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Neutron Generator Instrumentation at the Department 2350 Neutron Generator Test Facility

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NEUTRON GENERATOR INSTRUMENTATION AT THE DEPARTMENT 2350 NEUTRON GENERATOR TEST FACILITY

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ABSTRACT

The computer and waveform digitizing capability at the test facility has allowed several changes in the techniques used to test neutron generators. These changes include methods used to calibrate the instrumentation and changes in the operation of the test facility. These changes have increased the efficiency of the test facility as well as increasing both timing and amplitude accuracy of neutron generator waveforms.

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I. INTRODUCTION

The digitizing of neutron generator waveforms has led to increased computer control of the test facility which has caused changes in the techniques and instrumentation used to test neutron generators. Digitized waveforms are now the primary method of recording data from the testing of neutron generators. Oscilloscopes are used to back up the digitizing system when testing explosively activated neutron generators and for immediate access to the data after the test. Oscilloscopes are not used in the testing of electronic neutron generators.

To fully utilize the computer, major changes in the methods used to determine timing of the various neutron generator waveforms and to calibrate the digitizers have been implemented. Since these changes affect the data used by neutron generators engineers, it is essential that the test facility instrumentation as it now exists be fully documented. The basic digitizing system will not be covered here since it is described in other documentation.[1,2]

II. SYSTEM OVERVIEW

Figure 1 is a block diagram of the new method of instrumentation.

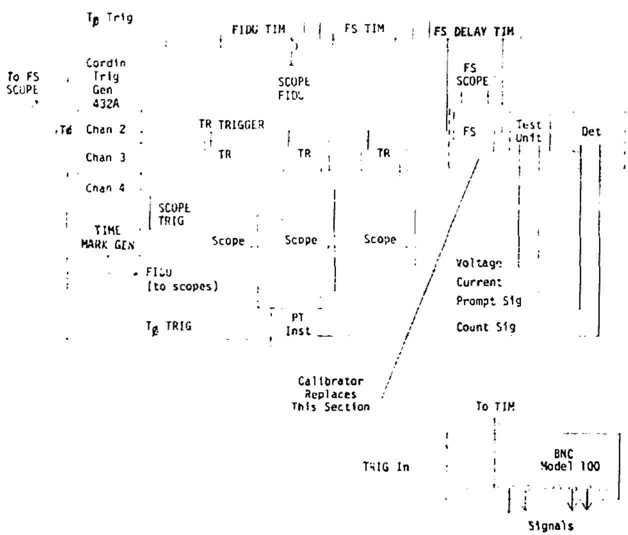

Figure 1. Block Diagram

A major change to the system is that the bridgewire burst (BWB) waveform is not used for triggering with the new system, although BWB is still the timing reference. This change means that the initial trigger ($T_\emptyset$) and BWB are not aligned in time.

A calibrated multichannel signal generator called "the calibrator," is used to simulate the waveforms from the neutron generator to be tested. This signal generator is calibrated by Sandia Standards, and various channels are used to provide waveforms similar to the waveforms from any explosive or electronic neutron generator.

A Cordin Model 432 delay generator is used to trigger the oscilloscopes, transient recorders, PT instruments, and the firing set (explosive neutron generators) or trigger signal (electronic neutron generators).

Timing corrections (TCORR) for non-real differences between trigger and signal arrivals at the transient recorders are calculated by the computer using an interfaced Eldorado Model 796 time interval counter. The TCORR for each transient recorder, along with the time interval between the input trigger to the firing set and the neutron generator detonator bridgewire burst or trigger are used to calculate the actual time of the digitized waveforms.

Trigger levels throughout the system have dropped from 300 V to 28 V or less. A new firing set (U8331) was purchased from Monsanto Research Corporation to provide consistency among Monsanto, General Electric Company Neutron Devices Department, and Sandia Laboratories. This firing set is compatible with the lower trigger levels now in use.

Details of the calibrator and timing, as well as some evaluation of the system, are given in the following sections of this report.

III. CALIBRATION

Two methods are used for calibration of the transient recorders. A dc calibrator applies a known voltage to the transient recorder input.(3) This dc input is digitized and a calibration factor calculated by the BASIC program. This method is used to eliminate the effects of any drift of the transient recorder circuitry and is done before each operation of the transient recorder. In addition to this method, before each neutron generator test, a set of waveforms which simulate the neutron generator to be tested are generated by the calibrator, which is physically located in place of the neutron generator. The BASIC program checks the digitized amplitude of each waveform and calculates a calibration factor for each transient recorder based on the known amplitude of the signal at the calibrator and the amplitude of the digitized waveform. The trailing slope of the flat-topped waveform from the calibrator may also be used to check the input amplifier crossover of the Biomation Model 8100. The calibrator is calibrated and certified by the Sandia Standards Department.

There is a BASIC program used to check the transient recorders on an occasional basis. It uses a 1 MHz sine wave input and checks for the fit of the digitized waveform to a 1 MHz sine wave.

Figure 2 is a photograph of the calibrator, connected to the transformer board. The calibrator consists of modified Berkley Nucleonics Corporation signal generators and an unmodified delay generator. The calibrator is arbitrarily called the BNC Model 100 and provides 10 channels of pulse output delayed in increments of 0.1 μs.

A BNC Model 7020 is used to generate the required delay; two Model 8016-4s provide four positive 50 V pulses; two Model 8016-5s provide four positive or negative switch-selectable 50 V pulses; and a Model 8016-6 provides two positive or negative 5 or 10 V pulses. These units are mounted in a Model TB-4 chassis which also provides power.

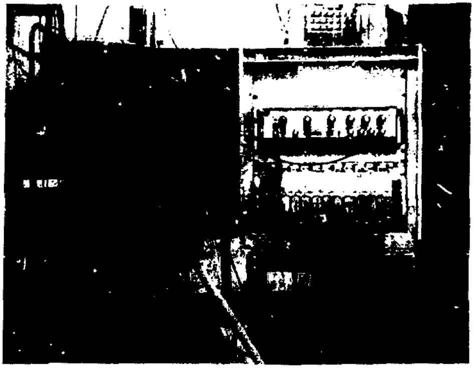

Figure 2. Calibrator

The 50 V channels were modified at the factory by clamping the outputs with zener diodes to improve reproducibility. The calibrator was further modified at the test facility by putting 50 Ω resistors in series with the 50 V outputs to provide short-circuit outputs of approximately 1 A.

Before each explosive neutron generator test series, all instrumentation is calibrated and TCORR determined for digitized data by using the calibrator. With all instrumentation connected, a set of waveforms with known amplitudes is generated by the calibrator (i.e., currents through current transformers, 10 V for the pick-up plate (PUP) measurement, and a dummy neutron waveform). Each TR determines the apparent time delay of its signal and then corrects this time by the interfaced time interval counter reading. This produces a TCORR for each TR.

At the same time, each TR digitizes and measures the amplitude of its waveform. Sandia Standards lists the current output of each current channel with an accuracy of ±5% and the output of each voltage channel with an accuracy of ±4%. These values are stored on the computer's RK05 disk file which is accessible by the BASIC program. Since the exact value of the calibration waveform is known, any inaccuracies in the current transformers, attenuators, or cable losses are eliminated by the computer since it compares the amplitude of the waveform from the calibrator as read by a transient recorder with the value from the disk and adjusts the sensitivity accordingly.

IV. NEUTRON MEASUREMENT CALIBRATION

The neutron calibration is based on the barium bolt count as read by the scaler. The neutron measurement is determined by the scaler reading and the probe factor.

Sensitivity for the neutron prompt waveform is determined by the ratio of the scaler reading, as read by the computer using the scaler interface, to the integral of the neutron waveform, as calculated by the computer using the digitized waveform from the transient recorder.

The neutron prompt waveform is set to a convenient amplitude by selecting appropriate attenuator and transient recorder ranges. The rate level is not set on the oscilloscope, but a voltage equivalent of the rate level is recorded.

Although calculating the neutron sensitivity on a shot-to-shot basis eliminates any errors caused by prompt neutron detector drift, another problem is generated. If a waveform goes off-scale and is clipped, the sensitivity is in error by the ratio of the integral of the clipped area and the normal integral. To avoid clipping and still use at least 75% of the available digitizing window, two digitizers are used with the dual-probe neutron detectors, when possible. A software check is made to see if the more sensitive transient recorder is off-scale. If it is off-scale, the neutron prompt waveform is taken from the transient recorder which is set to the less sensitive scale. On neutron generators which have too many waveforms to allow two transient recorders to be dedicated to the neutron waveform, conservative scales are selected and lower resolution accepted.

An additional advantage of the system described in this section is that attenuators for the neutron waveform transient recorders may be added or subtracted with no changes in program input since the calibration is done on each waveform.

V. TIMING

Functional testing of neutron generators determines not only the neutron output, but the time of the neutron pulse as well. However, in order to measure the time of a neutron pulse, it must be referenced to some initial time. On electronic generators, this reference time is the initial trigger to the neutron generator. On explosive generators, the usual reference timing point is the detonator bridgewire burst. The time interval until neutron output, etc., can then be measured from the initial time reference.

The measurement of timing information on explosive neutron generators presents some unusual difficulties not present with electronic types. Ideally, all instrumentation would be triggered at bridgewire burst time. However, the bridgewire burst waveform is not necessarily an ideal trigger waveform. In addition, this event occurs remotely, and a time delay is introduced bringing the signal to, and triggering, numerous delay generators for all the instruments used on the test. Also, should the bridgewire burst waveform be lost or of insufficient amplitude to trigger the delay generator, all information regarding the test would be lost. The one-time operation of the explosive generator makes it imperative that all instruments be triggered and ready to accept data. These and other considerations produced the system shown in block diagram form in Figure 3. For clarity, only the neutron measurement is shown.

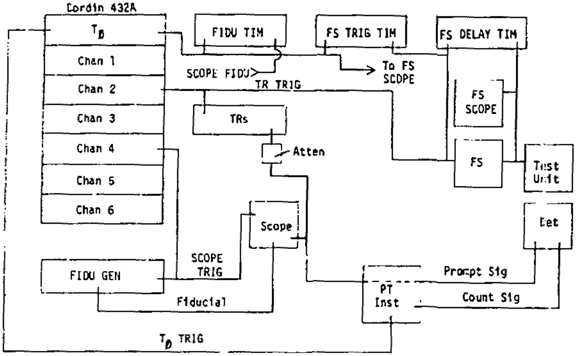

Figure 3. Typical Timing Setup, Block Diagram

The heart of this timing system is the Cordin 432A six-channel delay generator. The 432A provides six independent delays variable by front panel switches from 0.10 to 999.99 μs in 10 ns increments referenced to the zero delay output ($T_\emptyset$). The manufacturer's stated accuracy is ±20 ns ± 0.1% of the delay setting. However, the jitter is quoted at ±5 ns referenced to the zero delay output. While these figures seem to have the accuracy required, other delays and variations make it more convenient to monitor important delays with time interval meters.

An external trigger applied to the Cordin 432A starts the following sequence of events (Figure 3). The zero delay output ($T_\emptyset$) from the Cordin starts the firing set trigger time interval meter (FS TRIG TIM), the firing set monitor scope, the scope fiducial time interval meter (FIDU TIM), and the production testing (PT) equipment.

The Channel 2 delayed trigger from the Cordin (normally set for a delay of 1.00 μs) triggers the transient recorders (TRs) and the firing set. The TRs are triggered somewhat earlier than the firing set due to cable transit time to the test area. The Channel 2 delayed trigger applied to the firing set is used to stop the firing set trigger time interval meter (FS TRIG TIM) and to start the firing set delay time interval meter (FS DELAY TIM) which is interfaced to the computer. This trigger is also monitored by the firing set monitor scope to confirm the delay read by the FS DELAY TIM.

Bridgewire burst as seen at the firing set output is used to stop the FS DELAY TIM. The start and stop cable lengths to this time interval meter are equal to cancel their time delays. The bridgewire burst waveform (Figure 4) is monitored by the firing set monitor scope to ensure that the FS DELAY TIM is stopping on the proper portion of the waveform. The bottom trace in Figure 4 is an added waveform. The first portion of

Figure 4. Detonator Current and Bridgewire Burst Waveform

the trace is the trigger applied to the firing set, while the second half shows the bridgewire burst waveform added. The time of interest is the time from the trigger (negative-going step) until the spike produced when the bridgewire actually bursts. Care should be taken during set-up to verify that the FS DELAY TIM does not read the time to the first step on the bridgewire burst waveform instead of BWB. The step on the waveform indicates the firing set dump time, but a short time is required for the detonator current to reach a sufficient level to cause burst of the bridgewire.

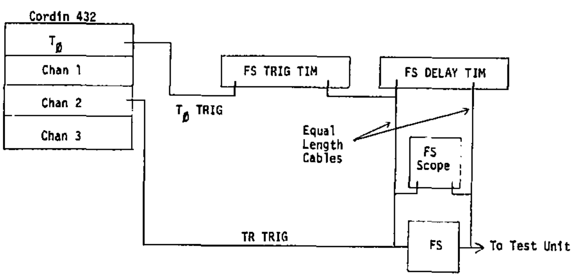

Figure 5. FS TRIG & FS DELAY Time Interval Meters

Figure 5 shows the firing set delay time interval meter (FS DELAY TIM) in simplified form. The FS DELAY TIM provides accurate timing information on the internal delay of the firing set. The time read by the FS DELAY TIM is used to correct the digitized timing information to bridgewire burst reference.

The Channel 4 delayed trigger (Figure 3) from the Cordin is used to trigger most of the scopes that are used during testing. This delay may be set as required to produce a scope sweep that covers the desired time interval. In addition to triggering the scopes, it triggers a pulse generator that provides a scope trace blanking pulse for timing comparison about 2 μs after the scope sweep begins. The time interval from the Cordin zero time delay reference to the time mark is measured by the SCOPE FIDU TIM.

The scope fiducial time and any timing information determined by the PT instruments is referenced to the Cordin zero time output. However, the difference between Cordin zero time output and bridgewire burst has been measured by the FS TRIG TIM and the FS DELAY TIM (Figure 5). The sum of these two time measurements is used to correct the scope fiducial time and the PT timing information to the bridgewire burst reference.

In order to improve the timing accuracy of the digitized data, a time correction (TCORR) has been applied to the digitized data timing information.

The need for TCORR can be seen by referring to Figure 6. The block diagram portion of Figure 6 shows the same trigger used for the transient recorder and the firing set. The transient recorder portion of the timing diagram shows that the trigger signal to the TR and the firing set, if patched directly to the TR signal line, would appear as a signal at time "C" later (A + B). However, this apparent "signal" is actually the firing set trigger as seen by the transient recorder. Time "C" is measured by the TR and referred to as TCORR. In effect, by subtracting time "C" from a delay measured by the TR, the TR trigger and the firing set trigger now occur simultaneously.

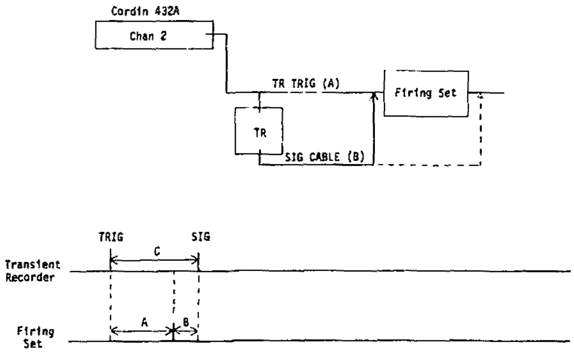

Figure 6. Simplified TCORR Block Diagram

In actual practice when determining TCORR for as many as six TRs, it is not practical to patch the trigger line to each signal line and repeat the TCORR operation until time "C" has been determined for each TR in use. Instead, the calibrator described in Section III of this report is used to determine TCORR for all TRs in use for a particular test.

One difficulty that arises when determining TCORR is the internal delay of the Model 100 calibrator. The internal delay of the Model 100 is repeatable when referenced to its own zero time output. However, from trigger in to pulse out, the variations are great enough to require that these variations be measured with a time interval meter.

In order to include the Model 100 calibrator variability in TCORR measurement, the FS DELAY TIM is used to measure the time delay from trigger in to the Model 100 until pulse out, Figure 7. This time is subtracted by the computer from the apparent signal delay (time "C") and the actual TCORR determined. Variations in the delay of the Model 100 are accounted for in this manner. Since the pulse generator delay is equal for all channels, this time is subtracted by the computer from the apparent signal delay measured by each TR. The remaining apparent signal delay is then due to differences in trigger and signal cables and represents the actual TCORR for each TR.

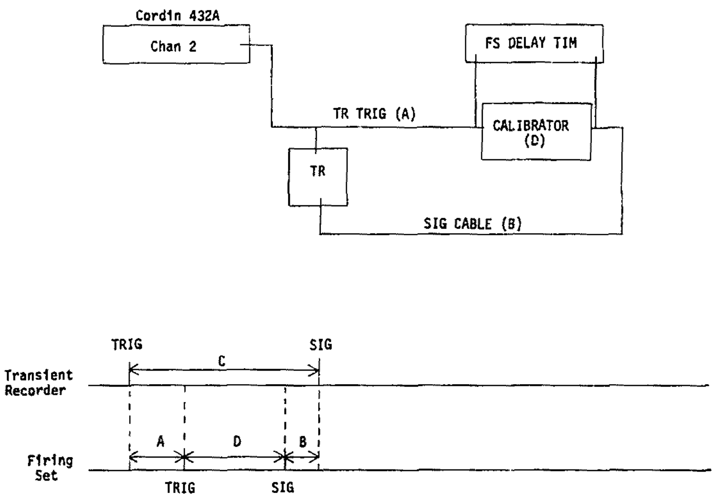

Figure 7. TCORR Block Diagram

VI. OPERATION

Testing of either explosive or electronic neutron generators is done under computer control using BASIC, assembly language drivers, and the hardware illustrated in Figure 8. The primary differences in testing electronic units as opposed to explosive units is that oscilloscopes are used as a backup on explosive neutron generators, and much more automation is used on electronic neutron generators.

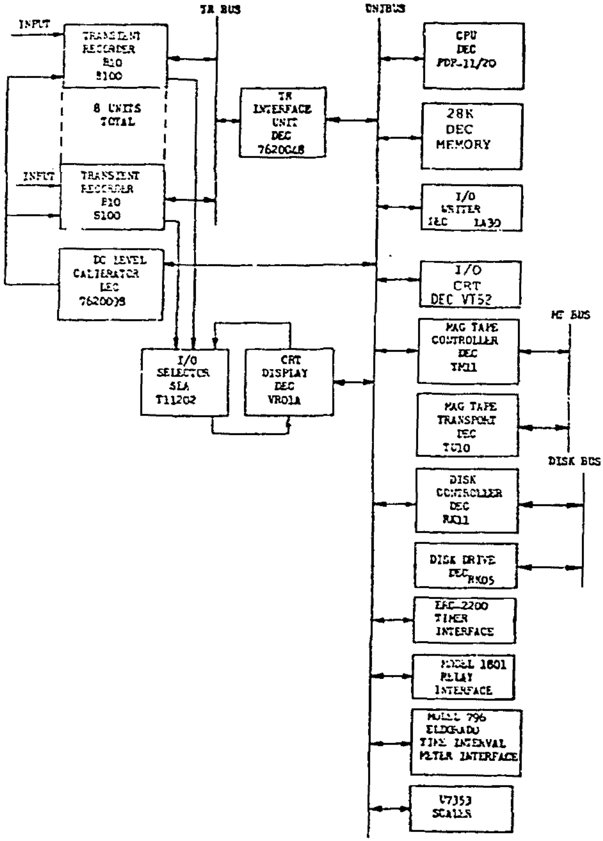

Figure 8. Digitizer Hardware Block Diagram

For either type unit, the calibrator is first used to amplitude calibrate the transient recorders and determine TCORR. The calibrator is then used to simulate the unit to be tested to dry run the system.

A neutron source is used to verify the neutron detector. The source is either a Controllatron or an electronic neutron generator. Since the neutron calibration is obtained from the scaler and the integral of the prompt pulse, the amplitude of the output of the neutron source is not important.

The transformer assembly, Figure 9, has connections for the calibrator to conveniently put current through the appropriate transformers.

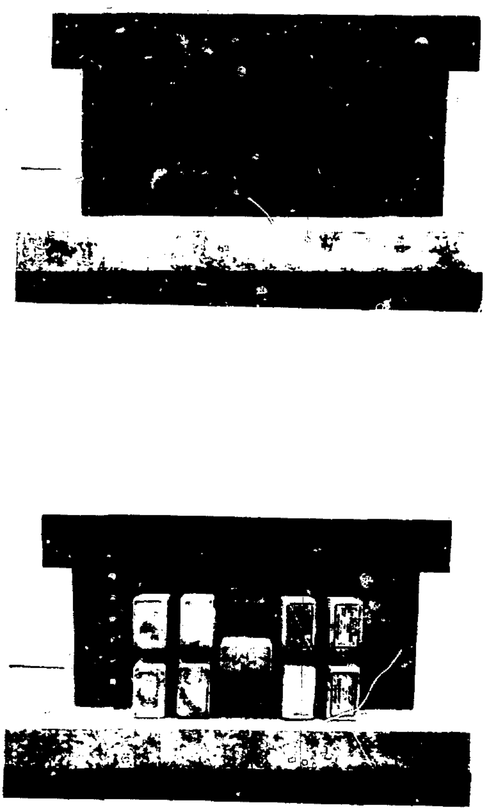

Figure 9. Transformer Assembly

The computer program reads the amplitude calibration values from the RK05 disk and compares these values with the amplitudes actually read from the transient recorders, and stores a value which will be used to correct the sensitivites used for all signals except neutrons. The values from the disk are printed along with the values from the transient recorder so the computer operator can check for any drastic discrepancies.

As a final check of the system, including the neutron detector, the timing is changed to correspond to the time of the neutron generator to be tested and a neutron waveform is provided by triggering the system and the Controllatron.

Except for the calibration factors, the system functions close to methods described elsewhere.[1]

VII. SYSTEM VERIFICATION

The final check on the digitizing system was made by digitizing waveforms from the Model 100 calibrator and measuring the time of the waveforms with an Eldorado Model 796 time interval counter. The waveforms were then placed on the tape in the CDC 6600 library [1,2] and the waveform time-amplitude array printed and plotted under NOS using the Tektronix Model 4051 computer graphics terminal and 4631 plotter. Table I contains the comparison of the time and amplitudes as measured at the calibrator and as measured from the digitized waveforms.

Table I. Comparison Between Calibrator Output and Digitized Waveforms

Test 1

	Calibrator		Digitized Waveforms	
	Time	Amplitude	Time	Amplitude
	30.328	--	30.30	--
SIG 2		2.02		2.03
SIG 3		1.03		1.045
SIG 4		2.02		2.045
SIG 5		4.77		4.791

Test 2

	Calibrator		Digitized Waveforms	
	Time	Amplitude	Time	Amplitude
	30.337	--	30.30	--
SIG 2		2.02		2.03
SIG 3		1.03		1.045
SIG 4		2.02		2.045
SIG 5		4.77		4.791

Since the Biomation Model 8100 is operated with a time increment of 0.02 μs, its accuracy cannot be better than ±0.02 μs. The data in Table I indicates that the data is within ±2 digitized values or 0.04 μs. This agrees with data taken at the test site by E. L. Jacobs, Division 2352.

The amplitude agreement in Table I, along with the timing agreement, indicates the system is operating correctly, without defining ultimate accuracy.

VIII. ACCURACY

The fact that a new system has been implemented naturally leads to questions of accuracy. It is difficult to compare the new methods with the old, since accuracy of the old system has never been carefully defined. It can readily be seen that the new system is more accurate than the old and certainly accurate enough for any presently known applications. From Section VII, Table I, the timing accuracy is ±0.04 μs. Although it would take a lot more data to defend the ±0.04 μs figure, it seems very safe to say that the system is within our requirement of ±0.1 μs.

The amplitude accuracy of the system using known signals can also be easily verified from Table I. Since the reproduction of the waveforms fed into the system is well within the calibration of the calibrator as stated by Sandia Standards, the amplitude accuracy of the system is the limits set by Standards which is ±5%

Since the digitized neutron sensitivity is determined by the scaler reading and the computer-derived integral of the prompt waveform, the new system should be more accurate than the old since the neutron sensitivity is calculated each time the generator is functioned which compensates for detector drift. However, absolute neutron measurements depend on many factors beyond the scope of this report.

The PUP measurement depends on both the calibrator and the calibration of the unit PUP. If the PUP calibration is done at the neutron generator test facility, E. L. Jacobs' investigation indicates the PUP measurement should be between ±5 and ±10%. The agreement of the Area II measurements with the predicted output of varistor-controlled units indicates the ±5% is probably close. If the units are calibrated at GEND, no accuracy can be arrived at when the units are tested in the Area II facility; however, no serious discrepancy between the measured target voltage of units calibrated at GEND and at the Area II test facility have been reported by the staff members responsible for the various neutron gennerators.

Other information on the reproduction of waveforms by the transient recorders is available [1,3] so it will not be covered here.

It seems that all measurements, with the possible exception of neutron output, are accurate enough for the measurement of waveforms from neutron generators and other known applications.

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3. N. A. Bourgeois, Jr., "A Waveform Digitizing System (U)," SAND74-0152, February 1975, unclassified.

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