A Research Report for Westinghouse Hanford Company

1991 Yearly Calibration of Pacific Northwest Laboratory's Gross Gamma-Ray Borehole Geophysical Logging System

R. J. Arthur

August 1991

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1991 YEARLY CALIBRATION OF PACIFIC
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Richland, Washington 99352

MASTER

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SUMMARY

This report describes the 1991 yearly calibration of a gross gamma-ray geophysical pulse logging system owned by the U.S. Department of Energy (DOE) and operated by the Pacific Northwest Laboratory. The calibration was conducted to permit the continued use of this system for geologic and hydrologic studies associated with remedial investigations at the Hanford Site.

Primary calibrations to equivalent uranium units were conducted in DOE borehole model standards that reside on the Hanford Site. The calibrations were performed in borehole models SBL/SBH and SBA/SBB, which contain low-equivalent uranium concentrations.

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

A new field source (Ra-20S-82) was fabricated to replace the old source (Ra-20S-204), whose activity led to variable field calibration results previously caused by a nonfixed geometry. A cross-calibration study was performed to compare the operation of the new source relative to the old source.

A digitally based collection/recording system was recently acquired, so that many of the procedures were performed with the old analog system and the new digital system to compare the performance of the digital system.

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INTRODUCTION

This report presents the yearly calibration of a gross gamma-ray 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 basic function of the system.

The purpose of the yearly base calibration is to verify the quality of data obtained in the field. The system calibration involved in this report includes: 1) a check of basic instrumentation calibration (i.e., rate meters, strip chart recorder, signal generator, and depth-indicating equipment); 2) a check of the system dead time; 3) two primary calibrations using both the SBL/SBH and the SBA/SBB borehole models; 4) the use of a portable field source correlated to the primary standards to establish a unit of measure; and 5) a series of cross-calibration measurements to establish the behavior of a new field source (Ra-20S-82), whose radioactivity is in a geometry known to be fixed, relative to the old field source (Ra-20S-204), whose geometry was discovered to be variable (Arthur 1990).

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ABBREVIATED SYSTEM DESCRIPTION

The PNL gross gamma-ray logging system consists of a thallium-doped sodium iodide [NaI(Tl)] detector encased within a ruggedized probe, a winch-and-cable system for probe placement and high-voltage/signal transmission, a pulse rate meter, and a chart recorder. Ancillary equipment located within the mobile laboratory mounted on a vehicle includes a pulse generator, a high-voltage power supply, and diagnostic instrumentation. A more detailed description of the logging system can be found in the Gearhart-Owen Industries instruction manual for pulse logging systems (Gearhart-Owen, Not Dated).

The signals sent from the detector probe provide no information concerning the energy of detected gamma rays. A nuvistor located within the probe serves as a discriminator to set the energy cutoff value for signal generation. A univibrator located within the gamma-ray probe generates a constant voltage pulse that is sent along the 5000-ft-long cable. A 2-V triangular pulse with a full-width at half maximum of approximately 14 μ s arrives at the input of the rate meter. The rate meter employs a user-selected time constant to average statistical fluctuations of the incoming count rate. An analog voltage is generated for the chart recorder and is proportional to the input count rate. The chart recorder generates a hard-copy record of the data for subsequent analysis.

A digitally based system was recently acquired from Colog Inc., Golden, Colorado, and installed by a field representative. The digital system is connected to a personal computer-compatible card located within the 8-bit slot of a COMPAQ SLT 386/S20. The digital system currently serves as a backup recording device similar to the analog chart recorder.

INSTRUMENTATION CALIBRATION

The critical instrumentation for the gross gamma-ray probe geophysical pulse logging system includes: 1) a pulse generator for establishing scale integrity; 2) a rate meter to collect signals coming uphole, to average statistical fluctuations, and to create an analog voltage output; 3) a chart recorder or equivalent output medium to provide a hard-copy record of detected probe activity; and 4) depth-indicating equipment.

PULSE GENERATOR

The calibration of the pulse generator was performed by checking the output over several ranges against a calibrated frequency counter. The resulting data are provided in Appendix A. The data indicate excellent accuracy and precision in operation at all settings. The maximum observed deviation was 0.006%, which exceeds any realistic requirements for current well-logging activities.

RATE METERS

The rate meters were calibrated by disconnecting both the chart recorder and the digital recorder system. The rate meter time constant was set at 1 s, and the attenuation and output potentiometers were locked at the standard operating value of 10. Pulses from the pulse generator were fed into the cable to the line input of the rate meters (so that the cable/rate meter system was being calibrated) and the rate meter direct current output was measured with a calibrated voltmeter.

The base calibration report (Brodeur and Koizumi 1989) and the subsequent yearly calibration report (Arthur 1990) verified that both rate meters have a linear response. The data for similar measurements are contained in Appendix A and a summary of the results are in Tables 1 and 2. The results verify that the stability and the linear response of both rate meters have not changed during the past year [i.e., voltage measurements on rate meter RMM208 Serial No. 185 indicated a maximum variability in the output voltage of 0.22% full-scale counts/s and a measured linearity of $0.0017894 \pm 0.21\%$, compared to $0.001788 \pm 0.05\%$ (see Arthur 1990); voltage measurements on rate meter RMM208

TABLE 1. Recorder Output Voltage from Rate Meter RMM208 Serial No. 185

Time Const. (s)	Full-Scale Input (Hz)	Voltage Output as % of Full-Scale Input				Linearity Constant ($\times 10^2$)	Zero ($\times 10^2$)
		10%	20%	50%	100%		
1	100	0.0176		0.0891	0.1786	0.17889	-0.00031
1	500		0.0356		0.1786	0.17875	-0.00015
1	1000	0.0178		0.0893	0.1789	0.17901	-0.00014
1	5000	0.0178	0.0357		0.1789	0.17900	-0.00010
1	10000	0.0179		0.0894	0.1789	0.17889	-0.00001
1	50000	0.0178	0.0357		0.1790	0.17912	-0.00012
Average		0.01778	0.0357	0.08927	0.1788	0.178944	-0.000137
Maximum deviation		0.0003	0.0001	0.0003	0.0004	0.00037	0.00030
Maximum deviation (%)		1.7	0.28	0.33	0.22	0.21	>100
Maximum observed voltage output deviation = $0.0004/0.1788$ = 0.22% full-scale counts/s							
Maximum observed linearity deviation = $0.0003/0.17894$ = 0.17% of the counts/s value							

TABLE 2. Recorder Output Voltage from Rate Meter RMM208 Serial No. 182

Time Const. (s)	Full-Scale Input (Hz)	Voltage Output as % of Full-Scale Input				Linearity Constant ($\times 10^2$)	Zero ($\times 10^2$)
		10%	20%	50%	100%		
1	100	0.0182		0.0898	0.1794	0.17911	0.00027
1	500		0.0362		0.1796	0.17925	0.00035
1	1000	0.0183		0.0900	0.1799	0.17957	0.00030
1	5000	0.0182	0.0362		0.1799	0.17965	0.00025
1	10000	0.0183		0.0900	0.1799	0.17957	0.00030
1	50000	0.0183	0.0362		0.1799	0.17958	0.00031
Average		0.01826	0.0362	0.08993	0.17977	0.179455	0.000297
Maximum deviation		0.0001	0.0	0.0002	0.0005	0.00054	0.00010
Maximum deviation (%)		0.55	0.0	0.22	0.28	0.30	34
Maximum observed voltage output deviation = $0.0005/0.17977$ = 0.28% full-scale counts/s							
Maximum observed linearity deviation = $0.00054/0.179455$ = 0.30% of the counts/s value							

Serial No. 182 indicated a maximum variability in the output voltage of 0.28% full-scale counts/s and a measured linearity of $0.0017945 \pm 0.30\%$, compared to $0.001788 \pm 0.05\%$ (see Arthur 1990)]. Measured linearity refers to a least-squares fit of output voltage versus percentage of full-scale input.

The error in both rate meters is insignificant for any logging measurements to be made with this system.

CHART RECORDER

The chart recorder consistently reads zero on the strip chart for no input and full scale for full input. However, the recorder reads approximately 51% for input, which is half of full scale. Because of the strict linearity for the rate meters, as indicated in Tables 1 and 2, it was previously concluded (Arthur 1990) that the chart recorder had a nonlinear response in the middle region.

A more thorough chart recorder calibration was performed using a calibrated voltage standard. The actual test data are contained in Appendix A.

The nonlinear behavior of the chart recorder is evident in the data presented in Table 3. A graph showing the percent deviation of the observed reading relative to the expected reading is illustrated in Figure 1. A maximum error of 1.4% is found in the 30%-40% of full-scale region. Figure 2 is a graph based on the data in Table 3 of the multiplicative factor needed to convert a count rate observed on the chart recorder to true count rate. Such a conversion is generally only required on measurements that are very sensitive to count rate fluctuations, such as dead-time measurements. The calibration was performed in one direction only, starting with zero input voltage and progressing to full-scale input voltage (0.17980 V), so that none of the chart recorder hysteresis noted previously (Arthur 1990) could be quantitated.

TABLE 3. Results from Calibration of Chart Recorder Against a Known Input Voltage

<u>Input Voltage (V)</u>	<u>Observed Chart Recorder Reading (in.)</u>	<u>Deviation from Expected Reading (%)</u>
0.0	0.0	0.0
0.01798	1.002	0.2
0.03596	2.020	1.0
0.05394	3.043	1.43
0.07192	4.057	1.42
0.08990	5.063	1.27
0.10788	6.072	1.19
0.12586	7.073	1.05
0.14384	8.053	0.67
0.16182	9.037	0.41
0.17980	10.017	0.20

DEPTH-INDICATING EQUIPMENT

The depth-indicating and chart recorder control equipment were checked against depth, as measured with a calibrated steel tape. Data collected during the measurement are contained in Appendix A.

At a depth of 400.0 ft, as indicated by the chart recorder, the mechanical depth indicator showed 400.0 ft and the steel tape showed 399.85 ft. The maximum absolute deviation of the tape depth from the indicated depth was between 300 and 350 ft, amounting to 0.22 ft in 300 ft or 0.07% of the indicated depth. Such a deviation is similar to the error reported in the base calibration report (Brodeur and Koizumi 1989).

FIGURE 1. Deviation of Observed Chart Recorder Reading from Expected Reading

FIGURE 2. Multiplicative Factor Required to Convert Observed Chart Recorder Reading to Actual Reading

DEAD-TIME DETERMINATION

CURRENT MEASURED VALUE

With the results of the chart recorder calibration in mind, data were collected to compute a more rigorous value for the dead-time correction. A summary of the observed data are presented in Table 4, and the resulting dead-time correction values are given in Table 5. Uncertainties associated with the dead-time correction values are caused by count rate uncertainties only and are computed by summing the uncertainties in quadrature (Bevington 1969). The two-source method described in the base calibration document (Brodeur and Koizumi 1989; Scott 1980) was used for the experiment. The scale was not changed during the course of any one run for the series of measurements (source 1 only, both sources, source 2 only, and background).

The technique employed in the current measurements used two radium secondary field calibration sources placed at equal distances, such that each 0.020-mCi source gave an equivalent reading on the chart recorder when counted individually, which met the one simplifying assumption used in the two-source method described by Scott (1980).

The experimental procedure used is straightforward. First, the two sources were placed adjacent to each other. Then, source 2 was removed to a significant 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 approximate dead-time correction for the system was calculated as follows:

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

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.

TABLE 4. Data Used for Recalibration of Dead-Time Correction Values

<u>Value Type</u>	<u>Chart Recorder Rate (observed)</u>	<u>Chart Recorder Rate (corrected)</u>
Scale = 10K counts/s		
Background (B)	55	55.
N ₁ + B	5435	5369.
N ₂ + B	5410	5344.
N ₁₂ + B	10075	10060.
Scale = 50K counts/s		
Background	50	50.
N ₁ + B53	50	5159.
N ₂ + B54	50	5251.
N ₁₂ + B102	50	10042.
Scale = 10K counts/s		
Background	50	50.
N ₁ + B	2795	2756.
N ₂ + B	2830	2791.
N ₁₂ + B	5480	5413.
Scale = 5K counts/s		
Background	70	70.
N ₁ + B	2845	2824.
N ₂ + B	2765	2746.
N ₁₂ + B	>5150	N/A
Scale = 5K counts/s		
Background	50	50.
N ₁ + B	1430	1397.
N ₂ + B	1345	1312.
N ₁₂ + B	2775	2731.
Scale = 5K counts/s		
Background	50	50.
N ₁ + B	2425	2394.
N ₂ + B	2275	2245.
N ₁₂ + B	4555	4470.

TABLE 5. Summary of Measured Dead-Time Correction Values

<u>Scale Used</u>	<u>t_{approx.} (μs)</u>	<u>t_{exact} (μs)</u>
10K	11.27 ± 2.73	11.99 ± 3.10 ^(a)
50K	6.17 ± 2.79	6.38 ± 2.98
10K	5.82 ± 7.22	5.91 ± 7.45
5K	N/A	N/A
5K	-20.6 ± 21.4	-20.0 ± 20.3
5K	11.86 ± 9.59	12.19 ± 10.10

(a) Recommended value = 12.0 ± 3.1.

The exact dead-time correction is then obtained using a second formula.

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

The chart recorder data from the dead-time measurements are contained in Appendix B, and the values and scale settings used to compute the dead-time correction are given in Table 4. The observed rate from the chart recorder is contained in the first column of Table 4. The second column of Table 4 contains the rate corrected for the chart recorder nonlinearity using multiplicative factors interpolated from the data shown in Figure 2.

To illustrate the need for correcting for chart recorder nonlinearity, consider the first set of measurements, where $N_1 = 5380$, $N_2 = 5355$, and $N_{12} = 10020$. These data yield $t_{\text{approx.}} = 13.29 \mu\text{s}$ and $t_{\text{exact}} = 14.32 \mu\text{s}$. When corrected for chart recorder nonlinearity, the value of $t_{\text{exact}} = 11.97 \mu\text{s}$ is obtained, which corresponds to a 20% error in the dead time resulting from only a 1.3% error in the chart recorder nonlinearity.

The dead-time correction value as reported in the base calibration report (Brodeur and Koizumi 1989) was not corrected for the chart recorder

nonlinearities. Additionally, the scale was changed when recording the count rate for the combined sources, so that the high reading could not be read as accurately.

The dead-time value determined in the previous calibration report (Arthur 1990) used a less accurate correction for chart recorder nonlinearities, which were not reflected in the associated uncertainties.

The dead-time correction value of $12.0 \mu\text{s}$ obtained from the first 10K-scale set of measurements (see Table 4) is probably the most representative value obtained in the past 3 years of measurements. Values computed by measurements on other scales and at different count rates suffer from either difficulty in precisely reading the count rate from the chart recorder output (at high count rates on high scales), sometimes coupled with the effects of hysteresis in the chart recorder, or insufficient statistics as a result of low count rates (low count rates on lower scales). Measurements taken on the 10K scale without switching to other scales will probably always give the most accurate dead-time correction value. For example, using data from the previous report (Arthur 1990) on the 10K scale, one obtains a dead-time correction value of $12.2 \mu\text{s}$ as shown by the data in Table 6.

A more stable and linear recording device would aid in the accurate determination of the true system dead time. The newly acquired digital system is a likely candidate for such requirements but would need to be evaluated to verify linearity.

The experimentally determined dead time is consistent with the Gearhart-Owen Industries instruction manual (Gearhart-Owen, Not Dated), which states that "a 1500' length of cable permits gross counting rates of over 70,000 counts per second" [corresponding to a dead time of $14.3 \mu\text{s}$]. A discrepancy does exist, however, in that the dead time alone does not explain the saturation of the system at the maximum count rate of 14500 counts/s originally observed in the course of the base calibration study (Brodeur and Koizumi 1989) when counting high gamma-ray fields. A maximum, well in excess of 70000 counts/s, is predicted when the dead time of $12 \mu\text{s}$ is the sole source of the system saturation.

TABLE 6. Data Used from Previous Recalibration of Dead-Time Correction Values

<u>Value Type</u>	<u>Chart Recorder Rate (observed)</u>	<u>Chart Recorder Rate (corrected)</u>
Scale = 10K counts/s		
Background (B)	285	285.
N ₁ + B	4915	4853.
N ₂ + B	4805	4744.
N ₁₂ + B	8900	8864.

Note: $t_{\text{approx}} = 11.57 \mu\text{s}$

$t_{\text{exact}} = 12.20 \mu\text{s}.$

PRIMARY CALIBRATION

SBL/SBH AND SBA/SBB BOREHOLE MODEL CALIBRATIONS

The primary calibration was performed just outside the 200 West Area of the Hanford Site, where the borehole models had been moved from the DOE's Spokane field calibration facility. The calibration was performed using first the SBL/SBH and then 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 with associated uncertainties are given in Table 7.

The calibrations were performed on March 21, 1991. Only the SBA and SBL zones gave useful recordings on both the 10K and the 50K scales. The SBB and SBH zones saturated the logging system equipment at an apparent 15000 counts/s.

The field calibration source readings following the primary calibration runs revealed that the probe had an excess of counts, indicating some mild external contamination consistent with events during the 1990 primary calibrations (Arthur 1990). The source of the contamination was later shown to be radon adhering to the cool surface of the probe. It is suggested that the probe be encased in a polyethylene bag for future calibration runs.

TABLE 7. Radioelement Assay Data for SBL and SBA Zones in the SBL/SBH and SBA/SBB Standard Borehole Models

<u>Zone</u>	<u>^{226}Ra (pCi/g)</u>	<u>Concentration (equivalent uranium ppm)</u>	<u>Thickness (ft)</u>
SBL	324.0 $\pm$ 9	971.0 $\pm$ 27.	4.00
SBA	61.2 $\pm$ 1.7	183.0 $\pm$ 5.	4.01

LINEARITY DETERMINATION

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

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

where P' = probe constant of proportionality

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

The value for the probe constant determined from using the two separate borehole models is presented in Table 8.

TABLE 8. Probe Constant of Proportionality for SBL and SBA Zones

<u>Zone</u>	<u>Apparent Count Rate (counts/s)</u>	<u>Dead-Time Correction Count Rate (counts/s)</u>	<u>Equivalent Uranium Concentration (ppm)</u>
SBL	9945 ± 100	11267 ± 128	971 ± 27
SBA	2286 ± 46	2349 ± 49	183 ± 5

Note: Probe constant (equivalent uranium ppm/count/s) = 0.0884

Linear intercept constant (equivalent uranium ppm) = -24.6

FIELD SOURCE CORRELATION

The method currently being used for field source calibration is described in Environmental Investigations Instruction 11.1, Appendix A, Rev. 1 (WHC 1991). The calibration procedure is to place 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 caused by variable amounts of backscatter.

The net apparent values (corrected for background but uncorrected for dead time) used for Positions 1 and 2 control purposes on data collected after May 4, 1991, are 3466 and 608 counts/s, respectively.

Field calibration values obtained during the primary calibration are contained in Appendix C. The net apparent values for Positions 1 and 2 of 3553 and 617 counts/s agree, verifying a consistency of probe behavior.

A series of measurements was also performed on December 12, 1990, using the old (Ra-20S-204) and new (Ra-20S-82) radium field calibration sources to obtain a cross calibration of the two sources. Data from these cross-calibration measurements are contained in Appendix D and are summarized in Table 9.

The recommended net apparent count rates for use of the new field source (Ra-20S-82) for Positions 1 and 2 are 3364 and 727 counts/s, respectively. The acceptable ranges to satisfy the 8% limit are (3094 - 3633) and (669 - 786) counts/s, respectively.

TABLE 9. Data Used to Cross Correlate Old Field Source with New Field Source

<u>Identification</u>	<u>Old Source Ra-20S-204 Gross Count Rate (counts/s)</u>			<u>New Source Ra-20S-82 Gross Count Rate (counts/s)</u>		
	<u>Pos. 1</u>	<u>Pos. 2</u>	<u>Background</u>	<u>Pos. 1</u>	<u>Pos. 2</u>	<u>Background</u>
GA0	3620	666	47.5	3460	780	47.5
GA1	3620	665	46	3450	775	47
GA2	3590	660	49	3375	770	46.5
GA3	3545	659	46.5	3420	772	45
GA4	3490	679	44	3395	775.5	47.5
GA5	3500	666	45	3425	786	46.5
GA6	3590	665	45.5	3400	765	45
GA7	3580	658.5	45	3385	770	45
GA8	3580	647	46.5	3405	774	45.5
GA9	3550	653	46.5	3380	765.5	45
	<u>Net Count Rate (counts/s)</u>			<u>Net Count Rate (counts/s)</u>		
GA0	3572.5	618.5		3412.5	732.5	
GA1	3574	619		3403	728	
GA2	3541	611		3328.5	723.5	
GA3	3498.5	612.5		3375	727	
GA4	3446	635		3347.5	728	
GA5	3455	621		3378.5	739.5	
GA6	3544.5	619.5		3355	720	
GA7	3535	613.5		3340	725	
GA8	3533.5	600.5		3359.5	728.5	
GA9	3503.5	606.5		3335	720.5	
Average =	3520.4	615.7		3363.5	727.3	
Standard deviation	44.2	9.3		28.4	5.8	
8% lower limit =				3094.4	669.1	
8% upper limit =				3632.6	785.5	

CONCLUSIONS

The original dead-time correction was calculated as $7.4 \mu\text{s}$ from data in which a change of scale was made and without any correction for chart recorder nonlinearity (Brodeur and Koizumi 1989). A new value was determined the next year as $17 \mu\text{s}$, but with a fairly large uncertainty because of an approximate correction for the nonlinear response of the chart recorder readings. A current recommended value of $12.0 \mu\text{s}$ is based on analog data that have been more accurately corrected for nonlinear response.

The raw primary calibration data have not significantly changed since they were determined and documented most recently (Arthur 1990): a gross count rate of 9945 counts/s, determined on the 10K scale for the SBL/SBH borehole model, compared to 9980 counts/s last year. The calculated probe constant of 0.0884 equivalent uranium ppm/counts/s and the intercept of -24.6 equivalent uranium ppm reflect a more thorough calibration of the chart recorder.

A cross-calibration experiment between the old field source (Ra-20S-204) and the new field source (Ra-20S-82) gave for the new source net apparent count rate values for Positions 1 and 2 of 3364 and 727 counts/s, respectively; the corresponding 8% ranges are (3094 - 3633) and (669 - 786) counts/s, respectively.

The potential for increased accuracy and ease of working with numbers generated using a digital system point to the need for evaluating the digital system as a replacement for the chart recorder as the recording medium.

RECOMMENDATIONS

The following recommendations should be considered for implementation in 1991:

- calibrate an additional gamma-ray probe and/or system as a backup
- use the digital collection system as the primary data collection instrumentation, possibly with the chart recorder as a secondary (confirmation) or backup system
- perform an additional series of dead-time correction measurements using the digital recorder system if that system is linear
- ensheath the probe in polyethylene during calibration in the borehole models.

REFERENCES

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APPENDIX A

DATA FROM INSTRUMENT CALIBRATION MEASUREMENTS

Test #320200

①

A. Pearson
S. Kos
G. Poorman
D. Rasmussen
5/3/91

Dan Rasmussen

1) Pulse generation check PGM 103 Gearhart Mineral Logging System

Variable amplitude + output F.S. 3.5 V Peak
50 kHz - output F.S. -2.6 V Peak
other ranges + output F.S. > 3.0 Volts
- output F.S. > 2.0 Volts

- pulse	Frequency Hz Setting	Reading 1	Reading 2 (1sec readings)
	10	10.0	10.0
	50	50.0	50.0
	100	100.0	100.0
	500	500.0	500.0
	1,000	1000.0	1000.0
	5,000	5000.0	5001.
	10,000	10,000.	10,000
	50,000	50,002.	50,002.
+ Pulses	Hz setting	Reading 1	Reading 2
	10	10.0	10.0
	50	50.	50.
	100	100.	100.
	500	500.	500.
	1,000	1001.	1000.
	5,000	5000.	5000.
	10,000	10,001.	10,000.
	50,000	50,003.	50,002.

5/6/91

(2)

Rate Meter Module RM208 Serial #182
 Suppression set & locked @ 10
 Recorder output set & locked @ 10

Input from pulse generator through cable to Line Input
 Output Reverse/Normal @ Normal
 Negative Input

Time Constant = 1 sec. Chart Recorder & A → D Converter (Serial #182) (Serial #185)

Scale	Input	Output (bits)	Output (volts)
Scale 100 cps	10 Hz	0.0182	0.0176
	50 Hz	0.0898	0.0891
	100 Hz	0.1794	0.1786

Scale 500 cps	100 Hz	0.0362	0.0356
	500 Hz	0.1796	0.1786

Scale 1000 cps	100 Hz	0.0183	0.0178
	500 Hz	0.0900	0.0893
	1000 Hz	0.1799	0.1789

Scale 5,000 cps	500 Hz	0.0182	0.0178
	1000 Hz	0.0362	0.0357
	5,000 Hz	0.1799	0.1789

Scale 10,000 cps	1000 Hz	0.0183	0.0179
	5,000 Hz	0.0900	0.0894
	10,000 Hz	0.1799	0.1789

Scale 50,000 cps	5,000 Hz	0.0183	0.0178
	10,000 Hz	0.0362	0.0357
	50,000 Hz	0.1799	0.1790

Internal Oscillation 100 Hz	100 cps	0.1798	0.1791
	500 cps	0.0364	0.0360
	1000 cps	0.0185	0.0181

Chart Recorder Calibration

Set full scale w/ Internal Oscillation on Rate meter

Recorded on Chart	Inputs	Divisions
0.01788	10 divisions	
0.03596	20 divisions	
0.05374	30 divisions	
0.07172	40 divisions	
0.08970	50 divisions	
0.10768	60 divisions	
0.12566	70 divisions	

5/6/91

3

Chart Recorder Calibration
Input from AC Standard Voltage
Input Chart Recorder Divisions

0.01748	10.00
0.03596	20.15
0.05394	30.40
0.07192	40.70
0.08990	50.75
0.10788	60.80
0.12586	70.80
0.14384	80.60
0.16182	90.30
0.17980	100.00

Recorded these on Chart

Systems Standards Code # 517-79-03-001

Chart Recorder Calibration

21887
21887

Full Scale
Span
0.17980 V

5-6-41 Alvin Pearson
George K. S.
Don R. [unclear]

APPENDIX B

DATA FROM DEAD-TIME DETERMINATION MEASUREMENTS

DATE: 17 JANUARY 1964

800-274-0400 ON

ALSO BY THE AUTHOR

APPENDIX C

DATA FROM PRIMARY CALIBRATION MEASUREMENTS

APPENDIX D

DATA FROM FIELD SOURCE CROSS-CALIBRATION MEASUREMENTS

Wpawożenie na 2000-2001, 2002-2003, 2004-2005, 2006-2007, 2008-2009, 2010-2011, 2012-2013, 2014-2015, 2016-2017, 2018-2019, 2020-2021, 2022-2023, 2024-2025, 2026-2027, 2028-2029, 2030-2031, 2032-2033, 2034-2035, 2036-2037, 2038-2039, 2040-2041, 2042-2043, 2044-2045, 2046-2047, 2048-2049, 2050-2051, 2052-2053, 2054-2055, 2056-2057, 2058-2059, 2060-2061, 2062-2063, 2064-2065, 2066-2067, 2068-2069, 2070-2071, 2072-2073, 2074-2075, 2076-2077, 2078-2079, 2080-2081, 2082-2083, 2084-2085, 2086-2087, 2088-2089, 2090-2091, 2092-2093, 2094-2095, 2096-2097, 2098-2099, 2100-2101, 2102-2103, 2104-2105, 2106-2107, 2108-2109, 2110-2111, 2112-2113, 2114-2115, 2116-2117, 2118-2119, 2120-2121, 2122-2123, 2124-2125, 2126-2127, 2128-2129, 2130-2131, 2132-2133, 2134-2135, 2136-2137, 2138-2139, 2140-2141, 2142-2143, 2144-2145, 2146-2147, 2148-2149, 2150-2151, 2152-2153, 2154-2155, 2156-2157, 2158-2159, 2160-2161, 2162-2163, 2164-2165, 2166-2167, 2168-2169, 2170-2171, 2172-2173, 2174-2175, 2176-2177, 2178-2179, 2180-2181, 2182-2183, 2184-2185, 2186-2187, 2188-2189, 2190-2191, 2192-2193, 2194-2195, 2196-2197, 2198-2199, 2200-2201, 2202-2203, 2204-2205, 2206-2207, 2208-2209, 2210-2211, 2212-2213, 2214-2215, 2216-2217, 2218-2219, 2220-2221, 2222-2223, 2224-2225, 2226-2227, 2228-2229, 2230-2231, 2232-2233, 2234-2235, 2236-2237, 2238-2239, 2240-2241, 2242-2243, 2244-2245, 2246-2247, 2248-2249, 2250-2251, 2252-2253, 2254-2255, 2256-2257, 2258-2259, 2260-2261, 2262-2263, 2264-2265, 2266-2267, 2268-2269, 2270-2271, 2272-2273, 2274-2275, 2276-2277, 2278-2279, 2280-2281, 2282-2283, 2284-2285, 2286-2287, 2288-2289, 2290-2291, 2292-2293, 2294-2295, 2296-2297, 2298-2299, 2300-2301, 2302-2303, 2304-2305, 2306-2307, 2308-2309, 2310-2311, 2312-2313, 2314-2315, 2316-2317, 2318-2319, 2320-2321, 2322-2323, 2324-2325, 2326-2327, 2328-2329, 2330-2331, 2332-2333, 2334-2335, 2336-2337, 2338-2339, 2340-2341, 2342-2343, 2344-2345, 2346-2347, 2348-2349, 2350-2351, 2352-2353, 2354-2355, 2356-2357, 2358-2359, 2360-2361, 2362-2363, 2364-2365, 2366-2367, 2368-2369, 2370-2371, 2372-2373, 2374-2375, 2376-2377, 2378-2379, 2380-2381, 2382-2383, 2384-2385, 2386-2387, 2388-2389, 2390-2391, 2392-2393, 2394-2395, 2396-2397, 2398-2399, 2400-2401, 2402-2403, 2404-2405, 2406-2407, 2408-2409, 2410-2411, 2412-2413, 2414-2415, 2416-2417, 2418-2419, 2420-2421, 2422-2423, 2424-2425, 2426-2427, 2428-2429, 2430-2431, 2432-2433, 2434-2435, 2436-2437, 2438-2439, 2440-2441, 2442-2443, 2444-2445, 2446-2447, 2448-2449, 2450-2451, 2452-2453, 2454-2455, 2456-2457, 2458-2459, 2460-2461, 2462-2463, 2464-2465, 2466-2467, 2468-2469, 2470-2471, 2472-2473, 2474-2475, 2476-2477, 2478-2479, 2480-2481, 2482-2483, 2484-2485, 2486-2487, 2488-2489, 2490-2491, 2492-2493, 2494-2495, 2496-2497, 2498-2499, 2500-2501, 2502-2503, 2504-2505, 2506-2507, 2508-2509, 2510-2511, 2512-2513, 2514-2515, 2516-2517, 2518-2519, 2520-2521, 2522-2523, 2524-2525, 2526-2527, 2528-2529, 2530-2531, 2532-2533, 2534-2535, 2536-2537, 2538-2539, 2540-2541, 2542-2543, 2544-2545, 2546-2547, 2548-2549, 2550-2551, 2552-2553, 2554-2555, 2556-2557, 2558-2559, 2560-2561, 2562-2563, 2564-2565, 2566-2567, 2568-2569, 2570-2571, 2572-2573, 2574-2575, 2576-2577, 2578-2579, 2580-2581, 2582-2583, 2584-2585, 2586-2587, 2588-2589, 2590-2591, 2592-2593, 2594-2595, 2596-2597, 2598-2599, 2600-2601, 2602-2603, 2604-2605, 2606-2607, 2608-2609, 2610-2611, 2612-2613, 2614-2615, 2616-2617, 2618-2619, 2620-2621, 2622-2623, 2624-2625, 2626-2627, 2628-2629, 2630-2631, 2632-2633, 2634-2635, 2636-2637, 2638-2639, 2640-2641, 2642-2643, 2644-2645, 2646-2647, 2648-2649, 2650-2651, 2652-2653, 2654-2655, 2656-2657, 2658-2659, 2660-2661, 2662-2663, 2664-2665, 2666-2667, 2668-2669, 2670-2671, 2672-2673, 2674-2675, 2676-2677, 2678-2679, 2680-2681, 2682-2683, 2684-2685, 2686-2687, 2688-2689, 2690-2691, 2692-2693, 2694-2695, 2696-2697, 2698-2699, 2700-2701, 2702-2703, 2704-2705, 2706-2707, 2708-2709, 2710-2711, 2712-2713, 2714-2715, 2716-2717, 2718-2719, 2720-2721, 2722-2723, 2724-2725, 2726-2727, 2728-2729, 2730-2731, 2732-2733, 2734-2735, 2736-2737, 2738-2739, 2740-2741, 2742-

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