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DESIGN AND FABRICATION
OF A SODIUM PURIFICATION LOOP

By

V. P. Kelly and T. J. Owen

Applied Chemistry Section
Chemistry and Chemical Engineering Department

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DESIGN AND FABRICATION OF A SODIUM PURIFICATION LOOP

V. P. Kelly and T. J. Owen

INTRODUCTION

The Sodium Studies Facility (SSF) has been established within the Chemical and Materials Engineering Laboratory⁽¹⁾ as a site for test loops to support the Fast Flux Test Facility in the field of coolant chemistry. These loops include the Sodium Purification Loop.

The purpose of this Sodium Purification Loop is to prepare sodium of known and controlled purity to supply characterized sodium for analytical methods calibration, for loading test capsules and loops, and for tests of sodium samplers and chemistry instruments.⁽²⁾

This report covers the design and fabrication of a forced-convection sodium loop rated for a nominal flow of 2 gpm and equipped with both a cold trap and hot trap. It has been prepared as a reference manual for personnel associated with the Sodium Studies Facility.

SUMMARY

A Sodium Purification Loop was designed, fabricated, and installed in Pacific Northwest Laboratory's Sodium Studies Facility to serve as a source of supply of sodium of specified purity for other FFTF program needs.

Major components in the loop are:

- A 10-gal expansion-storage tank
- A 5-gal mesh-filled cold trap
- A 3-gal hot trap filled with Zircaloy-2 tubing ferrules 3/8-in. OD x 1/2-in. long, and designed to operate at 1400 °F.

Other loop features are the electromagnetic (EM) pump for forced-convection circulation, EM flowmeters for the main circulating loop and the by-pass plugging indicator loop, a coil-type air cooler, and the forced-draft air cooling system for the air cooler and cold trap. The loop is housed in a metal framework 88 in. high, 53 in. wide, and 40 in. deep designed to fit within a previously existing recess in the building structure for containment.

The loop components, interconnected with a 1/2-in. stainless steel piping system and with suitable valving to provide various modes of operation are designed to:

- Import sodium from other loops for storage, or for continuous cycling through the traps or through the plugging indicator system.
- Export sodium to other loops directly from the expansion/storage tank, or from storage through traps or plugging indicator.
- Internally circulate sodium through the traps or the plugging loop.

The loop is filled through the import line or from external containers through the bottom outlet on the cold trap. Thus, sodium of questionable purity may be partially purified before entering the loop.

The loop was fabricated from Type 304 stainless steel to meet the requirements of the PNL pressure systems code for liquid-metal systems operating at temperatures above 700 °F. The requirements include use of material of certified composition, strict materials control, performance of welding by qualified welders and radiograph of all welds. In addition to these steps taken to insure a safely operating loop, the control and instrumentation system is interlocked so that

excessive temperatures, liquid levels, or pressures will deactivate the loop until corrective control measures can be taken.

LOOP DESIGN CRITERIA

The SSF purification loop must be capable of exporting sodium of a specified purity to primary test loops within the SSF or, in turn, of receiving and purifying sodium from the test loops. Design criteria were established to provide that the loop shall:

1. Operate as a forced-convection sodium system with a hot trap, a cold trap, and related coolers and economizers.
2. Be of piping designed to circulate sodium through either the cold trap or the hot trap. Further, the piping shall be designed to export sodium to other loops while purification is in process.
3. Meet applicable pressure piping and pressure vessel codes, shall be fabricated from 304 stainless steel, and shall be instrumented adequately for safe operation.
4. Be designed for the following operating conditions:
 - Sodium flow - 2 gpm maximum
 - Maximum pressure - 50 psig at pump discharge
 - Vessel pressure - 12 psig in hot trap
 - Maximum temperature - 1400 °F in hot trap
 - Minimum temperature - 230 °F in cold trap
 - Sodium storage volume - ~10 gal
5. Include the following loop safety features:
 - Metal and concrete enclosure for containment
 - Circulating air for trap cooling
 - Bottom enclosure pan filled with vermiculite for sodium spill containment

- Automatic loop shutdown at high temperatures, low flows, high and low pressure, and high and low liquid levels
- Smoke sensors for fire alarm.

LOOP DESIGN

MECHANICAL AND PIPING SYSTEMS

General Arrangement

The general arrangement of the loop is shown in the Engineering Flow Diagram (Figure 1) and the assembly (Figure 2). As shown, the primary vessels are the cold trap, hot trap, expansion tank, and air cooler. In the flow system are the main loop EM pump and flowmeter, the plugging valve system, United Nuclear Corporation (UNC) oxygen probe and valves, the air cooling system, and the expansion tank cover gas system. The loop is housed in a steel framework as shown in Figure 2.

The loop components, except for tubing runs through the flowmeters and pumps, are interconnected by a 1/2-in. Sch 40 piping system to provide for:

- Pumping sodium in from other loops through import Nozzle "A" (Figure 1) for storage or for continuous cycling through the cold or hot traps and return through export Nozzle "B"
- Cycling sodium to and from the expansion tank through either the hot trap or the cold trap, individually or in series (hot trap first)
- Operating the plugging valve system during trap operation or independently
- Exporting sodium to other loops by pumping from the expansion tank either directly or through hot or cold traps.

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FIGURE 1. Sodium Purification Loop
Engineering Flow Diagram

FIGURE 2. Sodium Loop Assembly
(Sheet 1 of 7)

H-3-27671

The mode of operation is selected by opening or closing the manual bellows-sealed valves. A detailed description of components follows below.

Cold Trap

The cold trap (Figure 3) is designed to cool a stream of flowing sodium to a temperature at which impurities will precipitate in the trap. The trap consists of a section of 8-in. pipe with a total capacity of about 5 gal. Fins on the outside of the shell give an extended surface area of 10 ft² to promote air cooling. Inside is a 16-in. long inverted bucket filled with a stainless steel mesh.

Sodium enters the trap at the top through Nozzle "A", flows downward through the annulus between the bucket and the vessel wall, then passes upward through the mesh bed to return to the main loop flow system. Cooling air enters Nozzle "E" at the bottom of the trap duct, flows past the cooling fins, and discharges to the loop air exhaust header through Nozzle "F".

Thermocouples in the loop assist in measuring trap performance and controlling its operation. Three thermowells extend into the mesh bed, with one thermocouple installed in each well. The lower couple is connected into the cold trap air supply damper control system to control air flow rate through the trap duct. Inlet and outlet thermocouples are installed in the air ducts to monitor heat rise of the air across the trap.

The trap, using 400 cfm of air, is designed to cool sodium flow (2 gpm) from 400 °F to 230 °F.

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FIGURE 3. Cold Trap Assembly and Details
(Sheet 3 of 7)

Hot Trap and Economizer

The hot trap (Figure 4) is a 6-in. pipe vessel of 30-in. length with a total internal volume of 3 gal. It is designed to operate at 1400 °F with normal pressure below 15 psig. The vessel contains a bed of Zircaloy-2 ferrules 3/8-in. OD by 1/2-in. long. Total zirconium metal area is 75 ft². The rings are supported and contained by perforated plates at the top and bottom of the vessel. Sodium enters the hot trap through upper Nozzle "A" after passing through the economizer. The sodium flows downward through the Zircaloy bed, leaves the trap through Nozzle "B", and returns to the loop after passing through the inner economizer tube. Other hot trap features are:

- One internal thermowell, Nozzle "D", for single or multiple thermocouples.
- Three external thermowells (Nozzles "F", "G", "H") for shell temperature measurement.
- Sheathed, tubular heaters rated at 7.5 kW, strapped to the outside of the shell.
- Two-inch thick Ceraform* insulation strapped circumferentially and confined on the ends by plates.

The hairpin economizer (Figure 4) is a tube-in-pipe assembly designed to heat incoming sodium from 600 °F to 1250 °F and to cool sodium leaving the trap from 1400 °F to 650 °F. Design flowrate is a nominal one gal/min.

Expansion Tank

The expansion tank (Figure 5) is fabricated from 12-in. pipe components to provide both expansion and storage capacity (about 10 gal) for the loop. Tank features include:

- Sodium inlet, outlet, and drain connections
- Two vapor traps for cover gas supply and exhaust

* A Product of Johns-Mansville Company

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FIGURE 4. Hot Trap and Heat Exchanger Detail
(Sheet 2 of 7)

- A 1 1/2-in. pipe sample nozzle
- Top-entry liquid level probes for high and low-level indication
- Dual bottom-entry liquid level probes for continuous level monitoring
- Flexible heating tape wrapped around the outside
- 1 1/2-in. of Ceraform thermal insulation banded to the shell between end flanges.

Liquid-level probes described below are the dc resistance type. Vapor traps, also shown on Figure 5, consist of a section of 2-in. pipe filled with stainless steel wire mesh and fitted with a center heater well. One 500-watt cartridge heater is placed in the well to melt sodium plugs which may form. Gas connections on the vapor traps are compression tube fittings.

Air Cooler

The air cooler (Figure 1) consists of a coil of 1/2-in. pipe assembled in an air duct. The duct is arranged so that the coils are centered in a 1 1/4-in. wide annulus to increase cooling efficiency. The air cooler, with an airflow of 200 cfm is designed to cool sodium flowing at a rate of 0.5 gpm from 800 °F to 300 °F. Flexible heating tapes wrapped around the outer shell maintain cooler temperature during system startup.

Air Cooling System

Air cooling is used for the sodium cooler and cold trap. The system is represented schematically in Figure 1. Cooling air is supplied by a 500-cfm blower to a header duct connected to three branch ducts. Passing through

control dampers, the air flows through the cooler, bypass, or cold trap ducts. Air then flows through the exhaust header and discharges into the building ventilation system. Use of the by-pass duct to maintain maximum air flow through the loop enclosure reduces ambient temperature in the enclosure.

Control dampers are two-blade, rotary types with a 6-in.² throat opening. Blades are gear-driven by a single input shaft.

The control dampers are driven by Modutrol^{*} motors. Details of the control follow below.

Plugging Indicator System

Plugging indicator systems are used for inline measurement of the oxide content of a stream of flowing sodium⁽³⁾. In operation, sodium entering the system is cooled at a nominal rate of 5 °F/min. The sodium then flows through a valve with a slotted seat. Sodium oxide in the stream precipitates at the plugging temperature and partially plugs the valve to reduce flow. A system calibration curve of flow versus temperature is then used to determine the oxide level in the system.

The plugging indicator system (Figure 1) operates in parallel with, or independently of, the cold and hot traps. This system consists of a magnetic flowmeter, an economizer, a cooler, a plugging valve, and a thermocouple with the hot junction adjacent to the valve seat.

The economizer is a conventional tube-in-tube unit. The inner tube has a 3/8-in. diam x 0.065-in. wall, and an effective length of about 24 inches. Sodium enters

^{*} Made by Minneapolis-Honeywell Company

through the outer annulus and exits through the center tube. The cooler is an 18-in. length of 3/4 in. OD finned tubing enclosed in 1 1/4 in. pipe to confine the air flow past the fins. Cooling air up to 100 cfm is supplied from the building compressed air supply header. Flowrate is manually regulated with a diaphragm-operated control valve.

The diaphragm operated plugging valve, welded-bellows sealed, has a Stellite^{*} plug. Four 1/32 in. square grooves in the seating face of the plug provide a restricted flow path when the valve is closed. The valve is opened after indicator runs to flush oxide from the plug and seat.

The plugging temperature thermocouple is installed in the system with the hot junction immersed in the sodium stream immediately adjacent to, and upstream from, the plugging valve seat. The thermocouple is a 1/16-in. diam stainless steel sheathed type K thermocouple with a grounded junction sealed in with a compression tube fitting.

Cover Gas System

Pressure transducers are not used in the loop to measure directly the pressure of the flowing sodium. Instead, argon cover gas is circulated to the expansion tank through its vapor traps to maintain a nominal minimum system pressure. The argon also provides the inert gas blanket required at the free surface of the sodium. As indicated in Figure 1, the argon (or other inert gas as required) is supplied through a manually adjusted bleed-off regulator. This type regulator permits closing Valve V-19 when a non circulating system is required.

Cover gas may also be circulated by connecting discharge Valve V 19 to a suitable press relief valve so that system pressure may be maintained

^{*} A product of Haynes-Stellite Company

Pressure-actuated switches connected between cover gas shutoff Valves V-18 and V-19 and the expansion-tank vapor traps electrically deenergize the entire loop in case of excess pressure.

Flow System Components

Flow system components include the EM pump and flowmeters, valves, and connectors. Descriptions of these components follow.

EM Pump

The ac electromagnetic pump is a General Electric Company pump (Cat #9159849G3). Power to the pump is in single-phase, 60-cycle, 30 amp, and 240 volts supplied through a manually adjustable variable-voltage autotransformer rated at 0-270 volts. A 500 μ F capacitor is connected in parallel with the pump for power factor correction.

The pump flow cell is a four-loop tube section (Figure 6). Cell geometry is varied to meet the flow and pressure requirements for any particular system. The multi-loop cell shown in Figure 6 is used for the low-flow requirements (about 2 gpm) of the Purification Loop.

Flowmeters

MSAR^{*} permanent-magnet flowmeters are used for the main loop and plugging indicator system flowmetering. Flowmeter FM-1 (Figure 1) has a 3/8-in. flow tube, while Flowmeter FM-2 has a 1/4-in. flow tube. Calibration curves are given in Figure 7.

Valves

Welded bellows-sealed valves are used throughout the system. The valves, with exception of the

^{*} *Mine Safety Appliance Research Corporation*

SK-3-13150

FIGURE 6. E. M. Pump Cells

FIGURE 7. Flowmeter Calibration Curves

diaphragm-operated plugging indicator valve, are manually operated. Valves of various manufacturers used in the system are listed in the Parts List, Figure 2. Vendor literature should be consulted for complete valve specifications.

Connectors

Mechanical connectors instead of welded joints are used at various points in the system to meet special requirements. These connectors are:

- Conoseal* pipe and union connectors on the expansion tank sample port and on the oxygen probe
- Swagelock** compression tube fittings to connect both flowmeters and the EM pump into the system and to blank off system drain valves.

Mechanical connectors are used only in the lower-temperature portions of the loop.

Loop Enclosure

The loop piping system is packaged in a single enclosure to facilitate containment of sodium fires and for efficient shop assembly and field installation.

The enclosure (Figure 2) is a structural steel framework fabricated from 3-in. angle iron and dimensioned to a 53-in. width, a 88-in. height, and a 40-in. depth. The enclosure is designed to fit into a concrete cavity formed in the building structure. The right side (facing), back, and top are not enclosed since the concrete walls of the cavity effectively blank off those portions of the enclosure. The left side is covered with a sheet of

* Marman Division, Aeroquip Corporation

** Crawford Fitting Company

fire-resistant Transite*. Two hinged, steel doors seal the front of the enclosure. The enclosure rests in a stainless steel pan filled with vermiculite for fire-retardation and heat insulation.

ELECTRICAL AND INSTRUMENTATION

Electrical and Instrumentation System

The elementary electrical diagram (Figure 8) identifies the major electrical systems and illustrates the system safety features.

The system one-line diagram shows that the Loop electrical components can be energized only when Relay K-3 is energized. The energizing coil of Relay K-3 is wired in series with relay contacts K4, K6, K8, and K7. Thus, the following events will completely deenergize the loop:

1. Actuation of the cover gas system pressure switches (Contacts PS-1 and PS-2) due to high pressure
2. Energizing of Relay K-6 due to high or low levels in the expansion tank
3. Disruption of power to the blower and deenergizing of Relay K-8 to open "normally-open" contacts
4. Any high temperatures occurring at the points connected into the 24-point recorder to energize Recorder Relay K-7.

The smoke sensors required for the loop fire alarm are located in the Facility ventilation and, hence, do not appear in Figure 8.

In general, loop wiring is asbestos-insulated for high temperature service. Thermocouple lead wires are

* *Johns-Mansville Company*

also glass-sleeved. They extend, without an intervening connector, from a high-temperature rated junction at the end of the thermocouple sheath to a junction box outside the loop enclosure.

Trace Heater System

Trace heating is used to maintain the loop system at the required temperatures for trapping and pumping. The three types of heaters used are (1) metal-sheathed tubular heaters on the hot and cold traps, (2) cylindrical cartridge heaters on the valves, and (3) flexible tape heaters on the piping.

The piping and valve heaters are arranged for maximum flexibility in controlling the loop temperature and for heating the loop sequentially from a free surface. This flexibility is provided by the use of a large number of separately controlled trace heaters, as indicated in Figure 1, so that relatively short sections of piping can be heated selectively. This approach was made economically feasible by the development of special low-cost, solid-state heater controllers. Figure 9 shows a diagram of the controllers as well as the manner of applying the heaters and insulation to the system.

To apply the trace heating system, a section of pipe is first wrapped with a double-insulated, 1600 °F-rated Briskeat^{*} heating tape of a standard 96-in. length. The number of tape wraps are varied to fit the length of the pipe section, although a minimum power density of 6 watts/in. is maintained.

A 4-mil thick stainless steel band is spiral-wrapped over the heating tape for mechanical protection

* *Brisco Manufacturing Company*

FIGURE 9. Trace Heater System

and for heat reflection to minimize heat loss. Outer insulation is then applied by splitting cylindrical Risasleeves* along one side and strapping them in place over the reflector strip. Risasleeves are tubular preforms of an alumina-silica fibrous insulation rated for 2300 °F. Multiple sleeves, one over the other, are used as required to reduce heat loss.

Welding pad-type stainless steel-sheathed Type K thermocouples are attached at various locations in the system and connected directly to recorders or indicating meters as shown in Figure 1.

Each trace heater is connected to a controller as shown in Figure 9. Each controller consists of a terminal strip, fuse block, ammeter, potentiometer, and a SCR (Silicon Controlled Rectifier) controller mounted on a welded aluminum chassis. The SCR unit is rated for 10 A at 240 V and consists of the following:

- The aluminum housing which acts as a heat sink for dissipating heat from the components
- The TRIAC**, a high-speed switching device formed by connecting two SCR's in reverse-parallel with the load
- The DIAC**, a gating device for pulsing the TRIAC
- A variable resistance-capacitance circuit for controlling the pulse time of the DIAC.

A voltage pulse from the gating circuit DIAC is introduced into one of the SCR units on the TRIAC. The pulse causes the SCR to conduct current and allows power

* *Johns-Mansville Company*

** *General Electric Company*

to be dissipated into the load from the positive side of the alternating current sine wave.

When a pulse is received from the gating circuit on the negative half of the sine wave, the second SCR conducts and power is again dissipated to the load.

Proportional control is achieved by the variable RC circuit which allows each SCR to be pulsed at a specific time in the appropriate half-cycle of the line voltage frequency. The SCR Unit thus has a continuously variable power output.

The trace heater controllers are pictured in Figure 10. Also shown is the 42-unit control panel assembled for the Purification Loop. Figure 10 shows two types of controllers, one using an indicating ammeter and the other an indicating light. Ammeters, preferred on the basis of operating experience, will be used on all future units. Cost is virtually the same.

The indicating ammeter and thermocouple selector switch are used to monitor loop temperatures. Selected thermocouples may be also connected to a 24-point recorder located on the main control panel and are described below.

Liquid-Level Control System

Direct current resistance probes are used in the expansion-storage tank for liquid-level indication and control as illustrated schematically in Figure 11. Two top-entry probes are used for high and low-level alarms and two bottom-entry probes are used for continuous indication of level. The probes will function at temperatures up to 1600 °F.

FIGURE 10. Trace Heater Controllers

FIGURE 11. D-C Resistance Probe Liquid Metals Level Control System

Construction of each probe is similar to that of metal-sheathed thermocouples, with inner dual wires insulated from the outer metal sheath along its length. The probe wires are stainless steel. The tips of the wires and the sheath are fusion-welded at the probe tips. Welding of the probe into the vessel grounds the sheath to the vessel. Both the wires and the probe sheath comprise a circuit of electrical resistances interconnected as shown in the elementary diagram in Figure 8.

A dc voltage impressed across the input terminals of the probe circuit produces a millivolt output signal proportional to the combined resistances of the wires and sheath. Sodium present in the system will change the effective resistance of the probe sheath and hence the magnitude of the output signal. When sodium contacts the tips of the top entry probes, circuit resistance decreases to minimum value. Top entry probes, therefore, may be used for high and low level alarms. However, sodium contacting the bottom entry probes effectively provides a variable potentiometer and, hence, continuous level indication. In the Purification Loop, only one dc power supply and one indicating meter are provided so that the level control read out mode must be selected by the operator.

Bottom entry probes are of equal length and extend to within 3 in. of the tank top. The top low-level probe extends to within 1 in. of the tank bottom; the top high-level probe extends downward 3 in. from the tank top. Each probe consists of two stainless steel, 26-gage wires insulated with magnesium oxide and contained within a 304 stainless steel, 1/4 in. OD sheath. One end of the probe is plugged and seal welded to form a grounded

junction between the sheath and wires. A junction box is installed on the opposite end of the probes for lead wire terminations. A welding adaptor is provided on each probe so that the thin-wall probe sheath can be welded into the relatively heavy wall tank. Power is supplied to the probes from a 5-volt, 6-ampere, dc power supply unit. The indicating meter is a 25 mV optical relay type.

Air Cooling System

Air flow to the loop is controlled by a Minneapolis-Honeywell damper control system (Figure 12) using proportioning type controllers and proportioning damper drive motors. While each of the three dampers in the system has its own drive motor, only the cold trap and cooler damper drives have controllers.

The input signal to the controller from a thermocouple is summed with an internally-generated set point reference voltage to form an input error signal at summing point No. 1. The error signal then feeds through an attenuating resistor to summing point No. 2 to be summed with the position feedback signal, opposite in polarity from the motor, to thus form the output error signal. The output signal is amplified and, depending on the polarity, energizes one of the two relays to drive the motor in the proper direction. The motor, in turn, drives both the damper and the wiper of the rebalancing potentiometer. As the wiper moves, the position feedback signal changes. The motor continues to turn until the output error signal decreases to zero. The system is then balanced at the null point determined by the controller.

FIGURE 12. Air Cooling Control System (From Minneapolis-Honeywell Instruction Sheet #75-6122)

Main Loop Control Panel

The major pieces of instrumentation and electrical control equipment are mounted in the loop control panel (Figure 13). The panel is designed to nest alongside the loop enclosure in the building structure recess. Functions of the various panel components are shown schematically in electrical and piping diagrams (Figures 1 and 8) and are described more fully as part of the various systems to which they are connected.

Oxygen Probe

The United Nuclear liquid-metal oxygen meter is an "on-line" instrument providing continuous indication of effective oxygen chemical activity concentration in liquid alkali metals. It is intended for operation in the range of from less than one part per million to the oxygen solubility limit in the liquid metal.

The active element is a galvanic cell consisting of a reference electrode, a solid thoria-yttria ceramic electrolyte tube, and the liquid metal into which the electrolyte tube is immersed. Oxygen will transfer from the copper/copper oxide reference electrode, through the ceramic electrolyte, into the liquid metal. Transference is prevented by balancing the generated voltage of about 1 V against a calibrated voltage source in the meter. Variations in the liquid metal oxygen chemical activity concentration of the order of parts per million cause the generated voltage to vary by a few millivolts. The reference voltage, adjustable in millivolt steps, is balanced or nulled against the generated voltage by means of a very sensitive electrometer. Voltage measurements may be used directly to determine the relative changes in oxygen activity or, by means of a

FIGURE 13. Sodium Purification Loop Main Control Panel

calibration curve, to determine quantitative oxygen concentration in the liquid metal.

The meter consists of two major components identified as a sensor and an indicator, interconnected as shown in Figure 14.

The sensor consists of an electrode assembly and a housing coupled together to form a pressure-tight unit. The electrode assembly is a factory-assembled unit containing the reference electrode and the solid ceramic electrolyte tube. The connection from the reference electrode emerges from the top of the assembly through hermetically sealed triaxial connectors. The electrode assembly is fitted with the male flange of a Conoseal coupling to provide a pressure-tight joint when connected to the sensor housing.

Major components of the indicator are (1) a stable reference voltage supply, (2) a highly accurate voltage divider, and (3) a very sensitive electrometer.

The reference voltage supply maintains a stable and accurate output voltage. A switch permits the selection of 1 or 10 V as the full-scale reference. The reference voltage, applied across a voltage divider, can be adjusted from 0.0001 to 10.000 volts.

The electrometer receives the outputs from the voltage divider and sensor(s). It may be used either as a null indicator for these voltages or to measure the difference between the voltage divider and sensor outputs. The electrometer is fitted with a multiplier switch to permit adjusting the voltage sensitivity. A connection is also provided for attaching a recorder. The recorder output is a measure of the difference between the reference voltage and the sensor voltage.

FIGURE 14. *Liquid Metal Oxygen Meter System
(From United Nuclear Corporation
Instruction Book #5131)*

LOOP FABRICATION

Special procedures were followed in fabricating the loop to meet the requirements for liquid-metals pressure piping systems⁽⁴⁾ expected to operate at temperatures above 700 °F. These procedures provided that:

- In general, the piping and vessels be designed, fabricated, tested, and installed in accordance with Section XIII of the ASME Unfired Pressure Vessel Code, and with ASA B31.1-1955, Code for Pressure Piping
- The selection of materials of construction and the design of the components be based on the allowable stresses listed in Section XIII. Type 304 stainless steel with a minimum carbon content of 0.04% was used throughout the loop with the exception of the 316L valves
- Welding be performed by welders certified in accordance with Section XIII. All welds were radiographed and identified by stencilling the weld number in the vicinity of the weld. The weld numbers were then recorded on a drawing for reference.
- Strict material control procedures be followed. The two parts of this control consisted of (1) requesting and obtaining a notarized certification of material composition for each component, and (2) maintaining identification of certified material by transferring heat numbers of the parent material to pieces cut off.

When fabrication is complete, the material composition certifications, weld radiographs, and weld identification records will be compiled in a piping completion record. This record becomes a reference document for use when modifying piping, or when evaluating loop malfunctions.

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