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TECHNICAL INFORMATION SERIES

Title Page

AUTHOR	SUBJECT CLASSIFICATION	NO. / DATE
C.R. Droms	Metals, Liquid Indicators	R55GL1 DATE 12/21/54

TITLE

SECOND REPORT ON LIQUID METAL LEVEL INSTRUMENT

ABSTRACT

Results of additional development work and test results obtained since the issuance of the first report R52GL85 in 1952 are given. Basic theory of operation has remained the same.

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CONCLUSIONS

The liquid metal level instrument will operate at tank temperatures up to 1000 F. Overall system accuracy depends on operating conditions, as described in the report. Test accuracies from 2 to 8% have been obtained from full to empty tank. The primary detector unit successfully passed Navy HI shock test.

For list of contents—drawings, photos, etc. and for distribution see next page (FN-610-2).

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SECTION General Instruments LOCATION Schenectady, New York

GL-16-B (4-53)

OUTLINE

LIQUID LEVEL INSTRUMENTATION REPORT #2

2. Temperature Tests - GEL

3. Alarm and Liquid Level - KAPL

B. Calculations

1. Lead length effects

2. System estimated accuracy

OUTLINE

SECOND REPORT ON LIQUID METAL LEVEL INSTRUMENTATION

I. Introduction

This report covers the additional development and testing done on the prototype liquid level instrumentation system since the issuance of the first report R52GL85, March 1952. It also includes the development and testing of a prototype liquid level alarm (scram) instrument system.

II. General theory of operation

A. Liquid Level Instrumentation

The basic operation of the revised instrumentation system is the same as that described in the first report. There have been changes in various details of the component parts due to design improvements, specification revisions, and changes in magnetic amplifier characteristics. These changes will be described in detail for each of the component parts.

The liquid level instrument system includes a sensing element called the primary detector which is inserted in the liquid metal system. A current is passed through this element and, as the liquid metal level changes, the voltage drop across the detector is changed, due to partial short circuiting by the liquid metal. The voltage drop across the unit is then a measure of the immersion of the primary detector in the liquid metal. The remainder of the instrumentation serves to supply current to the primary detector and to measure the voltage drop across it.

B. Alarm (Scram) Instrumentation

The alarm (scram) instrumentation includes a sensing element called the alarm detector, which is placed in the liquid metal system. A current is passed through this element and, as the liquid metal level reaches the detector level, a step change in resistance is obtained by shorting of the rods by the liquid metal. The remainder of the instrumentation serves to supply current to the detector, and to operate a relay from the voltage change.

III. Details of operation of component parts

A. Primary Detector

1. Operation

The sketch of the primary detector on drawing #69997-2282 shows two rods supported in the tank by sections of tubing. As shown on the equivalent circuit, it is the resistance of these rods that is shorted out by the liquid metal. As the metal level changes, the amount of resistance shorted is varied, changing the output voltage.

As can be seen on sketch #69997-2282, the sections of tubing serve two purposes. They support the rods in the liquid metal and prevent the tank walls from short circuiting the rods. A current lead is provided inside of each tubing section to supply current to the rods. These current leads also provide temperature compensation by changing current proportional to the resistance temperature change. This compensation is described fully in report #52GL85. There are several differences between the original primary detector and the one in current use. The present detector consists of two rods compared to the single-rod original unit. The principal reason for this change is that the two-rod unit eliminates any use of the tank wall as part of the current path. Therefore, the tank resistance has no effect on the level indication. As discussed in the first report, no details on the tank construction were available at the time of the initial development work, and therefore, the effect of its resistance on the level indication was considered negligible. After additional details of the tank were available, however, it was calculated that the resistance of the return current path through the tank walls might be more than 10% of the total resistance. After making this determination, it was decided to eliminate the tank resistance as an unknown variable by adopting the two-rod type of detector. An idea of the importance of resistance in this circuit can be obtained by realizing that the maximum detector resistance is 0.002 ohms. At the same time that the change was made to a two-rod detector, it was decided to maintain the tubing length for all detectors at a constant 4 inches instead of varying tubing length with the detector length as was described in R52GL35 for the single rod unit. In the new design, the tubing and rod resistances are kept equal by varying the cross-sectional area of the rods proportional to their length. By keeping the rod and tubing resistances always equal regardless of the detector length, a constant scale distribution and interchangeability of other components is obtained for all length rods.

Since no measurements of level can be made above the junction of the rod and tubing, keeping the tubing a constant 4 inches also maintains the dead zone at the top of the rods at a minimum.

Two different lengths of detectors are shown in the photographs; #1131 085 shows a 24-inch detector and #1134 369 an 8-inch detector. The longer primary detectors, Cat. 124B619G1, have the rods mounted inside of a two-inch guard pipe which serves to support the ends of the rods. The detector itself is designed to be mounted on a three-inch pipe stub (not supplied) on the tank. The shorter detectors are a modification to be used for freeze seal measurements. At the request of KAPL, the two-inch guard on these units is omitted since no support is required. These units can be mounted on the pipe stub supplied welded to the detector head in place of the guard. Leads to the primary detector are nickel plated MI cables. The nickel plating serves to reduce oxidation of the copper sheath on the MI cables. The head is packed with MgO and sealed by a cap welded in place.

2. Test

Based on the above design, a number of primary detectors were built. Tests as follows were performed on these units. On each primary detector rod, the electrical resistance of the solid and the tubing sections were measured and compared. The design scale distribution on the indicating instruments was based on having the resistance of the solid section equal to the tubing section on the detector rods. The maximum difference in these resistances found by test was 3.8%, giving a calculated maximum error in scale distribution of less than 0.5% of full scale in the indicated level.

Sketch 69997-2282 of the primary detector shows two leads labeled "Reference". These leads are connected across a portion of the series temperature compensation resistance, as described in the previous report. The function of the signal obtained from these reference leads is to permit more accurate spot readings of level to be made. Since the level instrumentation primarily measures the voltage drop across the primary detector, due to a current supplied from the line voltage, the level indication will vary directly proportional to the line voltage. The reference resistor, however, acts as a calibration resistor, whereby the gain of the amplifier can be adjusted so that the instrument indicates a predetermined value when switched across the reference output. Thus, one point near full-scale on the indicator is set to read accurately. With this point and the zero adjusted, the remainder of the scale is correct.

The resistance between these reference leads was measured and compared on each unit with the design value of 0.037 ohm at room temperature. Resistance values were adjusted to be either at or slightly higher than the design value. The reference units were then installed in the detectors and final adjustments made in place by shunt resistors, so that the reference setting to obtain the correct empty tank reading at room temperature on all units was the same within $\pm 2\%$.

In addition to the electrical tests, each unit was leak tested according to specifications at each stage of manufacture.

Another test made on three of the freeze seal units at room temperature was the scale distribution. Tests were made by soldering a copper bar across the bottom of the two rods, and setting the amplifier gain so that the unit read 0% immersion. A copper shorting bar was then clamped across the rods at various immersions. The measured immersion on the three units tested was within 0.5% of the calculated values for the shorting bar position. A total of twenty 8" freeze seal units were built. Two were delivered immediately upon completion to KAPL for test. Of the remainder, one developed a leak during manufacture, and was rejected. The room temperature tests on the remaining seventeen are summarized in Table I. Tests were made under three conditions, with a copper bar soldered across the bottom of the two rods in place of the stainless steel spider to simulate zero immersion, with the steel spider, and with a copper bar shorting to simulate 20% immersion. The copper bar in place of the steel was necessary because resistance of the steel bar was appreciable compared to the rods. Tests were made upon initial completion of the units, which were then shipped to Badger. Subsequently, revised specifications were received, requiring additional cleaning on the units. They were therefore returned from Badger, cleaned, retested, and reshipped.

The initial test at room temperature with a copper bar soldered in place showed that the reference setting for the units averaged 2%, with extremes of 0 and 4% measured. These were the most reliable tests, since the shorting bar soldered in place gave the lowest value of contact resistance. Results on the second condition, with the steel spider, were less reliable, due to variations in the resistance across the steel spider. Tests with a 20%

immersion short (after return) showed greater variation in the reference setting, averaging 1%, with extremes of -2 and +7%. The greater spread was probably due to variations in contact resistance between the shorting bar and the rods. The importance of the contact resistance can be estimated by realizing that the total circuit resistance of the detector is 0.002 ohm.

The design value of the reference setting was 16%. Tests on these units showed an average value of 2%. One reason for the difference between the two values was that the design measure transformer ratio was 20/1, whereas tests showed the actual value to be 19.1/1 under operating conditions. This 5% difference in ratio means a 10% change in immersion indication at zero immersion, due to the non-linearity of the scale at this point. The remaining difference was probably due to an increase in reference resistor resistance as a result of self-heating. Due to the guard around the 24" detectors, no tests could be made, other than the relationship between reference and zero immersion readings at room temperature. On three of the four units built, the reference setting was found to be 4%. On the fourth unit, the value was found to be -2%.

On May 29, 1953, one primary detector was successfully shock-tested, recorded as test No. 4782. This test was witnessed by C.E. Whitney, Navy Inspector.

Since the revision in specifications calling for pressure tests was added after manufacture of most units, only two units were subjected to the pressure and temperature tests. These two units were subjected to 300 psi at room temperature, 50 psi at 580 F, and 120 psi at 700 F. No failures were experienced on either of the units subjected to these tests.

3. Comments

The single and double rod detectors were designed on the basis that it was necessary to mount the units from the top of the tank. With the removal of this restriction, an improvement in design can be affected by mounting the unit from the bottom. The bottom mounted unit has the advantage of being linear in output, requiring only a single rod, and having no dead zone.

B. Alarm (Scram) Detector

1. Operation

The sketch of the alarm detector on drawing No. 69997-22813 shows two tubing sections held horizontally in the system. As seen on the sketch, it differs from the primary detector in that the solid sections are formed by filling the tubes with silver for low resistance, and that the unit is mounted horizontally. With the high conductivity silver in the rods, any sodium that forms a continuous contact between the rods at any point along the length will short out the unit, and, in combination with a current passed through the unit, will give a step change in voltage output. An alarm detector is shown on photo 1136 946.

Referring to the equivalent circuit of the alarm detector on drawing No. 69997-2283, current is supplied to the alarm detector from the power supply. The current is limited to the correct value by resistors in the power supply. This current then passes through the series resistor and the tubes in the alarm detector. Thus, if the tubes are not shorted out by the sodium, an output voltage is obtained. If the tubes are shorted, this value changes as a step function to a lower value. This combination was designed to operate as a fail safe feature, in conjunction with a special magnetic amplifier characteristic. The amplifier is arranged to give an alarm signal for either zero or maximum voltage. At an intermediate value, obtained when the rods are shorted, a safe signal is obtained. Thus, if either line voltage fails, giving zero output, or if sodium is lost, giving maximum output, an alarm signal will be given.

The alarm detector design was based on the requirement that the magnetic amplifier be supplied with a current between 45 and 55 microamps for safe operation, and either 0 or approximately 200 microamps for alarm conditions. To provide these signals, a current of 3.24 amperes was required from the power supply, obtained by placing a current limiting resistor of 0.67 ohm in series. The design values of the tubing resistance was 0.0029 ohm, and the series resistance 0.00102 ohm.

The length of the rods filled with silver was based on the requirement that the unit should not be affected in operation by roll and pitch. With a long section filled with silver, liquid metal shorting between the rods at any point should give a safe signal.

2. Test

Three alarm detectors were built. The total resistance of the tubing section of each was measured at room temperature as 0.0029 ohm. The series resistance in each was measured at room temperature to be 0.00102 ohm. Each was leak tested during manufacture, and retested after being subjected to 300 psi at room temperature and 120 psi at 700 F, with no failures. No shock tests have been performed on this unit.

For operational test, a unit was installed in a test loop by KAPL and tested in June 1954. The results of these tests are described in section IV-B-3--Alarm and Liquid Level Tests--KAPL and summarized in Table I.

C. Power Supply

1. Operation

The function of the power supply, as reported in R52GL85, is to provide the low voltage, high current necessary for the primary and alarm detectors and step up the low signal voltage to a value suitable for rectification by the discriminator. It was designed as a separate unit from the rest of the circuit, so that it could be placed as close as possible to the primary detector, minimizing the effects of lead length on error. There has been no change in its function since the previous report. A transformer in the unit steps the 120 volt supply down to 2 volts and a second transformer steps up the signal from the rods from 0 to 10 m.v. to 0 to 200 m.v.

Two power supplies have been designed, one for the liquid level instrumentation and one for the alarm unit. The two are identical, except for the addition of current limiting resistors in the one used with the alarm unit. Both types are made as an enclosed box, with terminal tubes through which the MI cables from the detectors can be run (see photographs 1134 367, 1134 366, 1136 945, and drawing 143A444).

2. Tests

Polarity tests were made on each power supply, and the measure transformer ratio was determined. At no load, the measure transformer ratio on the seven units tested was 20.7/1, ± 1/2%. With a discriminator and amplifier load, the transformer ratio was 19.1/1, ± 1 1/2%.

D. Discriminator

1. Operation

The function and operation of the discriminator are the same as described in R52GL85. Briefly, its principal use is to rectify the Low Level AC output of the detector to DC for use by the magnetic amplifier. This rectification is accomplished by a ring modulator circuit, as described in the previous report. Some of the details of the changes that have been made are:

1. Germanium diodes in place of selenium rectifiers for improved circuit characteristics.
2. Removal of current adjusting resistor in supply to primary detector.
3. Addition of a D.C. signal supply for an external circuit to prevent alarm while operational adjustments are being made.
4. Addition of switch contacts to remotely control circuits according to switch position.
5. Chassis and mounting arrangements.

2. Test Performance

Nine discriminators were built and each was given an operational test. The temperature at which the thermostat held the block was adjusted to 120 F, and the units tested for zero adjustment.

A test was made on a power supply and discriminator to determine the characteristics of the combination at higher levels of signal voltage than the normal 0.010 input to the signal transformer. This was done to aid in the circuit design features including "fail safe" for the alarm detector. A 200 ohm load was connected across the output of the discriminator (Pins 14 and 15) in place of the magnetic amplifier. Voltage across this output was measured with a DC potentiometer. Measure transformer input, output, and discriminator input were measured with a Ballantine voltmeter. Temperatures of the measure transformer were found to be less than 4 C above ambient. Results of these tests are plotted on curves 1,2, and 3.

After completion of the discriminators, operational tests in a simulated circuit indicated excessive zero drift with variation in ambient temperature. Tests on the original model as reported in R52GL85 indicated satisfactory operation at varying ambients. Tests were, therefore, made on the revised discriminator to determine operation characteristics over a range of ambient temperatures from 40 F to 140 F. These tests were made with zero voltage input, and a 500 ohm output load connected to simulate the magnetic amplifier. This was done so that all changes would be due to discriminator zero drift only. The change in discriminator output current from zero was noted as its ambient was varied, with switches in the balance position. Soon after the tests were started, it was found that the thermostated block on the discriminator was not operating at the correct temperature. The thermostat was adjusted until the block was at the correct temperature, and testing was continued. During further tests, the thermostat setting changed several times and had to be reset. A new thermostat of the same type was installed but it also shifted from time to time. Since the zero drift was small when the block was at the design temperature, it was felt that the principal source of trouble was in the thermostat. Some trouble was also experienced in holding block temperature at very low ambients due to low heater power. To correct the troubles, the original thermostats were replaced in all discriminators by Fenwall thermostats, and at the same time the heater units were rewired to increase the power available to improve control of temperature at low ambients.

After making these changes, tests conducted on one unit at ambients from 40 to 140 F with a 500 ohm lead indicate zero drift of approximately 3 microamps, without adjustment of zero, and approximately 4 microamps when used with a 200 ohm lead. It was also determined that the D.C. output current obtained was .52 microamps per millivolt of A.C. input with the 500 ohm lead. With the 200 ohm lead, the output current was .85 microamps per millivolt of A.C. input. These values were constant from room temperature to 140 F.

The new thermoswitches noted above were ordered factory pre-set to the desired temperature. Each was checked for stable and satisfactory operation after installation.

E. Magnetic Amplifier

1. Liquid Level

Magnetic amplifiers were used during the course of testing the instrumentation. The latest model requires a special adapter for use in liquid level instrumentation. This program did not include tests of characteristics of these units.

2. Alarm

The magnetic amplifier as used in the alarm circuit also needs a special adapter. No tests, except operational in a loop at KAPL as described later, were made on the characteristics of this amplifier.

F. Indicator

To indicate the output of the magnetic amplifier, General Electric type DB15 0-5 milliampere instruments were used as specified. The original scale on these units was marked 0 to 100 percent immersion, as shown on photo 1135 703. Most of the testing on which this report is based was done using this instrument, and the percent immersion data given refers to the readings on this scale. The reason for marking the scale as shown was to make all indicating instruments interchangeable, regardless of detector length. Subsequently, instructions from NRB were received through KAPL to mark scales in inches immersion for the detector length being used. This was done, and approval for the new scale was received. (Photo 1141 430)

IV System Performance

A. Test Performance

1. Liquid Level

One of the primary detectors was delivered to KAPL for test. Tests were conducted by KAPL in a sodium loop at Alplaus, and curves representing the data taken were furnished the General Engineering Laboratory. From these curves the data and curves presented in this report were abstracted. The data for the temperature tests is presented as the difference between the empty tank reading and the reference reading at various temperatures. The reason for this is that the reference voltage was designed to furnish a set point for adjustment of the amplifier gain, somewhat like the adjustment on ohm meters for correct full scale reading. No provision is made in the unit for effects of line voltage variation, and the output indication varies proportional to line voltage. This manual adjustment, however, makes it possible to eliminate the effects of line voltage variation on spot readings of level. The test for satisfactory reference operation is that the reference setting required for correct operation be constant at all temperatures. Thus, the difference between the reference setting used and the indication obtained for an empty tank is the correct reference setting required for zero level indication at empty tank for the test temperature. This value, for accurate operation, should be constant at all temperatures. The results of the tests in the Alplaus loop are summarized in Curve 4.

Two sets of data are presented for two sets. After conducting the first tests, trouble developed in the unit, and it was removed from the system for repair. In order to make the repairs, it was necessary to remove the guard and cap from the detector head. This was necessary to rebraze one of the lead wires in the tubing. KAPL reported that the unit had been exposed to temperatures in excess of 1200 F, which caused the failure.

In addition to the results summarized on curve 4, extensive data were taken by KAPL on the scale distribution, by comparing level as indicated by the level unit with dipstick readings. According to these data received from KAPL, the scale distribution agreed with the marked scale to within 2%.

2. Temperature Tests - General Engineering Laboratory

The changes in the reference setting with temperature noted on curve 4 could have been due to either a change in reference resistance, or to a change in probe resistance. To test for this, a unit was subjected to temperature cycling up to 1000 F, and tested for reference setting. No appreciable change was detected. It was therefore concluded that the change was due to film of sodium over the rods.

Calculations were made of the effects of various thicknesses of sodium film on the rod indication. These results are plotted on curve 5. As can be seen, a film of a few mils of sodium would cause a change of 10% in indication.

3. Alarm and Liquid Level - KAPL

At the request of KAPL, assistance was given in testing and evaluating an alarm unit and a level unit installed in the KAPL test loop. A summary of the test data taken by GEL is given in Table II, and additional comments on it follow. Sodium was first admitted into the tank after pre-heating the tank to 350 F. After opening the valve to admit sodium, the alarm relay did not operate until it had been tapped. The entire tank was filled in approximately 50 seconds. The liquid level unit was observed to deflect almost immediately after the valve was opened. It was noted that it did not change indication after the valve was closed. An electronic voltmeter connected across the alarm unit output was observed to flicker as soon as the valve was opened and to decrease in value almost immediately. Although the alarm relay did not operate, these observations indicate that wetting took place in much less than the 50 seconds required to fill the tank.

For the next test, the level was varied, and the level instrument indication was compared to the dipstick readings with the following results:

Level Measured by Dipstick	Level Instrument Indication
99	92.4
85.4	81.0
60.4	57.6
31.3	25.8
0	0

After these tests, indicating that the indicator was operating, the level was raised to 99% and left overnight with the tank at 350 F. During further operational tests on the next day, it was noted that the level indication was considerably in disagreement with the dipstick measurements. Sodium was therefore removed from the tank, and measurements made. In Table II, it can be seen that the level unit readings for empty tank conditions were different after exposure to sodium. Calculations based on measurements of detector output voltage measured by an electronic voltmeter showed that the instrumentation was indicating correctly for the detector voltage. Measurements of detector resistance showed that the level unit indication then agreed with the measured resistance. These two checks indicate the change was due to a change in the primary detector. The change could have been caused by:

1. Sodium coating on the rods

Assuming that the entire change was due to a coating of sodium on the rods, calculations show that a coating 0.019 inch thick would be required (see curve 5).

2. Sodium coating on the detector tubing

Since the tubing is much smaller, a coating of only 0.007 inch over its entire length would give the change in output noted. According to the test records, the tubing had not been immersed in sodium, but only exposed to its vapors.

It should be noted that this is the same unit tested twice previously by KAPL. In each case, the change in indication was of the order of 10%.

The changes noted in this third test were considerably greater than in the first two tests. One difference between the tests is that care was exercised in the first two cases to insure cleanliness of the sodium and the system, whereas such precautions were not taken prior to the third test.

Calculations were also made to determine the effects of these tests on the alarm unit. The change in resistance noted corresponded to a sodium coating of 0.001 inch at room temperature. The change in values at 350 F corresponded to a coating thickness of 0.008 inch. No explanation is known for these discrepancies.

B. Calculations

1. Lead Length Effects

As described in the previous report and elsewhere in this report, the power supply was designed as a separate unit, so that its transformers could be mounted as close as possible to the primary detector. This was done to minimize the effects of lead resistance between the transformers and the primary detector on the temperature compensation. A distance of not more than twenty feet between the two units was specified. Subsequent installation difficulties made this close a mounting of the two units impractical. At the request of KAPL, therefore, an analysis of the effects of extra lead length on temperature compensation was made. This analysis was made by Mr. F. B. Foody and results are given in his report "Lead Length Analysis Liquid Level Measuring Equipment Primary Coolant Systems" July 1954. Results are summarized in Table III and curve 6 of this report.

In addition to these calculations showing the effects of temperature on indication for various leads, Mr. Foody also calculated that the reference setting would change 2.6% at room temperature if the lead length were increased from 10 to 50 feet, and would change an additional 1.6% if the lead length were further increased to 75 feet. These calculations show that a reference value determined at room temperature with short leads might be in error by approximately 4% if the lead length were increased to 75 feet, without a change in temperature.

2. System estimated accuracy (Liquid level instrumentation)

There are a number of factors which can affect the indication of the liquid level instrumentation. The effects of some of these variables are known, and their effects on accuracy can be estimated fairly well. Other effects are not as well known, and their effects can only be estimated on the basis of observations to date.

The following factors are known to affect the output of the level instruments. It should be noted that the effects of variation in the magnetic amplifier and instrument were not tested as part of this program, and therefore, their effects are not included.

a. Line voltage - as discussed in the first report, the signal voltage used for indication of level varies directly with the line voltage. A variation of ±10% in line voltage, therefore, causes a ±10% variation in signal voltage. Due to the non-linearity of the scale of the indicating instrument (photo 1135 703), a change of 10% in voltage at empty tank will cause a 20% change in indicated immersion. At full immersion, on the other hand, the indication will be independent of line voltage, since the signal voltage is zero at this point. Points in between these two extremes will vary between these two limits.

b. Line frequency - This factor has no effect on the level instrumentation itself, although it may affect the magnetic amplifier.

c. Ambient temperature variation - This factor will be considered for each component separately.

The primary detector has been compensated for the effects of temperature variation, as discussed in the original report. This compensation is based on uniform temperature distribution over the length of the detector, and rapid changes in temperature may cause a transient error. Under steady state conditions, information received on tests performed by KAPL show that the series stainless steel leads in the detector provide compensation correct to within approximately ±1%.

The power supply was designed as a separate unit, to minimize the effect of lead length on temperature compensation. It is not affected by ambient temperature. However, installation difficulties made it necessary to use 75 foot leads between the primary detector and the power supply. The effects of this increase have been discussed previously. To minimize the effects of leads on indication, it is recommended that the tank temperature be raised to about 400 F, and the relationship between reference and operate readings for empty tank conditions be determined. If this is done, the total effects of lead temperature variations will be reduced over the normal operating range of 400 to 600 F to about one-quarter that shown on curve 6 for temperature variations from 68 to 850. This would be ±1% for the recommended operation, for best accuracy (resetting reference value) and ±2% for other operation.

The effect of ambient temperature variation on the discriminator is primarily to cause its zero to drift.

With rezeroing, this effect can be eliminated. Without rezeroing, a drift of several microamps is possible, which corresponds to an average of about ±2% in immersion, depending on the immersion level, and the characteristic of the amplifier.

d. Primary detector sodium film - Tests conducted by KAPL indicate that a change in the relationship between the reference signal and the empty tank signal takes place after exposure of the detector to sodium. Changes of 10% in indicated immersion have been noted, as discussed previously.

Based on the above factors, the following overall system accuracies can be estimated for various modes of operation (not including amplifier and instrument error). These figures were obtained by the following assumptions:

Best Accuracy

a. The instrumentation system has been zeroed just prior to reading, an operation taking between 30 and 45 seconds.

b. The relationship between reference and empty tank reading has been obtained by test, and has not changed.

Test accuracy obtained at Alplaus

a. Same as (a) above.

b. An average value of the relationship between reference and empty tank indication was used, and this value did not change more than 12%.

Worst Accuracy

a. Instrumentation was not zeroed, and line voltage and temperature changed.

b. Same as (b) for test accuracy.

Estimated Error

Factor	Best Accuracy Empty tank	Best Accuracy Full tank	Test Accuracy Empty tank	Test Accuracy Full tank	Worst Accuracy Empty tank	Worst Accuracy Full tank
Line Voltage	0	0	0	0	±20	0
Ambient temperature						
Primary detector	±1	±2	±1	±2	±1	±2
Leads	±1	0	±1	0	±2	0
Power supply	0	0	0	0	0	0
Discriminator	0	0	0	0	±2	±2
Primary detector sodium film	0	0	±6	0	±6	0
Total Error	±2	±2	±8	±2	±31	±4

TABLE I

Room Temperature Tests on 8" Freeze Seal Primary Detectors

Unit No.	Ia Meas.	Ia Ref.	IIA Meas.	IIA Ref.	IIB Meas.	IIB Ref.	IIIA Meas.	IIIA Ref.	IIIB Meas.	IIIB Ref.
3237703	0	1			0	4			20	-.5
704	0	0			0	9			20	0
5	0	.5							20	.5
6	0	2			0	10			20	0
7	0	2.5					21	2	20	2
8	0	2	0	8	0	8			20	2
9	0	4	0	9	0	8			20	4
10	0	2					20	2	20	2
11	0	4					20	4	20	7
12	0	0			0	6	20	0	20	-1
13	0	1					20	1	20	-2
14	0	4							20	2
15	0	0	0	4	0	5			20	-2
16	0	2			0	10	21	2	20	1
17	Leak Test Reject									
18	0	0			0	7	21	0	21	0
19	0	0			0	7	19	2	20	2
20	0	0	0	6	0	7			20	5

Column No.	Test Condition
I	Copper spider soldered in place before completion
II	Stainless steel spider welded
III	Copper short at 20% immersion
A	Before shipment to Badger
B	After return from Badger

All readings in percent immersion

Date - June 1954

	14	14	15	16	17	17	18	18	21	23
Tank Temperature	Room	300-600 F	Room	Room	300 F	350 F	350 F	350 F	Room	Room
Tank Condition	Empty	Empty	Empty	Empty	Empty	Full	Empty	Some Sodium	Empty	Empty
Level Unit										
Res. (rod) ohms x 10^{-3}		2.62	2.06	2.06					1.35	1.33
Res. (Ref.) ohms x 10^{-3}									38.5	38.5
Detector signal output MV				10.2	10.3	.19	7.6			6.9
Signal XFMR output M.V.				198	200	36.6	145			133
Reference voltage M.V.				186	190	190	188			189
Measure reading %	0			0	0	92.4	42			50
Reference reading %	4			4	6	6	6			7
Alarm Unit										
Resistance ohms x 10^{-3}*		4.84	3.77						3.50	3.52
Input signal XFMR M.V.**				12.6	14.4	5.5	10.5	5.6		11.8
Output signal XFMR M.V.				240	273					250
Relay coil current M.A.				1	1	12.8				

* Resistance includes series "fail safe" resistance of .001 ohms.

** Voltage includes 5.5 M.V. drop across series "fail safe" resistor.

TABLE III

Summary of Results of Lead Length Calculations
from report of F. B. Foody, July 1954

Cable Length Feet	Change in Conditions Resultant Error A	B	C	D	E	F	G
10	-0.287	-.287	+.039	-1.760	+2.474	+2.852	+.714
50	-1.380	-1.380	+.038	-6.514	+5.246	+6.475	-1.268
75	-2.024	-2.023	+.037	-9.194	+6.768	+7.888	-2.426

Condition	Reference	Probe	MI Cable
A	Reset before reading signal	68	68 to 268
B	Reset before reading signal	850	68 to 268
C	Reset before reading signal	68 to 850	68
D	Not reset before reading signal	68	68 to 268
E	Not reset before reading signal	68 to 850	68
F	Not reset before reading signal	68 to 850	268
G	Not reset before reading signal (found by adding D and E)	68 to 850	68 to 268

GENERAL ELECTRIC

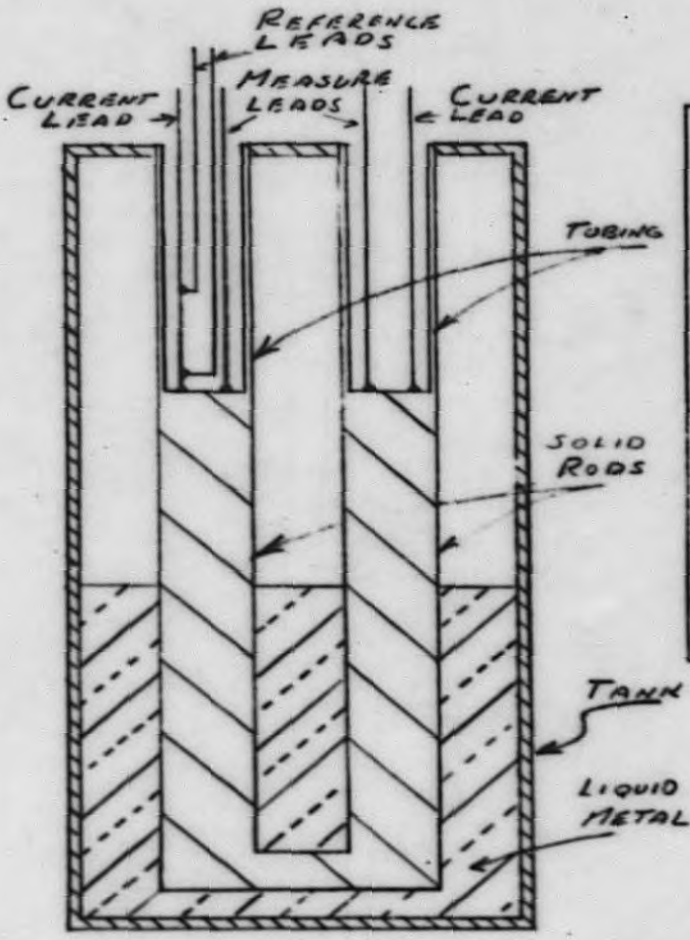
69997-2282
CONT ON SHEET — SH NO. 1.

REV NO. 69997-2282
CONT ON SHEET — SH NO. 1

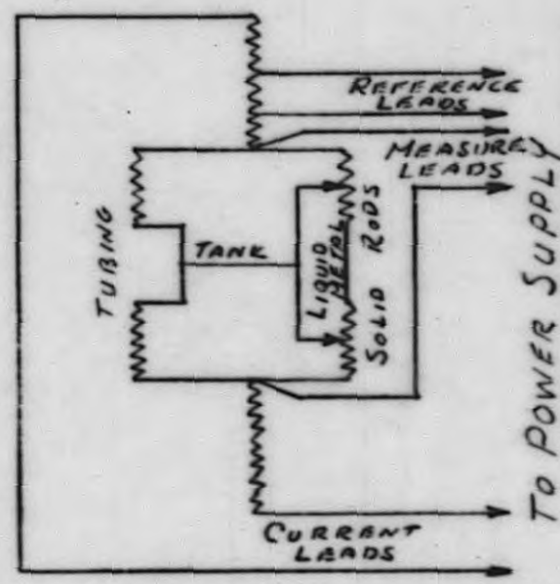
TITLE PRIMARY DETECTOR (OUTLINE)

FIRST MADE FOR LIQUID METAL LEVEL INDICATOR

REVISIONS



PRIMARY DETECTOR



EQUIVALENT CIRCUIT OF PRIMARY DETECTOR

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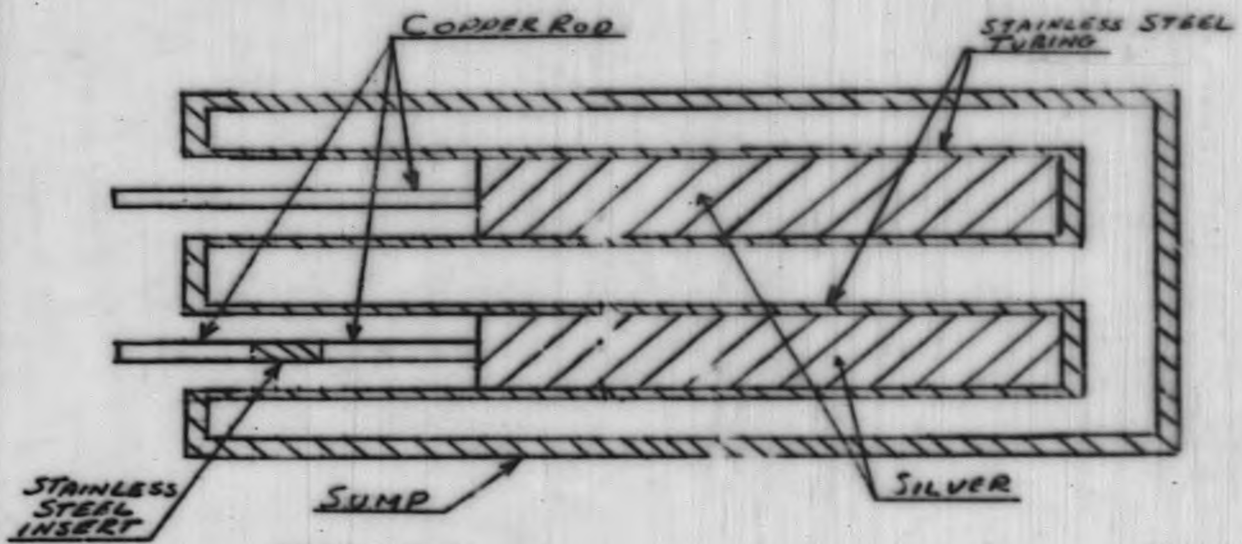
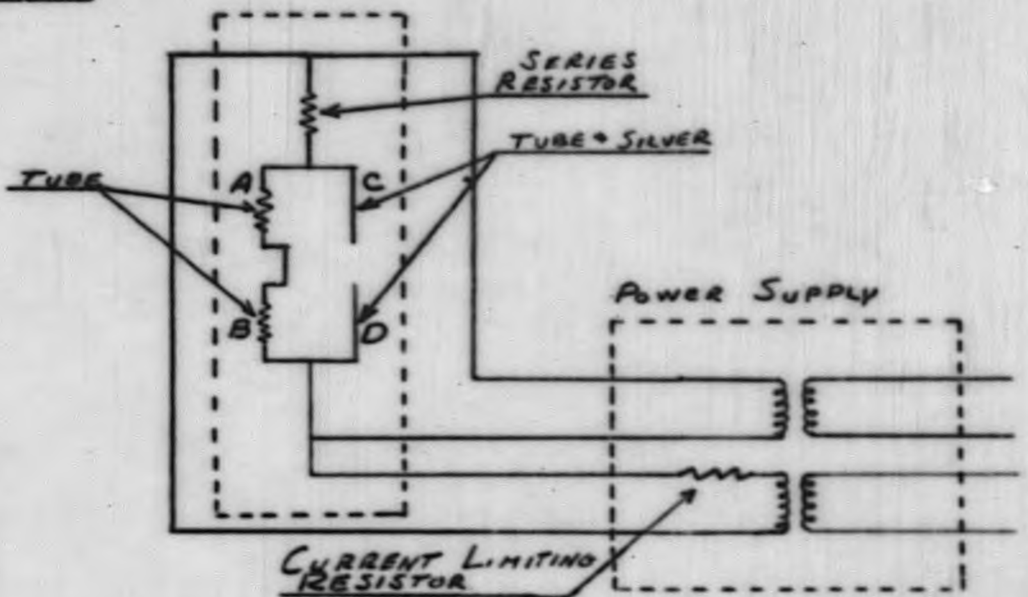
REVISIONS

ALARM DETECTOR (TOP VIEW)





EQUIVALENT CIRCUIT- ALARM DETECTOR AND POWER SUPPLY

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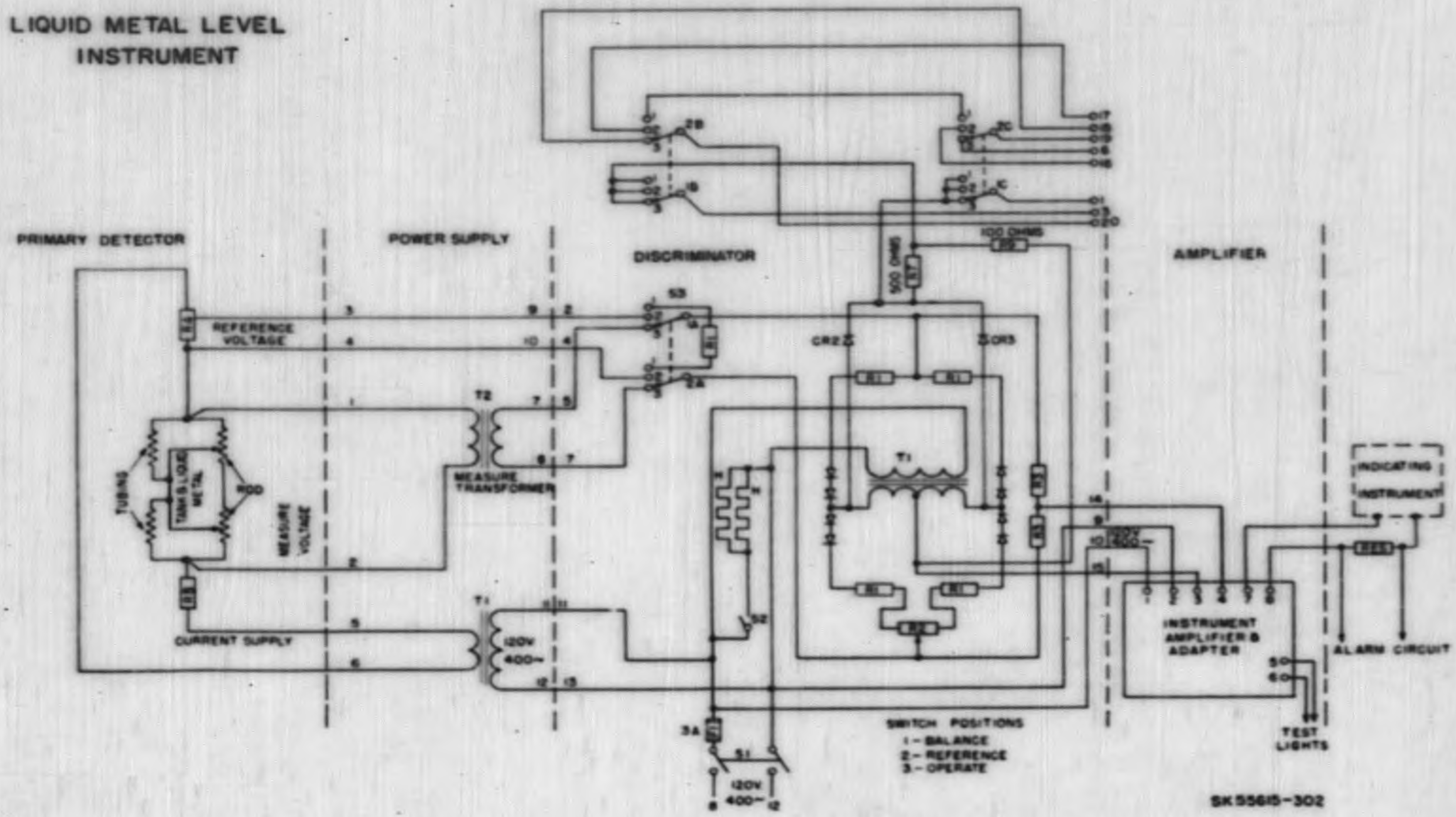
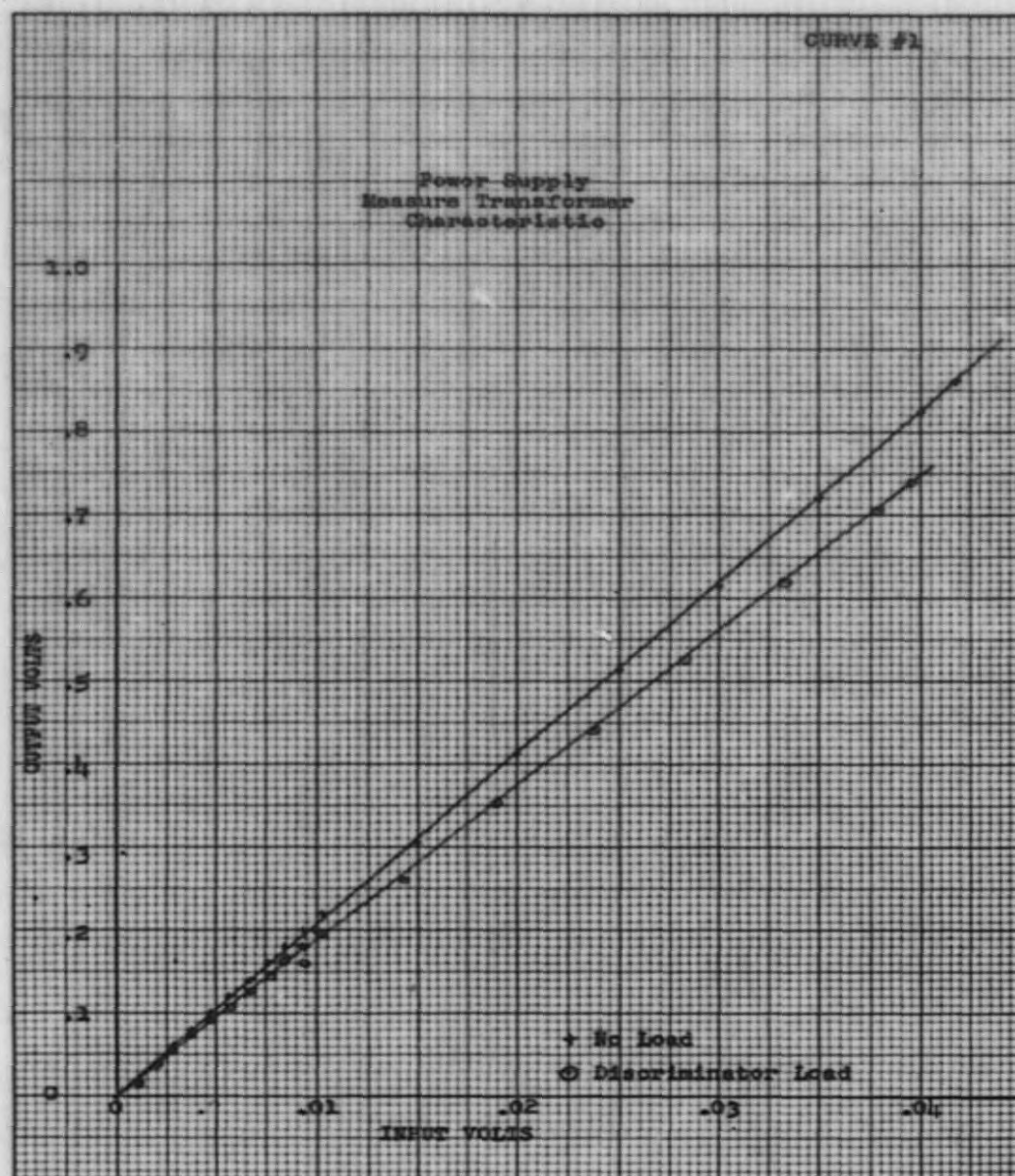
LIQUID METAL LEVEL INSTRUMENT





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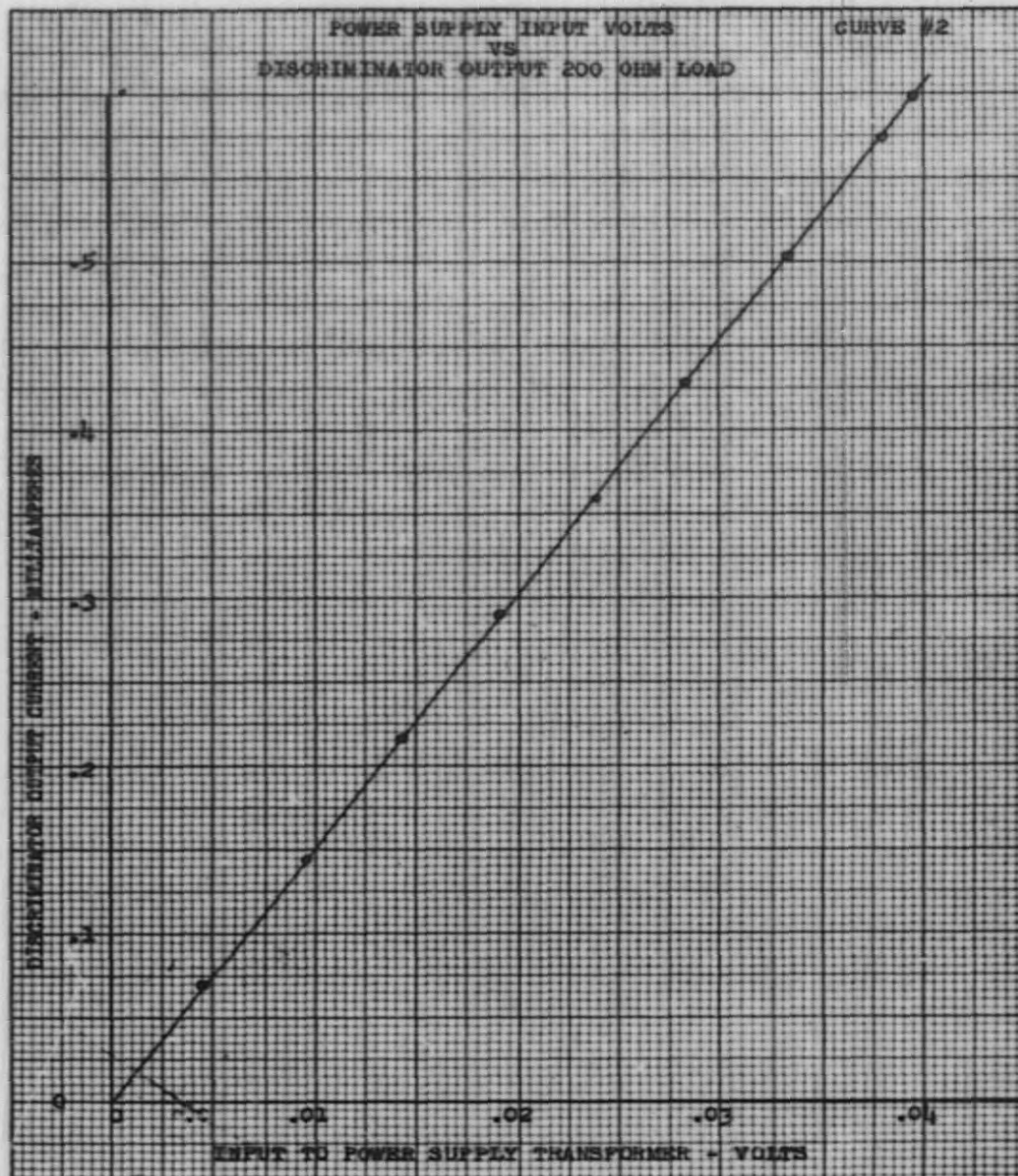
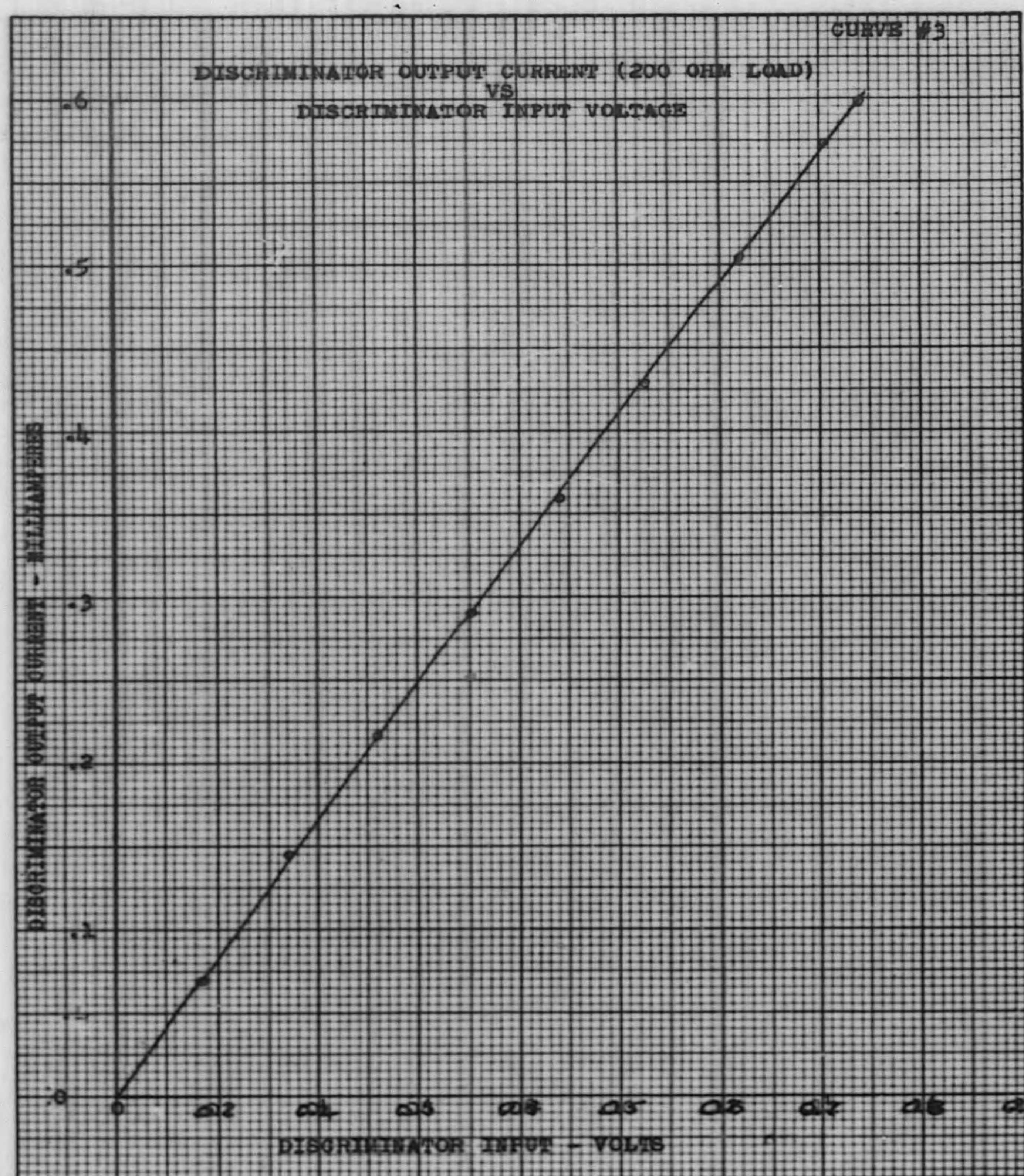
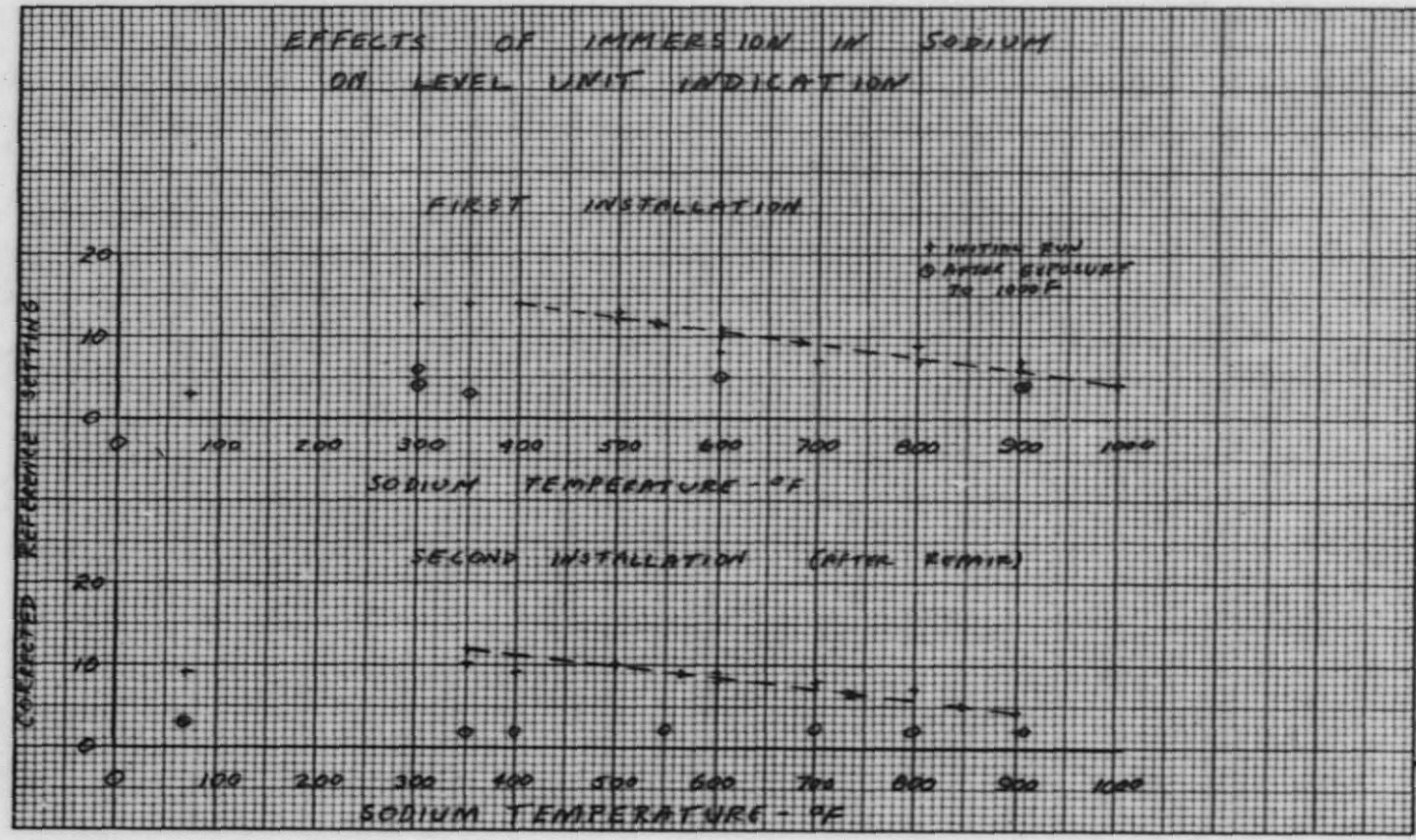


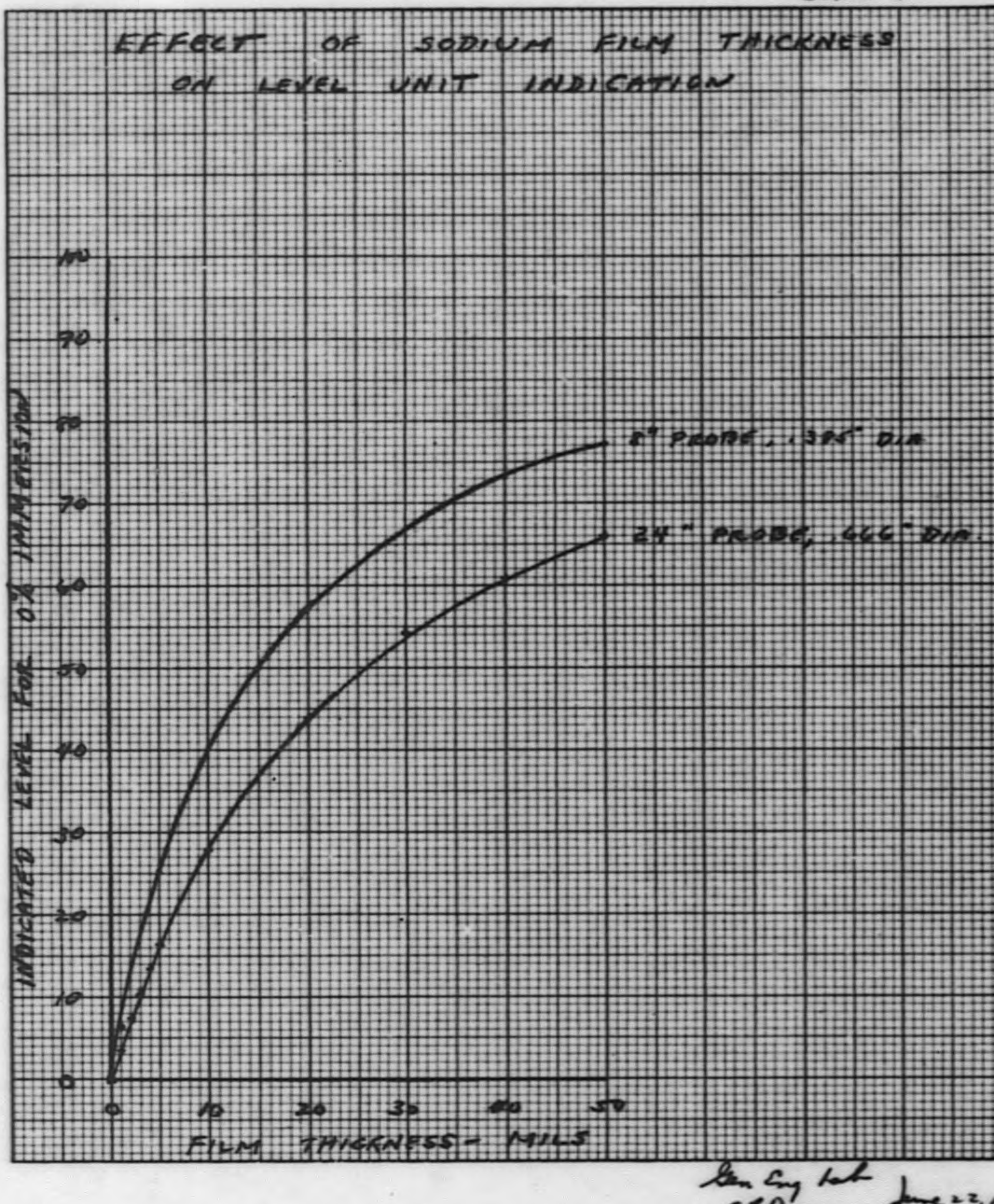
POWER SUPPLY INPUT VOLTS
VS
DISCRIMINATOR OUTPUT 200 OHM LOAD
CURVE #2
DISCRIMINATOR OUTPUT CURRENT - MILLIAMPERES
INPUT TO POWER SUPPLY TRANSFORMER - VOLTS
0
.01
.02
.03
.04


CURVE #3
DISCRIMINATOR OUTPUT CURRENT (200 OHM LOAD)
VS
DISCRIMINATOR INPUT VOLTAGE
DISCRIMINATOR OUTPUT CURRENT - MILLIAMPERES
DISCRIMINATOR INPUT - VOLTS
.6
.5
.4
.3
.2
.1
0
0


EFFECTS OF IMMERSION IN SODIUM
ON LEVEL UNIT INDICATION
FIRST INSTALLATION
SECOND INSTALLATION (AFTER REPAIR)
CORRECTED REFERENCE SETTING
SODIUM TEMPERATURE - °F
0
10
20
100
200
300
400
500
600
700
800
900
1000

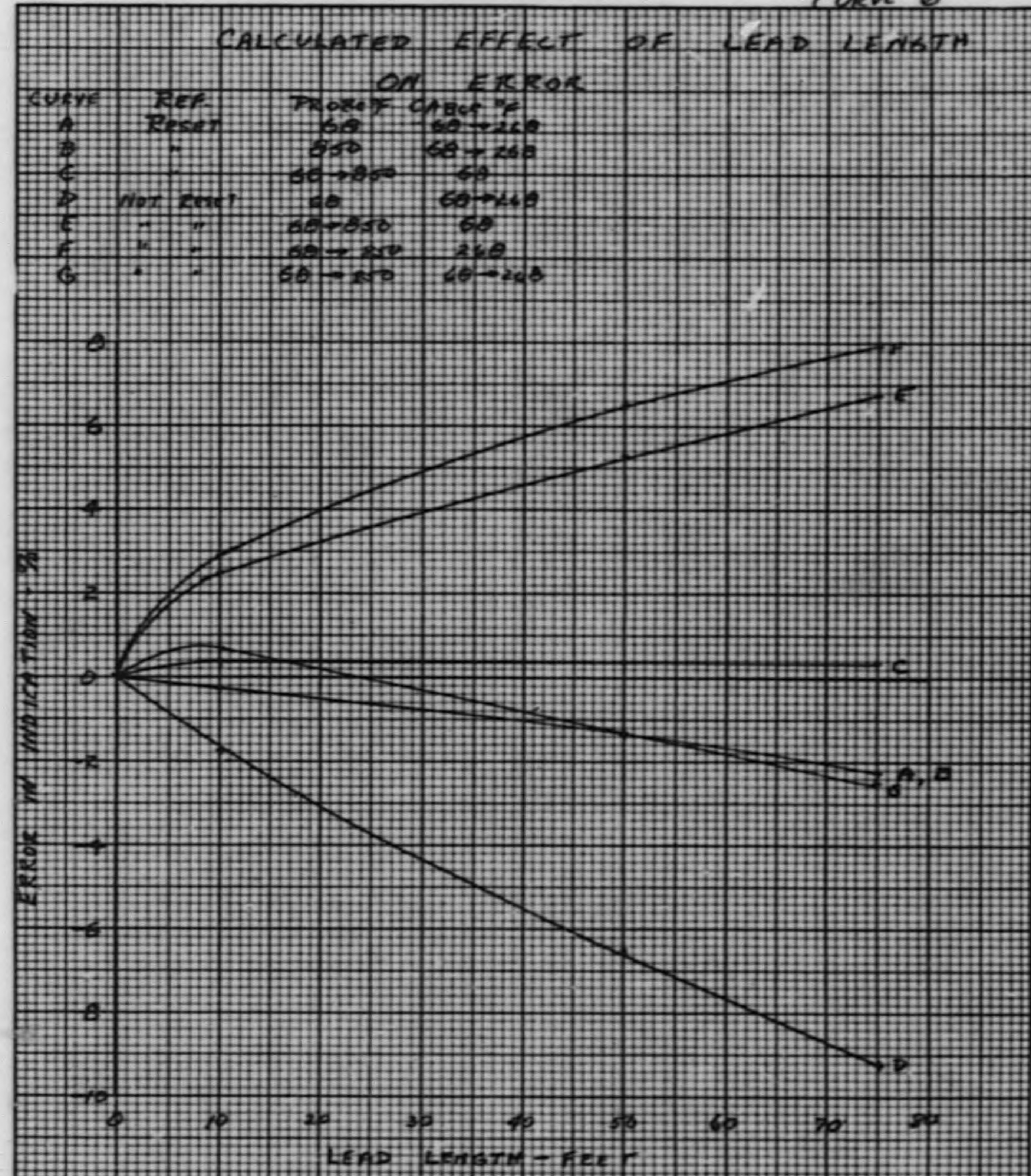
CURVE 4

CURVE 5

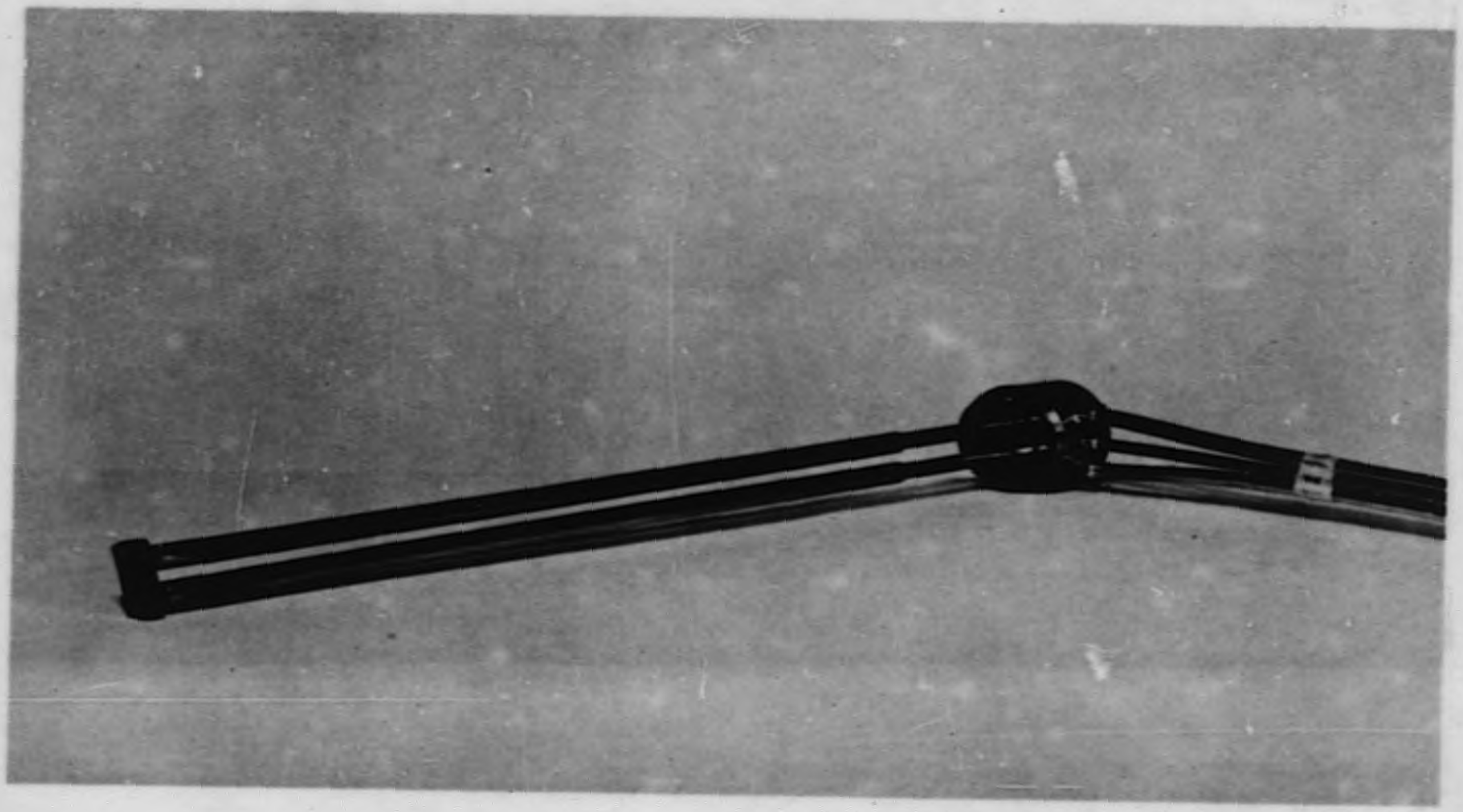


Gen Eng Lab
June 22, 1954

CURVE 6

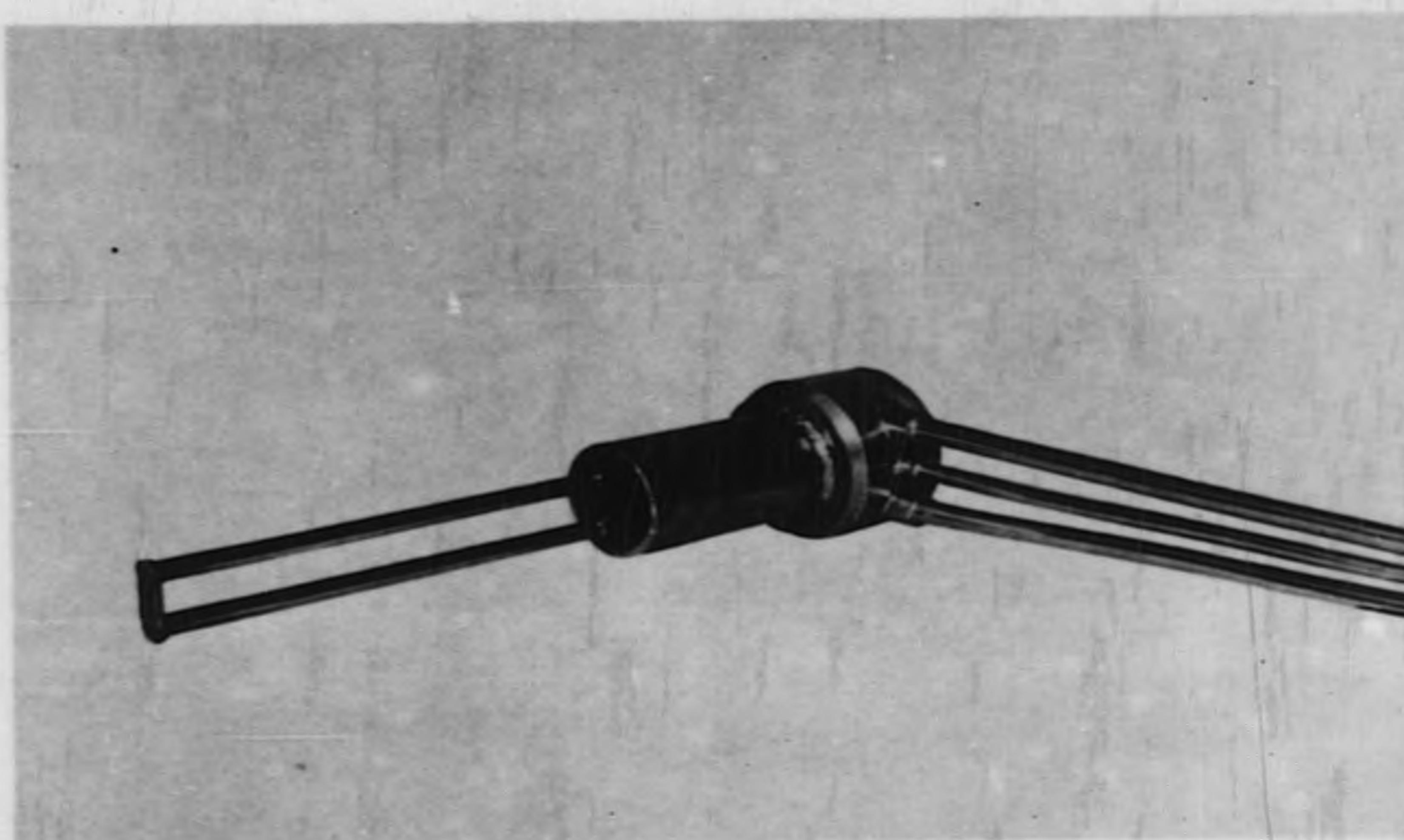


CALCULATED EFFECT OF LEAD LENGTH ON ERROR
CURVE REF. PROBE °F CABLE °F
A RESET 68 68 → 268
B " 850 68 → 268
C " 68 → 850 68
D NOT RESET 68 68 → 268
E " " 68 → 850 68
F " " 68 → 850 268
G " " 68 → 850 68 → 268
ERROR IN INDICATION - %
LEAD LENGTH - FEET
8
6
4
2
0
-2
-4
-6
-8
-10
0
10
20
30
40
50
60
70
80
F
E
C
A, B
G
D



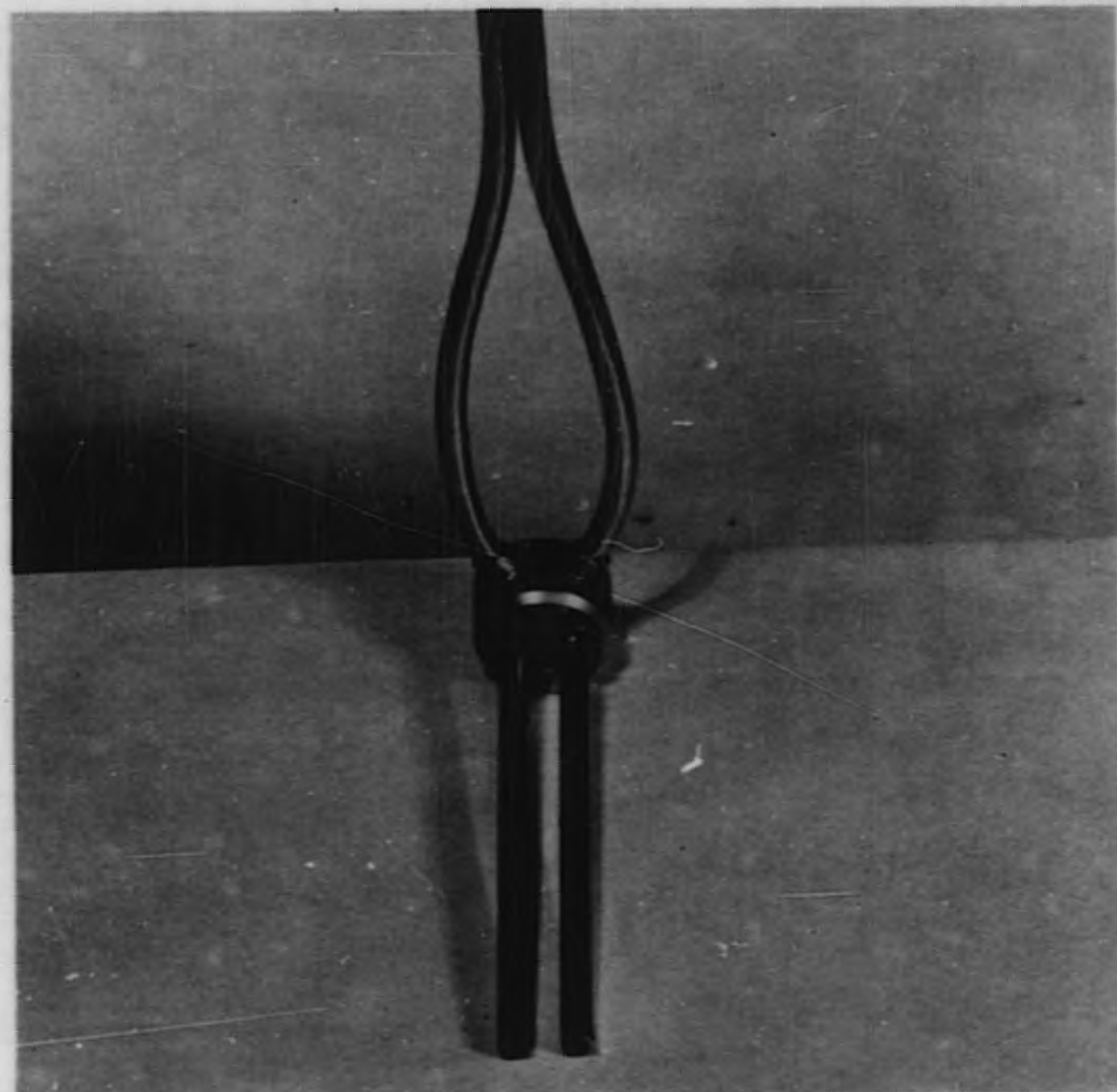
1131 085 PRIMARY DETECTOR, CAT. #124B619G1, (WITHOUT GUARD) USED WITH LIQUID METAL LEVEL EQUIPMENT, CAT. #112L807G1.

11-9-53



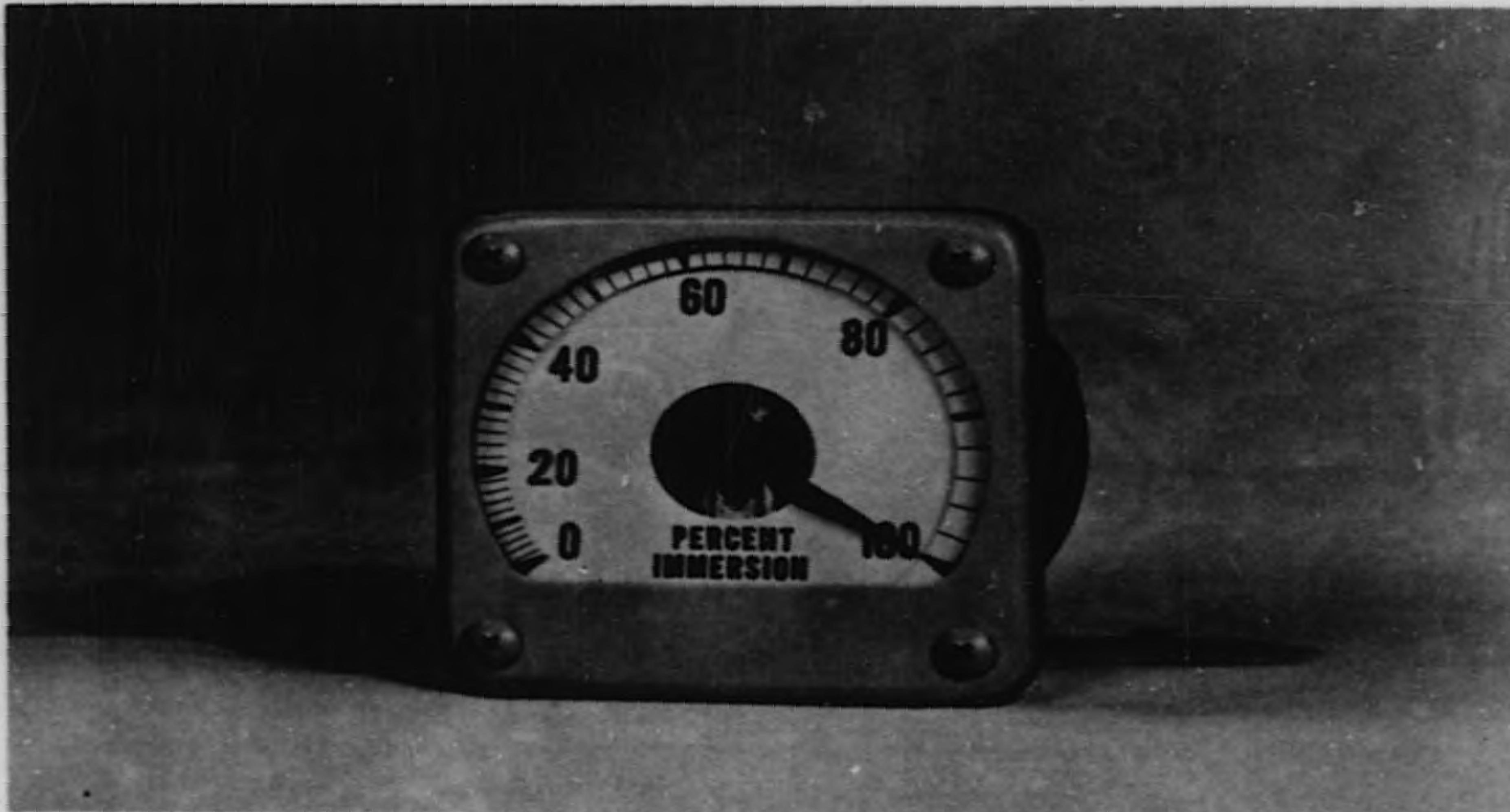
1134 369 PRIMARY DETECTOR, CAT. 124861902.
E369.9

12-31-53



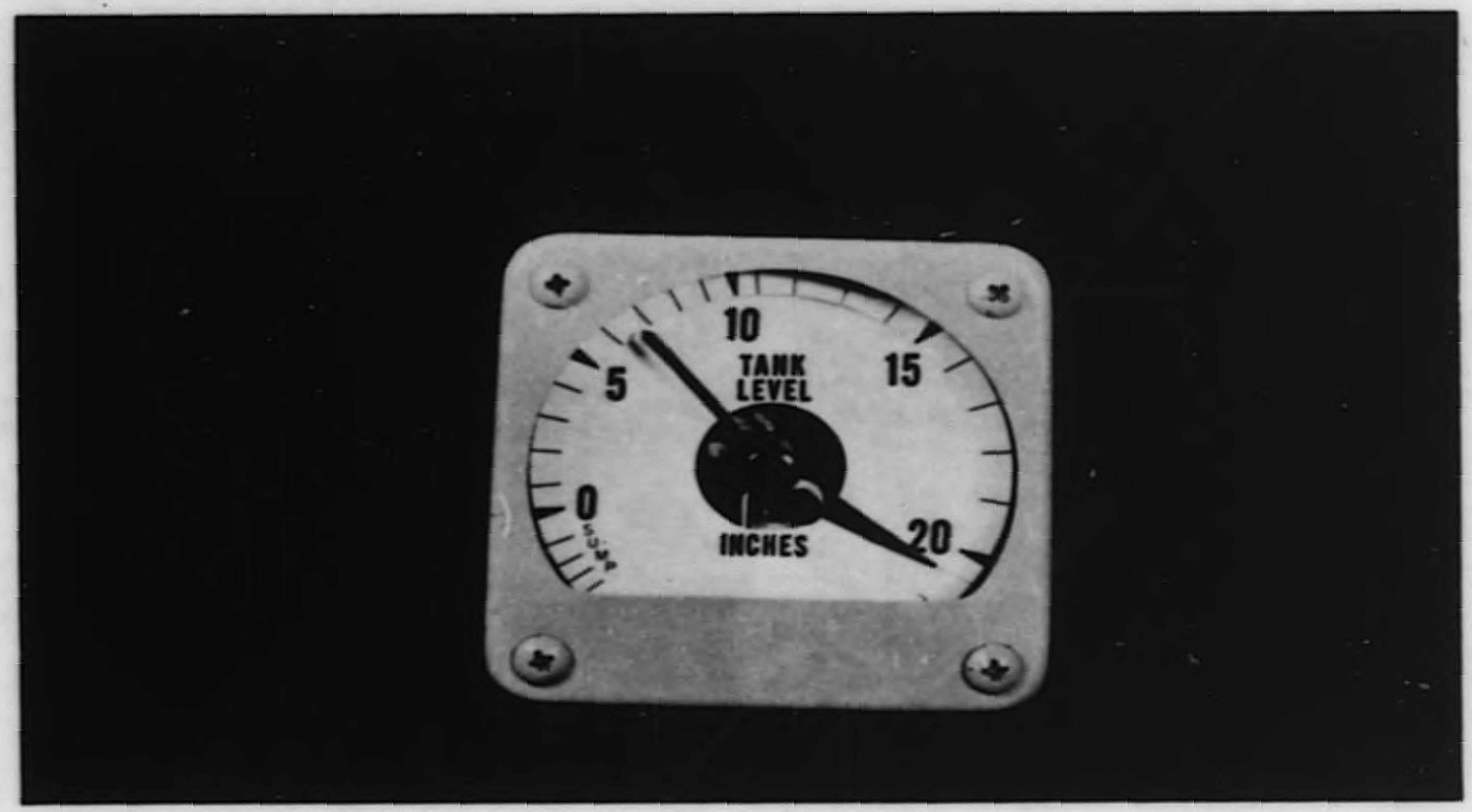
1136 946 ALARM DETECTOR CAT. NO. 124B66301.
E309.9

2-23-64



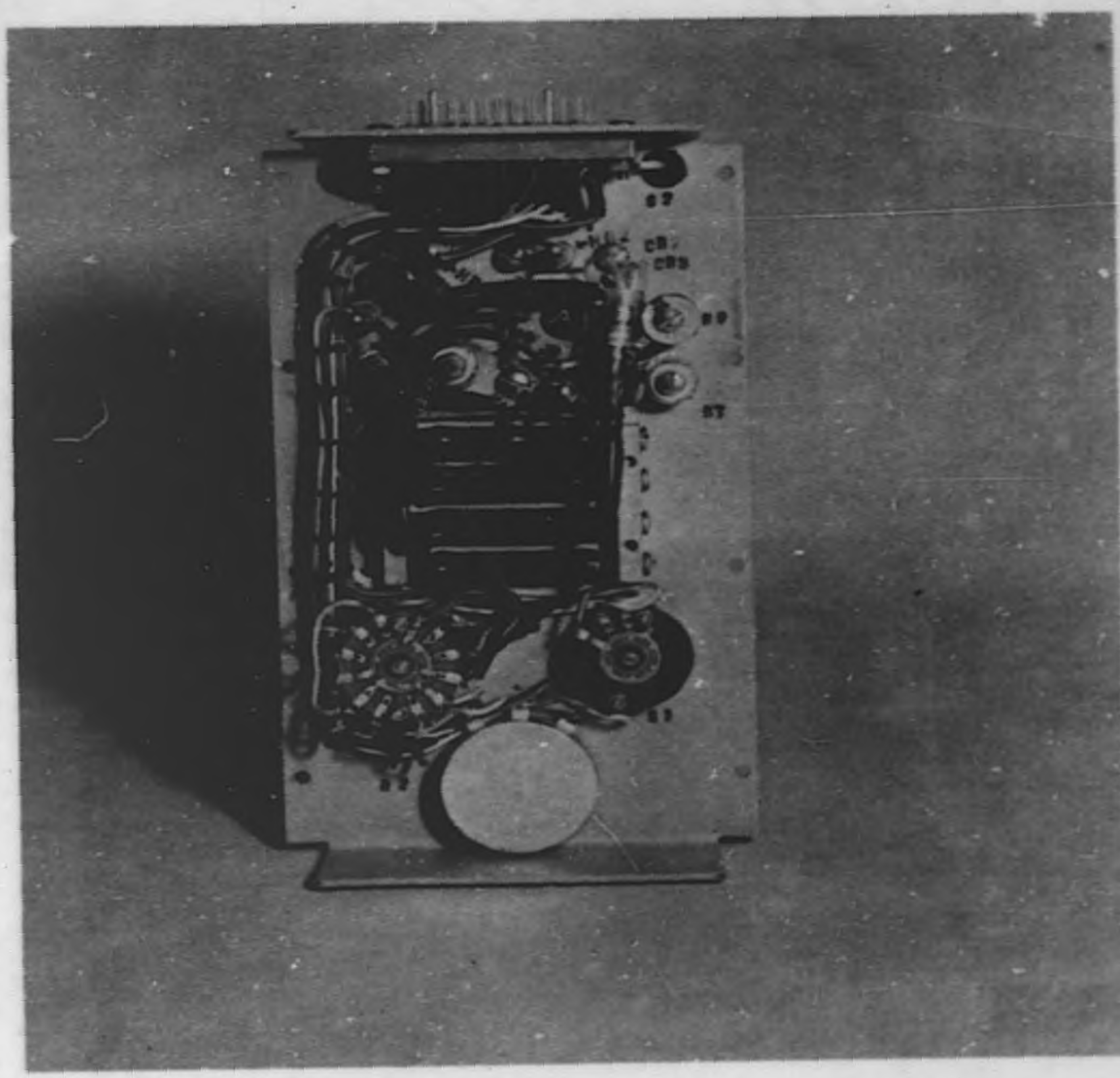
1135 703 INDICATING INSTRUMENT, MODEL 808-14A-55,
E369.9

1-15-54

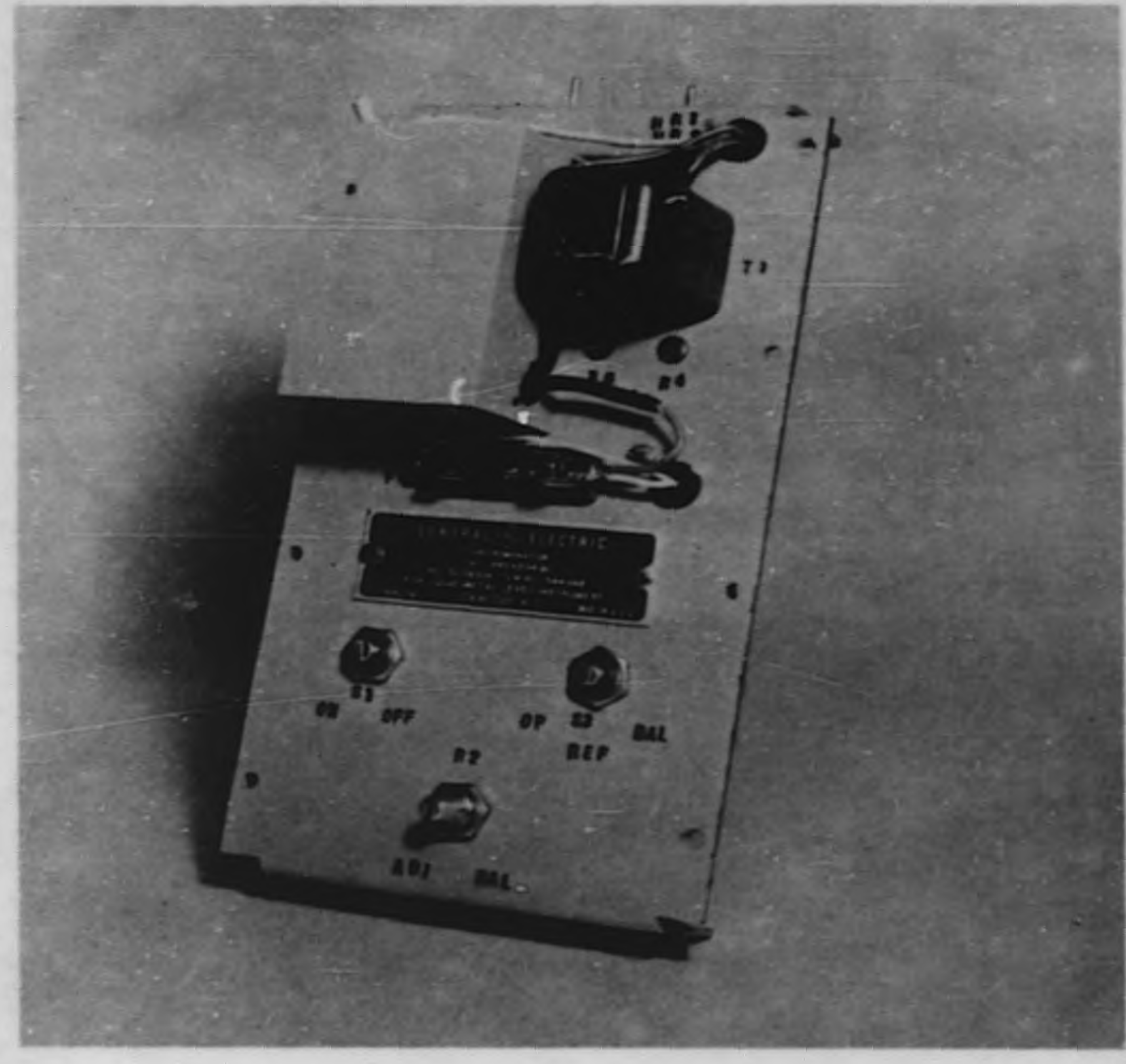


1141 430 INDICATING INSTRUMENT MODEL 808-14A-512,
E369.4

7-14-64

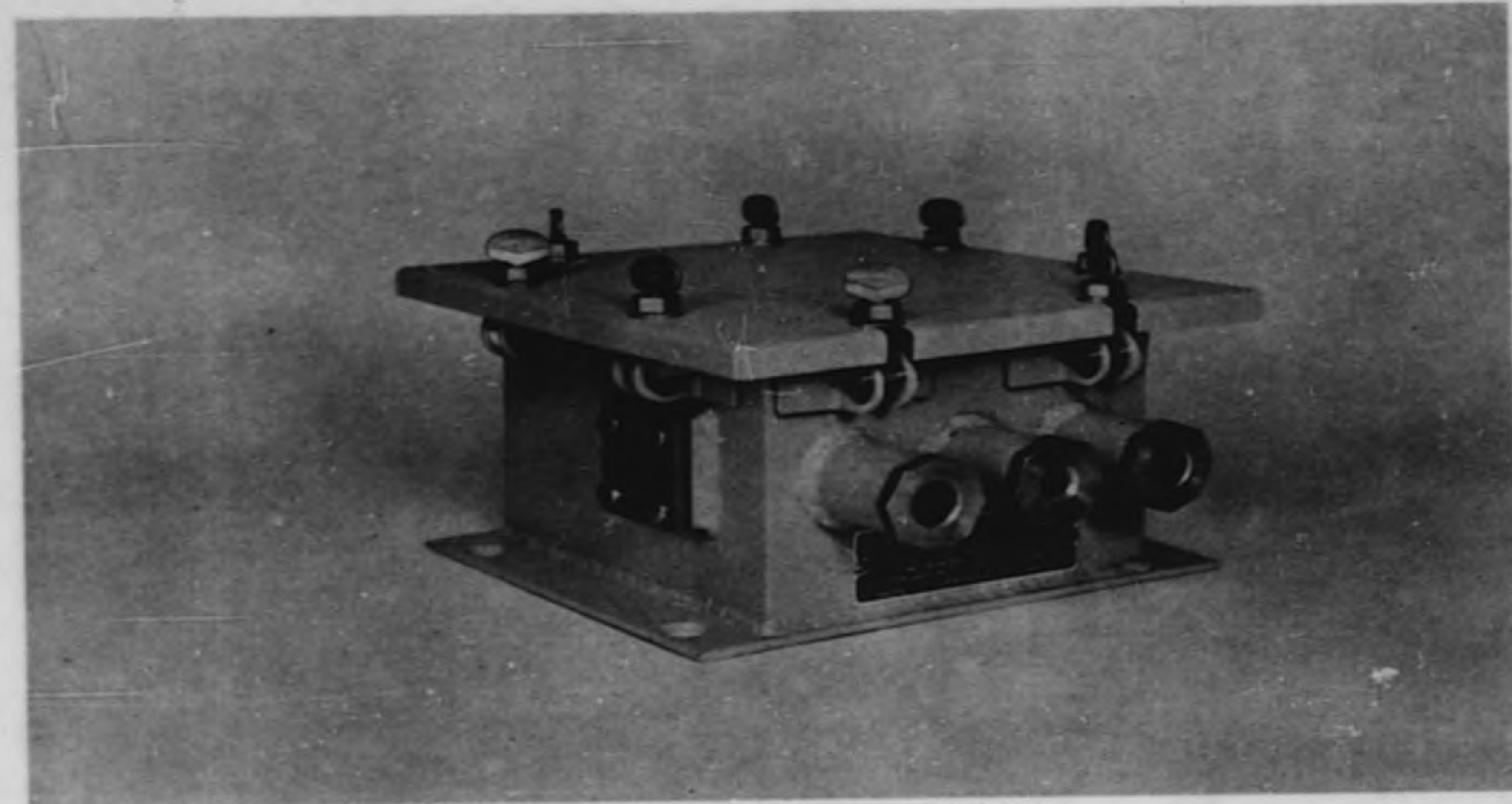


1134 364 DISCRIMINATOR, CAT. 662A204G1, BOTTOM VIEW. 12-31-53
E369,9



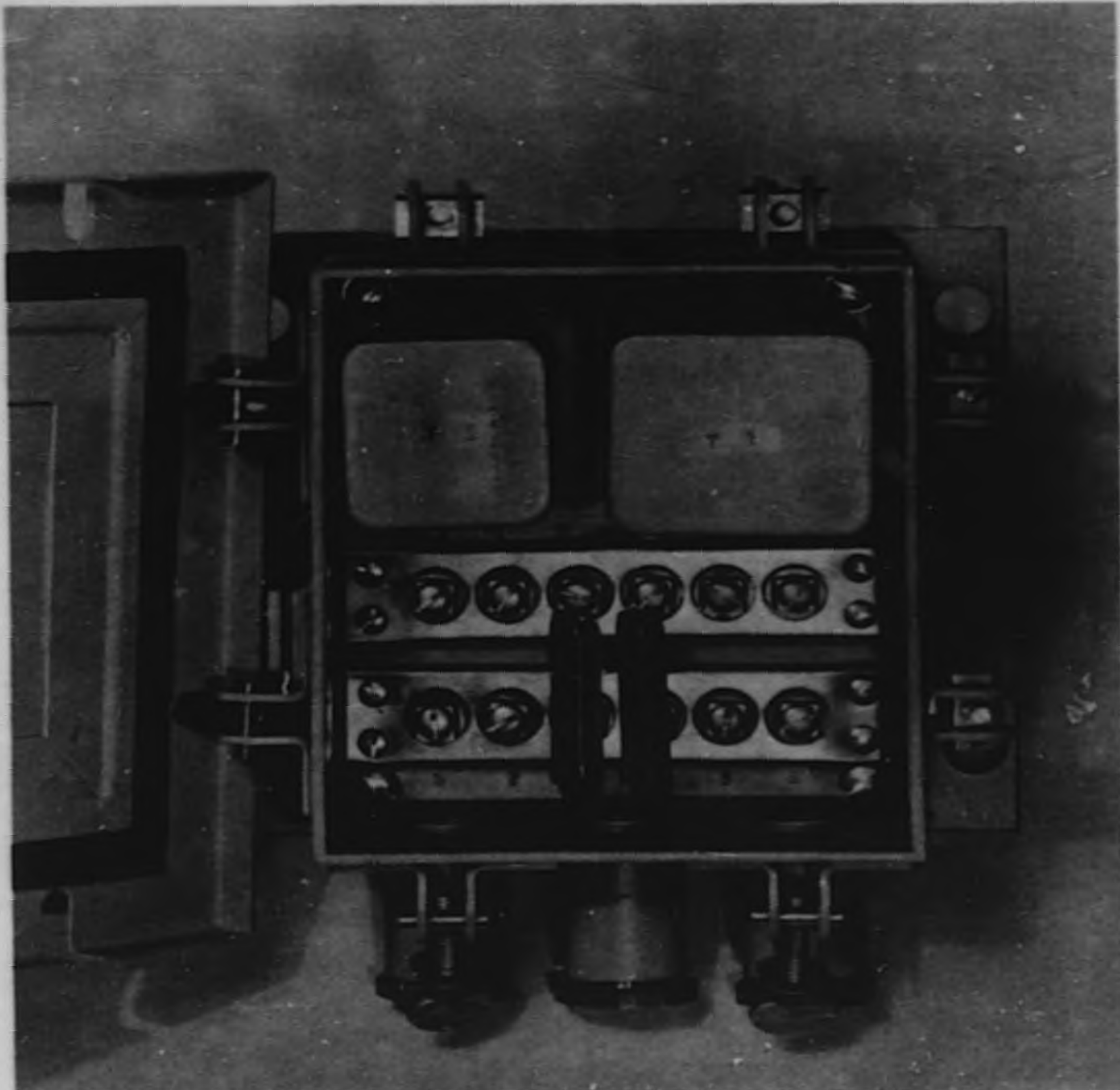
1134 368 DISCRIMINATOR CAT. 662A204G1, TOP VIEW.
E369.9

12-31-59

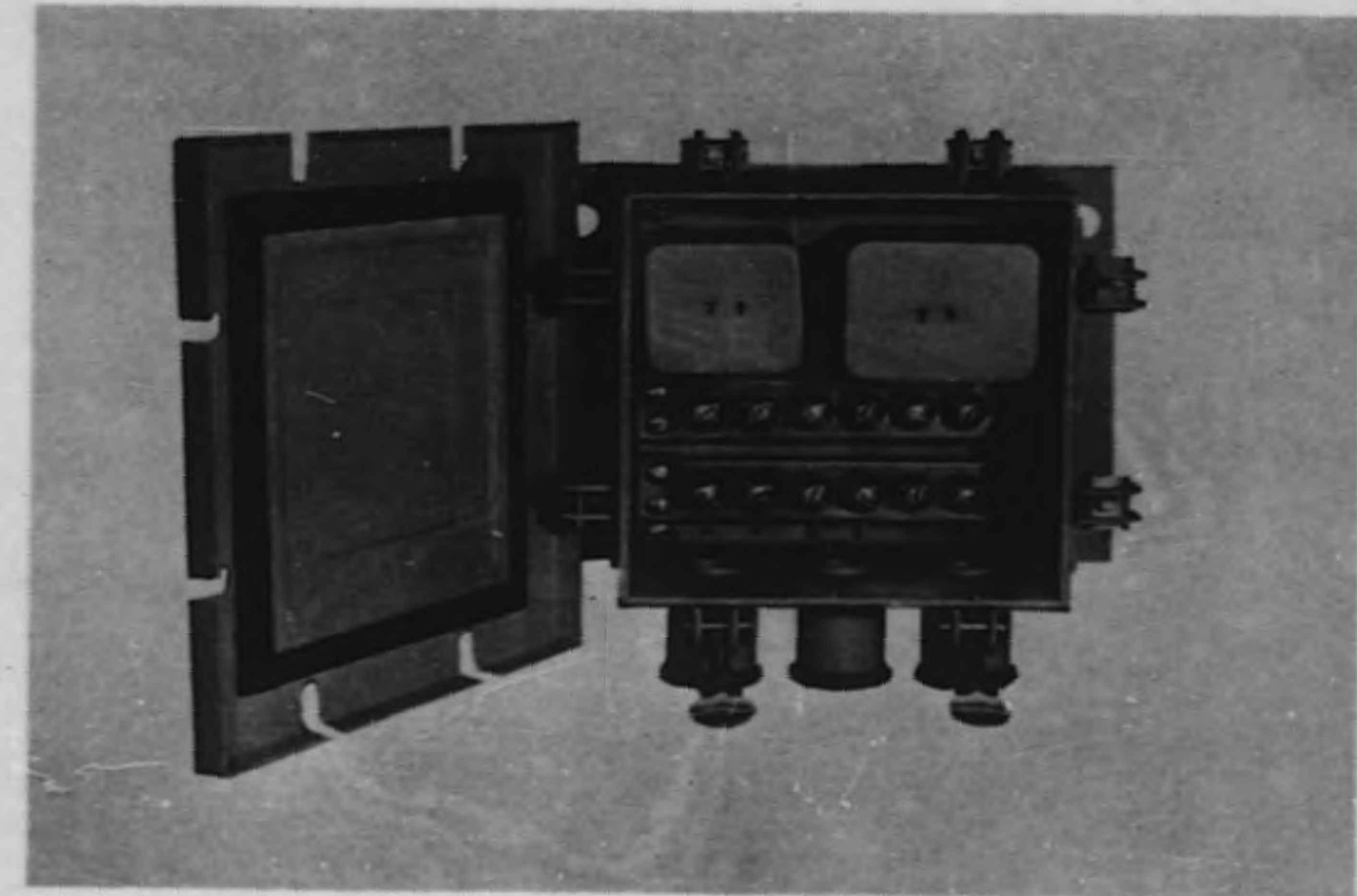


1134 367 POWER SUPPLY, CAT. 118D309G1.
E351.32

12-31-53

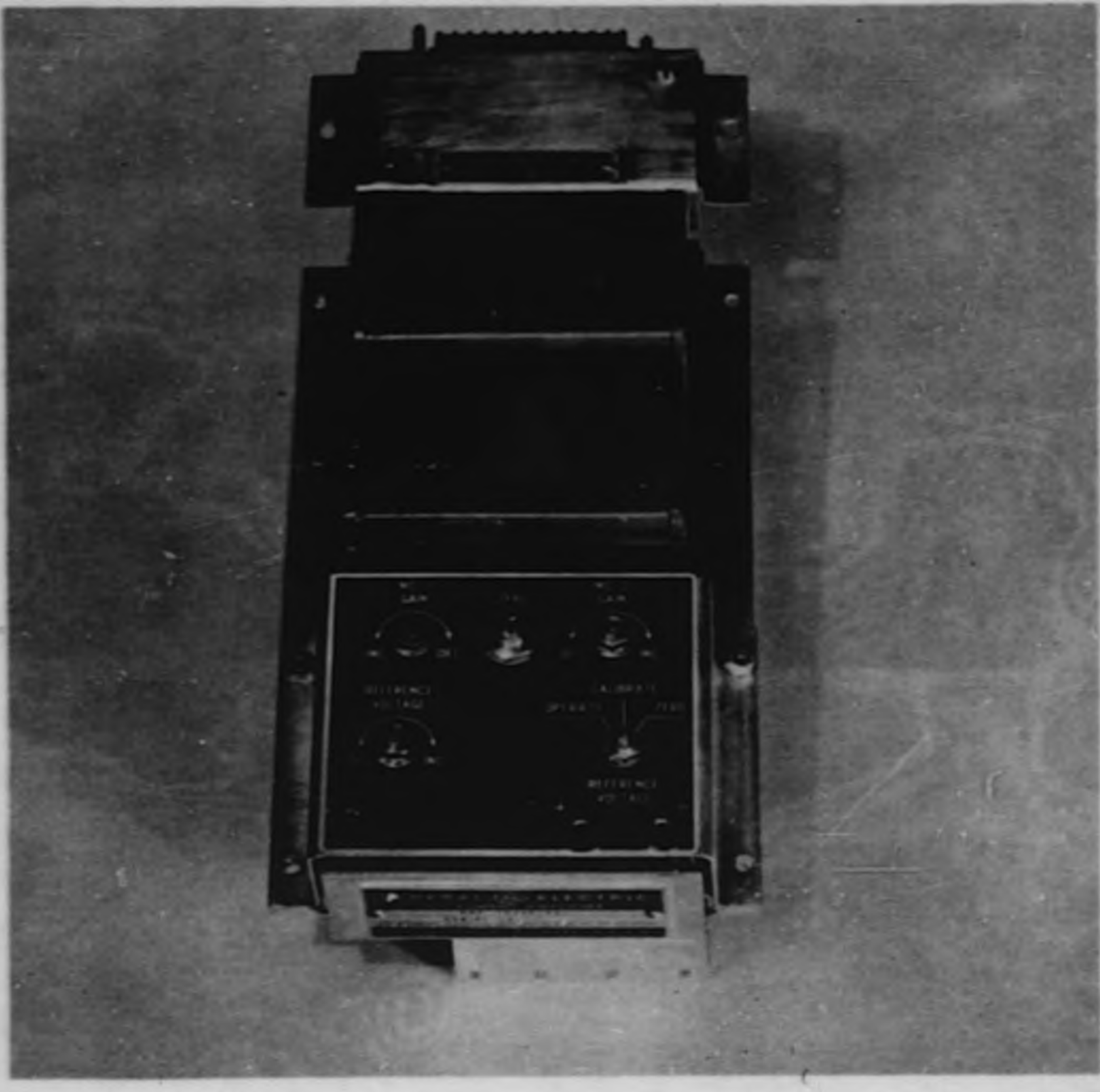


1136 945 POWER SUPPLY. CAT. NO. 118D38902. VIEW OF INTERIOR.
E300.9 2-25-54



1134 366 POWER SUPPLY, CAT. 1180380G1, VIEW OF INTERIOR.
C351.32

12-31-63



1134 722 INSTRUMENT AMPLIFIER WITH (LIQUID LEVEL) ADAPTER (TOP VIEW) 1-12-64
E369.9

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TECHNICAL INFORMATION SERIES
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SUPPLEMENT

to

REPORT NO. R55GL1

SECOND REPORT ON LIQUID METAL LEVEL EQUIPMENT

TESTS ON PRIMARY DETECTOR

G.E. Cat. 124B619G1

APPENDIX I Indication Accuracy Tests

APPENDIX II Effects of Sodium Exposure and Temperature Change

APPENDIX III Conclusions and Recommendations

February 1, 1955

C. R. Droms
General Engineering Laboratory

P. W. Marks
Knolls Atomic Power Laboratory

Right Hand Page

APPENDIX I

Second Report on Liquid Metal Level Instrument

Tests on Primary Detector

G.E. Cat. 124B619G1

for

Indication Accuracy

SIR Mark A

Tests Conducted

at

KAPL Alplaus Area

August 1953 thru February 1954

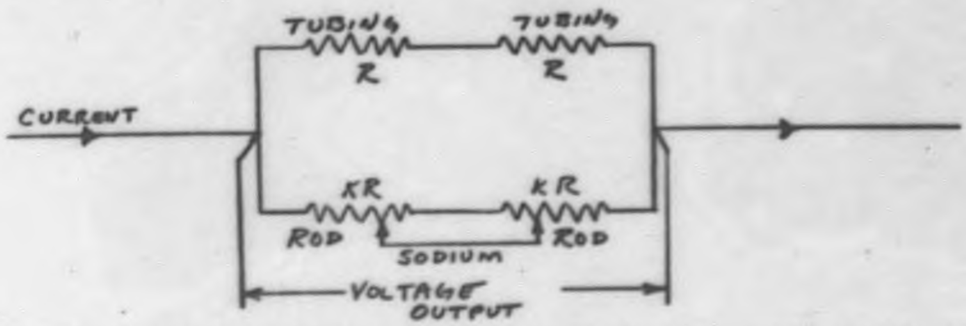
INDICATION ACCURACY TESTS ON LIQUID LEVEL INSTRUMENT

In order to determine the accuracy with which the liquid level instrumentation will indicate level, two factors must be considered, the accuracy of the calculated scale distribution and the constancy of the reference voltage adjustment setting.

A. Scale Distribution

1. Calculations

The scale distribution as marked on the indicating instrument was calculated theoretically by considering the voltage a constant current would develop across four equal resistors connected as the rod and tubing resistances of the detector are connected, as one pair of resistors is gradually shorted out. The equivalent circuit considered is given below,



where R is the resistance of any tube or rod, assumed to be adjusted to be equal, and K is the multiplying factor accounting for the portion of the rod resistance shorted out by the sodium. K will be equal to the fraction of the rod not shorted by sodium.

The equivalent resistance of the circuit of Figure 1 will be

$$R_{eq} = \frac{(2R)\ (2KR)}{2R + 2KR} = \frac{2KR^2}{(1+K)R} = \frac{2K}{1+K}\, R$$

at empty tank, k = 1

$$R_{eq} = R$$

The voltage developed at empty tank would be

$$E_{ET} = IR$$

at partially full tank

$$E_T = I \frac{2K}{1+K} R$$

The ratio of these two voltages would then be

$$\frac{E_T}{E_{ET}} = \frac{I \frac{2K}{1+K}}{IR} = \frac{2K}{1+K}$$

Modifying this relationship to the form necessary for calculating the scale distribution on the 5 milliamp instrument in the output of the magnetic amplifier leads to the following expression

$$I = \frac{2K}{1+K}\ 5$$

For initial calculations, the length of the detector required was not known. In order to mark an instrument scale for test purposes, it was decided to mark the scale in per cent full scale immersion, thus providing a universal indicating instrument which could be used for all tests. When the actual lengths of the detectors were known, scales marked directly in inches could be furnished. The instrument current values for various immersions for the 8" and 24" units are given in Table I. Since full immersion results in zero current through the indicating instrument, the instruments were modified so that mechanical zero was at the right. Thus the scales could be marked with empty tank at the left and full tank at the right, corresponding to the conventional scale marking practice.

For the percentage scales, the above relationship leads to the following values, and the scales were marked accordingly.

Per Cent Immersion	K	$\frac{2K}{1+K}$	I
0	1.0	1.000	5.00
10	0.9	.947	4.74
20	0.8	.889	4.44
30	0.7	.824	4.12
40	0.6	.750	3.75
50	0.5	.667	3.33
60	0.4	.571	2.86
70	0.3	.462	2.31
80	0.2	.333	1.67
90	0.1	.182	0.91
100	0.0	.0	0.00

Using the values given in the table above, a scale was marked in per cent immersion, as shown in photograph 1,135,703 of the main body of the report.

In the calculations for the scale distribution, it was assumed that the sodium shorted the rods with negligible resistance in either the contact or in the sodium. In order to test the validity of this assumption, a series of tests were run by KAPL at their Alplaus test station in a sodium tank where the level and temperature could be varied as required. The General Engineering Laboratory was kept informed of the progress made in these tests, so that consulting advice on the tests could be given. After the conclusion of the tests, copies of the data sheets taken were furnished the General Engineering Laboratory by KAPL. The results discussed in the following summary were taken from this data.

2. Alplaus Tests - First Installation

a. Test Set-up

The test procedure followed during these Alplaus tests consisted of installing primary detector, serial #3237699, Cat. 124B619G1, of the liquid level instrumentation in a tank, with auxiliary tanks and control so that the sodium level could be varied at will. Heaters were provided to vary the tank temperature, and thermocouples were installed to measure temperature. A dipstick was installed as a reference for determining actual sodium level. The dipstick was inserted into the tank through an insulating bushing and a battery and light connected in series with the dipstick and ground. The light, being on, indicated contact between the sodium and the dipstick. These installations were made by KAPL. G.E.L. furnished a developmental sample instrumentation unit consisting of a power supply, discriminator, magnetic amplifier, and indicating instrument, and connected it to the detector. G. E. L. personnel were also present as observers during the first filling with sodium.

b. Initial Filling

Before transferring sodium to the test tank for the first time, the sodium temperature was raised to approximately 350 F. The test tank was also preheated to about the same temperature. Sodium was first admitted to the test tank on August 10, 1953.

Sodium was admitted first to a level approximately 1" above the bottom of the detector, as accurately as could be determined by the dipstick. No motion of the level instrument unit was observed in 12 minutes. The level was then raised an additional inch, and the level instrument was observed to start indicating in a noted time one minute later. The level instrument indication gradually changed until 23 minutes after the level was raised from a dipstick indication of 1" to 2", the level instrument changed from 0 to 4% immersion, a change in indication of slightly less than 1". The level was then again raised gradually in about 4 minutes from 2" to 6.6". It was noted on the record sheet that the liquid level instrument started to change immediately after the level started to change. Readings were taken 2 minutes after the sodium flow was stopped, at which time the level instrument indication agreed with the dipstick to about 0.6".

Shortly after taking these readings, the level was raised to 12", as indicated by the dipstick. In a noted time of one minute, the level instrument indicated 46% (11" immersion), and 12 minutes later, 47% (11.3"). The level was then raised to 24" in 2 minutes. At the time that the dipstick light turned on, indicating a 24" level, the level unit read 88% (21.6") and at a noted one minute later, 92% (22.1"). A dipstick reading at this time showed a level of 24.2". About 10 minutes later, the two readings were 24.2" (dipstick) and 92.5% (22.2") level unit.

After a short time, the level was dropped in steps, and the level unit indications compared to the dipstick. At the lower levels, the two agreed to within about 0.3". The tank temperature was still 350 F.

In the preceding observations, it should be noted that the level instrument was observed to change gradually for the first 23 minutes at a sodium level of 1", but that, when the level was further raised, the indication changed immediately. One factor which might explain this is that there is a bar welded across the bottom of the two detector rods, and that some of the weld oxide is formed at the bottom where it is difficult to clean, and may not have been completely removed. This oxide may have prevented immediate shorting by the sodium. This concluded the initial fill tests at which G.E.L. observers were present.

c. Calibration Tests

Immediately after the initial filling, KAPL started a program to test the instrument over the range of temperatures at which the instrument would be used. Fifteen calibration runs were made during the remainder of August, comparing the dipstick indication with the liquid level indication at 2 1/2" intervals with tank temperatures from 300 to 1000 F. In each run, the procedure was to first adjust the temperatures of the sodium and tank to the desired test level, then fill the tank in steps, comparing the dipstick indications to the level indications. This comparison was also made as the level was decreased in steps. Curves 7, 8, and 9 show typical results on three of the runs. Calculations were performed on the remaining data, and curve 10 was plotted to summarize all of the data. This curve shows the differences between the level instrument readings and the dipstick values at immersions from empty to full tank, and at temperatures from 300 to 1000 F.

Estimating from the scatter of points above and below the zero difference line on curve 10 indicates that the assumptions made to calculate level instrument scale distribution were valid, except perhaps near full immersion. The consistent difference here indicates that the probes cannot be completely shorted out by the sodium, and that a residual resistance remains. In the case of this 24 1/2" detector, the residual resistance is equivalent to about 1/2" of sodium. Other detector lengths would probably be affected to a different degree.

d. Overheating of Unit

As these tests were in progress, the tank in which the detector was located was overheated. Records indicate that the temperature exceeded 1200 F, the limit of the temperature measuring instrument, for several hours. Trouble was reported in operation, and G.E.L. personnel inspected the unit. A high resistance connection was found in one of the measure leads, inside of the detector head. The cap weld was then ground off, and the cap removed from the detector head. The MgO powder packed in the head was removed. Upon inspection, all of the visible braze joints at the top of the detector were good. However, the resistance to ground off the copper lead located in the same tubing section as the series lead would be varied by pushing on it. It was assumed, therefore, that the brazed connection in the bottom of this tubing had opened.

This unit (#3237699) was then removed from the system and returned to G.E.L. for repair. Inspection showed that the copper connection had separated at the hole where it was brazed to the steel rod. The unit was then disassembled, repaired, reassembled and leak tested. Electrical tests were then made to insure proper operation, and the unit was returned to KAPL.

3. Alplaus Tests - Second Installation

After the repair of the detector, it was decided to reinstall it in the test tank, and to conduct further tests. The principal reason for these additional tests was to determine the reason for the change in the reference setting to give correct indication under empty tank conditions, as discussed in R55GL1, starting on page 17.

a. <u>Test Results</u>

In order to test further for the indication accuracy, essentially the same procedure was followed as in the first installation. The tank and sodium were preheated to the desired temperature, and the sodium again admitted in steps, the level being measured by a dipstick, and the results compared to the level instrument reading. Readings were taken at 6 1/8", 12 1/4", 18 3/8", and 24 1/2" level, at both increasing and decreasing levels.

The corresponding immersion readings should have been 25%, 50%, 75%, and 100%. The actual readings obtained, corrected for slight differences between actual sodium level obtained (as measured by the dipstick) and the level desired, and also corrected for variation in reference setting required for correct empty tank readings, are plotted on curve 11.

The results shown on this curve agree with the results shown on curve 10, with the equal scattering of points above and below the calculated nominal value showing that the assumptions upon which the scale distribution was calculated and the instrument marked were correct.

b. Removal of Unit

After the conclusion of the above tests, the detector was removed from the test system, cleaned, and stored by KAPL.

B. Reference Settings

1. Theory

The theory upon which the use of the reference resistor is based is described in the main report, pages 5 and 17. Briefly, the reason for the inclusion of the reference resistor is that the liquid level instrument is primarily a voltage measuring unit, which measures the voltage drop across the rods in the detector. With known current, then, the voltage is a measure of rod resistance. The voltage drop, however, will also depend on the line voltage, since no provision is made for line voltage variations. Variations in voltage due to changes in rod temperature are compensated by the series resistor in the detector. In addition, the actual indicated output will vary with the gain of the magnetic amplifier, and with the lead resistance. In order to provide a check on all of these factors, the reference resistor was furnished to provide a constant value of resistance to be measured. The overall system can then be set to a value to give correct indication, by connecting across this reference resistor and adjusting the gain of the system. This setting is similar to the operation of setting an ohmmeter on zero with leads shorted.

2. Alplaus Tests - First Installation

As mentioned previously, detector #3237699 was installed in test tank at Alplaus, and tests were started on August 10, 1953. As the test temperature was gradually raised on succeeding test days, it was noted that the reference resistor setting necessary for correct empty tank indication did not stay constant. Tests were continued to determine the extent of the change, and if possible, the reason for it. The results obtained are given on curve 4 of R55GL1, and discussed on page 18. It should be noted that each of the points plotted represents a full day of operation at various immersions at the indicated temperature.

3. Alplaus Tests - Second Installation

After cleaning and repairing the unit, it was given bench tests at G.E.L. under a variety of conditions to accurately determine its condition before re-installation. This was done to insure that the changes observed were due to changes in the detector itself, rather than in the instrumentation. These bench tests showed that the correct reference setting at room temperature was 4%.

The unit was then re-installed in the test tank at Alplaus. A series of room temperature tests showed that the reference setting for correct empty tank reading at room temperature was 9%. The principal difference between the two measurements was that, in the bench tests, the unit was not grounded, whereas in the Alplaus tests, it was welded into the system. One possible reason for the difference might be stray voltage pickup. The change in indication was calculated to be equivalent to a change in voltage of 0.0003 volts A.C. in the measure circuit.

In observing the results of these tests, it should be noted that the original reference setting on the first installation at 350 F was 14%, and gradually changed with temperature and sodium exposure to 4%. After removing the unit from the tank, cleaning, disassembly, repair, and re-installation, the value at 350 F was between 10 and 12%.

A series of 15 test runs were made in January and February of 1954. Each run consisted of maintaining a given temperature level for a day, during which time the sodium level was raised and lowered, and the indication compared with dipstick level. A gradual shift was again observed, similar to the results of the first installation tests. These results are plotted on curve 4 of R55GL1 for comparison.

4. G.E.L. Tests - Temperature

Since the reference setting method of adjustment is essentially a comparison of the resistance of the rods at empty tank to the resistance of the reference, the changes noted in the tests could have been due to a change in either resistance. Also, the exposure to which the detector had been subjected was a combination of temperature and sodium wetting. In order to evaluate these effects, a detector, #3237700, of the same type, made at the same time and used only for shock tests, was subjected to a series of exposures for several days to temperature cycles up to 1000 F, thus exposing this detector to the same temperatures without the sodium that the test detector had been exposed to. Tests made before and after showed no changes of comparable magnitude in the unit exposed only to temperature.

A further indication that the shift was due to exposure of the rods to sodium is that the cleaning procedure between the first two installations restored the unit to its original condition, as far as comparison of measure and reference voltages is concerned. Thus, if the change were due to a film of sodium built up on the rods, this film was removed in the cleaning process, and the probes restored to their original condition.

5. Additional Tests

The same unit used in the two installations described above was installed by KAPL in a test tank at L-2. An alarm unit was also installed at the same time. This installation and the test observations are described on page 19 of the main section of the report, and in Appendix II. Further information from KAPL received after the completion of the tests indicated that the sodium used was in a very contaminated state, due to an inadvertant exposure during assembly of the system. This casts extreme doubt on the value of any of the observations during these tests. The tank with the installed unit was then removed from the system and cleaned.

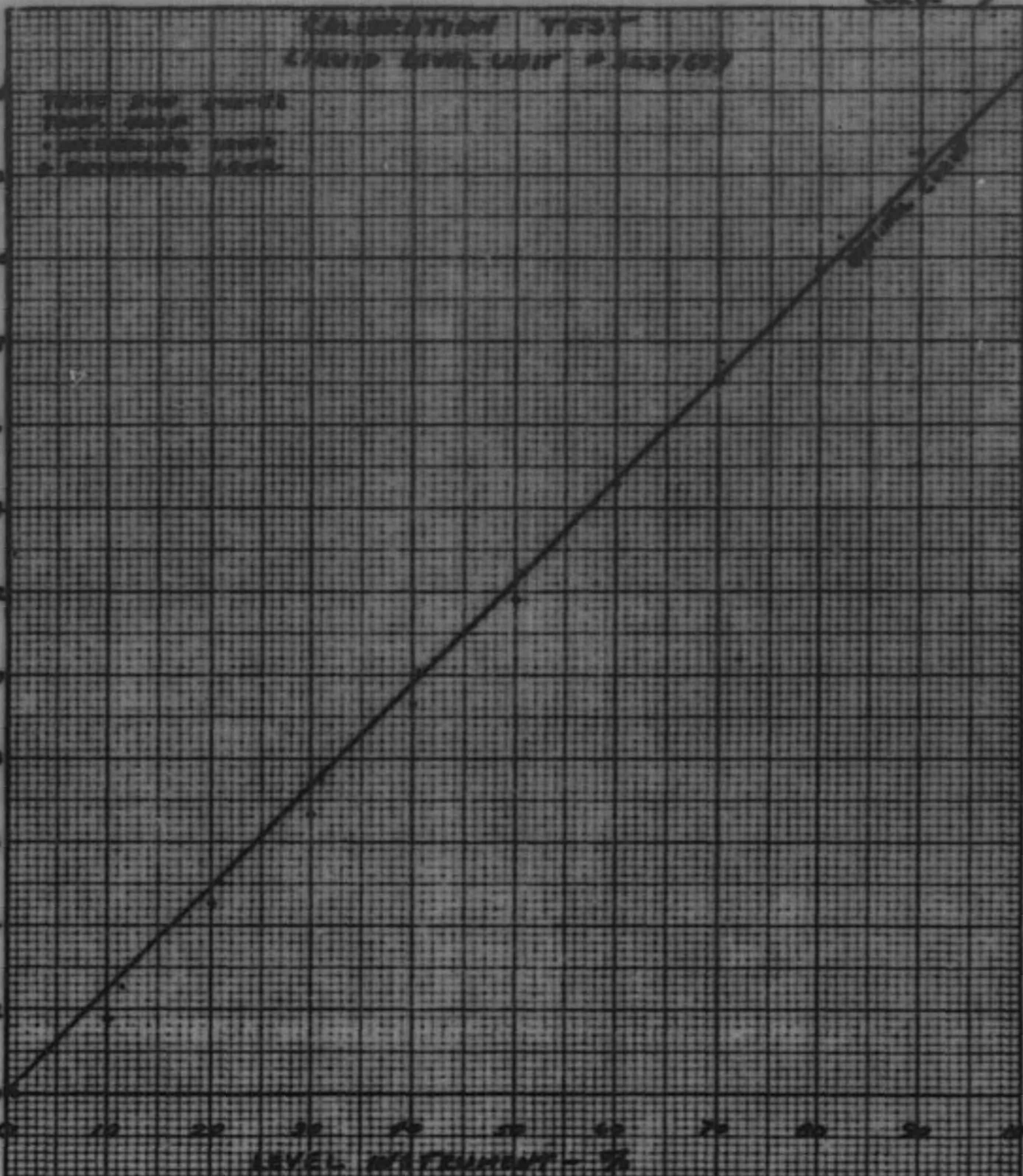
The tank was then re-installed in the system at L-2, and preparations were made to test for the wetting time of the probe, for the effects of continued exposure to sodium, and for sudden changes in sodium temperature. The results of these tests are reported in Appendix II.

TABLE I

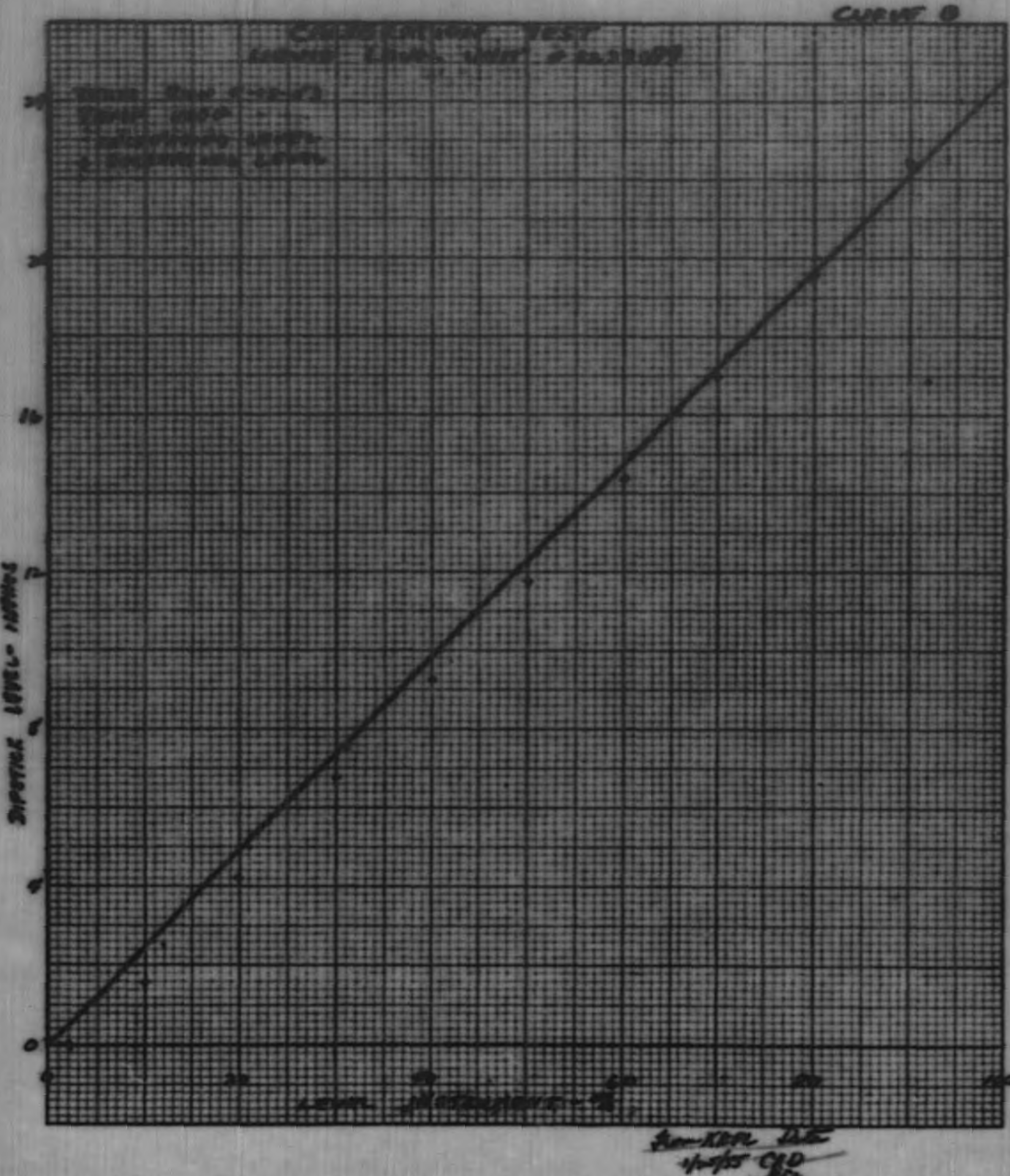
Calibration currents for DB indicating instruments used on liquid level instruments.

8" Probes		24" Probes	
Indicated Immersion	Instrument Current Milliamps	Indicated Immersion	Inst. Current Milliamps
0	5.00	-4	5.04
1/2	4.84	-3 5/8	5.00
1	4.67	-3	4.93
1 1/2	4.48	-2	4.82
2	4.29	-1	4.71
2 1/2	4.07	0	4.59
3	3.85	2	4.34
3 1/2	3.60	4	4.06
4	3.33	6	3.75
4 1/2	3.04	8	3.40
5	2.73	10	3.02
5 1/2	2.38	12	2.59
6	2.00	14	2.10
6 1/2	1.58	16	1.54
7	1.11	18	0.90
7 1/2	0.59	20	0.15
8	0.00	20 3/8	0.00
		21	-0.25

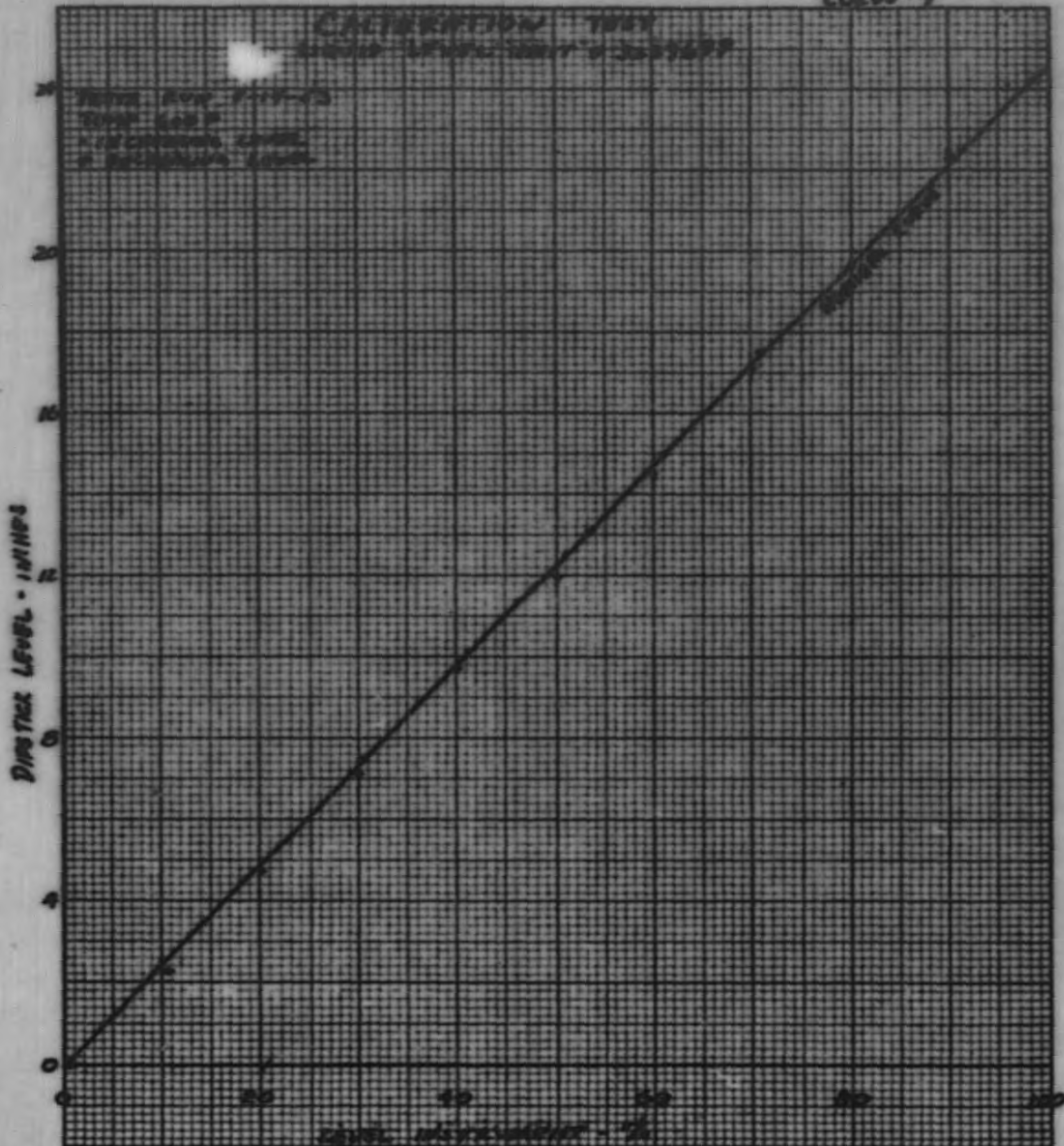
CURVE 7



CALIBRATION TEST
LIQUID LEVEL UNIT
0
2
4
6
8
10
12
14
16
18
20
22
24
DIPSTICK LEVEL - INCHES
0
10
20
30
40
50
60
70
80
90
100
LEVEL INSTRUMENT – %

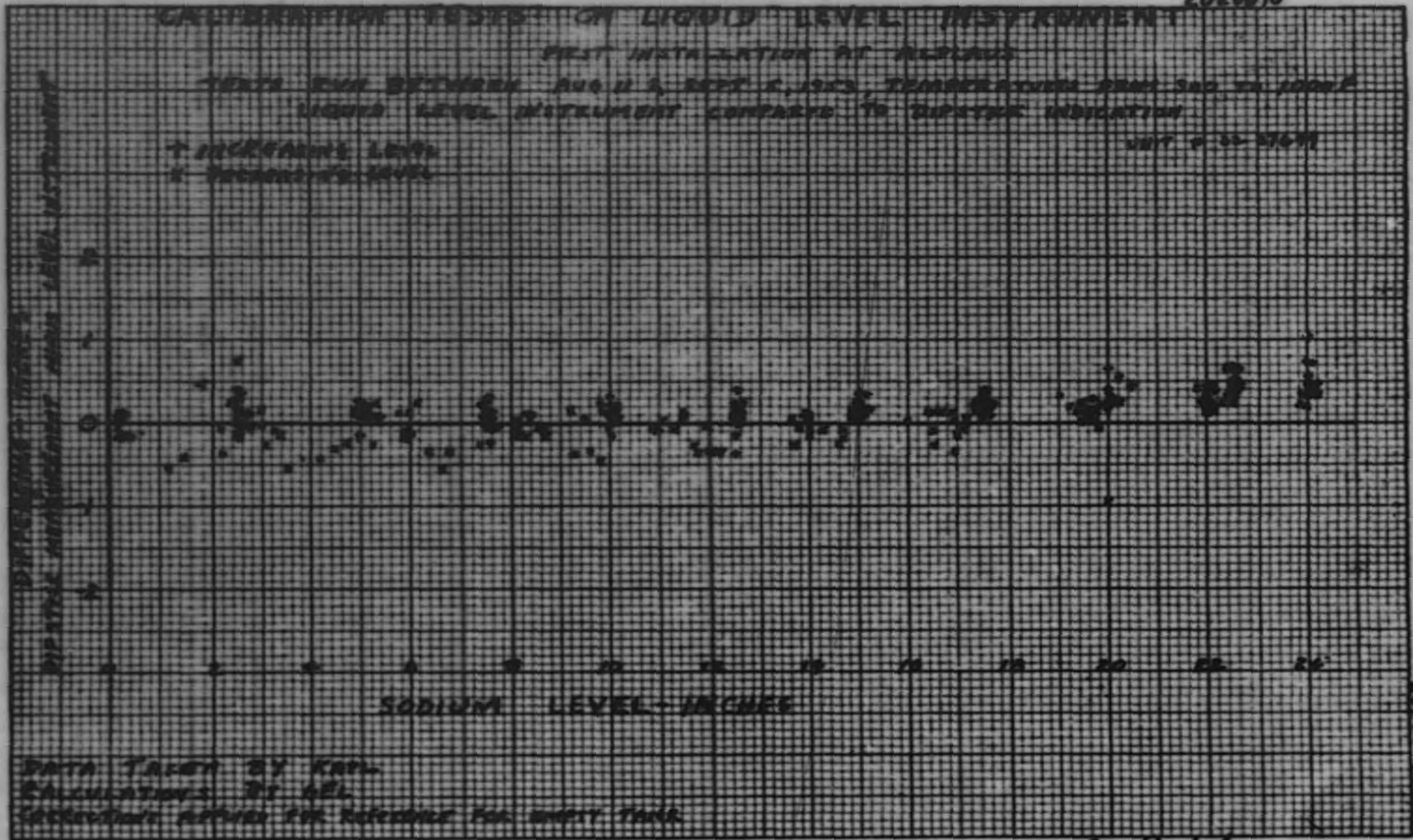

CURVE
TEST

CURVE 9

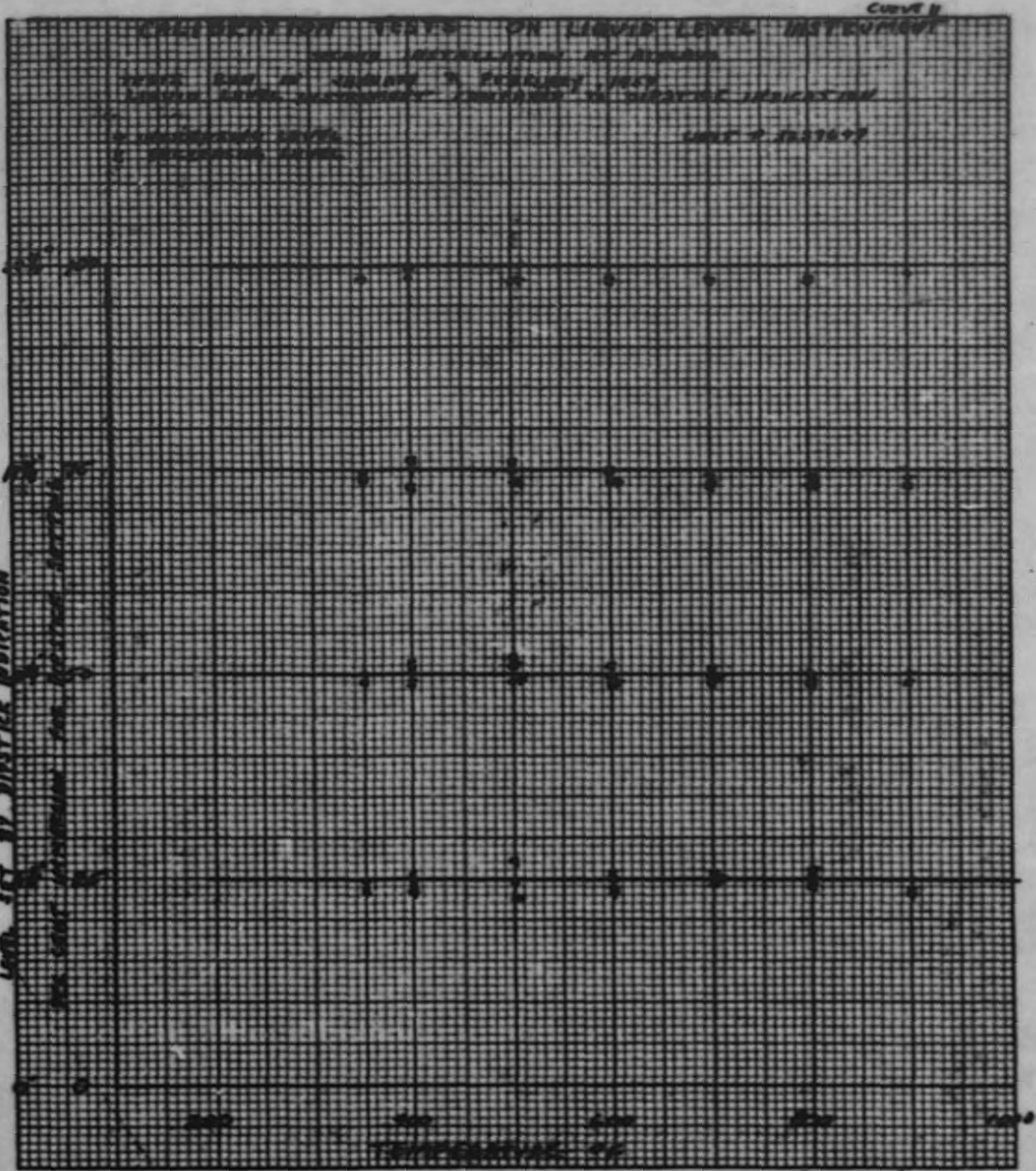


CALIBRATION TEST
DIPSTICK LEVEL - INCHES
0
4
8
12
16
20
0
20
40
60
80
100

CURVE 10



CURVE 10



DATA TAKEN BY KAPL
CALCULATIONS BY GEL
CORRECTIONS APPLIED FOR REFERENCE FOR EMPTY TANK

APPENDIX II

Tests on Primary Detector

G.E. Cat. 124B619G1

for

Effects of Sodium Exposure and Temperature Change

for

SIR Mark A

Sodium Liquid Level Instruments

KAPL Spec. KPP544-14

Tests Conducted

at

L-2 Area

KAPL

October 15 through November 1, 1954

EFFECTS OF SODIUM EXPOSURE AND TEMPERATURE CHANGE

A. Introduction

Between October 15 and November 1, 1954, sodium tests were conducted on a SIR Mark A type sodium liquid level primary detector (24 1/2 inch expansion tank type) G.E. Drawing No. 124B619G1, Serial No. 3237699. This primary detector had been used in previous sodium tests at Alplaus conducted during 1953 and early 1954. For the tests described in this report, the detector was alcohol and steam cleaned* prior to installation in the test tank. In addition, the sodium used was equivalent in purity and oxide content to that specified for SIR Mark A use at the time, having a cold trap temperature of 350 F (oxygen content 0.0035% by wt.).

B. Purpose

The purpose of these tests was threefold:

1. To determine the wetting time of a sodium treated, alcohol-steam cleaned, SIR Mark A type detector in producing an electrical signal proportional to sodium level with both detector and sodium at 350 F.
2. To determine changes in level indication due to time exposure to sodium at elevated temperatures to 900 F.
3. To determine the effect of a sudden change in sodium temperature (up to 100 F/minute) on level indication.

* Removal of sodium residue consists of soaking unit in alcohol and flushing resulting caustic away with steam. Unit is then given final rinse in clear tap water and allowed to dry.

C. Results

The results of the tests conducted indicate the following:

1. This type detector (sodium treated, alcohol steam cleaned) will wet against 350 F sodium (produce an electrical signal proportional to level) within a time span of 11-17 seconds upon initial immersion. At the same temperature this wetting time is reduced to 1-6 seconds for the second immersion.

2. The detector produces a gradual change of 4% in indicated level during the first 24 hours soak in sodium at 700 F (this is equivalent to changing from an initial level indication of 0 inches to an approximate 1 inch level indication for the SIR Mark A expansion tank detector). An additional 72 hours soak at 700 F plus 34 hours at 900 F caused no further change in indicated level.

3. The detector under sudden sodium temperature changes produces the following:
   a. No change in indicated level (25 minutes observed time) for a 40 F/minute change in tank and detector temperature (350 to 430 F).
   b. No change in indicated level (30 minutes observed time) for approximately 100 F/minute change in tank and detector temperature (350 to 540 F).

D. Test Set Up

The test set up consisted of two tanks each made from 8 inch stainless steel pipe and interconnected by a small valved line at the bottom. One tank was used to contain the sodium and maintain its required temperature for the tests. The other tank contained the primary detector and a dipstick, both mounted from the top. Tank temperatures were maintained by calrod heaters and each tank was equipped with two thermocouple wells which projected into the sodium. By using a special design packing fitting it was possible to safely raise and lower the dipstick to determine sodium level. An inert blanket of helium gas was kept in both tanks to provide system pressure and also maintain sodium purity. By varying the pressure of this helium in either tank, and operating the valve in the interconnecting line, it was possible to raise and lower the sodium level around the detector and to hold the level at any point.

The circuitry used to measure outputs of the primary detector consisted of the standard SIR Mark A liquid level measuring system components plus additional recording instruments and their amplifiers. This equipment is listed at the end of this report and a schematic (SK55615-302) of the Mark A components appears in G.E.L. Report No. R55GL1. To this system were connected two electronic voltmeters (Ballantine) for obtaining both "measure" and "reference" voltages. These voltages were in turn amplified and recorded on G.E. photoelectric recorders. The electronic voltmeters were connected at leads 3 and 4 and 7 and 8 of the power supply to provide true detector voltage outputs and eliminate errors at the indicating instrument due to possible drift in the discriminator and instrument amplifier. On the output side of the instrument amplifier was connected one channel of a two channel Brush recorder to record milliamp output. The other channel was used to record the contact of the dipstick with liquid sodium. By means of a switch on a Variac controlling the 400 cycle 115 volt power it was possible to simultaneously introduce on each recorder a signal giving a common time reference point. The chart records could then be compared with each other to show primary detector output at the time the dipstick made contact with the liquid sodium.

E. Test Procedures

For the wetting test the sodium hold tank and primary detector were stabilized at 350 F. The bottom of the dipstick was set at a level corresponding to the top surface of the spider connecting the two resistance rods of the primary detector (see G.E. photograph 1131 085 in G.E.L. Report No. R55GL1). This is the point at which the primary detector first starts to indicate the presence of liquid sodium.

A time reference point was indicated on all recording instruments as described in the preceding section and the valve was opened admitting sodium to the bottom of the tank containing the primary detector and dipstick. In approximately 3 minutes time the sodium level had risen and contacted the dipstick which produced both a visual light signal and a change in trace on one channel of the Brush recorder. An operator, noting the light signal, marked the dipstick and then raised it approximately 3 inches breaking contact with the sodium surface. When the sodium level rose and again contacted the dipstick, the above procedure was repeated.

For time exposure tests to sodium at elevated temperatures, empty tank* readings of both the "reference" and "measure" voltages of the primary detector were made at 700 F. Sodium at this temperature was then admitted to the tank until it completely covered the detector rods. Maintaining this temperature and level, the detector rods were soaked for periods of approximately one hour. At the end of each period, the sodium was forced out into a hold tank and then empty tank voltage readings of the detector were again taken. Sodium was then immediately re-admitted and the soaking procedure repeated.

* Empty tank condition chosen because (1) it is the most reliably known level during tests and (2) detector voltage changes are relatively large for small level increments at this end of the detector rods.

The procedure for determining the effect of a sudden change in sodium temperature upon the primary detector consisted of raising the temperature of the hold tank containing sodium well above that of the tank with the primary detector. After allowing both tanks to stabilize at specific temperatures, the valve in the interconnecting line was opened and the hotter sodium forced in against the primary detector until both it and the dipstick indicated that the sodium level was approaching 12 inches (covering approximately half the detector rods). At this point the valve was closed and both temperatures and level indications were carefully observed for approximately 30 minutes. During each test, thermocouple readings indicated that the resultant temperature of tank, detector, and sodium had become stable approximately 2 minutes after sodium was first admitted to the tank.

F. Data

Wetting data was taken for two immersions of the primary detector in sodium; the first filling allowed sodium to rise and cover approximately half the length of the rods (about 12 inches). Sodium was then forced back out of the test tank to the hold tank. The second filling allowed the sodium to rise to an indicated dipstick level of some 21 1/8 inches (approximately 86% of the effective length of the resistance rods).

The chart records of "measure" and "reference" voltage were compared to the corresponding dipstick level signal, all from a common time reference point. Since there was no significant change in "reference" voltage trace, no corrections were necessary to the "measure" voltage trace. Immediately upon completion of each filling the "measure" voltage recorder was calibrated against dipstick readings as the sodium level was lowered. This in effect gave a known detector output ("measure" voltage) for particular dipstick settings. It was then possible to retrace the chart and determine the time delay between the original "measure" voltage trace (for increasing sodium level) and the dipstick contacts. This data has been summarized on Data Sheet I.

Data for the time exposure tests consisted of empty tank readings of "measure" and "reference" voltages covering a period of several days. During this time readings were taken approximately once an hour. A gradual change in "measure" voltage occurred during the first 24 hours at 700 F as complete wetting occurred. It amounted to a 2% voltage change at empty tank which would give a change in level indication of 4% at empty tank due to the non-linearity of the scale. To show that complete wetting* of the detector rods had occured during this 24 hour period the test was continued an additional 72 hours

* Complete wetting determined when there is no change in ratio of measure to reference voltage with increase in time and temperature.

at 700 F. As final proof the temperature was then raised to 900 F and readings noted for an additional 34 hours. A short summary of this data is given on Data Sheet II.

Data for determining the effect of a sudden change in sodium temperature upon the primary detector was taken for two rates of change. For the first, sodium at approximately 650 F was transferred into the test tank which contained the detector at 350 F. This produced a rate of change of 40 F/minute since the resultant temperature stabilized at approximately 430 F in two minutes time. The indicating meter of the primary detector was observed to reach a final reading when the sodium flow was stopped with no change in indicated level for the next 25 minutes. For the second test, sodium at approximately 900 F was transferred into the test tank. The detector was at 350 F. Once again temperatures stabilized in approximately two minutes, producing a rate of change of 100 F/minute since the resultant temperature leveled out at 540 F. The indicating meter was observed when the sodium flow was stopped and for the next hour. A decrease in level indication of 3/8 inch was observed during this period, but a re-check at the end of this period with the dipstick showed that the sodium level had dropped 3/8 inch. The data for these tests has been summarized on Data Sheet III.

DATA SHEET I

	Column 1 Dipstick Contact No.	Column 2 Dipstick Level (inches)	Column 3 Dipstick Chart Time*	Column 4 "Measure" Voltage Chart Trace Reading**	Column 5 "Measure" Voltage Chart Time*	Column 6 Time Delay (Seconds)***
First Filling	1	0	3:14	8.6	---	
	2	3.1	3:42	8.0	3:53	11
	3	6.2	4:03	7.4	4:16	13
	4	9.1	4:33	6.6	4:50	17
	5	12.1	5:07	5.8	5:18	11
Second Filling	1	0	2:25	8.4		
	2	3.1	2:45	7.9	2:47	2
	3	6.1	3:05	7.2	3:08	3
	4	8.9	3:25	6.6	3:26	1
	5	12.1	3:46	5.6	3:52	6
	6	15	4:07	4.6	4:12	5
	7	17.9	4:30	3.3	4:36	6
	8	21.1	4:55	1.8	5:00	5

* Minutes from common time reference point.
** These values correspond to dipstick levels in Column 2 - calibrated against dipstick readings after each test as sodium level dropped.
*** Time difference between Columns 3 and 5

SIR Mark A Sodium Liquid Level Detector - Serial 3237699
Wetting Tests, L-2 Area, KAPL
Data recorded 10-18-54

DATA SHEET II

Time	Temperature ° F	Ratio Measure to Reference
After reaching temperature	700	1.01
After 1 hour soak		1.00
After 10 hour soak		0.99
After 24 hour soak		0.98
After 96 hour soak		0.98
After reaching temperature	900	0.98
After 34 hour soak		0.98

SIR MARK A Sodium Liquid Level Detector - Serial 3237699
Wetting Tests, L-2 Area, KAPL
Data Recorded 10-19-54 thru 10-28-54

DATA SHEET III

Time	Instrument Amplifier Output (Milliamps) Ref.	Meas.	Sodium Level Test Tank — Indicating Meter (Inches)	Indicating Meter %Immersion	Dipstick Inches	Average Test Tank Temperature °F.
			10/25/54			
1040	5.00	4.91	0	0	0	370
1055	5.00	4.91	0	0	0	360
1103	Transferred Sodium To Test Tank					
1105	5.00	3.35	12.1	49.5	12.2	430
1115	5.01	3.36	12.1	49.5	NR	437
1130	5.00	3.33	12.2	50.0	NR	410
1155	Transferred Sodium Back to Hold Tank					
			10/26/54			
1440	5.00	4.95	0	0	0	350
1445	5.00	4.95	0	0	0	350
1450	Transferred Sodium To Test Tank					
1451	5.00	3.35	12.1	49.5	12.2	NR
1453	---	---	---	---	---	540
1455	5.00	3.40	11.9	48.5	NR	NR
1505	5.00	3.40	11.9	48.5	NR	540
1520	5.00	3.40	11.9	48.5	NR	510
1540	5.00	3.43	11.7	47.9	11.8	490
1540	Sodium Level Noted to Drop - Verified by Dipstick					
1620	5.00	3.43	11.7	47.9	11.8	NR

NR-Not Recorded/Noted

SIR MARK A Sodium Liquid Level Detector - Serial 3237699
Wetting Tests, L-2 Area, KAPL
Data Recorded 10/26/54

G. Graphs

The results of the data taken on wetting tests have been plotted on two graphs. Graph I shows a plot of "sodium level-inches" vs. "time-minutes" for both the dipstick and the primary detector indication for the initial filling. The detector indicated level lagged behind that of the dipstick by roughly 12 seconds. Of interest is the fact that the indicated level remained essentially constant (within 1/2% of detector range) as soon as the valve was closed. Several seconds were consumed in closing the valve. This fact, coupled with the 1/2% detector variation noted, allowed plotting of the sharp transition from rising level to constant level.

Graph II is plotted in an identical manner to Graph I but for the Second Filling. It is of interest to note that here the primary detector level indication lagged behind that of the dipstick by only 2 to 3 seconds until the sodium level approached the previous high immersion area between 10 and 12 inches. As the sodium level continued to rise through this area the time delay between detector and dipstick gradually increased to an average of approximately 6 seconds. Although these areas are not sharply defined, the data would indicate that the first immersion treated the surface of the detector rods through actual contact with liquid sodium over the first 12 inches; at the same time an effect was being made on the uncovered portion of the detector rods by the sodium vapor present. Time records show that these vapors were present for a period of 2 hours - 40 minutes prior to the second filling.

EQUIPMENT

SIR Mark A Sodium Liquid Level System Components

1. Primary Detector - GE Dwg. 124B619G1, Serial No. 3237699,
   KAPL Item
   Effective measuring length 24 1/2 inches.

2. Single Power Supply - GE Dwg. 118D389G2, Serial No. 3238330,
   KAPL Item 544-14S

3. Discriminator - GE Dwg. 662A204G1, Serial No. 3238313,
   KAPL Item 544-15C

4. Instrument Amplifier - GE Dwg. 102D614G1, Serial No. 21

5. Indicating Meter - GE Type DB-14 Milliammeter - 0 - 5 Milliamps
   Scale 0 - 100% immersion.

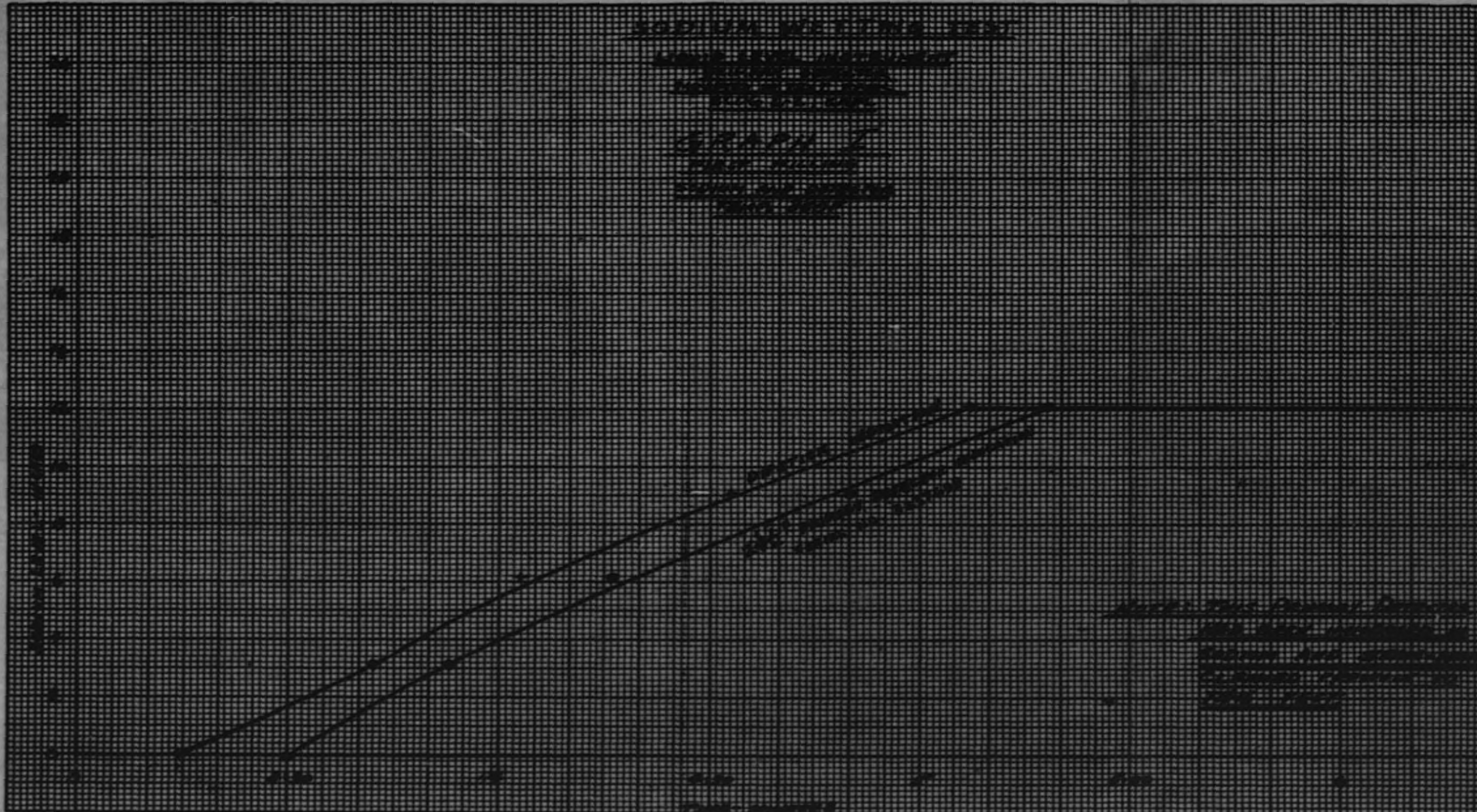
Additional Instruments

1. AC Electronic Voltmeter (Ballantine) - Model 300, 1 millivolt to 100 volts.

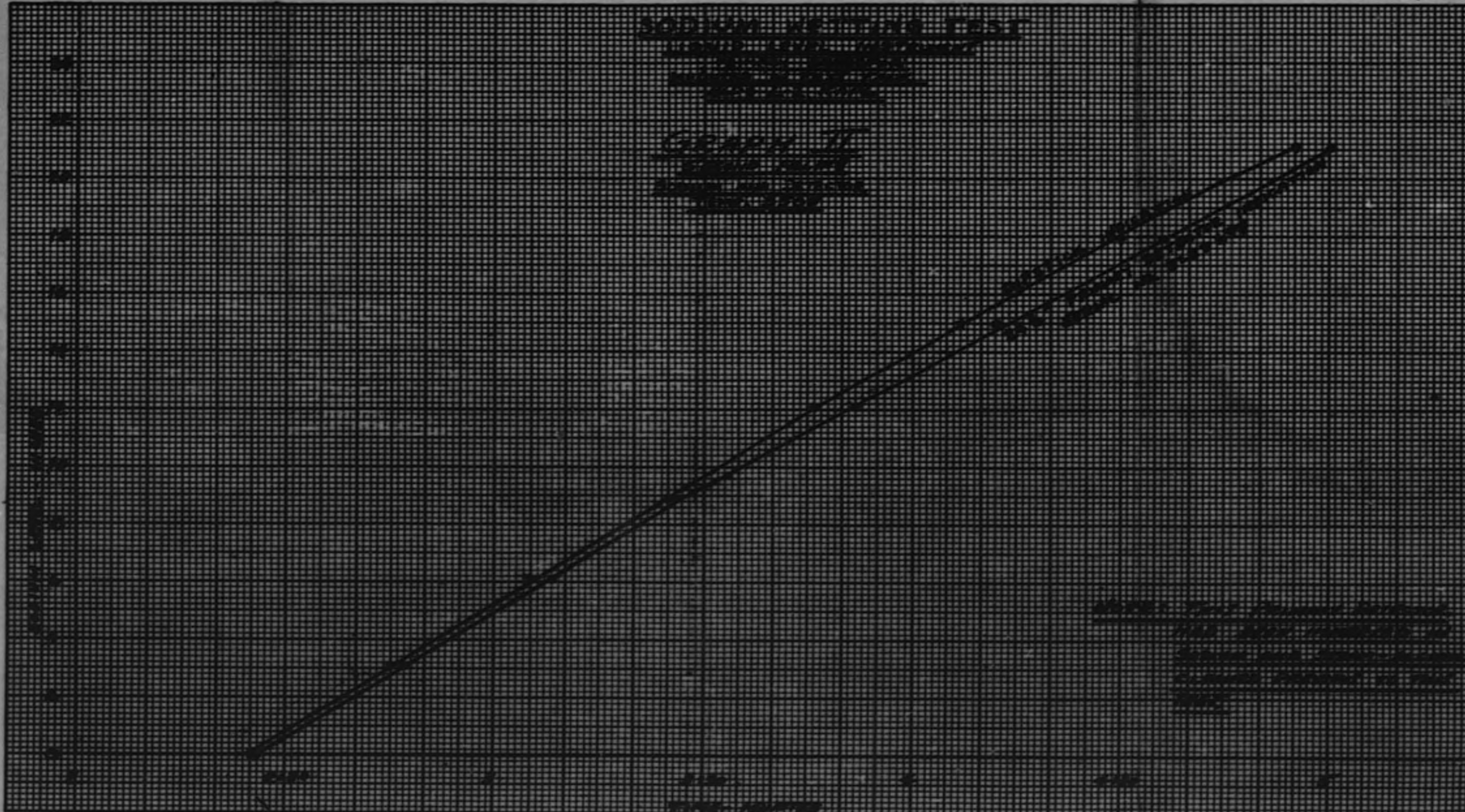
2. GE DC Milliammeter - Type DP2, 0-10 Milliamps.

3. GE Photoelectric Recorder - Model 32C199, 0.2-500 MV DC

4. Brush Recorder - Model BL 202 - Sensitivity 1.1 mm per volt, maximum 20 volts.



Gen. Eng. Lab
1/13/55



Gen. Eng. Lab
4/13/55 C.B. Dean

APPENDIX III

Conclusions and Recommendations

for

Liquid Metal Level Instrument

for

SIR Mark A

Sodium Liquid Metal Level Instrument

KAPL Spec. KPP544-14

CONCLUSIONS AND RECOMMENDATIONS

A. Estimated Accuracy

1. Initial Use in Sodium

Based on the results and observations of the tests discussed previously in this report, it is estimated that the SIR Mark A Type sodium liquid level measuring system will provide an indication of the presence of sodium approximately one minute after the sodium at 350 F first contacts the detector rods. After this initial delay, the response time will probably drop to about 1/2 minute. Thus, if the level is rising at a given rate in inches per minute, the indicated level will be not more than 1/2 the rate in inches per minute behind the actual level. If the level is rising at 1 inch per minute, the indication will be 1/2" behind the actual level.

Due to this time delay on initial filling, it is recommended that on SIR Mark A, as soon as an indication of the presence of sodium is obtained, the flow of sodium be stopped, and that the final filling of the expansion tanks be done at the minimum rate possible. If the actual rate of increase of level can be held to less than 1 inch per minute, indicated level while filling should not be more than 1 inch below true level.

2. Conditioning for Best Accuracy

It is recommended that the primary detector be conditioned after the initial fill by immersing it to full immersion (24") in sodium at 700 F for a period of not less than 24 hours. This should be sufficient time to obtain complete wetting of the resistance rods, so that the relationship between the "reference" and "measure" signals will remain constant for further use. During this 24 hour period, the sodium should be lowered below the level of the probes once each 4 hours. At this time, readings should be taken to ascertain the relationship between the "measure" and "reference" signals. Complete conditioning will be indicated by no change in the measure - reference signal relationship in a four hour period. After this conditioning, spot checks including balancing and zeroing of the system will result in an overall accuracy of ±3%.

3. Continued Use in Sodium

Test results to date all tend to emphasize the importance of clean, non-contaminated sodium at all times to permit level indications to be made reproducibly with the above accuracies. Any contamination of the primary coolant may effect the level indication. The only known reliable method for determining the overall indication accuracy of a unit installed in a system is to make observations of the instrument indication under empty tank conditions. Empty tank observations should be made before operational reliance is again placed on the instrumentation for level indications after possible contamination.