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LEVEL TRANSDUCERS FOR LIQUID METALS

R. G. Affel G. H. Burger R. E. Pidgeon

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Printed in USA. Price $1.50. Available from the
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Contract No. W-7405-eng-26

INSTRUMENTATION AND CONTROLS DIVISION

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R. G. Affel G. H. Burger R. E. Pidgeon

DATE ISSUED

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LEVEL TRANSDUCERS FOR LIQUID METALS

R. G. Affel G. H. Burger R. E. Pidgeon

ABSTRACT

Twenty-two resistance-type, continuously sensing level transducers for use in NaK (56% sodium, 44% potassium) pumps were constructed according to a reasonably simple design that led to high reliability. Brown Electronik recorders were slightly modified for use with the transducers, and the performance of recorders having $4\frac{1}{2}$- and 12-sec balance speeds was very good. A simple calibrator was used.

In a testing apparatus the results were: total range, $8\frac{1}{4}$ in.; linear range, $7\frac{1}{4}$ in.; linearity, $\frac{1}{3}$%; 2% zero-level shift and ~0.4% maximum-level shift over a NaK temperature range of 300 to 1400°F, temperature error less than 1.5% over the range 800 to 1400°F, using the 1200°F calibration curve; system resolution, better than 0.030 in.; reproducibility, better than 1% in the test rig and 3% assumed for operation in other systems; wetting errors, negligible for NaK temperatures above 600°F, variable when first exposed to NaK below 400°F; expected life, good, 16 ORNL-made transducers operated in NaK with no failures, six (three purchased from G.E.) operated >3000 hr, 19 of 20 operated satisfactorily up to 1400°F, two operated for 21,702 hr, four others operated for 19,300, 18,952, 7800, and 9672 hr, respectively, two failed because of defective welds, another was removed after 8928 hr because of a flange leak.

On-off level probes were made but not life-tested. They should be reliable if the center conductor does not rupture. Circuit readjustment is not necessary over the range 100 to 1400°F. Of 40 probes, three have failed, one because of improper circuit adjustment and two because of defective welds; 16 have operated more than 3000 hr up to 1500°F without failure, and the remainder have operated at all temperatures of interest for various periods without failure.

1. LEVEL-MEASURING SYSTEM FOR NaK PUMPS

1.1 INTRODUCTION

A system was required to accurately measure the NaK level in the bowl of NaK pumps. Since there are no known electrical insulators that will withstand a NaK atmosphere at the required operating temperatures without deterioration, the transducer was required to be of all-welded construction, that is, constructed and installed so that only metal surfaces were exposed to NaK or NaK vapors, and to have a leak rate less than 10^{-8} or 10^{-9} standard cc/sec.

The required operating specifications are given below:

1. temperature – 1300°F normal, 1400°F maximum, 1000°F minimum,
2. accuracy – ±5%,
3. pressure – 10 psig normal, 220 psig maximum,
4. level range – 0 to $8\frac{1}{4}$ in.,
5. NaK surface – calm to slightly turbulent,
6. reliability – minimum of 3000 hr of proved reliability at normal operating conditions.

Five resistance-type level transducers, J-tubes, designed to meet the above specifications were purchased from the General Electric Company (G-E catalog No. 172D717G1). Figure 1 shows this level-sensing probe. These units were installed in three NaK pumps and in a level-test apparatus. On the basis of preliminary tests, it was decided to use a modified version of this type of transducer for all continuous-level applications in sodium or NaK.

Approximately 42 of these level probes were required, including those necessary for operation in the pumps, for testing, and for spares. The units were made at the ORNL shops, using a modified and improved design of the sensing probe purchased from G.E.; Fig. 2 shows one of the level-sensing probes built at ORNL. Twenty-two were completed

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Fig. 1. Level Transducer Manufactured by G.E.

at the time of termination of the project. Of these ORNL units, two have operated in NaK pumps and 16 have been tested in the level-test apparatus.

1.2 PRINCIPLE OF OPERATION

The resistance type of level transducer is shown diagrammatically in Fig. 3. The input current leads are of $\frac{1}{8}$-in.-dia Inconel, the output voltage leads are of $\frac{1}{16}$-in.-dia Inconel, and the body is of $\frac{3}{8}$-in. sched-40 Inconel pipe. The input to the transducer is approximately 3 v at 20 amp and 60 cps. With the NaK level below the transducer, *all* the input current will flow through the sensing tube, the shorter vertical section of pipe, resulting in approximately 40 mv developed across the sensing tube. This voltage is measured by the recorder. As NaK rises on the sensing tube, it shorts that portion of the tube, since NaK is a good electrical conductor. The output voltage will therefore drop an amount proportional to the rise of NaK on the sensing tube and becomes approximately zero when the sensing tube is completely submerged. The output voltage, and consequently the recorder reading, is therefore a linear function of NaK level. The theory of operation is explained in more detail in Sec 1.9.

1.3 DESIGN OF TRANSDUCER

The level transducer for the NaK pumps is welded onto a riser mounted on top of the pump bowl. The level probe extends into the pump bowl at an angle 5° from the vertical, and the total level range of the transducer is $8\frac{1}{4}$ in. (Fig. 4).

The design of the transducer was based on an evaluation of those purchased from G.E. and included ORNL design specifications. The G-E transducer showed a good choice of Inconel wire size for the body, when considering the output

voltage and linearity, input power, and structural aspects. However, $\frac{1}{8}$-in.-dia Inconel wires were used because $\frac{3}{32}$-in. Inconel wire was not available.

It was decided to use packed magnesium oxide (MgO) as the insulator for the wires inside the transducer. One of the G-E level probes that failed had bulges and cracks in the Inconel pipe, the result of internal forces built up around the solid spacers in the pipe. Figure 5 is a photograph of this unit. It failed due to an internal short after about 30 hr of operation but remained in the

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Fig. 2. ORNL Level Transducer.

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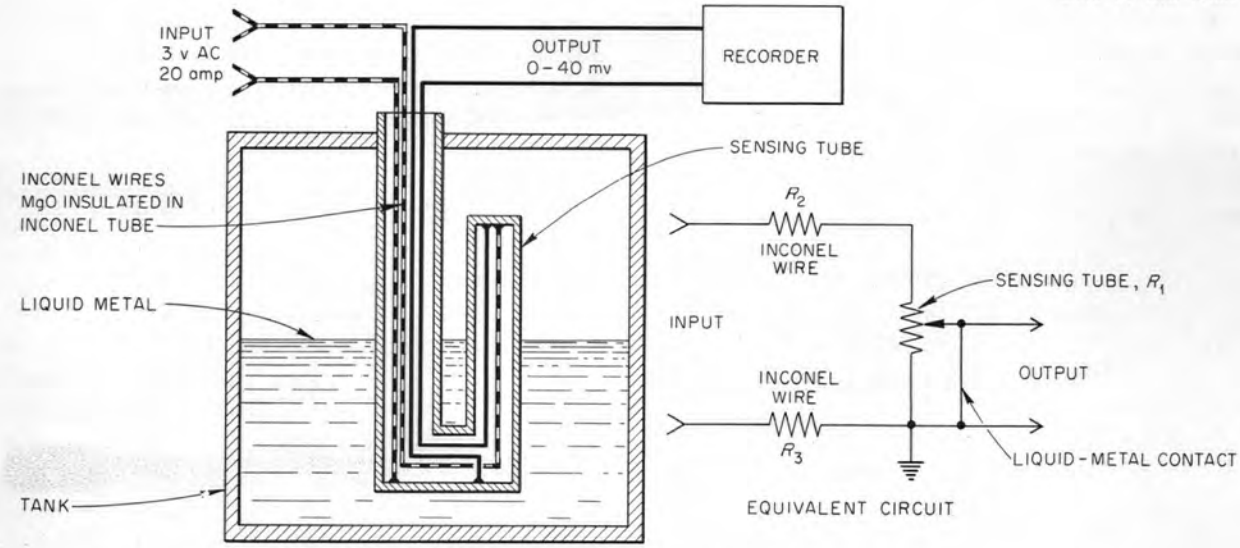

Fig. 3. Operating Principle of the Level Transducer.

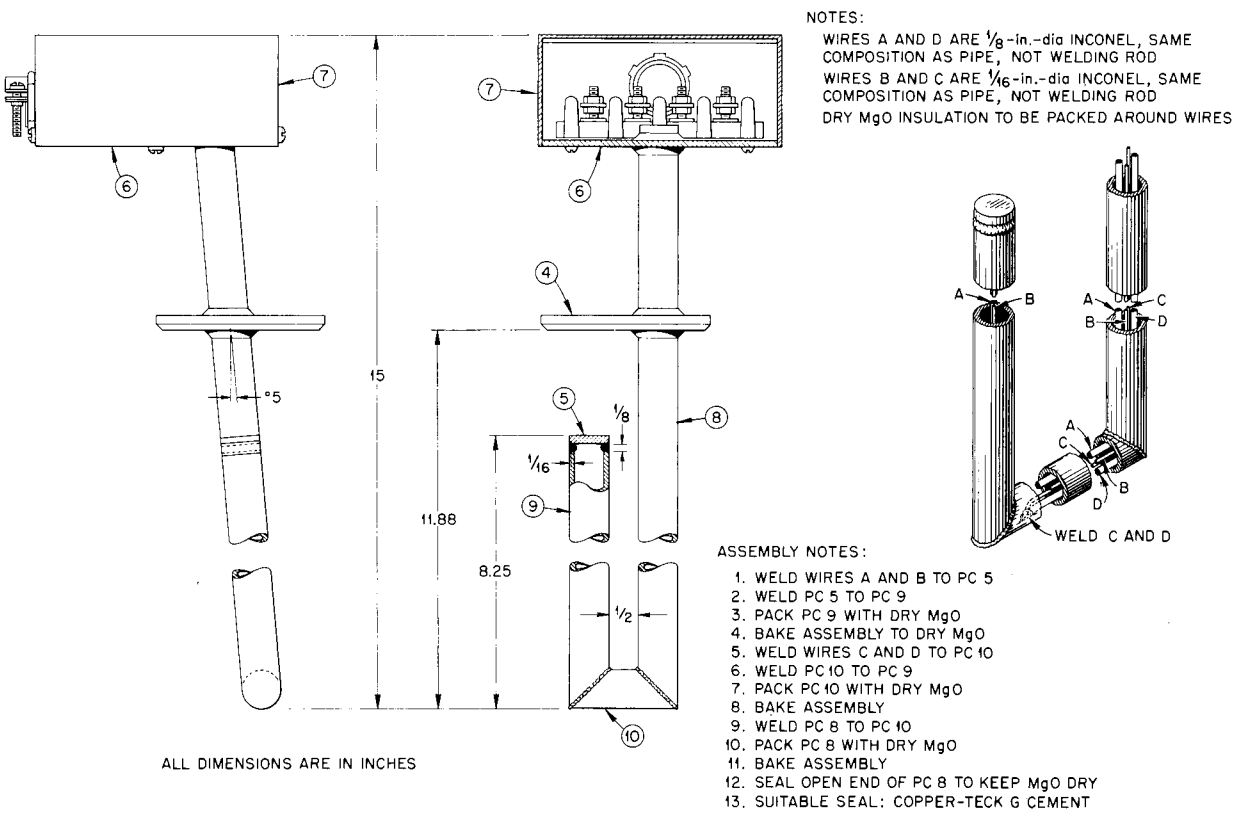

Fig. 4. Assembly Drawing for Level Transducer.

test system for 3730 hr. It appeared that during thermal cycling, Lavite (Al_2SiO_3) particles had broken from the solid Lavite and had settled between the solid spacers and the Inconel pipe wall, causing the spacer to exert a force on the pipe when it cooled and contracted. Repeated thermal cycling caused additional cracking and settling of the hard Lavite and eventually caused bulging and cracking of the pipe wall due to this "ratcheting" effect. For this reason, solid beads or other insulation forms of this material were avoided in the construction of the level probes at ORNL. Figure 6 is a photograph of an ORNL level transducer after 3150 hr of operation in the level-test equipment.

Since the transformer feeding power to the transducer could be mounted remotely only, a small terminal box for electrical connections to the transducer was required (see Fig. 2). The terminal block is rated at 475°F, and Teflon-insulated wire rated at 460°F was specified for the power and signal leads to the transducer. These temperature ratings were accepted, based on a temperature of 300°F in a typical installation in a pump (for a NaK temperature of 1200°F), measured just below the terminal box on the pipe supporting the terminal box.

1.4 FABRICATION OF TRANSDUCER

The fabrication of the level transducer was done in the Central Machine Shop at ORNL. All material which would be in contact with NaK was inspected by visual, dye-check, x-ray, and ultrasonic methods. All MgO used in the assembly was of high purity and within standards established by ORNL Specification 7444-1, which is included in the Appendix along with other specifications and a complete list of drawing references. The transducers were fabricated according to detail drawing Q-1716-135 (not included in this report) and assembly drawing

Q-1716-136, Fig. 4. The item numbers which will be used in this discussion are given in Fig. 4.

The first group of four transducers was fabricated according to the assembly procedure shown in Fig. 4, using coarse (approximately 50-mesh) MgO. The MgO was placed in the tube, a teaspoonful at at time, vibrated into place, and tamped down with a tamping tool and a hammer. The tamper also served as a spacer for the wires during the packing. These four units were accepted and were operated satisfactorily in the level-test apparatus and in the pumps of two NaK test loops.

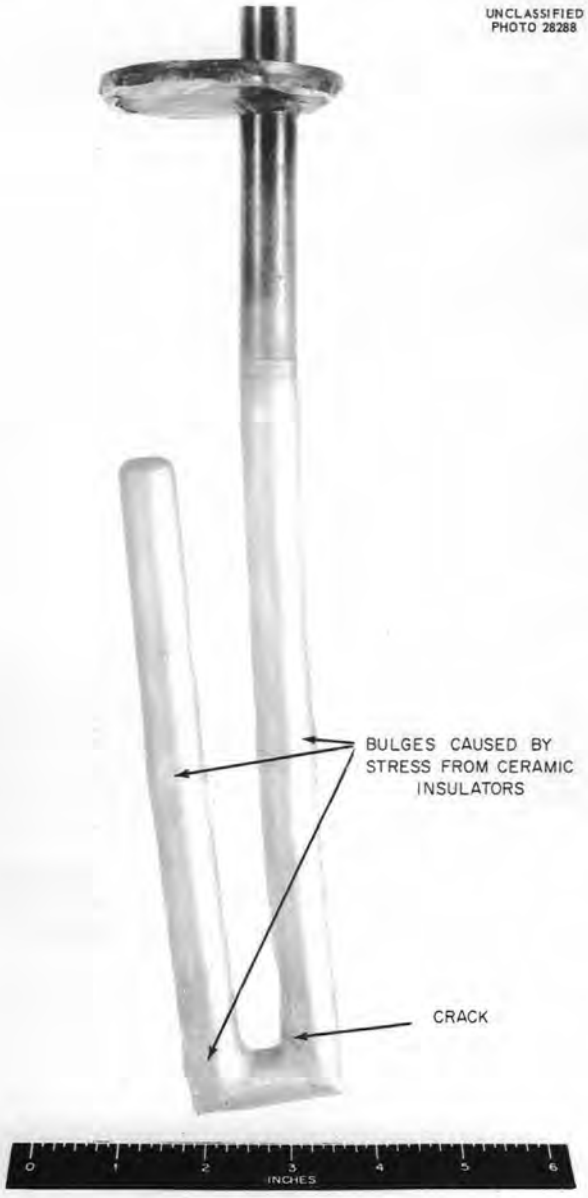

Fig. 5. Level Transducer (Manufactured by G.E.) After 3730 hr in NaK.

The possibility exists of a NaK leak into the tubing of the transducer, allowing the liquid metal to be forced up the tube and to escape from the system. An effort was made to reduce this hazard by using a more dense MgO pack. Extremely fine powder (10-μ particle size) was used in the next group of probes, which were then made in the same manner as the first group. Considerable difficulty was experienced in the fabrication of these units; the trouble resulted from the welding technique used and the difficulty in packing the 10-μ powder. In order to have joints with good integrity, the shop drawings called for full-penetration welds. In some cases there was excessive weld penetration, which caused an appreciable reduction in the cross section inside the Inconel pipe at the joints between pieces 9 and 10, and 8 and 10. This welding problem was corrected by a refined welding technique.

In packing the 10-μ MgO powder in piece 8, the wires galled in the tamper, resulting in dislocation of the wires and shorting of the wires against themselves or against the pipe wall. This problem was sometimes aggravated by excessive weld penetrations, as mentioned above. The majority of the probes constructed in this group had the wires shorted. Sometimes the shorts could be corrected by moving the wires after the packing had been completed. No packing technique or change in the tamping tool could be found that would prevent galling. In an attempt to give more rigid support of the wires in the bend of the J-tube, some of the units were made with 50-mesh powder in this section only, and 10-μ MgO in the balance, but none of these methods gave satisfactory results. Figure 7 is a radiograph of two transducers: one with the wires shorted, and one that is good.

Since it was felt that the bulk of the trouble was caused by using the fine MgO, it was decided that either a new packing technique had to be found or the transducers would be built by using 50-mesh MgO. A comparative test was devised to determine which method of packing and what type of MgO produced the most dense pack. Vacuum-packing under heavy vibration was tried, but it was shown that hand-packing 50-mesh MgO, as done with the first group of transducers, gave a considerably more dense pack. Eleven more units were made in this manner, and all these units

Fig. 6. ORNL Level Transducer After 3150 hr of Operation in NaK.

were completed satisfactorily, with no shorts occurring in any of them.

In view of the difficulty of getting rigid support for and proper spacing of the wires in the bottom section of the transducer, solid insulators were considered for use in that section. It was felt that solid insulators of a material different from that used in the G-E units could be used in the bottom section without the occurrence of the ratcheting effect. Insulators made of MgO were purchased from the American Lava Corporation. These spacers were not tried because of the termination of the program; however, it is believed that these spacers would give better support and spacing of the wires, eliminating the possibility of the wires shorting in the bottom section.

1.5 RECORDING SYSTEM

Equation (1) in Sec 1.9 shows that the output voltage of the transducer is proportional to the input voltage and a function of the liquid level. Obviously, a variety of ordinary millivolt a-c indicating and recording equipment could be used. Two types of recorders were used for indicating and recording the level: the Foxboro model 9650 Dynalog recorder, and a modified d-c Brown Electronik potentiometer strip-chart recorder.

The circuitry for the Foxboro Dynalog recorder used with the level transducer is shown in Fig. 8; the recorder performance was satisfactory. The circuit is arranged to provide a balance input, since the recorder was built for a balanced input.

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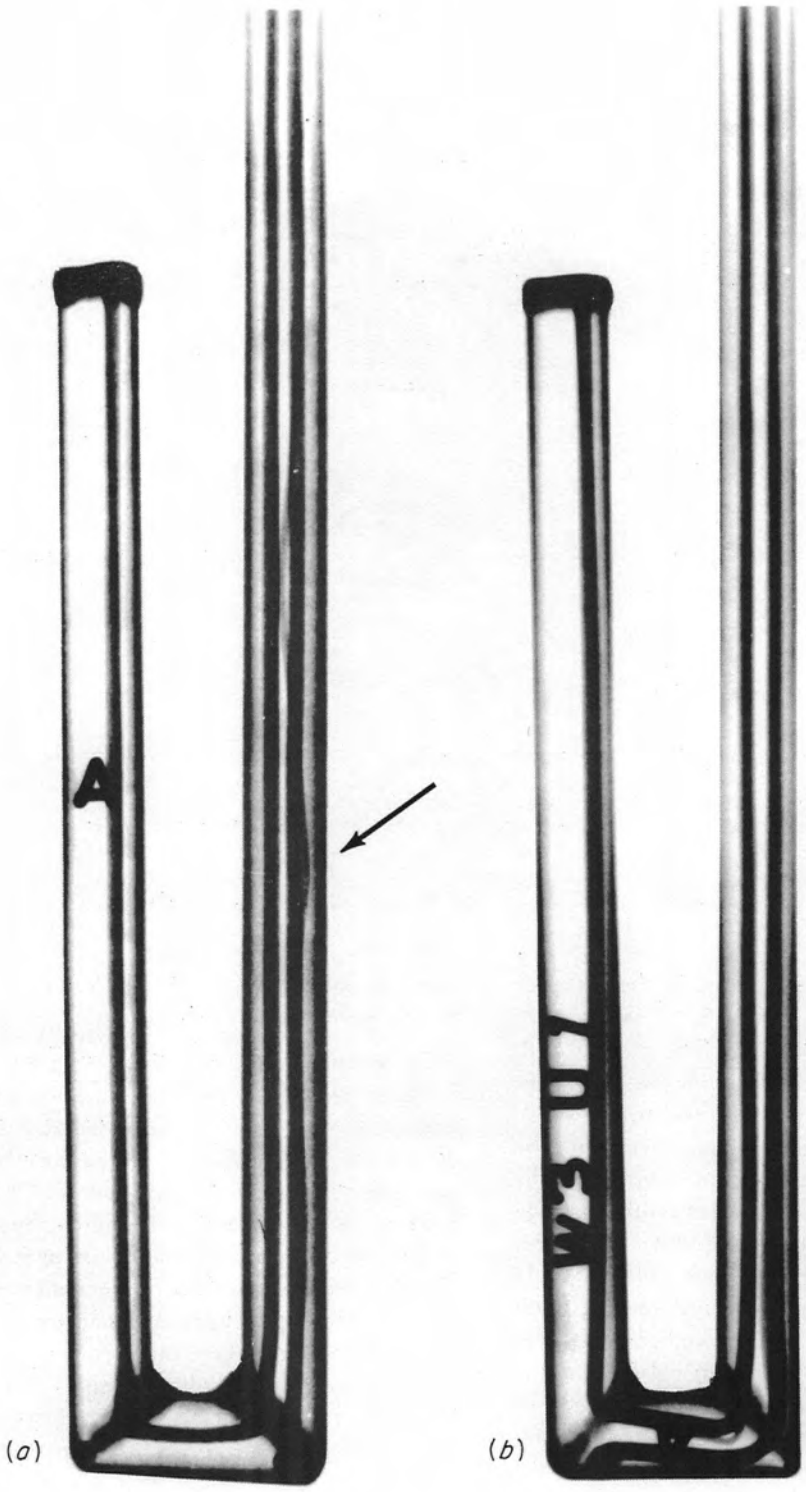
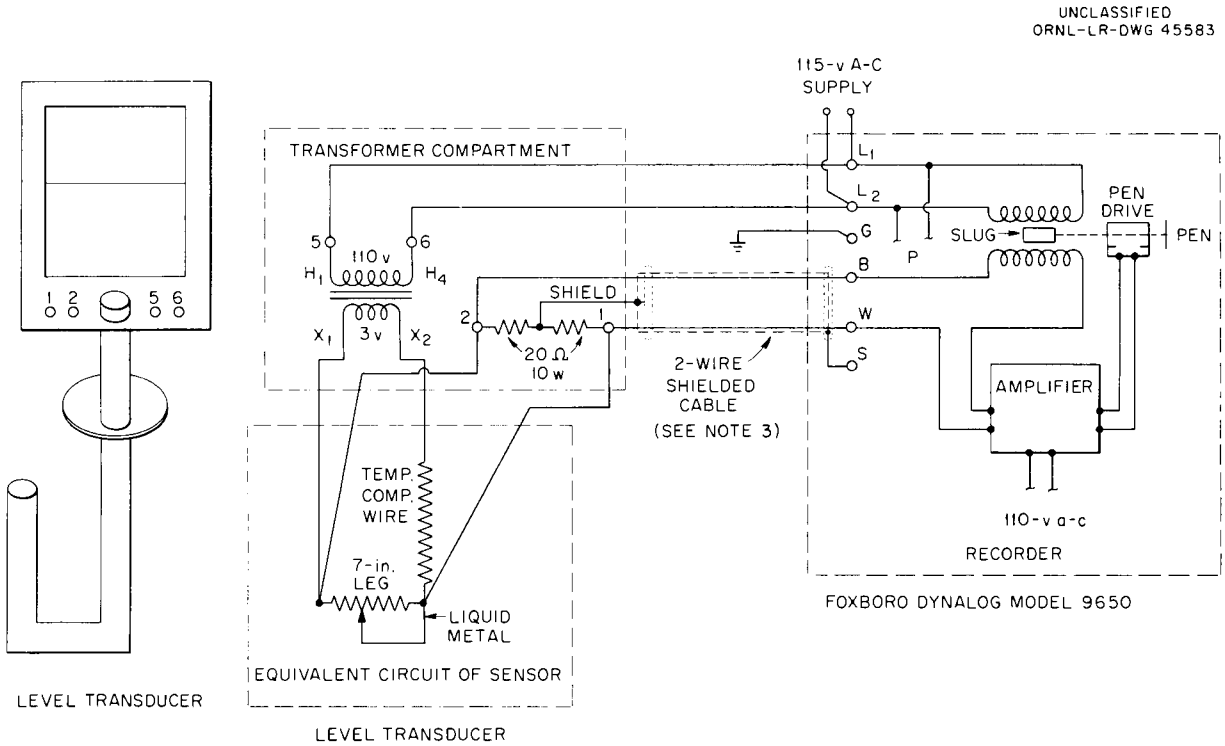


Fig. 7. Radiograph of Two Transducers. (*a*) Rejected because of short at point indicated by arrow; (*b*) acceptable. Short circuit occurred during manufacture.



NOTES:

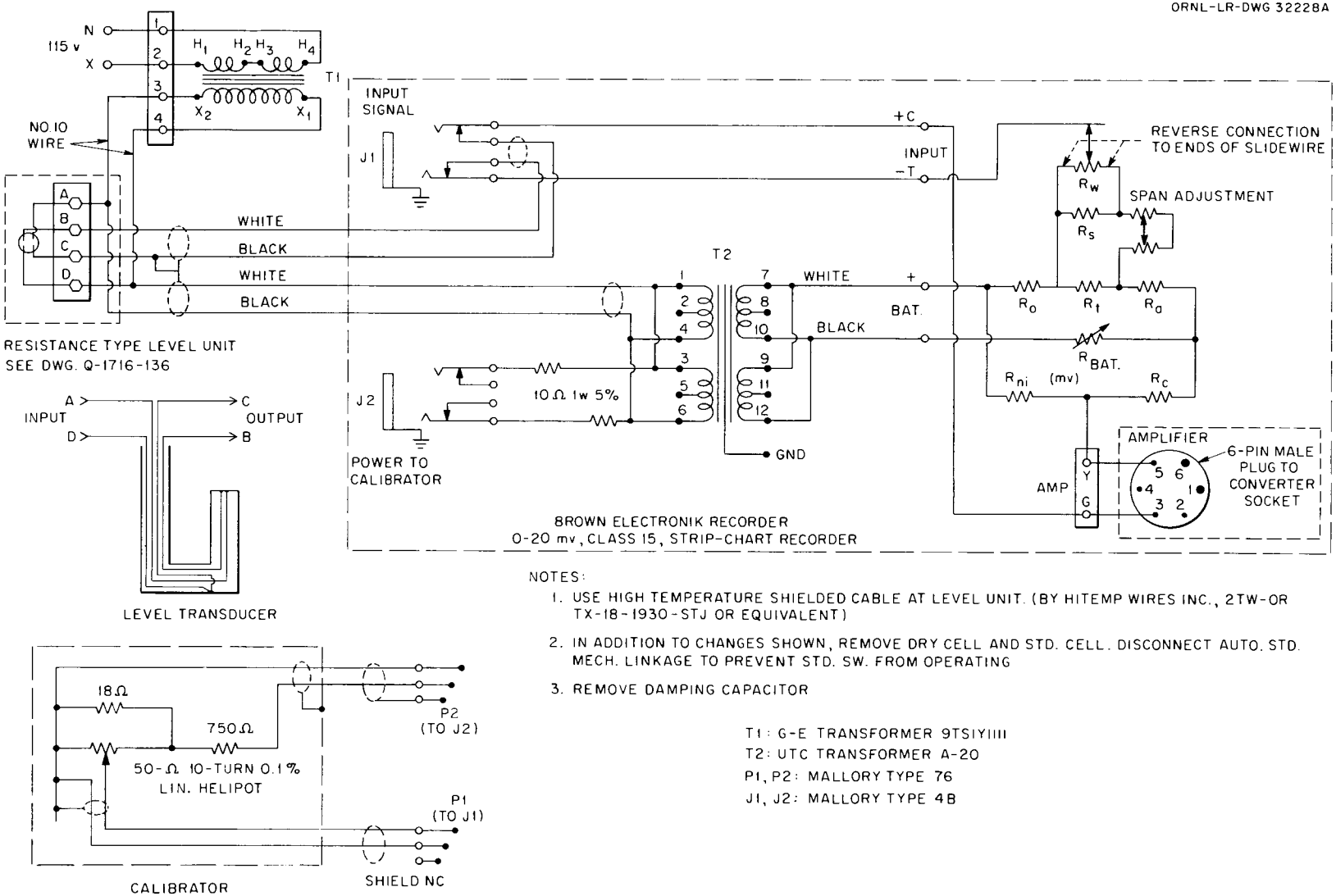
1. WHEN LIQUID IS BELOW PROBE, RECORDER SHOULD BE AT LOW END OF SCALE. REVERSE B AND W LEADS IF NECESSARY.
2. POWER TO LEVEL ELEMENT MUST COME FROM RECORDER.
3. 2-WIRE SHIELDED CABLE BY HI-TEMP WIRES, INC. CAT. NO. 2 TW OR TX-18-1930 STJ OR EQUIVALENT.

Fig. 8. Interconnection Diagram for Level Transducer and Foxboro Recorder.

For proper operation, the grounding of the recorder input must be as shown in Fig. 8. The Foxboro recorder null-balances the measured voltage with a variable a-c voltage obtained from the a-c power source. The transducer and the recorder are fed from the same power source, and, therefore, the level reading is independent of line voltage. The level reading is, however, dependent on the voltage regulation of the transformer feeding the level transducer. If desired, the balance voltage could be derived from the input voltage to the level transducer, thereby making the indicated level reading independent of the input voltage to the transducer. This principle was used in the modification of the Brown Electronik potentiometer discussed in the following paragraph. By making the recorder reading independent of input voltage to the level transducer, the transducer did not have to be calibrated for a particular input voltage, a decided advantage when using a large number of level elements. Transformer regulation and lead length were not critical, either.

The changes made to the Brown Electronik potentiometer are shown in Fig. 9. This type of application is discussed in the Minneapolis-Honeywell technical bulletin B15-13. The modification consists essentially in feeding the bridge circuit with a 60-cycle a-c voltage and feeding the error (input) voltage directly to the amplifier input transformer. The automatic standardizing mechanism is disabled, and all damping or bypass capacitors in the bridge circuit are removed. The bridge circuit is then grounded at the transducer only. Transformer T2 shown in Fig. 9 is used to remove the ground from the bridge excitation. The span of the recorder can be changed by:

1. the normal method used for a d-c recorder (changing the bridge range resistors or adjusting the span slide wire),



NOTES:

1. USE HIGH TEMPERATURE SHIELDED CABLE AT LEVEL UNIT. (BY HITEMP WIRES INC., 2TW-OR TX-18-1930-STJ OR EQUIVALENT)
2. IN ADDITION TO CHANGES SHOWN, REMOVE DRY CELL AND STD. CELL. DISCONNECT AUTO. STD. MECH. LINKAGE TO PREVENT STD. SW. FROM OPERATING
3. REMOVE DAMPING CAPACITOR

T1: G-E TRANSFORMER 9TSIYIIII
T2: UTC TRANSFORMER A-20
P1, P2: MALLORY TYPE 76
J1, J2: MALLORY TYPE 4B

Fig. 9. Brown Recorder Modification for Use with Level Transducer.

2. changing the bridge excitation voltage (T2 secondary voltage), or
3. adjusting the "battery" potentiometer $R_{bat.}$ in the bridge circuit.

The third method is used for small changes in span. Note also that the slide-wire connections are reversed to give an upscale reading for the maximum level (maximum level is indicated by the minimum voltage from the level transducer).

Three factors in the above modification of the recorder could lower the performance over that of the unmodified d-c recorder.

1. Any phase shift in the bridge circuit will add to the null or error voltage, decreasing the resolution of the system.
2. The damping capacitors used in the bridge circuit must be removed, thus removing the damping of the servo.
3. Hum pickup interferes with the operation of the recorder.

A slight quadrature voltage was observed by looking at the error voltage at the secondary of the input transformer. The quadrature voltage was reduced almost to zero by a 0.25-μf capacitor across the bridge excitation terminals and a 0.015-μf capacitor across R_c in the bridge circuit (Fig. 9). However, the phase shift in the bridge circuit was small enough so that the performance appeared to be the same with or without the phase-shift correction; therefore these capacitors are not normally used.

With the damping network in the bridge circuit removed, there is a decrease in the performance of the recorders having a high pen speed. The pen speed is defined as the time required for full-scale travel of the pen and indicator. For the 1-sec-speed recorders tested, the feedback network of Fig. 9 in the Minneapolis-Honeywell bulletin B15-13 was added to provide damping. Even so, the transient response was poor (excessive overshoot, with a tendency for large-amplitude oscillation), and the dead zone was high, up to $\frac{1}{4}$% of the span. Damping is not required for recorders using a 12-sec (or longer) balance-speed motor, and, for that reason, these recorders are preferred for this a-c application. The 12-sec recorder tested had about the same performance as that of a similar unmodified recorder. The $4\frac{1}{2}$-sec recorders tested had good transient response and a dead zone of less than 0.2% of the span.

Because of the low impedances of the transducer and bridge circuit, these circuits are relatively insensitive to hum pickup or interference. The recorder was checked for hum by turning off the excitation to the bridge and transducer and observing that the recorder reading did not drift. This indicated that the 60-cycle pickup was less than the equivalent dead-zone voltage (hum less than 0.2% of the span, or 90 μv).

The United Transformer Company UTC A-20 transformer used in the recorder modification is unsatisfactory because changes in ambient temperature result in changes in the secondary voltage. Calculations show that the poor temperature regulation is due to changes in primary and secondary winding resistance. A rough check showed that the secondary voltage decreased about 0.4% for a 10°F change in ambient temperature. To overcome this effect expediently, the transformers were installed in a small, temperature-regulated oven, thereby eliminating the drift in the recorder calibration. A United Transformer Company UTC type LS-30 transformer appears to be suitable as a replacement for the above transformer, although this unit was not tested.

To check the operation and to calibrate the recorder, a millivolt a-c signal is derived from a 0.1% linear Helipot and is connected to the recorder input by plugging the calibrator (voltage divider) into the jacks J1 and J2 (see Fig. 9). The recorder reading is then compared with the Helipot dial reading. Use of the calibrator is explained in Sec 1.6.

An L & N Speedomax H recorder was modified in a manner similar to that for the Brown Electronik recorder previously discussed. The result was somewhat inferior to that of the $4\frac{1}{2}$- or 12-sec Brown recorders because of insufficient damping of the servo and excessive phase shift in the bridge circuit.

A d-c system could be used (and might be advantageous when using level transducers that draw a lower current) by employing a rectifier to feed the transducer and bridge circuit of a slightly modified d-c recorder. The method shown in Fig. 10 would make the recorder reading independent of input voltage to the transducer.

1.6 RECORDER CALIBRATION

To check the performance of and to calibrate the recorder, a calibrator was constructed, the circuit

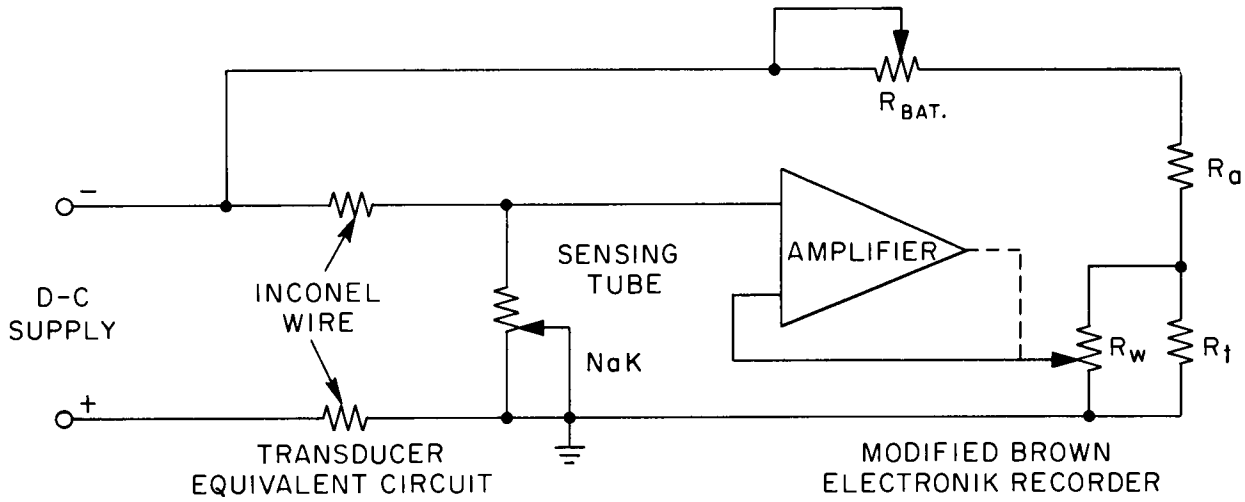


Fig. 10. D-C System Using Resistance-Type Level Transducer.

of which is shown in Fig. 9. The calibrator, which consists of a voltage divider and a ten-turn Helipot, is plugged into jacks J1 and J2 in the recorder. Plugging in the calibrator (voltage divider) connects the input voltage of the transducer to the calibrator divider and substitutes to the recorder input the output voltage of the calibrator for the output voltage of the transducer.

The output of the calibrator was measured to determine the relationship of Helipot dial reading and output voltage for an input to the calibrator of 3.0 v. For example, for an input of 3.0 v the calibrator had an output of 51.33 mv for a Helipot dial reading of 10.00 (ten turns). By plugging the calibrator into the recorder jacks, the recorder reading can be obtained in terms of a-c millivolts, for an input of 3.0 v.

When each level transducer was installed in the test apparatus, the recorder span was set to give an arbitrary reading of ten scale divisions when the liquid level was below the transducer. An up-scale reading was chosen for the zero level so that the zero shift could be observed. The transducer calibration curve was obtained by measuring and plotting the recorder readings vs the known dial reading or a-c millivolts, as explained in the previous paragraph. In setting up a recorder for a transducer that has been calibrated, it is necessary to duplicate the recorder readings vs the calibrator dial readings previously measured by adjusting the recorder span ("battery" potentiometer) and making the normal zero adjustments. The same calibration curve (recorder reading vs liquid level) will then result.

Although the calibration was discussed for an input of 3.0 v to the transducer, the recorder measures the transducer output/input voltage ratio; therefore, the 3.0-v reference is arbitrary.

1.7 LEVEL-TEST RIG

The rig consists of two NaK-filled type 316 stainless steel tanks mounted on opposite ends of a pivoted frame, with fluid and gas equalizer lines connecting the tanks. The tanks are rocked up and down by an electric motor driving a variable-speed transmission linked to the rocking frame, giving a change in NaK level in each tank of up to 10 in. Figure 11 illustrates the level-test rig, and Fig. 12 is a photograph of the test apparatus. Figure 13 is a photograph of the rig showing the top of one of the tanks. In each tank are mounted two level transducers, four per rig; two such rigs were built. Each level transducer is connected to an individual Brown Electronik recorder modified as discussed previously.

In view of the large number of transducers that had to be tested, it was decided to have the transducers flanged into the tank by using an O-ring type of seal instead of welding the transducers to the tank. The transducers can be seen clamped

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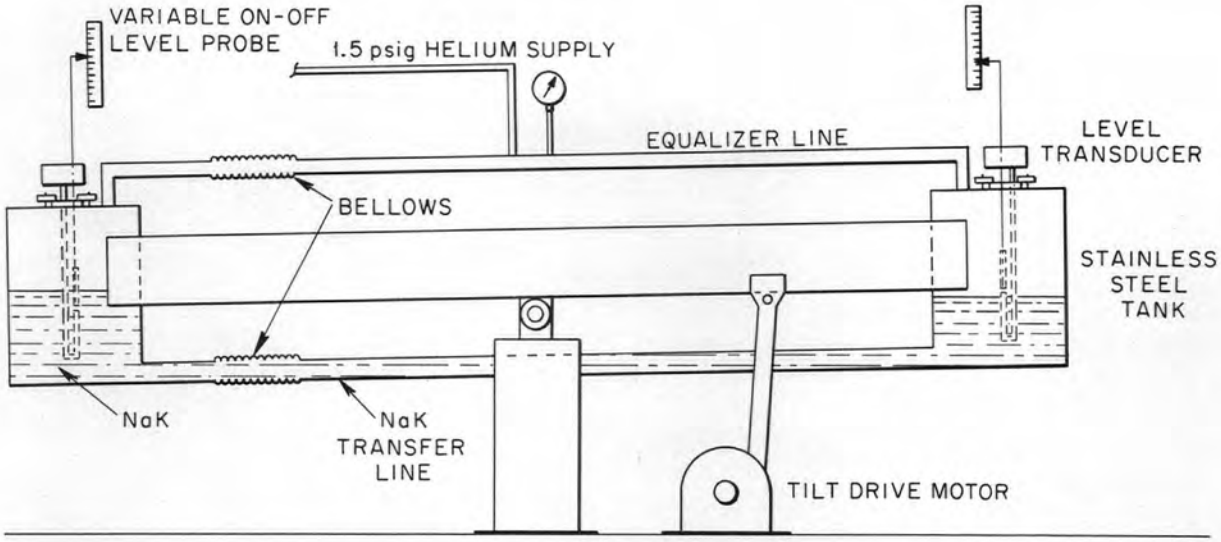

Fig. 11. Diagram of Level-Test Rig. The NaK is heated by clamshell heaters attached to pots and transfer lines.

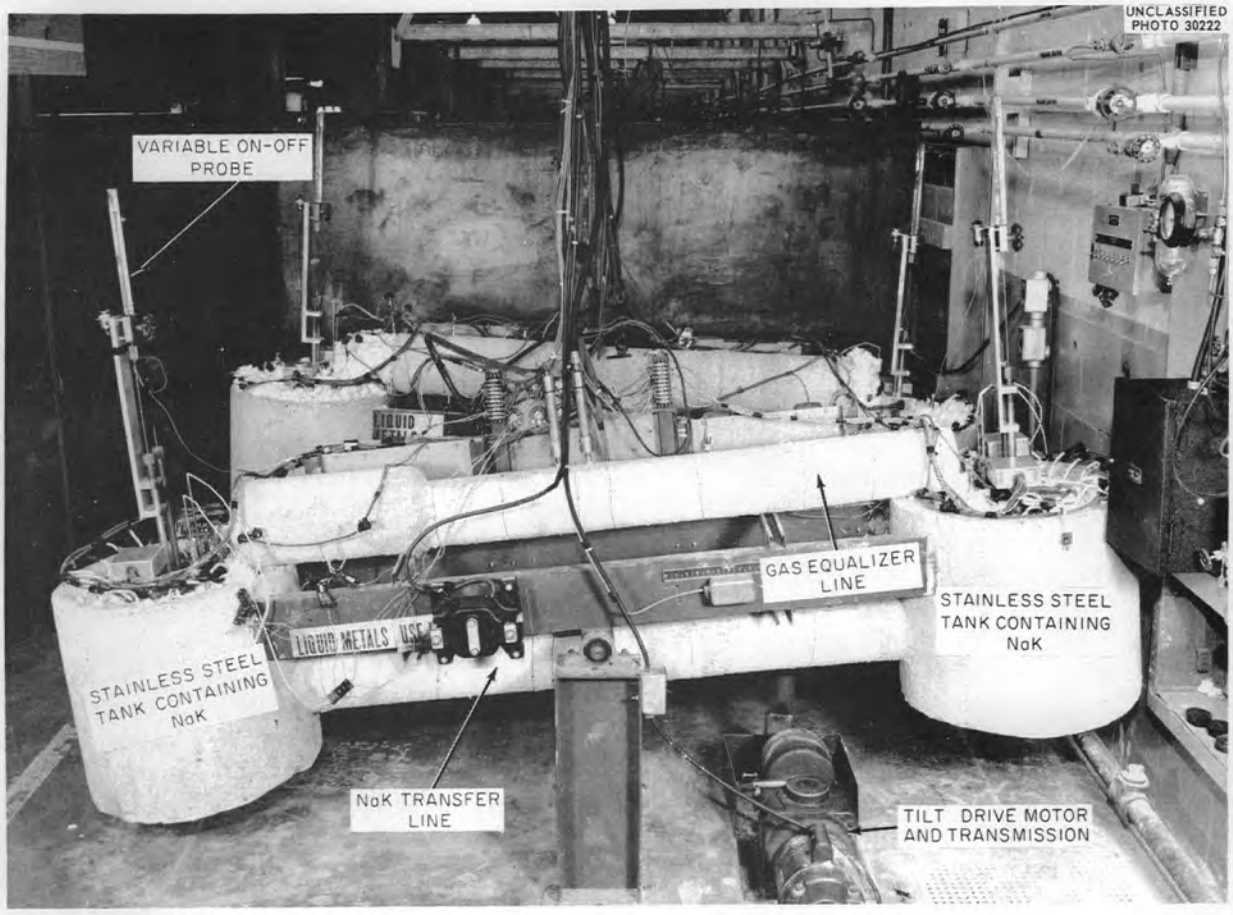

Fig. 12. Level-Test Rig.

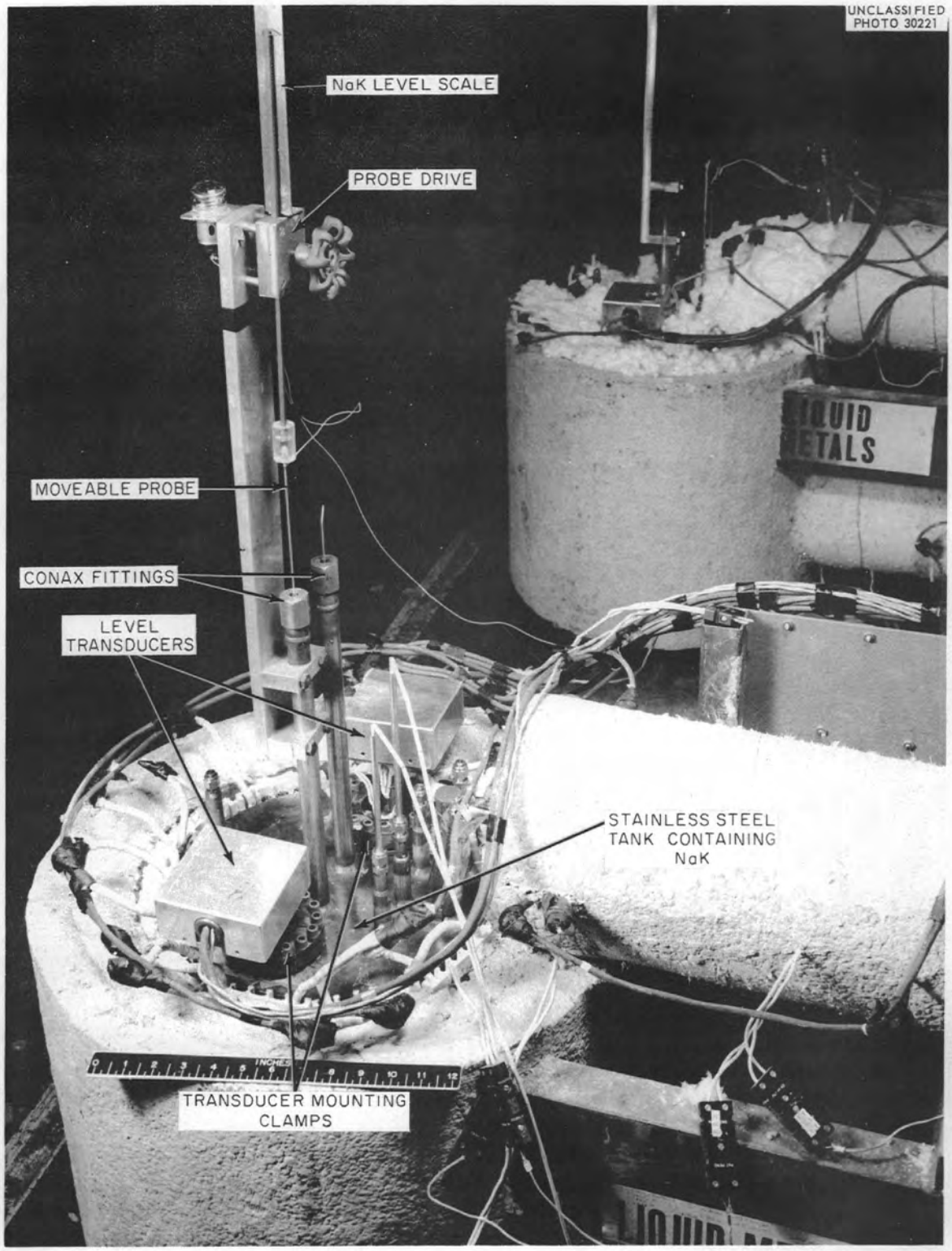

Fig. 13. Closeup of Level-Test Rig.

to the tank in Fig. 13. The O-ring seals the mounting flange of the transducer to the top of the tank. The rings initially used were made of copper and annealed dead soft, but they leaked vapor, resulting in corrosion of the transducers and the ring seals by NaK vapor. Seals were then made of nickel stock having a triangular cross section. They appeared to work well; even though a small helium leak could be detected, the leak rate was small enough for the intended use of the seals in this system. Thin-wall, pressurized O-rings were to be tried, but the rings of this type which were procured were not the correct size.

The NaK level is measured in each pot by using an adjustable or movable probe consisting of a $^3/_{32}$-in.-dia Inconel rod inserted through a Conax (packing gland type) fitting shown in Fig. 13. The Inconel rod is moved through the Conax insulating gland, and contact of the rod with the NaK surface is indicated by a light connected in a circuit which is in series with the rod and tank walls. In measuring the level, the probe is lowered and the position of the probe is read on a fixed scale when the light comes on. This variable probe is the standard for measuring the NaK level during the testing and calibrating of the transducers; the probe and its associated equipment can be seen in Fig. 13. Various materials for the insulating sealants of the Conax fitting were tried. Magnesium silicate, magnesium oxide, and aluminum oxide powder (with molybdenum disulfide for lubrication) were tried unsuccessfully; Teflon was tried with some success. To remedy previous troubles encountered with this movable probe, the Conax fitting was welded to the top of a 12-in. length of $^3/_4$-in. pipe. By mounting the Conax fitting 12 in. above the tank and by maintaining the Conax fitting at a low temperature, trouble-free operation was obtained because NaK could not be wiped onto the Teflon gland.

1.8 TEST PROCEDURE

The reference from which the NaK level is measured is the lowest point on the transducer (J-tube). The scale reading of the variable probe which corresponds to the lowest point on each J-tube is called the zero-level reading for that tube. The zero-level reading is determined in the following manner (see Fig. 9 for circuitry):

1. The input current lead to terminal D of the transducer is grounded by a jumper to the frame of the test rig. This connects the J-tube as an on-off probe, discussed in Sec 3.
2. Voltage is measured from terminal C on the transducer to ground and is approximately 70 mv when NaK is below the J-tube and drops to approximately zero when NaK touches the J-tube.
3. Starting with the NaK below the J-tube, the NaK level is raised very slowly, and the scale reading for the movable probe is noted when NaK just touches the J-tube, as indicated by the light. This reading is the zero-level scale reading.

This zero-level scale reading can be repeated with an error of about ±0.010 in. and is substantially independent of NaK temperature. Zero-level readings taken for four J-tubes at NaK temperatures of 200, 300, 600, 1000, and 1200°F varied less than 0.020 in. for each tube except for the readings at 200°F, which varied up to 0.060 in. Therefore the bottom of the J-tube is considered as the reference point regardless of operating temperatures.

The calibration curves shown in Figs. 18 and 19 were plotted as recorder readings vs NaK level, where the NaK level is, by definition, the scale reading of the movable probe minus the zero-level reading. The NaK level is therefore measured in inches from the bottom of the J-tube. The calibration procedure is to vary the NaK level (at a constant NaK temperature) in about 18 steps over the entire level range from the minimum to the maximum and back to the minimum level. The data provide a calibration curve for that temperature. A family of calibration curves then is obtained for different NaK temperatures. For the systems in the test apparatus, each recorder was initially set, upon installation of the transducer, to give an arbitrary minimum recorder reading of about 10 scale divisions. The recorder readings therefore vary from a zero of about 10 scale divisions to 100 scale divisions full scale. The calibration of the recorder is discussed in Sec 1.6.

1.9 TEST RESULTS

In analyzing the test results for the transducers, reference is made to the equivalent circuit of the transducer (Fig. 3) and the equation for this circuit. As stated earlier, the input current leads are of $^1/_8$-in.-dia Inconel wire, the output voltage leads are of $^1/_{16}$-in.-dia Inconel wire, and the body

is of $\frac{3}{8}$-in. sched-40 Inconel pipe. In the equivalent circuit the current leads are shown as R_2 and R_3. The current wires are compensating resistances and therefore are made of the same material as the sensing tube. The resistance of the sensing tube is designated R_1. Since the electrical conductivity of NaK is high, it is assumed here that the effective resistance of that part of the sensing tube below the NaK surface is zero. The output voltage is then given by the equation

$$E_{out} = E_{in} \frac{R_1}{R_1 + R_2 + R_3} \tag{1}$$

and is approximately equal to

$$E_{out} \cong E_{in} \frac{R_1}{R_2 + R_3} , \tag{2}$$

since $R_1 << R_2 + R_3$. Typical measured values (at 1200°F operating temperature) are:

E_{in}	2.7 v
I_{in}	17.5 amp
E_{out}(zero level)	36.8 mv
R_1	2.1 milliohms
$R_2 + R_3$	152 milliohms

The approximation given by Eq. (2) shows that the output voltage is a linear function of the height of the sensing tube above the NaK surface (assuming perfect shorting of the sensing leg by NaK and neglecting end effects). The linearity and temperature effects are discussed below, using Eqs. (1) and (2).

1.9.1 Linearity

The calibration curve of output voltage vs NaK level is slightly nonlinear because the total input resistance $(R_1 + R_2 + R_3)$ changes slightly with NaK level. For the typical values just given, the input resistance changes from 152 to 154 milliohms over the total range in level, or a change of 1.3%. If the curve of output vs NaK level is a straight-line approximation connecting the ends of the curve, then the maximum deviation appears as 0.333%. The output curve is therefore said to be linear, although a small curvature can be seen in the calibration curve shown on Fig. 14. The linear range of the transducer is $7\frac{1}{4}$ in., with a total range of $8\frac{1}{4}$ in.

1.9.2 End Effects Due to Terminations of Current and Voltage Wires

The end effect at the zero-level end is dependent in part on the location of the welds for the current and voltage wires. Three different locations were tried, and the calibration results are shown in Figs. 14–16. Figure 14 indicates the results of the accepted method. In this method the current and voltage leads are attached by *separate* (but adjacent) welds to reduce the output voltage that remains when the sensing tube is completely shorted by NaK on the outside surface. Figure 15 shows a discontinuity when the NaK just touches the bottom horizontal section of the J-tube. In Fig. 16 the decrease in indicated level when NaK touches the bottom of the transducer is caused by the redistribution of current in the bottom section of the J-tube when NaK just touches that section.

1.9.3 Temperature Effects

The resulting change in the calibration curve of output voltage vs level as a function of operating temperature is considered from three aspects: (1) a change in the zero-level reading, (2) a change in maximum-level reading, and (3) thermal expansion of the equipment. Since the transducer has its maximum output for NaK levels below the probe, the change in the zero-level reading is similar to a change in the calibration span. Equations (1) and (2) show that if the sensing tube and current leads are at the same temperature, and if R_1, R_2, and R_3 have the same temperature coefficient or resistivity, the output voltage is independent of operating temperature. Ideally, when the temperature changes, the numerator and the denominator of Eq. (1) change by the same factor, resulting in the output voltage being invariant with temperature. In reality, a small temperature error does exist because all parts of the transducer are not at the same temperature, and the temperature coefficient of resistivity of the Inconel wire and Inconel pipe may not be the same. Figure 17 shows how the zero-level reading varies with temperature for a typical transducer. This zero-level reading was taken while the NaK level was cycling from below the transducer to above the sensing tube, and the data are shown for three temperature cycles. This change in zero-level reading is caused by, at least in part, the Inconel current wires in the top section of the transducer operating at a lower temperature than that of the NaK or the sensing tube. As the

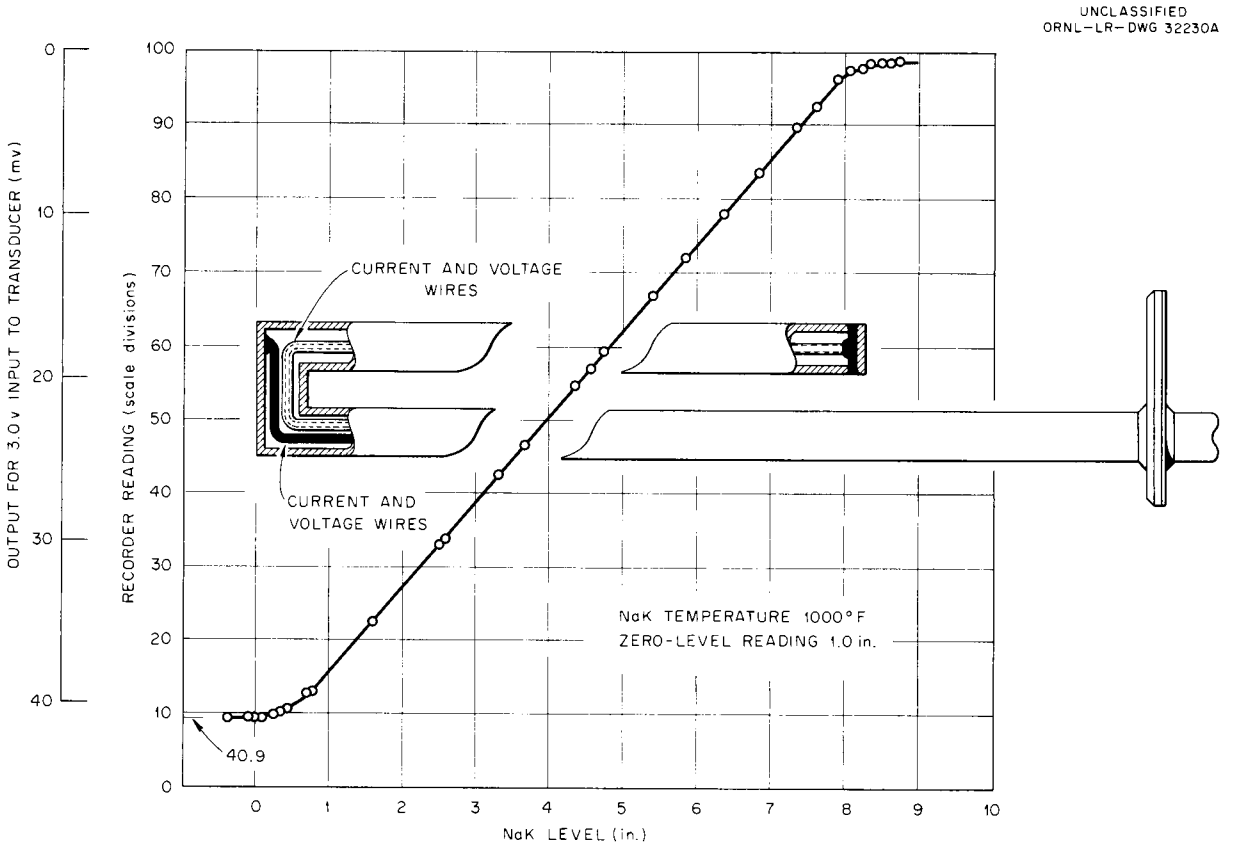

Fig. 14. Calibration Curve as Affected by Termination of Current and Voltage Wires. NaK temperature, 1000°F; zero-level reading, 1 in.

NaK temperature increases to 900°F, the resistance of the current (compensating) wires increases slower than the sensing tube resistance (since part of the current wire is at a lower temperature than that of the sensing tube) and therefore the output voltage increases. A curve showing the resistivity of Inconel as a function of temperature is given in Fig. 34.

The curve of Fig. 17 is typical for the transducers *clamped* to the NaK tank in the test rig and shows a change in zero-level reading of about 2% of span. The same test was conducted on a transducer purchased from G.E. which was *welded* onto a 2½-in.-high pipe on the top of the NaK test tank. In this case the zero-level shift was about 3%. The greater zero shift in the latter case is attributed to the lower operating temperature at the top of the transducer.

Figure 17 also shows the change in the recorder reading with temperature when the sensing tube is completely submerged in NaK. The reading changes from about 98.5 to 98.1 scale divisions. This reading is slightly lower at the higher NaK temperatures because of the increase in resistivity of NaK with temperature and because NaK does not completely short the sensing tube. This change in the maximum-level reading is about 0.4% of the level range. A curve showing the resistivity of NaK as a function of temperature is given in Fig. 33.

Figure 18 shows the calibration curves for temperatures of 300, 600, 900, and 1200°F. It can be seen that the zero-level readings shift, as explained earlier. Upon examination of these and similar curves it is seen that the indicated level near the top of the transducer reads lower than would be expected for the higher NaK temperatures, even considering the 0.4% decrease in the maximum-level reading. The recorder reading for a level of 8.0 in., for example, varies from 98.2 scale divisions at 300°F to 96.5 at 1200°F. The reason for a change of this magnitude is not known,

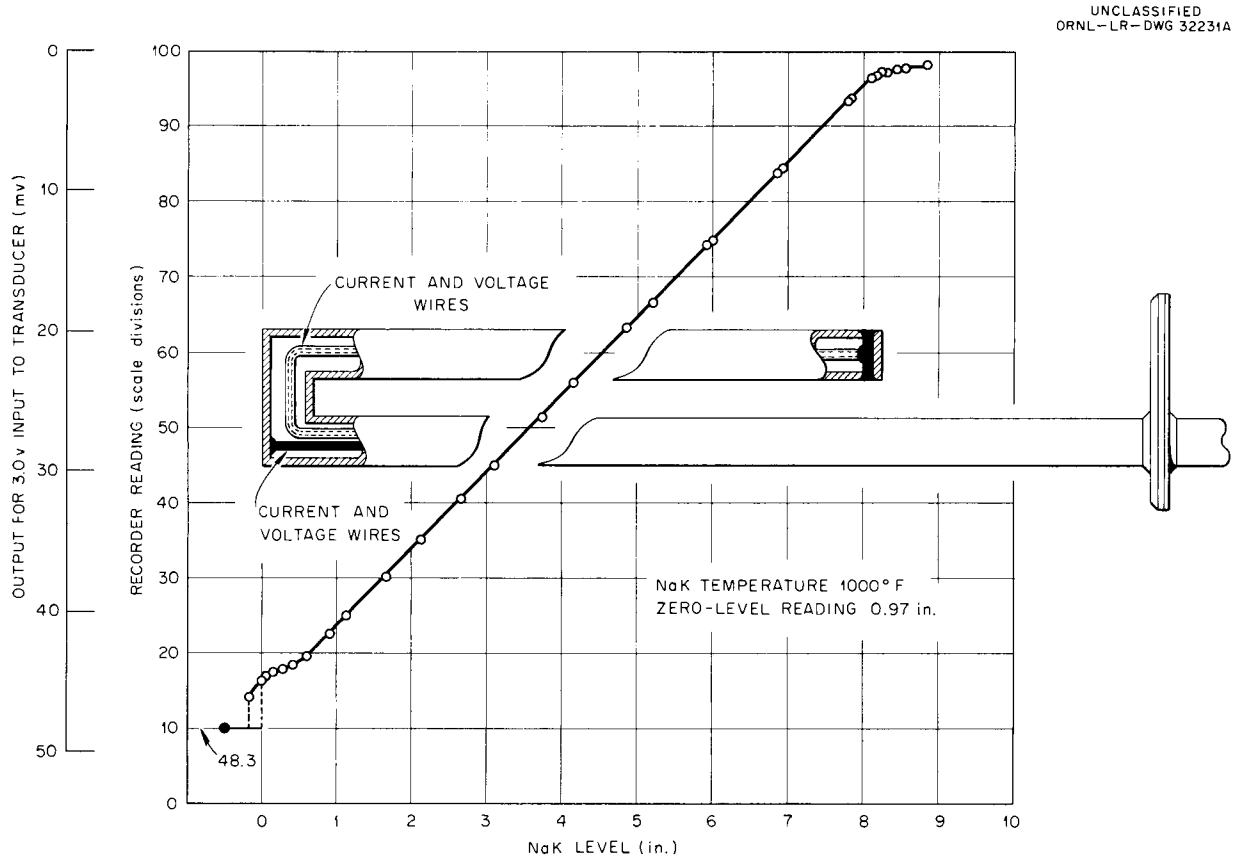

Fig. 15. Calibration Curve as Affected by Termination of Current and Voltage Wires. NaK temperature, 1000°F; zero-level reading, 0.97 in.

although differential expansion between the transducer and the movable reference-level probe may be a factor, as well as the increased amount of NaK vapor at the higher temperatures.

Figure 19 shows indicated level points plotted for NaK temperatures of 800, 900, 1000, 1100, 1200, and 1400°F. The straight line drawn is the 1200°F calibration curve. This figure shows the error that can be expected if the level is measured for NaK temperatures between 800 and 1400°F by means of the 1200°F calibration curve. The maximum deviation for these data is less than 1.5% of the level range.

1.9.4 Resolution

Figure 20 shows the attainable resolution of the system. These data were taken for NaK levels between 2.90 and 4.43 in. on the transducer, using the normal calibration procedure and equipment. One scale division on the recorder represents 1.1% of the level range. This figure shows that the measuring system can be quite accurate, with very good resolution.

1.9.5 Drift in Indicated Level

It was observed that if the transducer was first submerged and the NaK level was then dropped below the transducer, the indicated level would drift to a lower reading after the NaK level dropped. The indicated level would drift 0.2% in some cases, to a maximum of 1% in other cases, within 10 to 20 min. This is assumed to be caused by NaK draining off the transducer; no other film effect was observed.

1.9.6 Reproducibility

Recorder readings taken for the calibration tests were reproducible to within ±1% of the level range. The minimum level readings (maximum output voltage of the transducer) were

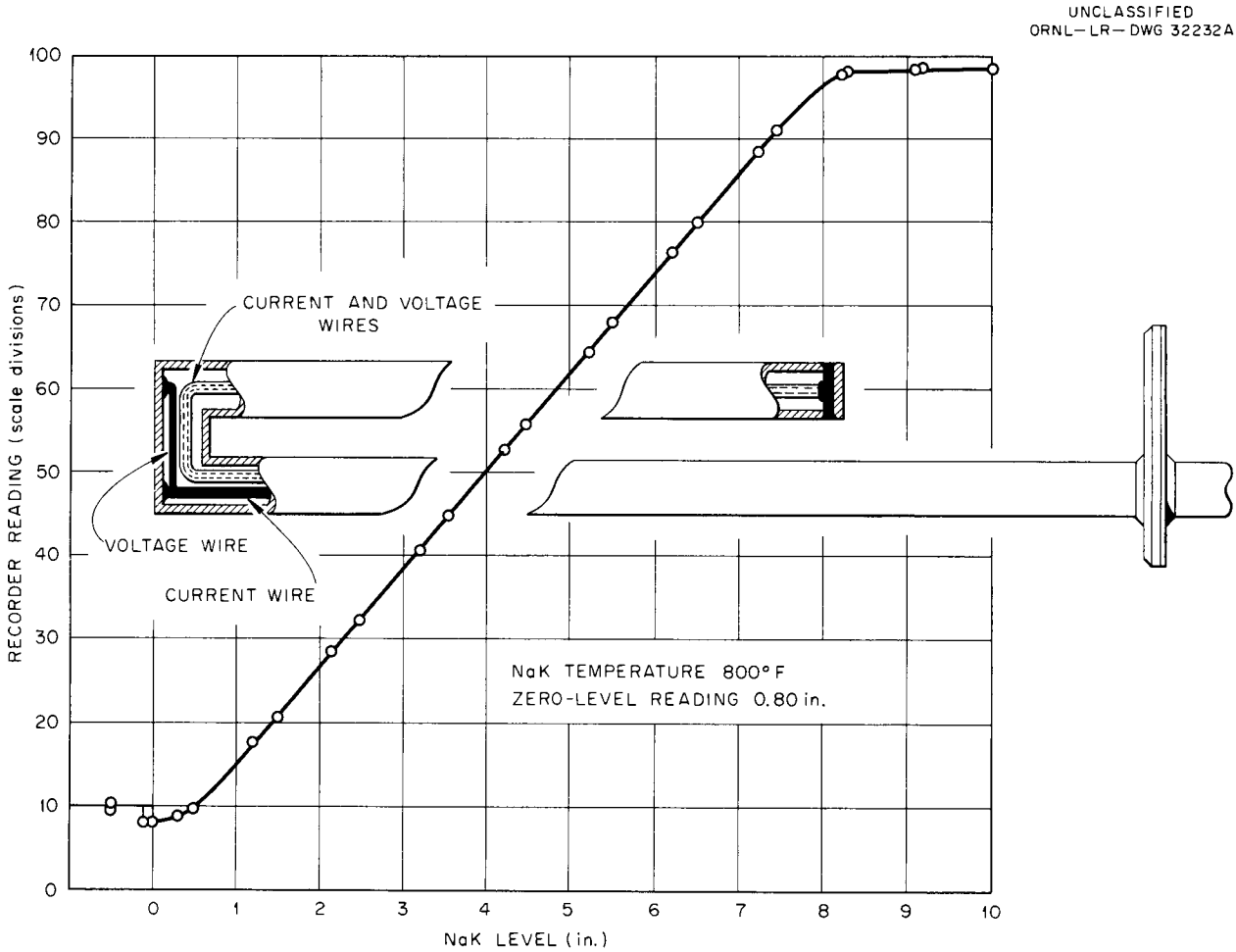

Fig. 16. Calibration Curve as Affected by Termination of Current and Voltage Wires. NaK temperature, 800°F; zero-level reading, 0.80 in.

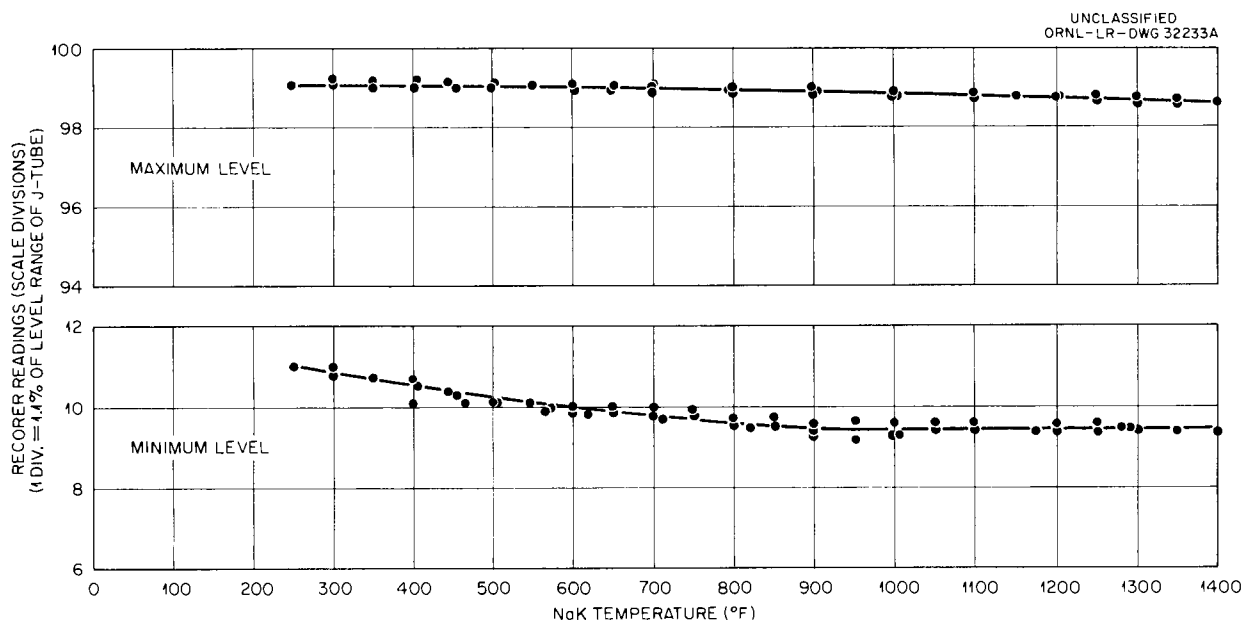

Fig. 17. Zero-Level Shift and Maximum-Level Shift vs NaK Temperature.

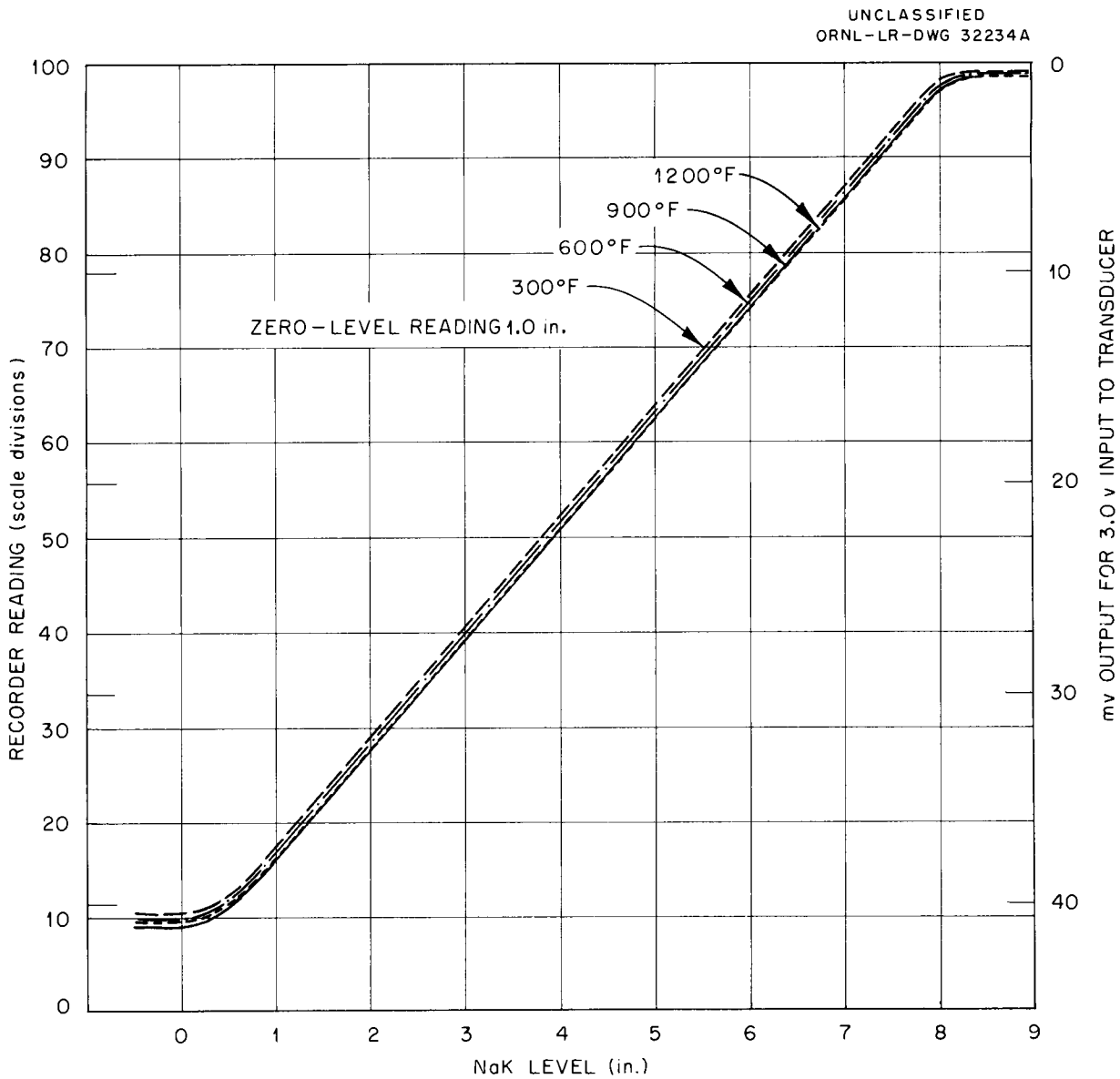

Fig. 18. Transducer Calibration Curve for NaK Temperatures of 300, 600, 900, and 1200°F.

reproducible to within ±1% of level range over the entire duration of the tests, up to 3500 hr.

1.9.7 Accuracy

The accuracy of the calibration tests (apart from transducer errors) is dependent on the accuracy of the NaK-level standard and the accuracy and stability of the level recorder. The NaK level with reference to the bottom of the transducer could be measured with an accuracy within 0.030 in., using the movable probe, over the temperature range 300 to 1400°F. There was nc apparent drift in the recorder calibration. In the calibration tests, the indicated level deviated less than 1% of full scale from the calibration curves. The over-all accuracy of the calibration test is therefore ±1% or less of full scale. The accuracy of the transducer when used in a different installation will depend on the accuracy with which dimensions can be measured for the transducer welded into the system, thermal expansion of the equipment, temperature distribution

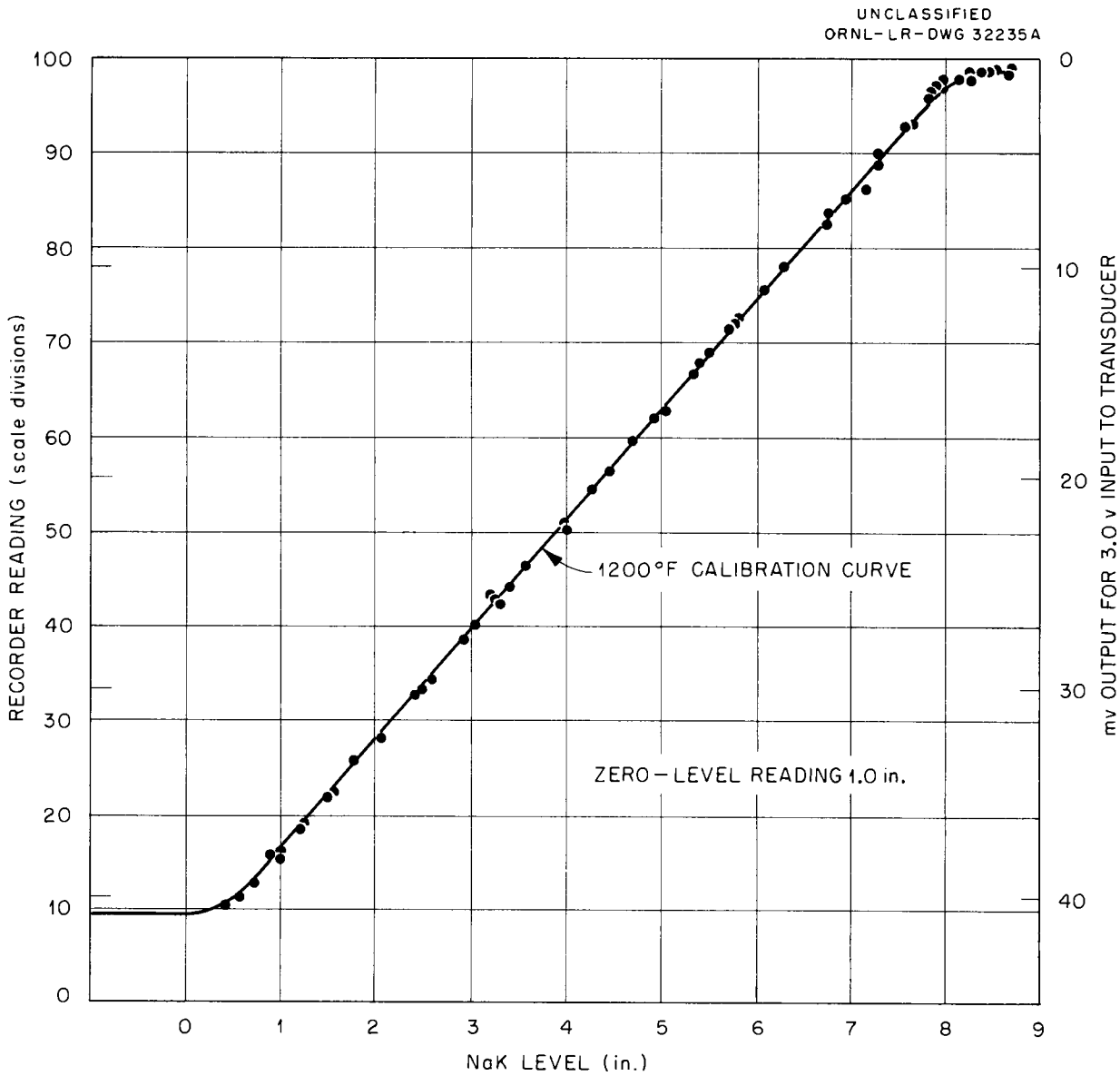

Fig. 19. Transducer Calibration Curve for NaK Temperatures of 800, 900, 1000, 1100, 1200, and 1400°F. Straight line represents the calibration curve for 1200°F NaK. Maximum deviation for the data is less than 1.5% of the level range. Zero-level reading was 1.0 in.

of the transducer relative to that of the transducer when calibrated in the test rig, and the accuracy of calibrating the recorder. Also, it is assumed that in practice one calibration curve would be used for the range of temperatures encountered, unless extremely high accuracy were required. Considering these factors, a reasonable expected accuracy would be better than ±3% of full scale.

1.9.8 Wetting Tests

Tests were conducted to determine the error due to a nonwetted probe. Before the transducer

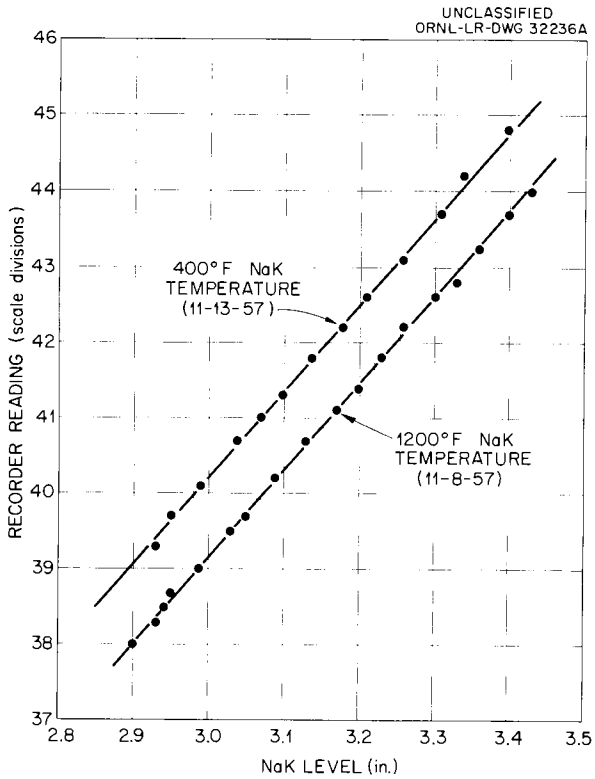

Fig. 20. Resolution Test for the System.

is wetted there is contact resistance between the surface of the Inconel and NaK due to an oxide film on the Inconel, resulting in the indicated level being lower than normal. Wetting is a function of NaK temperature, immersion time, cleanness of the Inconel, and degree of contamination of the NaK. The results previously given apply for a wetted transducer only.

A wetting test consisted in raising the NaK to about 4 in. on a new level transducer and then recording the output voltage vs time with the NaK at constant level and temperature. Other large level changes were made, and then a calibration run was made (approximately 18 points, with level increasing and decreasing) after the probe had been completely immersed. The probe was then heated to 1200°F to ensure complete wetting, and then the correct calibration curve was obtained for the temperature of the wetting test. The calibration curve of the wetted probe was then used to get the wetting error.

Figure 21 shows the error for the initial change in NaK level from below the probe to approximately 4 in. on the level probe. Curves 1, 2, 3, and 5 are for new probes which were cleaned with emery cloth and rinsed with alcohol just prior to their installation. The transducers of curves 4 and 6 had seen NaK service previously but had been removed from the system for 1 and 7 weeks, respectively. Curves 4, 5, and 6 were taken during filling of the test rigs. In curves 4, 5, and 6 the temperature rise shown is a result of the heat applied to the system by the transducers. With no other heat applied, the transducers themselves will bring the NaK temperature in the test rig to 200°F. A calibration run was made on each of the transducers of Fig. 21 after the transducers had been completely immersed. All points for this calibration test of the nonwetted probe were within the error limits shown in Table 1. Calibration runs were made at 600°F on several nonwetted transducers, with the maximum error as small as 0.050 in., in some cases, and as high as 0.25 in. in others. The discrepancy seemed to depend in part on the procedure and the elapsed time since the probe had been submerged prior to the calibration run. In other tests there was erratic behavior of the nonwetted probe which is believed to have been caused by an oxide scum on the NaK during the wetting tests.

1.9.9 Life History

These level transducers have operated in the test apparatus and in NaK pumps in the pump hot-test loops. Table 2 is a summary, as of December 15, 1957, for all level transducers tested.

The G-E transducer that failed at 20 hr did so as result of a NaK leak in a weld in the bottom section of the transducer. This transducer did not pass the ORNL weld inspections but was tested nevertheless. The one that failed at 30 hr had an internal short; this failure is discussed in Sec 1.3.

During the life-test program, the NaK temperature remained at 1200°F, and the level was continually cycled over the entire level range at a rate of 15 to 30 cycles/hr. The two transducers (see Table 2) with 3480 hr in the test rig had accumulated 40,000 level cycles at that time.

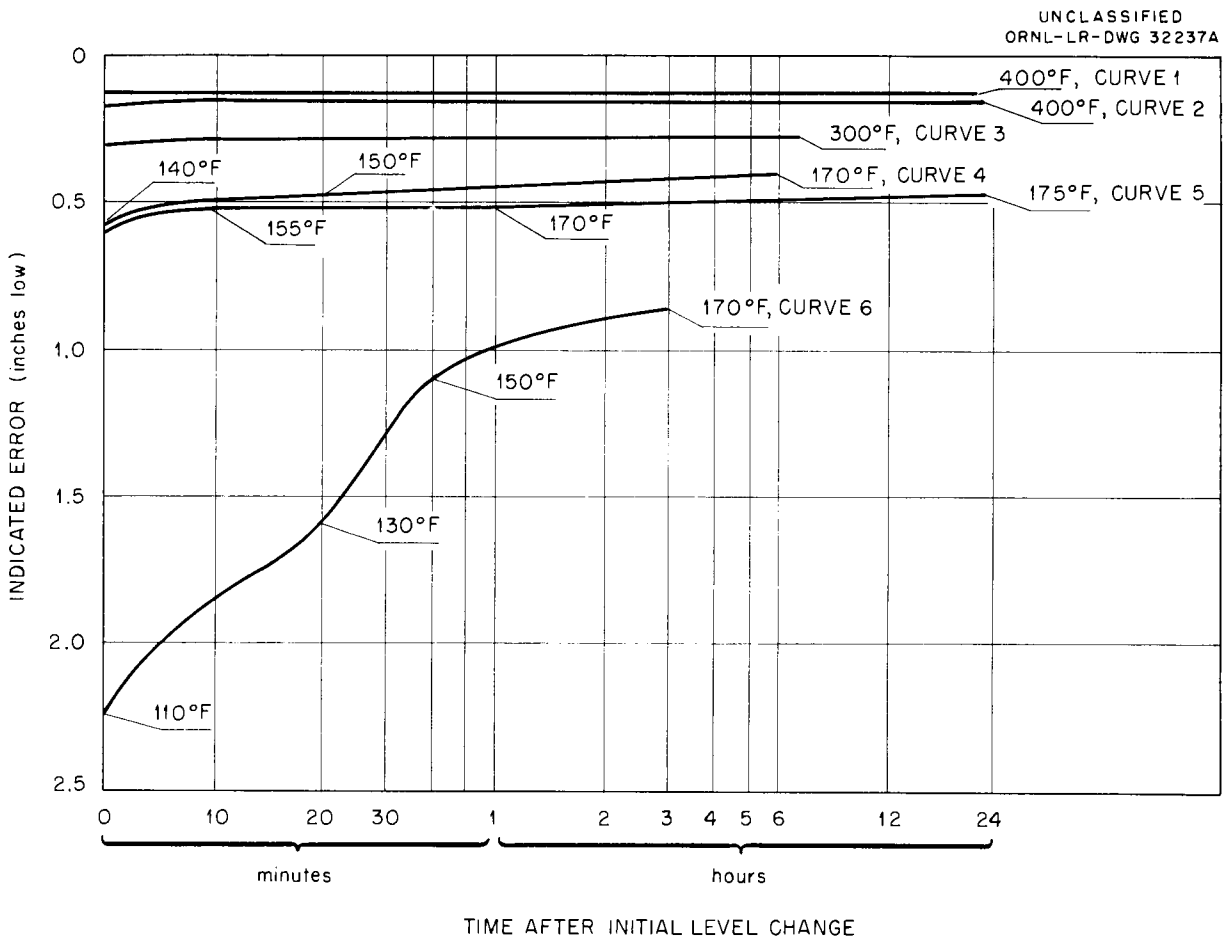

Fig. 21. Effect of Temperature on Wetting and Resultant Accuracy of Six Transducers.

Table 1. Error Limits for the Six Transducers Shown in Fig. 21

Transducer Identification and Curve No.	NaK Temperature (°F)	Error Limits (in.)	Error in Level Range (%)
Curve 1	400	0 to −0.09	0–1.1
Curve 2	400	0 to −0.07	0–0.9
Curve 3	300	−0.15 to −0.24	1.8–2.9
Curve 4	180	−0.35 to −0.56	4.3–6.8
Curve 5	180	−0.25 to −0.52	3.0–6.3
Curve 6	180	−0.23 to −0.35	2.8–4.3

Table 2. Operating Summary of Transducers in Test Rig or Loop*

Quantity	Operating Time (hr)	Remarks
1 (G.E.)	20	NaK leak failure
1 (G.E.)	30	NaK leak failure
1 (G.E.)	5900	Test loop
1 (G.E.)	3730	
1 (G.E.)	3070	Test loop
	500	Test rig
	3040	Test loop
2	3480	
1	500	Test rig
	2040	Test loop
2	2440	
1	2080	
1	1100	
1	1500	
1	1340	
1	1190	
1	1120	
4	<1220	

*Unless otherwise noted, the transducers are the ORNL type, and operation time is in the level-test rig. There were no failures except those noted above.

2. LEVEL-TRANSDUCER DESIGN

The design of the resistance-type level transducer depends, of course, upon the specific application. The mechanical construction and the electrical performance are determined by the intended use; there are, however, design considerations that will apply in general. This section discusses some general design considerations and describes some transducers which were designed for use in other tanks.

There are different forms of the resistance-type level transducer. Two forms are considered here: the J-tube, which is mounted in the top of the tank, and the straight-tube probe, which should be mounted only in the bottom of the tank (see Figs. 22 and 23). For transducers that are welded into the top of the tank, the J configuration is used, since this configuration eliminates the shunting effect of the tank walls. For a straight probe welded to the *top* of the tank, the probe is shunted by the low resistance of the tank wall, which is in parallel with the probe. This shunt resistance in parallel with the sensing-tube resistance causes the calibration curve to be nonlinear. In the J configuration, the sensing tube rises

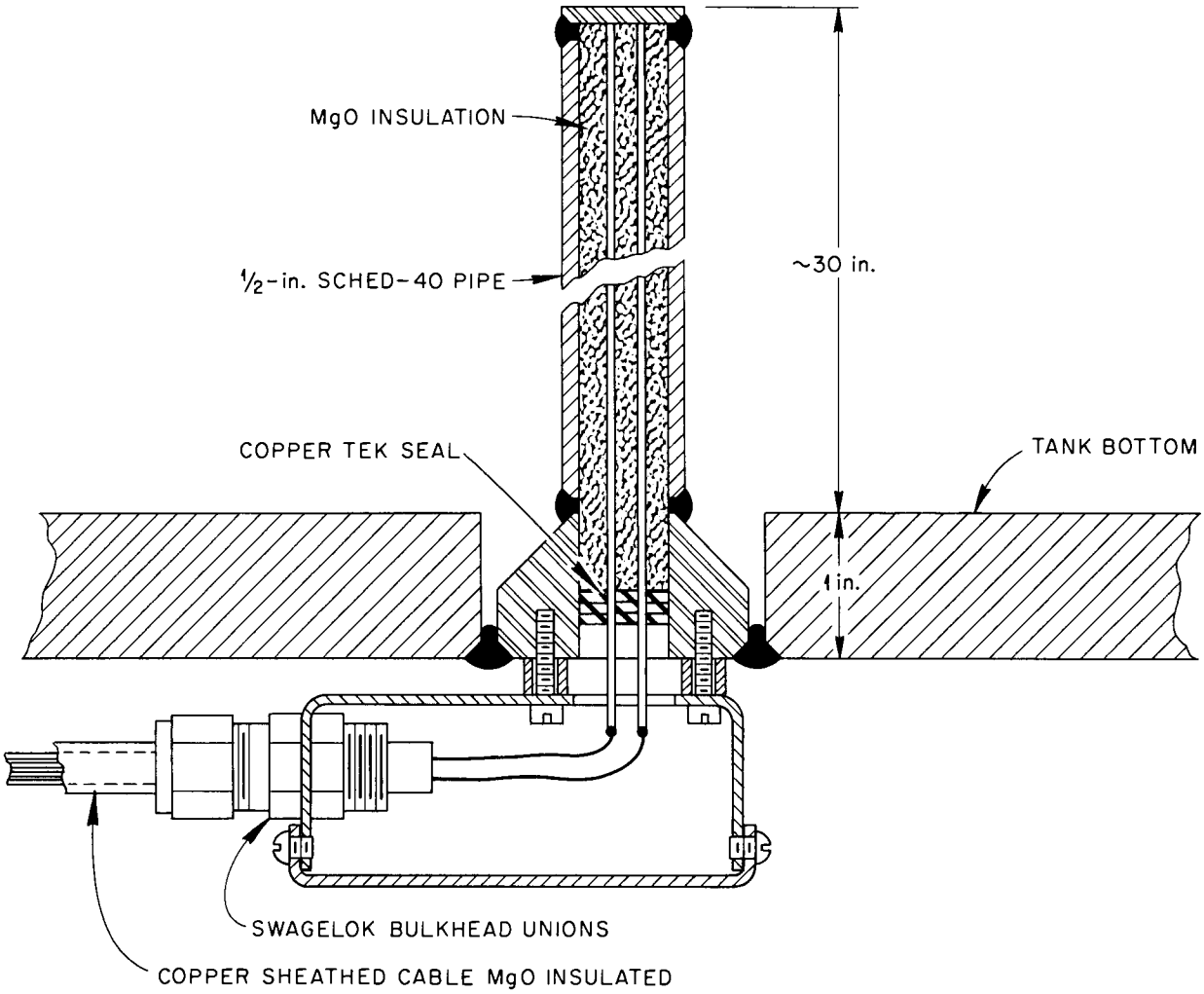

Fig. 22. Level Transducer for Drain Tank.

above the NaK surface; since there is no path in parallel with the sensing tube, the tank walls do not shunt the sensing tube. The J-tube is similar in operation to the straight-tube probe welded in the bottom of the tank except that the leads for the J-tube are brought out through the top of the tank. There is obviously no shunting effect by the tank walls in the case of the probe welded in the *bottom* of the tank.

The straight-tube probe welded in the bottom of the tank should have very good temperature compensation since the current (compensating) wire and the sensing tube will be at a uniform temperature. This probe would therefore be preferred to the J-tube where very good temperature compensation or higher accuracy is required. This straight-tube transducer is, of course, easier to fabricate. The obvious disadvantage of mounting the probe through the bottom of the tank is the greater consequence due to a leak in the transducer: often the probe would be inaccessible or difficult to replace if mounted through the bottom of the tank.

The size of the pipe or tube for the body of the transducer is selected according to the following considerations:

1. The body must be structurally strong.
2. The wall should be thin enough to allow nearly perfect shorting by the liquid metal. It was shown for the transducer discussed in Sec 1.9.3

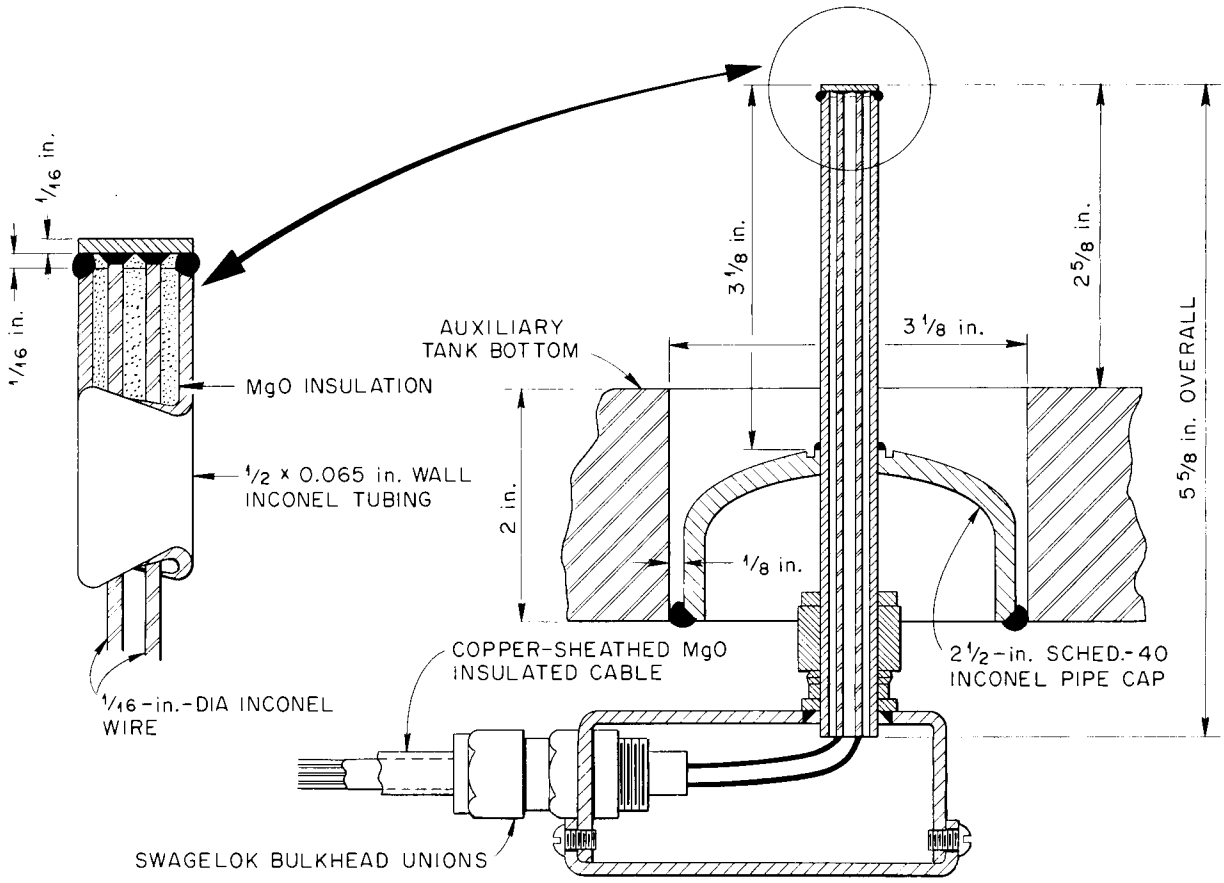

Fig. 23. Level Transducer for Expansion Tank.

that there was a slight error introduced because the NaK did not completely short the transducer at the higher NaK temperatures. The maximum-level reading for this transducer, which had a sensing-tube wall thickness of 0.091 in., was shown to drop 0.4% for high NaK temperatures. Therefore, this wall thickness would be an upper limit for NaK use, generally speaking.

3. The ratio of sensing-tube resistance to the total resistance of the current (compensating) wires should be low enough to give the desired linearity. If the sensing-tube resistance is 2% of the current-wire resistance, it can be shown that the calibration curve will deviate by 0.5% from a straight line connecting the ends of the curve.
4. The resistance of the sensing tube and the input current determine the transducer output voltage. A practical minimum limit cannot be given for the output voltage span, but a 1.0-mv span can be handled with the Brown Electronik recorder modified as previously discussed.
5. Possible film effects would be worse for thin-wall sensing tubes. It should not be necessary to use tubing having a wall thickness less than 0.062 in. in order to give sufficient output voltage, since even a $\frac{3}{8}$-in. sched-40 Inconel pipe developes 2.6 mv/in. with a 10-amp input current.

The current wire of the transducer has a maximum diameter determined by item 3, above. In addition, the current wire should carry the desired current without excessive temperature rise. If the transducer contains a tightly packed MgO powder, the temperature of the current wire will not be much higher than the transducer body temperature. The current wires of the transducer

described in Sec 1.2 had a temperature rise of less than 50°F over the body temperature when tested with body temperatures up to 1500°F and with a current of 18 amp in the $\frac{1}{8}$-in. current wires.

Finally, the input voltage is selected to give the desired current. The voltage used for the transducers of Figs. 22 and 24 is 3.0, and 1.0 v is used for the probe shown in Fig. 23. The power dissipation of the transducer must also be considered: for the transducer discussed in Sec 1.2 is approximately 60 w with an input of 3.0 v. This dissipation is higher than necessary; it would be better to use $\frac{3}{32}$-in. current wires, giving a dissipation of about 34 w.

Mineral-insulated connecting cables can be used to advantage for radioactive areas or for high-temperature requirements. Two-conductor and four-conductor MgO-insulated cables were ordered under ORNL Specification 4998-23 for use with these level transducers, and they are attached to the terminal box on the transducer through Swagelok fittings.

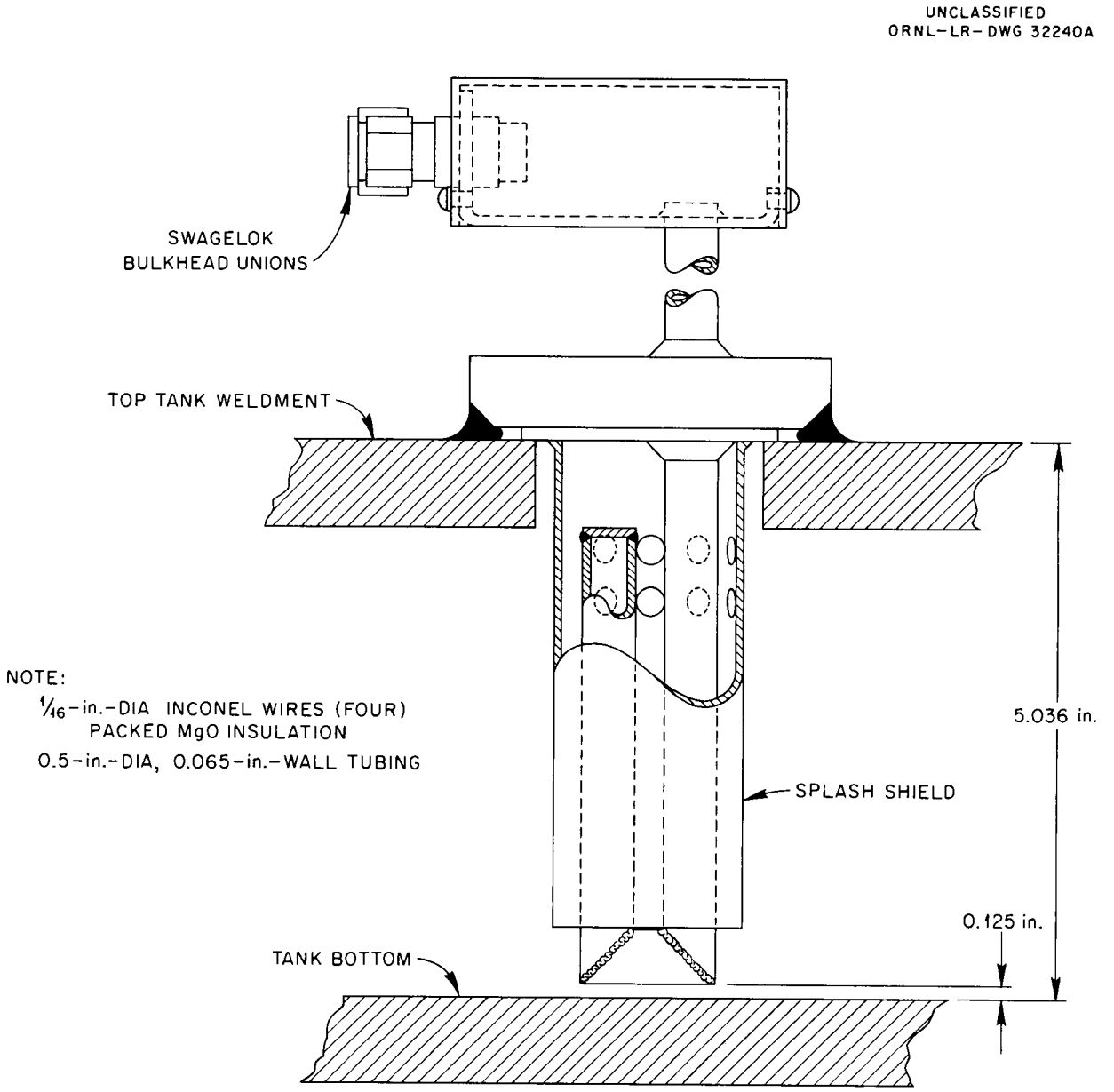

Fig. 24. Level Transducer for Expansion Tank.

3. ON-OFF LEVEL-MEASURING SYSTEM

3.1 INTRODUCTION

Considerable use had been made of the spark plug type of level probe. This probe, in some respects the simplest of the liquid-level indicating devices, indicates that the liquid has touched the probe by completing a series 110-v a-c circuit through an indicating light, the probe, and the NaK. This type of probe is used to serve as a level set-point alarm or monitoring device in cases where a continuously monitoring unit is not needed, as in fill and drain tanks, to indicate maximum and minimum fill levels. The probes generally used for this function have been of the spark plug type (see Fig. 25). They consist of regular spark plugs with a long center electrode, or plugs of the same general type but of special insulator design and were used and tested with varying degrees of success. Several Champion 344-X1 spark plug probes were tested in a NaK level-test rig at various operating temperatures of the shell body. They operated at least a month with the shell body at 450°F, but failed within 24 to 48 hr at a shell-body operating temperature of 600 to 750°F. Some were left in the NaK system for six days, with the shell-body temperature between 600 and 750°F; this resulted in complete deterioration of the lower insulator by the NaK vapor (see Fig. 26). An especially fabricated spark plug having a beryllium oxide insulator was tested in NaK. It failed after 20 hr at a NaK temperature of approximately 950°F because of short circuiting of the insulator. A photograph of this spark plug after removal from the test apparatus is shown in Fig. 27.

A level probe for liquid metal use only was designed to overcome the operating limitations of the spark plugs previously used and to provide a very reliable level indication. Figure 28 is a photograph of two of these new on-off level probes. The principle of operation is shown in Fig. 29.

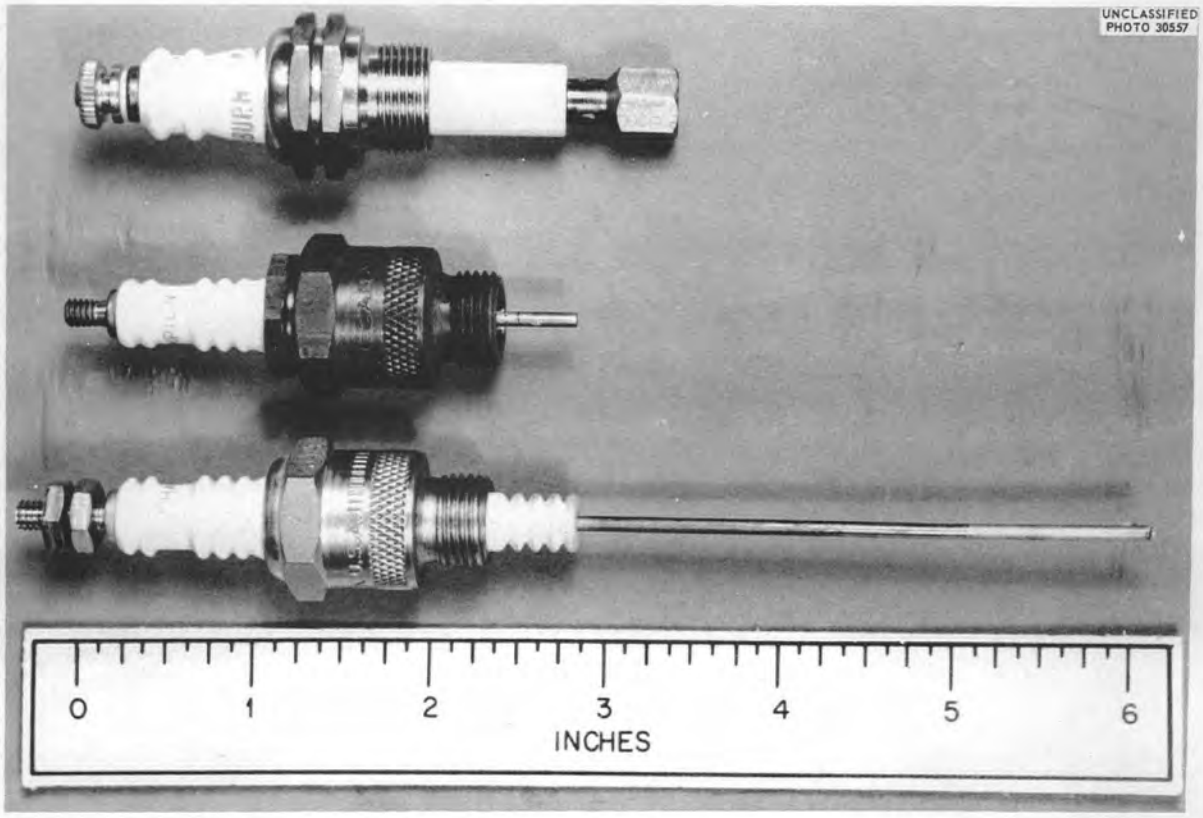

Fig. 25. Spark Plug Level Probes, New.

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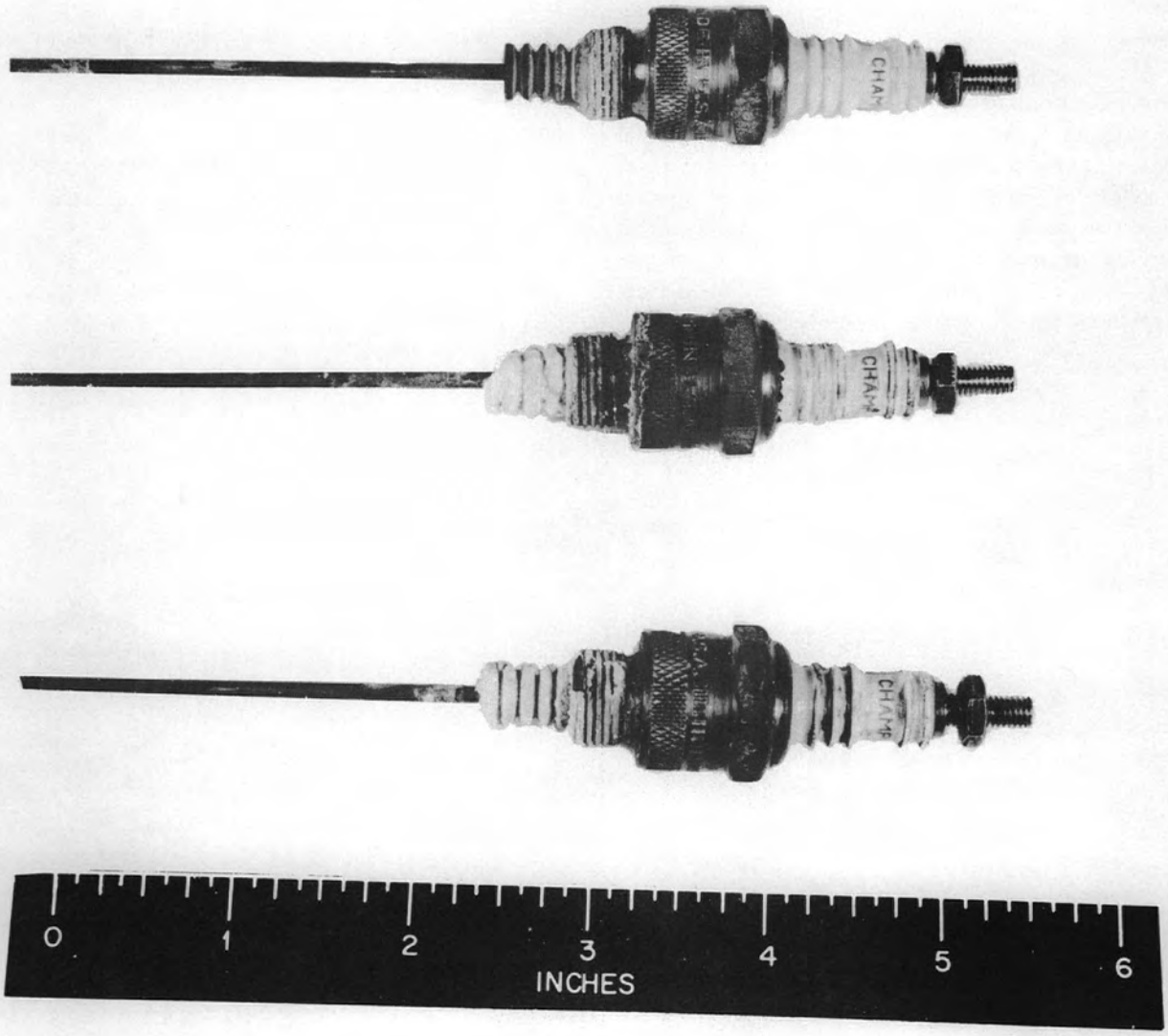

Fig. 26. Spark Plug Level Probes, Used.

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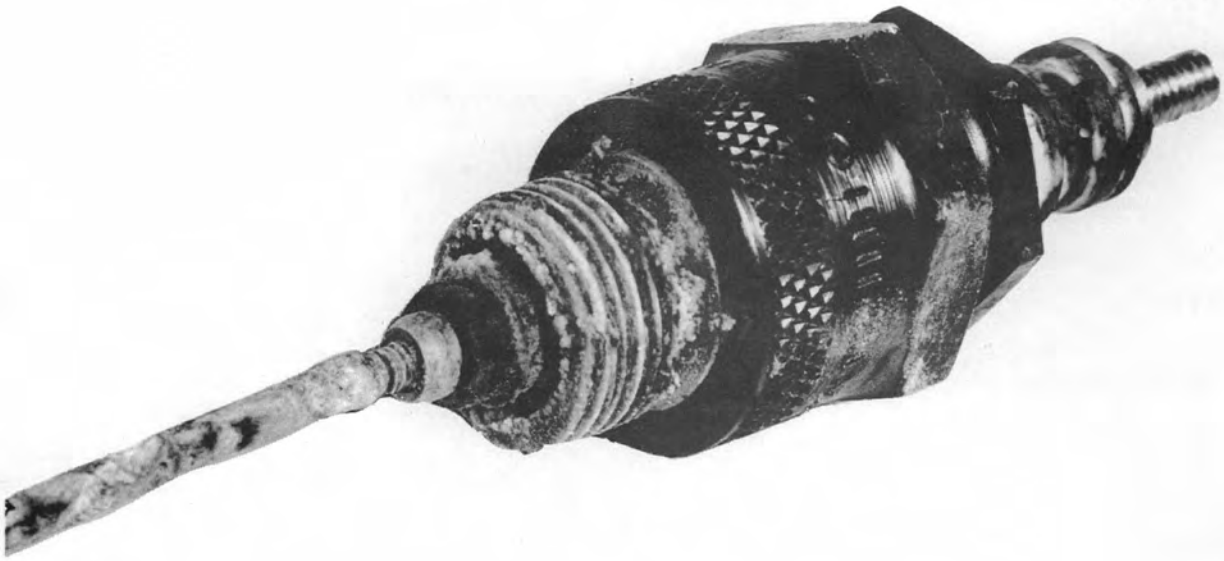

Fig. 27. Beryllium Oxide–Insulated Spark Plug Level Probe, Used.

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Fig. 28. On-Off Level Probes.

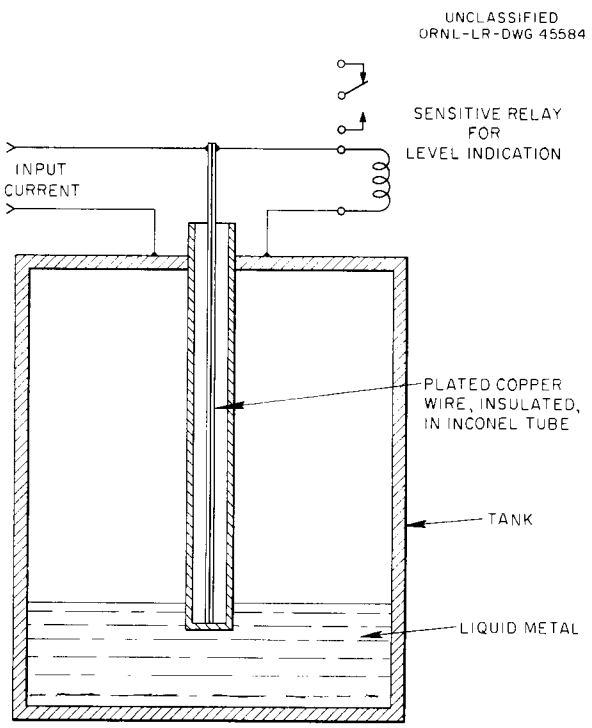

Fig. 29. Operating Principle of On-Off Level Probes.

The probe consists of an Inconel tube ($\frac{1}{4}$-in. OD, 0.025-in. wall) with an insulated copper conductor inside and with the tips of the tube and copper conductor brazed to an end cap. A 60-cycle current is applied between the center electrode of the probe and the tank in which the probe is installed. When the liquid metal touches the probe, the probe resistance decreases, causing a relay across the probe to be de-energized. The relay is energized when the liquid level is below the probe.

3.2 DESIGN

In designing this on-off probe, it was decided for simplicity to use a single conductor, insulated in an Inconel tube. (A two-conductor all-Inconel probe is described in Sec 3.6.) For this probe, it is desired to have a high ratio of tube resistance to the center conductor resistance while still maintaining a small cross section for the Inconel tube in order to keep the tube resistance high. As a compromise, Inconel tubing of $\frac{1}{4}$-in. OD and 0.025-in. wall was chosen. A No. 8 AWG copper wire was chosen as the center conductor because of its low resistance. This design gives a large change in the electrical resistance of the probe when NaK touches it. For example, a probe with the tubing extending 10 in. below the probe fitting has the following resistances, in milliohms, at low and high temperature:

Temperature	75°F	1400°F
Inconel tube resistance	24.5	25.5
Copper conductor resistance	0.8	3.4

The resistances were measured at room temperature and calculated for 1400°F, based on the room-temperature measurements.

An a-c circuit was chosen in preference to a d-c circuit for the following reasons.

1. For a 20-mw d-c relay, the current required per probe would be approximately 2 to 3 amp. A d-c supply would be more of a problem if a large number of these probes were used.
2. The ratio of pull-in to drop-out voltage is high for most sensitive d-c relays.
3. Thermal emf from the copper-Inconel junction would be appreciable and would be detrimental if a very sensitive d-c relay were used.
4. The reliability of very sensitive d-c relays is questionable.

An a-c relay furnished by the Sigma Instrument Corporation (series 41, Specification 92038) was used. This relay has the pull-in and drop-out voltage nearly the same, about 35 mv. This relay when de-energized has an impedance of about 19 milliohms and when energized an impedance of about 31 milliohms. This special relay was selected for use with level probes between 6 and 14 in. long. For longer or shorter level probes, different relay characteristics would be more suitable.

The transformer secondary voltage used for the probe circuit was 3 v. For an installation of several probes for one test, it was decided to use a low-resistance rheostat for each probe for adjusting the probe current.

3.3 INSTALLATION

These on-off probes have either a 14- or an 18-mm fitting. The units are screwed into the vessel as a spark plug probe would be, but the on-off probes can also be welded into the vessel if an all-welded system is necessary.

The schematic diagram of a typical installation is shown in Fig. 30. The current-input lead resistance must be considered, and it is important

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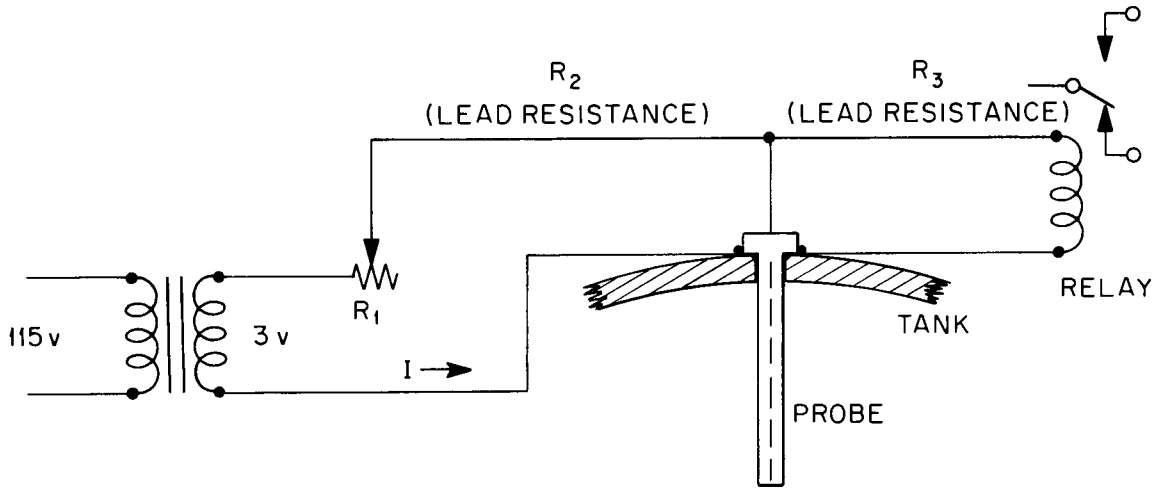

R_2 : 0.15 ohm (NOT CRITICAL) FOR 60 ft NO. 14 WIRE
R_3 : 10 milliohms FOR 10 ft (ROUND TRIP) NO. 10 WIRE
RELAY: SIGMA SERIES 41, SPEC. 92038
PULL-IN VOLTAGE, 35 mv
IMPEDANCE WHEN DE-ENERGIZED, 19 milliohms
IMPEDANCE WHEN ENERGIZED, 31 milliohms

DATA FOR 6-in. AND 14-in. PROBES

PROBE LENGTH (in.)	6	14
R_1 (ohm)	0.37	0.57
I (amp)	7.1	4.2
NaK BELOW PROBE PROBE RESISTANCE (milliohms) VOLTAGE ACROSS RELAY (mv)	 15.2 60	 35.4 60
NaK TOUCHING PROBE VOLTAGE ACROSS RELAY (mv)	 ~14	 ~14

Fig. 30. Schematic Diagram of On-Off Level Probe.

that the lead resistance for the relay coil be kept low. With these low-impedance relays it is necessary that the relays be mounted close to the installed probe; it is desirable to mount the relays within 6 ft of the probes and then to use No. 10 wire for connection to the relay coil. When more than one probe is used in an installation, two leads are used for each relay coil instead of using a common ground. The leads are fastened to the copper conductor of the probe. Upon installation of the probe, the probe current is adjusted, normally at room temperature, for 60 to 65 mv across the relay coil, with the NaK level below the probe. The relay voltage should then drop to about 14 mv when NaK touches the probe. These voltage readings were observed in actual installations and did *not* vary appreciably with temperature. It should not be necessary to readjust the probe current after the initial adjustment; however, the relay voltage should be monitored occasionally.

3.4 CONSTRUCTION OF PROBE

The first on-off probes constructed had the tip of the probe welded shut. It was necessary to weld a $\frac{3}{8}$-in.-long piece of $\frac{1}{8}$-in.-dia Inconel wire to the copper wire and then to weld the tip of this Inconel wire to the tip of the Inconel tube. This was done because a copper-Inconel weld is subject to corrosion when exposed to NaK. Probes constructed in this manner failed repeatedly at the higher operating temperatures; the copper wire ruptured near the copper-Inconel weld junction. It appeared that a layer of oxide was formed at the weld interface during welding, resulting in weakening of the copper wire. It is possible that the complete cause of the stress failure was thermal cycling of the probe combined with the weakened condition of the copper wire. In order to eliminate these failures, subsequent probes were made with the tip of the probes furnace-brazed to a small end cap. These probes have not yet been tested sufficiently to evaluate their construction.

All probes were made by using quartz or glass sleeving, manufactured by the H. I. Thompson Co., for insulating the copper wire. Although probes can be constructed in a simple and reliable manner by using this quartz or glass sleeving, a better way for the construction of a large number of probes would be to use MgO-insulated Inconel sheath stock for the probe. This sheath material was ordered from the Thermo Electric Co. under ORNL Specification 7444-11. A description of the material follows:

Center conductor	No. 8 AWG copper, nickel plated
Sheath outside diameter	0.225 in.
Sheath thickness	0.022 to 0.025 in.
Insulation	MgO, compacted by swaging the sheath

A detail and assembly drawing of this on-off probe using this sheath material is shown in Fig. 31.

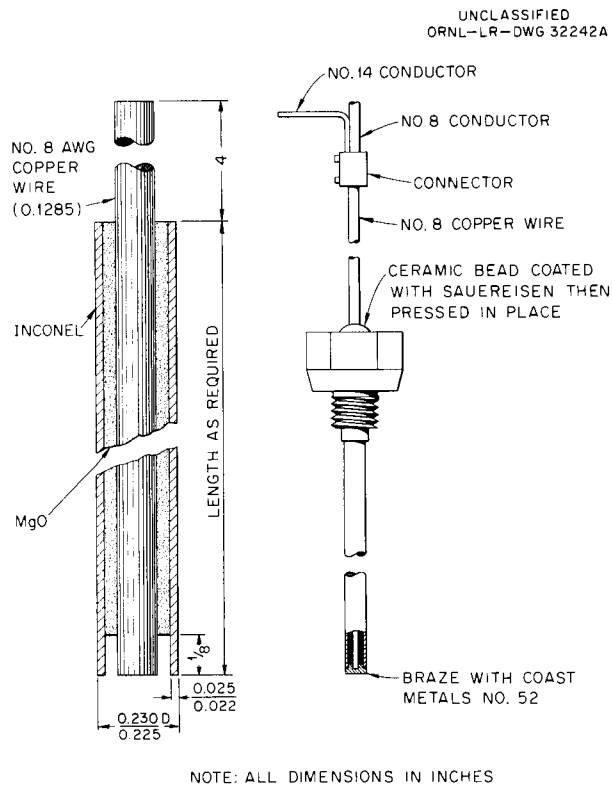

Fig. 31. Assembly Drawing of On-Off Level Probe.

3.5 OPERATING RESULTS

The early models of this on-off probe failed at the higher operating temperatures for the reason given above: corrosion of the copper-Inconel weld. The latest design has not been life tested. However, 16 probes constructed with the tip welded shut operated in a critical circuit in two pump-test loops for approximately 3000 hr without a probe failure. They were operated with the

NaK temperature generally below 800°F. There was a failure of the sensing circuit of the probe in one of the test loops because of improper circuit adjustment. The on-off probe circuit for the other test loop operated without failure and required no maintenance or readjustment.

Since this probe requires good electrical contact to the NaK for its operation, the wetting problem applies. Several of these probes were initially used in rigs being filled with NaK below 200°F. The on-off circuit functioned during this initial filling, but the exact accuracy of the indicated level was not known. However, an accurate indication can be expected during filling of the rig with cold NaK by observing the probe voltage with a vacuum-tube voltmeter. A voltage change will be seen when the probe contacts the cold NaK.

3.6 ALL-INCONEL ON-OFF PROBE

A probe was considered which would have two Inconel conductors instead of one copper conductor, as in the probe discussed above, but would otherwise be similar. This all-Inconel probe is of interest because of the following advantages over the on-off probe which is made of copper and Inconel:

1. It is not known whether the copper-Inconel probe will be mechanically reliable under all operating conditions. The all-Inconel probe appears to be more reliable since the oxidation problem referred to in Sec 3.4 would be avoided.
2. The probe circuit previously described requires that the particular sensing relays used be mounted close to the probe. These relays may not be accessible in a radioactive system.
3. The circuit for the copper-Inconel probe requires large leads and a relatively high probe current.

The all-Inconel probe is shown in Fig. 32.

This all-Inconel probe would require a very sensitive relay or an amplifier driving a relay. Note that there is no thermal emf; so a sensitive d-c relay or d-c amplifier could be used. An Edison sensitive relay was considered. This probe should have a good output voltage ratio (ratio of the voltage with NaK below the probe to the voltage with NaK touching the probe), even better than that of the on-off probe previously described.

Sheath material for this probe was ordered under ORNL Specification 7444-12. However, plans for testing this probe have been canceled because of termination of the test program.

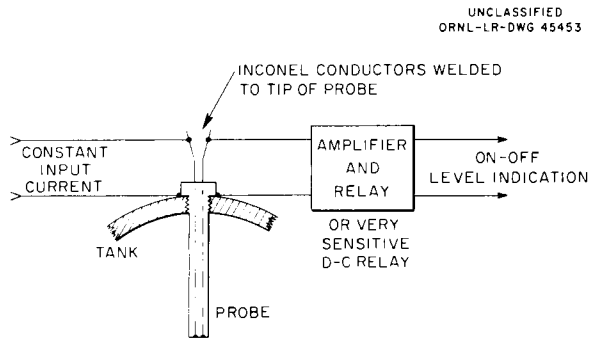

Fig. 32. All-Inconel On-Off Level Probe.

4. DISCUSSION

In considering the design of the level systems described in this report, two primary objectives were established: reliability and operating characteristics such as good accuracy, linearity, and precision.

The reliability of the system was considered from two aspects, the physical reliability of the transducer in relation to the process system into which it is placed and the operational reliability of the transducer and its associated indicating and recording system.

In considering the physical reliability of the system, it is to be noted that all the level elements described, with the exception of the spark plugs, were constructed of material compatible with the system into which it was to be placed and that the units were of all-welded construction and were to be welded into place for final operation. Since the units were to be placed in systems which would cause very hazardous conditions in case of a gas or liquid leak, this all-welded construction and installation was of prime importance, and careful consideration was given to the selection and inspection of the materials of construction of the probe. It was felt that the materials and methods used in the fabrication and installation of the various level elements provided units that were as reliable as the systems into which they were placed.

The use of spark plugs is also prohibited in any system in which a hazard exists because of the possibility of escaping gas or liquid, and it is felt that their use for level measurement is justified only in systems in which no hazard exists and in systems where level indications are not required but are a matter of convenience.

The required operational reliability of the level systems dictated simplicity of design and operation of the entire level measuring system. The transducers themselves were designed with this in mind, and it is believed that the objective was met in all respects. In addition to simplicity, the basic reliability requirement of any instrumentation system – self-monitoring – was considered. The continuous level-measuring system fulfills this requirement to the degree required since, by observing the recorder, the operational behavior can be observed and the record examined for any unusual characteristics, which can then be checked quickly against other operation data. From the nature of the continuous level probes, any failure of the probe will be evident by observing the level recorder and, if desired, by installing an indicator-light system in the recorder to indicate voltage failure or any unusual increase or decrease in the supplied current or voltage to the probe.

It is to be noted that the on-off probe system does not meet this self-monitoring requirement, since the indicator light may well indicate a false level condition caused by faulty operation of the relay or failure of the indicator lamp. For this reason, it is desirable to use continuous level probes even in systems in which only maximum and minimum levels are of interest.

The recorder or indicator systems used with the level probes were constructed by using the most reliable equipment available. The use of the a-c system allows the standard a-c supply line to be used, eliminating extra power supplies, and, in the case of the on-off probes, allows the use of commercial relays. The recorders used are also widely used in all industrial instrument systems, and the modification did not affect their reliability or accuracy.

The required operational characteristics of the level-measuring system were met in all respects and exceeded in most. As is evident from the data, the accuracy, linearity, and precision are sufficient for almost all operational requirements. If higher accuracies are required, it is believed that the calibration system could be improved in order to achieve this goal. It is to be pointed out, however, that in order to obtain the maximum possible accuracy and related operational characteristics from the level-measuring system, actual calibration is required, since the physical and chemical properties of the fluid being measured and of the material of the probe may not be accurately known or may vary from probe to probe or from system to system in the case of the process fluids.

Life and operational tests on all the units to date indicate that the level-measuring systems described in this report are of sufficient quality, with regard to reliability and operational characteristics, to be used in all types of liquid-metal systems at temperatures from 200°F, or lower, to 1500°F, or as limited by the materials of construction of the probes and fluid containers.

5. APPENDIX

Drawing References

Title	Drawing Number
Resistance-Type Level Transducer – Details	Q-1716-135
Resistance-Type Level Transducer – Assembly	Q-1716-136
Model 2 Resistance-Type Liquid-Metal Level Transducer – Details	Q-1717-5
Model 2 Resistance-Type Liquid-Metal Level Transducer – Assembly	Q-1717-6
Liquid-Metal Level Transducer for Expansion Tank – Details and Assembly	Q-1717-32
Liquid-Metal Level Transducer for Drain Tank – Details and Assembly	Q-1717-46
Liquid-Metal On-Off Probe – Details and Assembly	Q-1717-47
Brown Recorder Modification for 60-Cycle Operation	Q-1722-17
Interconnection Diagram Resistance-Type Level Transducer and Foxboro Recorder	Q-1724-9
NaK Level-Test Facility	
Test Rig – Details and Assembly	Q-1717-30 Q-1785-2 Q-1785-3 Q-1785-4 Q-1785-5
Test Panels – Wiring, Cutouts, and Miscellaneous Details	Q-1716-110 Q-1785-6 Q-1785-8 Q-1785-9 D-2-02-054-4676
Heater and Thermocouple Layout	Q-1717-19 Q-1717-24 Q-1717-25 D-2-02-054-4686
Probe Actuator – Details and Assembly	Q-1717-20 Q-1717-21
Seal for J-Tube	SK-AML-1615
Conax Fitting Guide	SK-RFH-1254
Conax Fitting Sealant	SK-RFH-1256
Sodium-Level Transducer Life-Test Facility	Q-1717-11 Q-1717-12 Q-1717-13 Q-1717-14 Q-1717-15 Q-1717-16 Q-1717-17 Q-1717-39 Q-1717-40 Q-1717-41 Q-1717-42 Q-1717-45

Title	Drawing Number
On-Off Probe-Test Facility	Q-1717-49 Q-1717-50 Q-1717-51
On-Off Probe Installation, PKA-2 Test Loop	D-2-02-054-3999 SK-REP-70412-1 SK-REP-70416-1 SK-REP-70426-1

ORNL Specifications

7444-1. Magnesium Oxide. – This specification covers electrically fused magnesium oxide having an impurity content below that required to meet a specified reactivity coefficient maximum.

7444-11. Inconel Sheathed Cable – Copper Conductors. – This specification covers the Inconel-sheathed material for on-off level transducers.

7444-12. Inconel Sheathed Cable – Inconel Conductors. – This specification covers the Inconel-sheathed material for on-off level transducers.

4998-23. Magnesium Oxide–Insulated Cable. – This specification covers two-conductor and four-conductor MgO-insulated copper-sheathed cables used as connecting cables for the level transducers.

Resistivity Curves

Resistivity Curves for Sodium and NaK. – The data used to plot the resistivity curves of both sodium and NaK (Fig. 33) were obtained from TID-5277.[1] The NaK composition for which the data applies is 56% Na–44% K, by weight.

Resistivity Curve for Inconel. – The data used to plot the resistivity curve of Inconel were obtained by J. C. Wilson, Solid State Division, ORNL (see Fig. 34). Specimens from five different heats of Inconel were used in obtaining the data. It is to be noted that the resistivity values in the temperature region below 950°F depend upon the fabrication and heating and cooling history of the Inconel.

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[1] *Liquid Metals Handbook, Sodium–NaK Supplement*, TID-5277, a joint publication by the AEC and the Department of the Navy (July 1, 1955).

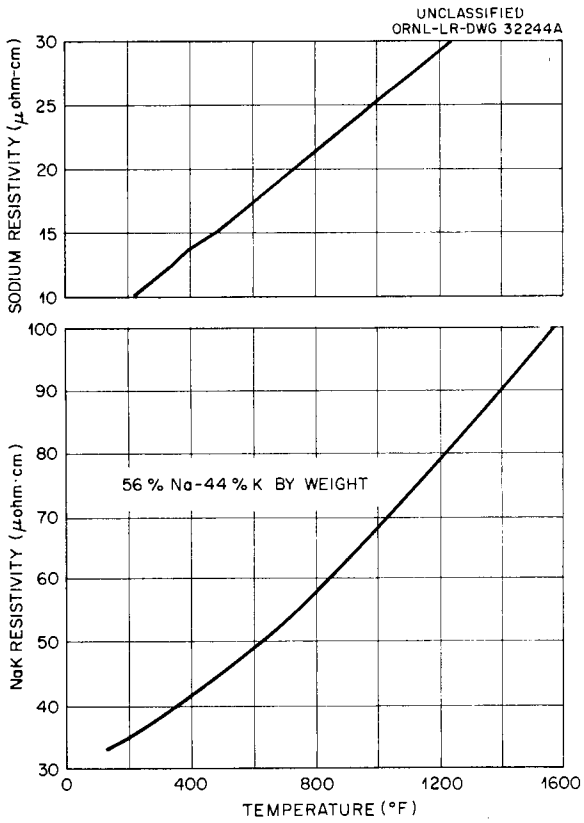

Fig. 33. Resistivity of NaK and Sodium.

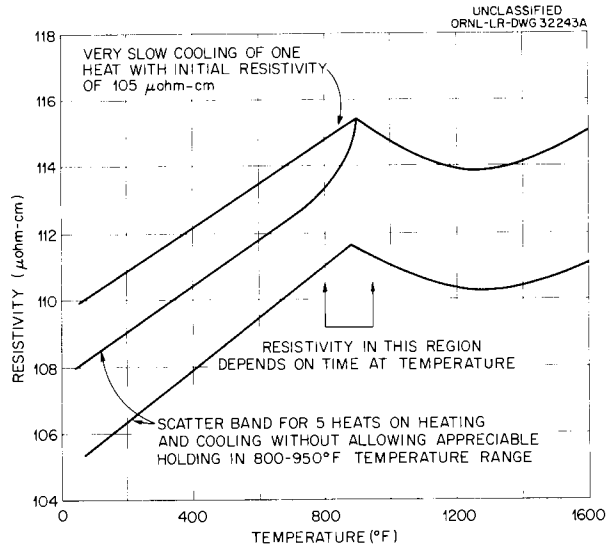

Fig. 34. Resistivity of Inconel (Five Heats) vs Temperature. Prepared by J. C. Wilson, Solid State Division, ORNL.

Pages 38–43 are exact duplications of the material submitted.

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A Division of Union Carbide and Carbon Corp.

ORNL SPEC. 4998-23
April 26, 1957

MAGNESIUM-OXIDE-INSULATED CABLE

SPECIFICATIONS

1. Four conductor cable:

   1.1 Conductors: Two No. 10 and two No. 18 gauge wires.

   1.2 Sheath OD: .375 ± .002 in.

   1.3 Sheath thickness: .020 in. minimum, .030 in. maximum.

   1.4 Minimum spacing between wires or between wires and sheath: .036 in.

2. Two conductor cable:

   2.1 Conductors: Two No. 18 or two No. 16 gauge wires.

   2.2 Sheath OD: .250 ± .002 in.

   2.3 Sheath thickness: .020 in. minimum, .030 in. maximum.

   2.4 Minimum spacing between wires or between wires and sheath: .036 in.

GENERAL SPECIFICATIONS

1. Type cable: Two conductor and 4 conductor sheath cable for high temperature operation.

2. Sheath: Copper.

3. Insulation: High purity Magnesium Oxide in accordance with ORNL SPEC. 7444-1.

4. Conductors: Solid high-conductivity copper, nickle plated.

5. Test requirements: Insulation resistance greater than 10 megohms for a 10 foot length with bends of radius equal to twice the cable diameter.

Resistance measured at 500 volts D.C. at room temperature.

6. Piece Length: 12 to 30 ft. random lengths.

Prepared by: /s/ R. E. Pidgeon
R. E. Pidgeon

Approved by: /s/ R. G. Affel
R. G. Affel
Instrument Department

OAK RIDGE NATIONAL LABORATORY
Operated by
UNION CARBIDE NUCLEAR COMPANY
P.O. Box Y, Oak Ridge, Tenn.

ORNL SPEC. 7444-11
June 12, 1957
Page 1 of 1

INCONEL SHEATHED CABLE-COPPER CONDUCTORS

TITLE

Inconel-sheathed material for "on-off" level transducers.

SPECIFICATIONS

1. Center conductor: One No. 8 AWG wire.

2. Sheath OD: .225 in. minimum, .230 in. maximum.

3. Sheath thickness: .022 in. minimum, .025 in. maximum.

GENERAL SPECIFICATIONS

1. Sheath material: Inconel. Maximum scratch depth 5% of wall thickness.

2. Insulation: High purity magnesium oxide in accordance with ORNL Spec. 7444-1. The insulation shall be compacted by swaging the sheath tightly over the insulated wire.

3. Center conductor: Solid high-conductivity copper, nickle plated to thickness of .0005 to .001 inches.

4. Test requirement: Insulation resistance greater than 10 megohms for a 10 foot length with bends of radius equal to twice the cable diameter. Resistance measured at 500 volts dc at room temperature.

5. Piece length: 10 to 12 foot random lengths, minimum length 2 ft.

6. Handling: The furnished material shall be straight. All tubing must be handled and packed with care in order not to scratch or otherwise damage the surface.

7. Each piece of material shall be packed and shipped with both ends heliarc welded closed.

Prepared by: /s/ R. E. Pidgeon
R. E. Pidgeon

Approved by: /s/ R. G. Affel
R. G. Affel
Instrument Department

OAK RIDGE NATIONAL LABORATORY
Operated by
UNION CARBIDE NUCLEAR COMPANY
P.O. Box Y, Oak Ridge, Tenn.

INCONEL SHEATHED CABLE-INCONEL CONDUCTORS

TITLE

Inconel-sheathed material for "on-off" level transducers.

SPECIFICATIONS

1. Conductors: Two .062" ± .006" diameter wires.

2. Sheath OD: .250 ± .005 in.

3. Sheath thickness: .022 in. minimum, .025 in. maximum.

4. Wire spacing: Minimum spacing between wires or between wires and sheath .020 in.

GENERAL SPECIFICATIONS

1. Sheath material: Inconel. Maximum scratch depth 5% of wall thickness.

2. Insulation: High purity magnesium oxide in accordance with ORNL Spec. 7444-1. The insulation shall be compacted by swaging the sheath tightly over the insulated wire.

3. Conductors: Two straight .062" ± .006" diameter inconel wires. This material will be supplied by the purchaser.

4. Test requirement: Insulation resistance greater than 10 megohms for a 10 foot length with bends of radius equal to twice the cable diameter. Resistance measured at 500 volts dc at room temperature.

5. Piece length: 10 to 12 foot random lengths, minimum length 2 ft.

6. Handling: The furnished material shall be straight. All tubing must be handled and packed with care in order not to scratch or otherwise damage the surface.

7. Each piece of material shall be packed and shipped with both ends heliarc welded closed.

Prepared by: R. E. Piegeon /s/ REP:vcc
R. E. Pidgeon

Approved by: /s/ R. G. Affel
R. G. Affel
Instrument Department

OAK RIDGE NATIONAL LABORATORY
UNION CARBIDE NUCLEAR COMPANY
A Division of Union Carbide and Carbon Corporation
Post Office Box "P"
Oak Ridge, Tennessee

MAGNESIUM OXIDE (MgO)

1.0 RAW MATERIAL

THE SUPPLIER OF THIS MATERIAL SHALL BE RESPONSIBLE FOR ALL REQUIREMENTS OF THIS SPECIFICATION EXCEPT THOSE ITEMS REFERRING SPECIFICALLY TO ORNL RESPONSIBILITY.

1.1 Material

This specification covers electrically fused magnesium oxide (magnesia (MgO) having an impurity content below that required to meet a specified reactivity coefficient maximum.

1.2 Samples and Procurement Procedure: Raw Material

1.2.1 Each homogenous batch of material shall be sampled by the vendor. The samples shall be properly identified with the respective batch and sent to ORNL for the tests in Section 1.3.

1.2.2 The vendor shall hold the balance of each batch pending notification of results and disposition of the material.

1.3 Tests Raw Material (ORNL Responsibility)

1.3.1 Reactivity Coefficient

1.3.1.1 ORNL shall measure the reactivity coefficient for each batch on sample submitted by the vendor under section 1.2.1, notify the vendor regarding compliance with this requirement of this specification and regarding disposition of the material.

1.3.1.2 The following table of reactivity conversion factors is submitted for the guidance of the vendor. It is to be used to convert the concentration of impurities (in ppm) to equivalent boron concentrations (in ppm) as follows:

(PPM of impurity) x (C.F.) = (PPM of Equivalent Boron)

The sample can be expected to pass the ORNL reactivity coefficient test if the sum of the equivalent boron concentrations of all impurities is less than 75 ppm.

Included in the table is a list of impurities to be found in a typical sample of MgO. The conversion to ppm of equivalent boron for each impurity is shown.

Material	Conv. Factor (C.F.)	Typical Conc. (ppm)	Equiv. Boron Conc(ppm)
Fe	.00062	230	.14
V	.0013	5	.0065
Ti	.0017	75	.13
B	1.0	6	6.0
Cd	.31	10	3.1
Hg	.027	100	2.7
Mn	.0033	20	.066
Co	.0085	20	.17
Li	.14	250	35.
Ni	.0011	20	.022
Cu	.00082	20	.016
In	.024	10	.24
Ag	.0080	1	.0080

This lot meets reactivity coefficient requirements having less than 75 ppm B equiv. conc.

1.3.2 Chemical Composition: ORNL shall verify the chemical composition as furnished by the vendor by check analysis and compare the results with the analysis shown in section 1.4.

1.4 Chemical Composition
The MgO content shall be 96.0% minimum.

* * * * * * * *

Prepared by: /s/ J. T. De Lorenzo
J. T. De Lorenzo

Approved by: /s/ R. G. Affel
R. G. Affel

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