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The EBR-II Radioactive Sodium Chemistry Loop (RSCL)

by

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ABSTRACT

The EBR-II radioactive sodium chemistry loop (RSCL) was designed and constructed to provide a facility for demonstration and testing of prototypal sodium samplers and on-line impurity monitors in coolant representative of liquid-metal-cooled, fast breeder reactors. The RSCL is a pipe circuit for circulating primary-reactor-system sodium. Five pairs of supply and return lines branching off the main circuit furnish continuously flowing sodium to each of five subsystems consisting of the on-line monitoring devices and associated equipment. The facility permits conducting multiple experiments simultaneously with a minimum of interaction among them. An in-depth safety evaluation, especially of fire safety, commensurate with the expected experimental program was included in the design effort.

I. INTRODUCTION

The need to demonstrate and test on-line devices for impurity monitoring for the LMFBR sodium technology program has been strongly emphasized.[1] To meet these needs, AEC-RDT authorized, in January, 1968, construction of the radioactive sodium chemistry loop and cells (RSCL) to be added to the EBR-II primary system. This loop, which was completed in February, 1971, provides the facilities in which prototypal impurity monitors and related devices are tested. Successful operation of on-line impurity monitors in the RSCL will increase the coolant-surveillance capability of EBR-II and will help to characterize the coolant environment of experimental fuel elements and materials specimens being irradiated.

The RSCL is a nominal 2-in.-dia pipe circuit for circulating primary-reactor-system sodium. Five pairs of supply and return lines branching off the main circuit furnish continuously flowing sodium to each of five subsystems consisting of the on-line monitoring devices and associated equipment. Three of the subsystems are to be housed in a complex of three cells (A, B, and C) large enough to permit entry. The other two systems will be shielded by lead brick.

The RSCL is used for testing and demonstrating on-line sodium analytical instrumentation by using the radioactive primary-sodium coolant of EBR-II. The sodium-chemistry conditions in the loop are nominally the same as those for EBR-II bulk primary sodium; concentrations of impurities cannot be purposefully varied in the loop.

Since its inception, several experiments have been proposed for the RSCL. All have been reviewed with regard to such factors as program objectives, approximate size of the equipment, and desired location in RSCL. At the time of completion of the RSCL, the following experiments were under consideration for installation:

Cell A: On-line vacuum-distillation sampler; and deposition sampler (analytical cold trap).

Cell B: Oxygen-hydrogen meter module.

Cell C: Vanadium-wire equilibration device.

II. DESCRIPTION

The radioactive sodium chemistry loop is in the basement of the EBR-II reactor building, next to the primary-purification-system area and beneath the equipment air lock. The loop is shown in Figs. 1 and 2. The RSCL is connected to the inlet and outlet lines of the primary purification system and uses the improved surge tank and siphon break in common with that system. A flow schematic is shown in Fig. 3. The RSCL and the primary purification system can be operated independently of each other. The flow rate in the main loop is variable up to a maximum of 30 gpm at a dynamic head of 16 psig.

The same type of construction is used for the main loop as for the three cells--lead-brick walls in a steel framework. Shielding of individual cells is designed to permit personnel access to any cell without interrupting flow in the main loop or adjoining cells after the sodium in the branch line has been allowed to freeze and radioactivity has decayed to permissible levels.

An air atmosphere, with an exhaust rate of 115-120 cfm, is maintained in each cell. Normally, the exhaust air is routed through a roughing filter and a HEPA filter. Under incident conditions the air is automatically routed to a high-capacity, graded-media prefilter followed by a HEPA filter.

A. Access

The shielding of the RSCL is arranged to provide access to any individual cell when the main loop and adjacent cells are in operation. Main-loop piping and components will be accessible only through a hatch in the top of the vertical section of the pipe gallery. Normal access to each cell is through a vertically rising shield door, but a removable overhead hatch is also provided. A monorail hoist serves Cells A, B, and C and the main-loop hatchway. Manually operated chain hoists are provided for each cell door.

B. Cells, Structure, and Shielding

The three shielded cells are for the large experimental subsystems. The pipe gallery houses the main-loop piping, valves, pump, flowmeters, and other minor components. The area to the rear of the three cells and beneath the pipe gallery is unshielded, but it is available for smaller experimental subsystems, which can be individually shielded. The subsystems involve new monitoring devices for characterizing sodium quality.

The cells are constructed of steel framework and lead brick. The three cells will face the aisle way. Cell A is 5 ft, 6 in. wide; 5 ft, 6 in. deep; and 7 ft, 4 in. high. Cell B is the same height and depth but is only 4 ft wide. Cell C has a truncated right-triangular shape with a front of 7 ft, 8 in.; a depth of 5 ft, 6 in.; a rear length of 2 ft, 3 in.; and a height of 8 ft, 2 in. The area beneath the pipe tunnel and to the rear of Cells A, B, and C is 12 ft long, 5 ft deep, and 4 ft, 7-1/2 in. high. This area is served by two pairs of pipe stubs from the main loop and will serve the small individually shielded subsystems.

The steel framing of the cells was designed in accordance with requirements of the Uniform Building Code for earthquake loading within a seismic intensity zone of 2, and in accordance with the AISC Manual of steel construction. Structural members were fabricated from ASTM A-36 steel.

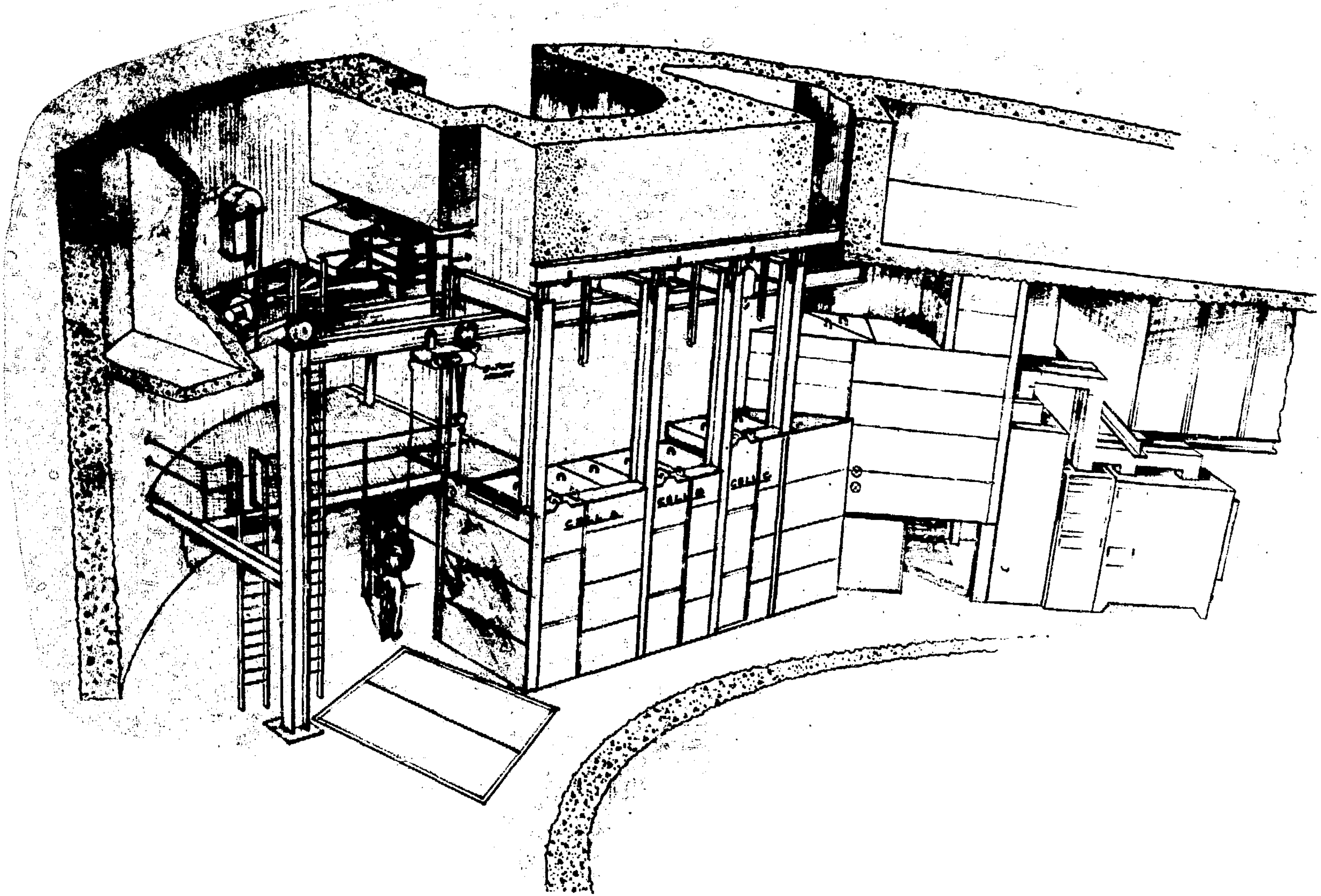


Fig. 1. EBR-II Radioactive Sodium Chemistry Loop (RSCL)

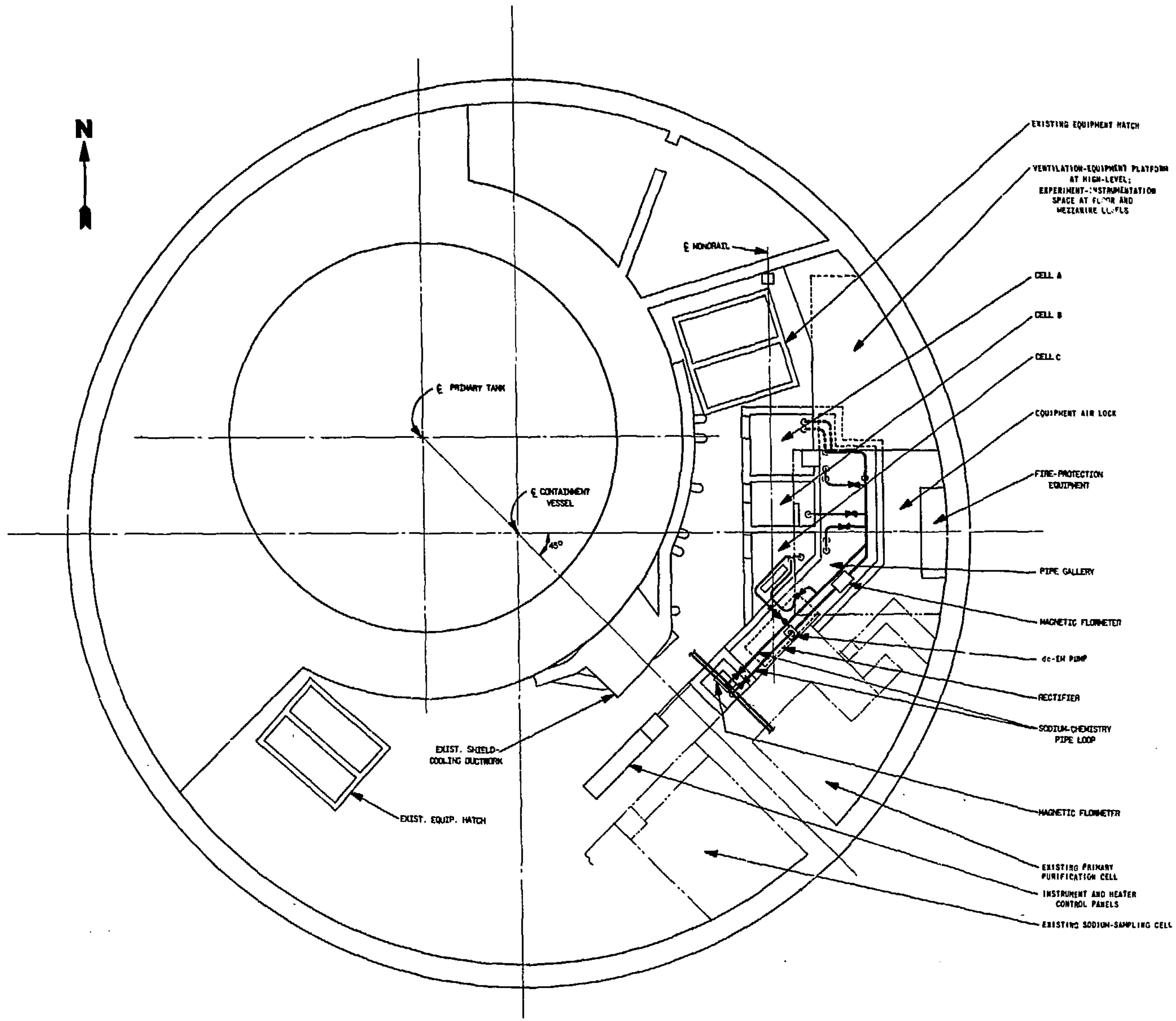


Fig. 2. RSCL Layout

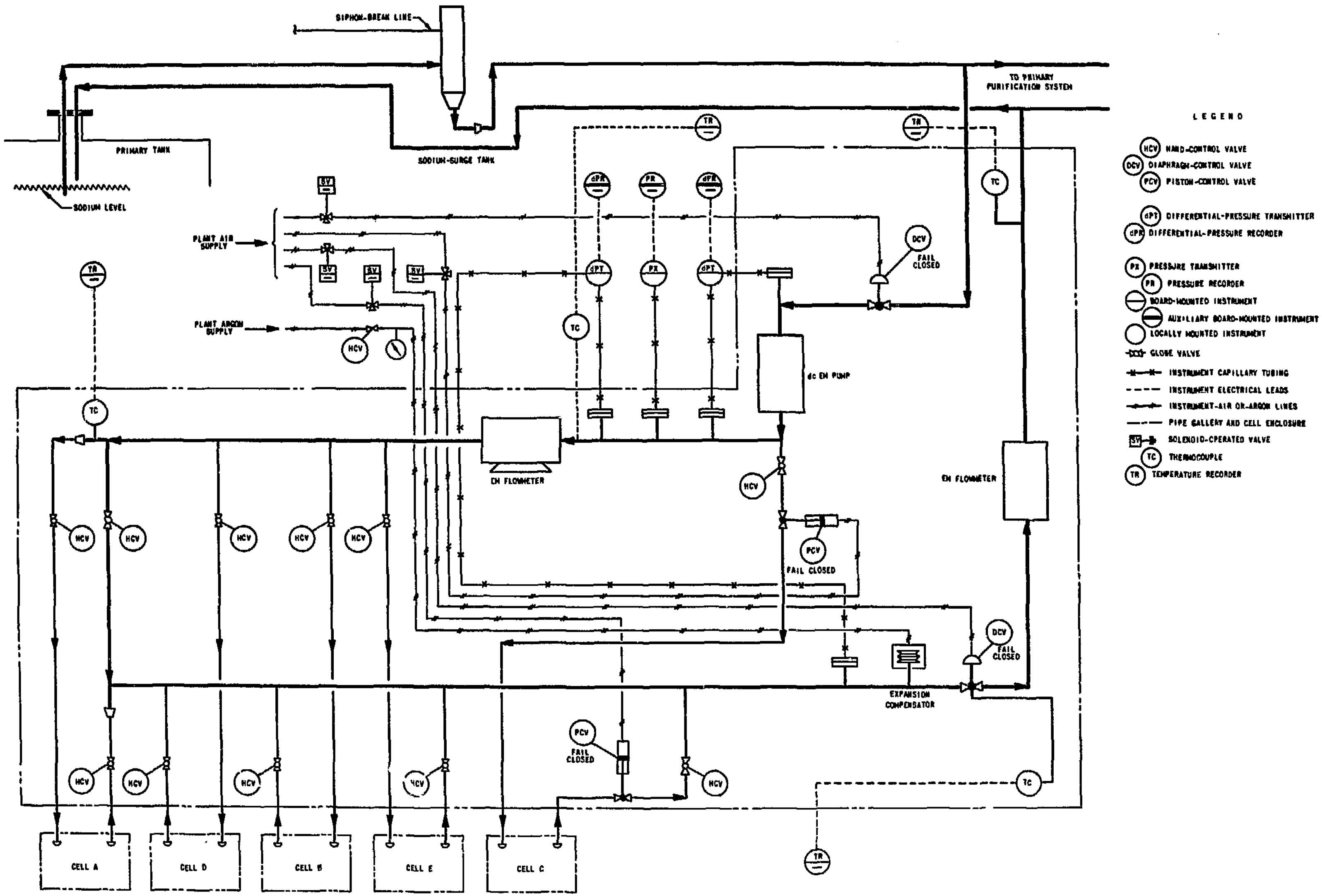


Fig. 3. RSCL Flow Diagram

Engineering analysis showed that no shoring of the reactor building basement floor is needed to support the cell structure. Floor plates are employed under steel columns and the lead walls to provide a more uniform floor loading. The engineering analysis also shows that a live floor loading of 100 psf is still permissible after cell construction.

The shielding consists mainly of stacked lead brick enclosed in either 1/8-in. or 1/4-in. steel plate. The thickness of plate depends on the location. Small and irregularly shaped voids were filled with lead shot or lead wool, or both. The external walls and hatch covers are 8 in. thick, and the internal walls are 6 in. thick. Four inches of lead was added over the concrete floor. Lead brick was used in preference to high-density concrete to better utilize the very limited space available in the reactor-building basement.

Drip pans with perforated-plate covers (for fire suppression) comprise the floor areas of all the cells. Shadow shields are mounted in appropriate locations to shield against radiation streaming through the pipe penetrations leading from the pipe gallery. The shields are necessary for entry into a particular cell while the main loop is in operation.

C. Piping

The main RSCL consists of 2-in. supply and return headers connected to the corresponding line in the primary purification system at one end and connected together by a 1-in. bypass line at the other end. Stub lines are provided to connect five subsystems to the supply and return headers. The stub lines for Cell C are 1-in. pipe, but all other stub lines are 1/2-in. pipe.

The piping system was designed in accordance with USAS B31.1.0-1955, except that some piping was procured to ASTM A376 rather than ASTM A312. Installation was in accordance with the EBR-II specification for Process and Service Piping No. 16. All pipe is Type 304 stainless steel. Except for the connections to the primary purification system and the expansion compensator, which are socket welds, the pipe joints are all butt-welded. The piping was installed with a slope to insure elimination of entrained gas bubbles. A detailed stress analysis was made of the installed piping configuration.

D. Valves

The stub lines and the bypass line each include a remotely operated manual globe valve appropriate to the line size. The 1-in. valves are Powell, Fig. 2474. The 1/2-in. valves are Nupro, Series U. These valves serve as both stop and throttling valves.

A 2-in. modified globe valve, Powell, Fig. 2474, equipped with a second bellows in series with the first (to reduce bellows travel and to prolong bellows life), is installed at the inlet and outlet of the main loop. These valves, equipped with Fisher-Governor diaphragm operators, isolate the RSCL from the primary purification system. They operate on 25-psi air pressure

The stub lines for Cell C also each include a Powell, Fig. 2474, 1-in. valve, equipped with a Tomkins-Johnson, Style 6, piston operator. These valves operate on 80-psi air pressure. They are in the pipe gallery to conserve space in Cell C. Other automatically operated isolation valves for the cells will be in the cells.

All valves used in the RSCL are bellows-sealed, with stem packing serving as the secondary containment. Leak detectors are installed to monitor the space between the bellows and stem packing.

The mechanisms for remotely operated manual valves are made up of rigid shafting, gear boxes, flexible shafting, bearings, and handwheels as required for specific locations. The torque that can be applied to a valve stem is limited by a shear pin securing the handwheel to the shaft. For the 1-in. valves, the torque is limited to about 200 lb-in. For the 1/2-in. valves, the torque is limited to about 140 lb-in. Mechanical position indicators are included as part of the remote-operating mechanism.

Each automatically operated valve is equipped with two limit switches for remote monitoring of open and closed positions. Lights for monitoring the position and pushbuttons for operation of the main-loop isolation valves are on the RSCL instrument panel. These valves will also be operated automatically in response to various alarm indications (see Section II J).

E. Expansion Compensator

A canned-bellows type of expansion compensator is connected to the return header. This can accommodate an expansion of 7.5 $in.^3$ of the sodium in the loop. Its purpose is to reduce the chance of damage to the loop in the event of overheating, or bellows-valve operation while the loop isolation valves are closed to create a hydraulically "solid" system. The space between the bellows and the can is maintained pressurized with argon to about 19 psig. A gauge for monitoring this pressure is mounted near the heater control panel. A valve and regulator are provided to repressurize in the event of pressure reduction.

F. Flowmeters

Direct-current electromagnetic flowmeters, manufactured by Mine Safety Appliances Company, are included in the supply header downstream of the pump and in the return header.

G. Pump and Rectifier

A dc electromagnetic pump, fabricated by ANL, circulates the sodium in the RSCL. The pump provides a maximum flow of 30 gpm at 16 psig, which is considered adequate for projected needs. For any experiments requiring additional head, small EM pumps must be included in the experimental packages to supplement the available head of the main-loop pump. The pump characteristics are shown in Fig. 4.

The low-voltage rectifier, manufactured by the American Rectifier Company, is rated at 0-8000 A, with the output voltage adjustable between 0 and 2 V.

H. Trace Heating

The trace-heating system for the RSCL includes the main-loop piping and components, the cell-isolation valves in the pipe gallery, and the piping between these valves and the main loop. The remaining part of the stub lines will be heated as part of the individual subloops to be installed in the cells.

There are 14 heater segments, consisting of 32 ft of mineral-insulated heater wire rated at 25 W/ft. For each segment, except the EM pump, there is an installed spare.

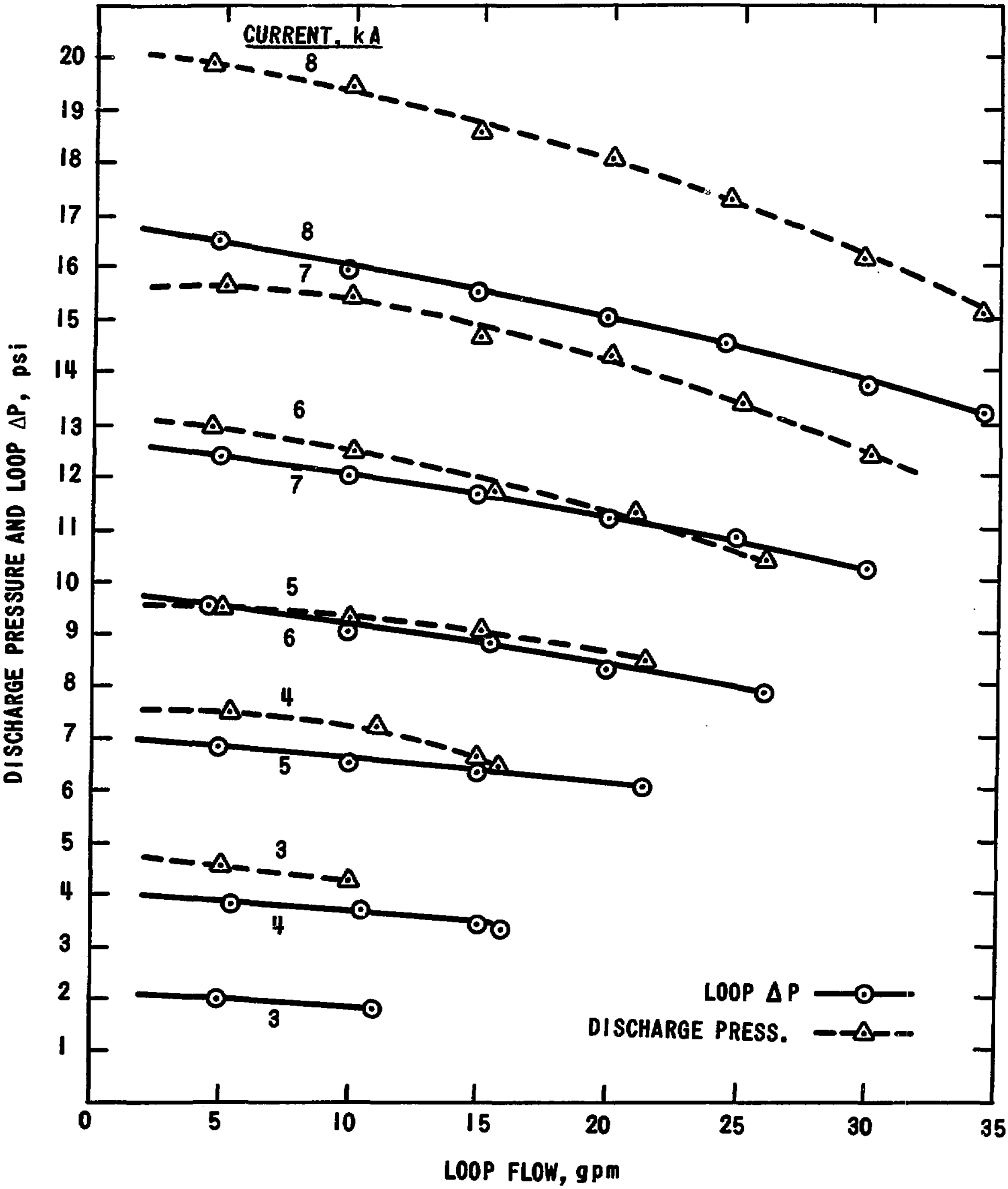


Fig. 4. RSCL Pump Characteristics

The segments of the trace-heating system are automatically controlled to progressively heat the piping, starting at the connections to the primary purification system. There are five sequences in the heating program. The first sequence heats the RSCL piping from the connections to the primary purification system to and including the main RSCL isolation valves. The four remaining sequences heat the rest of the main loop. Figure 5 is a diagram of the heater-control system.

Starting the heating program will operate only heaters in Sequence 1. When the piping in the first sequence is heated to 350°F, a light will illuminate on the RSCL instrument panel indicating SEQ 1 COMPLETE. This light must be illuminated before the valves will operate. Then the isolation valves must be opened before the heating program will proceed to Sequence 2 and continue through Sequence 5. These interlocks insure that sodium in the valves is melted before the valves are operated and that heat is not applied to a hydraulically "solid" system.

When the pipe in heater Sequence 5 has reached 350°F, the light for HEATER CONTROL SEQUENCE INCOMPLETE in the alarm annunciator unit on the RSCL instrument panel will extinguish. This indicates that all the sodium in the loop is melted and flow through the loop can be started.

Power to the heater segments is controlled by "on-off" control units that monitor the temperature by a representative thermocouple attached to the pipe in the corresponding heated section. The automatic-transfer and over-temperature alarm functions are performed by an associated temperature-indicator-alarm unit.

I. Power

Power is fed to the RSCL from cubicle 5E of MCC-R3 through a new 480-V distribution panel on the reactor-building wall south of the RSCL area. Circuit breaker No. 11 feeds the 120/208-V RSCL distribution panel on the south end of the RSCL instrument panel. Circuit breaker No. 9 feeds the rectifier and No. 5 feeds the RSCL hoist.

Power to the RSCL ventilation blower and smoke-detection system is fed through circuit breakers on a new emergency-power panel just south of the RSCL instrument panel from circuit breaker No. 3 in the RE-3. The power to the ventilation blower is also fed through a motor-starter unit mounted above the ventilation-equipment platform.

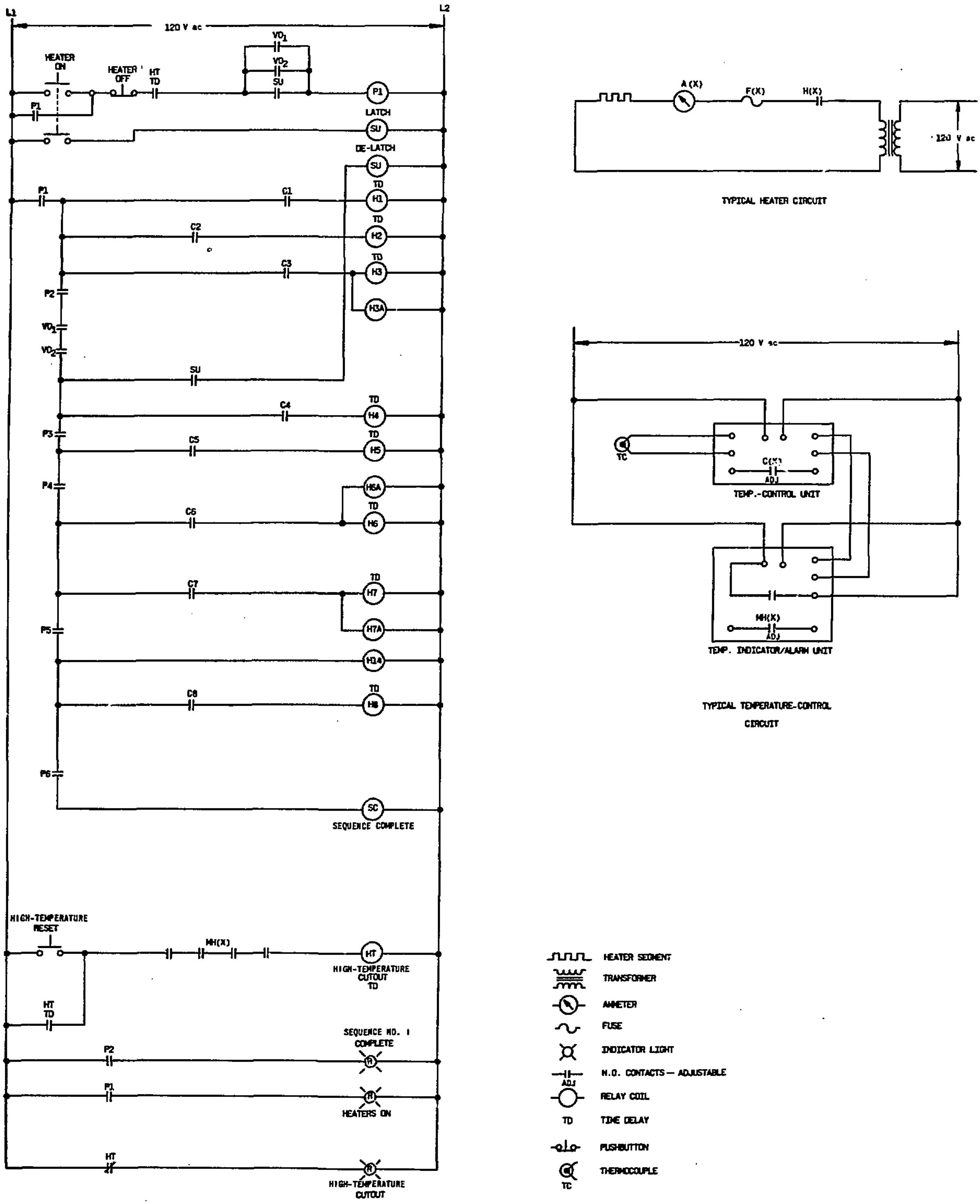


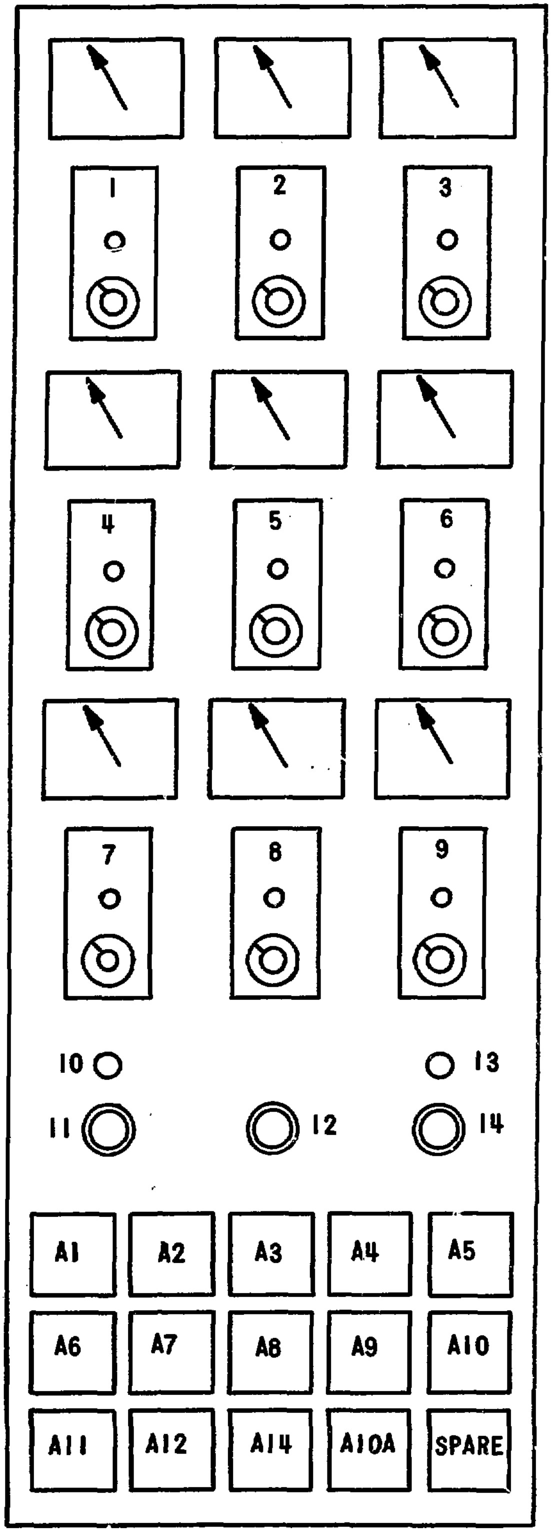
Fig. 5. RSCL Heater Control

J. Instrumentation and Control

The heater-control panel (Fig. 6) is at the south end of the RSCL facility (see Fig. 2) next to the RSCL control panel. Figure 7 shows the RSCL instrument panel. Listed below are the features shown in Figs. 6 and 7.

RSCL Instrument Panel

(1) Alarm annunciator unit (12 windows)
(2) Rectifier-output voltmeter
(3) Zero adjustment for change in pump-tube resistance (meter)
(4) Change in pump-tube resistance (meter)
(5) Alarm for change in pump-tube resistance (light)
(6) Rectifier-output ammeter
(7) Pipe-gallery exhaust temperature (gauge)
(8) Piping temperature (40-position selector switch)
(9) Differential pressure for high-capacity filter (gauge)
(10) Piping temperature (digital meter)
(11) Leak-detector alarm (light)
(12) Alarm acknowledge (pushbutton)
(13) Alarm-unit-light test (pushbutton)
(14) Rectifier increase (pushbutton)
(15) Rectifier lower (pushbutton)
(16) Vent-valve check (pushbutton)
(17) Vent-valve bypass (pushbutton)
(18) Vent valves abnormal (light)
(19) Vent valves normal (light)
(20) Inlet valve closed (light)
(21) Inlet valve open (light)
(22) Outlet valve closed (light)
(23) Outlet valve open (light)
(24) Sequence 1 complete (light)
(25) Open inlet valve (pushbutton)
(26) Close inlet valve (pushbutton)



1,2,3. TEMPERATURE INDICATOR/ALARM (TIA) AND CONTROL (CONT) UNITS FOR SEQ. 1

4. TIA & CONT. FOR SEQ. 2

5. TIA & CONT. FOR SEQ. 3

6,7. TIA & CONT. FOR SEQ. 4

8. TIA & CONT. FOR SEQ. 5

9. TIA & CONT. (SPARE)

10. HEATERS-ON INDICATOR LIGHT

11. HEATER ON

12. HEATER OFF

13. HIGH-TEMP-CUTOUT INDICATOR LIGHT

14. HIGH-TEMP RESET

A1-A14. AMMETERS

Fig. 6. Heater Control Panel

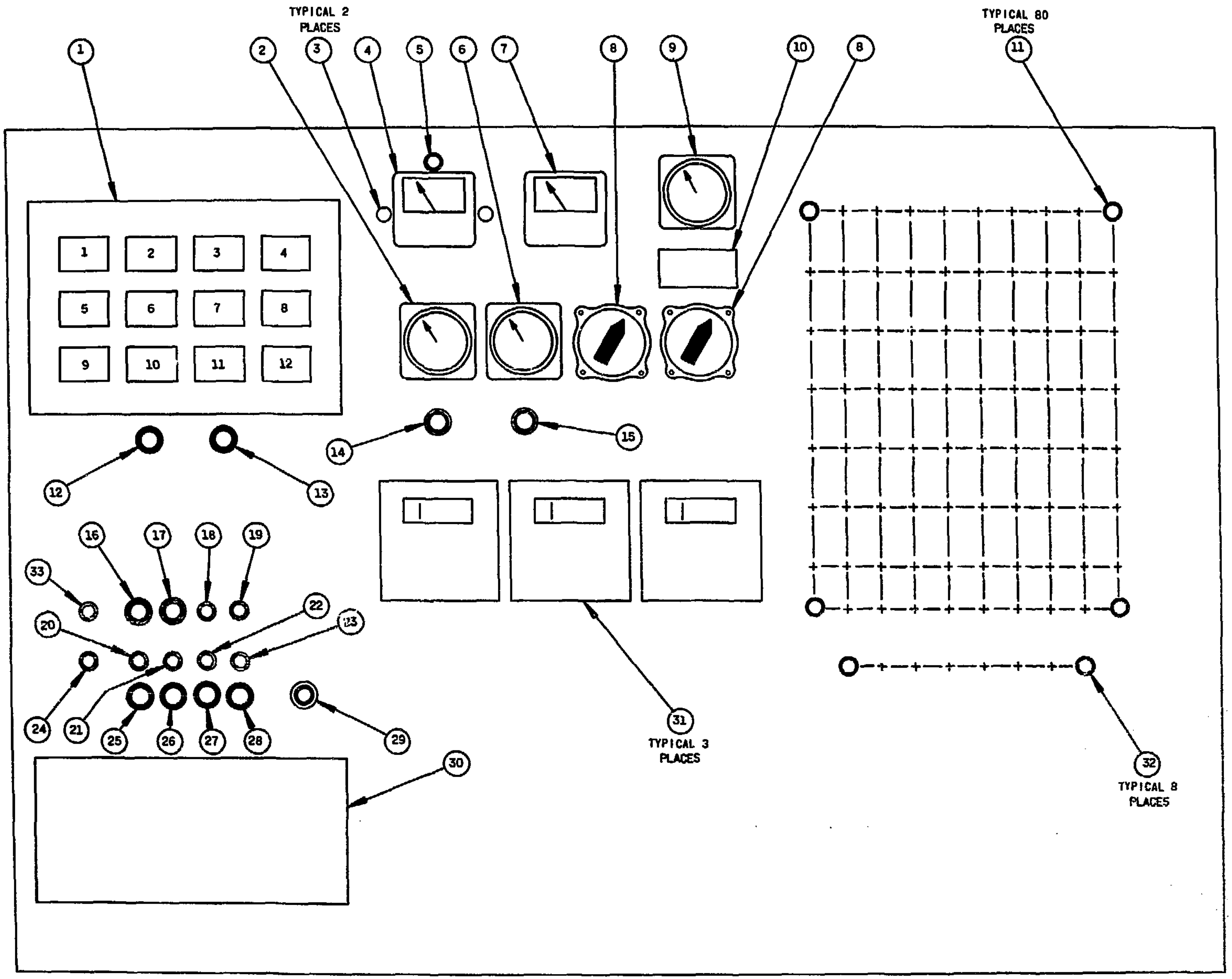


Fig. 7. Instrument Panel

(27) Open inlet valve (pushbutton)
(28) Close inlet valve (pushbutton)
(29) RSCL emergency shutdown (pushbutton)
(30) ^{24}Na monitor unit
(31) Flow, pressure, temperature (three-pen recorder)
(32) Smoke-detector alarm (light)
(33) Vent-fans-abnormal alarm (light)

Alarm-unit Window

(1) Sodium from system: low flow
(2) Sodium to reactor: low temperature
(3) Sodium to reactor: high temperature
(4) Pump discharge: low pressure
(5) Exhaust: ^{24}Na high
(6) Any smoke detector
(7) Exhaust: temperature high
(8) Any leak probe
(9) Heater-control sequence: incomplete
(10) Heater: abnormal
(11) Rectifier: abnormal
(12) Graded-media filter: Δp abnormal

The set points for temperature control, transfer, and high-temperature alarm are adjustable from the front of the panel.

The pump-duct resistance meter includes zero and trip-point adjustments operable from the front of the panel.

The three recorders on the RSCL instrument panel record the following:

(1) Differential pressure across the loop
(2) Differential pressure across the pump
(3) Pump discharge pressure
(4) Pump inlet temperature
(5) Bypass-valve temperature
(6) Return-line isolation-valve temperature

(7) Return-line temperature near connection to primary purification system

(8) Supply-header flow

(9) Return-header flow

The HEATER ABNORMAL alarm will occur when any heater segment has not heated the piping included in that segment to 350°F within a specified length of time. The specified times vary somewhat between segments.

The control panel on the front of the rectifier will further define a RECTIFIER ABNORMAL alarm. Alarms displayed there are:

(1) Cooling fans; off

(2) Low air flow

(3) Rectifier transformer; temperature too high

(4) Diode: temperature too high

(5) DC: current too high

The leak-detector and smoke-detector alarm indicator lights and the emergency-shutdown pushbutton on the RSCL control panel are duplicated on a panel in the corridor outside the reactor building near the personnel entrance. See Fig. 8.

There are three RSCL alarm-annunciator windows on the radiation-monitoring panel in the control room: RSCL SMOKE, RSCL LEAK, and RSCL ABNORMAL. If an RSCL SMOKE or RSCL LEAK annunciator illuminates in the control room, either the RSCL instrument panel or the corridor panel must be examined to determine the location of the smoke or leak. If the RSCL ABNORMAL annunciator illuminates, the alarm annunciator on the RSCL instrument panel must be examined to determine the cause for the alarm. A differential-pressure gauge for the high-capacity filter in the RSCL ventilation system is also in the control room.

Chromel-alumel thermocouples are used to monitor temperatures of the piping system. Each heater segment includes more than one thermocouple location, but only one location in each segment is used for temperature-control and alarm functions. There is an installed spare for most thermocouples. A thermocouple at each location reads out through the temperature indicator-alarm unit, a recorder, or the 40-position selector switch and the digital indicator.

Automatic safety controls and the response of the system are summarized in Table I.

Operation of the loop, startup, and shutdown, are controlled by the position of the main-loop isolation valves. Opening the inlet isolation valve starts the rectifier and the directly connected EM pump. The rectifier remains at minimum output until the output is manually raised.

Figure 9 shows a diagram of the isolation-valve control system. A low-flow interlock prevents overheating of the EM-pump tube. The surge-tank pressure and siphon-break interlocks protect the pumps against loss of suction. The interlock with the outlet isolation valve prevents pumping against a shutoff head. The interlocks, however, are momentarily bypassed when the inlet valve is opened to permit flow to be established. There is also a time delay on the pump-control relay to prevent rapid cycling of the rectifier controls.

TABLE I. Automatic Safety Instrumentation

Condition, Signal, or Sensor	Response
Leak Detector in the Pump Containment	1. Pump shutdown 2. Main-loop-supply isolation valve closes 3. Audiovisual alarm
Low flow through return flowmeter (Time delay provided for startup)	1. Pump shutdown 2. Main-loop-supply isolation valve closes 3. Audiovisual alarm
Leak detectors in all valves and cell components	1. Audiovisual alarm
Leak detectors in drip pans	1. Pump shutdown 2. Both main-loop isolation valves close 3. Particular cell-isolation valves close 4. Valves for ventilation-air supply close 5. Ventilation exhaust routed to high-capacity filter 6. Audiovisual alarm 7. Siphon breaker actuates

TABLE I (contd)

Condition, Signal, or Sensor	Response
Na^{24} Radiation detector in ventilation system	1. Pump shutdown 2. Both main-loop isolation valves close 3. Ventilation-air-supply valves close 4. Ventilation exhaust routed through high-capacity filter 5. Audiovisual alarm
Smoke detector (photoelectric)	1. Pump shutdown 2. Both main-loop isolation valves close 3. Particular cell-isolation valves close 4. Ventilation-air-supply valves close 5. Ventilation exhaust routed through high-capacity filter 6. Audiovisual alarm 7. Siphon breaker actuates (Gallery-exhaust smoke detector only)
Gallery exhaust: temperature	1. Audiovisual alarm
Heater: temperature too high	1. All heaters off 2. Audiovisual alarm
Closure of either main-loop isolation valve	1. Heaters between isolation valves off 2. Audiovisual alarm
Ventilation-fan failure	1. Audiovisual alarm
Loss of electrical power	1. Total system shutdown
Loss of instrument air	1. Main and cell-isolation valves close 2. Pump shutdown 3. Ventilation-air-supply valves close 4. Ventilation exhaust routed through high-capacity filter 5. Audiovisual alarm.

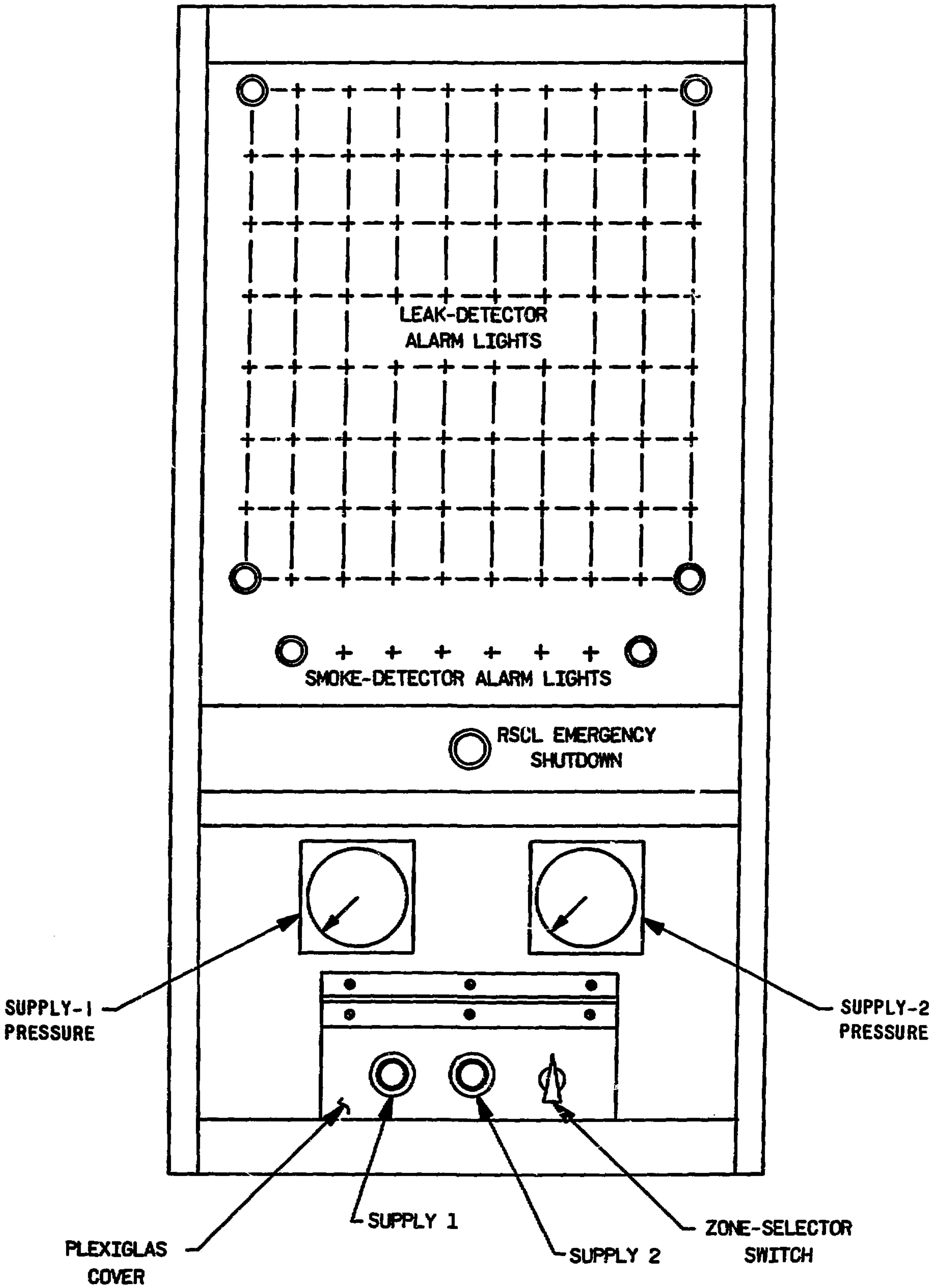


Fig. 8. Corridor Panel

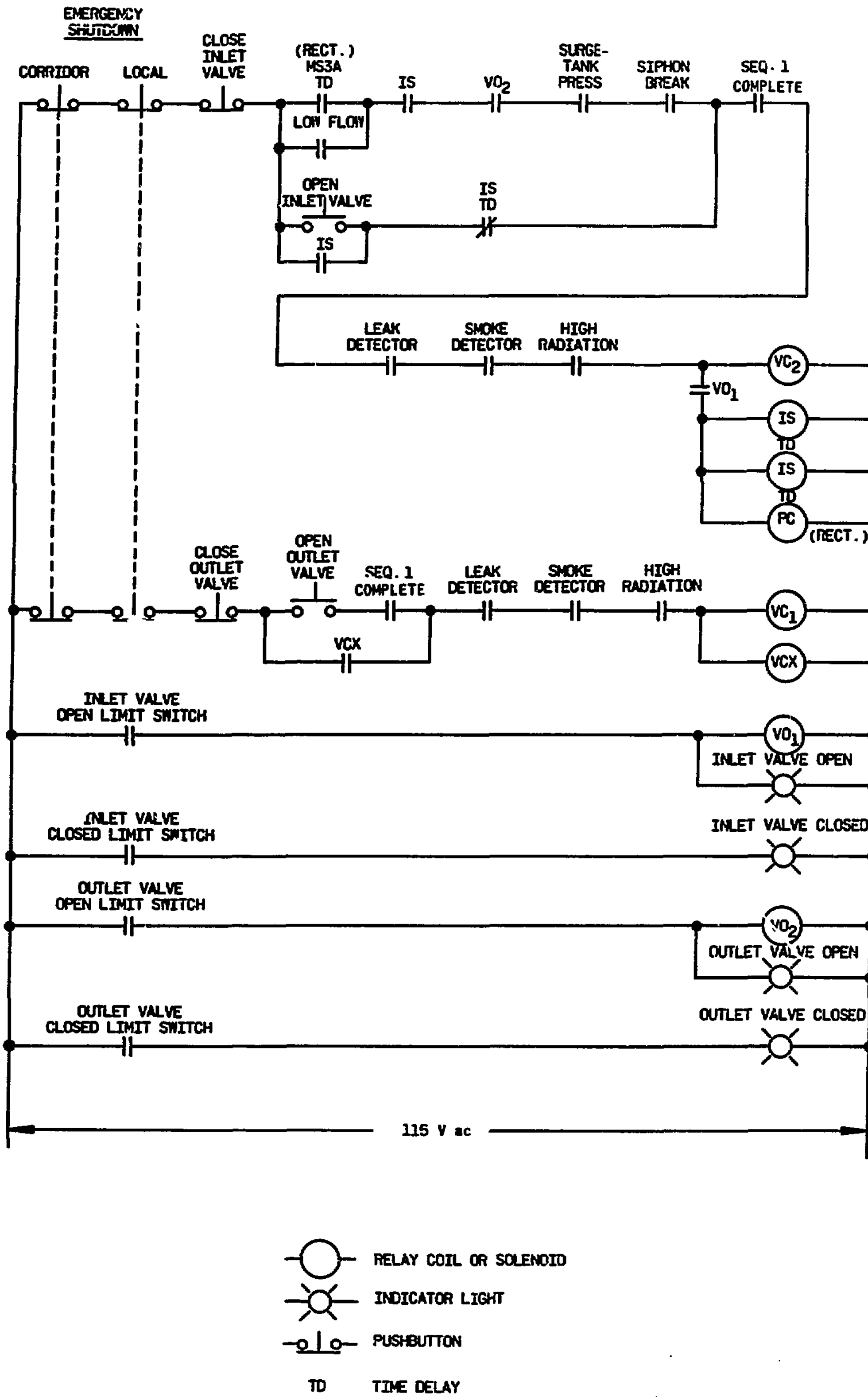


Fig. 9. Isolation-valve Control System

Flow through the main RSCL is manually regulated. Within the limits of capability of the EM pump, the flow rate and the related differential pressure across the loop are a function of the output of the rectifier, the position of the manual bypass valve, and the flow rates in the subcells. The output of the rectifier, which is directly connected to the pump, is manually established with INCREASE and LOWER pushbuttons on the RSCL instrument panel.

Space for instrumentation for experiments is available in the test-instrument room above the south end of the facility and on the basement floor and mezzanine levels at the north end of the facility.

K. Ventilation

Air for ventilation of the RSCL is drawn from and exhausted to the reactor-building basement. Air is drawn into each of the cells and the vertical section of the pipe gallery through 4-in. butterfly vent valves. The cells exhaust into the pipe gallery through the pipe-sleeve penetrations. A 950-cfm blower exhausts the pipe gallery through parallel filters in the ventilation exhaust system between the pipe gallery and the blower. The normal exhaust air path is through a roughing filter and a HEPA (absolute) filter. Figure 10 shows a schematic of the ventilation system. See III.C.3.

The ventilation equipment, blower, silencer, filters, etc., are on a platform above the mezzanine level at the north end of the RSCL facility.

In "incident" conditions, the 8-in. valve at the outlet of the high-capacity filter will automatically open to permit flow through that filter as the normally used filter becomes plugged. The 4-in. inlet valves will also close to aid in containment of any hazard.

The valves in the ventilation system utilize diaphragm operators that operate on 25-psi air pressure. Solenoid valves controlling instrument air to the operators and pressure gauges showing instrument-air pressure and pressure to the valve operators are mounted on a panel located on the ventilation-equipment platform.

Differential-pressure indicators are provided to locally monitor the condition of each filter. The differential pressure across the high-capacity filter can also be monitored remotely at the RSCL instrument panel and on the auxiliary panel in the reactor control room.

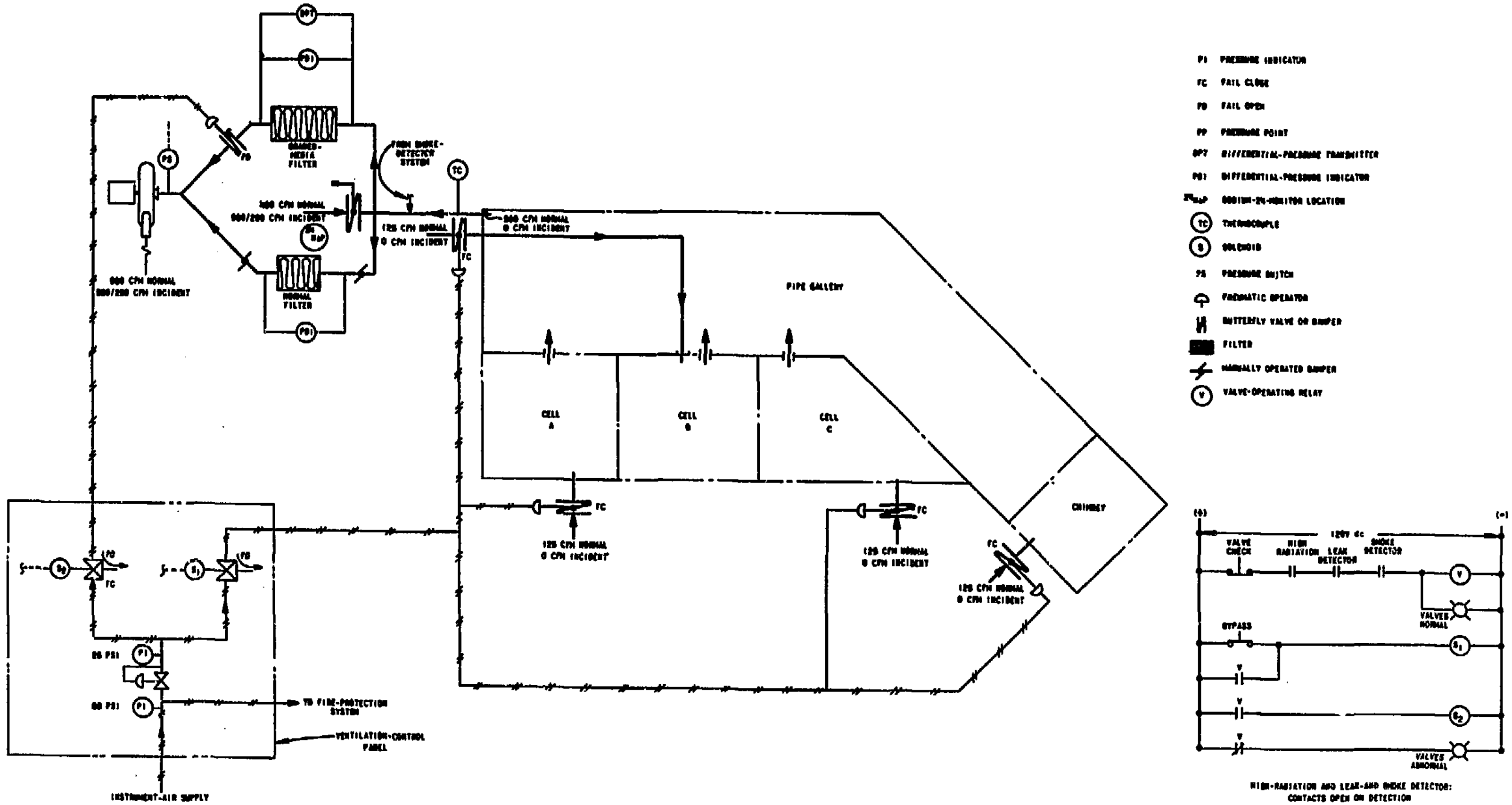


Fig. 10. Ventilation Flow and Control

A pressure switch monitors the intake of the exhaust blower and a thermostat monitors the temperature of the blower-motor winding. Stoppage of the exhaust fan or excessive temperature of the windings will result in an alarm on the RSCL instrument panel and in the control room.

A counterweighted relief damper prevents a negative pressure within the cells sufficient to distort the walls, and it minimizes air infiltration to the cells in the event of an incident in which the intake valves would be closed.

The normal rate for each cell is 115-120 cfm. The pipe gallery itself serves as the "duct" for the exhaust air. The air from the pipe gallery is exhausted through a duct behind a shadow shield in the northeast corner of the pipe gallery. Because of the slow flow rate in the pipe gallery, any airborne material will tend to settle there. This settling is an asset in the event of a sodium fire, because much of the sodium oxide aerosol will settle out before reaching the filtering system; thus the life of the high-capacity filter is prolonged.

Two pushbuttons on the RSCL instrument panel control the position of the valves in the ventilation system. All the valves in this system can be moved to the incident position by the VENT VALVE CHECK pushbutton. Under incident conditions, the cells and pipe gallery can be purged by the VENT VALVE BYPASS pushbutton. This control opens all the air-inlet valves and keeps the valve on the outlet of the high-capacity filter open.

L. Radiation Protection

Shielding of the RSCL facility has been described. It is designed to protect personnel outside the facility and personnel working in any cell while the main loop and other cells are in operation. Access to the main loop will require shutdown of the main loop and sufficient time for radioactivity to decay to safe levels.

A ^{24}Na detector is mounted in the ventilation system in a position to monitor the inlet side of the normal filter. This detector will initiate an alarm if any radioactive particulate sodium accumulates on the normal filter in the ventilation system.

III. FIRE SAFETY

Many components of the RSCL mentioned in Section II have been included for safety reasons. Their final design was the result of an ongoing safety analysis that was part of the overall design effort. The chief area of analysis was in fire safety.

A. Analysis

The safety implications of the experiments that will be installed in RSCL must be considered together with those of the main loop. The most important information concerns the maximum credible sodium spill. This will possibly be determined by the test systems rather than the main loop of RSCL.

When the fire-safety analysis was begun, the experiments then proposed were reviewed to establish a maximum credible spill. It was determined to be from the breaching of the largest sodium-containing component, causing an estimated maximum spill of 53 lb. The test systems now planned show little resemblance to the one that gave rise to the 53-lb figure; most of the experiments considered since then, particularly those now planned, involve much smaller sodium inventories. Thus, the accident basis is conservative for planned experiments.

To obtain a better estimate of the temperatures and pressures that would result within a cell in the event of a sodium spill and fire, such an accident was analyzed by Atomics International using their SOFIRE II computer code. It was hypothesized that such an accident would probably result in a pool-type fire. The possibility of a spray-type fire was discounted for two reasons. First, the loop will operate at only a moderate pressure because the circulating pump develops a maximum head of 16 psig and a highly penetrating jet cannot be developed. Second, all the piping and equipment (e.g., the EM pump) will either be insulated or canned. Consequently, development of a spray-type leak is difficult to conceive, because it would be restricted by the can or the insulation. The largest-pool type spill considered possible was that from rupture of the largest single component plus: (1) loss of flowing sodium until closure of the main-loop valves; and (2) loss of sodium from the piping adjoining the ruptured component.

The input data for the computer runs, (see Table II), assumed a spill of 53 lb at a mixed mean temperature of 910°F. The code also provided an air inleakage term. Inleakage would be through cracks along doors and hatches and the cracks between sections of steel plate encasing the lead-brick walls. Of course, the exact leak rate cannot be estimated with certainty. Consequently, a rough but conservative estimate was included in the input data--leakage in cfm equal to $20(hw)^{1/2}$--as indicated in Table II. Because of the importance of air inleakage, all known cracks or leaks in the RSCL cells will be caulked or taped. Accordingly, the actual leak rate is expected to be less than the computer-input value.

The rate of air exhaust in the code is taken as a constant value, and it is an input to the code. Three cases were run, for 125, 225, and 500 cfm. The constancy of the exhaust rate does not truly simulate the actual situation, because the exhaust blower will have a varying output, which depends on its inlet pressure. However, this difference does not seriously affect the usefulness of the results, because prime interest is in identifying periods of positive pressurization of the cell.

The results of the SOFIRE-II analyses were as follows:

(1) The quenching action of the steel floor plate on the liquid sodium reduces its temperature so much that burning cannot be easily sustained.

(2) The temperatures of the floor and walls are much too low to result in any structural damage.

(3) Positive pressurization occurs briefly in all three exhaust-air rates, varying from 7 sec and 0.5 psig overpressurization to 1.7 sec and 0.07 psig overpressurization respectively for the 125-cfm and 500-cfm exhaust rates. For 500 cfm, the outleakage woud be 1/2 ft^3.

From the results, the following design and operating criteria were established.

(1) The exhaust rate on the cell containing a fire should be greater than 525 cfm to preclude any outleakage from the cell.

(2) The initial heat release is primarily due to the sensible heat of the sodium and not its heat of combustion. Accordingly, the quenching characteristic of the floor plate should not be overwhelmed and rendered ineffective, as would result should vigorous combustion be sustained. Therefore, immediate shutting off of the ventilation-air supply is essential.

TABLE II. Computer-code Input Data

(Hypothetical Sodium Spill and Ensuing Fire, Cell C, EBR-II Radioactive Sodium Chemistry Loop)

Hypothetical sodium spill	53 lb
Sodium temperature	910°F
Cell-floor area	27.3 ft^2
Cell height	8.17 ft
Cell-air volume (cell volume less volume of equipment)	205 ft^3
Initial air temperature	110°F
Ambient air pressure	12.3 psia
Initial differential pressure of cell air	0.3 in. H_2O
Cell-air exhaust rate[a]	125 cfm
Cell-air inleakage rate	$20(hw)^{1/2}$ cfm, where hw is in in. of H_2O differential pressure
Cell interior walls	1/8 in. carbon-steel plate over 8 in.-thick lead-brick shielding
Cell ceiling	8-in.-thick lead-filled hatches encased in 5/16-in. steel plate
Cell floor	1/4-in. steel plate over 4 in. of lead; lead over 1 ft of concrete

[a]Cell inlet-air damper closes automatically on start of a fire.

A heat-transfer computer program was used to determine the temperature rise of the cell walls in Cell B for a sodium fire in that cell. This cell was chosen because it has the least wall area to absorb heat. For this program the following assumptions were made:

(1) Seventy pounds of sodium spills into the cell. This weight includes all the sodium in the main-loop piping on the loop side of the isolation valves and the stub lines into Cell B.

(2) The sodium spreads over the entire floor area.

(3) The resulting sodium fire is supplied with enough air containing the normal 21% oxygen for the sodium to burn freely.

(4) All energy released by the burning sodium is transferred through the inside area of the cell walls.

(5) The initial inside and outside temperatures are 125° and 75°F, respectively.

These assumptions are conservative because they disregard: "corners" of the walls; interfaces between the steel skin plate and lead brick; fire-suppressant effects of the perforated floor plate; oxygen depletion of the air in the cell; sodium oxide formation; energy removed as air and combustion products are withdrawn from the cell by the ventilation system; only partial draining of the piping; and the heat sink provided by the floor.

The results of this computation indicate the inside surface temperature would reach 257°F and the outside surface temperature would reach 159°F--well below the ignition temperature of paint, tape, caulking compound, or other materials that might be on the exterior of the walls.

B. Detecting and Locating Sodium Leaks and Fires

Four means of leak and fire detection are provided: electrical leak probes, radiation monitor to detect ^{24}Na in the exhaust air, smoke detection, and temperature rise of the exhaust-ventilation air. System responses to signals from these detectors are given in Table I.

1. Leak Detectors

Leak-detector probes, of the mineral-insulated-wire type, are installed in all the valves between the bellows and the stem packing. These detectors will indicate a failure in the bellows. Similar detectors are on the floor drip pans. Detectors are in or under components in which leaks could occur. An example of the latter category is the detector in the EM-pump housing.

The response to signals from the leak detectors varies, depending upon the magnitude and seriousness of a leak that each would indicate. The leak detector in the EM-pump housing will shut off the pump, close the supply-isolation valves, and give an audiovisual alarm. Leak detectors in any of the drip pans will stop the pump, close both isolation valves, close the ventilation-air supply, route the exhaust air to the high-capacity filter, and give an audiovisual alarm. The leak detectors in the valves give only an audiovisual alarm. Upon indication of a leak, the operators can immediately determine by a light on the control panel which leak detector is giving the signal.

2. Radiation Detection

The sensitivity of the radiation monitor installed to detect the presence of ^{24}Na in the ventilation air as it enters the filter (see Sec. II) for ^{24}Na is 10^{-7} $\mu Ci/cm^3$ of air (assuming the detection element to be suitably shielded from extraneous radiation). This concentration will result in a count rate of 50 cpm. If a sodium leak of 0.1 cm^3/min should develop and only 10% of this sodium becomes airborne, the resulting concentration would be 4.4×10^{-7} $\mu Ci/cm^3$ of air upon dilution with 525 cfm of air. Consequently, even a small leak will be detectable.

3. Smoke-detection System

Smoke detectors are provided for each cell and for three locations in the pipe gallery. The latter three locations are: the exhaust duct, near the EM pump, and the vertical section of the pipe gallery. Flow indicators and manual flow-adjusting valves are provided for each smoke-detector unit.

Indications of alarms from the smoke detectors are displayed on the RSCL instrument panel, on the corridor panel, in the control room, and in the site fire station. A short circuit in the smoke-detector wiring will initiate an ALARM signal. An open circuit in the wiring or interruption of air-sample flow in the system will produce a TROUBLE indication in the fire station.

The smoke detectors, manufactured by Pyrotronics, use photo-electric sensor units. The units are mounted outside the shielding and sample air from within. They are mounted where air-sampling lines may penetrate the shielding without causing radiation-streaming problems. Typical locations are in high corners of the cell where penetrations do not line up with sources of radiation--i.e., sodium-filled pipes or components. Sample-air lines are relatively short, extending only a short distance inside the shield wall, and air velocities are of the order of 10 ft/sec. Consequently, smoke-laden air would reach the detectors in a few seconds. The discharge line of each sampler is connected to the ventilation system, just upstream of the filter. A small blower maintains air flow through the smoke-detecting units.

4. Temperature Rise of Ventilation Air

If the temperature of the exhaust air rises to 135°F, an audio-visual alarm will be given. This could be an indirect indication of a sodium fire. Because other conditions could also cause a temperature rise (e.g., decrease of ventilating-air flow), the response will be limited to an annunciator signal, necessitating investigation by operators.

C. Fire Control

The most difficult safety problem is coping with a possible sodium leak or spill and the sodium fire that would probably result. The compounding problems of radiation and the causticity of sodium smoke add to the seriousness of such a failure or accident. In the design of the system, many preventive measures were taken to avoid such an accident. In spite of these measures, there is still the possibility of a sodium fire. To cover this eventuality, the fire-control measures are as follows:

(1) Shut off the source of sodium immediately on indication of a leak, spill, or fire.

(2) Simultaneously shut off the ventilation-air supply, thus helping to suffocate the fire.

(3) Provide an air-exhaust system that will preclude significant positive pressurization of the cells and prevent contamination of the reactor-building atmosphere with sodium smoke.

(4) Provide additional fire-suppression equipment to aid in controlling the fire.

1. Stopping Sodium Flow

Three automatic actions are provided for stopping the flow of sodium: closing both subsystem isolating valves; closing both main-loop isolating valves; and actuating the siphon-breaker system (stopping sodium flow to both the RSCL and to the purification system).

Automatic actions ensuing from detector signals are:

a. On indication of leaking sodium in any of the drip pans--i.e., sodium has reached the atmosphere in any one of the cells or subsystems--both isolation valves for that subsystem and both isolation valves of the main loop will close automatically. In addition, the siphon breaker will be actuated automatically.

b. On indication of fire (smoke) in any of the cells or subsystems or in the pipe gallery, the isolation valves of the subsystem and of the main loop will close automatically. The siphon breaker will also be actuated automatically in case of a signal from the pipe-gallery detector.

c. On indication of airborne radioactivity in the exhaust-ventilation air, the same automatic actions will be taken as in items a and b above, except that the siphon breaker will not actuate.

2. Suffocating the Fire

Listed in Table I are the signals that will close the ventilation-air supply. This step will be the means to suffocate the fire and will take place simultaneously with cutoff of the sodium. The ventilation-air supply to all cells and subsystems will be stopped, rather than to only the cell in which the fire is detected. This action reduces the load on the exhaust blower so that, effectively, it will be pulling only the combustion products and expanding air from the cell in which the fire is occurring, thus preventing positive pressurization of the cell.

3. Containment of the Radioactive Aerosol

In a radioactive-sodium fire, a major concern is adequate containment of the smoke. The needs are: (a) to protect personnel from contact with the caustic aerosol, (b) to protect personnel from the radiation hazard, and (c) to minimize the contamination of equipment. To meet these requirements, a high-capacity, high-efficiency filtering unit was installed, through which the exhaust air will flow in case of fire detection. The filtering unit consists of a graded, multilayer deep-bed prefilter for high collection capacity followed by an absolute filter for high efficiency. The design of the unit has been modeled after an experimental filter developed by the Harvard Air Cleaning Laboratory.[2] The unit consists of: (a) a 4-in. depth of Style 326 Yorkmesh Demister; (b) a 3-in. depth of 95-μ-dia steel fibers, packed 4-5 lb/ft^3, (c) a 3-in. depth of 76-μ-dia steel fibers, packed 4-5 lb/ft^3; (d) a 1.5-in.-depth of 47-μ-dia steel fibers, packed 4-5 lb/ft^3; (e) a 1.5-in.-depth of 27-μ-dia K115 glass fibers, packed 1.5 lb/ft^3; (f) a 1.5-in.-depth of K115 fibers, packed 3.0 lb/ft^3; and (g) a pleated HEPA filter. In the development program carried out by the Harvard Air Cleaning Laboratory, loadings in excess of 0.75 lb/ft^2 of frontal area were obtained. A loading of 0.5 lb/ft^2 was suggested for a variable-flowrate system (a typical fan-performance characteristic involving decreasing flow as the filter becomes loaded).

The cross section of the filter is 6 by 4 ft, giving 24 ft^2 of frontal area. The total holding capacity is 12 lb of sodium in oxide form. An accident might involve more than 12 lb of sodium, but many factors reduce the amount of sodium that would become airborne and would finally reach the filter. In a pool-type fire, about 80% of the sodium is retained as residue.[3] Of the portion that becomes airborne, settling and plating out removes an appreciable fraction. In a sodium-fire experiment wherein the smoke was carried in a ducted system to a scrubber, from 50% to more than 90% plated out before reaching the scrubber.[4] Agglomerating[5] and thermophoretic[6] effects are known to promote plating out and settling. For a hypothetical fire in RSCL, it appears conservative to estimate that 20% of the sodium would reach the filter. On this basis, the filter should be able to cope with a 60-lb spill.

4. Application of Extinguishing Agent

In the development of sodium technology, studies have been conducted to control liquid-metal fires by using an extinguishing agent. Thus far, the most effective agents have been materials containing principally sodium chloride. These have not been completely effective, but they do offer some help if applied so as to coat the burning surface. Accordingly, a Met-L-X (a proprietary mixture of sodium chloride with other materials) system has been provided as an added aid in extinguishing a fire. Separate discharge systems for the Met-L-X powder are provided in each cell and in the high and low sections of the pipe gallery. This system requires manual actuation after the operator has determined: (a) in which cell the fire exists; and (b) that the flow of sodium has been stopped.

The RSCL area is divided into seven fire-control zones. Each cell is a zone, and there are two zones in the pipe gallery. The lower part of the gallery is one zone; the area including the pump, flowmeters, and isolation valves is another zone.

The fire-protection system has a "two-shot" capability. A single zone can receive two 500-lb discharges of Met-L-X, or two zones can each receive one discharge of 500 lb of Met-L-X. Two separate Met-L-X supply systems are connected to a common distribution system. Either of the two supply systems is to be expended completely once discharge has been started.

Normal operation of the fire-protection system will be from the panel in the corridor near the entrance to the reactor building. A multiposition rotary switch is provided for zone selection and two pushbuttons are provided to actuate either SUPPLY 1 or SUPPLY 2. One of the zones must be selected before either pushbutton will actuate the system. Pressure indicators are provided for monitoring the pressure in the nitrogen tanks in each of the Met-L-X units. A schematic of the control system is shown in Fig. 11.

Emergency operation of the fire-protection system will be from a pneumatic panel adjacent to the personnel air lock inside the reactor building. This mode of operation is independent of electrical power. Valves are used to select the zone and the Met-L-X unit to be discharged. Pneumatic pressure for this mode of operation is provided by a nitrogen bottle mounted locally at the panel.

Discharge of a Met-L-X unit will introduce nitrogen into the cell at the rate of ~100 scfm. In Cell B, for example, with a volume of ~160 ft^3 this gas could be cause for concern were it not for the ~36 in.^{2} of free area between the insulated loop piping and the penetration sleeves. This large free area, typical of all the cells, will prevent the development of a significant pressure differential between the cells and the larger volume of the pipe gallery.

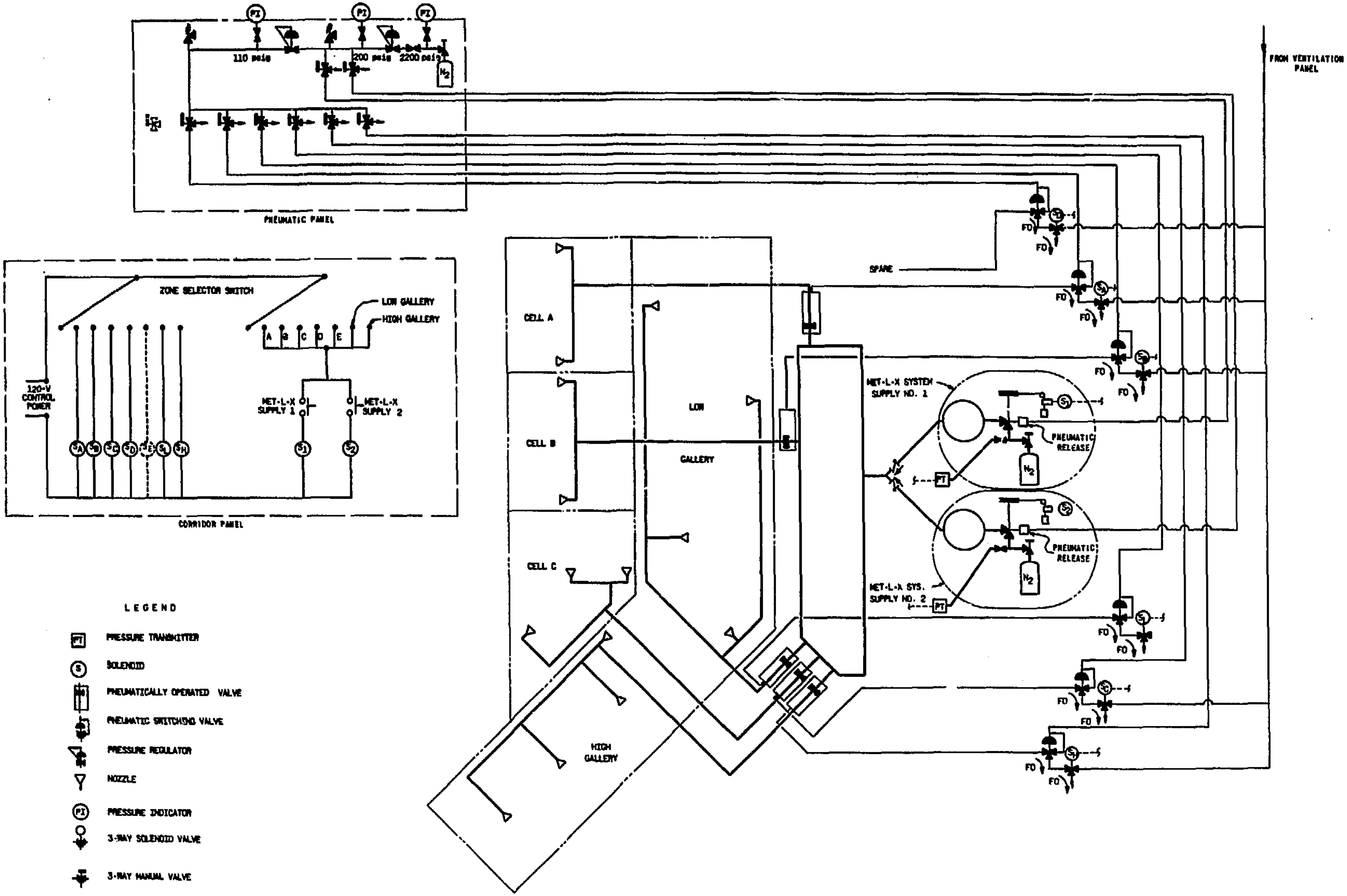


Fig. 11. Fire-protection Control System

D. Fire Door

A portable fire door has been provided for use when a cell is opened for personnel entry. This door is installed outside the shield door on Cell A, B, or C. The door is spring-closing and is held open by a latch mechanism that will release the door on a signal from the RSCL smoke-detector system. The fire door will also close on loss of power. It can be pushed open readily from within the cell.

IV. OPERATING EXPERIENCE

Other than minor troubleshooting and shakedown problems at the start of operation in February, 1971, the RSCL has operated reliably for long periods. As of August, 1972, more than 4000 hr of useful operation has been logged. Other than the remote extension of the Cell-C return valve becoming disengaged, there have been no component failures. The fire-safety equipment, although tested, has never had to be used for a fire. The nearest thing to a fire occurred during the initial startup of the experiments in both Cells B and C. Fumes from the newly installed insulation actuated the smoke alarms. These incidents proved to be a very good test of the fire-safety system; the system operated exactly as intended.

Utilization of the RSCL to date has been partial. Active experiments have been under way in Cells B and C since September, and December, 1971, respectively. The ANL Sodium Technology Program is the test sponsor of field testing of the oxygen-hydrogen meter module in Cell B and wire-equilibration module in Cell C. Several other experiments have been proposed but have yet not materialized because of programmatic considerations or have not gone beyond the planning stage. Nevertheless, RSCL is now serving a vital function in the sodium technology program and it could accommodate three additional experimental systems.

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