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(Section 10)

List of Tables

10. INSTRUMENTATION AND CONTROL

10.1. General Description

The reactor instrumentation and control is divided into five major systems:

1. Control rod drive (CRD) system.
2. Nuclear instrumentation (NI) system.
3. Safety system.
4. Nonnuclear instrumentation.
5. Radiation monitoring (RM) system.

The RM system is independent of the other major systems and is operated as an open loop, which the operator can close manually. The RM system supplies information to the operator, who then initiates the required action.

The reactor control system is basically a manually operated open loop; however, it may be considered a closed loop system when the operator closes the loop as shown in Figure 10-1.

The reactor is monitored by the safety system. Whenever established nuclear limits are exceeded, the safety system sends an overriding command to the control rods, forcing a reactor shutdown. The safety system is an automatic, closed loop system, shown in Figure 10-1. Since the safety system protects the reactor core against damage, performance of the system must be highly reliable.

10.2. Plant Control Arrangement

10.2.1. Introduction

The ship's nuclear power plant is controlled both remotely and locally. Remote automatic control and manual control are achieved through six basic control areas:

1. Main control room.
2. Hydraulic power supply room.
3. GE cubicle.
4. Emergency generator room.
5. Forward control area.

The functions and contents of each control area are described in the following sections.

10.2.2. Main Control Room

The main control room (see Figure 10-2) houses most of the control equipment for the nuclear power plant, the main switchboard for the ship, and several small distribution panels. This control area is aft of the machinery space on D-deck; entrances are from the machinery space, the crew's passages on C-deck, and instrument-electrical shop through the water-tight door.

The main control console is located between the machinery space entrances in the center-forward section of the control room. The main electrical switchboard extends across the aft wall of the control room. A rubber-matted false floor extends across the entire length behind this main switchboard. The RM system cabinets are aft of the starboard machinery space entrance, and the instrumentation and safety system cabinets are aft of the port machinery space entrance. Three transformers and the automatic bus transfer panel are located in the aft port corner. In the aft starboard corner are the vent control panel and a watertight door, which allows access to the instrument and electrical machine shop. The port side of the control room is open to the hot and cold water chemistry laboratory, where routine analytical tests are performed for maintenance of water standards.

10.2.2.1. Main Control Console

The main control console (see Figure 10-3 and Drawing RC-04-J-406) occupies a rectangular area 19 feet by 7 feet in the center portion of the main control room. Several angular console sections form a semicircular panel, which faces forward. Mounted on the top of the vertical sections of the console is the annunciator panel. The console consists of a vertical panel mounted on an operating desk. Grab bars are provided for the operator just below the operating desk on all sections of the console.

The main control console is divided into six sections: the left and right wings, the left and right corners, and the left and right center portions. The sections are further subdivided into the desk and panel sections. Much of the instrumentation for the nuclear power plant is mounted on the center console. Startup and support instrumentation flank this normally operating console section.

Operators for valves, pumps, and motors generally employ an illuminating pushbutton. Pushbuttons for diaphragm-operated valves (represented in the graphic panels) have position lights installed in the graphic panel, which shows amber for a closed position and green for an open position. The pushbuttons for other equipment employ the lighting scheme shown in Table 10-1.

The left wing section of the console houses the control rod instruments for the reactor. On the left wing panel are individual position indicators for each rod. Located on the left wing desk are in-out switches, which allow the operator to position the control rods individually. There is no automatic control from this desk. A pushbutton is provided at the right of the desk to test all indicating lights on this section of the panel.

Located on the left corner section of the console is a graphic panel that shows the flow scheme of the purification loop (purple) with respect to the feedwater flows (blue) to the filters, the buffer seal and makeup flows (orange), and the component drain lines (black). The operating variables are indicated by gages in this graphic panel. The CW system operating variables are indicated along the bottom of this panel section. The pressurizer switches and valve controls are located on the right portion of the desk. The light test pushbutton for this panel section is located just below and to the right of the pressurizer controllers.

Extending across the top of the center section is a graphic panel that illustrates the heart of the power system. The primary flow (red) passes through the reactor, on through the boilers, and returns to the reactor. The feedwater (blue) flows to the boiler, where it forms a steam path (yellow) to drive the turbine and then circulates to the condenser (blue), from where it recirculates as feedwater. Indications of the operating variables are blended in the schematic arrangement, along with primary valve and pump pushbuttons to complete this graphic panel. A manual scram button is provided directly below the primary system graphic display.

At the bottom of the left center panel are nuclear indicators and controls for log count rate, log N, and power level. At the bottom of the right center panel are the engine telegraph instruments and the propeller shaft revolution indicator.

Table 10-1. Pushbutton Light Color Code at Main Control Console

Equipment controlled	Light Position	Light Color
Diaphragm-operated valves		
Closed	left	yellow
Open	right	green
Auto-manual diaphragm-operated valves		
Closed	left	yellow
Automatic	center	green
Manual or open	right	green
Electric motors and heaters		
Motor off, but power available	left	white
Motor on	right	green
Primary pumps		
Motor off, but power available	left	white
Motor on low speed	center	amber
Motor on high speed	right	green
Buffer seal charge pumps		
Motor off, but power available	left	white
Motor on low speed	center	green
Motor on high speed	right	green
Primary and boiler feed gate valves		
Closed	left	amber
Open	right	green

On the left center desk are the period indicators and an individual rod indicator and controller. Next are the rod group indicators and controllers. On the right center desk are the throttle controls and the controllers for the feedwater and shutoff valves. Pushbuttons for testing the indicating lights of this panel section are located in the center and on the right of this desk section.

The station selector and digital voltmeter readout assembly for the DA system is located above the control rod group position indicator. On the right corner panel is a graphic schematic (copper) of the main electrical distribution system. This schematic pictures the main buses from the ship's generators to the distribution buses. Wattmeters indicate the power supplied from each of these main generators. At the bottom of this panel, gages indicate the operating variables of the drain tanks, the condenser systems, and the generators. Pushbuttons and selector stations at the bottom left of this panel and on the desk are provided for the condensate, steam, and feedwater equipment. A manual starting switch for the auxiliary diesel generators is provided on this panel for rapid startup of the system if required. A light test pushbutton is provided on the right of this panel.

The upper section of the right wing supports a linear power recorder and a channel selector switch. The DK system indicator lights are mounted directly on the panel face, as is the reactor space ventilation system control switch. The desk section houses the RSV system control switches and the waste tank vent controllers.

10.2.2.2. Nuclear Instrumentation and Safety System Equipment

Cabinets A, B, C, D, and E (Figure 10-2) contain most of the equipment for the nuclear instrumentation and safety system. The remaining equipment for the system is located in the 10 instrument wells adjacent to the reactor vessel and on the main control console. The following equipment is installed in the five cabinets:

1. Startup channels 1, 2, 3, and 4.
2. Intermediate range channels 5, 6, and 7.
3. Power range channels 8, 9, and 10.
4. Safety system equipment.
5. Fast insertion equipment.

These cabinets are located just aft of the port machinery space entrance.

10.2.2.3. Nonnuclear Instrumentation

Auxiliary cubicles A (port) and B (starboard) are located adjacent to the two control room entrance doors from the main machinery space. These cubicles house most of the nonnuclear electrical and pneumatic control elements provided for normal operation. Auxiliary cubicle A houses the electrical and pneumatic controllers associated with the three-element feedwater regulators, primary system high-temperature bistables, and numerous electrical relays and fuse blocks. Auxiliary cubicle B contains the controls and relays used in the operation of the PP system, SL system, PE system, and various other primary support systems.

Major primary and secondary system parameters are recorded on circular indicators mounted on the outboard side of the main console assembly and are readily accessible for review by operating personnel. Dual electrical teletypewriters are mounted in front of the main control console on a steel desk assembly. These devices are directly connected to the DA system and provide a periodic log and off-normal printout and alarm.

10.2.2.4. Radiation Monitoring Cabinets

Two radiation monitoring cabinets are located on the starboard side of the main control room outboard of the main control console. These cabinets contain a recorder and a meter readout of the various radiation detector channels located throughout the ship.

Cabinet A contains the power supply scanning system and ship chart recorder for channels 1 through 6 of the RM system together with the meter readout assembly. A variable set point arrangement is provided on each indicator to permit periodic checking by operating personnel. The primary system high- and low-pressure scram assembly and system checkout equipment are mounted below the RM system equipment.

Cabinet B contains the power supply and meter readouts for channels 7 through 13. The variable alarm point selector dials are included for individual channel checkout.

10.2.3. Hydraulic Power Supply Room

This room contains three hydraulic power units with accessories, a 200-gallon hydraulic storage tank, and the hydraulic power supply control cubicle. One power unit is for operation, one for standby, and one for reserve. The hydraulic power supply room is located in the reactor space on the starboard side of the reactor cupola on the B-deck (see Figure 10-4).

10.2.4. GE Cubicle

The GE cubicle and Scott-T transformer rooms are located on the port side of the cupola on B-deck. They contain the hydraulic pump control station, electical breakers for isolating the two-phase T-bus from the Scott-T transformers, the C-bus normal power, the F-bus vital power, control rod drive system indicating lights, control rod drive system breaker and relay cabinets, Scott-T transformers, two vent control panels, an automatic bus transfer switch, a junction box, and a circuit breaker panel.

10.2.5. Emergency Generator Room

The emergency control station, emergency switchboard, emergency diesel generator, and other equipment necessary for the operation of the ship under emergency conditions are located in the emergency generator room on the navigation deck.

10.2.6. Forward Control Area

This area (bounded by hold 4, the upper reactor space, D-deck, and A-deck) contains the equipment drain and waste system remote controls, the sampling station, channels 3, 8, 9, 10, and 11 of the RM system, the exhaust portion of the reactor space ventilation filtering system, and a cold-chemistry sink.

10.2.7. Data Acquisition System

The Bailey 750 data acquisition system (the DA system) is an important part of the control room arrangement. The system automatically prints out on a log sheet the measured value of 39 instrumentation points. The frequency of the logging is established by the operator. Additionally, the system compares each of the points against a high and/or low limit. When a point exceeds the limits, a second printer begins to log the off-normal point, and the operator is notified of the condition.

The normal logging printer and the off-normal printer are located on either side of the log desk. Drawing RC-04-J-406 shows the location of the DA system control panel on the control console center desk.

The operator may utilize the full capabilities of the DA system from the operator's control panel. By setting in the code number of any point, the operator can cause the value of that point to be continuously displayed as a digital readout on the control panel. He can also cause the DA system to display the high or low set point value, or he can cause the system to log the value of all points by printing their values on the normal log. Similarly, the operator can cause the system to review all off-normal points and log their values on the off-normal printer.

Basically, the DA system scans all of its inputs and stores their values in its memory. The memory also contains the set point limits. Every few seconds the system reviews the information, and as long as all points are within normal limits, nothing occurs until time for normal logging, which can be every 15, 30, or 60 minutes as selected by the operator. Upon finding an off-normal point, an alarm is sounded, and the point is logged on the off-normal printer. The operator, by use of his control panel, has access to all information within the system. He can have the information either displayed or printed.

The DA system currently has the capability of accepting and scanning up to 100 points. Over 50% of the points are presently monitored, the principal ones of which are listed in Table 10-2.

The DA system equipment (logic, memory, power supplies, etc.) is housed in heavy-duty cabinets located in an instrument room just aft of the main electrical switchboard in hold 5. The operator has convenient access to the equipment through an entrance from the main control room.

Table 10-2. Data Acquisition Points

Parameter measured	Alarm High	Alarm Low
Neutron shield tank temp	×	
Upper containment temp, port		
Upper containment temp, starboard		
Bottom containment temp		
Bottom containment dew point		
Containment dome temp	×	
Containment cooling duct temp		
Containment pressure	×	
Containment oxygen	×	
Effluent condensing tank level	×	×
Effluent condensing tank temp	×	
Pressurizer pressure	×	×
Pressurizer level	×	×
Pressurizer temp	×	
Boiler pressure, port	×	
Boiler pressure, starboard	×	
Boiler level, port	×	×
Boiler level, starboard	×	×
Feedwater temp		×
Reactor inlet temp, port		
Reactor inlet temp, starboard		
Reactor outlet temp, port		
Reactor outlet temp, starboard		
Channel 8, % full power	×	
Channel 9, % full power	×	
Channel 10, % full power	×	
DA system check point	×	×
DA system, +5 vdc	×	×
DA system, −10 vdc	×	×
DA system, −15 vdc	×	×
DA system, −24 vdc	×	×
Lube oil temp 1		
Lube oil temp 2	×	×
Buffer seal surge tank temp	×	×
Buffer seal outlet temp	×	
Intermediate HX inlet temp	×	
Intermediate HX outlet temp	×	
PP system water temp	×	
DK system discharge pressure		
CW system header pressure	×	×

10.3. Instrumentation

10.3.1. Nuclear Instrumentation System

The NI system measures the reactor neutron flux level and its rate of change and supplies this information to the reactor operator, the reactor control system, and the safety system. Measurements are indicated at the main control console for the operator's information.

The NI system is designed to provide maximum reliability and safety with a minimum of spurious shutdowns. This is accomplished by using multiple channels within each measuring range. A coincidence arrangement in the power range requires that at least two channels agree that an unsafe condition exists before a scram is initiated. Any one power range channel may be checked for maintenance during reactor operation as long as the system is operated in coincidence. All other channels may be checked once operation is established above 10% of full power.

The NI system has 10 neutron flux measuring channels covering the entire range of reactor flux with four measuring ranges from source power through 150% of full power. The four ranges are covered by three basic channel groups—the source, the intermediate, and the power range channels. Figure 10-5 shows the designed overlap and relationship between channels, and Figure 10-6 shows the measured overlap between channels.

At the time of initial core loading, two 100-curie Po-Be neutron sources were located in two of the central fuel elements to ensure a substantial source level count rate. The sources and their strengths were important initially because the natural neutron flux level in a new core due to spontaneous fission, cosmic rays, etc., even with subcritical multiplication is not of sufficient magnitude to be detectable in the reactor shield water tank where the neutron detectors are located. Later in core history, a buildup of neutron emitters and photoneutrons acts as a natural source of sufficient strength to be seen by the nuclear instrumentation. After a long shutdown, the source level may decay to below 1-1/2 counts/sec. When this happens, a scaler is connected to one of the BF_3 channels to provide a more positive measurement of neutron counts since the time constants of the log microammeters restrict their use to count rates of one count per second or more.

The thermal flux external to the reactor vessel varies as a logarithmic function of the distance from the vessel. The detectors are mounted in instrument wells in the shield water tank at an angle of 6-1/2 degrees to the vertical and close to the wall of the reactor vessel. This location minimizes the gamma flux gradient across the detectors. Detector placement is shown in Figures 6-3 and 10-7.

10.3.1.1. Nuclear Instrumentation Cabinets

The nuclear instrumentation and safety system equipment is housed in five moisture-tight cabinets located in the control room. All calibration adjustments, test points for critical voltages, trip indications, local channel indications, and safety plugs are located on the face of the equipment panels so that an operator may visually ascertain the state of the system locally at the cabinets without disturbing the equipment.

Cabinet A contains most of the equipment for source range channel 1 (BF_3), intermediate range channel 5, and power range channel 8. This equipment (all chassis-mounted) includes the following (reading from top to bottom of the cabinet):

1. Recorder control equipment (calibration and channel-switching equipment to portable recorders).
2. Power range equipment (power range channel).
3. Bistable (BF_3 source range channel 1, fast-insertion signal; intermediate range channel 5; scram and fast-insertion signals).
4. Meter and test (channels 1 and 5).
5. Log microammeter (intermediate range channel).
6. Low-voltage power supply (intermediate range channel).
7. Log microammeter (BF_3 source range channel).
8. Pulse integrator (BF_3 source range channel).
9. Low-voltage power supply (BF_3 source range channel).
10. Proportional counter (BF_3 source range channel).

Cabinet B contains most of the equipment for source range channel 2 (BF_3), intermediate range channel 6, and power range channel 9. This cabinet contains the same equipment as cabinet A in the same physical arrangement. The bistable, meter, and test chassis are for channels 2 and 6 and have the same functions stated for cabinet A.

Cabinet C contains most of the equipment for source range channel 3 (fission chamber), intermediate range channel 7, and power range channel 10. This equipment (all chassis-mounted) includes the following (reading from top to bottom of the cabinet):

1. Recorder control equipment (calibration and channel-switching equipment to portable recorders).
2. Power range equipment (power range channel).
3. Bistable (fission chamber source range channel 3, fast-insertion signal; intermediate range channel 7, scram and fast-insertion signals).
4. Meter and test (channels 3 and 7).
5. Log microammeter (intermediate range channel).
6. Low-voltage power supply (intermediate range channel).
7. Log microammeter (fission chamber channel).
8. Fission counter pulse integrator (fission chamber channel).
9. Low-voltage power supply (fission chamber channel).
10. Blank panel.

Cabinet D contains most of the equipment for source range channel 4 (fission chamber). This equipment (all chassis-mounted) includes the following (reading from top to bottom of the cabinet):

1. Bistable panel (fission chamber source range channel 3 scram signal; fission chamber source range channel 4, and scram.

2. Meter and test panel (fission chamber channel).

3. Log microammeter (fission chamber channel).

4. Fission counter pulse integrator (fission chamber channel).

5. Low-voltage power supply (fission chamber channel).

6. Auctioneer panel (feeds meter indicators with highest log count rate and rate readings for channels 3 and 4, 5, 6 and 7, 8, 9, and 10).

7. Signal operator panel 1 (panels 1 and 2 contain the minimum log count rate interlock, the BF_3 high-voltage interlock, and the rate interlock above 10% of full power).

8. Signal operator panel 2.

9. Voltage-regulating transformer.

Cabinet E contains safety system equipment (all chassis-mounted) including the following (reading from top to bottom of the cabinet):

1. Coincidence panel.
2. Scram sequence indicator.
3. Alarm and scram 1.
4. Alarm and scram 2.
5. Scram amplifier 1.
6. Scram amplifier test panel.
7. Scram amplifier 2.
8. Blank panel.
9. Voltage-regulating transformer.

The dimensions of the cabinets are 67 inches high by 23 inches wide by 18 inches deep. Each cabinet has vibration mounts or pads. Power and signal jacks are provided for cable connections to ready the recorders for service. The recorders may be plugged into the recorder control panels of cabinets A, B, and C to record the parameters of channels 1 through 7.

Mounted adjacent to the nuclear instrumentation and safety system are two preamplifiers and two binary scalers provided for correct rate checks during low source rate conditions. Additionally, a log micromicroammeter and a primary system temperature recorder are mounted for easy access during operation.

Equipment is arranged within each cabinet as shown in Figure 10-8. Cabinets A and B contain absolutely identical and interchangeable equipment. Cabinet C is only slightly different from the first two, having a fission counter channel instead of a proportioned counter. With the exception of the pulse integrator, all equipment in cabinet C is interchangeable with that of A and B. Cabinet D contains a fission counter channel identical to that in cabinet C. Cabinet E contains the safety system and associated equipment.

10.3.1.2. Power Supply

The primary 120-volt, 60-cycle power for the nuclear instrumentation and safety system is derived from a battery-backed source called the vital power system. The vital power system is used exclusively for instrumentation purposes. Should the turbo-generators and all three of the diesel electric generators be inoperative, the batteries are capable of supplying the normal 25-kw load for 5 hours.

The vital power system is basically two independent ac-to-dc converters followed by two dc-to-ac generators. Both units may be operated in parallel or singly. The reliability of the system is thus maintained at a very high level.

Vital power to the nuclear instrumentation is divided, as shown in Figure 10-9. Primary power is fed to a Sola voltage regulator in cabinet E. The regulated power output of this regulator feeds the equipment in cabinets A, C, and E. A similar power feed goes to a Sola regulator in cabinet D, whose output serves the equipment in cabinets B and D.

Loss of power to cabinets B and D results in an alarm, but does not shut down the plant since the safety system and the redundant instrumentation in cabinets A and C are unaffected. Loss of power to cabinets A, C, and E results in an automatic scram by the safety system.

10.3.1.3. Neutron Detectors

The 10 neutron detectors are a rugged type built to military shock and vibration specifications. Their useful life is estimated to be 3 years of operation or an integrated dose of 10^{19} nvt. The lifetime of the BF_3 chambers is a function of the number of reactor startups and shutdowns. Their operating life is best stated as a function of the number of output pulses actually delivered while energized and as such exceeds 10^9 counts.

10. 3. 1. 4. Detector Characteristics

The major characteristics of the neutron detectors follow. The values given the high voltage are typical for the NS Savannah application and may be different for similar applications of the same detector. The neutron flux range and sensitivity is based on manufacturer's data taken under very controlled conditions in a standardized neutron flux. The neutron flux actually seen by the detectors has a totally different energy spectrum; therefore, the detector's sensitivity in operation is not the same as the published sensitivity. This is not important since absolute flux measurements are not required of the system. The important consideration is that the relation between detectors remains constant over a long period and that the detector outputs are a linear function. The detectors give excellent agreement and meet this criteria, as can be seen in Figure 10-6.

BF_3 Detectors

High sensitivity BF_3 proportional counters are used in source range channels 1 and 2. The detector employed is a multielement type WL-7087 containing a cluster of four individual counters. Typical operating characteristics are:

1. High voltage of 2000 volts dc.
2. Sensitivity of 40 counts/sec-nv.
3. Output range of 1 to 10^5 counts/sec.
4. Neutron flux range of 2.5×10^{-2} to 2.5×10^3 nv.

Fission Chambers

Channels 3 and 4 use type WL-6376 fission chambers. These detectors ensure an overlapping of flux measurement between the source and intermediate ranges. There is a two-decade overlap between the BF_3 detector and the fission chambers, and there is a three-decade overlap with the intermediate range detectors. Typical operating characteristics are:

1. High voltage of 200 volts dc.
2. Sensitivity of 0.4 count/sec-nv.
3. Output range of 1 to 10^5 counts/sec.
4. Neutron flux range of 2.5 to 2.5 x 10^5 nv.

Compensated Ionization Chambers

Channels 5, 6, and 7 of the intermediate range each receive an input signal from an electrically compensated ionization chamber of the WL-6377 type. Electrical compensation discriminates against output current produced by gamma radiation, thus increasing the chamber's effective neutron sensitivity. Typical Operating characteristics are:

1. High voltage of 200 volts dc.
2. Compensating voltage of -10 to -80 volts dc.
3. Sensitivity of 4 x 10^{-14} ampere per nv.
4. Neutron flux range of 2.5 x 10^2 to 2.5 x 10^{10} nv.
5. Output current of 10^{-11} to 10^{-3} ampere.

Uncompensated Ionization Chambers

The detectors used in the power range (channels 8, 9, and 10) are uncompensated ionization chambers (type WL-6937). These boron-lined counters have the following characteristics:

1. High voltage of 1100 volts dc.
2. Sensitivity of 4 x 10^{-14} ampere per nv.
3. Neutron flux range of 2.5 x 10^3 to 2.5 x 10^{10} nv.

10. 3. 1. 5. Low-Level Startup Channels

Channels 1, 2, 3, and 4 (Figure 10-10) are startup channels and provide information on neutron flux level and startup rate (rate of rise of neutron flux). Channels 1 and 2 each have a range from source power to approximately 10^{-5} rated power. Channels 3 and 4 each cover the range from 10^{-7} to 10^{-2} full power.

Channels 1 and 2 have the same equipment, consisting of a multielement BF_3 proportional counter, a pulse integrator, a log microammeter, and log count rate and period meters (Figure 10-11).

The multielement BF_3 proportional counter is used to obtain high sensitivity. After the neutron flux level rises into the range of the intermediate channels, the proportional counter channels are electrically secured to minimize the dissociation rate of the BF_3 gas and to avoid high currents to electronic equipment.

As the power level of the reactor increases, the rise in neutron flux level is accompanied by an increase in the gamma flux level. Fission chambers are used for channels 3 and 4 (Figure 10-12) since they are less sensitive to gamma flux than are the BF_3 counters used in channels 1 and 2.

In operation, channels 1, 2, 3, and 4 are similar. Pulses from the detectors enter a pulse integrator, which contains an amplifier and a discriminator. The amplifier increases the amplitude of the pulses; the discriminator passes only those of magnitudes greater than the discriminator setting, which eliminates most gamma pulses and noise. The pulses are accumulated in the count rate circuit, from which the output current is proportional to the pulse rate from the detector. The log microammeter receives this current and provides outputs proportional to the reactor startup rate and the logarithm of the neutron flux level. The outputs are displayed as startup rate and log count rate. A scram signal is fed to the safety system if the startup rate exceeds 2.8 decades/min from channels 3 or 4.

10.3.1.6. Intermediate Range Channels

A functional block diagram of the intermediate range channels is presented in Figures 10-13 and 10-14. Compensated ion chambers are used in channels 5, 6, and 7. These channels overlap the range of the fission chambers in startup channels 3 and 4 by about 3 decades. The intermediate range channels cover a range of approximately 10^{-5} to 1.5 times full power.

Since the output of these chambers is affected at very low levels by statistical fluctuations, a level-sensitive adjustment in the log microammeter prevents operation of these channels below 10^{-10} ampere. Above this level, the chamber current is transmitted to a log microammeter of the type used in the startup channels.

Information developed in these channels is indicated as startup rate and log N (log of the ion chamber current). Rate information is also sent to the safety system to initiate a reactor shutdown when the startup rate equals or exceeds 2.8 decades/min.

Figure 10-14 shows one arrangement that may be employed with channels 5, 6, and 7; however, it has not been employed for normal plant operation. A more versatile arrangement employes only channels 5 and 7, as shown in the figure. The channel 6 detector output, instead of going to the normal channel 6 microammeter, is taken to a linear micromicroammeter having multiple ranges from 10^{-13} to 10^{-3} ampere. The output of the micromicroammeter is displayed on a 10-inch strip chart recorder mounted in the right wing of the control console.

The linear display provides a more definitive indication of reactor changes during startup than that attainable from a log level indication. This is particularly important when establishing criticality or performing physics tests.

The output of any two of the startup channels may also be displayed on the right wing recorder. A switch below the recorder lets the operator select the channels to be recorded. The recorder is a dual-pen type so that the outputs of the linear micromicroammeter and one other channel may be displayed concurrently. The versatility of the system permits the operator to record and display any combination of two signals available from the startup channels.

10.3.1.7. Power Range Channels

Uncompensated ion chambers are used in the power range channels (channels 8, 9, and 10). A functional block diagram of the power range channels is presented in Figures 10-15 and 10-16. These channels operate over a range of approximately 0.1 to above 1.5 times full power. The output from these chambers enters the power range panel, where the signals are linearly amplified to a usable level. The linear output is then displayed as percentage of full power. A scram level trip signal is sent to the coincidence panel in the safety system.

10.3.2. Reliability

The necessity for channel calibration and adjustment is a function of system stability and core life. The system is very stable and shows no tendency to drift; however it is recognized that this characteristic is a function of the condition of the systems components. Operating procedures require frequent equipment checks to observe any unexpected deterioration of any part of the system.

10.3.2.1. Power Range and Safety System

The power range channels and safety system are basically solid-state systems using magnetic amplifiers and semi-conductor diodes. The absence of components with high failure rate histories, such as electron tubes, contributes to the demonstrated reliability and thus the high level of confidence placed upon the power range channels and the safety system.

10.3.2.2. Startup Channels

The startup channels employ electron tubes and are, therefore, subject to some drift as tubes age and change characteristics. The effects of the characteristic changes have been held to an absolute minimum through the use of feedback and other circuit features. Other circuit components are of the best quality. Components are not subject to high thermal or electrical stresses, which again accounts for the low failure rate and demonstrated reliability of the equipment.

10.3.2.3. Calibration and Testing

The plant standard operating procedures require that all channels be checked and tested prior to startup and that the operator perform certain tests and checks at regular intervals during plant operation. These tests are performed with the test facilities built into each channel or system unit.

10.3.2.4. Startup Channel Calibration

A meter and test panel in each of the first four cabinets, A, B, C, and D, are used to locally monitor the output of each of the startup channels and to check its alignment and calibration. The panel provides a calibrated pulse generator for checking and calibrating the count rate channels.

Each of the log microammeters has a built-in startup rate generator for calibrating the startup rate circuits and a calibrated current generator for calibrating the log level circuits. A test current is also available for checking and setting any safety system trips associated with the channel.

Power supply and discriminator voltages are checked with an external voltmeter by means of test points on the faces of the various equipment panels.

Each of the log microammeters has a multiposition test switch allowing an operator to quickly check all of the vital functions of the channel without the use of any special or external test equipment. Thus, the system's built-in facilities provide a convenient means for calibrating the system and locating equipment faults.

10.3.2.5. Power Range Calibration

Each power range panel has a built-in current generator for calibrating the power level trip points. All other power range adjustments are performed in conjunction with a plant heat balance. With the reactor at a steady state load, a heat balance is run, from which the true power level is established. Any difference between the true power and the power range channel indication is compensated by changing the gain of the channel. The gain change is made by means of a narrow range adjustment on the front of the panel. Setting the level trip and channel gain are the only calibration adjustments required.

The power range channels are very stable and do not require calibration unless the reactor power-to-leakage flux relationship at the detector changes. This change, a function of core burnup, is slow. During core life there is a necessary change in rod position. For any given rod pattern there is a definite flux leakage pattern or relation of detector output to reactor power. As the rod withdrawal pattern slowly changes, so does the leakage flux. Since the plant heat balance is carried out under equilibrium xenon and steady state conditions, a conservative power figure is always obtained as a basis from which power range calibration is made to compensate for any change in flux leakage. Procedures require recalibration whenever a 6% difference exists between the heat balance and the channel readings.

Should the indication of any channel differ from the average of the other two channels by 6% or more, that channel is considered to be inoperative, and corrective measures must be taken. Corrective measures require that the cause of the deviation be determined. During this investigation, operation continues as if only two of the three channels were operative. A channel may show large deviations as a result of internal failure within the power range panel, a failure in a detector, a breakdown in the detector cable, or even a disturbed control rod pattern, as would occur from a stuck rod.

10.3.3. Safety System

The reactor safety system monitors signals from the nuclear and nonnuclear instrumentation systems to detect unsafe conditions. When necessary, the safety system initiates a scram. For scram action, all withdrawn control rods are rapidly inserted into the core by hydraulic pressure. Block diagrams of the safety system are presented in Figures 10-16 through 10-21.

10.3.3.1. Arrangement

All inputs to the safety system are collected in the alarm and scram panels, where they are combined to form a pair of scram-initiating signals. Scram signals into and out of these panels go from an on-off level to an on or energized state to initiate scram. This means that the output of each alarm and scram panel is two independent isolated signals terminating in a pair of scram buses, A and B. Isolation is of such a nature that one bus may fail in any manner without affecting the operation of the remaining bus.

Scram signals entering the alarm and scram panels pass through alarm trip units before consolidation in the scram bus. The scram signal is electrically isolated from the trip unit because the signal passes through the control winding of a magnetic bistable amplifier. Passage of the signal upsets the balance of the magnetic amplifier tripping the unit on. The scram signal is not changed or affected in any way by the trip unit, i.e., the scram functions of the system are not dependent upon the alarm trip unit or its functions. The passage of a scram signal through the alarm trip unit results in two actions: an alarm lamp on the panel is lighted to indicate the source of the scram, and a signal is passed to the sequence annunciator, where the source and the time sequence of the trip are indicated.

The sequence annunciator is a solid-state semiconductor device. It is composed of several levels of logic, which are able to determine the sequence of scram-initiating events. It will resolve the first seven events so that, following a scram, the operator may determine the order in which various events occurred. This is extremely valuable in evaluating plant shutdowns.

Scram buses A and B terminate in two identical scram amplifiers. The outputs of the amplifiers are also isolated to form two identical scram lines terminating in the rod drive system scram relays. The output of each amplifier passes through an either/or circuit, which maintains the electrical isolation. Should either amplifier demand a scram, the either/or circuit gives that amplifier control of the scram lines, and a scram is initiated as if both amplifiers had operated. Thus, in effect, the system is totally redundant and is not dependent upon any single element.

The scram amplifier test panel provides all facilities for checking the operation of the scram amplifiers. Should the need arise, the scram amplifiers may be tested in service, or a faulty amplifier may be removed without disturbing the system's functions. This flexibility is possible because each amplifier is capable of carrying the entire system.

As shown in Figure 10-16, the nonnuclear test panel is just ahead of alarm and scram panel 2. Each of the nonnuclear scram signals passes through an interlocked test plug on the panel. Removal of a plug trips the main console annunciator and removes the corresponding input from the safety system.

The test panel allows complete testing of the safety system while the reactor is shut down. By means of the test plugs on the nonnuclear test panel, the operator can electrically isolate the nonnuclear scram signals and the outputs of the scram amplifiers from alarm and scram panel 2. This permits the operator to test the safety system during shutdown without cycling the scram mechanism in the control rod drive system. Nonnuclear scram signals isolated by the nonnuclear test panel are as follows:

1. Rod test.
2. One scram—all scram.
3. Loss of rod drive voltage.
4. Pump monitor.
5. High temperature of primary coolant.
6. Low flow of primary coolant.
7. High-low primary pressure.
8. Rod drive hydraulic power supply.

Other signals isolated by the nonnuclear test panel are:

1. Scram amplifier 1 output.
2. Scram amplifier 2 output.
3. Emergency cooling system defeat.

In the shutdown condition it is difficult to check the entire safety system without isolating the nonnuclear scram signals. Isolation of the scram amplifiers is necessary in order not to energize the scram relays, which cycle the scram mechanism for the control rod drives. The emergency cooling system signal is defeated to test the pump monitor without activating the emergency cooling system.

Before operating the reactor, each of the test plugs must be replaced. An annunciator alarm indicates an open test plug.

10.3.3.2. Scram Action

The scrams to protect the reactor are summarized in Table 10-3. The tabulated power level trip points are based on the results of the accident studies. All trip points are adjustable so that new information on the present or subsequent cores can be accommodated. These trip points are, in most cases, more conservative than those required by the technical specifications.[40]

The scram on high neutron flux during power operation is set at a power level 120% of 80 MWt. During startup, the scram level is decreased to an indicated power level of about 16 MWt to prevent high-power operation under possibly reduced primary system flow and temperature conditions. The change in scram level is controlled by the START-RUN switch, which is in the START position during startup and the RUN position for power operation, thus setting the two scram levels.

Table 10-3. Reactor Safety System Scram Signals

Scram signal	Detector	Trip level	Remarks
Neutron flux	Uncompensated ion chambers	96 MWt 16 MWt indicated (startup)	Scram initiated on 2 out of 3 coincidence Trip level transfer by START-RUN switch
Primary coolant temperature	Resistance thermometers	535 F	Coincidence of 2 out of 4 signals
Primary system pressure	Bourdon tube, movable core transformer	1505 psig 1950 psig	Low pressure trip High pressure trip Coincidence of 2 out of 3
Primary coolant pump power monitor	Voltage-current product relays	Electrical power decreases below normal value	Scram initiated on loss of all pumps Alarm sounded on each pump loss
Manual scram	--	--	Initiated by operator at any time
Hydraulic supply manifold pressure	--	2700 psig	Scram energy from accumulator on 2 out of 3 low-pressure indications
Startup rate	Fission chambers (channels 3 and 4) Compensated ion chambers (channels 5 and 7)	2.8 decades/min	Startup rate safety input disabled above 8 MWt (no coincidence)
Rod drive system voltage lost	Undervoltage relay	Voltage drops below minimum value	Scram initiated on loss of two-phase power supply
Primary coolant flow	Heat exchanger pressure drop	Flow less than 36% of full flow in both loops	--
Rod test	--	Any rod test switch closed	
One scram — all scram	Scram solenoid power monitor (K-13 relay)	Loss of power to any scram solenoid	

The primary system high-temperature scram provides an independent backup for the neutron flux scram. A high-temperature scram setting of 535 F was selected to prevent cladding surface burnout at the coolant flow rates obtained with one or more pumps in operation. The scram on low primary system pressure prevents boiling in the hot channel. The primary coolant low-flow scram requires at least two pumps operating on low speed or one pump on high speed in one loop.

The low-pressure scram assures shutdown in the event of a major primary system rupture. It also assures that a suitable NPSH is available to the pumps during normal reactor operations.

The high-temperature and the reactor-pressure instrumentation employed for scram action is discussed in greater detail in section 10.3.6.

The primary coolant pump monitor scram is based on loss of primary coolant flow. This scram also shuts the reactor down in the event of total loss of electrical power. The details of the monitor are given in section 10.3.6.4.

Reactor startup rate from channels 3, 4, 5, and 7 is an input to the safety system. At any time the startup rate exceeds 2.8 decades/min, a scram is initiated. Above 8 MWt, this action is automatically dropped from the system. Likewise, the startup rate scram is automatically reinstated below an indicated power of 3% of full power.

In addition to the scrams listed in Table 10-3, the reactor safety system provides a scram on loss of power to the scram solenoids in the control rod drive mechanism hydraulic system. These solenoids are energized during normal reactor operation. A scram will result, too, from the removal of the safety amplifiers or the alarm scram panels. Interlock switching permits either scram amplifier to be withdrawn for servicing by transferring the 21-rod scram relays to the remaining amplifier.

10.3.4. Interlocks

A number of interlocking circuits are included to restrain the operator and ensure the proper sequence of operating events. The function of each interlock associated with reactor operation is listed in Table 10-4.

Table 10-4. Functions of Interlocks

Title	Function	Source	Setting
Primary System Pump-valve	Prevents pump from operating or starting with reactor outlet valve closed	Gate valve limit switches	80% open
Primary System Δ T	Prevents pump from being started if idle loop temperature is a set amount below the active loop	Primary system thermometers	75 F Δ T
Primary System Pump-valve	Prevents pump from being started if reactor inlet valve is open	Gate valve limit switches	Fully closed
Primary System Pump-valve	Prevents pump from operating unless reactor inlet gate valve is 50% open within 0-165 sec. after the pump was started	Time-delay relay	50% open in less than 165 sec.
Primary System Pump-valve	Prevents pump from being started at full speed with reactor inlet valve closed	Gate valve limit switches	50% open
Pressurizer heaters	Interrupts or prevents power supply to pressurizer heaters unless water level is above highest heater	Level transmitter	6 inches
Rod Bottom	Prevents starting primary pump in idle loop with reactor operating	21 control rod limit switches in series	All rods inserted in core
Startup	Prohibits rod withdrawal without count rate indication	Source range nuclear instrumentation	1.5 cps
Period-trip	Prevents period scram above 5 MWt	Power range nuclear instumentation	5 MWt
Start-run	Start position a. Sets over power scram trip point at lower than design power b. Allows individual rod movement from operator's desk panel		Manual switch on console

c. Includes half-speed windings in pump monitor

Run position

a. Sets over power trip point at 96 MW

b. Transfers pump monitor to full speed windings

c. Disallows individual rod movement from operator's desk panel-Individual rod movement from rod control panel only

10.3.5. Fast Insertion

The operator may initiate a fast insertion of all reactor control rods by pushing the fast insertion pushbutton. Fast insertion is halted as soon as the operator releases the pushbutton. A scram signal also initiates a fast insertion. As soon as a control rod is bottomed, the fast insertion signal to the rod is automatically defeated by the rod bottom switch. A fast insertion initiated by the operator and a scram from within the CRD system are similar to the extent that they share a set of relays within the drive system; otherwise, their functions are different. The purpose of the automatic rundown is to bring the drive mechanism quickly back to a state from which controlled rod movements may begin. The intent of operator fast insertion is to shut down or lower reactor power.

10.3.6. Nonnuclear Instrumentation

The nonnuclear instrumentation system comprises the instruments and controls necessary to measure, indicate, record, alarm, and interlock such variables as temperature, pressure, flow level, pH, and conductivity throughout the reactor system. Independent nonnuclear instrumentation is supplied for the reactor safety system. The detectors and controls are designed to perform the specific functions listed in Table 10-5. Most of the instruments are conventional in their design and application; therefore, only those directly involved in safety or of unique significance to the operator are described in the following sections.

Table 10-5. Nonnuclear Instrumentation

System	Parameter	Instrument No.	Indication[a]	Record	Annunciator alarm	Scram	Control[b]	Remarks
Primary	Temperature differential of reactor outlet and boiler outlet (each loop)	PS-1, 2	C					
	Temperature average of reactor outlet and boiler outlet (each loop and plant)	PS-1, 2	C		High		CV	Manual switch selects loop or plant average for reactor control
	Pump cooling water temperature	PS-P1, P2, P3, P4	C					
	Reactor outlet temperature (each loop)	PS-1, 2, 15	C	×	High	×	RV	High-temperature scram system
	Boiler outlet temperature (each loop)	PS-1, 2, 14	C		Low		RV	Temperature differential between loops
	Reactor outlet pressure	PS-5	C	×	High & low		RV	
	Flow (each loop)	PS-6, 7	C	×	Low	×		Low-flow scram
Secondary	Drum pressure (each loop)		C	×	High		RV	All four primary signals are used to maintain the proper relationship between feedwater and steam flows.
	Drum water level (each loop)		C	×	High & low		CV	
	Steam flow (each loop and plant)		C	×	High		RV	
	Feedwater flow (each loop)		C	×			RV	
Primary pressurizing	Pressurizer temperature	PE-3	C	×	High			Manual switch selects water or steam signal; both are recorded
	Surge line water temperature	PE-6	C					
	Pressure	PE-2	C	×	High & low	High & low	CV	For control of pressurizer heaters and spray control valve
	Water level	PE-1	C	×	High & low		CV	Water level signal controls makeup rate to primary system
Relief	Effluent condensing tank temperature	PR-3	C					
	Effluent condensing tank pressure	PR-1	C		High			
	Effluent condensing tank water level	PR-2	C, L		High & low			

(a) C = indicated on main control console; E = indicated on emergency cooling panel; L = indicated locally; B = indicated on Auxiliary Panel B.

(b) CV = controlled variable; RV = reference variable.

Table 10-5. (Cont'd)

System	Parameter	Instrument No.	Indication[a]	Record	Annunciator alarm	Scram	Control[b]	Remarks
Primary purification	Primary water temperature from letdown coolers	PP-4	C		High		CV	Controls cooling water flow through coolers
	Pressure at inlet to ion exchangers	PP-6	C		High			
	Differential pressure across effluent filters	PP-7	C		High			
	Flow from effluent filters	PP-10	C					
	Makeup flow from letdown coolers	PP-3	C		High & low		CV	
	Flow from primary makeup pump	PP-1	C					
Hydrogen addition	Makeup pressure	HA-1, 2, 3, 4	L					
	Hydrogen flow	HA-5, 6	L					
	Concentration of H_2 in air in containment vessel, inside secondary shield area, and at WL-P1	HA-7, 8	C		High			
	Pressure	HA-10					CV	
Equipment drain and waste collection	Water level of tanks PD-T1, 2, 3, 5, 6	PD-1, 2, 3, 5, 6	C		High			
	Containment drain tank PD-T4 water level	PD-4	C		High			
	Pressure in waste storage tanks PD-T1, 2, 3	PD-7, 8, 9	C		High			
Buffer seal	Surge tank water temperature	SL-6	C		High			
	Desurger tank temperatures (3)	SL-13, 14, 15	B				CV	
	Desurger tank temperatures (3)		C		High			
	Cooler outlet temperature	SL-11	C		High		CV	Controls cooling water flow
	Surge tank pressure	SL-7	C, L		High			
	Booster pump discharge pressure	SL-3	C		Low		CV	
	Buffer seal inlet manifold pressure	SL-1	C					

[a] C = indicated on main control console; E = indicated on emergency cooling panel; L = indicated locally; B = indicated on Auxiliary Panel B.

[b] CV = controlled variable; RV = reference variable.

Table 10-5. (Cont'd)

System	Parameter	Instrument No.	Indication[a]	Record	Annunciator alarm	Scram	Control[b]	Remarks
Buffer seal (cont'd)	Buffer seal bypass line pressure	SL-12	L					
	Buffer seal inlet flow	SL-9	C		High		CV	
	Buffer seal outlet flow	SL-4	C		High		CV	
	Return flow to surge tank	SL-10	C					
	Surge tank water level	SL-5	C		High & low		CV	Controls makeup or drain line flow
	Seal return flow	SL-16	C					
Intermediate cooling	Intermediate cooler outlet temperature	CW-5	C		High			
	Discharge pressure of sea water pumps	CW-4	L					
	Suction pressure of intermediate feedwater pumps	CW-2	L					
	Discharge pressure of intermediate feedwater pumps	CW-3	L					
	Cooling water pressure at exit of control valve	CW-7	C		High & low		CV	Controls positioning of control valve
	Cooling water flow downstream of main control valve	CW-6	C					
	Cooling water flow from each of 6 primary pumps	CW-8, 9, 10, 11			Low			Alarm on low flow
	Cooling water surge tank level	CW-1	C		High & low			Float valve control water level
Containment cooling	Ambient temperature in containment	CC-1, 5	C					
	Relative humidity in containment	CC-2, 3, 4	C					
	Containment pressure	CC-6, 7, 8	C		High		CV	To control containment isolation valves
Shield water	Temperature	SW-2	C					
	Water level	SW-1	C		High & low			
Sampling	Primary water pressure	SA-1	C		High			
	Sample line pressures	SA-9, 10, 11, 12	L					
	Conductivity	SA-6, 7	C	×	High			

(a) C = indicated on main control console; E = indicated on emergency cooling panel; L = indicated locally; B = indicated on Auxiliary Panel B.

(b) CV = controlled variable; RV = reference variable.

Table 10-5. (Cont'd)

System	Parameter	Instrument No.	Indication[a]	Record	Annunciator alarm	Scram	Control[b]	Remarks
Sampling (cont'd)	Flow	SA-2, 3, 4, 5	L					
	pH	SA-8	C					
Emergency cooling	Outlet cooling water temperature from canned pump DK-P2	DK-7	E					
	Discharge pressure of emergency sea water pump DK-P1	DK-8	E					
	Total primary water flow through DK system	DK-5	E					

[a] C = indicated on main control console; E = indicated on emergency cooling panel; L = indicated locally; B = indicated on Auxiliary Panel B.

[b] CV = controlled variable; RV = reference variable.

10.3.6.1. Primary System Temperature

There are two independent arrangements for measuring primary system temperature: one specifically for control and reactor operation purposes and one for safety system functions.

For operator control, four matched resistance thermal elements (RTE) are located in the reactor outlet and boiler outlet of each primary loop. These platinum element RTE's are certified to secondary standards by the manufacturer. The RTE's are installed in wells so that their response time is 20 seconds. From these thermometers, the following measurements are derived and displayed on the main control console:

1. Reactor outlet temperature
2. Boiler outlet temperature
3. Average temperature

Identical measurements are derived and displayed for both the port and the starboard loops.

The loop temperatures are also combined and processed to form a single measurement of the average reactor temperature.

10.3.6.2. High-Temperature Scram

Two high-speed resistance element thermometers are located in the reactor outlet of each primary loop. Each platinum temperature-sensing element is open and exposed to the direct flow of the primary system, thus cutting the thermal time constant to a minimum. The response time of the elements is 2 seconds. They measure the reactor outlet temperature for exclusive use by the safety system (see Figure 10-18). The system has solid-state semiconductor design.

Normally, the system is operated in a two-out-of-four coincidence mode; however, the operator may select a one-loop mode, in which case only the RTE in the selected loop may initiate a scram on a noncoincidence basis.

The RTE is one arm of a precision resistance bridge, which forms the input to a trip unit (see Figure 10-18). The bridge-trip unit has a built-in calibration system for checking the operation of the RTE and setting the scram trip point.

In the output of the bridge-trip unit there is a meter for providing continuous indication of the temperature. Since the temperature is continuously displayed for all four RTE's, an operator may quickly spot any disagreement between units.

The outputs of the four bridge-trip units are routed into two identical sets of logic. In normal operation both sets of logic are active in the coincident and single-loop operating modes and provide complete redundancy at all times. To calibrate or test the system, the operator must place the system in either the port or the starboard loop mode. If he selects the port loop, he may test the starboard loop by correctly positioning the calibration switch. The test-calibration mode isolates the RTE's and bridge-trip units of one loop together with one set of logic. The testing is, therefore, extended from the RTE through to the output of the logic.

The system is designed to provide total redundancy, total monitoring, and input-to-output testing in normal operation without disturbing plant operation.

10.3.6.3. High-Low Pressure Scram

A reactor scram is initiated for either a high or a low primary system pressure condition. Reactor pressure is measured by three bourdon-tube, movable core transformer pressure sensors, as shown in Figure 10-19. The outputs of the three pressure transmitters are analog electrical signals going to three high-low trip units, from which two outputs are derived: one for high pressure and one for low pressure. The three high-pressure trip signals are collected in a two-out-of-three coincidence logic, and the low-pressure trip is collected in a second coincidence logic. The operating mode of the logic can be set for either coincident or noncoincident tripping. Trip units and logic are solid-state semiconductor units.

The linear pressure signal from two of the pressure transmitters is continuously recorded in the control room, while the output of the third transmitter, which is associated with the pressurizer, is continuously scanned and logged by the DA system. The DA system also checks the pressure against high and low values, providing an off-normal alarm and log.

The system has a built-in calibration function, permitting the operator to calibrate and test any single channel independent of all others. Operation of the calibration switch trips the console annunciator, since the resulting isolation of one trip unit reduces the system's redundancy. Calibration does not affect the pressure transmitter outputs, so the operator is never deprived of pressure information or the monitoring functions of the DA system.

10.3.6.4. Pump Monitor

The primary coolant pump monitor circuit is shown schematically in Figure 10-20. The system is basically a primary coolant pump current-monitoring device, which initiates a scram and starts the DK system when all primary coolant pumps fail.

The system has two modes of operation: one for reactor operation during startup to about 20% of full power, at which time both high- and low-speed pump operation is monitored; and the other for reactor operation above about 20% of full power, at which time only high-speed pump operation is monitored. The two modes permit or give credit for high-speed pump operation above about 20% of full power.

The mode of operation is established manually by the operator setting the START-RUN switch in either the START or the RUN position. In the START position all pumps operating in either full or low speed must fail before the pump monitor takes any action. In the RUN position a pump operating at low speed gives the same indication as a failed pump, and the monitor acts upon loss of all pumps operating at full speed.

10.3.6.5. Low-Flow Monitor

As a backup to the primary coolant pump monitor, primary system flow is measured from the differential pressure across the two boilers, as shown in Figure 10-21. The low-flow scram is set at a value which requires at least two primary coolant pumps running at low speed in one loop or one pump at high speed.

10.3.6.6. Loss of Power

Loss of power to the nuclear instrumentation automatically scrams the reactor because such a loss would deprive the scram lines of power for holding the rods.

A loss of the vital or battery-backed power to the rod drive system would drop the rods automatically because such a loss would deprive the scram solenoids of power.

A loss of normal ship's power to the rod drives would initiate a scram by way of the rod drive voltage monitor on the Scott-T two-phase power bus. Similarly, a loss of two-phase power by any other means would initiate a scram through the voltage monitor.

10.3.6.7. Rod Test Scram

Operation of the rod drive system without moving the control rods may be desirable when the reactor is shut down. To be absolutely sure that a control rod is held in the core, interlocks within the rod drive system prevent the drive carriage from being uncoupled from the control rod unless the rod test switch for the individual rod is placed in the test position. Placing the switch in the test position sends a continuous scram signal to the safety system and bypasses the interlock functions of the rod-engaged and rod-bottom switches. The safety latches and hydraulic system pressure hold the rod in the core and permit the carriage to be safely moved.

10.3.6.8. Loss of Hydraulic System Pressure

The rod drive hydraulic system pressure is normally maintained at 3075 psig. This pressure is monitored from a common header by four pressure sensors. One sensor controls the standby pump, which automatically comes on when the pressure drops to 2900 psig. The remaining three sensors are connected in a two-out-of-three coincidence initiating a scram when the pressure falls to 2700 psig. The scram point is set well above the minimum pressure required for optimum scramming of the rods.

10.3.6.9. One Scram—All Scram

Auxiliary scram relays are connected in parallel with each of the rod drive scram solenoids. The basic function of the auxiliary scram relays is to ensure a positive reactor scram. Thus, when any single rod receives a scram signal, the auxiliary scram relay holds the individual rod scram circuits in a scram condition and sends a scram lockup signal back to the safety system, which is held in a scram state. The lockup action of these relays cannot be cleared until all rods have reached their lower limit.

10.4. Reactor Control

10.4.1. Control Philosophy

Reactor control is achieved by a combination of manual manipulation of the control rods and inherent negative reactivity feedback characteristics of the fuel and coolant.

The reactor control system is designed to operate the reactor within the following restrictions:

1. Constant average primary system water temperature in steady state operation.

2. Load transient variations in primary system water temperature compatible with the capacity of the pressurizing system.

Variations in primary system water temperature and steam flow are detected by sensors, which, by action of either the operator or the control system, supply any necessary corrective action to the control rods.

10.4.2. Control Requirements

The NS Savannah reactor control system meets the following requirements:

1. Compensation for all the reactivity deficits encountered during core life.

2. Sufficient reactivity override to provide adequate shutdown capability at all times.

3. Reactivity adjustment at a rate that controls both large and small transients.

4. Maintenance of the total power-peaking factor within safe limits.

The excess reactivity requirements to cover reactivity deficits encountered are shown in Table 10-6. This table, a reactivity balance and the control rod worths at the beginning the end of life of Core Ia.

Table 10-6. Core Ia Reactivity Balances in Absolute Reactivity Units

Core condition (xenon free and no rods inserted)	0 EFPH reactivity (ρ)
Zero power at 68F	0.0834
Full power at 508F, No Xe	0.0639
Full power at 508 F, Equil Xe	0.0478
Control rod worth	
Total worth, cold	0.1392
Subcritical margin, cold	0.0520

The minimum shutdown margin required by the technical specifications[18] is 4.5% subcritical with all rods inserted and the reactor cold.

The NS Savannah reactor power plant is designed to increase power from 20 to 85% in 10 seconds and to decrease power from 100 to 20% in 3 seconds. During these rapid load transients, the change in primary system temperature and the change in secondary system boiler drum pressure depend on the amount and speed of reactivity change by the control rods. The maximum reactivity change during operation is 80 cents using the 100-to-20% transient as the criterion. Converted to absolute reactivity this is 0.0056 . The speed with which this reactivity must be either added to or withdrawn from the core was determined to be 2 to 3 minutes during the 1964 sea trials.[14] Evaluation of these results has led to the establishment of a reactivity ramp rate of 0.5% /min.

The design power-peaking factor for the NS Savannah is 4.31. This design value is based on the following peaking factors:

Axial	=	1.79
Radial-Local	=	2.41
Total	=	4.31

These power-peaking factors occur at 2000 EFPH. Thermal analyses of the core demonstrate that the 4.31 power-peaking factor is very conservative. The analyses indicate that a power-peaking factor of 4.7 is acceptable with the reactor operating at a power of 96 MWt and with only one primary loop in use.

10.4.3 Rod Withdrawal Sequence

The rod withdrawal sequence that was adopted in August 1965 is designated the group overlap sequence. This sequence will be used for all future core operation. The group overlap sequence is a modified out-in withdrawal scheme. The control rods are pulled in groups in the following order: E, D, C, B, X, and A. Table 10-7 gives the exact sequence in terms of inches and total stroke numbers used with the present drives. The assignment of control rods to groups A, B, C, D, E, and X is as shown in Figure 6-3.

Table 10-7 indicates that as many as three rod groups are partially pulled at one time and are at various withdrawal positions. With the present CRD system this multigroup withdrawal must be simulated. The simulation procedure consists of pulling each of the partially withdrawn rod groups (one at a time) a distance of 2 inches (or less).

The rod group withdrawn to the highest position is pulled first, the middle rod group second, and the least withdrawn group third or last. After each group is pulled a total of 2 inches (one or more individual pulls), the pattern position is then at an exact total stroke position that is in exact agreement with the group overlap sequence. This procedure is used for all operations at base load or higher propulsion power levels except during maneuvering. During maneuvering the middle rod group (group closest to the midplane of the core) is used exclusively to ensure fast reactivity compensation for fast load changes. At the end of each maneuvering period the rod groups are then returned to the correct positions prescribed by the withdrawal sequence.

Table 10-7. Group Overlap Sequence

Total stroke number	Control rod group positions, in.					
	E	D	C	B	X	A
0	0	0	0	0	0	0
4	4	0	0	0	0	0
8	8	0	0	0	0	0
12	12	0	0	0	0	0
16	16	0	0	0	0	0
20	20	0	0	0	0	0
24	24	0	0	0	0	0
28	28	4	0	0	0	0
32	32	8	0	0	0	0
36	36	12	0	0	0	0
40	40	16	0	0	0	0
44	44	20	0	0	0	0
48	48	24	0	0	0	0
50	50	26	0	0	0	0
54	54	30	4	0	0	0
58	58	34	8	0	0	0
62	--	38	12	0	0	0
66	--	42	16	0	0	0
70	--	46	20	0	0	0
72	--	48	22	0	0	0
74	--	50	24	0	0	0
76	--	52	26	0	0	0
78	--	54	28	2	0	0
80	--	56	30	4	0	0
82	--	58	32	6	0	0
84	--	--	34	8	0	0
86	--	--	36	10	0	0
88	--	--	38	12	0	0
90	58	58	40	14	2	0
92	--	--	42	16	4	0
94	--	--	44	18	6	0
96	--	--	46	20	8	0
98	--	--	48	22	10	0
100	--	--	50	24	12	0
102	--	--	52	26	14	0
104	--	--	54	28	16	0
106	--	--	56	30	18	0
108	--	--	58	32	20	0
110	--	--	--	34	22	0
112	--	--	--	36	24	2
114	--	--	--	38	26	4
116	--	--	--	40	28	6
118	--	--	--	42	30	8
122	--	--	--	46	34	12
126	--	--	--	50	38	16
130	--	--	--	54	42	20
134	--	--	--	58	46	24
138	--	--	--	--	50	28
142	--	--	--	--	54	32
146	--	--	--	--	58	36
150	--	--	--	--	--	40
154	--	--	--	--	--	44
158	--	--	--	--	--	48
162	--	--	--	--	--	52
166	--	--	--	--	--	56
168	--	--	--	--	--	58

The group overlap sequence has been subjected to an extensive analytical and test program.[19] The major results of the analytical study—control rod positions, power peaking, and reactivity loss per time step as a function of core lifetime—are given in Table 10-8. The program demonstrated the adequacy of the sequence and that no unresolved safeguards problems exist.

10.4.4. Transient Performance

A series of tests were carried out during the sea trials of 1964 to investigate the transient characteristics of the plant in response to load changes. These tests, summarized in Table 10-9, included uncontrolled transients (no control rod movement) and controlled transients (control rod movement). In all cases the plant was running with four primary pumps at full speed with the pressurizer level control in manual so that the level controller would not counteract the expansion and contraction of the primary coolant. Except for control rod positions, the plant operating conditions for the controlled transients were the same as for uncontrolled transients.

Examination of the test results led to the following general conclusions:

1. A smoother primary pressure time curve is achieved by making the whole anticipated control rod movement at the beginning of the transient rather than by trying to maintain the mean primary temperature constant during the transient.

2. An uncontrolled power increase from base load to 60% of full power when the pressurizer is controlled at its normal operating pressure (1735 psi) allows pressure to fall within the low-pressure alarm range (1585 ± 20 psi). However, there is sufficient margin above the low-pressure scram setting (1505 ± 20 psi).

3. An uncontrolled power reduction from 60% of full power to base load from normal operating conditions does not cause the pressurizer safety valves to lift.

4. There is a considerable margin available between the extreme upper and lower limits of pressurizer pressure operation. Apparently, the plant could be made self-controlling with some readjustment of primary system alarms and operating set points.

Table 10-8. Core Lifetime Using Anticipated Control Rod Withdrawal Sequences

Time in life		Rod positions, inches withdrawn				Effective power peaking, peak-to-average ratios			Axial rod pattern in which total peak occurs	Reactivity loss per time step, $\Delta\rho$	Excess reactivity remaining, $\Delta\rho$
EFPH	EFPD	C	B	X	A	Axial	Radial × Local	Total			
0	0	34.0	0	0	30.0	1.84	1.78	3.28	BX	0.000	0.0810
96	4.0	34.0	0	0	30.0	1.81	1.78	3.22	BX	– .0150	.0660
245	10.2	37.6	0	0	30.0	1.78	1.78	3.17	BX	– .0025	.0635
1,072	44.7	58.0	5.0	0	30.0	1.56	1.77	2.76	BX	– .0060	.0575
1,662	69.2	58.0	7.8	0	30.0	1.50	1.92	2.88	X	– .0017	.0558
2,434	101.2	58.0	11.5	0	30.0	1.73	1.91	3.30	X	– .0019	.0539
2,608	108.7	58.0	12.5	0	30.0	1.78	1.90	3.38	X	– .0008	.0531
2,848	118.6	58.0	13.8	0	30.0	1.82	1.90	3.46	X	– .0006	.0525
3,220	134.2	58.0	14.4	0	30.0	1.81	1.89	3.42	X	– .0013	.0512
3,500	145.8	58.0	16.0	0	30.0	1.85	1.89	3.50	X	– .0011	.0501
4,000	166.7	58.0	18.0	0	30.0	1.87	1.88	3.52	X	– .0013	.0488
4,500	187.5	58.0	19.6	0	30.0	1.86	1.87	3.48	X	– .0018	.0470
4,500	187.5	58.0	42.0	30.0	8.0	1.29	2.38	3.07	0	--	.0470
5,000	208.3	58.0	43.0	31.0	9.0	1.34	2.36	3.16	0	– .0018	.0452
6,000	250.0	58.0	46.2	34.2	12.2	1.43	2.32	3.32	0	– .0038	.0414
7,000	291.7	58.0	49.9	37.9	15.9	1.47	2.27	3.34	0	– .0039	.0375
8,000	333.3	58.0	54.0	42.0	20.0	1.49	2.23	3.32	0	– .0040	.0335
9,000	375.0	58.0	57.6	45.6	23.6	1.47	2.19	3.22	0	– .0041	.0294
10,000	416.7	58.0	58.0	49.2	27.2	1.47	2.15	3.16	0	– .0043	.0251
11,000	458.3	58.0	58.0	53.4	31.4	1.46	2.11	3.08	0	– .0045	.0206
12,000	500.0	58.0	58.0	57.4	35.4	1.47	2.07	3.04	0	– .0047	.0159
13,000	541.7	58.0	58.0	58.0	42.7	1.53	2.03	3.11	0	– .0050	.0109
14,000	583.3	58.0	58.0	58.0	49.0	1.60	1.99	3.18	0	– .0053	.0056
15,000	625.6	58.0	58.0	58.0	58.0	1.66	1.95	3.24	0	–0.0056	0.0000

Notes:
1. The critical rod positions from 96 through 3220 EFPH are measured positions.
2. The power-peaking values given are those that determine the maximum total value.
3. EFPD and EFPH are based on 69 MWt.
4. For comparison purposes the initial excess reactivity is assumed equal to 0.081 $\Delta\rho$.
5. The initial rod positions indicate equilibrium xenon, but the calculation assumes no xenon for the initial time step.

Table 10-9. NS Savannah Transient Tests

Run No.	Type of transient	Nominal range[a]	Initial power, MWt	Intermediate power, MWt	Final power, MWt
1	Uncontrolled	30% FP to BL	25.4		15.3
2	Uncontrolled	BL to 30% FP	15.3		25.7
3	Uncontrolled	40% FP to BL	33.2		16.1
4	Uncontrolled	BL to 40% FP	15.8		32.2
5	Uncontrolled	50% FP to BL	37.9		16.1
6	Uncontrolled	BL to 50% FP	16.1		38.9
7	Uncontrolled	50% FP to BL	38.9		15.6
8	Uncontrolled	BL to 50% FP	16.1		38.9
9	Uncontrolled	60% FP to BL	47.2		15.6
10	Uncontrolled	BL to 60% FP	15.8		47.4
11	Controlled	60% FP to BL	46.8		15.0
12	Controlled	BL to 60% FP	15.0		50.0
13	Controlled	Ahead to astern to ahead	48.6	58.2	50.4
14	Controlled	75% FP to BL to 75% FP	59.5	10.5	58.6
15	Controlled	80% FP to BL	65.0		11.0

(a) BL = base load; FP = full power of 80 MWt.

10.5. Control Rod Drive System

10.5.1. Design Basis

The control rod drive (CRD) system is designed to operate under the following conditions:

1. A continuous oscillating roll having a roll center approximately 15 feet below the top of the pressure vessel, a roll amplitude of 30 degrees to each side from the vertical, and a roll period of not less than 12 seconds.
2. A continuous oscillating pitch having a period of 5 seconds and, when combined with heaving, imposes an additional load not exceeding 0.3 g in the vertical direction.
3. Fore and aft acceleration not exceeding 0.25 g.
4. A permanent list of 15 degrees and a permanent trim of 5 degrees.

The design environment for equipment inside of the containment vessel is:

1. Salt atmosphere.
2. Atmospheric pressure.
3. Maximum continuous temperature of 150 F.
4. Maximum continuous relative humidity of 90%.
5. Gamma radiation level of 100 r/hr.

The minimum design life of the mechanisms is 4000 full-stroke cycles and 500 scrams.

10.5.2. System Description

On the upper head of the reactor vessel are located 21 electromechanical, hydraulic control rod drives (see Figure 10-22). Each drive is connected to a control rod assembly by a vertical shaft located in a nozzle in the reactor vessel head. A buffer seal assembly prevents the primary coolant from leaking through the nozzle into the containment. The control rod is moved by the hydraulic and mechanical forces acting on the control rod and drive assembly. A high-pressure hydraulic oil system within the CRD system provides pressure, which:

1. Exerts a large driving force to scram the rod.
2. Provides an auxiliary lifting force at zero reactor pressure to enable testing the mechanisms while maintaining scram capability.

3. Counteracts the reactor pressure to reduce wear on the mechanical parts of the mechanism.

Each of the 21 drives is independent with respect to scram action. The electromechanical and hydraulic portions are independent of each other. No action of the mechanical portion can affect the hydraulic scram capabilities.

For convenience of description, the CRD system is separated into four subsystems:

1. The drive mechanisms.
2. The hydraulic system.
3. The electrical control and instrumentation system.
4. The buffer seals.

10.5.2.1. Control Rod Drive Mechanisms

Each control rod drive mechanism consists of upper and lower sections (see Drawings SK13-G-881 and SK13-G-882). The upper section includes the gear motor, drive shaft assembly, position indicator, limit switch, and hydraulic cylinder. The lower section of each mechanism consists of shrouds, upper and lower flanges, two leadscrews with a drive chain and drive sprockets, a drive carriage and drive nuts, tie rod assemblies, a scram time test spring, a latch assembly, latch rods, and two limit switches. The gear motor acting through the drive shaft assembly serves to position the drive carriage through the action of two drive nuts on the leadscrews. In normal operation the control rod shaft is held against the drive carriage by the force of the primary system pressure acting on the shaft, which penetrates the reactor vessel. A thimble platform scram stop assembly is located below each lower section. This assembly will be discussed as a part of the mechanisms.

Drive Motors and Reduction Gears

The drive motor and reduction gear assembly is attached to a flange on the top of the hydraulic cylinder. The upper section consists of a 115v, a-c two-phase drive motor, a 115v, a-c blower motor, and a drive motor high-temperature switch. The lower section is a three-stage reduction gear box with a 40:1 gear ratio. The gear box output shaft drives the drive shaft assembly.

Drive Shaft Assembly

The drive shaft assembly consists of three shafts, a support bearing, and a spur gear. At its upper end, the assembly is driven by the output shaft of the gear box. A support bearing secures the upper end of this shaft in the upper flange on the hydraulic cylinder. A spur gear is mounted immediately below the bearing and drives the input gear for the position indicator torque transmitter. The lower end of the drive shaft assembly passes into the upper end of one leadscrew, driving that leadscrew and the drive sprocket mounted on it.

Position Indicator Torque Transmitter

Position indicators actuate the upper limit switch when a control rod drive actuating shaft has been positioned to its upper limit of travel. The position indicators also drive the torque transmitter, which provides indication of drive carriage position to readout assemblies located in the reactor control room.

The position indicator torque transmitter input gear is driven by the spur gear on the drive shaft assembly. The other components of the position indicators include a speed changer, gears, an upper limit switch, and a switch actuating cam, all located on an indicator mount.

Shrouds

Two stainless steel sheet metal shrouds encircle the lower, or leadscrew, section of each control rod drive mechanism to protect it from foreign material or damage. Clamps are located at the top and at the bottom of the two shrouds to hold them in place.

Leadscrews

Two acme thread leadscrews extend from the upper to the lower flange in the lower section of each control rod drive mechanism. They are threaded to within approximately 8 inches of their lower ends. The leadscrews can be rotated only through the action of the drive shaft assembly and a drive chain. A drive chain sprocket is mounted on each of the leadscrews. One leadscrew, directly driven by the drive shaft, drives the second leadscrew by action of the drive chain and sprockets.

Drive Carriage

The drive carriage fits over and travels vertically on the leadscrews. The carriage is positioned by drive nuts on each leadscrew. The drive nuts are not rigidly attached to the carriage. Under normal positioning of an actuating shaft, the carriage engages a drive pin, which is located in the coupling piece of the latch assembly. Reactor or hydraulic pressure forces the actuating shaft upward and seats the drive pin against the drive carriage. The drive carriage overcomes the hydraulic force when an actuating shaft is engaged and is being positioned downward.

Tie Rod Assemblies

The two tie rod assemblies provide longitudinal support and tie the two flanges together. They extend from the upper to the lower flange of the leadscrew section of each control rod drive mechanism. Each assembly consists of a rod and a shroud anchor.

Scram Time Test Spring

The scram time test spring, which provides a signal for scram timing, is threaded onto a nylon stud screwed into one of the tie rod assemblies. An electrical lead is connected to the spring, which is located 23 inches (about 1/3 of the full 70-inch rod stroke) above the zero position.

Latch Assembly and Latch Rods

The latch assembly provides two mechanical locks, which engage the latch rods to prevent outward rod motion whenever an actuating shaft and carriage become disengaged. Each lock consists of a coupling piece, two spring-loaded latch arms guided on the latch rods, and a covered felt wrapping, which absorbs minor hydraulic leakage from the hydraulic cylinder. The end of the hydraulic cylinder piston rod recesses into and is pinned to the coupling piece at the upper end of the assembly, and the buffer seal shaft recesses into and is pinned to the lower end of the coupling piece. The drive pin which transmits the load from the actuating shaft to the carriage, is mounted in the coupling piece immediately above the latch arms.

In the event of hydraulic or electrical failure resulting in a net upward force on the actuating shaft following scram at any vessel attitude and at primary pressures up to 2000 psi, the latch arms bind on the latch rods and prevent outward motion when the carriage is separated from the drive pin. The latch assembly permits free inward motion of an actuating shaft in this condition. The latch arms and latch rods also prevent the actuating shaft from rotating and causing accidental uncoupling of a control rod.

Limit Switches

Two switches, the lower limit switch and the engaged switch, are installed in the leadscrew section of each control rod drive mechanism. The lower limit switch prevents the drive motor from driving downward and provides positive indication that the actuating shaft is at its lower limit of travel. The lower limit switch is mounted on a bracket that extends upward from the lower flange of the mechanism. It is actuated by the shoulder on the latch assembly coupling piece.

The engaged switch provides positive indication that the drive carriage and drive pin are disengaged. When the carriage is disengaged, a post insertion occurs. The engage switch overrides the lower limit switch, allowing the carriage to drive down and re-engage the drive pin. The switch is mounted on a bracket, which extends downward from the upper flange of the drive mechanism. The switch is actuated by an angle assembly, which extends the full length of the leadscrew section of the drive mechanism. The angle assembly is rotated by the angle assembly actuator located on one latch arm. Whenever the drive carriage separates from the drive pin, the actuator rotates the angle assembly and actuates the engaged switch.

Thimble Platforms

The thimble platforms are the transition pieces between the lower mechanism sections and the buffer seal assemblies. Each thimble platform houses the scram stops for one rod and permits inspection, coupling, or uncoupling of the buffer seal shafts. Each thimble platform is made up of two square horizontal plates and four vertical support rods. The buffer seal shaft penetrates the bottom plate, which is bolted to the buffer seal assembly. The upper plate is penetrated by the control rod drive actuating shaft. The thimble platform supports the weight of its drive mechanism.

Scram Stops

The scram stop assemblies consist of two half-circle pieces that encompass the shaft inside the thimble platform. Each half assembly has a machined ridge, on which the control rod drive actuating shaft rests when the control rod is at its zero indicated position in the core. The scram stop assemblies can be removed by raising the control rod 1/4 inch, lifting the scram stops up, and pulling them outward from the bottom. This procedure allows the control rod to be lowered approximately 2 inches to a point where it rests on a hydraulic snubber in the lower flow baffle. This point is the coupling or uncoupling position for the rod.

10.5.2.2. Hydraulic System

The hydraulic system provides the capability for scram insertion of the control rods and a balance force during normal operation to minimize mechanical forces due to the reactor pressure (see Drawing RC-04-J-813). Under conditions of zero reactor pressure, which may exist during test periods, the hydraulic system provides an auxiliary force to lift the control rods. Scram capabilities are maintained in the zero lift mode.

The major components of the hydraulic system include the three hydraulic power units, headers and lines, accumulators, seven hydraulic control panels, three heat exchangers, and several pressure switches. This hydraulic equipment is located on the drive structure in the containment vessel or in the hydraulic cubicle on the starboard side of B-deck (see Figure 10-4).

Hydraulic Power Units

Each power unit provides the high-pressure hydraulic oil necessary for operation of the system. These units include a pump, a motor, an 85-gallon stainless steel reservoir (which is an integral part of each unit), a liquid level switch, gages, valves, and filters.

The hydraulic pump, rated at 5000 psi, pumps 6.9 gpm at 3075 psi and 1800 rpm. Only one pump is required to provide hydraulic fluid for the operation of the hydraulic system. One of the two remaining power units is held as a standby unit and automatically starts operating in the event of reduced operating unit output pressure. The third unit is held in reserve and may be manually switched to either an operational or a standby status. Any of the three power units may be in the operational or reserve status at any time. Only one pump at a time may be on standby.

Headers and Lines

The headers and lines of the hydraulic system provide the piping circuitry through which all components of the system are interconnected. The headers include a pressure header, a tank header, a drain header, a bias header, and a power unit equalizing header. The pressure, tank, bias, and drain headers are located in the hydraulic cubicle with the power supply units or in the containment. The relief valve exhaust, power unit return, and power unit equalizing header are located in the hydraulic cubicle only.

The hydraulic lines of the system include steel lines and 52 flexible hoses, which connect individual components of the system and the headers. Flexible hoses connect couplings on the headers located on the containment inner wall to steel headers on the support structure. The drain header is equipped with a loop seal inside of the containment vessel to prevent nitrogen from leaking out of the containment vessel at pressures less than 4 psi. Another loop seal protects the low pressure tubing on the drain header by discharging to the oil catch tanks if the drain header pressure exceeds 6.5 psi.

Accumulators

Each of the 21 control rod drives is equipped with a nitrogen-charged accumulator to provide the stored energy and the oil volume necessary for scramming the control rod. The accumulators are mounted around the periphery on the lower half of the support structure. They are 5-gallon, piston-type units, rated at 4500 psi (see Figure 10-23). Each accumulator has sufficient oil to hold its control rod in the core independently of the latch arms on the carriage for an interval of several minutes following a 58-inch scram.

The accumulators are built with an O-ring-sealed sliding piston separating the oil side (top side) from the gas side (bottom side), which is precharged with nitrogen to 1825 psig at 70 F. A mechanical stop restricts the downward movement of the piston in the event of low gas pressure. A pressure switch is located on the gas side of each accumulator to provide remote indication of decreasing pressure which would limit scram capabilities. A float-actuated liquid detector is located on the gas side of each accumulator to provide remote indication of oil leakage into the gas side of the accumulator. A 38.5-gpm flow orifice is located in the oil discharge line of each accumulator to provide a constant rate of oil flow to the hydraulic cylinder during a scram. The orifice controls the rod velocity to a maximum of 10 fps, but allows 2/3 insertion in less than 0.807 second. An orifice plate located downstream from each flow control valve limits oil flow to 50 gpm in the event of flow orifice failure.

An additional accumulator is located on the pressure header in the hydraulic cubicle. This accumulator extends the pressure decay time when a pump is lost, thus allowing more time for a second pump to come on the line before the reactor is scrammed due to low hydraulic system pressure.

Hydraulic Cylinder and Piston

The hydraulic cylinder and piston transform the hydraulic pressure to a mechanical force acting on the control rod. Drawing 10446F-1 shows the main components of the hydraulic cylinder. Both heads of the cylinder are flanged to provide mounting and mating surfaces for other components of the control rod drive mechanism. The overall length of the cylinder is approximately 98 inches. Its piston rod has a full extension of 81 inches. Under normal operating conditions a balance pressure of 750 psi acts on both piston faces and works against the force of reactor pressure to reduce mechanism wear. During a scram the hydraulic pressure is increased to 3075 psi on both piston faces to overcome reactor pressure and insert the rod. Hydraulic pressure is applied on the bottom of the piston only to supplement reactor pressure for zero-lift operation.

10.5.2.3. Electrical System

The electrical distribution system distributes power and control signals to the CRD system. The major components of the electrical distribution system are contained in the electrical cubicle and anteroom located on the port side of B-deck athwartships of the reactor space (see Figure 10-4). The following is a description of the major components of the electrical portion of the CRD system.

Scott-T Transformers

The Scott-T transformers provide 115-volt, two-phase power to the control rod drive mechanism gear motors. The transformers are located in the anteroom adjacent to the electrical cubicle.

Rod Position Indicators

Twenty-seven rod position indicators are located on the main control console in the main control room; twenty-one are for individual control rod position indication, five are for group indication, and one is for individual rod selector readout (see Drawing SK13-G-880). The indicator assemblies consist of an indicator and a selsyn receiver, which receives its position-indicating signal from a torque transmitter on the control rod drive mechanism. Under normal and zero-lift conditions, this indication corresponds to the position of the control rod. In the scram mode or when any drive pin becomes disengaged from its carriage, only the position of the drive carriage is reflected until the carriage reengages the drive pin.

The rotors of both the transmitter and its corresponding receiver in the main control room are excited from the same power supply, and their stators are electrically connected. When the position of a torque transmitter rotor is changed through action of a drive mechanism and the position indicator gearing, an electrical imbalance occurs, and a current is produced in the transmitter stator circuitry. Current flows in the transmitter and receiver stators simultaneously, and the receiver stator produces torque, which causes the receiver rotor to turn until it has reached the same electrical position held by the transmitter rotor. The transmitter rotates 4.583 degrees per inch of control rod travel.

The output shaft of each selsyn receiver is directly connected to the pointer of an indicator. The dial is calibrated in half-inch increments from 0 to 70 inches of withdrawal. The zero reference mark indicates the position of the rod resting on the scram stop assembly. The actual point for coupling and uncoupling is between 1/2 inch and 2 inches below the zero mark. When a control rod drive shaft is lowered for coupling or uncoupling, the individual readout assemblies may be observed for correct positioning of the actuating shafts to prevent overtravel.

Power Supplies and Distribution

Four power supplies provide electrical power to control rod drive components outside of the main control room. Two additional power supplies provide electrical power to console-mounted equipment.

Power to the drive motors and the hydraulic power units is supplied from both sides of the 450v, a-c main switchboard in the main control center. The supplies pass through isolation breakers to the 23 kva, Scott-T transformers. The transformer output is 115v, two-phase ac. The two supplies then pass through an automatic bus transfer switch to the T-bus breaker on the front of the electrical cubicle. The power is distributed to each of the 21 drive motors through 100 amp panel breakers and 15 amp individual-drive power supply breakers on the front of the GE cubicle.

The hydraulic power units are powered by 450v, a-c motors. The power supply for the motors is from the 450v, a-c side of the Scott-T transformers. Power unit 2 is equipped with a manual bus transfer switch that allows power to be received from either side of the main switchboard.

Power for noncritical instrumentation on C-bus originates from the 115v, a-c panel on the port side of the main switchboard. The power supply passes through an isolation transformer located in the upper reactor compartment. Ground detector lights indicate the presence of grounds on the output side of the transformer. The power enters the cubicle through a C-bus breaker located on the front of the electrical cubicle. The C-bus supplies power to switches and lights used to monitor the system operation. No equipment that affects the scram capabilities of the system is powered by C-bus.

The F-bus supplies power to switches, solenoids, and relays that are vital to the operation of the control rod drive system. Its power source is the vital bus power supply on the starboard side of the main control room. This power supply passes through an isolation transformer in the upper reactor compartment. Ground detector lights indicate the presence of grounds on the output side of the isolation transformer. The power supply passes through two F-bus breakers on the front of the electrical cubicle.

The power to hold the scram relays originates in the scram amplifiers of the safety system. Loss of the nominal 28v, d-c voltage results in the scramming of any withdrawn control rods.

Operational Monitoring Equipment

Float switches, pressure switches, ammeters, and thermocouples monitor the drive system components and actuate alarms in the main control room. Located in the bottom of each of the rod accumulators and in the pressure leader accumulator are float switches that monitor fluid leaks past the piston. Energizing a float switch completes a circuit, which lights a master light on the electrical cubicle and an annunciator in the main control room.

Thermocouples monitor the temperature of each drive motor. They are annunciated in the same manner as the liquid-level detectors.

Fuses

One fuse panel located in the electrical cubicle contains 21 drive-control relay fuses and a drive motor high-temperature indicating light fuse. The drive-control relay fuses protect the drive-control relay circuit. The drive motor high-temperature indicating light fuse protects the light circuits. A second fuse panel contains 21 delayed action fuses that protect the scram solenoids.

Blowers

Two vane-type fans provide 300 cfm of filtered air to keep the GE cubicle pressurized and to keep dirt out of the cabinets. To prevent drive motor overheating, 21 delayed action blowers pull air through each of the 21 drive motors when they are operating and for 15 minutes after they are deenergized.

Annunciators and Controls

Eleven annunciators in the control room indicate malfunctions in the various components of the CRD system (see Drawing RC-04-J-406 and Table 10-10). When any annunciator is energized, it may be reset by depressing the acknowledge button on the main control console. It will stay lighted, however, until the malfunction is cleared or the signal is removed from the annunciator circuit.

Operation

The reactor operator may perform the following control rod drive functions from the left center portion of the main control console (see Drawing SK13-G-880).

1. Raise and lower groups of four control rods.
2. Raise and lower any individual control rod with the START-RUN switch in the START position.
3. "Fast Insert" all withdrawn control rods.
4. Scram all withdrawn control rods.
5. Observe the position of any individual control rod.
6. Observe the positions of the rods patched into the rod-grouping patch panel located under the main control console. (Normally rods A-1, B-1, C-1, D-1, and E-1 are plugged into the rod-group patch panel.)

The operator may perform the following additional functions from the left wing panel of the control console:

1. Observe the position of all 21 rods.
2. Observe which rods are fully inserted (rod-in lights).
3. Observe which rods are fully withdrawn (rod-out lights).
4. Observe which rods are disengaged (engage lights).
5. Insert any withdrawn rod.
6. Withdraw any rod.

Table 10-10. Control Rod Drive System Annunciators

Annunciator No.	Nameplate designation	Set points	Reset	Limits	Function
68	SCRAM	--	--	--	Indicates that the nominal 28v, d-c safety system voltage has been lost and any withdrawn control rods are being inserted.
69	SCRAM CIRCUIT CONNECTOR REMOVED	--	--	--	Indicates that one or more of the scram circuit connector plugs in the safety system have been removed. A scram input through a removed plug will not be recieved by the scram amplifiers and will not cause a scram.
70	FAST INSERTION CRHS	--	--	--	Indicates that all withdrawn control rods are being inserted into the core. Annunciation caused by depressing the manual "fast insertion" button on the console.
71	LIQUID DETECTOR ACCUMULATOR CRHS	7 in^3	--	±2 in^3	Indicates that oil is leaking by the piston in an accumulator, causing the float to rise.
72	LO-PRESS ACCUMULATOR GAS CRHS	2900 psig	3000 psig	+0 psi to –50 psi	Indicates that the nitrogen precharge has decreased, the oil volume has reached its maximum, and the piston is resting on the mechanical stop in the accumulator or the rod is in isolation.
73	LO-PRESS ACCUMULATOR OIL CRHS	2900 psig	3000 psig	+60 psi to –0 psi	Indicates that oil pressure has decreased due to rod being in isolation or low gas pressure.
74	LOW LEVEL HYDRAULIC OIL CRHS	9 in.	10 in.	+1/2 in. to –0 in.	Indicates that oil level in one reservoir is dropping due to improper valving in the hydraulic cubicle or leakage in the system.
76	BALANCE PRESSURE FAILURE CRHS	970 psig 600 psig	960 psig 610 psig	+100 to 0 psi +140 to 0 psi	Indicates that the B-T3 bias pressure adjusting valve setting has changed and one of the set points has been exceeded. Operator must check the GE or hydraulic cubicle to determine if failure is high or low.
77	LOW PRESSURE OIL HEADER CRHS	2700 psig	3000 psig	+50 psi to –0 psi	Indicates that standby pump failed to start when pressure dropped. Should be preceeded by annunciator number 78 and followed by annunciator number 68.
78	POWER FAILURE HYDRAULIC SUPPLY CRHS	2900 psig	3000 psig	+60 psi to –0 psi	Indicates that the operational power unit has failed and the standby power unit has been signaled to start.
79	HI-TEMP CONTROL ROD MOTOR CRDS	350 F	350 F	±10 F	Indicates that the load on the motors is excessive (would also be reflected by different drive speeds) or that the cooling blower fan is inoperative.
80	NON-SERVO PWR UNDER-VOLTAGE CONTROL RODS	102v	105v	--	Indicates that power to the drive motors has decreased. Should be followed immediately by annunciator 68, and then 78 and 76 simultaneously.
154	2 CB 10 "F" BUS FAILURE	--	--	--	Indicates that F-bus or vital bus voltage to the system has been interrupted.

The controls are designed to limit the reactivity insertion rate by limiting the number of rods being withdrawn at any time and the rate of withdrawal. All control switches used to move rods will remain in the out position only while so held.

10.5.2.4. Buffer Seals

The buffer seals are multiple-bushing-type pressure breakdown devices consisting of Stellite floating rings having a close fit about the 1.5-inch-diameter, chrome-plated ARMCO 17-4 PH seal shaft. Four rings control leakage of injection water into the reactor and 18 rings control leakage of injection water to the low-pressure outlet (see Drawing SK13-G-883).

Injection water is introduced into a lantern ring between the two groups of rings. Each ring seats on the transverse face of an L-shaped diaphragm plate, the counterbore of which forms the holder for the next ring of the series with an axial clearance of 1 to 2.5 mils and adequate radial clearance to accommodate all reasonable transverse motions of the shaft. Each floating ring seals along the shaft surface and against the spacer plate. It is pressure relieved to be free to move laterally with a minimum resultant radial load on the shaft. A shaft eccentricity of 25 mils is permitted before interference occurs on the spacer plates.

The seal shaft is guided by two Stellite bushings located at the ends of the stack of spacers and floating rings. The overall stackup is assembled and clamped in a capsule, which is fitted into a housing. One end of this housing is flange bolted to the reactor nozzle, and the other end is flanged to join to the drive line mechanism thimble platform. To control the leakage within the specified limits, the guide bushings are designed with a diametral clearance of 4 to 5 mils, and the floating rings have a diametral clearance of 2.0 to 2.8 mils about the seal shaft.

An orifice is incorporated in the capsule to limit inflow of injection water into the reactor nozzle between the shaft and a surrounding thermal shield.

During a scram the shaft travels into the reactor vessel. Rod withdrawal following loss of buffer seal injection water is administratively limited. Therefore, the cooler part of the shaft enters the seal, and there will always be ample clearance of the rings on the shafts.

A spring-loaded, chevron-type packing seals the low-pressure collection drain from the containment vessel atmosphere. A second chevron-type backup seal of larger diameter is seated at the end of the scram stroke by overtravel of the rod, but is inoperative during normal stroking.

The buffer seal charge pumps provide water to the buffer seals. The inlet pressure is maintained at approximately 50 psi above reactor pressure.

A turbine rotameter flowmeter measures the leakage from each buffer seal housing. The readout is calibrated from 0 to 100%, with 100% on the scale representing a flow rate of 10 gpm.

Visual inspection of buffer seal shafts A-3, B-3, C-3, E-3, and X is performed quarterly by removing the scram stops and observing each shaft as it rises. The results of these inspections, which have been performed approximately ten times between June 1962 and January 1965, lead to the following conclusions:

1. The chromium cladding on the 17-4 PH shafts is pitting primarily in the area of the buffer seal rings. The maximum pitting is in the area of seal injection water, decreasing in magnitude in both directions of flow into and out of the vessel.

2. The pitting is increasing very slowly, but no excessive water leakage has developed. No flaking or spalling has developed.

10.5.3. System Requirements

The CRD system must function throughout all modes of reactor operation and must be capable of operating through long periods with no maintenance being performed inside the containment vessel. The maintenance outside the containment vessel must be limited to that which may be done with the reactor operating. To achieve this, the system has backup equipment for those components prone to failure or requiring scheduled short-term preventive maintenance (such as filters).

10.5.3.1. Control Rod Grouping

The 21 control-follower rods are located at the intersections of the corners of the fuel elements in the core (see Figure 6-3). Rods are normally withdrawn in groups of four, with the exception of the center rod. The rods in each group are located symmetrically about the center of the core. Each group is designated by a letter (A through E), and each rod in each group is designated by a numeral (1 through 4). The center rod is designated as X-rod and normally moves independently of any of the five groups.

The rods are programmed into groups by patching 21 plugs into a 25-receptable patchboard under the left wing of the main console (see Drawing SK 13-G-880). Each row of five plugs is numbered by an Arabic numeral (1 through 5) from the top of the patchboard down. All rods patched into any horizontal row move simultaneously, and the position of the carriage of the rod patched into the extreme left receptacle of each horizontal row will be reflected by one of the five rod group position indicators located on the main console and designated by the letters A through E.

The operator may select any one of the five groups for movement by rotating a five-position switch and by placing the GR-IND switch in GR. The group selected will be indicated by an amber light above the indicator.

10.5.3.2. Hydraulic Isolation

The system design permits the isolation of the hydraulic system within any individual rod drive line by use of its isolation switch located in the back of the electrical equipment cubicle. This switch energizes the isolation solenoid located on the drive structure hydraulic panel and bleeds the pressurized oil in that drive line back to the reservoirs in the hydraulic cubicle. An isolated mechanism will not have scram capabilities nor balance pressure, but it may be withdrawn from the core to permit continued reactor operation. The rod will not scram due to the loss of scram capabilities, but will be inserted at approximately the normal fast insertion rate following a scram. The accumulator low oil pressure and low gas pressure alarm lights will be on for any rod in isolation.

10.5.3.3. Adequacy of Power Units

The total 6.9 gpm of oil pumped by the system during normal operation is divided as follows:

1. Approximately 1.2 gpm flows to the system to make up for internal leakage. This leakage is returned to the reservoirs through the tank and the drain header.
2. Approximately 5.7 gallons is bypassed back to the reservoirs through the coolers.

For approximately 1.5 minutes following scram, all flow is directed to the system to make up for the volume formerly occupied by the shafts in the cylinders (based on power operation of B-group at 18 inches).

Tests performed without an accumulator installed on the pressure header show that the time interval between operating pump failure and standby pump starting is approximately 2.3 seconds. The time interval between the failure of the standby unit and scram actuation caused by lost pressure at the oil header is 5.65 seconds.

Tests performed following the installation of the accumulator in the area of the scram and standby pump starting pressure switches indicates that the time delay between operating pump failure and standby pump starting is increased to approximately 24 seconds with the system in the scram mode and 22 seconds with the system in the reset mode. The time delay between operating pump failure and scram is approximately 145 seconds in the scram mode and 90 seconds in the reset mode. Leakage through the 21 bias pressure valves accounts for the shortened times in the reset mode.

These data indicate that in either case the standby power unit should start in time to prevent a reactor scram under normal circumstances. If an air volume exists in the lines or filters between the pump discharge and the pressure control relief valve, the time required for the standby pump to start will be lengthened.

10.5.3.4. Electrical System Adequacy

The total normal ratings of the circuits supplying the control rod drive equipment are:

1. A 125-amp, 450-volt breaker on each side of the main switchboard.
2. A 15- and a 30-amp, 115-volt, a-c breaker supplying F-bus.
3. A 200-amp, 115-volt, a-c breaker supplying C-bus.

Under normal steady-state conditions the buses carry approximately the following loads:

1. On the 450v, a-c bus, one pump at 27 amp.
2. On the 115v, a-c F-bus, 21 scram solenoids and miscellaneous equipment at 18 amp.
3. On the 115v, a-c C-bus, miscellaneous equipment at 5 amp.

The load on the 125-amp, 450v, a-c bus in the 4-minute period following a scram will increase to approximately 65 amp assuming a second pump is on and all 21 drive motors are running. The 45-amp, F-bus load will decrease to approximately 5 amp with the solenoids deenergized, and the 200-amp C-bus load will increase to 10 amp.

10.5.4. Safety Interlocks

The interlocks covered in this section are the major interlocks that eliminate possible operator errors and ensure the plant safety. They are discussed primarily with respect to CRD system operation.

Rod Bottom

The rod bottom interlock prevents the starting of a primary pump in an idle loop with any rod not bottomed. This interlock prohibits a cold water accident due to a cold loop startup.

Scram Reset

The scram reset interlock prevents the scram from being reset (which removes the hydraulic scram pressure) until all rod actuating shafts and carriages are engaged.

T-Bus

The T-bus interlock prevents the drive motors from being energized until there is power on the rod-bottom, rod-out, and engaged switches.

START-RUN Switch

The START-RUN switch interlock allows the movement of single rods from the center console in the START position, but prevents the movement of any single rod from the center console in the RUN position.

Disengaged

The disengaged interlock automatically drives down any carriage that has become disengaged from its drive pin. This ensures that rods will not be disengaged in normal operation and that carriages will be run in following a scram.

Automatic Scram Insertion

The automatic scram insertion interlock automatically drives all carriages down following a scram until the rods are bottomed.

IN Signal Override

The IN signal override interlock makes any IN signal override any OUT signal.

One Scram—All Scram

The one scram—all scram interlock scrams all control rods when any one of the 21 auxiliary scram relays is deenergized. This interlock prevents a single rod scram in all cases except failure of the scram valve solenoid, scram valve solenoid fuse, or scram valve solenoid ammeter.

Auto Disable

The auto disable interlock automatically closes the main engine throttle and starts the two 750 kw diesel generators if they are set for an automatic start when a scram occurs.

10.5.5. Hydraulic Operation

The control rod drive hydraulic system (see Figure 10-23) functions in the normal operating, scram, zero reactor pressure, and hydraulic isolation modes of operation. Each mode of hydraulic operation is discussed below.

10.5.5.1. Normal Positioning

In the normal positioning mode of hydraulic system operation, the force exerted by the hydraulic fluid acts against the internal reactor pressure through the piston to reduce the load on the mechanism.

Oil is pumped at 3075 psig through the pressure header and into each drive's hydraulic valve complex (see Figure 10-24 and Drawing RC04-J-813). The oil passes through check valve 139 and isolation valve 121. The oil flows to the accumulator and then through scram solenoid valve 134 to bias valve 132 and the pilot line. The high-pressure oil closes hydraulic scram valve 125 and opens pilot-operated check valve 135. Manual lockout zero-lift valve 126 does not perform any function in this mode of operation.

The oil compresses the nitrogen in the bottom of the accumulator, which becomes a source of stored energy held by check valve 139. Bias valve 132 reduces the pressure of oil passing through it from 3075 psig to the 750 psig bias pressure observable at the hydraulic cylinder and at the discharge of the valve to the bias header. The 21 bias valve discharges are manifolded in a header in the containment vessel. BT-3 pressure adjusting relief valve 275 in the hydraulic cubicle maintains a 750 psi back pressure on the bias header, the discharge lines, and the pressure lines to the cylinders. The BT-3 valve, number 275, is a hand wheel set, spring loaded relief valve which is set at 750 psig.

When a control rod is being positioned upward, oil is displaced by the piston and flows from the top of the cylinder through manual lockout zero-lift valve 126 to the bottom of the cylinder. A quantity of oil equal to the volume of the piston shaft entering the cylinder is ejected through hydraulic check valve 135, through bias valve 132, and to the bias header. When a control rod is being positioned downward, oil is displaced by the piston and flows from the bottom of the cylinder through the manual lockout zero-lift valve to the top of the cylinder. A quantity of oil, equal to the volume of the piston shaft leaving the cylinder, flows from the pressure header through bias valve 132, hydraulic check valve 135 and manual lockout zero-lift valve 126 to the top of the piston.

10.5.5.2. Scram Positioning

The hydraulic scram action shown in Figure 10-25 is initiated by the shifting of scram solenoid valve 134. This action bleeds the pilot pressure from the pilot line, which opens hydraulic scram valve 125 and closes hydraulic check valve 135. The high-pressure oil in the accumulator flows through flow orifice 224, the backup flow orifice, and hydraulic scram valve 125 to the cylinder. The 3075 psi oil acts on the upper and lower piston faces to drive the piston down and insert the control rod into the core. Manual lockout zero-lift valve 126 does not serve any function in this mode of operation.

During the downward stroke, oil is ejected from the bottom of the cylinder through manual lockout zero-lift valve 126 and into the top of the cylinder. A creep valve assembly decelerates the rod slowly in the last 14 inches of travel. The operating hydraulic power units recharge the accumulator by pumping oil through check valve 139, isolation valve 121, the backup flow orifice plate, flow orifice 224, and the latter's bypass check valve.

10.5.5.3. Zero Reactor Pressure Positioning

When the reactor pressure is not adequate to push the rods out against the carriages, the system may be set up to exert an auxiliary force on the bottom of the piston only, as shown in Figure 10-26. In this mode, the accumulator precharge must be reduced to 400 psi at 70 F, the pressure header pressure must be set at 800 psi, and special low-hydraulic-pressure scram switches must be installed on the pressure header to maintain scram capability.

Bypass valve 136 is opened to vent the oil on top of the piston. Relief valve exhaust header outout valve 267 in the hydraulic cubicle is closed to apply slight back pressure to the top of the piston and prevent air cavities from forming. Manual lockout zero-lift valve 126 is adjusted for zero-lift operation. Oil flows through check valve 139, isolation valve 121, scram solenoid valve 134, and into the pilot line. Hydraulic scram valve 125 is closed, hydraulic check valve 135 is opened, and manual lockout zero-lift valve 126 is closed by the pilot line pressure. The accumulator is charged with oil to provide scram capability. When BT-3 bias pressure adjusting valve 275 in the hydraulic cubicle is adjusted to 550 psi, the force is exerted against the bottom of the piston, driving the rod out against the carriage. Oil flows through the check valve around the creep valve in the bottom of the cylinder to allow the rod to rise. If a scram occurs, the system shifts into the normal scram mode, as shown in Figure 10-25, and a normal scram insertion occurs.

10.5.5.4. Hydraulic Isolation Operation

Any individual rod hydraulic system may be isolated by energizing solenoid-operated isolation valve 121. In this mode of operation, the oil stored in the accumulator is released through this isolation valve to the tank header. Oil entering from the pressure header passes through check valve 139, but is blocked by the isolation valve. The result is a near-zero pressure in that drive's hydraulic system. For further explanation of this mode of operation, see paragraph 10.5.3.2.

10.5.6. Control Rod Drive Testing

10.5.6.1. Prototype Control Rod Drive Tests

The prototype control rod drive mechanism was subjected to a complete life test. This mechanism closely resembled the production mechanism in that standard production parts and methods of fabrication were used wherever possible. The prototype test served to uncover any minor defects in the design and to demonstrate the ability of the mechanism to stand up to rigorous performance conditions. The prototype testing was divided into two phases. The first included a 30% life test of the drive mechanism only.[51] In the second phase the satisfactory performance of the mechanism and its supporting equipment was demonstrated under simulated shipboard conditions during an accelerated life test.[52] The tests are summarized in Table 10-11.

The first phase consisted of 13,800 feet of travel and 150 scrams and was completed in November 1958.

The second phase tested the entire drive line including the seal shaft, control rod, and buffer seal. The control rod and simulated reactor internals were contained in an autoclave capable of simulating the reactor pressure and temperature. Provisions were included for simulating misalignment of drive line components. A main circulating loop and a buffer seal loop provided flow conditions comparable to those expected in the reactor. Typical variations in the reactor water purity (nonradioactive) were also used in the test. Tests at 15 degrees of inclination were conducted under normal atmospheric conditions.

Vertical tests (80% of the total) were conducted at 150 F and 90% relative humidity. A saline environment was maintained by open tanks of saline solutions within the test cubicle.

Table 10-11. Prototype Control Rod Drive System Tests

Test condition	Travel, ft	Scrams
Phase I Tests		
Vertical, no misalignment	13,800	150
Phase II Tests		
Vertical, no misalignment vessel internals	10,000	181
Inclined 30 degrees, no misalignment	500	29
Vertical, with misalignment	9,000	73
Inclined 15 degrees, with misalignment (97-hour continuous operation)	8,000	50
Vertical, no misalignment	5,000	23
Phase I and II total	46,300	506
Separate Tests on Drive Line Components		
Buffer seal 1st type	32,000	350
Buffer seal 2nd type	60,000	500
Control rod and follower	21,000	200

. . . . The drive mechanism and hydraulic system were subjected to the following tests:

1. Drive-motor speed and electrical load tests under extreme conditions of friction and balance pressure.
2. Zero balance pressure run-in capability at 2000 psi simulated reactor pressure.
3. Leadscrew lubrication.

4. Latch tests at different positions with 2000 psi simulated reactor pressure. Three tests each were run on two latches.
5. Drive position tests.
6. Breakaway tests.
7. Stability tests.
8. Ramp tests to determine maximum and minimum ramp rates.

10.5.6.2. Production Mechanism Tests

Each of the production control rod drives was subjected to a series of performance tests and inspections. During these tests a total of 12 hours of operation was accumulated on each mechanism under various operating conditions. These tests and inspections included:

1. Hydraulic cylinder friction, hydrostatic, and leakage tests.
2. Hydraulic valve panel hydrostatic, internal leakage, and operational tests.
3. Hydraulic power supply leakage, noise, vibration, pump delivery, and hydrostatic tests.
4. Hydraulic accumulator leakage and hydrostatic tests.
5. Magnetic amplifier sensitivity, gain, and transient response.
6. Thimble platform inspection of all dimensions.
7. Support structure dimensional and alignment checks.
8. Motor and gear box torque, efficiency, backlash, slippage, break-loose torque, and leakage.
9. Group demand unit gain adjustment, sensitivity, stability, and calibration.

10.5.6.3. Operational Testing

Extensive testing of the control rod drive system was conducted at New York Shipbuilding Corporation to demonstrate the ability of this system to fulfill its design functions. These tests ranged from electrical continuity checks to the functional demonstration of the entire system. In addition to these tests, the control rod drives were operated for more than 5% of their design life, including more than 50 scrams on each mechanism.

During a following maintenance period, the buffer seal shafts were changed, drive mechanisms were removed and cleaned, and minor maintenance items were performed on the equipment mounted on the reactor head.

Following the initial fuel loading, additional tests and operational checkouts were made on the control rod drive system. Principal objectives of these tests were to:

1. Prove that equipment operation was satisfactory following system maintenance and reactor core loading.
2. Prove the readiness of the system immediately prior to criticality.
3. Add to the operating experience by which the reliability of the system could be judged.

10.5.7. Scram Capabilities

The scram system design and operation are based on individual and independent action of each actuating shaft during a scram. In addition, all hydraulic scram action is independent of mechanical rod action.

Each accumulator is precharged with nitrogen to 1825 psig at 70 F with the hydraulic system pressure at zero. This precharge is based on the full accumulator volume of 1070 cubic inches. The precharge is increased to 2050 psig at 136 F during the process of heating the plant up. When the hydraulic system pressure is increased to 3075 psig, each accumulator oil volume is raised to 355 cubic inches.

Whenever a scram occurs with an accumulator hydraulic pressure in excess of 2315 psig, the driving force and oil volume (121 cubic inches for a full 70-inch insertion) will be available to fully insert the rod even if the hydraulic power units are inoperative. The oil volume at a scram pressure of 2700 psig is 257 cubic inches more than the oil volume at 2315 psig. The accumulators bleed oil out slowly following failure of the hydraulic power units. The total internal leakage rate is approximately 342 cubic inches per minute. If all accumulators leak at the same rate, each loses approximately 15.75 cubic inches of oil per minute. At this rate, each accumulator will have oil in it for approximately 10 minutes following a scram at 2700 psig and 58 inches withdrawal with loss of the hydraulic power units and normal accumulator precharge.

All accumulators will not leak at the same rate; however, an additional accumulator (identical to the 21 on the structure) is installed on the pressure header near the start pressure switches for the scram and standby pumps. The primary function of this accumulator is to add a time delay prior to low hydraulic oil pressure scram initiation. All precharges will not be exactly 1825 psig at 70 F, but any precharge between normal and the minimum necessary to clear the low accumulator gas pressure alarm (approximately 1500 psig at 70 F) will result in an additional volume of oil in the accumulator at scram pressure and increased scram hydraulic holddown capability.

10.5.8. Maintenance

The control rod drive maintenance program achieves the following objectives:

1. Decreases oil leakage.
2. Gives the operator more control over the equipment.
3. Removes unused or redundant equipment and increases the overall reliability of the system.

The following major maintenance and upgrading efforts have been carried on in addition to the electrical and mechanical maintenance program.

Accumulators and Flow Orifices

All 22 accumulators and 21 flow orifices were disassembled, cleaned, and rebuilt between April 1964 and July 1965. Accumulators were found to be clean and operable with no evidence of galling. Approximately four accumulators had small quantities of oil in their gas sides, but only one had the 7 cubic inches necessary to actuate the liquid level detector alarm. One accumulator piston O-ring was hard and brittle, but all others were still soft and resilient.

Hoses

All 52 flexible hoses on the control rod drive structure and in the hydraulic cubicle were replaced in May 1965. The upper and lower cylinder hoses had several blisters about 1 inch in diameter on their outer jackets.

Rod Mechanism Inspection

Rod C-3 shrouds were removed in March 1965. This afforded an adequate view of the rod mechanism for inspection purposes. The mechanism was found to be in excellent condition with all microswitches tight, no shavings or foreign material in evidence, and no play in any bearings or threads. The carriage worked normally when it was cycled with the shrouds removed. All shrouds were previously removed in 1963. At that time, five drive chains had enough play to allow them to be taken up.

Bias Pressure Adjusting Plug

The unused bias pressure adjusting stem of each of the 21 panel-mounted bias valves was removed and replaced with a static O-ring seal and flange. This reduced the overall leakage and the number of O-ring failures.

Bias Pressure Adjusting Valve

The bias pressure adjusting valve was removed from the containment and placed in the hydraulic cubicle, where it is accessible to the operator during reactor operation. It is equipped with a pressure gage, sample point, isolation valves, and a bypass relief valve set at 1000 psig.

Transducer Panel Removal

The unused transducer panel, its interconnecting piping to other systems, and its wiring were completely removed. This eliminated a source of oil leakage and electrical grounds.

Reservoirs

Stainless steel reservoirs that inhibit rusting were installed in place of the three power unit reservoirs and the main reservoir.

Time-Delay Accumulator

A 5-gallon accumulator has been installed on the pressure header near the start pressure switches for the scram and standby pumps. This accumulator is equipped with a pressure switch to indicate low gas pressure and a liquid level detector to indicate the presence of oil in the gas side.

Scram Pressure Switches

Scram and standby pump start pressure switches with an accuracy of ±0.5% (approximately 15 psi) of the set pressure have been installed on the pressure header. The switches are equipped with individual shutoff valves and calibration ports.

Filters

Filters rated at two microns nominal and ten microns absolute have been installed as the postfilters in all three power units. Each filter is equipped with a constant reading differential pressure indicator.

Coalescer

A portable coalescer that removes entrapped moisture and particulate matter from the hydraulic fluid has been installed in the hydraulic cubicle.

Low-Level Trip Circuitry

The circuitry has been modified to trip off only the pump that senses a low level in its reservoir.

Cooler

An additional cooler has been installed to dissipate the pump heat put into the fluid if two hydraulic pumps are operated simultaneously.

Manual Pump Switches

ON-OFF switches that enable the operator to run any number of pumps at any time have been installed on the electrical cubicle.

GE Cubicle Hydraulic Pressure Gage

A four-position switch and 0 to 5000 psig pressure gage have been installed in the GE cubicle. The gage reflects the output pressure of any of the three pumps or the pressure on the pressure header. (Pumps are normally started and stopped from the cubicle.)

Ammeters and Fuses

A 0- to 5-ampere meter and a 1.5-ampere delayed blow fuse has been installed in series with each scram valve solenoid. They monitor the system amperage and protect the scram valve solenoids from excessive current.

Scram Relays and Arc Suppression

To prevent arcing and the possibility of welded contacts, bimetallic contact relays have been installed in place of the monometallic scram relays. An arc suppression circuit has been installed in parallel with each scram valve solenoid and auxiliary scram relay. This increases the reliability of the system during scram action.

Magnetic Amplifier

The magnetic amplifiers associated with servo control have been removed. This eliminates unused equipment.

Buffer Seal Housing Bolt Inspection

To comply with USCG regulations, ten buffer seal housing bolts are removed and replaced annually. The bolts are tested for soundness and dated.

Scram Times

To ensure each rod's operability, scram times from 58 to 23 inches are recorded semiannually. Scram times are also determined on any rod following electrical or mechanical maintenance work that might affect its scram capability.

10.6. Radiation Monitoring System

10.6.1. System Philosophy

The radiation monitoring system (RM system) provides information for personnel protection against possible radiation hazards.

In addition, it provides necessary functional radiation data from the plant and information on the radioactivity levels of the waste disposal, stack, and ventilating system intake ports.

The monitoring points (see Table 10-12) have been selected to provide maximum support to the overall ship's health physics program. The system in no way replaces the health physicist, nor is the converse true. It is intended that identical and redundant functions be performed by both the health physics group and the RM system. These functions include area monitoring, checking demineralizer depletion, and monitoring for radioiodine to detect the presence of a possible fuel element rupture. Routine health physics surveys, film packs, and secondary system water chemistry analyses are made to detect the presence of any abnormal activity level.

10.6.2. General Description

The RM system is divided in two parts; each part is housed in one of two adjacent cabinets located on the starboard side of the main control room. Figures 10-27 and 10-28 are block diagrams of the two cabinets.

Cabinet A contains the power supply, scanning system, readout meters, recorders, and associated equipment for channels 1 through 6. These channels have adjustable set point indicators located on the meter faces. These indicators can be manipulated by the operators. The first four channels form a simple, reliable gamma detection system with a range of detection from background to 100 r/hr for channels 1 and 2 and to 10 r/hr for channels 3 and 4. This range is adequate for gamma monitoring from normal to hazardous conditions. The first four channels use Geiger-Muller tubes as detectors, and the fifth channel uses a photomultiplier tube and a NaI crystal. Channel 6 is set up to detect any neutrons that may escape into the containment area. The detector used for this purpose is a BF proportional counter. All six channels are displayed on individual meters and on a six-point recorder located in Cabinet A.

Table 10-12. Radiation Monitoring System Summary

Channel No.	Area monitored	Detector location	Set point	Maximum set point	Detector type	Sensitivity	Radiation	Meter range	Purpose
1	Containment	Inside entry	10^3 mr/hr	1.5×10^3 mr/hr	Geiger-Muller tube	0.1 mr/hr	Gamma	10^{-1} to 10^5 mr/hr	Environmental monitor
2	Secondary shield	Demineralizers	10^3 mr/hr	1.5×10^3 mr/hr	Geiger-Muller tube	0.1 mr/hr	Gamma	10^{-1} to 10^5 mr/hr	Environmental monitor
3	Stack exhaust	Absolute filter in RM room on C-deck	2 mr/hr	5 mr/hr	Geiger-Muller tube	0.01 mr/hr	Gamma	10^{-2} to 10^4 mr/hr	Filter monitor
4	Stack exhaust	Charcoal filter in upper reactor void	2 mr/hr	5 mr/hr	Geiger-Muller tube	0.01 mr/hr	Gamma	10^{-2} to 10^4 mr/hr	Filter monitor
5	CW system	Lower engine space	5500 counts/min (10^{-4} μc/cc)	2.6×10^5 counts/min (5×10^{-3} μc/cc)	Photomultiplier and crystal (thallium activates sodium iodide)	50 counts/min (10^{-6} μc/cc for Co-60)	Gamma	10 to 10^6 counts/min	Detects primary leakage to CW system
6	Containment	Aft shieldwater tank	10^4 counts/min	10^5 counts/min	BF_3 proportional counter	300 counts/min per nv (thermal) 400 counts/min per nv (fast)	Neutron	10 to 10^6 counts/min	Environmental monitor
7	Gland seal exhaust	Lower engine space	8×10^{-9} μc/cc	8×10^{-9} μc/cc	Photomultiplier and crystal (Pilot-B plastic)	8×10^{-10} μc/cc for Sr-89	Beta	8×10^{-10} to 8×10^{-7} μc/cc	Detects primary leakage to secondary system
8	Stack exhaust	RM room on D-deck	2500 counts/min (1.3×10^{-10} μc/cc)	8.8×10^4 counts/min (3×10^{-9} μc/cc)	Photomultiplier and crystal (anthracene)	500 counts/min (1.3×10^{-11} μc/cc for Sr-89)	Beta	10 to 10^6 counts/min	Samples total stack airflow
9	Stack exhaust	RM room on D-deck	1800 counts/min (3×10^{-6} μc/cc)	1800 counts/min (3×10^{-6} μc/cc)	Photomultiplier and crystal (thallium activates sodium iodide)	400 counts/min (6.5×10^{-7} μc/cc for A-41)	Gamma	10 to 10^6 counts/min	Samples total stack airflow
10	1. Gaseous waste manifold 2. Secondary shield 3. Containment	RM room on C-deck	2500 counts/min (1.3×10^{-10} μc/cc)	1.8×10^5 counts/min (10^{-8} μc/cc)	Same as channel 8				Samples waste-collecting manifold discharge air
11	Same as channel 10		1.6×10^4 counts/min (3×10^{-5} μc/cc)	1.6×10^4 counts/min (3×10^{-5} μc/cc)	Same as channel 9				Samples waste-collecting manifold discharge air
12	1. Engineering spaces 2. Living berths	Housetop Prom deck	2500 counts/min (1.3×10^{-10} μc/cc)	8.8×10^4 counts/min (3×10^{-9} μc/cc)	Same as channel 8				Samples ventilation intakes for living and engineering spaces
13	Same as channel 12		1000 counts/min (1.7×10^{-6} μc/cc)	1000 counts/min (1.7×10^{-6} μc/cc)	Same as channel 9				Samples ventilation intakes for living and engineering spaces
14	DK system salt water return				Same as channel 5				Detects activity leakage into cc system

Channel No.	Air flow, cfm	Filter paper speed, in./hr
7	2	0.5
8	10	1.0
9	10	None
10	10	1.0
11	10	None
12	10	1.0
13	10	None

Cabinet B contains equipment for channels 7 through 14. These channels, with the exception of channels 7 and 14, form a complete system for continuous detection and measurement of radioactive gases and particulates dispersed in working and living areas. Radioisotopes present in the air as particulates or adhering to dust particles are concentrated by drawing a large volume of air through an efficient moving paper filter. A scintillation-type, beta-radiation detector views the collected particulates at the deposition area. When the detector is bombarded by beta particles, electronic signals are formed. The signals, indicative of the radiation level, are displayed on readout meters and strip chart recorders located at the various remote locations.

After the air has passed the filter, it flows through a gas sampler, which measures the gamma radiation level. Again signals are formed and displayed on readout meters and recorders. The stack effluent monitors (channels 8 through 11) and the ventilation intake monitors (channels 12 and 13) differ only in the remote cabinet locations—operation, circuitry, and flow path are identical.

Channel 7 monitors the turbine gland seal in the engine room. This channel uses a photomultiplier and Pilot-B plastic crystal to detect any beta radiation in the steam coming to the turbine. Channel 7 does not have a recorder. A high radiation level would indicate a leak between the primary and secondary systems.

The detectors used in channels 8 through 13 are photomultiplier tubes used in conjunction with the two types of scintillation crystals listed below:

1. Anthracene crystal, used to detect beta radiation coming from particulate matter in the air.
2. Thallium activated sodium iodide crystal, used to detect gamma radiation coming from radioactive gases in the air.

All channels have adjustable set points located on the primary meters with the exception of channel 7, which has an electronic set point. The first six channels have their primary meters located in cabinet A. The primary meters for channels 7 through 13 are located at the remote equipment panels. Channel 14 has a readout in cabinet B. The airflow in channels 8 through 13 can be controlled by throttling valves located on the back sides of the remote equipment cabinets;

airflow meters are located on the front panels. The low airflow alarms are red lights mounted between the secondary meters on cabinet B. These alarm lights are duplicated on the remote cabinets. All electrical power used by the RM system is supplied by the vital bus. Each channel has a red alarm light located directly below the readout meter at cabinets A and B. The outputs of channels 1 through 6 are continuously recorded on a six-point strip chart recorder in cabinet A. A switch is provided to allow recording of channel 14 in place of channel 5.

10.6.3. Detector Locations and Functions

Table 10-12 is a summary of the detector and channel functions and limits. Figure 10-29 is a functional block diagram of channels 1 through 6 and 14. Figures 10-30, 10-31, and 10-32 are functional block diagrams of the air-monitoring channels. The location of each detector and its function is described below.

Detector 1 is located inside the containment below the airlock and provides information for initial entry into the containment.

Detector 2 is located directly below the entrance into the demineralizer area and provides information for initial entry into this area.

Detectors 3 and 4 provide dose rate information about buildup of activity in the absolute and charcoal filters of the stack exhaust system. The information from these detectors can indicate corrosion or fission product release to the stack. Channel 3 monitors the absolute filter, while channel 4 monitors the charcoal filter.

Detector 5 is located in the discharge header of the intermediate feedwater pumps (CW-P3 and CW-P4). This RM system channel detects leakage from the primary system to the CW system. Calibration curves enable the pulse count rate output of the channel to be converted to μc/cc for the radioisotopes of interest.

Detector 6 is a thermal neutron detector located inside the containment as an environmental monitor. This detector may be converted to measure fast neutrons by using an available moderator shield. Curves are supplied by converting the count rate output to flux in n/cm^2-sec for both fast and thermal neutrons.

Combination air particulate and radiogas detectors sample the following points and warn of activity in the intakes which could endanger the ship.

Detector 7 is an air particulate monitor which normally samples the gland seal exhaust, but may be valved to sample the machinery space. This monitor, which senses the solid daughters of fission gases, detects primary- to secondary-system leakage. Activity in μc/cc is based on Sr-89 calibration.

Detector 8 is an air particulate detector capable of sampling upstream or downstream of the stack exhaust filters. This detector is normally valved to sample upstream of the filters. Calibration is based on Sr-89.

Detector 9 is a radiogas detector that samples the filtered air from the output of channel 8. Calibration is based on Kr-85. Calibration curves enable the output to be converted to a measurement of A-41, Kr-85, and I-131 activities in μc/cc. Detectors 8 and 9 are used to indicate the radioactivity of the total stack airflow prior to discharge to the atmosphere.

Detector 10 is an air particle detector capable of sampling directly from the containment vessel, the waste collection manifold, and the secondary shield area. This detector is normally valved to sample the point of highest concentration, i.e., the waste collection manifold. Calibration is based on Sr-89 activity. Readings are converted to μc/cc.

Detector 11 is a radiogas detector that samples the filtered air from the output of channel 10. Calibration is based on Kr-85, and curves permit reading in terms of A-41, Kr-85, and I-131 activities in μc/cc.

Detector 12 is an air particle detector that samples at either the intake at the housetop, where air for the engineering spaces flows in, or at the intake of air for the public areas on the promenade deck. Sampling is normally valved to sample the intake for the engineering spaces, and calibration is based on Sr-89 activity.

Detector 13 is a radiogas detector that samples the filtered air from the output of channel 12. Calibration is based on Kr-85.

Detector 14 is identical to detector 5 and is located on the DK system salt water return line in the engine room near the main condenser. This channel detects any activity which may leak into the system. All other features are the same as those for channel 5.

10.6.4. Alarm Procedure

The meter relays provide a readout of the monitored radioactivity levels and give an alarm when a level equals or exceeds a preset amount. When the indicated activity reaches the alarm setting, the meter needle touches the alarm needle and completes the alarm circuit. The circuit locks in the alarm relay until the operator manually resets the relay.

When a channel alarms, an audible signal as well as a visual signal is initiated. The operator must acknowledge the alarm by pressing an alarm acknowledge button on the console to silence the audible alarm. The operator then proceeds to the radiation monitoring cabinets, where the alarmed channel will be indicated by its activated alarm light. The operator then tests the validity of the alarm with the channel reset button. The health physicist is notified immediately of the location of the excessive radiation.

10.6.5. Special Surveys

The radiological safety program requires performance of the following surveys relative to various alarms in the RM system.

10.6.5.1. Beta-Gamma Surveys

Beta-gamma surveys will be made in pertinent areas upon an alarm on detector 3 or 4 or when abnormal radiation levels are reported on routine surveys. Special beta-gamma surveys will be made in watchstanding and working areas when abnormally high primary water activity is found. Special beta-gamma surveys will be made in the engine room at the detector location upon an alarm on detector 7. A special beta-gamma survey will be made upon request of the Engineering Watch Officer or the Chief Engineer or upon the recommendation of the senior health physics member on board.

10.6.5.2. Neutron Surveys

A special neutron survey will be made in watchstanding and working areas following a low-level alarm from the neutron shield tank, a high radiation level with normal primary water activity, and an alarm from detector 6. A special neutron survey will be made upon reporting of abnormally high gamma levels on routine surveys. A special neutron survey will be made at any time and in any area upon request of the Engineering Watch Officer or the Chief Engineer.

10.6.5.3. Airborne Particulate Surveys

Following an alarm on RM system detector 7, 8, 10, or 12, special grab samples for airborne particulate activity will be obtained at the location of the alarm. The sampling points are:

1. Detector 7, machinery spaces.
2. Detector 8, stack sampling plugs.
3. Detector 10, stack sampling plugs.
4. Detector 12, outside air.

10.6.5.4. Radiogas Surveys

If detector 9, 11, or 13 alarms, special radiogas grab samples will be obtained from the alarming detector area. The sampling points are:

1. Detector 9, stack sampling plugs.
2. Detector 11, stack sampling plugs.
3. Detector 13, outside air.

Upon acquisition of a radiogas sample showing sufficient activity, an analysis will be made to determine the specific radiogases present.

10.6.6. Calibration Procedures

Calibration is performed monthly to ensure that the actual radiation level is compatible with the radiation level indicated by the log count rate meter and/or the log count rate follower meter. This is usually done by placing a radioactive source of known strength on the detector and adjusting the LCRM circuitry, the amplifier gain, or the detector high voltage. Calibration is also required on all channels before startup and after maintenance is performed on any channel. Calibration may be performed by instrumentation technicians except for channel 6, which requires a health physicist.

Figure 10-1. Reactor Control Loops

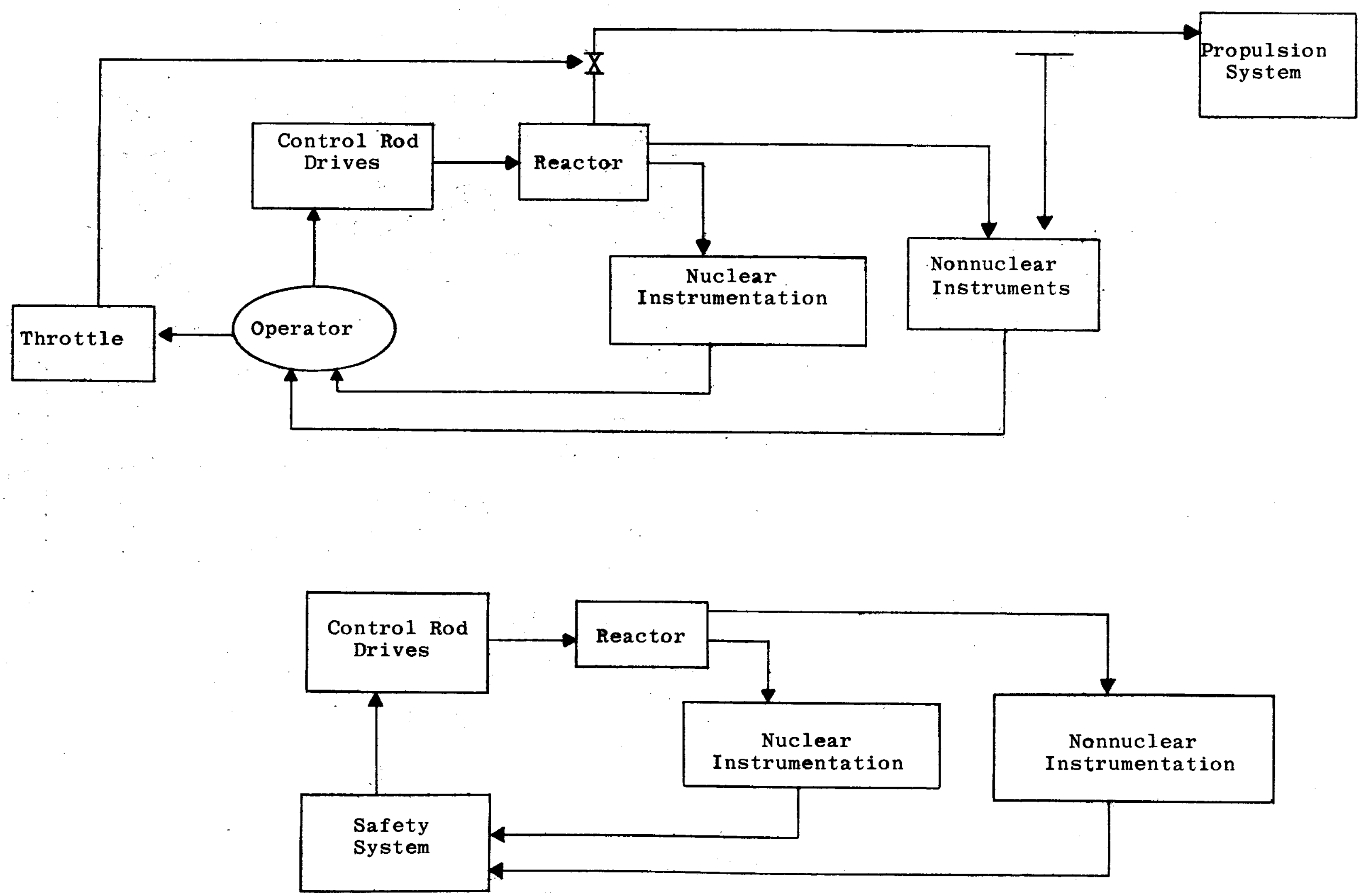
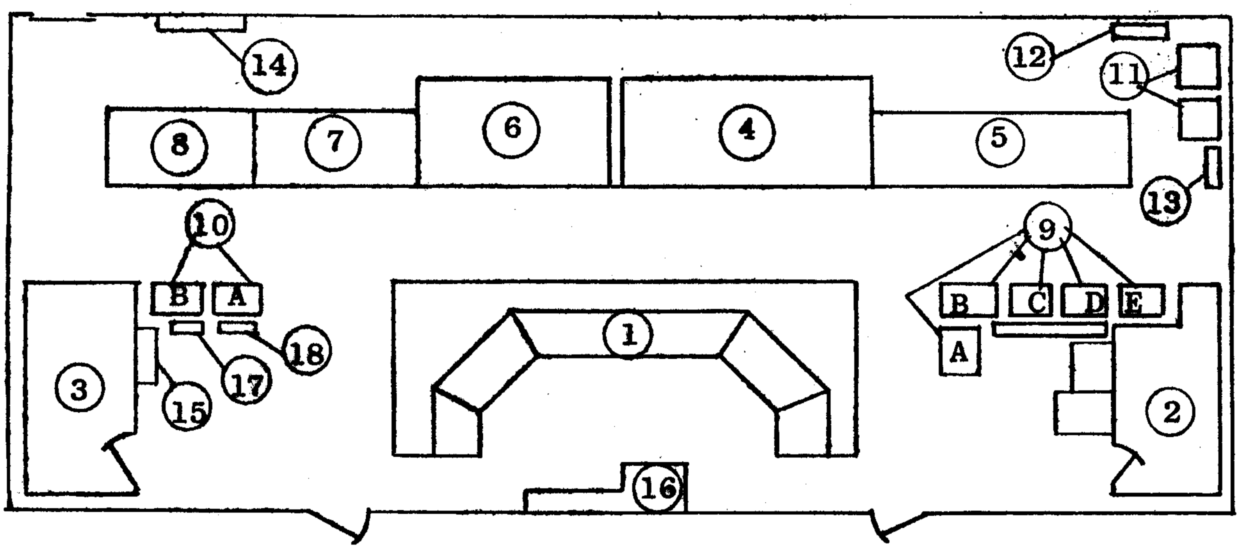


Figure 10-2. Main Control Room Arrangement



Electrical Equipment in Main Control Room

1. Main Control Console
2. Auxiliary Cubicle - A
3. Auxiliary Cubicle - B
4. Main Switchboard-Bus 2-450v ac-3phase
5. Main Switchboard-Bus 2-120v ac-3phase
6. Main Switchboard-Bus 1-450v ac-3phase
7. Main Switchboard-Bus 1-125v dc
8. Main Switchboard-Bus 1-120v ac-1phase
9. Instrumentation and Safety System Cabinets
10. Radiation Monitoring System Cabinets
11. 50 kva Transformers
12. Automatic Transfer Switch-120v ac-3phase Bus
13. Lighting Panel
14. Vent Control Panel
15. Critical Instrumentation Switch Panel
16. Data Logger Readout
17. Automatic Bus Transfer
18 Instrumentation Switch Panel

FIGURE 10-3. MAIN CONSOLE ARRANGEMENT

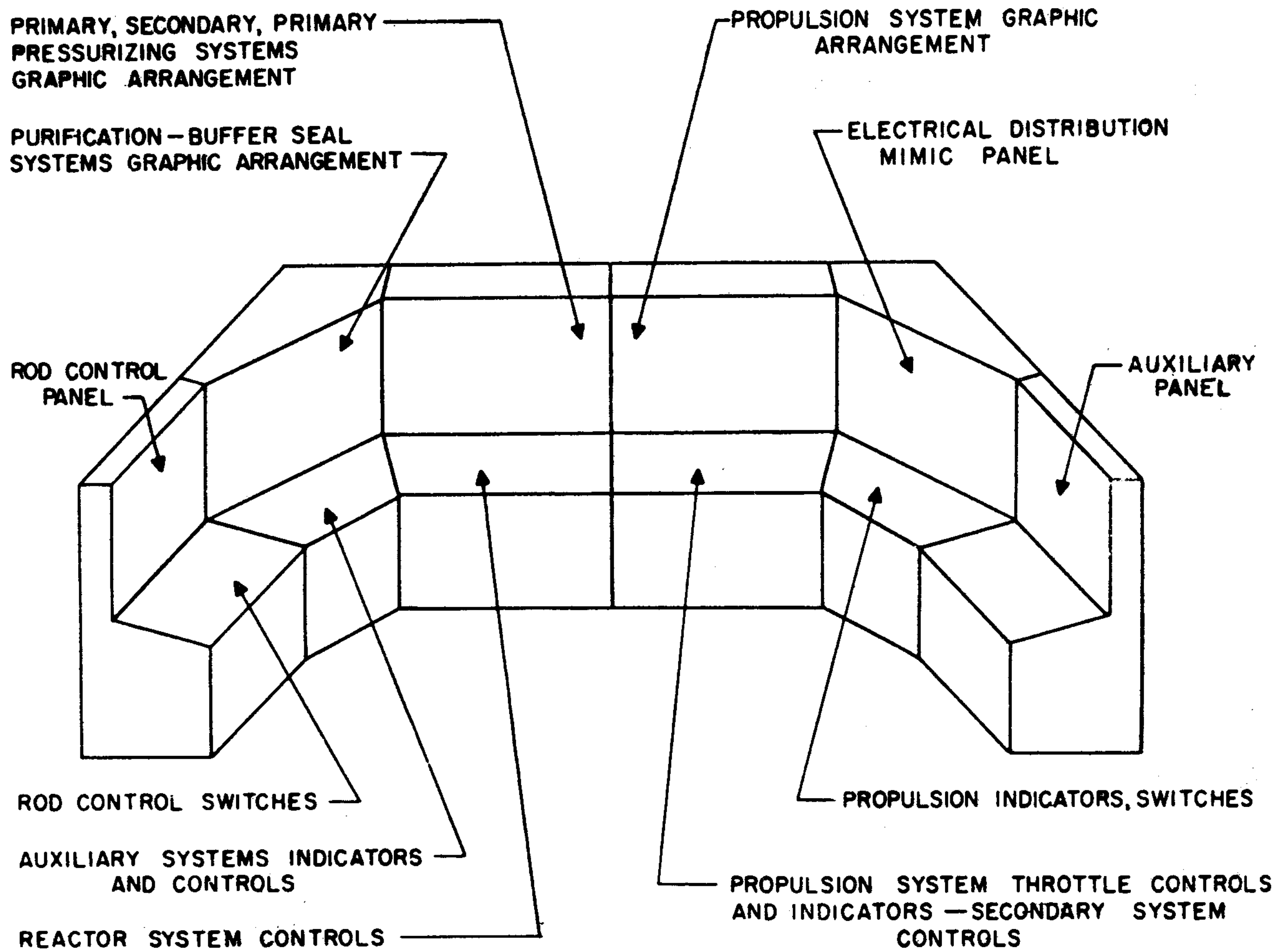


FIGURE 10-5. NUCLEAR INSTRUMENTATION RANGE AND ACTION

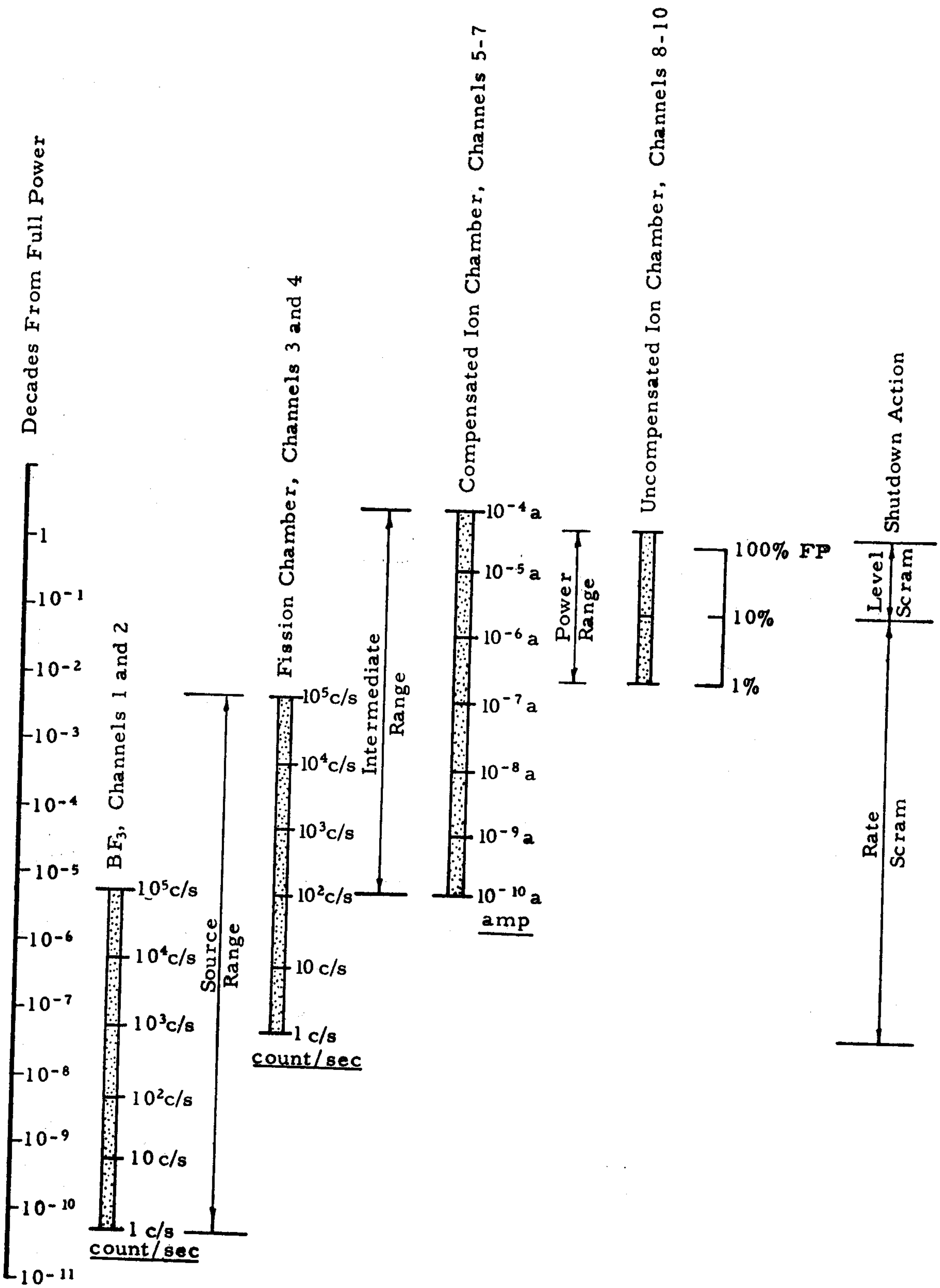


Figure 10-6. Measured Nuclear Instrumentation Overlap

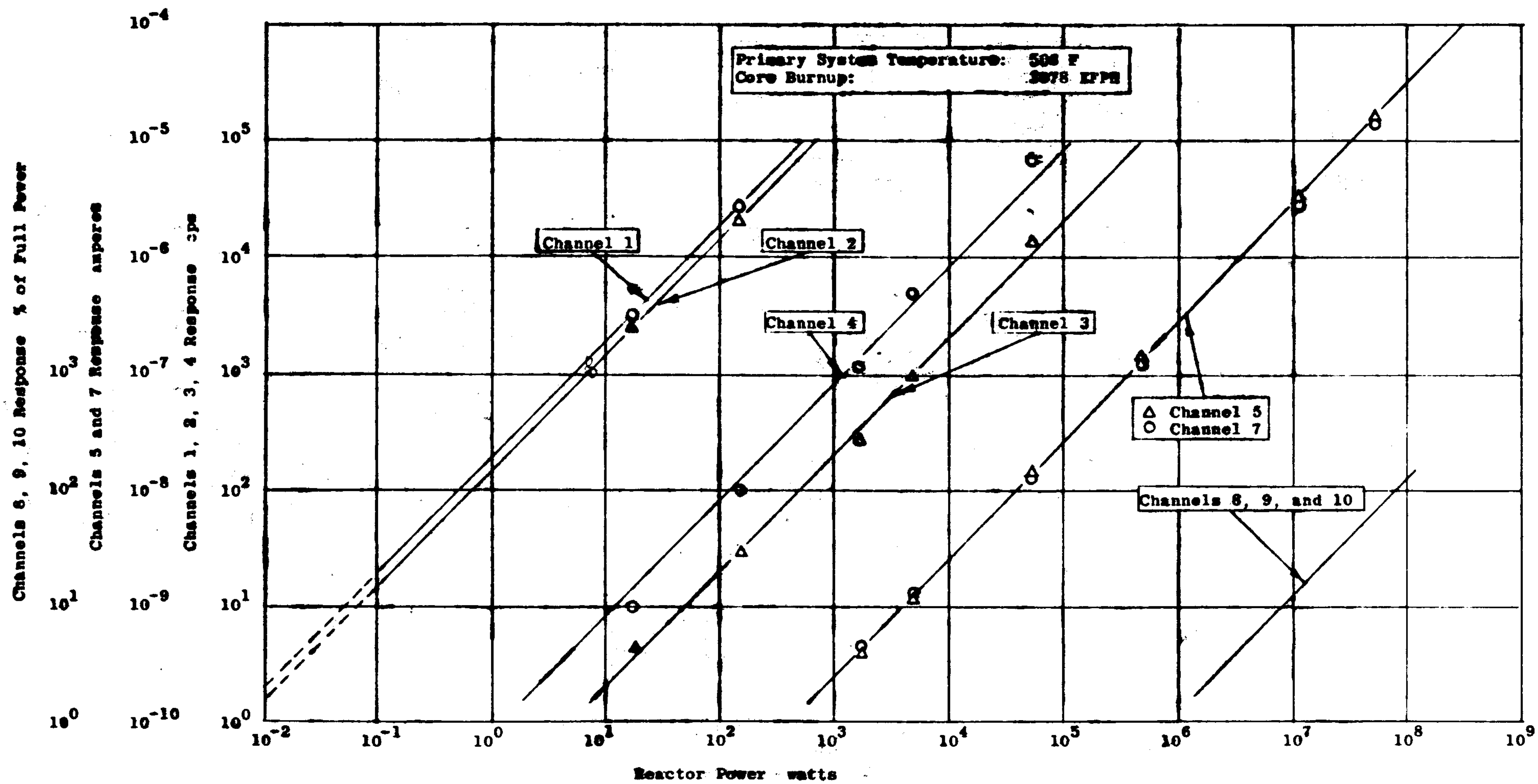
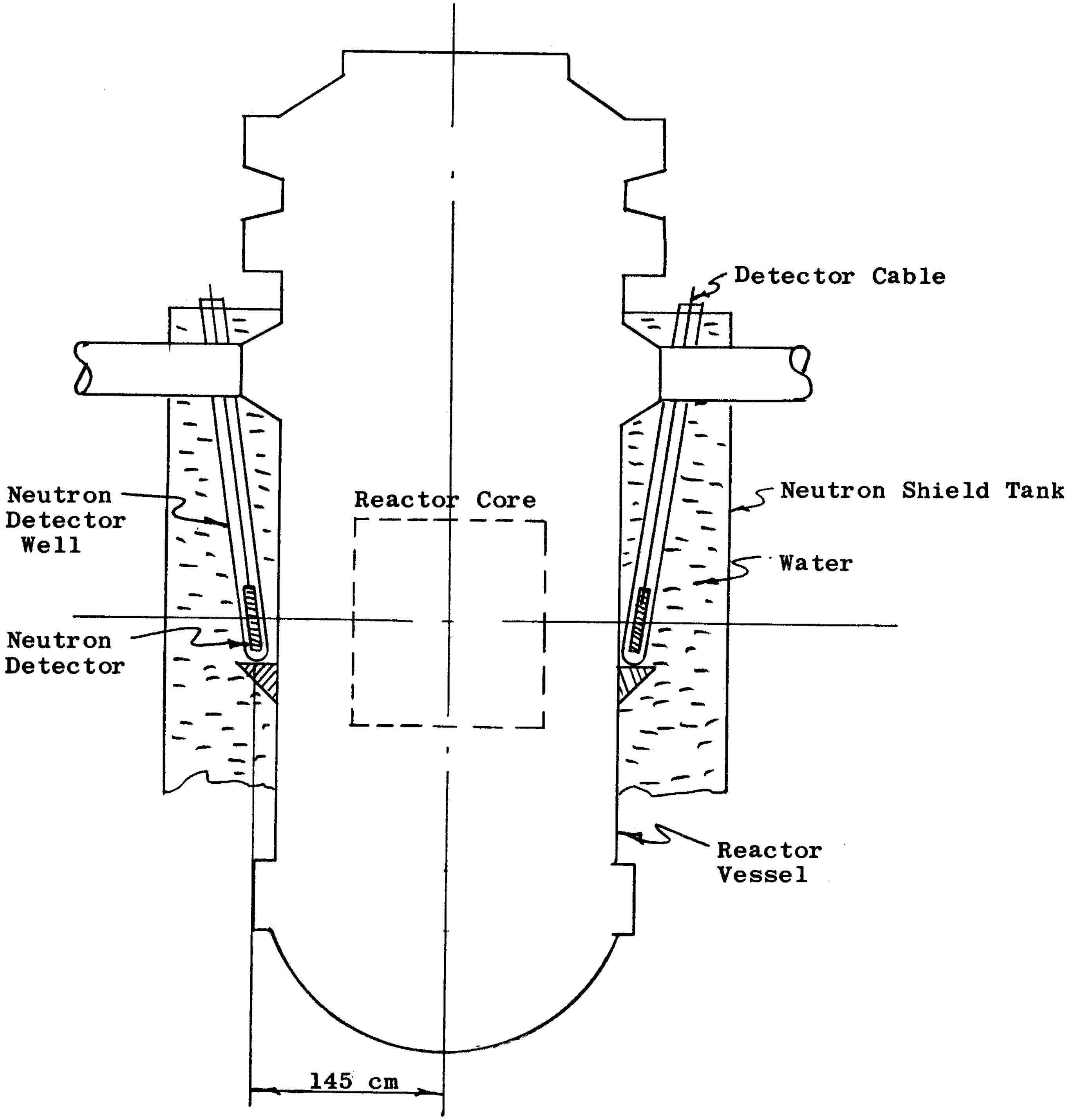


Figure 10-7. Neutron Detector Positions, Side View



Note: See Figure 6-3 for a Plan View of the Neutron Detector Locations.

Figure 10-8. Nuclear Instrumentation Cabinets

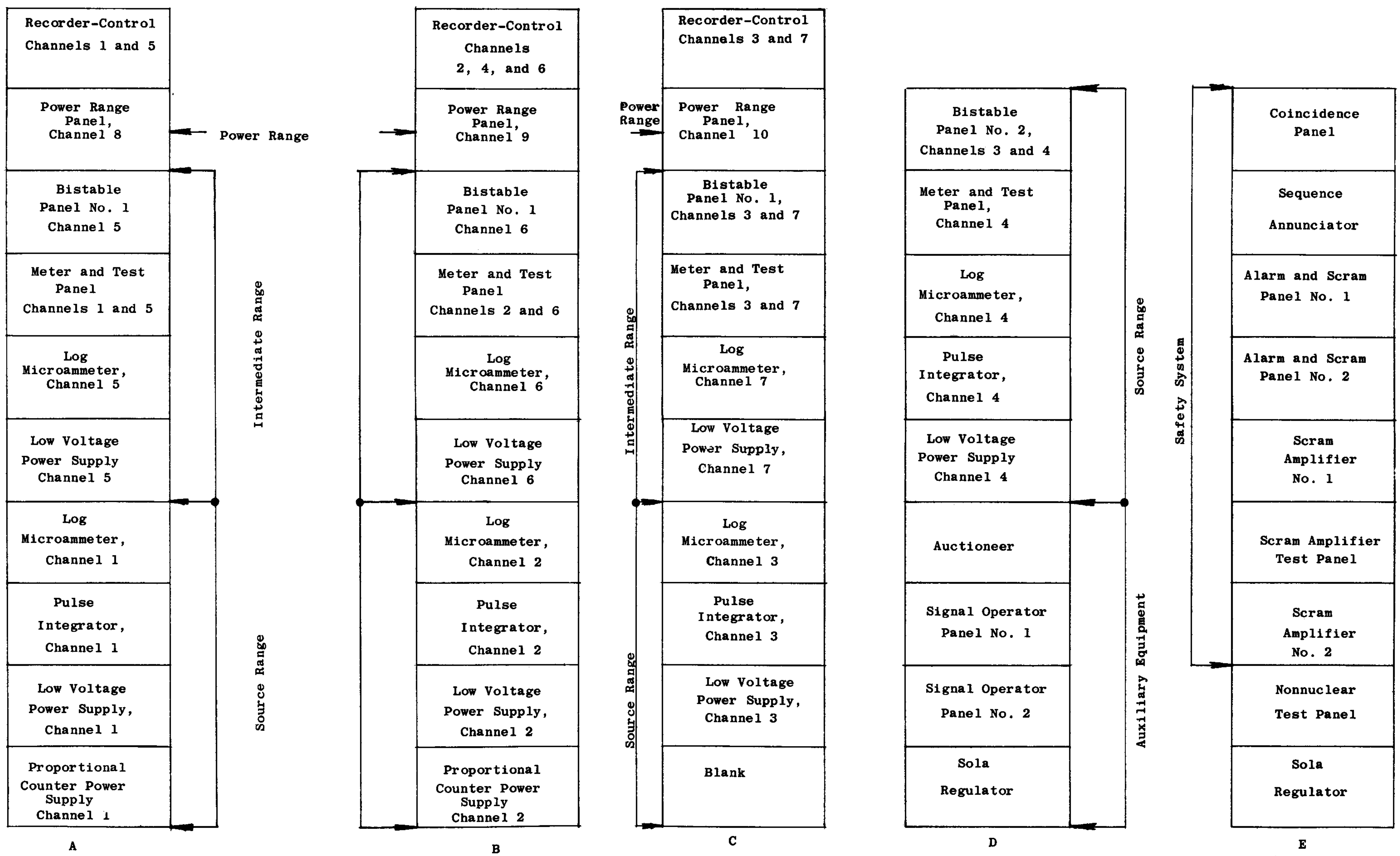


Figure 10-9. Nuclear Instrumentation Power Supply

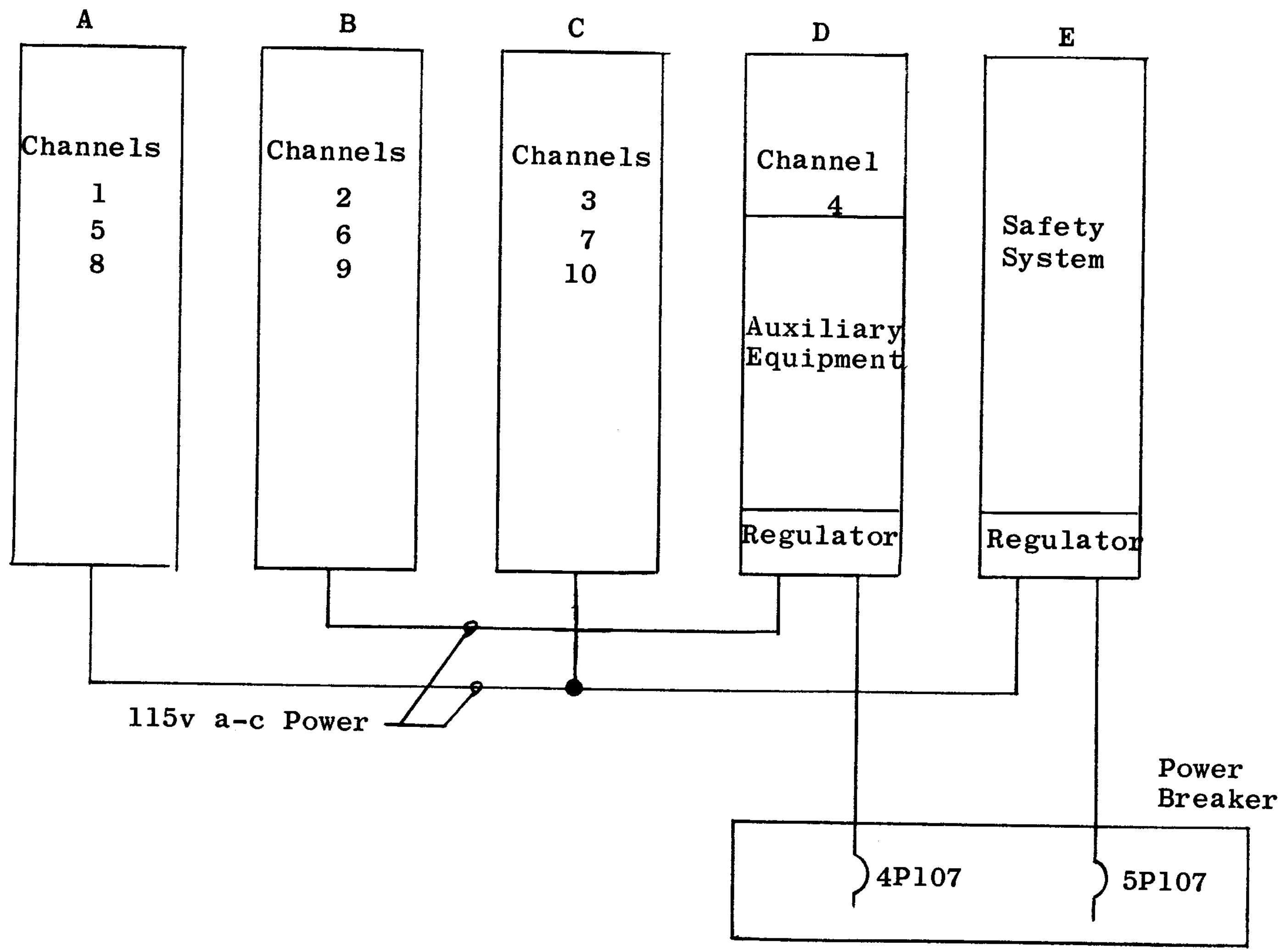


FIGURE 10-10. Source Range Instrumentation Block Diagram

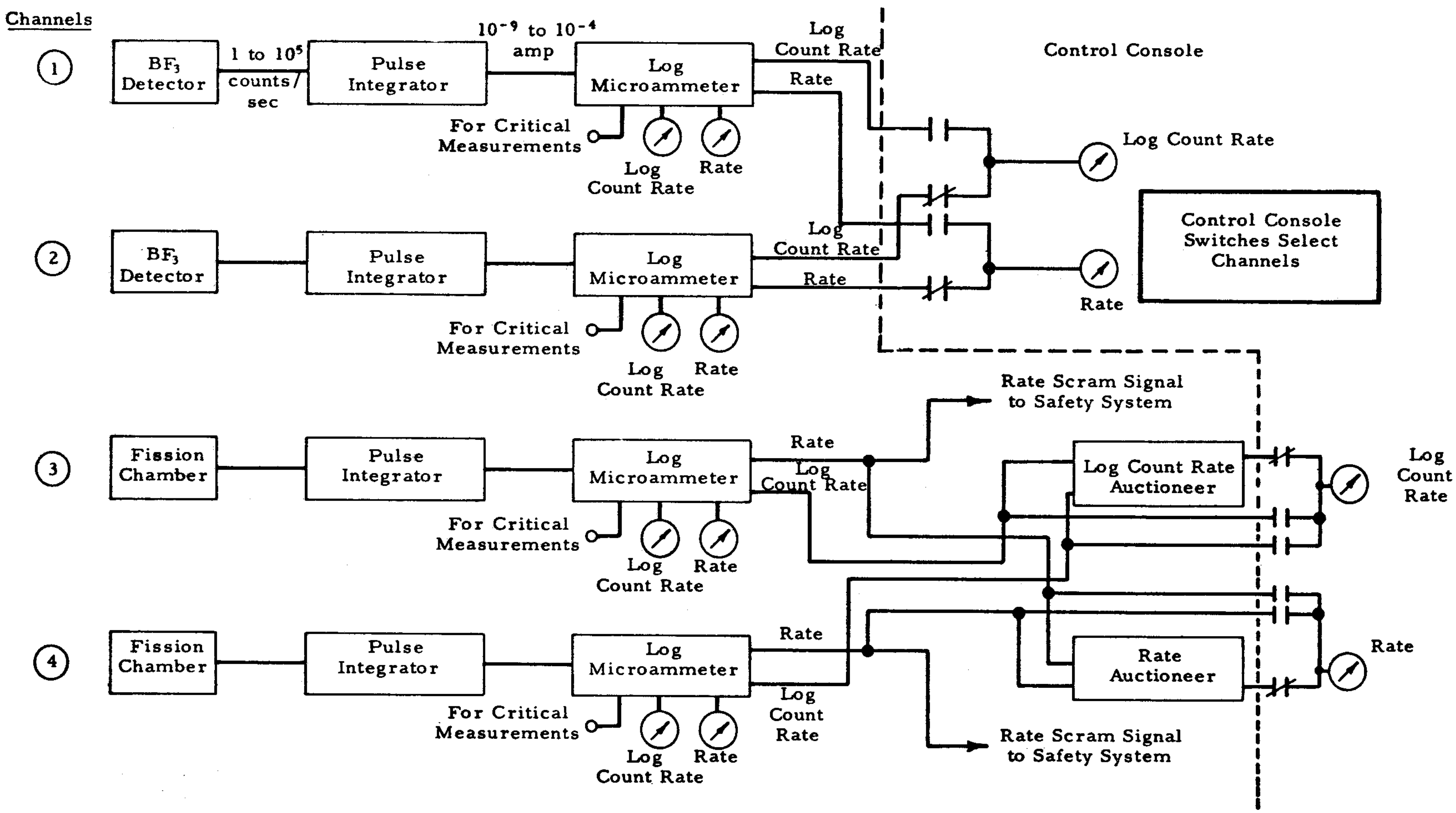


Figure 10-11. Source Range Instrumentation Channel 1

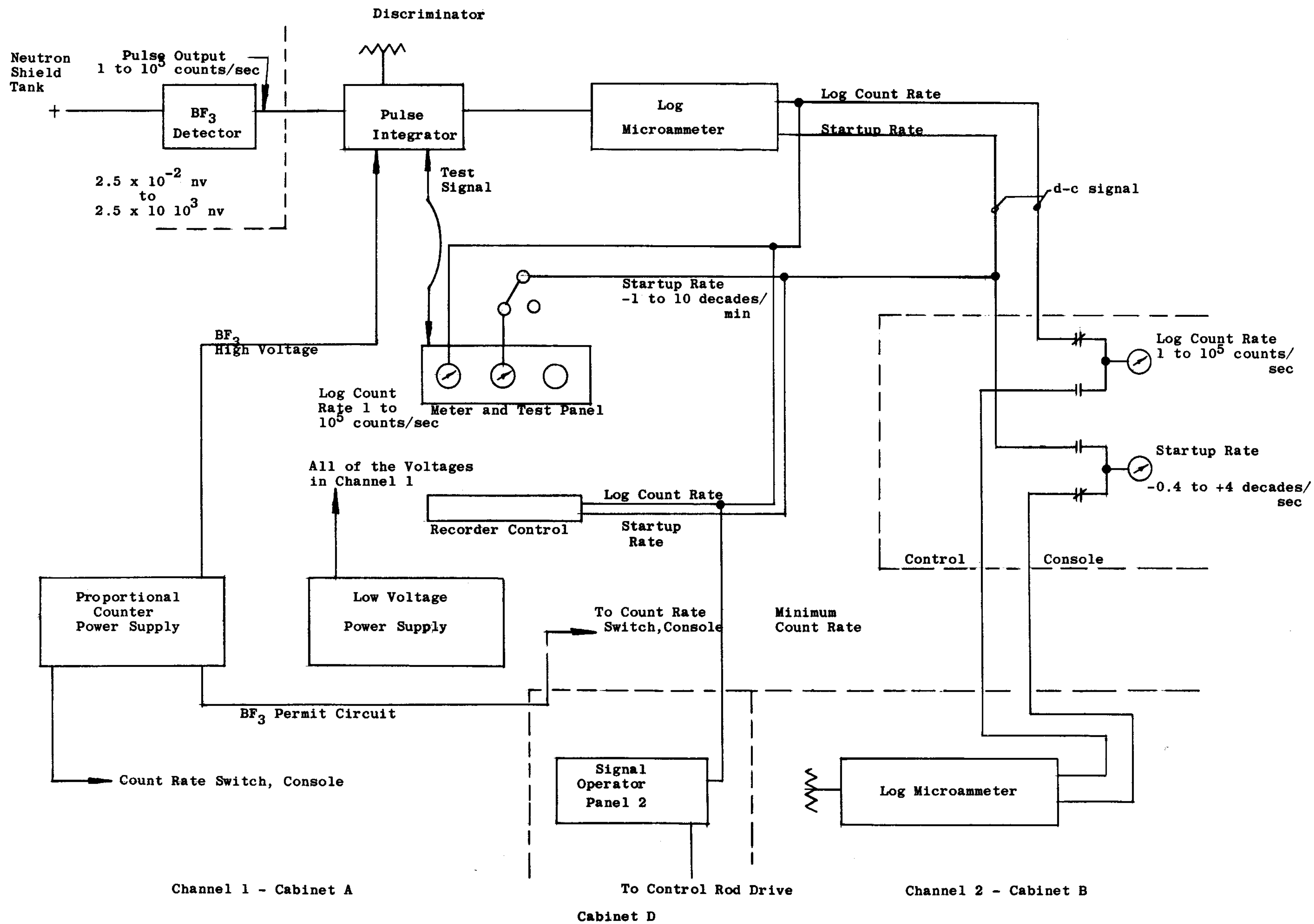


Figure 10-12. Source Range Instrumentation Channel 3

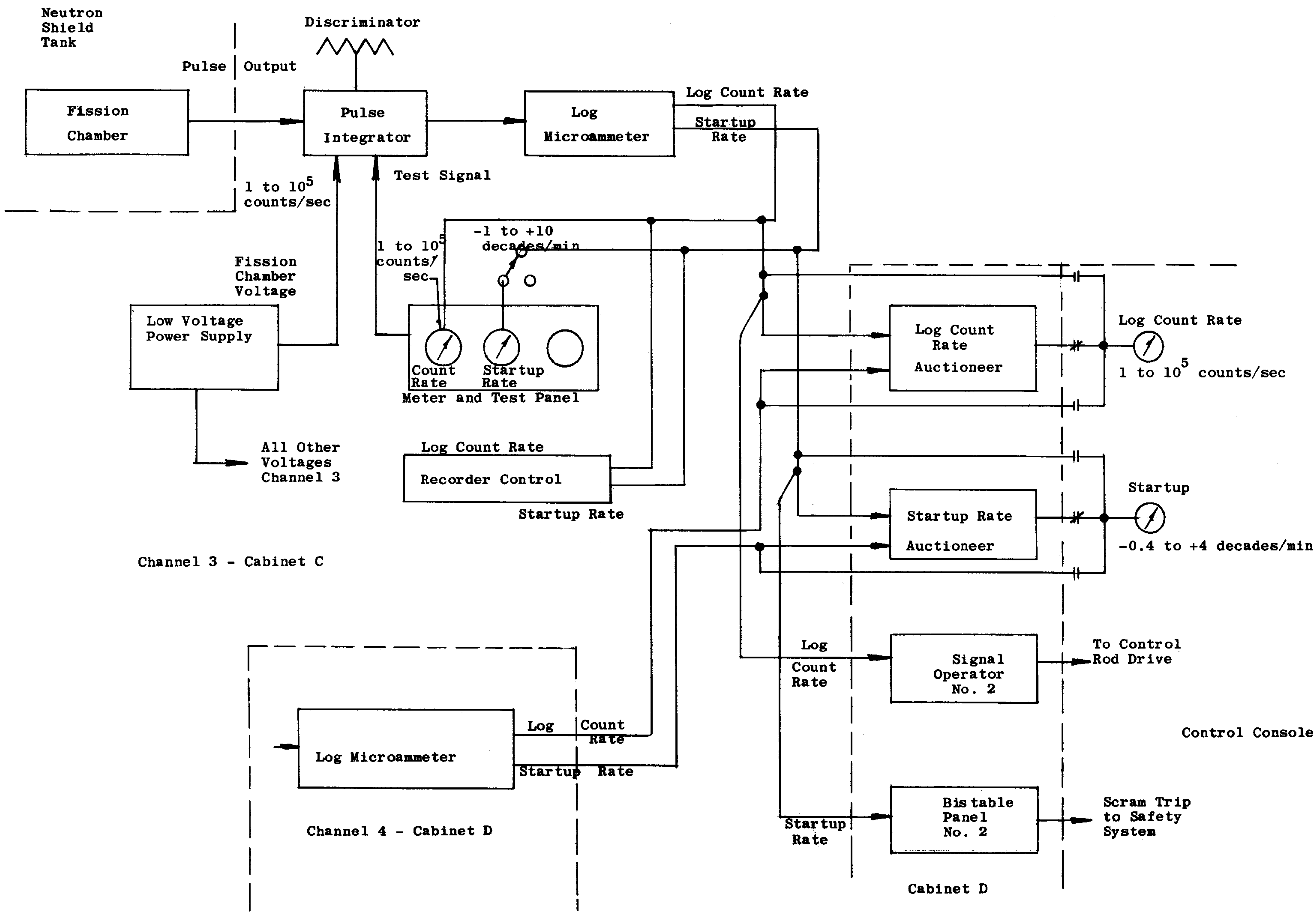


Figure 10-13. Intermediate Range Instrumentation Block Diagram

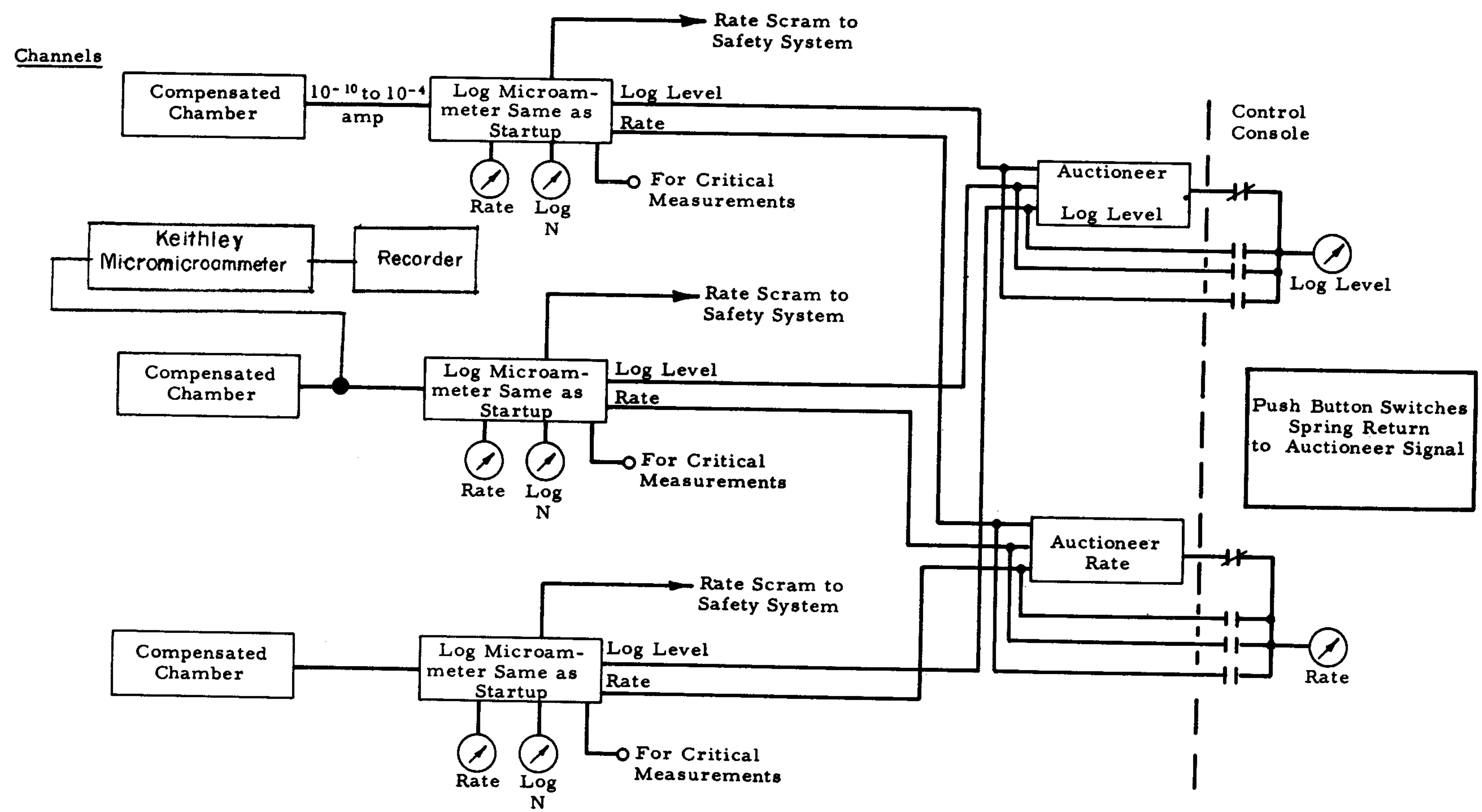


Figure 10-14. Intermediate Range Instrumentation

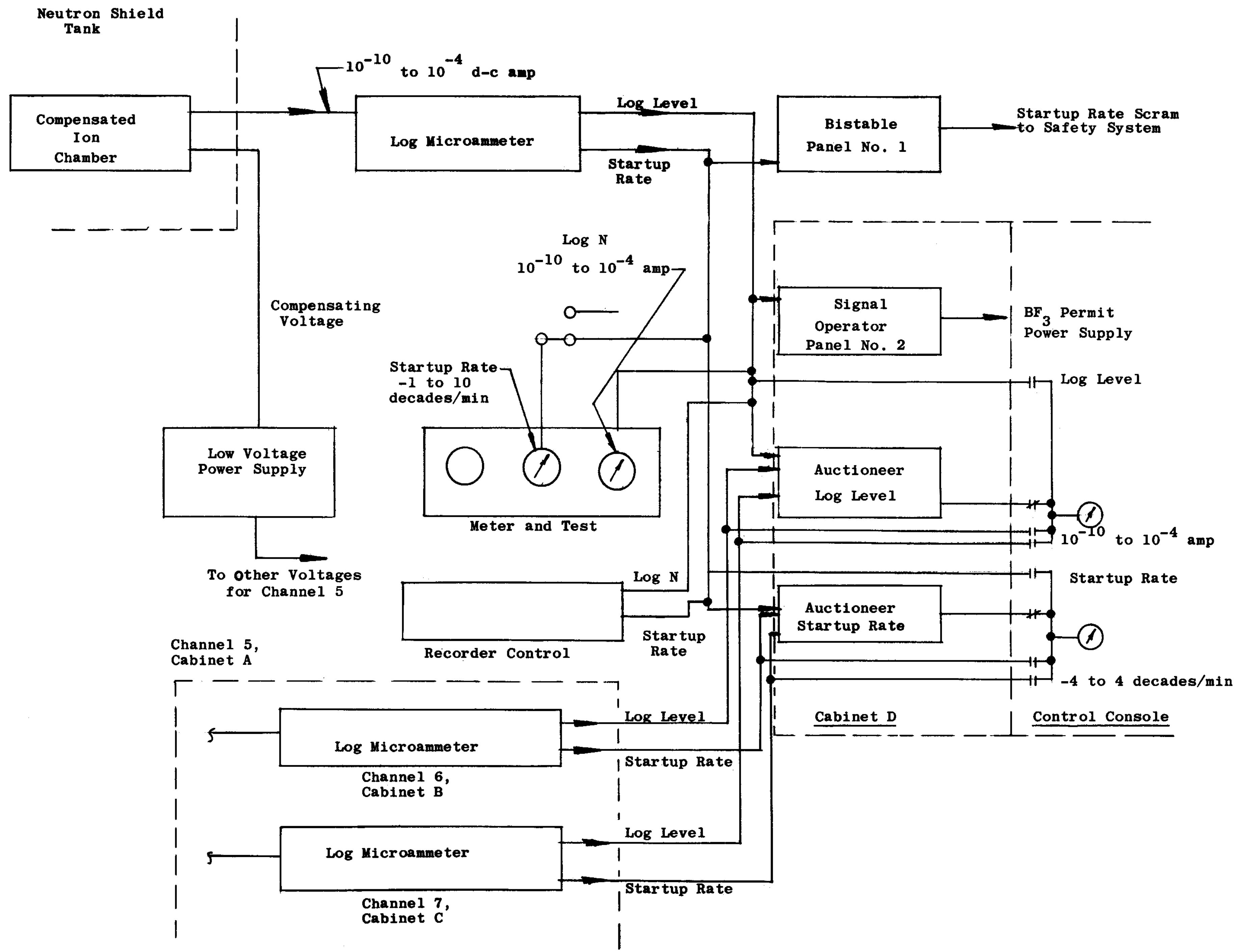


Figure 10-15. Power Range Instrumentation Block Diagram

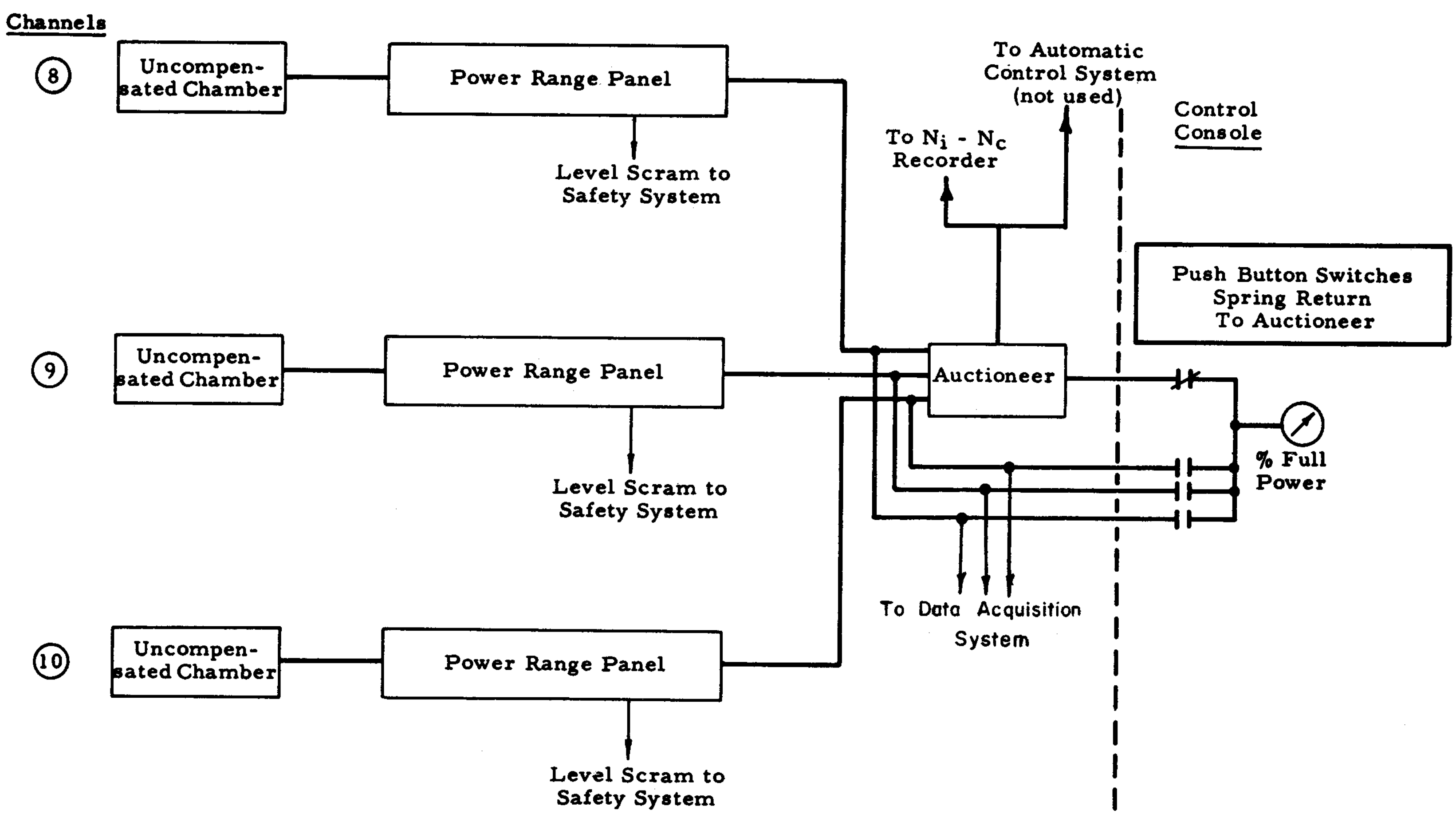


Figure 10-16. Power Range Instrumentation

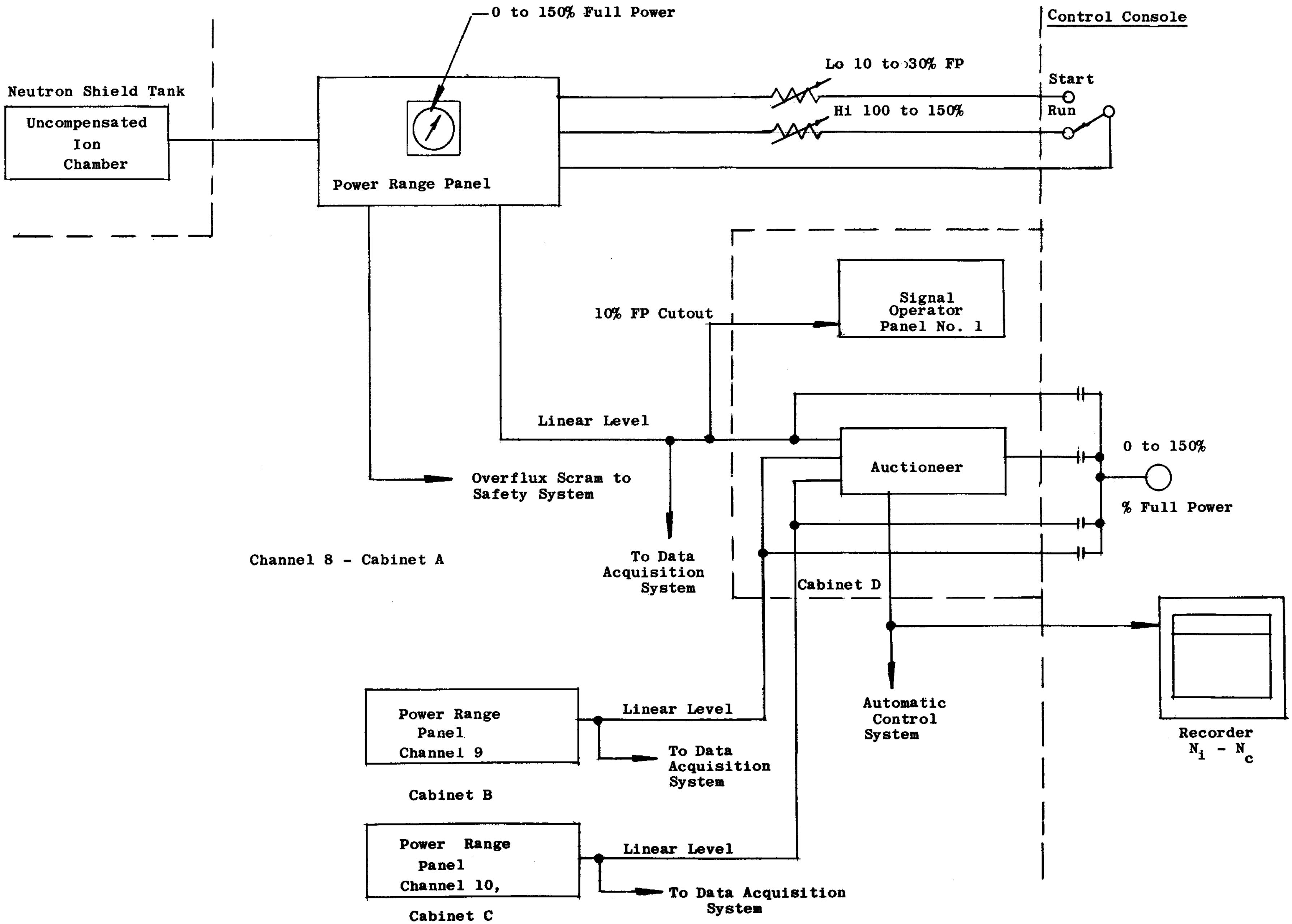


FIGURE 10-17: REACTOR SAFETY SYSTEM-BLOCK DIAGRAM

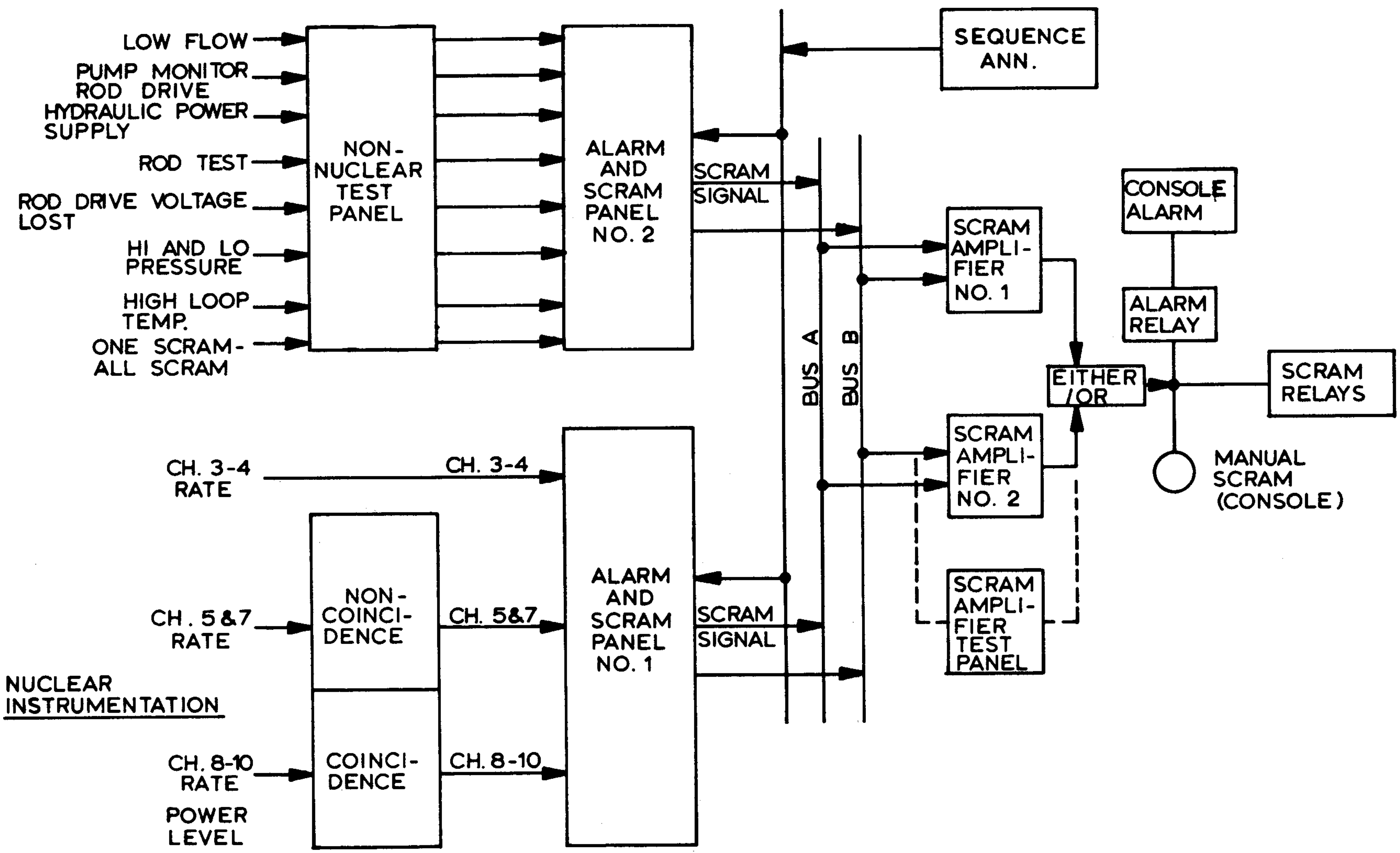


Figure 10-18. Reactor High-Temperature Scram Instrumentation

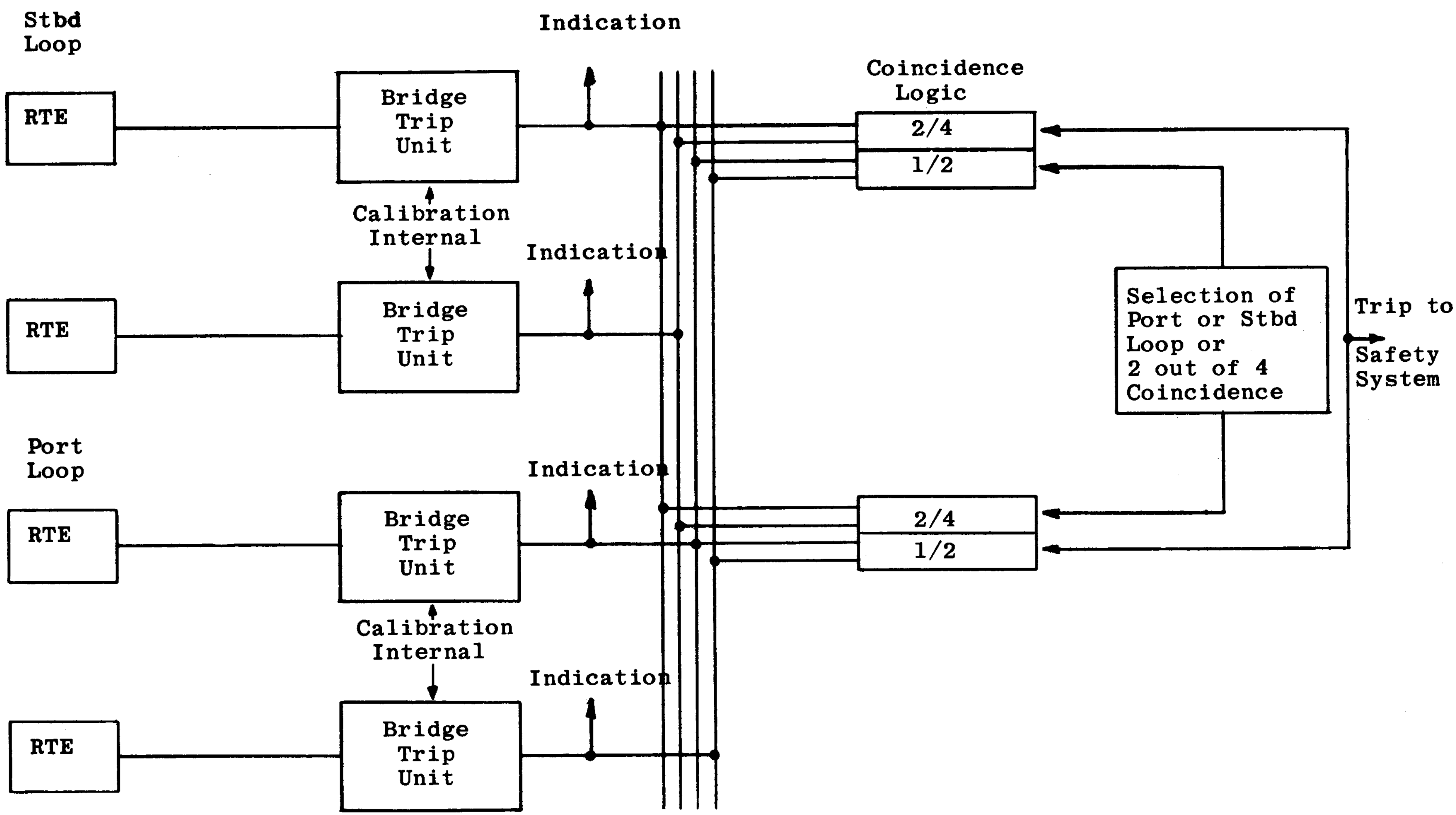


Figure 10-19. Reactor High-Low Pressure Scram Instrumentation

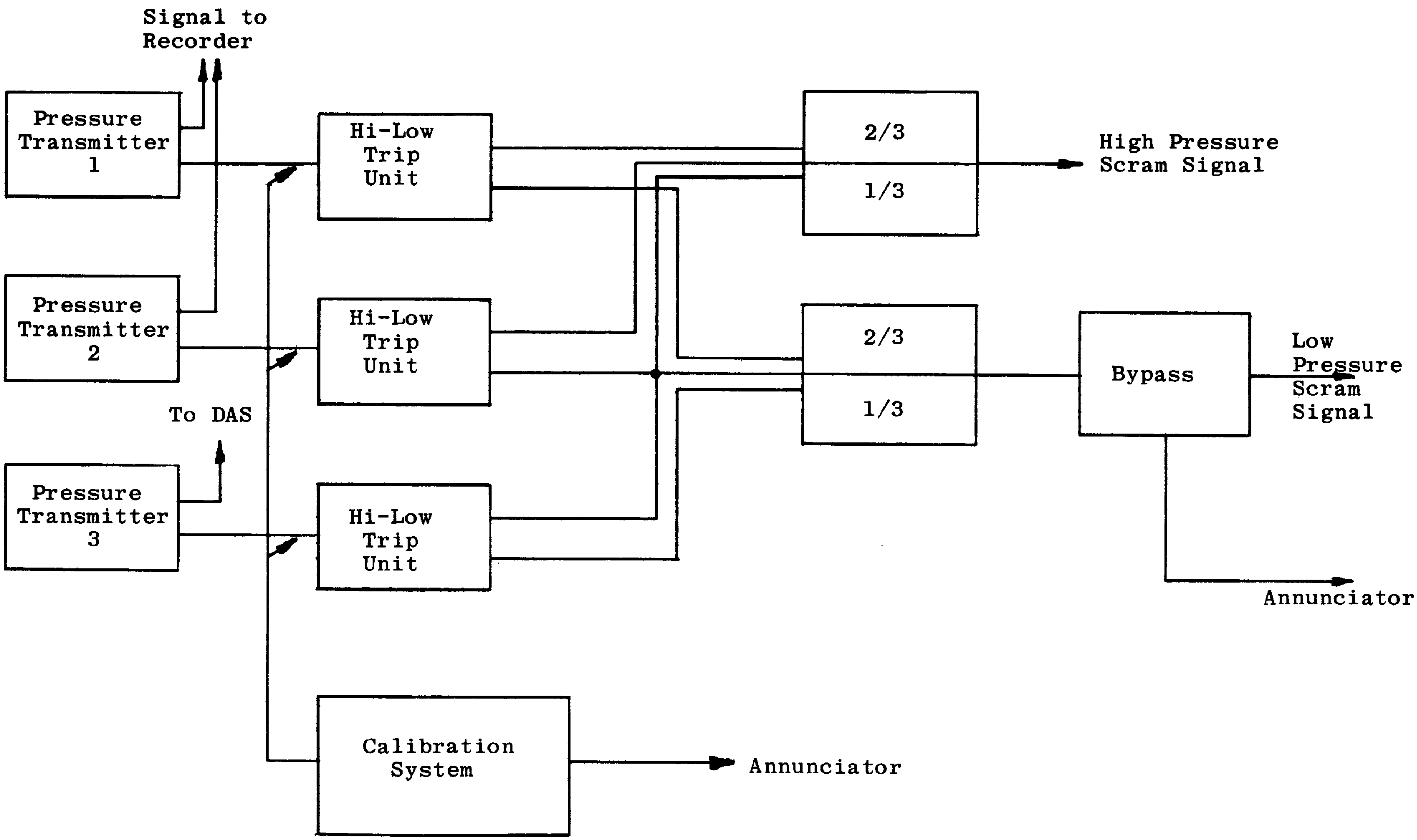


Figure 10-20. Pump Monitor Circuit

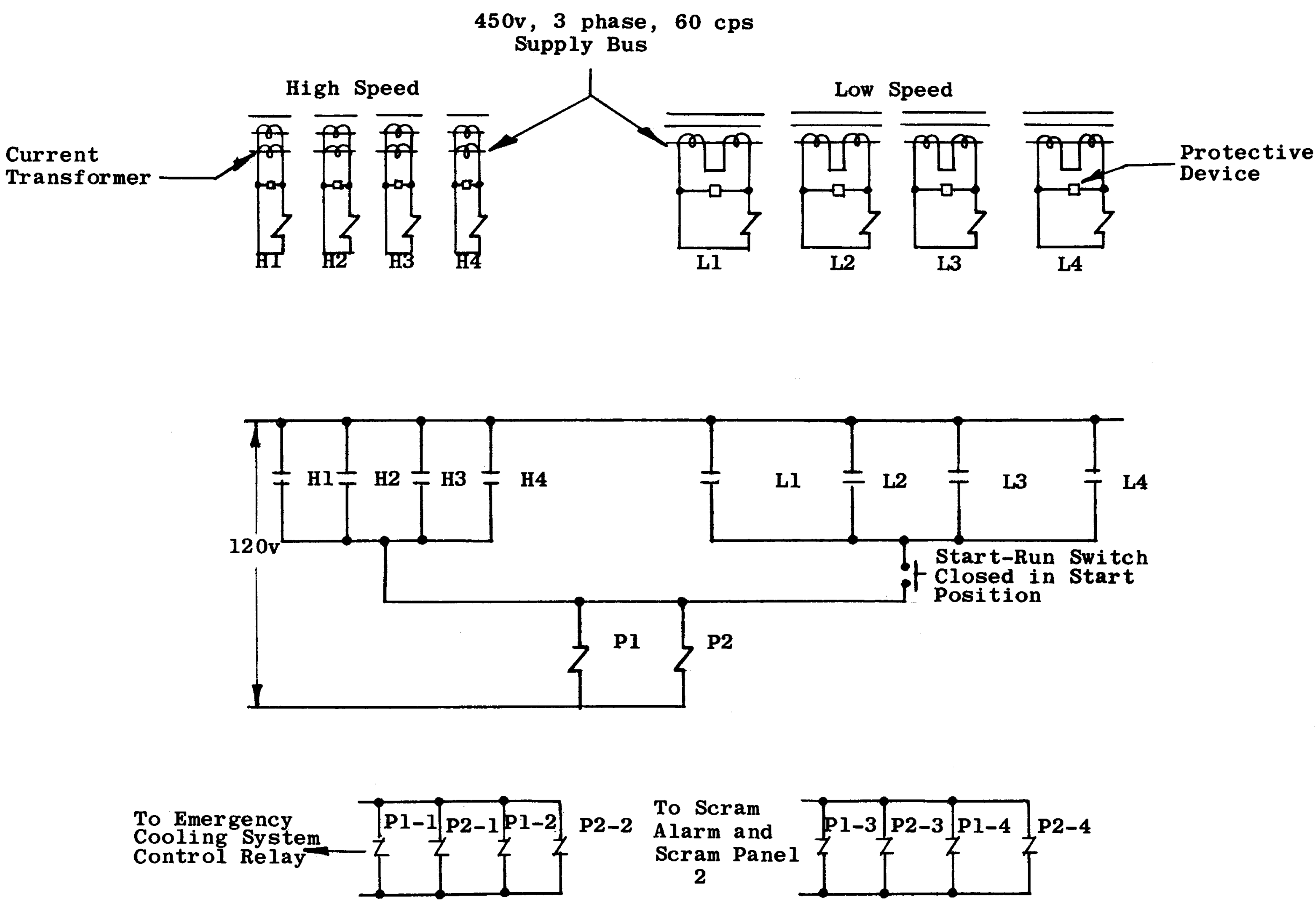


Figure 10-21. Low Flow Scram

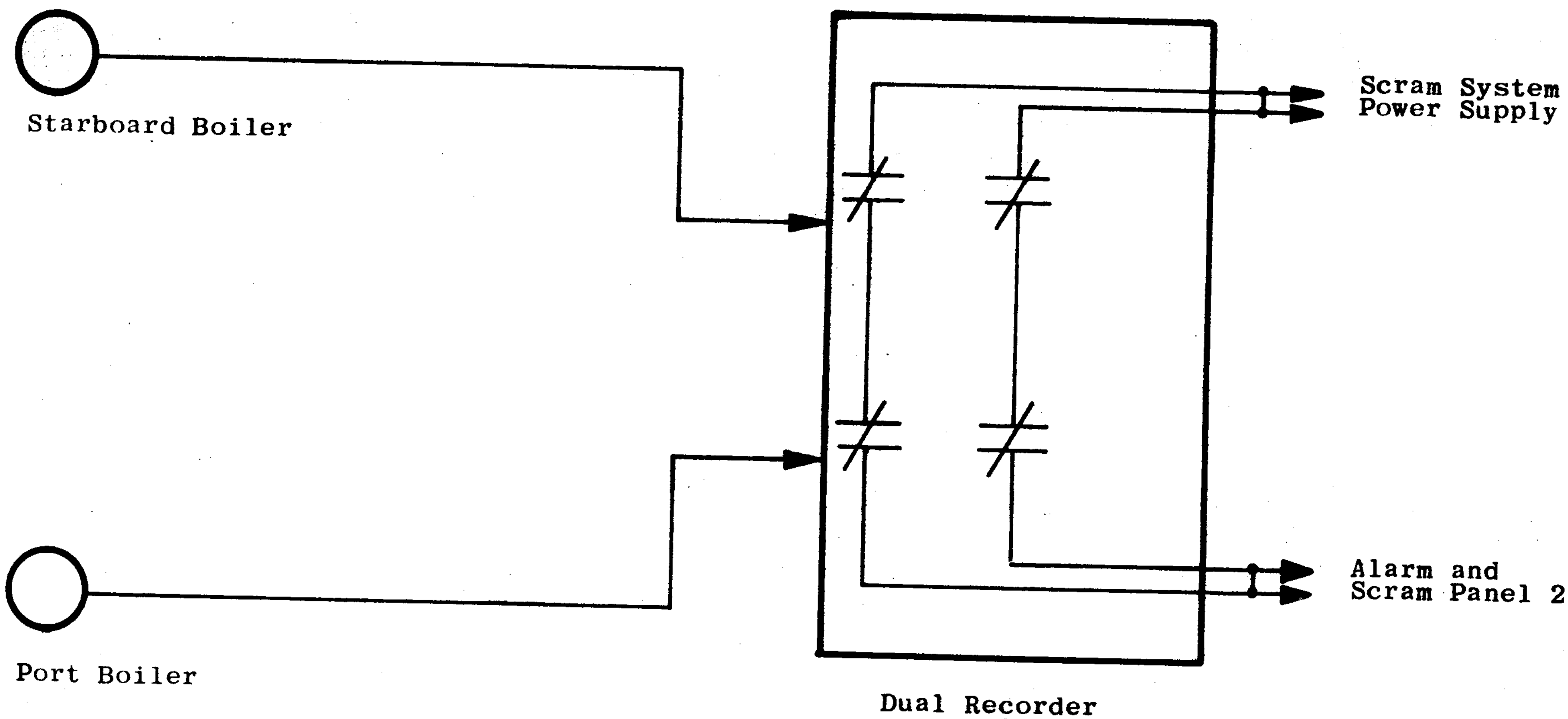
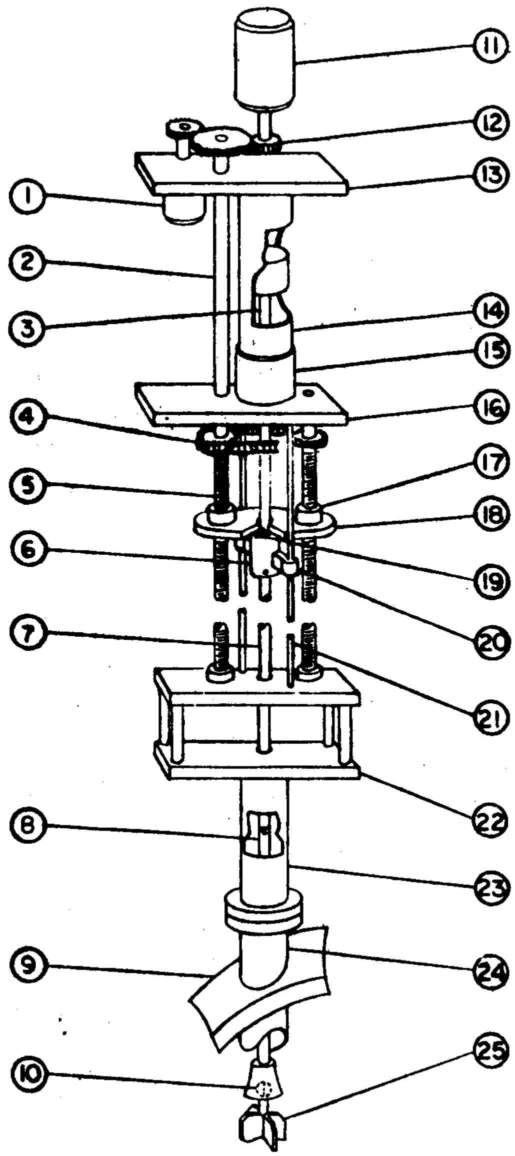


Figure 10-22 Control Rod Drive Assembly



(1) Position Indicator
(2) Lead Screw Drive Shaft
(3) Hydraulic Piston Shaft
(4) Chain and Sprocket Drive Assembly
(5) Lead Screw
(6) Coupling Piece
(7) Buffer Seal Shaft
(8) Buffer Seal Extension Shaft
(9) Reactor Vessel Head
(10) Handling Knob
(11) Rod Drive Motor
(12) Reduction Gear
(13) Upper Mechanism Flange
(14) Hydraulic Cylinder
(15) Dash-Pot
(16) Lower Mechanism Alignment Plate Flange
(17) Drive Nut
(18) Carriage
(19) Drive (Actuator) Pin
(20) Latch Arm
(21) Tie Rod
(22) Thimble Platform
(23) Buffer Seal
(24) Control Rod Nozzle
(25) Control Rod

Figure 10-23. Control Rod Drive Hydraulic System Schematic

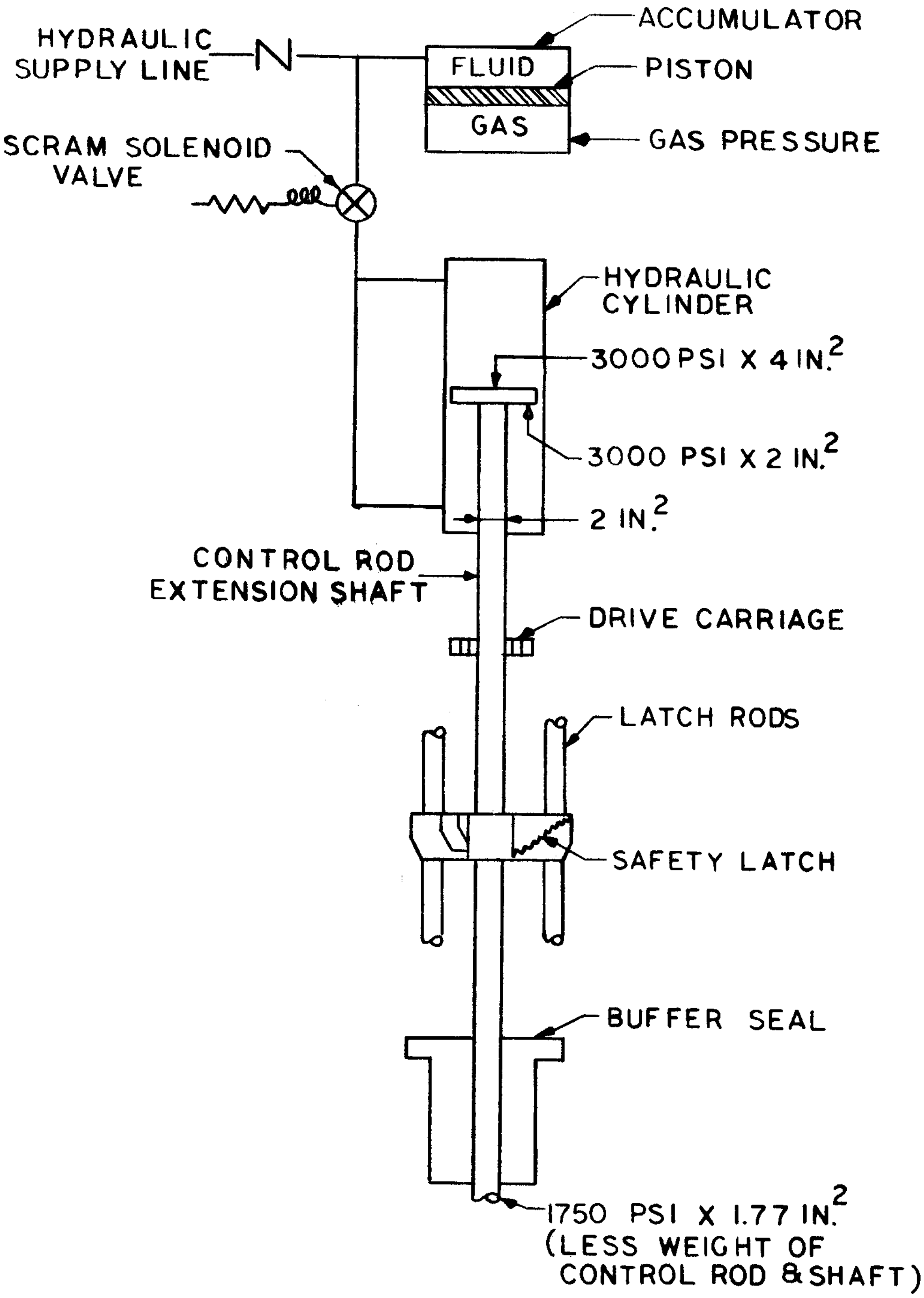


Figure 10-24. Normal Positioning and Pressure Balancing Simplified Flow Diagram

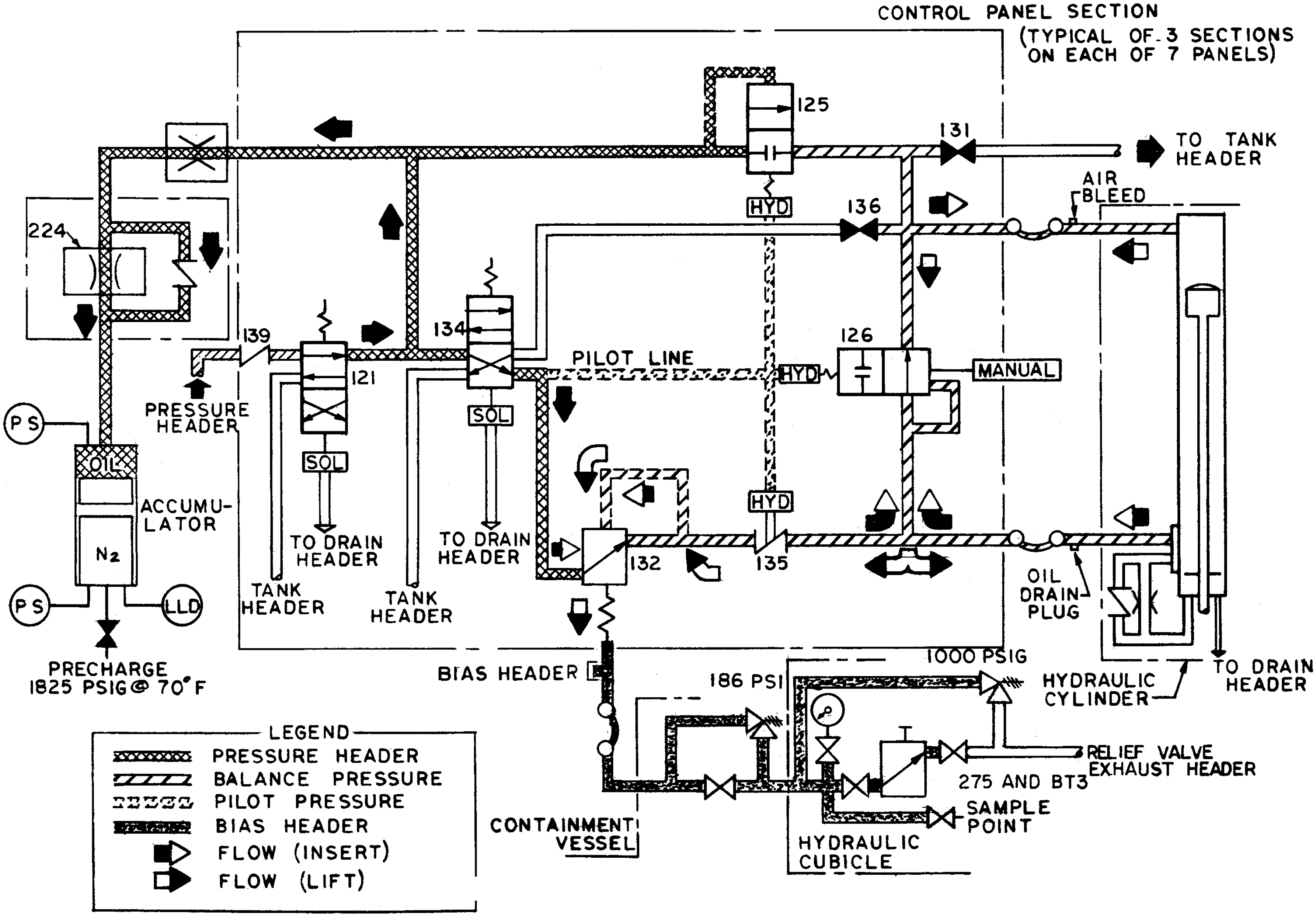


Figure 10-25. Scram Simplified Flow Diagram

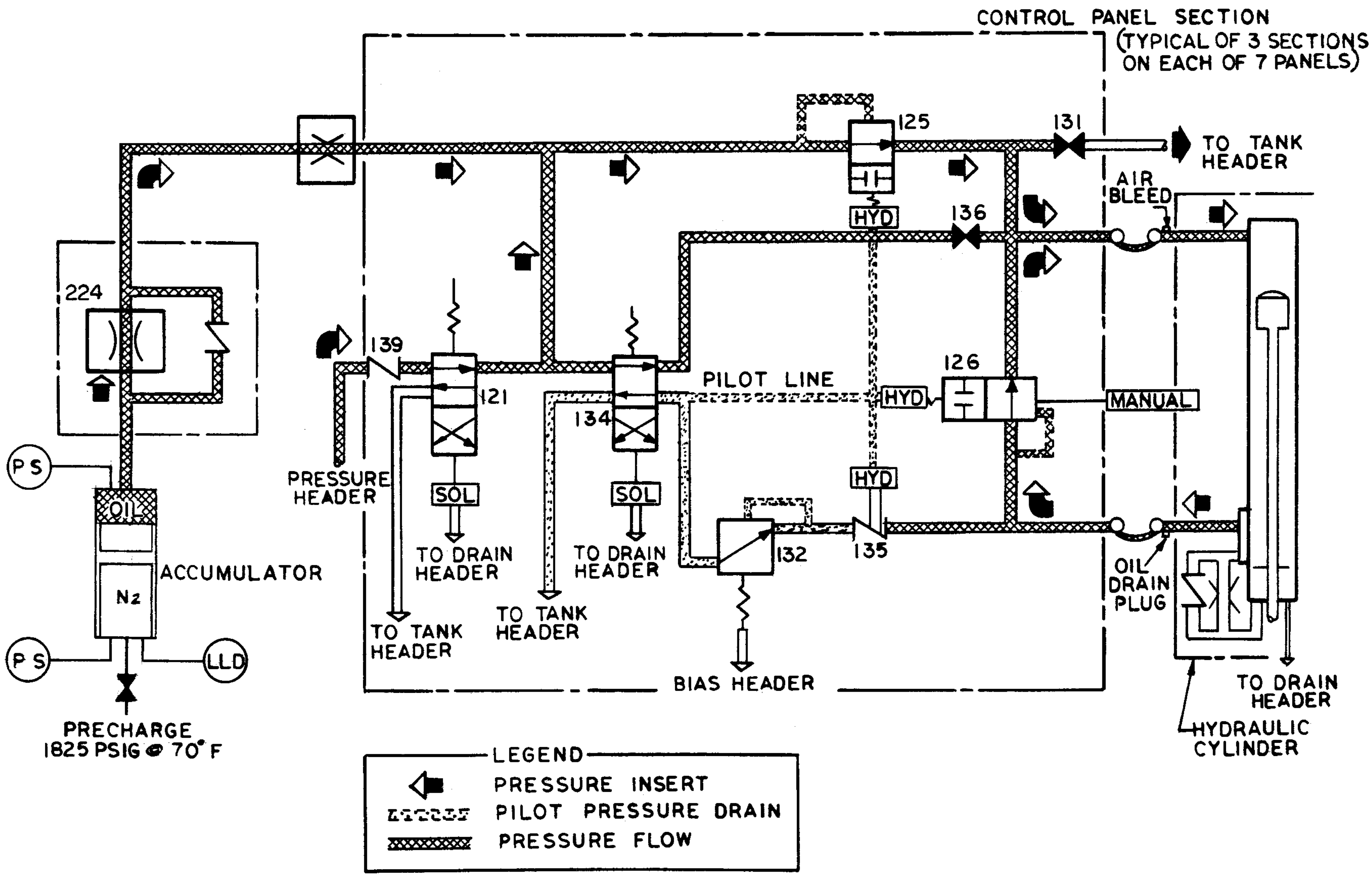


Figure 10-26. Zero Pressure Operation Simplified Flow Diagram

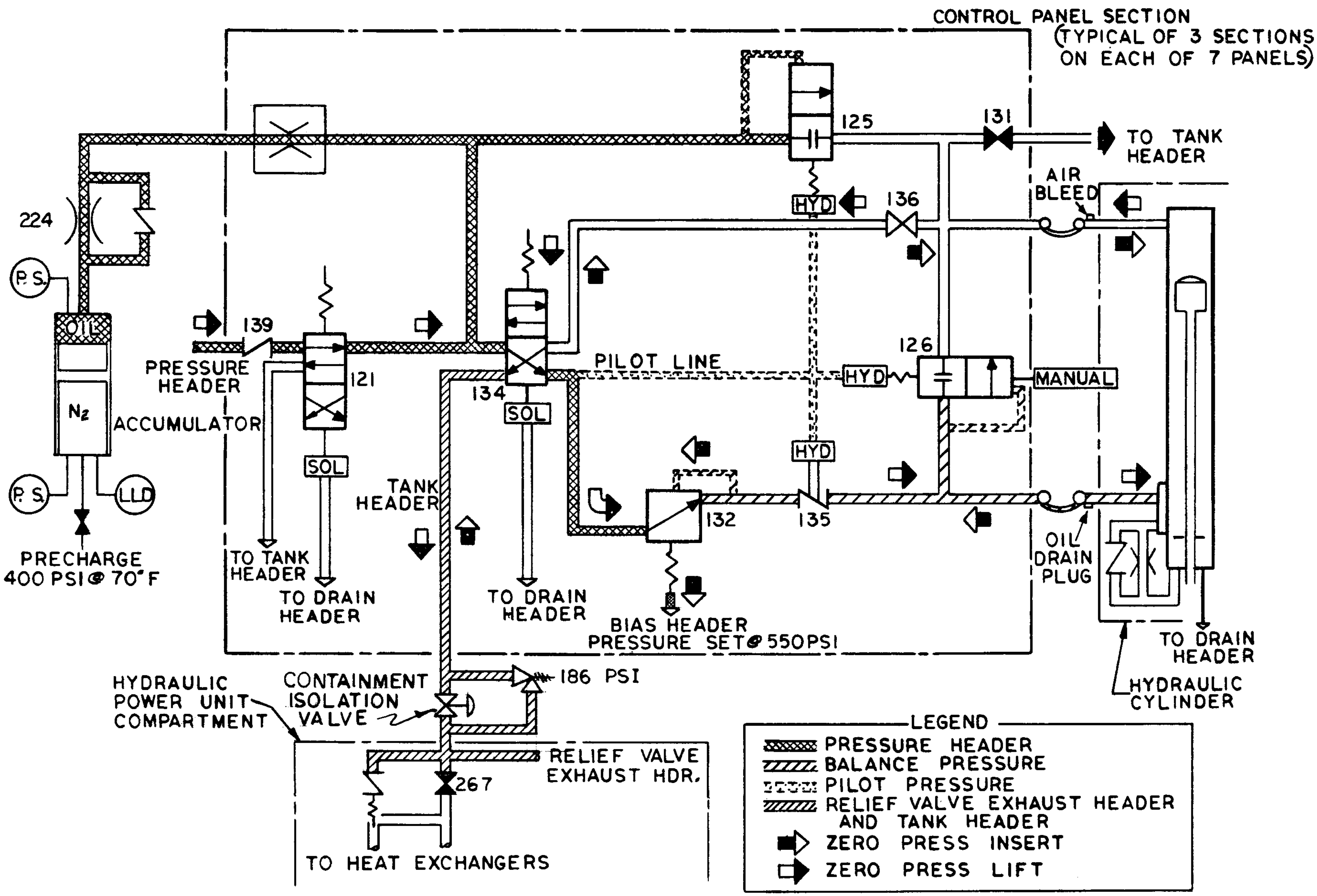


Figure 10-27. Radiation Monitoring Equipment Cabinet A

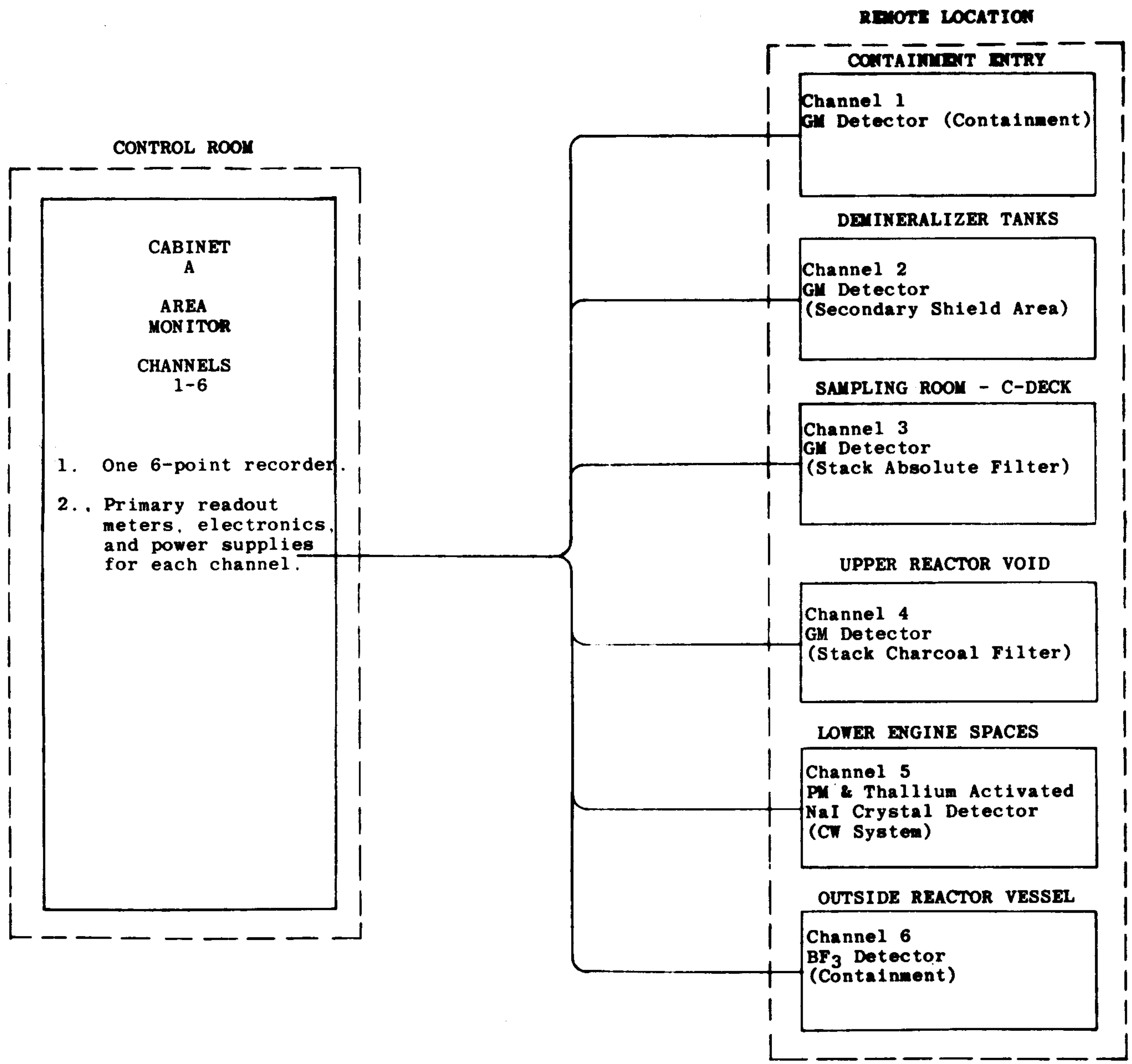


Figure 10-28. Radiation Monitoring Equipment Cabinet B

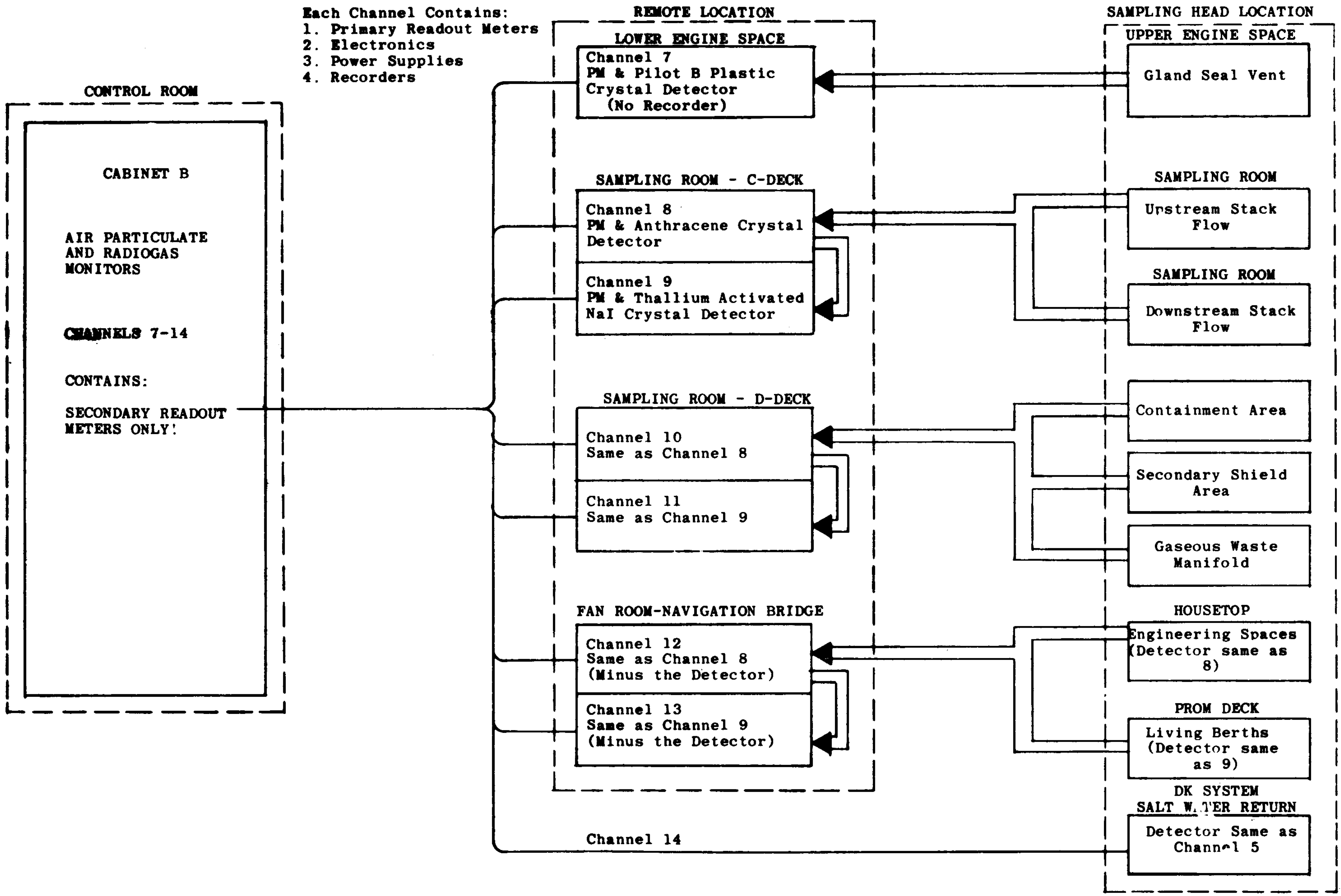


Figure 10-29. RMS Channels 1 through 6 and 14

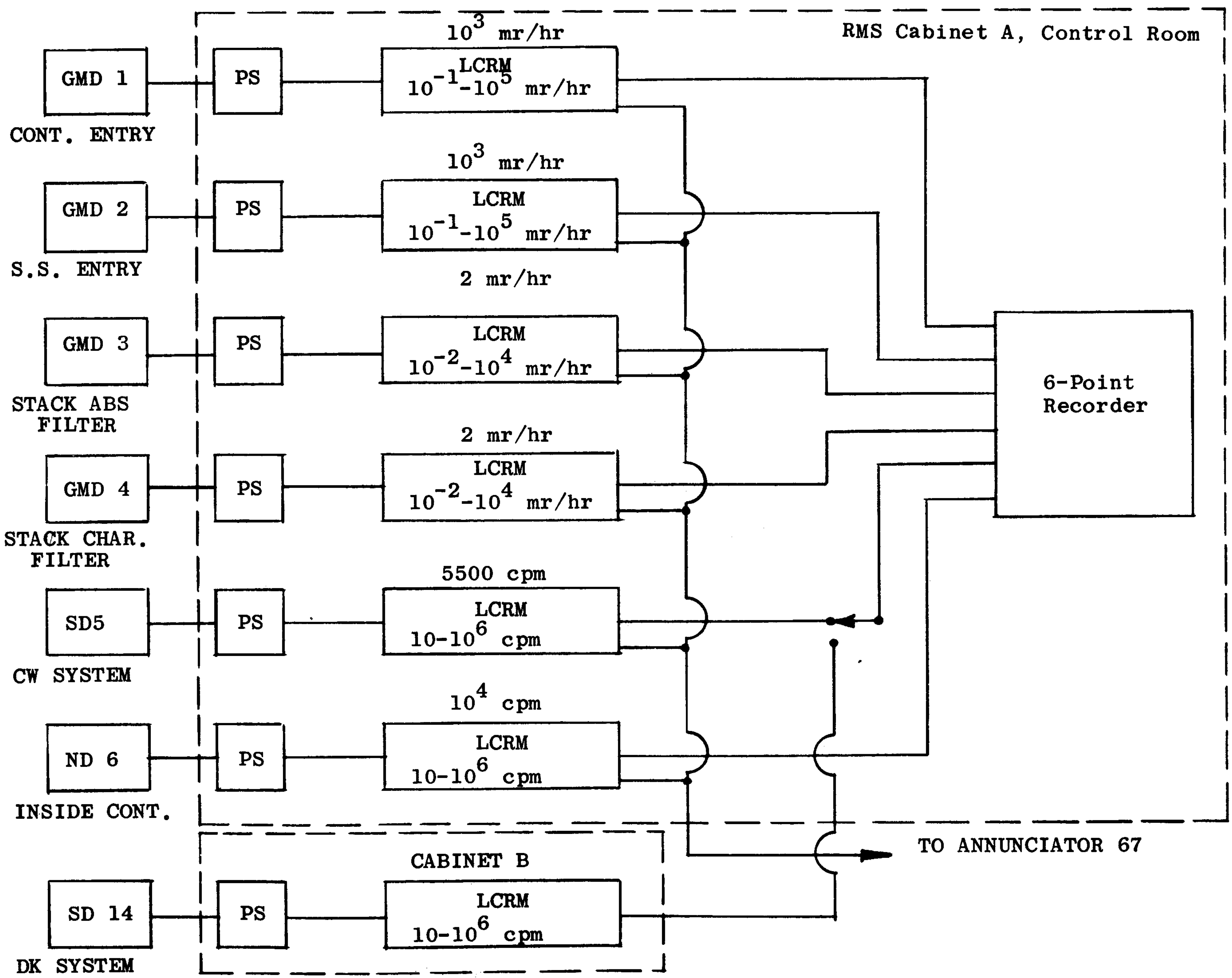


Figure 10-30. RMS Channels 8 & 9

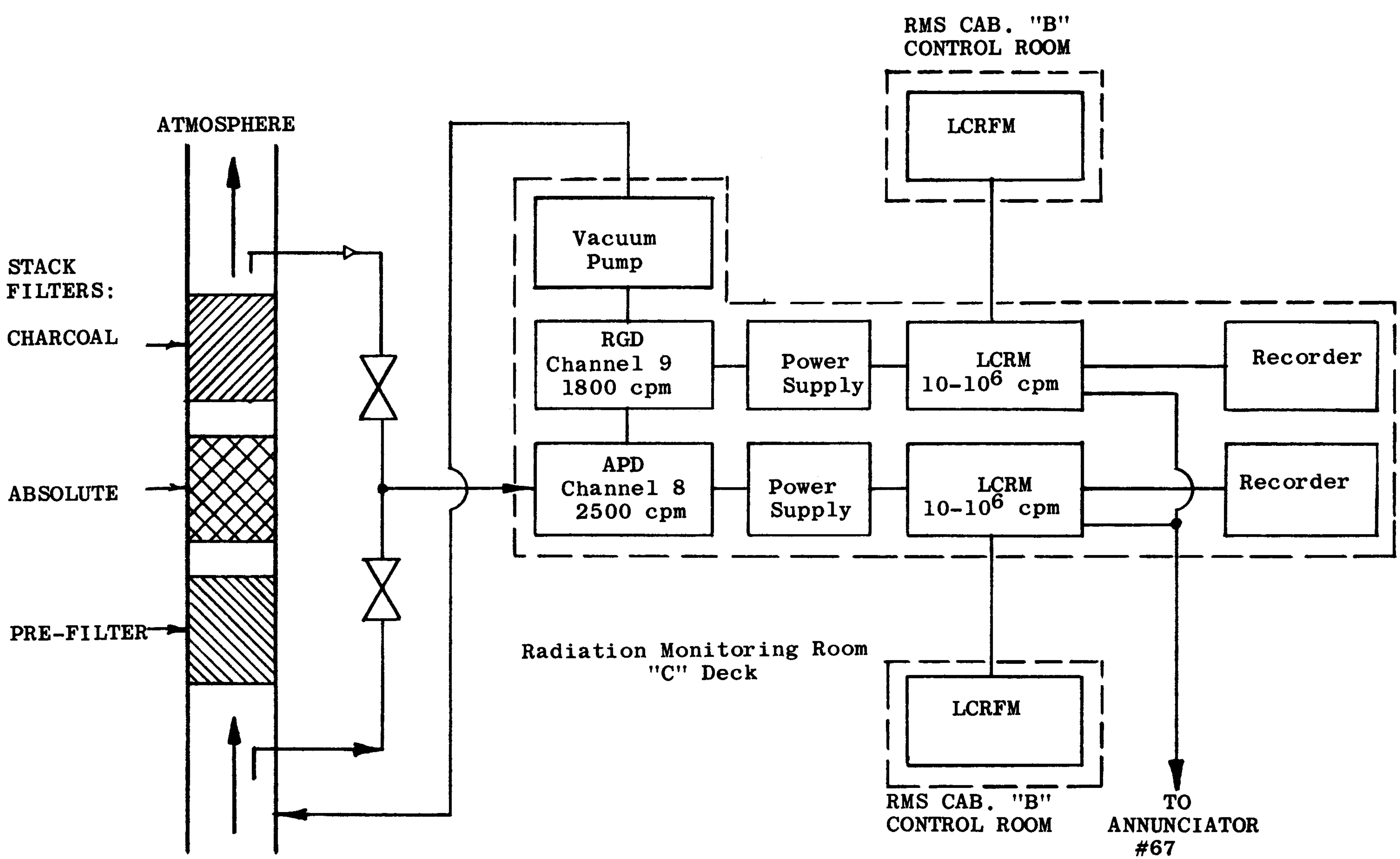


Figure 10-31. RMS Channels 10 and 11

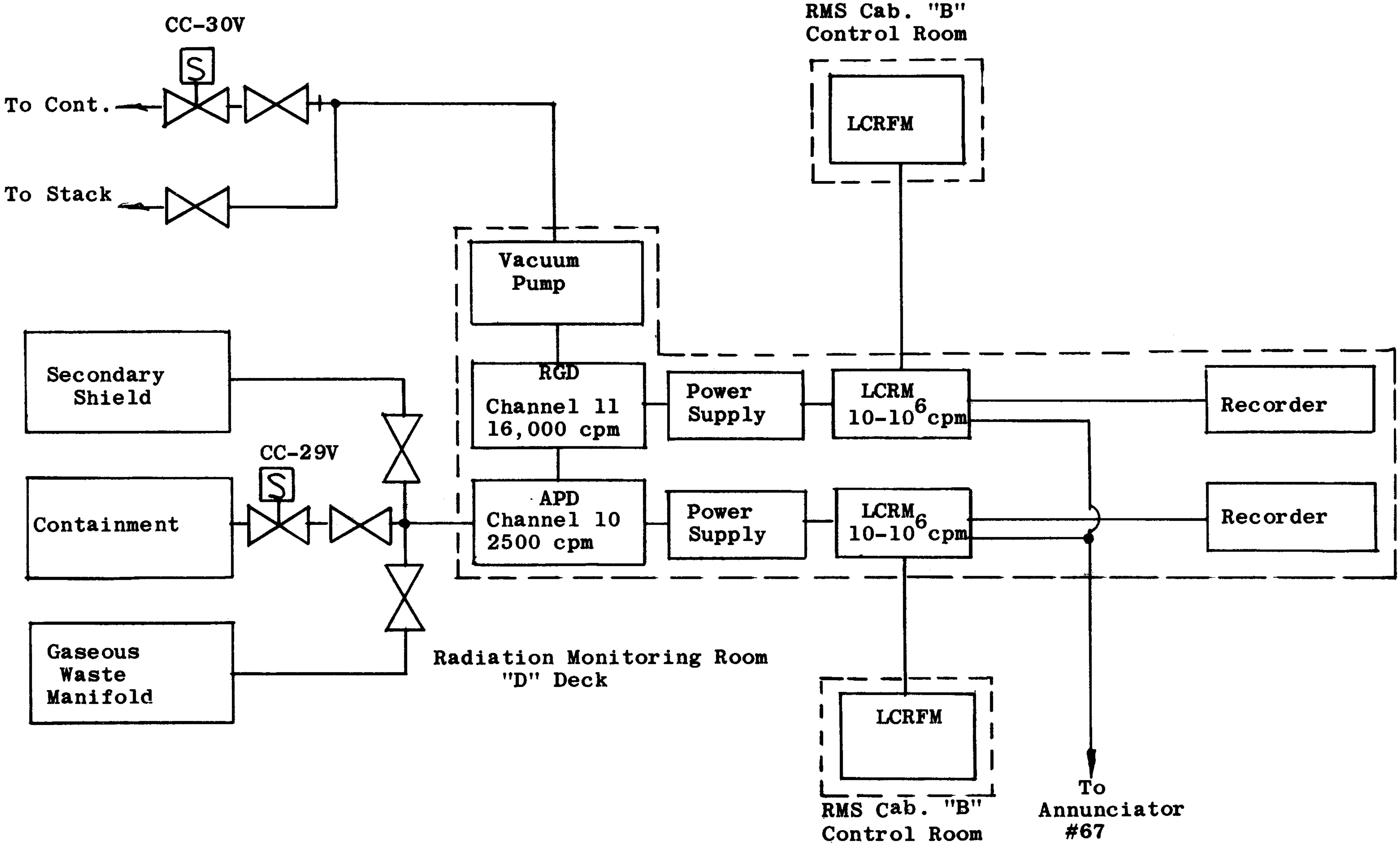


Figure 10-32. RMS Channels 12 and 13