Pressurized Water Reactor
B&W Technology
Crosstraining Course Manual

Chapter 7.0

Incore Monitoring System

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7.0 INCORE MONITORING SYSTEM

Learning Objectives:

1. List the purposes of the incore monitoring system.

2. Explain the operation of the self-powered neutron detectors.

3. Describe the construction of the detector assembly.

4. List the outputs provided by the detector assembly components.

7.1 Introduction

The incore monitoring system continuously monitors the core neutron level to provide information on axial flux shape and quadrant power tilt. The system consists of 65 strings of self-powered neutron detectors (SPNDs) installed in pre-selected core locations. In addition to sensing neutrons, the incore system also provides fuel assembly exit temperature measurements.

7.2 Neutron Detection

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

$$^{103}_{45}\text{Rh} + ^{1}_{0}\text{n} \Rightarrow ^{104}_{45}\text{Rh} \Rightarrow ^{104}_{46}\text{Pd} + ^{0}_{-1}\beta + \text{Energy}$$

Furthermore, if the rhodium is insulated from electrical ground, then the emission of the beta particles (electrons) will represent a charge deficiency that is proportional to the number of neutron interactions. 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 7-1. 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 Rh-104 isotope. The decay scheme for rhodium involves two half-lives and is illustrated in Figure 7-2. The majority (~93%) of the rhodium-neutron reactions result in an isomer of Rh-104 which decays to palladium by beta emission with a 42-second half-life. A small number of the reactions (~7%) result in an isomer of Rh-104 which requires additional decay by gamma emission, with a 4.4-minute half-life.

As previously stated, these two half-lives affect the detector response time and are of particular interest during changing neutron flux levels. As seen in Figure 7-3, approximately 5 minutes are 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.

7.3 System Description

The arrangement of the incore monitoring system is shown in Figure 7-4. The system consists of 65 incore detector assemblies, with each assembly consisting of 7 neutron detectors, a background detector, and a thermocouple. The incore detector assemblies are inserted into the fuel assembly instrument tubes at pre-selected core locations. These locations are chosen to provide the necessary quadrant symmetry. The seven individual rhodium neutron detectors are arranged in the vertical direction so that the detectors are positioned between fuel assembly spacer grids. This arrangement provides 455 (65 x 7) flux measurements.

The installation of the incore detectors is illustrated in Figure 7-5. The incore detectors are inserted into the pre-selected core locations following initial core loading or subsequent refuelings when the reactor coolant system is depressurized. This is accomplished by physically pushing the detectors through the conduits that lead from the incore instrument tank to the bottom of the reactor vessel. Guide tubes that are located inside the reactor vessel provide the mechanical interface between the incore instrument conduits and the fuel assembly guide tubes.

The mechanical portion of the incore instrument system terminates at closure assemblies located in the incore instrument tank. The required electrical connections are also made at the closure assemblies. The conduit and closure assemblies are a part of the reactor coolant pressure boundary and are designed for 2500 psig.

7.4 Component Description

7.4.1 Detector Assembly

Each incore detector assembly (Figure 7-6) consists of seven neutron detectors, a background detector, a chromel-alumel thermocouple, and a spacer tube enclosed in a solid inconel sheath. Aluminum oxide insulation separates the rhodium emitter from ground.

The use of rhodium neutron detectors permits the manufacture of nearly identical units. However, each detector consists of a controlled mass of material that is swaged during manufacturing until the correct diameter for the detector is obtained. This swaging procedure results in detectors with slightly different lengths and surface areas, which gives each detector a different neutron sensitivity. This is corrected by x-raying

each detector assembly and calculating a sensitivity correction factor for each detector. The sensitivity correction becomes a part of the computer signal processing program.

In addition to sensitivity corrections, the SPND signal is also corrected for background, burnup, and leakage. The background correction is necessary because of the gamma reactions that occur in the rhodium detector and leadwire. These reactions also cause beta emission; therefore, a portion of the detector's current flow is due to gammas rays. To compensate for this additional signal, a background detector is installed in each incore detector assembly. The background detector consists of the same material as the detector with the exception of the rhodium, and is of the same length as the detectors and leadwire. Because the background detector is located in the same assembly, it is subject to the same gamma flux; therefore, its output current represents the same gamma current that is present in the neutron detector signal. The plant computer receives the background signal and corrects the SPND output for gamma interactions. The burnup correction is required because of rhodium depletion. The plant computer stores detector exposure history and uses this information to correct the output of each SPND. The leakage correction is also performed by the plant computer and compensates the detector's output for any signal loss resulting from changes in the resistances of detector circuit components.

7.4.2 High-Pressure Closure Assembly

The high-pressure closure assembly, shown in Figure 7-7, provides the final pressure barrier for the incore monitoring system. The closure assembly consists of a plug, O-rings, and a nut ring assembly. The silver-plated O-rings surround the seal assembly and are deformed to form a seal by tightening the nut ring.

7.4.3 Incore Instrument Tank

To facilitate plant refueling operations, the incore instruments must be withdrawn from the fuel assembly instrument tubes. This evolution is performed, after depressurization, by disassembly of the high-pressure closure assemblies; the incore detector assemblies are then manually retracted until they are about 25 ft inside the incore instrument conduit. Essentially zero exposure occurs during this evolution because the irradiated portion of the detector remains within the conduit. However, if replacement of a detector is required, shielding must be provided. The incore instrument tank can be flooded from the spent fuel system to provide shielding, and the malfunctioning detector is withdrawn from the system. The defective detector is cut into small pieces by a specifically designed cutting tool and is disposed of as solid waste.

7.5 Incore Detector Outputs

The incore neutron monitoring system supplies signals to multipoint recorders and the plant computer (Figure 7-8). Each recorder displays selected incore detector power levels. A calibrating potentiometer is used to compensate each recorder input signal for

detector burnup. At some plants, the symmetry monitors (Figure 7-4) provide signals to a separate backup multipoint recorder, which can be accessed by the operators for power distribution information when the plant computer is not available.

The plant computer uses the incore detector neutron signals to calculate the nuclear heat flux hot channel factor (F_Q), the nuclear enthalpy rise hot channel factor ($F_{\Delta H}^{N}$), the axial power imbalance, and the radial flux distribution (quadrant power tilt).

Compliance with the limits for the hot channel factors (F_Q and $F_{\Delta H}^{N}$) is verified when some other power distribution technical specification is not satisfied.

Axial power imbalance (API) ([% core upper-half power] - [% core lower-half power]) can be measured by either the excore or incore nuclear detectors. If the API exceeds the allowable technical specification (TS) limit, an alarm is generated. The value of the TS limit depends on the number of reactor coolant pumps (RCPs) operating and on the detectors used. If incore detectors are used (the normal method), the TS limit further varies depending on the number of operable detectors. The Full Incore System measurement requires at least 75% of the detectors in each quadrant to be operable. The Minimum Incore System measurement, as illustrated in Figure 7-9, requires the following:

1. There must be three detector strings with three operable neutron detectors per string.

2. One of the operable detectors of each string must be located at the core mid-plane, one detector of each string must be located in the same axial plane in the upper half of the core, and one detector of each string must be located in the same axial plane in the lower half of the core.

3. The axial planes in each core half must be symmetrical about the core mid-plane.

4. The detector strings shall not have radial symmetry.

A specific set of nine detectors (described above) is needed to perform API determinations in accordance with the Minimum Incore System measurement requirements. The API limits for both excore and incore detectors are covered in greater detail in Chapter 22, Plant Operating Limits.

Quadrant power tilt (QPT) is defined by the following equation:

$$QPT = 100\% \left[\frac{power\ in\ any\ quadrant}{average\ quadrant\ power} - 1 \right]$$

Similar to the API limits, if the QPT exceeds the allowable TS limit, an alarm is generated. The value of the TS limit depends on the detectors used to determine the QPT. If incore detectors are used (the normal method), the TS limit further varies depending on the number of operable detectors.

The Minimum Incore System measurement, as illustrated in Figure 7-10, requires the following:

1. Two sets of four detectors shall lie in each core half (eight detectors/core half).

2. Each set of detectors shall lie in the same axial plane. The two sets in each core half may lie in the same axial plane.

3. Detectors in the same plane shall have quarter core radial symmetry.

The Full Incore System measurement requires at least 75% of the detectors in each quadrant to be operable; the operable detectors <u>must include</u> the specific set of 16 detectors needed to perform QPT calculations in accordance with the Minimum Incore System measurement requirements described above.

The QPT limits for both excore and incore detectors are covered in greater detail in Chapter 22, Plant Operating Limits.

7.6 Temperature Measurement

A chromel-alumel thermocouple, located at the top of each incore detector assembly, provides fuel exit temperature data. These data are used in the plant computer to generate a gross power distribution core map that provides an indication of core conditions to the operator. In recent years, use of thermocouple information has been incorporated into the plant emergency procedures. Thermocouple indications are used to determine proper natural circulation response and the degree of inadequate core cooling, if any.

7.7 Summary

The incore monitoring system provides continuous information pertaining to axial and radial flux distributions. These data are used to generate alarms if the allowable values of these parameters are exceeded. In addition, fuel assembly exit temperatures are measured to provide an indication of core power distribution.

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$${}^{103}_{45}Rh + {}^{1}_{0}n \rightarrow {}^{104}_{45}Rh \rightarrow {}^{104}_{46}Pd + {}^{0}_{-1}\beta + ENERGY$$

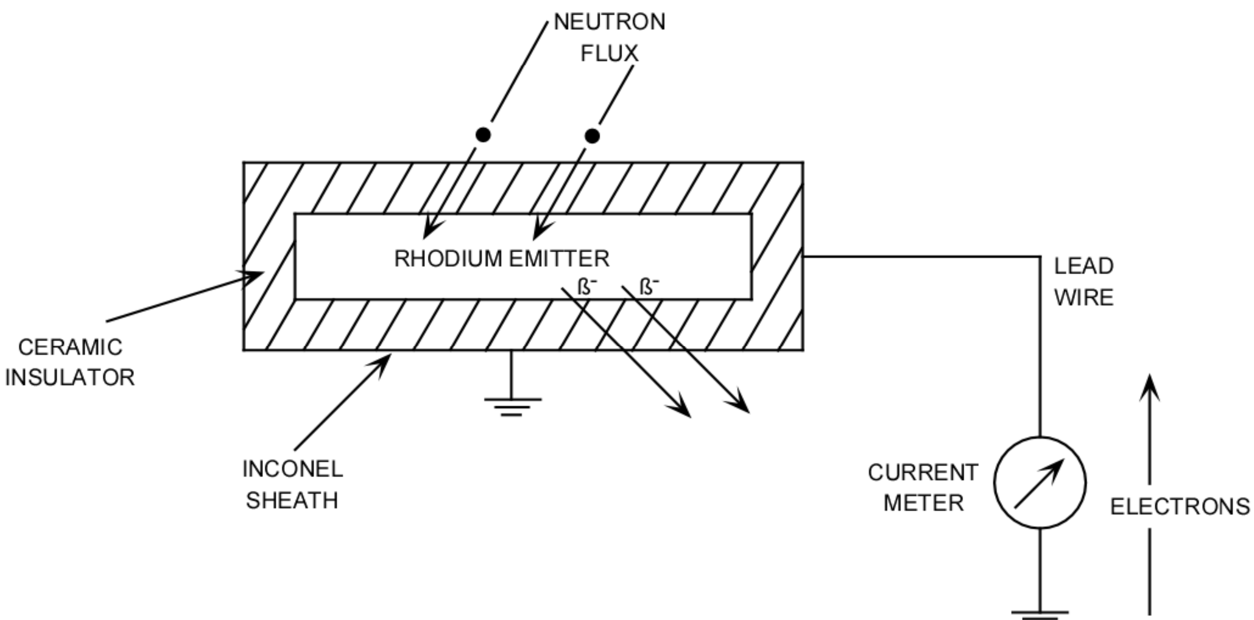

Figure 7-1 Self-Powered Neutron Detector

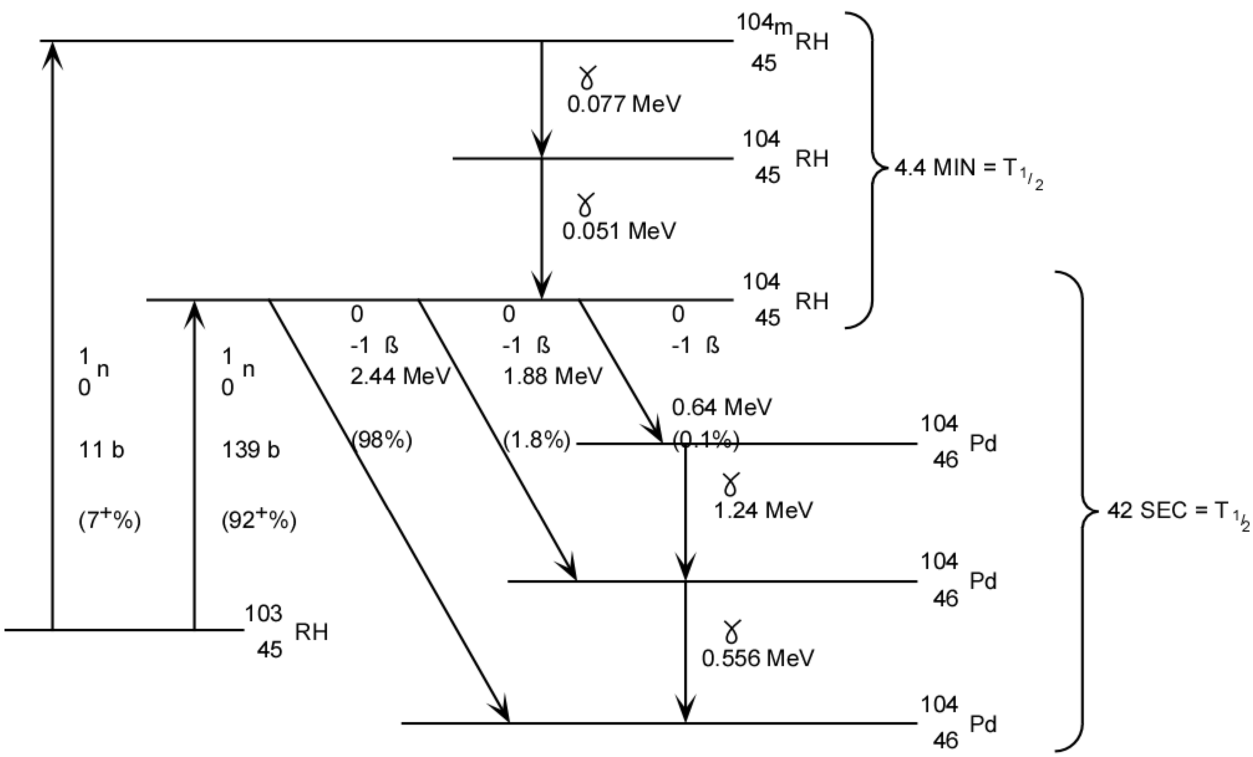

Figure 7-2 Rhodium Decay Scheme

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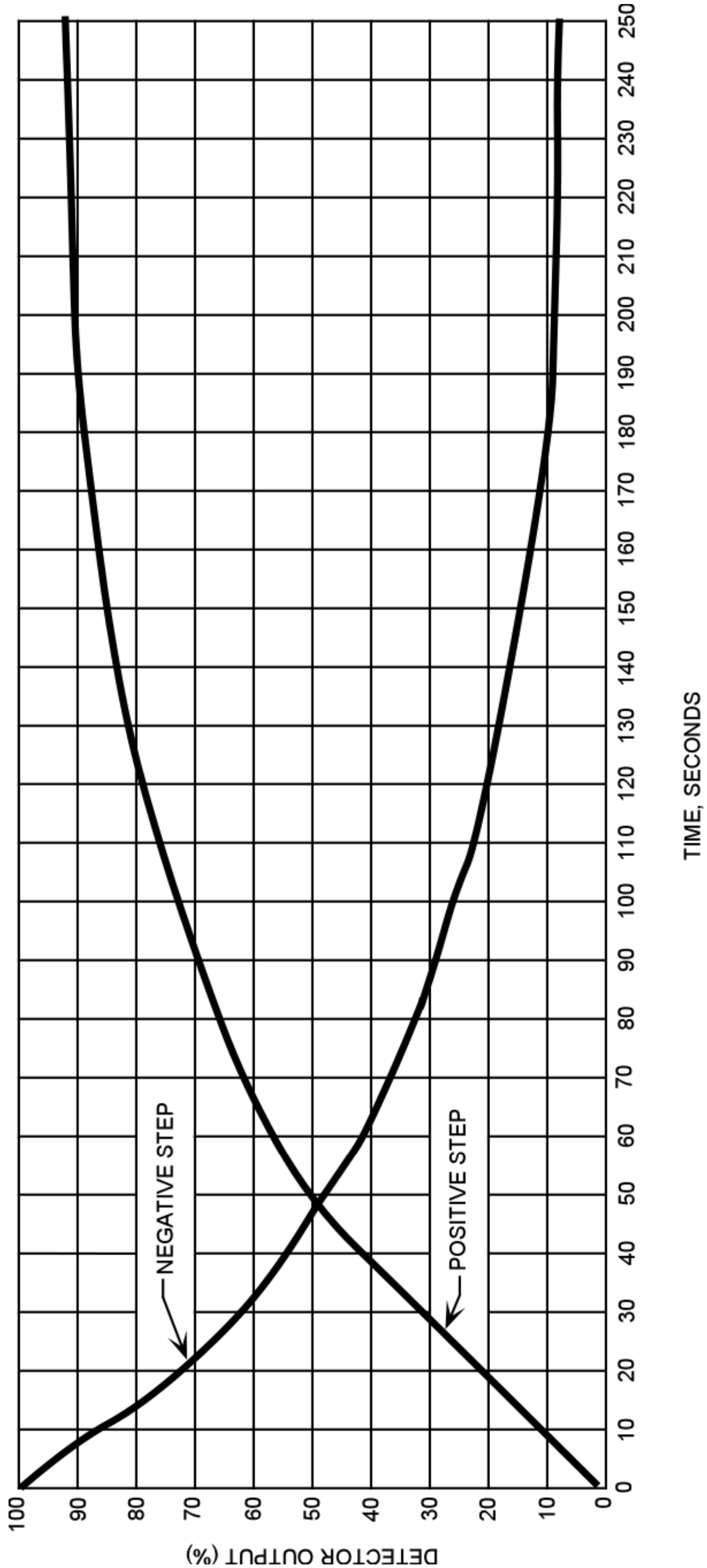

Figure 7-3 Response of Rhodium Detectors

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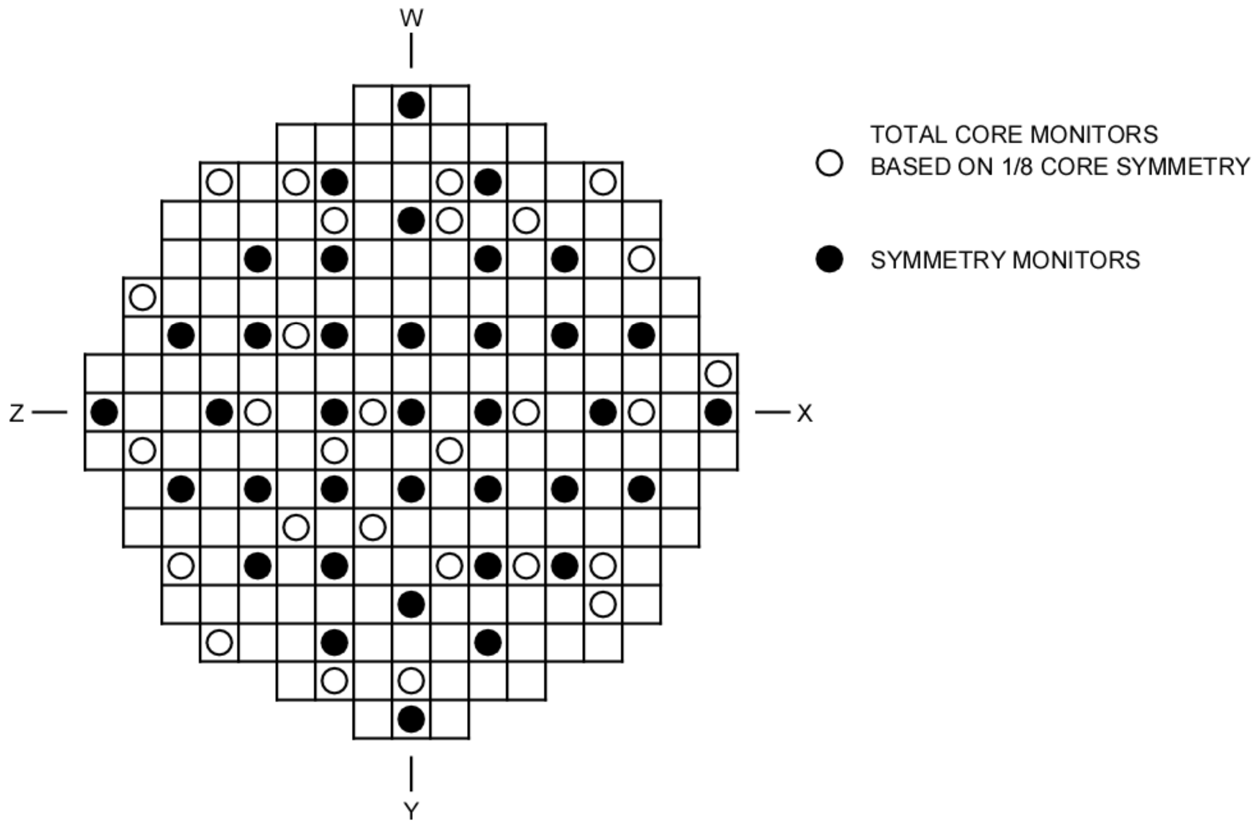

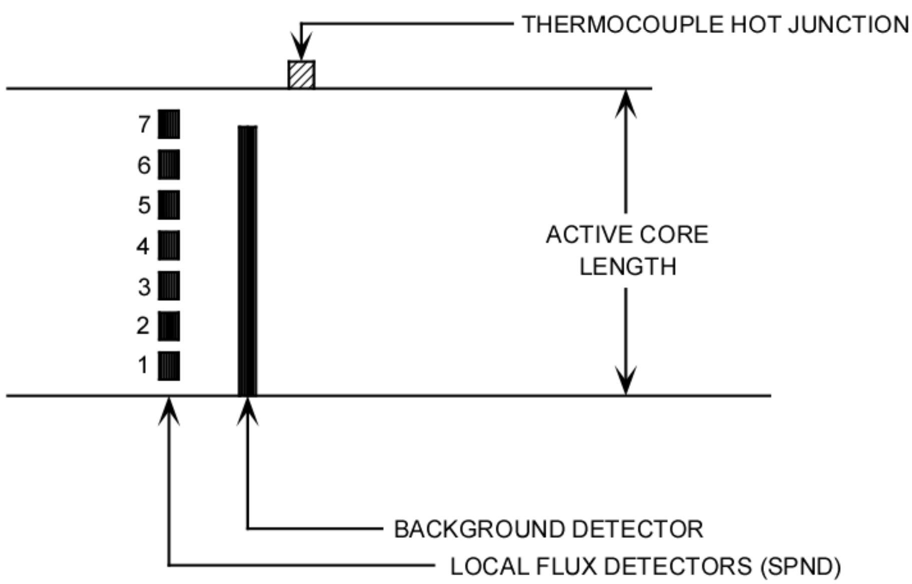

Figure 7-4 Incore Detector Arrangement

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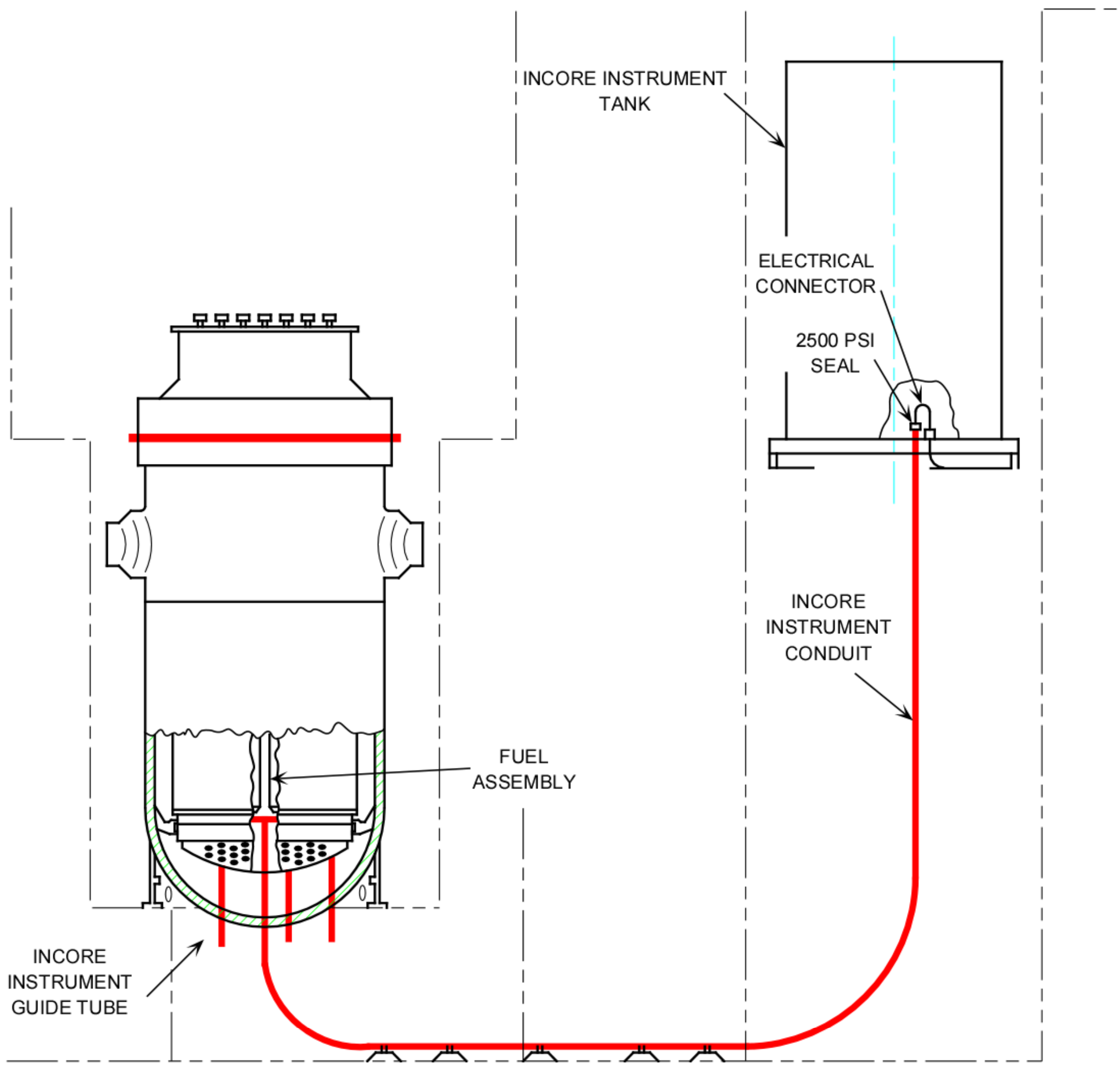

Figure 7-5 Incore Detector Assembly Installation

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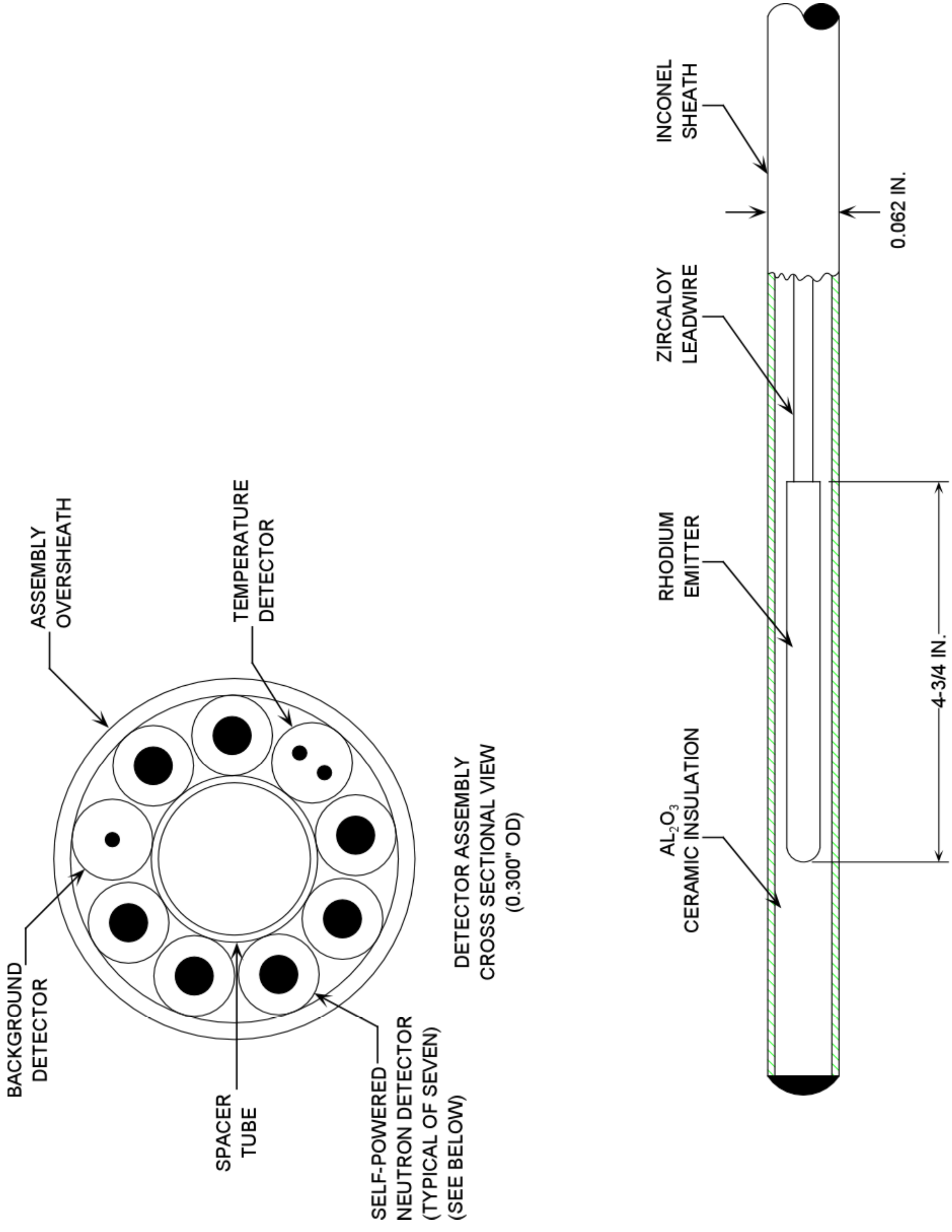

Figure 7-6 Incore Instrument Assembly

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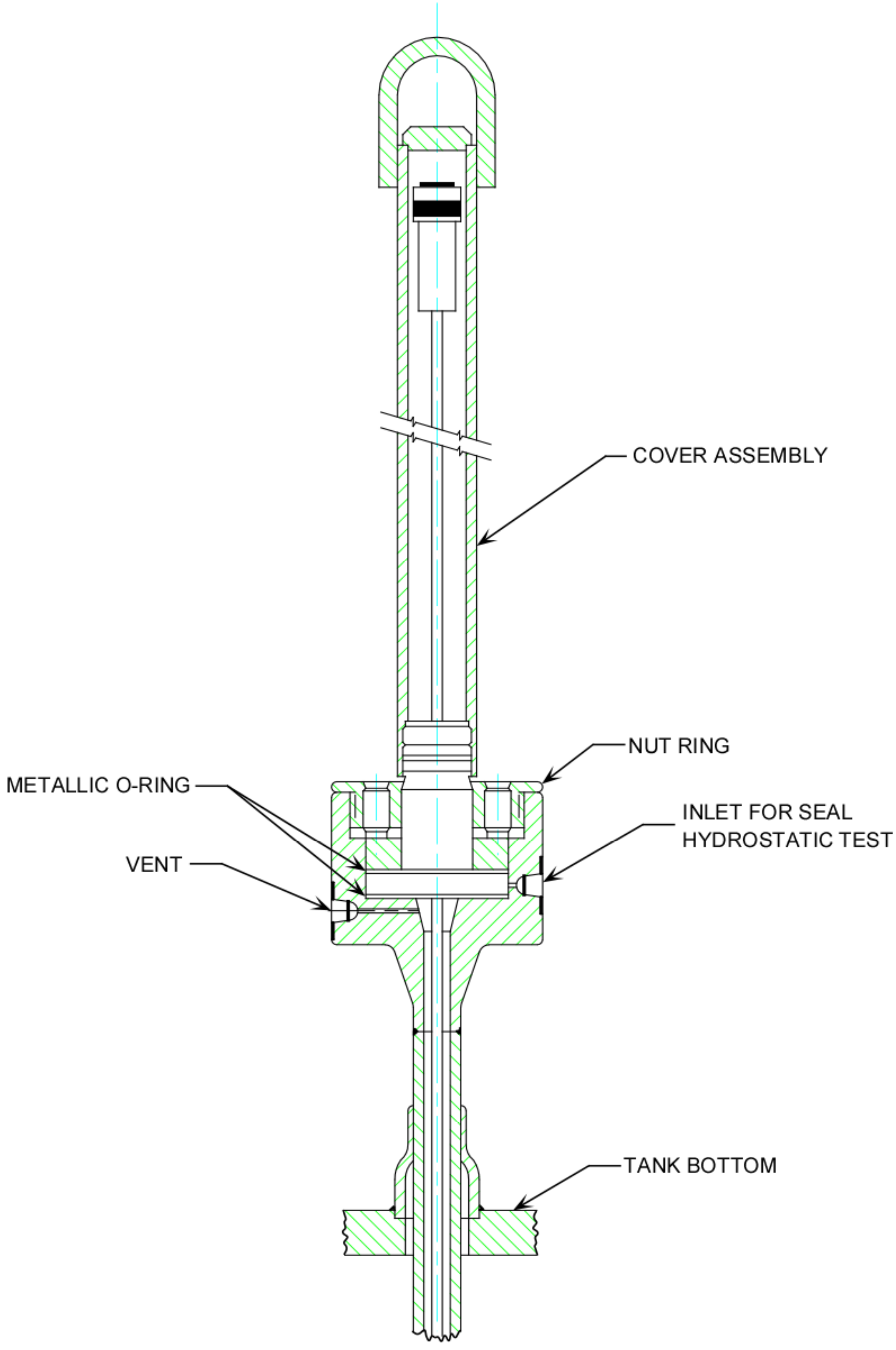

Figure 7-7 High Pressure Closure Assembly

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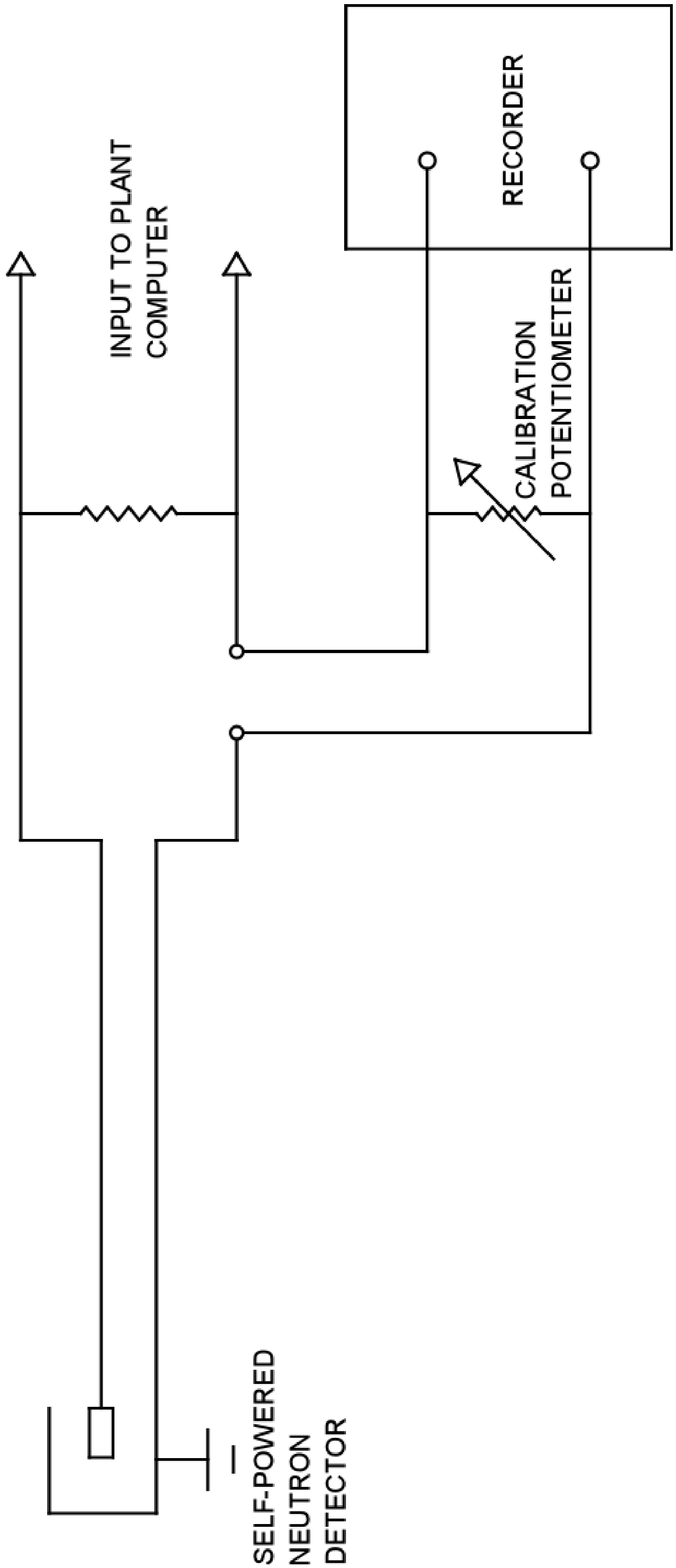

Figure 7-8 Self-Powered Neutron Detector Outputs

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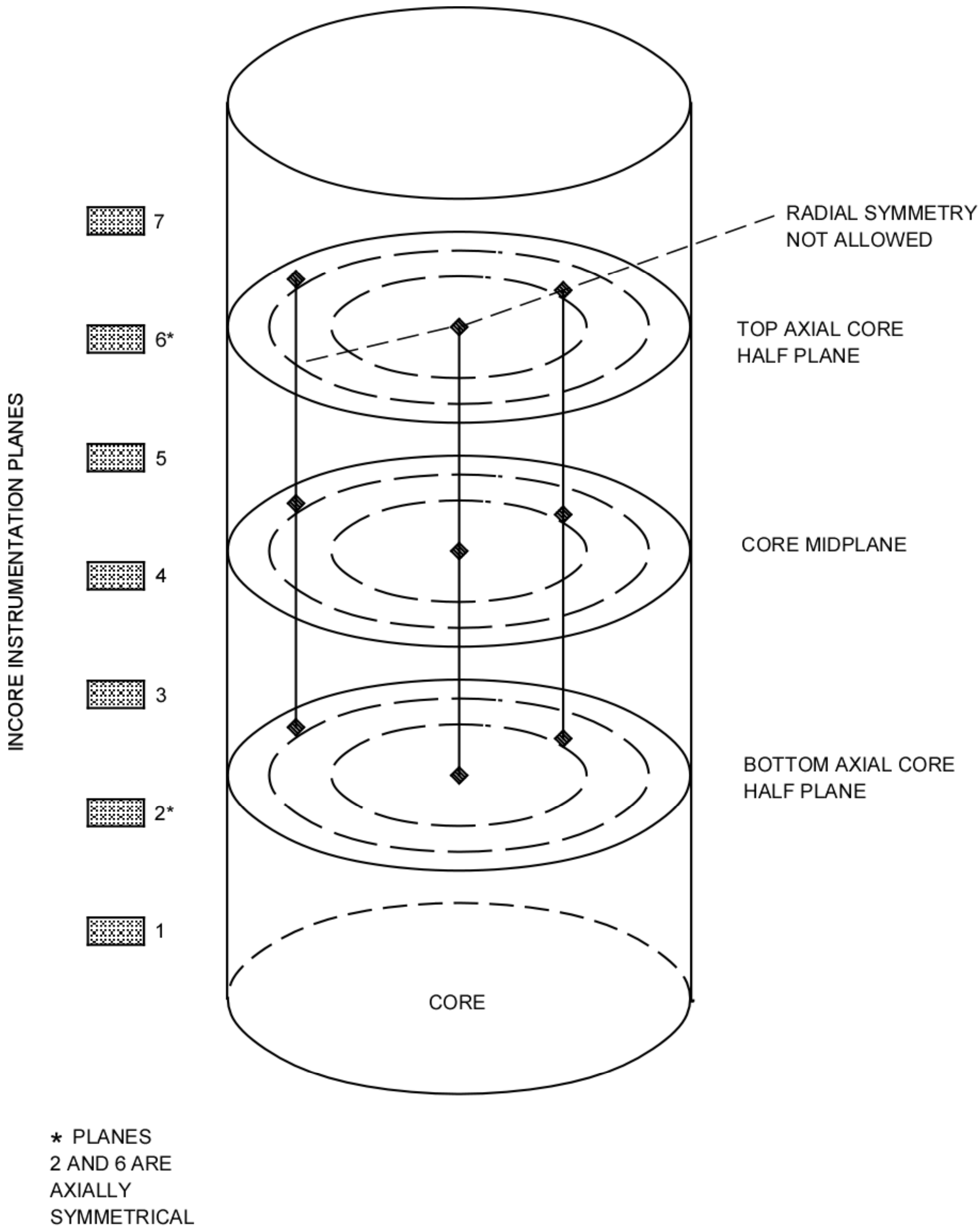

Figure 7-9 Minimum Incore System for Axial Power Imbalance Measurement

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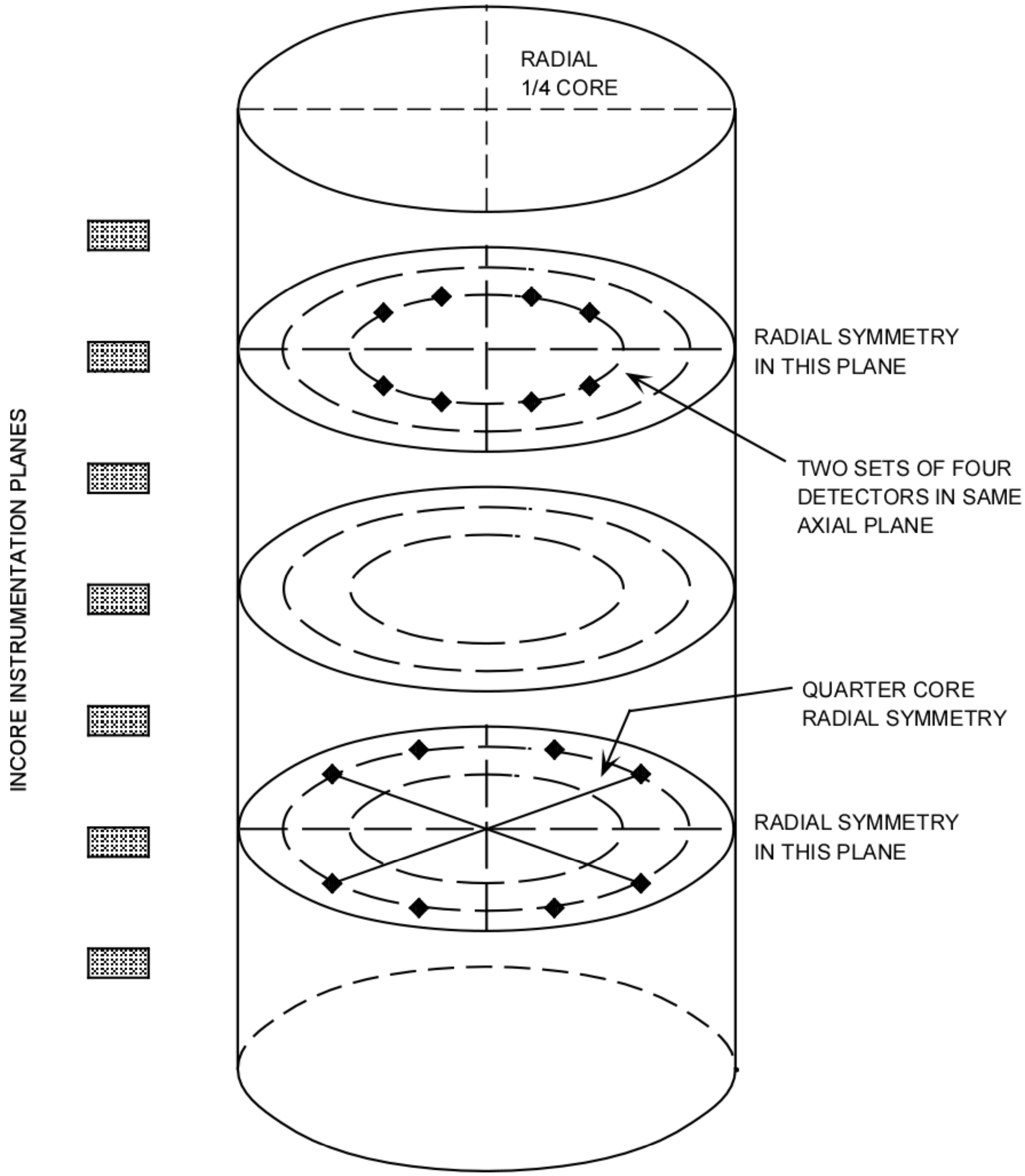

Figure 7-10 Minimum Incore System for Quadrant Power Tilt Measurement

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