7.5 NEUTRON MONITORING SYSTEM

7.5.1 Safety Objective

The safety objective of the Neutron Monitoring System is to detect conditions in the core that threaten the overall integrity of the fuel barrier due to excessive power generation and to provide signals to the Reactor Protection System, so that the release of radioactive material from the fuel barrier is limited.

7.5.2 Power Generation Objective

The power generation objective of the Neutron Monitoring System is to provide information for the efficient, expedient operation and control of the reactor. Specific power generation objectives of the Neutron Monitoring System are to detect conditions that could lead to local fuel damage and to provide signals that can be used to prevent such damage, so that plant availability is not reduced.

7.5.3 Identification

The Neutron Monitoring System consists of six major subsystems as follows:

a. Source range monitor subsystem (SRMS),

b. Intermediate range monitor subsystem (IRMS),

c. Local power range monitor subsystem (LPRMS),

d. Average power range monitor subsystem (APRMS),

e. Rod block monitor subsystem (RBMS), and

f. Traversing in-core probe subsystem (TIPS).

7.5.4 Source Range Monitor Subsystem

7.5.4.1 Power Generation Design Basis

1. Neutron detectors shall be provided which result in a signal count-to-noise count ratio of no less than 3:1 and a count rate of no less than three counts per second with all control rods fully inserted.

2. The SRMS shall be designed to indicate a measurable increase in output signal from at least one detecting channel before the reactor period is less than 20 seconds during the worst possible startup rod withdrawal conditions.

3. The SRMS shall be designed to indicate substantial increases in output signals with the maximum permitted number of SRM channels out of service during normal reactor startup operations.

4. The SRMS shall be designed so that SRM channels are on scale when the IRMS first indicates neutron flux during a reactor startup.

5. The SRMS shall provide a measure of the time rate of change of the neutron flux (reactor period) for operational convenience.

6. The SRMS shall be capable of generating a trip signal to block control rod withdrawal if the count rate exceeds a preset value or if the SRMS is not operating properly. Coincident and non-coincident RPS trips will be provided as necessary for core alterations.

7.5.4.2 Description (Figures 7.5-1a, 1b, and 1c)

7.5.4.2.1 Identification

The SRMs provide neutron flux information during reactor startup and low-flux-level operations. There are four SRM channels, each of which includes one detector that can be physically positioned in the core from the control room. The detectors are normally inserted during reactor shutdowns to provide core monitoring. During reactor startup SRM detectors may be withdrawn after the neutron flux has sufficient indication on the IRMs.

7.5.4.2.2 Power Supply

The power for the monitors is supplied from the two separate 24-V DC buses, two monitors on one bus and two monitors on the other (see Subsection 8.8, "Auxiliary DC Power Supply and Distribution").

7.5.4.2.3 Physical Arrangement

Each detector assembly consists of a miniature fission chamber operated in the pulse counting mode and attached to a low-loss transmission cable (See Figure 7.5-2.). The sensitivity of the detector is 1.2×10^{-3} cps/nv nominal, 5.0×10^{-4} cps/nv minimum, and 2.5×10^{-3} cps/nv maximum. The detector cable is connected underneath the reactor vessel to a triple-shielded coaxial cable. This shielded cable carries the pulses formed to a pulse current preamplifier located outside the primary containment.[1]

1 Morgan, W. R., "In-core Neutron Monitoring System for GE Boiling Water Reactors," APED-5706, November 1968.

The detector and cable are located inside the reactor vessel in a dry tube sealed against reactor vessel pressure. A remote-controlled detector drive system can move the detector along the length of the dry tube, allowing vertical positioning of the chamber at any point from 15 to 18 inches above the reactor (fuel) centerline to approximately 2 1/2 feet below the reactor fuel region (Figure 7.5-3a). The detector can be stopped at any location between the limits of travel, but only the end points of travel are indicated. When a detector arrives at a travel end point, the detector motion is automatically stopped.

The electronics for the source range monitors, their trips, and their bypasses are located in one cabinet. Source range signal conditioning equipment is designed so that it may be used for open-core experiments.

7.5.4.2.4 Signal Conditioning

A current pulse preamplifier provides amplification and impedance matching to allow signal transmission to the signal conditioning electronics (Figure 7.5-4).

The signal conditioning equipment is designed to receive a series of input current pulses, to convert the current pulse series to analog DC currents corresponding to the logarithm of the count rate (LCR), to derive the period, to display the outputs on front panel meters, and to provide outputs for remote meters and recorders. The LCR meter displays the rate of the occurrence of the input current pulses, and the period meter displays the time in seconds for the count rate to change by a factor of 2.72(e). In addition, the equipment contains integral test and calibration circuits, trip circuits, power supplies, and selector circuits.

A high-voltage power supply supplies a polarizing potential for the fission counter detectors. The potential is introduced to the detector through a filter network to minimize noise coupling.

The pulses from the pulse preamplifier are of various heights. In general, the pulses produced by neutrons are larger than pulses due to gamma and noise. To count only neutrons, the pulse height discriminator (PHD) is set to reject the small pulses and to accept only the large pulses, the threshold being adjustable.

One output of the PHD has two stable states represented by full voltage and zero voltage. Each time an input pulse exceeds the threshold, the output of the PHD reverses state and holds that state until the next pulse causes another reversal. The PHD provides the pulse train input required by the log integrator. The PHD also has a scaler output, which produces an output pulse for every two input pulses crossing the threshold. The various signals are shown in the block diagram on Figure 7.5-4 outlined by circles. At (a), the current pulses are shown as four different amplitudes to illustrate the action of the discriminator. At (b), the absolute amplitudes are increased, but the relative amplitudes remain proportional. A dashed line representing the threshold level is indicated. At (c), there is an output pulse for every input pulse exceeding the threshold. This pulse is shaped to be compatible with the scaler input requirements. At (d), the PHD cuts off the second pulse because it did not attain the threshold level.

The log integrator is a network arranged to synthesize the response, which is a logarithmic function of the counting rate. The log integrator circuit is a composite of several frequency-sensitive networks with their frequency breakpoints appropriately distributed to synthesize the response. Each network has a time constant that is selected so that the overall response time of the instrument varies with the counting rate. Thus, at low counting rates, the time constant is large to provide an adequate smoothing effect on the reading. At high counting rates, the time constant is small to provide for a faster overall response time.

The output of the log integrator is a current output requiring amplification. Operational amplifier No. 1 is used to convert the current output from the log integrator to the standard signal used to drive the meter, recorders, trip circuits, and the period amplifier. Operational amplifier No. 2 is a differentiator with a resistor feedback and a capacitor input. The gain of the amplifier is scaled to produce a full-scale period reading of +10 seconds.

Calibration features are included to enable the accuracy of all measuring circuits to be verified and the trip level of the trip circuits to be set and checked. A signal generator provides two discrete frequencies for use in verifying the calibration of the log integrator and provides an operational check on the PHD.

7.5.4.2.5 <u>Trip Functions</u>

The trip outputs of the SRMS are all designed to operate in the fail-safe mode; the loss of power to the trip auxiliaries causes the associated trips to function.

The SRMS provides SRM upscale, downscale, detector improper position, and inoperative signals to the reactor manual control system to block rod withdrawal under certain conditions. Any one SRM channel can initiate a rod block. These rod blocking functions are discussed in Subsection 7.7, "Reactor Manual Control System." Appropriate lights and annunciators are actuated to indicate the existence of these same conditions (Table 7.5-1). Any one of the four SRM channels can be bypassed by the operation of a switch on the operator's console.

By removing the shorting links from the RPS circuitry, an interface is created with the SRMs such that SRM trips will result in a reactor scram. The links can be removed in combinations so as to provide one out of two taken twice logic or so that any SRM upscale Hi Hi will cause a scram. This feature may be used during the performance of core alterations. During core loading, an operable SRM or fuel loading chamber is required to be in the core quadrant where fuel is being loaded and at least one in an adjacent quadrant.

7.5.4.3 Power Generation Evaluation

Examination of the sensitivity of the SRM detectors (paragraph 7.5.4.2.3) and their operating ranges of 10^6 cps indicates that the IRMS is on scale before the SRM reaches full-scale (see Figure 7.5-25). Further overlap is provided by retraction of the SRM chambers to any position between full-in and full-out. SRM detector retraction is possible without the occurrence of a rod block only if the indicated SRM count rate remains above the rod block trip level (10^2 cps), or if the IRM has been ranged to the third or any less sensitive (higher) IRM range.

7.5.4.4 Inspection and Testing

Each SRM channel is tested and calibrated using procedures developed from the SRM instruction manual. Inspection and testing are performed as required on the SRM detector drive mechanism; the mechanism can be checked for full-insertion and retraction capability. The various combinations of SRM trips can be introduced to ensure the operability of the rod blocking functions.

7.5.5 Intermediate Range Monitor Subsystem

7.5.5.1 Safety Design Basis

1. The IRMS shall be capable of generating a trip signal that can be used to prevent fuel damage resulting from abnormal operational transients that occur while operating in the intermediate power range.

2. The independence and redundancy incorporated in the design of the IRMS shall be consistent with the safety design basis of the Reactor Protection System.

3. The design bases setpoint for neutron monitoring in the STARTUP mode is the APRM 15 percent trip.

7.5.5.2 Power Generation Design Basis

1. The IRMS shall be capable of generating a trip signal to block rod withdrawal if the IRMS reading exceeds a preset value or if the IRMS is not operating properly.

2. The IRMS shall be designed so that overlapping neutron flux indications exist with the SRMS and power range monitoring subsystems.

7.5.5.3 Description (Figures 7.5-1a, 1b, and 1c)

7.5.5.3.1 Identification

The IRMS monitors neutron flux from the upper portion of the SRM range to the lower portion of the power range monitoring subsystems. The IRM subsystem has 8 IRM channels, each of which includes one detector that can be physically positioned in the core by remote control. The detectors are inserted into the core for a reactor startup (MODE 2) and are withdrawn after the reactor mode selector switch is turned to RUN (MODE 1). They are normally inserted any time the reactor is not at power.

7.5.5.3.2 Power Supply

Power is supplied separately from two 24-V DC sources (see Subsection 8.8, "Auxiliary DC Power Supply and Distribution"). The supplies are split according to their use so that loss of a power supply will result in loss of only one trip system of the Reactor Protection System. Conduits and physical separation isolate the power buses external to the IRM cabinet.

7.5.5.3.3 Physical Arrangement

Each detector assembly consists of a miniature fission chamber attached to a low-loss, transmission cable. When coupled to the signal conditioning equipment, the detector produces approximately a 30 percent reading on the most sensitive range with a neutron flux of 10^8 nv. The detector cable is connected underneath the reactor vessel to a triple-shielded cable, which carries the pulses generated in the fission chamber through the primary containment to the preamplifier. The detector and cable, which are located in the drywell, are movable in the same manner as the SRM detectors and use the same type of mechanical arrangement.

7.5.5.3.4 Signal Conditioning

A voltage preamplifier unit located outside the primary containment serves as a preamplifier. This unit is designed to accept superimposed current pulses from the fission chamber, remove the DC component, convert the current pulses to voltage pulses, amplify the voltage pulses, establish the bandpass characteristics for the system, and provide a low impedance output suitable for driving a terminated cable. The gain of the low range of the preamplifier is fixed, but the gain of the high range is variable over a limited range to permit tracking between low and high ranges. The preamplifier output signal is coupled by a cable to the IRM signal conditioning electronics (Figure 7.5-7).

The signal conditioning equipment for each IRM channel contains an input signal attenuator, additional stages of amplification, an inverter, a mean-square analog unit, a calibration and diode logic unit, a range switch, power supplies, trip circuits, and integral test and calibration circuits. Each IRM channel receives its input signal from the preamplifier and operates upon it with various combinations of preamplification gain and amplifier attenuation ratios. The amplification and attenuation ratios of the IRM and preamplifier are selected by a remote range switch which provides ten ranges of increasing attenuation (the first six called low range and the last four called high range) acting upon the signal from the fission chamber. As the neutron flux of the reactor core increases from 1×10^8 nv to 1.5×10^{13} nv, the signal from the fission chamber becomes larger. The signal from the fission chamber is attenuated to keep the input signal to the inverter in the same range. The output current is proportional to the power contained in the pulses received from the fission chamber. This output signal, which is proportional to neutron flux at the detector, is amplified and supplied to a locally mounted meter. The meter has two linear scales on a single meter face. The appropriate range being used is indicated by the range switch position. Outputs are also provided for a remote meter and recorder. There is in the amplifier a potentiometer with a gain effect of 1 to 1.85, which provides an adjustment greater than one range position (approximately a factor of 3 in flux) in the output signal. The calibration and diode logic unit include a circuit to develop a triangular wave shape signal of adjustable amplitude to provide a means of full scale calibration of the power meter. Calibration settings of 40 percent and 125 percent on a 125 percent scale are possible.

The high-voltage supply associated with IRM supplies the polarizing potential for the fission chamber detector through a filter network to minimize noise coupling.

7.5.5.3.5 Trip Functions

The IRMS is divided into two groups of IRM channels arranged in the core as shown in Figure 7.5-8. Each group of IRM channels is associated with one of the two trip systems of the Reactor Protection System. Four IRM channels and their trip auxiliaries (two from each RPS group) are installed in one bay of a cabinet; the other four channels and their trip auxiliaries are installed on another bay of the cabinet. Full-length side covers on the cabinet bays isolate the IRM groups. The arrangement of IRM channels allows one IRM channel in each group to be bypassed without compromising intermediate range neutron monitoring.

Each IRM channel includes four trip circuits as standard equipment. One trip circuit is used as an instrument trouble trip. It operates whenever the high voltage drops below a preset level or whenever one of the modules is not plugged in. It also operates when the Operate-Calibrate switch is not in the "operate" position and the Operate-Calibrate bypass switch is not depressed. Depressing the Operate-Calibrate bypass switch will allow the inop trip function to be bypassed in order to perform functional tests of the downscale and upscale level trips. Each of the other trip circuits can be chosen to operate whenever preset downscale or upscale levels are reached. A simplified IRM circuit arrangement is shown in Figure 7.5-26.

The trip functions actuated by the IRM trips are indicated in Table 7.5-2. The reactor mode switch determines whether IRM trips are effective in initiating a rod block and a reactor scram.

Subsection 7.7, "Reactor Manual Control System," describes the IRM rod block trips. With the reactor mode switch in "REFUEL" or "STARTUP," an IRM upscale or inoperative trip signal actuates a Neutron Monitoring System trip of the associated channel of the Reactor Protection System. Only one IRM channel must trip to initiate a Neutron Monitoring System trip of the associated trip system of the Reactor Protection System (See Figure 7.2-8). If an IRM from each channel causes a channel trip, a full reactor trip follows.

7.5.5.4 Safety Evaluation

The safety evaluation in Subsection 7.2, "Reactor Protection System," evaluates the arrangement of redundant input signals to the Reactor Protection System. The Neutron Monitoring System trip input to the Reactor Protection System and the trip channels used in actuating a Neutron Monitoring System trip are of equivalent independence and redundancy to other Reactor Protection System inputs.

The number and locations of the IRM detectors have been analytically and experimentally determined to provide sufficient intermediate range flux level information under the worst permitted bypass and detector-failure conditions. For verification of this, a range of rod withdrawal accidents has been analyzed. The most severe case assumes that the reactor is just subcritical with one-fourth of the control rods, plus one more rod, removed in the normal operating sequence. This configuration is shown in Figure 7.5-9. The error or malfunction is the removal of the control rod adjacent to the last rod withdrawn. The location of this rod has been chosen to maximize the distance to the second nearest detector for each Reactor Protection System trip system. It is assumed that the nearest detector in each Reactor Protection System trip system is bypassed. A scram signal is initiated when one IRM detector in each Reactor Protection System trip system reaches its scram trip level. The neutron flux versus distance resulting from this withdrawal is shown in Figure 7.5-10. Note that the second nearest detector in trip system B is farther away than the second nearest detector in trip system A. The ratio of the neutron flux, at this point, to the peak flux is 1/4100. This detector reaches its high scram trip setting of 120/125 full-scale at a local flux approximately 3.3×10^8 nv. At that time, the peak flux in the core is 1.35×10^{12} nv or 2.7 percent rated average flux. The core average power is 0.07 percent when scram occurs. For this scram point to be valid, the IRM must be on the correct range. To assure that each IRM is on the correct range, a rod block trip is initiated any time the IRM is both downscale and not on the most sensitive (lowest) scale. A rod block is initiated if the IRM detectors are not fully inserted in the core and the reactor mode switch is not in the "RUN" position. The IRM scram trips are automatically bypassed when the reactor mode switch is in the "RUN" position and the APRMs are on scale. The IRM rod block trips are automatically bypassed when the reactor mode switch is in the "RUN" position.

The IRM detectors and electronics have been tested under operating conditions and verified to have the operational characteristics given in the description and, as such, provide the level of precision and reliability required by the Reactor Protection System safety design basis.

7.5.5.5 Power Generation Evaluation

The intermediate range monitor subsystem is the primary source of information on the approach of the reactor to the power range. Its linear, approximately half-decade steps, with the rod blocking features on both high-flux level and low-flux level, require that the operator keep all the IRMs on the correct range to increase core reactivity by rod motion. The SRM overlaps the IRM as shown in Figure 7.5-25. The sensitivity of the IRM is such that the IRMS is on scale on the least sensitive (highest) range with the reactor power about 15 percent.

7.5.5.6 Inspection and Testing

Each IRM channel is tested and calibrated using procedures developed from the IRM instruction manual. The IRM detector drive-mechanisms and the IRM rod blocking functions are checked in the same manner as for the SRM channels. Each of the various IRM channels can be checked to ensure that the IRM high-flux scram function is operable.

7.5.6 Local Power Range Monitoring Subsystem

7.5.6.1 Power Generation Design Basis

1. The LPRMS shall provide signals proportional to the local neutron flux at various locations within the reactor core to the average power range monitor subsystem (APRMS), so that accurate measurements of average reactor power can be made.

2. The LPRMS shall supply signals to the rod block monitor subsystem, so that measurement of changes in local relative neutron flux can be made during the movement of control rods.

3. The LPRMS shall be capable of alarming under conditions of high or low local neutron flux indication.

4. The LPRMS shall supply signals proportional to the local neutron flux to the process computer to be used in power distribution calculations, rod power

density calculations, minimum critical power calculations, and fuel burnup calculations.

5. The LPRMS shall supply signals proportional to the local neutron flux to drive indicating meters and auxiliary devices to be used for operator evaluation of the power distribution, rod power density, minimum critical power, and fuel burnup.

7.5.6.2 Description (Figures 7.5-11a, 11b, and 11c)

7.5.6.2.1 Identification

The LPRMS consists of the fission chamber detectors, the signal conditioning equipment, and trip functions. The LPRM signals are also used in the APRMS, RBMS, and process computer.

7.5.6.2.2 Power Supply

Detector polarizing voltage for the LPRMs is supplied by redundant pairs of DC power supplies. Each DC power supply pair powers approximately one-eighth of the LPRMs. Power for the DC power supplies comes redundantly from the two 120 VAC Reactor Protection System buses via intermediate DC power supplies. These intermediate DC supplies also provide power for the LPRM amplifiers.

The power supplies can supply up to 3 milliamps for each LPRM detector, which ensures that the chambers can be operated in the saturated region at the maximum specified neutron fluxes. The voltage applied to the detectors varies no more than 2 VDC over the maximum variation of electrical input and environmental parameters.

7.5.6.2.3 Physical Arrangement

The LPRMS includes LPRM detectors located throughout the core at different axial heights. Figure 7.5-12 illustrates the LPRM detector radial layout scheme, which provides a detector assembly at every fourth intersection of the narrower of the water channels around the fuel bundles (narrow-narrow water gap). Thus, every narrow-narrow water gap has either an actual detector assembly or a symmetrically equivalent assembly in some other quadrant.

The 43 LPRM detector assemblies, each containing four fission chambers, are distributed to monitor four horizontal planes throughout the core. The detector assemblies (Figure 7.5-13) are inserted into the core in spaces between the fuel assemblies through thimbles that are mounted permanently at the bottom of the core lattice and which penetrate the bottom of the reactor vessel. These thimbles are welded to the reactor vessel at the penetration point. They extend down into the access area below the reactor vessel where they terminate in a flange, which mates to the mounting flange on the incore detector assembly. The detector assemblies are locked at the top end to the top fuel guide by means of a spring-loaded plunger. This type of assembly is referred to as top entry-bottom connect, since the assembly is inserted through the top of the core and penetrates the bottom of the reactor vessel. Special water sealing caps are placed over the connection end of the assembly during installation and over the penetration at the bottom of the vessel during installation or removal of an assembly. This prevents the loss of reactor coolant water upon removal of an assembly and also prevents the connection end of the assembly from being immersed in the water during installation.

Each LPRM detector assembly contains four miniature fission chambers with an associated solid sheath cable. Each fission chamber produces a current which, when coupled with the LPRM signal conditioning equipment, provides the desired scale deflection throughout the design lifetime of the chamber. Each individual chamber of the assembly is a moisture-proof, pressure-sealed unit. Each assembly also contains a calibration tube for a traversing incore probe (TIP). The enclosing tube around the entire assembly contains holes to allow circulation of the reactor coolant water to cool the fission chambers. Numerous tests have been performed on the chamber assemblies, including tests of linearity, lifetime, gamma sensitivity, and cable effects. These tests and experience in operating reactors provide confidence in the ability of the LPRM subsystem to monitor neutron flux to the design accuracy throughout the design lifetime.

The four miniature fission chambers used on each assembly are designed to operate up to a temperature of 599°F and a pressure of 1250 psig. The chambers are vertically spaced in the LPRM detector assemblies in such a manner as to give adequate axial coverage of the core, complementing the radial coverage given by the horizontal arrangement of the LPRM detector assemblies. Each miniature chamber consists of two concentric cylinders, which act as electrodes. The gas between the electrodes is ionized by the charged particles produced as a result of neutron fissioning of the uranium coated electrode. The negative ions produced in the gas are accelerated to the collector by the potential difference maintained between the electrodes. In a given neutron flux, all the ions produced in the ion chamber can be collected if the polarizing voltage is high enough. When this situation exists, the ion chamber is considered to be saturated. Output current is then independent of operating voltage and has a linearity of 1 percent (1 percent) over the design operating range.

7.5.6.2.4 Signal Conditioning

The current signals from the LPRM detectors are transmitted to the LPRM amplifiers in the control room. The amplifiers are arranged on "LPRM Input Modules" mounted inside the APRM chassis assembly. The current signal from a chamber is transmitted to its amplifier through coaxial cable. The amplifier is a linear current amplifier whose voltage output is proportional to the current input and, therefore, is proportional to the magnitude of the neutron flux. Additional low-level output signals are provided which are suitable as an input to the computer, recorders, etc. The outputs of each LPRM amplifier are isolated to prevent interference of the signal by inadvertent grounding or application of a stray voltage at the signal terminal point.

The amplifier output is "read" by digital processing electronics. The digital electronics applies hardware gain corrections, performs filtering, and applies the LPRM gain factors. The digital electronics provides output signals suitable for the computer, recorders and annunciators. The LPRM amplifiers also isolate the detector signals from the rest of the processing so that individual faults in one LPRM signal path will not affect other LPRM signals.

The LPRM amplifier signals can be read by the operator on the reactor console. When a central control rod is selected for movement, the output signals from the amplifiers associated with the nearest sixteen LPRM detectors are displayed by selecting summary LPRM displays on digital operator displays. Subsection 7.7, "Reactor Manual Control System," describes in greater detail the indications on the reactor console.

7.5.6.2.5 Trip Functions

The trip circuits for the LPRMs provide trip signals to activate digital displays indicating either upscale or downscale conditions. The outputs of the LPRM trip functions are designed to go to the "tripped" state on loss of power to the processing electronics. Table 7.5-3 indicates the trips.

The trip levels can be adjusted to within ±0.5 percent of 0-to-125 percent range and are accurate to ±1 percent of 0-to-125 percent range in the normal operating environment.

7.5.6.3 Power Generation Evaluation

The local power range monitor subsystem, as calibrated by the traversing incore probe subsystem, provides detailed information about the neutron flux throughout the reactor core. The total of 43 LPRM assemblies, and their distribution, is determined by extensive calculational and experimental procedures. The division of the LPRMS into various groups for DC power supply allows operation with one DC power supply failed, or being serviced, without limiting reactor operation.

Individual failed chambers can be bypassed, and neutron flux information for the failed chamber location can be interpolated from nearby chambers. The core power monitoring software automatically accounts for a bypassed chamber. A substitute reading for a failed chamber can be derived from an octant-symmetric chamber, or an actual flux indication can be obtained by insertion of a TIP to the failed chamber position, this value can be manually input into the core power monitoring software.

The LPRM outputs provide for the functions required in the LPRM power generation design basis. Each output is electrically isolated so that an event (grounding the signal or applying a stray voltage) on the reception end does not destroy the validity of the LPRM signal. Tests and experience demonstrate the ability of the detector to respond proportionally to the local neutron-flux changes.

7.5.6.4 Inspection and Testing

LPRM channels are calibrated using data from previous full power runs and TIP data and are tested by procedures in the applicable instruction manual.

7.5.7 Average Power Range Monitor Subsystem

7.5.7.1 Safety Design Basis

1. The design of the APRMS shall be such that for the worst permitted input LPRM bypass conditions, the APRMS shall be capable of generating a scram trip signal in response to average neutron-flux increases resulting from abnormal operational transients in time to prevent fuel damage.

2. The design of the APRMS shall be consistent with the requirements of the safety design basis of the Reactor Protection System.

7.5.7.2 Power Generation Design Basis

1. The APRMS shall provide a continuous indication of average reactor power from a few percent to 125 percent of rated reactor power.

2. The APRMS shall be capable of providing trip signals for blocking rod withdrawal when the average reactor power exceeds pre-established limits set to prevent scram actuation.

3. The APRMS shall provide a reference power level for use in the rod block monitor subsystem.

7.5.7.3 Description

7.5.7.3.1 Identification

The APRMS has four APRM channels, each of which uses input signals from a number of LPRM channels. Each of the four APRM channels provides inputs to four two-out-of-four Trip Voter channels. Two of the voter channels are associated with one automatic trip system of the Reactor Protection System (RPS); the other two voter channels are associated with the other automatic trip system of the RPS. Because all four APRM channels provide inputs to each of the four voter channels, all four APRM channels are associated with both trip systems of the RPS.

7.5.7.3.2 Power Supply

The APRM channels receive power from the 120-V AC supplies used for the Reactor Protection System power (see Subsection 7.2).

Power for each APRM instrument channel is supplied redundantly by both 120 VAC RPS power buses. However, power for each 2-out-of-4 Trip Voter channel is supplied only by the 120 VAC bus which provides power to the voter's associated RPS trip system.

7.5.7.3.3 Signal Conditioning

The APRMS uses digital electronic equipment which averages the output signals from a selected set of LPRMs, generates trip outputs via the 2-out-of-4 voter channels (see Section 7.5.7.3.4), and provides signals to readout equipment. Each APRM channel can average the output signals from up to 43 LPRM channels. Assignment of LPRM channels to an APRM is shown in Figure 7.5-14c. The letters at the detector locations in Figure 7.5-14c refer to the axial positions of the detectors in the LPRM detector assembly. Position A is the bottom position, positions B and C are above position A, and position D is the topmost LPRM detector position. The pattern provides LPRM signals from all four core axial LPRM detector positions throughout the core. Some LPRM detectors may be bypassed, but the averaging logic automatically corrects for these by removing them from the average. The APRM value calculated from the LPRM inputs is adjusted by a digitally entered factor to allow calibration of the APRM to core thermal power based on heat balance.

Each APRM channel calculates a flow signal, representative of total core flow, which is used to determine the APRM's flow-biased rod block and scram setpoints. Each signal is determined by summing and processing flow signals from the two recirculation loops. These signals are sensed from two flow elements, one in each recirculation loop. The differential pressure from each flow element is routed to four differential pressure transmitters (eight total). Signals from a pair of differential pressure transmitters, one from each flow element, are routed to the input of an associated APRM chassis for processing. Each pair of differential pressure transmitters is associated with only one of the four APRM instrument channels.

During transients, the instantaneous fuel surface heat flux is less than the instantaneous neutron flux by an amount depending upon the duration of the transient and the fuel time constant. For this reason, the flow-biased scram APRM flux signal is passed through a filtering network (Thermal Power Monitor) with a time constant which is representative of the fuel time constant. As a result of this filtering, APRM flow-biased scrams will only occur if the neutron flux signal is in excess of the setpoint and of sufficient time duration to overcome the fuel time constant and result in an average fuel surface heat flux which is equivalent to the neutron flux trip setpoint. This setpoint is variable up to 120 percent of rated power based on recirculation drive flow.

7.5.7.3.4 Trip Function

The digital electronics for the APRMs provides trip signals directly to the Reactor Manual Control System and via the APRM 2-out-of-4 Trip Voter channels to the Reactor Protection System (RPS). Any two unbypassed APRM channels, via the APRM 2-out-of-4 voter channels, can initiate an RPS trip in both RPS trip systems. Any one unbypassed APRM can initiate a rod block, depending upon the position of the reactor mode switch. Tables 7.5-4a and 7.5-4b list the APRM trip functions. Subsection 7.7, "Reactor Manual Control System," describes in more detail the APRM rod block functions.

The APRM simulated thermal power upscale rod block and scram trip setpoints are varied as a function of reactor recirculation flow. The slope of the upscale rod block and scram trip response curves is set to track the required trip setpoint with recirculation flow changes.

At least two unbypassed APRM channels must be in the upscale or inoperative trip state to cause an RPS trip output from the APRM 2-out-of-4 voter channels. In that condition, all four voter channels will provide an RPS trip output, two to each RPS trip system. If only one unbypassed APRM channel is providing a trip output, each of the four APRM 2-out-of-4 voter channels will have a half trip, but no trip signals will be sent to the RPS. The trips from one APRM can be bypassed by operator action in the control room. Trip outputs to the RPS are transmitted by removing voltage to a relay coil, so loss of power results in actuating the RPS trips.

In the startup mode (MODE 2) of operation, the APRM "fixed" upscale trip setpoint is set down to a low level. This trip function is provided in addition to the existing IRM upscale trip in the startup mode (MODE 2). The trip settings are listed in Table 7.5-4b.

The trip functions are performed by digital comparisons of APRM electronics. The APRM flux value is developed by averaging the LPRM signals and then adjusting the average, using gain adjustment factors from heat balance calculations, to be the APRM power. The APRM power is processed through a first order filter with a six second time constant to calculate simulated thermal power. These calculations are all performed by the digital processor and result in a digital representation of APRM and simulated thermal power. For each RPS trip and rod block alarm, the APRM power or simulated thermal power, as applicable (see Table 7.5-4b), is digitally compared to the setpoint (which was previously entered and stored). If the power value exceeds the setpoint, the applicable trip is issued.

7.5.7.3.5 Oscillation Power Range Monitor

The Oscillation Power Range Monitor Subsystem (OPRMS) is a firmware-based function that utilizes APRMS equipment. The OPRMS is designed to detect reactor core thermal hydraulic instability and to provide control room indication, alarms, and trips associated with a potential reactor power instability event.

The OPRMS uses period-based, amplitude-based, and growth rate-based algorithms to detect core power oscillations. Only the period-based algorithm (PBA) is credited with providing an oscillation suppression trip before the fuel MCPR safety limit is violated. The amplitude-based (ABA) and growth rate-based (GRBA) algorithms are categorized as defense-in-depth features.

The OPRMS consists of four independent OPRM channels. Each OPRM channel consists of multiple OPRM cells. Each OPRM cell consisting of three or four LPRM inputs which are summed together and divided by the total number of active LPRM inputs to the OPRM cell. Each OPRM channel provides an oscillation suppression trip signal when one or more of the instability algorithms (PBA, ABA, or GRBA) for an operable OPRM cell has detected an instability condition. Each OPRM channel also provides an oscillation pre-trip alarm and control rod block when one of the instability algorithms has exceeded a predetermined value.

When the reactor is operating in regions of the power/flow map where it has been determined that unstable power oscillations cannot occur, the OPRMS trip outputs are automatically bypassed. Each OPRM channel provides an input to the OPRM trip enable alarm that indicates when the reactor has entered the operating region where instability can occur and the oscillation trip output is no longer bypassed. The operating region where instability can occur is defined as below a predetermined value of total core flow and above a predetermined value of reactor power.

The OPRM and APRM scram trip signals are processed through 2-out-of-4 trip voters in each channel which provide RPS trip input signals. The OPRM scram trip signals are voted separately from the APRM scram trip signals so that a trip in one OPRM channel and a trip in one APRM channel will not cause an RPS scram.

If the OPRMS should become inoperable, pre-planned manual actions may be implemented to monitor and scram the reactor as required until the OPRMS is returned to service.

7.5.7.4 Safety Evaluation

Each APRM derives its signal from information obtained from the LPRMs. The assignments, power separation, cabinet separation, and LPRM signal isolation are in accord with the safety design basis of the Reactor Protection System. There are four APRM channels with the Reactor Protection System trip outputs from each routed to each of four APRM 2-out-of-4 voter channels. Two voter channels are associated with each Reactor Protection System trip system. This configuration allows one APRM channel to be bypassed plus one failure while still meeting the Reactor Protection safety design basis.

APRM power (and simulated thermal power) are adjusted periodically based on heat balance to match true reactor power. This adjustment is made regularly at a rate sufficient to compensate for LPRM burnup and the related change in APRM values. However, coolant flow changes and control rod movements can also affect the relationship between APRM measured flux and true reactor power and introduce errors. To accommodate the predictable APRM variations due to coolant flow and control rod changes, analysis are performed to determine limiting case values for both. Bounding values are then used in APRM setpoint calculations as an expected error. This analysis assures that there is adequate margin in the actual setpoints to assure safety limits are not exceeded even if the worst case error in APRM values is introduced due to coolant flow changes or control rod movements after heat balance calibration of the APRM has been performed.

The APRM scram setpoint is demonstrated to be adequate in preventing fuel damage as a result of abnormal operational transients by the analyses documented in Reference 1 of Section 14.0, "Plant Safety Analysis."

7.5.7.5 Power Generation Evaluation

The APRMS provides the operator with four continuous recordings of the average reactor power. The rod blocking function prevents operation above the region defined by the design power response to recirculation flow control. The flow signal used to vary the rod block level is supplied from the recirculation system flow instrumentation. Two flow comparators monitor the four flow signals and initiate an alarm if the four signals are not in agreement. Because any one of the APRMs can initiate a rod block, this function has a high level of redundancy and satisfies the power generation design basis. One APRM channel may be bypassed. In addition, a minimum of 20 LPRM inputs, with three per axial level, is required for each APRM channel to be operative. If the number is less than this, an automatic APRM inoperative alarm and rod block are generated.

7.5.7.6 Inspection and Testing

APRM channels are calibrated at power by a heat balance or using data from previous full-power runs and are tested by procedures in the applicable instruction manual. Each APRM channel can be individually tested for the operability of the APRM scram and rod blocking functions by introducing test signals.

7.5.8 Rod Block Monitor Subsystem

7.5.8.1 Power Generation Design Basis

1. The RBMS shall be designed to prevent local fuel damage as a result of a single rod withdrawal error under the worst permitted condition of RBM bypass.

2. The RBMS shall provide a signal to permit operator evaluation of the change in the local relative power level during control rod movement.

7.5.8.2 Description

7.5.8.2.1 Identification

The RBMS has two RBM channels, each of which uses input signals from a number of LPRM channels. A trip signal from either RBM channel can initiate a rod block. One RBM channel may be bypassed without loss of subsystem function.

7.5.8.2.2 Power Supply

The RBMS power is received from the 120-V AC supplies used for the Reactor Protection System (RPS) (see Subsection 7.2).

Each RBM receives power redundantly from both RPS buses.

7.5.8.2.3 Signal Conditioning

The RBM signal is generated by averaging a set of LPRM signals. The LPRM signals used depends on the control rod selected upon selection of a rod for withdrawal or insertion, the conditioned signals from the LPRMs around that rod will be automatically selected by the two RBM channels. (Figure 7.5-17a shows examples of the four possible LPRM/selected rod assignment combinations.) For a typical non-edge rod, each RBM channel averages LPRM inputs from two of the four B-position and D-position detectors, and all four of the C-position detectors. (See Figure 7.5-17b.) (This configuration is part of the RBM improvements described in Reference 1 of Section 14.0, "Plant Safety Analysis.") A-position LPRM detectors are not included in the RBM averages, but are displayed to the operator. When a rod near, but not at, the edge of the core is selected, where there are fewer than four, but at least two, LPRM strings around the rod, the number of detectors used by the RBM channels is either six or four depending on how many LPRM strings are available. If a detector has been bypassed in the LPRM System, that detector is automatically deleted from the RBM processing and the averaging logic is adjusted to average only the remaining detectors.

After selection of a control rod, each RBM channel calculates the average of the related LPRM detectors and calculates a gain factor that will adjust the average to 100%. Thereafter, until another rod is selected, the gain factor is applied to the LPRM average to obtain the RBM signal value. The RBM signal value is compared to RBM trip setpoints (see 7.5.8.2.4).

When a peripheral rod is selected, or if the APRM value for the RBMs associated APRM is below the automatic bypass level (approximately 30% power), the RBM function is automatically bypassed, the rod block outputs are set to "permissive," and the RBM average is set to zero.

7.5.8.2.4 Trip Function

The RBM supplies a trip signal to the Reactor Manual Control System to inhibit control rod withdrawal. The trip is set whenever the RBM signal value exceeds the RBM setpoint. As described in Reference 1 of Section 14.1, there are three different power-dependent setpoints, each a percentage above the RBM initial value of 100%. The particular setpoint that is applied is selected based on the simulated thermal power value from the RBM's associated APRM channel (an alternate APRM channel is assigned and is automatically used for inputs if the primary APRM channel is bypassed or inoperative). Higher APRM simulated thermal power values select a lower setpoint. That is, at higher power levels, the percentage increase in the RBM value allowed is less than at lower power levels. One of the two RBMs can be bypassed by the operator. Either RBM channel can prevent rod movement.

7.5.8.3 Power Generation Evaluation

Motion of a control rod causes the LPRMs adjacent to the control rod to respond strongly to the change in power in the region of the rod in motion. Typical RBM channel responses are documented in Reference 1 of Section 14.1. This reference also provides documentation of rod withdrawal error analysis results which demonstrate that under limiting assumptions of LPRM failures the RBM setpoints will halt rod motion well before local fuel damage can occur.

7.5.8.4 Inspection and Testing

The rod block monitor channels are tested and calibrated by procedures given in the applicable instruction manuals. The RBMs are functionally tested by introducing test signals into the RBM channels.

Local alarm lights representing upscale and downscale trips will be verified. The inoperative trip will be initiated to produce a rod block. The functions that cannot be verified to produce a rod block directly will be verified during the operating cycle.

7.5.9 Traversing Incore Probe Subsystem

7.5.9.1 Power Generation Design Basis

1. The TIPS shall be capable of providing a signal proportional to the axial gamma flux distribution at selected small axial intervals over the regions of the core where LPRM detector assemblies are located. This signal shall be of high precision to allow reliable calibration of LPRM gains.

2. The TIPS shall provide accurate indication of the position of the flux measurement to allow pointwise or continuous measurement of the axial gamma flux distribution.

7.5.9.2 Description

7.5.9.2.1 Identification

The TIPS includes five traversing incore probe (TIP) machines, each of which has the following components:

a. One traversing incore probe (TIP),

b. One drive mechanism,

c. One indexing mechanism,

d. Up to 10 incore guide tubes, and

e. One chamber shield.

The subsystem allows calibration of LPRM signals by correlating TIP signals to LPRM signals as the TIP is positioned in various radial and axial locations in the core. The guide tubes inside the reactor are divided into groups. Each group has its own associated TIP machine. The assignment of LPRM strings to the five TIP machines is shown in Figure 7.5-20.

7.5.9.2.2 Physical Arrangement

A TIP drive mechanism uses a gamma sensitive detector attached to a flexible drive cable, which is driven from outside the primary containment by a gear box assembly. The flexible cable is contained by guide tubes that continue into the reactor core.

The guide tubes are a part of the LPRM detector assembly and are specially prepared to provide a durable, low-friction surface. The indexing mechanism allows the use of a single detector in any one of ten different tube paths. The tenth tube is used for TIP cross calibration with the other TIP machines. The control system provides both manual and semi-automatic operation. Additionally, for Unit 1, only fully automatic operation is possible with all drives capable of operating concurrently. The TIP signal is amplified and displayed on a meter or digital display (Unit 1 only). Core position versus gamma flux is recorded in the Main Control Room on an X-Y recorder for Units 2 and 3. For Unit 1, the information is stored digitally and transmitted to the process computer. A block diagram of the drive system is shown in Figure 7.5-21.

The heart of each TIP machine is the probe (Figure 7.5-22), consisting of the detector and the associated signal drive cable. The detector is an argon filled chamber 0.213 inches in diameter and 1.0 inches in active length. The body of the detector is made of stainless steel with a titanium anode. Sensitivity of the detector is approximately 3×10^{-14} amps/R/hr. The detector can operate in a maximum gamma flux level of 2.8×10^{9} R/hr. The nominal detector operating voltage is 100-V DC.

The signal current from the detector is transmitted from the TIP to amplifiers and readout equipment by means of a triaxial signal cable, which is an integral part of the mechanical drive cable. The outer sheath of the drive cable is constructed of carbon steel in a helix array. The cable drive mechanism engages this helix to effect movement in and out of the guide tubes. The inner surface of the guide tubing between the reactor vessel and the drive mechanism is coated with a ceramic bonded lubricant to reduce friction. The guide tubing inner surface is nitrided within the reactor vessel.

The cable drive mechanism contains the drive motor, the cable take-up reel, an analog probe position indicator for the recorder, and a mechanical counter to provide digital pulses to the control unit for positioning the TIP at specific locations along the guide tube.

The drive mechanism inserts and withdraws the TIP and its cable from the reactor and provides detector position indication signals. The drive mechanism consists of a motor and drive gearbox, which drives the cable in the manner of a rack and drive-pinion. A two-speed drive motor is used providing a high speed for insertion and withdrawal and a low speed for scanning the reactor core. (See Figure 7.5-23a, b, c, and d.)

A take-up reel is included in the cable drive mechanism to coil the drive cable as it is withdrawn from the reactor. This reel makes it possible to connect the TIP and its cable to the amplifier through a connector rather than slip rings which reduces possible noise and maintenance problems.

The analog position indicator and the mechanical counter (digital) are also driven directly from the output shaft of the cable drive motor. The analog position signal from a potentiometer and a flux amplifier output are used to plot gamma flux versus incore position of the TIP. The TIP position signal is also available to the process computer. The digital counter is used to position the TIP in the guide tube through the control logic with a linear position accuracy of 1 inch. The digital counter can control TIP positions at the top of the core for initiation of scan, and at the bottom of the core for changing to fast withdrawal speed.

A position limit switch provides an electrical interlock release when the probe is in the nominal zero position to allow the indexing mechanism to index the TIP to the next guide tube location. The limit switch is actuated when the end of the TIP passes a switch in the indexer. The cable drive motor includes an AC voltage-operated brake to prevent coasting of the TIP after a desired incore position is reached. When the system is not in use, the detector probe can be completely withdrawn to a position in the center of the chamber shield.

A circular transfer machine with ten indexing points functions as an indexing mechanism. Nine of these locations are for the guide tubes associated only with that particular TIP machine. The tenth location is for the guide tube common to all the TIP machines. Indexing to a particular tube location is accomplished manually at the control panel by means of a position selector switch which energizes the electrically actuated rotating mechanism.

The tube transfer mechanism is part of the indexing mechanism and consists of a fixed circular plate containing ten holes on the reactor side, which mate to a rotating single-hole plate. The rotating plate aligns and mechanically locks with each fixed hole position in succession. The indexing mechanism is actuated by a motor-operated rotating drive. Electrical interlocks prevent the indexing mechanism from changing positions until the probe cable has been completely retracted beyond the transfer point. Additional electrical interlocks prevent the cable drive motor from moving the cable until the transfer mechanism has indexed to the preselected guide tube location.

A valve system is provided with a ball valve on each guide tube entering the primary containment. These valves are closed except when the TIP subsystem is in operation. A ball valve and a cable shearing valve are mounted in the guide tubing just outside the primary containment. They prevent the loss of reactor coolant in the event a guide tube ruptures inside the reactor vessel. A valve is also provided for an air purge line to the indexing mechanisms. A guide-tube ball-valve opens only when the TIP is being inserted. The shear valve is used only if a leak occurs when the TIP is beyond the ball-valve and power to the TIPS fails. The shear valve, which is controlled by a manually-operated, protected switch, can cut the cable and close off the guide-tube. The shear valves are actuated by detonation squibs. The continuity of the squib circuits is monitored by front panel indicator lights in the control room.

A guide-tube ball-valve is normally deenergized and in the closed position. When the TIP starts forward, the valve is energized and opens. As it opens, it actuates a set of contacts which gives a signal light indication at the TIPS control panel and bypasses an inhibit-limit switch, which automatically stops TIP motion if the ball valve does not open on command.

7.5.9.2.3 Signal Conditioning

The TIP control and readout instrumentation is mounted in a cabinet in the control room. Since there are five groups of guide tubes, each with an associated TIP machine, there are also five groups of drive control equipment. For Units 2 and 3, there is a flux probe monitor which consists of six individual flux amplifiers (one spare) and associated DC power supplies. For Unit 1, a flux amplifier and associated DC power supply is located in each drive control drawer. For Units 2 and 3, a common X-Y recorder records the flux variations of each scan. An X-Y output is provided for use by the process computer. For Unit 1, the information is stored digitally in the drive control drawers and transmitter to the process computer. The TIP output is linear to within +1 percent of full scale when operated at a detector voltage of 100V-DC in a thermal neutron flux of between 2.8×10^{13} nv to 2.8×10^{14} nv. The probe and cable leakages contribute less than 1 percent of full scale output during the life of the detector. For normal operating conditions, the flux amplifier is linear to within $\pm$1.0 percent of full scale and drifts less than 1.0 percent of full scale during a 100-hour period at design operating conditions. Actual operating experience has shown the system to reproduce within 1.0 percent of full scale in a sequence of tests.

7.5.9.3 Power Generation Evaluation

An adequate number of TIP machines is supplied to assure that each LPRM assembly can be probed by a TIP, and one LPRM assembly (the central one) can be probed by every TIP to allow intercalibration. Typical TIPs have been tested to prove linearity. The system has been field tested in an operating reactor to assure reproducibility for repetitive measurements, and the mechanical equipment has undergone life testing under simulated operating conditions to assure that all specifications can be met. For Units 2 and 3, the system design allows semi-automatic operation for LPRM calibration and process computer use. For Unit 1, fully automatic operation is possible. The TIP machines can be operated manually to allow pointwise flux mapping.

7.5.9.4 Inspection and Testing

The TIPS equipment is tested and calibrated using heat balance data and procedures based on the applicable instruction manual.