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Westinghouse Astronuclear Laboratory

TEST CELL "C" ACCURACY STUDY
PHASE I RESULTS

MASTER

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Submitted by

Westinghouse Electric Corporation
Astronuclear Laboratory
Pittsburgh, Pennsylvania, 15236

PREPARED BY:

G. S. Jones, II
Systems Development

W. H. Horton
Reliability

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APPROVED BY:

R. F. Roller, Manager
Systems Development
Electronics and Instrumentation

G. L. Wagner, Manager
Reliability

A. C. Sanderson, Manager
Test Operations and Systems

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1.0 INTRODUCTION

In conjunction with the Phoebus 1B-EP10A test run several data acquisition system calibration runs were made. Prior to this test run discussions among personnel from SNPO, AGC, WANL, NTO, and LASL-NRDS had been held to establish a plan for an accuracy study of the Test Cell "C" narrow-band system, using data from these calibration runs. The Test Cell "C" system is quite similar to that for Test Cell "A" for which an extensive accuracy study was completed in 1965 (for more information, see WANL-TME-1372, dated February 1966). Because of the similarity, all agreed that a complete study for Test Cell "C" would be unwarranted at this time, but that some study was needed to demonstrate the similarity and to ascertain whether or not there are any inconsistencies between the two cells. This report is to present the test plan used to sample the Phoebus 1B calibration data, a brief discussion of the sampled data and their analysis, and the results and conclusions derived from the analyses of the data for this study.

2.0 TEST PLAN

The Test Cell "C" narrow-band system can be broken down into two categories; the low-level system, containing approximately 850 data channels, and the high-level system, containing approximately 470 data channels (for a complete description, see LASL J-17-547, dated October 7, 1967). Texas Instrument (TI) multiplexers are used in the high-level system as contrasted to the use of both "old" and "new" Systems Engineering Laboratory (SEL) multiplexers in the low-level system. Test Cell "A" accuracy study results had indicated that system accuracy is dependent upon multiplexer type. That study also proved that the data channel configuration (dependent upon the transducer input) affected the system accuracy. To evaluate the applicability of these same effects at Test Cell "C", the test plan derived from earlier discussions required data from at least two multiplexers for each multiplexer type and from at least two (if possible) data channels for each channel configuration on each type of multiplexer. The test plan also required data from two runs per day over at least four different days (to evaluate possible "short term"

and "long term" drift). As indicated earlier, data to satisfy these requirements were to be selected from those data obtained during the Phoebus 1B calibration runs. Table 1 gives the data channels (multiplexer-channel configuration combinations) selected for study; the calibration run dates and times for which data were to be sampled are also given. As may be noted from this table, the requirements of the test plan were fulfilled by the selection of 40 channels, covering two multiplexers for each of the three multiplexer types; covering, for the most part, two channels for each multiplexer (overall, five basic channel configurations are represented); and covering data from two runs per day over six different days (actual test period was 18 days). Data for these 40 channels, as taken during the calibration runs (as given in Table 1, data taken at 12 different times) were to be evaluated to estimate the noise, linearity and drift components of the Test Cell "C" Data Acquisition System.

3.0 DATA COLLECTION AND PRELIMINARY DATA REDUCTION

Activation of a transducer during a reactor test or stimulation by a power supply during calibration produces an analog signal which is conditioned by the data acquisition channel components. The transformed signal is transmitted over the long lines to the control point where it is recorded in analog format on a tape designated as N1. Over specific time intervals and at specific sampling rates, the analog data are digitized and demultiplexed by equipment under control of the CDC-160A computer (controlled by input cards and manual switches) to produce a digital tape, designated N2. In converting the analog data to digital data, either of two computer codes, ENIGMA or NDRS may be used. Use of ENIGMA results in data that are termed "normalized" while use of NDRS results in "unnormalized" data. Digital data on these N2 tapes are further processed to yield a tape designated N3, containing data expressed in engineering units. Calibration run data on N2 tapes are processed by a special program to produce a tape for print output containing a normal statistical analysis of the calibration data. Calibration run data for the 40 channels were processed by this special program, consolidated on a single tape, and

TABLE 1
SELECTED CHANNEL PIN NUMBER VERSUS CHANNEL CONFIGURATION
(TRANSDUCER TYPE)

<u>Multiplexer Type</u>	<u>Strain Gage</u>	<u>Swept Pot</u>	<u>Resistance Thermometer</u>	<u>Thermocouple</u>	<u>Bridge</u>
HL-11 Texas Inst.	03 & 29	35 & 36	37 & 38	11 & 12	30 & 31
HL-18 Texas Inst.	42	09 & 21	13 & 14	19	07 & 08
LL-13 New SEL			24 & 25	39 & 40	27 & 28
LL-15 New SEL			04 & 05	10 & 11	06 & 07
LL-19 Old SEL			21	25 & 26	05 & 27
LL-20 Old SEL			37	26 & 27	47 & 48

PHEOBUS 1B CALIBRATION RUN DATES AND TIMES

<u>Date</u>	<u>Control Room Time (Seconds from 0700)</u>		<u>Approximate Time of Day</u>
1-30-67	5871	6021	0830
1-31-67	4761	4901	0815
2-1-67	6451	6611	0845
2-2-67	77451	77811	0430
2-3-67	77061	77241	0415
2-15-67	19401	19541	1230

the tape shipped to WANL for further analysis. In processing the analog data for these channels, both the ENIGMA and NDRS computer codes were used; thus both "normalized" and "unnormalized" data were to be analyzed.

Tables 2 and 3 contain examples of the normal statistical analysis of the calibration data for a particular channel at a particular time. Table 2 contains the analysis of the data from the 11 calibration steps (0% to 100% of full scale in 10% intervals) as resulting from the use of the ENIGMA code (normalized data) while Table 3 contains that resulting from the use of the NDRS code (unnormalized data). For the 12 calibration runs for each of the 40 channels selected for this accuracy study, an analysis like that in either Table 2 or 3 was performed at NRDS, using both the normalized and unnormalized data. This preliminary analysis resulted in 960 sets of data in summarized form. As mentioned earlier, these sets of data were consolidated on a single tape and sent to WANL for further analysis.

Referring to either Table 2 or Table 3, the data of interest in this accuracy study are those data found in the columns headed "average step value E.U." (engineering units as a per cent of full scale) and "standard deviation" (as a per cent of full scale). In the special program used to generate these data (to summarize the calibration run data) the average step value E.U. is an arithmetic average of 18 values sampled from the values obtained at a particular calibration step during a single calibration run. The standard deviation, s , is obtained from the expression,

$$s = \sqrt{\frac{\sum_{i=1}^{18} (X_i - \bar{X})^2}{17}}.$$

Where: X_i is the digital value of the i^{th} data point, $\bar{X}$ is the average of all 18 data points taken on this calibration step.

HL11 P-18 EP4

1-30-6 AT565.H.011					
AVERAGE STEP VALUE		CALCULATED STEP VALUE		MAXIMUM DEVIATION	STANDARD DEVIATION
%CNTS $\square$	E.U.	%CNTS $\square$	E.U.	%PCT $\square$	%PCT $\square$
999.582	99.922	1000.361	100.193	0.173	0.167
899.893	89.957	900.319	90.170	0.204	0.180
800.288	80.001	800.277	80.147	0.251	0.221
701.410	70.117	700.236	70.123	0.323	0.260
600.526	60.033	600.194	60.100	0.203	0.174
500.059	49.991	500.152	50.077	0.209	0.169
400.358	40.025	400.110	40.053	0.208	0.223
300.119	30.005	300.068	30.030	0.278	0.290
200.262	20.024	200.026	20.007	0.393	0.366
100.130	10.015	99.984	9.983	0.406	0.344
-0.958	-0.000	-0.058	-0.000	0.311	0.338
PCT MAXIMUM DEVIATION FROM STRAIGHT LINE FIT				0.117	
PCT STANDARD DEVIATION FROM STRAIGHT LINE FIT				0.057	
PCT MAXIMUM DEVIATION FROM AVERAGE STEP VALUE				0.406	
PCT MAXIMUM STANDARD DEVIATION FROM AVERAGES				0.366	

TABLE 2

EXAMPLE OF NORMALIZED DATA

HL11 P-13 EP4

9-30-6 AP191.H.003					
AVERAGE STEP VALUE		CALCULATED STEP VALUE		MAXIMUM DEVIATION	STANDARD DEVIATION
%CNTS□	E.U.	%CNTS□	E.U.	%PCT□	%PCT□
982.944	99.986	983.074	100.000	0.113	0.137
889.556	89.973	889.810	90.000	0.060	0.110
796.722	80.019	796.545	80.000	0.137	0.143
703.722	70.047	703.281	70.000	0.244	0.161
610.167	60.016	610.017	60.000	0.125	0.184
516.444	49.967	516.753	50.000	0.167	0.168
423.389	39.989	423.488	40.000	0.149	0.150
329.944	29.970	330.224	30.000	0.220	0.187
237.056	20.010	236.960	20.000	0.220	0.226
144.444	10.080	143.695	10.000	0.274	0.246
49.889	0.000	50.431	0.	0.310	0.254
PCT MAXIMUM DEVIATION FROM STRAIGHT LINE FIT				0.080	
PCT STANDARD DEVIATION FROM STRAIGHT LINE FIT				0.040	
PCT MAXIMUM DEVIATION FROM AVERAGE STEP VALUE				0.310	
PCT MAXIMUM STANDARD DEVIATION FROM AVERAGES				0.254	

TABLE 3

EXAMPLE OF UNNORMALIZED DATA

From these summarized data, the average step value E.U. and the standard deviation were extracted to estimate (by additional analysis) the accuracy components of noise, linearity, and drift. With 11 values for each of the 960 sets of data, there then existed 10,560 values from which the accuracy of the Test Cell "C" data system could be estimated.

4.0 DEFINITION OF ACCURACY COMPONENTS

4.1 Noise

The data system accuracy component of noise is evaluated by a measurement derived from a comparison of the random fluctuations in signal output to the average of the output under essentially constant input conditions. In this analysis the noise measurement is obtained by the calculation of a standard deviation of the data signals from the average signal value, as discussed earlier. The noise component is thus estimated by this standard deviation.

4.2 Linearity

For a constantly-varying signal applied at the data system signal conditioner, a corresponding proportional output should be obtained if the system is linear. In actuality, deviations from a linear relationship may be experienced; such deviations reflect the non-linearity of the data system.

Non-linearity is determined by taking the average step values, fitting to these data a linear relationship by the method of least squares, and comparing the deviations from the linear relationship to the noise for the same data. Only when the non-linearity deviations are greater than the noise of the system is the linearity component said to exist.

4.3 Drift

For a full scale input signal applied at several distinctly separate times, some variation in indicated output may be expected. This variation represents full scale drift (or gain instability) in the channel. In a manner similar to full scale drift, zero offset

drift is represented by the variations in indicated output for zero input signals applied at several distinctly separate times. For this study, an evaluation of the data system drift component was made by comparing the variations in the average calibration curves taken at several distinctly separate time periods with the variation expected from the system noise. Thus, full scale and zero offset drift were combined into one overall drift value.

5.0 DATA ANALYSIS AND RESULTS

From the previous discussion, it is obvious that each calibration run produced 11 estimates of noise for a single channel, these estimates being the standard deviations computed in the special program used by NTO to reduce the data. Standard deviations, $\underline{s}$'s, are difficult to analyze per se; however, variances, $\underline{s}^2$'s, are readily amenable to analysis if their logarithms are used. The analytical technique used is the analysis of variance as described in many texts on statistical methods and as briefly described in WANL-TME-1372 covering the Test Cell "A" accuracy study.

5.1 Noise

For each channel, the 132 noise variances were analyzed by the analysis of variance technique. The results of the analyses for those channels within a multiplexer were essentially the same. Average variance estimates for the 40 channels are given in Table 4. Referring to this table, it can be seen that the channels within any multiplexer are not markedly different insofar as their average variance estimates of noise are concerned. (From a single analysis for each multiplexer, channels within any multiplexer were not significantly different statistically.) However, a comparison of the average variance estimates for each multiplexer will indicate that the new SEL multiplexers are nearly alike and much less noisy than either the old SEL or TI multiplexers. In addition, it might be noted that the two TI multiplexers are in turn almost the least noisy and the most noisy, indicating a high variability in noise capability. One additional fact seen in this table is that the normalized data reduction increases the estimates significantly. Apparently, this normalizing data reduction produces an increase in noise.

TABLE 4
AVERAGE VARIANCE ESTIMATES OF NOISE (PER CENT OF FULL SCALE)

<u>Multiplexer Type</u>	<u>Average Multiplexer Variance</u>	<u>Resistance Thermometer</u>	<u>Thermocouple</u>	<u>Bridge</u>	<u>Swept Pot</u>	<u>Strain Gage</u>
<u>Unnormalized Data</u>						
Texas Inst. HL-11	.03191	.03162	.03008	.03251	.03273	.03303
		.03089	.03239	.03523	.03236	.03141
HL-18	.07592	.07956	.07466	.07501	.07589	.07668
		.07398		.07562	.07610	
New SEL LL-13	.02825	.02769	.02856	.02898		
		.02743	.02870	.02815		
LL-15	.03171	.03298	.02992	.03175		
		.03274	.02995	.03320		
Old SEL LL-19	.05756	.06250	.05855	.05814		
			.05418	.05482		
LL-20	.04522	.04938	.04675	.04153		
			.04349	.04537		
<u>Normalized Data</u>						
Texas Inst. HL-11	.06559	.06634	.06022	.06941	.06723	.06205
		.06433	.06281	.06869	.06728	.06822
HL-18	.09505	.08791	.10570	.07498	.07632	.16630
		.09129		.07774	.10620	
New SEL LL-13	.04835	.04599	.05237	.04647		
		.04665	.05157	.04745		
LL-15	.03421	.03296	.03537	.03197		
		.03390	.03653	.03464		
Old SEL LL-19	.09997	.10540	.10630	.09055		
			.09803	.10040		
LL-20	.08301	.08742	.08505	.08076		
			.07803	.08412		

Although the noise estimates for channels within a multiplexer were not significantly different, this is not to say that noise estimates within calibration steps, either within a calibration run or between calibration days (times) were consistent. Table 5 summarizes the results of the analyses for each channel with the significance of the variability in the noise estimates shown. With but one exception (probably a random occurrence), the variability in noise within calibration steps is significant for all channels. The variability within days is not significant with but one exception (again, probably a random occurrence) and the variability between days is significant for some multiplexers but not for others. Of those significant variations, the most important (greatest in magnitude) is that seen within calibration steps. In all 40 analyses (80, if the analyses of noise for both normalized and unnormalized data are counted), system noise is fairly consistent for calibration steps from 40% to 100% and quite variable and significantly greater from 0% to 30%. Examples of this can be seen in the standard deviation data of Tables 2 and 3. These variations will be discussed in later paragraphs.

5.2 Linearity and Drift

Similar to the analyses of the noise estimates, the analysis of variance technique was used to evaluate the 132 average step values for each channel. The purpose of these analyses was to evaluate the linearity and drift components of accuracy. The results of these analyses are easily summarized. As compared to the average channel noise, no significant drift component was found for any channel.

For the new SEL multiplexers a significant linearity component was noted for all channels. Variance estimates expressing noise plus linearity components are given in Table 6. Comparing these values with those found in Table 4, the linearity effect for the new SEL multiplexers, though significant, is seen to be relatively small. Probably because of the low values for noise on these new SEL units is the linearity effect found significant. In any case, the new SEL multiplexers are still the preferred multiplexers.

TABLE 5
SUMMARY OF THE EVALUATION OF VARIABILITY IN NOISE ESTIMATES

	<u>Unnormalized Data</u>			<u>Normalized Data</u>		
	<u>Within</u>	<u>Within</u>	<u>Between</u>	<u>Within</u>	<u>Within</u>	<u>Between</u>
	<u>Calibration</u>	<u>Days</u>	<u>Days</u>	<u>Calibration</u>	<u>Days</u>	<u>Days</u>
	<u>Steps</u>			<u>Steps</u>		
Texas Inst. HL-11 -03	*	-	-	*	-	-
-11	*	-	*	*	-	*
-12	*	-	-	*	-	*
-29	*	-	-	*	-	-
-30	*	-	-	*	-	-
-31	*	-	-	*	-	-
-35	*	-	-	*	-	-
-36	*	-	-	*	-	-
-37	*	-	-	*	-	*
-38	*	-	-	*	-	-
HL-18 -07	*	-	*	*	-	-
-08	*	-	*	*	-	-
-09	*	-	*	*	-	-
-13	*	-	*	*	-	-
-14	*	-	*	*	-	-
-19	-	-	*	*	-	*
-21	*	-	*	*	-	*
-42	*	-	*	*	-	*

TABLE 5 (Cont'd)

			<u>Unnormalized Data</u>			<u>Normalized Data</u>		
			<u>Within</u>	<u>Within</u>	<u>Between</u>	<u>Within</u>	<u>Within</u>	<u>Between</u>
			<u>Calibration</u>	<u>Days</u>	<u>Days</u>	<u>Calibration</u>	<u>Days</u>	<u>Days</u>
			<u>Steps</u>	<u>Days</u>	<u>Days</u>	<u>Steps</u>	<u>Days</u>	<u>Days</u>
New SEL	LL-13	-24	*	-	-	*	-	-
		-25	*	-	-	*	-	-
		-27	*	-	-	*	-	-
		-28	*	-	-	*	-	-
		-39	*	-	*	*	-	-
		-40	*	-	-	*	-	-
	LL-15	-04	*	-	-	*	-	-
		-05	*	-	*	*	-	-
		-06	*	-	*	*	-	-
		-07	*	-	*	*	-	-
		-10	*	-	-	*	-	-
		-11	*	-	*	*	-	*
Old SEL	LL-19	-05	*	-	-	*	-	-
		-21	*	-	-	*	-	-
		-25	*	-	-	*	-	-
		-26	*	-	*	*	-	-
		-27	*	-	-	*	-	-
	LL-20	-26	*	-	*	*	-	*
		-27	*	-	*	*	-	-
		-37	*	-	*	*	-	*
		-47	*	-	*	*	-	-
		-48	*	*	*	*	-	*

*Variability Significant

-Variability not Significant

TABLE 6
VARIANCE ESTIMATES FOR NOISE PLUS LINEARITY (PER CENT OF FULL SCALE)

<u>Multiplexer Type</u>	<u>Average Multiplexer Variance</u>	<u>Resistance Thermometer</u>	<u>Thermocouple</u>	<u>Bridge</u>	<u>Swept Pot</u>	<u>Strain Gage</u>
<u>Unnormalized Data</u>						
Texas Inst. HL-11		No Linearity Effect - See Noise				
HL-18						
New SEL LL-13	.03220	.03170 .03115	.03252 .03295	.03340 .03147		
LL-15	.04047	.04278 .04196	.03736 .03893	.04090 .04115		
Old SEL LL-19		No Linearity Effect - See Noise				
LL-20						
<u>Normalized Data</u>						
Texas Inst. HL-11		No Linearity Effect - See Noise				
HL-18						
New SEL LL-13	.05233	.04998 .05032	.05637 .05590	.05105 .05077		
LL-15	.04492	.04479 .04506	.04468 .04752	.04310 .04450		
Old WEL LL-19		No Linearity Effect - See Noise				
LL-20						

The previous statement is verified in Table 7. Table 7 gives three accuracy values for each multiplexer. These values are an average, maximum and minimum. The average values are computed by taking the square roots of the average variances of Table 4 and multiplying these square roots by 2.6 to give $\pm 99\%$ confidence limits. The maximum and minimum values were obtained in a similar manner after first considering the variability in noise as summarized in Table 5. To be assured of a proper value, the maximum values should be used; however, the average values would be realistic for signal outputs in the upper half of the full scale range. Minimum values are included primarily to indicate how good the system accuracy could be in isolated, though not predictable, cases.

6.0 COMPARISON OF TEST CELL "C" AND TEST CELL "A" RESULTS

As stated earlier, one of the purposes of this study was to make a comparison of the accuracy values from the Test Cell "A" study with those from this study of Test Cell "C". Table 8 contains accuracy values which might be compared. The values for Test Cell "A" were taken from Table XIII of WANL-TME-1372 while those for Test Cell "C" are those maximum values of Table 7 adjusted for the inconsequential differences between channels as shown in Table 4. As may be seen from the data of Table 8, a direct comparison of the accuracy values from these two studies cannot be reasonably made because of the differences in multiplexer types between the two systems. However, in the Test Cell "A" study there were three old SEL multiplexers which compare with the two selected for the Test Cell "C" study. This limited area of comparability is insufficient to provide a comprehensive application of Test Cell "A" results to Test Cell "C". On the basis of this study, Test Cell "A" results cannot be considered to apply at Test Cell "C".

6.1 Accuracy at Test Cell "C"

Even though a comparison with Test Cell "A" cannot be drawn, sufficient data are available to predict channel accuracy at Test Cell "C" from the signal conditioner through the data reduction system. These data are sufficient in all respects but one,

TABLE 7
ACCURACY VALUES ($\pm$ 99% CONFIDENCE LIMITS) FOR
PHOEBUS 1B-EP10A CALIBRATION RUNS
(PER CENT OF FULL SCALE)

		<u>Unnormalized Data</u>			<u>Normalized Data</u>		
		<u>Average</u>	<u>Maximum</u>	<u>Minimum</u>	<u>Average</u>	<u>Maximum</u>	<u>Minimum</u>
Texas Inst.	HL-11	0.46	0.94	0.23	0.67	1.30	0.34
	HL-18	0.72	1.59	0.34	0.80	1.60	0.40
New SEL	LL-13	0.44	0.90	0.21	0.57	1.10	0.30
	LL-15	0.46	0.97	0.22	0.48	0.99	0.23
Old SEL	LL-19	0.62	1.30	0.30	0.82	1.60	0.41
	LL-20	0.55	1.10	0.27	0.75	1.50	0.38

TABLE 8

COMPARISON OF ACCURACY VALUES ($\pm$ 99% CONFIDENCE LIMITS) FOR
CALIBRATION RUNS OF PHOEBUS 1B-EPI0A AND
TEST CELL "A" ACCURACY STUDY

<u>Test</u>	<u>Multiplexer Type</u>	<u>Multiplexer</u>	<u>Resistance Thermometer</u>	<u>Thermocouple</u>	<u>Bridge</u>	<u>Swept Pot</u>	<u>Strain Gage</u>
Phoebus 1B	TI	HL-11	0.93	0.94	0.96	0.94	0.94
		HL-18	1.49	1.50	1.49	1.49	1.50
TCA	EG&G	HL-04				1.14	
		HL-05				1.08	
		HL-01		0.48			0.42
		HL-02		1.27			0.68
Phoebus 1B	New SEL	LL-13	0.89	0.90	0.89		
		LL-15	0.98	0.96	0.97		
	Old SEL	LL-19	1.33	1.30	1.30		
		LL-20	1.12	1.10	1.10		
TCA	Bendix	LL-05	1.14				1.21
		LL-06	1.28				1.25
	Old SEL	LL-09	0.60	0.60			
		LL-10		1.34			1.30
		LL-02	1.76				1.66

crosstalk. This effect was not significant using the old and new SEL multiplexers at Test Cell "A", and probably would exhibit a similar character if tests had been performed at Test Cell "C".

Data system accuracy is again multiplexer dependent, but independent of the type of channel, transducer, and signal conditioner. Accuracy values, to 99% confidence are:

Texas Instrument Multiplexer Channels	1.6%
Old Style SEL Multiplexer Channels	1.6%
New Style SEL Multiplexer Channels	1.1%

It is felt that these figures are valid, and will serve adequately until better information is obtained with future testing.

Cable effects existing between the test car and the signal conditioner, thermocouple referencing effects, crosstalk and frequency response have not been evaluated in this study.