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A Research Report for
Westinghouse Hanford Company

1993 YEARLY CALIBRATION OF PACIFIC
NORTHWEST LABORATORY'S GROSS GAMMA-RAY
BOREHOLE GEOPHYSICAL LOGGING SYSTEM

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SUMMARY

This report describes the 1993 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. 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. The calibration is limited to the probe identified as CG27A-97 and applies to a new probe detector crystal that replaced the former detector in January 1993, after a crack was discovered.

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 both contain sections with relatively low equivalent-uranium concentrations. Model SBH/SBL has now been countersunk at the site so that data were taken by suspending the probe downhole. Model SBA/SBB is still lying horizontally above ground at the site, so data were logged as in previous calibrations at the Hanford site by pushing the probe into the hole and drawing it out with the logging equipment.

A previous correlation for relating observed count rate in before- and after-logging field calibrations to equivalent-uranium concentrations was confirmed for field source Ra-20S-82.

A computer-based digital collection/recording system was used simultaneously on many of the procedures with the original analog system so that the performance of the two collection systems could be correlated and compared. The digital system was calibrated this year to confirm its linearity and to establish correlation with the analog data (i.e., chart-recorder output).

Values (determined during the course of calibration) used to meet requirements of the logging technical procedure include 1) the deadtime, 2) the probe constant, and 3) values to compare the field check source against, before borehole logging to ensure that the probe is operating within acceptable limits.

The dead time was determined to be 11.85 μ s. The probe constant is (0.830 ± 0.0025) equivalent-Uranium parts-per-million (eU ppm)/count/s. The values used to determine that the probe is operating within acceptable limits are 3655 counts/s in Position 1 and 749 counts/s in Position 2, which correspond to values of 303.4 eU ppm and 62.2 eU ppm using the appropriate probe constant.

The equation used to calculate concentration based on the probe constant is assumed to be a linear function with a intercept that passes through zero. The equation used is

$$\text{Concentration (eU ppm)} = (0.0830 \pm 0.0025) \cdot R \text{ (count/s)}$$

where R is the dead-time corrected count rate.

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INTRODUCTION

This report presents results of 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 was 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 calibration is to verify the quality of data obtained in the field and to establish the current correlation between observed count rate and the amount of radioactive material present relative to natural uranium in secular equilibrium. 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 the SBL/SBH and the SBA/SBB borehole models; and 4) the use of portable field source Ra-20S-82, correlated to the primary standards, to confirm a unit of measure.

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SYSTEM OVERVIEW

The PNL gamma-ray logging system consists of a 0.75-in. round by 2.5-in. long 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 includes a pulse generator, a high-voltage power supply, diagnostic instrumentation, and a computer-based digital collection system. A more detailed description of the logging system can be found in the Gearhart-Owen instruction manual for pulse logging systems (Gearhart-Owen Industries, Inc., Not Dated).

ABBREVIATED SYSTEM DESCRIPTION

The signals sent from the detector probe provide no information concerning the energy of detected gamma rays. Transistor-transistor logic (TTL) circuitry within the probe serves as a discriminator to set the energy cutoff value [currently set between 46.5 keV and 59.5 keV (Arthur 1990)] for signal generation and to generate a constant voltage pulse that is sent along the 5000-ft-long cable. A resulting 2-volt triangular pulse provides input to the rate meter. The rate meter employs a user-selected time constant (typically set at 1 second) to average statistical fluctuations of the incoming count rate. An analog voltage proportional to the input count rate is generated for the recording media, analog and digital, which then generate hard-copy records of the data for subsequent analysis and documentation.

A digitally based system has been installed as a backup recording device similar to the analog chart recorder. The digital system is connected to a COMPAQ SLT 386/S20 with an interface card located within the 8-bit slot of the computer data bus. Two signals are used by the digital system: the Gamma Direct monitors the counts coming from the probe, whereas the Gamma Analog monitors the output of the ratemeter through a NIM-bin based analog-to-digital converter. The digital system was calibrated against known voltage inputs as part of the 1993 calibration. This is the first year that the digital system has been calibrated.

MODIFICATIONS TO THE PROBE

In January 1993, a test was conducted using a ^{137}Cs point source to assess the integrity of the NaI(Tl) scintillating crystal. A slight but distinct decrease in signal was noted, a correlation between count rate and azimuthal position of the check source, indicative of cracked crystal. The probe was subsequently opened, the crystal was found to be fractured, and the crystal was replaced. A dead-time check indicated that the system was not responding correctly.

The probe was again opened and a burned-out potentiometer in the TTL circuitry was replaced. Adjustment of the potentiometer enabled the system to respond to higher count rates than were obtainable in previous years. The system was previously limited to measuring radiation levels below 14,000 counts/s because the instrumentation saturated at count rates in excess of that value. Replacing and/or adjusting an internal potentiometer has raised this saturation level to an apparent 22,500 counts/s.

The dead time of the system was again measured and found to be comparable to previous values. The system was also verified as operating within acceptable limits by performing a field check against the 20- μCi NIST-traceable radium source, Ra-20S-82. The yearly system calibration against the U.S. DOE standard borehole models SBL/SBH and SBA/SBB were conducted, in part, as a final verification of system performance.

INSTRUMENTATION CALIBRATION

The critical pieces of instrumentation for the geophysical pulse logging system include 1) a pulse generator for establishing scale integrity for the ratemeter and the recording media; 2) a gamma-ray probe for detecting radiation with associated electronic circuitry for transmitting detector responses uphole; 3) a rate meter to collect signals coming uphole, to average statistical fluctuations, and to create an analog voltage output; 4) a chart recorder or equivalent output media to provide a hard-copy record of detected probe response; and 5) depth-indicating equipment.

PULSE GENERATOR

The calibration of the Gearhart PGM103 (Serial No. 14) pulse generator was performed by checking several ranges of the pulsed output 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 0.002% (0.1 in 5000), which greatly exceeds any realistic requirements for current well-logging activities.

RATE METERS

Two Gearhart RMM208 rate meters (Serial Nos. 182 and 185) 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. The system consisting of logging cable and ratemeter was calibrated since pulses from the pulse generator were fed into the cable to the line input of each rate meter and the rate-meter direct current (DC) output was measured with a calibrated voltmeter.

The base calibration report (Brodeur and Koizumi 1989) and subsequent yearly calibration reports (Arthur 1990, 1991, 1992) verify that both rate meters have a linear response. The data for similar measurements are contained in Appendix A, and the results are summarized in Tables 1 and 2.

TABLE 1. 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	0.0184		0.0899	0.1795	0.179008	+0.000462
1	500		0.0364		0.1801	0.179625	+0.000475
1	1000	0.0185		0.0905	0.1806	0.180115	+0.000472
1	5000	0.0186	0.0365		0.1805	0.179932	+0.000563
1	10000	0.0186		0.0905	0.1806	0.180008	+0.000562
1	50000	0.0185	0.03648		0.1805	0.180010	+0.000489

Average 0.01852 0.03646 0.09030 0.18032 0.179783 +0.000504
Maximum Deviation 0.0002 0.0001 0.0006 0.00044 0.000415 0.000046
Maximum Deviation (%) 1.08 0.27 0.66 0.61 0.616 20.

Maximum Observed Voltage Output Deviation = $0.0011/0.18032$
= 0.61% full-scale count/s

Maximum Observed Linearity Deviation = $0.00137/0.179637$
= 0.76% of the count/s value

TABLE 2. 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	0.0177		0.0891	0.1783	0.178443	-0.000136
1	500		0.0357		0.1785	0.178500	0.000000
1	1000	0.0178		0.0894	0.1789	0.179000	-0.000100
1	5000	0.0178	0.0357		0.1789	0.179000	-0.000100
1	10000	0.0179		0.0894	0.1789	0.178893	-0.000010
1	50000	0.0179	0.0357		0.1789	0.178932	-0.000037

Average 0.01782 0.0357 0.08930 0.17873 0.178795 -0.000064
Maximum Deviation 0.0002 0.0 0.0003 0.0006 0.000557 0.000136
Maximum Deviation (%) 1.12 0.0 0.34 0.34 0.31

Maximum Observed Voltage Output Deviation = $0.0006/0.17873$
= 0.34% full-scale count/s

Maximum Observed Linearity Deviation = $0.00056/0.178795$
= 0.31% of the count/s value

The results of the rate-meter calibration for 1993 verify that the stability and the linear response of both rate meters have not changed during the past year. A comparison of linearity constants for previous years is summarized in Table 3. 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 logging measurements performed using this system.

Measurements made using the 100-Hz internal oscillator (used for full-scale input during the chart-recorder check) are also given in Appendix A and indicate a rate-meter output voltage consistent with the output from the pulse generator through the cable.

CHART RECORDER

The strip chart recorder consistently reads zero for no input and full scale for full input, but consistently shows a deviation of between 51%-55% for half of full scale. Because of the strict linearity observed for the rate meters, as indicated in Tables 1 and 2, Arthur (1990) previously concluded that the chart recorder had a nonlinear response in the mid-region, which continues to be manifest.

A chart-recorder calibration was performed using a calibrated voltage standard. The chart-recorder output containing the test data are presented in Appendix A. Calibration of the digital system was also performed at this time and the output is also presented in Appendix A.

The nonlinear behavior of the chart recorder is evident in the data resulting from the calibrated voltage check (Table 4). Figure 1 shows the

TABLE 3. Comparison of Measured Linearity Constants for RMM208 Rate Meters

<u>Reference</u>	<u>Linearity Constant</u> <u>RMM208 Serial No. 182</u>	<u>Linearity Constant</u> <u>RMM208 Serial No. 185</u>
Arthur 1990	0.0017911 $\pm$ 0.05%	0.0017883 $\pm$ 0.05%
Arthur 1991	0.0017945 $\pm$ 0.30%	0.0017894 $\pm$ 0.21%
Arthur 1992	0.0017931 $\pm$ 0.06%	0.0017896 $\pm$ 0.07%
Present Work	0.0017978 $\pm$ 0.62%	0.0017880 $\pm$ 0.31%

TABLE 4. Results from Calibration of Chart Recorder Against a Known Input Voltage

<u>Input Voltage as % of Full Scale</u>	<u>Observed Chart- Recorder Reading (in.)</u>	<u>Deviation from Expected Reading (%)</u>	<u>Multiplicative Correction Constant</u>
<u>Ascending Values</u>			
0	0.	0.0	1.0000
10	0.984	-1.4	1.0142
20	2.016	0.80	0.9921
30	3.034	1.13	0.9888
40	4.048	1.20	0.9881
50	5.060	1.20	0.9881
60	6.050	0.83	0.9917
70	7.054	0.77	0.9923
80	8.044	0.55	0.9945
90	9.020	0.22	0.9978
100	9.988	-0.12	1.0012
<u>Descending Values</u>			
90	9.010	0.11	0.9989
80	8.040	0.50	0.9950
70	7.060	0.86	0.9915
60	6.048	0.80	0.9921
50	5.064	1.28	0.9874
40	4.044	1.10	0.9891
30	3.018	0.60	0.9940
20	1.998	-0.10	1.0010
10	0.984	-1.60	1.0163
0	0.010	--	--

percent deviation of the observed reading relative to the expected reading, together with the deviation noted in previous years (Arthur 1991, 1992). A maximum error of roughly $\pm 1.5\%$ is found in the region between 10 to 50% of full scale.

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

The recorder calibration is performed by first increasing the standard voltage from zero to full scale input voltage (0.17980 volt), then decreasing the voltage incrementally back to zero. The deviation between the two readings is shown in Figure 1 as a heavy bar connecting the two values. Such an approach demonstrates hysteresis in the chart-recorder, as observed and described previously (Arthur 1990).

Figure 2 contains a graph (based on the data in Table 4) of the multiplicative factor needed to convert a count rate observed on the chart recorder to true count rate. The multiplicative factors determined from previous years' calibrations (Arthur 1991, 1992) are also presented. In general, such a conversion is required only on measurements that are very sensitive to count-rate fluctuations, such as dead-time measurements and primary calibration measurements, as emphasized in a previous calibration report (Arthur 1991, p.13).

DEPTH-INDICATING EQUIPMENT

The depth-indicating and chart-recorder-control equipment was checked against depth as measured with a calibrated steel tape. A summary of data collected during the measurement is contained in Appendix A.

At a depth of 400.0 ft (as indicated by the chart recorder), the mechanical depth indicator (odometer) showed 400.0 ft, the steel tape showed 399.90 ft, and the digital reading was 399.71 ft. The chart recorder is driven by the mechanical depth indicator whereas the digital reading is taken from the depth encoder and recorded on the computer output. When the digital reading is corrected for the non-zero offset (-0.31 ft in Appendix A) then the digital reading deviates from the odometer reading by no more than 0.02 ft in the 0 - 400 ft range.

The maximum absolute deviation of the tape depth from the indicated depth between 250 and 400 ft amounted to 0.30 ft in 400 ft, or 0.075% of the indicated depth. Such a deviation is similar to the error reported in the base calibration report (Brodeur and Koizumi 1989). The logging operator indicates that he notices some slop in the logging cable when reversing directions.

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

DEAD-TIME DETERMINATION

Data were collected using both the chart recorder and digital recorder to compute a current value for the dead-time correction. Data from the digital recorder were used in preference to the chart-recorder data to minimize the effects of nonlinearity in the chart-recorder operation. A summary of the observed data and corrected count rates is presented in Table 5 and the resulting dead-time correction values are given in Table 6. Uncertainties associated with the dead-time correction values are due to count-rate

TABLE 5. Data Used for Determination of Dead-Time Correction Value

<u>Value Type</u>	<u>Chart-Recorder Rate (Observed)</u>	<u>Digital-Recorder Rate (Observed)</u>
(Scale = 50K count/s)		
Background (B)	30	35.40
$N_1 + B$	4730	4649.2
$N_2 + B$	4995	4894.9
$N_{12}^2 + B$	9110	8984.0
(Scale = 10K count/s)		
Background (B)	30	34.92
$N_1 + B$	4820	4751.5
$N_2 + B$	5120	5024.2
$N_{12}^2 + B$	9290	9169.7
(Scale = 5K count/s)		
Background (B)	30	33.7
$N_1 + B$	2220	2183.1
$N_2 + B$	2320	2261.4
$N_{12}^2 + B$	4413	4363.2
(Scale = 50K count/s)		
Background (B)	50	55.8
$N_1 + B$	9500	9938.7
$N_2 + B$	9900	9523.8
$N_{12}^2 + B$	16450	16519.2

TABLE 6. Summary of Measured Dead-Time Correction Values

<u>Scale Used</u>	<u>t_{approx.}</u> <u>(μs)</u>	<u>t_{exact}</u> <u>(μs)</u>
50K	12.4	13.2
10K	12.9	13.7
5K	5.02	5.08
50K	18.13	22.18

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. To minimize the effects on non-linearity in the chart recorder, 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 the two radium secondary field calibration sources placed at equal distances such that each 0.020-mCi source gave an approximately equal reading on the chart recorder when counted individually. This technique met the one simplifying assumption used in the two-source method described by Scott (1980).

The experimental procedure that was followed is straightforward. First, the two sources are placed adjacent to each other to establish that the combined count rate will not exceed the scale on the recorder. Then, source 2 is removed and a 1.5- to 2.0-min count of the rate is recorded. Then, source 2 is placed adjacent to source 1 and a 2-min count of the combined rates is recorded. Next, source 1 is removed and the count rate is recorded with only source 2 in place. Finally, source 2 is removed and a background count rate is recorded on the same scale. The approximate dead-time correction for the system is calculated as

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

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.

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 original chart-recorder data for the dead-time measurements are contained in Appendix B. The values as read from the strip chart, the scale settings, and the digital values used to compute the dead time are given in Table 5. Table 6 summarizes values obtained for the dead-time correction at the different count rates listed in Table 5.

Previous dead-time values computed by measurements on other scales and at different count rates suffered from either difficulty in precisely reading the count rate from the chart-recorder output (at high count rates on high scales), coupled with the effects of hysteresis in the chart recorder, or insufficient statistics resulting from low count rates (low count rates on lower scales). Using values from the digital recorder eliminates much of the uncertainties and provides clearer insight into the operation of the probe. One observation is that the dead time appears to be count-rate dependent. Such a phenomenon is probably due to a shift in baseline as the count rate increases and is directly related to the relatively broad signal arriving at the input to the rate meter. The effect becomes significant at high count rates where the dead time exceeds 22 μs , as shown in Table 6. This effect may warrant further investigation.

A practical dead-time correction value of 11.85 μs was chosen as a trade-off between accuracy in the range of highest acceptable count rate, the minimization of error in the range of lower count rates, and obtaining a zero intercept. A dead-time value of 11.85 μs also agrees favorably with the 12.0- μs and 12.34- μs values obtained previously (Arthur 1991, 1992) when the recommended maximum combined-source count rate on the 10K setting is used.

The experimentally determined dead time is consistent with the Gearhart-Owen instruction manual (Gearhart-Owen Industries, Inc., 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 22,500 counts/s originally observed in the course of the base calibration study (Brodeur and Koizumi 1989) when counting high gamma-ray fields. A maximum count rate, well in excess of 70,000 counts/s, is predicted when dead time of $12 \mu\text{s}$ is the sole source of the system saturation.

PRIMARY CALIBRATION

SBL/SBH AND SBA/SBB BOREHOLE MODEL CALIBRATIONS

The primary calibration was performed at the site selected for maintaining the DOE borehole models that were moved from the Spokane field calibration facility. The site is due north of the main gate of the 200 West Area of the Hanford Site. The calibration was performed using both the SBL/SBH and the SBA/SBB standard borehole models. Complete descriptions of the models and the radioelement assays were provided by Steel and George (1986). The pertinent equivalent concentrations of uranium with associated uncertainties are given in Table 7. The values of the actual count rate (observed count corrected for recorder non-linearity) are corrected using a dead time of 11.85 μ s using the following formula:

$$N = \frac{n}{1 - n \cdot t}$$

where N = actual (dead-time corrected) count rate

n = apparent count rate

t = system dead time.

TABLE 7. Probe Constant of Proportionality for SBL and SBA Zones

<u>Zone</u>	<u>Observed Count Rate (counts/s)</u>	<u>Dead-Time Corrected Count Rate (counts/s)</u>	<u>Equivalent-Uranium Concentration (ppm)</u>
SBL	10,228 $\pm$ 55	11,640 $\pm$ 55	971 $\pm$ 27
SBH	--	--	9369 $\pm$ 539
SBA	2411.0 $\pm$ 19.2	2,482 $\pm$ 19	183 $\pm$ 5
SBB	18,173 $\pm$ 64	23,160 $\pm$ 130	2703 $\pm$ 81

Probe Constant (eU ppm/count/s) = 0.0830 $\pm$ 0.0025

Linear Intercept Constant (eU ppm) = 0

The value for the probe constant presented in Table 7 is determined using two low-activity borehole models, SBA and SBL, by fitting a straight line through the points and forcing the intercept through zero. The equation used to compute equivalent-uranium concentration based on an observed count rate is

$$\text{Concentration (eU ppm)} = (0.0830 \pm 0.0025) \cdot R \text{ (count/s)}$$

where R is the dead-time corrected count rate.

The calibrations were performed on 23 February 1993. The SBA, SBB, and SBL zones all gave useful recordings, on several scales; the SBH zone saturated the logging-system equipment at an apparent 22,500 counts/s.

The count rate for the calibration zone in each model was obtained in two separate modes. The dynamic mode consisted of pulling the probe through the zone at a rate of approximately 4 ft/min. The static mode involved stopping the probe movement at the apparent maximum activity in the borehole model zone and obtaining an extended count. The results of both modes of measurements for both models on several scales are summarized in Table 8. The estimated uncertainties were obtained by assuming that excursions of the pen from the mean count rate represent a 4σ variation (i.e., 95% of the time, the pen does not exceed a given level). A weighted average of the observed count rates yielded the apparent count rate and uncertainty for the corresponding zone (Bevington 1969).

Figure 3 shows graphically the comparison of values presented in Table 7 as the bore-hole model equivalent uranium concentration as a function of dead-time corrected count rate. A probe rate constant of 0.0830 eU ppm /count/s and a dead-time value of 11.85 μ s over the entire range of count rates provide a linear function that matches the higher-end count rate while possessing a zero-value intercept. Note that the dead-time value is insufficient to bring the high-level SBB zone into the linear region.

The field calibration source readings following the primary calibration runs revealed that the probe had an excess of counts, indicating some mild

FIGURE 3. Comparison of Dead-Time-Corrected Count Rate Against Model Equivalent-Uranium Concentration

TABLE 8. Apparent and Observed Count Rates for SBA, SBB, and SBL Zones in Dynamic and Static Modes

<u>Mode</u>	<u>Borehole Model Zone</u>	<u>Scale</u>	<u>Apparent Count Rate (counts/s)</u>	<u>Observed Count Rate (counts/s)</u>
Dynamic	SBA	5K	2428 ± 20	2390 ± 31
		10K	2352 ± 50	2401 ± 16
		50K	2040 ± 100	2433 ± 41
Static	SBA	5K	2428 ± 40	2420 ± 32
		Weighted Average:		<u>2411.0 ± 19.2</u>
Dynamic	SBB	50K	18130 ± 100	18218 ± 169
Static	SBB	50K	18060 ± 50	18128 ± 190
Weighted Average:				<u>18173 ± 64</u>
Dynamic	SBL	10K	10165 ± 52	10151 ± 72
		50K	9940 ± 75	10226 ± 101
Static	SBL	10K	10165 ± 80	10271 ± 51
		50K	--	10265 ± 52
Weighted Average:				<u>10228 ± 55</u>

external contamination, consistent with events during previous primary calibrations (Arthur 1990, 1991). The source of the contamination has been identified as radon adhering to the cool surface of the probe. The Radiation Protection Technician (RPT) present at the site confirmed the nature of the contamination's radon decay products. The suggested practice for calibration runs is that the probe is encased in a vinyl or polyethylene bag. A count of the SBA zone with and without a protective vinyl sheath confirmed that the coating does not affect the apparent count rate observed in the calibration model.

FIELD-SOURCE CONSISTENCY CHECK

The method currently being used for field-source consistency check is described in WHC-CM-7-7, Environmental Investigations and Site Characterization Manual EII 11.1, Appendix A, Rev. 1, 1991. The consistency check (field 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 resulting from variable amounts of backscatter. Position 1 refers to the field source clamped into position directly above the detector crystal while Position 2 refers to the source located off-center relative to the crystal.

CONTROL RESULTS

Field calibration values obtained during the primary calibration are contained in Appendix C. The average of the net apparent values (corrected for background but uncorrected for dead time) obtained from Position 1 counts before and after the primary calibrations of this work using field source Ra-20S-82 is 3655 counts/s (303.4 eU ppm using a probe constant of 0.0830 eU ppm/count/s). The average obtained from Position 2 counts is 749 counts/s (62.2 eU ppm). These count rate values are higher than the previous Position 1 and Position 2 values of 3364 counts/s and 727 counts/s, respectively, confirming a consistent rise in source activity over time, as described below and as demonstrated in Figure 4.

POSITION 1 AND POSITION 2 CONTROL MEASUREMENTS

Figures 4 through 7 illustrate the performance of probe CG27A-97 from 18 April 1989 through 01 December 1992. The data covering the period between 18 April 1989 and 26 February 1992 are listed in a previous report (Arthur 1992), whereas data from 26 February 1992 through 01 December 1992 are listed in Appendix D.

FIGURE 4. Comparison of Field-Source Check Values for Position 1 Measurements Before and After Logging on an Absolute Time Scale

FIGURE 5. Comparison of Field-Source Check Values for Position 2 Measurements Before and After Logging on an Absolute Time Scale

FIGURE 6. Comparison of Field-Source Check Values for Position 1 Measurements Before and After Logging on a Relative Time Scale (equally spaced data)

FIGURE 7. Comparison of Field-Source Check Values for Position 2 Measurements Before and After Logging on a Relative Time Scale (equally spaced data)

The oscillating solid line in the figures represents the pre-logging values while the oscillating gray line represents the post-logging values. The fine parallel lines above and below represent the upper and lower $\pm 8\%$ control limits.

Figures 4 and 5 show the data plotted against an absolute chronological time, whereas Figures 6 and 7 represent the data equally spaced (1 unit per measurement).

FIELD-SOURCE CHECK OBSERVATIONS

Four distinct regions are evident in Figures 4 through 7. The first region shows more variability among its values than does any of the other three regions. Such variability is particularly evident in the Position 2 measurements (Figures 5 and 7). The observed variability, as explained in a previous calibration report (Arthur 1990), was the result of a loose source within the Ra-20S-208 control standard previously used.

The second region, which begins after 4 May 1990, uses the same probe constant as before but with new net apparent count rates of 3466 counts/s and 608 counts/s instead of 3366 counts/s and 686 counts/s.

The third region, beginning in October 1990, uses the same net apparent count rates as used in the previous region but with a new probe constant (0.0789 eU ppm/count/s).

The fourth region marks the use of a new field source (Ra-20S-82) as well as a recalibration of the system, so that new net apparent count rates and the new 1991 probe constant were used. A similar change in count rates in the middle of the fourth region marks the use of the new 1992 probe constant.

In Figure 6, a general trend of values toward the high end of the control limit is evident. Such a trend may be the result of the radioisotopes of the field source coming into equilibrium or may represent a systematic drift within the well-logging instrumentation. The phenomenon will probably require more thorough investigation within the next year.

A few excursions of value beyond the 8% control limit are noted for the Position 2 measurements in the third and fourth regions. These correspond to measurements taken on 22 March 1991 at well #BH3C-1, which has a higher background than the runs that bracket it, and on 10 October 1991 at well #299-E34-10, which has the same Position 2 values as background count rate (i.e., possibly an error in data entry).

CONCLUSIONS

In 1989, 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. A new value was determined in 1990 as $17 \mu\text{s}$, but with a fairly large uncertainty resulting from an approximate correction for the nonlinear response of the chart-recorder readings. The current value of $11.85 \mu\text{s}$ agrees with the more accurate value of $12.0 \mu\text{s}$ obtained in the 1991 calibration report, which was based on analog data that were more accurately corrected for the nonlinear response of the chart recorder.

The primary calibration data have not significantly changed since they were established in the baseline as shown by the data summarized in Table 9. This is particularly important for the present calibration with the radiation detector that was replaced after the previous one cracked. It indicates that the data taken in 1992 were valid, as supported by the field-source checks.

Increased accuracy and ease of working with numbers generated using a digital system confirm the validity of using the digital system as a replacement for the chart recorder as the recording medium.

A drift is evident in the Position 1 values taken using the new field source, Ra-20S-82. This phenomenon may need close examination since the upper 8% control limit is being approached.

TABLE 9. Comparison of Measured Probe Constant from Previous Reports

<u>Reference</u>	<u>Probe Constant</u> <u>eU ppm /count/s</u>
Brodeur 1989	0.0853
Arthur 1990	0.0787 ± 0.0045
Arthur 1991	0.0884 ± 0.0034
Arthur 1992	0.0908 ± 0.0032
Present Work	0.0830 ± 0.0025 (new detector crystal)

RECOMMENDATIONS

The following activities are recommended based on the 1993 yearly calibration of PNL's gross gamma-ray geophysical pulse logging system.

- Calibrate an additional gamma-ray probe and/or system as a backup.
- Use the digital collection system as the primary data collection instrumentation, 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 to further characterize the relationship between observed dead-time value and count rate.
- Continue the practice of ensheathing the probe in polyethylene or vinyl during calibration in the borehole models.
- Examine the cause of the drift evident in Position 1 measurements taken using field source Ra-20S-82.
- Purchase a new logging probe that is built using current technologies.
- Consider shifting to a spectral gamma-ray [NaI(Tl)] system to provide some sensitivity to the identity of radionuclides.
- Open the probe at least once a year to visually inspect the condition of the radiation detector crystal.

REFERENCES

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- Westinghouse Hanford Company. 1991. *Environmental Investigations and Site Characterization Manual EII. 11.1*, WHC-CM-7-7, Rev. 1, Appendix A.

APPENDIX A

DATA FROM INSTRUMENT CALIBRATION MEASUREMENTS

WESTINGHOUSE STANDARDS LABORATORY PHYSICAL AND ELECTRICAL REPORT									
CUSTODIAN/ADDRESS BRODEUR JR H6-06		STANDARDS CODE NUMBER 999-23-01-006				NEW MODIFY		REFERENCE NUMBER 368019	
INSTRUMENT LOGGING SYSTEM GEARHART MINERAL		SERIAL NUMBER N/A		PROPERTY NUMBER N/A		RECALL STATUS 1 ACTIVE 2 NONRECALL 3 SUSPENDED 4 DELETED		ORGANIZATION CODE D7D81	
SENDER A PEARSON 6-8333		ROOM LOG.		BUILDING TRUCK		SERVICE DEPARTMENT 3		TOLERANCE HISTORY TNN	
INSTRUMENT SPECIFICATIONS CEL 82LAW		COMMENTS				DATE RECEIVED 930130		TOLERANCE AS RECEIVED	
						SHIPPING DAY		1 IN 2 OUT 3 MA 4 FAILED	
						TRAINING HOURS			
						CALIBRATION HOURS		7.0	
						REPAIR HOURS			
						OTHER HOURS		1.5	
						MATERIALS			
						TOTAL CHARGE = (\$120 x SUM OF HOURS) + MATERIAL			
						DATE CALIBRATED		DATE DUE	
						2-4-93		2-4-94	
						AMBIENT TEMPERATURE = 10.3°C			
STANDARD(S) USED IN CALIBRATION TRACEABLE TO NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY OR NATIONALLY RECOGNIZED STANDARDS									
EXPIRATION DATE									
003-51-01-020 2-2-94 004-56-03-003 11-23-93									
002-45-06-047 1-14-94 002-79-06-025 6-93									
015-23-01-003 3-11-93									
REMARKS									
- DATA SHEETS IN HAND									
- SET UP TIME									
PROCEDURE NUMBER									
PNL-MA-567 GL-7B REV 8									
APPROVED BY									
CALIBRATED BY									
Hanford Operations and Engineering Contractor for the United States Department of Energy									
Westinghouse Hanford Company Subsidiary of Westinghouse Electric Corporation Box 1970, Richland, WA 99352									
PAGE 1 OF 4									

National Engineering Development Laboratory <small>Department of Electronics and Communications Engineering P.O. Box 1000, Nairobi, Kenya</small>		REPORT OF CALIBRATION PHYSICAL & ELECTRICAL STANDARDS LABORATORY		CODE NO. 999-23-01-006																																					
ITEM IDENTIFICATION (MANUFACTURER, MODEL, SERIAL NO.) PULSE GENERATOR PL-M 103 (GAEHART MINERAL) LOADING SYSTEM		DATE 2-4-93		JOB AUTHORIZATION NO.																																					
		DUE DATE		STD. SER. NO.																																					
CUSTOMER		LOCATION		RM. NO.																																					
SPECIFICATIONS:																																									
50 KHz { + OUTPUT FS $\geq$ 2.9 V PEAK																																									
- OUTPUT FS $\geq$ 3.0 V PEAK																																									
OTHER { + OUTPUT FS $\geq$ 3.0 "																																									
RANGES { - OUTPUT FS $\geq$ 3.0 V "																																									
EQUIPMENT USED SCOPE																																									
METHOD OF MEASUREMENT (PROCEDURE NO.)																																									
Calibration Traceable To The National Bureau of Standards Or Nationally Recognized Standards																																									
REMARKS:																																									
VARIABLE AMPLITUDE CHECK																																									
50K HZ { + OUTPUT FS. 75V V PEAK																																									
- OUTPUT FS. 3.1 V PEAK																																									
OTHER RANGES { + OUTPUT FS. 75V V PEAK																																									
- OUTPUT FS. 3.1 $\geq$ 3.1V V PEAK																																									
FREQUENCY CHECK (10 SEC COUNTS) ⁰⁵⁻⁴⁻⁹³																																									
<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>- PULSES</th> <th>FREQ. HZ</th> <th>READING 1</th> <th>READING 2</th> </tr> </thead> <tbody> <tr><td></td><td>10</td><td>10.0</td><td>10.0</td></tr> <tr><td></td><td>50</td><td>50.0</td><td>50.0</td></tr> <tr><td></td><td>100</td><td>100.0</td><td>100.0</td></tr> <tr><td></td><td>500</td><td>500.0</td><td>500.0</td></tr> <tr><td></td><td>1000</td><td>1000.1</td><td>1000.0</td></tr> <tr><td></td><td>5000</td><td>5000.1</td><td>5000.1</td></tr> <tr><td></td><td>10000</td><td>10000.2</td><td>10000.2</td></tr> <tr><td></td><td>50000</td><td>50001.3</td><td>50001.3</td></tr> </tbody> </table>						- PULSES	FREQ. HZ	READING 1	READING 2		10	10.0	10.0		50	50.0	50.0		100	100.0	100.0		500	500.0	500.0		1000	1000.1	1000.0		5000	5000.1	5000.1		10000	10000.2	10000.2		50000	50001.3	50001.3
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	10000	10000.2	10000.2																																						
	50000	50001.3	50001.3																																						
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Chart Recorder Check 2/4/95
(See p4 of 4 WAC Calibration Form Sheets)

The following is the output of the digital recorder for data taken using the standart NIST-traceable voltage supply used to calibrate the chart recorder.

"C:CHART RECORDER CHECK"

"P: ACQUIRE 5.20(2/28/1991) Serial Number 082 2/4/1993 11:40"

"N: 6" "GAMMACCL.PB1"

"DD00"	"DS00"	"CS10"	"CH02"	"CN04"	"CX04"
"I: 0"	0	0	2431	2400	2400
"J:1000"	1000	1000	1699	2000	2000
"A: 0"	0	0	8	99	99
"Z:0.0"	0.0	0.0	0.0	-100.0	-100.0
"F:1000.0"	1000.0	1000.0	1000.0	100.0	100.0
"D:0.0"	0.0	0.0	0.0	-3.4	-3.4
"Depth"	"Speed"	"GAMMA"	"GAM-AN"	"CCLMIN"	"CCLMAX"
"Feet"	"Ft/Min"	" CPS"	" CPS"	" mV"	" mV"
0.0	0.0	0.0	0.0	-24.5	-25.0
0.0	0.0	0.0	-0.5	-24.5	-25.0
0.0	0.0	0.0	0.0	-24.5	-25.0
0.0	0.0	0.0	1000.8	-24.5	-25.0
0.0	0.0	0.0	0.0	-25.0	-25.5
0.0	0.0	0.0	0.0	-25.0	-26.0
0.0	0.0	0.0	0.0	-25.0	-25.5
0.0	0.0	0.0	100.0	-25.5	-26.0
0.0	0.0	0.0	100.5	-25.0	-26.0
0.0	0.0	0.0	100.0	-25.0	-25.5
0.0	0.0	0.0	100.0	-25.5	-26.0
0.0	0.0	0.0	200.0	-25.0	-26.0
0.0	0.0	0.0	200.0	-25.5	-26.0
0.0	0.0	0.0	200.2	-25.5	-26.0
0.0	0.0	0.0	301.5	-25.5	-26.0
0.0	0.0	0.0	301.5	-25.5	-26.0
0.0	0.0	0.0	301.4	-25.5	-26.0
0.0	0.0	0.0	301.4	-25.5	-26.0
0.0	0.0	0.0	401.9	-25.0	-26.0
0.0	0.0	0.0	401.7	-25.0	-26.0
0.0	0.0	0.0	401.4	-25.0	-25.5
0.0	0.0	0.0	502.0	-25.5	-26.0
0.0	0.0	0.0	501.4	-25.5	-26.0
0.0	0.0	0.0	502.0	-25.5	-26.0
0.0	0.0	0.0	601.4	-25.5	-26.0
0.0	0.0	0.0	601.5	-25.5	-26.0
0.0	0.0	0.0	601.5	-25.5	-26.0
0.0	0.0	0.0	702.0	-25.5	-26.0
0.0	0.0	0.0	702.0	-25.5	-26.0
0.0	0.0	0.0	701.7	-25.5	-26.0
0.0	0.0	0.0	701.5	-25.5	-26.0
0.0	0.0	0.0	802.2	-25.5	-26.0
0.0	0.0	0.0	801.9	-25.5	-26.0
0.0	0.0	0.0	801.5	-25.5	-26.0
0.0	0.0	0.0	902.5	-25.5	-26.0
0.0	0.0	0.0	902.5	-25.0	-26.0
0.0	0.0	0.0	902.7	-25.5	-26.0
0.0	0.0	0.0	1000.0	-25.0	-26.0

0.0	0.0	0.0	1000.0	-25.5	-26.0
0.0	0.0	0.0	1000.0	-25.5	-26.0
0.0	0.0	0.0	1000.0	-25.5	-26.0
0.0	0.0	0.0	900.0	-25.5	-26.0
0.0	0.0	0.0	900.0	-26.0	-26.0
0.0	0.0	0.0	900.0	-26.0	-26.5
0.0	0.0	0.0	900.2	-26.0	-26.0
0.0	0.0	0.0	800.0	-26.0	-26.0
0.0	0.0	0.0	800.2	-26.0	-26.0
0.0	0.0	0.0	800.2	-25.5	-26.5
0.0	0.0	0.0	801.2	-26.0	-26.5
0.0	0.0	0.0	701.5	-26.0	-26.5
0.0	0.0	0.0	701.5	-26.0	-26.5
0.0	0.0	0.0	701.4	-26.0	-26.5
0.0	0.0	0.0	701.5	-26.0	-26.5
0.0	0.0	0.0	600.0	-26.0	-26.5
0.0	0.0	0.0	600.0	-26.0	-26.5
0.0	0.0	0.0	600.2	-26.0	-27.0
0.0	0.0	0.0	500.0	-26.0	-26.5
0.0	0.0	0.0	500.8	-26.0	-26.5
0.0	0.0	0.0	501.2	-26.0	-26.5
0.0	0.0	0.0	501.4	-26.0	-26.5
0.0	0.0	0.0	403.9	-26.0	-26.0
0.0	0.0	0.0	403.9	-26.0	-26.5
0.0	0.0	0.0	402.9	-26.0	-26.5
0.0	0.0	0.0	298.8	-26.0	-26.0
0.0	0.0	0.0	299.3	-26.0	-26.5
0.0	0.0	0.0	298.6	-25.5	-26.0
0.0	0.0	0.0	298.6	-26.0	-26.5
0.0	0.0	0.0	198.0	-25.5	-26.0
0.0	0.0	0.0	197.3	-25.5	-26.0
0.0	0.0	0.0	198.0	-25.5	-26.0
0.0	0.0	0.0	97.3	-25.5	-26.0
0.0	0.0	0.0	97.1	-25.5	-26.0
0.0	0.0	0.0	96.3	-25.0	-26.0
0.0	0.0	0.0	97.1	-25.5	-26.0
0.0	0.0	0.0	-4.1	-25.5	-26.0
0.0	0.0	0.0	-4.1	-25.5	-26.0
0.0	0.0	0.0	-4.1	-25.5	-26.0

10

4/5/93

Performed Depth Calibration at well #399-5-2. Attached Calibrated Steel Tape #L500-k to probe ran to bottom of well. Positioned Chart Recorder to proper depth ran up hole. Stopped every 50.0' recorded Tape reading Odometer & Digital below. Also recorded positive on chart recorder.

Tape	Odometer	Digital
414.93	415.0	414.72
399.90 AWT 4/5/93	400.0	399.71
349.85 349.84	350.0	349.69
299.83	300.0	299.71
249.70	250.0	249.68
199.89	200.0	199.70
149.87	150.0	149.70
99.89	100.0	99.69
49.9	50.0	49.71
10.15	0.0	-0.31

Steve Koss help and witnessed activities.

Alan Pearson 4/5/93

APPENDIX B

DATA FROM DEAD-TIME DETERMINATION MEASUREMENTS

APPENDIX C

DATA FROM PRIMARY CALIBRATION MEASUREMENTS

Hand-drawn stratigraphic column on graph paper. The column consists of several layers, some of which are labeled with handwritten text:

- Top layer:** Labeled "Red Shale" and "Limestone".
- Second layer:** Labeled "Limestone".
- Third layer:** Labeled "Limestone".
- Fourth layer:** Labeled "Limestone".
- Fifth layer:** Labeled "Limestone".
- Sixth layer:** Labeled "Limestone".
- Seventh layer:** Labeled "Limestone".
- Eighth layer:** Labeled "Limestone".
- Ninth layer:** Labeled "Limestone".
- Tenth layer:** Labeled "Limestone".
- Eleventh layer:** Labeled "Limestone".
- Twelfth layer:** Labeled "Limestone".
- Thirteenth layer:** Labeled "Limestone".
- Fourteenth layer:** Labeled "Limestone".
- Fifteenth layer:** Labeled "Limestone".
- Sixteenth layer:** Labeled "Limestone".
- Seventeenth layer:** Labeled "Limestone".
- Eighteenth layer:** Labeled "Limestone".
- Nineteenth layer:** Labeled "Limestone".
- Twentieth layer:** Labeled "Limestone".
- Twenty-first layer:** Labeled "Limestone".
- Twenty-second layer:** Labeled "Limestone".
- Twenty-third layer:** Labeled "Limestone".
- Twenty-fourth layer:** Labeled "Limestone".
- Twenty-fifth layer:** Labeled "Limestone".
- Twenty-sixth layer:** Labeled "Limestone".
- Twenty-seventh layer:** Labeled "Limestone".
- Twenty-eighth layer:** Labeled "Limestone".
- Twenty-ninth layer:** Labeled "Limestone".
- Thirtieth layer:** Labeled "Limestone".
- Thirty-first layer:** Labeled "Limestone".
- Thirty-second layer:** Labeled "Limestone".
- Thirty-third layer:** Labeled "Limestone".
- Thirty-fourth layer:** Labeled "Limestone".
- Thirty-fifth layer:** Labeled "Limestone".
- Thirty-sixth layer:** Labeled "Limestone".
- Thirty-seventh layer:** Labeled "Limestone".
- Thirty-eighth layer:** Labeled "Limestone".
- Thirty-ninth layer:** Labeled "Limestone".
- Fortieth layer:** Labeled "Limestone".
- Forty-first layer:** Labeled "Limestone".
- Forty-second layer:** Labeled "Limestone".
- Forty-third layer:** Labeled "Limestone".
- Forty-fourth layer:** Labeled "Limestone".
- Forty-fifth layer:** Labeled "Limestone".
- Forty-sixth layer:** Labeled "Limestone".
- Forty-seventh layer:** Labeled "Limestone".
- Forty-eighth layer:** Labeled "Limestone".
- Forty-ninth layer:** Labeled "Limestone".
- Fiftieth layer:** Labeled "Limestone".

93 SBA/SBA & SBA/SBA Models
2/23/83

APPENDIX D

SUMMARY OF DATA FOR FIELD-SOURCE MEASUREMENTS

Well Number	Date	Pre-Background	Pre-Posn. 1	Pre-Posn. 2	Post-Background	Post-Posn. 1	Post-Posn. 2
299-W11-70	2/27/92	90	303.7	64.5	85	299.7	64.1
116-H-9	2/27/92	50	309.4	64.1	50	305	64.1
199-B2-13	3/2/92	62	302.2	63.5	62	299.5	63
199-B2-12	3/2/92	65	308.1	64.5	68	307.8	63.8
116-H-7	3/3/92	70	312.1	64.5	68	310	63.8
299-W15-8	3/4/92	55	302.3	64.5	52	302.6	63.9
199-B9-3	3/4/92	45	298.8	64.1	45	303.2	64.1
199-B2-13	3/5/92	62	308.3	63.8	62	303.9	63.9
199-B3-46	3/5/92	55	306.7	64.5	55	304.5	64.1
299-W18-10	3/6/92	55	306.7	64.5	55	302.3	63.6
199-B9-2	3/6/92	55	304.5	64.5	50	304.1	65
199-B4-8	3/6/92	45	305.4	65.9	45	301	65.6
299-W18-7	3/9/92	55	306.7	65.4	55	304.5	64.1
299-W18-32	3/10/92	57	306.6	64.4	52	298.2	63.9
299-W15-84	3/10/92	55	306.7	64.5	55	304.5	64.5
699-48-77A	3/12/92	53	303.4	66	52	296	65.2
299-W14-4	3/13/92	115	294.8	63.2	118	299	62.5
299-W11-30	3/16/92	89	297.5	64.1	85	295.3	64.5
199-B9-2	3/17/92	48	305.2	64.3	48	300.7	63.8
699-57-59	3/24/92	53	304.7	65.2	52	302.6	63.9
299-W18-247	3/24/92	53	304.7	64.7	53	304.7	64.7
199-B9-3	3/25/92	50	305	64.5	50	305	64.1
199-B8-6	3/25/92	47	305.2	65.2	47	303	64.4
199-B2-12	3/25/92	65	303.7	64.5	62	303.9	64.4
699-57-59	4/3/92	58	302.1	63.8	60	297.5	62.8
299-W18-247	4/3/92	55	300.1	64.1	55	300.1	64.1
199-B2-12	4/6/92	68	307.8	63.8	63	303.8	65.2
299-W18-96	4/7/92	52	304.8	65.2	50	302.8	65
699-48-77A	4/9/92	60	304.1	65	58	302.1	63.8
699-57-59	4/10/92	55	304.5	65	50	300.6	64.5
199-B5-2	4/10/92	55	309	64.1	52	300.4	64.4
299-W10-19	4/15/92	50	305	64.1	50	305	64.1
299-W6-12	4/15/92	55	304.5	63.6	52	302.6	63
299-W18-246	4/22/92	45	305.4	65	45	305.4	64.5
299-W6-11	4/24/92	55	304.5	65	50	302.8	64.5
199-N-76	4/28/92	860	288.6	52.2	860	282	52.2
199-N-75	4/29/92	1050	278.5	50.8	1050	282.9	53
299-W10-19	5/5/92	58	306.5	64.7	58	299.9	63.8
299-W18-5	5/5/92	70	305.4	63.2	72	303	64.4
299-W15-63	5/6/92	68	305.6	62.9	68	294.5	62.5
299-W15-210	5/6/92	75	302.8	61.9	75	302.8	61.9
299-W22-74	5/7/92	78	300.3	62.1	78	298	62.1
299-W22-75	5/12/92	58	306.5	63.4	58	304.3	63.4
299-W18-248	5/12/92	52	300.4	63.5	50	305	64.1
299-W18-246	5/14/92	52	307	64.8	52	304.8	64.4
299-E27-19	5/15/92	70	301	64.5	72	300.9	63.5
299-E27-18	5/15/92	80	302.3	63.2	82	297.7	62.1
299-W11-61	5/15/92	72	303	64.4	68	303.4	63.4
299-W6-11	5/18/92	55	304.5	63.2	55	302.3	63.2
299-W26-1	5/20/92	55	306.7	65	52	304.8	64.8
199-K-37	5/20/92	58	306.5	63.8	58	304.3	63.4
299-E27-19	5/22/92	78	306.9	64.7	78	302.5	62.9
299-E27-18	5/22/92	90	301.4	63.2	90	303.7	63.6
299-W11-81	5/26/92	72	309	64.7	72	306.7	64.7
299-W15-216	5/26/92	52	313.1	65.6	50	311	64.9
299-W18-248	5/26/92	48	311.2	66	48	311.2	66
199-K-32B	5/29/92	68	307.1	64.2	68	309.4	65.1
299-E25-44	6/1/92	55	308.3	65.8	55	308.3	64.9
199-K-32B	6/2/92	60	312.4	64.9	55	308.3	63.4
119-K-34	6/2/92	60	314.6	65.8	55	312.8	64.9
299-W18-248	6/3/92	50	313.3	65.4	52	308.5	63.4
199-K-32A	6/9/92	68	309.4	65.1	68	307.1	65.1

Well Number	Date	Pre-Background	Pre-Posn. 1	Pre-Posn. 2	Post-Background	Post-Posn. 1	Post-Posn. 2
299-W15-217	6/11/92	45	316	66.7	45	311.4	65.8
299-E33-12	6/17/92	275	308.7	64.9	270	306.9	64.5
299-E33-13	6/18/92	345	306.9	64	340	305.1	62.2
199-K-32A	6/19/92	67	314	65.2	70	306.9	64
199-K-34	6/19/92	62	312.2	64.7	62	309.9	64.7
299-W15-217	6/19/92	52	310.8	65.2	52	308.5	65.2
299-E33-24	6/22/92	165	307.4	63.6	162	303.1	62.5
199-K-33	6/22/92	67	307.2	65.2	68	304.8	64.6
199-K-35	6/25/92	50	313.3	65.8	47	309	65.2
299-W15-216	6/25/92	50	308.7	64.9	52	308.5	64.3
199-K-33	6/30/92	82	314.9	65.2	80	310.5	65.4
299-E25-45	7/1/92	57	314.9	65.6	55	312.8	66.3
299-W15-217	7/1/92	52	313.1	65.2	52	310.8	66.1
199-K-35	7/7/92	45	316	65.8	47	309	65.2
299-W18-249	7/9/92	48	306.6	65.6	50	311	65.4
299-W18-249	7/14/92	52	301.7	65.2	55	308.3	64.9
199-K-35	7/17/92	50	308.7	64.9	52	313.1	64.7
199-B3-1	7/17/92	57	312.6	65.2	58	310.3	65.1
199-N-80	7/17/92	2225	261.1	40.9	2175	265.6	29.5
299-E25-46	7/20/92	260	307.8	62.6	260	307.8	61.3
199-B4-1	7/20/92	48	315.7	66.5	48	315.7	65.1
199-B4-4	7/20/92	62	312.2	65.6	62	309.9	64.7
199-B9-1	7/21/92	52	313.1	65.6	50	308.7	66.3
299-W18-249	7/22/92	58	317.1	65.1	55	315.5	65.8
299-E25-47	7/29/92	62	310.4	66.1	65	309.6	66.3
299-W22-45	7/29/92	245	302.4	64.5	240	302.8	64.5
199-K-36	7/30/92	40	302.8	65.4	38	305.3	64.6
299-E24-160	7/30/92	62	314.4	66.6	60	310.1	65.8
299-E25-46	7/30/92	280	306	62.2	285	305.5	62.2
299-E33-14	7/31/92	75	308.7	65.8	75	311	65.8
199-N-80	7/31/92	2250	263.3	38.6	2250	263.3	38.6
299-E33-21	8/1/92	118	311.6	64.6	115	307.4	64
299-E33-290	8/3/92	100	313.3	64.9	100	311	64.9
299-E28-18	8/3/92	55	311	65.4	58	303.5	64.2
299-E25-191	8/4/92	58	305.7	67.8	55	306	65.8
299-E26-7	8/4/92	73	313.4	64.6	75	308.7	64.5
299-E17-3	8/4/92	65	314.2	66.7	63	309.8	66
299-E33-26	8/5/92	102	313.1	65.6	105	312.8	65.4
299-E17-4	8/5/92	60	316.9	65.8	58	310.3	66.5
299-E27-1	8/7/92	60	314.6	64.9	60	312.4	64.9
199-K-36	8/7/92	45	313.7	66.3	45	313.7	67.6
199-N-80	8/7/92	2200	276.9	38.6	2200	272.4	38.6
299-W18-9	8/8/92	50	313.3	66.7	50	311	65.4
229-W18-11	8/8/92	55	312.8	65.4	52	306.3	64.3
299-W18-98	8/8/92	50	313.3	65.8	53	313	65.6
299-W15-9	8/9/92	52	309.4	64.3	50	306.5	65.8
299-W22-45	8/14/92	252	306.3	64.3	250	304.2	64
299-E25-48	8/19/92	52	310.8	65.2	50	308.7	65.8
199-F5-48	8/19/92	52	310.8	65.2	50	308.7	65.8
199-F5-45	8/19/92	68	311.6	64.6	68	309.4	64.6
199-F6-1	9/17/92	58	317.1	65.6	55	315.1	64.9
199-F8-4	9/17/92	58	314.8	67.4	58	314.8	66
199-F6-46	9/17/92	58	318	66.9	55	317.3	67.2
199-F5-42	9/17/92	45	316	66.3	43	314	65.6
699-41-42	9/18/92	60	314.2	65.8	58	312.5	66.5
299-E28-16	9/19/92	60	313.7	66.7	60	310.1	65.8
299-E24-2	9/20/92	60	310.1	64.9	55	310.5	65.8
299-E28-25	9/20/92	55	313.3	66.3	52	308.5	63.4
699-42-37	9/21/92	50	313.3	64.5	50	311	65.4
299-E33-18	9/21/92	155	303.7	64.5	150	308.7	63.1
299-E13-5	9/21/92	55	315.1	65.4	55	315.1	64.9
299-E33-58	9/22/92	145	313.7	64.9	145	311.4	64

Well Number	Date	Pre-Background	Pre-Posn. 1	Pre-Posn. 2	Post-Background	Post-Posn. 1	Post-Posn. 2
299-E33-15	9/22/92	125	311	64	125	308.7	64
199-N-51	9/22/92	73	311.2	64.6	80	308.3	65.4
199-N-53	9/23/92	810	303.3	64.9	810	301	64.9
699-40-36	9/24/92	48	311.2	64.6	48	308.9	64.2
199-N-50	9/24/92	80	312.8	65.8	82	312.6	64.7
699-41-35	9/24/92	52	315.3	65.6	50	313.3	65.4
199-H4-2	9/25/92	52	308.5	67	52	313.1	66.6
299-E33-20	9/25/92	145	309.2	62.7	145	304.6	62.7
199-F5-43A	9/25/92	48	313.7	64.9	50	315.5	65.8
199-F5-43B	9/25/92	45	311.4	66.3	45	311.4	66.3
199-N-49	9/27/92	175	315.5	65.4	175	315.5	64
199-N-52	9/27/92	185	312.4	66.3	190	314.2	64.5
199-N-19	9/28/92	308	312.5	64.2	310	312.4	64.9
199-N-17	9/28/92	580	312.4	63.1	575	308.7	63.6
199-N-18	9/28/92	380	310.5	65.4	378	308.4	65.6
199-N-22	9/28/92	365	309.6	64.5	365	305.1	64.5
199-N-21	9/28/92	280	313	64.5	290	305.1	64.5
199-N-20	9/28/92	318	311.6	61.9	320	311.4	63.6
199-N-26	9/29/92	130	317.3	64.5	125	311	63.1
199-N-16	9/29/92	182	317.2	64.3	182	314.9	63.4
2008P1 GP-4	9/29/92	162	309.9	64.3	160	307.8	63.6
199-N-25	9/29/92	335	307.8	62.7	330	308.3	63.1
199-F5-44	10/1/92	52	315.3	64.7	52	317.6	64.7
199-F5-43A	10/1/92	45	311.4	65.4	45	309.2	64.9
199-F5-44	10/2/92	50	315.1	64.9	52	311.7	63.8
699-25-34D	10/6/92	45	318.3	65.8	45	311.4	65.4
699-40-36	10/9/92	45	311.4	64	45	311.4	64.2
199-N-77	10/12/92	83	311.2	66	80	308.3	64
699-40-36	10/12/92	48	313.4	66	48	311.6	65.6
299-W15-6	10/13/92	55	317.3	65.8	55	312.8	64.5
199-F5-43B	10/15/92	48	313.4	65.1	48	316.6	65.1
116-K-1	10/15/92	80	312.8	64	80	315.1	64.5
699-26-34B	10/19/92	58	314.8	64.6	55	312.8	64.9
299-W27-2	10/23/92	60	312.4	64.9	58	312.5	65.6
699-44-39B	10/28/92	68	318.4	65.6	65	314.2	66.7
199-F5-43B	11/19/92	45	306.9	64.9	45	304.6	64.5
299-W27-2	11/20/92	55	312.8	64	55	312.8	65.4
299-W27-2	12/2/92	60	316.9	64.9	60	316.9	60

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