Westinghouse Technology Systems Manual

Section 9.2

Incore Instrumentation System

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9.2 INCORE INSTRUMENTATION SYSTEM

Learning Objectives:

1. State the purposes of the incore instrumentation system.

2. Briefly describe the two types of incore instrumentation and the information available from each.

3. Describe the method used to detect flux thimble leakage.

4. Deleted.

5. List the uses of the data obtained from the incore instrumentation.

9.2.1 Introduction

The purposes of the incore instrumentation system are to provide information on neutron flux distribution and fuel assembly outlet temperatures at selected core locations. The incore instrumentation system provides data acquisition only and performs no protective or plant operational control functions. The incore instrumentation system includes the movable incore neutron flux monitoring system and the incore temperature monitoring system. The number of incore temperature monitoring thermocouples and the number of flux thimble paths available within the core for the movable detectors varies according to whether the plant is a two-, three-, or four-loop Westinghouse design. The locations of the incore flux thimbles and thermocouples within the reactor core of a four-loop Westinghouse plant are shown in Figure 9.2-1.

The incore neutron monitoring system consists of miniature fission chambers with sufficient sensitivity to permit measurement of localized neutron flux distribution variations within the reactor core. The data obtained from the incore neutron flux monitoring system is used to:

1. Routinely verify that the following power distribution hot channel factors are in compliance with technical specification limits:

   a. Heat flux hot channel factor ($F_Q(Z)$), and
   b. Nuclear enthalpy rise hot channel factor ($F^N_{\Delta H}$);

2. Calibrate the excore power range nuclear instruments for axial flux difference (AFD);

3. Verify control rod positions when the rod position indication system is inoperable; and

4. Verify that the quadrant power tilt ratio (QPTR) meets the technical specification limit with core power > 75% and with one or more power range neutron flux channels inoperable.

The incore temperature monitoring system consists of fixed thermocouples, referred to as core-exit thermocouples (CETs), positioned at the top of the upper core plate. They measure the core outlet coolant temperatures of instrumented fuel assemblies. This data is used to:

1. Provide inputs to the subcooling margin monitors,

2. Provide the operators with indications of inadequate core cooling conditions during emergency situations, and

3. Provide inputs to plant computer computational applications which use core-exit temperatures to determine fuel assembly enthalpy rises and limited power distribution information. This information is not used to verify compliance with technical specification requirements. Anomalous core-exit thermocouple readings may indicate a serious core condition and should be investigated.

9.2.2 System Description

9.2.2.1 Incore Neutron Monitoring System

Movable miniature fission chamber detectors (Figure 9.2-2), containing U_30_8 (uranium oxide) enriched to greater than 90 percent in U-235, enable detailed neutron flux (power level) mapping of the reactor core. Each detector is attached to a flexible drive cable that can be driven into selected core locations by the plant operating staff. When not in use, the detectors are stored in a shielded concrete vault to minimize radiation exposure to plant personnel.

Figure 9.2-3 shows the basic system for the insertion of the movable miniature fission chamber into the core. Retractable detector thimbles, into which the miniature detectors are driven, are positioned as shown. Since these retractable detector thimbles are sealed at the leading (reactor) end, they are dry inside. The thimbles thus serve as a pressure barrier between the reactor water pressure (design pressure of 2500 psig) and the atmosphere. Mechanical high pressure seals between the retractable thimbles and the conduits are provided at the seal table. During normal plant operation, these retractable thimbles are stationary and fully inserted into selected fuel assemblies. The detector thimbles are retracted from the core before refueling or during core maintenance periods at which time the reactor coolant system is depressurized.

The drive system for the insertion and withdrawal of miniature fission chamber detectors consists of drive units, limit switch assemblies, five-path rotary transfer devices, ten-path rotary transfer devices, and isolation valves. The drive units are mounted permanently on a platform directly above the seal table. The remaining components, between the drive units and the seal table, are mounted on a movable support assembly which is moved aside when the retractable detector thimbles are withdrawn from the core. The drive units push the hollow helical-wrap drive cables, with the miniature fission chamber detectors attached, into the core. The helical-wrap drive cables have small diameter coaxial cables threaded through their hollow

centers for transmitting the current signal produced by the miniature fission chamber detector.

The six movable incore detectors, a typical number for a Westinghouse designed four-loop unit, are designated Detector A through Detector F, as shown on Figure 9.2-4. Additional movable incore detector information may be found in Table 9.2-1. During normal operation, each detector is used to measure the relative neutron flux in the detector thimbles connected to the correspondingly-lettered ten-path rotary transfer device; i.e., detector A is normally selected to a core path provided by the "A" ten-path transfer device. However, by means of the operation selector switch (five-path transfer device), each detector can also be routed through several other paths. Each detector can be sent into each path of the next sequentially-lettered ten-path transfer device to serve as an operational spare detector for those thimbles (i.e., A for B, B for C, C for D, etc.). For detector normalization purposes, each detector can be routed separately into a common calibrate path, thus providing direct correlation of the detectors. Each detector can also be routed into any path of common group "C", or to a shielded area for storage.

The readout and control equipment is mounted in a control console (equipment racks) located in the control room. This equipment provides indication and control to make flux maps of the reactor core either by semiautomatic control or by manual manipulation of the controls. The control console contains separate controls, digital position display and power supplies for each detector.

Common equipment, including core path display panel, one common control panel, special low level readout, and two-pen recorders, are also included in the console assembly (Figures 9.2-5 and 9.2-6).

9.2.2.2 Incore Temperature Monitoring System

Fixed incore thermocouples, made of chromel-alumel, are provided to monitor the outlet temperature of selected fuel assemblies. Fuel assembly inlet and outlet temperatures are used to determine the heat input, or enthalpy rise (Δh), of the fuel assembly. When the enthalpy of the monitored assemblies at various locations is compared, a radial power distribution map can be generated. The core locations for the CET's for a typical four-loop plant are shown in Figure 9.2-1. Additional thermocouple information is provided in Table 9.2-2.

The thermocouple sensing elements are mounted on and above the upper core plate at the point where the reactor coolant exits the fuel assemblies (Figure 9.2-7). The thermocouple leads are sheathed in stainless steel conduits and are routed from the upper core plate to the upper support plate inside of support columns. The conduits are then routed from above the upper support plate to the reactor head penetrations via thermocouple port columns which exit the reactor vessel head with thirteen thermocouple leads exiting from each of the five thermocouple port columns. A sealing arrangement is provided for each of the thermocouple port column penetrations and is part of the reactor coolant system pressure boundary (Figure 9.2-8).

The thermocouple leads are routed to either of two reference junction boxes. The reference junction box temperature is controlled where the transition is made between the chromel-alumel thermocouple leads and the copper instrument wires. If the temperature at this transition is allowed to vary unacceptable errors would be introduced in the temperature signal.

The core exit thermocouples have the advantage of continuously providing data which is easily converted to power by determining the enthalpy rise in the instrumented fuel assemblies. As opposed to the incore flux detectors, which are operated on an intermittent basis, the CETs provide continuous on-line radial power sharing measurements. However, this instrumentation system has the disadvantage of measurement uncertainties and possible errors due to reactor coolant flow mixing patterns at the detector location. To reduce the uncertainty in the thermocouple measurements and provide an accurate radial power measurement for on-line monitoring, the incore thermocouples are normalized to incore flux detector data during periodic surveillance tests. The CET readings are continuously monitored by the plant computer and may be read individually in the control room.

9.2.3 Component Descriptions

9.2.3.1 Conduits, Guide Thimbles, Isolation Valves, and Seal Table

Referring to Figure 9.2-3, stainless steel conduits extend from the bottom of the seal table down through the instrument tunnel and then up to the bottom of the reactor vessel. The conduits are welded, to the bottom of a seal table and to the penetration nozzles on the lower reactor vessel head, to form a leak-tight boundary. Therefore, the conduits, once filled with reactor coolant, become an extension to the reactor coolant system pressure boundary. The conduits guide and protect the guide thimbles between the seal table and the lower reactor vessel head.

The guide thimbles are closed at their leading (reactor) end and open at their trailing (seal table) end. The guide thimbles are dry on the inside and serve as a pressure boundary between the reactor coolant system (2500 psia design pressure) and the atmosphere. The somewhat flexible stainless steel guide thimbles are inserted through the seal table into the conduits. They are pushed from the seal table to the bottom of the reactor vessel head and pass through the penetration nozzles. From here they are inserted through the instrument guide tubes or the instrument guide extensions. Finally the guide thimbles are routed through the lower internals to the fuel assemblies. The guide thimbles remain stationary in the fuel assemblies during reactor operation and are retracted for refueling, maintenance, periodic inservice inspections, and work on the reactor vessel internals. Since the guide thimbles are withdrawn by pulling them upward on the trailing ends, ample room for the 14 feet of withdrawal must be provided. To accomplish this, the five and ten path rotary transfer devices are configured so they are capable of being moved away from the seal table.

The seal table is a 3/8-in. thick, rectangular (8'6" by 2'6"), stainless steel plate mounted over the instrument tunnel. The seal table has 58 penetrations for guide

thimbles and has two drain holes. The seal table guide thimble penetrations are sealed with high pressure swagelok fittings during normal operations and low pressure swagelok fittings during refueling.

A manually operated stainless steel isolation valve is provided at the seal table for each guide thimble. When closed, the isolation valve forms a 2500 psia barrier to prevent steam leakage from the reactor coolant system in the event of rupture of the guide thimble. The isolation valves are not designed to isolate a guide thimble with a detector or a drive cable inserted into the guide thimble. Therefore, prior to closing this isolation valve, the incore detector and its drive cable must be withdrawn to a position above the isolation valve.

9.2.3.2 Drive Unit Assemblies

As shown in Figure 9.2-9, each movable detector has a drive unit assembly. Each drive unit assembly is comprised of the following components:

1. Gear motor and slip clutch - One two-speed reversible synchronous gear-motor is provided. The drive motor is 3-phase, 460 volts, 60 Hz, 3600/600 rpm with a gear reducer and is capable of starting under maximum load. The motor incorporates an integral brake when not in operation. The continuous duty rating of this motor provides sufficient power to push a drive cable and detector through any guide path.

2. Drive box - The drive box is designed to operate with the helical-wrap drive cable. The 5-inch hobbed drive wheel is driven by the gear-motor through a slip clutch. Low speed for the drive cable is 12 ft/min, and high speed is 72 ft/min.

3. Storage reel - The storage equipment consists of a spring-loaded take-up reel with an integral locking device. The reel has sufficient take-up torque to prevent the drive unit from overrunning the reel at maximum speed during a change from low to high speed, or during braking. The storage reel accommodates 175 feet of drive cable and includes slip-ring assemblies which permit lead-out of electrical signals while the reel is rotating.

4. Position transmitter - A position encoder is supplied which is capable of operating control panel indicators reading from 0000.0 to 9999.9 inches. The encoder is driven at a speed proportional to the drive cable speed by means of a gear train from the drive wheel shaft. Signals from the encoder are in binary-coded-decimal form for position readout and controlled through the control console.

5. Withdrawal limit switch (Figure 9.2-6) - A withdrawal limit switch, actuated by the detector, is provided at the inlet of each of the five-path rotary transfer devices. This withdrawal limit switch provides the following functions:

    a. Prevents the operation of both the five- and ten-path transfer devices associated with it when the detector is forward of the limit,

b. Stops automatic withdrawal when the detector reaches the withdrawal limit, and

c. Actuates cable position lamps on the drive unit control panel in the control room.

6. Safety Switch - A safety switch located near the outlet of the drive unit prevents any attempt to withdraw the detector back over the wheel.

9.2.3.3 Transfer Device Assemblies and Isolation Valves

1. Five Path Rotary Transfer Device and Limit Switch (Figure 9.2-9):

    a. One five-path rotary transfer device is provided with each drive unit for routing the detector into one of the five possible paths. The 5-path transfer device consists of an S-shaped tube mounted inside a rotating assembly. This assembly is bearing-mounted at each end and can be positioned to any one of the five outlets. When an electrical signal is applied to change the detector path, the S-shaped tube is moved to the selected outlet path position. Cam-actuated microswitches send signals to the control panel for feedback of path selection.

    b. A withdrawal limit switch, actuated by the detector, is provided near the inlet of each five-path transfer device. This switch prevents operation of the five-path rotary transfer device unless the detector and cable is in the withdrawn position. The switch also stops automatic withdrawal when the detector reaches the withdrawal limit switch.

2. Wye Units - Wye unit assemblies are mounted as required to reduce the amount of interconnecting tubing between the five-path and ten-path rotary transfer assemblies. Wye units are also installed between the five-path transfer devices and the calibration path.

3. Ten-path Rotary Transfer Device - Each ten-path rotary transfer device is capable of routing a movable incore detector into each of ten different selectable flux thimbles. Cam-actuated microswitches send signals to the control console for feedback of path selection. Detector-actuated path indicator switches near the outlets of the ten-path transfer devices send signals to the path display panel in the control console for verification of proper core paths.

9.2.3.4 Interconnecting Tubing Runs

Interconnecting tubing runs are supplied for connecting the drive unit assemblies to the safety and withdrawal limit switches, and for connecting the 5-path transfer devices to its associated wye units and 10-path transfer devices. Additional tubing runs are supplied for connecting the 5-path transfer devices to the calibration path and to the concrete shielded storage area. Tubing runs also connect the 10-path transfer devices to the isolation valves, and connect the isolation valves to the seal table. The isolation valve to seal table tubing runs are designed for 2500 psia and 650°F.

9.2.3.5 Detector and Drive Cable Assemblies

The incore flux detector, a fission chamber, is 0.188 inches in diameter and 2.1 inches long. A bullet-shaped stainless steel shell (0.199 in. O.D.) encapsulates the fission chamber. The stainless steel shell is welded to the leading end of a helical-wrap drive cable. Each incore flux detector is designed to have a minimum thermal neutron sensitivity of 1.0×10^{-17} amps/nv (where nv = neutron flux in neutrons / cm^2-sec) and a maximum gamma sensitivity of 3.0×10^{-14} amps/R/hr.

The carbon steel drive cable is a hollow-core helical wrapped cable which meshes with the hobbed drive wheel within the drive box. Each drive cable has an outside diameter of 0.199-inches, and an inside diameter of 0.065 inches. The flux detector is attached to a coaxial cable, 0.040 inches in diameter, which is threaded back through the hollow drive cable and terminates at the trailing end, with several feet of slack ending in an amphenol connector. The drive cables (when new) are approximately 175 feet long. This length allows one or two subsequent cuts of a 12 - 14 foot section before the cable becomes too short for use. Such cuts may be required for factory replacement of the flux detectors.

9.2.3.6 Readout and Control Equipment

Readout and control equipment is provided as described below and as shown on Figures 9.2-5 and 9.2-6.

1. Position Indication and Control - One position indication and control panel is provided for each detector. As an example the position indication and controls for the “A” detector are derived from signals sent from the “A” drive unit, and similarly for the other detectors. The binary-coded-decimal (BCD) position signal from each encoder is presented as a nixie tube display of five decimal digits from 0000.0 to 9999.9 inches.

2. Operation Selector Switch - A six-position switch is provided for each detector drive to align the five-path rotary transfer device to the position associated with the selected mode of operation. Indicator lights, adjacent to the switch position, are energized by microswitches. These microswitches actuate when the five-path rotary transfer device has reached the selected position. The operation selector switch positions are discussed below:

    a. OFF - When the operation selector switch is placed in the OFF position, a red light adjacent to the switch is actuated, the detector is prohibited from moving, and the drive motor control relays are prevented from being energized. In addition the five-path rotary transfer device is aligned to its NORMAL position.

    b. NORMAL - When the operation selector switch is placed in the NORMAL position, the five-path rotary transfer device is positioned to its normal ten-path rotary transfer device.

c. CALIBRATE - When the operation selector switch is placed in the CALIBRATE position, the five-path rotary transfer device is positioned to the wye units for the calibrate path.

d. EMERGENCY - When the operation selector switch is placed in the EMERGENCY position, the five-path rotary transfer device is positioned to the next sequentially lettered ten-path rotary transfer device (drive A to ten-path rotary device B, drive B to ten-path rotary device C, etc.).

e. COMMON GROUP - When the operation selector switch is placed in the COMMON GROUP position, the five-path rotary transfer device is positioned to ten-path rotary transfer device C.

f. STORAGE - When the operation selector switch is placed in the STORAGE position, the five-path rotary transfer device is positioned to the lead shielded concrete storage area located in the seal table room.

3. Ten-Path Selector Switch - A ten-position individual path selector switch is provided for each group to align the ten-path transfer device with the selected detector thimble within that group. Indicator lights adjacent to the switch positions are energized by microswitches on the associated ten-path rotary transfer device. These microswitches close when the ten-path rotary transfer device has reached the selected position.

   Path selection is always achieved on the path selector switch associated with the ten-path transfer device through which the detector must pass (e.g., if the A detector is to be operated in the EMERGENCY mode, path selection is made on the B path selector switch). Detector-actuated microswitches at the outlet of the ten-path transfer devices energize path-display lights on the control console to indicate that the detector has actually reached that position in the selected path.

4. Common Controls - Common control of all detectors (simultaneous detector operation) or individual detector insertion and plotting are provided. The operating circuits are electrically interlocked to prevent attempted simultaneous insertion of two detectors into the same path under automatic control. The withdrawal limit switch is interlocked with the five-path and ten-path rotary transfer devices to prevent their rotation or realignment unless the associated detector is in the withdrawn position.

5. Position Control - The position readout devices are also used in the control system to provide stop signals to the detector drive unit at a preset distance from the bottom of the core and at the top of the core for each selected path during automatic insertion. The position readout devices also furnish an additional stop signal at the preset distance from the bottom after plotting. A set of ten patchboard matrix selector switches (five top-of-core position pins and five bottom-of-core position pins) for each path is provided to preset the bottom-of-core and top-of-core stop signals for normal operation.

   The stop positions are selected by insertion of pins of the correct lengths into the patchboard matrix to make contact as required. Thumbwheel switches are

provided for position control settings in Emergency, Common Group, Storage and Calibrate modes of operation. Top-of-core and bottom-of-core position settings are always established on the position control panel of the detector being run.

Detector position control is accomplished by comparing the encoder binary-coded-decimal (BCD) information with a decimal number created by the patchboard or thumbwheel switches. Each comparator accepts the associated encoder BCD information and compares it with the decimal number presented by the setpoint limits. To make this comparison, the decimal limit setting is converted into a BCD by the comparator.

6. Drive Motor Control - When any operation selector switch is in an ON position and the automatic-manual switch is in the AUTOMATIC position, pushbuttons (INSERT, SCAN, RECORD, WITHDRAW) will control the drive motors. When the automatic-manual switch is in the MANUAL position, the speed switch controls motor speed and the insert-withdraw toggle switch controls motor direction. The drive selector switch (single/multiple) on the common control panel selects either all drives or any single drive.

7. Detector Power Supplies - One power supply is mounted on each detector readout panel. The power supply provides a “floating” dc voltage output continuously variable to 300 volts.

8. Detector Current Readout - A current readout meter, having a range of 0-50 microamperes, is provided in the return circuit from the detector to the power supply. A range switch is provided to shunt the meter so that full scale can also correspond either to 150 or 500 microamperes, or to 1.5 or 5 milliamperes. A 1000-ohm multi turn potentiometer and precision shunts in series with the meter provide outputs to the recorder and plant computer. The full current output can also be supplied temporarily to an external picoammeter for special low current measurements.

9. Recorders - Strip-chart recorders are provided for each detector. The chart speed is synchronized with the low speed of the drive motors so that one inch of chart movement corresponds to 10-inch movements of the detectors. Each recorder is started automatically by the associated SCAN or RECORD pushbuttons, or can also be started at any other time by using the manual start switch.

10. Special Low Signal Level Equipment - A picoammeter is provided for making special low level measurements when the detector currents are less than five microamperes. The external connectors at the rear of all detector readout chassis are connected in parallel by coaxial cables to the input of the picoammeter. Input to the picoammeter is individually selected by switches on the detector readout panels. Also, in case the rectifier power supplies are too noisy for very low level signals, a special low-noise battery supply is provided.

9.2.3.7 Gas Purge System

The gas purge system, as shown in Figure 9.2-10, consists of a source of dry CO_2 gas which is introduced into the thimble runs whenever the movable detectors are being withdrawn from the reactor core. In order to do this, the transfer devices are contained in metallic enclosures and the gas is allowed to flow into these enclosures whenever the detectors are being withdrawn.

A pressure regulator and a throttling valve (a Hoke flow gage) are mounted near the 10-path transfer devices. A normally-closed ac solenoid operated off-on valve is located at the outlet of the throttling valve, which is electrically opened whenever a RECORD or WITHDRAW operation is called for on any of the detector drive motors. Stainless steel tubing connects the gas source to the enclosures through the valves. (The inlet gas tubing is disconnected when the transfer device's assembly is moved aside during refueling.)

These enclosures are designed to withstand an internal pressure of 1.0 psig without damage. The system is sufficiently leak-tight so that with an internal gas pressure of 0.02 inch of water applied, the total gas leakage rate will not exceed 15.0 cubic feet per hour.

9.2.3.8 Leak Detection System

The leak detection system comprises of; a drain header, a liquid level actuated pressure switch, and a 1/4-inch ac solenoid-operated valve, as shown in Figure 9.2-10. The inlet connection to the drain header is made at the 10-path transfer device enclosure, while the outlet connection is made to the plant drain system.

If water leaks from any of the transfer devices, it enters the leak detection system causing the level to rise. When the pressure switch actuates, it energizes the leak alarm and the 1/4-inch solenoid valve. The alarm is acknowledged by pressing the reset pushbutton, which silences the audible alarm and seals in the alarm light. When the water level in the drain header decreases below the level actuating pressure switch setpoint, its contact opens, de-energizing the solenoid drain valve and the alarm light. The drain line is disconnected during refueling preparations.

9.2.3.9 Thermocouples

Sixty-five chromel-alumel thermocouples are provided for a four-loop plant. Each thermocouple is 1/8 inch (nominal) in diameter, stainless steel sheathed, and aluminum oxide insulated, with the trailing end terminated in a male thermocouple connector. Each thermocouple is supplied to the specific length required for its assigned location.

9.2.3.10 Thermocouple Reference Junction Box

Two thermocouple junction boxes are provided to permit transition from chromel-alumel thermocouple extension wiring to copper field wiring. These units provide a controlled 160°F temperature reference for the incore thermocouples. Each reference junction box contains three platinum resistance temperature detectors

(RTD). Two of the RTDs from each unit are connected directly to the plant computer for monitoring of reference junction temperature. The third RTD in each unit is an installed spare.

9.2.3.11 Thermocouple Indicator

One indicator is mounted in the flux mapping control console to provide backup readout capability (normal is via the plant computer). This instrument is supplied with a double range measuring circuit which permits measurement within the ranges of 100°F to 400°F or 400°F to 700°F. Selection of a single thermocouple to be indicated is made by nonlocking toggle switches on the front of the indicating panel. The toggle switch must be manually held in position (left or right) to monitor the desired thermocouple. The switch returns to the center position (neutral position) when released. Since the thermocouple input signal to the indicator is in parallel with the plant computer, a contact closure signal is provided to inform the computer when any thermocouple is being monitored by the indicator.

9.2.4 Operation and System Interrelationships

9.2.4.1 Detector Calibration

When using the movable incore detectors, the power supply voltages are set near the predicted centers of the plateau regions. The range switches are set at the expected ranges for on scale readings and the selector switch is in the RECORDER position. The following sequence of operations is typically performed:

1. Select one of the detectors and run it into the calibration path by placing its five-path operation selector switch in the CALIBRATE position and using the INSERT and SCAN pushbuttons. During the scan, set the range switch so that the peak output is between one-third and full scale.

2. After reaching the top-of-core, use manual control to withdraw the detector downward. Stop at or near the point of highest detector output. Take data of voltage versus meter readings for a saturation curve in 10-volt steps from 20 to 160 volts. Plot these readings on linear graph paper or run the strip chart for this plot. Select and set the voltage that will provide operation near the center of the plateau region.

3. Repeat this procedure for the remaining detectors and normalize each detector's output voltage to provide consistent readings from detector to detector.

9.2.4.2 Flux-Mapping Procedure

After detector calibrations are performed, full or partial core flux maps are typically made in the following semiautomatic steps:

1. Turn one or more operation selector switches to the NORMAL position and observe the green light indication. Select the desired individual paths with the ten-path selector switches. During the flux mapping operation, record the reactor

core power level to insure that measurement conditions are stable during the mapping procedure.

2. On the common control panel, turn the mode switch to the AUTO position. In this mode, the speed is determined automatically as described below. (An override can be made by turning the mode switch to MANUAL, which causes all manually controlled movements to be at the speed selected by the speed switch.)

3. Turn the computer switch to the ON position to log the flux-mapping data in the computer. Select the desired operation on the drive selector switch. The ALL position is normally selected to simultaneously insert all detectors. Note that the operation selector switch of the desired drive(s) unit must be in the NORMAL position to obtain flux mapping data from its respective ten-path transfer device.

4. Press the INSERT pushbutton momentarily. The detectors will be driven at high speed to the preselected bottom-of-core position and stopped automatically, as indicated by the position indicator digital displays. When the detectors pass through the path indicator switches, contact-closure signals are fed back to the path display panel.

5. Press the SCAN pushbutton momentarily. The detectors will be driven at slow speed to the top-of-core and stopped automatically as indicated by the digital displays. During this scan, the recorder is automatically started and a continuous readout of the flux profile is obtained as a function of core height. This serves as a permanent record of the measurement. At this time, observe the current level and recorder response and make all necessary scale changes and adjustments.

6. Press the RECORD pushbutton momentarily. The detectors will be withdrawn at slow speed downward through the core and a contact-closure signal will be supplied to the plant computer to indicate that the readouts should be logged. The associated strip-chart recorder automatically starts and again will provide a flux profile as a function of core height. The detectors stop automatically at the bottom of the core. During the record operation, the flux profile data is transmitted to the plant computer further data reduction and evaluation.

7. Press the WITHDRAW pushbutton. The detectors will be withdrawn at high speed back to the withdrawal limit switches as indicated by the digital displays. Repeat the above steps for the other paths to give a full or partial core map, including running all detectors in the calibration path for normalization.

9.2.4.3 Incore-Excore Calibration

The movable incore neutron flux detectors (incore detectors), in conjunction with the plant computer (INCORE Code) present a true representation of the actual neutron flux distribution within the reactor core. Meanwhile, the excore nuclear instruments (excore detectors) rely upon leakage neutrons to determine the flux distribution within the core. Due to the distance and shielding between the reactor core and the excore detectors, these detectors cannot provide a true representation of the flux

distribution within the core. Since the excore detectors provide reactor protection signals and also provide the reactor operator with continuously monitored indication of power and flux distributions within the core, it is necessary to calibrate the excore detectors.

Recall from Section 9.1(Excore Nuclear Instrumentation) that the excore power range instruments consist of two six-foot detectors (one upper detector and one lower detector) per power range instrument channel. In theory the upper detector should indicate the power in the upper six feet of the core while the lower detector indicates the power in the lower half of the core. In practice, however, this is not the case, as neutrons leaking from the core do not necessarily leak out of the core at 90 degree angles. Some of the leakage neutrons generated in the lower half of the core will be detected by the upper detector and conversely the lower detector will indicate neutrons that were produced in the upper half of the core. Since the core must be protected from departure from nucleate boiling (DNB) and excessive power generation in both the upper and lower halves of the core, it is essential that the inputs to the protective circuitry be reflective of the actual conditions in the core. This protection is provided by trip signals generated from the overtemperature ΔT trip circuitry (OTΔT) and the overpower ΔT trip circuitry (OPΔT) of which both circuits receive axial flux difference (AFD) inputs from the excore power range detectors.

The outputs of the upper and lower excore detectors are calibrated to the incore detectors at the beginning of each fuel cycle and when the monthly surveillance shows a significant difference between the adjusted excore AFD and the incore AFD. AFD is defined as the flux at the top of the core minus the flux at the bottom of the core divided by the flux at the top of the core plus the flux at the bottom of the core at 100% power. This calibration must demonstrate the linear relationship that should exist between the incore and the excore outputs. Electronically the AFD is expressed in terms of difference in current (ΔI) between the upper and lower excore detectors. The slope of that relationship is used to calibrate the following: the $F_1(\Delta I)$ penalty to the (OTΔT) trip setpoint in the reactor protection system, the $F_2(\Delta I)$ penalty to the (OPΔT) trip setpoint in the reactor protection system, the AFD meters on the control board, the output to the detector current comparators, and the AFD monitor program in the plant computer.

In order to establish the existence of a linear relationship between the incore and excore detector outputs, an adequate number of data points (different flux distributions) must be obtained. This is accomplished by inducing an axial xenon transient, which causes an axial flux oscillation. During this induced transient, incore and excore measurements are obtained. These measurements are used to calculate the equation for the line that best fits the data by using linear regression. The incore measurements are taken by performing full core and quarter core flux maps at various times during the xenon transient. Each time an incore AFD is obtained by a flux map, all power range excore detector currents are recorded.

The current output from the excore detectors is then plotted against the incore AFD. After the linear relationship between the two detector systems is established, the gains of the excore detector isolation amplifiers are adjusted. Adjusting the gain on an isolation amplifier only affects its output signal to the reactor protection system, the detector current comparators, and the various AFD meters and recorders. This

adjustment has no effect on the raw current transmitted from the associated excore detector, which in addition to supplying the isolation amplifier also provides an input to the summing and level amplifier. Once made, the adjustment to the isolation amplifier gain is such that when there is an actual 0% incore delta flux, the excore detectors will indicate 0% AFD.

9.2.4.4 Computer

In addition to the strip chart records, on-line computers are installed to provide gross analyses of current core conditions for use on a complementary basis with other on-line monitoring systems.

9.2.4.5 Incore Data Collection

Signal Inputs - A number of active signals are supplied from the flux mapping system to the on-line computer. First, there are analog signals proportional to flux levels as measured by the movable detectors. Second, there are three sets of contact closure signals from each detector position control - one to show selection of detectors, another set to show the group 5-path transfer position, and a third set to show the individual 10-path transfer position. The latter two automatically indicate the flux thimble being measured. Finally, there are three interrupt signals, COMPUTER OFF-ON, SCAN, and RECORD.

SCAN and RECORD Programs - The on-line measurements provide an accurate method of determining a three-dimensional power distribution of the reactor core at periodic intervals in order to evaluate current core performance. The SCAN interrupt is received when the movable detector drive mechanism is energized to drive the selected detectors to the top of the core. However, data collection commences only after the RECORD interrupt is received when the movable detector drive mechanism is energized to withdraw the previously inserted detectors from the top of the core.

The objective of the on-line rapid data collection is to provide a high priority scheme by which all pertinent flux mapping data are collected for later reduction either on an offsite basis or for low priority reduction by the plant computer. Also, on-line priority data reduction provides a gross analysis of current core conditions immediately for use on a comparative basis with other on-line monitoring systems such as incore thermocouples, and excore detectors.

Signal Quality Checks - The program also includes provisions to evaluate the quality of the data as the measurement is taken. Briefly, there are two main quality checks made. For each data point on a pass, three consecutive readings are made (maximum 1/15 second apart). Also, each data point is compared with the preceding and succeeding data points, although relatively large variations are normal at the core grid locations.

Normalization - In order to provide a consistent set of measured relative reaction rates, it is important that all flux mapping data be normalized to one reference condition. Discrepancies which affect measurement results and must be corrected for are:

1. Reactor power drift during the flux mapping period,
2. Dissimilarities between the individual movable detectors,
3. Different readout scale settings, and
4. Leakage current in the detector, normally at low power levels.

During each pass, the total reactor power must be known in order to provide a means of converting each pass to one common reactor power level. This is accomplished by integrating the total output from the excore nuclear power channels during each pass. Changes in subsequent excore readings after the first pass provide correction ratios for subsequent passes.

In order to establish the normalization factors associated with each detector, it is necessary to insert each detector into a common thimble location. Differences between range settings are accounted for by multiplying each detector output by its appropriate range setting. Leakage current correction is made by subtracting from the appropriate detector output.

After the data is collected by the computer, it can be processed to provide a full-core flux map. By using the symmetry of the core (attained by fuel and poison loading), the data from the selected core locations can be extrapolated to include all fuel assemblies in the core. This may be accomplished by the plant computer, or a more powerful offsite computer.

Thermocouple Input - Use of the on-line computer is the normal means for recording thermocouple readings. The thermocouple signals originating above the core pass through reference junctions in the plant containment and then to terminal strips in the flux-mapping console. From there, they are paralleled with one set going to the computer and the other to a precision indicator with manual selector switches. The latter are intended for use in case of a malfunction of the computer.

Computations Based on Thermocouples - The information received from the thermocouples complements the movable detector system by providing periodic on-line checks on reactor core conditions. Calibrations of the thermocouples and the thermocouple reference junctions are made from tests at known thermal core and system conditions.

Computations are made periodically of the enthalpy rise at each thermocouple location, relative fuel assembly powers and core radial tilting factors. Printouts are made of alarm messages when any of the relative fuel assembly power values or incore thermocouple-based radial tilting factors exceeds established limits. A listing of averaged incore thermocouple readings and fuel assembly power values is made for reference usage. Complete core maps and daily thermocouple history are made when requested by the operator.

9.2.5 Summary

Miniature fission chamber detectors can be remotely positioned in retractable guide thimbles to provide flux mapping of the core. The detector is welded to the leading end of a helical wrap drive cable and to a sheathed coaxial instrumentation cable. The retractable guide thimbles are closed at their leading ends, and serve as the pressure boundary between reactor coolant pressure and atmosphere.

The drive assemblies are motor operated, with a hobbed wheel engaging the helical drive cable, a take-up reel and position encoders. The five-path rotary transfer device is used to select the mode of operation (normal, calibrate, storage, etc.). A five-path rotary transfer device is provided for each detector-drive assembly. A ten-path transfer device is supplied for each detector-drive assembly and is used to route a detector into any one of up to ten preselectable fuel assemblies.

Flux mapping consists of a moving detector scan of each provided core location (Figure 9.2-11). The information obtained is collected by the plant computer, which will either directly analyze the data obtained or record it for analysis by more sophisticated offsite computers.

Thermocouples are provided to give rough approximations of core conditions. They have the advantage of being on-line and are immediately available to the operator. The thermocouples are inserted into guide tubes that penetrate the reactor vessel head and terminate at the flow exits just above the fuel assemblies. Thermocouple readings are monitored by the computer with backup readout at a manual point selection.

Table 9.2-1
Movable Detector Design Parameters

Movable Detectors	
4-loop plants, number	6
3-loop plants, number	5
2-loop plants, number	4
Outside diameter, in.	0.199
Length, in.	2.1
Performance Data	
Cable speed (low), ft/min	12
Cable speed (high), ft/min	72
Position indication, in.	0.5
Flux Thimbles	
4-loop plants, number	58
3-loop plants, number	50
2-loop plants, number	36
Nominal O.D., in.	0.300
Nominal I.D., in.	0.199

Table 9.2-2
Thermocouple Design Parameters

4-loop plants, number	65
3-loop plants, number	51
2-loop plants, number	39
Outside diameter, in.	0.111
Type	Chromel-alumel

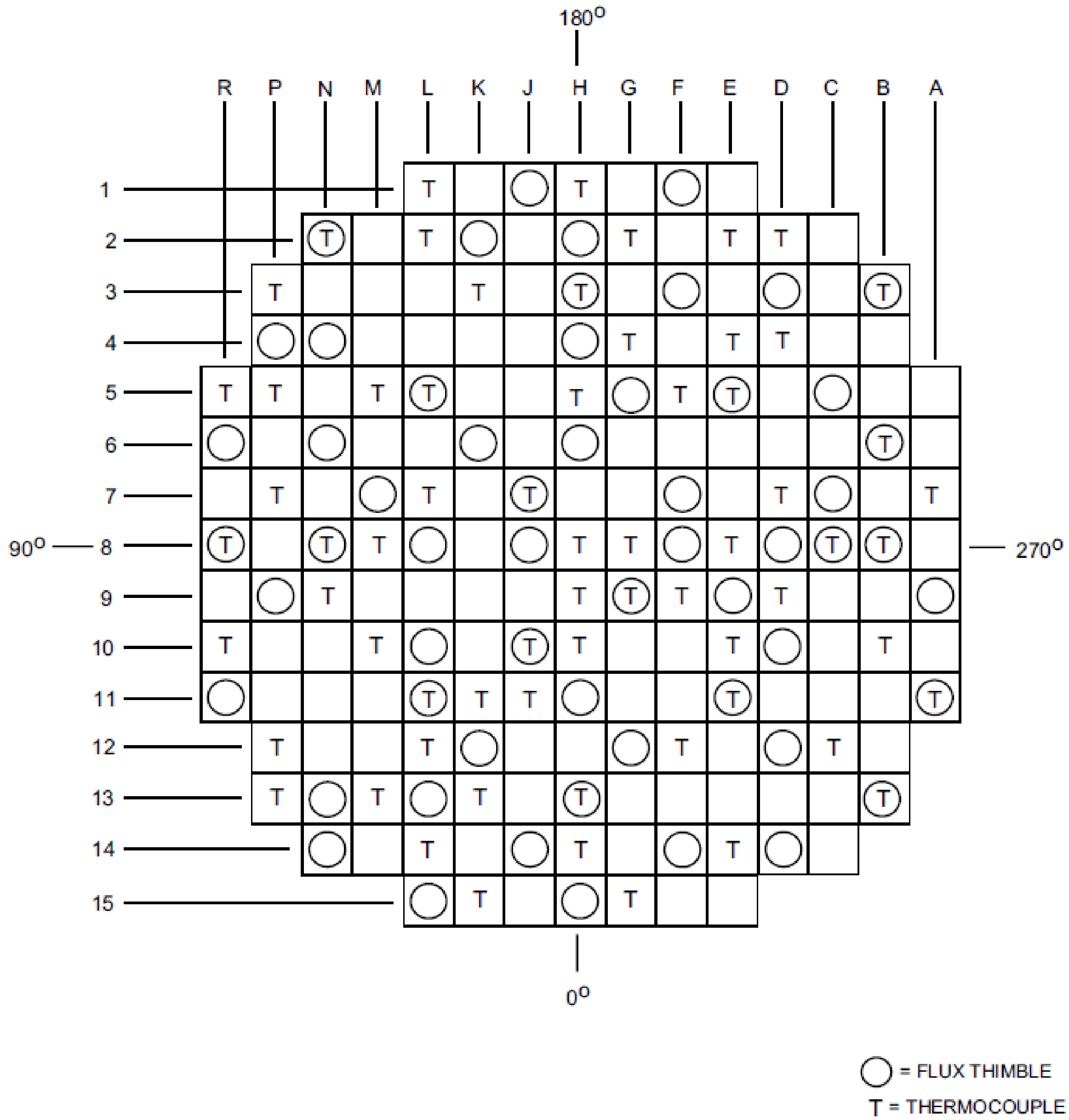

Figure 9.2-1 Thermocouples and Flux Thimble Locations (4 Loop Plant)

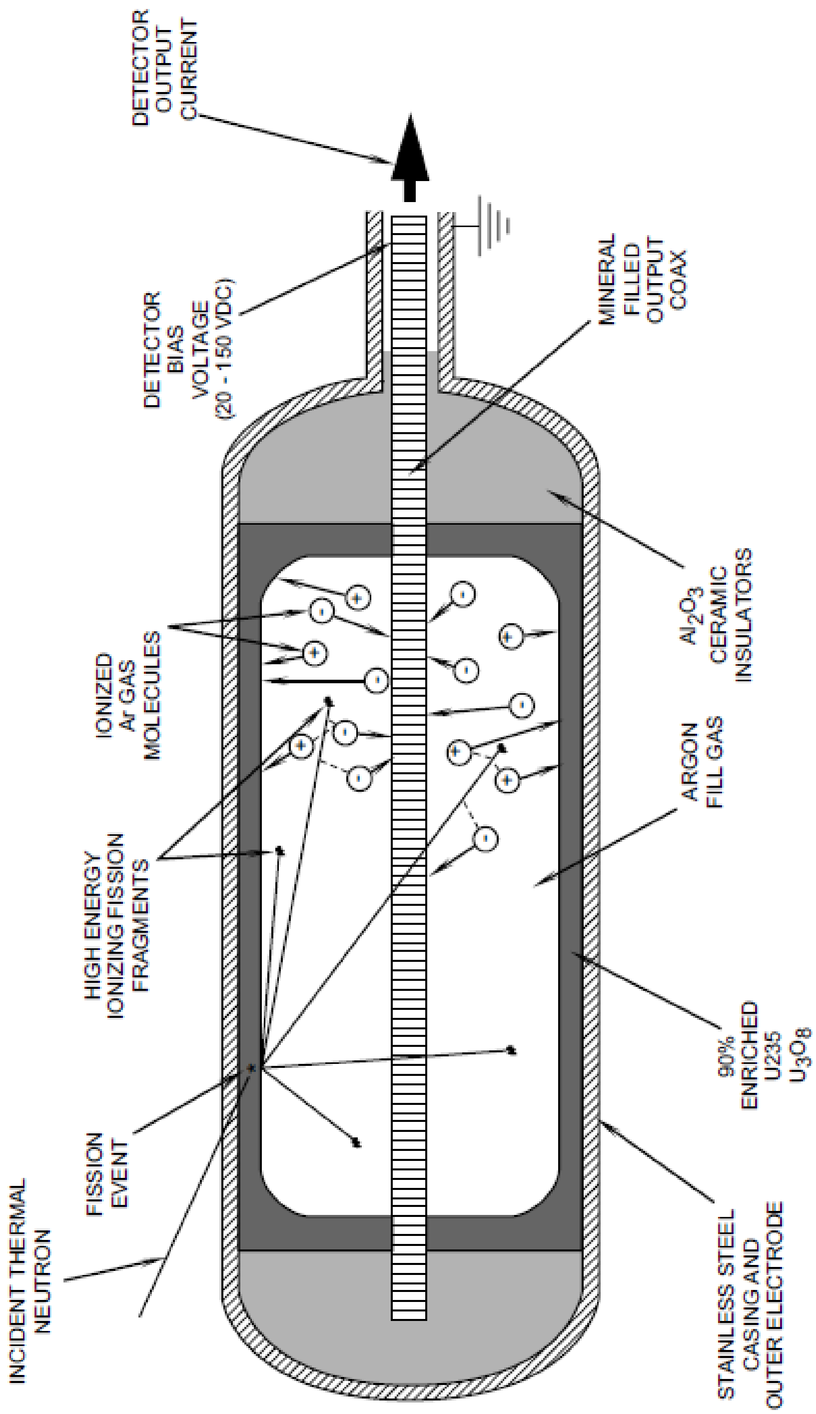

Figure 9.2-2 Incore Fission Chamber

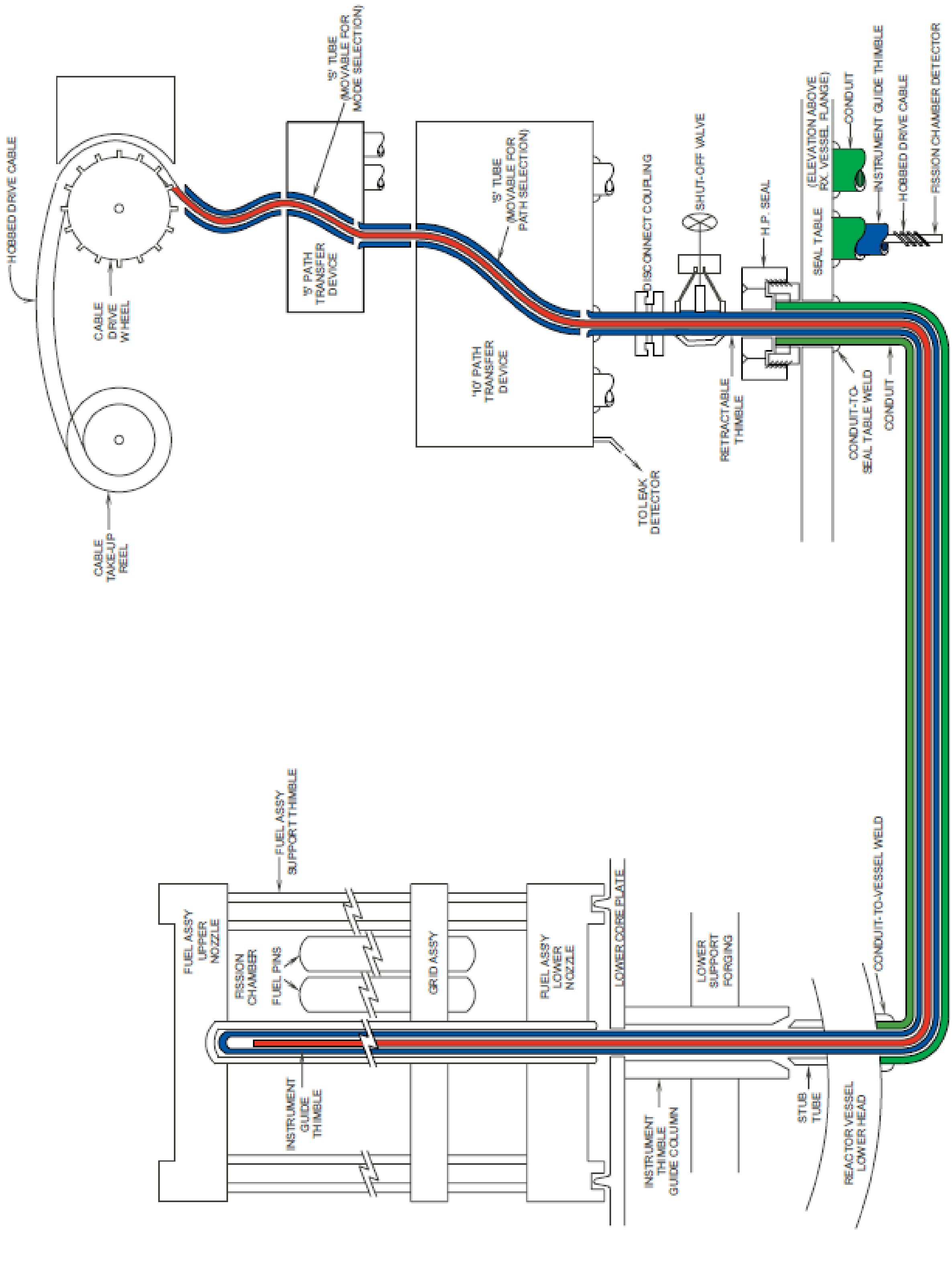

Figure 9.2-3 Movable Detector System

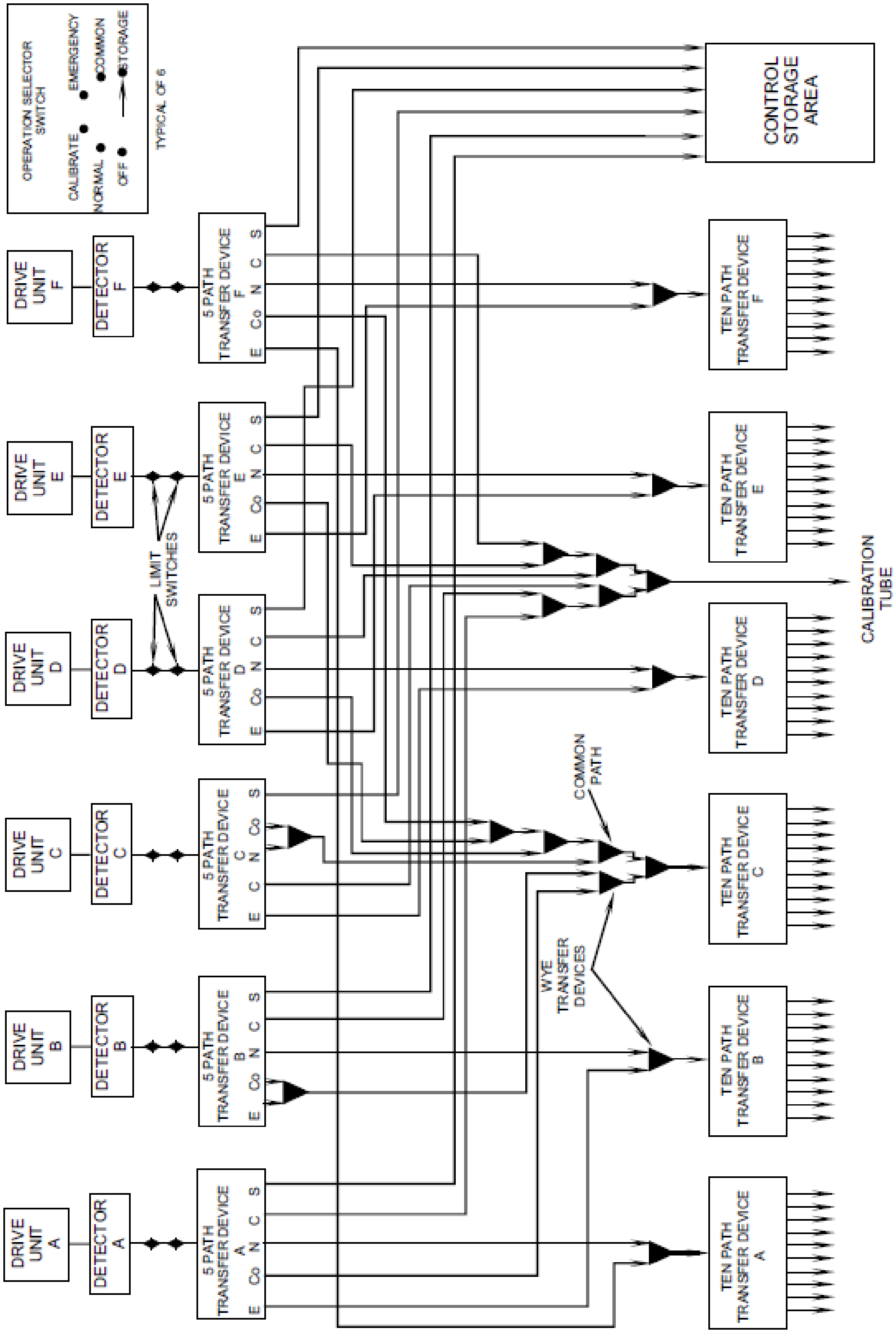

Figure 9.2-4 Incore Nuclear Instrumentation Drive System

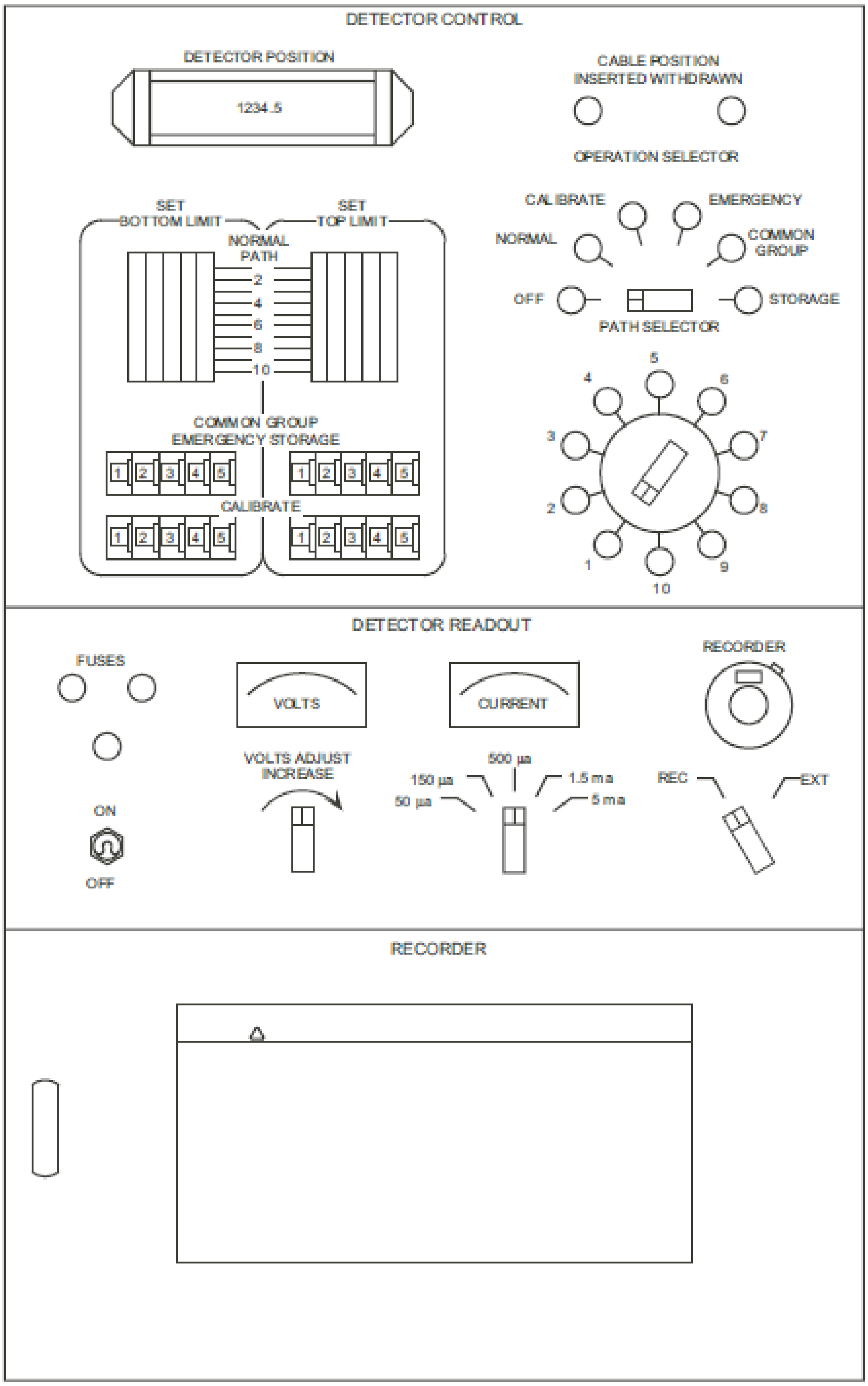

Figure 9.2-5 In-Core Detector Control and Readout

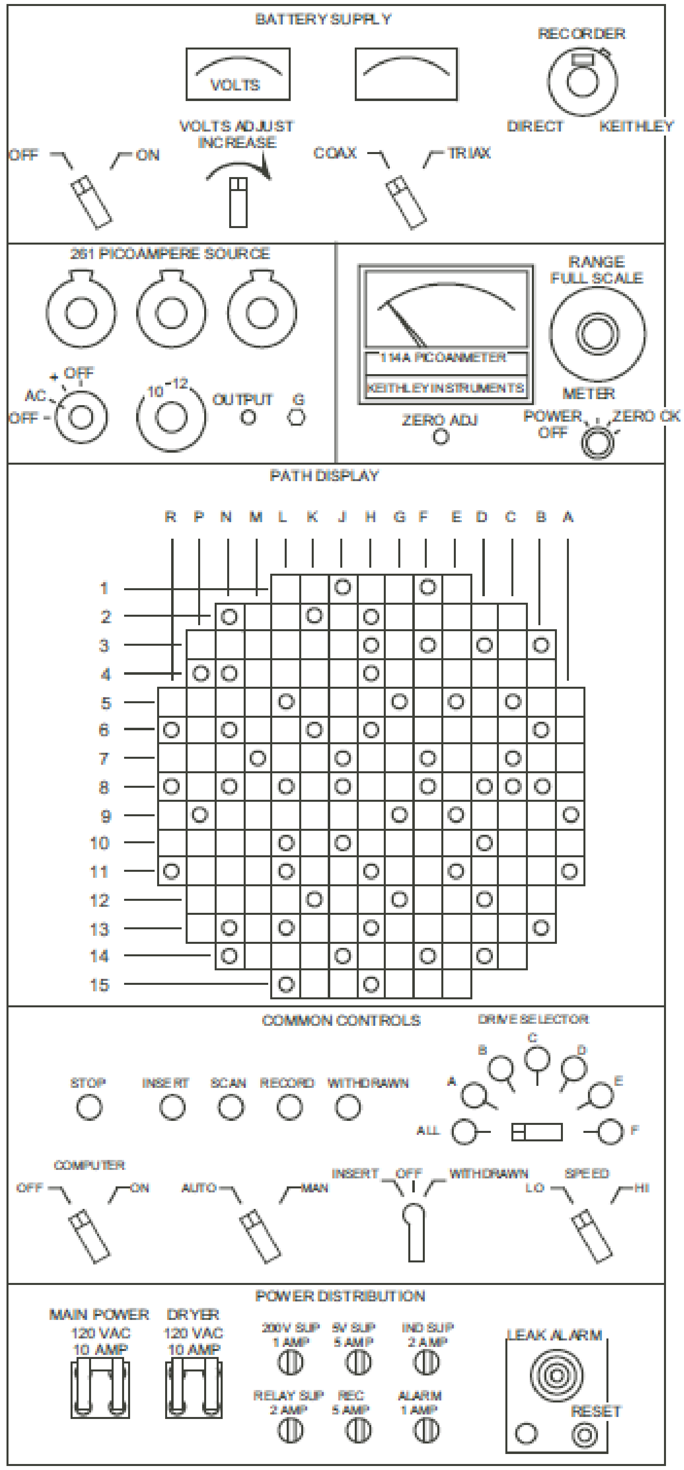

Figure 9.2-6 InCore Common Controls and Display

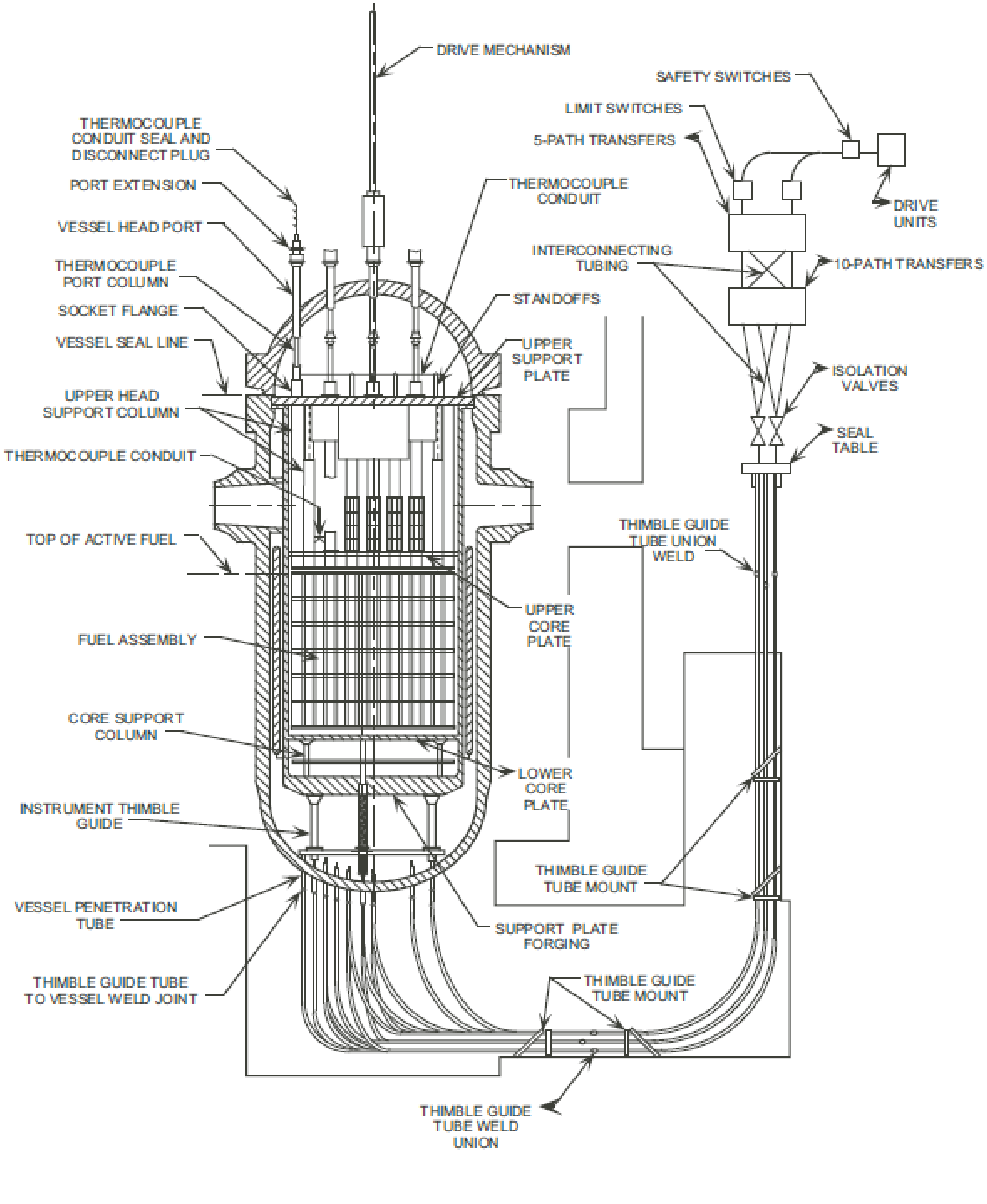

Figure 9.2-7 In-Core Instrumentation

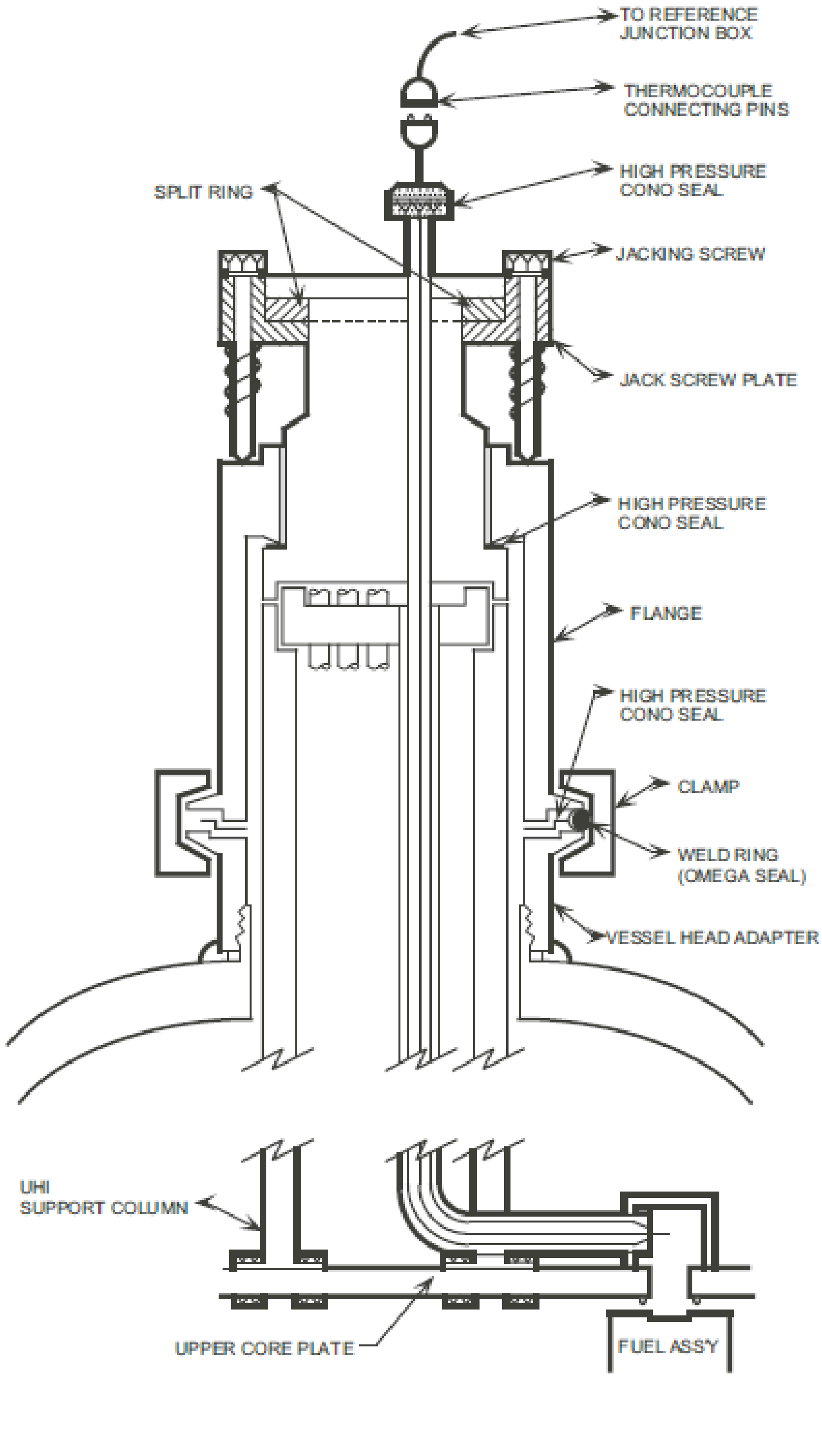

Figure 9.2-8 In-Core Thermocouple Arrangement

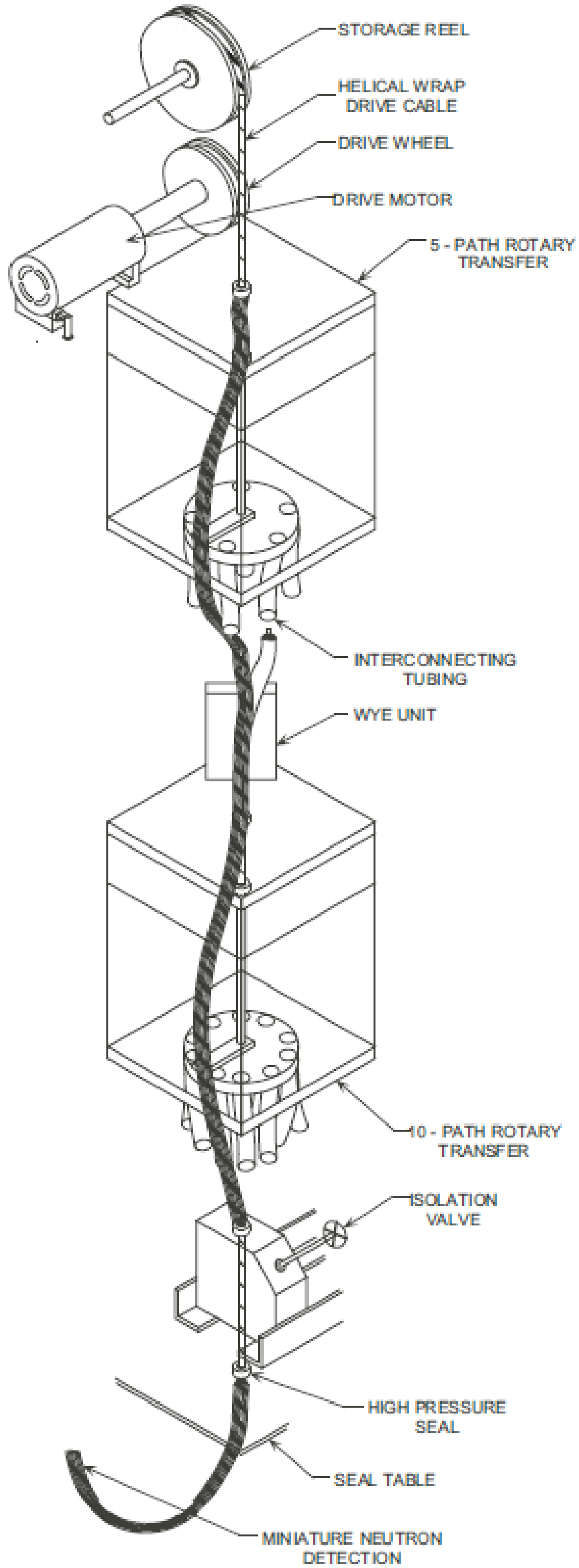

Figure 9.2-9 Drive System for In-Core Instrumentation

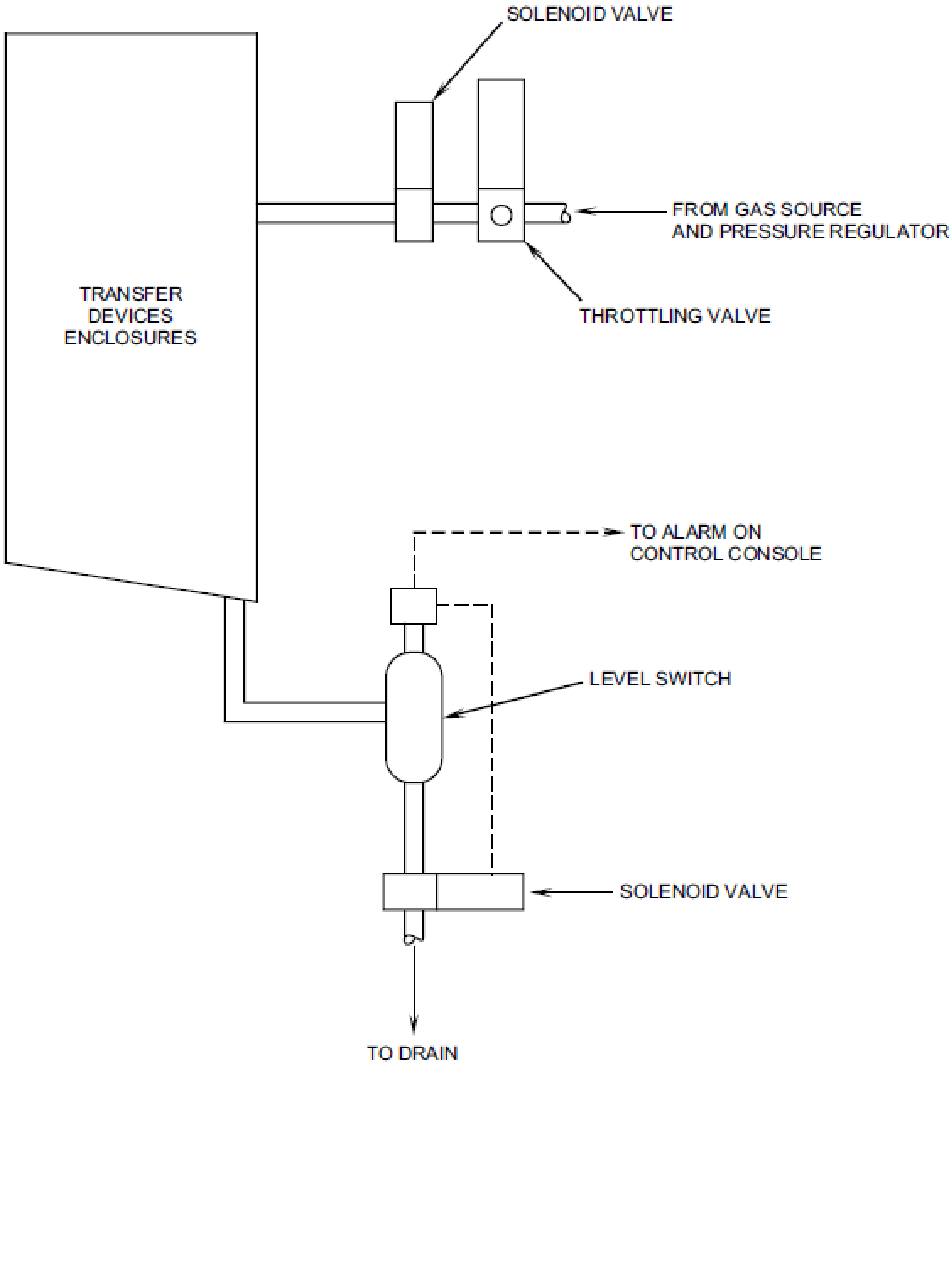

Figure 9.2-10 Gas Purge and Leak Detection System

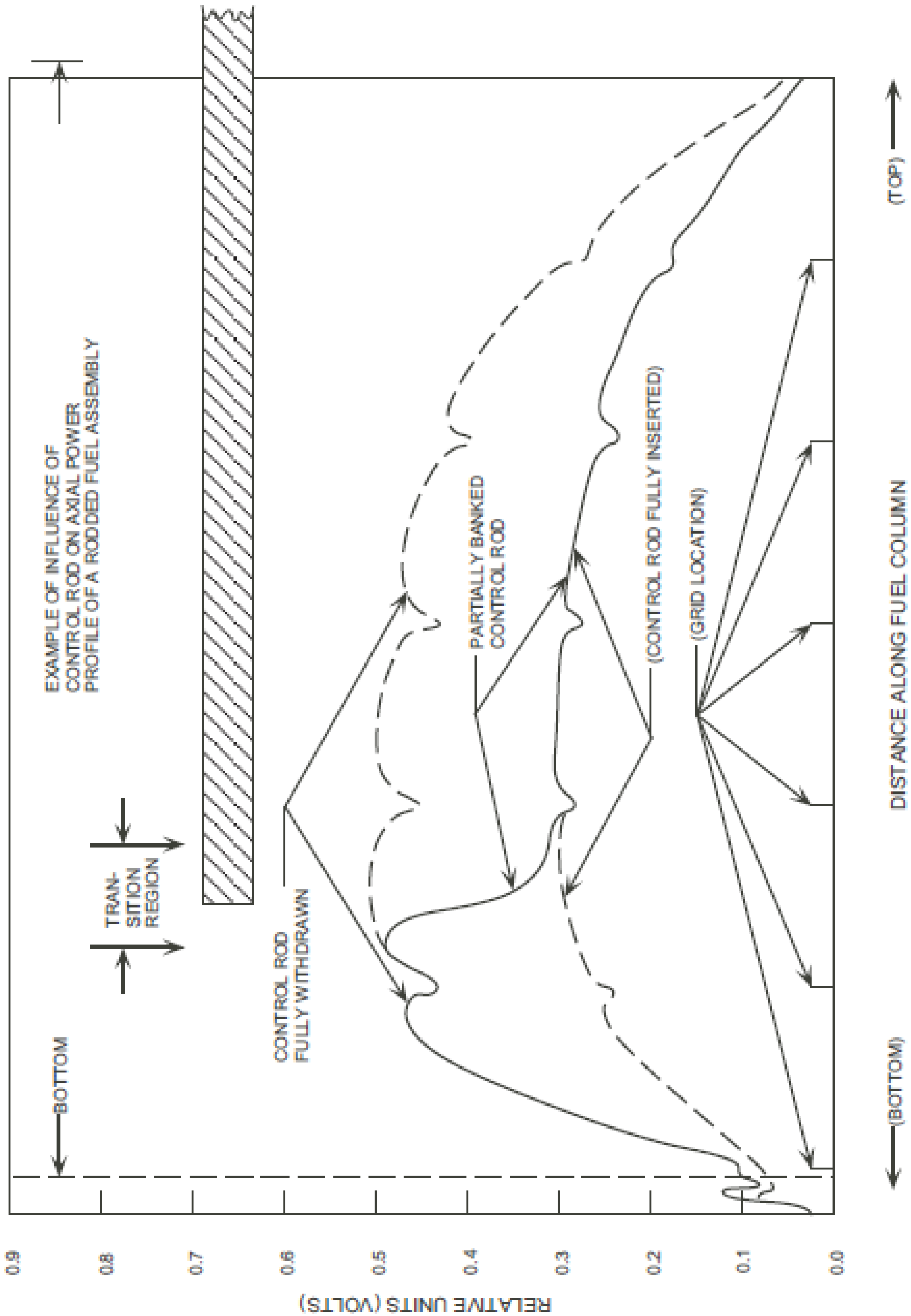

Figure 9.2-11 Flux Profile Curves