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## **9.2 INCORE INSTRUMENTATION**

Learning Objectives:

1. Describe the basic operation of the incore instrumentation system (ICIS).
2. Explain the functions of the incore neutron monitoring system.
3. Explain the functions of the core exit thermocouple system (CET).

### **9.2.1 Introduction**

The incore neutron monitoring system continuously monitors the core neutron level to provide information on the axial and radial flux distribution within the core. The system consists of a fixed incore detector system, core exit thermocouples, amplifiers for both systems, and associated hardware with computer interfaces. In addition to sensing neutrons, the incore system also provides fuel assembly exit temperature measurements.

The functions of the ICIS system are as follows:

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 among quadrants and
7. To provide signals to alert the operator to abnormal or unexpected occurrences in the core.

## 9.2.2 Neutron Detection

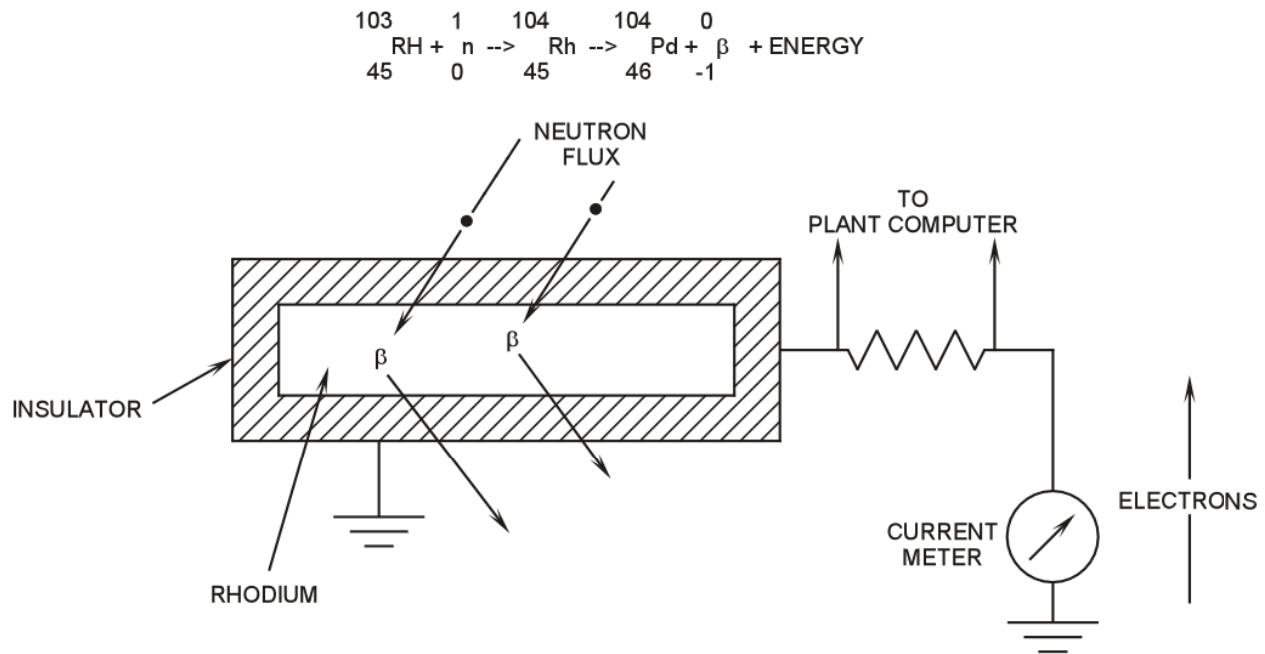
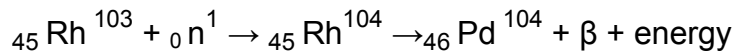


Figure 9.2-1 Self Powered Neutron Detector

When the element rhodium is bombarded with a neutron flux, it becomes radioactive and will decay by emitting a beta particle. The reaction takes place as follows:



Furthermore, if the rhodium is insulated from electrical ground, then the emission of the beta particle (electron) will represent a charge deficiency that is proportional to the number of neutron reactions. A method of measuring this charge exists when the rhodium detector material is connected to ground, and the flow of electrons required to replace the emitted beta particles is measured. A simplified version of the circuit needed to accomplish this function is shown in Figure 9.2-1. Since no external source of detector power is required, the neutron detector is self-powered. The neutron detector response time is proportional to the decay of the  ${}_{45}\text{Rh}^{104}$  isotope.

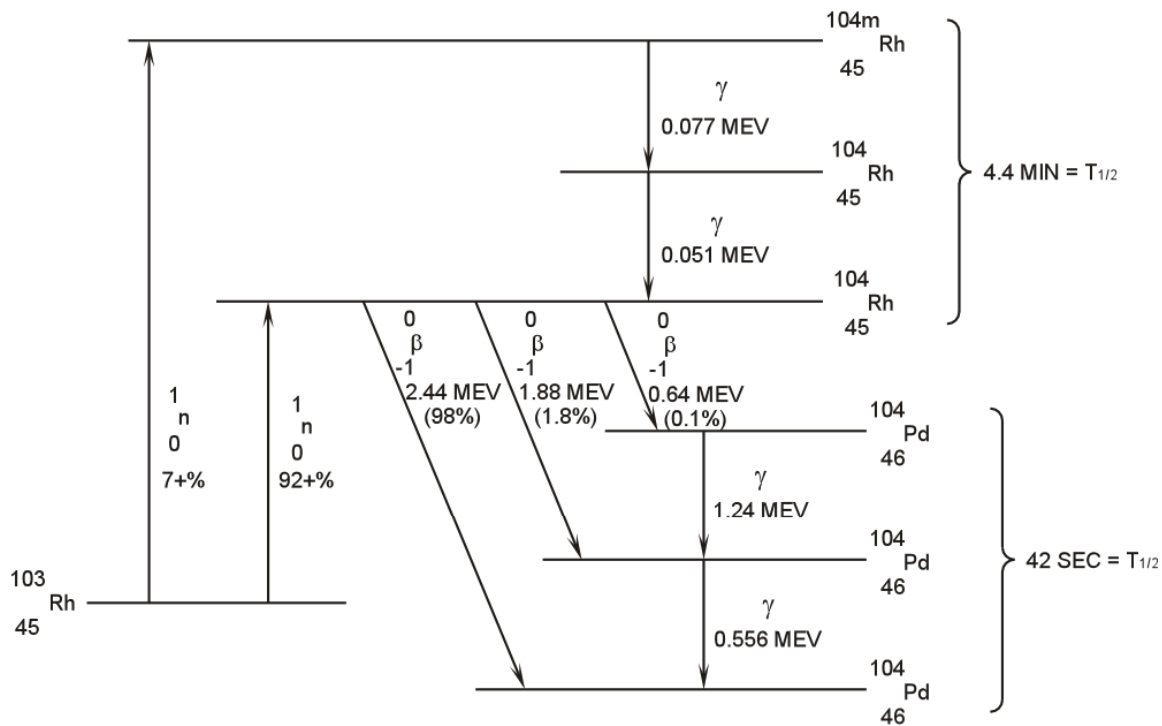


Figure 9.2-2 Rhodium Decay Scheme

The decay scheme for rhodium involves two half-lives, and is illustrated in Figure 9.2-2. The majority (~93%) of the rhodium-neutron reactions decay to palladium by beta emission in 42 seconds, while a small number of the reactions (~7%) requires four and four-tenths (4.4) minutes to complete the transmutation. As previously stated, these two (2) half-lives effect the detector response time, and are of particular interest during changing neutron flux levels.

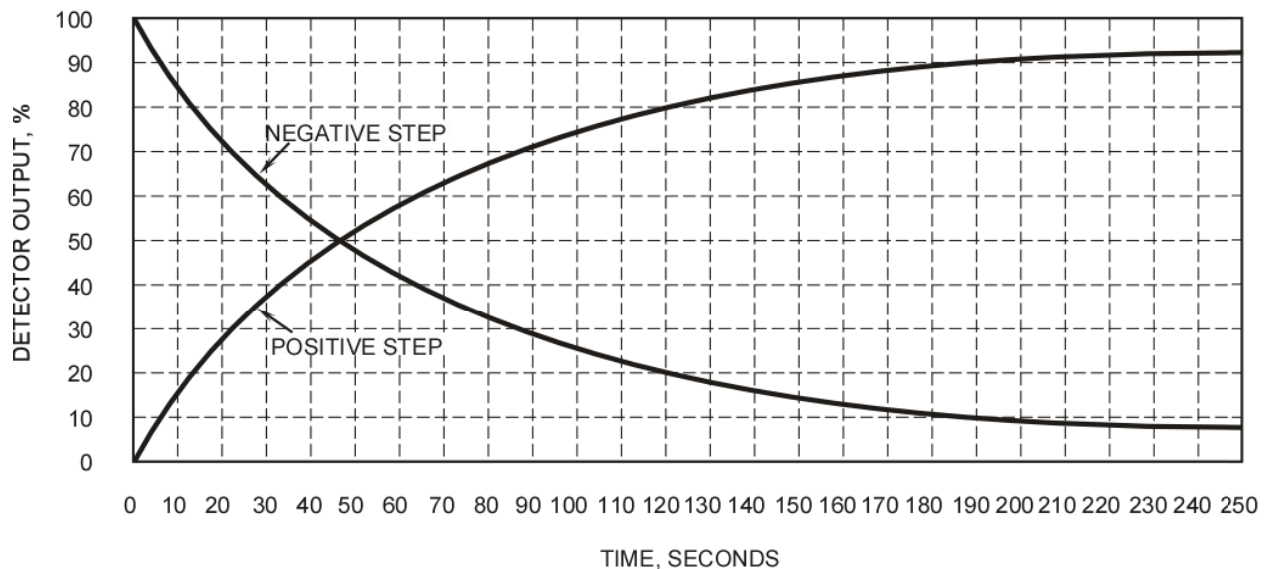


Figure 9.2-3 Rhodium Detector Response

As seen in Figure 9.2-3, approximately five (5) minutes is required for the detector's output to reach the new equilibrium output if a step change in power (flux) level occurs. This long time period precludes the use of the incore detector's output in core protection systems.

The self powered neutron detector signal is influenced by electrons from sources other than the beta decay of  ${}_{45}\text{Rh}^{104}$ . Gammas directly from fission, fission product decay, or neutron capture in the  ${}_{45}\text{Rh}^{103}$  detector, produce electrons by Compton scattering, the photoelectric effect, or pair production. A background detector is installed in the incore detector assembly and is used to correct the self powered neutron detector's output for gamma induced current. The background detector is subject to the same gamma field as the neutron detectors. The plant computer uses information from the background detectors to correct the output of the detector signal for gamma radiation.

### 9.2.3 Signal Processing

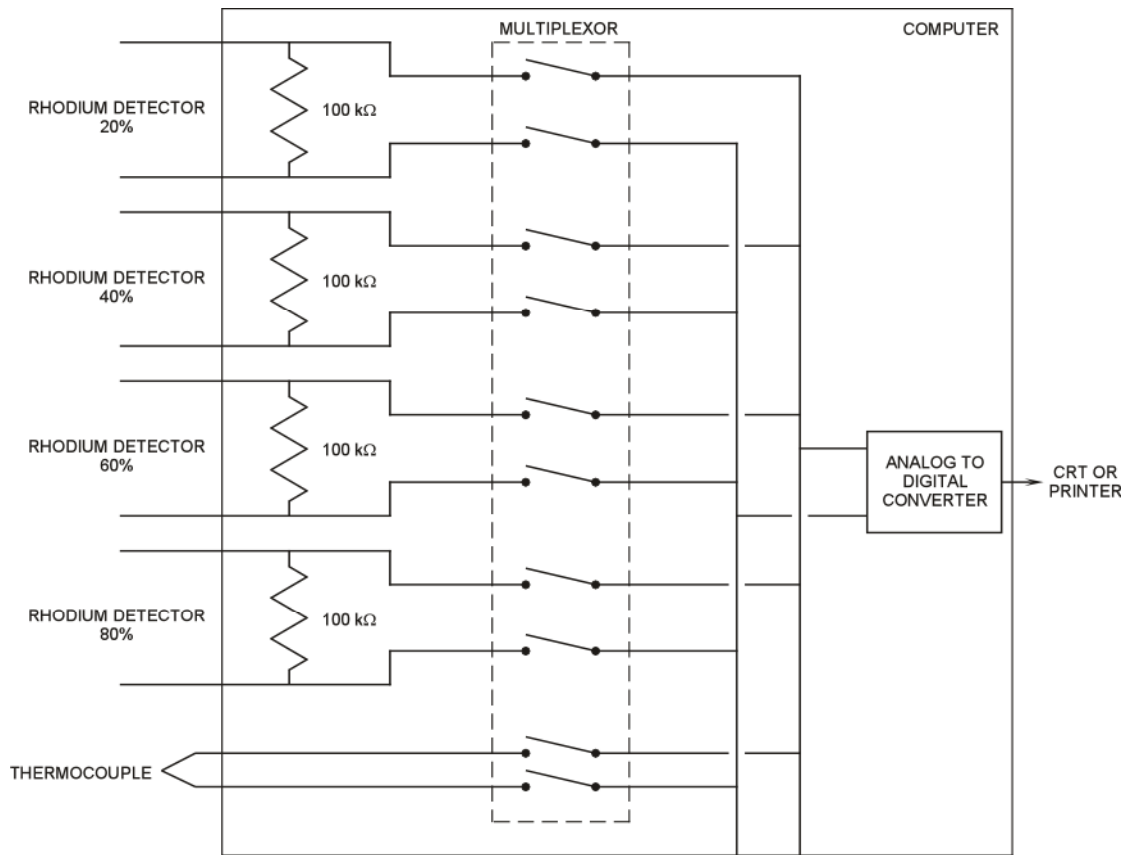


Figure 9.2-4 Incore Detector Interface With Plant Computer

Each incore detector assembly provides signals to the plant computer for analysis. Figure 9.2-4 illustrates the interface between the inputs from the detector assemblies and the plant computer, and is typical of all incore detector inputs.

The output current from the neutron detectors and the background detector is routed through a 100,000 ohm resistor to convert the current signal to a voltage signal. The voltage output is supplied to a multiplexor that connects a specific input signal to an analog to digital converter. The analog to digital converter changes the signal to a digital voltage that is used by the computer. Since the thermocouple output is a millivolt signal, a direct connection can be made to the multiplexor.

### 9.2.4 Computer Processing

The plant computer utilizes the neutron and background detector inputs, constants, and correction factors to calculate neutron flux at 20, 40, 60, and 80% levels of core height. The formula used to calculate neutron flux at a particular core elevation is:

$$\Phi = I \div [(S)(L)(K_s)(K_b)(K_o)]$$

Where:

I = the neutron detector input current.

S = the thermal neutron sensitivity of the  $^{45}\text{Rh}^{103}$  detector and is equal to  $1.15 \times 10^{-21}$  amperes/nv/cm.

L = detector length.

$K_s$  = a correction factor for the decrease in  $^{45}\text{Rh}^{103}$  due to detector burnup.

$K_b$  = a correction factor for the effects of  $\gamma$ ,  $\beta$  reactions.  $K_b$  is calculated by the plant computer using the signals from the background detector.

$K_o$  = a correction factor for the effects of the change in neutron energies over core life.

As the neutron energy changes, the  $^{45}\text{Rh}^{103}$  absorption cross section changes.

The computer uses the calculated neutron flux ( $\phi$ ) in a resident program called INCA (CENPD-145 provides a detailed description of INCA software). INCA performs the calculations necessary to ensure that power distribution Limiting Conditions for Operation (LCO) are met. Since the incore detectors are used to determine these values, plant technical specifications require the operability of the system.

### 9.2.5 Core Exit Thermocouples

A chromel-alumel thermocouple is located at the top of each incore detector assembly and measures the temperature of the water exiting the control element assembly (CEA) guide tube at 45 different locations. The thermocouple has a maximum operating temperature of 2300°F and an approximate output voltage of 55 millivolts.

Each core exit thermocouple (CET) is located in a CEA guide tube about one foot above the active core and is influenced by water that has not passed along the fuel rods. Under full RCS flow conditions, the CETs read about 10 to 15°F less than the  $T_h$  indication. Under reduced flow shutdown cooling system operations, conduction of heat into the CEA guide tube causes the CET to closely track the  $T_h$  reading.

CET temperatures are used by the operating staff during the implementation of emergency operating procedures to determine:

1. Proper core cooling during natural circulation events,
2. Core subcooling margin during a loss of coolant event and
3. Core uncover (indicated by superheated CET readings during inadequate core cooling conditions).

## 9.2.6 Mechanical Construction

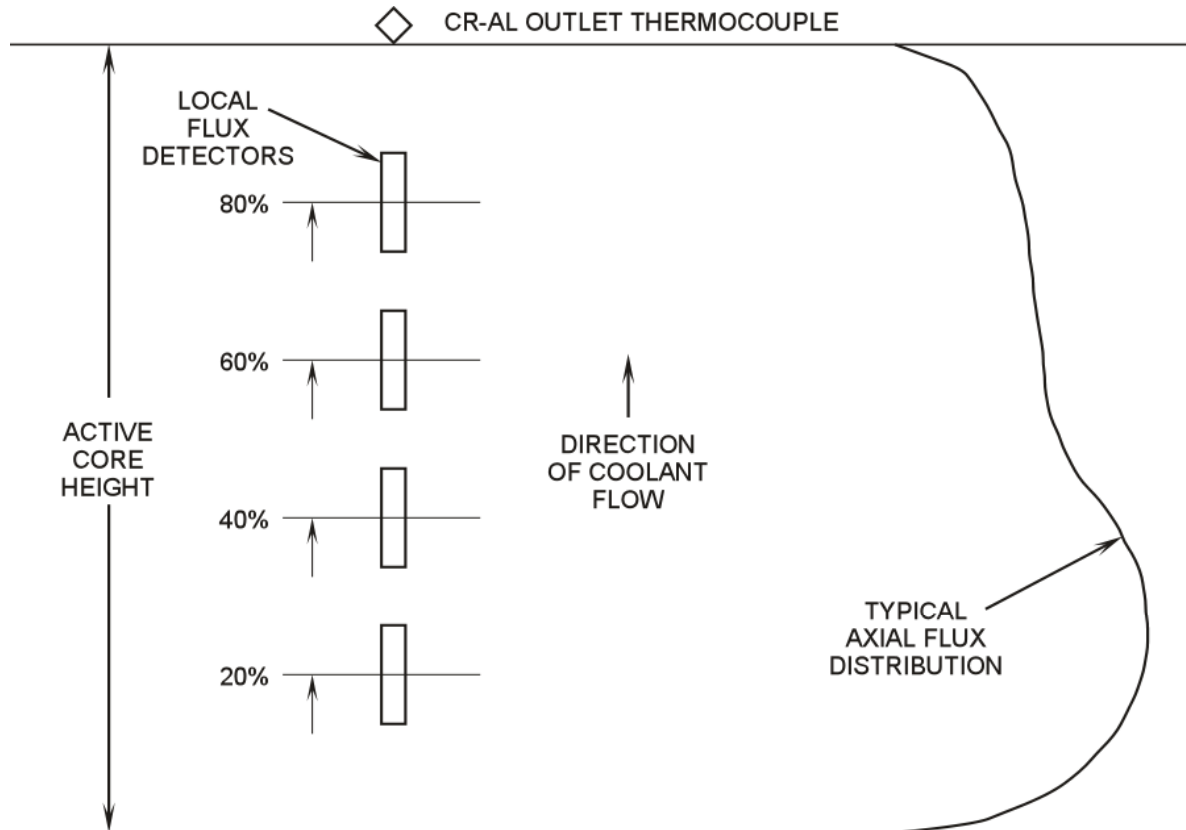


Figure 9.2-5 Incore Detector Axial Arrangement

The incore detector contains four rhodium neutron detectors and one (1) Cr-Al thermocouple. The four rhodium detectors have their centers spaced at 20%, 40%, 60%, and 80% of the active core height as seen in Figure 9.2-5.



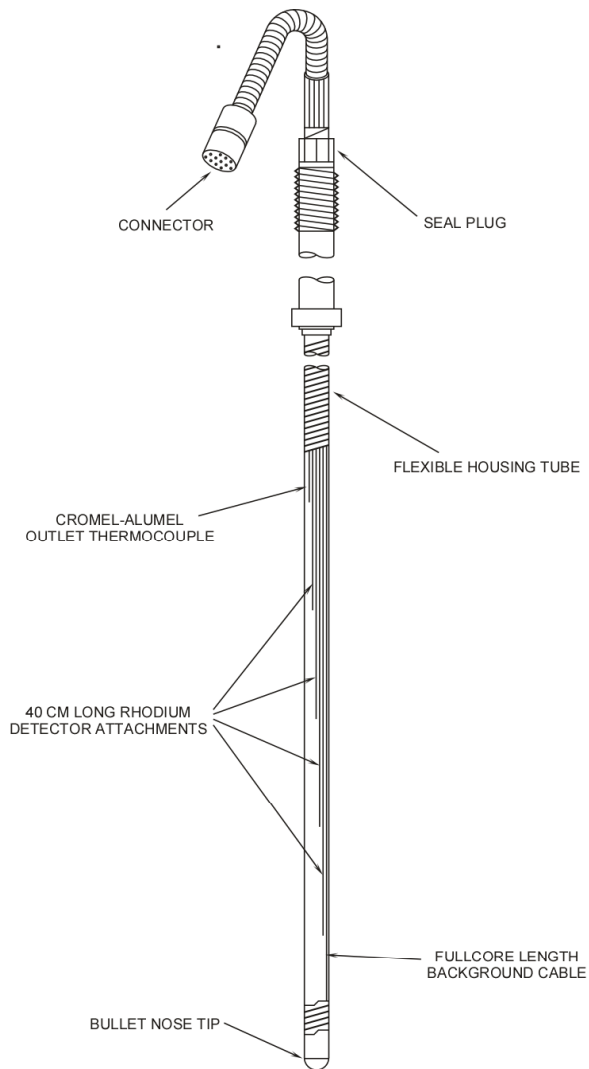


Figure 9.2-6 Incore Detector Assembly

Thermocouples are located at the top of the detector assembly so they can measure the outlet coolant temperature of the instrumented fuel assemblies. The arrangement of the incore detector assemblies is shown in Figure 9.2-6.

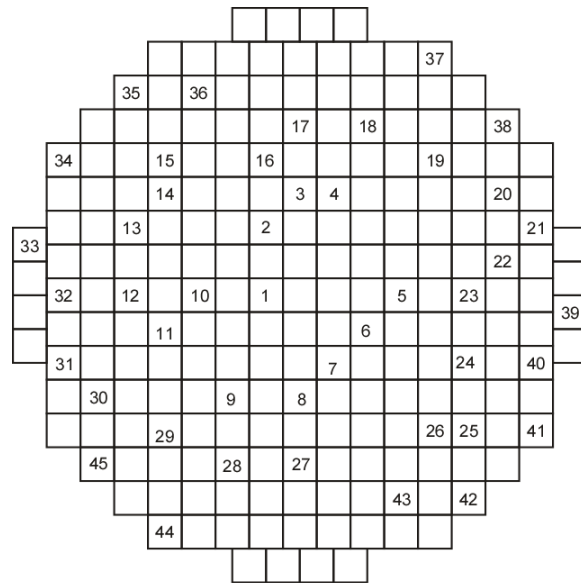


Figure 9.2-7 Incore Detector Location

The detector assemblies are inserted through the instrumentation nozzles. The assemblies go into guide tubes and finally into zircalloy thimbles within the fuel assemblies. The

detectors have to be bent (amount varies with different assemblies) to reach the required thimbles. The detector is located within the core as shown in Figure 9.2-7. During refueling, the detector assemblies are withdrawn into their guide tubes and are lifted out of the vessel together with the upper guide structure by means of a lift rig.

### 9.2.7 Summary

The incore monitoring system provides continuous information pertaining to axial and radial flux distributions. This data is provided by self powered rhodium detectors at various locations throughout the core. In addition, fuel assembly exit temperatures are measured to provide temperature indications during emergencies.



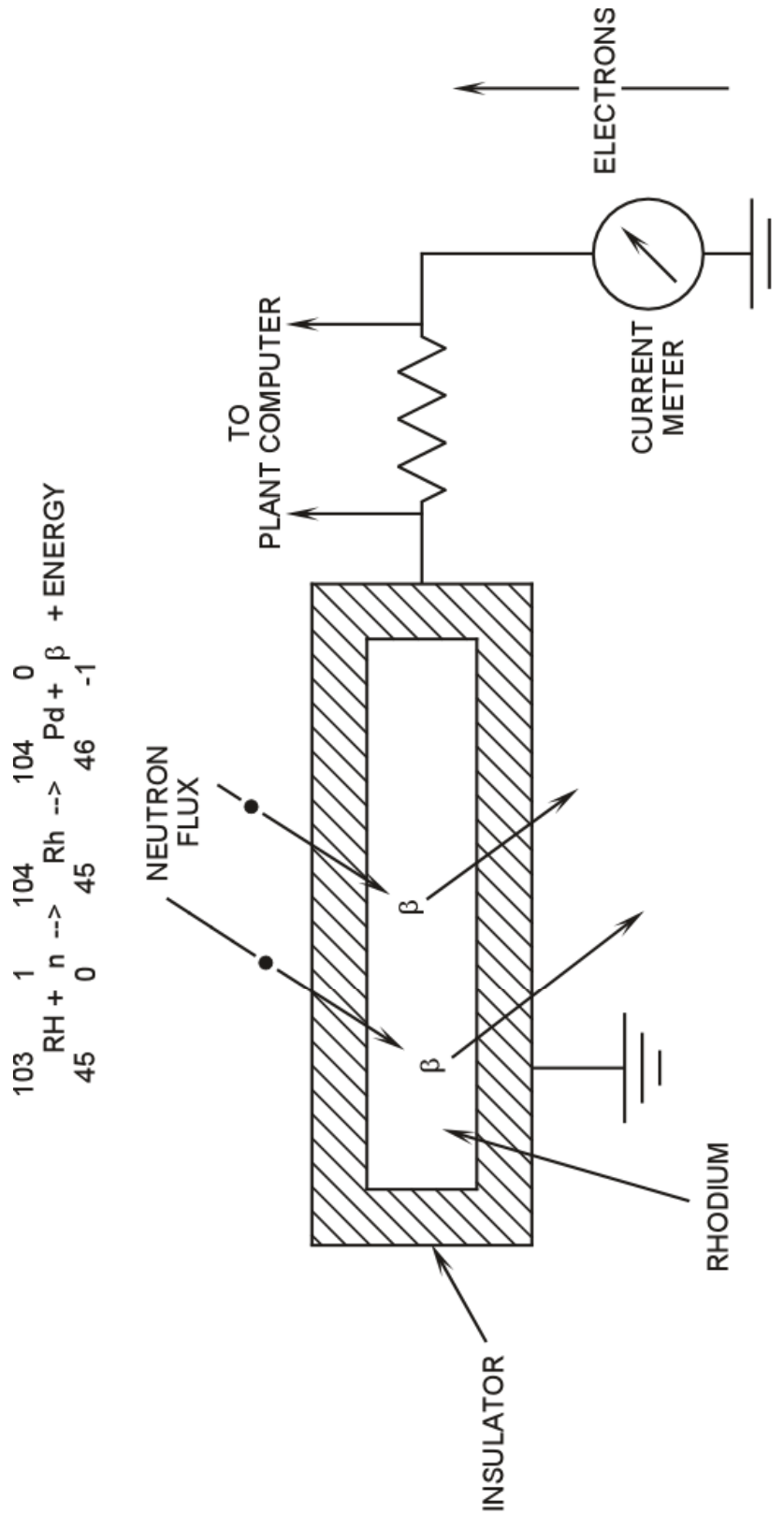


Figure 9.2-1 Self Powered Neutron Detector



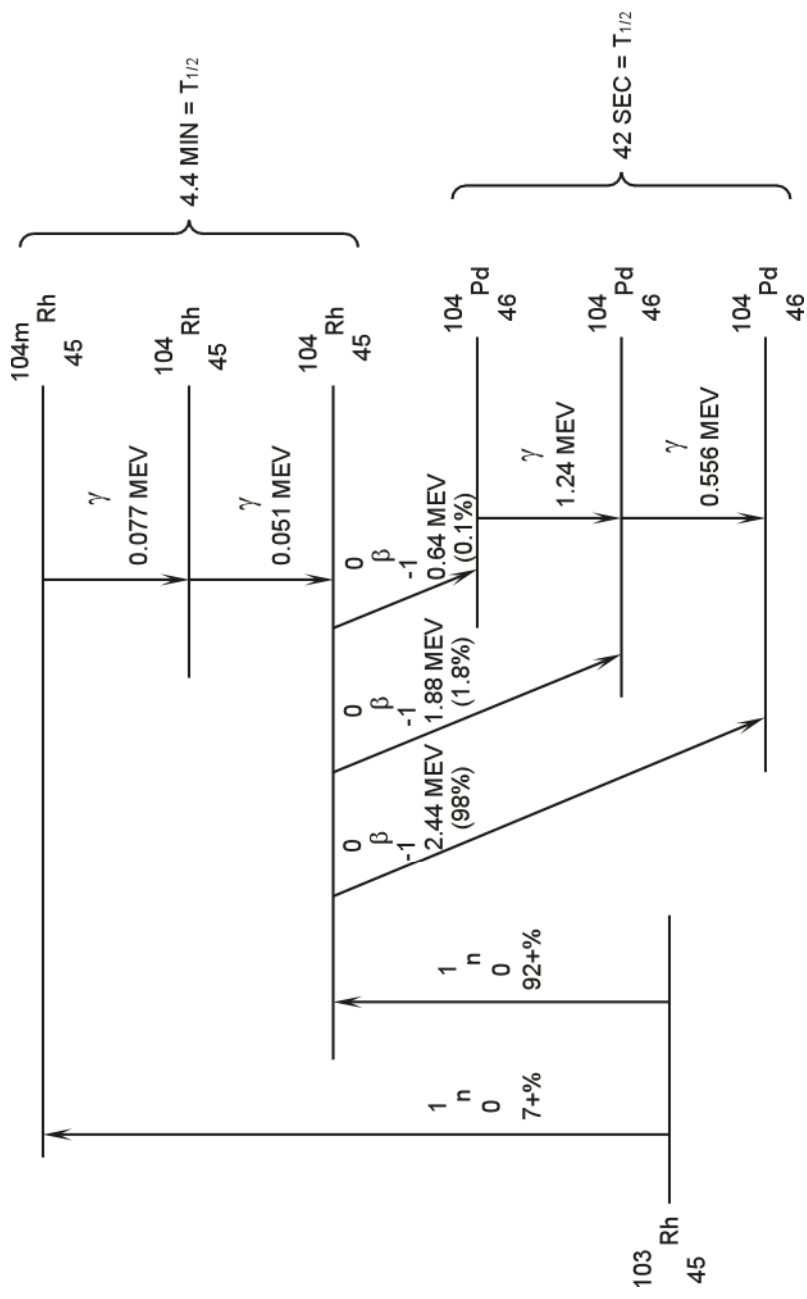


Figure 9.2-2 Rhodium Decay Scheme



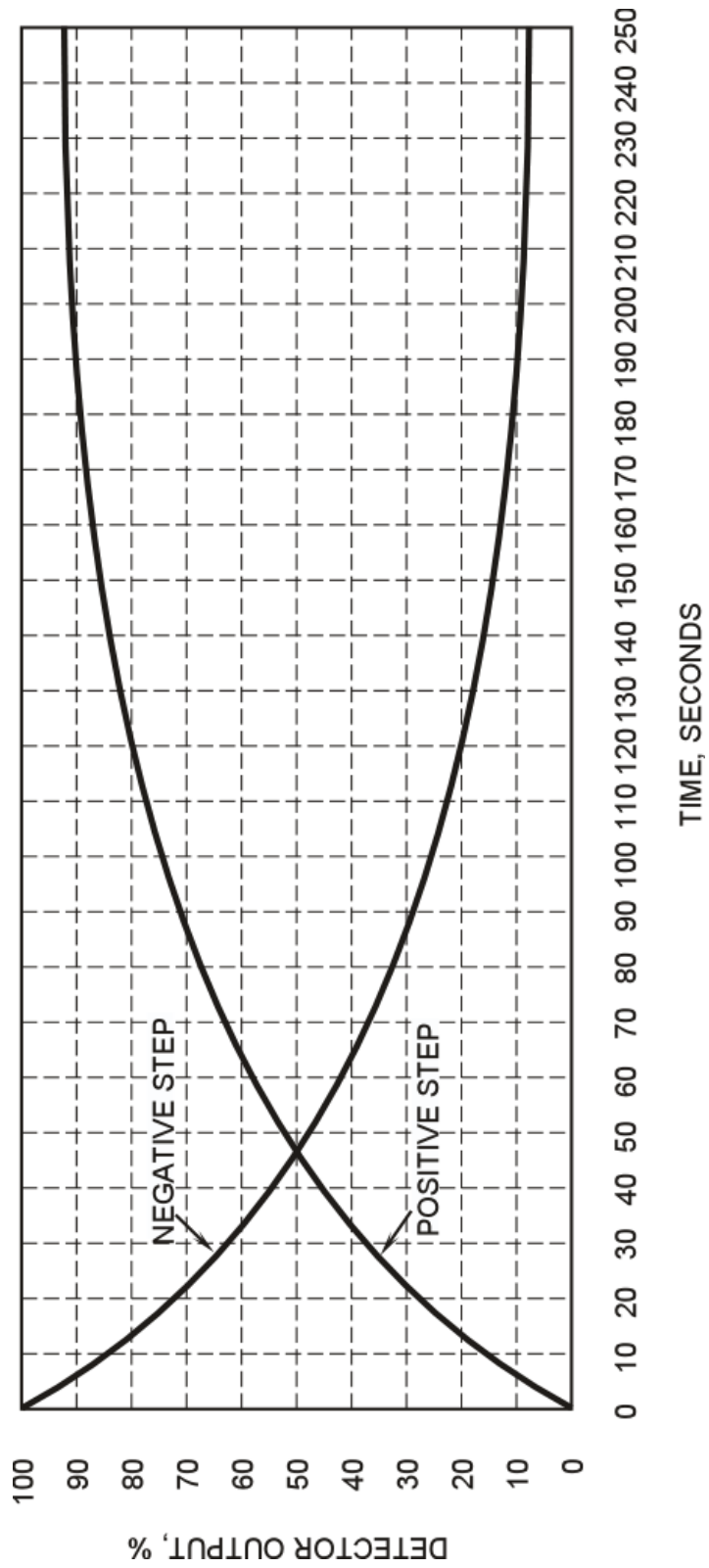


Figure 9.2-3 Rhodium Detector Response





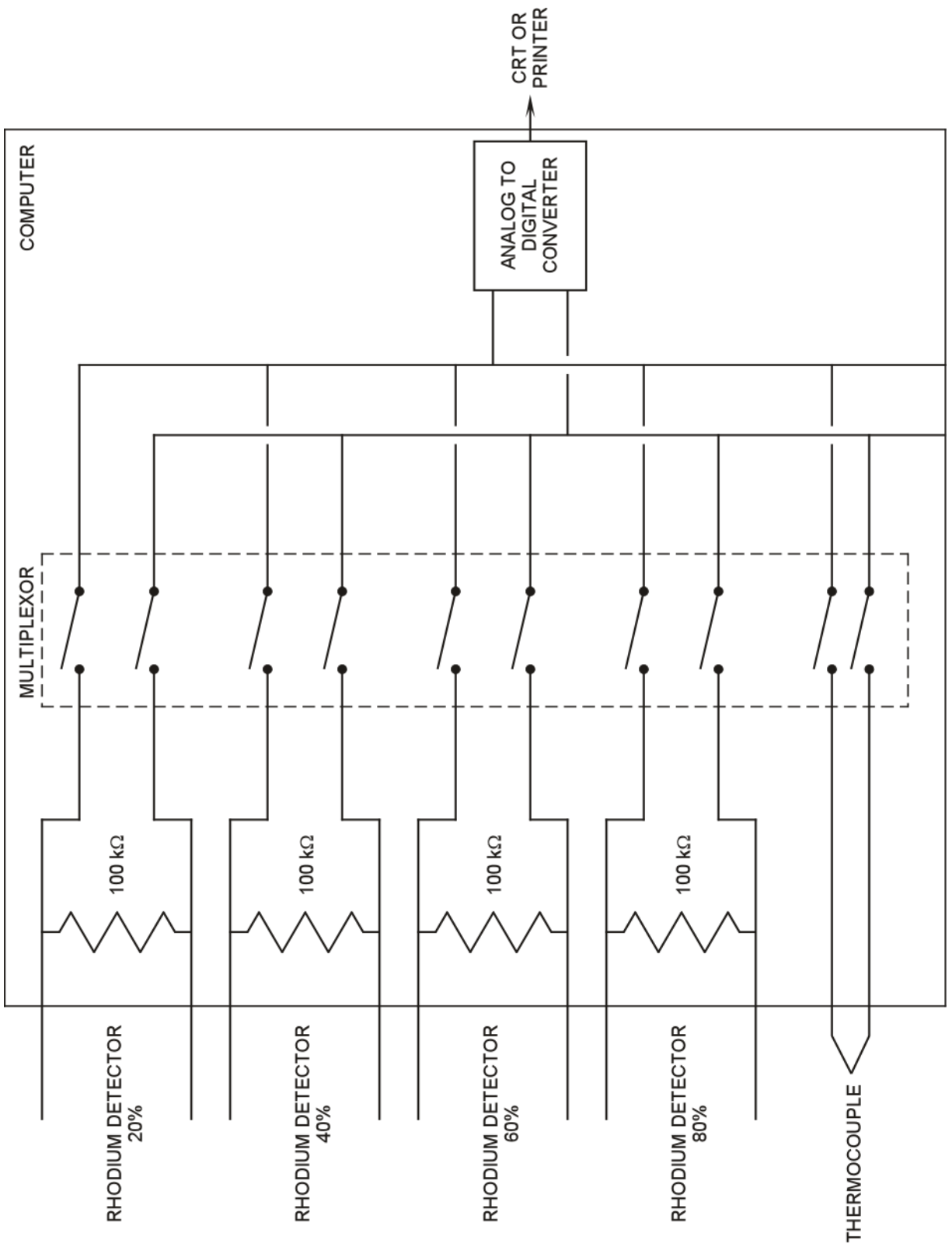
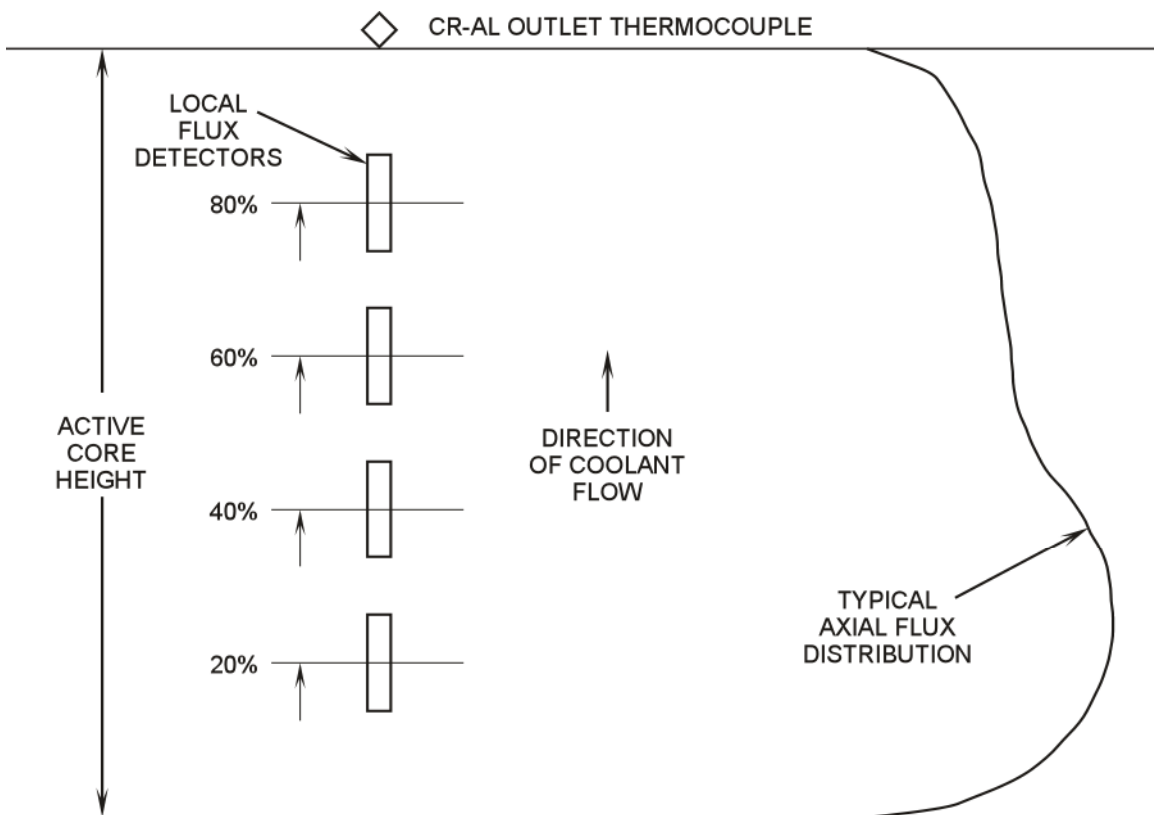


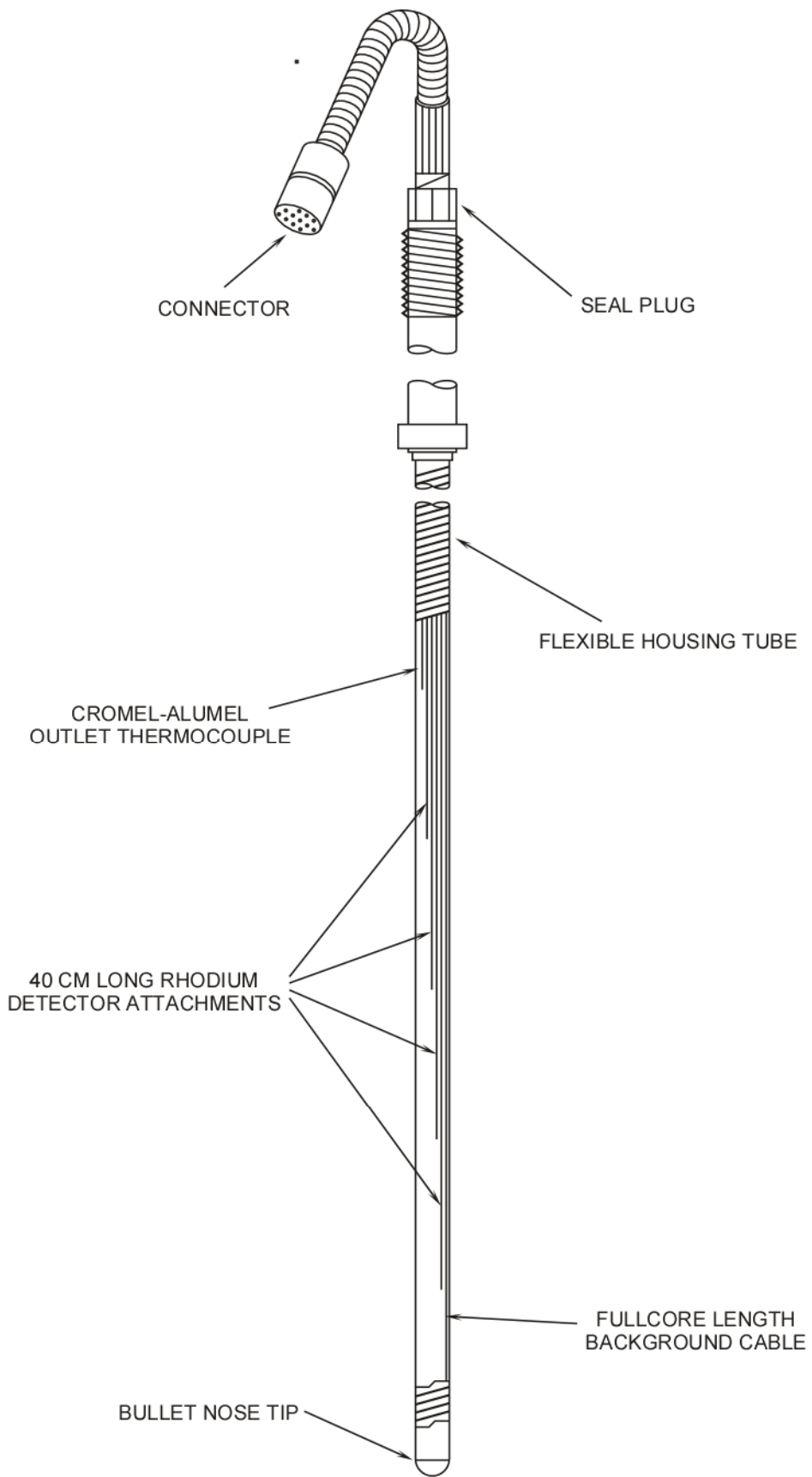
Figure 9.2-4 Incore Detector Interface With Plant Computer





**Figure 9.2-5 Incore Detector Axial Arrangement**





**Figure 9.2-6 Incore Detector Assembly**



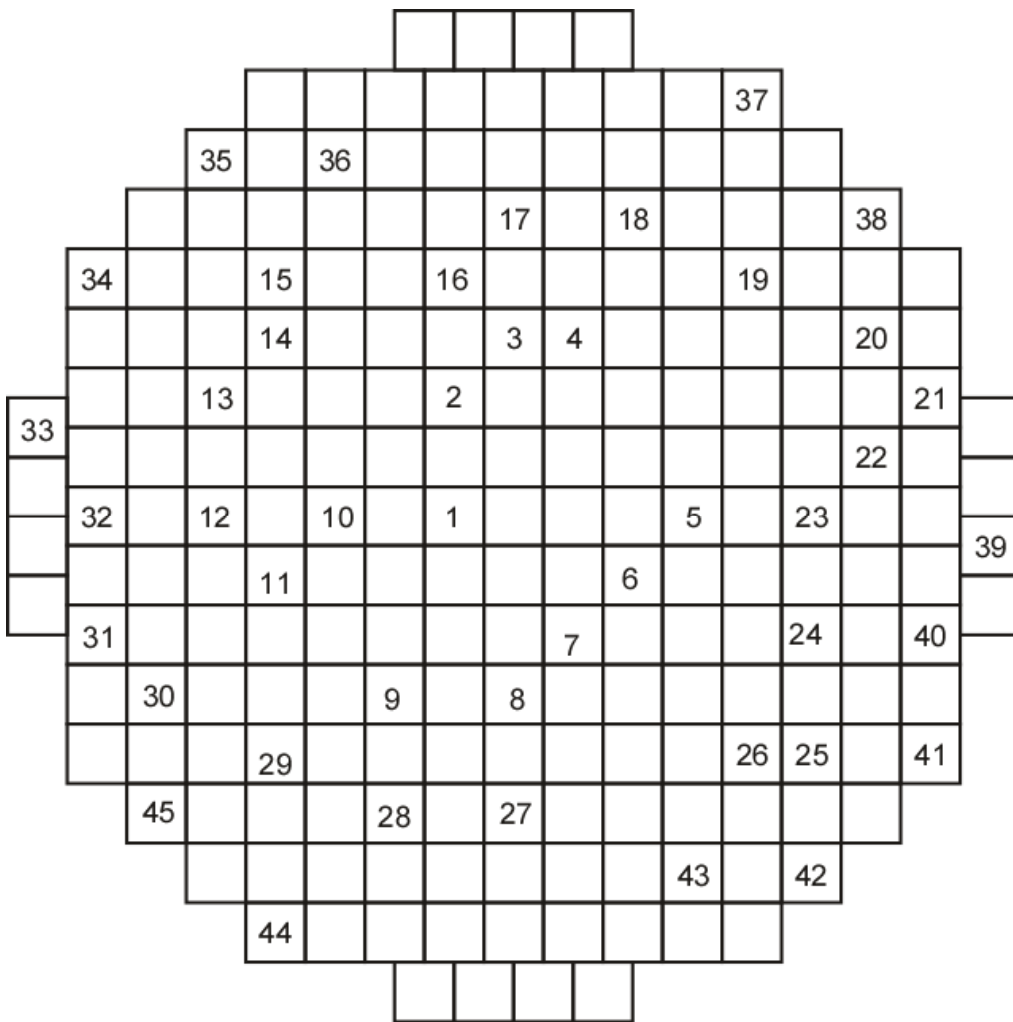


Figure 9.2-7 Incore Detector Location