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TITLE

Identification of Real and Spurious Scrams Initiated by the SRE Log N - Period Circuit

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STATEMENT OF PROBLEM

Continuous reactor operation has always been plagued by scrams initiated by spurious disturbances in the Log N-period circuitry. Reactor restart after scram is predicated, of course, upon the recognition of core normalcy as indicated by the various nuclear parameter recorders. Identification of a scram as being real or spurious is difficult in the absence of criteria for interpreting these nuclear parameters.

ABSTRACT

Theoretical and experimental analysis of the time response of SRE period range instrumentation shows that real reactor scrams can be identified by prescram upscale spikes on the Log N, Period, Electrometer, and Flux Controller recorders. Spurious scrams will not cause this type of response. These identification criteria are valid only if periodic maintenance of the recorder pens is performed to ensure their operation during fast transients.

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FORM 701-C REV. 10-62

I. INTRODUCTION

Spurious scrams are important not only because they interfere with operations, but because they can, under certain operating conditions, be detrimental to the plant. For this reason, elimination of these scrams without compromising the safety of plant operation has been one of the major developmental efforts at the SRE.

In addition to the direct problems created by spurious scrams, an associated physchological problem arises on the part of the operating crew. It is skepticism regarding the validity of indications presented by plant instrumentation. This loss of confidence can be a critical operational weakness in certain circumstances. Since the basis of the difficulty is uncertainty in interpretation of the indications, the problem can be solved, or at least mitigated, by providing definite criteria for the identification of real and spurious scrams.

The specific objective of this report is delineation of criteria for differentiation in the particular case of period scrams initiated by the Log N-period circuit. This circuit has been a continuing source of spurious scrams during the entire history of SRE operation. Although efforts to eliminate noise by isolating the input and power-supply circuits have been very successful, sporadic spurious scrams continue to occur. The problem of operator confidence is made particularly difficult by the complexity of the nuclear instrumentation. A concise reference discussion of the period range instrumentation will be provided here.

II. SRE PERIOD RANGE NUCLEAR INSTRUMENTATION

A. General Comments

The reactor power range from 0.001% to 1% of full power, approximately 0.2 to 200 Kw, is usually referred to as the "period" range. This name is derived from the fact that, during a normal startup to full power, the reactor is controlled primarily on the basis of the reactor period. Reactor period is defined here as

(1) $$T = \frac{\phi}{\frac{d\phi}{dt}}$$

where, T = reactor period

ϕ = reactor flux

t = time

As of August 1961, six different flux-monitoring circuits are in operation in the period range; viz., two channels of Log N-Period, two flux limiting safety channels, a linear flux channel serving the automatic flux controller, and a linear flux (vibrating capacitor) electrometer channel.* Figure 1 shows a block diagram of the six nuclear channels[2]. The major characteristics of each will be discussed in the following sections. The safety circuits are not actually period-level instrumentation, since they do not come on scale until about 1% of full power. However, discussion of these circuits is included here for the sake of completeness.

* The electrometer channel has temporarily been taken out of service.

B. Log N - Period Circuit

The primary function of the Log N - Period circuit is to provide an indication of the reactor period, over the six-decade range ending at full power, as a guide to operation. In the range 0.0001% to 1% of full power, the circuit provides for scramming the reactor if the period becomes less than 5 seconds. Certain qualifications on the 5-second scram are discussed below. The period scram is disabled above 1% of full power on the basis that (1) its necessity is questionable in this range, where the level safety trip circuits limit the power, and (2) unnecessary scrams are particularly undesirable near full power.

In association with its period function, the circuit provides a single-scale logarithmic indication of power over the six decades, ending at full power. Although the single-scale feature is useful in monitoring the power, the logarithmic scale makes the indication insensitive to small power changes. The linear multirange micro-microammeter circuit discussed in a later section is the primary power-level instrument.

The major components of the Log N - Period circuit are a compensated ionization chamber (Westinghouse type WL-6377), a modified ORNL type Q-915 Log N amplifier, and a modified ORNL type Q-1093 Period amplifier. Partial schematic diagrams (power supplies deleted) of the Log N and period amplifiers are shown in figures 2 and 3, respectively. In general, the modifications of the standard circuits consist of increased capacitance values in order to make the circuits less sensitive to noise in the input circuit. The Log N value is recorded on a Brown Electronik model 153X12 chart recorder. The period is recorded on a Brown Electronik model 153X18.

The Log N circuit, figure 2, operates on the logarithmic relationship between the plate voltage and current in a type 9004 diode operated at low filament voltage. The plate-to-ground voltage across the 9004 diode in figure 2 is approximately

(2) $$V = 0.25 \log i + 2.60$$

where V is in volts, i in amperes, and log i is the logarithm to the base 10. The constant 2.60 volts depends somewhat on the CAL ADJ setting. The voltage appearing across the log diode is amplified by the circuit involving tubes 5803, 5693, and 5692. The last tube provides a cathode-follower output to the Log N recorder and the differentiating circuit to the period recorder. Since the compensated ionization-chamber current is proportional to the reactor flux level, the amplifier output is proportional to the log of the flux;

(3) $$V_{out} = C_1 \log \phi + C_2$$

where C_1 and C_2 are constants and ϕ is the reactor flux.

If the flux is increasing exponentially as

(4) $$\phi = \phi_o e^{\frac{t}{T}}$$

where T = reactor period

then the RC differentiating circuit on the Log N output produces an output to the period recorder of:

$$V = \frac{C_3}{T} + C_4 e^{-\frac{t}{RC}} + C_5 \qquad (5)$$

where C_3, C_4, and C_5 are constants.

Notice that while the differentiating network in the Log N output provides the signal for the period recorder, the period-amplifier circuit following it controls the period scram.

The time response of the Log N circuit and its associated Log N and period recording arrangement is controlled by the time constants of the input circuit, the amplifier, and the differentiating circuit, plus the response times of the Log N and Period recorders. The input time constant is determined primarily by: (1) the plate resistance of the 9004 diode, since this is small compared with the leakage resistance of the ionization chamber and connecting cable, and (2) the 0.02-microfarad smoothing capacitor, since this is large compared with the capacitance of the chamber and cable. Thus the input RC time constant is:

$$RC_{IN} = \frac{0.26 \log i + 2.60}{i} (0.02) \times 10^{-6} \text{ seconds.} \qquad (6)$$

Current i varies from 10^{-10} to 10^{-4} amperes as the power varies from 0.0001% to 100% of full power. For example, at 0.001% of full power, equation (6) gives RC_{in} = 5.2 seconds; at 1% of full power RC_{in} = 21 milliseconds.

The amplifier time constant is controlled by the 0.05 microfarad capacitor in the second stage and the parallel combination of the plate and load resistors in the 5693 circuit. Plate resistance of the 5693 is about 1 megohm, giving an RC time for the amplifier of about 35 milliseconds. Thus the time response of the amplifier is controlled by the input time constant at low power and by the amplifier time constant at high power.

As a preliminary step in the test of the scram-or-trip identification technique described in the following sections, the combined input-amplifier time constant of the SRE Log N amplifier was measured, using the chamber simulator shown in figure 4. This simulator has an effective input impedance of infinity and negligible shunt capacitance. The device can produce steady-state currents in the range from 10^{-10} to 10^{-3} amperes and stepped current changes with microsecond rise times.[3]

With the reactor shut down, the simulator was connected in parallel with the regular input circuit (chamber plus cable) so that the normal input time constant was active. Doubling current steps at 0.001% and 1% of full power were inserted, and the resulting voltage response was measured at the Log N output (cathode of 5692) with an oscilloscope. The measured time constants are shown in Table 1, with the calculated values included for reference.

Table 1: SRE Log N Amplifier Time Constants

% of Full Power	Calculated Input Time Constant	Calculated Amplifier Time Constant	Measured Overall Time Constant
0.001	5.2 sec	35 ms	5.75 sec
1.0	21 ms	35 ms	58 ms

The values in Table 1 can be compared with measured overall time constants for the same circuits without the 0.02- and 0.05-microfarad smoothing capacitors: 300 msec at 0.001% of full power and 0.75 msec at 1%.

The Log N recorder responds to an input signal at 2.3 inches/sec on a 10-inch scale (corresponding to 6 decades of power) after a 200-millisec dead time.[4] The minimum detectable change in flux level is limited by normal jitter to about 1% of full scale or, considering the log scale, a power change of approximately 15% at any level. Thus, in order to be seen on the Log N recorder, a flux change of at least 15% (i.e., 15% of the initial power level) must occur for about a second at 0.001% of full power or about 300 msec at 1%.

The period recorder operates in series with the Log N output through about a 1-second differentiating time constant. The recorder itself responds to a signal at about 10 inches per second after a 20-millisecond dead time. The 10-inch scale corresponds to period between -30 and +3 seconds. Normal jitter limits detectability of period changes to about 0.1% of full scale. If the initial period is assumed to be infinite, then this minimum discernible period would be about 270 seconds. Thus, a period shorter than approximately 300 seconds must occur for about one second in order to be detectable on the period recorder.

The actual period scram circuit is incorporated in the period amplifier, figure 3, working on the Log N output. This circuit differentiates the Log N output, RC $\simeq$ 225 millisec, and causes cutoff of the second halves of tubes 5691 and 5692 when the grid of the first half of 5691 reaches 375 millivolts. The 375 millivolts corresponds to a steady 5-second period. Cutoff of the second half of 5692 causes the opening of the relay RY1 and, after a delay time of about 500 milliseconds, the opening of RY2, which initiates the scram in the safety amplifier, Relay RY1 and its associated delay circuit are for the purpose of preventing cutoff of 5691 by short-term noise.

The total effect of the time constants and the delay circuit in the Log N and period amplifiers is to require that the minimum period for scram, 5 seconds, be sustained about 1.5 seconds at 0.001% of full power or about 600 milliseconds at 1% of full power in order to open RY2 in the period amplifier. The safety amplifier scrams in about 5 milliseconds, and the safety rods reach the core about 300 milliseconds after the magnet release.[1] Thus a total time-to-scram of 1.8 to 0.9 seconds is required for a sustained 5-second period. Shorter periods require less time, approaching 0.9 seconds for a 1-second period, independent of the power level. These statements were verified by direct test as described in Part III of this report.

C. Safety Circuits - Safety Amplifiers

The function of the safety circuit is twofold: (1) it provides for a reactor scram if the flux exceeds a given level (normally 125% of full power), and (2), it serves as the central element in the scram circuit. The major components of the circuit are two uncompensated ionization chambers (Westinghouse model WL-6376), the safety amplifier (a modified ORNL Q-947), and a linear flux-level recorder. A simplified circuit diagram is shown in figure 5.[2]

The basic scram loop is a series of relay contacts shunting a resistor, R, which in turn controls the grid voltage on the tubes controlling the current to the safety-rod holding magnets. Opening of this scram loop produces a cutoff bias of the magnet supply tubes. The safety-trip flux-level scram operates by cutting off the 5691 tube, opening its plate relay. There are actually two scram mechanisms built into the safety amplifier: (1) the "fast" scram, initiated by opening the plate relay, and (2) a backup "slow" scram, caused by cutting off AC power to the magnet power supply. Power-level indications are given by a bridge circuit in the 5691 cathode circuit.

Action of the fast scram is accomplished by opening the plate relay within 5 milliseconds of the time that the power level exceeds 125% of full power. The time constants in the recorder input are negligible. The recorder itself is a Brown Electronik model 153X27, which responds at 5 inches/sec after about 100 milliseconds of dead time. Because the safety circuit is designed for operation at full power, its recorder is calibrated for 0-150% of full power and is insensitive below about 1%.

D. Electrometer Channel

The electrometer channel functions as the primary flux-level indicator in the six-decade range from 0.0001% to 100% of full power. The electrometer covers this range by switching into 20 linear power ranges. This instrument channel consists of a compensated ionization chamber (Westinghouse model WL-6377), a 410 micromicroammeter (Keithley), and a linear one-decade flux recorder (Microsen type 150 Electronic Recorder).

The time response of the micromicroammeter channel is faster than that of the other instrument channels because of negative feedback in the instrument. At 0.001% of full power, the overall (input plus amplifier) time constant is about 120 ms, at 1% of full power about 0.5 microseconds. The normal jitter limits the detectable flux change to about 0.1% of whatever range the instrument is on. Thus a flux-level signal representing a change of at least 0.1% maintained over a period of approximately 100 ms (20 ms at 1% FP) will be seen on the recorder.

E. Flux-Controller Channel

The primary function of the flux-controller channel is to provide a linear flux-level signal for the automatic reactor-control system. As part of this function, the flux level is linearly displayed on a recorder in the range 0.1% to 100% of full power. This instrument channel is particularly simple, consisting only of a compensated ionization chamber (Westinghouse type WL-6377), a pair of precision resistors, and a recorder (Speedomax type G).

During operation, the ionization-chamber current is passed through a 500-ohm resistor on low range (0 to 10% of full power) and through a 100-ohm resistor on high range (0 to 100% of full power) to develop the input voltage for the recorder.

Time response of the input circuit depends on the cable-and-chamber capacitance of about 1500 micromicrofarads. Thus the input time constant is about 1 microsecond. The recorder that controls the overall channel time responds at about 10 inches per second after approximately 20 ms of dead time. Normal recorder jitter is about 0.1% of full scale (10 inches).

III. TEST OF SCRAM IDENTIFICATION TECHNIQUE

A. Hypothesized Identification Technique

Although the electronic mechanism of the spurious period scram is not entirely understood, its operational characteristic is well known. That is, a period scram will occur, as identified by the associated scram-origin monitoring equipment, but none of the flux- and period-monitoring recorders will note a flux rise before the scram. In contrast to this, a real reactor period scram requires a period of 5 seconds or shorter acting for approximately 1 second, as discussed in Section II-B. In 1 second, a 5-second period causes a flux rise of about 22%; shorter periods will cause relatively greater increases. Based on the discussions of Section II, it can be seen that these are a flux rise and a rate of rise sufficiently large and sustained long enough to be recorded on all of four flux-monitoring recorders operating in the period range; i.e., the Log N, Period, Electrometer, and Flux Controller. The Safety Trip circuit is not included, because it is not on scale in the period range of power. It can therefore be hypothesized that a real period scram can be identified through the criterion that all four of the above-mentioned recorders must show a flux rise before the scram occurs.

B. Method of Test of Identification Technique

A direct test of the hypothesized scram-identification technique was made under actual operating conditions by inserting into the Log N - Period, Electrometer, and Flux-Controller circuits a 5-second period, then 4-, 3-, 2-, and 1-second periods. The simulated flux rise was allowed to continue until 300 milliseconds after the period amplifier opened the scram loop. At the end of this time, the simulated flux was set to zero. The 300-ms scram delay was introduced to account for the period between release of the magnet and the time that safety rods reach the core, in which the flux may continue to rise. Actual operating conditions were simulated in the test, except that the reactor was shut down and the simulator substituted for the normal compensated ionization-chamber inputs. All of the response tests were performed starting at a simulated 1% of full power. At lower power levels, the slow Log N response time allows more time for instrument responses before the scram occurs. Thus if the flux rise is observable at 1% of full power (i.e., for the shortest "time-to-scram"), then it will be observable throughout the period range. The period-simulator circuit is shown in figure 6.

As a matter of experimental convenience, the voltage input to the Log N circuit was simulated, rather than the current input. This method of simulation eliminates the Log N input time constant. However, since at 1% of full power the Log N time constant is primarily due to the time constant of the internal Log N amplifier (see Table 1), no appreciable effect on the overall time response results from neglecting the input time constant. Thus, in order to simulate an exponential rise of period T, a voltage of the form

(7) $$V = \frac{kt}{T} + V_o,$$

where
- k = a constant
- T = reactor period
- t = time
- V_o = initial voltage level

is required at the Log N input. Substituting $i = i_o \exp \frac{t}{T}$ into equation (2) shows that the constants k and V_o in (7) are

(8) $$k = 0.11 \text{ volts}$$

$$V_o = 0.26 \log i_o + 2.60 \text{ volts}$$

where i_o is the current corresponding to the initial power level. In the case of 1% of full power, i_o is about 7×10^{-7} amps, and $V_o = 1.07$ volts. In the simulator, figure 6, the initial level is set by the "Log N level" circuit operating through diode T2 and the voltage divider connected to the "Log N input." The linear increase in voltage, of slope $k/T = 0.02$ volts/sec in the case of the 5-second period, is produced in the simulator by adjusting the frequency and amplitude of a triangular-wave generator. As the triangular wave becomes positive, the current switches from the initial condition through T2 to a positive ramp through T1. The simulator run is terminated when the Log N input is grounded by closing the relay in the 300-millisecond delay circuit. This delay circuit, in turn, acts when scram relay RY2 (figure 3) opens in the period amplifier.

In the case of the two linear channels, the exponential power rises were simulated with current inputs, but with a linear approximation to the exponential. The linear approximation was chosen because it was simpler to set up and did not introduce much error over the short time period involved. From the discussion in section II-B, the time interval of a run was expected to be about 1 second. The criterion for the linear approximation of the exponential was that they agree at 1 second. This approximation produces a maximum deviation between the linear and exponential functions of less than 1% for a 5-second period and about 14% for a 1-second period. This, the current required at the input to the electrometer and flux controller channels in figure 6 is

(9) $$i = i_o (e^{\frac{1}{T}} - 1) \ t + i_o.$$

The initial power level is set by the "linear level" circuit, and the gain of the DC amplifier and output circuit is set to give the correct voltage sweep.

C. Results

The responses of the Log N, Period, Electrometer, and Flux Controller recorders at a simulated 1% of full power for 5-, 4-, 3-, 2-, and 1-second periods are shown in figures 7, 8, 9, 10, and 11. Figure 7 shows the time required to open the scram loop (relay RY2 of figure 3) as a function of reactor period. The components of this time-to-scram, which are the time required for the grid of the first tube in the period amplifier to reach cutoff and the RY1-RY2 delay, are also shown in figure 3. Three hundred milliseconds more than the total scram time shown in figure 7 is required for the safety rods to reach the core. Figures 8, 10, and 11 show percent-full-scale responses, 10-inch scale, as a function of reactor period. It should be noted that these figures show minimum responses. At lower power levels, the longer Log N time constant delays the scram and allows more time for flux rise and instrument response.

A significant operational problem encountered during the test was the difficulty in keeping the recorder pens operating sufficiently well that they would record the transients. It was found that unless the pens had been cleaned within the previous few hours, they would not ink the paper during the transients.

IV. CONCLUSIONS AND RECOMMENDATIONS

The test described in section III shows that a 5-second period at 1% of full power will be seen by the Log N, Period, Electrometer, and Flux Controller recorders before the scram occurs. From the discussion in section II, it follows that shorter periods and lower power levels would yield larger responses, because of the longer time-to-scram in those cases. Thus it can be concluded that real reactor period scrams will always be observable as positive-going flux spikes just prior to the scram on the Log N, Period, Electrometer, and Flux Controller recorders. Based on the discussion in section II, if the safety trip channels are on scale, they also will give a positive-going spike just before a real scram occurs. Any period-initiated scram not causing a prescram rising spike on all four (or five) of the above-mentioned recorders is spurious. One very important qualification on this identification technique must be made: periodic (perhaps twice daily) cleaning must be performed on the recorder pens to ensure their operation during fast transients.

V. REFERENCES

1. C. Starr and R. W. Dickinson, "Sodium Graphite Reactors," Addison-Wesley, Massachusetts (1958).

2. R. J. Hall, unpublished work.

3. S. G. Barnes, "Photo Electric Micro-Microampere Current Source," TDR No. 4159 (July 1959).

4. M. B. Ruegamer, unpublished work.

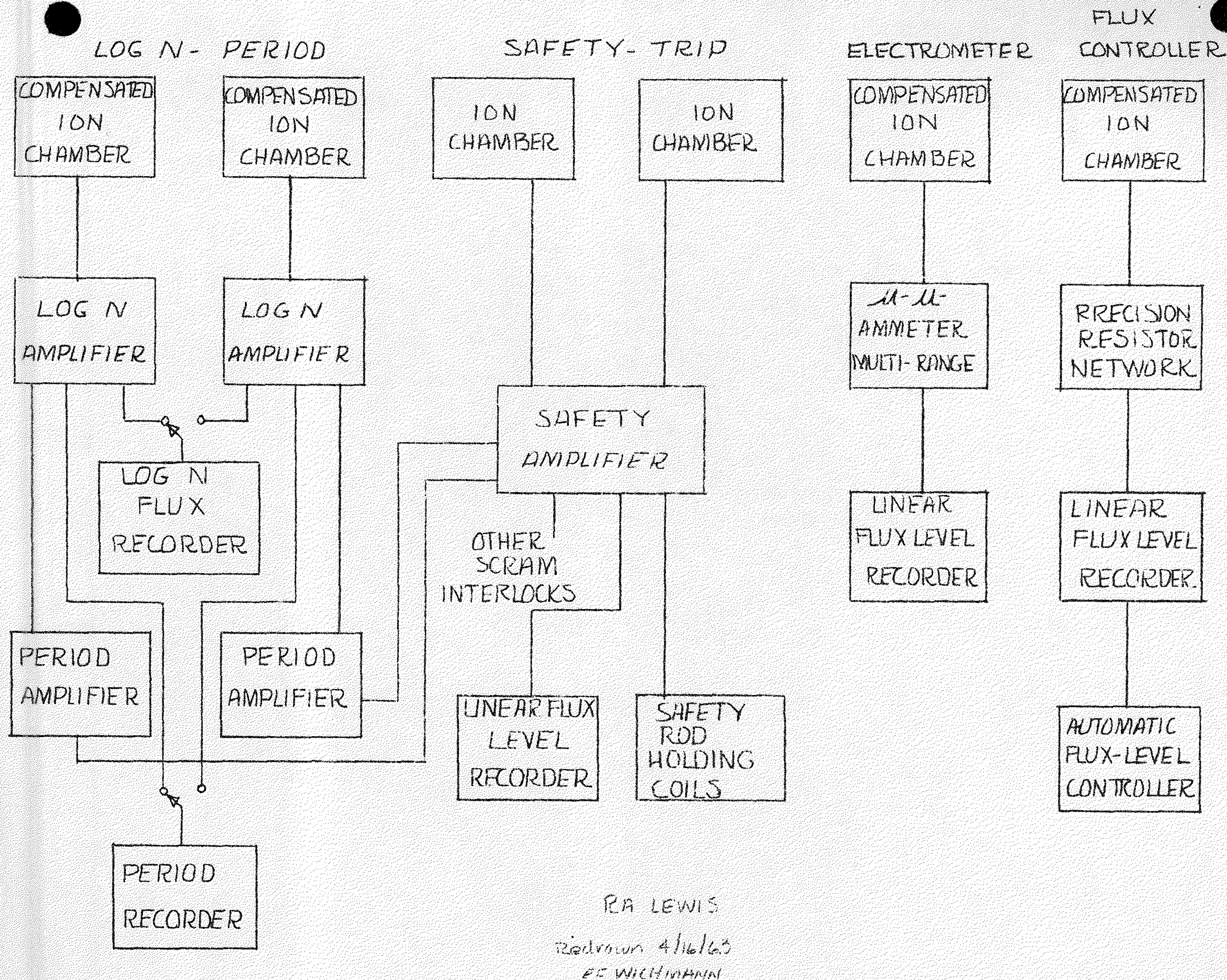
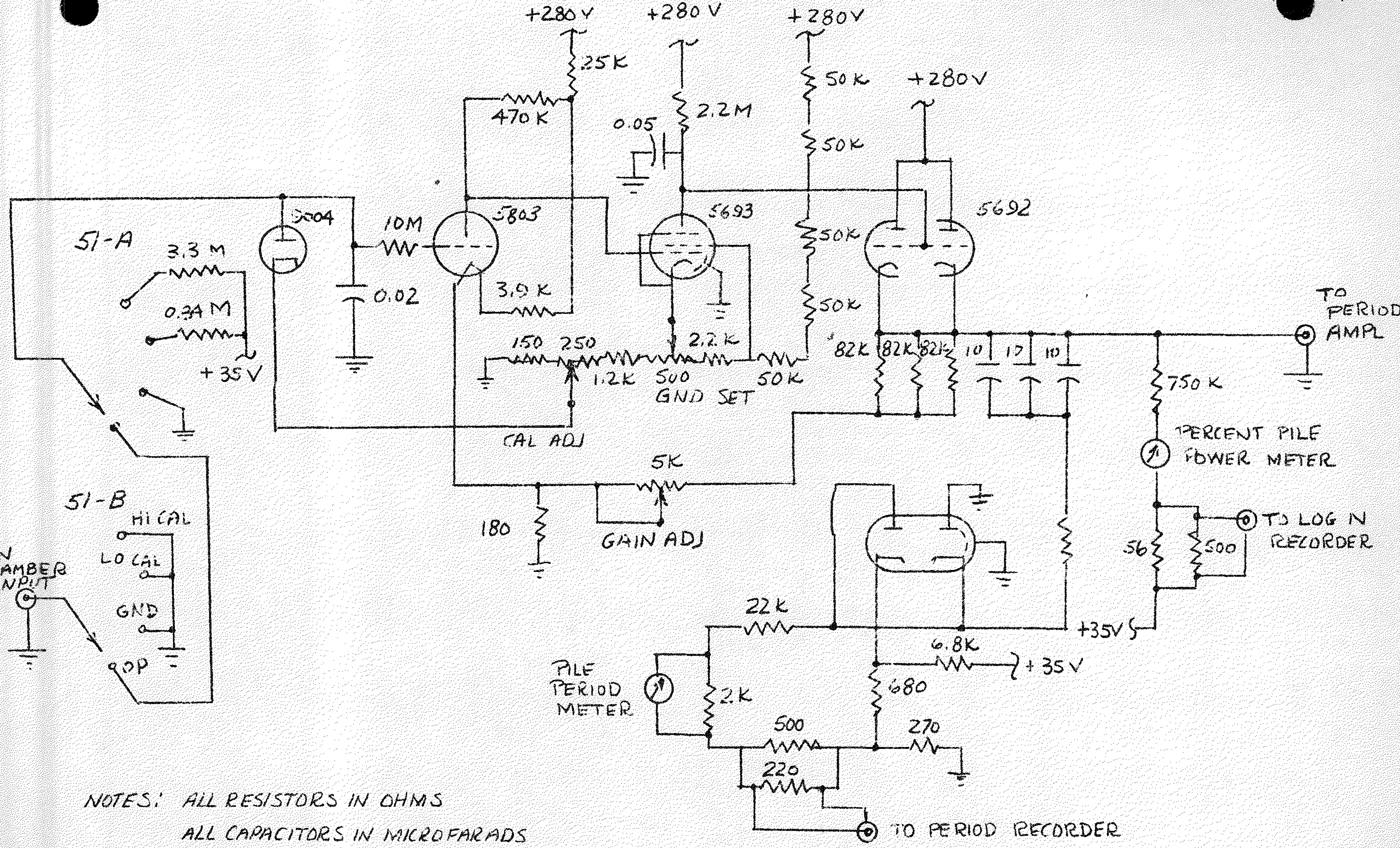


FIGURE 1 : SRE PERIOD RANGE INSTRUMENTATION



NOTES: ALL RESISTORS IN OHMS
ALL CAPACITORS IN MICROFARADS

FIGURE 2: PARTIAL SCHEMATIC OF LOG N - PERIOD CIRCUIT

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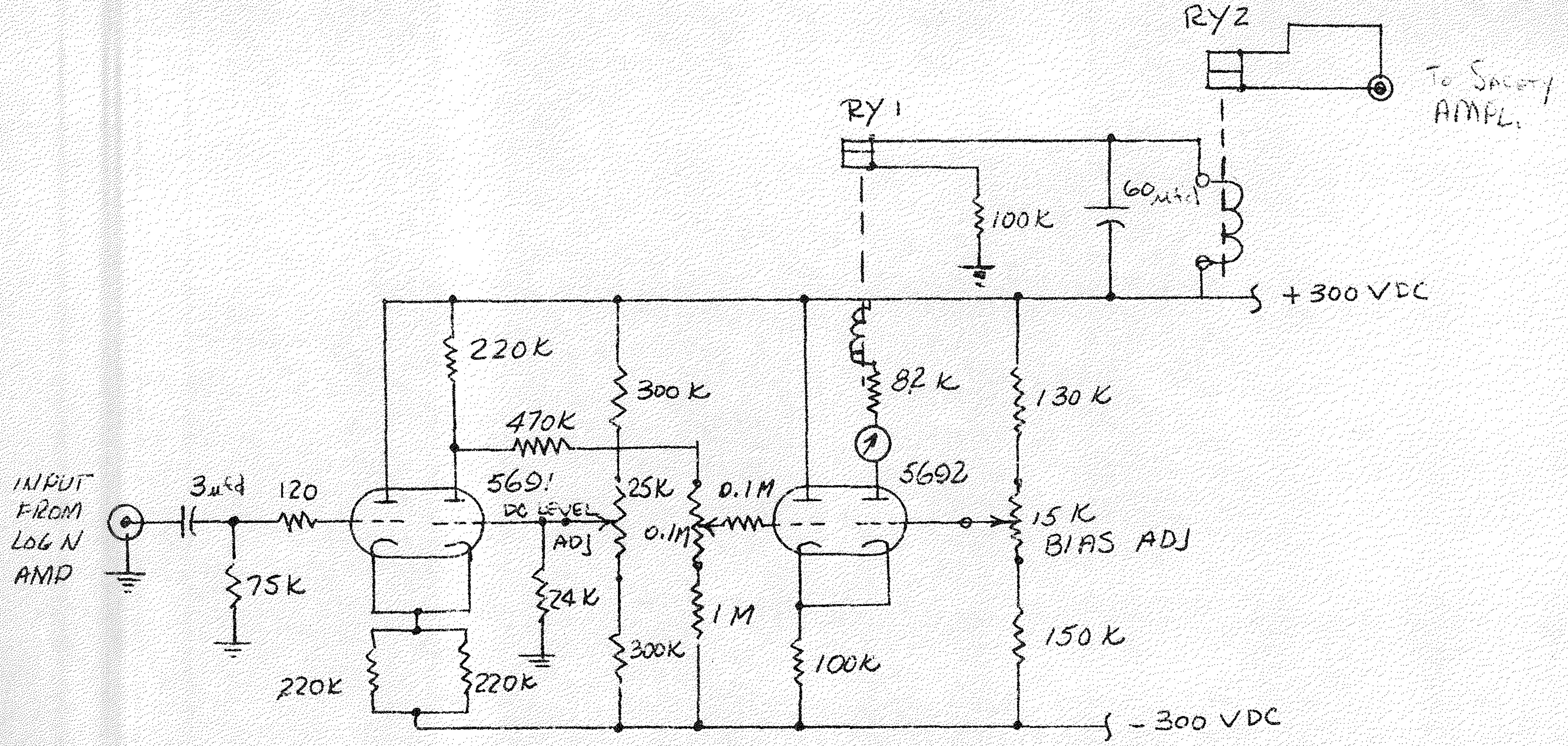
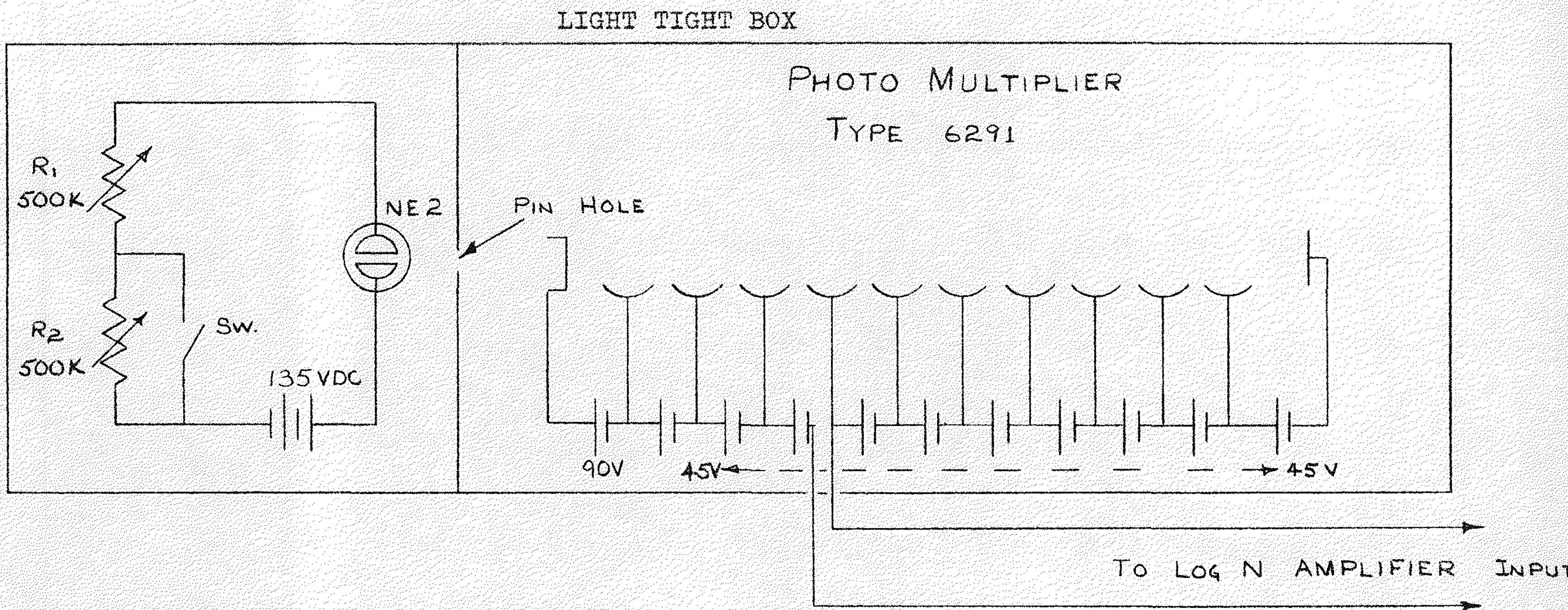


NOTES: 1. ALL RESISTANCE VALUES IN OHMS
2. CAPACITANCE VALUES IN MICROFARADS
3 RELAYS SHOWN IN NON-SCRAM CONDITION

RA LEWIS

FIGURE 3: PARTIAL SCHEMATIC OF PERIOD AMPLIFIER

REDRAWN 4/16/63 F WICHMANN



With switch Sw closed set R_1 for final power indication on log N amplifier power meter. Open switch and set R_2 to give one half final power indication.

FIGURE 4 PHOTOELECTRIC MICRO-MICRO AMPERE CURRENT SOURCE

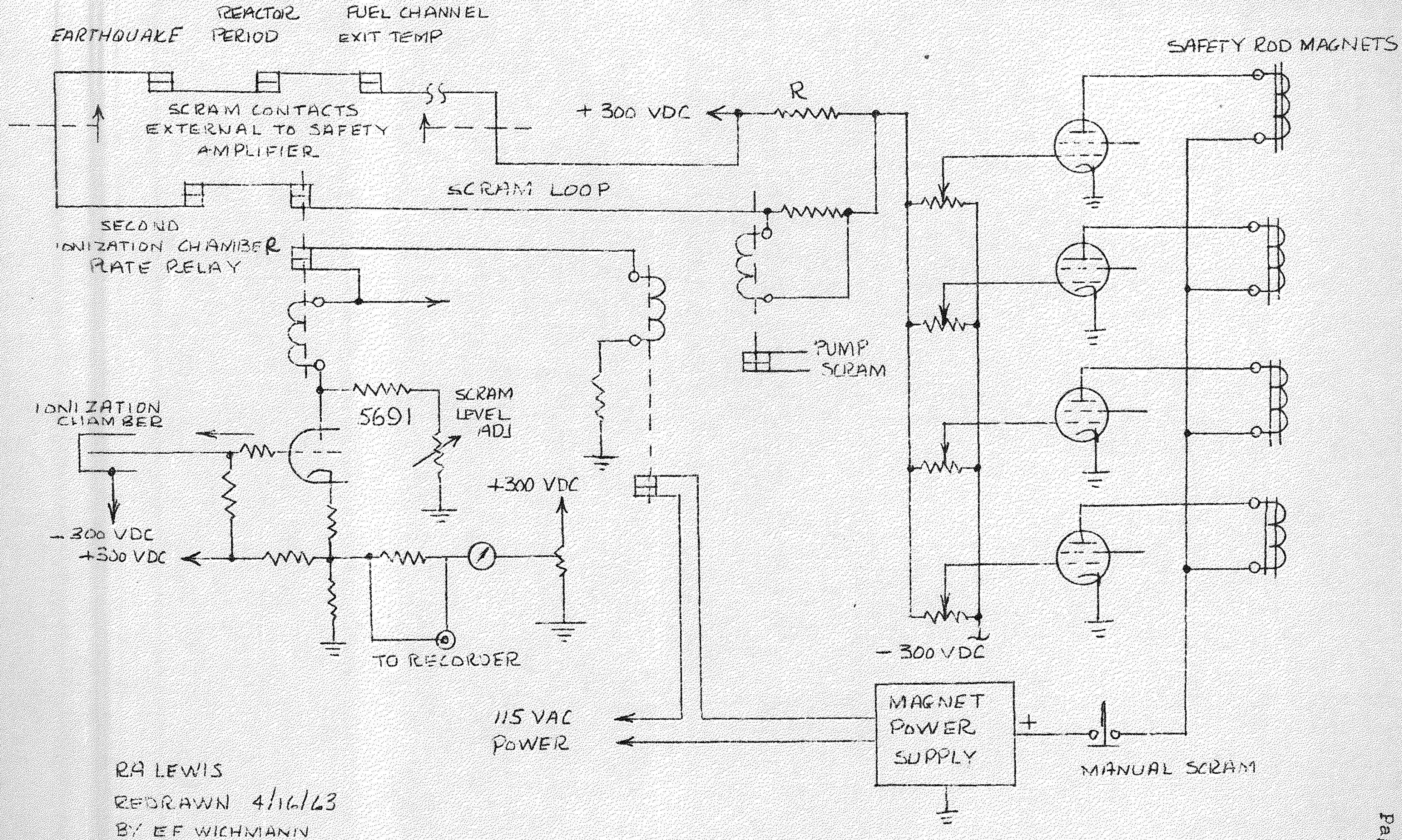


FIGURE 5: SIMPLIFIED DIAGRAM OF SAFETY AMPLIFIER

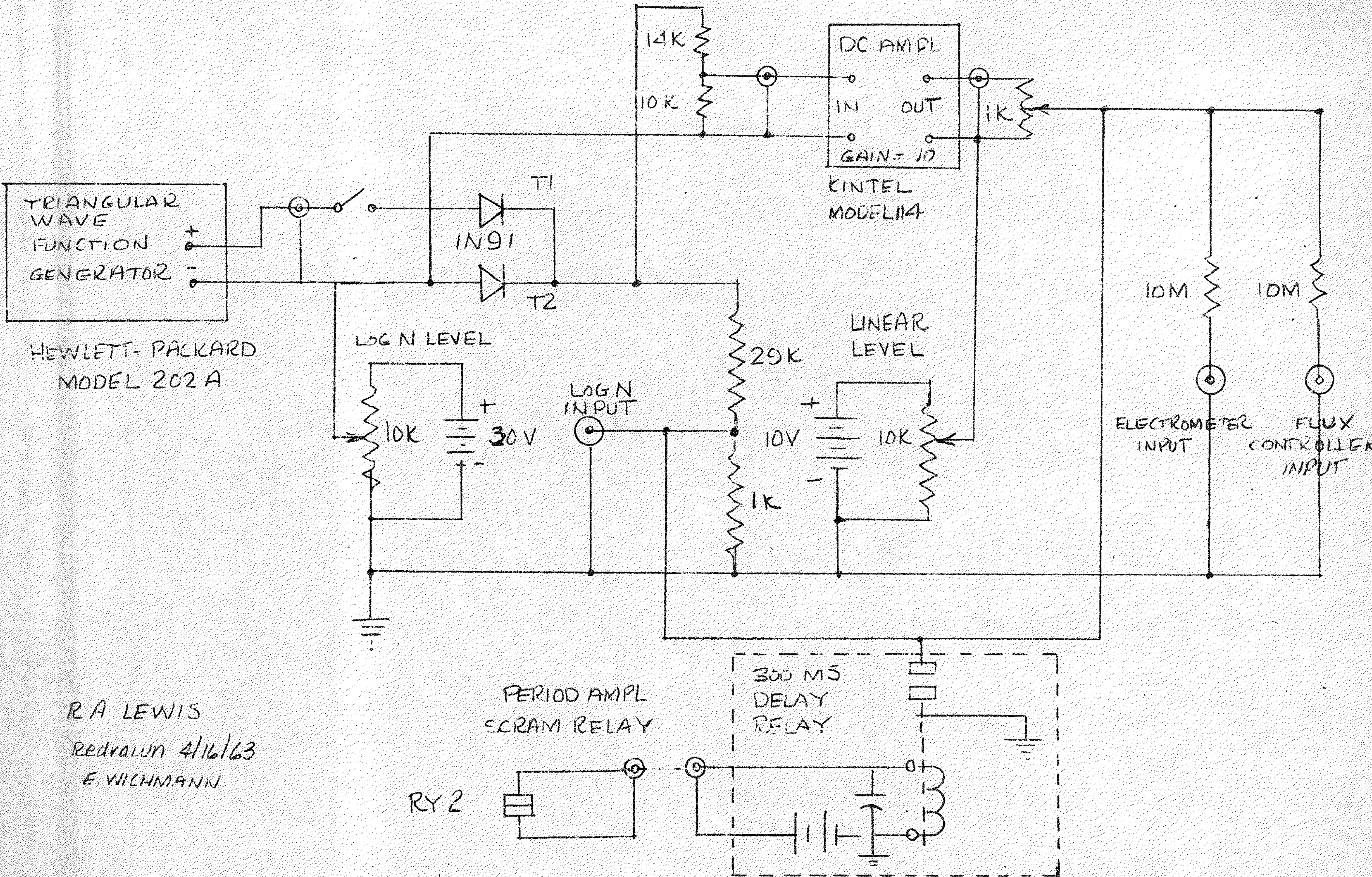


FIGURE 6: PERIOD SIMULATOR

LOG N - PERIOD AMPLIFIER RESPONSE TO A 5 - SECOND REACTOR PERIOD AT 1% OF FULL POWER.

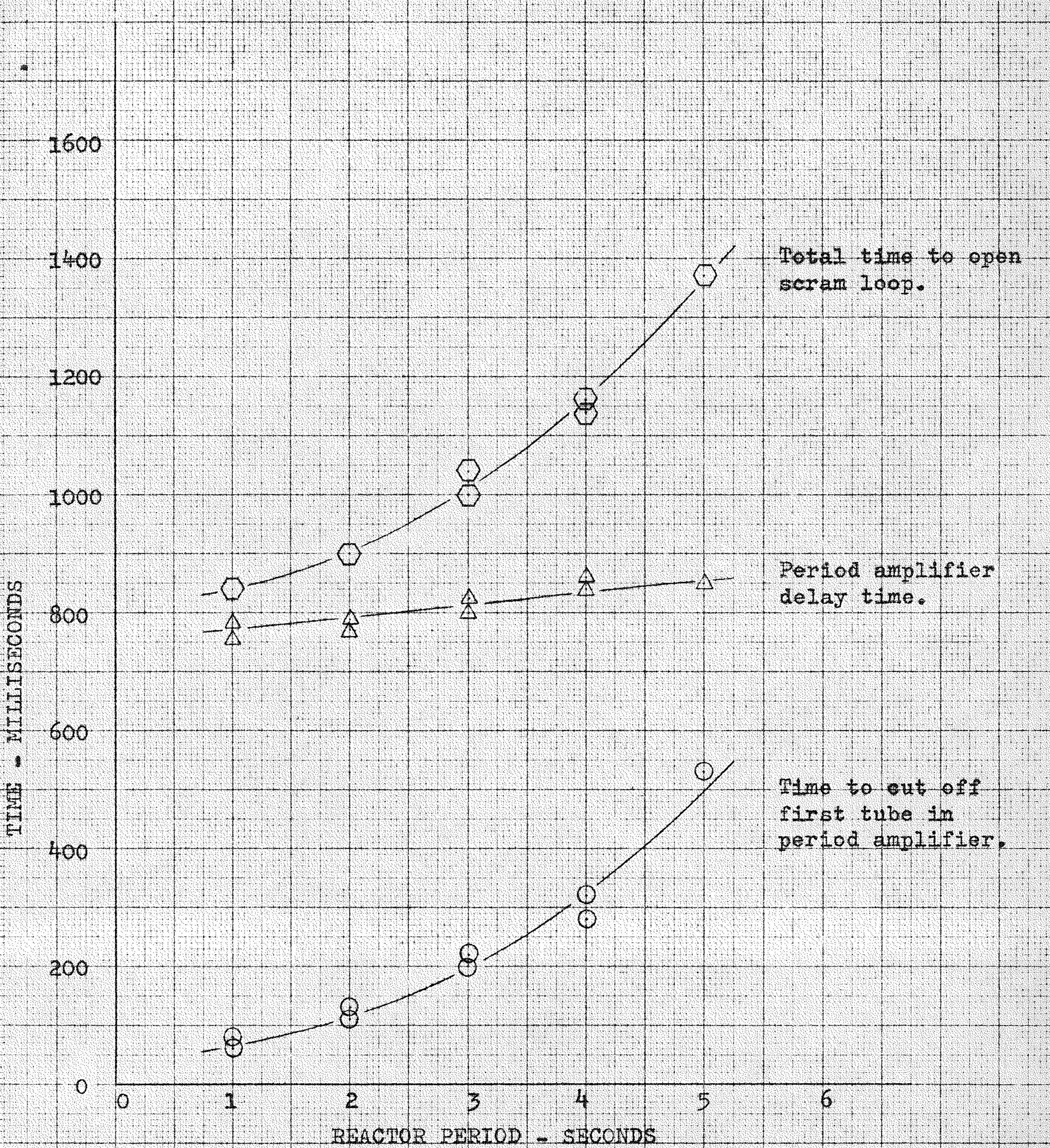


FIGURE 7

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FIGURE 8
LOG N DEFLECTION

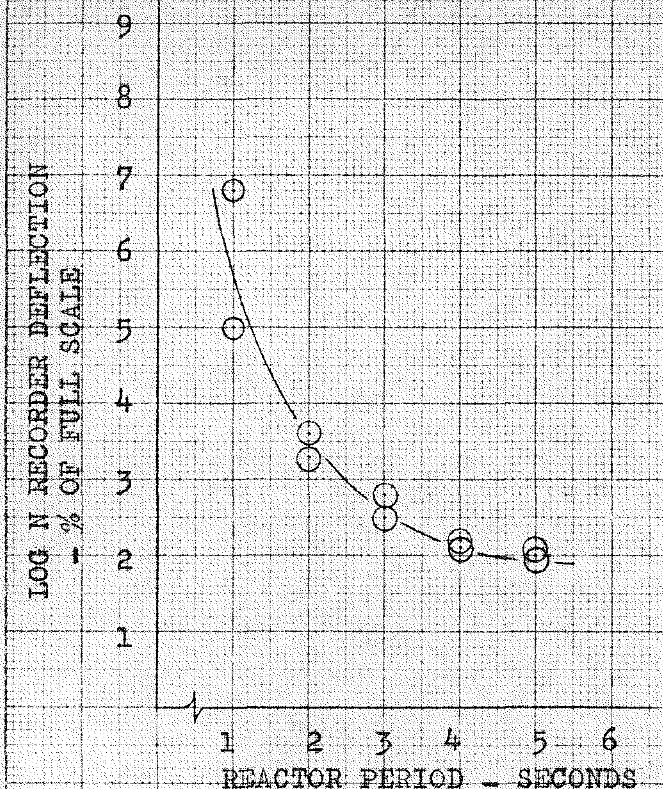


FIGURE 9
PERIOD RESPONSE

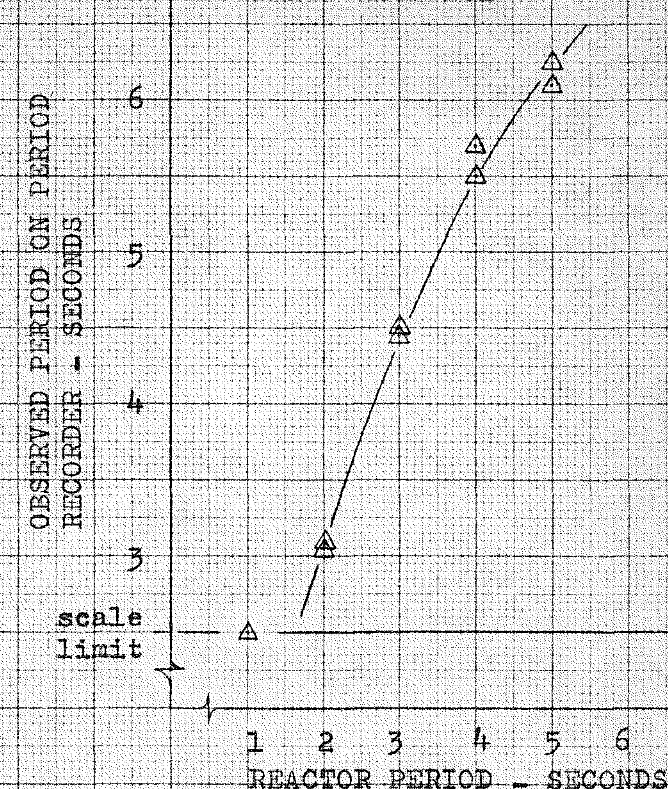


FIGURE 10
ELECTROMETER DEFLECTION

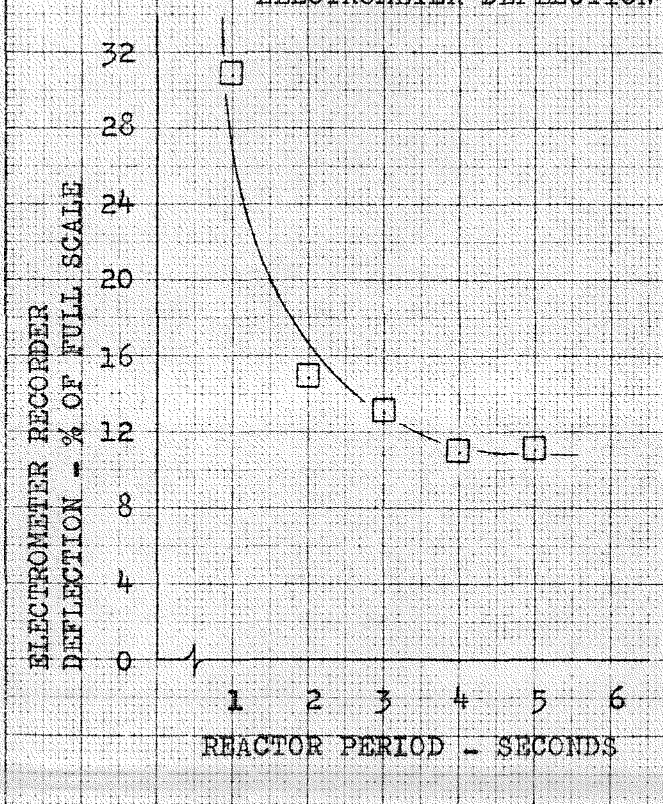
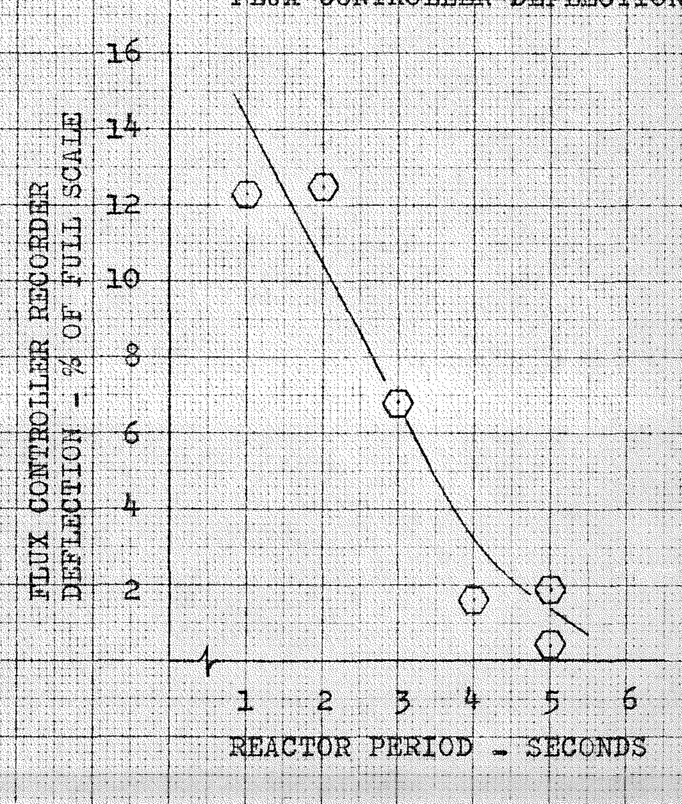


FIGURE 11
FLUX CONTROLLER DEFLECTION



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