

Westinghouse Technology Systems Manual

Section 9.1

Excore Nuclear Instrumentation

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9.1 EXCORE NUCLEAR INSTRUMENTATION

Learning Objectives:

1. List the purposes of the excore nuclear instrumentation system.
2. List the reactor protection system inputs provided by the excore nuclear instrumentation system and the purpose (basis) of each.
3. List the interlocks and permissives provided by the excore nuclear instrumentation system and the purpose (basis) of each.
4. Explain how the excore nuclear instrumentation system is capable of detecting both axial and radial (azimuthal) power distribution.
5. Explain how the power range signal is calibrated to indicate reactor thermal output.
6. Explain why gamma compensation is required only in the source and intermediate ranges.
7. Explain the effects of an improperly compensated intermediate range.
8. Explain why channel test signals are additive to the channel outputs.

9.1.1 Introduction

The purposes of the excore nuclear instrumentation system are to:

1. Provide indication of reactor power from shutdown to full power conditions,
2. Provide inputs to the reactor protection system during startup and power operation,
3. Provide reactor power information to the automatic rod control system, and
4. Provide axial and radial power distribution information during power operations.

The excore nuclear instrumentation system monitors the power level of the reactor by detecting neutron leakage from the reactor core. Leakage neutron flux from the core is monitored for two primary reasons. First, core neutron leakage is directly proportional to the core neutron flux (power level), and second, it is much easier to design and maintain neutron detectors which do not need to operate within the hostile environment of the reactor core.

Three overlapping ranges of excore instrumentation monitor the neutron flux level generated in the core from a few counts per second up to approximately 10^{15} neutrons/cm²/sec (200 percent of full power). The three different ranges of indication are source, intermediate, and power. Monitoring and protective functions are provided by two independent source range channels, two independent intermediate range channels, and four independent power range channels. The

power range instruments also provide an input into the automatic rod control system.

Auxiliary channels provide a source range audio count rate signal or “beeper,” for audible indication of changes to the neutron flux rate. In addition, the source and intermediate range startup rates are provided to the reactor operator. This information is used by the reactor operator to determine the approach to criticality and to monitor how rapidly reactor power is changing.

The instrument racks for this system are usually located in the control room area, where they may be visible to the operator. Information generated by this system is displayed on individual channel drawers installed in the excore instrumentation cabinets and on the reactor control section of the main control board. The excore nuclear instrumentation system is considered a safety related system and its components are powered from vital (Class 1E) power supplies.

9.1.2 System Description

9.1.2.1 Excore Nuclear Instrumentation System

Neutron detectors, utilizing solid-state electronic circuitry, are used to monitor the leakage neutron flux from a completely shutdown condition up to 200% of full power. Since the neutron flux covers a wide range (12 decades), three ranges of instrumentation are used to obtain accurate flux level measurements (Figure 9.1-1). The lowest level (source range) covers six decades of neutron flux.

The lowest observed count rate (indicated by the source range) depends on the strength of the neutron sources in the core and the core multiplication associated with the shutdown reactivity. The next higher range of nuclear instrumentation (intermediate range) spans eight decades. The design of this instrument is chosen to provide overlap between the upper output of the source range channels and the full span of the power range instruments. The highest range of indication (power range) spans approximately two decades. The power range provides a linear display of power and overlaps with the upper portion of the intermediate range channels.

The primary function of the excore nuclear instrumentation system is to protect the reactor core from overpower by monitoring the neutron flux and generating appropriate alarms and reactor trips to shutdown the reactor when required. Each range of instrumentation (source, intermediate, and power) provides overpower reactor trip protection during operation in that range. The overlap of instrument ranges provides reliable protection at all flux levels. During reactor startup, as the neutron flux level is increased and satisfactory instrumentation operation is obtained in a higher range, the overpower protection trip for the lower range may be manually removed by the operator in accordance with administrative procedures. However, automatic reinstatement of the lower range trip settings is provided when reducing power level.

The source, intermediate and power range detectors are placed in instrument wells located within the concrete shield surrounding the reactor vessel (Figure 9.1-2). The instrument well is movable and is positioned by a push-bar located outside the concrete shield wall. If an individual detector requires maintenance or replacement, the instrument well is pulled away from the reactor vessel to a location under an access pipe which is sealed by a water tight cap. After maintenance is complete, the instrument well is pushed back to a position adjacent to the reactor vessel. Failure to return the instrument well to its original position results in an incorrect indication of power due to the change in detector-core geometry.

9.1.2.2 Source Range

The source range instrumentation consists of two independent channels, designated as source range channels N-31 and N-32. Both channels are physically and functionally identical. As shown in Figure 9.1-3, the source range detectors are located 180 degrees apart outside the bottom half of the core. This location provides the maximum sensitivity to low power neutron level increases. The source range circuits monitor and indicate the neutron flux level of the reactor core and the rate by which the neutron flux changes during a reactor shutdown and the initial phase of start-up. The rate of change of the neutron population is indicated as startup rate (SUR). The SUR is the number of decades (powers of ten) that the neutron flux (reactor power) is changing per minute and is indicated as decades per minute (DPM).

Indication of source range neutron population and its rate of change are provided at the nuclear instrumentation cabinets and at the reactor control panel. The source range indication has a span of 10^0 to 10^6 cps (counts per second) and the source range SUR has a range of - 0.5 DPM to + 5 DPM.

Each source range channel, Figure 9.1-4, utilizes a preamplifier assembly which amplifies the neutron pulses from the BF_3 proportional counter detector to a workable level (a discussion of the BF_3 proportional counter is provided in section 9.1.4). The circuitry of each channel shapes and integrates the pulses, provides amplification, discriminates against gammas and background noise, produces a logarithmic neutron level signal, and amplifies the log signal prior to its indication.

One of the principal problems in the source range is trying to distinguish the relatively small number of pulses produced by neutrons from the large number of pulses produced by gamma radiation during source range operation. Thus gamma discrimination is of particular interest during shutdown after the reactor core has operated long enough to establish an accumulation of fission products. This condition produces a high gamma field and a low neutron flux around the detector.

The meter face is calibrated to indicate counts/sec and represents the number of neutron pulses generated per second. This instrument can indicate up to a maximum neutron count rate of 10^6 cps. The count rate signal is also applied to bistable relay assemblies which in turn generate signals for remote protection equipment. The noise-discriminated pulse signal from either source range channel is also applied to an audio count rate drawer assembly and, together with a scaler-

timer assembly, converts and amplifies the neutron pulses into an audible tone heard in the control room and in the containment.

Source range channel selection for audio monitoring is accomplished at the front panel of the audio count rate drawer. Integrated pulses are also applied to the comparator and rate drawer assembly where the rate of change of neutron flux is computed. The output rate signal is coupled to local and remote SUR meters.

9.1.2.3 Intermediate Range

The intermediate range instruments consist of two independent channels, designated as intermediate range channels N-35 and N-36. Both channels are physically and functionally identical. As shown on Figure 9.1-3, the intermediate range detectors are located 180 degrees apart outside the midpoint of the core. The detectors share the same instrument well as the source range detectors. The midpoint of the core location allows the detectors to monitor the neutron population changes from low power operations to full power. The intermediate range channels monitor the neutron flux of the core and provide signals to the rate circuits to compute its rate-of-change. The intermediate range channels, which cover a span of eight decades, come on scale when the source range channel indications reach approximately 10^3 counts/sec. The intermediate instruments monitor neutron flux from this level through full power operation.

As shown in Figure 9.1-4, each intermediate range circuit receives a signal proportional to neutron flux from a compensated ion chamber detector. Gamma compensation is accomplished by the electronic arrangement of the detector. The intermediate range channel, with the exception of the detector, is housed in the intermediate range drawer assembly.

A logarithmic current measuring circuit is used to monitor reactor power over a range of eight decades (10^{-11} to 10^{-3} amperes). Indications of intermediate range neutron flux level and SUR are provided at the nuclear instrumentation cabinets and at the reactor control panel. The neutron flux level signal is also applied to bistable relay assemblies, which in turn generate signals for a protection-grade permissive, an interlock, and a reactor trip on high neutron flux.

9.1.2.4 Power Range

The power range circuits consist of four independent channels, designated as power range channels N-41 through N-44. All four channels are physically and functionally identical. Each power range channel employs an upper and a lower uncompensated ion chamber detector which provide current signals to the power range circuits. As shown on Figure 9.1-3, the power range detectors are located 90 degrees apart. Each location consists of an upper detector and a lower detector, mounted inside the same instrument well. The outputs of both detectors (upper and lower) are combined to produce a channel total power signal. The eight detector outputs (four upper detectors and four lower detectors) are compared to each other to provide power distribution information to the reactor operator.

Within each power range channel, as shown in Figure 9.1-5, the upper detector and lower detector current signals are monitored, summed and amplified, at the summing and level amplifier, to develop a voltage which is directly proportional to reactor power. The summed signal is monitored in percent full power, ranging from zero to 120 percent. The output of each power range channel provides reactor trip signals, alarms and input for control functions. In addition, electronic signals are sent to a channel and a detector current comparator. The channel current comparator assembly uses the output of the four power range channels to verify that the detectors are properly calibrated with respect to each other. The detector current comparator (one comparator for the upper detectors and one for the lower detectors) monitors the four upper or four lower detector outputs to determine if power is being evenly produced throughout the core.

9.1.3 Component Descriptions

9.1.3.1 Source Range Channel

The nuclear instrumentation system is supplied with two independent source range channels as shown in Figure 9.1-4. Boron trifluoride proportional counters (N-31 and N-32) provide pulse signals to the source range channels. These detectors are installed on opposite flat portions of the core, near the primary/secondary neutron sources, at an elevation approximating one quarter of the core height. The preamplified detector signal is received by the source range instrumentation conditioning equipment located in separate drawers in separate control room racks.

The detector signal, which is a count rate proportional to the neutron flux leakage, is conditioned for conversion to an analog signal proportional to the logarithm of the neutron flux count rate. The signal received from the counter has a range of 1 to 10^6 pulses per second and is received through a fixed-gain pulse preamplifier.

The preamplifier is located close to the detector to increase the signal-to-noise ratio and also furnishes high voltage coupling to the detector. The preamplifier assembly has internal provisions for generating self-test frequencies of 60 to 10^6 counts per second. These test oscillator circuits are energized by a switch located on the associated source range drawer. The source range channel power supplies furnish low voltage for preamplifier operation and for the drawer-mounted modules.

The preamplifier output is received at the pulse-amplifier/discriminator located in the source range drawer. This module provides amplification and discrimination, both of which are adjustable. Discrimination is provided between neutron flux pulses, and gamma-generated pulses. The discriminator circuit cuts off the low amplitude gamma-induced pulses. The discriminator provides two outputs; one output (isolated) to a scaler-timer unit in the audio-visual channel and the other to a pulse shaper (transistorized) circuit which supplies a constant amplitude pulse to the log integrator module in the source range drawer.

The pulses from the pulse amplifier are supplied to the pulse shaper which shapes it into a square wave. The output waveform has a constant amplitude at half the frequency of the input frequency. Two input pulses are required to produce an

output pulse. The pulse driver receives the standard amplitude pulse from the pulse shaper and provides the drive through impedance matching stages to apply the pulses to a log pulse integrator.

The log pulse integrator assembly receives the square wave pulses from the pulse drive assembly and integrates these pulses to provide a current output proportional to the logarithm of the average pulse rate. The current is then applied to a current summing network and the level amplifier for amplification.

The level amplifier receives the log-level voltage output from the log pulse integrator. The assembly amplifies the voltage to produce an output which is displayed on a meter calibrated logarithmically from 10^0 to 10^6 cps. The output is also applied to bistables, and an isolation amplifier for remote indication.

Reactor trip signals provided by these bistables are transmitted to the protection logic cabinets where the necessary matrices involved in generating reactor trip signals are formed. All logic matrices associated with plant protection or control functions are located in the protection logic or auxiliary relay cabinets, respectively.

During shutdown periods, a high neutron flux in the core actuates a bistable which alerts plant personnel to abnormal reactivity increases. This alarm provides both local visual and audible annunciation (high flux at shutdown), and remote audible annunciation (containment evacuation).

These annunciators ensure that the plant operator is alerted to any unusual or unsafe condition. The bistable alarm function is manually blocked by deliberate operator action during a reactor startup. Blocking is continuously annunciated at the control board during source range operation. The high flux at shutdown alarm setpoint is normally set at approximately one decade above the steady-state shutdown flux level.

The high source range flux level reactor trip bistable provides an input into the reactor protection system. Its purpose is to initiate a reactor trip to mitigate startup reactivity excursions during power operations in the source range. When the intermediate range indication is on scale, P-6 (the source range block permissive) is energized and the source range reactor trip may be manually blocked by the operator. Once the channels are blocked, the high voltage is removed from the source range detectors. Removing the high voltage protects the detectors from damage due to the high currents produced by the increased neutron flux levels present at higher reactor power levels. The blocking action is physically accomplished by actuating two momentary-contact switches located on the main control board. While these trips are blocked, the SOURCE RANGE TRIP BLOCKED annunciator is continuously illuminated on the main control board.

If a one decade overlap exists between the top of the source range and the bottom of the intermediate range, the source range block permissive P-6 is generated. The one decade overlap insures that the intermediate range is available and indicating before increasing reactor power above the source range. This permissive, P-6, is generated when at least one of the two intermediate range instruments exceeds the setpoint of 10^{-10} . At the moment the permissive is made up, the source range

indication is approximately 3/5 decade below the source range HIGH FLUX LEVEL REACTOR TRIP setpoint (10^5 cps).

A bistable is used to indicate that the voltage to the detector has failed. A loss of high voltage on either source range channel provides control board annunciation. During a reactor startup when the source range high voltage is intentionally turned off (as mentioned above), the loss of high voltage annunciator is backlit until reactor power exceeds 10% (P-10 Nuclear power above 10%). When P-10 is made up the source range loss of high voltage annunciator is de-energized which prevents the annunciation of a condition which is not abnormal.

Testing of the source range channels is accomplished by switches on the individual source range instrument drawers. An operation selector switch on the source range instrument drawer selects the test signal to be inserted. All test signals are additive to the signal from the detector. Therefore, the resultant channel level will be conservative, equal to the imposed test signal plus the detector signal.

An electrical interlock between the Level Trip Bypass switch and the Operation Selector switch prevents inadvertent actuation of the reactor trip circuits (i.e., the channel cannot be put into the test mode unless the trip is bypassed). The trip bypass is annunciated on the source range drawer and on the main control board.

Each source range channel supplies signals to the following instrumentation.

- Remote count rate meter (NI-31B and NI-32B) - The remote meters are driven by isolation amplifiers. The meters are mounted on the main control board and calibrated logarithmically from 1 to 10^6 counts per second.
- Remote recorder (NR-45) - This two-pen recorder is capable of continuously recording any two nuclear instrumentation channels. Each pen receives a signal through a multi position switch which can select any one of the eight nuclear channels.

The source range channel instrument drawer is shown on Figure 9.1-6. The instrument drawer switches and indications are discussed individually below:

- Detector volt meter - monitors the high voltage power supply output to the BF_3 proportional counter.
- Neutron Level Meter - Indicates the neutron level output of the BF_3 proportional counter for the source range channel. The meter indication is in counts per second between 10^0 and 10^6 , calibrated logarithmically.
- Instrument Power On Lamp - Indicates that 118 Volts ac instrument power is applied to drawer instrument power supplies.
- Control Power On Lamp - Indicates that 118 Volts ac control power is applied to drawer control signal circuits.

- Channel On Test Lamp - Indicates that the drawer OPERATION SELECTOR switch is in a test position.
- Loss of Detector Volts Lamp - Indicates that the high voltage supplied to the BF₃ proportional counter is removed, or is low due to a fault in the system. Setpoint is 70% of normal voltage.
- Level Trip Lamp - Lights when the neutron count rate exceeds 10⁵ cps.
- Level Trip Bypass Lamp - Lights when LEVEL TRIP switch is placed in the BYPASS position to test and calibrate the source range channel circuits.
- High Flux at Shutdown Lamp - Indicates when the neutron level exceeds the preset level during reactor shutdown.
- Bistable Trip (Spare) Lamp - A spare indication lamp designed and manufactured into the cabinet for possible use in the future.
- AC Instrument and Control Power Fuses - Provide overcurrent protection for drawer circuitry.
- Level Trip Switch - A two position rotary switch which enables test and calibration of the source range channel in conjunction with the OPERATION SELECTOR switch. In the BYPASS position, the LEVEL TRIP BYPASS lamp illuminates, the OPERATION SELECTOR switch is enabled, and a signal is continuously provided to the reactor protection system to prevent a reactor trip during testing (see bistable detail on Figure 9.1-4).
- Operation Selector Switch - An eight position switch enabled by the LEVEL TRIP switch permits the generation of test signals for test and calibration of the source range channel. In the 60 CPS, 10³ CPS, 10⁵ CPS or 10⁶ CPS positions, a Test Calibrate Module inserts an appropriate signal to the input of the pulse amplifier. This allows verification of the operating accuracy of the circuits within the source range drawer. In the 60 CPS PREAMP and the 10⁶ CPS PREAMP positions one of two test oscillator modules in the preamplifier is energized to generate a known signal for testing the preamplifier and the long run of triaxial cable between the preamplifier and the source range drawer.
- Level Adjust Potentiometer - Provides an adjustable test signal for insertion directly into the level amplifier. This enables the adjustment of the trip level of the various bistable circuits within the drawer assembly. The control is effective only when the OPERATION SELECTOR switch is in the LEVEL ADJ position.

9.1.3.2 Intermediate Range Channel

As shown in Figure 9.1-4, two independent, compensated ionization chambers provide extended neutron flux coverage from the upper portion of the source range

to approximately 200 percent reactor power. Compensated ionization chambers (N-35 and N-36) serve as neutron sensors for the intermediate range channels and are located in the same instrument wells as the source range detectors (a discussion of the compensated ion chamber is given in section 9.1.4). Each intermediate range channel consists of one compensated ionization chamber which uses high density polyethylene as a moderator and as an insulator. The detectors are positioned at an elevation corresponding to half the core height. Each intermediate range channel is supplied with a positive high voltage and high negative compensating voltage to its respective detector. Compensating voltage is used to cancel out the gamma contribution to the total current signal. Therefore, the signal current delivered to the intermediate range channel circuitry is from neutrons only (Figures 9.1-15 and 9.1-16). Both high voltage supplies are adjustable through controls located inside the channel drawer.

The equipment for each channel, including the high voltage and compensating voltage power supplies, is mounted in separate drawers. The detector signal is received by the intermediate range logarithmic amplifier. This unit produces an analog voltage output signal which is proportional to the logarithm of the input current. This output signal is used for local indication and is sent to the inputs of the various bistables within the intermediate range drawer. Local indication is provided by a meter mounted on the front panel of the drawer. The meter face has a logarithmic scale with a span of 10^{-11} to 10^{-3} amperes. The isolation amplifier is similar to that used in the source range. Six separate bistables are used in the intermediate range drawer to perform the following functions:

- Loss of high voltage (alarm),
- Loss of compensating high voltage (alarm),
- Permissive P-6 (10^{-10} amps),
- Rod stop C-1 (blocks automatic and manual rod withdrawal at 20% power current equivalent),
- Reactor trip (25% power current equivalent), and
- Spare.

The intermediate range permissive, P-6, allows the blocking of the source range trip. Bistable outputs from each intermediate range channel are combined in a one-of-two matrix to provide the permissive function and control board status indication of the availability of the permissive. As explained earlier, this permissive (P-6) permits the manual blocking of the source range trip and removes the high voltage from the source range detector. One blocking switch is provided for each logic train. The source range trip is automatically reinstated, as required by IEEE 279 1971, if the power level as indicated by both intermediate range channels decreases below the P-6 setpoint.

The source range high voltage and trip functions may also be manually reactivated if required. This is accomplished by operation of two control board-mounted, momentary contact switches. This provision, however, is only operable below permissive P-10 (10% reactor power), which is generated by the power range channels. Above P-10, the capability to reinstate the source range is automatically blocked. A one-of-two logic from the intermediate range channels supplies a rod

withdrawal rod stop and control board annunciation. Blocking of the rod withdrawal stop is manually performed when nuclear power is above permissive P-10.

The intermediate range reactor trip is provided to limit a reactivity excursion when operating in the intermediate range during a reactor startup. Redundant control board switches are used to block the rod stops and the reactor trip on high current equivalent power. These blocks are manually inserted when the power range instrumentation indicates proper operation through activation of the P-10 permissive. As with the source range instrumentation when power decreases, the intermediate range trip functions are automatically reinstated. High voltage failure monitors provide both local and remote annunciation upon failure of the respective high voltage supplies. A common INTERMEDIATE RANGE LOSS OF DETECTOR VOLTAGE and separate INTERMEDIATE RANGE LOSS OF COMPENSATING VOLTAGE control board annunciators are provided.

Testing of each intermediate range channel is provided by a test-calibrate module which injects a test signal at the input to the log amplifier. The signal is controlled by the OPERATION SELECTOR switch on the front of each intermediate range drawer.

As in source range testing, the OPERATION SELECTOR switch on the intermediate range must be operated in coincidence with a LEVEL TRIP BYPASS switch. An electrical interlock between these switches prevents the interjection of a test signal unless the LEVEL TRIP BYPASS is in operation. Removal of the trip bypass also removes the test signal. The test signals, like the source range test signals, are superimposed upon the detector output signal.

Each intermediate range channel supplies signals to the following instrumentation.

- Remote level meter (NI-35B and NI-36B) - The remote meters are driven by isolation amplifiers. The meters are mounted on the main control board and calibrated logarithmically from 10^{-11} to 10^{-3} amperes.
- Remoter recorder (NR-45) - This is the same 2-pen recorder described for the source range. A level signal from the isolation amplifier is supplied to the recorder.

The intermediate range channel instrument drawer is shown on Figure 9.1-7. The instrument drawer's switches and indications are discussed individually below:

- Neutron Level Meter - Indicates the current level output of the compensated ion chamber. Meter indication is in amperes ranging over eight decades between 10^{-11} and 10^{-3} .
- Instrument Power On Lamp - Indicates that 118 Volts ac instrument power is applied to drawer instrument power supplies.
- Control Power On Lamp - Indicates that 118 Volts ac control power is applied to drawer control signal circuits.

- Channel On Test Lamp - Indicates that a test signal has been applied to the drawer through the operation of the OPERATION SELECTOR switch.
- Level Trip Bypass Lamp - Lights when LEVEL TRIP switch is placed in the BYPASS position to perform test and calibration functions.
- High Level Trip Lamp - Lights when the neutron flux level signal in the intermediate range channel reaches a current equivalent to 25% power.
- High Level Rod Stop Lamp - Lights when the neutron flux level in the intermediate range channel reaches a current equivalent to 20% power.
- Power Above Permissive P-6 Lamp - Lights when the current level reaches 10^{-10} amps increasing.
- Bistable Trip (Spare) Lamp - A spare indication lamp designed and manufactured into the cabinet for possible use in the future.
- Loss of Detector Voltage Lamp - Indicates a loss of or reduced high voltage supplied to the compensated ion chamber.
- Loss of Compensating Voltage Lamp - Indicates a loss of, or a reduced voltage, supplied to the compensating circuit of the compensated ion chambers.
- AC instrument and control power fuses - Provide overcurrent protection for drawer circuitry.
- Level Trip Switch - Enables test and calibration of the intermediate range channel in conjunction with OPERATION SELECTOR switch and TEST MODE switch. In the BYPASS position the LEVEL TRIP BYPASS indicator lights, the test/calibrate module is energized, and a signal is provided to the reactor protection system to prevent a reactor trip during testing (see bistable detail on Figure 9.1-4). In the bypass position, the IR Rod Stop C-1 is also defeated.
- Operation Selector Switch - A ten-position switch which applies test signals from the test calibrate module to the intermediate range channel circuits.
- Test Mode Switch - A two-position switch (FIXED/VARIABLE). In the FIXED position, it allows the test/calibrate module to provide a fixed current level selected by the OPERATION SELECTOR switch. In the VARIABLE position, a potentiometer is switched into the test calibrate module circuitry to provide current variations about the selected level.
- Variable Potentiometer - Varies current output from the test/calibrate module above or below the current level selected by the OPERATION SELECTOR switch. Control is activated only when the TEST MODE switch is in the VARIABLE position.

9.1.3.3 Power Range Channel

As shown in Figures 9.1-3 and 9.1-5, four, dual section, uncompensated ionization chambers (N-41A and N-41B through N-44A and N-44B) are used for power range neutron flux leakage detection. Each channel provides two current signals corresponding to the neutron flux in the upper (A) and lower (B) sections of a core quadrant. Each detector has a total neutron-sensitive length of ten feet. A description of an uncompensated ionization chamber is provided in Section 9.1.4.

The four power range channels are energized from separate vital ac instrument power supplies and are housed in separate racks so that a single failure will not cause a loss of protective functions. Each power range channel drawer B converts the vital ac instrument power into a regulated low (± 25 volts dc) and a high (+300 to +1500 volts dc) voltage source. The high voltage power supply has a current limiting feature so that for extreme current demands by the detector (such as an overpower condition), the power supply is maintained at a constant current output. This feature maintains an output from the detector (prevents the detector from becoming saturated and its indication failing off-scale low) and assures an output for proper reactor protection actions.

The individual current signals, one from each of the two sections of the detector, are proportional to upper and lower core neutron flux levels. These signals are received at the channel input and pass through separate ammeter shunt assemblies. The meter range switch selects shunt resistors for the meter, but never interrupts the ion chamber signal to the power range channel. The circuit is designed so that a failure of the meter or its associated switch will not interrupt the signal to the power range circuitry. Individual detector currents are displayed on two drawer-mounted meters. Isolation amplifiers in the detector current circuit supply signals to the overpower and overtemperature ΔT protection circuitry in the reactor protection system.

The isolation amplifiers also provide an output for the remote recorders (NR-41, NR-42, NR-43, or NR-44), the remote meters (NI-41C, NI-42C, NI-43C, or NI-44C), the computer, and the axial and radial flux deviation circuitry. The individual detector current signals (top and bottom) are sent to a summing and level amplifier which produces a linear signal proportional to the neutron flux in the core quadrant associated with that channel.

The output signal from the summing and level amplifier (calibrated to a thermal power value as calculated by a secondary heat balance) corresponds to 0 to 120 percent of full power, and is displayed on a power meter on the power range drawer. This same signal is delivered directly to the remainder of the power range circuitry for control, protection, and indication.

The rate circuit associated with each power range channel calculates the rate of change of nuclear power and a reactor trip signal is generated on either a high positive or a high negative rate. A high positive rate is indicative of an ejected rod, while a high negative rate indicates one or more dropped full length rods. The rate unit compares actual power with a delayed power signal received through a lag network and amplifies the difference between the two signals. This amplified difference signal is simultaneously delivered to two bistables set to trip when the

difference signal exceeds a preset amount. Both of these bistables if actuated, seal in ensuring that the necessary protective action is initiated and carried to completion even though the rate-of-change signal is only momentary.

A switch on the power range drawer (RESET-NORMAL) must be manually operated to remove the seal in function and reset the bistable. This action also removes the trip signal from the RPS trip logic matrix. The rate trips cannot be blocked and are always active. The setpoints are chosen so that normal design transients do not actuate either of the rate trips.

Other bistables which receive the power level signal from the summing and level amplifier are non-seal in and perform the following functions:

- Overpower rod stop C-2 (blocks automatic and manual rod withdrawal),
- Permissive function P-8 (single loop loss of flow permissive),
- Permissive function P-9 (turbine trip - reactor trip permissive),
- Permissive function P-10 (nuclear at power permissive),
- Power range trip, low setpoint (25%), and
- Power range, high setpoint (109%).

The overpower rod stop (C-2) is a nonprotective function that actuates at 103% nuclear power to stop control rod withdrawal. This action may prevent the high range reactor trip from occurring at 109% nuclear power. Logic for the rod stop is one-out-of-four channels (1/4). Individual channel rod stops may be manually defeated to allow testing or continued operation with a failed channel.

The nuclear at power permissive (P-10) employs a 2/4 logic at 10% nuclear power. When this permissive is actuated, the operator is permitted to manually block both the Power Range Low Setpoint Trip (25% power), the Intermediate Range Hi Flux Trip (also at 25%), and the Intermediate Range Rod Stop (20%). The P-10 permissive prevents manual reinitiation of the high voltage power supply to the source range detectors. At high flux levels the source range detectors would be damaged if energized.

The turbine trip - reactor trip permissive (P-9) allows the unit to withstand a turbine trip below 50% power without a direct reactor trip. P-9 requires a 2/4 logic from the power range channels.

The single loop loss of flow permissive (P-8) is provided to allow loss of flow in one reactor coolant system loop (single reactor coolant pump trip) without a direct reactor trip when power is below 39%.

The power range high flux, low setpoint trip (25% increasing) provides startup reactivity excursion protection and can be manually blocked when power is above the nuclear at power permissive P-10.

The power range high flux, high setpoint trip (109%) limits reactor power due to reactivity addition events and limits the maximum power level to a value consistent with that assumed in the accident analysis section of the plant's FSAR. The trip cannot be blocked and remains active at all times to prevent an overpower

condition. An additional bistable monitors the high voltage power supply to the detectors. If voltage drops to a preset level, a LOSS OF DETECTOR HIGH VOLTAGE alarm is actuated at the control panel.

A test-calibrate module provides a means of superimposing a test signal onto the detector output. The variable test signal can be directed either to detector A, to detector B, or to both detectors simultaneously. Since the test signal is additive, a channel in test cannot indicate less than actual detector output. This feature prevents a technician from inadvertently lowering the output of a detector, thereby changing the trip logic from a two-out-of-four to a two-out-of-three coincidence. The test signal is used to raise the output of the summing and level amplifier to check the setpoints of all the bistables associated with each channel and to calibrate the isolation amplifiers in the individual detector current circuitry.

Operation of the rate trip bistables is verified by changing the test signal rapidly (i.e. increasing or decreasing the potentiometers position). During such tests, only one channel at a time is checked. Bypassing the channel in test is not necessary (and physically cannot be done) since a 2/4 trip logic is used in the reactor protection system and the channel in test still responds to reactor power changes.

Each power range channel provides signals to the following:

- Remote recorder (NR-45) - Each power range supplies a 0 to 120 percent of full power signal to the selector switches for the two pen nuclear recorder NR-45. Any two nuclear instrument channels can be monitored continuously during power range operation. Also, any two of the four power range channels can be selected for recording axial flux difference (AFD) on NR-45.
- Remote meters (NI-41B through NI-44B) - These meters (located on the main control board) continuously display the power level signal from each channel on a linear scale calibrated from 0 - 120% of full power.
- Overpower recorder (NR-46 and NR-47) - A pair of two-pen recorders are used to monitor the individual nuclear power indications from the four power ranges. Each recorder provides continuous monitoring of two power range channels and has a full scale deflection time of 0.25 seconds. The recorders are capable of displaying overpower excursions up to 200 percent of full power.
- Ion chamber output recorders (NR-41 through NR-44) - Four two-pen recorders are provided on the control board to record the calibrated upper and lower detector outputs. Comparison of the traces provides quadrant power distribution indication.
- Remote delta flux meters (NI-41C through NI-44C) - Four control board mounted meters display the flux difference between the upper and lower ion chambers for each of the power range detectors. The indication is calibrated to conform with the axial offset as determined by incore flux measurements. The scale of this meter is ± 30 percent.

The power range channel instrument drawers are shown in Figures 9.1-8 and 9.1-9. The instrument drawer switches and indications are discussed individually below:

Power Range Drawer A

- Percent full power meter - output of the summing and level amplifier. Meter indication is 0 - 120 percent.
- Control Power Fuses - Protect control power line against current overloads.
- Control Power On Lamp - Indicates 118 Volts ac control power is applied to drawer assembly control circuits.
- Loss of Detector Voltage Lamp - Indicates a loss of or reduced high voltage supplied to the uncompensated ion chamber.
- Overpower Trip High Range Lamp - Indicates that reactor power has reached the high flux, high setpoint of 109% of full power.
- Overpower Rod Stop Lamp - Indicates that reactor power has reached the overpower rod stop setpoint of 103% (control-grade interlock C-2).
- Reactor Trip Low Range Lamp - Indicates that reactor power has reached the high flux, low setpoint of 25%.
- Power Above Permissive P-10 Lamp - Indicates that reactor power has reached 10% allowing operator action to block the intermediate range trip and rod stop, and the power range high flux, low setpoint (25%) trip.
- Power Above Permissive P-8 Lamp - Indicates that reactor power has reached 39% which enables the single loop loss-of-flow trip.
- Positive Rate Trip Lamp - Indicates, that a rapid increase in power has been sensed indicating an ejected control rod. Setpoint is + 5% change in 2 seconds.
- Negative Rate Trip Lamp - Indicates that a rapid decrease in power has been sensed indicating one or more dropped control rods. Setpoint is - 5% change in 2 seconds.
- Rate Mode Switch - A switch that resets the positive and negative rate trip bistables.

Power Range Drawer B

- Detector Current Meter (A) - Indicates the current level output of the upper uncompensated ion chamber section (detector A) of the power range channel. Meter indication is current level ranging between 0 to 5 milliamperes.

- Detector Current Meter (B) - Indicates the current level output of the lower uncompensated section (detector B) of the power range channel. Meter indication is current level ranging between 0 to 5 milliamperes.
- Detector A and B Range Milliamperes Switches - Four-position range switches which select the correct shunt resistor for the detector current meters. The meters display the detector A and B current including test current level. Selectable ranges are 0.1, 0.5, 1 and 5 milliamperes full scale.
- Detector A Test Signal Potentiometer - Varies the test current level to the power range channel circuit through the detector current meter for the detector A source. Current is inserted only when the DETECTOR A or DETECTOR A & B position is selected by the OPERATION SELECTOR switch.
- Detector B Test Signal Potentiometer - Varies the test current level to the power range channel circuit through the DETECTOR CURRENT meter for the detector B source. Current is inserted only when the DETECTOR B or DETECTOR A & B position is selected by the OPERATION SELECTOR switch.
- Operation Selector Switch - A four-position switch which enables the test circuitry of the power range channel. In the DET A or DET B position, the DETECTOR A or B TEST SIGNAL potentiometer output is connected in parallel with the associated detector. In the DET A & B position, both potentiometers are connected simultaneously.
- Gain Potentiometer - Adjusts gain of summing and level amplifier to calibrate the power range channel to the power output as determined by secondary plant heat balance (calorimetric) measurements.
- Instrument Power Fuses - Protect instrument power line against current overloads.
- Instrument Power On Lamp - Indicates 118 Volts ac instrument power is applied to drawer assembly power supplies.
- Channel on Test Lamp - Indicates a test signal position has been selected through the operation of the OPERATION SELECTOR switch.

9.1.3.4 Audio Count Rate

The audio count rate circuit (shown on Figure 9.1-4) provides an audible signal, in the control room and in containment, which is proportional to the neutron flux level in the core when the reactor power is in the source range. The purpose of the system is to alert plant personnel to reactivity changes which might affect shutdown margin and radiation levels inside containment.

The audio count rate channel assembly (Figure 9.1-10) receives pulses from either source range channel. The pulses are transmitted through a selector switch to the

scaler-timer chassis. The scaler-timer (Figure 9.1-11) provides binary coded decimal (BCD) signal output in accordance with the counting rate of the input signal.

The resultant digital data is decoded and used to trigger an oscillator, subsequently producing an audible tone burst at a repetition rate proportional to the source range count rate. Switch selection of appropriate BCD output, divides the input count rate by factors of ten, one hundred, one thousand, or ten thousand to maintain a discrete audible signal. A speaker mounted on the drawer assembly and one mounted near the reactor (in containment) provides audible monitoring of reactor power level during shutdown conditions. Therefore, if the count rate increases, the rate at which the audible tone burst occurs also increases. The local and remote speakers receive their signals from separate audio amplifiers. A selector switch on the rear panel of the drawer assembly provides the means of powering the remote speaker from either amplifier in the event of an amplifier failure.

Audio Count Rate Circuit

- Sources of Signals - The signals come from either source range channels N-31 or N-32.
- Scaler-Timer - The scaler-timer receives signal pulses from the discriminator output of the selected source range channel. The pulses are counted through decimal counters and then read out to the audio count rate channel drawer assembly in the form of BCD logic. The scaler-timer can also be used as a means of accurate counting to obtain plateau values for the source range detectors at low count rates. The scaler-timer also provides accurate measurement of the source range counts for calculating the inverse count rate ratios.
- Audio-Multiplier - A range switch which controls the division of the pulses received from the selected source range channel to obtain a suitable listening rate.
- Speakers - The local speaker at the nuclear instrumentation system rack and a remote speaker near the reactor (in containment) produce audible pulses for monitoring the neutron flux count rate.

Audio Count Rate Drawer - Figure 9.1-10

- Audio Power On Lamp - Indicates 118 Volt ac power is applied to the drawer assembly.
- Scaler Power On Lamp - Indicates 118 Volt ac power is applied to the scaler-timer assembly.
- AC Audio Channel Power Fuses - Protect input circuit transformer against primary power current overloads, and isolates audio channel faults from the scaler-timer circuitry.

- AC Timer Scaler Power Fuses - Protect scaler-timer against primary power current overloads.
- Channel Selector Switch - Selects source range channel N31 or source range channel N32 input signals for the input to the scaler-timer for audio monitoring.
- Volume Potentiometer - Controls the audio level output from the local loudspeaker.
- Audio Multiplier Switch - Selects the division of the audible count rate to produce a discernible rate. Division is accomplished in 4 steps; by 10, 100, 1000, and 10,000.
- Amplifier Selector Switch - Selects an amplifier circuit in the drawer assembly to drive the local and remote loud speakers. In the NORMAL position, amplifier A1 is used for the local speaker and amplifier A2 is used for the remote speaker. In the A1 position, amplifier A1 is used only to drive the remote speaker; in the A2 position, amplifier A2 is used only to drive the remote speaker. In the A1 only and A2 only positions, the local speaker is inactive.

9.1.3.5 Rate Calculating Circuit

The startup rate circuits in the comparator and rate drawer assembly receive signals from each source range channel and each intermediate range channel. The rate unit computes the rate of change of neutron flux (startup rate) for each input channel. The rate circuit assemblies within the comparator and rate drawer derive an output proportional to the rate at which the power level signal is changing; an independent rate output is computed for each channel. Each rate output signal can be selected for display on a common panel meter and is supplied to its dedicated main control board meter.

Rate Calculating Circuit - Figure 9.1-4

- Source of Signals - The signals for computing startup rate (SUR) come from four sources; NC-31 or NC-32 (source range channels) or NC-35 or NC-36 (intermediate range channels).
- SUR Amplifier - The startup rate amplifiers receive signals from the source range and intermediate range drawers. The startup rate amplifier produces a signal directly proportional to the rate-of-change of the input.
- Indication - There is one local meter for SUR information plus 4 SUR meters on the main control board. The SUR meters read between - 0.5 dpm and 5.0 dpm.

Comparator and Rate Drawer - Figure 9.1-12

- Startup Rate Meter - Indicates the rate-of-change of neutron level from a selected source or intermediate range channel. Meter indication is in decades per minute (DPM) over a range of -0.5 to 5.
- Instrument Power On Lamp - Indicates 118 Volts ac control power is applied to drawer assembly instrumentation.
- Control Power On Lamp - Indicates 118 Volts ac control power is applied to drawer assembly control signal circuits.
- Rate Channel Test Lamp - Lights when RATE TEST switch is placed in the 1 DPM or 5 DPM position to perform test and calibration functions.
- Channel Selector Switch - Selects either source range channel or either intermediate range channel.
- Rate Test Switch - Enables generation of rate test signals for calibration of the source range and intermediate range channel rate amplifiers.

9.1.3.6 Power Range Channel Current Comparator

The comparator circuit compares the power indications from the four power range channels and generates a signal proportional to the percent of full power deviation between channels. The purpose of this alarm is to alert the operator to a possible miscalibration between power range instruments. A bistable is tripped at a deviation level of 2 percent to provide an alarm function.

Channel Current Comparator Circuit - Figure 9.1-5

- Sources of Signals - Four power range level signals are generated by isolation amplifiers in power range channels NC-41 through NC-44.
- Comparator - These power range channel input signals are compared to monitor radial power distribution. If a deviation in indicated output power does occur between any two channels, the comparator develops an output proportional to the amount of deviation, which is then applied to a bistable.
- Bistable - If the deviation between the highest indicating and the lowest indicating power range channel is greater than 2 percent, the bistable is tripped. The comparator also can indicate a power range channel drift or failure. Using the COMPARATOR CHANNEL DEFEAT switch, any single channel output can be eliminated from comparison during a test or the failure of a channel.

Comparator and Rate Drawer - Figure 9.1-12

- Channel Deviation Lamp - Lights when the average power level of any two of the four power range channels deviate from each other by 2 percent.

- Comparator Defeat Lamp - Lights when the CHANNEL DEFEAT Switch is placed in one of the four power range positions in order to remove a power range channel from the comparator circuits.
- Comparator Channel Defeat Switch - Removes a power range channel which is faulty or in test so that the three remaining channels may be compared.
- AC Instrument Power Fuses - Protect instrument power line against current overloads.
- AC Control Power Fuses - Protect control power line against current overloads.

9.1.3.7 Power Range Detector Current Comparator

The power range detector current comparator monitors core radial power distribution by comparing the relative power of the 4 quadrants of the upper half of the core and by comparing the relative power of the 4 quadrants of the lower half of the core.

The output of each upper detector is compared with the average of the upper detectors. If a ratio of 1.02 is calculated, a DETECTOR FLUX DEVIATION alarm is generated. This ratio is the technical specification limit for quadrant power tilt ratio. An identical calculation is performed for the lower detectors. This circuit provides an alarm function only. The technical specification limits are satisfied by performing a quadrant power tilt ratio calculation manually or through the use of the plant computer.

Detector Current Comparator Circuit - Figure 9.1-5

- Calibrated signals from each upper detector and each lower detector of the four power range channels are sent to their respective averaging amplifiers via isolation amplifiers.
- Averaging Amplifier - The averaging circuits combine the inputs to generate an average of the upper detectors and an average of the lower detectors.
- Comparator - The comparator circuit performs two functions:
 - Compares each of the four calibrated detector inputs with the average, and
 - Energizes an annunciator if any input is greater than the average by a ratio of 1.02. This alarm function is automatically defeated when all channels are below 50% of their full power output. This is indicated by a lamp on the drawer and by actuation of the "detector flux deviation" alarm on the main control board.

Detector Current Comparator (Upper Portion of Drawer) - Figure 9.1-13

- All (upper) Channels Below 50% of Full Power Lamp.

- Channel Defeat Lamp - Lights when UPPER SECTION defeat switch is placed in any position except the normal. This lamp indicates that one channel is not being compared with the others.
- Upper Section Deviation Lamp - Indicates that a radial power deviation has occurred in the upper half of the core.
- Instrument Power On Lamp - Indicates 118 volts AC power is applied to drawer instrumentation.
- Spare Lamp.
- All (lower) Channels Below 50% of Full Power Lamp.
- Channel Defeat Lamp - Lights when LOWER SECTION defeat switch is placed in any position except normal. This lamp indicates that one channel is not being compared with the others.
- Lower Section Deviation Lamp - Indicates that a radial power deviation has occurred in the lower half of the core.
- Upper Section Defeat Switch - A five position switch which removes a channel which is faulted or being tested from the upper detector comparator.
- Lower Section Defeat Switch - A five-position switch which removes a channel which is faulted or being tested from the lower detector comparator.
- AC Instrument Power Fuses - Protects drawer assembly power supply circuits.

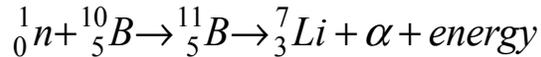
9.1.3.8 Miscellaneous Control And Indication Drawer

As shown in Figure 9.1-13 the miscellaneous control and indication drawer contains switches to bypass channels from control circuitry during testing or failed channel conditions.

- Rod Stop Bypass - Automatic rod withdrawal is inhibited following an overpower rod stop condition. Positioning either ROD STOP BYPASS switch to the indicated channel bypass position removes the rod stop function for that channel.
- Power Mismatch Bypass - The four power range channel levels are normally transmitted to a high auctioneer circuit in the automatic reactor control programmer for comparison with turbine power for the rod drive system. Bypass switches allow up to two power range channels to be removed from the auctioneering circuit during testing or failed channel operation.

9.1.4 Neutron Detector Operation

Neutrons are uncharged particles and as such cannot cause ionizations directly. Neutrons must interact with matter by means of a nuclear reaction which in turn generates charged particles. The charged particles cause ionization within a gas-filled detector and the ion pairs produce a voltage pulse or some mean level current when collected at the electrodes of the detector. The nuclear reaction which produces these charged particles in the excore detector is as follows:



The charged particles resulting from this reaction are:



These charged particles produce ionizations as they pass through the gas-filled detectors.

9.1.4.1 Source Range Detector

The source range detector, Figure 9.1-14, is a BF_3 gas-filled detector. In this detector, the incident neutron generates the charged particles (Li and α) which are highly ionizing. Due to the voltage at which the detector is operated, additional ionizations called secondary ionizations are caused by the initial ionization. This produces a large pulse for each neutron event. Gamma radiation also produces ionization of the gas in the detector, but at a lower amplitude. Gamma-induced pulses are, therefore, of a lower amplitude than neutron-induced pulses.

9.1.4.2 Intermediate Range Detector

The intermediate range detector (Figure 9.1-15) is a gas-filled, compensated ion chamber. This detector is actually two detectors in one case. One of the chambers is coated with boron enriched with B-10 and is, therefore, sensitive to neutrons and gammas. The second chamber is uncoated and is, sensitive only to gamma radiation. By connecting the two chambers so that their output currents are electrically opposed, the net electrical output from the detector will be an algebraic sum of the two ionization currents, which is equal to the neutron current only. Mathematically, it could be written as:

$$i_n + i_g = \text{neutron-induced current} + \text{gamma-induced current}$$

$$i_g = \text{gamma-induced current}$$

$$i_{total} = (i_n + i_g) - i_g$$

$$i_{total} = i_n$$

Normally, compensated ion chambers are designed to operate slightly undercompensated (Figure 9.1-16).

9.1.4.3 Power Range Detector

The power range detector, Figure 9.1-17, is an uncompensated ion chamber. The detector consists of a single cylindrical chamber whose operation is identical to that of the boron-lined chamber of the compensated ion chamber. This chamber is sensitive to both gamma and neutrons; however, in the power range of operation the neutron flux level is many times greater than the gamma flux. Also, while operating in the power range, gamma flux is proportional to the reactor power. Therefore, no gamma compensation is required in the power range. The power range instruments are calibrated on the bases of a secondary heat balance to display percent of full thermal power.

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.

9.1.5 System Interrelationships

9.1.5.1 Calibration of Excore Detectors

Each excore power range channel consists of two six-foot detectors (one upper detector and one lower detector). The upper detector, in theory, should monitor and provide an output that is representative of the power in the upper six feet of the core while the lower detector should provide an indication of the power in the lower half of the core. However, in reality this is not the case; neutrons leaking from the core do not necessarily leak from 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's essential that the inputs to the protective circuitry reflect the actual conditions in the core.

Providing the correct information to the reactor protection system is accomplished by calibrating the excore detectors to the conditions that exist within the core. This calibration procedure is called the incore-excore calibration. The core conditions and a synopsis of this calibration procedure can be found in Section 9.2 (Incore Nuclear Instrumentation), section 9.2.4.3.

9.1.6 Summary

The excore nuclear instrumentation system monitors reactor power from shutdown levels in the source range, through the intermediate range and to greater than 100 percent of full power in the power range. This is accomplished by means of thermal neutron flux detectors located in instrument wells in the primary shield adjacent to the reactor vessel. The system provides indication, control and alarm signals for reactor protection and operation. The location of the detectors at discrete axial and radial locations allows detection of core axial and radial power distribution. Power range channels are calibrated to indicate percent rated thermal power by a secondary heat balance (calorimetric). Excore power distribution circuitry is calibrated using information obtained from the movable incore instrumentation.

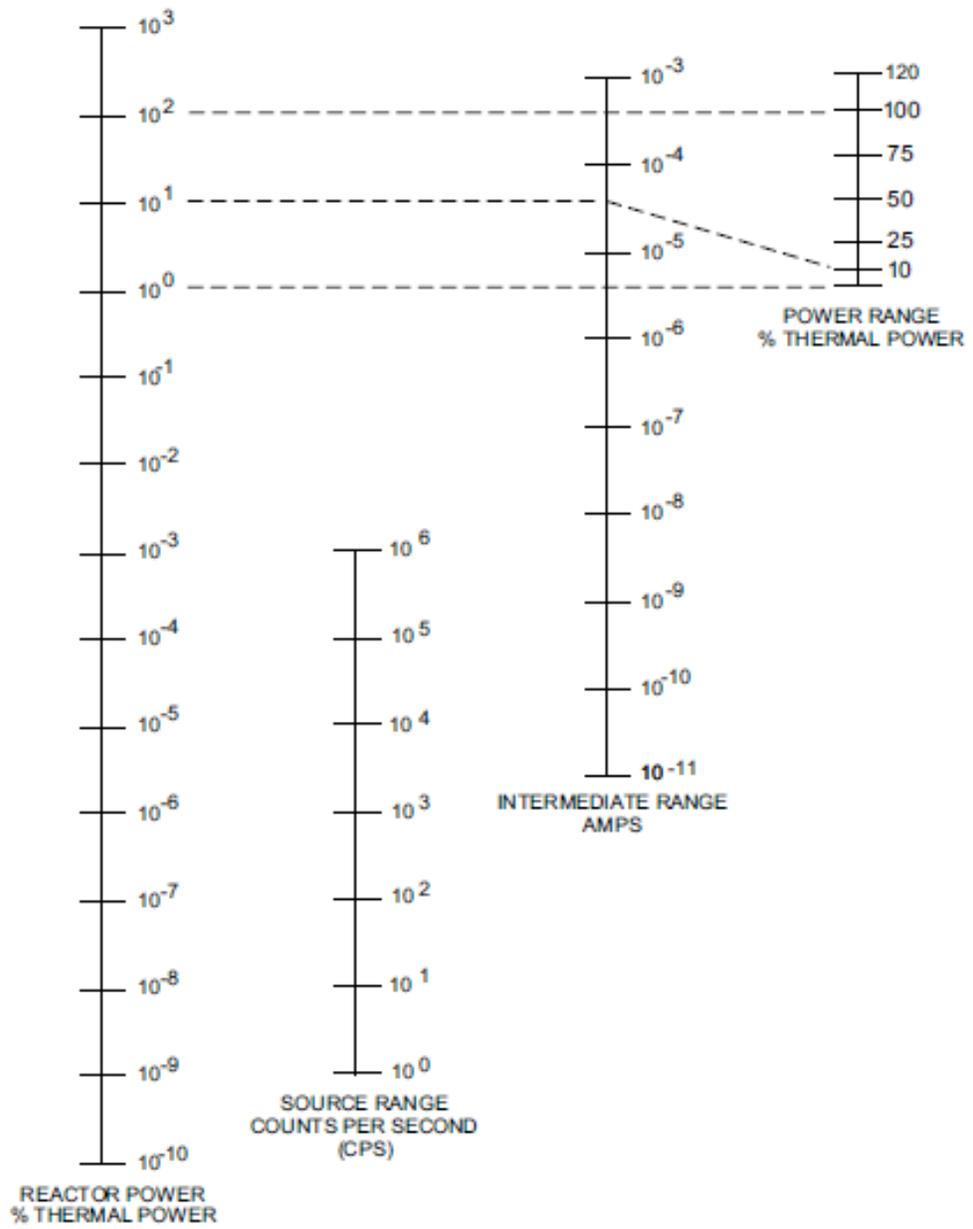


Figure 9.1-1 Neutron Detectors Range of Operation

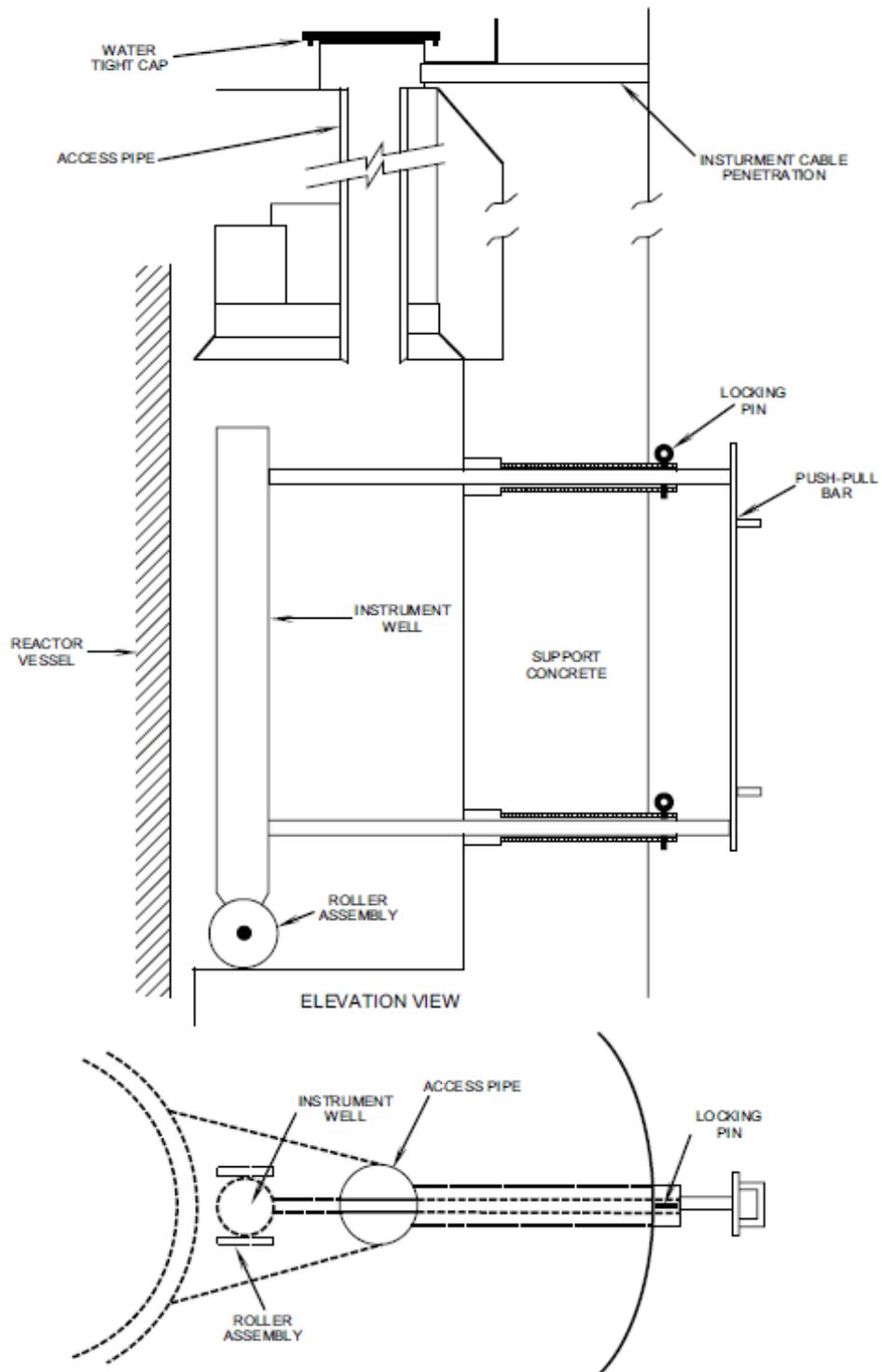


Figure 9.1-2 Detector Instrumentation Wells

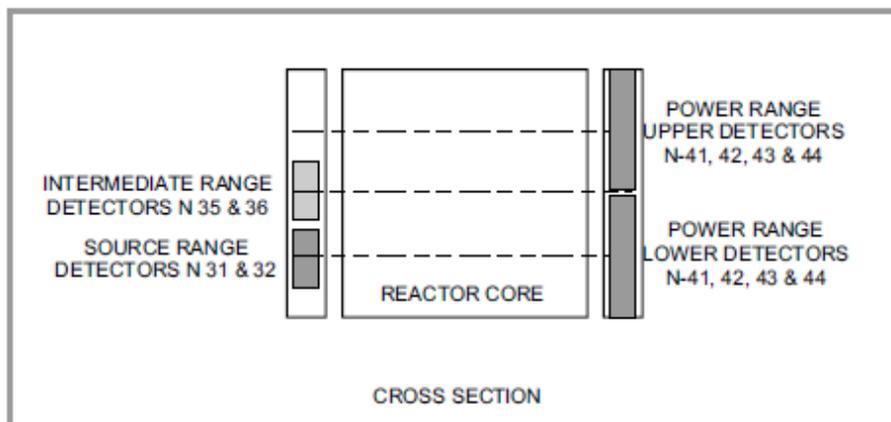
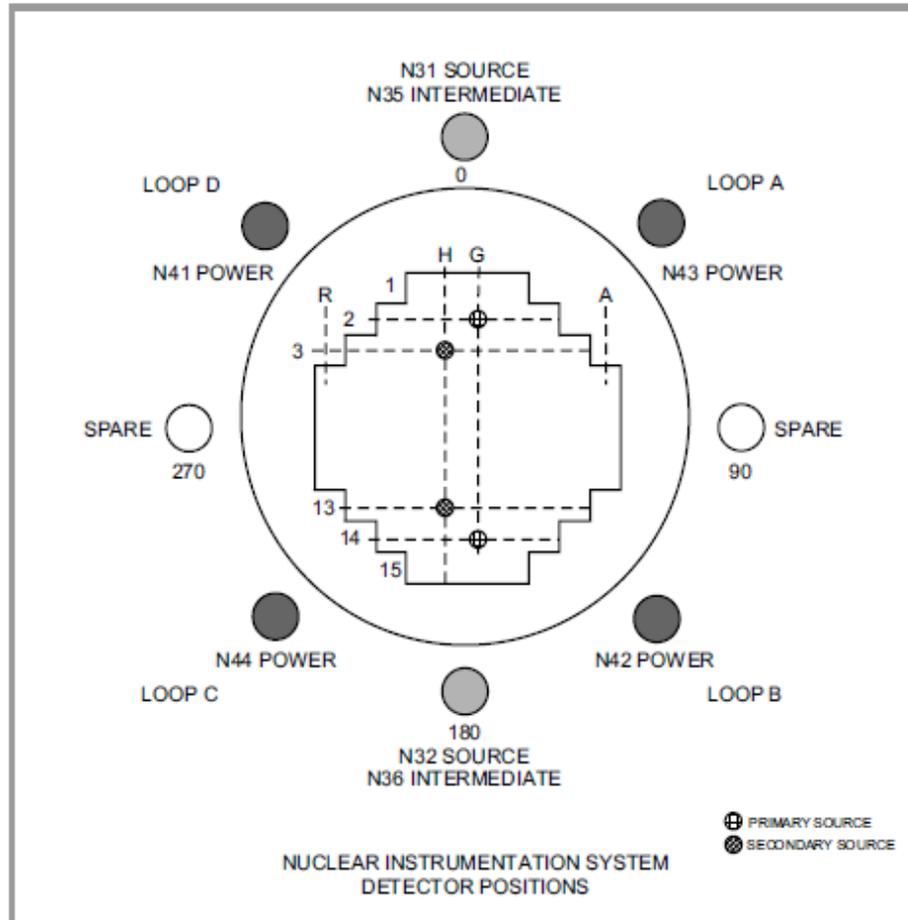


Figure 9.1-3 Nuclear Instrument Detector Locations

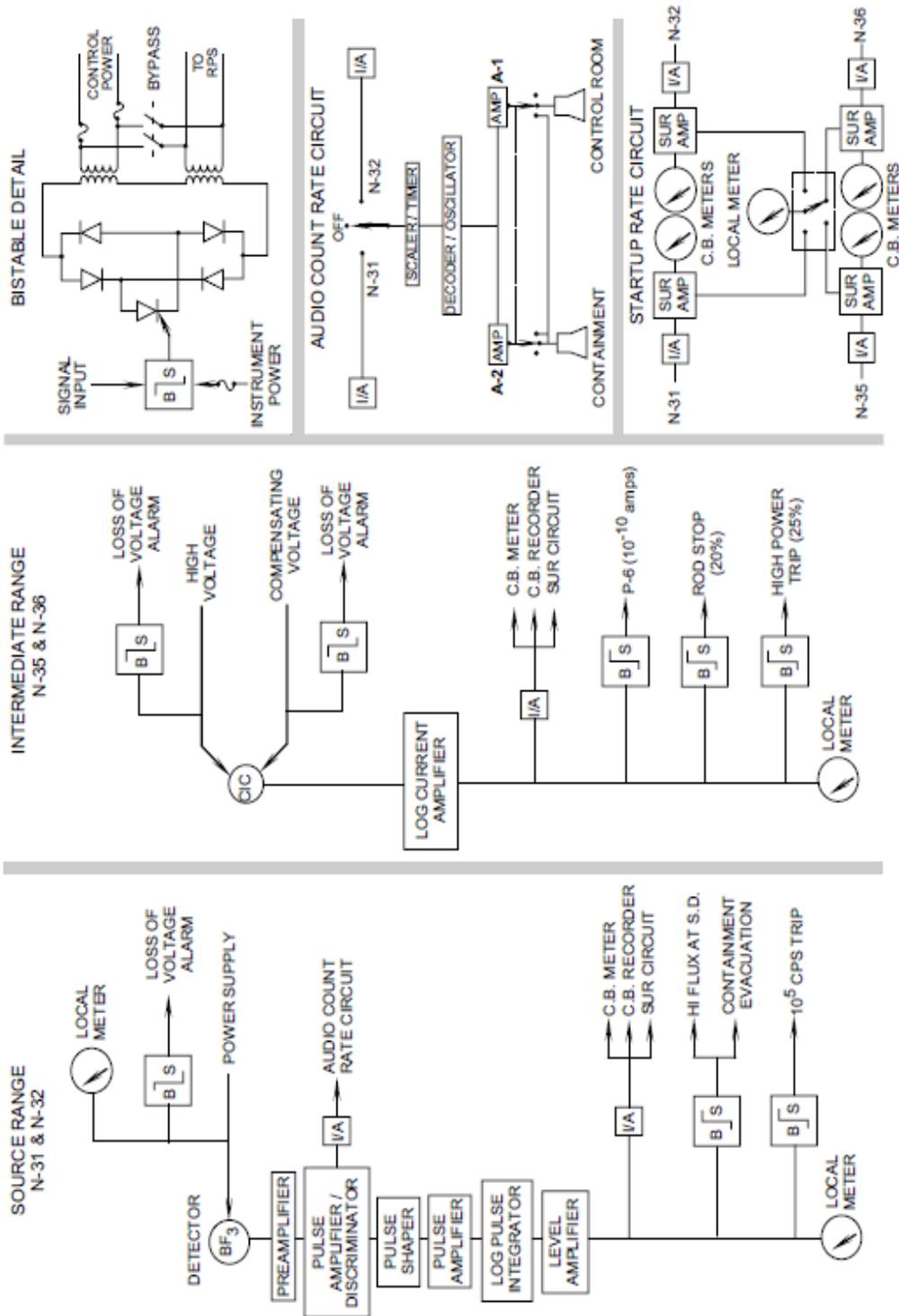


Figure 9.1-4 Source and Intermediate Range Block Diagrams

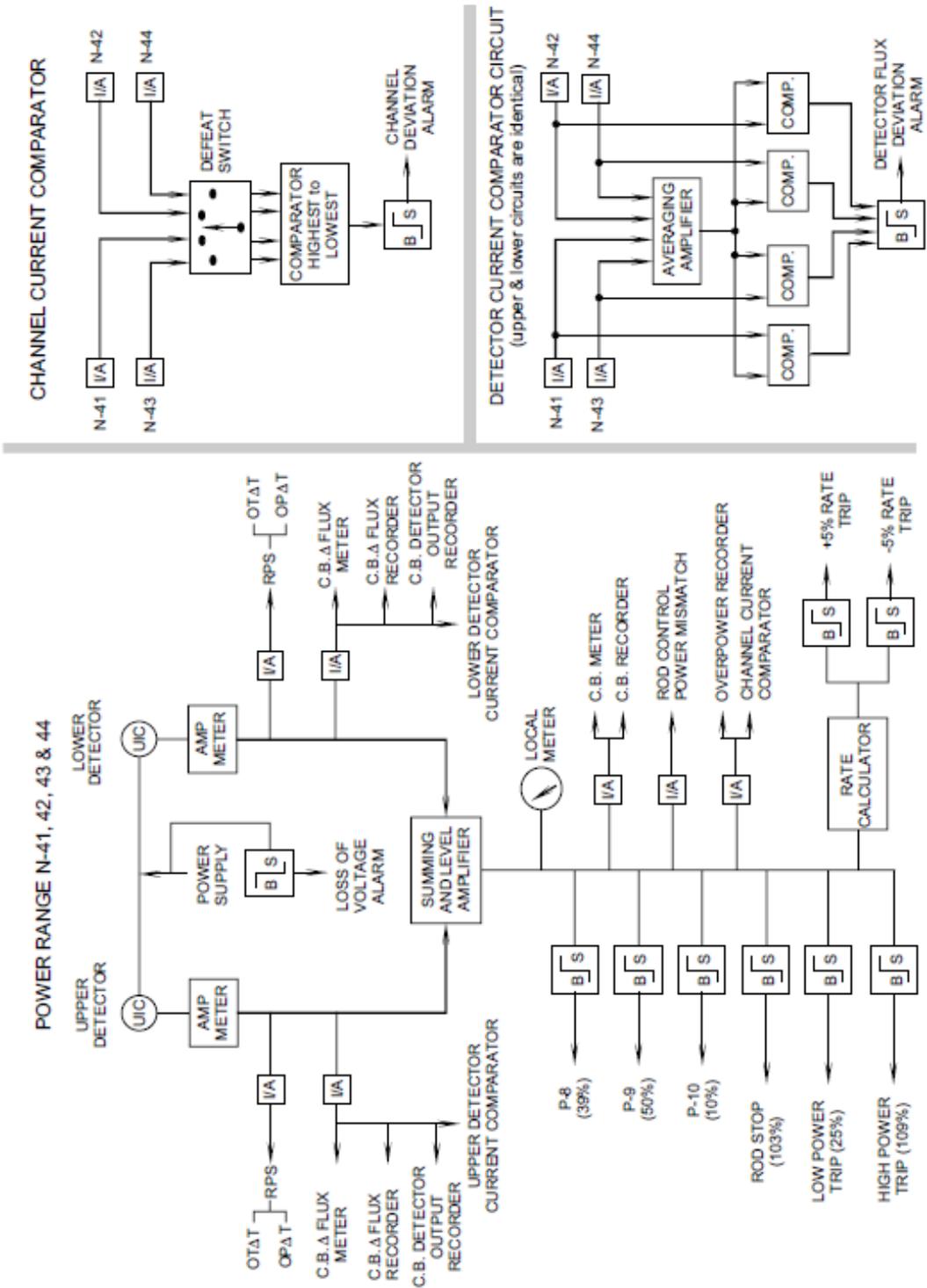


Figure 9.1-5 Power Range Channel Block Diagram

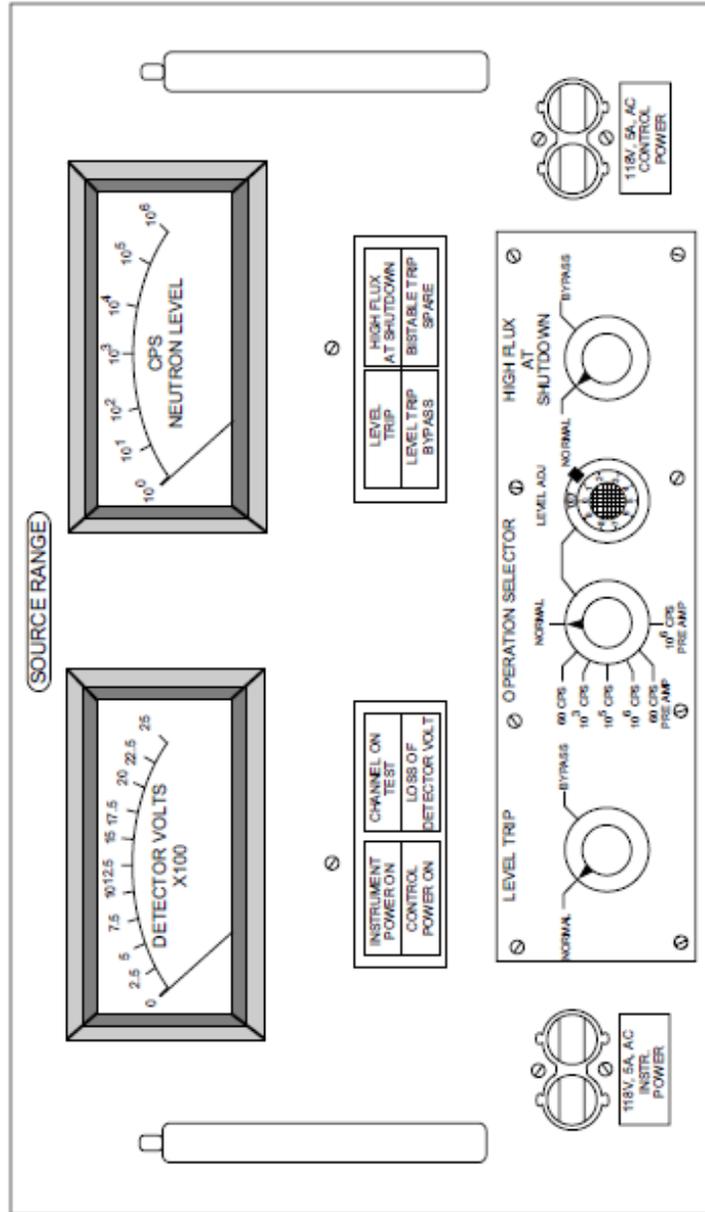


Figure 9.1-6 Source Range Drawer

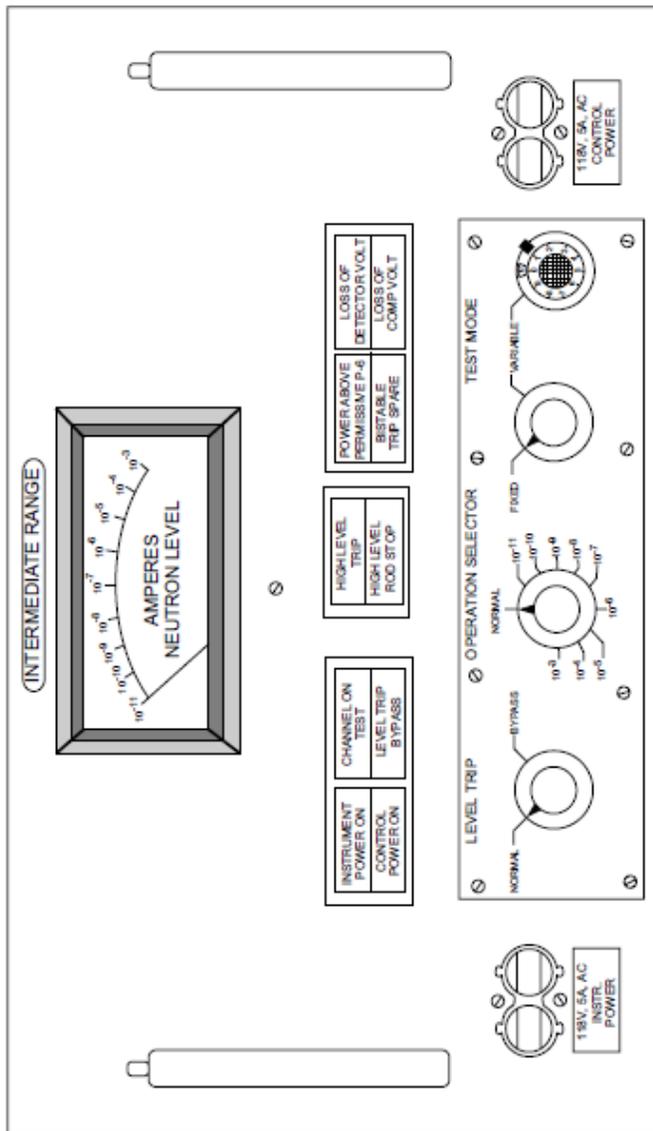


Figure 9.1-7 Intermediate Range Drawer

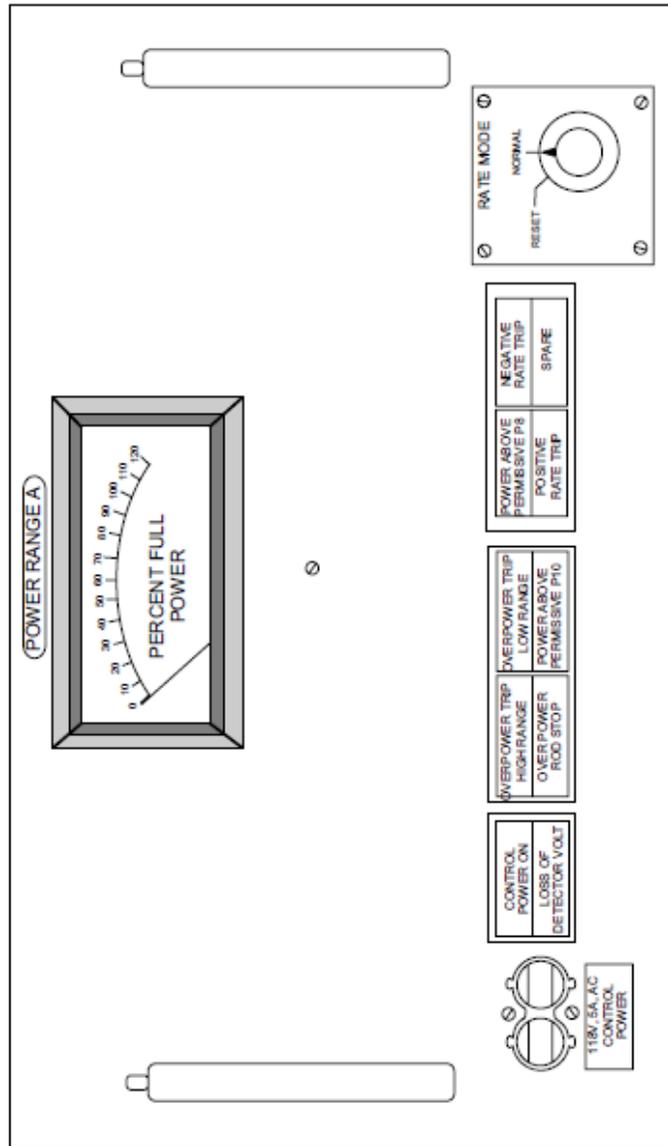


Figure 9.1-8 Power Range Drawer "A"

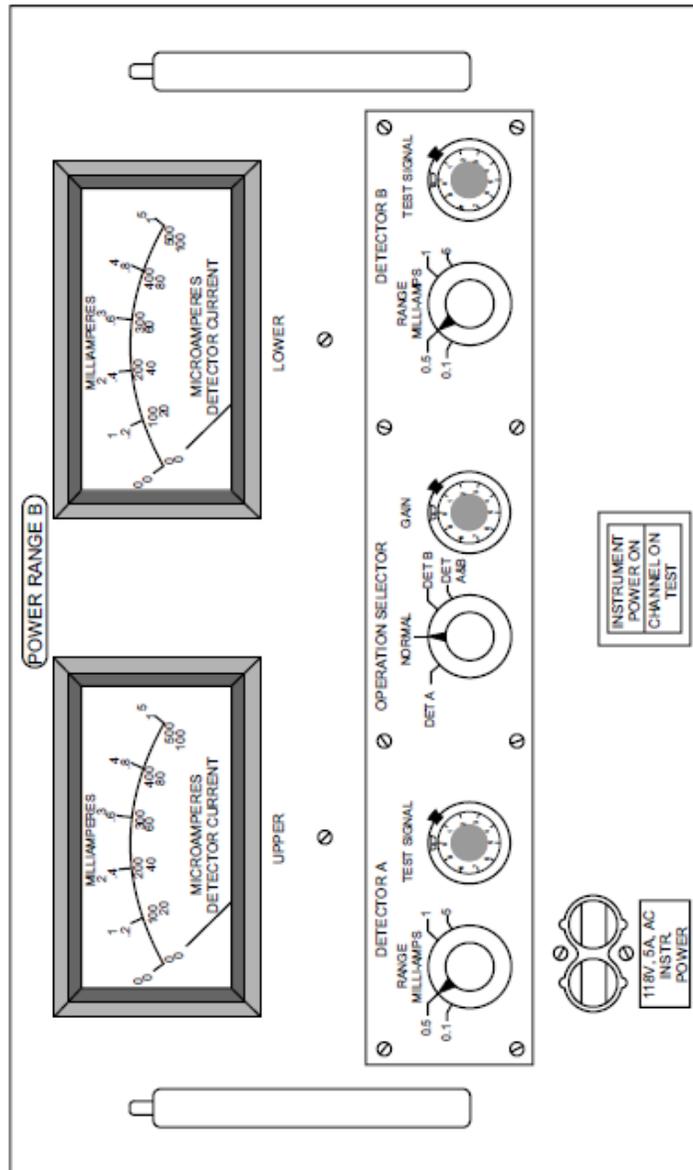


Figure 9.1-9 Power Range Drawer 'B'

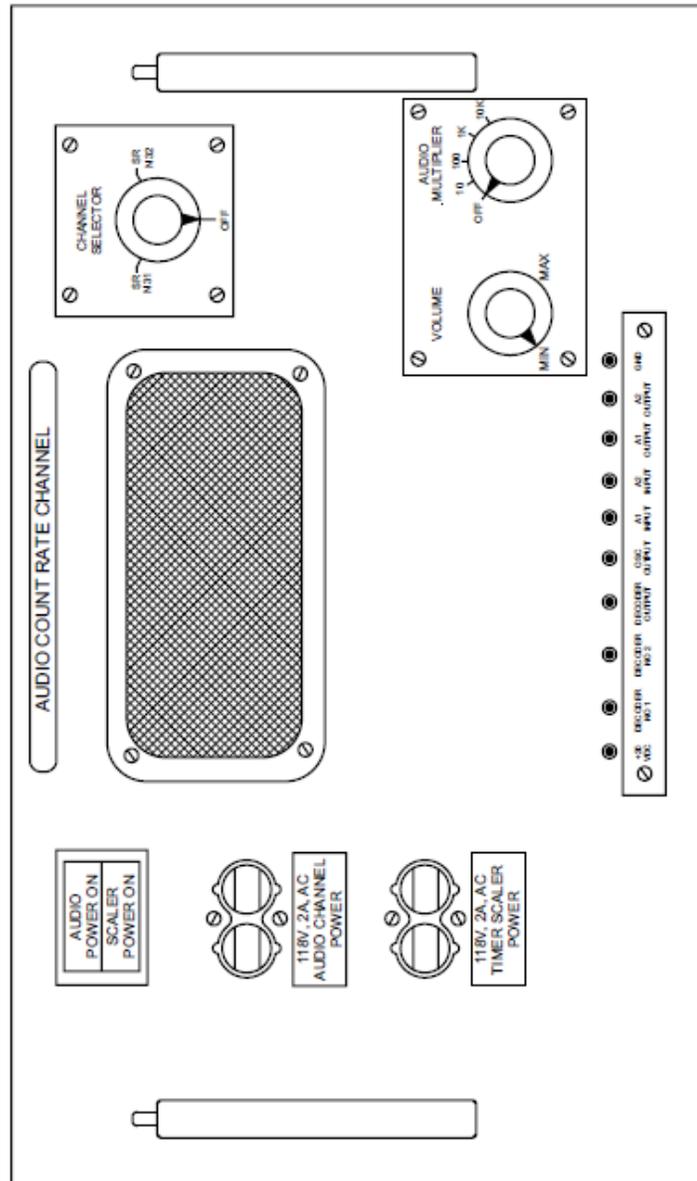


Figure 9.1-10 Audio Count Rate Channel

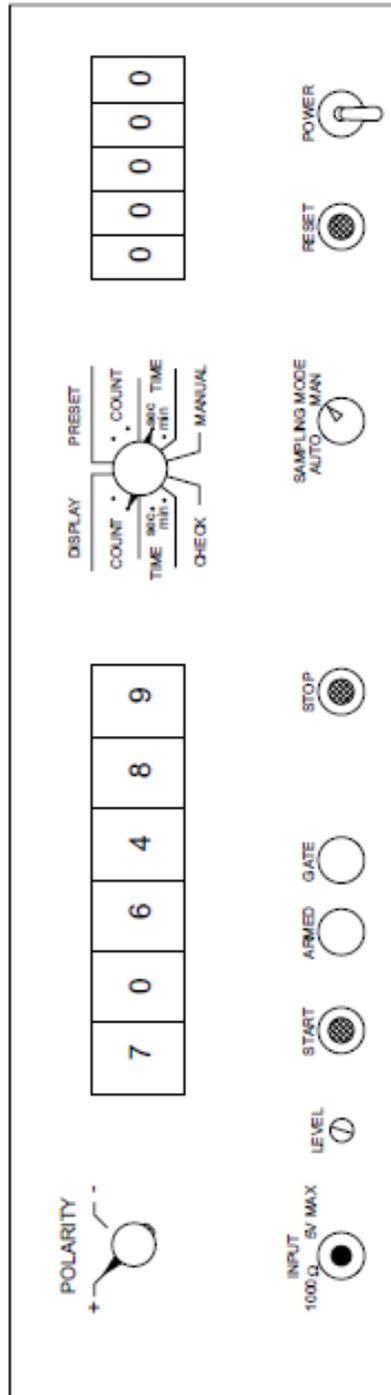


Figure 9.1-11 Scaler Timer Drawer

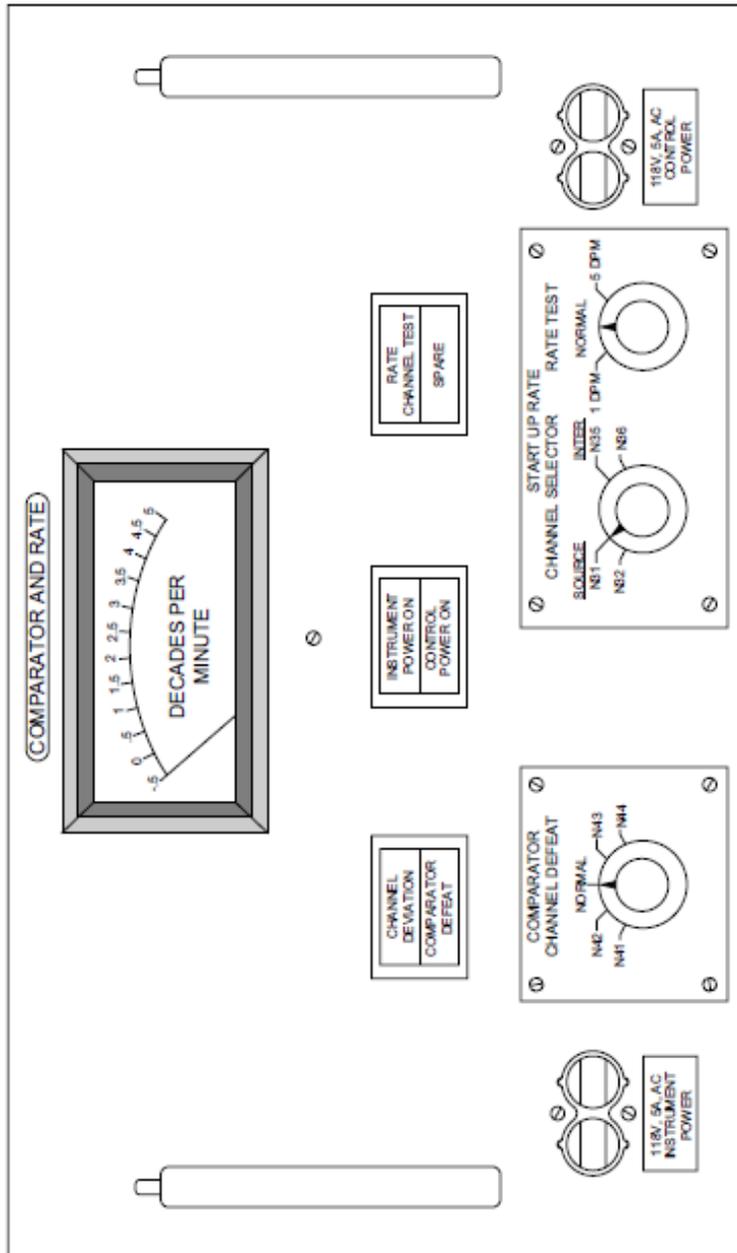


Figure 9.1-12 Comparator and Rate Drawer

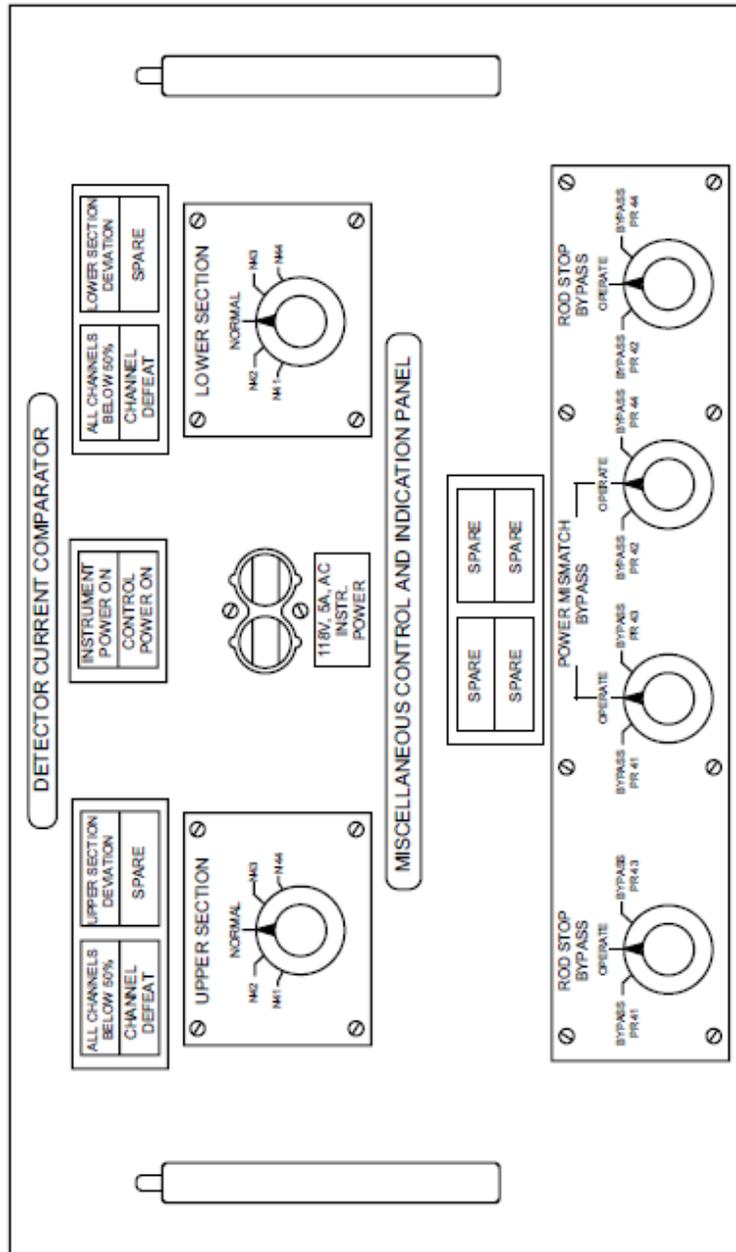


Figure 9.1-13 Detector Current Comparator

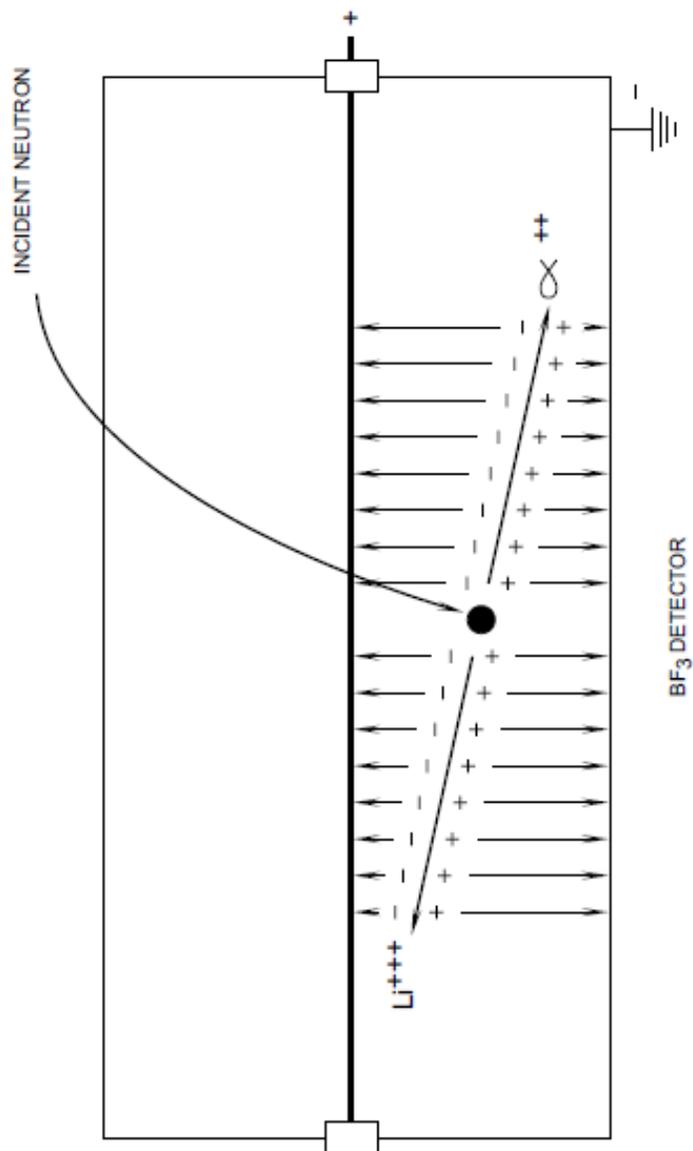


Figure 9.1-14 BF_3 Detector

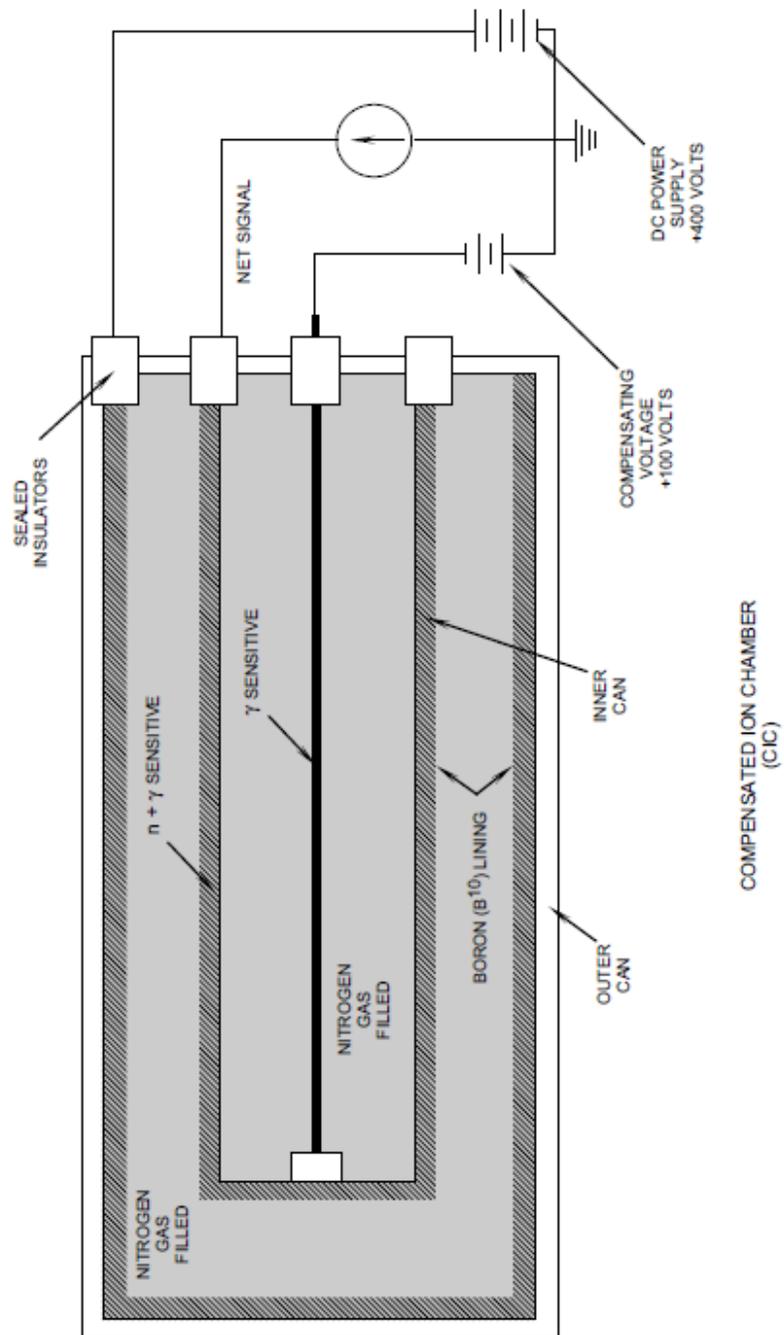


Figure 9.1-15 Gamma Compensated Ion Chamber

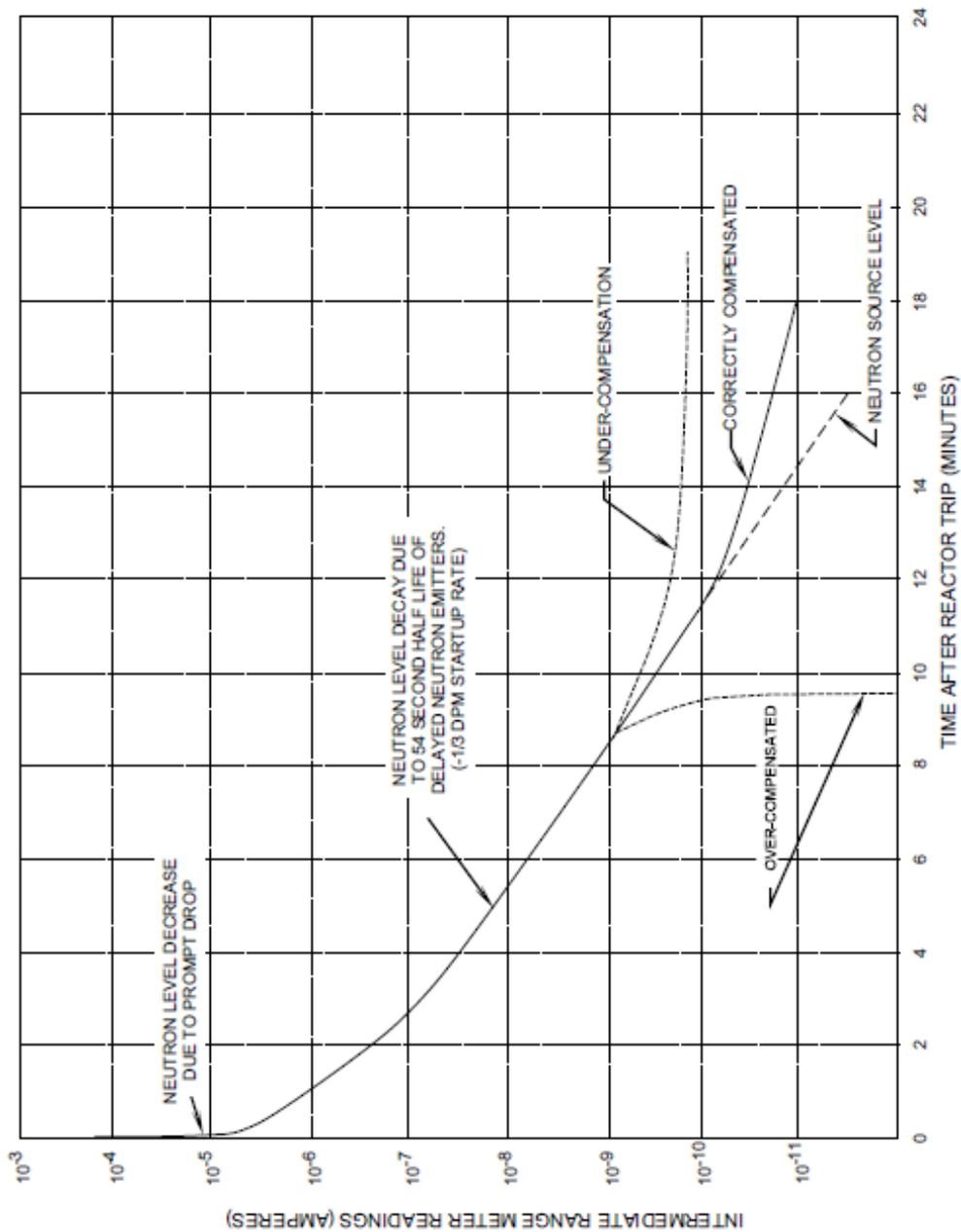


Figure 9.1-16 Gamma Compensated Curve

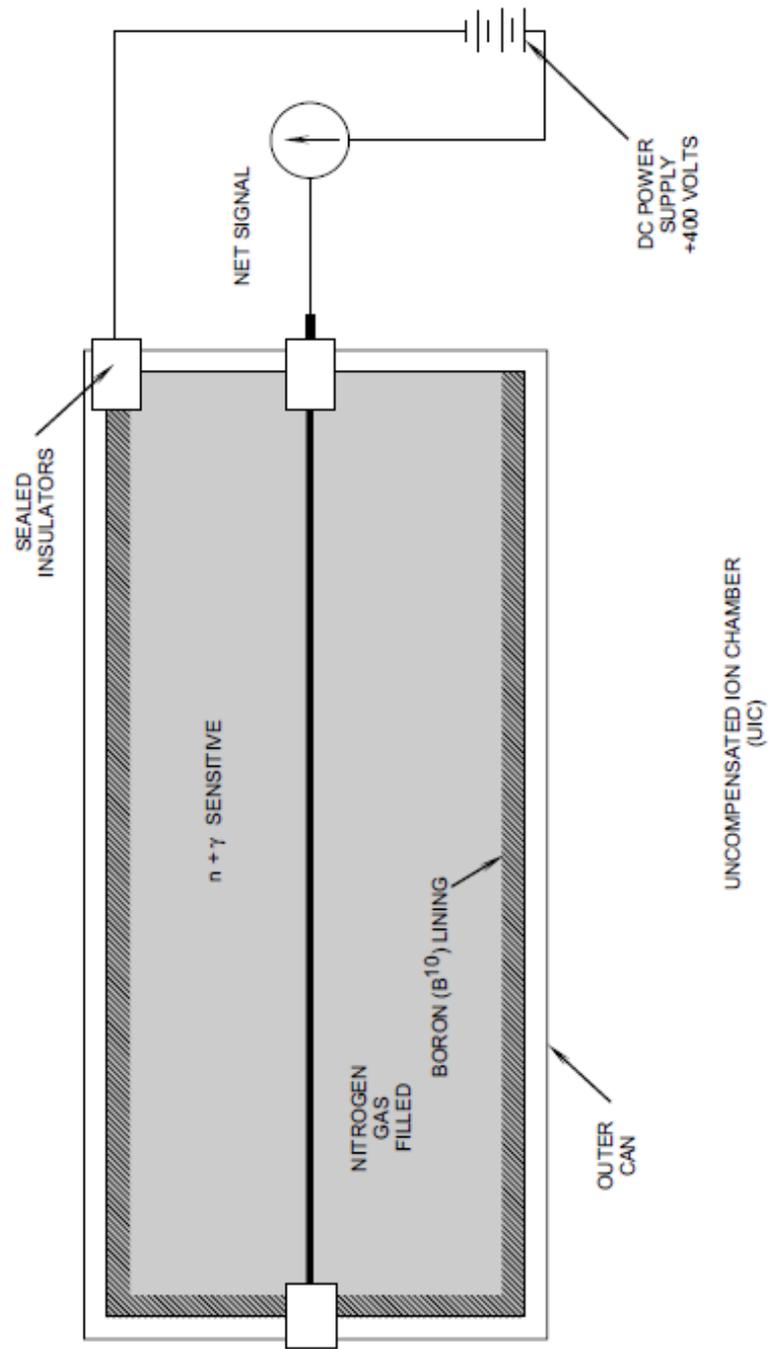


Figure 9.1-17 Uncompensated Ion Chamber