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THE MTR SAFETY SYSTEM AND ITS COMPONENTS

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REACTOR CONTROLS DEPARTMENT

THE MTR SAFETY SYSTEM AND ITS COMPONENTS

T. E. Cole, E. E. St John,* and S. H. Hanauer

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ABSTRACT

The safety requirements of the MTR are discussed, together with the devices built to meet these requirements. Three level and two period safety channels feed signals to a central control bus whose voltage in turn controls the current through electromagnets. The shim-safety rods suspended from these magnets fall into the reactor fast enough to catch the shortest expected period. The details of the various components used are discussed and the performance data are presented.

THE MTR SAFETY SYSTEM AND ITS COMPONENTS

GENERAL CONSIDERATIONS

The fundamental problem in the control of reactors built with large excess reactivity has been discussed by Newson.[1] He shows that, for rates of change of k consistent with reasonable startup times, prompt critical may be reached before accurate instruments are in range to indicate the flux. The short periods[2] on which the reactor then rises preclude, or make unlikely, corrective action by the pile operator in time to avert a disaster. A fast safety device which acts when the reactor reaches a predetermined value above the normal operating level may be made fast enough to shut down the reactor before damage results. Such a device will shut down the reactor in a time determined by the period of the reactor, by the delay in the safety system, and by the rate at which the safety system can decrease k.

In the MTR the primary safety device is a system of shim-safety rods. Six to eight rods, depending on the fuel loading, are suspended from electromagnets and are driven up and down by motors. Each rod is composed of two sections roughly 3 in. square and 2 ft long, one above the other. The upper section is cadmium, and is in the active lattice when the rod is seated all the way down. The lower sections of some rods are uranium elements essentially the same as fuel elements; the other rods have a lower section of beryllium like the reflector *A* pieces. Raising a rod therefore replaces cadmium with uranium or beryllium and increases the reactivity of the lattice. The rods are used in the top portion of their range as shims: a means of adjusting to compensate for large, slow changes in reactivity such as those caused by temperature changes or by poisoning. When it becomes necessary to decrease k quickly, the current in the electromagnets is turned off, and the rods go downward with an acceleration somewhat greater than g because the water-flow forces on the rods are also downward. This letting-go of one or more rods is known as a scram.

Newson calculated[3] the shortest period to be expected if one increases k at a constant rate from a cold clean start to the point at which the safety circuits work. The result is 48×10^{-3} sec (see Appendix). The level will rise on this period until the shim-safety rods start to drop, then decelerate, and finally the flux will decrease very rapidly, since the rods are now accelerating downward.

The overload above the flux at which the rods actually start to move in is less than a factor of 1.7, and this overload occurs about 3 ms after the rods start to move (see appendix). To determine the total overload one must add the rise during the delay in the safety system between the time that the pile is at the scram level (N_1 in Newson's report) and the time the rods actually begin to move. The MTR system has a design maximum delay of about 30 ms; a delay of 48 ms will let the neutron level rise by a factor of e. Even with this longer delay, the total overload will be a factor of about 5 or less, which is safe because of the fact that it lasts only 100 ms or so. Thus it is seen that a safety system which will drop the rods with an acceleration of g when the level exceeds the maximum safe operating level, will catch a reactor whose flux is increasing at its maximum rate and bring the power to zero in a safe manner.

[1] H. W. Newson, *The Control Problem in Piles Capable of Very Short Periods*, MonP-271 (April 21, 1947).

[2] The period is the time for the pile power to change by a factor of e.

[3] Newson, *op. cit.*, p. 7.

In spite of the foregoing, the fact that a potentially dangerous increase in k at low level must raise the power to the maximum operating level and beyond in order to scram is undesirable. Newson suggests a derivative safety system which will scram when d/dt (ln N) reaches an unsafe value. On the MTR, two period channels provide scram signals when the period is less than 1 sec.

The level safety and period safety channels discussed above constitute the fast safety devices wherein a short delay is achieved. There are other conditions, however, which are potentially dangerous to the point that the reactor will be required to scram. Examples of such conditions are lack of cooling water flow and loss of control power. Inasmuch as these conditions are not associated with short periods, it is not necessary to use the fast scrams, and the rods are dropped by simply cutting off, with a relay, the 60-cycle input power to the magnet-current supplies. A discussion of these slow scrams will be found in the MTR Project Handbook (ORNL-963).

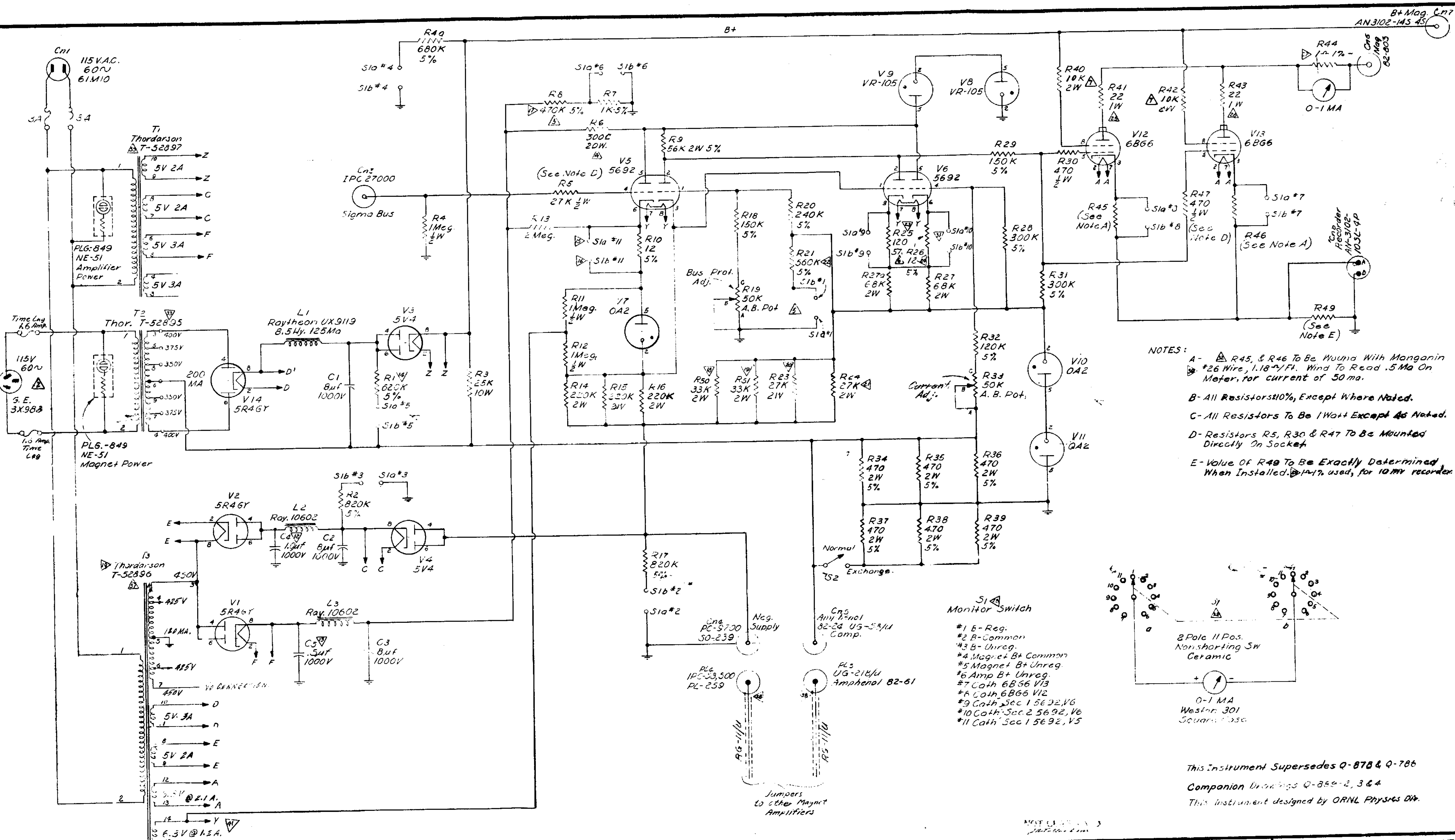
The electromagnets which support the rods are excited with direct current from magnet amplifiers (Fig. 1), two of which are used in parallel on each magnet. The input terminals of all the magnet amplifiers for all the rods are connected in parallel to the sigma bus. This point is the control center, so to speak, for all the magnets. Feeding the sigma bus are the various fast-scram safety channels, namely, three level and two period. For each channel one sigma amplifier (Fig. 2) feeds a signal into the sigma bus which will scram the reactor if the neutron flux or the period become dangerous. The level safety signal is supplied to the sigma amplifier by an ionization chamber (boron-coated, 3-in. PCP, Fig. 3)[4] and a safety preamplifier (Fig. 2); the period safety signal comes from a compensated ionization chamber (Fig. 4), a log N amplifier (Fig. 5) and a period amplifier (Fig. 6). The block diagram of the safety system is shown in Fig. 7.[5]

A number of electrical devices will perform the duties of some of the components of the safety system. In particular, the ordinary sensitive relay has many attractive features. It is a device which has been manufactured successfully for many years. Its reliability when used conservatively is very great. With little additional trouble it may, by use of multiple contacts, be made to serve several functions. Since, in this application, the primary signals are generated in ionization chambers, relays of adequate ruggedness cannot be operated directly with the small currents available. An amplifier of some sort is therefore required. This is a drawback, but not a fatal one. A much more serious shortcoming of the relay is its unpredictability; that is, the impossibility of applying any test which will predict its response (or lack of response) to the next signal requiring operation. Any trial operation by way of such a test is by its nature a "test to destruction," providing only that the relay *did* work, not that it *will*. What is required, then, is a device that acts like a relay in its operation but provides some means of testing or monitoring its condition. The electronic circuits to be described hereafter approach this mode of operation while retaining the feature that, with care, possible malfunction may be detected before a dangerous condition imperatively requires the ailing circuit to work.

---

[4]R. K. Abele and J. Gundlach, *The Neutron Sensitive PCP Ionization Chamber*, ORNL-1080 (Sept. 4, 1951).

[5]The conception of the system and the original design of most of the components were done by P. R. Bell, Physics Division, Oak Ridge National Laboratory.



NOTES:

A - R45, & R46 To Be Wound With Manganin #26 Wire, 1.18 Ω/Ft. Wind To Read .5 Ma On Meter, for current of 50 ma.

B - All Resistors ±10%, Except Where Noted.

C - All Resistors To Be 1 Watt Except As Noted.

D - Resistors R5, R30 & R47 To Be Mounted Directly On Socket.

E - Value Of R49 To Be Exactly Determined When Installed. 1-1% used, for 10 mv recorder.

This Instrument Supersedes Q-878 & Q-786

Companion Drawings Q-889-2, 3 & 4

This Instrument designed by ORNL Physics Div.

REVISIONS

DATE	CODE	CHANGE	CHK
5-21-51	36	Add Mag. Power cable	[illegible]
"	37	Was Ferranti 6889	[illegible]
6-22-51	38	Add cables	[illegible]
8-21-51	39	Modified Note A	[illegible]
"	40	Cable & Conn. Changes	[illegible]
11-29-51	41	Was connected To pin 12	[illegible]

REVISIONS

DATE	CODE	CHANGE	CHK
5-17-51	29	Added 2nd sentence of Note-E	[illegible]
"	30	Was S2	[illegible]
"	31	Removed R28a	[illegible]
"	32	Deleted R44 from Note-A	[illegible]
"	33	Was T-52820	[illegible]
6-21-51	34	Add Amp. cable	[illegible]
"	35	Was T-52827	[illegible]

REVISIONS

DATE	CODE	CHANGE	CHK
5-17-51	19	Added R51, 33K, 2W	
"	20	Was 15K	
"	21	Was 15K	
"	22	" 660K	
"	23	" 33 Ω	
"	24	" 15 Ω	
"	25	" ½W	
"	26	" ½W	
"	27	Added 1-1%	
"	28	Was S2	

REVISIONS

DATE	CODE	CHANGE	CHK
10-21-50	9	Removed thyrite	
10-21-50	10	Added Ferranti 6889	
11-19-50	11	Added 5% Tol. on Res.	
5-17-51	12	Added C4 .1µf	
"	13	" C5 .5µf	
"	14	Was 820K	
"	15	" S1b #11	
"	16	" S1a #11	
"	17	" 390K	
"	18	Added R50, 33K, 2W	

REVISIONS

DATE	CODE	CHANGE	CHK
10-5-50	1	Redrawn	
	2	[illegible]	
"	3	Was 450 ~	
"	4	Was 4.7K [illegible]	
"	5	R32 Removed	
"	6	Was 1K Resistor R5	
"	7	Was 33K.	
"	8	Note Added.	

DESIGNED	Cole
DRAWN BY	Weisley
STARTED	7-4-50
FINISHED	10-5-50
SCALE	NONE

OAK RIDGE NATIONAL LABORATORY
INSTRUMENT DEPARTMENT

Fig. 1 - Magnet Amplifier.

Q-889-1 D

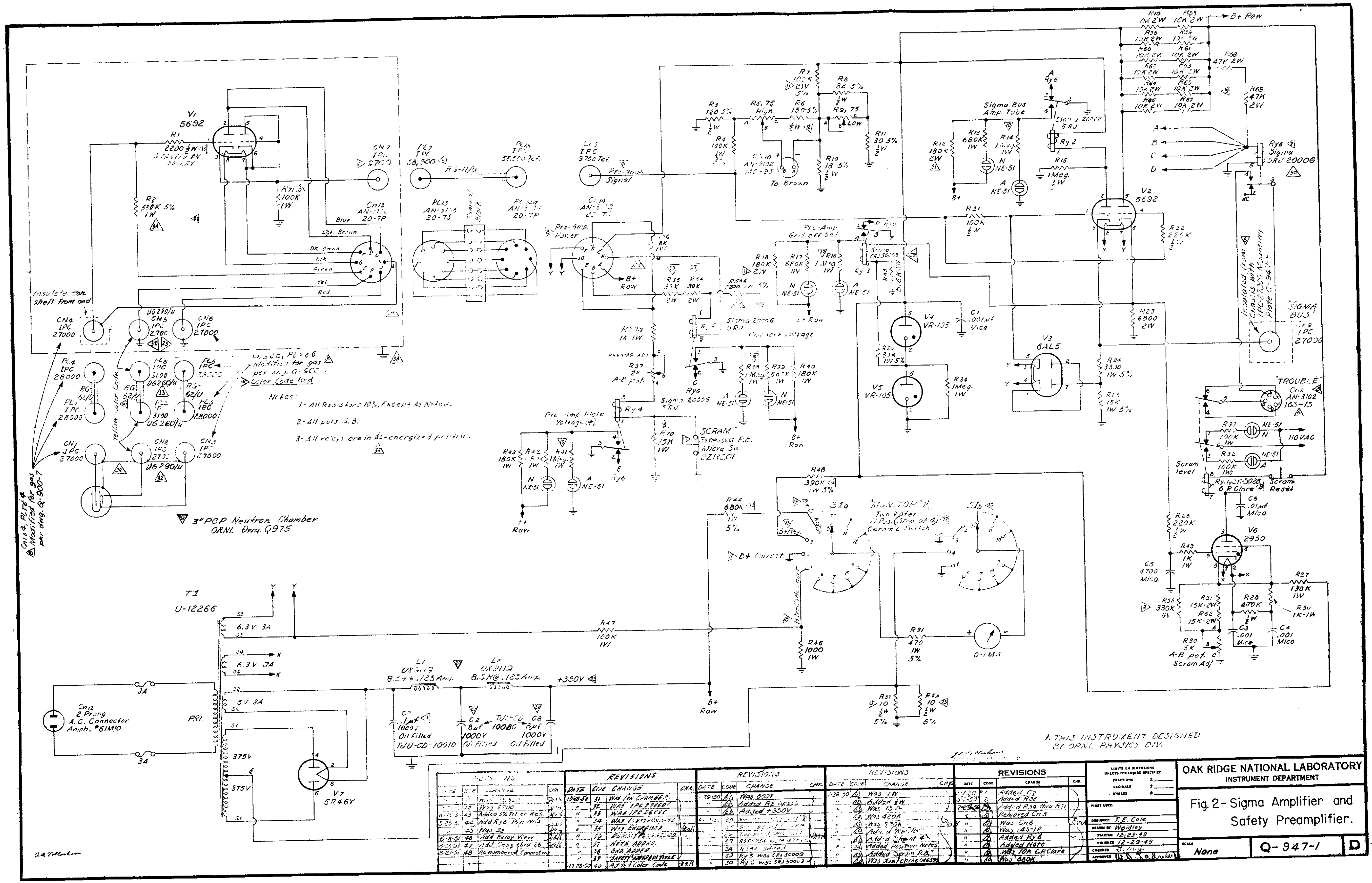


Fig. 2- Sigma Amplifier and Safety Preamplifier.

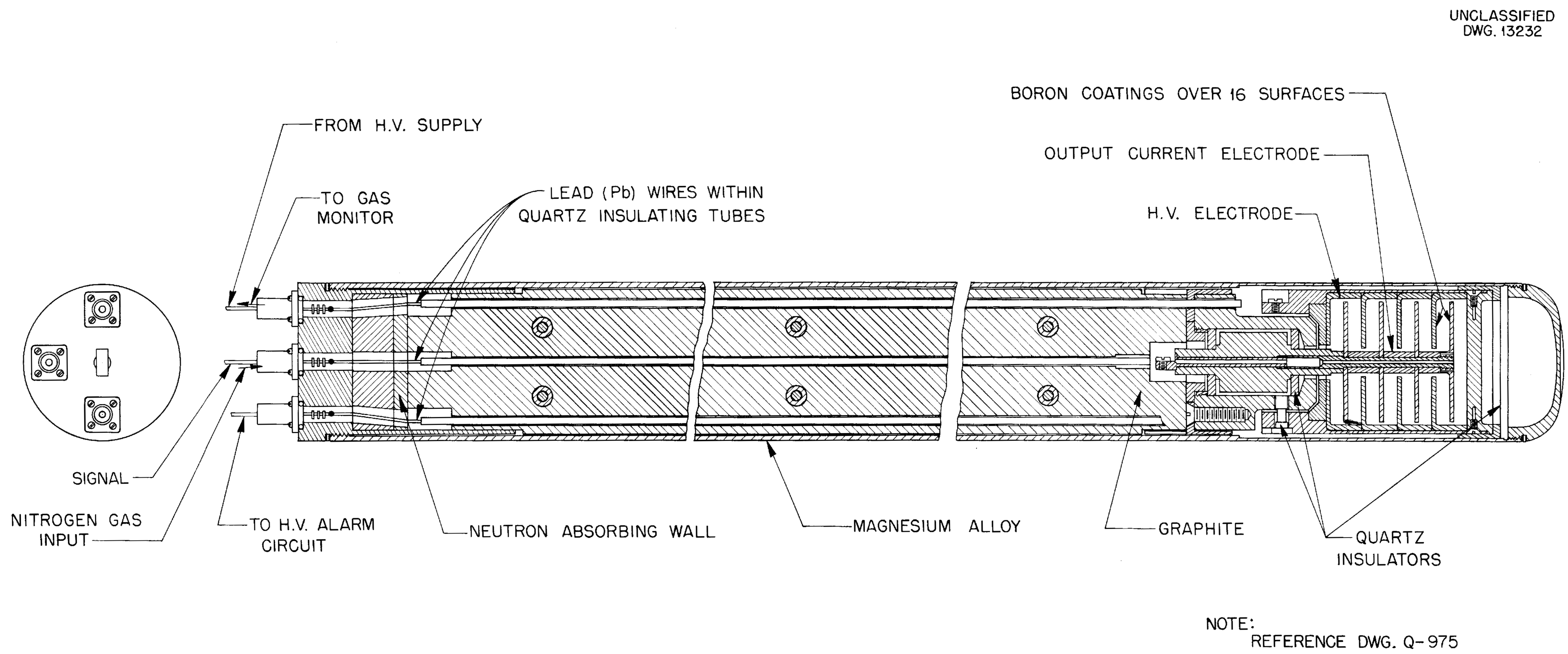


Fig. 3 - PCP Ionization Chamber.

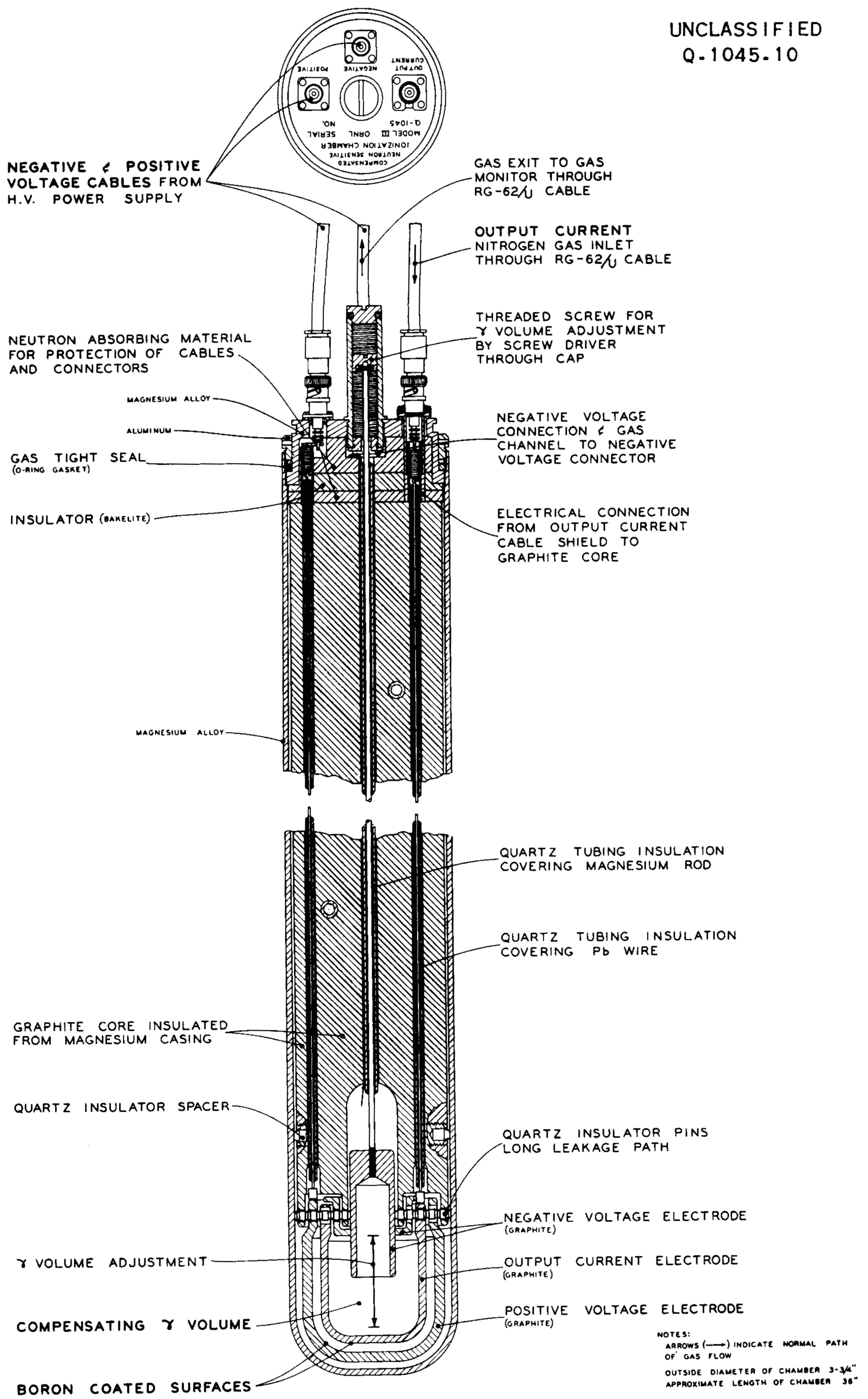


Fig. 4 - Compensated Ionization Chamber.

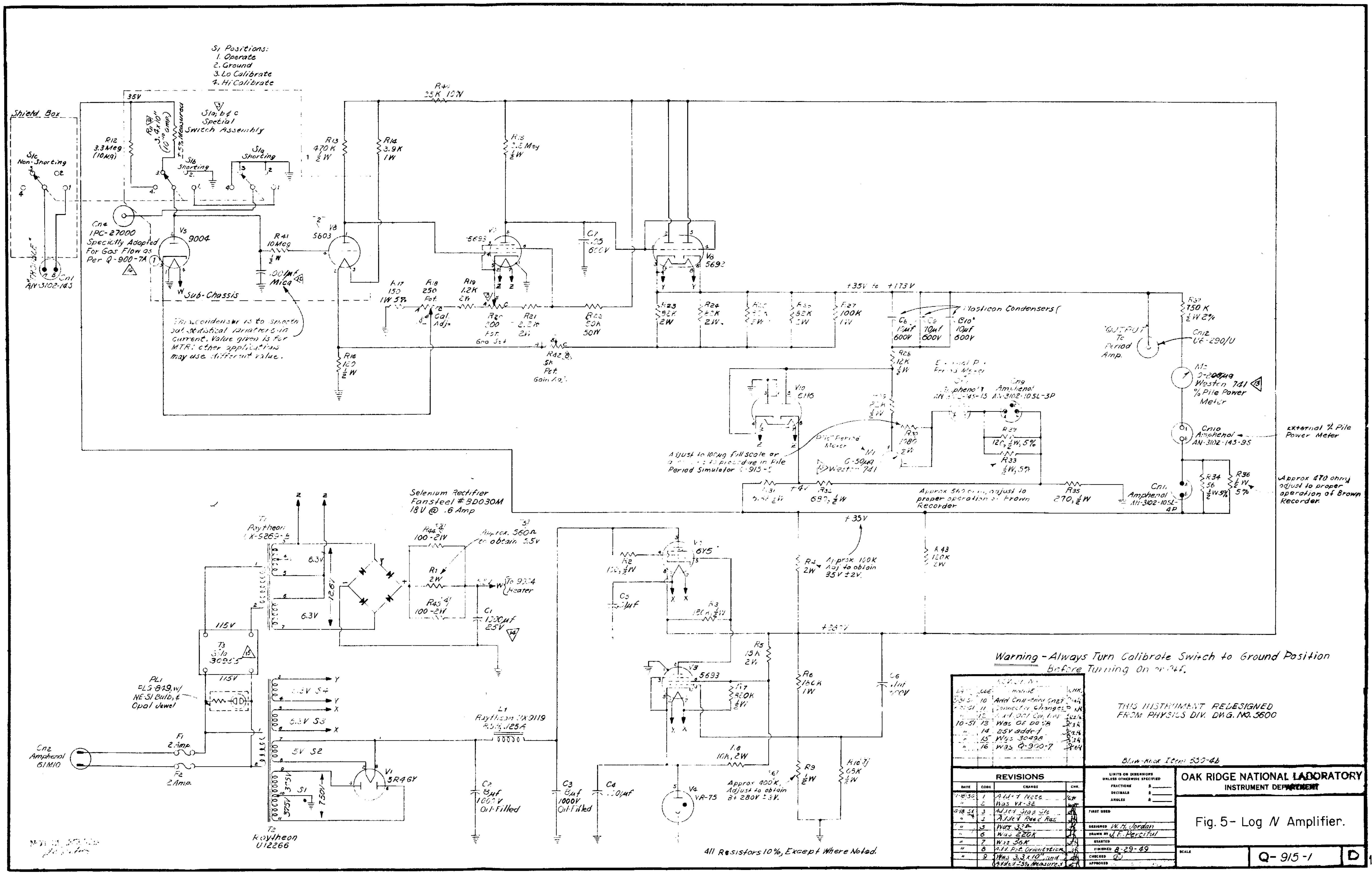
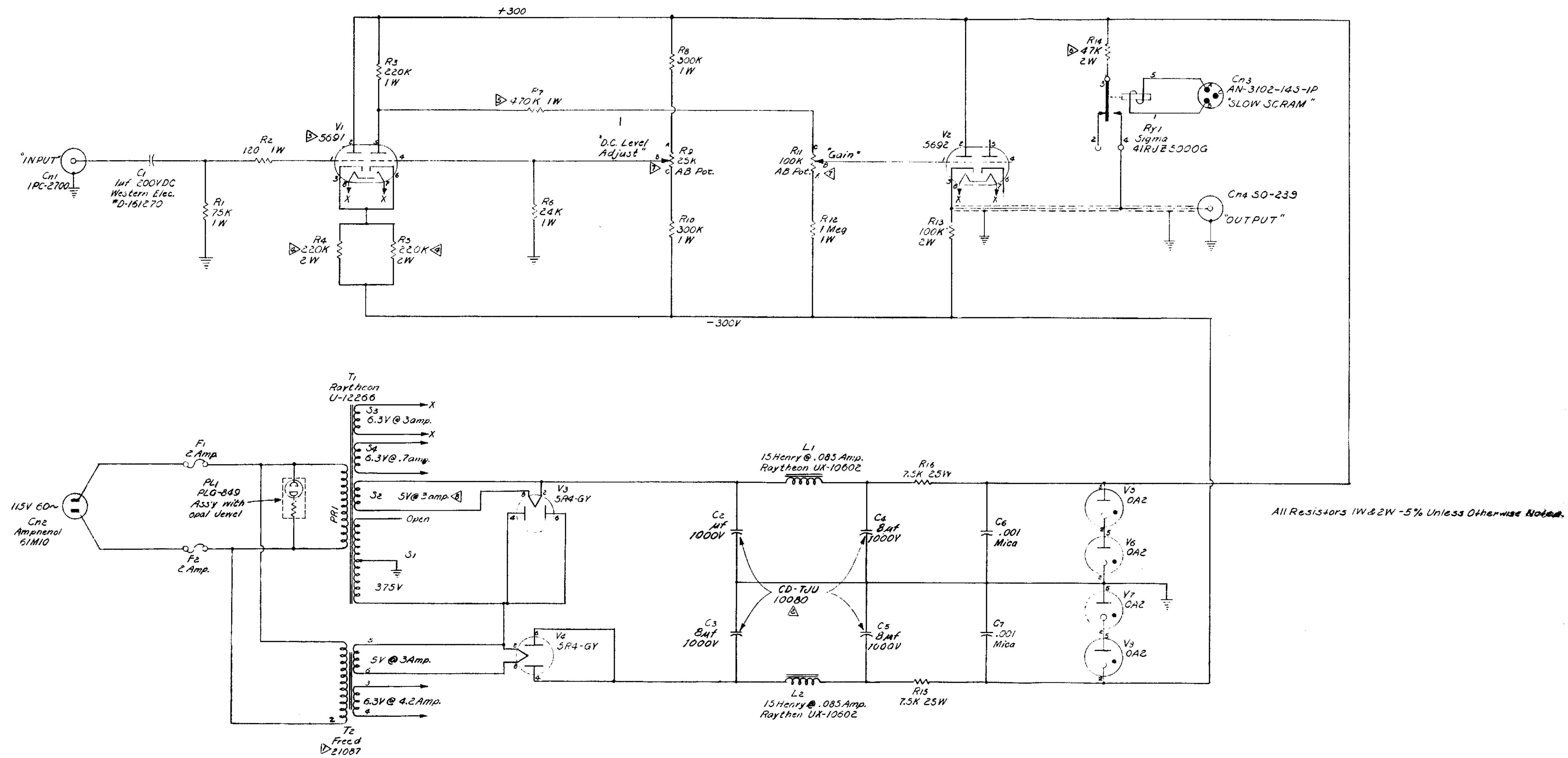


Fig. 5- Log N Amplifier.



REVISIONS			
DATE	CODE	CHANGE	CHK.
10-30-50	1	Added "Freed 21087"	JaH
10-30-50	2	Was Plasticon AOC6CK	JaH
5-15-51	3	Was 5692	JaH
"	4	Was 150K	JaH
"	5	Was 390K	JaH
"	6	Was 50K	JaH
5-23-51	7	Added Pot. Orientation	JaH
"	8	" 5V @ 3amp.	JaH
6-29-51	9	Added Cn3 & 6	JaH
8-21-51	10	Added PL1	JaH

LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED
FRACTIONS ±
DECIMALS ±
ANGLES ±

FIRST USED
DESIGNED T. E. Cole
DRAWN BY J. E. Perdiful
STARTED 10-19-50
FINISHED 10-20-50
CHECKED JaH
APPROVED

OAK RIDGE NATIONAL LABORATORY
INSTRUMENT DEPARTMENT

Fig. 6 - Pile Period Amplifier.

SCALE

Q-1093-1 D

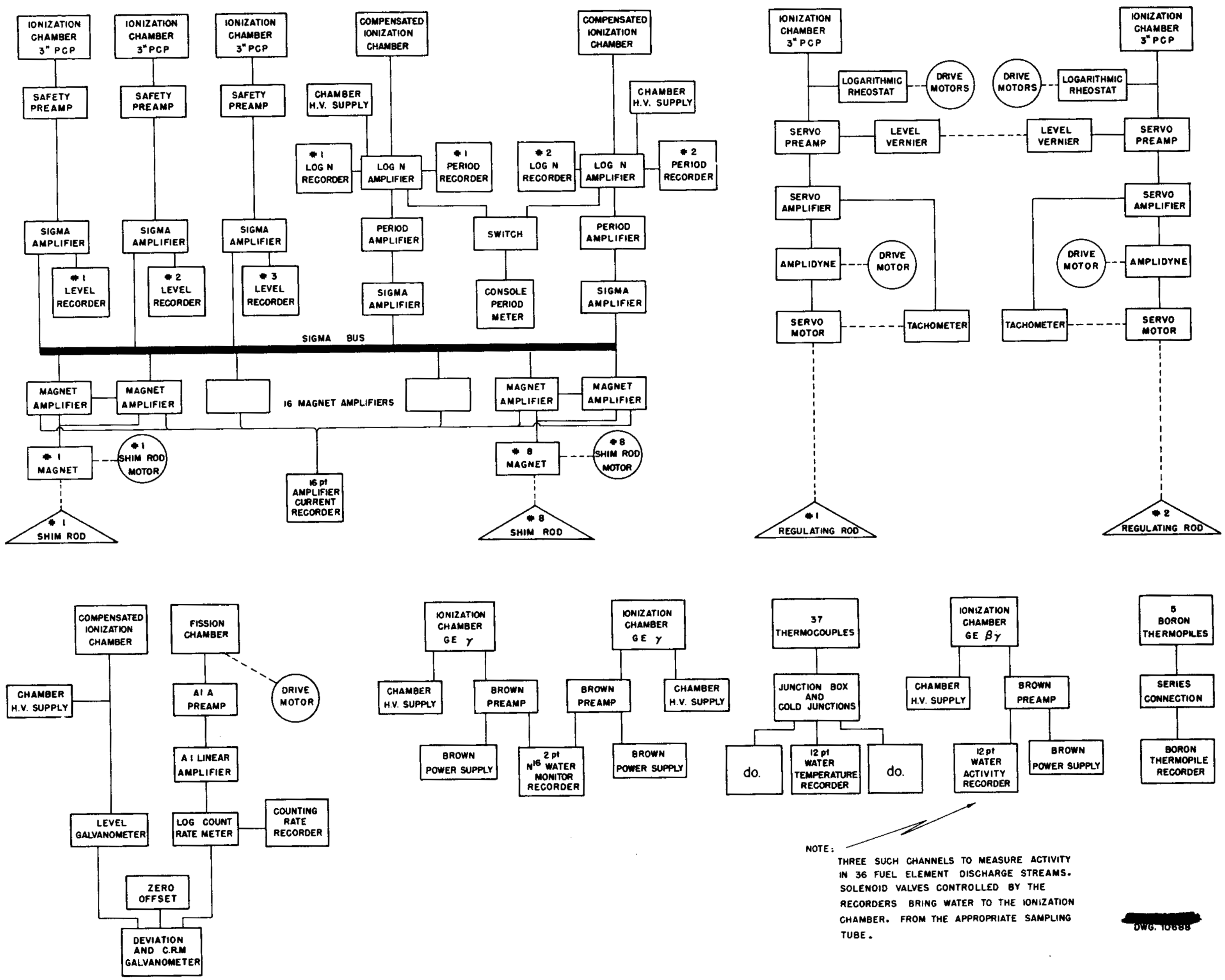


Fig. 7 - MTR Instrumentation Block Diagram.

MAGNET AMPLIFIERS

The magnet amplifier contains a d-c power amplifier for supplying current to the electromagnets and voltage amplifiers to regulate this current. V12 and V13 are the two power amplifier tubes (see Fig. 1 - all component numbers in this section refer to this drawing). Connected in parallel, with the magnet in the common plate lead, they provide safe and convenient means of quickly cutting off the current in this highly inductive circuit. Their high plate resistance and high plate-voltage rating provide the conditions necessary for this otherwise difficult and arc-provoking job. The total plate current passing through R49 provides a voltage to the 16-point monitor recorder. Malfunction of the magnet amplifier resulting in changes in amplifier current beyond expected limits will actuate limit switches on the recorder to warn the operator.

In order to make it amenable to monitoring, the sigma bus is normally run at a level of +35 volts. Any leakage serious enough to reduce this voltage should drop the rods, since this condition precludes raising the bus voltage to scram. Hence, the voltage amplifiers on the magnet amplifier must drop the rod when the bus voltage departs in either direction from its quiescent potential. The bus is connected to the grid of a cathode follower (½ of V5) in whose cathode circuit is a VR-75 (V7) in series with about 70,000 ohms, all returned to a regulated negative high-voltage supply. The function of the voltage-regulator tube is to change the d-c level of the signal without the sacrifice in gain which this usually entails in a d-c amplifier. R11 and R12 simply keep the heaters of V5 and V6 at a reasonable potential. R13 is returned to the B+ supply to keep V7 conducting under all conditions. The signal from the cathode of V7 is applied to the cathode of the second half of V5, and to the grid of the first half of V6. The plates of these two tubes are in parallel, drawing current from the positive high-voltage supply through the common plate resistance R9. The grids of the output tubes are connected to a voltage divider hung between the plate end of R9 and negative supply. Increasing the plate current of either tube connected to R9 will decrease the voltage on the grids of the output tubes and decrease the magnet current. Under normal conditions the amplifier portion of V5 is cut off and the amplifier half of V6 is drawing a little current. Increasing the bus voltage will increase the current in the amplifier half of V6 and provide a normal scram; decrease of the bus voltage will cause the amplifier half of V5 to conduct and scram via the bus protector route. R19 is used to set the bias on the bus protector tube so that at the bus voltage used the tube will just be cut off.

The negative end of the magnet high-voltage supply is not returned directly to ground. The output current flows through the combination of R34 to R39 in parallel (in "exchange" operation — only three of them in normal operation). The voltage developed at the hot end of this resistance network is a small negative potential proportional to the output current. This voltage is fed into the cathode follower half of V6, which is cathode-coupled to the amplifier half of this tube. A feedback loop is thus provided around the amplifier tube and the output stage, which provides partial compensation, at least, for drifts in tubes and components. Adjustment of the d-c feedback ratio with R33 provides a convenient means of setting the quiescent magnet current.

In order to cut down the incidence of accidental scrams due to equipment failure, two magnet amplifiers are used to excite each magnet, and the amplifiers are interconnected in such a way that failure of one amplifier in almost any conceivable way will not drop the rod, but will still be capable of responding to a scram signal on the sigma bus. The interconnections may be summarized as follows:

1. Since the output terminals are connected in parallel, failure of one magnet high-voltage supply will not drop the rod. The remaining supply is still connected through the magnet lead to both amplifiers. The malfunctioning supply is isolated by V3.

2. Paralleling two amplifiers permits four 6BG6G's in parallel to supply the magnet current, while two such tubes can carry the entire load without exceeding their ratings. It is exceedingly unlikely that all four tubes will fail before the monitor gives the operator warning that something is wrong.

3. By paralleling the compensation bus (negative end of the magnet high-voltage supply) the feedback voltages on the two amplifiers are connected. This has the effect of keeping constant the total magnet current, rather than the current in one amplifier. If only one amplifier is to be used on a magnet, such as during removal of a defective amplifier, throwing S2 to exchange changes the feedback resistance to provide correct operating parameters under these conditions.

4. The negative high-voltage supplies are connected, since failure of this voltage will remove the bias from the output tubes and also will not permit the voltage amplifier tubes to draw any current; hence, they then cannot decrease the output current. The malfunctioning supply is isolated with V4.

5. Failure of the *amplifier* positive high-voltage supply has the same effect as failure of both output tubes in the amplifier concerned. The other magnet amplifier will carry the load, and the monitor warns the operator of the failure.

A meter, together with a selector switch and suitable shunts and multipliers, is provided on the panel to monitor the voltage or current at vulnerable points in the amplifier. It is expected that a good preventive maintenance program will include periodic inspection and logging of all meter readings at regular intervals. An additional meter is provided which continuously reads the output current of the amplifier.

The 60-cycle supply for the plate transformer of the magnet high-voltage supply is brought out separately; slow scrams turn off this voltage.

SIGMA AMPLIFIERS

General Considerations. The signals which sigma amplifiers receive are in general continuous functions, often linear. The sigma bus should remain at its quiescent value for all safe values of the controlling variable, and rise quickly when a dangerous condition is reached. This requires a nonlinear device as a coupling; the sigma amplifier is this device.

Scram Circuit. The discussion that follows applies in all its details to the level safety channel. In a later section it will be indicated wherein sigma amplifiers in the period channel differ from this. Current is generated for the level safety circuits in the 3-in. PCP boron-coated chamber (Fig. 3). A cathode-follower preamplifier, V1, and its associated components measures the voltage developed by this current in flowing through R2 (see Fig. 2 - all component numbers in this section refer to this drawing). The output signal from the cathode follower is applied to the input terminal of the sigma amplifier. R4 through R11 constitute a bridge-measuring circuit which may be used to run a 10-mv continuous-balance recording potentiometer. The signal is also applied to the grid of a second cathode follower (½ of V2, hereinafter called the scram tube) whose cathode is connected to the sigma bus. A relay (Ry2) is in series with the plate of this scram tube. If this tube is arranged so it always draws current, Ry2 then monitors its readiness to react to a signal. This is the feature discussed above: Ry2 will give warning if at any time the tube is not prepared to act. (It may be argued that Ry2 is just as unpredictable here as any relay in a safety circuit. However, it would now require both tube failure and failure of an associated relay to produce an unmonitored dangerous condition. This is certainly less likely than relay failure alone. It will also be seen that Ry2, and all the other relays in the fast scram circuits, serve only monitoring functions. Misoperation or nonoperation of a relay cannot disable the scram.)

The signals to be encountered vary from zero chamber current to a maximum current set presumably by the maximum reactor operating level plus a safety margin. If the system is restricted to the use of linear amplifiers, it is difficult to insure that the scram tube (½ V2 already discussed) will always draw enough plate current to hold in Ry2. For this reason a somewhat unconventional feedback arrangement is used. A diode (V3, with the two diodes in series) is used as a unilateral clamp to keep the bias from reaching cutoff. By proper selection of operating voltages, the clamp is designed to hold over a range of chamber currents from zero to approximately one-half the desired scram chamber current. Signals above this level increase the voltage at the grid and as this voltage increases the diode becomes nonconducting and is no longer effective. In this way the scram tube acts in a manner approaching a relay, while maintaining the ability to have its condition monitored.

The output of the amplifier is the voltage at the cathode of the scram tube. The cathodes of all the sigma amplifiers are thus connected in parallel on the sigma bus. If something goes wrong within any one channel, it is desired to send out a trouble signal, and to scram the reactor only when the trouble is indistinguishable from a dangerous condition. If, on the other hand, all the sigma amplifiers fail for some reason, the reactor should scram immediately for lack of any fast-scram circuits. To accomplish these ends, the cathodes of the scram tubes are normally run at a d-c level above ground (+34 to +37 volts) by selection of the d-c offset of the preamplifiers. As explained above, the magnet amplifiers are so arranged that an appreciable excursion of the sigma bus in either direction from this normal voltage will cause a scram. The sigma amplifiers are designed so that any one sigma amplifier will reliably hold up the sigma bus, four other dead sigma amplifiers, and 16 magnet amplifiers with very little loss in gain. Thus, any one sigma amplifier can scram even if all the others are inoperative, and it follows that any one can scram with the others receiving normal (safe) signals.

Monitoring Circuit. Since the principal reason for choosing this relatively complicated type of safety circuit is its ability to be monitored easily, considerable effort was spent in perfecting the monitoring circuits. The occurrence of any trouble in the circuit should sound an alarm, indicating to the pile operator which circuit is out of order, and indicating to the technician and/or engineer the particular malfunction involved. The alarm and the general indication lie outside the scope of this report; the reader is referred to the MTR Project Handbook (ORNL-963) for an example of an elaborate annunciator system. The sigma amplifier is provided with means whereby the most vulnerable points are monitored, and the monitoring signals are collected so as to be available to an annunciator system. Figure 8 shows an elementary diagram of this monitor system. A monitoring meter is also provided.

Individual Alarms. Relays Ry2 through Ry5 monitor individual conditions or small groups of conditions. Each relay operates lights on the front of the amplifier panel and sends signals to the main trouble relay, Ry6.

Ry2 is the monitor for the sigma bus amplifier tube (scram tube). When energized the relay contacts indicate that the tube is drawing plate current.

Ry3 monitors the d-c level in the system. The relay contacts indicate normal operation when the d-c level at the input to the sigma amplifier is above +19 volts (normal level is +22 volts with zero chamber current, +32 volts with maximum safe chamber current, and about +37 volts for scram). It will be noted that half of V2 is used — the half not used as the scram tube. This monitor tube does not have the feedback present in the scram tube, so it is linear, and convenient for monitoring the d-c level. Failure in the preamplifier signal cable, or the preamplifier grid offset network will either alarm Ry3 or scram.

Ry4 is in series with the preamplifier grid offset network. Since the voltage supply for this network is furnished by a separate wire directly from the preamplifier tube plate, low B+ voltage at this point or any point back to the supply, will alarm this relay.

Ry5 serves two functions. First, it will be noted that two leads are connected to the chamber high-voltage electrode. One supplies the chamber with power; the other conveys a signal to the monitor relay, Ry5. Low voltage or misconnection of either high-voltage cable will alarm this relay. This takes care of the high-voltage electrode in the chamber; the second function of Ry5 is the monitoring of the position of the signal lead. The ground end of the relay coil, instead of being grounded directly, is grounded at the chamber, using insulated connections (note especially CN10) at the sigma amplifier and at the safety preamplifier. Thus the relay will alarm if the signal lead is not connected to complete the ground circuit in its shield.

Collection of Alarms for External Annunciator. One contact on each of relays Ry2 through Ry5 is connected to Ry6, the collector relay, in such a way as to drop it out if any one of the monitor relays alarms. Figure 8 shows the way this collector relay signal is used, at the same time monitoring the status of the cable connecting the sigma amplifier and the sigma bus. On the sigma amplifier monitor is a transformer to supply 5 volts a-c, and one master trouble relay for each sigma amplifier in the system. The master relay is held up when Ry6 is closed, if the sigma bus is properly connected to the sigma amplifier. Here again use is made of the shield of a coaxial cable to carry a monitoring signal through connectors whose shells

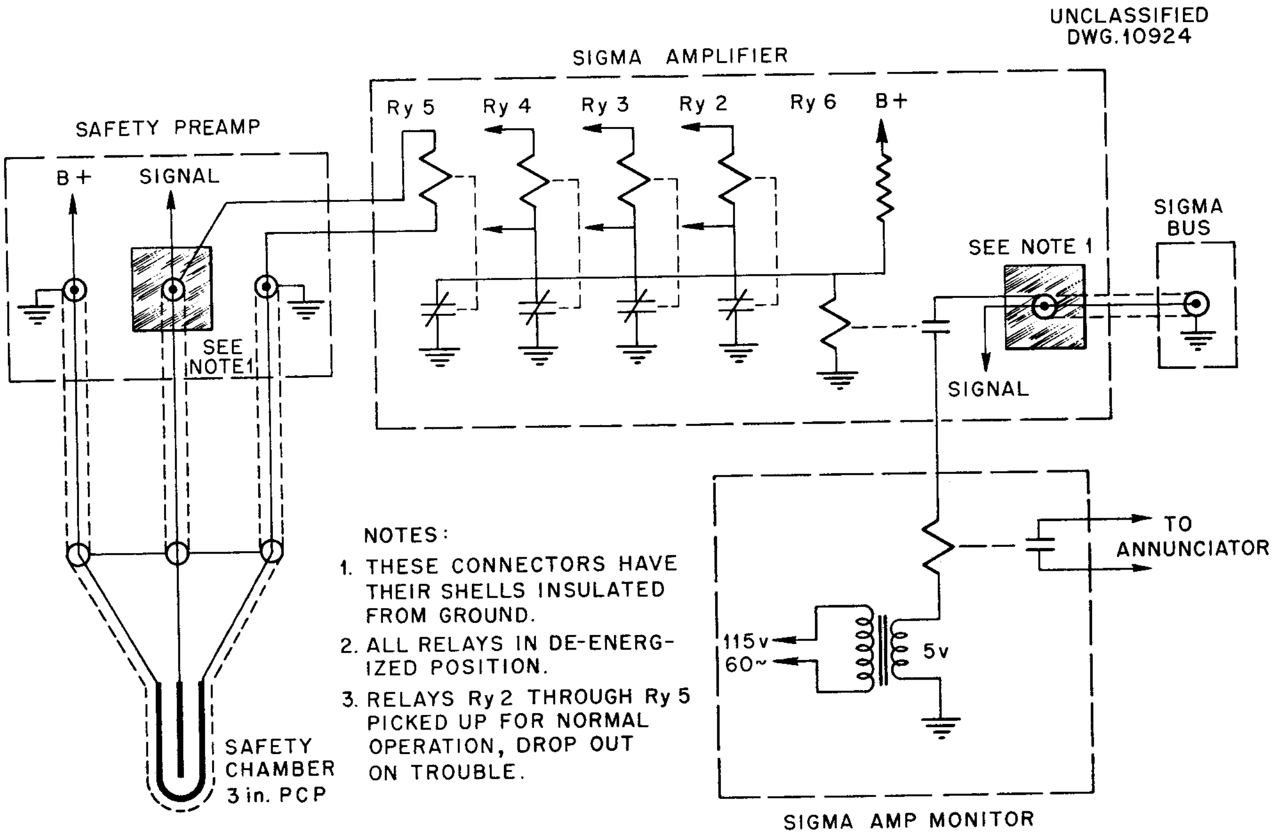


Fig. 8 - Sigma Amplifier Trouble Monitor.

are insulated from ground. An unmonitored sigma bus cable carelessly left unplugged would, of course, prevent the sigma amplifier from scramming, while the other sigma amplifiers on the sigma bus would hold up its voltage and avoid an undervoltage scram. Thus it is necessary to monitor this vital connection. The master relay contact goes to an annunciator.

Scram Indication. In a complex installation, scrams can come from any of a number of sources. When an apparently anomalous scram occurs, it is necessary to determine which channel was responsible in order to establish whether the scram was real or whether it was caused by equipment failure. For this reason the sigma amplifier has an indicator which will alarm when the signal seen by the scram tube reaches a level approximately equal to the scram level. This function is accomplished in V2 and V6. The linear half of V2 is used as a cathode follower (the monitor signal for Ry3 is generated here) driving a thyratron. Ry1, the scram monitor relay, is in series with the plate of V6. This relay operates an alarm light on the panel of the sigma amplifier, and in addition contacts are provided for an external alarm. Since different systems will be set to scram at somewhat different levels, an adjustment is provided to make the scram indicator alarm at the scram level in use. Experience indicates that it is probably advantageous to set the scram indicator to alarm at a few percent below the actual scram level. In this way the operator may possibly be warned in time to avoid the actual scram. It is important to note that the scram indicator circuit is a monitor only; it has no effect whatever on the actual scram function. Once the thyratron has fired, it is out of control of the grid, so a spring-return reset button is provided.

Monitor Meter. In monitoring certain conditions, and in tracking down trouble, a measurement is more useful than an indication which can only distinguish between "good" and "bad." A small d-c meter is supplied on the panel of the sigma amplifier for this use. A selector switch makes it possible to use this meter to measure the following quantities:

1. Heater-cathode current — by measuring the direct current flowing between heater and cathodes, a check is obtained on the possibility of heater-cathode leakage in one of the tubes.
2. Unregulated B+ voltage — also monitored by Ry5.
3. Regulated B+ voltage — also monitored by Ry4.
4. Total current drawn from B+ supply.

Scram Button. This button is in the preamplifier grid-offset network. Pressing the button raises the offset voltage on the preamplifier grid by an amount sufficient to scram. The entire system with the exception of the chamber may thus be tested by actual operation.

THE PERIOD SAFETY CHANNEL

General Remarks. Newson suggests a signal proportional to d/dt (ln N) as a useful indicator of excess k of the reactor. It is convenient to generate this signal by first obtaining a voltage proportional to ln N, and then passing it through a simple derivative circuit. The ln N signal is useful in its own right; it provides a wide-range indication of the flux level.

Unfortunately, fission-product gamma rays produce current in the ordinary boron-coated ionization chamber; while this is not objectionable at steady operating conditions, where the gamma-induced current will be but a small fraction of the neutron-generated current, the situation is not favorable after the reactor has been running at some high power for a while, and the neutron flux is then reduced. The gamma intensity will decrease slowly compared to the neutron flux because of the presence of long-life gamma emitters among the fission products. If the neutron flux is decreased by several decades, readings from an ordinary chamber will be almost wholly due to gamma ionization, and meaningless as far as neutrons are concerned. The compensated ionization chamber (Fig. 4) was developed to make valid readings of neutron flux in the presence of a large gamma flux. By careful attention to compensation details, it may be possible to achieve a compensation ratio of 10^{-2}. This means that the current for a given gamma flux is 10^{-2} times the uncompensated gamma-induced current. A discussion of the compensation problem and a description of the chamber is given by Straus.[6]

With a compensated chamber, currents proportional to neutron flux over a range of 10^6 or so are possible. A log N amplifier (Fig. 5) contains a diode operating in the logarithmic portion of its characteristic, and provides indications of ln N, and of the period obtained from d/dt (ln N).[7] The derivative safety does not make use of the derivative network in the log N amplifier, because the parameters of the circuit are unsuitable.[8] An additional amplifier, the period amplifier (Fig. 6), is used as a coupling device between the log N amplifier and the sigma amplifier. The compensated ionization chamber high-voltage electrodes are excited from a power supply (Fig. 9) designed for this purpose. Inasmuch as the compensated ionization chamber and the log N amplifier are discussed elsewhere,[6,7] only the period amplifier and the power supply will be discussed in any detail, although necessary remarks will be made about the other units in the channel.

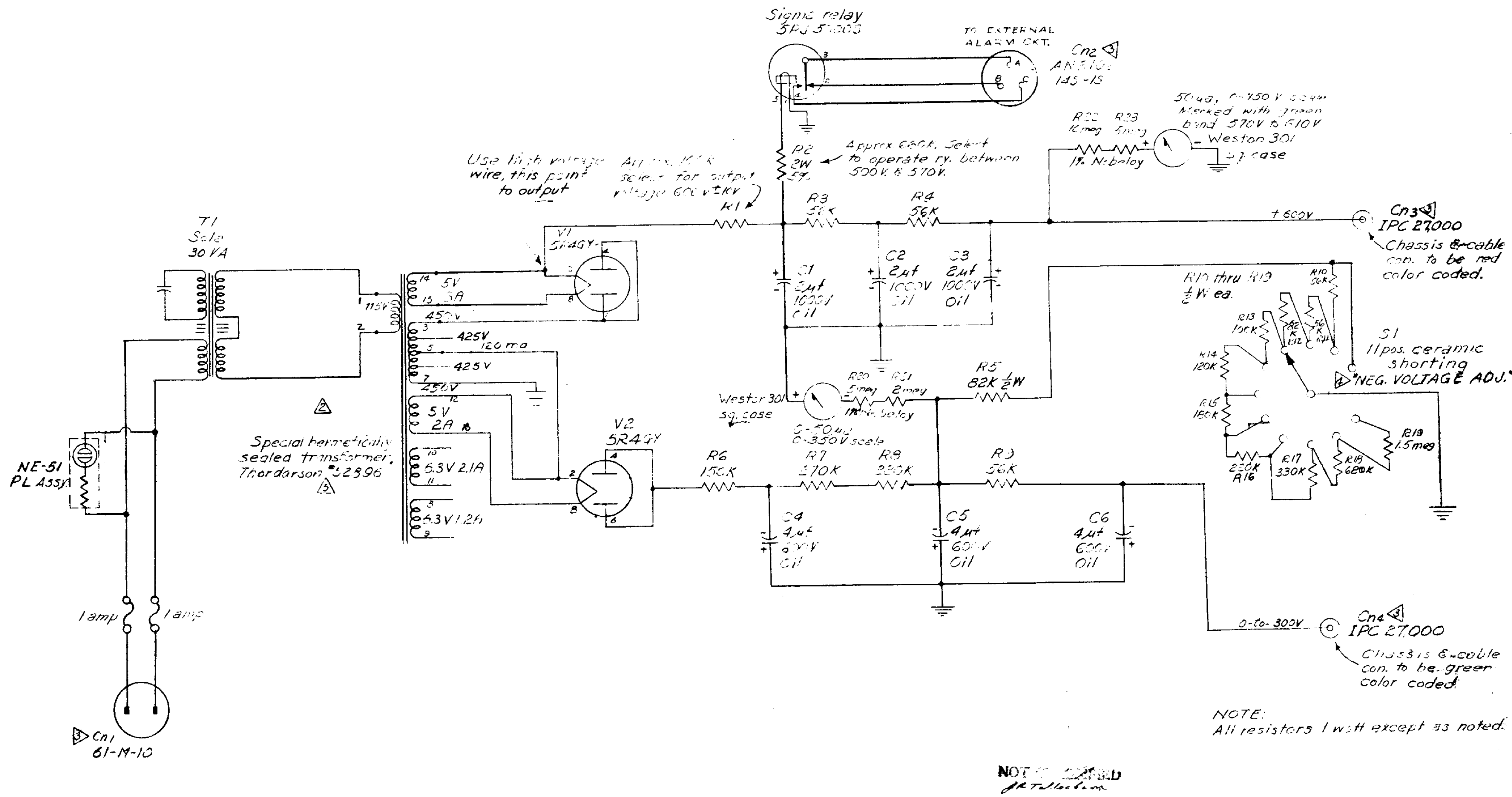
Period Amplifier. As mentioned above, the period amplifier serves as a matching device between the log N amplifier and the sigma amplifier. In particular, it serves instead of the safety preamplifier to set the d-c level of the sigma amplifier. This is accomplished by suitable selection of operating potentials; the output of the period amplifier provides a quiescent voltage of +22 volts at zero signal (infinite period), and increases this signal to +37 volts on a positive 1-sec period to provide a scram signal to the sigma amplifier.

The input to the period amplifier is a direct voltage proportional to ln N, taken from CN8 of the log N amplifier. This is applied to a differentiating network R1 C1. (See Fig. 6 - all component numbers in this section refer to this drawing.) The differentiated signal goes to the grid of a cathode follower (½ of V1) cathode-coupled to a voltage amplifier (other half of V1). The amplifier grid is returned to a suitable bias voltage, adjustable with R9 to set the d-c level of the system. The plate of the amplifier tube is connected to a

[6] H. A. Straus, *The ORNL Compensated Ion Chamber* (ORNL number to be assigned).

[7] W. H. Jordon, H. B. Frey, and George Kelley, *An Instrument for Measuring the Logarithm of Neutron Level and the Period of a Pile*, ORNL-110 (Nov. 23, 1948).

[8] The problem of the period safety is treated in ORNL-110, *op. cit.*, and MonP-437, *Physics Division Quarterly Report, Period Covered: September, October, and November, 1947*, p. 52 (Dec. 11, 1947).



REVISIONS

DATE	CODE	CHANGE	CHK.
5-17-50	1	General revision	
10-18-50	2	Transformer & tube change	
5-26-51	3	Add C1 thru C12	
"	4	Add "Neg Voltage Adj."	
6-29-51	5	Was Ferranti 6889	
8-21-51	6	Changed Cn's to PL's	
"	7	Added Notes	

LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED
FRACTIONS ±
DECIMALS ±
ANGLES ±

FIRST USED
DESIGNED J. Gundlach
DRAWN BY M. Bowelle
STARTED
FINISHED 4-14-50
CHECKED
APPROVED

OAK RIDGE NATIONAL LABORATORY

INSTRUMENT DEPARTMENT

Fig. 9 – Power Supply for Compensated Ionization Chamber.

SCALE

Q-995-1 C

voltage divider whose output drives a cathode follower (V2) whose cathode in turn provides the output signal of the period amplifier. The gain of the voltage divider is adjustable with R11 to vary the gain of the channel. Adjustments of R11 must be compensated for by adjustment of R9 to return the output d-c level to its proper value. The cathode resistors of all stages and the voltage-divider shunt resistor are all returned to a regulated negative high-voltage supply to give stabilization of gain.

Ry1 and its associated circuitry were devised to perform the slow scram function, but cutting off the magnet-amplifier magnet high-voltage supply does the job in a simpler and more reliable manner, so this circuit is not now used.

Power Supply. The compensated ionization chamber requires positive and negative high-voltage supplies for the high-voltage electrodes in the chamber. These voltages must be free of ripple,[9] the positive voltage should be accurately +600 volts, and the negative voltage should be adjustable to provide a vernier on the compensation. The power supply described here was designed to meet this need, and is conventional in every respect.

The provided relay monitors the positive high voltage, since its failure would prevent any chamber current from being collected. (Note that failure of the *negative* high-voltage supply merely takes out the compensation. This always results in a ln N reading higher than is correct, and may or may not influence the period reading.) Its use is discussed in the following paragraph.

[9] Straus, *op. cit.*

Sigma Amplifiers in the Period Channel. It will be noted that the absence of the safety preamplifier in the period channel will leave Ry4 and Ry5 in the sigma amplifier without signals. It is convenient to use these two relays to monitor two vulnerable points in the period channel. Ry4 is used to alarm if the calibrate switch on the log N amplifier is not in the "use" position. Ry5 is actuated by the contacts on a monitor relay in the power supply for the compensated ionization chamber. Trouble at either of these points will alarm Ry6 in the appropriate sigma amplifier, and notify the operator of trouble in the period channel. The operation of the period amplifier is monitored by Ry3 in the sigma amplifier, since trouble in the period amplifier will change the d-c level throughout the system.

PERFORMANCE AND CONCLUSIONS

When the MTR Mock-up was loaded with fuel and operated as a reactor, instrumentation similar to that on the MTR was installed, although it was reduced in complexity. Two level safety channels and one period channel were built and installed, and two shim-safety rods were used to control the reactivity and act as safeties. The components were built as nearly like the MTR prototypes as was practicable, and experience gained with the system was used to evaluate the design and to indicate needed changes. The safety-system components were found adequate in general design, although minor changes were needed. In particular, the shim-safety rods have undergone much redesign since the original ones were fabricated. The present system therefore represents over a year of "wringing out" and it is felt that performance is adequate. With the present magnets and rods, and with the magnets excited with current

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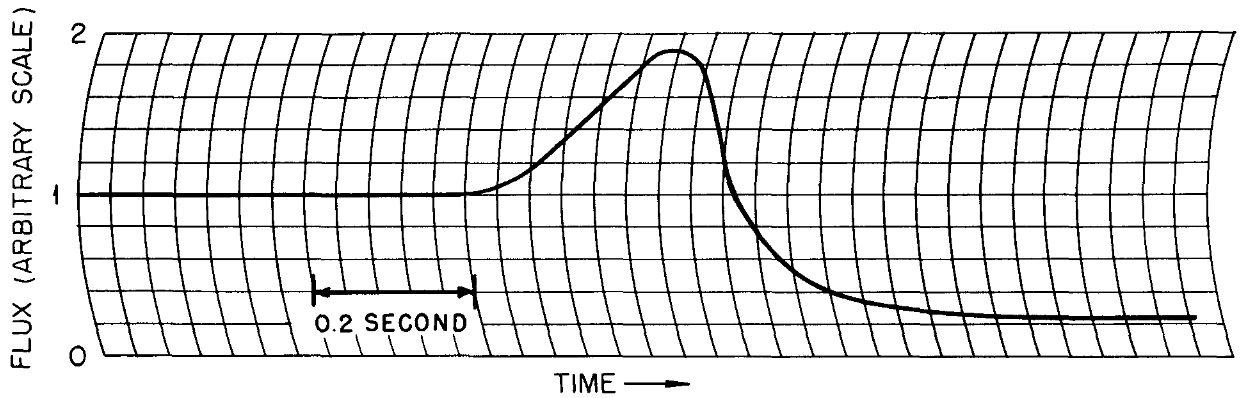

Fig. 10 - Performance Record.

1.5 times that needed to hold the rods, drop delay times of the order of 5 to 10 ms are experienced. Figure 10 shows a performance record. The regulating rod (containing about 0.6% δk) was moved from its halfway inserted position to its fully removed position as quickly as possible. The flux increased rapidly until the period safeties came into action and scrammed. The observed maximum slope has a period of the order of 1 sec. Most of the observed delay is due to the inductance of the magnet itself, and this probably means that an entirely different type of magnetic circuit must be designed if this delay time is to be decreased appreciably. In fact, the present magnets and rod armatures are probably the least satisfactory devices in the safety system. It would be desirable to have a device wherein a certain current would always hold the rod and another current a few percent less would always let go. Work is continuing on systems and components that approach this ideal more closely than the present one.

COMPUTATIONS CONCERNING SAFETY PARAMETERS

Shortest Expected Period. Newson's Eq. (5)[10] is applicable directly:

$$\theta \equiv \sqrt{\frac{L}{2R \ln \frac{N_1}{n_0}}} ,$$

where

θ = a quantity shown by Newson to be less than the shortest expected period,

L = mean lifetime of a neutron averaged over the entire pile,

R = rate of increase of K,

N_1 = neutron level at which safety devices operate, and

n_0 = start-up neutron level before rods are moved.

(10) Newson, *op. cit.*, p. 7.

Using the values

$$L = 2.63 \times 10^{-4} \text{ sec},$$

$$R = 10^{-3} \text{ sec}^{-1} \text{ average, and}$$

$$N_1/n_0 = 3 \times 10^{12},$$

the calculation gives

$$\theta = 48 \times 10^{-3} \text{ sec}.$$

Overload. The applicable relationship here is Eq. (16). There is, however, an error in MonP-271 at this point. The correct expression is

$$\ln \frac{n_{max}}{N_2} < 6.0 \times 10^{-2} \left[\ln \frac{N_1}{n_0}\right]^{3/4} \left[\frac{X^2 \Delta K}{LD^3}\right]^{1/4},$$

where

n_{max} = highest neutron level reached,

N_2 = neutron level at which the rods begin to move in,

X = total travel of rods,

ΔK = total δK in rods,

D = total time to withdraw rods,

and other parameters as before. With

$$X = 80 \text{ cm},$$

$$\Delta K = 0.45,$$

$$D = 360 \text{ sec},$$

the result is

$$\ln \frac{n_{max}}{N_2} < 0.523,$$

or

$$\frac{n_{max}}{N_2} < 1.7.$$

The time t_{max} at which n reaches n_{max} is given by Eq. (12):

$$(t_{max} - T_2) < \left[\frac{L}{\theta S}\right]^{1/2},$$

where

T_2 = time at which $n = N_2$,

$S = \dfrac{a\Delta K}{X}$,

a = acceleration of rod in downward direction.

With

$$a = g \text{ (980 cm sec}^{-2}\text{)}$$

one obtains

$$(t_{max} - T_2) < 3.15 \times 10^{-3} \text{ sec}.$$

SECRET

SECURITY INFORMATION

RESTRICTED DATA

This document contains Restricted [redacted] defined in the [redacted] Energy Act of 1946. [redacted] or the disclosure of its contents in any manner to any [redacted] person is prohibited.

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