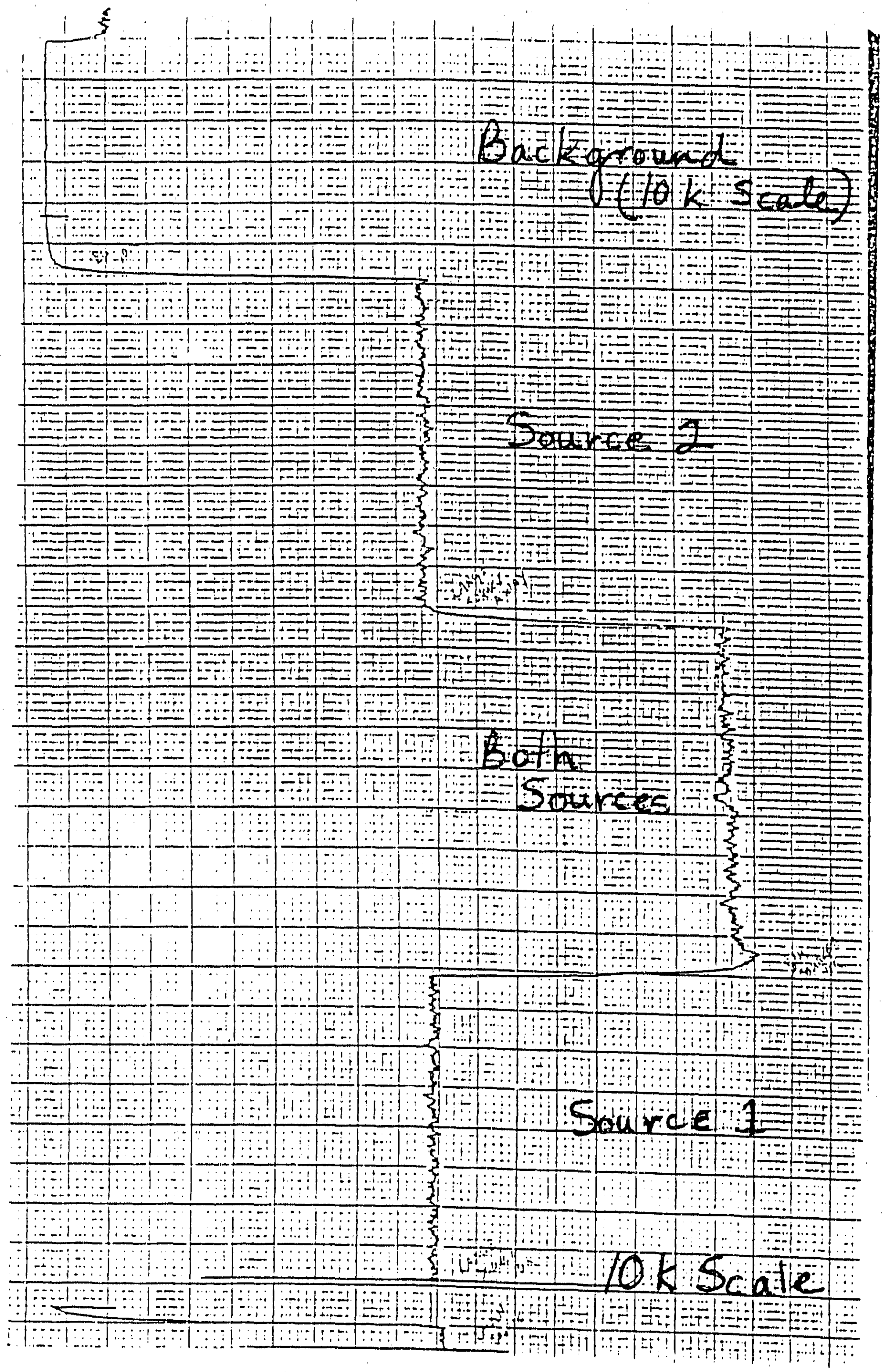
241 Am
50 k scale
210 Pb
1000 c/s
109 Cd
10 k Scale
Fe55
500c/s

APPENDIX B

DEAD-TIME CORRECTION MEASUREMENTS


Background
Source 2
Both Sources
Source 1
Both Sources
50 k Scale


Source 2
Both Sources
Source 1
Background 50k Scale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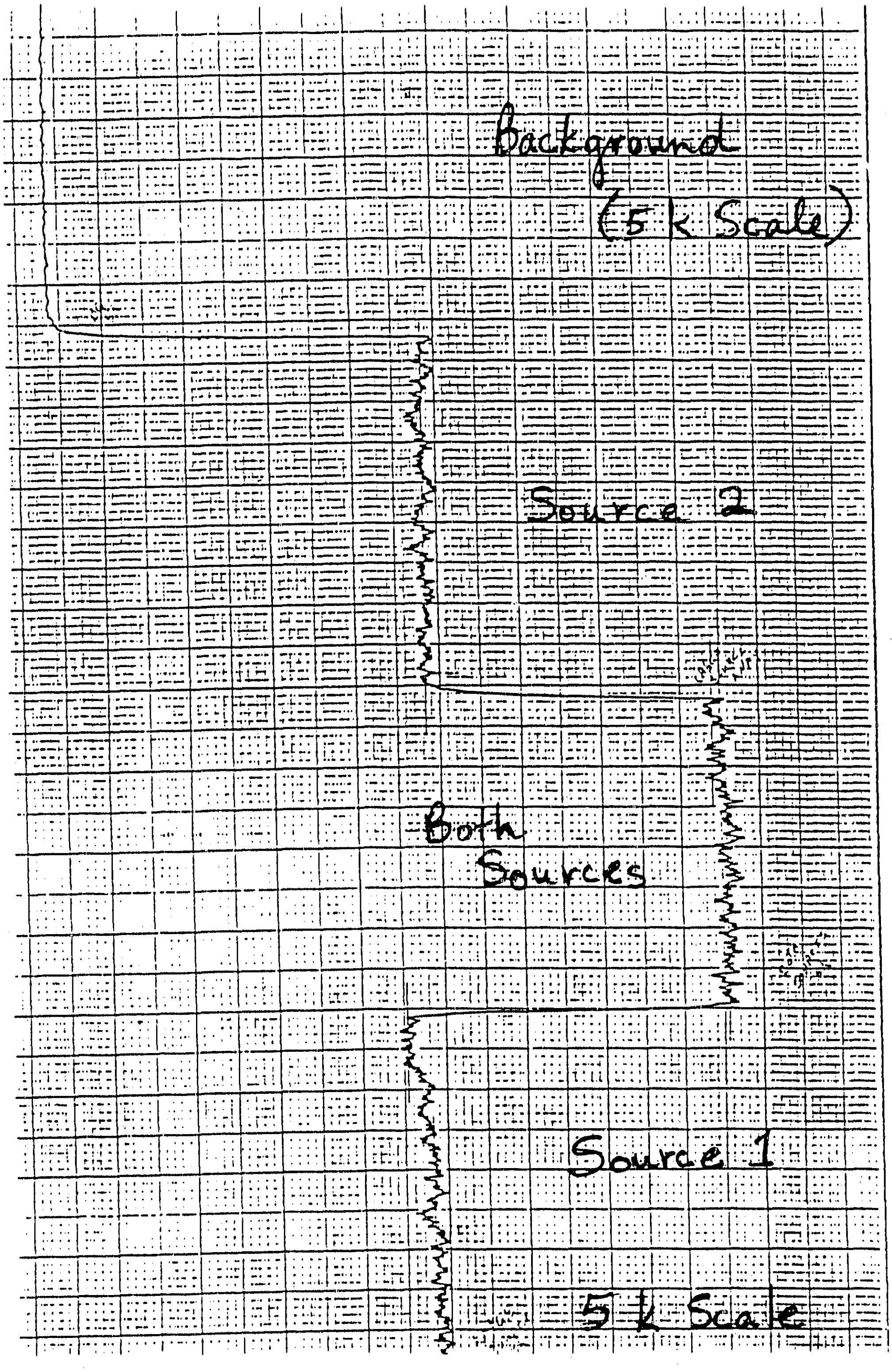
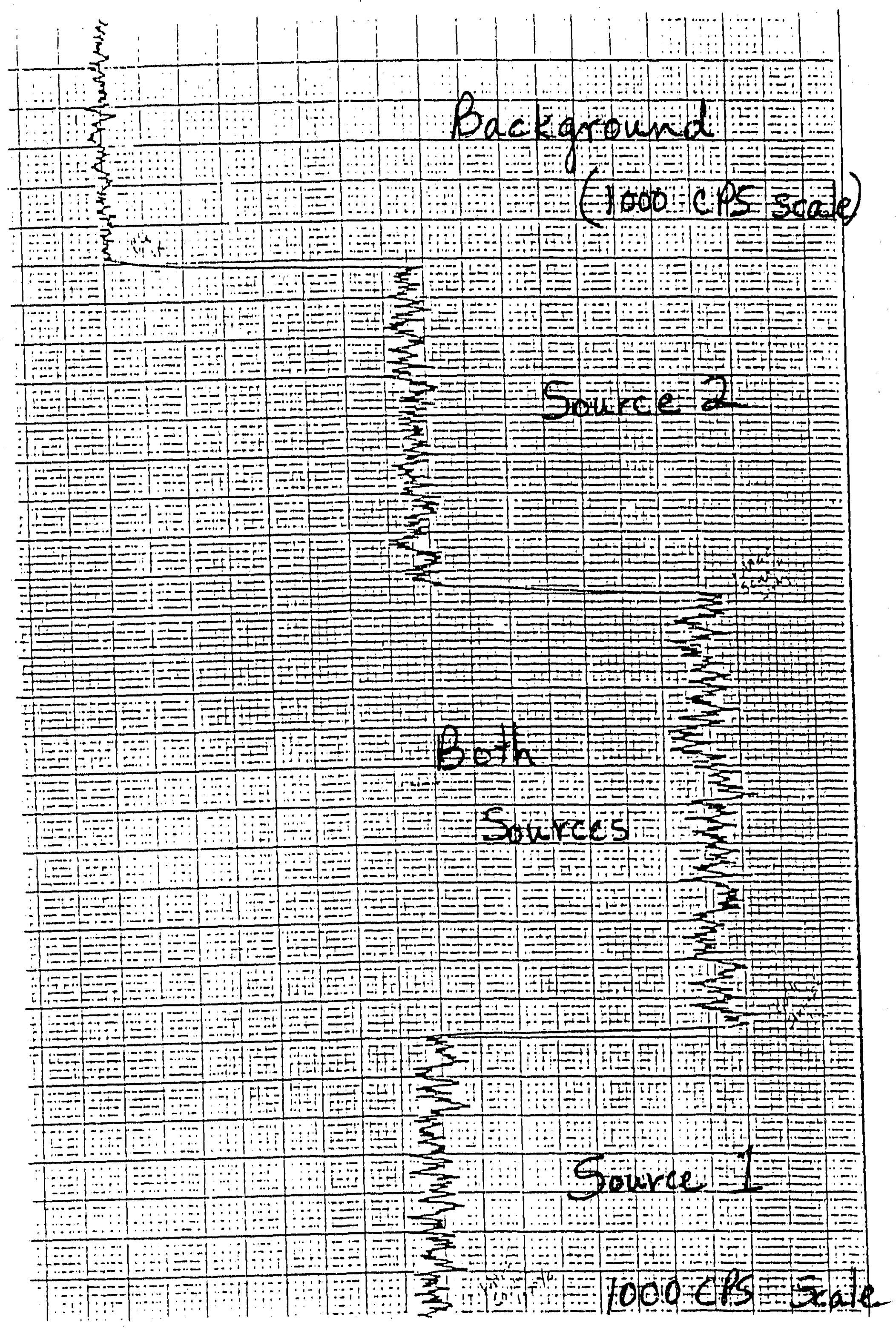
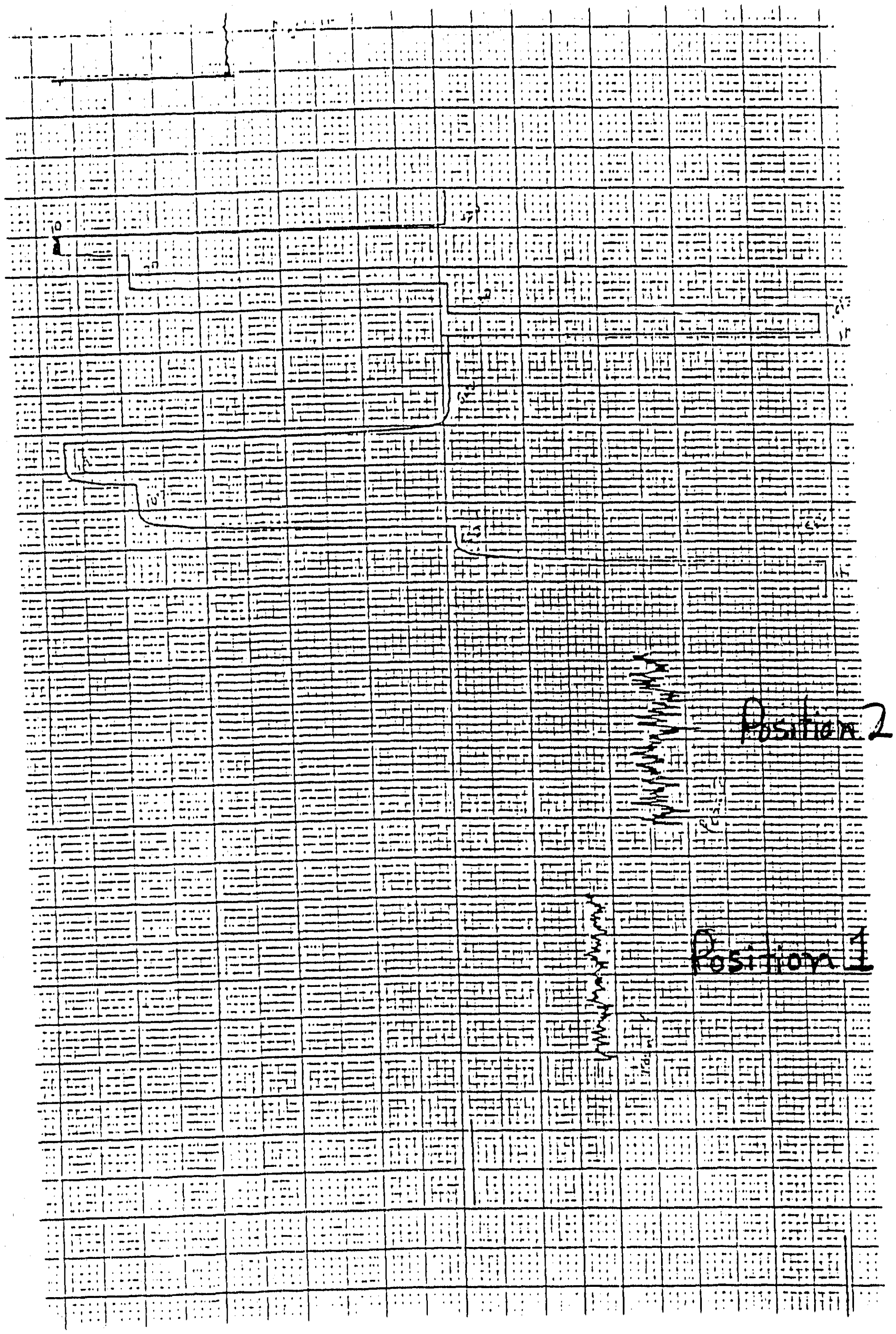
(10 k Scale)
Source 2
Both
Sources
Source 1
10 k Scale


Background
(5 k Scale)
Source 2
Both
Sources
Source 1
5 k Scale



Background
(1000 CPS scale)
Source 2
Both
Sources
Source 1
1000 CPS Scale


Position 2
Position 1

END

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