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SYSTEM FOR MEASURING SODIUM LEVEL IN EBR-II

by

James B. Waldo and Lynn J. Christensen

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EBR-II Project

October 1969

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SYSTEM FOR MEASURING SODIUM LEVEL IN EBR-II

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J. B. Waldo and L. J. Christensen

ABSTRACT

A system for measuring the level of liquid sodium has been designed and fabricated, and has been tested in the EBR-II primary tank. The transmitter of the system consists of a partially submerged buoyancy cylinder hanging from a force transducer. A stainless steel bellows is used as a gas seal. The system, which has a measuring range of 20 in., demonstrated an accuracy of ±1/4 in. during six months of test operation in the primary tank. It provides readout, and high- and low-level alarms and trips.

I. INTRODUCTION

Measuring sodium level in a reactor vessel is difficult because of the high temperature, corrosive action, electrical conductivity, and radioactivity of liquid sodium. Several transducers have been developed for measuring the level of liquid metals: electromechanical probes, resistance probes, differential-pressure units, and inductance probes. All these transducers, however, have inherent drawbacks as level-measurement devices.

Any system to be used for measuring sodium level on a reactor must be accurate and linear, must provide long-term stability without frequent calibration, and must be designed for low maintenance.

The device whose fabrication and testing are discussed in this report is of the buoyant type. The method used by the device uses the principle of Archimedes; i.e., the force measured by the transducer is equal to the weight (mass) of the cylinder minus the weight (mass) of sodium it displaces, or

$$F = W_c - W_s.$$

The amount of sodium displaced is a function of level and density.

II. THE NEED FOR MEASURING SODIUM LEVEL IN EBR-II

The primary tank (see Fig. 1) of Experimental Breeder Reactor II (EBR-II) contains 86,000 gal of sodium. Since the tank is of the pot type, no sodium is added or removed from the system. Normally, the only change in the sodium level is due to the variation of the bulk-sodium temperature. During reactor operation, the average bulk-sodium temperature is maintained at 700°F, which results in a sodium level that is approximately 297 in. above the floor of the primary tank, or 17 in. below the bottom of the primary-tank cover. A change of 1°F in the average bulk-sodium temperature will change the sodium level 0.0321 in. (approx 1/32 in.).* This

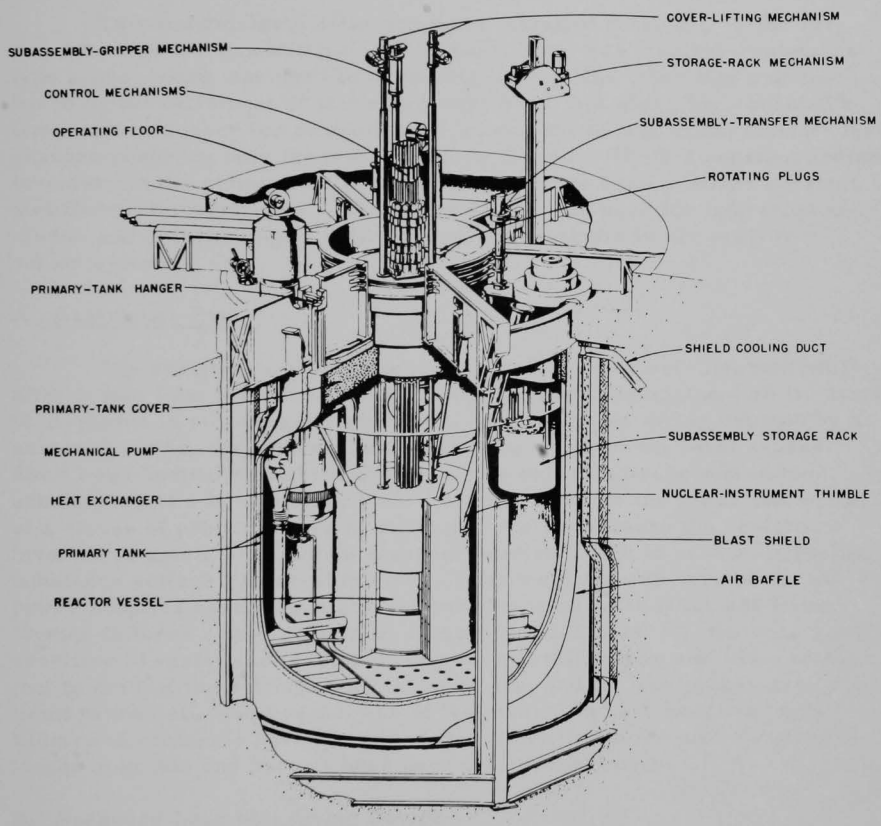

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Fig. 1. EBR-II Primary Tank

*This value for change in level is an average based on measurement of levels between 280 and 700°F with a spark-plug type probe.

means that the sodium level drops approximately 11 in. when the primary tank is cooled to 350°F for maintenance. Any other change in the sodium level that is not caused by temperature would immediately indicate an abnormal or serious condition. For example, a rising level during reactor operation could indicate a leak in the intermediate heat exchanger and allow secondary-system sodium to leak into the primary tank. On the other hand, a falling level (at constant temperature) would indicate a probable leak in the inner wall of the primary tank.

III. EBR-II EXPERIENCE WITH SODIUM-LEVEL INSTRUMENTATION

Two sodium-level detectors were installed originally in the primary tank before it was filled with sodium. One was a spiral-resistance type probe, which was used for indication only. The other was a device based on measurement of static pressure head, but which incorporated a temperature sensor (or compensator) so that the device would indicate level changes resulting only from temperature changes. (With a constant sodium inventory in the primary tank, the static pressure head remains constant at different temperatures.) The latter device was used for indication and alarm, and actuated high- and low-level trip circuits in the reactor scram system.

A. Resistance Probe

The resistance probe, shown in Fig. 2, worked only intermittently after it was first installed. Several problems are associated with it. Level is displayed in stepwise increments of several inches and is denoted by a series of lights, the number illuminated depending on the level sensed. Each level-indicating light is actuated by a relay that responds to the unbalancing of a bridge circuit when sodium contacts the lower end of one of a series of probes placed at different levels. Because the resistance involved is small, the current must be relatively high to produce a usable unbalance voltage. Some of the more common problems have been: (1) The power supplies have been high-maintenance units, with filter and transformer failures causing the most frequent breakdowns; (2) the relays are sensitive to variations in supply current, are difficult to set, and are subject to drift of the settings with temperature; and (3) the probes are difficult to insulate, and breakdowns of the insulation have been frequent. Electrical problems have hampered the reliability of the unit, which is no longer operable and has not been used for several years.

B. Pressure-head Measuring Device

The pressure-head measuring device, shown in Fig. 3, has been slightly more successful but has had problems also. The sensor of the device is a NaK-filled diaphragm pressure unit mounted on the floor of the primary tank. NaK-filled capillary lines, routed up through the primary-tank cover, connect the sensor to a strain-gauge transducer in an instrument

control center. Without temperature compensation, the pressure transmitter would measure only the static pressure head of the sodium in the primary tank and not necessarily the sodium level. To act as a level transmitter, the pressure device has to have a very wide-band temperature compensator added to indicate a level change due to temperature only. This was done by adding a thermocouple which reads the sodium temperature at the pressure-measurement point. In actual service, the pressure-transmitting part of the system was operable, but the addition of the temperature compensator caused many false level trips because of variations of the sodium temperature near the compensator thermocouple that were not representative of the average bulk-sodium temperature. In essence, the level detector became an over-sensitive bulk-sodium-temperature indicator that caused many unnecessary reactor scrams during power changes when the bulk-sodium temperature was being varied slightly.

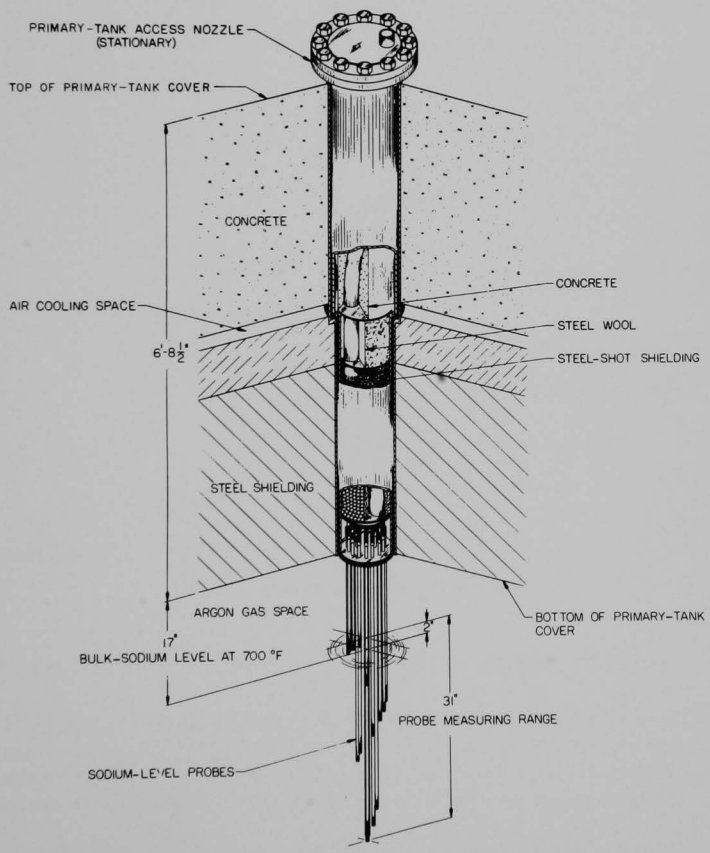

Fig. 2. Resistance Probe

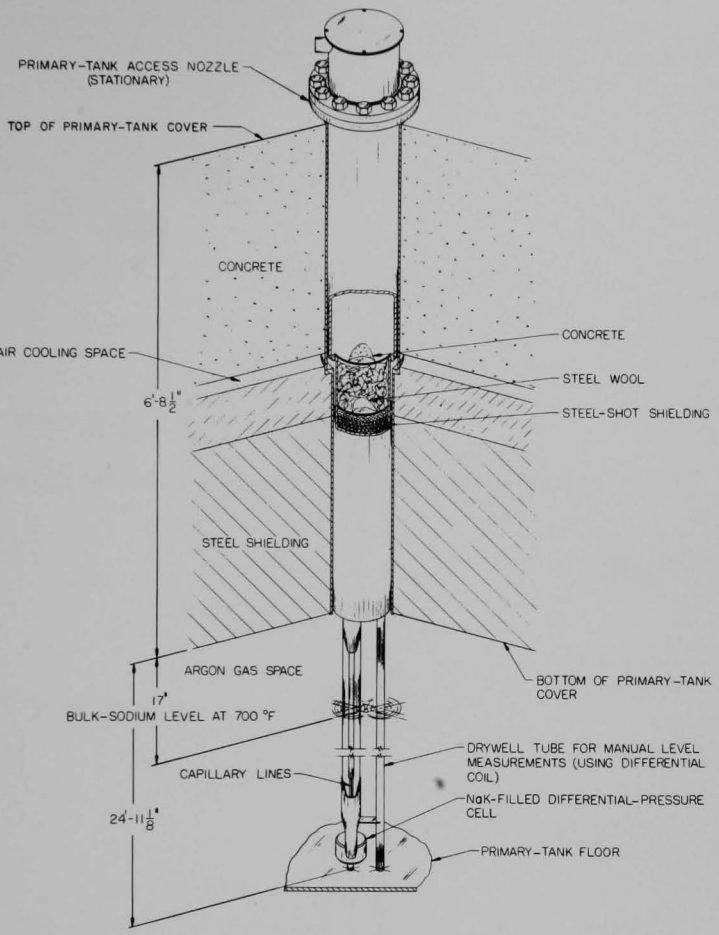

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Fig. 3. Pressure-head Measuring Device

IV. DESCRIPTION OF NEW SODIUM-LEVEL SYSTEM

Figure 4 is block diagram of the new system that was developed for measuring sodium level in EBR-II. The components of the system are: a level transmitter that includes a buoyancy cylinder and a force transducer; a modulator; an amplifier; reactor trip circuits; and an indicator.

Figure 5 is drawing of the level transmitter of the system. The transmitter is installed in a modified shield plug in the EBR-II primary-tank

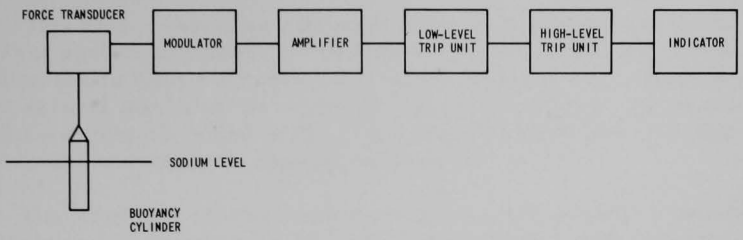

Fig. 4. New Sodium-level System for EBR-II

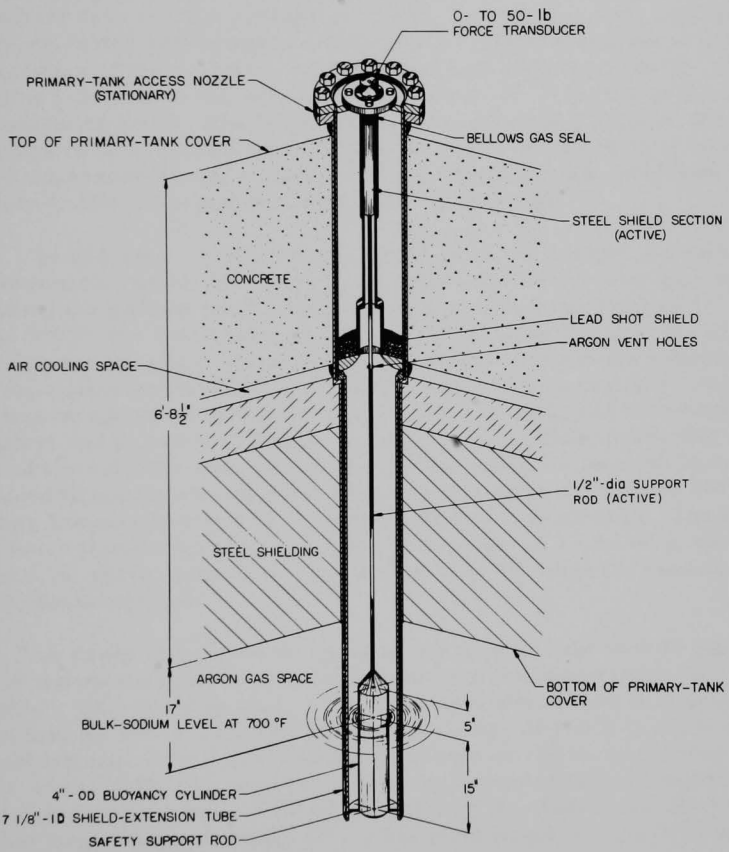

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Fig. 5. Level Transmitter for New EBR-II Sodium-level System

cover. This plug contains an extension tube which projects below the surface of the sodium to protect the buoyancy cylinder from local movements of sodium and to limit the exposure of the internals of the transmitter to sodium aerosol that is in the argon-gas space. Just below the shield plug, the extension tube is vented to the argon space to eliminate pressure effects as the sodium level changes in the tube.

The level transmitter consists of a force transducer, a stainless steel bellows that serves as a gas seal, a support rod, and a buoyancy cylinder. The stainless steel buoyancy cylinder (4-in. OD and 20 in. long) is hung from the force transducer on a 1/2-in.-diam support rod with a small shielding section. The force transducer is of the differential-transformer type and has a range of 0 to 50 lb. The buoyancy cylinder and support rod weigh approximately 45 lb in air. The transmitter is designed for placement of the cylinder 15 in. into the bulk sodium at 700°F. This allows the indicator to follow a level 5 in. above or 15 in. below the normal 700°F operating level. The bulk-sodium level changes 0.0321 in. for each 1°F change in bulk-sodium temperature, so the level can be monitored to 220°F if necessary during a plant cooldown. Normal tank cooldowns have gone only to 350°F for past maintenance requirements.

The buoyancy cylinder displaces 12.56 in.^{3} of sodium for each inch of its immersion below the liquid level. Since the unit is normally used for monitoring the sodium level between primary-tank temperatures of 300 and 700°F, the sodium density at 500°F is used as the average or reference value for the force-transducer calibration. The sodium density at 500°F multiplied by the 12.56 in.^{3} displaced per inch of cylinder immersion gives an average value of 0.4 lb for the change in weight of the cylinder and its support rod per inch of change in sodium level. This means that the weight of the cylinder and support rod (or the load), which is 45 lb in air, is reduced to approximately 39 lb when the tank is at the normal 700°F operating temperature and 15 in. of the cylinder is immersed. The load on the force transducer can vary from a minimum of 37 lb, when the sodium level is 5 in. above normal, to a maximum of 45 lb, when the sodium level is 15 in. below normal.

The error introduced by using an average sodium density rather than correcting the density to reflect actual sodium temperature is negligible. This error is calculated in the appendix, where it is shown to be less than 2% of the indicated change. A change of 350°F in the sodium temperature causes an actual measured change of $11\frac{1}{4}$ in. in the bulk-sodium level. With the use of the 0.4-lb/in. force-transducer calibration, the indicator would show a level change of $11\frac{1}{16}$ in. Therefore, the error over this large range of change in sodium level would be only 3/16 in.

A stainless steel bellows between the top flange and the support rod of the transmitter forms a leaktight argon-gas seal. Deflection of this

bellows causes a very small error, as explained in the following. The movable core of the force transducer deflects 0.005 in. at its rated load of 50 lb. Over the 20-in. range in sodium level in which the level transmitter can operate, the support rod and buoyancy cylinder move 0.0008 in. This deflection, multiplied by the bellows spring constant of 28 lb/in., gives a 0.022-lb error that is due to bellows deflection in a total weight change of 8 lb. This is an error of 0.3%, which is negligible. The transmitter is shimmed during assembly to place the bellows in its free-length or null position so that the force transducer "sees" the same buoyancy-cylinder load before and after the bellows is attached in the shield assembly. This method of assembly prevents possible drift of the zero setting if the bellows relaxes during a long period of use.

Figure 6 is a schematic diagram of the electrical circuit for the system. The level-measuring part of the circuit consists of a force transducer, a modulator, an amplifier, and an indicator. The circuit also includes high- and low-level alarm and trip circuits, which are part of the reactor shutdown circuit and are set to trip at ±3 in. from the normal 297-in. level.

The force transducer consists of a differential transformer with a movable core, which travels 0.005 in. for the full load of 50 lb. Mechanical safety stops are provided in both directions of applied load to prevent shift of calibration or damage from overloads. The unit has a linearity of 0.2%, a repeatability of 0.1%, and a maximum zero shift due to temperature changes of 0.02%/°F.

The modulator provides a 1650-Hz signal to the differential transformer and detects the output signal from the transformer. It sends an output current of up to 1 mA to a 1500-ohm load resistor, the output current being proportional to the load on the differential transformer. The force transducer-modulator arrangement has a sensitivity of 6 mV/lb as measured across the 1500-ohm load resistor.

The amplifier provides a 4-mA output for an input of 24 mV. This output drives the alarm switches and the indicator. The alarm switches, set to alarm at sodium levels of 301 and 292 in., are electronic, and trip at a preset current value.

When the force transducer is calibrated, it is removed from the shield plug and placed on a test stand. Weights of 37, 39, and 45 lb are suspended from the transducer, and the span and zero of the system are set.

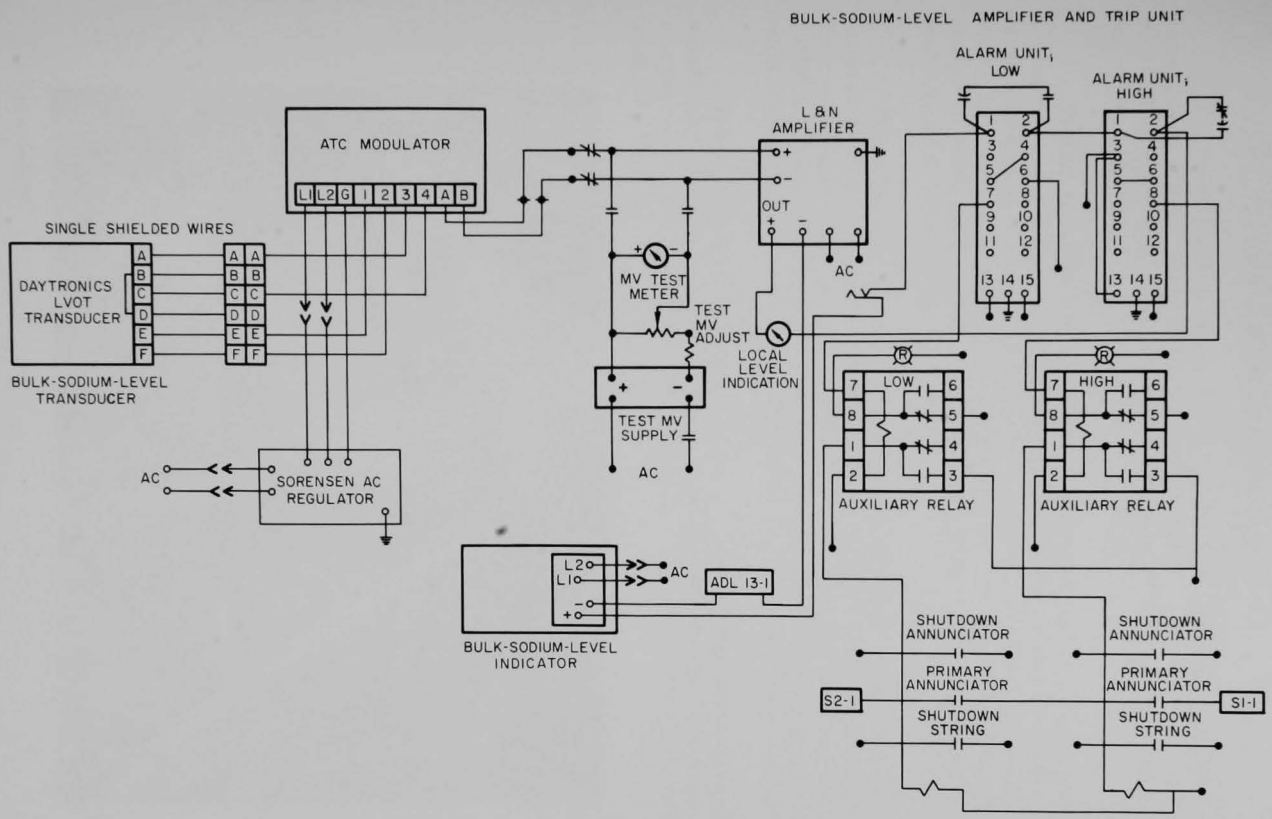

Fig. 6. Schematic Diagram of the Electrical Circuit for EBR-II Sodium-level System

V. OPERATIONAL RESULTS

The level system was test-operated in the primary tank for six consecutive months while the output of the amplifier was recorded on a strip-chart recorder. The readings remained within a ±1/4-in. band about the normal value.

The alarm units connected to the output signal were set to alarm at ±1 and ±3 in. from the normal sodium level. Several alarms were registered during the six-month test period. Each alarm could be attributed either to a change in bulk-sodium temperature, which resulted in an actual change in level, or to a power failure. No alarms were attributed to instability or drifting of the level system.

Thus, the new system operated well during the test. The variations in level could be correlated with variations in bulk-sodium temperature. Twice during the test period, for example, the primary tank was cooled to 350°F for maintenance. Both times, the level indicator showed a value within 1/4 in. of the calculated value of the level at this temperature.

After the completion of the test, the transmitter was raised in the shield plug, and the bellows seal was inspected for buildup of sodium or sodium oxide. No buildup was observed on any of the parts of the bellows seal (see Fig. 7).

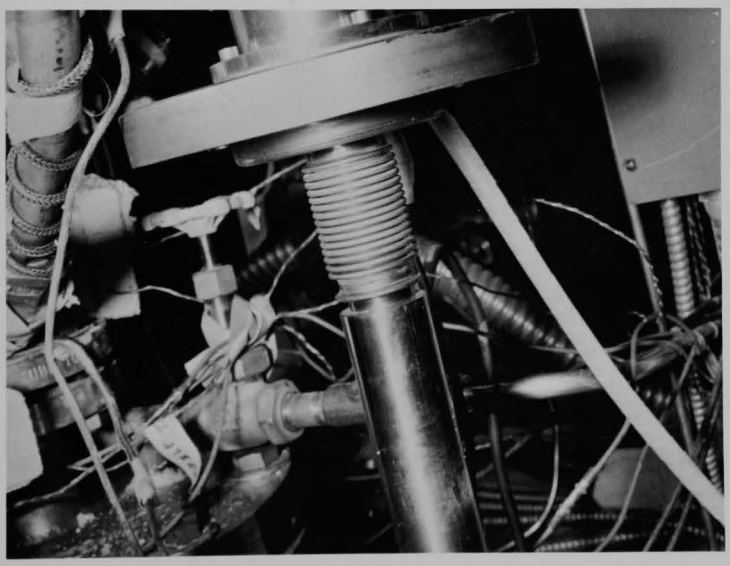

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Fig. 7. Upper Assembly of Level Transmitter, Showing Bellows Seal after Six Months of Exposure in EBR-II Primary Tank

VI. CONCLUSIONS

The level-measuring system described in this report operated well over an extended period of time during which it exhibited an accuracy of ±1/4 in. The system appears to be well suited for use in sodium systems. During the six-month test in EBR-II, it was not affected by the high temperature, corrosive action, or radioactivity of liquid sodium associated with the primary system of a fast breeder reactor.

APPENDIX

Calculation of Error Introduced by Using Average Sodium Density

This appendix presents the calculations used in determining the error in sodium-level readings that results from assuming an average sodium density over a temperature range of 350 to 700°F. The nomenclature for the equations precedes the calculations.

Nomenclature

D = diameter of float = 4 in. = 10.16 cm

Δh_1 = change in sodium level between 700 and 350°F, based on average calibration of 0.4 lb/in.

Δh_2 = change in sodium level between 700 and 350°F, based on actual change of 0.0321 in./°F

K = volumetric coefficient of expansion of stainless steel due to temperature = 3×10^{-5}/°F

ℓ_1 = length of float submerged at 350°F = 3.76 in.

ℓ_2 = length of float submerged at 700°F = 15 in.

ΔT = difference between temperature of sodium and 70°F

V_0 = volume of float per cm of length at 70°F

V_1 = volume of float per cm of length at 350°F

V_2 = volume of float per cm of length at 700°F

W_1 = weight of sodium displaced at 350°F

W_2 = weight of sodium displaced at 700°F

ΔW = change of weight on transducer between 700 and 350°F = $W_2 - W_1$

ρ_1 = density of sodium at 350°F = 0.907 g/cm^3

ρ_2 = density of sodium at 700°F = 0.863 g/cm^3

Calculations

Volume of float per cm at 70°F

$$V_0 = \pi D^2/4 = \pi(10.16)^2/4 = 81.1 \text{ cm}^3$$

Volume of float per cm of length at 350°F

$$V_1 = V_0(1 + K\Delta T) = 81.1[1 + (3 \times 10^{-5})280] = 81.8 \text{ cm}^3$$

Volume of float per cm of length at 700°F

$$V_2 = V_0(1+K\Delta T) = 81.1[1+(3\times10^{-5})630] = 82.6\ cm^3$$

Weight of sodium displaced at 350°F

$$W_1 = \rho_1 V_1 \ell_1 = (0.907)(81.8)(3.76)(2.54)(0.0022) = 1.56\ lb$$

Weight of sodium displaced at 700°F

$$W_2 = \rho_2 V_2 \ell_2 = (0.863)(82.6)(15)(2.54)(0.0022) = 5.98\ lb$$

Change of weight on transducer between 700 and 350°F

$$\Delta W = 5.98 - 1.56 = 4.42\ lb$$

Change in sodium level between 700 and 350°F based on average calibration of 0.4 lb/in.

$$\Delta h_1 = \Delta W/0.4 = 4.42/0.4 = 11.05\ in.$$

Change in sodium level between 700 and 350°F based on actual change of 0.0321 in./°F

$$\Delta h_2 = 0.0321\Delta T = 0.0321(350) = 11.24\ in.$$

Difference between Δh_2 and Δh_1 = 11.24 - 11.05 = 0.19 in.

Percentage difference based on Δh_2 = 0.19/11.24 x 100 = 1.7%

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