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Tests of a Resistance-type High-Temperature Sensor for the Continuous Measurement of Salt Level in Molten Salt Fueled Reactors

Robert F. Hyland

ABSTRACT

An accurate, reliable sensor is needed for the continuous measurement of salt level in molten salt fueled reactors at temperatures ranging from 1000°F to 1600°F.

Two types of all welded level elements which sense a resistance change that is a function of level were designed and tested in fuel #30 (50 mole % NaF, 46 mole % ZrF_4, 4 mole % UF_4) and in fuel #130 (62 mole % LiF, 37 mole % BeF_2, 1 mole % UF_4). The Project 7503 fuel #30 tests were inconclusive because of cancellation of the program before the work was completed.

In the molten salt power reactor program tests, the short term performance of one type of element in fuel 130 was satisfactory; however, a long term calibration drift was evident, necessitating frequent recalibration.

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Summary

The lack of an accurate, safe, reliable level element for the continuous measurement of salt level in high temperature molten salt fueled reactors dictated that a program be undertaken to develop such an element.

A prototype Inconel element (Figures 1 and 2) which senses a resistance change that is a function of level was first developed for use in Project 7503. The molten salt of interest in this program was known as composition 30 (50 mole % NaF, 46 mole % ZrF_4, 4 mole % UF_4). Design specifications for the element were as follows:

Temperature range - 1000°F to 1600°F

Accuracy - ± 2% of full range

Sensitivity - 0.05 inches of salt

Level range - 0-5 inches of salt

Design pressure - 15 psig at 1600°F

Material in contact with salt - Inconel

Construction - All welded - no seals, stuffing boxes or other possible sources of salt containment violation. No parts subject to radiation damage.

The prototype element was tested only briefly and inconclusively during Project 7503 and all work was discontinued when the project was cancelled.

A new requirement for a similar level element for the molten salt power reactor program reactivated an interest in the existing element. This requirement was resolved into the following set of specifications:

Salt - Composition 130 (62 mole % LiF, 37 mole % BeF_2, 1 mole % UF_4)

Temperature range - 1000°F to 1300°F

Accuracy - ± 5% of full range

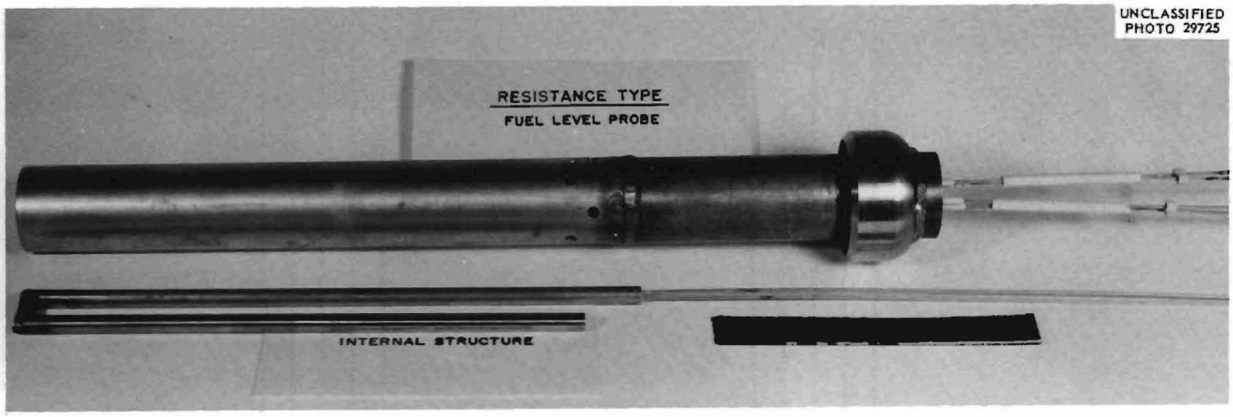

Fig. 1. Q1717-53 Level Element – Assembly and Internal Structure.

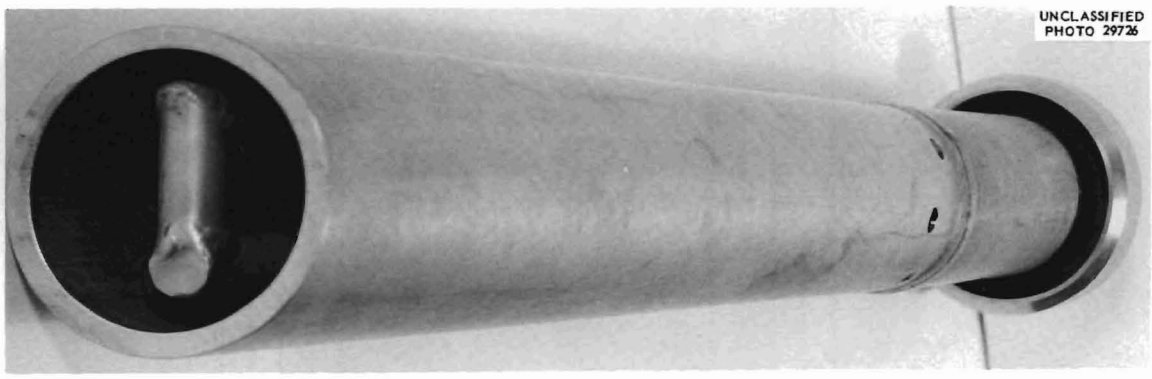

Fig. 2. Q1717-53 Level Element – End View.

Sensitivity - 0.2 inches of salt

Level range - Varied

Design pressure - 10 psig at 1300°F

Material in contact with salt - INOR-8

Construction - All welded - no seals, stuffing boxes or other possible sources of salt containment violation. No parts subject to radiation damage.

A modified version of the prototype element shown installed in a test vessel top plate and riser, (Figures 3 and 4), was designed which eliminated some of the fabrication problems involved. Inconel was chosen as the material of construction because of the unavailability of INOR-8. The two materials have similar resistivities and corrosion resisting properties.

Because of a lack of resistivity data on fuel 130, a simple go-no go test (Test #1, Section 2.20) was first run to determine if the element was useful at all in the new salt. Following the success of this test, two additional elements were fabricated without temperature compensation and were tested in composition 130 salt over a period of approximately 60 days at a temperature of 1200°F (Test #2, Section 2.30). The level range was 0-6 inches of salt. Both elements provided a slightly non-linear span of approximately 8.0 millivolts that was a function of level. The overall short term accuracy of the measuring system was $\pm$ 3.5% of maximum level. The precision of measurement was approximately 0.2 inches of salt.

During the third day of the test, the span of both elements began to decrease. Because a change in fuel resistivity with time was suspected as being a possible cause of this span decrease, at the conclusion of Test #2 the fuel in both vessels was dumped and replaced with a fresh batch. The result was that the pre-test span was restored on both level elements.

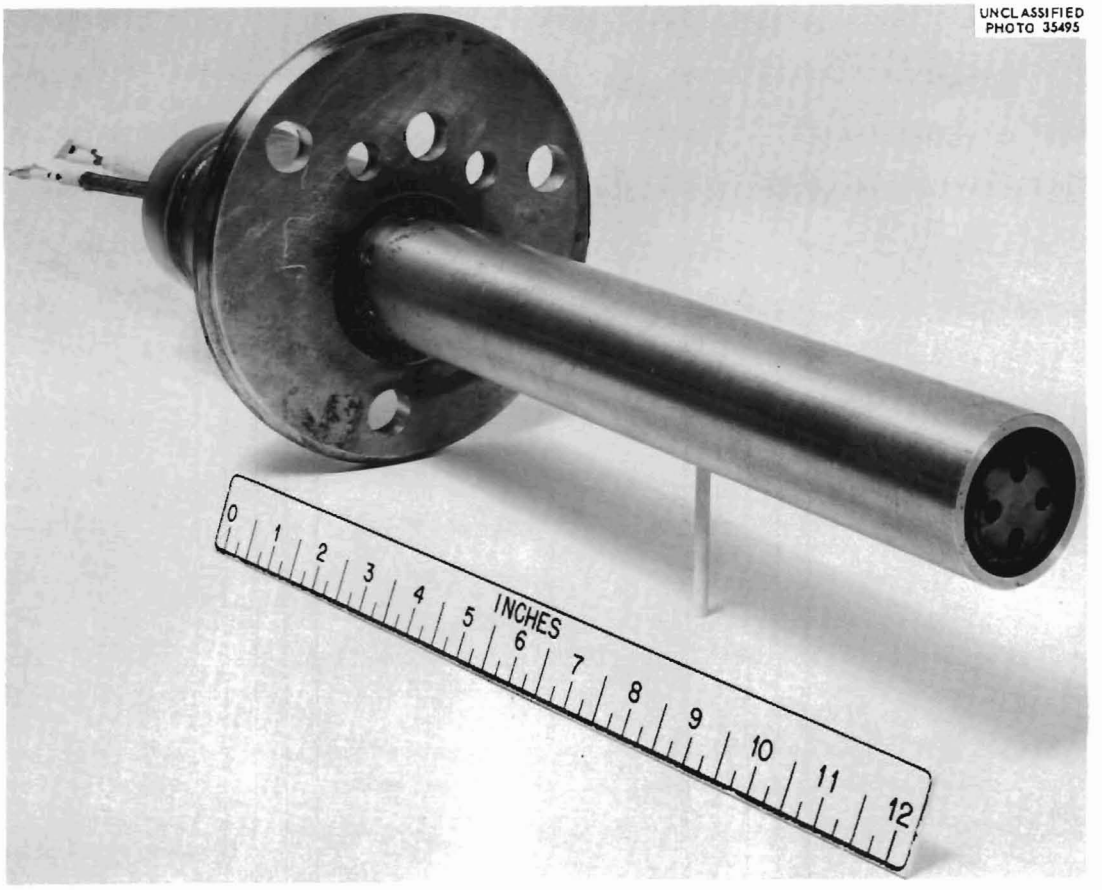

Fig. 3. Q1717-54 Level Element – Installed in Top Plate and Riser of Test Vessel.

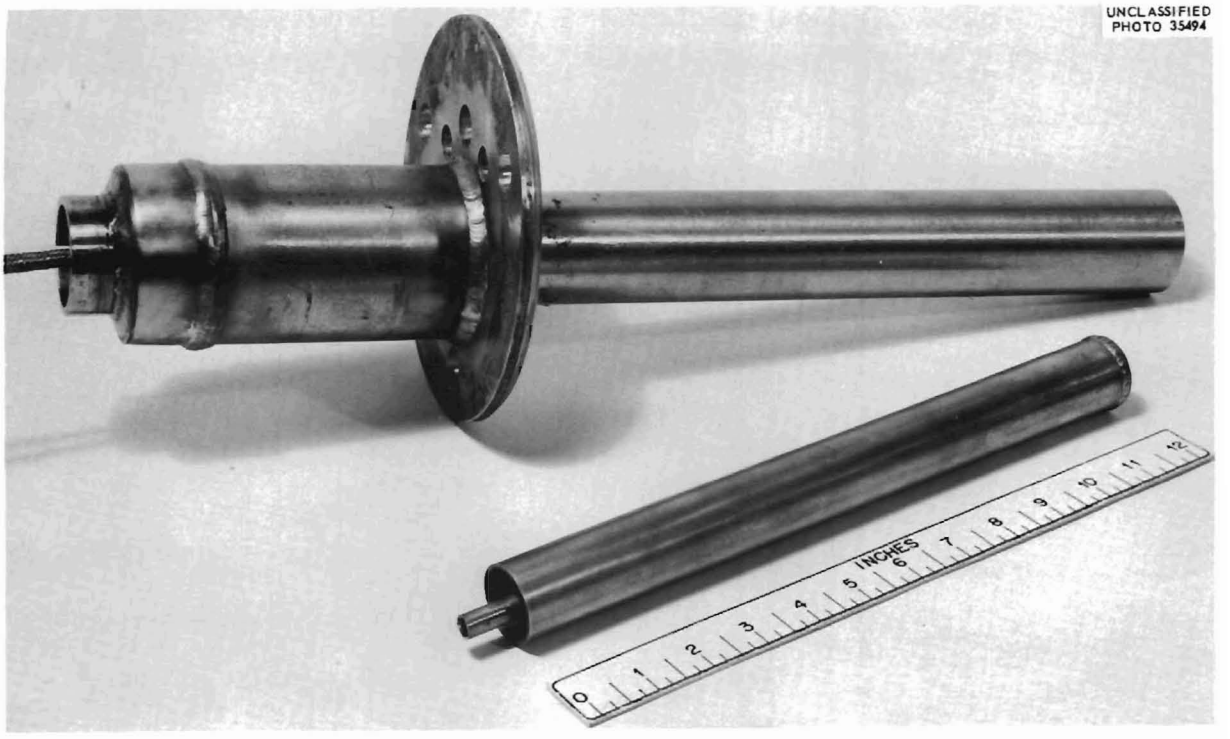

Fig. 4. Q1717-54 Level Element – Assembly and Internal Structure.

Comparative quantitative analyses of the fuel, both before and after the tests tended to dispute this evidence, however, because very little change was noted in the comparison.

Another mechanism which might have caused this span decrease was investigated in Test #3 (Section 2.40). Tests #1 and #2 were run with the salt below the level element completely, except during data taking periods. It was suspected that deposits from the vapor above the salt might be building up on the probe. Test #3, therefore, was run with the salt raised on the probe at all times except while taking data. The result was that the probe span increased for a period, levelled off, then decreased. It is postulated that an entirely new variable was added to an already difficult problem, namely, the corrosive action of the salt on an oxide film on the probe.

It can be concluded that the element is useful for level measurement in composition 130 salt on a short term basis only. Frequent recalibration would be necessary for its use in extended service. In addition, experimental proof of the theoretical method of temperature compensation must be obtained, in order to provide a useful element over the temperature range of interest.

Introduction

The work described in this report is divided into two sections. Section 1.00 covers the design, development and testing of a prototype element and its associated circuitry in connection with Project 7503. The salt of interest is known as composition 30 (50 mole % NaF, 46 mole % ZrF_4, 4 mole % UF_4).

The second section (Section 2.00) covers the modification of the prototype element for use in the Molten Salt Power Reactor Program and the subsequent testing of the element in composition 130 salt (62 mole % LiF, 37 mole % BeF_2, 1 mole % UF_4).

Acknowledgements

The conceptual designs and initial design calculations in connection with these level elements were the work of Theron V. Blalock of ORNL.

1.00 Project 7503 Work

1.10 Theory

The basic idea for the level element was suggested by a successful high temperature liquid metal level transducer developed by the General Electric Company Knolls Atomic Power Laboratory and modified by ORNL.[1]

The liquid metal level transducer is shown diagrammatically in Figure 5. The input current leads are 1/8 inch diameter Inconel, the output voltage leads are 1/16 inch diameter Inconel and the body is 3/8 inch schedule 40 Inconel pipe. The input to the transducer is approximately 3 volts at 20 amperes 60 cps. With the liquid metal level below the transducer, all of the input current will flow through the sensing tube (the shorter vertical section of pipe) resulting in approximately 20 millivolts (for NaK - 56% sodium, 44% potassium) developed across the 8 inch long sensing tube. The voltage is measured by the recorder. As the liquid metal level rises on the sensing tube, it "shorts" that portion of the sensing tube, since the liquid metal is a good electrical conductor. The output voltage will therefore drop an amount proportional to the rise of the liquid metal on the sensing tube and becomes approximately zero when the sensing tube is completely submerged. The output voltage is therefore a linear function of liquid metal level.

The molten salt level element, while similar in appearance, excitation and readout to the liquid metal element, is somewhat different in principle. Its operation depends on the fact that the salt has a relatively high resistivity compared to liquid metals. [Salt-0.97 ohm-cm (Figure 6), NaK - 7.9×10^{-7} ohm-cm[1], sodium-2.90×10^{-7} ohm-cm[1] at 1200°F].

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1. Liquid Metal Level Transducers, R. G. Affel, G. H. Burger, R. E. Pidgeon, ORNL-CF-58-8-19, August 11, 1958.

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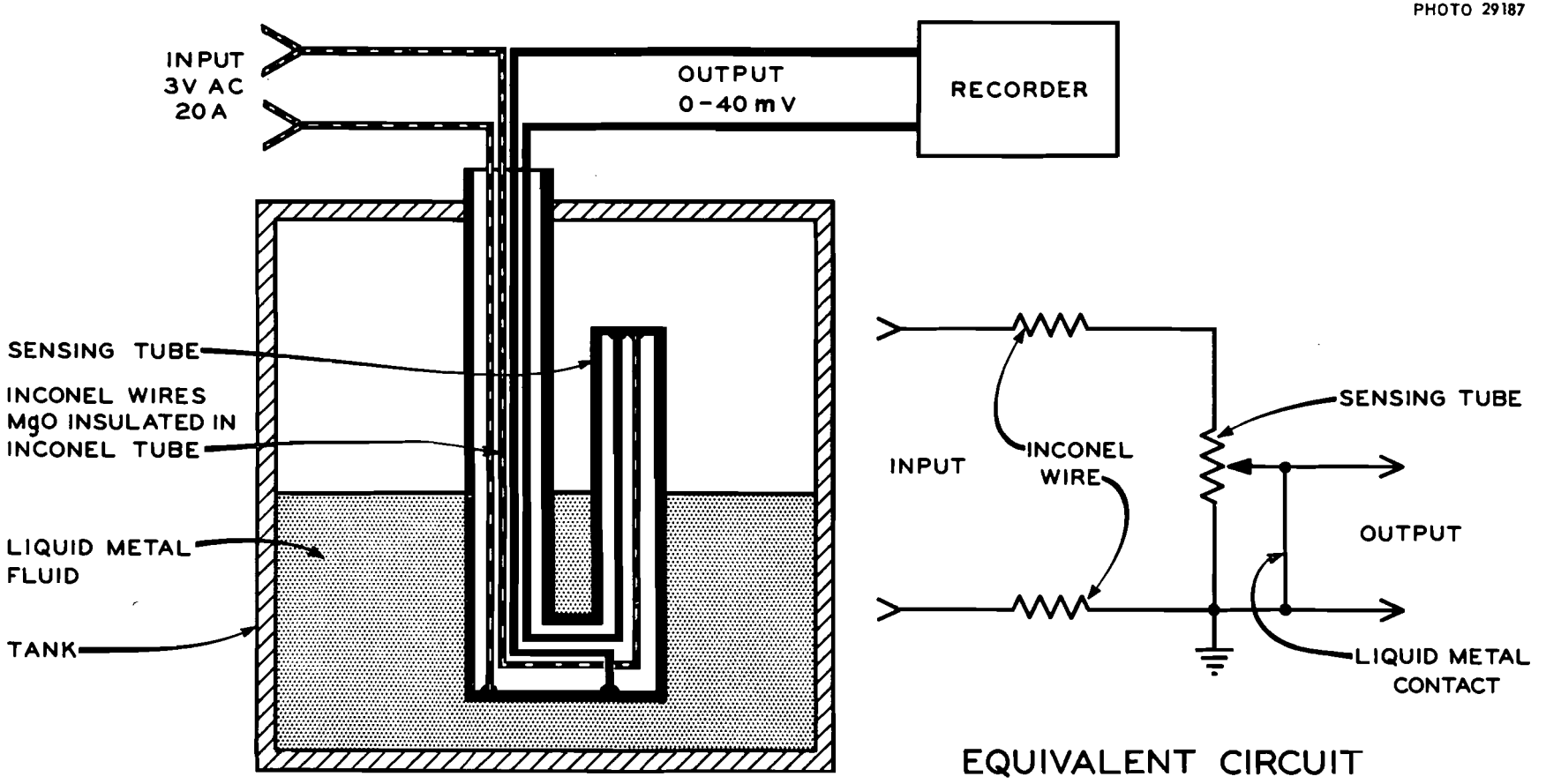

Fig. 5. Liquid Metal Level Transducer – Operating Principle.

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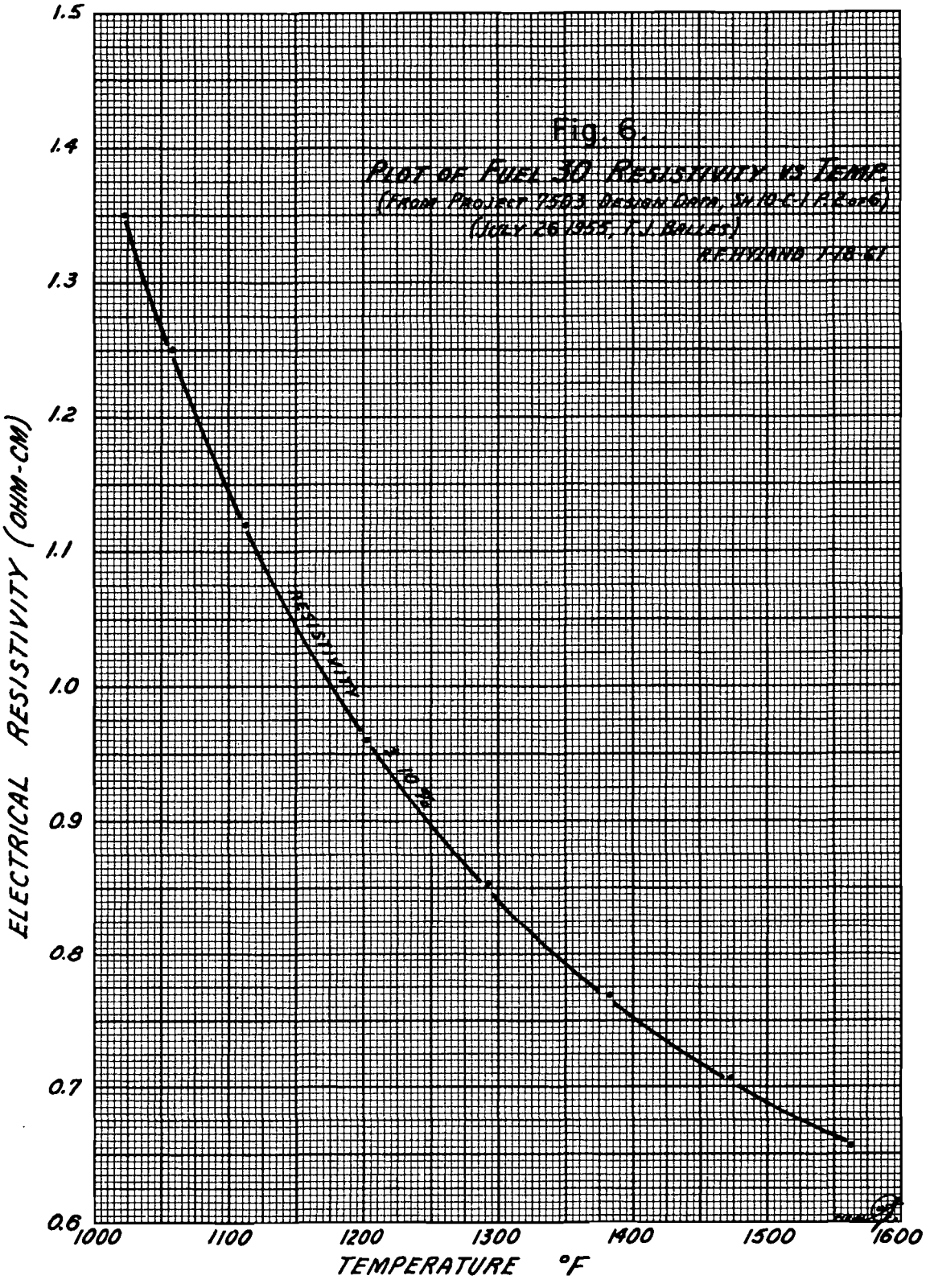

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The circuit of the molten salt level element measuring system is shown in Figure 7. A cross-sectional view of the level element installed in its test vessel is shown in Figure 8. Referring to Figures 7 and 8, R is the current adjusting potentiometer, R_L is the lead resistance, R_f is the salt resistance between the Inconel rod and the $1\frac{1}{2}$ inch Inconel pipe, R_t is the Inconel tube resistance, r_f is a resistance representing the shorting effect of the salt on the Inconel tube, and R_T is the total input resistance of the parallel section of the level element.

In reference to Figures 7 and 8, if $R \gg 2R_L + R_T$, the current "I" will depend primarily on R, and therefore the level element can be supplied with a constant current. The output voltage is measured across junctions "A" and "C" with an instrument having an input impedance at least as high as that of a potentiometer recorder or vacuum tube voltmeter. The current flows from the source through the temperature compensating resistance R_c to junction "B". From this point the current has three parallel paths to junction "C". The first path is through the Inconel rod, the salt, the $1\frac{1}{2}$ inch pipe and the $\frac{1}{4}$ inch plate; the second path is through the Inconel tube and the $\frac{1}{4}$ inch plate; and the third path is through the salt, the Inconel tube and the $\frac{1}{4}$ inch plate.

As the level rises, the current flow through the salt between the Inconel rod and the $1\frac{1}{2}$ inch pipe will become less inhibited because of the increase in the flow-path cross-sectional area. Assuming a purely resistive circuit, at zero level the element output will be given by the product of the supply current and the Inconel tube resistance, since R_f will be infinite for non-immersion. The maximum output will occur at zero level, and the output will decrease as the level increases. The resistance R_c is a function

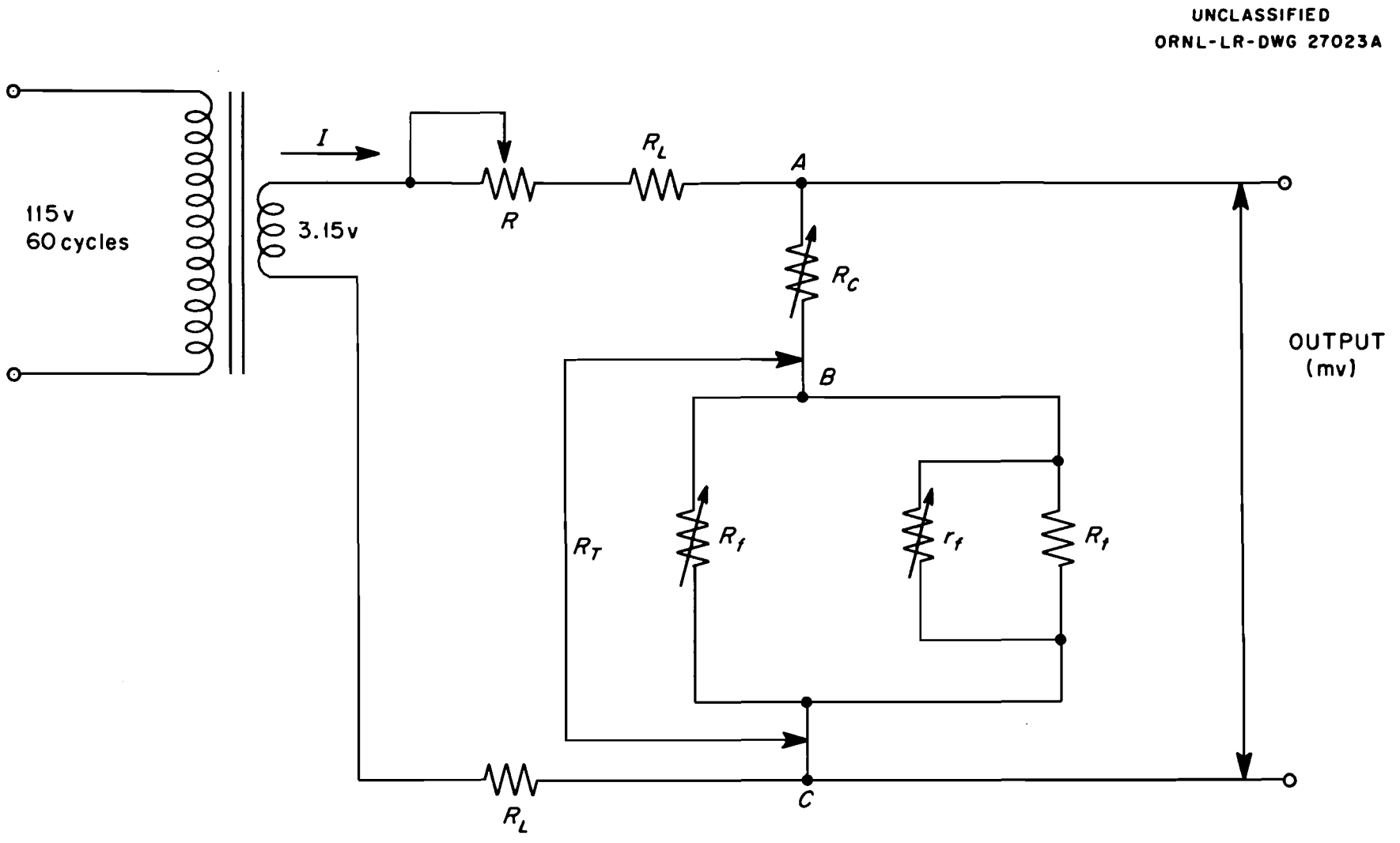


Fig. 7. Q1717-53, 54 Level Element-Schematic.

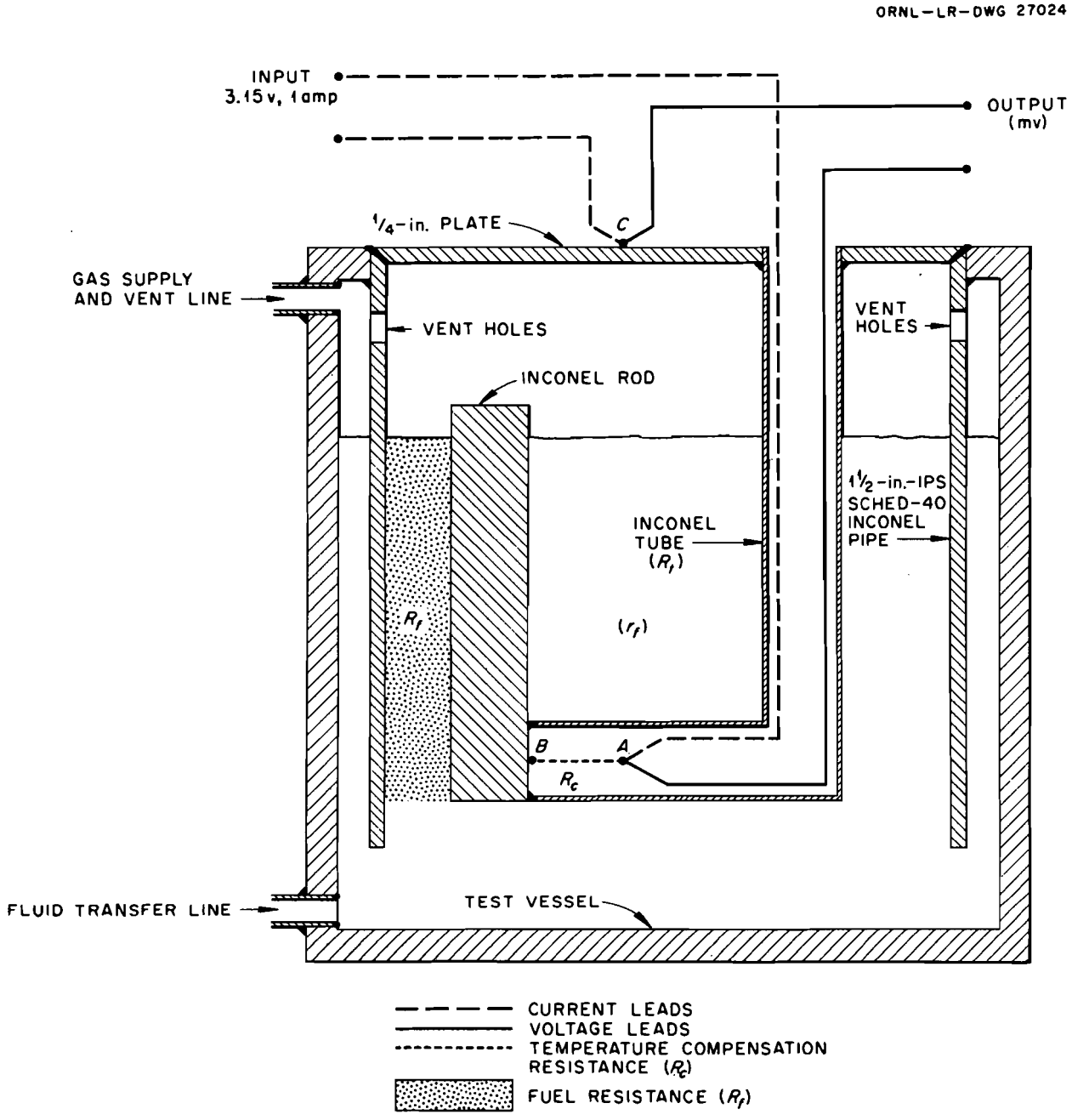


Fig. 8. Q1717-53 Level Element – Cross-Sectional View of Element Installed in Test Vessel.

of temperature only, and R_f and r_f are functions of both temperature and level.

The salt has a negative temperature coefficient of resistivity (Figure 6). The resistivity of Inconel[1] is almost constant over the temperature range under consideration, and therefore R_t can be assumed to be constant. It follows, then, that R_T will be a function of R_f and r_f and will decrease with increasing temperature.

An increase in salt temperature will have the same effect on the output as an increase in level if the system is not temperature compensated. One method of temperature compensation is described below. The element is to be compensated at some salt height h, so that a temperature excursion from T_1 to T_2 will produce no change in output. If the compensating resistance R_c is inserted in the probe as shown in Figure 8 and placed in series with R_T, the temperature compensation criteria will be satisfied if

$$\frac{V_{R_{C_1}} - V_{R_{C_2}}}{T_1 - T_2} = -\left[\frac{V_{R_{T_1}} - V_{R_{T_2}}}{T_1 - T_2}\right] \qquad (1)$$

Where $V_{R_{C_1}}$ = voltage across the temperature compensating resistor at temperature T_1.

$V_{R_{C_2}}$ = voltage across the temperature compensating resistor at temperature T_2.

T_1 = minimum probe internal temperature.

T_2 = maximum probe internal temperature.

$V_{R_{T_1}}$ = voltage across the parallel resistance R_T at temperature T_1.

$V_{R_{T_2}}$ = voltage across the parallel resistance R_T at temperature T_2.

or, for $\Delta T = T_2 - T_1$,

$$\frac{\Delta V_{R_c}}{\Delta T} + \frac{\Delta V_{R_T}}{\Delta T} = 0 \qquad (2)$$

1. See footnote on page 7.

As previously stated, $\frac{\Delta V_{R_T}}{\Delta T}$ is negative, and therefore $\frac{\Delta V_{R_c}}{\Delta T}$ must be positive and the resistivity curve of the compensating resistor must have a positive slope.

A short length of grade "A" nickel wire can be used for R_c, and its dimensions can be arrived at as follows:

$$V_{R_c} = IR_c = \frac{I\rho_c}{A_c} l_c,$$

$$V_{R_T} = IR_T,$$

$$V_{R_{C_1}} = I \frac{l_c}{A_c} \rho_{c_1} \text{ at temperature } T_1,$$

$$V_{R_{C_2}} = I \frac{l_c}{A_c} \rho_{c_2} \text{ at temperature } T_2,$$

$$V_{R_{T_1}} = IR_{T_1} \text{ at temperature } T_1,$$

$$V_{R_{T_2}} = IR_{T_2} \text{ at temperature } T_2,$$

$$I \frac{l_c}{A_c} \rho_{c_1} - I \frac{l_c}{A_c} \rho_{c_2} = -(IR_{T_1} - IR_{T_2}),$$

$$\frac{l_c}{A_c} = \frac{R_{T_1} - R_{T_2}}{\rho_{c_2} - \rho_{c_1}}, \qquad (3)$$

Where:

ρ_{c_1} = specific resistance of compensating wire, at temperature T_1

ρ_{c_2} = specific resistance of compensating wire, at temperature T_2

l_c = length of compensating wire

A_c = area of compensating wire

I = probe supply current.

Calculated performance curves for a level element, both temperature compensated and uncompensated, are shown in Figure 9. These curves are based on a constant current of one ampere through the level element and the following formulas and computations:

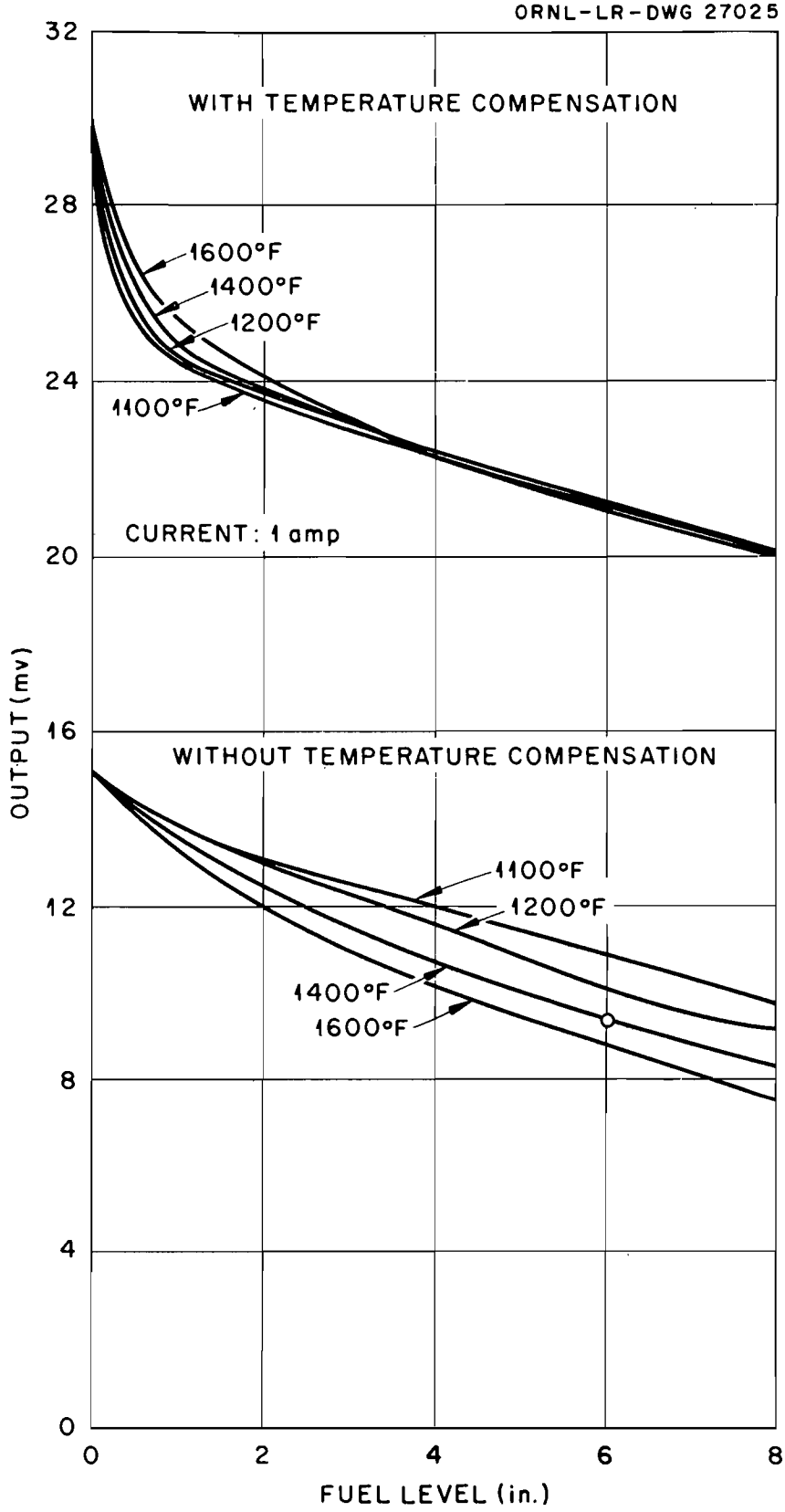


Fig. 9. Q1717-53 Level Element – Calculated Performance Curves.

A. Tube resistance - (R_t)

$$R_t = \frac{\rho_t \, l_t}{A_t} \qquad (4)$$

where R_t = 3/8" tube resistance (ohms)

ρ_t = 3/8" tube resistivity (ohm-inches)

l_t = 3/8" tube length (inches)

A_t = 3/8" tube area (in.^{2})

Substituting values for the prototype level element configuration, Figure 10:

$$A_t = \frac{\pi}{4} \left[(0.375)^2 - (0.305)^2 \right]$$

$$A_t = \frac{\pi}{4} \, (0.0475)$$

$$A_t = 0.0373 \text{ in.}^2$$

$$R_t = \frac{(\rho_t)(18.5)}{(0.0373)(2.54)}$$

$$R_t = 143 \, \rho_t \text{ ohms} \qquad (5)$$

B. Salt Resistance - (R_f)

$$R_f = \frac{\rho_f l}{A} \qquad (6)$$

where R_f = salt resistance (ohms)

ρ_f = salt resistivity (ohm-inches)

l = radial distance between the 3/8" Inconel rod and the $1\frac{1}{2}$" pipe (inches)

A = area of the plane surface 3/8" wide (rod O.D.) and with a height (h) that varies with the height of the salt on the level element.

Substituting values for the prototype element:

$$R_f = \frac{(\rho_f)(0.187)}{(0.373)\, h \, (2.54)}$$

h = salt height on level element

$$R_f = 0.196 \frac{\rho_f}{h} \text{ ohms} \qquad (7)$$

C. Temperature compensating resistance - (R_c)

$$R_c = \frac{l_c \rho_c}{A_c} \tag{8}$$

where R_c = nickel "A" wire resistance (ohms)

l_c = nickel "A" wire length (inches)

A_c = nickel "A" wire area (in.^{2})

ρ_c = nickel "A" wire resistivity (ohm-in.)

Substituting values for the prototype element:

$$R_c = \frac{(1.84)^* \rho_c}{(0.00306)^{**}(2.54)}$$

$$R_c = 236.0 \rho_c \tag{9}$$

D. Total parallel resistance - (R_T)

$$R_T = \frac{R_f \quad R_t}{R_f + R_t} \tag{10}$$

E. Output voltage - (V) for constant I of one ampere

$$V = R_c + R_T \tag{11}$$

The compensated performance curves in Figure 9 are based upon equation (11). The uncompensated curves are based on the expression $V = R_T$.

The resistance r_f (Figure 7) which represents the "shorting" effect of the salt on the 3/8 in. Inconel tube is neglected in all computations. Its effect is negligible because of the fact that the Inconel has a much lower resistivity than the salt (salt is 0.97 ohm-cm (Figure 6), Inconel 112.0 μohm-cm at 1200°F).[1]

Since the resistivity of Inconel is little effected by temperature changes over the temperature range of interest, it is assumed to be constant in all computations.

---

*Value of l_c obtained from equation (3) (compensated at a fuel height of 7").

**1/16" diameter nickel wire arbitrarily chosen.

The determination of R_f is an approximate calculation. An exact determination would involve an extremely intricate mathematical treatment which, in the light of probable experimental deviation from calculated values, would not be justified.

The use of the nickel "A" wire temperature compensation method is assumed in all calculations and designs.

A second method of temperature compensation could be effected as follows:

Referring to Figure 11, if the element is supplied with a constant current, then the following expression holds:

$$\frac{E\ out}{E\ in} = \frac{R_T}{R_T + R_c},$$

or $$E\ out = \frac{E_{in}\ R_T}{R_T + R_c}$$

If R_c was made $\gg R_T$ then:

$$E\ out \approx \frac{E_{in}\ R_T}{R_c} \qquad (12)$$

If R_c was allowed to vary with temperature, then E_{out} would be temperature dependent. R_T is inherently temperature dependent. However, if the resistivity vs. temperature curves of R_T and R_c were similar, and if a resistance R_c was inserted in the level element in a region where it would be exposed to the same temperature as R_T, then the ratio $\frac{R_T}{R_c}$ would remain unchanged with changes in temperature, because the numerator and denominator would change by the same amount; thus, temperature compensation would be effected.

The material chosen for R_c must have a negative temperature coefficient of resistivity. Thermistors and ceramics of various types appear to offer some of the desired properties for such a material.

A third possible method of temperature compensation would be to develop a voltage across a characterized recorder slidewire, proportional to the fuel resistivity change at a given temperature. This voltage would then be bucked against the probe output voltage, on a signal from a temperature sensor.

A fourth possibility would be the generation of the fuel resistivity vs. temperature curve by a function generator. A voltage corresponding to the proper correction factor for a given salt temperature would then be bucked against the probe output voltage, on a signal from a temperature sensor.

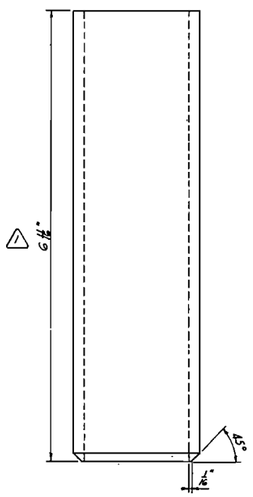
1.20 Level Element Construction

The Q1717-53 level element assembly and details are shown in Figure 10. The shield provides level stabilization in turbulent fuel such as might be encountered in salt pump bowls. The element is designed for insertion in a vessel which has a $2\frac{1}{2}$" IPS schedule 40 riser. A full penetration weld is made between the riser and the Inconel pipe cap on the element. (Item 2 of Figure 10). This design facilitates easy removal of elements with a heavy duty pipe cutter and provides the positive seal which is needed in high temperature molten salt systems. Element replacement is also quite easily accomplished.

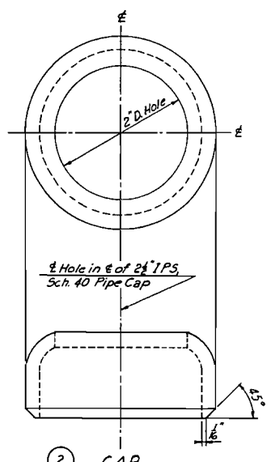
Some difficulty was experienced in the fabrication of these probes. Proper alignment between the tube and rod assembly and the $1\frac{1}{2}$" pipe was difficult to attain because of weld shrinkage at welds C-2, CN-5, CN-3, and CN-2 (Figure 10).

1.30 Power Supply and Measuring Circuit

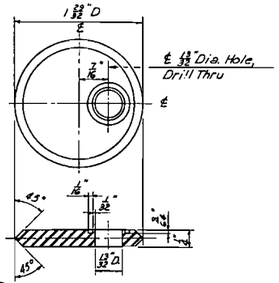
A schematic of the electrical system for the simultaneous testing of two level elements is shown in Figure 12. The system consists essentially



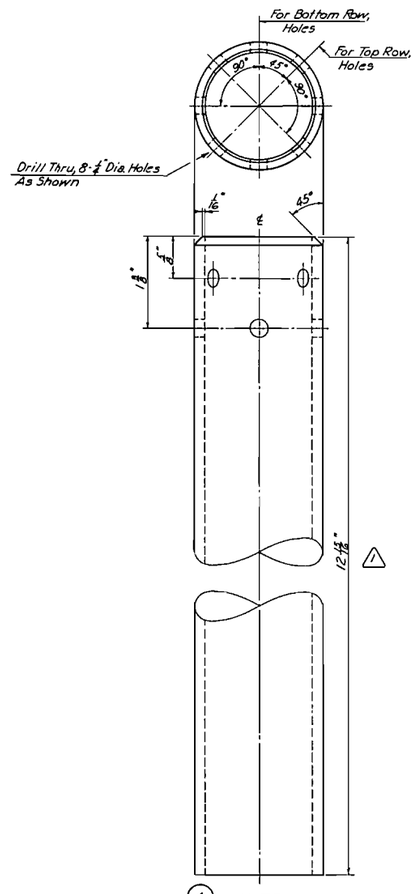
(1) PIPE
Mat'l.: 1½" IPS, Sch. 40, Inconel



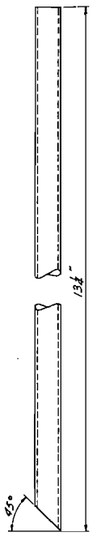
(2) CAP
Mat'l.: 2½" IPS, Sch. 40, Inconel Pipe Cap



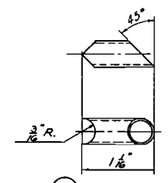
(3) PLATE
Mat'l.: Inconel Plate



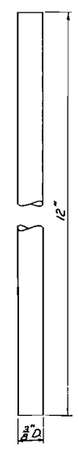
(4) PIPE
Mat'l.: 1½" IPS, Sch. 40, Inconel



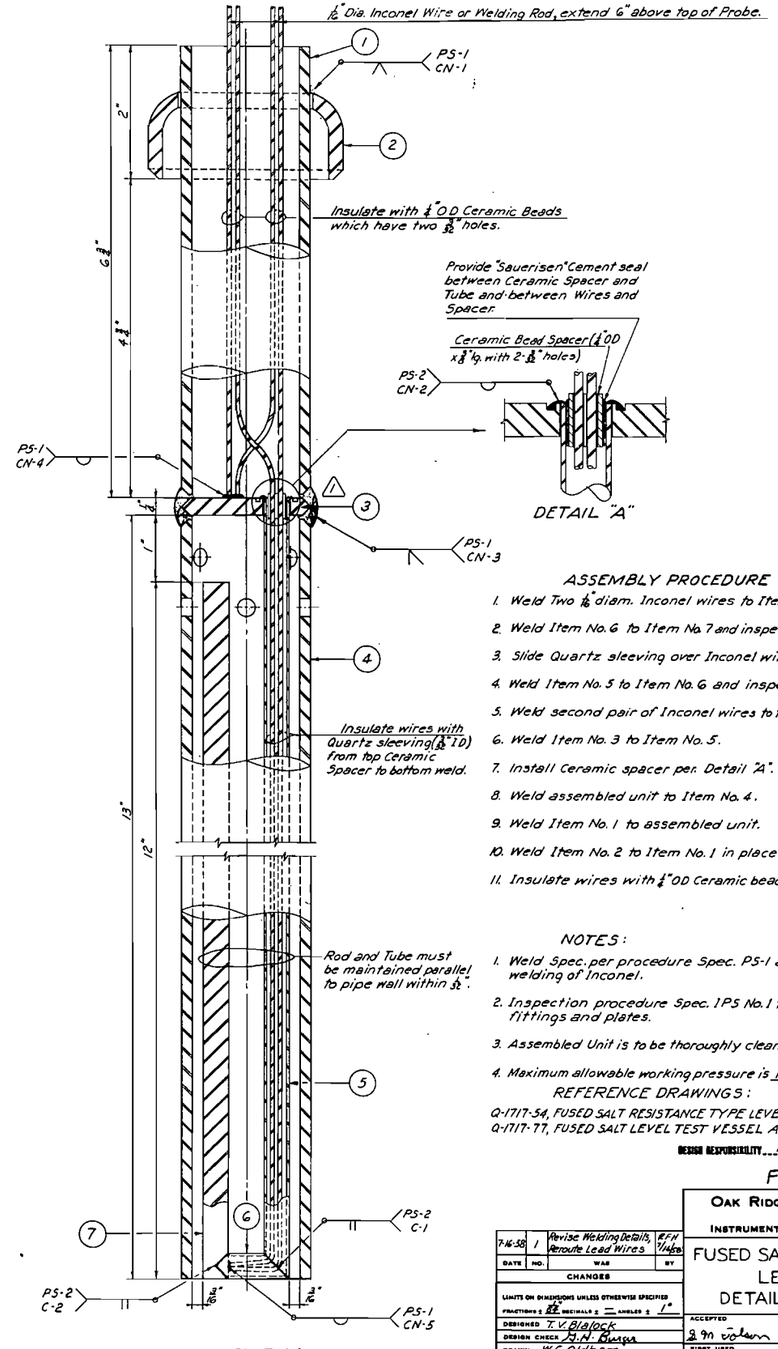
(5) TUBE
Mat'l.: 3/8" O.D. x .035 Wall, Inconel Tube



(6) TUBE
Mat'l.: 3/8" O.D. x .035 Wall, Inconel Tube



(7) ROD
Mat'l.: Inconel, round stock



ASSEMBLY

ASSEMBLY PROCEDURE

1. Weld Two 1/16" diam. Inconel wires to Item No. 7 as indicated.
2. Weld Item No. 6 to Item No. 7 and inspect weld per IPS No. 1.
3. Slide Quartz sleeving over Inconel wires as indicated.
4. Weld Item No. 5 to Item No. 6 and inspect per PS-1.
5. Weld second pair of Inconel wires to top of Item No. 3.
6. Weld Item No. 3 to Item No. 5.
7. Install Ceramic spacer per Detail "A".
8. Weld assembled unit to Item No. 4.
9. Weld Item No. 1 to assembled unit.
10. Weld Item No. 2 to Item No. 1 in place as indicated.
11. Insulate wires with 1/4" OD Ceramic beads which have two 3/32" holes.

NOTES:

1. Weld Spec. per procedure Spec. PS-1 and PS-2 for DC Inert arc welding of Inconel.
2. Inspection procedure Spec. IPS No. 1 for welds of Inconel pipe, fittings and plates.
3. Assembled Unit is to be thoroughly cleaned and degreased.
4. Maximum allowable working pressure is 10 PSI at 1200° F.

REFERENCE DRAWINGS:

Q-1717-54, FUSED SALT RESISTANCE TYPE LEVEL PROBE #2 DET. & ASS'Y.
Q-1717-77, FUSED SALT LEVEL TEST VESSEL ASSEMBLY & DETAILS.

DESIGN RESPONSIBILITY R. F. Hyland

Fig. 10

DATE	NO.	WAS	BY
7-16-58	1	Revise Welding Details, Reroute Lead Wires	RFH 7/14/60

CHANGES

LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED: FRACTIONS ± 1/32 DECIMALS ± ANGLES ± 1°

DESIGNED T. V. Blalock
DESIGN CHECK J. N. Bunger
DRAWN W. C. Oldham
DATE 9-20-57
COMPARED

ACCEPTED W. C. Oldham
FIRST USED
SCALE Full Size

ACCEPTED
APPROVED

OAK RIDGE NATIONAL LABORATORY
INSTRUMENTATION AND CONTROLS DIVISION

FUSED SALT RESISTANCE TYPE LEVEL PROBE NO. 1 DETAILS AND ASSEMBLY

Q-1717-53 R1 D

ORNL-LR-Dwg. 56680
Unclassified

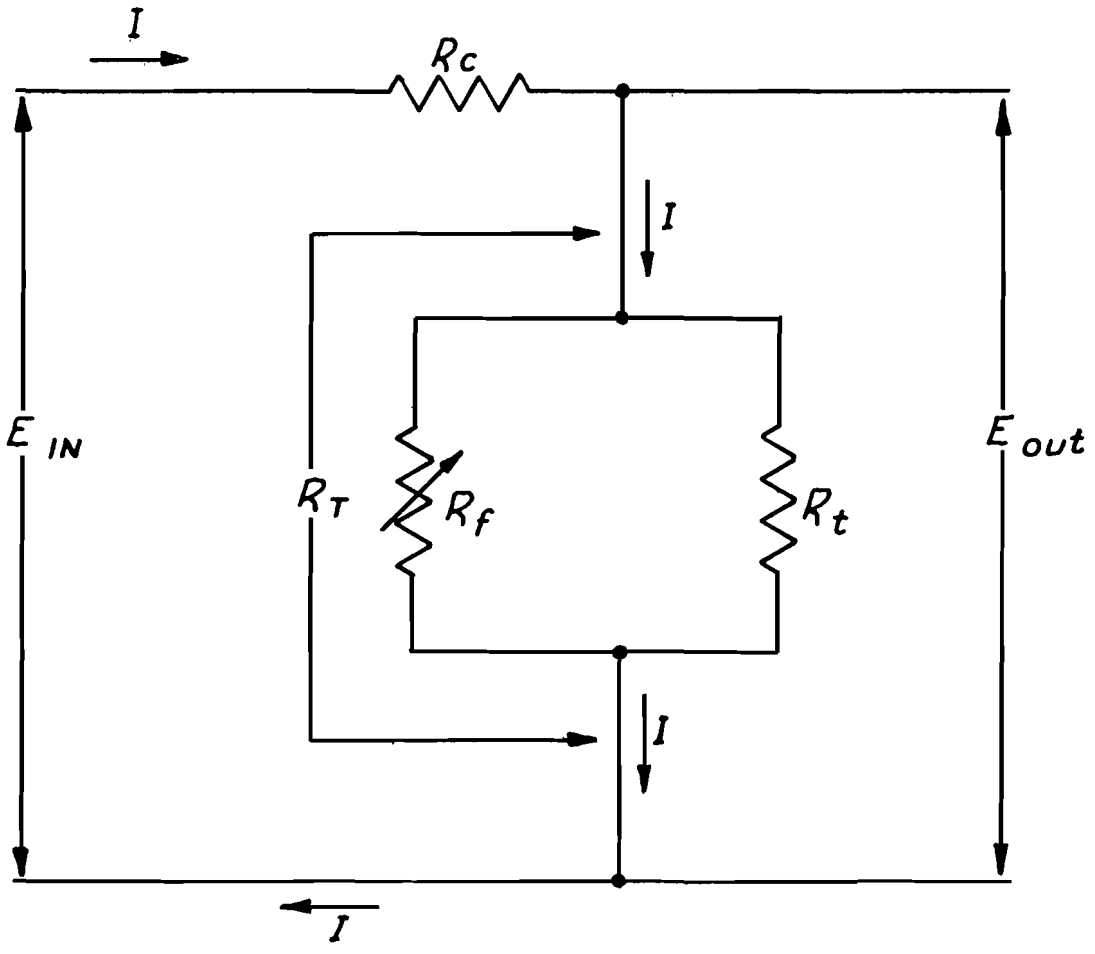


Fig. 11.
MOLTEN SALT REACTOR PROJECT
Q-1717-53, 54 LEVEL ELEMENT
TEMPERATURE COMPENSATION
SCHEMATIC.

R. F. HYLAND
1-18-61

SK I&C-EGM 6117

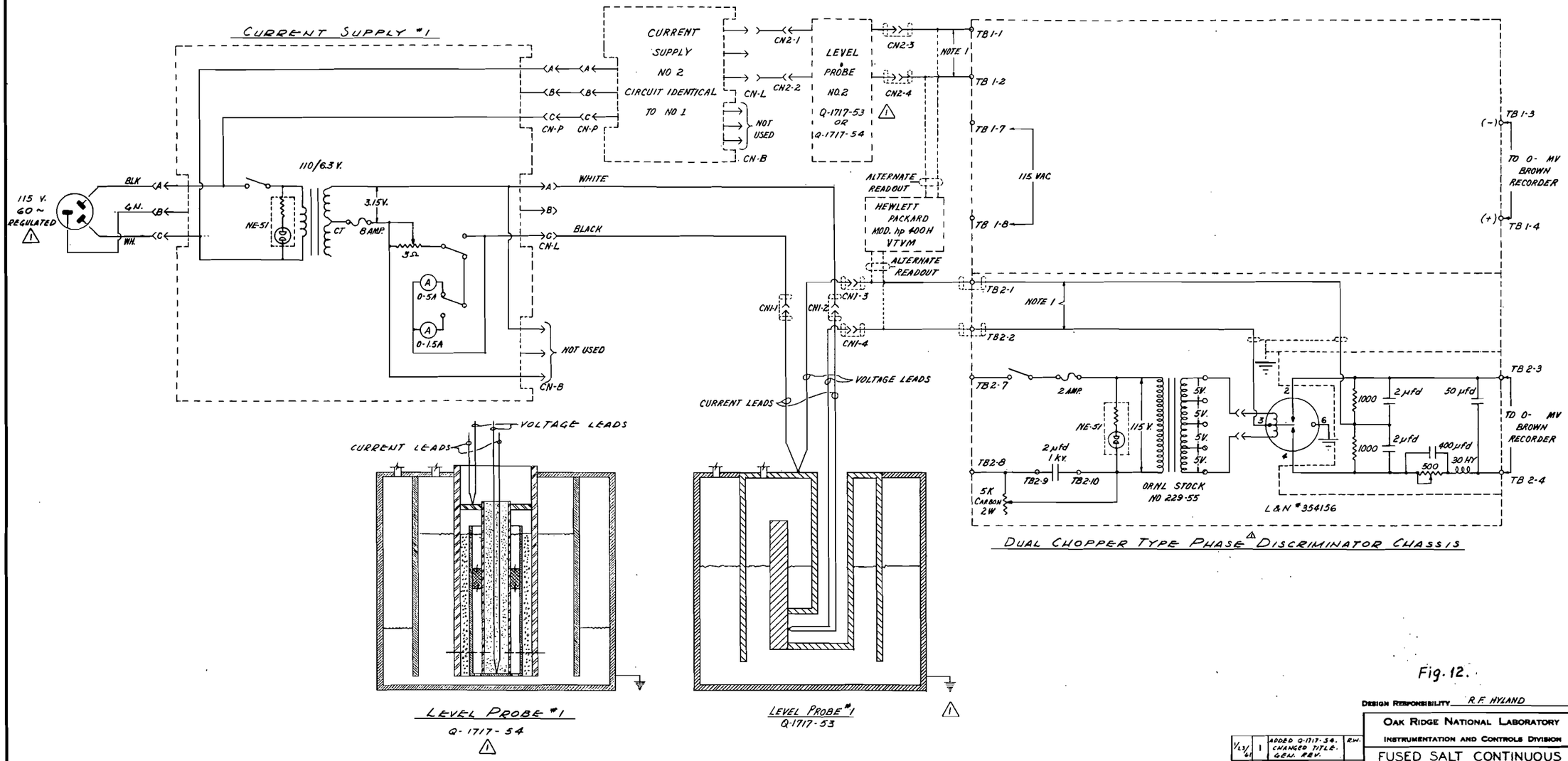


Fig. 12.

DESIGN RESPONSIBILITY R.F. HYLAND

DATE	NO.	CHANGE	BY
1/23/61	1	ADDED Q-1717-54. CHANGED TITLE. GEN. REV.	R.W.

REVISIONS

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

DESIGNED R.F. Hyland
DESIGN CHECK
DRAWN
DATE 4-21-1958
COMPARED

OAK RIDGE NATIONAL LABORATORY
INSTRUMENTATION AND CONTROLS DIVISION

FUSED SALT CONTINUOUS LEVEL PROBE
SCHEMATIC WIRING DIAGRAM

ACCEPTED Hornetz
ACCEPTED
APPROVED Hornetz
FIRST USED
SCALE NONE
Q-1717-78 REV. 1

of a current supply which is fed from a constant voltage source and two alternate methods of readout of the probe output signal. A Hewlett-Packard Model hp 400H V.T.V.M. proved to be quite satisfactory for the required measurements and was used for all data presented in this report.

The alternate method of readout would allow the data to be presented on a potentiometer type recorder. It was observed during the initial tests that the probe output signal contained a 1.4 mv quadrature voltage at maximum level and that a non-linear decrease in this voltage was obtained between maximum and zero level. Because the potentiometer type recorder is phase sensitive, a phase discriminator circuit was designed to eliminate this problem. The probe output voltage was fed into a synchronous chopper and filter network which provided a D.C. output proportional to the in-phase component of the applied A.C. voltage. Because the chopper reed lagged the excitation voltage by about 17°, it was also necessary to provide a phase shifting circuit to correct the phase of this excitation voltage.

1.40 Test Apparatus

A test apparatus, designed to test two elements simultaneously, was fabricated in accordance with the flow diagram shown in Figure 13. The level was varied by a helium forced exchange of the salt between the two vessels. For calibration purposes a variable Inconel probe was used which completed a lamp circuit when contacted by the salt. A "Conax" fitting with a Teflon seal provided the required insulation and seal requirements where the calibrating probe entered the test vessel. A probe actuator (Figure 14) was designed which allowed precise positioning of the calibrating probe.

Salt temperature was measured by a $\frac{1}{4}$" O.D., MgO insulated, Inconel sheathed, 22 gage, chromel-alumel thermocouple which was immersed in the salt approximately 1/8" from the bottom of the test vessel.

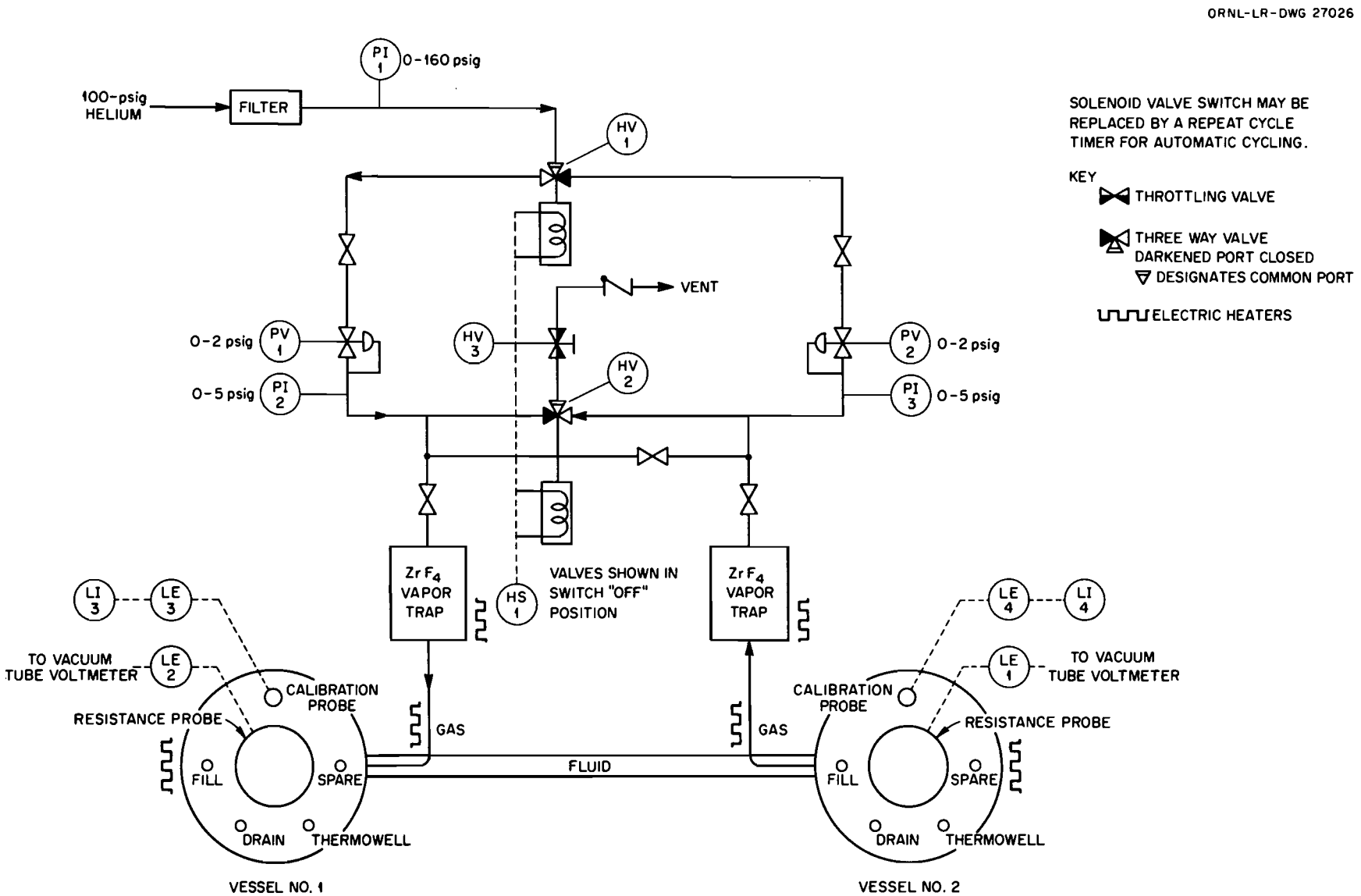
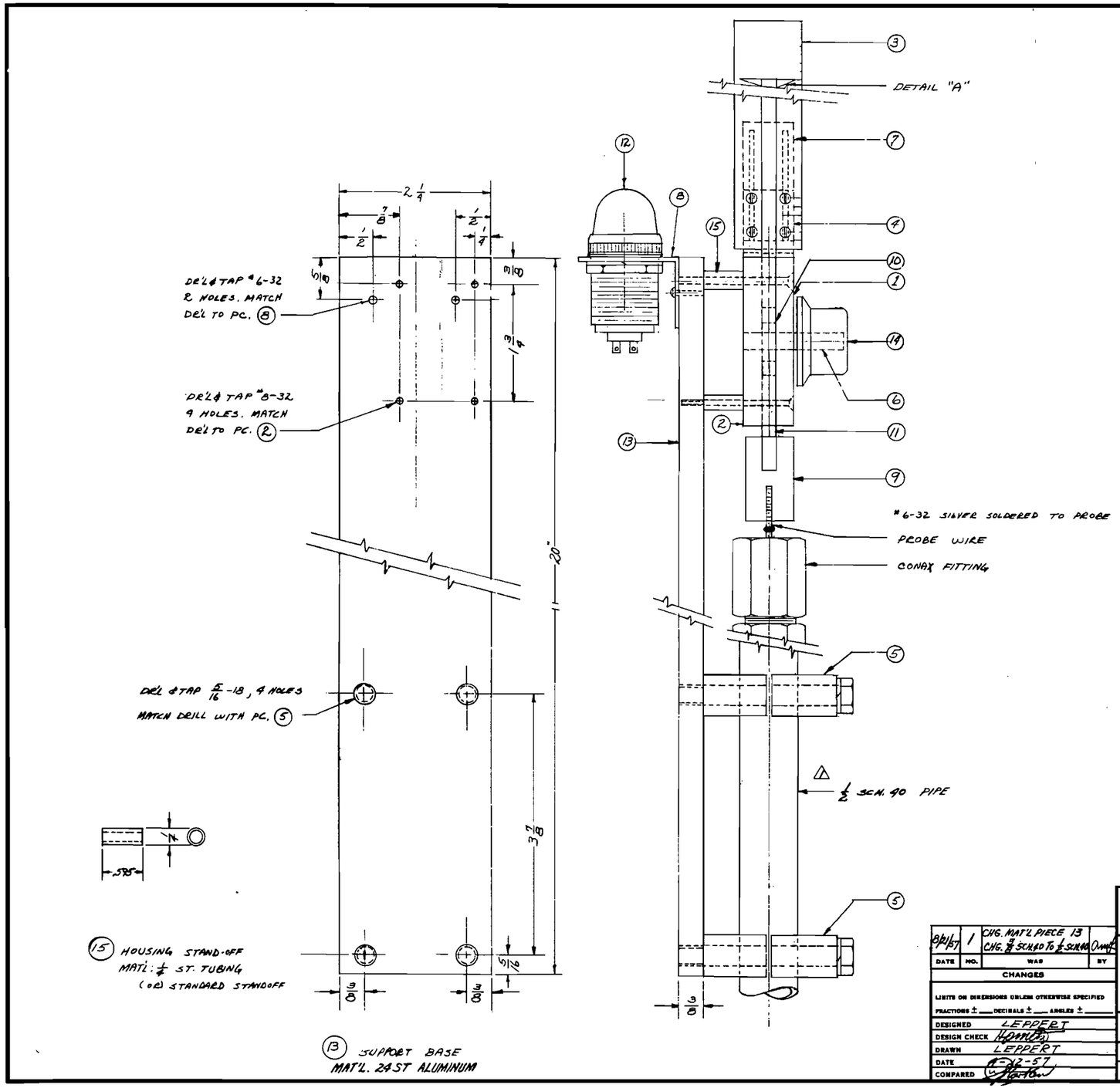


Fig. 13. Q1717-53 Level Element – Test Apparatus Flow Diagram.



NOTE:

ITEM	DESCRIPTION
1	COVER PLATE
2	HOUSING
3	SCALE
4	SCREW BASE
5	MOUNTING CLAMP
6	SHAFT
7	SCALE SUPPORT
8	LAMP BRACKET
9	INSULATOR
10	GEAR - BOSTON S-3220
11	RACK - BOSTON L-503
12	LAMP
13	SUPPORT BASE.
14	KNOB G.R. - KNS-6
15	HOUSING STAND OFF

ITEMS. 10, 11, 12 & 14 TO BE FURNISHED

Fig. 14.

DESIGN RESPONSIBILITY A. M. LEPPERT

DATE	NO.	WAS	BY
8/21/57	1	CHG. MAT'L PIECE 13 CHG. 3/8 SCH.40 TO 1/2 SCH.40	

CHANGES

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

DESIGNED LEPPERT
DESIGN CHECK
DRAWN LEPPERT
DATE
COMPARED

OAK RIDGE NATIONAL LABORATORY
INSTRUMENTATION AND CONTROLS DIVISION

PROBE ACTUATOR ASSEMBLY

ACCEPTED | ACCEPTED | APPROVED R.G. Affel

FIRST USED

SCALE FULL SCALE

Q-1717-21 REV 1

The test vessels were heated by slab type resistance wire heaters which were located uniformly around the periphery of the vessels. The interconnecting salt carrying line was uniformly heated by "clamshell" type resistance wire heaters. Temperature control was accomplished by means of on-off type controllers. Establishing a constant level element operating temperature while the level was being varied proved to be slow and cumbersome because of the uneven salt temperature distribution in the interconnecting line and test vessels.

1.50 Test Conditions

Two uncompensated Q1717-53 elements were installed in the rig described in Section 1.40 and were subjected to the following test conditions:

Fuel - Composition 30

Fuel temperature - 1200°F

Level range - 0-5 inches of salt

Fuel blanket pressure - 14.7 psia

1.60 Test Procedure

Each test run consisted of the following steps:

1. Establishing a stable salt temperature of 1200°F prior to each run.
2. Adjusting the probe supply current to read one ampere.
3. Recording the level element output with the salt completely off the element.
4. Recording the element output the moment the salt touched it. (This is the zero level point in Figure 15).
5. Raising the salt level in one inch increments, up to five inches, and verifying the actual level at each point with the variable calibrating probe.

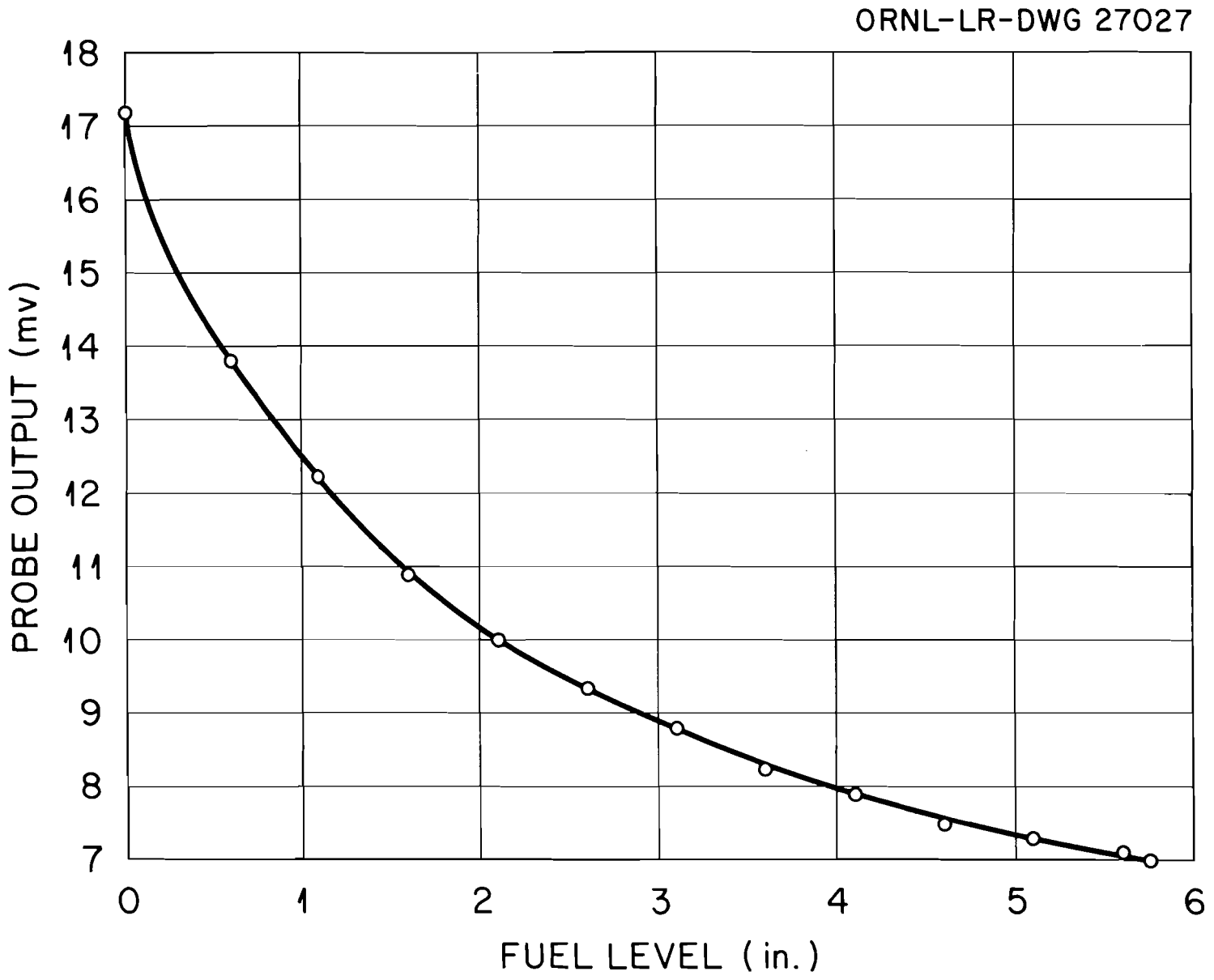


Fig. 15. Plot of Level Element Output vs. Level – Project 7503 Work.

6. Lowering the level in one inch increments until the salt was completely off the element.

7. Averaging the output values obtained while raising the level with those obtained lowering the level. (A slight hysteresis was evident, probably due to the high surface tension of the salt).

In addition, the salt temperature was stabilized, and the supply current checked at each point of measurement. Between calibration runs the salt was lowered completely off the level element.

1.70 Test Results

Level element #1 performed erratically during preheat and failed completely soon after the test vessel was filled with salt. Later examination revealed defects in the braided quartz sleeving which was used to insulate the wires inside of the element. This allowed the wires to "short" together, rendering the element inoperable.

Level element #2 provided a non-linear span of approximately 10.0 millivolts that was a function of level for approximately two days. A plot of output vs. level for this period is shown in Figure 15. The experimental curve was in reasonable agreement with the theoretical curve, Figure 9. It can be shown that the difference between the two curves could be due entirely to underestimating the assumed area which was used to calculate R_f (equation 6). The current apparently flows in a radial pattern from the rod to the pipe.

Because of the cancellation of Project 7503, all work on this level element was abandoned at this time.

2.00 Molten Salt Reactor Project Work

2.10 Purpose

A requirement for a continuous level element for the Molten Salt Power Reactor Program[2] caused a renewed interest in the existing Q1717-53 element. This requirement was resolved into the following set of specifications:

Salt - composition 130 (62 mole % LiF, 37 mole % BeF_2, 1 mole % UF_4).

Temperature range - 1000°F to 1300°F

Accuracy - ± 5% of full range

Sensitivity - 0.2 inches of salt

Level range - varied

Design pressure - 10 psig at 1300°F

Material in contact with salt - INOR-8

Construction - all welded - no materials subject to radiation damage

The existing element appeared to meet all specifications, provided that the resistivities of salt compositions 30 and 130 were similar and that the resistivity vs. temperature curves of Inconel and INOR-8 were similar.

Unfortunately, resistivity data on composition 130 fuel could not be obtained in the foreseeable future, but measurements made by D. L. Clark of the Reactor Division at ORNL on INOR-8 showed a marked similarity between its resistivity and that of Inconel.

It was decided that a simple "go-no go" test of a single level element without temperature compensation in composition 130 fuel was warranted and that an Inconel element would be used because of the inavailability of INOR-8. A successful test would then be followed by a more detailed test and evaluation program.

---

2. H. G. MacPherson, Molten-Salt Reactor Program - Quarterly Progress Report for Period Ending January 31, 1958, ORNL-2474, dated 5-1-58.

2.20 Test #1 - Go-No Go Test

2.21 Level Element Construction

Because of fabrication and insulation failure problems experienced with the Q1717-53 prototype level element, and the desire to improve the performance of the element by increasing the fuel surface area in contact with the element, a modified version of the prototype element was designed and designated as a Q1717-54 level element. A cross-sectional view of the modified element installed in a test vessel is shown in Figure 16 and the complete element assembly and details are shown in Figure 17. A completed element is shown in Figures 3 and 4 as it appears when welded into the top plate and riser of a test vessel. The "J" tube configuration of the prototype Q1717-53 element was abandoned in favor of the concentric cylinder design shown in Figure 17. As a result, the alignment of the center section of the probe (items 3, 4, and 5, Figure 17) with the outside section (item 2, Figure 17) was dependent on only one weld (weld CN-2, Figure 17).

The fuel surface area in contact with the probe was increased by a factor of three.

The insulation problem was eliminated by replacing the quartz sleeving which was used to insulate the internal wires of the Q1717-53 level element with a $\frac{1}{4}$" O.D. x 12 5/8" long ceramic sleeve.

2.22 Theory

The circuit and the theory of operation of the Q1717-54 element is identical to that of Q1717-53 element. However, it is necessary to redefine the variables and current paths in terms of the mechanical configuration of the Q1717-54 element.

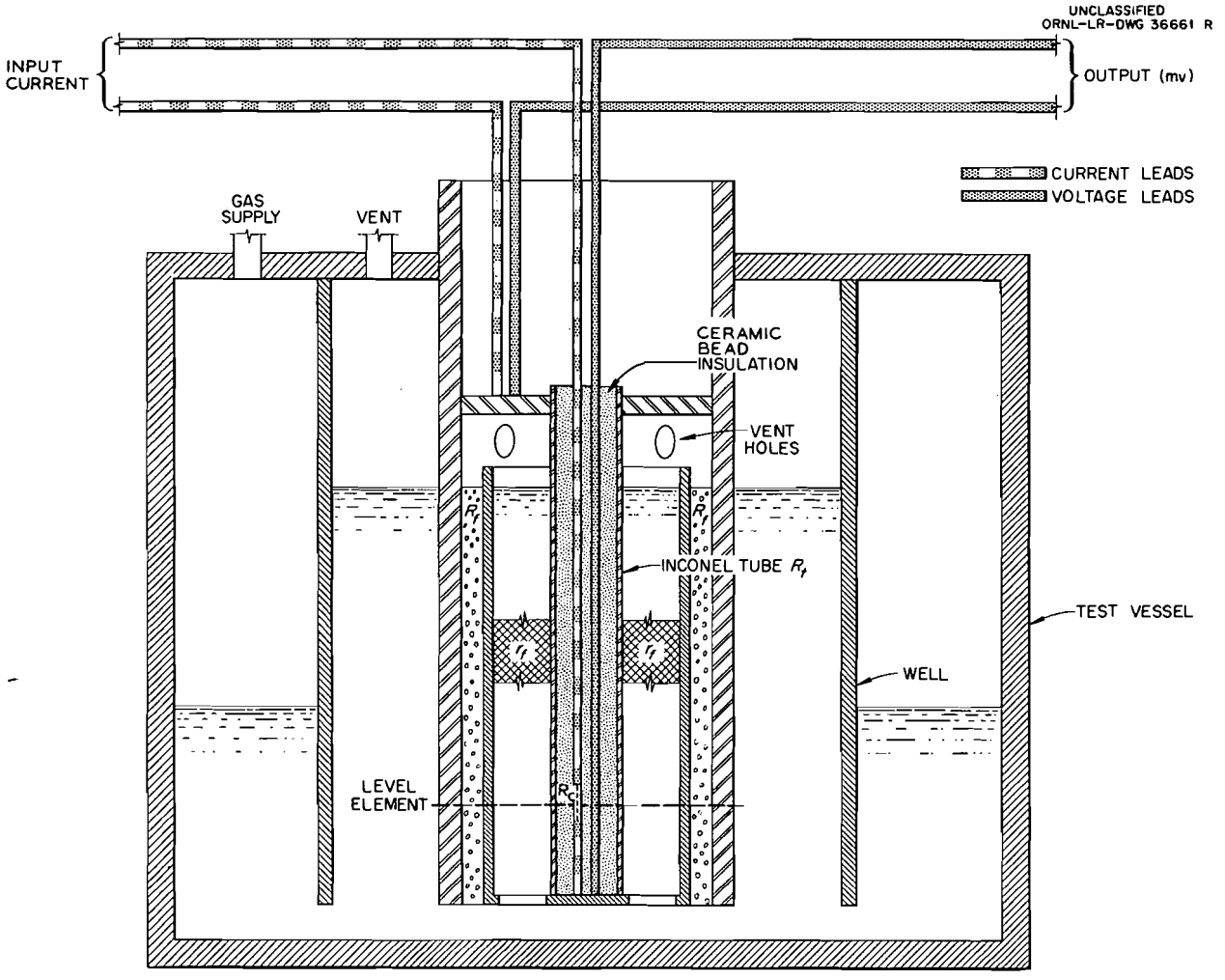
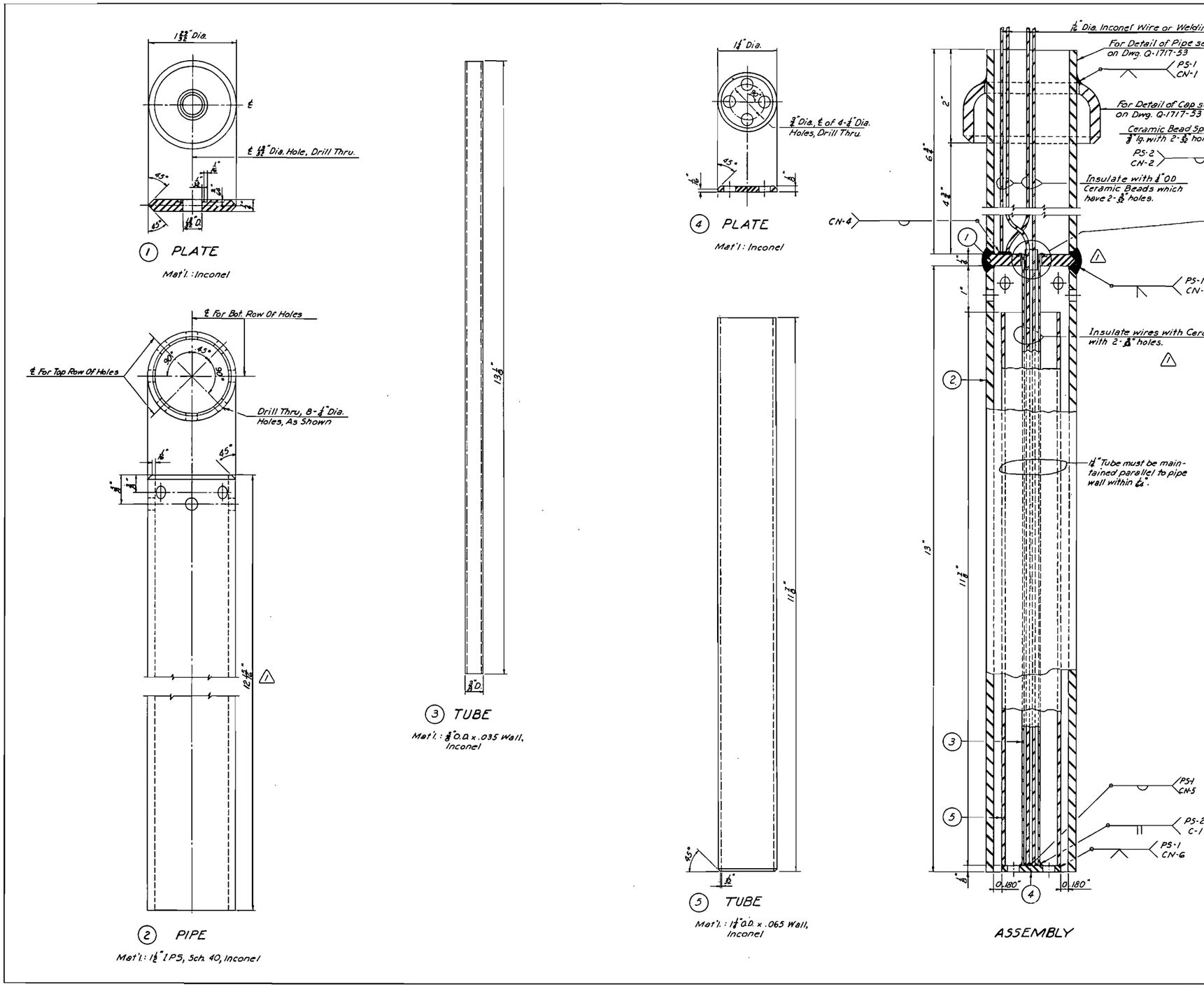


Fig. 16. Q1717-54 Level Element—Cross-Sectional View of Level Element Installed in Test Vessel.



ASSEMBLY PROCEDURE

1. Weld Two 1/16" diam. Inconel wires to Item No. 4.
2. Slide Quartz Sleeving over Inconel wires as indicated.
3. Slip Item No. 3 over insulated wires and weld to Item No. 4. Inspect per IPS-1.
4. Weld Item No. 5 to Item No. 4.
5. Weld second pair of Inconel wires to top of Item No. 1.
6. Weld Item No. 3 to Item No. 1.
7. Install Ceramic Spacer per Detail "A".
8. Weld assembled Unit to Item No. 2.
9. Weld assembled Unit to Item No. 1 on Dwg. Q-1717-53.
10. Weld Cap (Item No. 2 on Dwg. Q-1717-53) in place as indicated.
11. Insulate wires with 1/4" OD Ceramic Beads which have two 3/32" holes.

NOTES:

1. Weld Spec. per procedure Spec. PS-1 and PS-2 for DC Inert arc welding of Inconel.
2. Inspection procedure Spec. IPS No. 1 for welds of Inconel pipe, fitting and plates.
3. Assembled Unit is to be thoroughly cleaned and degreased.
4. Maximum allowable working pressure is 10 PSI at 1200° F.

REFERENCE DRAWINGS:

Q-1717-53 FUSED SALT RESISTANCE TYPE LEVEL PROBE #1 DET. & ASSY.
Q-1717-77 FUSED SALT LEVEL TEST VESSEL ASSEMBLY & DETAILS.
Q-1717-78 FUSED SALT LEVEL TEST WIRING DIAGRAM.

DESIGN RESPONSIBILITY R. F. Hyland

Fig. 17.

DATE	NO.	WAS	BY
7-16-58	1	Revise Welding Details Reroute Lead Wires	RFH 7/16/58

CHANGES

LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED
FRACTIONS ± 1/64 DECIMALS ± .005 ANGLES ± 1°

DESIGNED T. V. Blalock
DESIGN CHECK H. N. Bunya
DRAWN W. C. Oldham
DATE 9-25-57
COMPARED [signature]

OAK RIDGE NATIONAL LABORATORY
INSTRUMENTATION AND CONTROLS DIVISION

FUSED SALT RESISTANCE TYPE LEVEL PROBE NO. 2 DETAILS AND ASSEMBLY

ACCEPTED [signature] ACCEPTED APPROVED [signature]
FIRST USED
SCALE Full Size

Q-1717-54 R1 D

Referring to Figures 7, 16 and 17, R is the current adjusting potentiometer, R_L is the lead resistance, R_f is the salt resistance between the $1\frac{1}{4}$" Inconel tube and the $1\frac{1}{2}$" pipe, R_t is the 3/8" Inconel tube resistance, r_f is a resistance representing the "shorting" effect of the salt on the 3/8" Inconel tube and R_T is the total input resistance of the parallel section of the level element.

In reference to Figures 7, 16 and 17, if $R \gg 2R_L + R_T$, the current "I" will depend primarily on R, and therefore the level element can be supplied with a constant current.

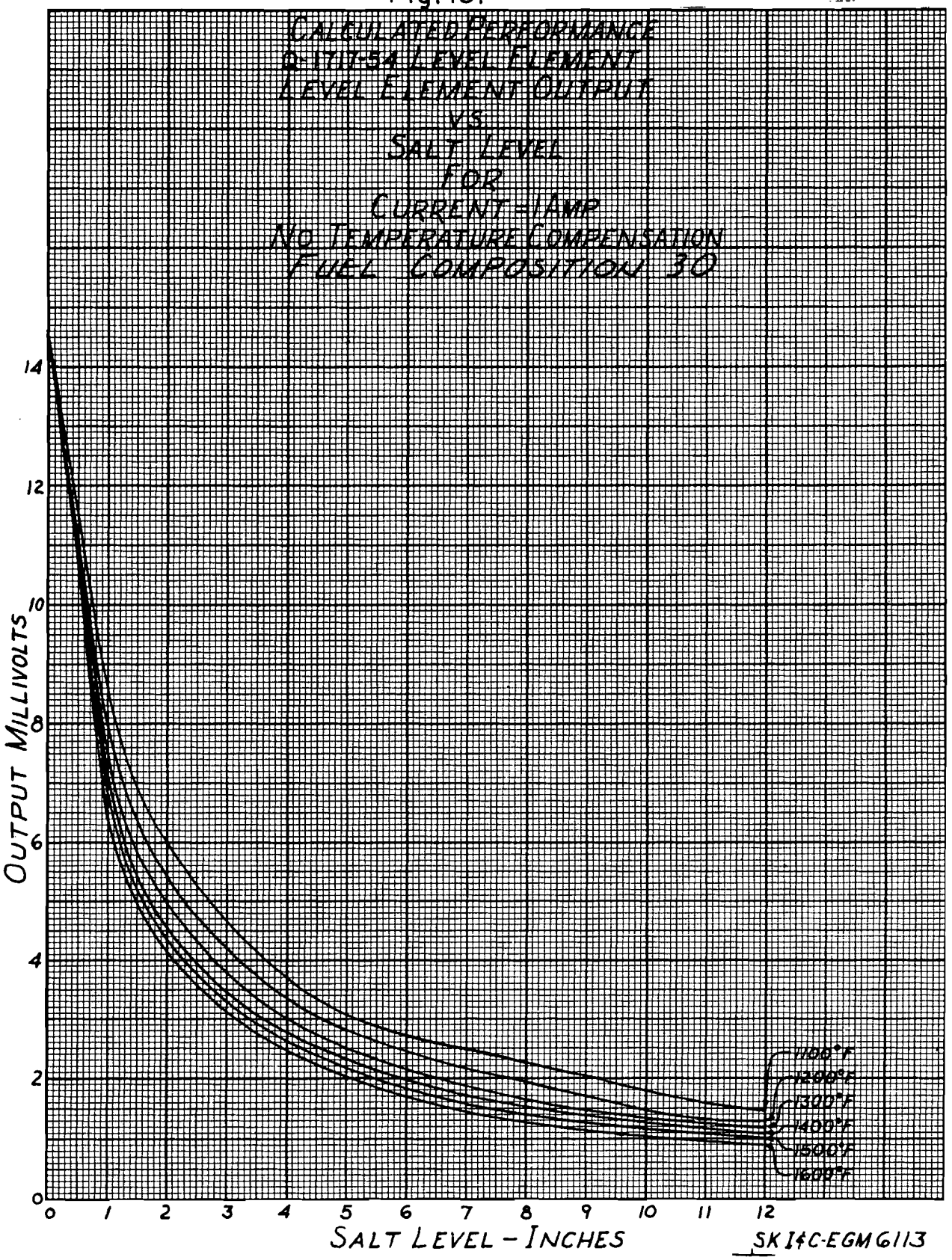
The current flows from the source through the compensating resistance R_c to junction "B". From this point the current has three parallel paths to junction "C". The first path is through the 1/8" bottom plate, the $1\frac{1}{4}$" tube, the salt and the $1\frac{1}{2}$" pipe; the second path is through the 1/8" bottom plate and the 3/8" tube; and the third path is through the 1/8" bottom plate, the salt and the 3/8" tube (the "shorting" effect of the salt on the tube).

As the salt level rises, the current flow through the salt between the $1\frac{1}{4}$" tube and the $1\frac{1}{2}$" pipe will become less inhibited because of the increase in the flow path cross-sectional area. Assuming a resistive circuit, at zero level the element output will be given by the product of the supply current and the 3/8" Inconel tube resistance, since R_f will be infinite for non-immersion. The maximum output will occur at zero level, and the output will decrease as the level increases.

Calculated performance curves for an uncompensated Q1717-54 element are shown in Figure 18. These curves are based on the following formulas and computations:

ORNL-LR-Dwg. 56681
Unclassified

Fig. 18.



A. 3/8" tube resistance (R_t)

$$R_t = \frac{\rho_i \, l}{A} \tag{13}$$

where ρ_i = Inconel resistivity[1] (ohm-in.)

l = 3/8" Inconel tube length (in.)

A = 3/8" Inconel tube area (in.^{2})

Substituting values for the Q1717-54 level element (Figure 17):

l = 13 in.

$$A = \frac{\pi}{4}\left[(0.375)^2 - (0.305)^2\right] = 0.0372 \text{ in.}^2$$

$$R_t = \frac{(42.3 \times 10^{-6})\,(12.875)}{0.0372}$$

$$R_t = 14.7 \text{ milliohms} \tag{14}$$

B. Salt resistance (R_f)

$$R_f = \frac{l}{\sigma A} \tag{15A}$$

where: l = radial distance between the $1\frac{1}{2}$ inch and the $1\frac{1}{4}$ inch tubes (inches).

σ = fuel #300 conductivity (ohm-in)$^{-1}$

A = area of salt through which current flows (in.^{2})

Substituting values for the Q1717-54 level element, Figure 17:

l = 0.18 inches

$A = \pi \, dh$

$A = \pi (1.25) h$

$A = 3.92 \, h$

$$R_f = \frac{0.18}{\sigma (3.92) h \, (2.54)}$$

$$R_f = \frac{18.1}{\sigma h} \text{ milliohms} \tag{15B}$$

1. See footnote on page 7.

C. Total parallel resistance (R_T), Figure 7

$$R_T = \frac{R_f R_t}{R_f + R_t} \tag{16}$$

D. Output voltage - (V) (Figure 18) (for constant I of one ampere)

$$V = R_c^* + R_T \tag{17}$$

The performance curves shown in Figure 18 were based upon equation (17).

As in the case of the prototype Q1717-53 level element, the resistance r_f (Figure 7) which represents the shorting effect of the salt on the 3/8 inch Inconel tube, is neglected in all computations. Its effect is negligible because of the fact that Inconel has a much lower resistivity than the salt (salt is 0.97 ohm-cm; Inconel 112μohm-cm at 1200°F).

Since the resistivity of Inconel is little affected by temperature changes over the temperature range of interest[1], it is assumed to be constant in all computations.

The determination of R_f is an approximate calculation. An exact determination would involve an extremely intricate mathematical treatment which, in the light of probable experimental deviation from calculated values, would not be justified.

Because the resistivity of fuel #130 was not known, fuel #30 values were used in all computations.

2.23 Power Supply and Measuring Circuit

The power supply and measuring circuit (Figure 12) for the Q1717-54 element is identical to that used for the Q1717-53 element and is described in paragraph 1.30.

A Hewlett-Packard model hp 400H V.T.V.M. was used for all level element output measurements.

---

*The methods of temperature compensation would be similar to those described for the Q1717-53 prototype element in paragraph 1.10.

1. See footnote on page 7.

2.24 Test Apparatus

In order to minimize the temperature variation of the salt as the level was varied, a test vessel[3] was designed which incorporated a well, concentric within the vessel wall. The level element is then inserted in the well and the level varied by a helium forced exchange of the salt between the vessel and the well. The flow diagram for the simultaneous testing of two elements is shown in Figure 19. A cross-sectional view of the element installed in the test vessel is shown in Figure 16.

Uniform heating was obtained by locating 4" x 14" slab resistance heaters around the test vessel and insulating the rig with 3 inches of Baldwin-Hill #19 "hi-temp" insulation. Power to the heaters was adjusted by means of continuously variable autotransformers.

Salt temperature was measured by a $\frac{1}{4}$" O.D., MgO insulated, Inconel sheathed, 22 gage, chromel-alumel thermocouple which was immersed in the salt approximately 1/8" from the bottom of the test vessel. Thermocouple readout was accomplished with a Brown recorder having a range of 0-2000°F.

A variable probe of the type shown in Figure 14 was used for all level calibrations.

The element was installed in one side of the dual test apparatus shown in Figure 19. The level was raised by applying a constant helium pressure to the vessel proper and venting the well. Excellent control of the level rate of rise was accomplished by adjusting the needle-type vent valve. To lower the level, the supply pressure was held constant, the vent valve was closed, and an equalizing valve was opened between the supply and the vent. Here, also, a needle valve was used with excellent results.

---

3. Fused Salt Level Test - Vessel Assembly and Details-ORNL Instrumentation and Controls Division Drawing Q1717-77.

UNCLASSIFIED
ORNL-LR-DWG 56682

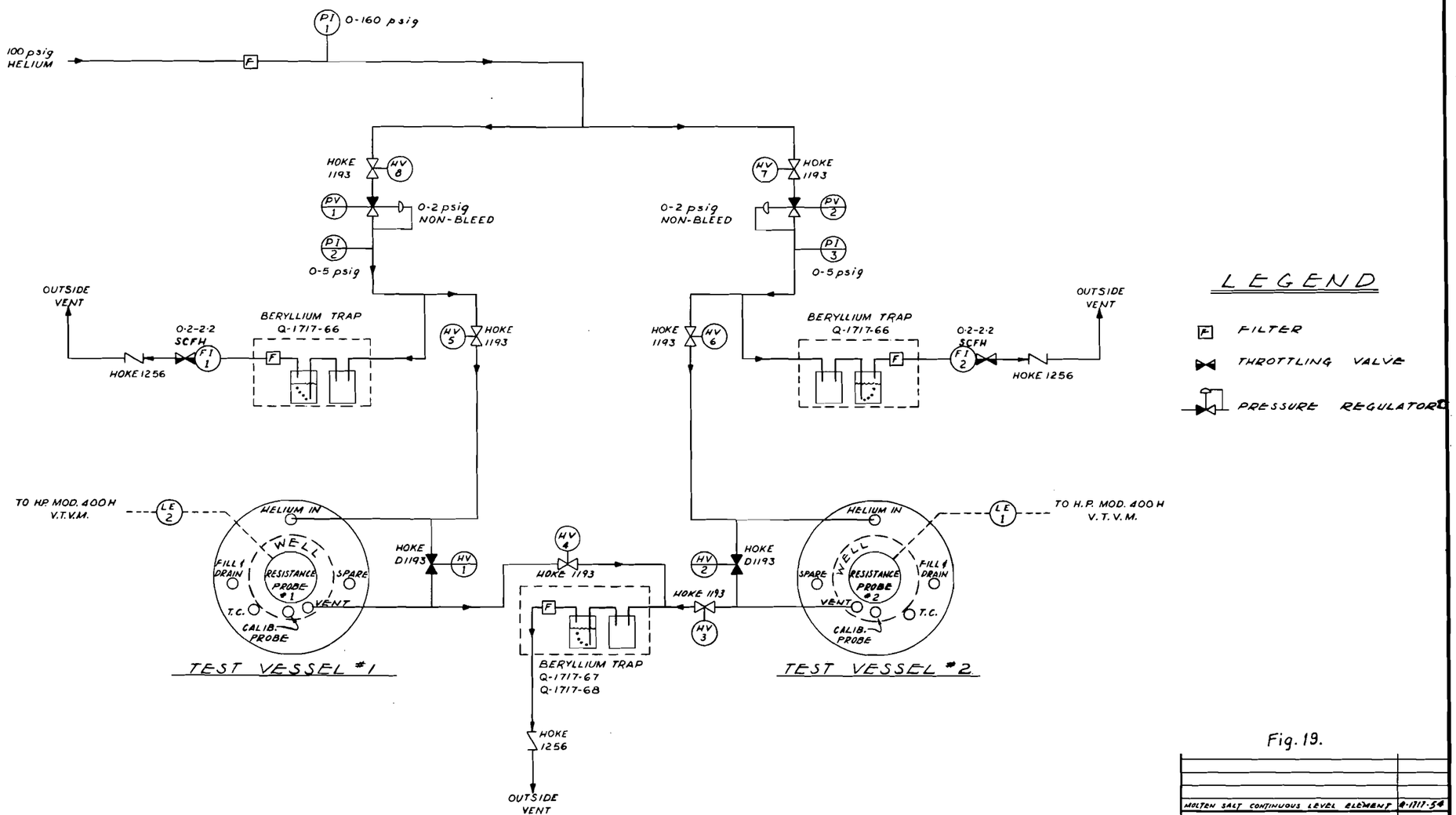


Fig. 19.

NO.	REVISIONS	DATE	APPD	APPD
	B.J. Hyer 12/19/60			
	12-27-60			

MOLTEN SALT CONTINUOUS LEVEL ELEMENT	Q-1717-54
REFERENCE DRAWINGS	DWG. NO.
DESIGN RESPONSIBILITY R. F. HYLAND	
MOLTEN SALT POWER REACTOR PROJECT	
RESISTANCE TYPE CONTINUOUS LEVEL ELEMENT FOR MOLTEN SALT	
TEST APPARATUS FLOW DIAGRAM	
INSTRUMENTATION AND CONTROLS DIVISION OAK RIDGE NATIONAL LABORATORY OPERATED BY UNION CARBIDE NUCLEAR COMPANY	
SUBMITTED / ACCEPTED / DATE / APPROVED / DATE	SK-RFH-1531 R1

Beryllium particle traps were needed on all vents because of the toxic nature of the salt vapor.

2.25 Test Conditions

Test conditions for the "go-no go" test may be summarized as follows:

Level element - Q1717-54

Salt composition - No. 130

Salt temperature - 1200°F

Helium blanket pressure - 14.7 psia

Level range - 0-6 inches

Power supply and measuring circuit - Q1717-78 (Figure 12)

Level element supply current - 1.0 ampere, 60 cps

Readout instrument - Hewlett-Packard, model hp 400H, V.T.V.M.

Calibrating probe - Q1717-21 (Figure 14)

Test apparatus flow diagram - SK-RFH-1531 (Figure 19)

Test vessel[3]

2.26 Test Procedure

Data was taken more frequently during the beginning of the test to establish the time at which the calibration drift occurred. The test consisted of the following steps:

a. Establishing a stable salt temperature of 1200°F prior to each run.

b. Recording the level element output with the salt completely off the element.

c. Recording the element output the moment the salt touched the probe. (This is zero level point in Figure 20).

---

3. See footnote on page 37.

d. Raising the salt on the probe in one inch increments up to six inches and verifying the actual level at each point with the variable calibrating probe.

e. Rechecking the salt temperature at each point of measurement.

f. Lowering the salt level in one inch increments until it was completely off the level element.

g. Leaving the salt completely off the level element when not taking data.

h. Averaging the output values obtained while raising the level with those obtained lowering the level. See test results for hysteresis values.

i. Rechecking the level element supply current at each point of measurement. (No drift was observed).

2.27 Test Results

Performance of the element under the above set of conditions proved to be very similar to that of the prototype element described in Section 1.00. A plot of level vs. probe output, obtained immediately after filling the test vessel, is shown in Figure 20.

This output was a function of level with an overall accuracy of $\pm$ 3.5% of full range and a precision of 0.2 inches of salt for a period of approximately two days. The precision of measurement was limited, primarily, by the resolution of the vacuum tube voltmeter. At this time a gradual time dependent decrease in the span of element was evident and the test was terminated.

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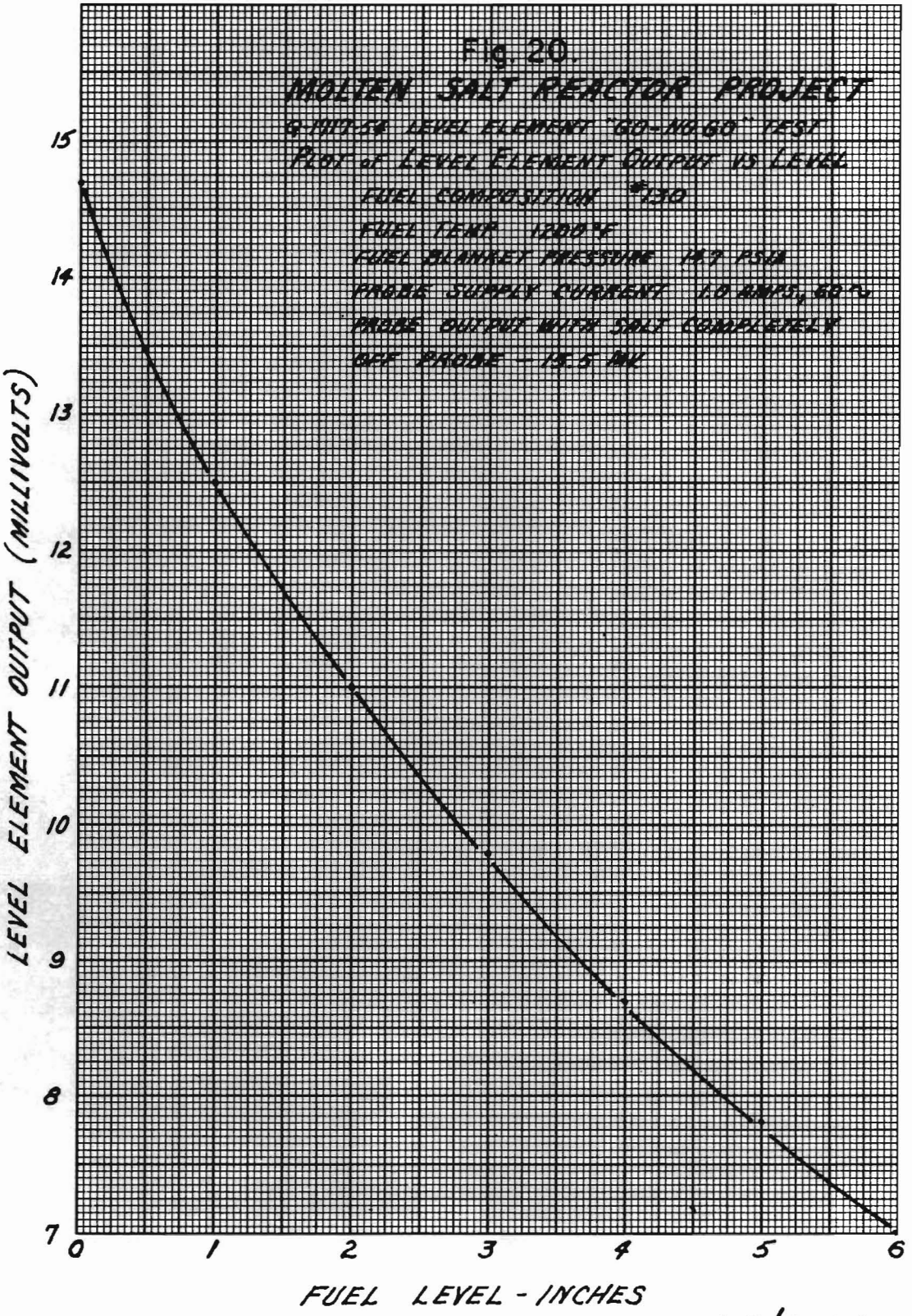
Unclassified



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1-18-61

2.30 Test #2

2.31 Purpose

To investigate the time dependent decrease in level element span which was observed on both the Q1717-53 and Q1717-54 level element tests.

All obvious possible sources of the calibration drift which was observed on previous tests had been checked and eliminated during these tests. Among these possibilities were supply current drift, vacuum tube voltmeter calibration and drift, temperature measuring errors and calibration procedure errors.

2.32 Method

A number of other explanations for the drift appeared to be possible. These are as follows:

1. Salt resistivity changes due to:
   a. Separation.
   b. Chemical changes.
   c. Oxide contamination of the salt prior to use.
   d. Oxide contamination of the salt due to oxygen in the helium blanket gas.
   e. Corrosion product contamination.
2. Level element defects.
3. Level element corrosion.
4. Polarization effects due to the low frequency of the probe excitation current.
5. The formation of a high resistance film on the probe.

Considerable difficulty with polarization was experienced by Greene[4] in his work on the measurement of the conductivity of composition 30 salt. However, his work with platinum cells, #30 salt and 1000 cycle excitation can hardly be extrapolated to cover the Q1717-54 level element work with #130 salt.

It is difficult to explain how the normal interface polarization effect could cause the observed calibration drift. However, a resistance film buildup on the probe as noted by Greene[4] seemed to be a very plausible explanation.

Because the level elements were not immersed in salt between data gathering periods, a possibility existed that salt vapor deposits were building up on the probe and forming a high resistance film.

A second, very strong, possibility for the calibration drift appeared to be a change in salt resistivity with time. It was therefore decided to attempt to isolate this mechanism during this test. It was reasoned that if the test batch of fuel was replaced with a fresh batch at the termination of the experiment, a comparison of the probe output at the end of the test with that in the new batch of salt would provide important evidence as to the relative fuel resistivities. In addition, careful quantitative chemical analyses were made of the test batches of salt, both before and after the tests and also of the replacement batch.

To minimize the possibility of a film buildup on the probe due to polarization, where the level elements had been excited on a continuous basis during previous tests, they were excited only while taking data on these tests.

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4. Measurements of the Electrical Conductivity of Molten Fluorides, N. D. Greene, ORNL-CF-54-8-64, August 16, 1954.

Fig. 21.

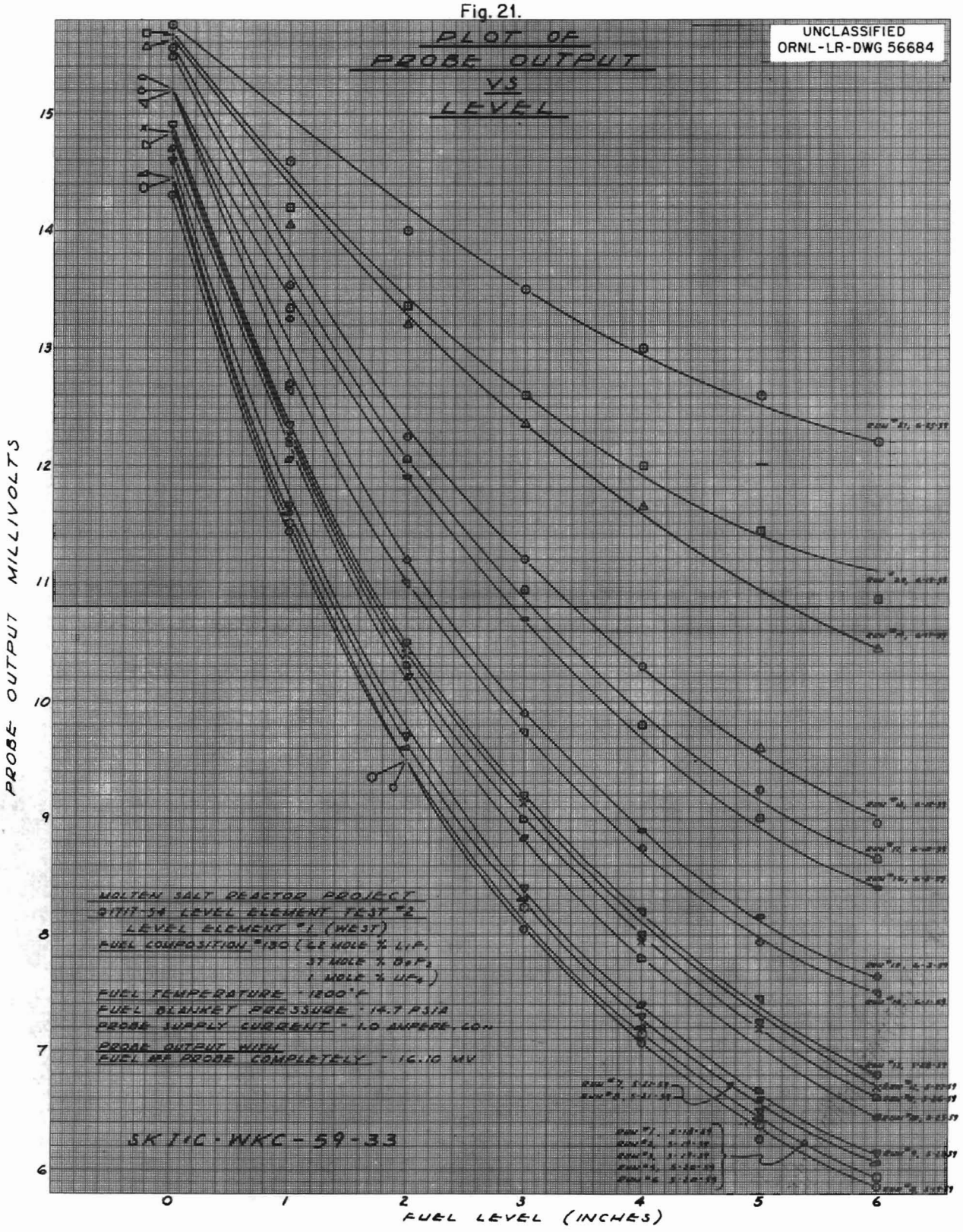
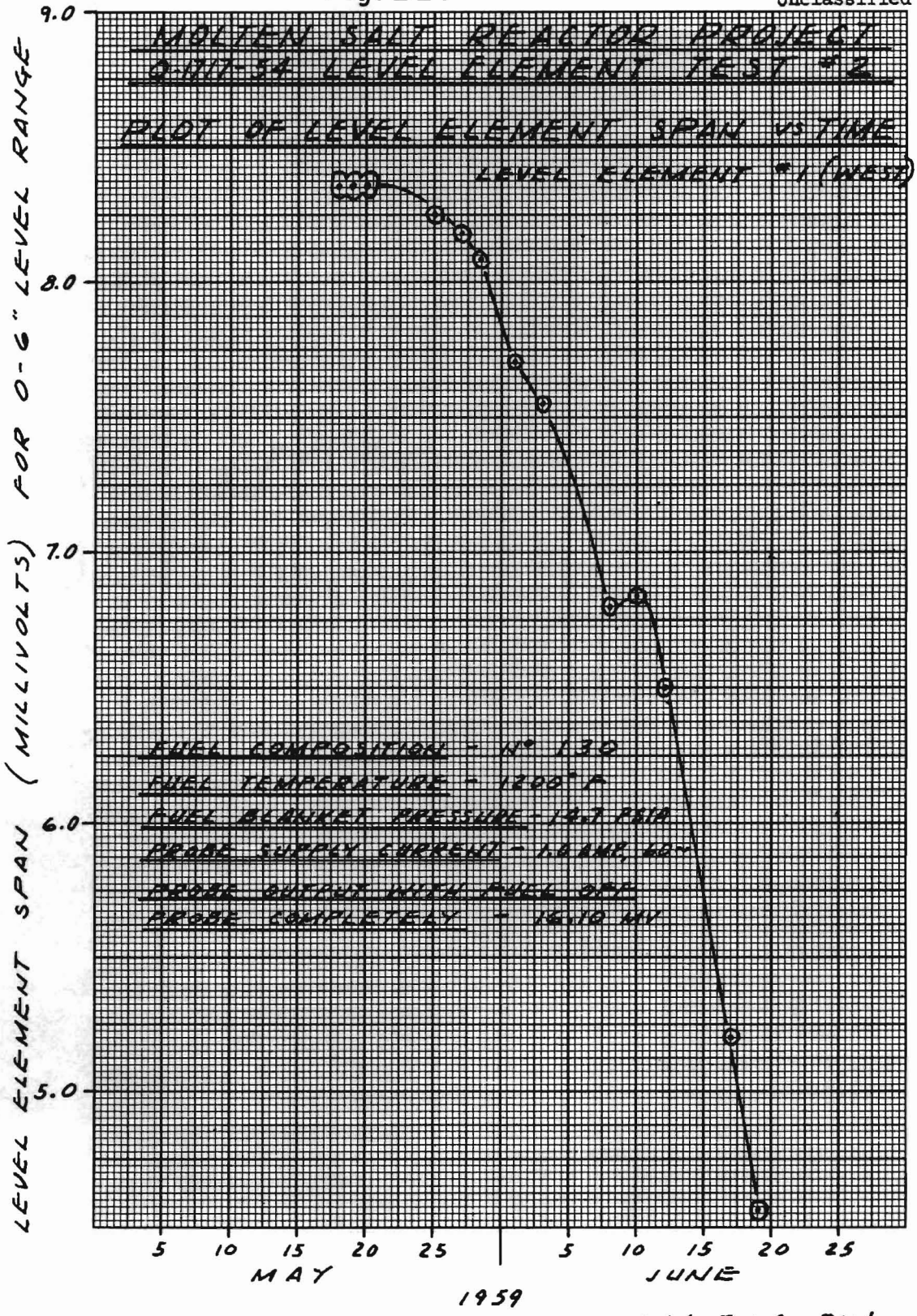

UNCLASSIFIED
ORNL-LR-DWG 56684
PLOT OF
PROBE OUTPUT
VS
LEVEL
PROBE OUTPUT MILLIVOLTS
FUEL LEVEL (INCHES)
MOLTEN SALT REACTOR PROJECT
21TT-54 LEVEL ELEMENT TEST #2
LEVEL ELEMENT #1 (WEST)
FUEL COMPOSITION #130 (62 MOLE % LiF,
37 MOLE % BeF2
1 MOLE % UF4)
FUEL TEMPERATURE - 1200°F
FUEL BLANKET PRESSURE - 14.7 PSIA
PROBE SUPPLY CURRENT - 1.0 AMPERE, CONT
PROBE OUTPUT WITH
FUEL IN PROBE COMPLETELY - 16.10 MV
SK I-C-WKC-59-33

Fig. 22.

ORNL-LR-Dwg. 56685
Unclassified



SK I&C RW-6114

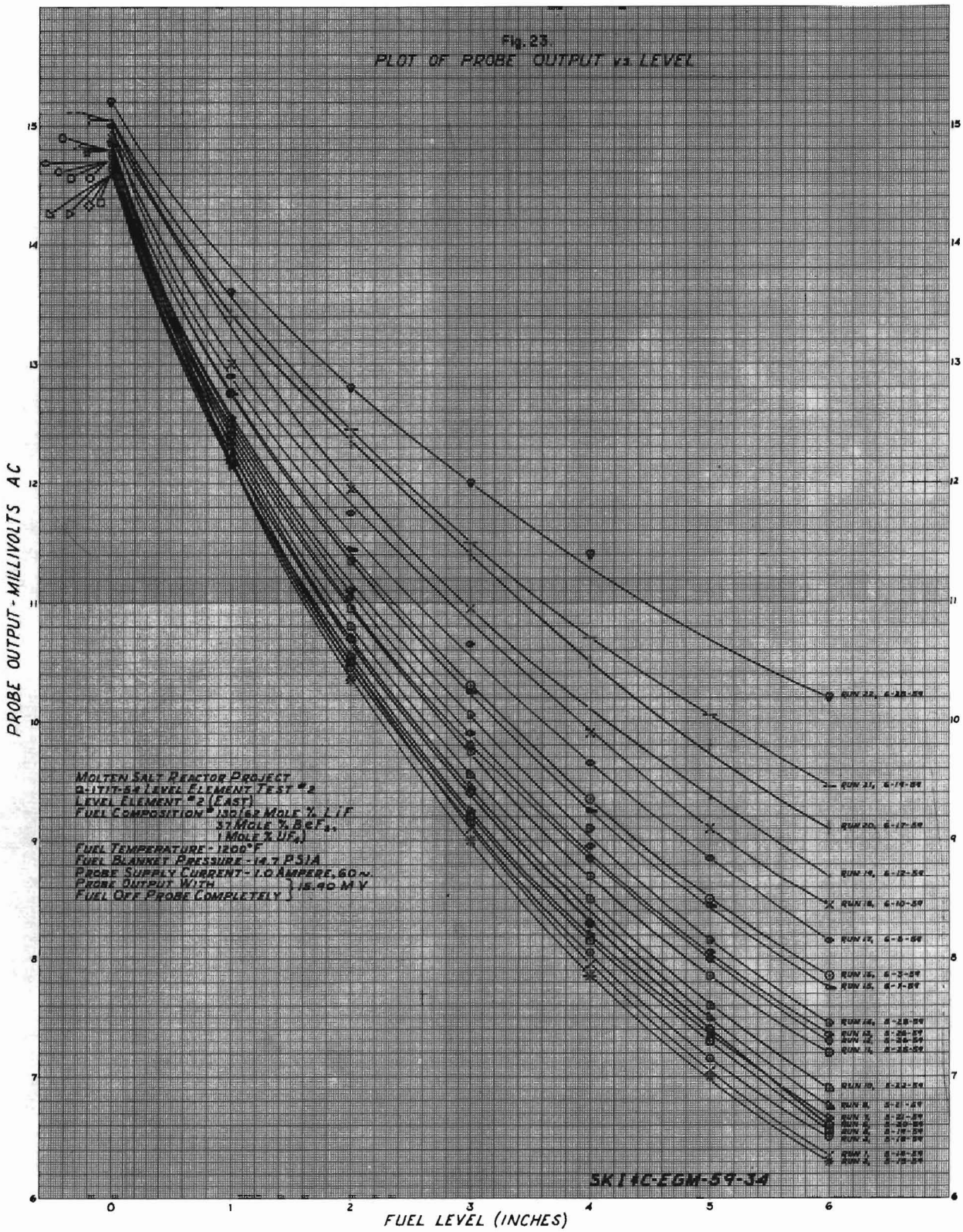
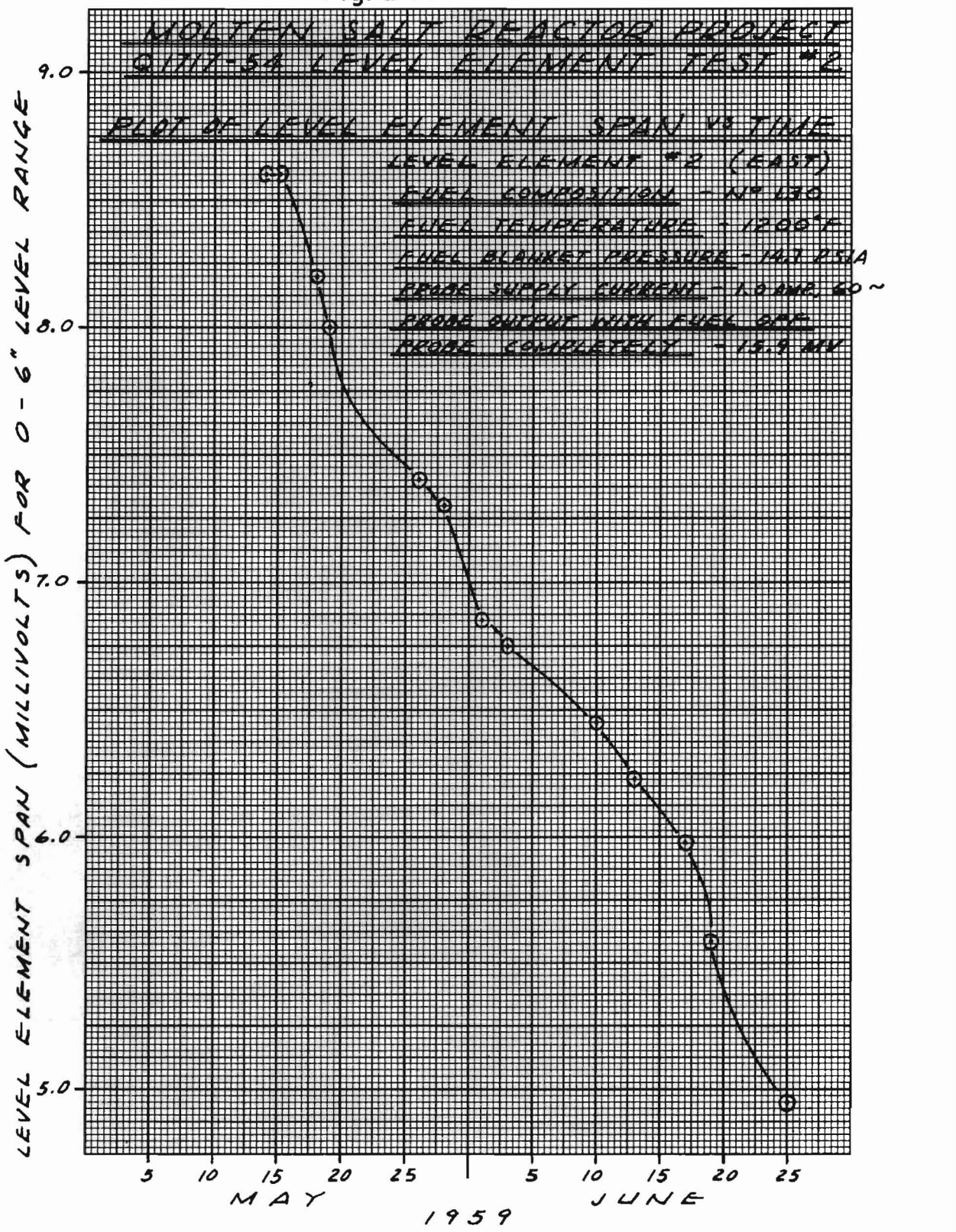


Fig. 23.
PLOT OF PROBE OUTPUT vs LEVEL
PROBE OUTPUT - MILLIVOLTS AC
FUEL LEVEL (INCHES)
MOLTEN SALT REACTOR PROJECT
0-1717-54 LEVEL ELEMENT TEST #2
LEVEL ELEMENT #2 (EAST)
FUEL COMPOSITION #130 62 MOLE % LiF
37 MOLE % BeF2,
1 MOLE % UF4
FUEL TEMPERATURE - 1200°F
FUEL BLANKET PRESSURE - 14.7 PSIA
PROBE SUPPLY CURRENT - 1.0 AMPERE, 60 ~
PROBE OUTPUT WITH FUEL OFF PROBE COMPLETELY } 15.40 MV
SK 14C-EGM-59-34

ORNL-LR-Dwg. 56687
Unclassified

Fig. 24.



SK I&C RW-6115

Corrosion photo-micrographs were made of the level elements at the termination of the tests.

2.33 Test Conditions

The conditions, including the test apparatus and power supply and measuring circuit, for this test were identical to those in the "go-no go" test described in Section 2.20. Two new Q1717-54 level elements without temperature compensation were tested under identical conditions in order to obtain comparative data, and will hereinafter be referred to as Level Element #1 and Level Element #2.

2.34 Test Procedure

Both level elements were tested during the period 5-14-59 to 6-25-59. The test procedure used was identical to that described in Section 2.26, except that both vessels were filled from the same batch of salt.

2.35 Test Results

The results of these tests for Level Element #1 are shown in Figures 21 and 22, and for Level Element #2 in Figures 23 and 24. The time dependent calibration drift observed in previous tests was clearly evident on both level elements. Both a span decrease with time and an upward shift of the entire span with time were obtained from each element.

A period of stable level element performance of approximately three days was achieved with Level Element #1 and approximately two days with Level Element #2.

Level Element #1 produced a span of 8.5 millivolts initially and Level Element #2, 8.65 millivolts.

Overall measuring system accuracy ranged from $\pm$ 3.2% of full range for the wide span data to $\pm$ 5.9% of full range for the narrow span data. Precision of measurement was approximately 0.2 inches of salt. Again, as in previous tests, it was limited, primarily, by the resolution of the vacuum tube voltmeter.

TABLE I

Sample No.	Date	Description	U%	Be%	Li%	Ni ppm	Cr ppm	Fe ppm	O_2 ppm
4071	5-10-59	Pre-filling Sample	6.88	9.10	12.3	135.0	270.0	515.0	9,700
4072	5-11-59	Filling Sample - Both Vessels	6.82	9.06	12.3	150.0	325.0	630.0	11,000
4099	6-29-59	East Vessel - Top - Dump - Oxide Filtered	6.96	8.83	12.3	60.0	480.0	325.0	Insuff. Sample
4200		East Vessel - Bottom - Dump - Oxide Filtered	6.85	8.71	12.3	50.0	710.0	290.0	14,000
4201		East Vessel - Top - Dump - Unfiltered	6.80	8.33	12.3	60.0	730.0	320.0	12,000
4202		East Vessel - Bottom - Dump - Unfiltered	6.90	8.40	12.3	50.0	725.0	320.0	9,600
4203		West Vessel - Top - Dump - Oxide Filtered	6.78	8.30	12.2	55.0	730.0	290.0	13,000
4204		West Vessel - Bottom - Dump - Oxide Filtered	6.96	8.34	12.2	55.0	760.0	305.0	11,000
4205		West Vessel - Top - Dump - Unfiltered	6.96	8.57	12.2	Insuff. Sample	715.0	315.0	11,000
4206		West Vessel - Bottom - Dump - Unfiltered	6.97	8.59	12.3	55.0	645.0	290.0	8,800

*Chromium replaces nickel and iron in solution by an oxidation-reduction reaction.

Molten Salt Reactor Project
Q-1717-54 Level Element Test #2
Fill and Dump Samples
R. F. Hyland, 1-19-61

Hysteresis was $\pm$ 1.5% of full range.

Replacement of the test batch of salt in both test vessels with a freshly prepared batch, resulted in the restoration of the pre-test span on both level elements. While this was strong evidence that the fuel was suspect, equally strong evidence tended to disprove this theory. Quantitative fuel analyses, made both before and after the tests, showed little change in fuel composition, corrosion products and oxides (see Table I). Both fill and dump samples were considered to be in good condition by Reactor Chemistry Division representatives. Taking samples from the top and bottom of the test vessels revealed no separation of the salts or precipitated oxides. One explanation for the restoration of the full span might be that the fresh fuel removed a high resistance film from the probes. Visual inspection of both level elements after the test revealed a rust colored film in the region where the fuel was in contact with the element. Attempts to remove a sample of the film were not successful; however, metallic samples containing the film were removed and given a mass spectrometer examination but the results were inconclusive.

Metallurgical examination of the elements revealed only negligible corrosion where fuel was in contact with the element. A typical photo-micrograph of the $1\frac{1}{4}$" tube from an element is shown in Figure 25. This portion of the tube was in contact with the salt while data was being taken.

Both level elements were in excellent condition, both electrically and mechanically at the conclusion of the tests.

These tests clearly left three important areas of investigation for the observed calibration drifts, namely, fuel resistivity changes, interface polarization, and a resistance film buildup on the probe. Because of the suspicious film noted on both level elements, test #3 was initiated to explore the possibility that this film was causing both the upward shift of the entire span and a gradual decrease in the span.

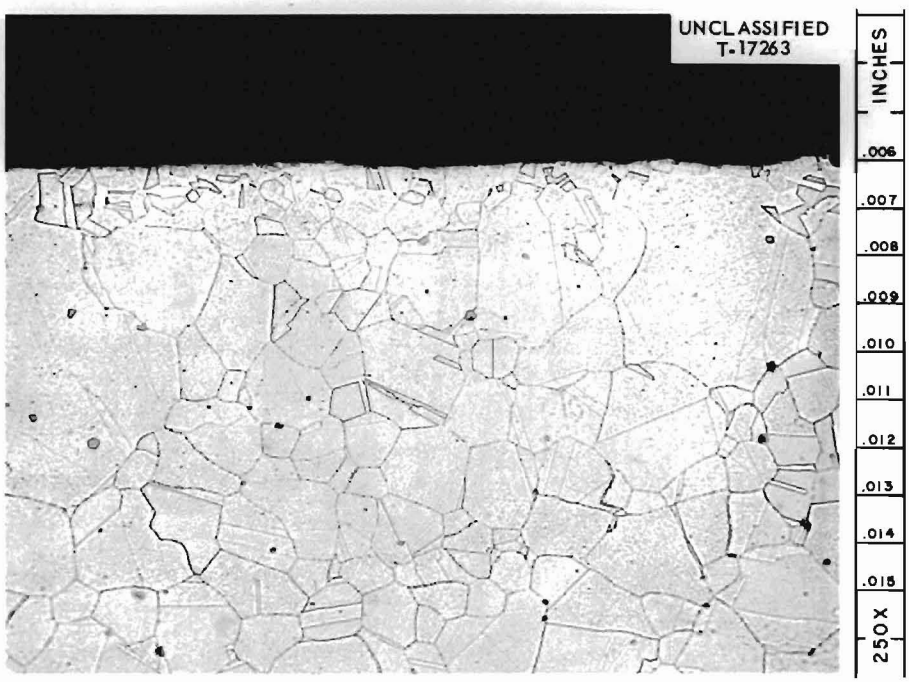


Fig. 25. Q1717-54 Level Element – Corrosion Photo-Micrograph of 1¼ in. Level Element Tube at Termination of Test No. 2.

2.40 Test #3

2.41 Purpose

To investigate the possibility that a time dependent high resistance film buildup was a cause of the observed calibration drift on previous tests.

2.42 Method

Where previous tests had been operated with the salt completely off the level element between data taking periods, during this test the salt was raised to the maximum level point on the element at all times except while taking data. It was reasoned that if the increased resistance was due to an accumulation of material from the salt vapor, elimination of the vapor except during data taking periods would drastically reduce its accumulative effect.

2.43 Test Conditions

All test conditions were identical to those described in test #2, Section 2.30, except for that described above. A new Q1717-54 level element, identical to those previously tested, was fabricated and installed in test vessel #2 and a fresh batch of fuel #130 was used for the test. A quantitative fuel analysis was made to assure that an uncontaminated batch was used.

A new test vessel was also fabricated for the test.

2.44 Test Results

The test results are shown in Figures 26 and 27. Referring to Figure 27, it can be seen that a complete reversal of the previously noted time dependent span decrease was evident. Instead of decreasing at a constant

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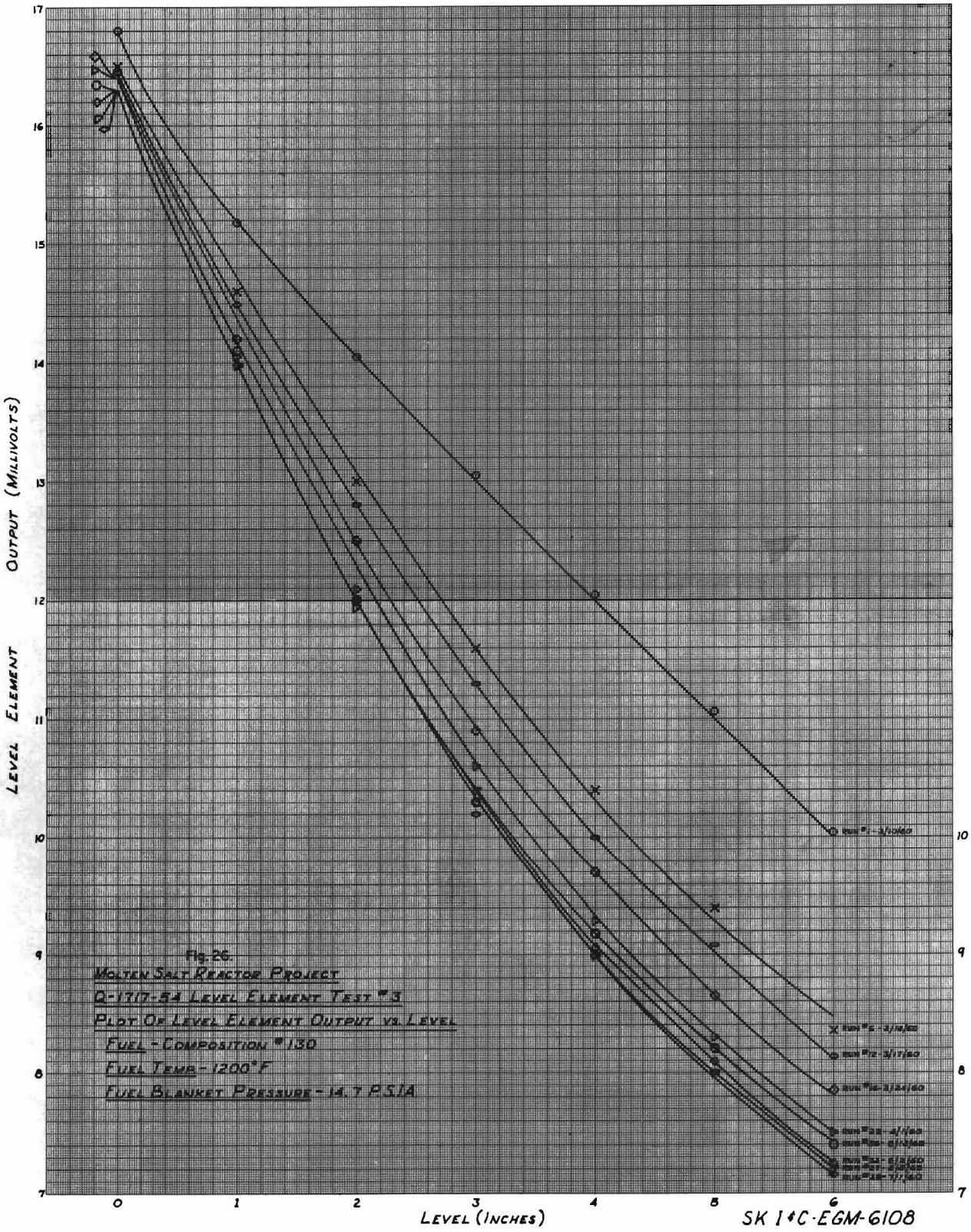

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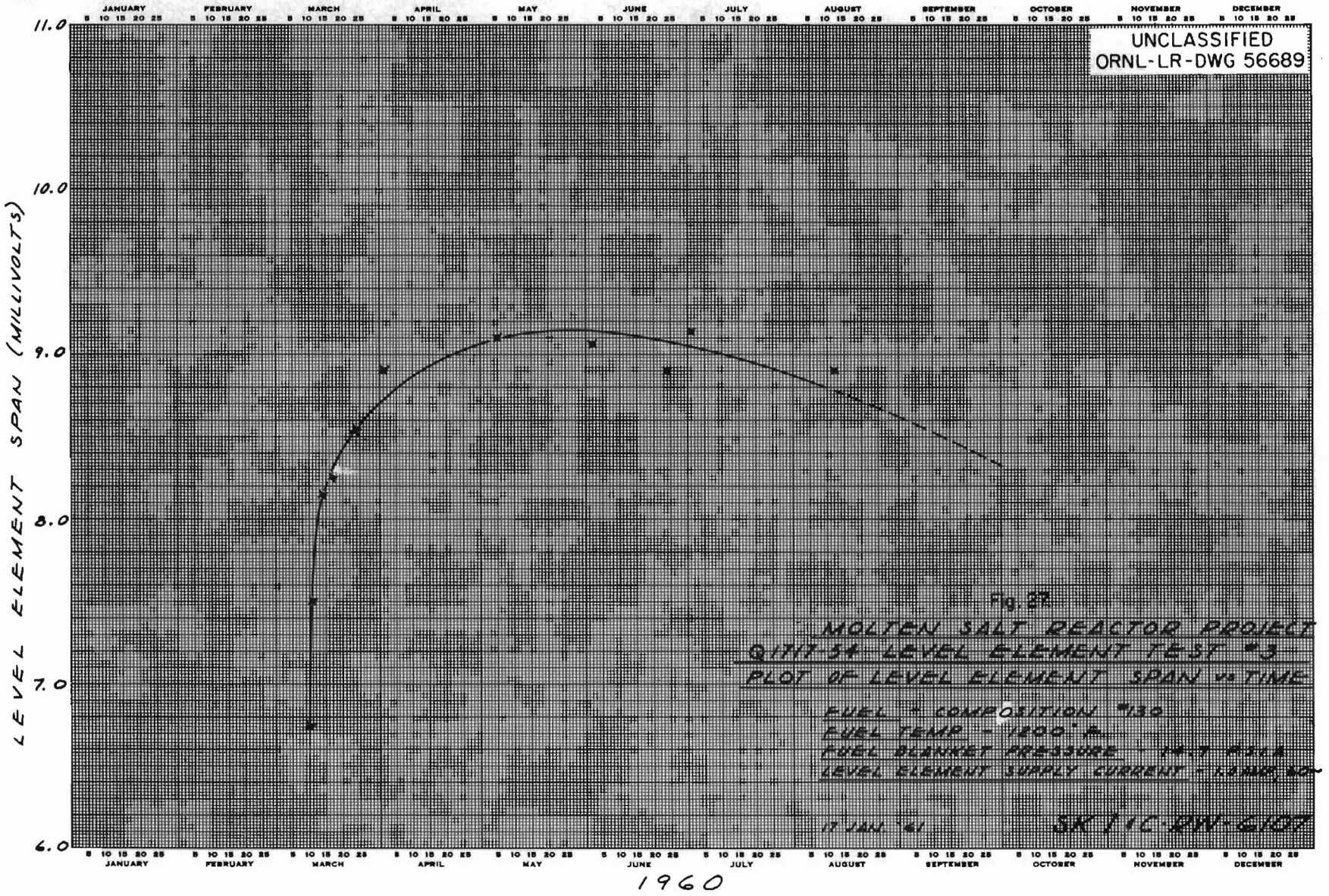
UNCLASSIFIED
ORNL-LR-DWG 56689
LEVEL ELEMENT SPAN (MILLIVOLTS)
11.0
10.0
9.0
8.0
7.0
6.0
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
1960
Fig. 27
MOLTEN SALT REACTOR PROJECT
Q1717-54 LEVEL ELEMENT TEST #3
PLOT OF LEVEL ELEMENT SPAN vs TIME
FUEL - COMPOSITION #130
FUEL TEMP - 1200° F
FUEL BLANKET PRESSURE - 14.7 PSIA
LEVEL ELEMENT SUPPLY CURRENT
17 JAN. '61
SK I & C-RW-6107

rate, the span increased for a period of about two months, levelled off, then began to decrease. The normal stable period of two to three days which was observed on previous tests was not present. It is postulated that an oxide film was present on the probe at the beginning of the test and that the corrosive action of the salt gradually removed this film until it was completely eliminated. In previous tests, periodic exposure of the probes to the salt while taking data may not have been of sufficient duration to allow this corrosive action to take place. Apparently, then, a new variable had been added to an already difficult problem.

3.00 Conclusions

Evidence has been accumulated which leaves considerable doubt that stable performance of these level elements will be achieved. If further work is to be carried out, it is recommended that a separate study of the stability of fuel #130 resistivity with time be undertaken.

It is also recommended that higher probe excitation frequencies be explored in an attempt to minimize polarization.

While the level element in its present form is not suitable for service in molten salt reactors, it is, nevertheless, the only device known to the author which is capable of continuous measurement of molten salt on a long term basis. While the purged dip tube - differential pressure method has been used successfully on a short term basis, it has been plagued by dip tube plugging. This method is also highly undesirable for molten salt reactors from a salt containment standpoint.

It is quite possible that the Q1717-54 element will prove useful for research and development work where a continuous level measurement is required and where a calibrating probe can be installed. The short term accuracy and reproducibility of the probe is satisfactory. The elements have proved to be rugged and failure free, once the initial insulation problem was solved.

Experimental confirmation of the proposed theoretical temperature compensation methods is necessary if the probes are to be used over a wide range of salt temperatures. Because of the instability of the probes tested, it was not possible to study temperature effects during these tests.

Although there is little doubt that the performance of INOR-8 level elements would be similar to Inconel elements, experimental verification of this is recommended.

Distribution

1-3. DTIE, AEC
4. M. J. Skinner
5-6. Central Research Library
7. Document Reference Section