A Research Report for
Westinghouse Hanford Company

1992 YEARLY CALIBRATION OF PACIFIC
NORTHWEST LABORATORY'S GROSS GAMMA-RAY
BOREHOLE GEOPHYSICAL LOGGING SYSTEM

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July 1992

Prepared for
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

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SUMMARY

This report describes the 1992 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.

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.

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 at some future date.

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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 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 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.

(a) Pacific Northwest Laboratory is operated by Battelle Memorial Institute for the U.S. Department of Energy under Contract DE-AC06-76RLO 1830.

ABBREVIATED SYSTEM DESCRIPTION

The PNL 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 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).

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-volt triangular pulse with a full-width at half maximum (FWHM) 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 proportional to the input count rate is generated for the chart recorder, which then generates a hard-copy record of data for subsequent analysis. The system is currently limited to measuring radiation levels below 14,000 counts/s.

A digitally based system was recently installed as a backup recording device similar to the analog chart recorder. The digital system is connected to a PC-compatible card located within the 8-bit slot of an IBM PC or clone, in this case a COMPAQ SLT 386/S20.

INSTRUMENTATION CALIBRATION

The critical pieces of instrumentation for the geophysical pulse logging system include 1) a pulse generator for establishing scale integrity; 2) a gamma-ray probe for detecting radiation and transmitting information 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 activity; and 5) 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 0.002% (0.1 in 5000), which greatly exceeds any realistic requirements for current well-logging activities.

RATE METERS

Two 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 actually was being calibrated), 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) 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. The current results 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

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	0.0184		0.0899	0.1795	0.179008	+0.000462
1	500		0.0362		0.1794	0.179000	+0.000400
1	1000	0.0185		0.0900	0.1796	0.179008	+0.000562
1	5000	0.0185	0.0364		0.1795	0.178884	+0.000617
1	10000	0.0184		0.0900	0.1795	0.179000	+0.000500
1	50000	0.0185	0.0364		0.1795	0.178884	+0.000617

Average 0.01846 0.0363 0.08997 0.1795 0.178964 +0.000526
Maximum Deviation 0.0001 0.0002 0.0001 0.0002 0.000124 0.000217

Maximum Deviation (%) 0.54 0.55 0.11 0.11 0.069 41.

Maximum Observed Voltage Output Deviation = $0.0001/0.17950$
= 0.11% full-scale count/s

Maximum Observed Linearity Deviation = $0.00053/0.178964$
= 0.069% of the count/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	0.0181		0.0897	0.1795	0.179344	0.000116
1	500		0.0361		0.1795	0.179250	0.00025
1	1000	0.0182		0.0899	0.1796	0.179336	0.000254
1	5000	0.0182	0.0361		0.1796	0.179349	0.000249
1	10000	0.0182		0.0900	0.1796	0.179328	0.000292
1	50000	0.0182	0.0361		0.1795	0.179233	0.000266

Average 0.01818 0.0361 0.08987 0.17955 0.179307 0.000238
Maximum Deviation 0.0001 0.0 0.0003 0.0001 0.000116 0.000176

Maximum Deviation (%) 0.55 0.0 0.33 0.056 0.065 74.

Maximum Observed Voltage Output Deviation = $0.0001/0.17955$
= 0.056% full-scale count/s

Maximum Observed Linearity Deviation = $0.00024/0.179307$
= 0.065% of the count/s value

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

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

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.

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 reads about 51% 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 actual test data are contained in Appendix A. Calibration of the digital system also needs to be performed but was not done at this time.

The nonlinear behavior of the chart recorder is evident in the data resulting from the calibrated voltage check (Table 4). Figure 1 shows the percent deviation of the observed reading relative to the expected reading, together with the deviation noted the previous year (Arthur 1991). A maximum error of between 1.5 and 1.75% is found in the region at 20 to 50% of full scale. 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 the previous

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>
0	0.	0.0	1.0000
10	1.015	1.5	0.9852
20	2.035	1.75	0.9828
30	3.055	1.67	0.9820
40	4.070	1.50	0.9828
50	5.085	1.80	0.9833
60	6.090	1.50	0.9852
70	7.090	1.29	0.9873
80	8.065	0.81	0.9919
90	9.035	0.39	0.9961
100	10.010	0.10	0.9990

year's calibration (Arthur 1991) 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.

Once again, the calibrated voltage measurement on the chart recorder was performed in one direction only, starting with zero input voltage and progressing to full-scale input voltage (0.17980 volt), so none of the chart-recorder hysteresis noted previously (Arthur 1990) could be quantitated.

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 showed 400.0 ft, the steel tape showed 400.30 ft, and the digital reading was 400.28 ft. The maximum absolute deviation of the tape

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

depth from the indicated depth between 300 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).

DEAD-TIME DETERMINATION

Data were collected to compute a current value for the dead-time correction. Data were corrected for nonlinearity displayed in the chart-recorder calibration. 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 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 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.

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

<u>Value Type</u>	<u>Chart-Recorder Rate (Observed)</u>	<u>Chart-Recorder Rate (Corrected for Nonlinearity)</u>
(Scale = 10K count/s)		
Background (B)	100	99.85
N ₁ + B	5150	5065.5
N ₂ + B	5430	5343.7
N ₁₂ + B	9755	9738.4
(Scale = 10K count/s)		
Background (B)	100	99.85
N ₁ + B	2670	2623.3
N ₂ + B	2750	2701.0
N ₁₂ + B	5200	5115.2
(Scale = 5K count/s)		
Background (B)	100	99.7
N ₁ + B	2545	2502.5
N ₂ + B	2650	2607.3
N ₁₂ + B	4930	4923.6

TABLE 6. Summary of Measured Dead-Time Correction Values

<u>Scale Used</u>	<u>t_{approx.} (μs)</u>	<u>t_{exact} (μs)</u>
10K	11.60 ± 2.91	12.34 ± 3.30
10K	7.30 ± 8.58	8.69 ± 8.43
5K	8.50 ± 8.06	8.69 ± 8.43

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

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

The original chart-recorder data for the most accurate dead-time measurements are contained in Appendix B. The values as read from the strip chart, the

scale settings, and the corrected values used to compute the dead time are given in Table 5. The observed rate from the chart recorder is contained in one column. The adjacent column contains the rate corrected for the chart-recorder nonlinearity using multiplicative factors interpolated from the data shown in Figure 2. The need for correcting for chart-recorder nonlinearity was discussed in a previous calibration report (Arthur 1991).

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 the reading on the highest scale could not be read with sufficient accuracy.

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 $12.34 \mu\text{s}$ in Table 6 agrees with the $12.0\text{-}\mu\text{s}$ value obtained previously (Arthur 1991) when the recommended maximum combined-source count rate on the 10K setting is used. 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 resulting from low count rates (low count rates on lower scales).

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 the system would need to be calibrated to verify linearity.

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 14,500 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 μ s is the sole source of the system saturation.

PRIMARY CALIBRATION

SBL/SBH AND SBA/SBB BOREHOLE MODEL CALIBRATIONS

The primary calibration was performed just outside the main gate of the 200 West Area of the Hanford Site, where the DOE borehole models have been moved from the Spokane field calibration facility. The calibration was performed using both the SBL/SBH and the SBA/SBB standard borehole model. 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 calibrations were performed on 28 February 1992. Only the SBA and SBL zones gave useful recordings, on both the 10K and the 50K scale; the SBB and SBH zones saturated the logging-system equipment at an apparent 14,500 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/s. 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

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	9895.8 $\pm$ 30.1	11,229 $\pm$ 39	971. $\pm$ 27.
SBA	2475.6 $\pm$ 12.1	2,551 $\pm$ 13	183. $\pm$ 5.

Probe Constant (eU ppm/count/s) = 0.0909 $\pm$ 0.0032
Linear Intercept Constant (eU ppm) = -48.7 $\pm$ 9.6

TABLE 8. Apparent and Observed Count Rates for SBA 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	2510 $\pm$ 20	2468.1 $\pm$ 20
		10K	2445 $\pm$ 50	2402.0 $\pm$ 50
		50K	2350 $\pm$ 100	2310.3 $\pm$ 100
Static	SBA			
		5K	2530 $\pm$ 40	2487.7 $\pm$ 40
		10K	2540 $\pm$ 19	2495.3 $\pm$ 19
		50K	2500 $\pm$ 50	2481.5 $\pm$ 50
		Weighted Average:		2475.6 $\pm$ 12.1
Dynamic	SBL			
		10K	9910 $\pm$ 52	9897.1 $\pm$ 52
		50K	10025 $\pm$ 75	9852.6 $\pm$ 75
Static	SBL			
		10K	10000 $\pm$ 80	9990.0 $\pm$ 80
		50K	10050 $\pm$ 50	9877.1 $\pm$ 50
		Weighted Average:		9895.8 $\pm$ 30.1

not exceed a given level). The apparent count rates were then corrected for chart-recorder nonlinearities to give the observed count rate. A weighted average of the observed count rates yielded the apparent count rate and uncertainty for the corresponding zone (Bevington 1969).

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 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 suggested practice continues to be that the probe is encased in a vinyl or polyethylene bag for calibration runs.

LINEARITY DETERMINATION

The appropriate method for determining the probe constant of proportionality uses measured equivalent-uranium values from both borehole 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 weighted averages of the observed count rates as listed in Table 8 are listed in Table 7 under the heading "Observed Count Rate." These values are then corrected with a dead time of 12.0 μ s using the formula

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

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

n = apparent count rate

t = system dead time.

The value for the probe constant determined from using the two separate borehole models is presented in Table 7.

FIELD-SOURCE CALIBRATION

The method currently being used for field-source calibration is described in WHC-CM-7-7, Environmental Investigations and Site Characterization Manual EII 11.1, Appendix A, Rev. 1, 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 resulting from variable amounts of backscatter.

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 3470 counts/s (315.1 eU ppm using a probe constant of 0.0908 eU ppm/count/s). The average obtained from Position 2 counts is 717 counts/s (65.1 eU ppm). These net apparent values agree with the stated Position 1 and 2 values of 3364 counts/s and 727 counts/s, respectively, verifying a consistency of probe behavior.

POSITION 1 AND POSITION 2 CONTROL MEASUREMENTS

Figures 3 through 6 illustrate the performance of probe CG27A-97 during the period 18 April 1989 through 26 February 1992. 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 $\pm 8\%$ control limits.

The data used to generate the illustrations are contained in Appendix D. Figures 3 and 4 show the data plotted against an absolute chronological time, whereas Figures 5 and 6 represent the data equally spaced (1 unit per measurement).

FIGURE 3. Comparison of Field-Source Check Values for Position 1 Measurements Before and After Logging on an Absolute Time Scale

FIGURE 4. Comparison of Field-Source Check Values for Position 2 Measurements Before and After Logging on an Absolute Time Scale

FIGURE 5. Comparison of Field-Source Check Values for Position 1 Measurements Before and After Logging on a Relative Time Scale (Equally Spaced Data)

FIGURE 6. Comparison of Field-Source Check Values for Position 2 Measurements Before and After Logging on a Relative Time Scale (Equally Spaced Data)

FIELD-SOURCE CHECK OBSERVATIONS

Four distinct regions are evident in Figures 3 through 6. 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 4 and 6). 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 (3364 counts/s and 727 counts/s) and a new probe constant (0.0884 eU ppm/count/s) are used.

In Figure 5, 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 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 $12.3 \mu\text{s}$ 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 raw primary calibration data have not significantly changed since they were determined in 1991: the calculated probe constant of $0.0908 \pm 0.0032 \text{ eU ppm/count/s}$ is statistically within a standard deviation unit of the previous probe constant, $0.0884 \pm 0.0034 \text{ eU ppm/count/s}$.

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.

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

RECOMMENDATIONS

The following activities are recommended based on the 1992 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, 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 proves linear.
- Continue the practice of ensheathing the probe in polyethylene or vinyl during calibration in the borehole models.
- Perform a linearity calibration on the digital recorder system.
- Perform a hysteresis check of the chart-recorder system during calibration by applying voltages in both ascending and descending order.
- Examine the cause of the drift evident in Position 1 measurements taken using field source Ra-20S-82.

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APPENDIX A

DATA FROM INSTRUMENT CALIBRATION MEASUREMENTS

1992 Annual Calibration of ANL's Gross Gamma Logging System. (2/12/92 0100)

- Instrument Calibration at 3717B building 300 Area
- Follow procedure ANL-MA-567 GL-7B Rev. 0

3) Pulse Generation Check (PGM 103) Gearhart M. Serial #14
 Variable amplitude + output full scale $\Rightarrow$ 2.9 Volt Peak (50 kHz) - output full scale $\Rightarrow$ 3.0 Volts AC
 Other ranges - output full scale $\Rightarrow$ 3.0 ~ 5.0 Volts AC
 - output full scale $\Rightarrow$ 3.0 Volts AC

Use Oscilloscope Cal # 002-51-01-020

- Pulses

Frequency Hz Setting	10 sec. Counts Reading 1 (Hz)	(10 sec. counts) Reading 2 (Hz)
10.	10.0	10.0
50	50.0	50.0
100	100.0	100.0
500	500.0	500.0
1,000	1,000.0	1,000.0
5,000	5,000.1	5,000.0
10,000	10,000.1	10,000.2
50,000	50,000.8	50,000.8

+ Pulses

Frequency Hz Setting	10 sec. Counts Reading 1 (Hz)	10 sec. Counts Reading 2 (Hz)
10	10.0	10.0
50	50.0	50.0
100	100.0	100.0
500	500.0	500.0
1,000	1,000.0	1,000.0
5,000	5,000.1	5,000.1
10,000	10,000.2	10,000.2
50,000	50,000.8	50,000.8

* Used 10 sec. readings instead of 1 sec. for more accuracy
 $\Rightarrow$ Deviation from procedure

* Used HP Electronic Counter Code # 559-23-01-008

* Followed ANL-MA-567 GL-7B Rev. 0 Section 4.2 steps 1.0 - 3.0 (a-j).

* Finished @ 0950 2/12/92

Project No Annual Calibration Gross Gamma System Date of Work 2/12/92

Entered By Alan Pearson / Alan Pearson Date 2/12/92

Disclosed To and Understood By

Signed 1. J. T. Pearson Date 2/12/92

2. Date

Instrument Calibration Continued
 PNL-MA-567 GL-7B Rev. 0
 Section 4.2 Instrument Calibration followed Steps
 4.0) Rate Meter Check (a-p)

Rate Meter Module RMM 208 Serial #182

Suppression set & locked @ 10.0

Recorder Output Set & locked @ 10.0

Input from pulse generator (AGM 103) through cable
 to line Input

Neg. Input

Time Constant = 1 sec.

Output Reverse/Normal @ Normal

Chart Recorder & A/D converter disconnected.

*All settings above are the same for RMM 208
 Serial #185 (Use Banana Plug Output)

*Voltage outputs read w/ Digital Voltmeter Code #002-45-08-033

Rate Meter Scale	Input (Hz)	Output #182 (Volts)	Output #185 (Volts)
100 cps	10	0.0181	0.0184
	50	0.0897	0.0899
	100	0.1795	0.1795
500 cps	100	0.0361	0.0362
	500	0.1795	0.1794
1,000 cps	100	0.0182	0.0185
	500	0.0899	0.0900
	1,000	0.1796	0.1796
5,000 cps	500	0.0192	0.0185
	1,000	0.0361	0.0364
	5,000	0.1796	0.1795
10,000 cps	1,000	0.0182	0.0184
	5,000	0.0899 ^{0.0900}	0.0900
	10,000	0.1796	0.1795
50,000 cps	5,000	0.0192	0.0185
	10,000	0.0361	0.0364
	50,000	0.1795	0.1795

Input	Internal Oscillator 100 Hz	Output #182 (Volts)	Output #185 (Volts)
* - Used for Full Scale input for Chart Recorder Check	100 cps (see note)	* 0.1796	0.1796
	500 cps	0.0362	0.0364
	1,000 cps	0.0183	0.0185

Project No. Annual Calibration Gross Gamma System Date of Work 2/12/92
 Entered By Alan Pearson / Alan Pearson Date 2/12/92
 Disclosed To and Understood By W.D.G.
 Signed 1. Pearson / J.T. Pearson 51 Date 2/12/92
 2. _____ Date _____

Instrument Calibration Continued.

PNL-MA-567 GL-78 Rev. 0

3

Section 4.2 followed steps 5.0) Chart Recorder

Calibration Check (a-i).

Steps a-c performed - OK

d) Channel (2) (pen #2) plugged into ^{AWR 2/2/92} ~~Fake~~ ^{Voltage Generator (Digital)} ~~HF 335A Function~~
~~Generator/Synthesizer~~ ~~Code # 002-62-07-002~~

e) Voltage output determined in step 4m of this procedure
(see page 2 this notebook) Voltage Output $\Rightarrow$ 0.1796
10% input value = 0.01796

(f-g) Input %	Input Voltage	Pen deflection (inches on chart)
10%	0.01796	1.0015 in.
20%	0.03592	2.0035 in.
30%	0.05388	3.0050 in.
40%	0.07184	4.0060 in.
50%	0.08980	5.009 in.
60%	0.10776	6.009 in.
70%	0.12572	7.009 in.
80%	0.14368	8.0065 in.
90%	0.16164	9.0035 in.
100%	0.1796	10.001 in.

PNL's Gross Gamma Geophysical Logging System Instrumentation consists of: a Pulse Generator (Model # PGM 10S, Serial # 14), (2) Rate Meter Modules (Model # RMM 208, Serial #s 182 & 185) #182 is primarily used w/ #185 as a back-up. Chart Recorder w/ 4 pens (recorders), Pen #2 is always used w/ this system & was therefore the only one checked.

All Instrument calibration was performed on Wednesday, February 12, 1992 (0900-1330 hrs). Personnel in attendance included $\Rightarrow$ Alan Pearson (PNL), Steve Koss (CWHC), John Baerman (CWHC) & Dan Rasmussen (CWHC).

Project No. Annual Calibration Gross Gamma System Date of Work 2/12/92
Entered By Alan Pearson / Alan Pearson Date 2/12/92
Discussed To and Understood By
Signed 1. [Signature] / J.T. Baerman Date 2/12/92
2. _____ Date _____

Chart Recorder Calibration Check

Placed on page 4 of Laboratory Record Book #4546

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Full Scale

3/5/92

Depth Calibration Check

A 500' Steel Tape L-500-17 was attached to the zero point on the tool. This was then lowered into Well #399-S-2 to 400'. This depth was checked against the steel tape, odometer (which controls the chart & the digital depth counter) - all depths recorded below

<u>Odometer</u>	<u>Tape</u>	<u>Digital</u>
400.0'	400.30'	400.28'
350.0'	349.85'	349.87'
300.0'	300.0'	299.91'
250.0'	250.0'	249.88'
200.0'	200.05'	199.90'
150.0'	150.05'	149.90'
100.0'	100.0'	99.89'
50.0'	49.9'	49.89'
2.6'	2.51'	2.47'

Steve Kos & Alan Pearson performed
this work 3/5/92

Alan Pearson 3/5/92

APPENDIX B

DATA FROM DEAD-TIME DETERMINATION MEASUREMENTS

APPENDIX C

DATA FROM PRIMARY CALIBRATION MEASUREMENTS

C.1

APPENDIX D

SUMMARY OF DATA FOR FIELD-SOURCE MEASUREMENTS

Well Number	Date	Surface Temperature	Pre-Background	Pre-Posn. 1	Pre-Posn. 2	Post-Background	Post-Posn. 1	Post-Posn. 2
699-43-41E	4/18/89	NA	65	289	68	65	280	58
699-43-41F	4/18/89	NA	60	281	56	60	298	63
699-40-39	4/25/89	NA	60	296	58	60	293	66
699-43-41F	4/28/89	NA	60	289	56	65	289	56
699-44-43B	5/18/89	NA	60	302	57	60	289	66
699-41-40	5/23/89	NA	65	289	63	60	293	77
699-43-45	6/6/89	27.5	65	284	56	65	272	56
699-41-40	6/8/89	28	60	285	57	60	289	59
299-E25-37	6/28/89	23.4	55	298	57	55	294	56
699-40-39	6/29/89	18.5	60	289	59	60	298	60
299-E25-38	7/5/89	18.2	60	285	64	60	285	55
299-E27-11	7/12/89	31.6	60	298	55	65	289	52
299-E27-11	7/21/89	28	75	288	58	75	284	
299-E33-32	7/21/89	29.4	280	332	52	285	331	52
299-E33-31	8/9/89	26.5	105	349	136	105	349	128
299-E33-32	8/9/89	21.2	690	252	31	680	257	27
299-E33-33	8/9/89	28.5	115	276	60	115	289	58
299-E24-40	8/15/89	27.2	120	297	61	135	291	55
299-E25-41	8/15/89	27.8	175	292	54	175	288	54
299-E24-19	8/17/89	20.5	350	286	51	345	290	60
299-W15-19	8/21/89	31.5	65	297	56	65	297	56
299-E34-7	8/22/89	21.6	65	284	57	65	284	63.5
299-E24-19	8/24/89	26.6	385	274	61	370	280	51
299-E25-40	8/24/89	25.8	150	281	61	160	285	63
299-E25-41	8/24/89	27.8	170	293	58	175	279	55
299-E24-19	8/29/89	25.5	390	287	56	385	287	57
299-E35-1	8/29/89	23	55	285	66	50	290	57
299-W15-19	9/5/89	21.1	60	281	64	60	304	65
299-E27-12	9/6/89	27.5	200	277	65	185	287	65
299-E27-15	9/6/89	26	120	284	61	120	282	56
299-E27-12	9/18/89	19.5	190	282	55	190	282	56
299-E27-13	9/18/89	17	155	280	55	160	285	61
299-E27-15	9/18/89	22.5	125	284	59	115	284	65
299-W10-16	9/22/89	23.3	85	291	61	80	296	54
299-E27-14	9/27/89	21	275	275	68	275	284	53
299-W18-26	9/27/89	18	300	273	56	295	282	52
299-E27-13	9/28/89	21.7	160	281	57	155	285	57
299-W15-21	9/28/89	27.3	125	279	56	130	270	61
299-W10-15	10/2/89	14.9	85	287	55	80	292	55
299-E27-14	10/11/89	14.7	265	250	61	260	280	61
299-W10-16	10/11/89	18.8	60	292	55	80	292	55
299-W15-20	10/12/89	16	70	288	60.1	65	293	61.4
299-W10-15	10/16/89	16.2	80	287	55	80	283	59
299-E32-5	10/19/89	22.3	55	281	68	55	281	66
299-W19-29	11/6/89	12.2	70	397	61	70	397	59
299-W19-28	11/6/89	11.7	80	287	54	80	292	56
299-W7-9	11/10/89	21.5	65	280	53	70	284	53
299-W7-8	11/17/89	6	60	285	59	60	298	64
299-W7-7	11/17/89	7.2	60	289	55	55	290	64
299-W15-24	12/5/89	7	120	284	64	115	297	68
299-E27-16	12/22/89	5.8	100	290	55	100	290	61
299-W15-23	12/22/89	1.9	105	298	61	105	294	62
299-E33-36	12/28/89	0.8	120	293	52	115	293	52
299-E33-37	12/28/89	-0.5	80	305	57	80	296	55
299-W7-9	1/9/90	9.1	60	300	55	65	287	58
299-W7-10	1/9/90	8.1	80	289	55	60	285	54
299-E33-38	1/9/90	<0	225	277.4	46	220	273.9	45.6

299-E28-28	1/10/90	5.3	65	297	58	65	301	54
299-E33-35	1/10/90	8.2	60	302	55	80	298	52
299-W15-23	1/16/90	10.3	125	298	53	125	296	52
299-W7-10	1/25/90	10.5	65	293	66	65	284	59
299-E33-34	1/29/90	8.4	65	289	58	65	297	54
299-E28-28	2/5/90	11.2	75	298	53	70	297	58
299-E27-16	2/8/90	12.5	105	290	53	110	289	54
299-E33-35	2/8/90	3.5	65	293	54	65	289	53
299-E33-37	2/8/90	4.2	85	287	61	85	287	55
299-W22-42	2/23/90	13.5	70	301	53	70	297	53
299-E33-34	3/5/90	14.3	75	288	51	70	288	53
299-W22-41	3/5/90	11.5	65	293	61	65	293	62
299-W22-42	3/5/90	15.4	70	301	54	75	292	52
299-W22-43	3/5/90	12.6	65	289	57	65	293	52
299-W22-40	3/12/90	NA	65	301	64	65	293	59
299-E34-8	3/12/90	12	115	284	64	110	285	64
299-W22-40	3/30/90	21.7	65	284	55	60	293	53
299-W22-43	3/30/90	20.4	65	293	63	65	289	61
299-E34-8	3/30/90	28.2	90	299	53	95	295	52
299-E33-34	4/4/90	18	70	293	54	70	297	55
299-W28-8	4/5/90	18.5	75	292	52	75	292	59
299-W28-11	4/5/90	14.8	75	298	60	70	288	64
299-W28-9	4/12/90	23.2	55	290	61	55	285	58
299-W28-11	4/13/90	24.6	60	285	61	60	289	62
299-W19-30	4/27/90	10.02	60	289	60	55	298	55
299-W22-42	4/27/90	10	60	298	58	60	298	55
699-48-50	4/30/90	20.8	60	281	65	60	281	65
299-W22-40	5/4/90	27.5	55	290	53	50	294	53
299-W22-41	5/4/90	21.8	55	290	66	60	289	53
299-W22-43	5/4/90	28.6	60	280	53	60	289	53
699-48-50	5/9/90	22.5	65	293	52	60	296	52
699-52-54	5/16/90	27.4	60	291	52	60	291	52
699-52-54	5/23/90	13.1	65	297	52	65	297	52
299-W28-8	5/29/90	22	65	302	52	65	293	52
299-W28-9	5/29/90	29.8	60	293	52	60	293	51
299-W28-11	5/29/90	23.5	60	289	52	55	290	53
299-E28-11	6/28/90	26.9	60	299	52	60	285	51
299-E35-2	7/5/90	26.6	55	298	52	55	294	51
299-E28-11	7/11/90	33.5	65	297	52	65	293	51
299-E35-2	7/13/90	28.5	50	299	52	50	299	52
299-E28-9	7/18/90	37.5	80	298	51	80	296	51
299-E28-11	7/18/90	32.9	55	305	52	55	302	52
299-E35-2	7/23/90	33.5	70	297	49	70	293	50
299-E28-9	7/25/90	24.5	75	301	52	75	303	52
299-E28-10	7/25/90	19.8	60	308	52	55	307	52
299-E28-9	8/1/90	36.6	65	297	52	65	297	52
299-E28-10	8/1/90	32	55	302	52	55	298	51
299-E28-10	8/9/90	31.3	50	299	53	50	299	52
299-E28-10	8/20/90	20.5	60	298	52	60	293	52
299-E25-39	8/23/90	26	60	293	50	60	298	51
299-E35-2	9/5/90	23.5	70	297	53	65	293	52
299-E28-9	9/5/90	30.9	75	298	52	75	296	51
299-E28-11	9/6/90	29.9	60	298	52	60	298	51
299-E28-10	9/6/90	27	80	292	51	75	292	52
299-E25-39	9/11/90	35.6	65	297	52	60	302	53
699-49-57B	9/18/90	30.5	65	297	52	65	293	52
299-E25-39	9/21/90	23.8	65	297	52	65	293	52
699-50-53B	9/21/90	27.9	70	288	53	65	293	52
699-48-96	9/28/90	30.7	55	271.1	48.4	55	263.3	47.6

699-49-57B	10/3/90	24.3	60	270.7	48.4	60	266.8	48
699-49-57B	10/10/90	18.9	60	266.8	48.8	65	278.2	48.4
699-50-53B	10/12/90	23.7	65	280.2	48	65	274.3	48
699-52-57	10/12/90	12.5	65	280.2	48	65	276.2	48
299-W19-32	10/17/90	9.4	260	276.6	45.6	265	276.2	46.4
699-55-55	10/17/90	13.7	65	270.3	46.8	65	272.3	46
299-W19-31	10/22/90	9.4	385	278.6	48.4	380	265.2	45.6
699-50-53B	10/22/90	24.1	255	275	47.6	245	266	46
699-48-96	10/23/90	10.4	305	275.1	46.8	295	268	46
299-W18-25	10/29/90	9.3	80	269.2	48	85	268.8	47.6
299-W23-13	11/5/90	14.5	120	269.9	48.8	120	268	46.4
699-52-57	11/6/90	13.1	65	276.2	48.4	60	272.7	48.4
299-W19-32	11/13/90	14.2	150	275.5	47.2	140	270.3	48
699-55-55	11/13/90	11.5	60	280.6	48	55	281	48.4
299-W18-25	11/29/90	14	75	269.5	48.4	75	269.5	48.4
299-W10-17	11/29/90	19.4	140	276.2	46.4	140	276.2	48
299-E33-40	11/29/90	12.8	110	270.7	47.2	110	270.7	48
299-W23-13	11/30/90	9.5	140	274.3	47.2	135	272.7	47.2
299-W10-18	11/30/90	10.5	170	271.9	46.8	165	272.3	46.4
299-E33-38	12/3/90	8	270	277.8	44.9	265	278.2	45.2
299-W15-22	12/5/90	4.2	195	269.9	46.8	195	269.9	46.4
299-W19-31	12/6/90	2.7	225	277.4	46.4	220	271.9	46.4
699-48-96	12/6/90	-2	60	282.5	48.4	57	280.8	48.2
299-W10-18	12/12/90	2	205	279	46	195	279.8	46.8
299-W10-17	12/13/90	3	140	284.1	46.4	140	280.2	48
299-E33-38	12/20/90	<0	225	269.5	45.6	225	273.5	44.9
299-E33-39	1/2/91	<0	95	266	47.6	95	268	46.8
299-E33-40	1/14/91	5.4	95	279.8	49.2	95	279.8	48.4
699-55-55	1/14/91	17.2	55	277	48.4	50	269.5	48
299-W23-14	1/15/91	9.2	215	276.2	47.6	215	268.4	47.6
299-W23-14	1/21/91	8.7	210	278.6	46.6	210	272.7	46.4
299-E33-39	1/21/91	-2	110	274.7	48	105	275.1	46.8
299-W22-39	1/24/91	<0	200	273.5	46	195	269.9	47.6
299-E33-40	2/7/91	8.4	100	275.5	48	95	273.9	49.2
BH3A-1	2/8/91	12.8	50	279.4	48.8	50	275.5	47.2
299-E33-40	2/14/91	14.6	100	265.6	48	105	271.1	47.6
299-W22-39	2/19/91	22.3	10.2 EU	273.1	48	9.8 EU	273.5	48.4
299-W18-171	2/21/91	11.5	55	275.1	48	55	273.1	46.8
299-E33-41	2/21/91	14.5	335	268.8	44.9	330	267.2	44.1
699-46-5	2/22/91	13.5	60	280.6	47.6	60	274.7	47.2
699-44-7	2/23/91	11.5	70	271.9	47.6	70	264	47.6
299-W26-12	2/27/91	12.4	65	274.3	48	65	274.3	46.8
BH3A-1	3/1/91	2.3	45	275.8	48.4	40	278.2	48.8
699-42-E9B	3/4/91	NA	75	271.5	47.2	75	273.5	48
BH3B-1	3/6/91	7.2	50	269.5	48	50	265.6	48
299-W26-10	3/8/91	13.8	55	275.1	46.8	55	265.2	49.2
BH3B-1	3/11/91	10.8	45	273.9	48.4	45	277.8	48.4
299-E24-20	3/12/91	5.4	150	275.5	45.6	150	263.6	46.4
299-W26-12	3/13/91	7.5	65	282.1	48.7	65	276.2	49.2
299-W26-7	3/14/91	2	55	281	48.7	50	277.4	48.8
699-42-E9B	3/18/91	8.5	60	274.7	48	60	278.6	48.4
299-W26-10	3/19/91	5.2	55	275.1	46.8	55	275.1	48.4
BH3B-1	3/19/91	11.4	45	275.8	48.8	45	277.8	48
BH3C-1	3/22/91	10.5	100	267.6	57.1	70	266	56.3
299-W26-7	3/25/91	3	50	279.4	47.6	50	271.5	48
699-42-E9B	3/27/91	4.2	55	273.1	49.2	55	279	48
BH3C-1	3/28/91	10.2	50	275.5	47.6	40	274.3	48
299-W18-29	4/17/91	12.5	60	278.6	48.4	60	274.6	48
299-W18-27	4/18/91	14.5	65	272.3	47.6	70	273.9	48

299-W18-28	4/19/91	15.6	55	282.9	48.8	60	278.6	47.6
299-W7-11	5/1/91	21.3	50	275.5	48.4	50	275.5	48
299-W7-12	5/3/91	9.5	55	279	48.8	55	275.1	48.4
399-1-8A	5/6/91	23.5	55	277	48	55	269.2	48
299-W18-27	5/7/91	19.3	75	279.4	48.4	70	273.9	48.4
299-W18-28	5/9/91	16.1	50	277.4	48.8	52	273.3	47.9
399-1-8A	5/9/91	20.1	55	277	48.4	55	275.1	47.6
699-32-22B	5/20/91	22.3	60	274.7	48.4	65	274.3	48
216-B-61A	5/21/91	18.7	100	277.4	49.2	95	277.3	48.8
299-W7-11	5/24/91	19.9	50	279.4	48.8	50	279.4	48.4
299-W7-12	5/29/91	17.9	75	275.5	48	75	275.5	48.4
299-E32-6	6/3/91	12.9	55	277	48	55	273.1	48
300-FF5-7C	6/3/91	17.9	55	275.1	48.4	55	277	48.4
299-W6-8	6/5/91	13.3	60	276.6	48.8	60	274.7	48
299-E32-9	6/5/91	16	50	277.4	48.8	50	279.4	48.8
299-E32-7	6/5/91	16.5	55	271.1	48.8	60	276.6	48.4
299-E32-8	6/11/91	19.6	60	280.6	49.2	60	280.6	48.4
299-E32-9	6/13/91	24.3	50	289.5	48.4	50	279.4	48.4
299-E32-7	6/13/91	23.9	55	281	48.8	55	281	48.8
300-FF5-4C	6/13/91	12.3	50	283.3	49.6	50	269.5	48.4
299-E26-13	6/14/91	13.3	65	278.2	47.6	60	278.6	47.6
699-32-22B	6/18/91	NA	120	271.9	44.1	115	268.4	43.3
299-E26-13	6/21/91	19.1	60	272.7	47.6	60	274.7	47.6
299-E26-12	6/21/91	14.5	60	276.6	47.6	60	276.6	48.8
299-E25-43	6/21/91	12.3	70	279.8	48.4	65	274.3	48
299-W6-8	6/24/91	16	55	277	48.8	55	277	48.4
299-E25-42	6/24/91	26.5	50	275.5	48	50	273.5	48
300-FF5-1C	6/25/91	17.3	50	277.4	49.2	50	275.5	48.4
299-W6-7	6/27/91	17.8	55	279	48.8	55	281	48.4
299-E32-6	6/27/91	26.5	50	277.4	48	50	271.5	47.2
299-E26-12	7/1/91	28.7	65	274.3	47.6	65	276.2	48
299-E25-43	7/1/91	26.1	70	275.8	47.6	75	273.5	46.8
300-FF5-7C	7/2/91	19.8	60	280.8	47.6	55	277	48.4
300-FF5-1C	7/17/91	24.7	50	279.4	48	50	277.4	48.4
299-W6-7	7/18/91	25.2	55	277	48	55	271.1	47.6
299-E32-6	7/18/91	20.1	60	276.6	47.6	60	274.7	48
299-E25-42	7/24/91	34	55	275.1	46	55	275.1	47.6
699-40-40B	7/24/91	40	55	275.1	47.6	55	271.1	47.6
300-FF5-4C	7/29/91	35.7	50	300.6	64.1	50	296.1	64.5
699-42-41	7/30/91	37.2	55	295.7	65.9	57	291.1	65.2
699-40-40B	7/31/91	32.7	50	298.4	64.5	50	302.8	65.4
699-42-39A	8/2/91	27.6	45	301	65.9	45	294.4	65
300-FF5-5C	8/6/91	26	50	300.6	65	52	296	64.8
300-FF5-1C	8/6/91	33	50	298.4	65.9	50	291.7	65.4
300-FF5-7C	8/8/91	33.1	55	293.5	63.6	55	291.3	62.3
300-FF5-4C	8/8/91	31	50	296.1	64.1	50	296.1	64.5
699-42-39A	8/9/91	29.2	47	298.6	64.4	45	296.6	64.5
699-40-40B	8/12/91	37.6	50	298.4	64.5	50	298.4	65
300-FF5-5C	8/20/91	34.1	50	293.9	64.5	48	294.1	63.8
300-FF5-7C	8/21/91	24.8	60	295.3	64.1	55	297.9	65
300-FF5-1C	8/21/91	34.8	55	300.1	65.4	60	299.7	64.5
699-43-40	8/27/91	26.7	60	299.7	64.5	60	293	65
300-FF5-3A	8/28/91	22.9	50	298.4	65.4	50	298.4	64.5
199-N-74	8/29/91	29.9	170	294.4	63.2	175	293.9	62.3
199-N-71	8/29/91	19.4	75	300.6	64.5	75	298.1	63.6
699-40-40A	8/30/91	32.3	50	296.1	64.5	50	296.1	64.5
699-43-41G	9/4/91	21.5	60	304.1	65.9	60	304.1	65.4
699-42-39B	9/5/91	36	50	300.6	64.1	47	298.6	64.4
UN-200E-63	9/5/91	24	175	300.6	63.2	170	294.4	63.2

299-W8-3	9/8/91	27	55	308.7	65.9	60	295.3	64.1
300-FF5-148	9/8/91	40.2	55	297.9	64.5	55	297.9	63.6
299-W8-6	9/9/91	27.9	60	301.9	64.1	60	297.5	63.2
299-W8-4	9/9/91	23.9	55	302.3	66.7	55	300.1	65
669-43-41G	9/10/91	20.3	65	301.4	64.1	65	301.4	65
300-FF5-13B	9/10/91	27.9	50	300.6	65	50	302.8	64.1
299-W18-31	9/12/91	21.3	92	305.7	65.2	90	301.4	63.6
199-N-73	9/16/91	21	70	303.2	65.4	70	303.2	65
199-N-72	9/16/91	24	80	302.3	63.6	80	279.9	63.2
300-FF5-10B	9/16/91	27.2	50	300.6	64.1	50	300.6	64.5
669-42-39B	9/17/91	21.3	45	303.2	65	45	298.8	64.5
669-40-40A	9/17/91	25.3	50	300.6	64.1	50	300.6	64.1
669-40-40B	9/19/91	28.1	47	303	64.4	45	305.4	64.1
300-FF5-14B	9/19/91	18.7	60	301.9	65.4	60	299.7	65
299-E33-43	9/20/91	23.6	245	296.6	61.9	250	291.7	61
299-E33-42	9/20/91	23.4	425	291.7	61.9	430	289.1	61.4
300-FF5-13B	9/20/91	19.1	50	305	64.1	55	302.3	64.1
299-W18-30	9/23/91	24.1	195	296.6	61.9	185	299.7	62.3
299-W8-5	9/24/91	18.9	55	302.3	65.9	55	304.5	64.5
299-W8-3	10/1/91	27.8	55	297.9	63.6	55	297.9	63.6
299-W22-46	10/2/91	24.7	85	301.9	63.2	85	299.7	64.1
299-W8-4	10/2/91	21.3	55	293.5	65	55	297.9	65.4
300-FF5-10B	10/2/91	18.1	53	304.7	64.7	50	300.6	64.5
299-W18-31	10/3/91	22.1	90	301.4	65.4	85	301.8	63.2
299-W14-12	10/3/91	19.3	150	300.6	64.1	150	298.4	61.9
299-W23-15	10/4/91	14	110	306.3	64.1	110	299.7	63.6
299-E34-10	10/4/91	20.1	65	303.7	66.3	65	301.4	65
299-W18-30	10/7/91	19.8	185	299.7	62.8	170	296.6	62.3
299-W8-6	10/7/91	11.6	62	297.3	64.3	62	303.9	64.3
299-E34-9	10/8/91	10.2	90	305.9	65	87	301.7	64.8
299-E33-43	10/9/91	22.9	240	297	63.6	240	297	62.8
299-E33-42	10/9/91	12.9	390	297	62.8	390	294.8	60.6
299-E34-10	10/10/91	12.1	75	302.8	75	75	300.6	64.1
299-W11-28	10/11/91	10.5	117	301.3	63.5	117	301.3	63.5
299-W8-3	10/15/91	21.5	57	299.9	64.8	55	297.9	65.4
299-W14-12	10/16/91	20.4	155	300.1	63.6	155	297.9	61.4
299-E34-9	10/17/91	17.9	80	300.1	65	77	300.4	63.9
299-E27-17	10/17/91	12.1	70	301	65.1	70	301	64.5
299-W22-46	10/18/91	6.5	85	306.3	64.5	87	297.3	63.2
669-32-22B	10/18/91	NA	62	299.5	64.4	65	303.7	64.1
299-W11-27	10/21/91	15.6	100	298.4	62.8	107	299.9	64.4
299-W8-6	10/24/91	10.3	52	302.6	65.2	52	302.6	65.7
299-W23-15	10/25/91	13.3	112	306.1	64.8	110	299.7	63.6
299-E27-17	10/28/91	0.6	67	303.5	65.7	65	299.2	65
199-D8-5	10/28/91	3.6	47	303	65.2	47	300.8	64.4
300-FF5-6B	10/29/91	-0.1	107	304.4	64.4	105	302.3	64.5
199-D5-13	11/1/91	6.1	47.5	305.2	65.2	47.5	305.2	64.3
299-W8-5	11/4/91	3.6	55	308.7	65.4	55	302.3	64.5
299-W11-28	11/7/91	8.6	105	302.3	64.5	105	302.3	64.1
116-D-1A	11/7/91	5.5	70	307.6	66.3	65	298.8	63.2
199-D8-4	11/8/91	9.2	47	296.4	65.2	47	305.2	65.2
299-W11-27	11/13/91	18.4	95	303.2	64.1	95	305.4	64.1
300-FF5-6B	11/13/91	10.7	110	301.9	63.6	110	301.9	63.6
299-W22-44	11/14/91	18.2	125	305	64.1	125	302.8	64.1
199-D8-54B	11/14/91	8.6	52	307	65.7	52	302.6	64.8
116-DR-2	11/15/91	3.9	48	307.4	64.3	45	298.8	63.2
116-DR-1	11/15/91	7.6	52	302.6	63	52	302.6	63.9
199-D8-6	11/22/91	6.1	45	305.4	64.5	45	301	64.1
299-W8-4	12/2/91	6.7	55	304.5	66.3	55	302.3	65.4

116-D-4	12/3/91	4.5	45	301	64.5	45	305.4	65.8
116-D-9	12/10/91	1.7	50	305	64.5	45	303.2	64.5
116-D-3	12/12/91	10.7	40	303.7	65	40	303.7	65
299-E34-11	12/16/91	2.1	60	308.3	65.9	55	279.9	65
199-D8-55	12/18/91	4.1	70	305.4	66.3	72	305.2	66.1
199-D5-18	12/18/91	3.6	50	305	65.9	47	305.2	66.1
199-D5-16	12/18/91	1.9	55	308.7	65.4	50	305	65.8
299-W6-3	12/31/91	2	55	309	67.2	55	304.5	64.5
116-D-7	1/3/92	2	55	304.5	64.6	50	305	64.5
299-E34-12	1/7/92	-1.5	75	305	65	78	304.7	65.2
199-D5-19	1/7/92	5	43	301.2	65.2	45	298.8	64.5
199-D5-18	1/7/92	2.3	45	305.4	65.9	45	305.4	65.4
199-D5-14	1/13/92	3.2	45	305.4	65.9	45	305.4	65
199-D2-6	1/13/92	2.1	52	309.2	65.9	50	307.2	65.4
299-E34-12	1/14/92	2.3	85	308.3	65	85	304.1	65
299-E32-10	1/14/92	3.8	55	309	65.9	55	304.5	65.9
199-D5-16	1/14/92	2.5	47	307.5	65.2	47	303	64.4
199-D5-20	1/15/92	1.4	62	303.9	65.7	65	303.7	65.9
199-D2-6	1/15/92	1.1	45	303.2	65	45	305.4	65.9
116-DR-9A	1/15/92	2.7	65	308.1	65	62	299.5	63.9
699-48-77	1/16/92	7	50	307.2	65.9	50	307.2	65.9
199-D8-2	1/17/92	2.1	50	307.2	65	45	301	65
199-H6-1	1/21/92	3.5	58	308.6	65.2	58	304.3	64.7
116-DR-9B	1/22/92	3.8	55	308.7	65	53	308.9	64.7
699-41-5	1/23/92	8.3	52	307	64.8	53	304.7	66
199-D5-14	1/24/92	10.6	47	303	65.2	45	305.4	64.5
199-H4-47	1/24/92	11.7	45	303.2	65.4	47	305.2	64.8
199-D5-15	1/24/92	14.2	45	305.4	65.4	45	303.2	64.5
199-D5-17	1/27/92	6.1	52	307	64.8	50	302.8	65
199-HR4-46	1/27/92	5.7	60	306.3	65.9	60	302.2	65.2
299-W18-32	1/28/92	12.2	50	305	64.5	50	305	65
299-W6-10	1/28/92	13.6	52	302.6	64.8	53	300.3	63.8
199-H6-1	1/28/92	14.5	55	302.3	63.6	55	302.3	63.6
116-D-5	1/29/92	12.3	47	303	65.2	45	301	63.6
130-D-1	2/10/92	NA	50	309.4	65	50	307.2	65
116-DR-5	2/10/92	NA	47	309.7	64.4	47	309.7	64.8
199-H4-48	2/10/92	NA	57	308.8	64.8	53	306.9	64.3
199-H4-45	2/10/92	NA	55	304.5	65.9	52	302.6	64.4
699-93-49B	2/13/92	NA	55	302.3	65.4	55	302.3	64.1
699-91-43	2/13/92	NA	60	301.9	63.6	60	301.9	65
199-H4-49	2/13/92	NA	65	308.1	65.9	65	299.2	65.4
199-H5-1	2/13/92	NA	60	301.9	65.9	55	304.5	65.4
299-W22-21	2/15/92	NA	85	308.5	65.9	82	304.4	64.4
299-W26-51	2/18/92	NA	55	309	64.5	55	302.3	64.1
299-W6-10	2/18/92	NA	55	308.7	66.3	55	297.9	65.9
G123	2/19/92	NA	53	304.7	65.6	55	302.3	65.4
116-D-2	2/20/92	NA	50	305	64.1	50	300.1	64.1
299-W6-9	2/20/92	NA	55	309	65.4	55	306.7	64.1
199-B3-47	2/20/92	NA	55	309	64.1	55	306.7	63.6
132-D-3	2/21/92	NA	52	307	64.4	50	305	64.5
699-48-77A	2/21/92	NA	55	309	64.5	55	304.5	64.1
199-B3-46	2/21/92	NA	57	304.4	63.9	57	299.9	63.5
299-W11-18	2/22/92	NA	55	309	65	52	304.8	63.9
299-W15-86	2/22/92	NA	55	302.3	63.6	52	304.8	63.9
299-W11-31	2/24/92	NA	57	308.8	64.4	55	302.3	63.6
299-W18-94	2/25/92	NA	55	304.5	65.9	55	300.1	65
199-B4-8	2/26/92	NA	43	305.6	64.7	43	307.8	64.3
699-93-46	2/26/92	NA	55	309	65.4	55	309	64.5
199-B3-47	2/26/92	NA	65	305.9	64.5	63	306	63.4

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