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Wide Range Neutron Monitoring (WRNM) System in Boiling Water Reactors (A Short Communication & Memorandum)

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Abstract: The WRNM (wide range neutron monitoring) is a newly developed neutron monitoring channel which was initially conceived as a means to meet Regulatory Guide 1.97 requirements for post-accident neutron monitoring. The scope was expanded to include the startup monitoring function with the aim of replacing both the source and IRMs (intermediate range monitors) in BWRs (boiling water reactors). The WRNMs, consisting of a newly designed fixed incore regenerative sensor and new electronics, which include both counting and MSV (mean square voltage) channels, have been tested in several reactors and its capabilities have been confirmed. The channel will cover the neutron flux range from 10^3 nv to 1.5×10^3 nv; it has greater than 1 decade overlap between the counting and MSV channels. Because of the regenerative fissile coating the sensor, even though fixed incore, has a life of approximately 6.0 full power years in a 51 kW/L BWR and similar situation has been proposed for newly designed small modular reactor such as BWRX-300 of General Electric Hitachi reactor.

Key words: BWR, light water reactor, advanced reactor, advanced small modular reactor, high temperature advanced reactor, Generation IV, nuclear power reactors, nuclear energy, nuclear radiation environment.

1. Introduction

Most nuclear power plants in operation were built in the 1970's and 1980's. Plants of this vintage would require extensive upgrade for the I&C (instrumentation and control) to be able to support plant life extension. The most challenging aspect of I&C upgrades for these plants is the upgrade of the NMS (neutron monitoring system) and the RMCS (reactor manual control system). These are specialized instrumentation and would require high quality design and engineering products to ensure safe and efficient plant operation. Companies like GEH (General Electric Hitachi) Energy's nuclear business provides a WRNM (wide range neutron monitoring) system to replace the existing SRMs (source range monitors) and IRM (intermediate range monitors), a PRNM (power range neutron monitoring) system to replace the APRM (average power range monitor), and a RCMS (rod control management system) [5] to replace the original RMCS in the GEH designed BWR (boiling water reactors, including their new generation of SMR fleet of reactor, known as Generation IV or GEN-IV) (Note: this design has been presented by Wimpee et al. [1] of GEH (General Electric Hitachi) in 1984 and now and updated version presented here as short communication purpose; Note: please bear in mind that due to the size of images and for clarity purpose all the illustration' images, and tables have laid out at the end of this article. Note also no content and information in this article have been provided from General Electric Hitachi and everything in this short communication is obtained from public domain as well

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as, which could have been searched on Internet or words of authors).

The WRNM, PRNM, and RCMS are based on the NUMAC (nuclear monitoring analysis and control) platform, which is a microprocessor-based system that provides improved system performance with standard features such as improved HMI (human machine interface), self-test and automatic calibration. In addition to enhancing the system functions, these upgrades also help to support the challenges of plant life extension. This paper presents the designs and experience of these GE-Hitachi Nuclear Energy systems in support for nuclear plants life extension.

In a typical BWR the startup neutron monitoring function is handled by two subsystems: one consists of four SRM channels which cover from 10^3 to 10^9 nV (nanovolt) and the other consists of eight IRM channels which cover from 10^8 nV to 1.5×10^3 nV.

Note that: The nanovolt (nV) is a unit of measurement of electric potential and nanovolt (nV) is a SI-multiple of the electronic potential unit volt and equal to one billionth of a volt (0.000000001 V = $1.0 \times^{9}$ V) which is electric potential instant conversions.

Both subsystems use incore fission chambers and insert-retract mechanisms for withdrawing the sensors from the core during power operation in order to prevent sensor burnup. The SRMs are operated in the counting mode and the signals are processed in separate pulse preamplifiers and log count rate monitors.

The IRMs are operated in the MSV (mean square voltage) or Campbelling mode (i.e., see Chapter One, Section 1.3.2.3 for more details of Campbelling Mode) with separate voltage preamplifiers and MSV monitors.

When RG (Regulatory Guide) 1.97 (Post-Accident Monitoring) was issued, a review of the existing SRM and IRM systems was made to determine if they would meet the new requirements. It was apparent that the requirements placed upon the existing equipment by RG 1.97 were above and beyond the original SRM and IRM requirements, and it was likely that some redesign of the drive mechanisms would be required [1].

These conclusions led to the search for a neutron monitoring concept which would provide coverage of the range required by RG 1.97, 10^6 percent to 100 percent of full power during the 100-day period following an accident. It was decided that the most reliable system would be a wide range startup monitor with a fixed incore sensor which would thus eliminate the potentially vulnerable drive mechanism. The sensor would provide input for both counting and MSV signal processing electronics and, since it would remain incore during full power operation it would contain a regenerative fissile coating in order to maintain adequate sensitivity for an extended period of time. The electronics would consist of a preamplifier and a control room monitor which would process signals in both counting and MSV modes. It was decided that the new concept could easily be applied to the normal startup neutron monitoring function for a BWR and should in fact be developed primarily for that purpose since there is a need to update the startup monitoring system. The new startup monitor would cover the range presently covered by the SRM and IRM systems or 10^3 to 1.5×10^{13} nV (10^9 percent to approximately 10 percent of full power). All components of the system would be qualified to the GE interpretation of NUREG-0588 and IEEE 344-1975. It is intended that the present power range monitors cover the range from 10 percent to 100 percent of full power [1].

A number of wide range startup systems have been developed. For example, Trenholme and Keefe [2] and Popper et al. [3], reported on systems which utilized counting and MSV signal processing techniques and large out-of-core sensors. Bjorkman et al. [4] described an incore wide range system for BWR application using miniature incore sensors and a newly designed drive mechanism. The design of a wide range system using a fixed incore sensor is a significant departure from previous work, and the benefits of such a system make it very attractive.

In addition to the reduction in the number of channels required, typically from 12 to 8, there is better coverage of the core in the counting mode, much simplified, and therefore more reliable mechanical arrangement with obvious savings in maintenance time and thus in human REM (roentgen equivalent man) exposure, and less under-vessel "clutter". With provision for a log power signal output from the monitor, the mechanics of starting a BWR are simplified because switching from the SRMs to IRMs and, range switching in the IRM mode will no longer be required.

Note that: REM is one of the two standard units used to measure the dose equivalent or effective dose, which combines the amount of energy (from any type of ionizing radiation that is deposited in human tissue), along with the medical effects of the given type of radiation. For beta and gamma radiation, the dose equivalent is the same as the absorbed dose. By contrast, the dose equivalent is larger than the absorbed dose for alpha and neutron radiation, because these types of radiation are more damaging to the human body. Thus, the dose equivalent (in rems) is equal to the absorbed dose (in rads) multiplied by the quality factor of the type of radiation (see Title 10, Section 20.1004, of the Code of Federal Regulations (CFR) (10 CFR 20.1004), "Units of Radiation Dose"). The related international system unit is the Sievert (Sv), where 100 rem is equivalent to 1 Sv. For additional information, see Doses in Our Daily Lives and Measuring Radiation.

The unit is a CGS unit of equivalent dose, effective dose, and committed does, which are again dose measures used to estimate potential health effects of low levels of ionizing radiation on the human body.

The system described in this article is the result of a joint development effort of the General Electric Company and Toshiba Corporation, according to NRC (Nuclear Regulatory Commission) report. General Electric prepared the system requirements, designed the sensor and mounting hardware and Toshiba designed the electronics which include a preamplifier and control room monitor. Both organizations participated in joint tests.

2. Description of the WRNM System

Currently, most BWRs use four SRMs and eight IRMs to provide approximately 10 decades of neutron flux for coverage in startup and intermediate ranges. The SRM and IRM detectors have to be inserted into the reactor core during shutdown and withdrawn after startup to preserve their limited life using non-Class 1E drive/retract mechanisms. In addition, range switches are used for linear IRM output to switch between decades during power ascension.

These old analog systems are difficult to operate, requiring operators to manage the range switches to avoid inadvertent reactor trips. The mechanisms for the detector insertion and retraction present challenging maintenance practices with ALARA concerns. A stuck detector would lengthen an outage and delay plant startup. The non-1E mechanism also presents a challenge for the plant to demonstrate compliance to regulations regarding post-accident monitoring [5].

To resolve these design and operational issues with the present SRM/IRM system, a new fixed detector system, WRNM, was developed to replace the SRM/IRM systems. The WRNM uses fixed location in-core regenerative breeder detectors. The WRNM monitors approximately 11 decades of neutron flux over the startup, intermediate, and power ranges. Use of regenerative sensors permits permanent in-core locations corresponding to present "full in" detector positions. The use of a single detector for both SRM and IRM functions eliminates the need for the SRM and IRM transitions. Due to the coverage in the power ranges, the WRNM also provides automatic verification of the overlap that is required for IRM and APRM. The fixed detectors also eliminate the need for the drive mechanisms for the SRM/IRM. In addition to eliminating maintenance and radiation dose issues associated with the drive mechanisms, the removal of the drive mechanisms also eliminates the under-vessel interferences and other space issues associated with this machinery. The vertical position of the WRNM detectors will be the same as the IRMs in their fully inserted condition. A further simplification of the new system is to use only 8 WRNM channels (2 trip systems with 4 channels per system) to replace the 12 combined SRM and IRM channels.

The number and locations of the sensors have been analytically and experimentally demonstrated that it can provide sufficient flux level information under the most limiting bypass and sensor failure conditions. Although there are fewer channels, the WRNM system enhances core coverage during fuel loading because it provides 8 channels, two per quadrant of core coverage, whereas the SRM only has 4 channels, one per quadrant of core coverage.

The WRNM uses the microprocessor based NUMAC control room monitors to calculate reactor parameters. It provides both counting and MSV modes of operation and automatic switching of the IRM ranges. The level-based trip in the MSV ranges has been changed to a rate-based period trip, thus eliminating the need for range switches. This allows the operator to focus on the rod movements and reactivity response as opposed to manipulating the range switches to avoid a scram. Consequently, the WRNM provides significant improvement in terms of operation and ease of maintenance. Fig. 27 provides a comparison between the SRM/IRM and the WRNM systems.

The mechanical arrangement of the WRNM is much simpler than that of the existing SRMs and IRMs in that the insert-retract mechanisms are eliminated. The sensor and its integral cable are electrically isolated from reactor ground, as is the case in the older systems in order to prevent the noise problems resulting from loop currents in a two-ground system.

The WRNM sensors perform their function in the same relative position as the present SRM and IRM sensors, about 15 inches above core center plane. See Fig. 1.

However, as described above, in the existing SRM/IRM systems the sensor is retracted to a point 2 feet below the bottom of the core during power operation to prevent rapid depletion of the U-235, whereas the WRNM sensor remains fixed in core. Fig. 1 is a block diagram of a WRNM channel.

2.1 Dry Tube

The dry tube is an ASME boiler and pressure vessel certified thimble designed to fit both “C” and “D” lattice BWR cores and fabricated using type 316 L stainless steel. The bottom end of the dry tube accommodates an arrangement for sealing the sensor and its connectors in place using post-LOCA (post-loss of coolant accident) qualified sealing materials.

2.2 Sensor

The sensor is a 0.5-inch-diameter regenerative fission chamber which is operated in both the counting and MSV modes. It is isolated from reactor ground by alumina insulators and can be inserted and removed from the bottom of the vessel.

A mechanism for removal of radioactive sensors will be developed in the future. The sensor and upper cable will be manufactured using low cobalt 304 L stainless steel in order to minimize activation. The sensor has a 0.172-inch-diameter silica-insulated cable manufactured by Electronic Resources Division of Whittaker Corp., Burbank, CA.

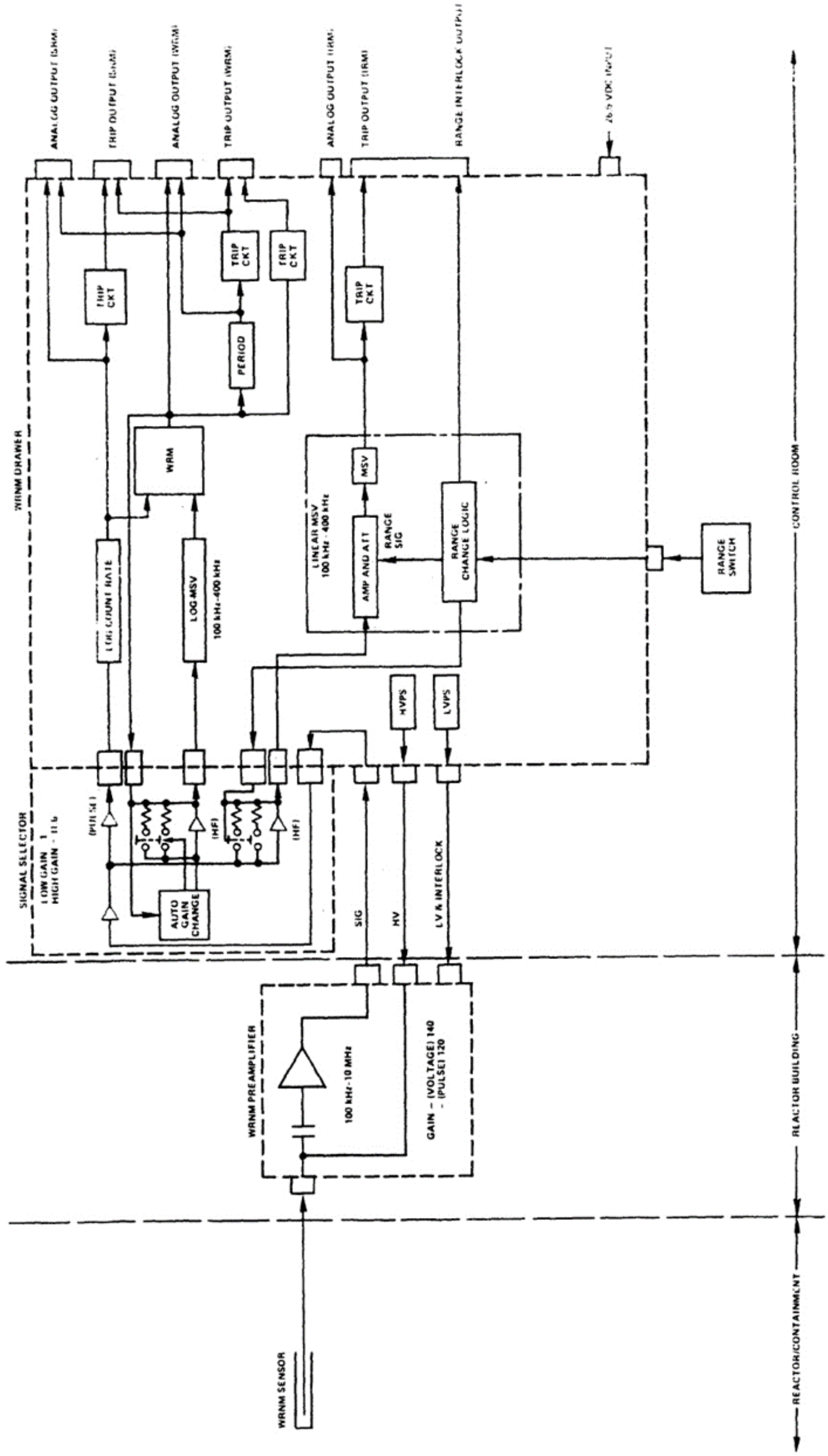


Fig. 1 Block diagram of WRNM system [1].

The sensor characteristics are listed in Table 1.

2.3 Preamplifier

The preamplifier is designed to perform its function during the post-LOCA period and after a design basis earthquake as well as under normal condition. It is mounted in a housing which is typically located in the reactor building outside the containment. The preamplifier has one output from a single pass band amplifier to handle both counting and Campbelling signals. Range selection circuitry for linear MSV is not included in the preamplifier, it is contained entirely within the Control Room Monitor. Power is provided by cable from the monitor.

The basic specifications for the preamplifier are listed in Table 2.

2.4 Control Room Monitor

The WRNM (wide range neutron monitor) control room equipment is designed to accept a single input from the preamplifier and, in a signal selector circuit, divide the signal to provide inputs to three separate channels. The output of the first channel is a signal proportional to the logarithm of the input pulse rate, and the output of the second channel is proportional to the mean square value of the input signal.

These two channels will interface directly with existing SRM and IRM front benchboard equipment and the existing SRM and IRM instruments would be removed. The monitor is designed for simplified operation with digital readout for count rate, linear MSV (mean square value) and percent power depending on which of the three mode selector switches is depressed.

The outputs of the three channels are, of course, not affected by mode selector switch position. There is an analog period meter in the form of a LED (light emission diode) bar graph.

The basic parameters of the monitor are outlined in Table 3.

Table 1 Sensor characteristics.

Neutron sensitivity (BWR, Unperturbed)	
Counting	2.72×10^{-3} cps/nV
MSV	0.672×10^{-28} A^2/Hz/nV
DC (direct current)	5.5×10^{-15} A/nV
Average charge per pulse	1.88×10^{-13} Coulomb
Gamma sensitivity	
MSV	4.4×10^{-28} A^2/R/h
DC	1.3×10^{-12} A/R/h
Alpha	
Counting	1.4×10^{6} cps
MSV	1.04×10^{-8} amps
DC	0.71×10^{-22} A^2/Hz
Average charge per pulse	7.65×10^{-15} Coulomb
Electron collection time	6.0×10^{-8} s
Ion collection time	2.25×10^{-5} s

Table 2 Preamplifier specifications.

Input impedance	75 Ohm nominal
Output stage	
Output impedance	< 75 Ohm
Output pulse characteristics	
Pulse shape	Bipolar proceeding negative pulse
Rise time	< 0.1 μs
Fall time	< 0.5 μs

Table 2 to be continued

Transfer characteristics	
Band width	200 kHz to 10 MHz (-3 dB points)
Voltage gain	140 ± 10%
Pulse gain	120 ± 10%
Linearity	±3% full scale
RMS noise	1.75 mV rms maximum
Drift at design center	2%/100 h maximum

Table 3 Control room monitor.

Mode selector switches	SRM/CPS, IRM %, WRM %
Monitor readout	Digital, 3 decades of mantissa and 2 decades of index
Period indicators	LED color coded
Counting channel (SRM)	10^{-1} to 10^{6} cps
Campbelling channel (IRM)	40×10^{-5} to 12.5%
Wide range channel	1.25×10^{-10} to 12.5%
Period meter	-100 to ∞ to ± 10 sec

3. Sensor Life

The regenerative fissile coating used in the sensor has a weight of 0.6 mg per square centimeter and is composed of 79 percent U-234 and 21 percent U-235. The uranium depletion is defined by Eqs. (1) and (2).

$$\frac{dN_4}{dE} = -N_4\sigma_4 - \alpha\frac{N_4}{N_5(0)}N_5\sigma_F \qquad (1)$$

$$\frac{dN_5}{dE} = -N_4\sigma_4 - N_5\sigma_5 - \alpha\frac{N_5}{N_5(0)}N_5\sigma_F \qquad (2)$$

where:

E = Exposure at detector location

N_4 = Number of U-234 atoms present at exposure = E

N_5 = Number of U-235 atoms present at exposure = E

$N_5(0)$ = Number of U-235 atoms present at exposure = 0

σ_4 = Absorption cross section of U-234

σ_5 = Absorption cross section of U-235

α = Sputtering coefficient

In a sensor with an unalloyed uranium oxide film, the value of *a* in Eqs. (1) and (2) varies from zero to approximately 0.20. However, in a sensor with an alloyed metallic uranium film such as the WRNM, the value of α is approximately zero.

Fig. 2 is a normalized plot of the two equations which has been verified by 6 years of experience in using this uranium mixture in power range sensors. Using the expected initial sensor sensitivity of 2.72×10^{-3} cps/nV and with the end of life arbitrarily chosen to be 1×10^{-3} cps/nV, it can be shown that the sensor has an expected life of 6.0 full power years in a 51 kW/L BWR.

However, as previously stated, a sensor with a sensitivity of 1 cps/nV will provide more counts than required at shutdown and therefore this is a conservative estimate of useful sensor life.

4. Calibration

The electronics portion of the WRNM channel is calibrated on the bench to adjust the gains of the log count rate meter and the log MSV channels to the same slope, i.e., volts output per decade of power change.

The first time to power with a new sensor, the signal selector gain is adjusted to precisely match the outputs of those channels for addition in the wide range channel.

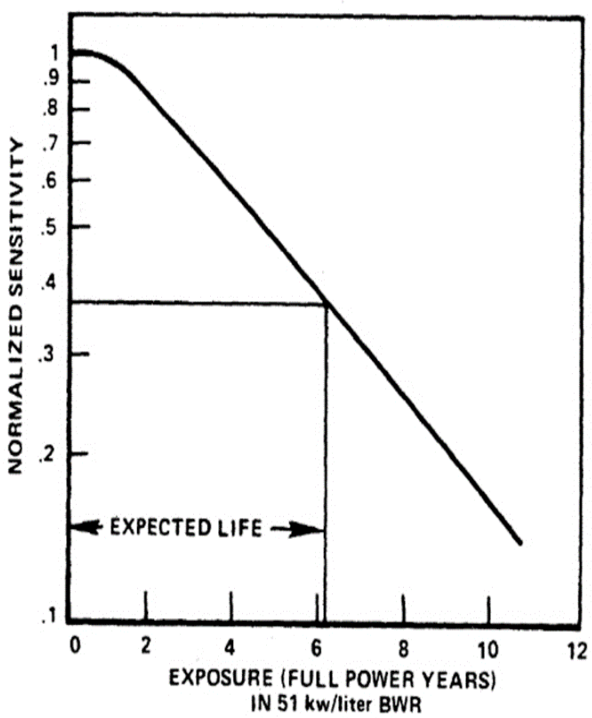


Fig. 2 Wide range sensor burnup characteristics.

There is no requirement in BWRs to precisely determine flux levels from startup neutron monitors, however, there is a need to periodically calibrate the system to accurately determine sensor burnup and to provide a means to predict remaining life and thus to determine when replacement would be required. This will be done at full power using a separate power supply and current meter and information obtained from calibration sensors (Traversing Incore Probes) in adjoining power range calibration tubes. The sensor calibration information would be used in conjunction with Fig. 2 to determine remaining life. A computer code which provides a best fit for a curve defined by Eqs. (1) and (2) will be used in conjunction with the calibration information to predict life.

5. Tests

Tests on the prototype channel were conducted at the GE Manufacturing site using a 1.68×10^4 nV Plutonium-Beryllium source, at the General Electric gamma pit at Vallecitos, CA, using a 2.29×10^6 R/h cobalt 60 source, at the GE-NTR test reactor at Vallecitos, CA, at the Aerotest Operations Inc. test reactor at San Ramon, CA, and at the Toshiba Training Reactor, Kawasaki, Japan. The tests in the plutonium-beryllium source, were for the purpose of quality assurance, calibration of the sensor, and for overall system checkout. The tests at the gamma pit were for the purpose of determining background gamma noise in both the counting and MSV modes.

The tests at the Aerotest Reactor were of course for the purpose of verifying performance of the entire system over the startup range. The cable lengths used were intended to simulate a BWR installation. Calibration sensors for gamma and neutrons were used to verify the Aerotest reactor instrumentation; at chosen power levels, the gamma sensor was inserted, the current measured and then the gamma sensor withdrawn.

The neutron sensor was then inserted for flux measurement and withdrawn prior to proceeding with measurements on the WRNM. During the startup test, the reactor power was increased in steps of 10 percent, 20 percent and 100 percent for each decade. The discriminator was set a 150 mV for counting and the sensor bias voltage set at 350 Vdc.

6. Discussion of Tests Results

The tests in the plutonium-beryllium source demonstrated that adequate sensitivity is obtained for source range monitoring and that discrimination against the alpha pulses caused by the uranium 234 is straightforward. These data indicate that the discriminator could be set at 130 mV, however, it was decided that 150 mV would be used in order to be consistent with previous tests.

Pulse-height distribution curves at two neutron flux levels are shown in Fig. 3 demonstrating ideal distributions over a wide range of neutron flux. Fig. 4 shows the MSV plateau curve at approximately the middle of the range for the MSV mode.

The most significant data are presented in Fig. 5. This shows the response of the three channels of the

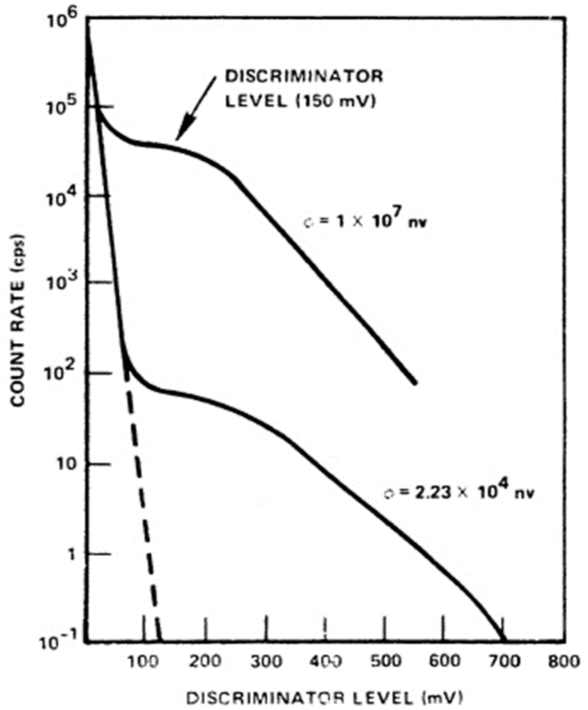


Fig. 3 Integral pulse height distribution Aerotest factor.

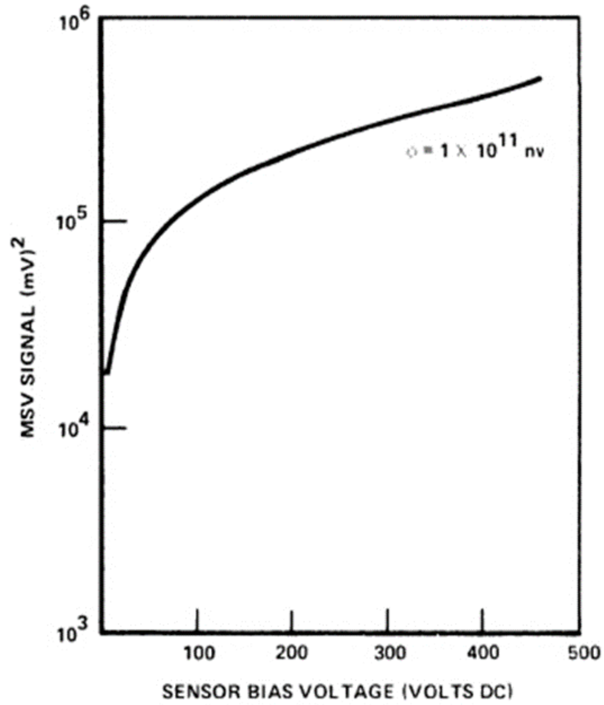


Fig. 4 Mean square value plateau curve.

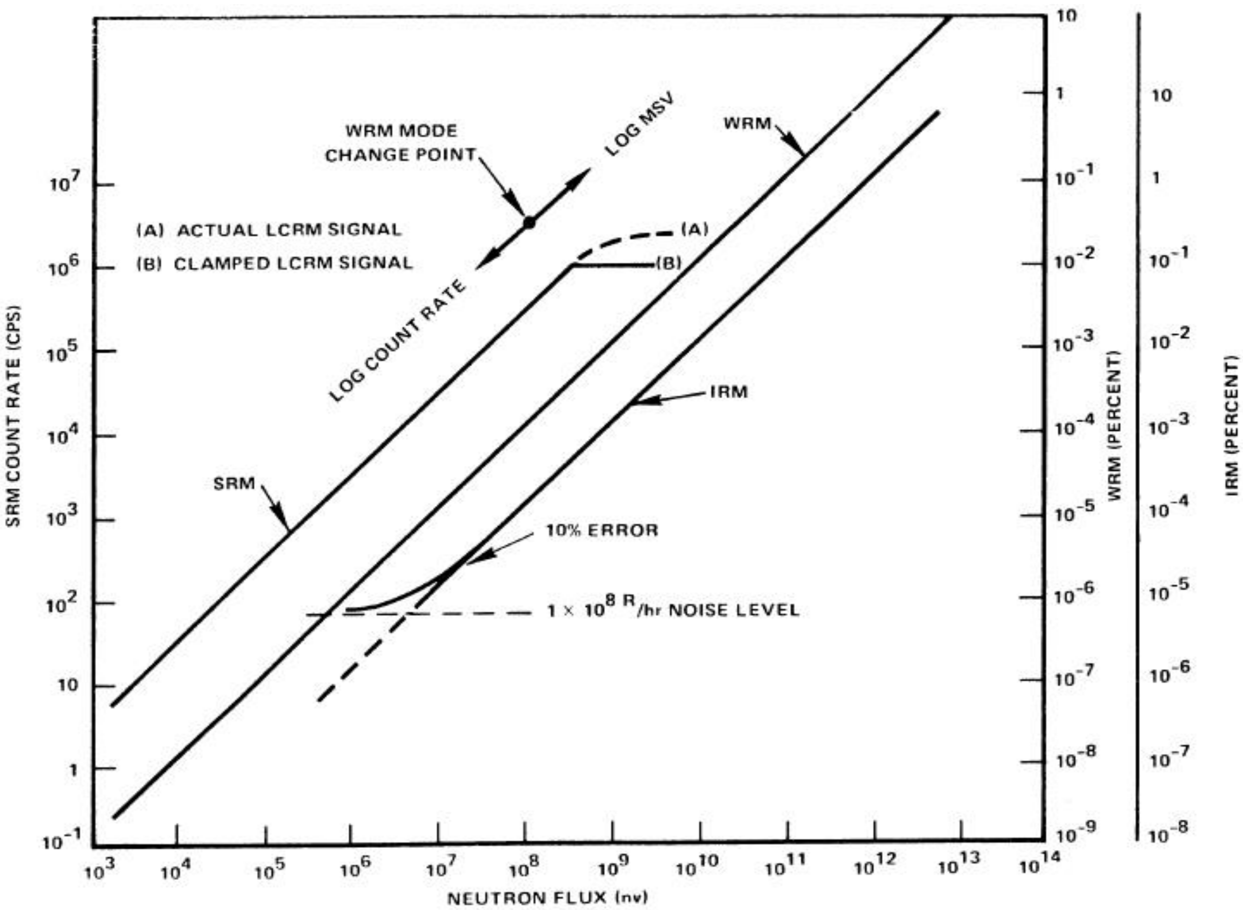


Fig. 5 Linearity of WRNM channel.

WRNM over the full range of the test. The counting, linear MSV and percent power are shown on different scales. The overlap region, shown as the range between the points where the MSV signal is 10 percent too high and where the counting signal is clamped at 1×10^6 cps, is more than 1.0 decade wide.

There is no discernable discontinuity at 1×10^8 nV, the point where the wide range channel switches over from log count rate to log MSV.

7. Some Conclusions about WRNM

It is obvious that this WRNM which combines the source range and intermediate range monitoring functions along with a post-accident monitoring capability in one channel is advantageous for a number of reasons.

There is the economic advantage which accrues from use of fewer channels, typically 8 rather than 12, increased coverage in the source range, smoother startups because counting and Campbelling signals are from the same sensor; and startup problems related to insert—retract mechanism problems are eliminated. The operator-equipment interface is significantly improved by use of a simple digital display. The new system does not impact the LPRM (local power range monitoring) system in any way; however, use is made of LPRM calibration data for life prediction [1].

For more granular information about LPRM system, refer to Chapter Two of this writeup, where this system is described.

The life of the fixed incore sensor will be about 6.0 full power years in a 51 kW/L plant using a conservative definition of end-of-life. The elimination of insert-retract mechanisms under the vessel significantly reduces the maintenance required and thus men-REM exposure.

The control room monitor design effectively resolves the switchover problem that has plagued other Counting-Campbelling wide range monitor designs. The equipment is seismic and post-LOCA qualifiable and it is expected that qualifications to IEEE 344-1975 and NUREG-0588 requirements would be completed in early 1984 thus providing a means to meet RG 1.97 requirements and at the same time providing for a significant upgrade of the startup neutron monitoring function for BWRs [1].

8. ENMS (Excore Neutron Monitoring System)

ENMS is divided into:

- SRM,
- IRM and,
- PRM (Power Range Monitor).

in accordance with its measurement range whose measurements are carried out with Boron-Trifluoride (BF_3) proportional counter or B10 proportional counter as illustrated in Fig. 6 below, fission chamber and ion chamber respectively. There have been lots of study to adopt the WR (wide range) measurement method where only fission chamber is used through the whole reactor power.

On purpose of this writeup, the whole system was considered using only fission chamber as detector. With its adoption, the system consists of fission chamber, wide range amplifier and signal processing device.

This newly-consisted system was designed conceptually in accordance with system requirements of KSNP (Korean Standard Nuclear Plant), then it was found that it can be adopted into KSNP without any impacts on other systems. Also, to support this configuration, it needs extending the power measurement range which is covered by fission chamber to lower power range. In lower power range the effect of noise in signal is greater relatively than that of high-power range. The existing signal processing method to measurement plant power range in ENFMS in which the individual neutron flux pulse can be countered as the reactor power increased is MSV measurement.

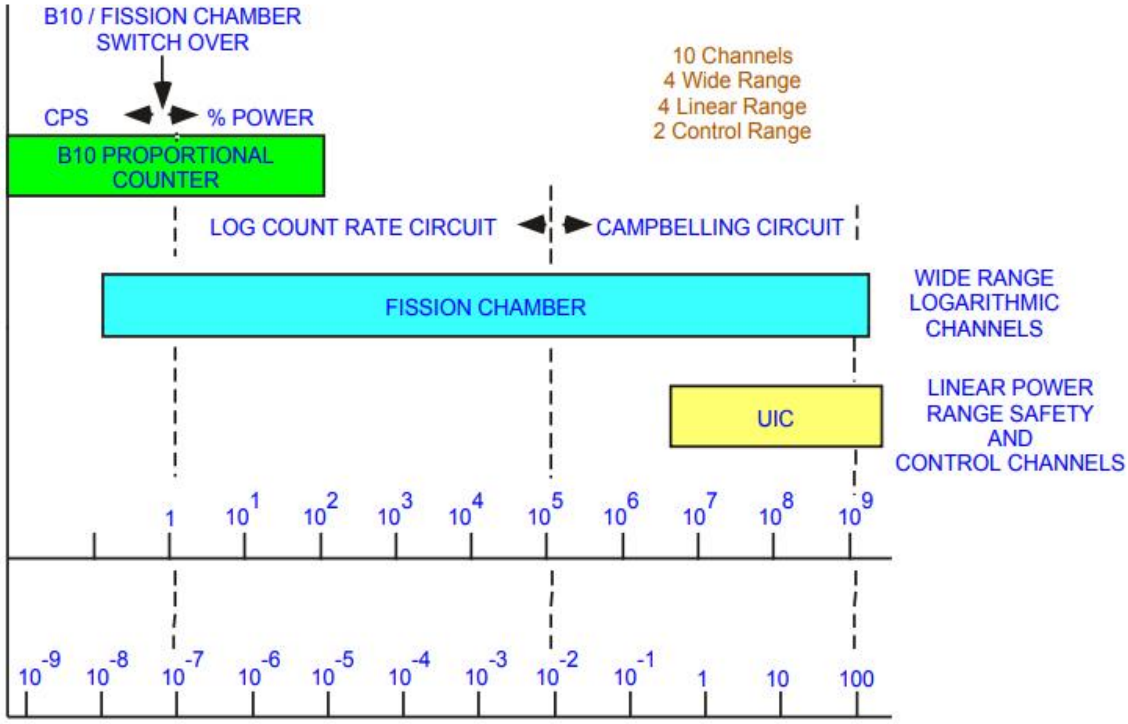


Fig. 6 Typical flux coverage with detectors.

Furthermore, bear in mind that the main purpose of ECNMS (excore core neutron monitoring system) of the NI (nuclear instrumentation) system is:

(1) To monitor neutron flux from the source level to 200% of full power.

(2) To provide indication in the control room of neutron power and the rate of change of neutron power.

(3) To provide power level signals to RRS (reactor regulating system).

(4) To provide power level signals and the rate of change of power signals to the RPS (reactor protection system).

(5) To provide information on axial power distribution to the control room and RPS.

The following series of Figs. 7-20 provided here are covering the above listed main purposes at least in case of B10 (Boron 10) proportional counter, where the following listed objectives can be met:

(1) List the purposes of the excore NIS (nuclear instrumentation system) as listed in above.

(2) Explain the basic operation of the following excore neutron detectors and state the detector type used in each range of the ENMS in case of B10:

(a) B10 proportional counter.

(b) Fission chamber.

(c) Uncompensated Ion chamber.

This objective extensively was described in Chapter One, Section 1.3 of this paper.

(3) Describe the following excore nuclear instrumentation system interfaces and interlocks as:

(a) WRLC (wide range logarithmic channel) high-voltage interlock.

(b) Wide range logarithmic channel and linear power range safety channel overlap.

(c) Wide range channel and linear power range safety channel RPS inputs.

(d) Non-safety related linear power range safety channel interfaces.

(4) Explain how the Excore Nuclear Instrumentation is capable of detecting both radial and axial power distributions.

(5) Explain how the LPRS (linear power range safety) channel is calibrated to indicate reactor thermal power.

(6) List the PRLC (power range linear control) channel outputs.

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.

As we stated above, 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/cm^2/s (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.

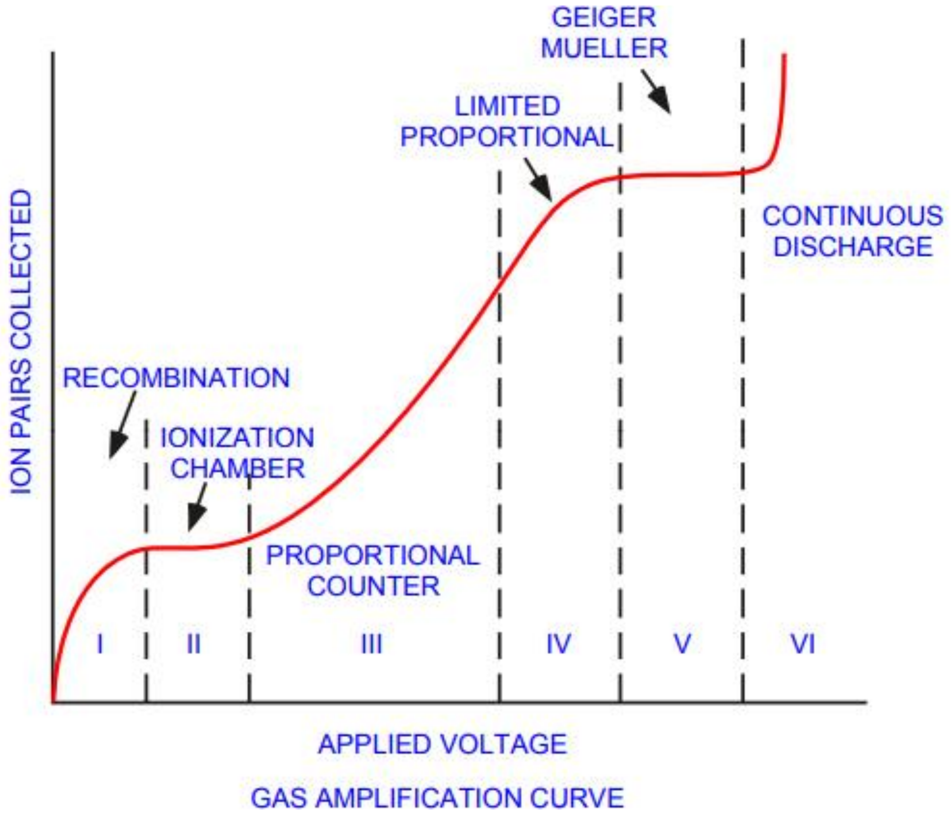


Fig. 7 Ion pairs versus applied voltage.

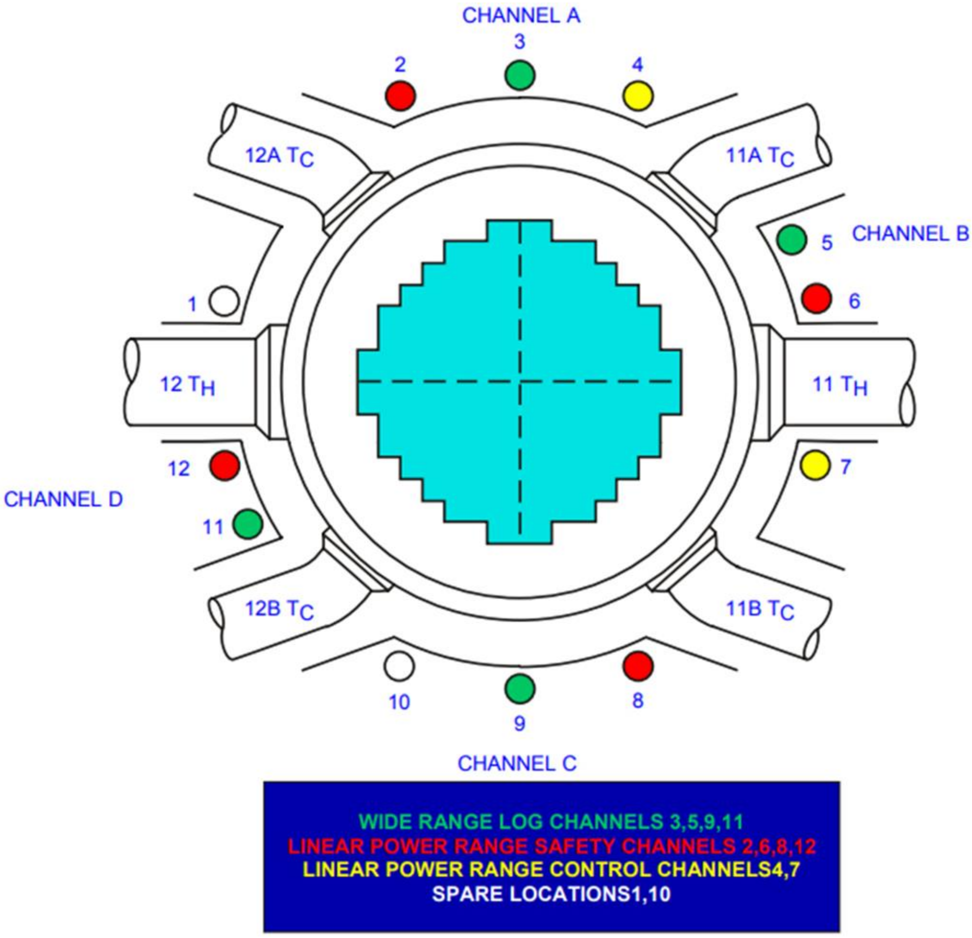


Fig. 8 Excore detector location.

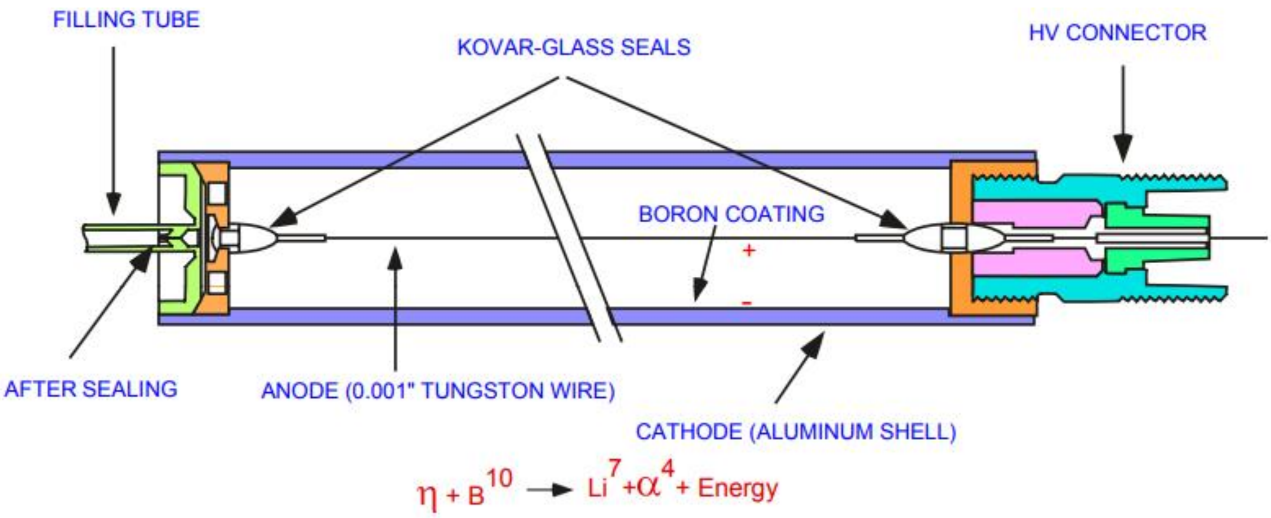


Fig. 9 Typical B10 proportional counter nuclear instrumentation.

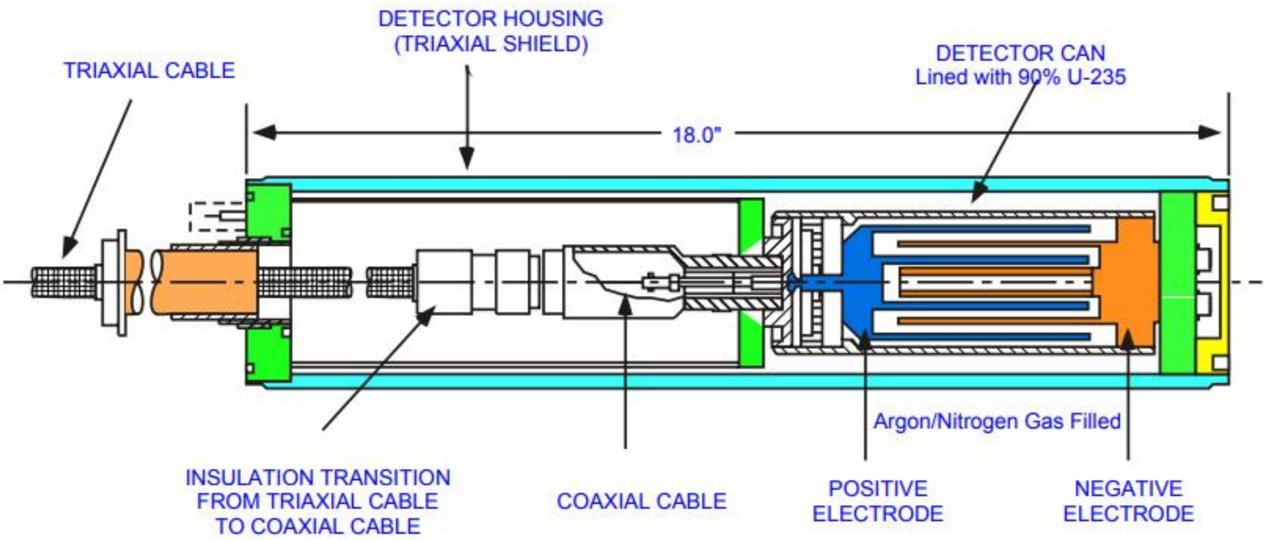


Fig. 10 Fission chamber (neutron sensitivity 0.7 Counts/nV) schematic.

The Fig. 12 below, is in support of Fig. 11 as well, which is objective and purpose of the TMLP (thermal margin low pressure) system and LPD (local power density) trips and includes the inputs to the TMLP and LPD trips, as well as stating the plant conditions used to determine when these trips are in effects.

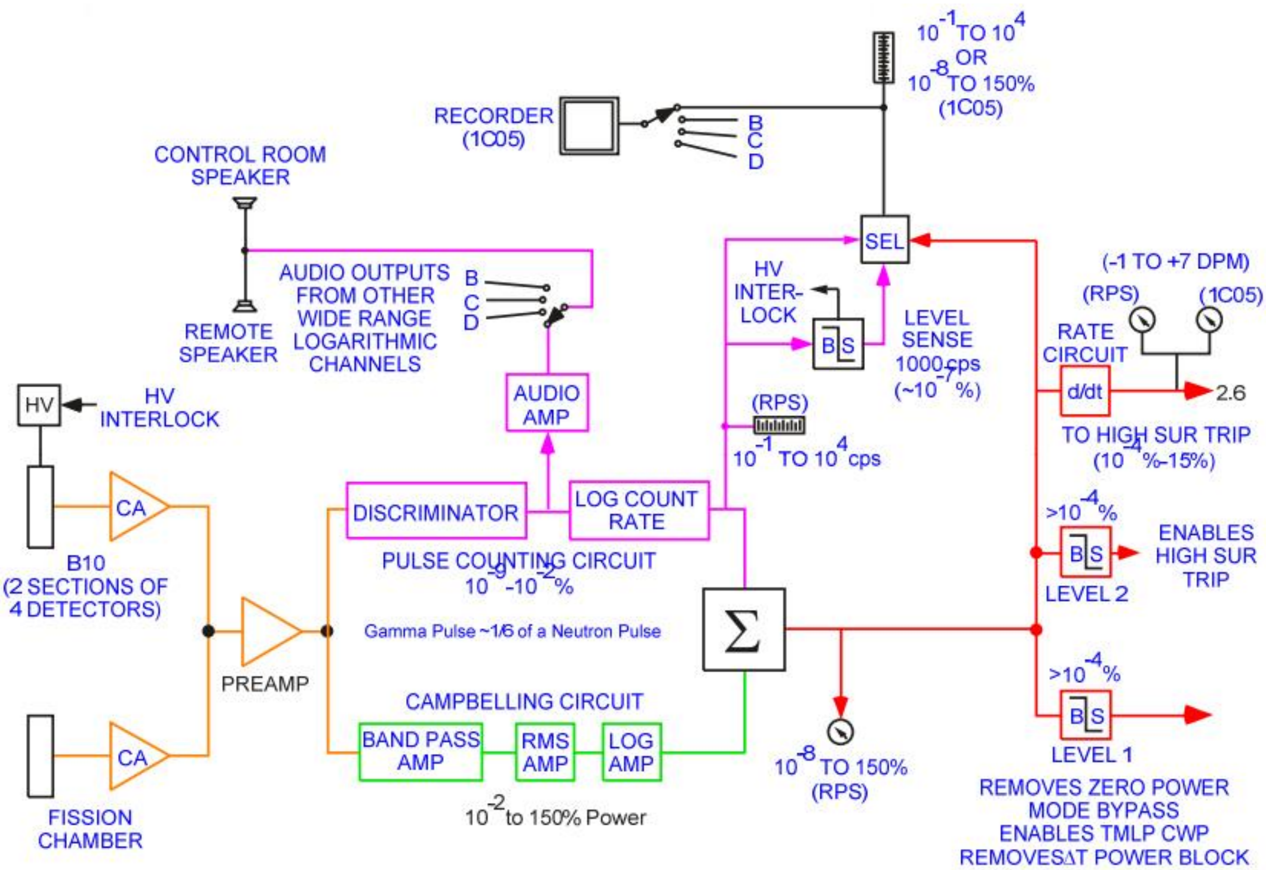


Fig. 11 Excore NI wide range logarithmic channel block diagram.

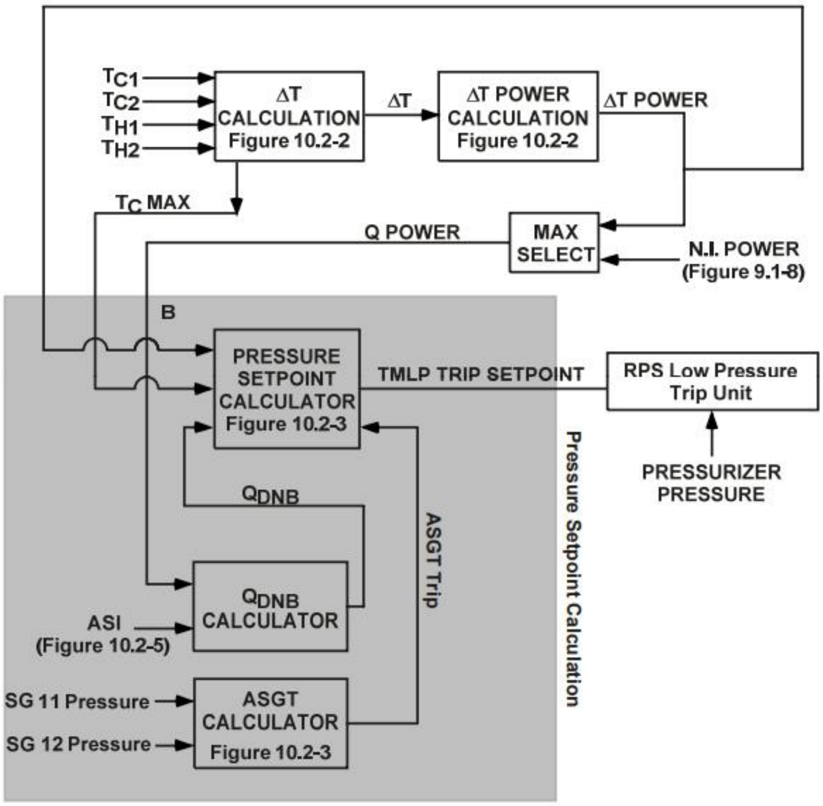


Fig. 12 ΔT/TMLP calculation block diagram.

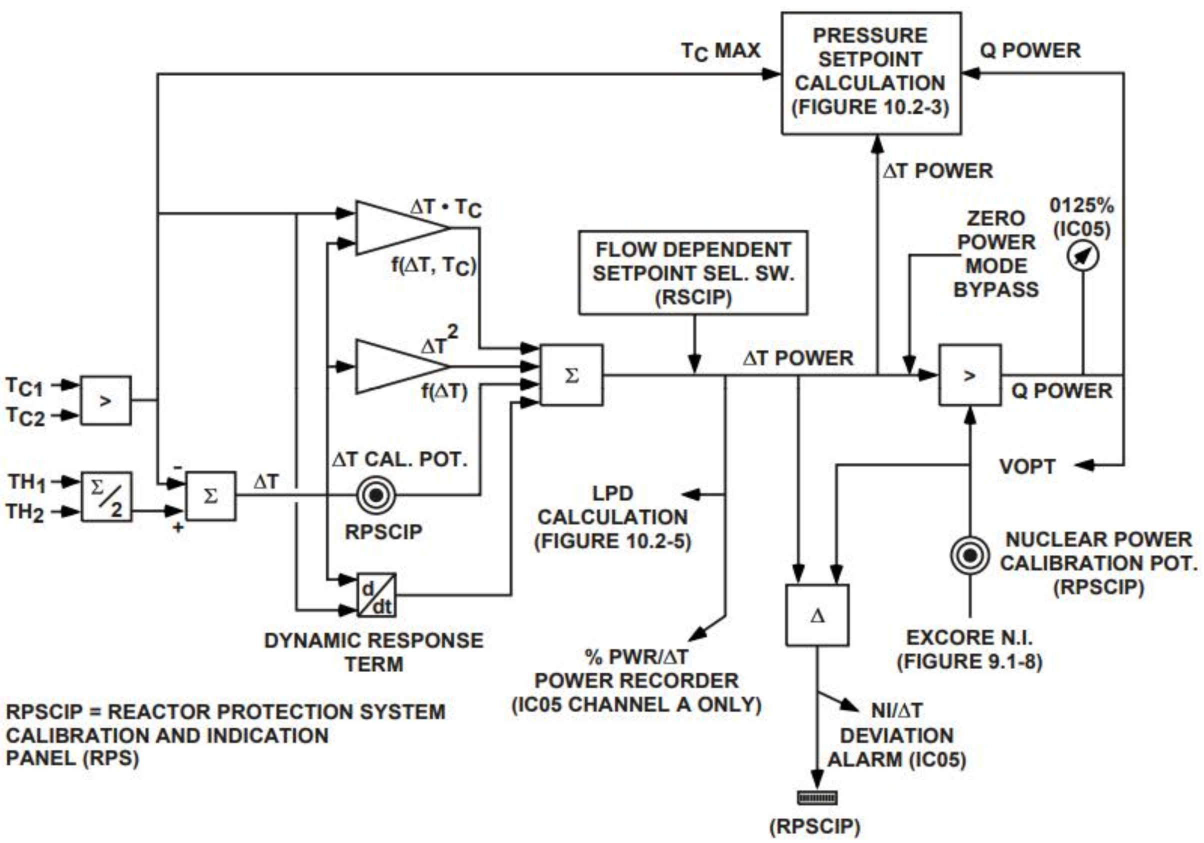


Fig. 13 TMLP ΔT power calculation diagram.

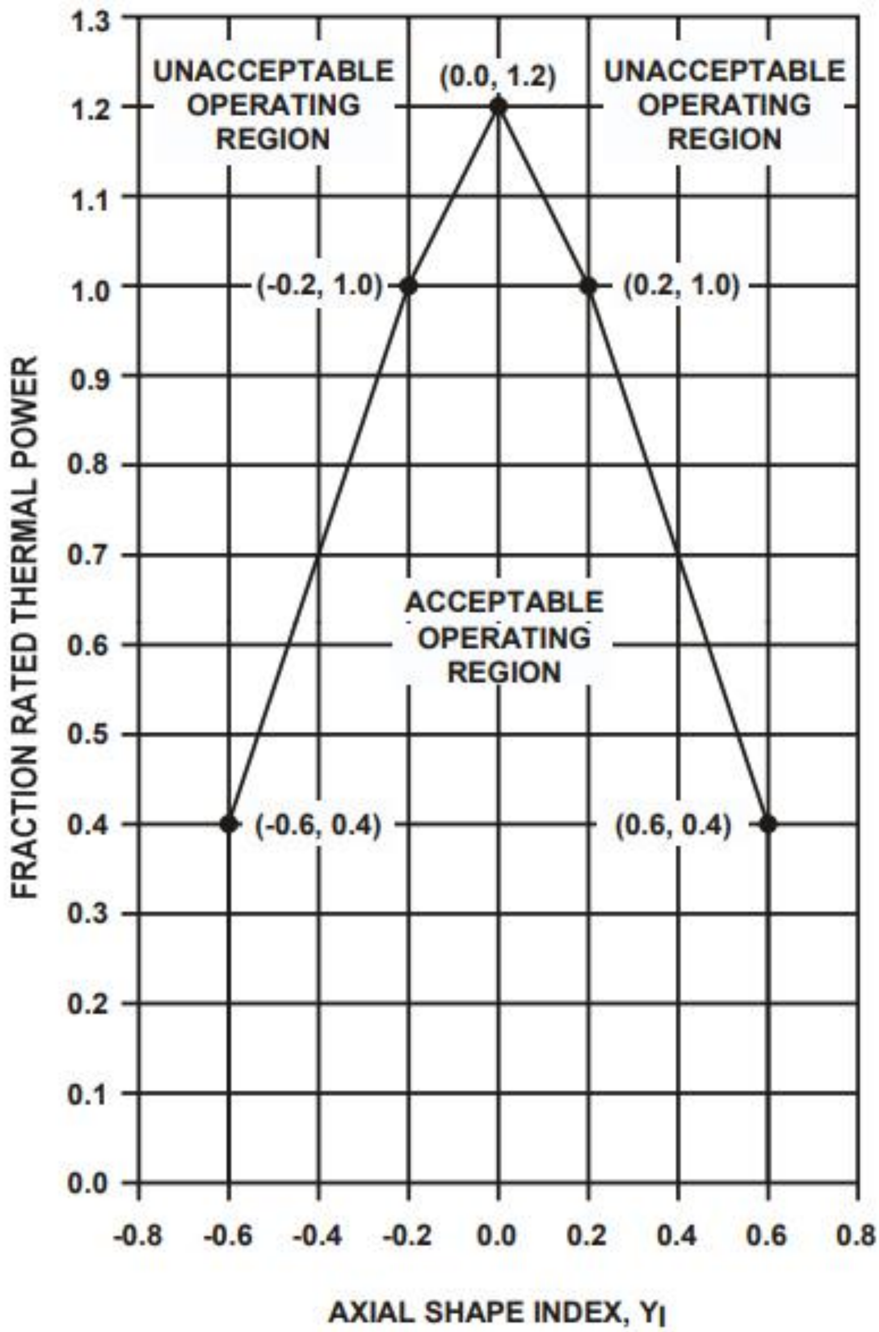


Fig. 14 Axial shape index boundary diagram.

In addition, the diagram in Fig. 13 demonstrates the TMLP system ΔT power calculation, the diagram in Fig. 13 represents the LPD (local power density) trip accordingly, while diagram in Fig. 14 illustrates of ASIB (axial shape index boundary).

Meanwhile, both diagrams in Figs. 16 and 17 are TMLP and pressure setpoint versus temperature, respectively.

Note that: all the figures from Figs. 18-20 are presenting TMLP and local power density trips respectively.

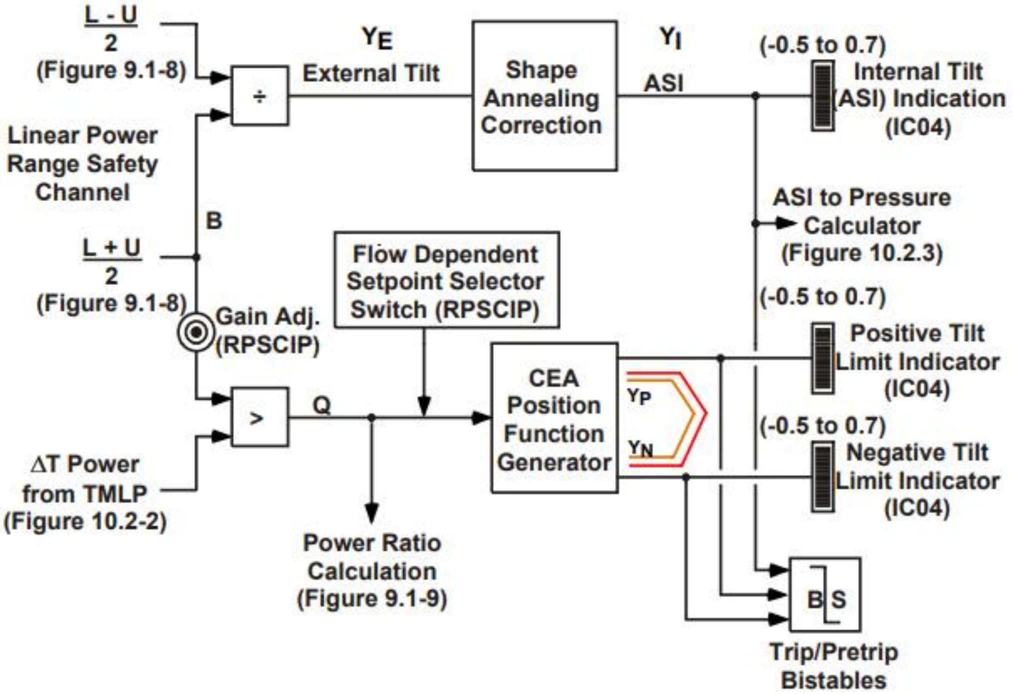


Fig. 15 Local power density trip diagram.

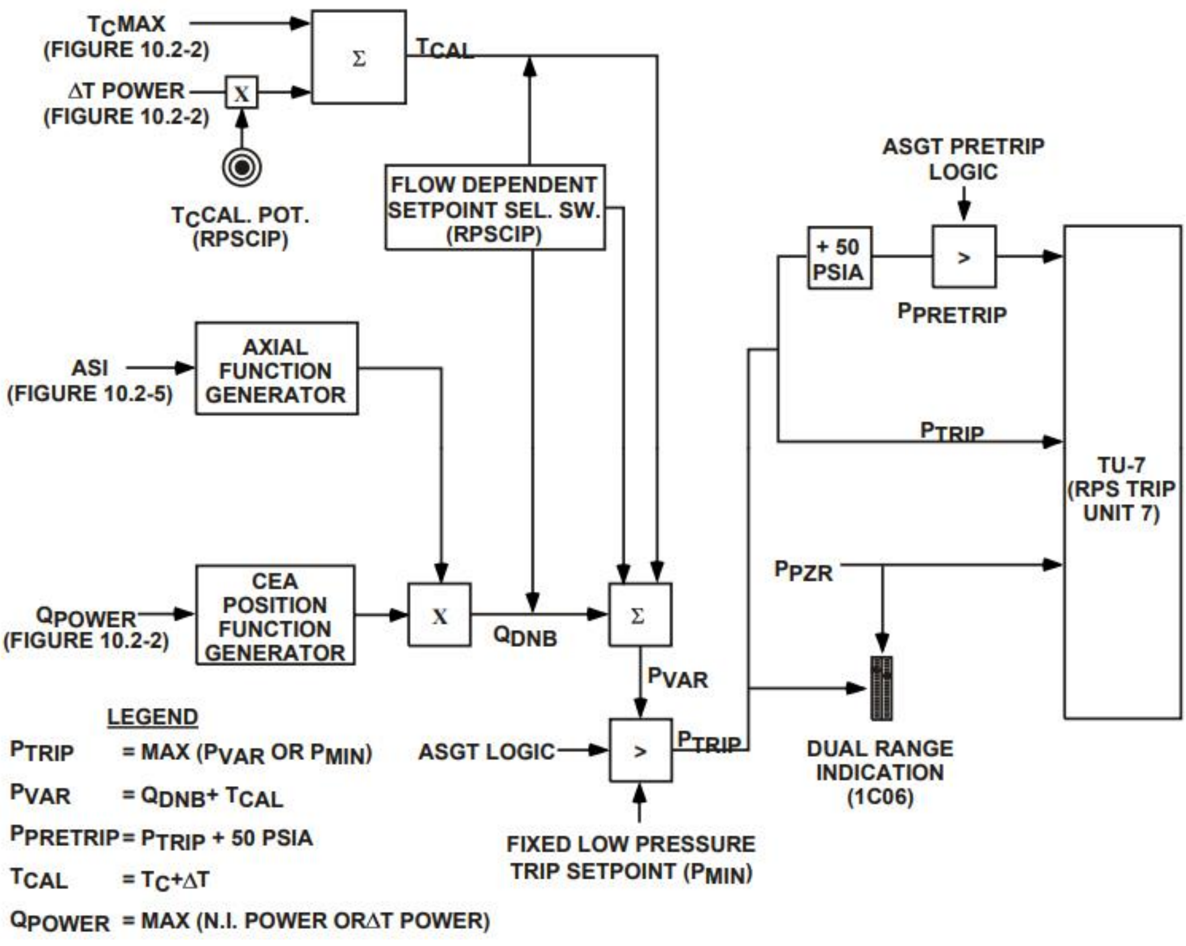


Fig. 16 TMLP pressure setpoint calculation.

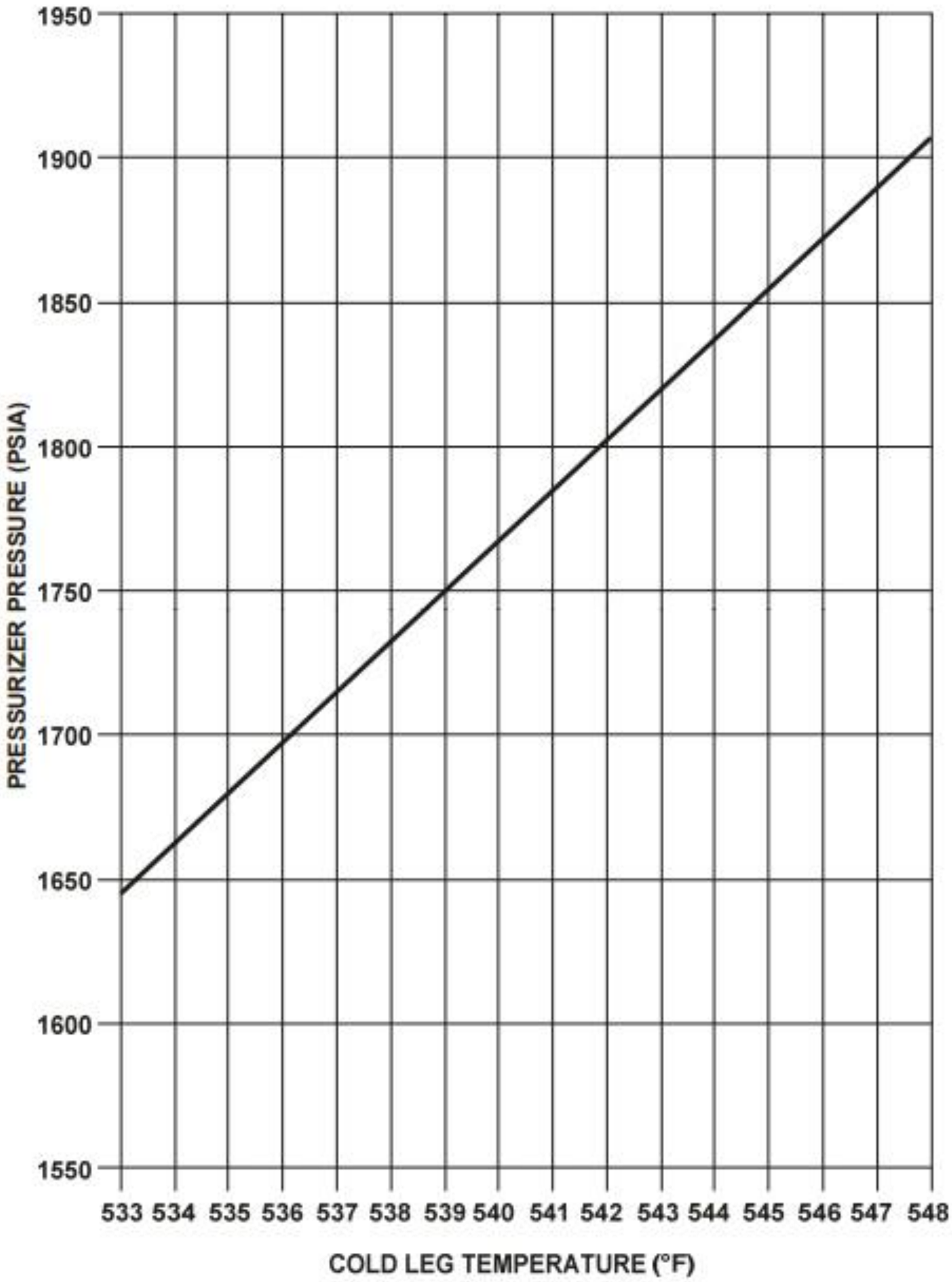
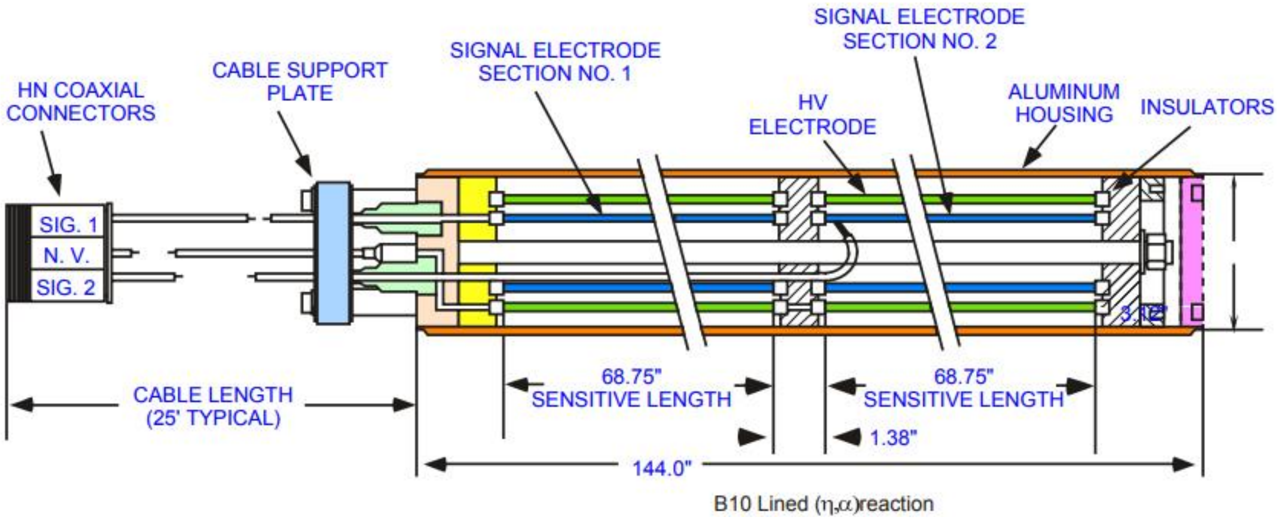


Fig. 17 Pressure setpoint versus temperature.



Neutron Sensitivity 3.5E-13 A/NV

Gamma Sensitivity 1.2E-10A/NV

Fig. 18 Uncompensated ionization chamber.

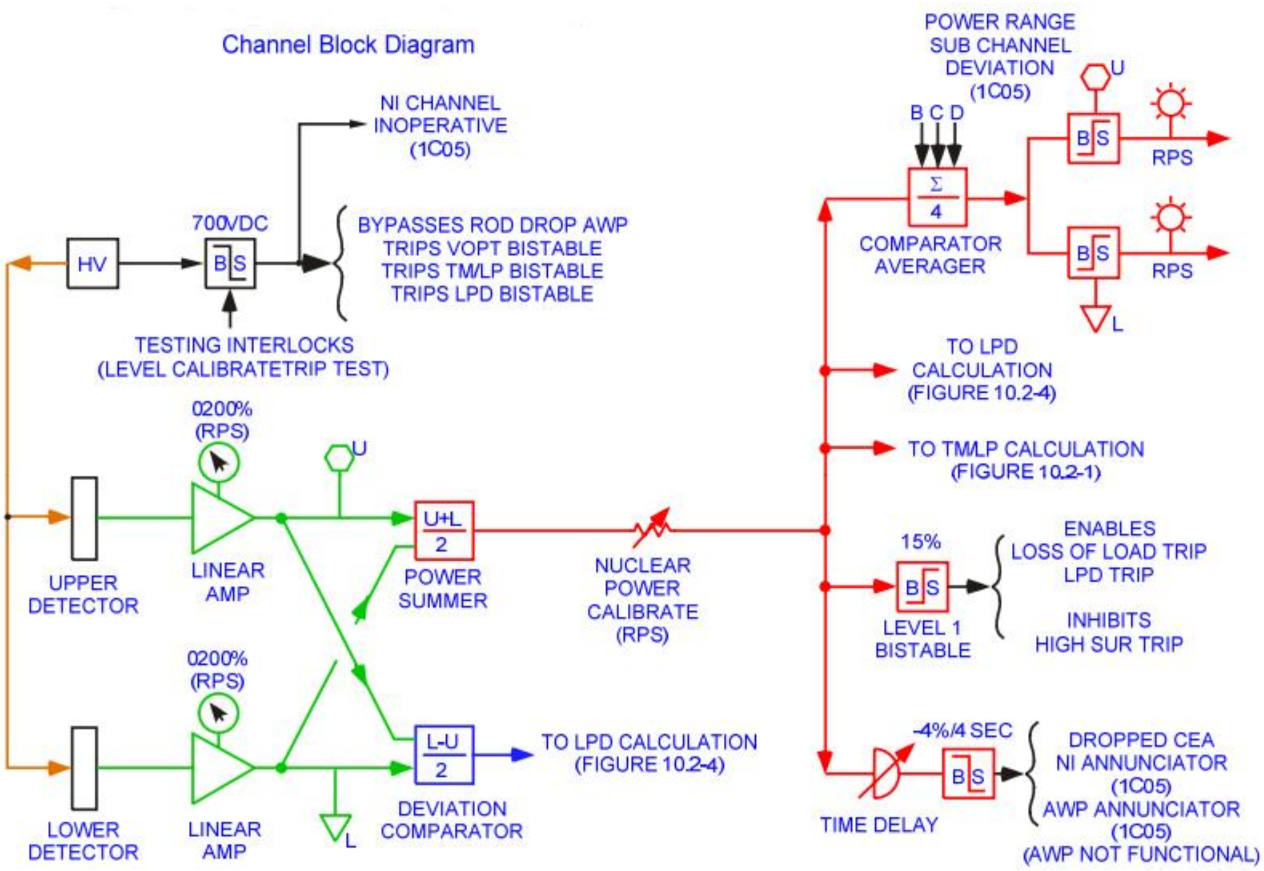


Fig. 19 Excore nuclear instrumentation narrow range linear.

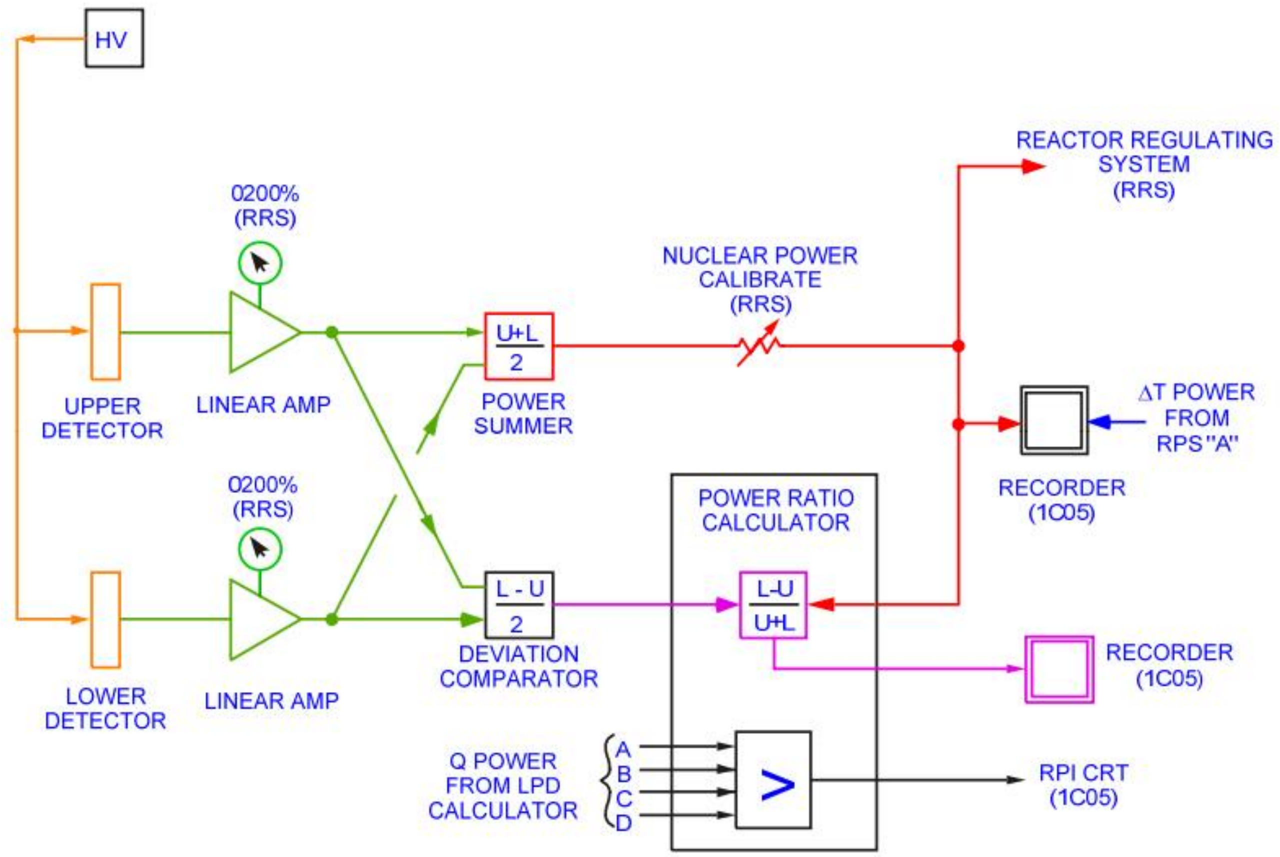


Fig. 20 Linear power control channel block diagram.

9. INMS (Incore Neutron Monitoring System)

(1) Describe the basic operation of the NMS.

(2) Explain the functions of the INMS.

(3) Explain the functions of the CET (Core Exit Thermocouple) system.

With these objectives in mind, we can pay our attentions to the functions of the ICI (in-core instrumentation) system that are listed here as well:

(1) To determine the gross power distribution in the core at different operating conditions over the range from 10% to 125% average reactor power.

(2) To provide data to estimate the fuel burnup in each fuel assembly.

(3) To provide information to guide the operation of control element assemblies in the control of xenon oscillations and to ensure that power peaking factors do not exceed allowable limits during this maneuvering of the control element assemblies.

(4) To provide data for the evaluation of thermal margins in the core.

(5) To provide data which will be used to verify core power distribution is consistent with calculated values.

(6) To provide data to periodically normalize the excore detector readings to assure that they indicate the correct top to bottom distribution and correct power distribution top to bottom distribution and correct power distribution among quadrants.

(7) To provide signals to alert the operator to abnormal or unexpected occurrences in the core.

The purposes of the incore instrumentation system are to provide information on neutron flux distribution and fuel assembly outlet temperatures at selected core locations. The incore instrumentation system provides data acquisition only and performs no protective or plant operational control functions. The incore instrumentation system includes the movable incore neutron flux monitoring system and the incore temperature monitoring system. The number of incore temperature monitoring thermocouples and the number of flux thimble paths available within the core for the movable detectors vary depending upon the Westinghouse design, i.e., two, three, or four loop designs. The location and distribution of the incore instrumentation, flux thimbles and thermocouples, within the reactor core of a 4-loop Westinghouse plant is shown in Fig. 11.

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

(1) Calculate the three-dimensional core power distribution for verification of safety-related predictions.

(2) Calculate the hot channel factors for compliance with technical specifications.

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

Detect and verify core radial and axial asymmetries.

Detect and verify control rod misalignments, such as dropped rods or rodlets, and rods above or below their respective bank position.

The incore temperature monitoring system consists of fixed thermocouples, positioned at the top of the upper core plate. These thermocouples, referred to as CETs (core exit thermocouples), are used to measure fuel assembly coolant outlet temperature. The data are used to:

(1) Determine the core radial power distribution.

(2) Conduct continuous on-line monitoring of core radial power sharing and incore thermocouple temperatures.

(3) Compute the coolant enthalpy rise in the instrumented fuel assemblies.

(4) Detect abnormal rod configurations.

(5) Confirm indications given by the excore instrumentation system and the INMS.

(6) Provide an input into the subcooling margin monitors and.

(7) Provide the operators with an indication of inadequate core cooling conditions during emergency situations.

The following Figs. 21-26 put the section on INMS in a proper prospective.

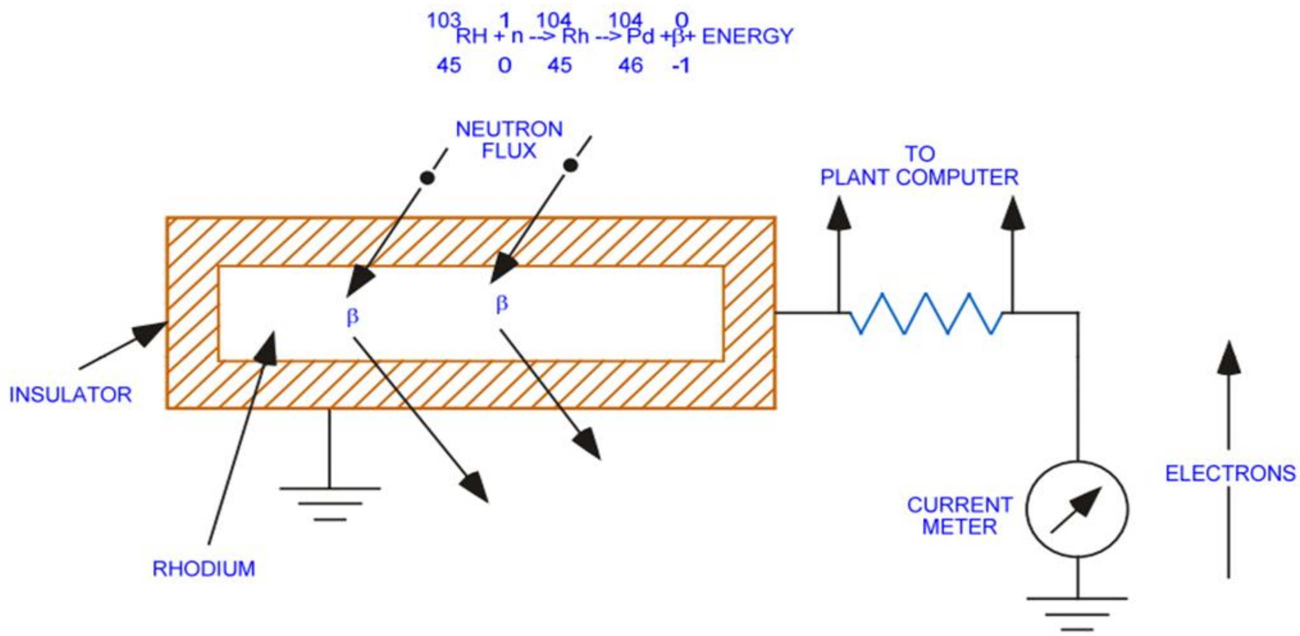


Fig. 21 Self-powered neutron detector.

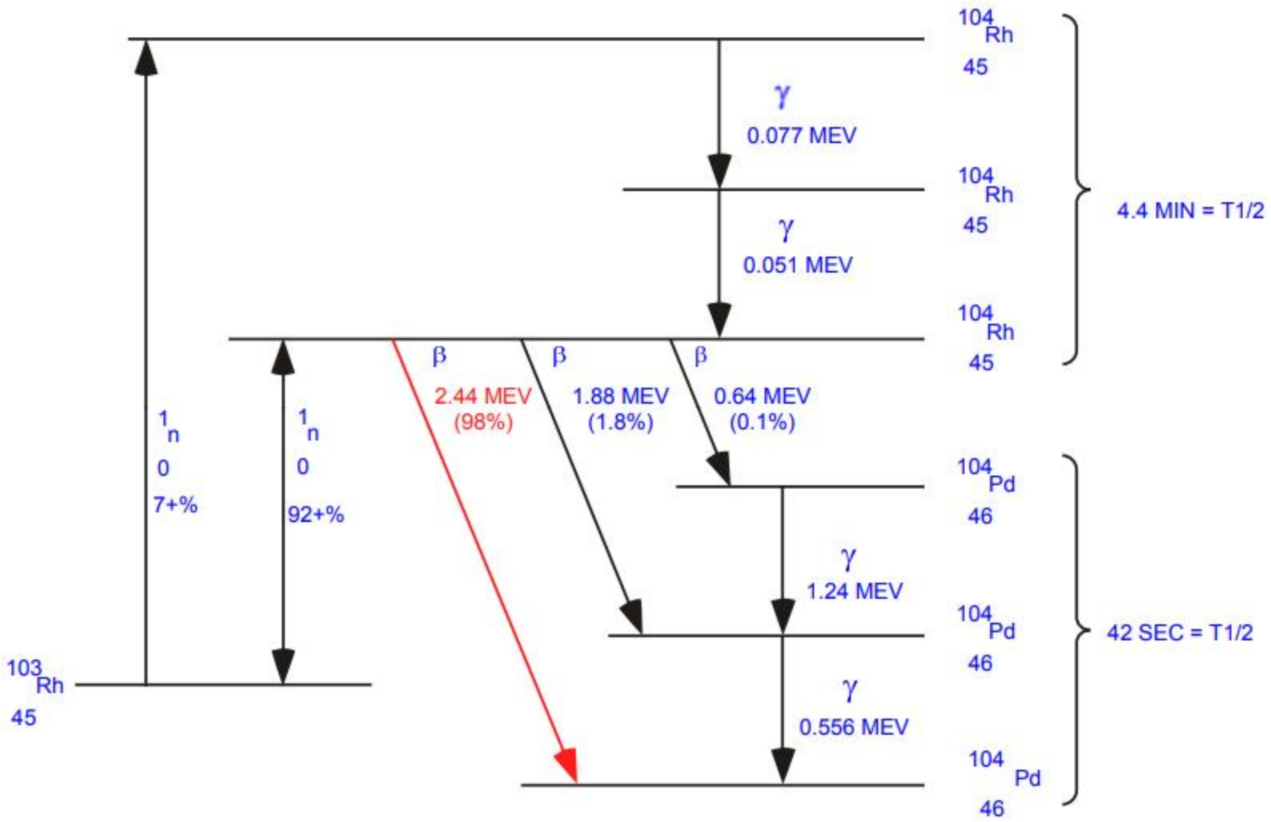


Fig. 22 Rhodium decay scheme.

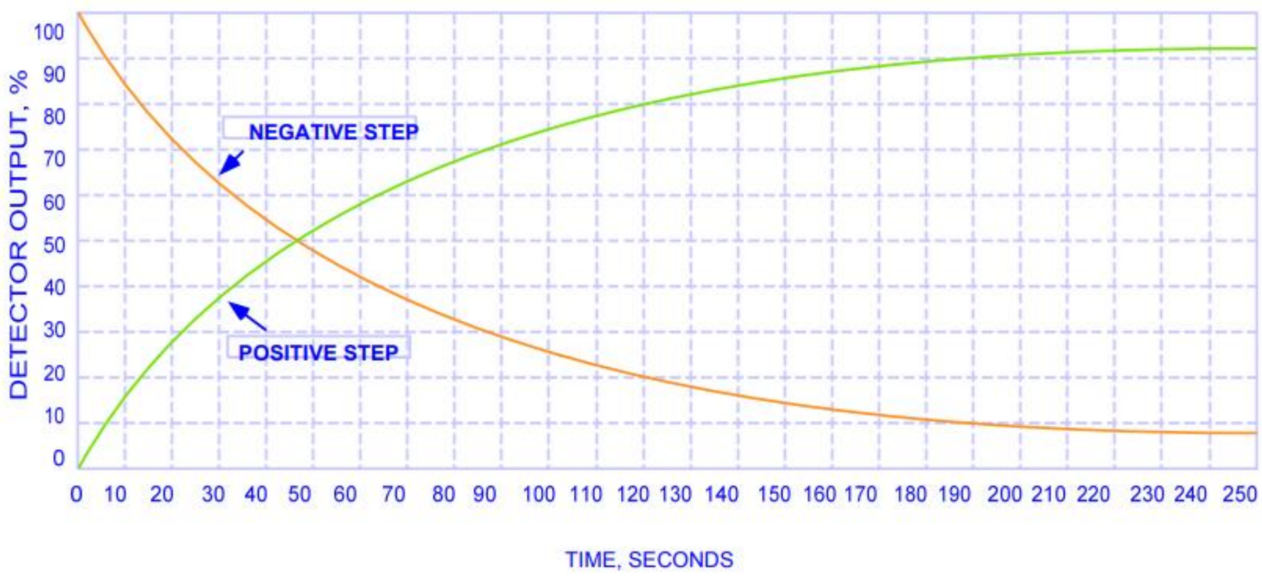


Fig. 23 (a) Rhodium detector response.

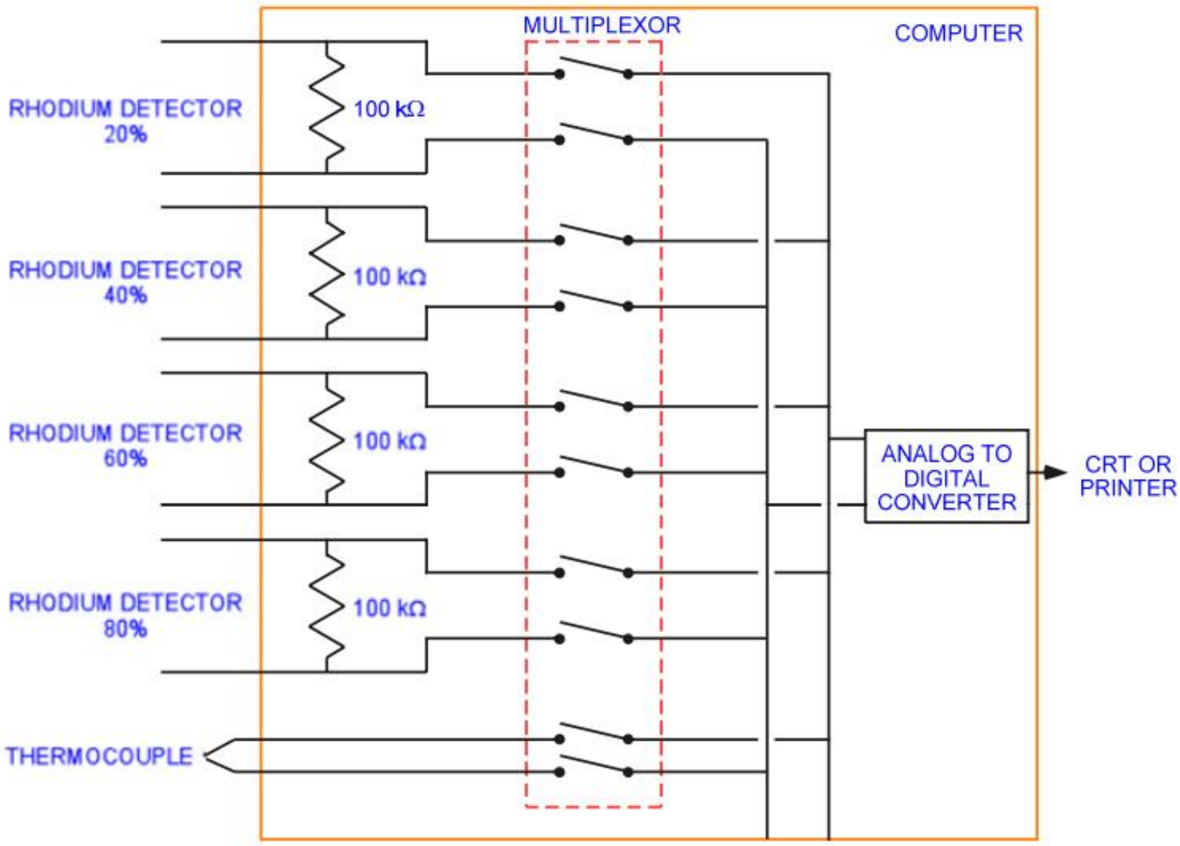


Fig. 23 (b) Rhodium detector response.

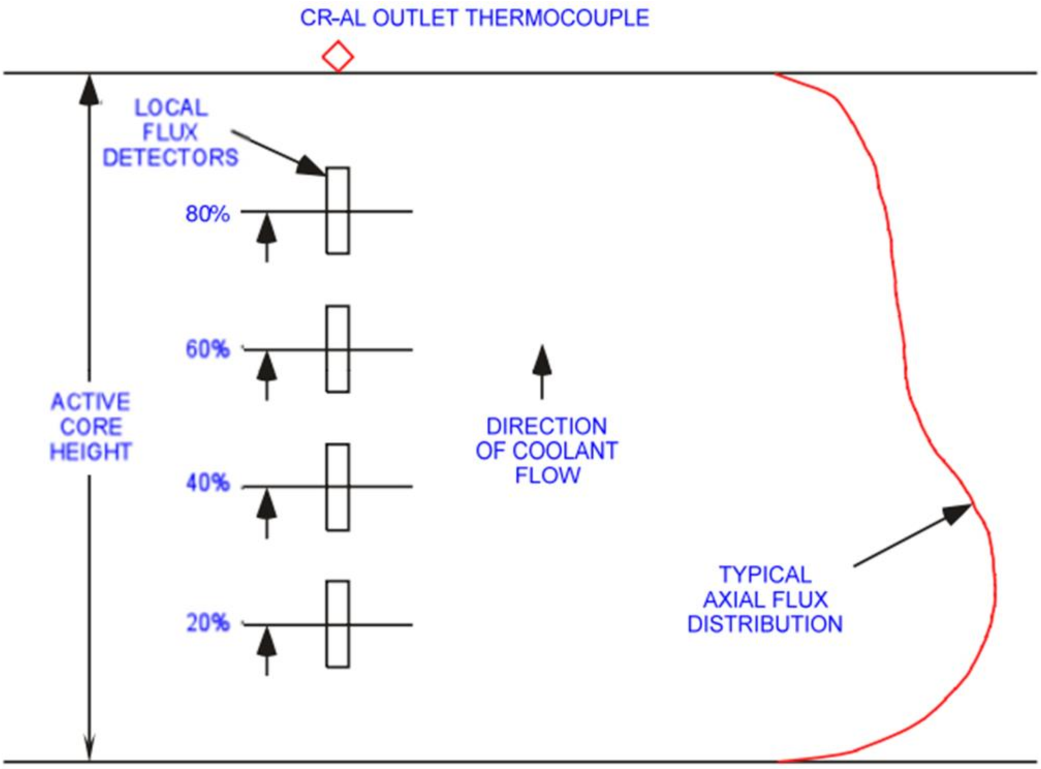


Fig. 24 Incore detector axial arrangement.

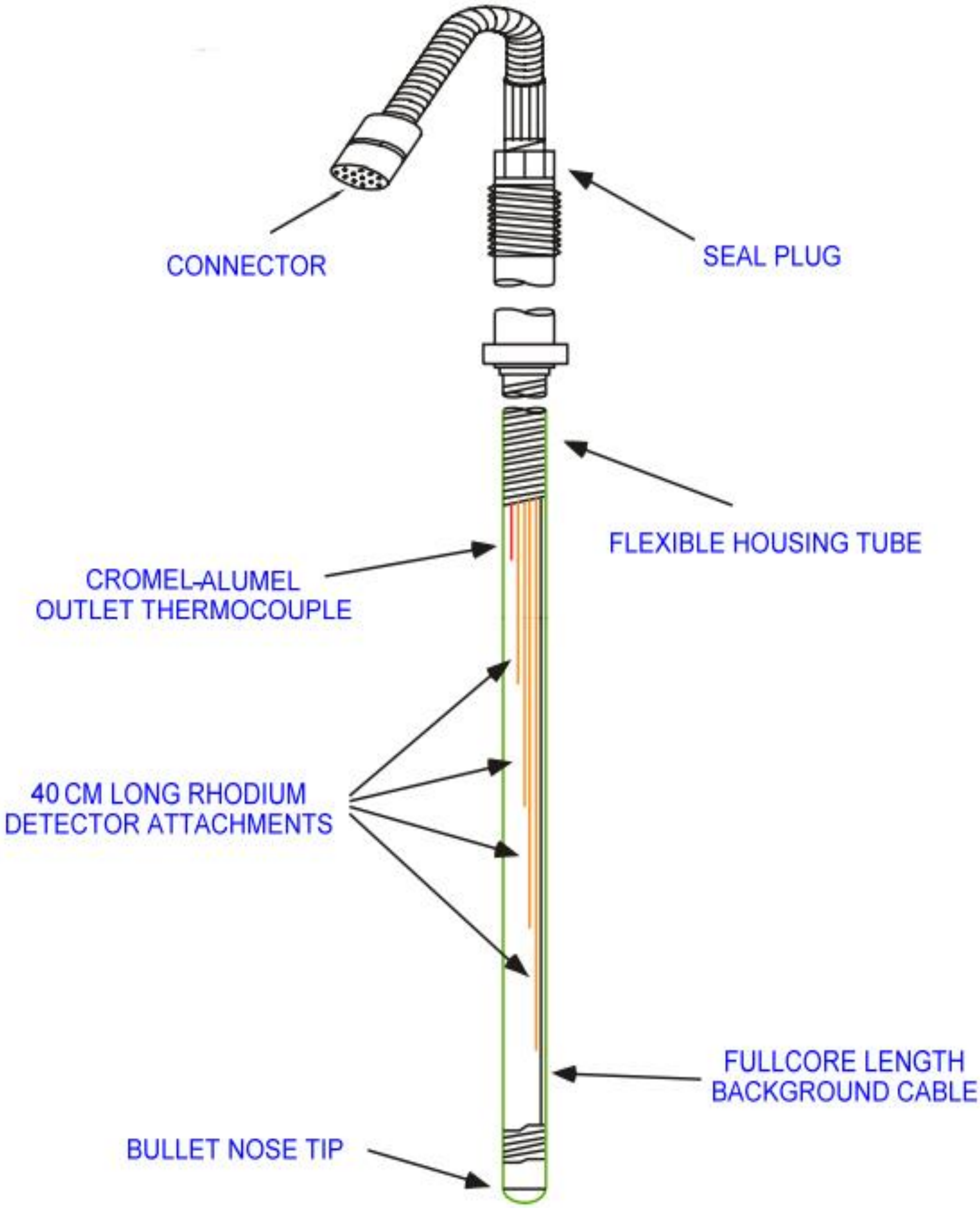


Fig. 25 Incore detector assembly.

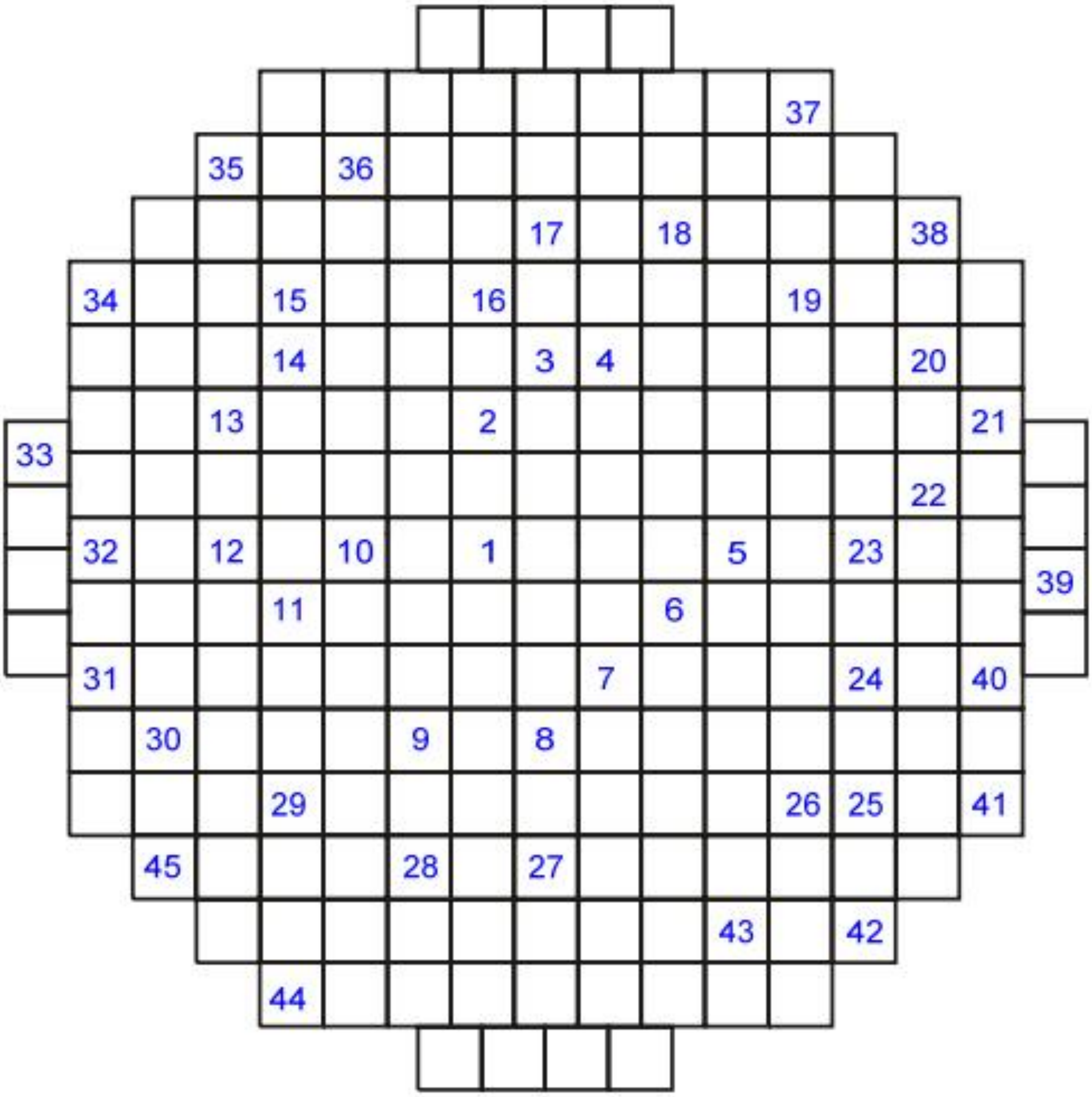


Fig. 26 Incore detector location.

10. Conclusion

The WRNM system was first installed in an operating BWR in 1987. To date, 25 BWRs worldwide have installed the WRNM. The WRNM is also installed in the ABWR at Lungmen, with scheduled startup in the later part of this decade. It is also one of the required NMS systems for the ESBWR (economic simplified boiling water reactor), the new generation of BWR. Although the installation of the WRNM is considerably involved, with work from the refuel floor, under reactor vessel, inside the containment, and with signal path from the containment penetration all the way to the control room, most installation can be accomplished within the outage window, typically approximately 14 days. Successful operational history of the WRNM and its enormous potential advantages suggests that this system can play a significant role in supporting the mission of plant life extension for the rest of the BWRs. Fig. 27 presents a picture of an installed WRNM system at one of the panels.

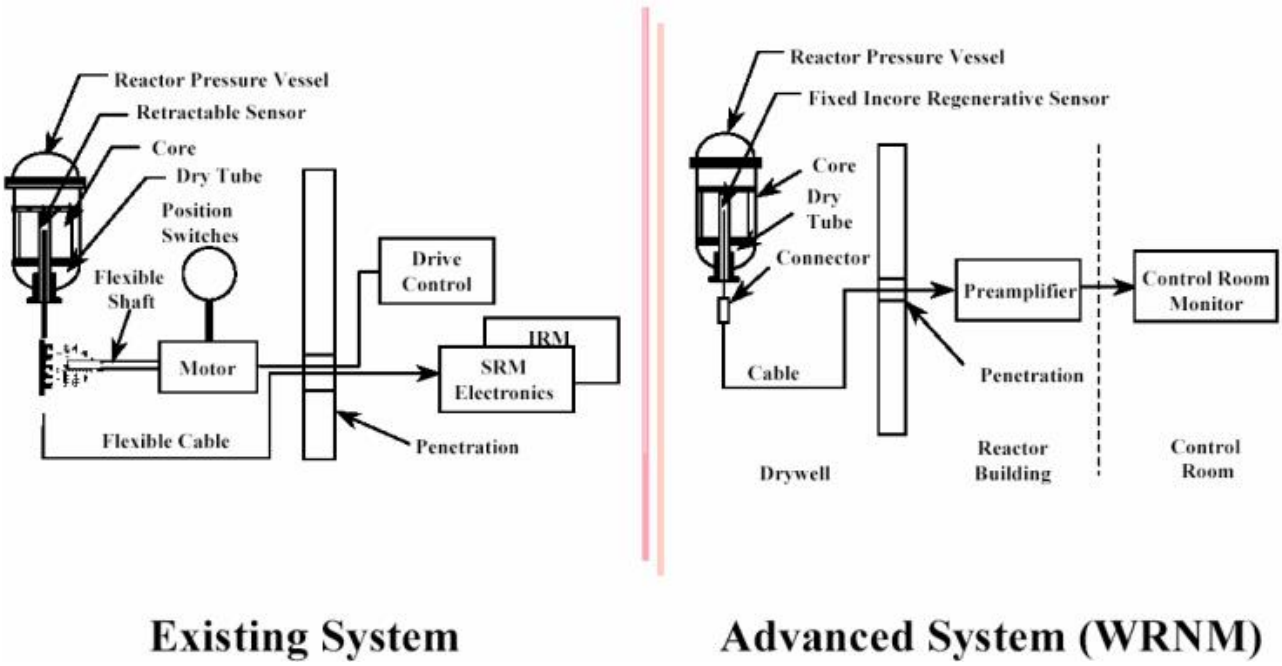


Fig. 27 Comparison between SRM/IRM and WRNM systems.

Fig. 28 NUMAC WRNM in a BWR.

GEH is the industry leader in BWR technology with over 50 years of experience in the nuclear industry. GE offers a wide range of products and services including instrumentation and control systems that ensure the safe operation and maintenance of the plant, while bringing greater efficiency and output.

The NUMAC product line is a family of digital instruments designed to improve plant performance. The design concept of NUMAC has proven to be in concert with the mission of plant life extension.

References

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[3] Popper, G. F., Lipinski, W. C., and Harrer, J. M. 1966. "Ten Decades of Continuous Neutron Flux Monitoring from a Single Fixed Position Detector." *Trans. Amer. Nucl. Soc.* 9: 6.

[4] Bjorkman, J., Fogelberg, B., Johansson, O., and Jonsson, G. 1978. "A New Incore Startup System with Combined Source Range Flux Monitoring System." Presented at the International Symposium on Nuclear Power Plant Control and Instrumentation, April 1978.

[5] The RCMS Interface Unit controls the power module as the power source for the Branch Amplifiers, stabilization valves and annunciators.