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U.S. EPR Nuclear Incore Instrumentation Systems Report

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AREVA NP Inc.

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For information address: AREVA NP Inc.
An AREVA and Siemens Company
3315 Old Forest Road
Lynchburg, VA 24506

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ABSTRACT

This report is developed by AREVA NP in connection with its U.S. EPR Design Certification Application to the Nuclear Regulatory Commission in accordance with the 10 CFR Part 52 licensing processes. This report documents two of the incore instrumentation systems, the Aeroball Measurement System and the Self Powered Neutron Detectors, used in AREVA NP's U.S. EPR.

Core monitoring is provided by a system employing fixed incore detectors, called the Power Density Detector System, which uses Self Powered Neutron Detectors. The Aeroball Measurement System is a neutron flux mapping system based on movable alloy balls, or Aeroballs. The Aeroballs are inserted into specific core locations for a brief period for activation, removed from the core, and their activation rates subsequently measured. After further processing of the data from the Aeroball Measurement System, the system computers generate a snapshot of key core parameters. The entire flux mapping process can be completed within a short period of time, and can be performed either on demand or at regularly scheduled intervals, as required by the technical specifications. The system also provides calibration factors, which are transferred to the Power Density Detector System.

Nature of Changes

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Nomenclature

Acronym	**Definition**
3D	Three-Dimensional
AMS	Aeroball Measurement System
Co	Cobalt
Cr	Chromium
DNBR	Departure from Nucleate Boiling Ratio
EFPD	Effective Full Power Days
IEEE	Institute of Electronics and Electrical Engineers
mm	Millimeter
NRC	Nuclear Regulatory Commission
$n/cm^2/sec$	Neutrons per square centimeter per second
PDDS	Power Density Detector System
PICS	Process Information and Control System
PS	Protection System
RCCA	Rod Cluster Control Assembly
RCSL	Reactor Control, Surveillance and Limitation System
RPV	Reactor Pressure Vessel
SPND	Self Powered Neutron Detector
V	Vanadium
VDC	Direct Current Voltage

1.0 INTRODUCTION

The nuclear core instrumentation concept applied to the U.S. EPR combines two complementary systems:

- A continuous core power monitoring system employing fixed incore detectors, called the Power Density Detector System (PDDS), which uses Self Powered Neutron Detectors (SPND)
- An on-demand neutron flux mapping system, called the Aeroball Measurement System (AMS)

The two systems (mounted from the top of the reactor vessel) are functionally linked by calibration. Since 1974, twelve Siemens nuclear plants have used these systems for core monitoring. For the U.S. EPR, the SPNDs are also used for core protection. Arrangement of incore instrumentation components within the core is shown in Figure 1-1.

Space- and time- dependent power density distribution of the U.S. EPR is accurately assessed using the SPNDs inside the core. For neutron flux measurement, incore neutron detectors are more accurate than excore neutron detectors.. The PDDS is designed to:

- Directly measure changes in power density
- Provide increased accuracy of localized power measurements under normal and transient operating conditions
- Provide increased core surveillance, limitation and protection information
- Provide superior measurement of core conditions for peak power density, departure from nucleate boiling ratio (DNBR), and axial offset

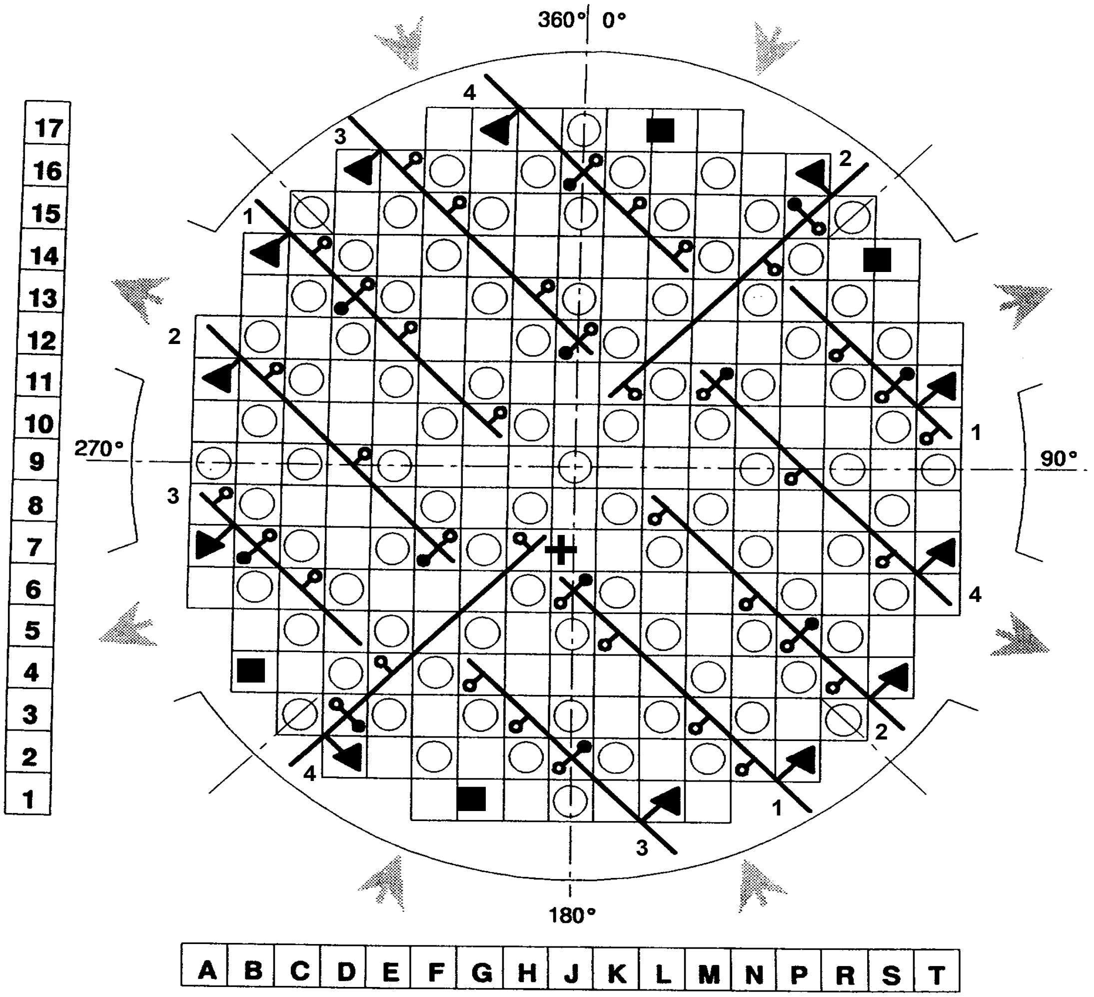
The AMS is a neutron flux mapping system based on movable activation probes (or balls) that operate on demand, and serves as a reference instrumentation system to determine relative neutron flux density in the core. The AMS has lances that extend downward into the core, uses a transport system located outside of the reactor vessel, and employs measuring equipment located in a remote area. The entire measuring and evaluation sequence is computer-controlled and is fully automated. The time between two successive measurements is about 15 minutes. The default measuring time (activation time) of the three-dimensional (3D) neutron flux distribution of the core is 3 minutes. The system accuracy and reproducibility of measured activations is generally better than current incore systems. The specific analysis of the system accuracy will be provided in a separate safety analysis setpoint methodology report. The resulting measured 3D power distribution is generated by the POWERTRAX/E core monitoring software. POWERTRAX/E uses the measured power distributions to generate the calibration factors for the SPNDs, which results in an increased accuracy of the SPND measurements. The U.S. EPR AMS provides an assessment of power density distribution for:

- SPND calibration
- Verification of core design predictions
- Verification of core behavior over cycle burn-up
- Determination of 3D flux and power density distribution
- Calibration of the 3D on-line core monitoring software system using POWERTRAX/E

A general overview of the AMS is shown in Figure 1-2.

POWERTRAX/E software provides a comprehensive system of on-line core monitoring for reactor physics core calculations, processing of measured data, and continuous calculations of the 3D power distribution within the core. The results are displayed on a dedicated POWERTRAX/E computer in the control room complex.

Figure 1-1 Arrangement of Incore Instrumentation Components



1 , 2 , 3 , 4 Electrical divisions which supply the lance yokes

□ 241 FUEL ASSEMBLIES

○ 89 CONTROL ASSEMBLIES

40 AEROBALL PROBES

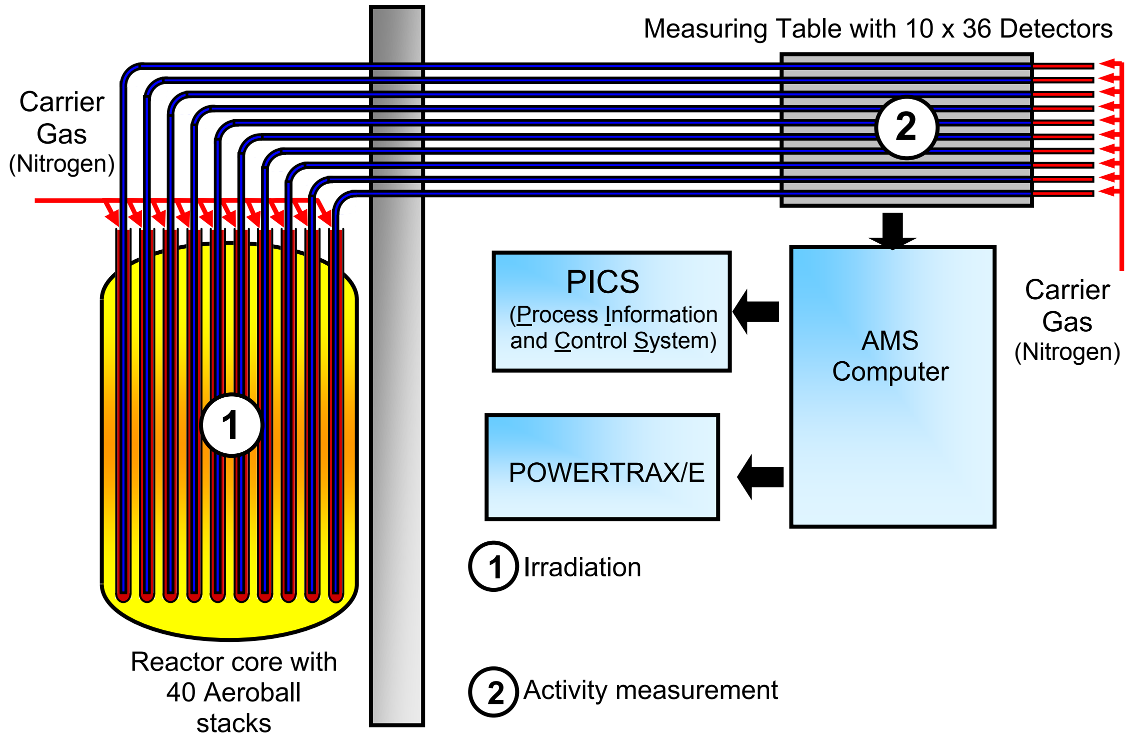
12 FINGERS WITH POWER DENSITY DETECTORS (PDDs) AND 3 CORE OUTLET THERMOCOUPLES EACH

▲ 12 RPV INSTRUMENTATION NOZZLES WITH INSTRUMENTATION LANCES

/ 12 LANCE YOKES

■	4	RPV-head penetrations	for RPVL
+	1	RPV-head penetration	for RPV-dome thermocouples (TC)
○	89	RPV-head penetrations	for RCCA
▲	12	RPV-head penetrations	for incore-instrumentation (PDD/TC/aeroball)

Figure 1-2 General Overview of the AMS



2.0 METHODS, PROCEDURES AND EQUIPMENT

2.1 *Self Powered Neutron Detector*

The PDDS delivers continuous measurements of the local neutron flux density at fixed positions in the core from 12 SPND strings as shown in Figure 2-1. The SPNDs can measure changes in power density that can be used, among other things, to protect the core from the consequences of spurious rod cluster control assembly (RCCA) drops or movement. Each SPND detector string contains six axial SPNDs, which are placed in specific radial core positions to provide information about the 3D neutron flux distribution inside the core. The axial arrangement of SPNDs shown in Figure 2-2 is for a typical Siemens Konvoi-design plant and is similar to the U.S. EPR plant. The U.S. EPR radial arrangement of incore instrumentation components is shown in Figure 1-1. The 72 SPNDs are equally distributed among four electrical divisions as shown in Figure 1-1.

The SPNDs are (n, β) detectors with cobalt emitters that do not require a polarization voltage power supply during operation. The cobalt isotope, Co-59, is used for emitter material because of its ability to promptly generate signals that follow the change of neutron flux with low gamma sensitivity. A cross-section of the SPND is shown in Figure 2-3. Incore detectors allow for a more direct measurement of localized power peak conditions than excore detectors, especially with the large size of the U.S. EPR core. Advantages of the PDDS over excore detectors include:

- Direct measurement of changes in power density
- Increased accuracy of localized power measurements under normal and transient operating conditions
- Increased core surveillance/limitation and protection information
- Superior measurement of core conditions for peak power density, DNBR, and axial offset

The neutrons and gammas generated in the fuel by nuclear fission produce Compton electrons in the Co-59 emitter material, insulation, and emitter conductor of the detector; therefore, the SPND is self-powered. The emitter conductor used for transmission of the detector signal is subject to the same gamma radiation as the emitter material and produces a current over its entire length (Reference 1). The effect of this induced current on the measurement signal is compensated for by running a compensating conductor alongside the emitter conductor. The emitter conductor and the compensating conductor both use mineral insulated metal sheathed cable. **[**

]

Main interactions leading to the formation of electrons contributing to the measured signal are:

- The radiative capture (n,γ) followed by a delayed β^-: global reaction is (n, β^-)
- The radiative capture *(n,γ)* followed by prompt secondary electron production by Compton, photoelectric and pair production *(γ,e)*: global reaction is *(n,γ)(γ,e)*
- Absorption of external gamma and secondary electron production by Compton, photoelectric, and pair production: global reaction is *(γ,e)*

After about 10 operating years, a Co-60 background signal will build up until it reaches a maximum value. The qualified lifetime of these detectors is not limited by burn-up of the emitter material (Co-59) or by buildup of the Co-60 background signal. The lifetime of a detector is determined typically by the endurance of the insulation resistance between the two inner conductors and cable sheath (Reference 2).

2.1.1 *Calibration Requirements of Cobalt SPNDs*

Detector sensitivity is the ratio between the measured signal (i.e., current which is proportional to the local neutron flux surrounding the position occupied by the detector itself) and the monitored physical value (i.e., the maximum linear power density or the integrated power density over the axial length). The power distribution surrounding an SPND changes during the fuel burn-up cycle. A power-to-signal ratio sensitivity loss occurs in the detectors due to emitter burn-up and the build-up of a Co-60 background signal.

Calibration of SPND instrumentation channels is performed to compensate for this decrease in SPND sensitivity during the fuel cycle and to account for peak power density factor change over the fuel cycle. The AMS assists in generating the measured relative neutron flux density in the core, which is used in conjunction with the predicted power distribution based on actual core operation to calibrate the incore SPND instrumentation. This is accomplished approximately every 15 effective full power days (EFPD). Siemens nuclear plant experience has shown that calibration factors determined two hours after power stabilization with RCCAs in full power demand position are valid for steady state conditions.

Criteria and actions will be defined in the U.S. EPR operating manual to address unavailability of the AMS and the resulting consequences for SPND signal calibration.

2.1.2 *Signal Conditioning*

A digital measuring system is provided for signal processing to ensure high reliability and flexibility, to automate performance of periodic tests, and to provide extensive diagnostic features for instrumentation channels. The currents delivered by the emitter conductor and the compensation conductor are amplified and processed within the conditioning cabinet of each division of the protection system (PS). Special measures are taken in the design of the input and output cables to ensure a high signal-to-noise ratio. These measures include general grounding requirements, special cable trays for routing signal cables, and separation from cable trays used for control and power cables.

SPND instrumentation cabinets have front panel connectors for connecting diagnostic tools. Power density perturbations are assessed with the SPNDs and are kept within permissible limits by the Reactor Control, Surveillance, and Limitation System (RCSL).

Wires and cables are selected and routed appropriately to obtain a high signal-to-noise ratio between the detectors and the conditioning equipment, and to ensure that the attenuation of the signals and disturbing noise is as low as possible. The cabinets are powered by internal 24 VDC power supplies.

The detectors and the signal conditioning equipment of the SPND instrumentation are electrically insulated from the signal processing equipment:

- The internal power supplies of the signal conditioning equipment are electrically insulated from the external power supply
- The output signals of the signal conditioning equipment are electrically insulated from the receiving signal processing equipment
- The input signals to the signal conditioning equipment are electrically insulated from the feeding signal processing equipment

2.1.3 *SPND Interface to the Protection System*

The incore instrumentation system provides indication of reactor power levels that are independent and diverse from the reactor power levels indicated by the excore instrumentation system. SPNDs are divided among the four quadrants of the core as shown in Figure 1-1.

- Quadrant 1 is 0° to 90°
- Quadrant 2 is 90° to 180°
- Quadrant 3 is 180° to 270°
- Quadrant 4 is 270° to 360°

The SPND signals are redundantly acquired by the PS. Details of SPND signal processing will be discussed in the U.S. EPR Protection System Design report.

2.1.4 *SPND Failure*

[

] SPND failures in Konvoi plants are automatically detected and registered; the U.S. EPR will also have this detection feature. Allowance for SPND detector failure will be addressed in a separate safety analysis setpoint methodology report for core safety limits trip setpoints. Details of SPND signal processing will be discussed in the U.S. EPR Protection System Design report.

Historical reasons for SPND detector string replacement in Konvoi plants are:

- A given number of failed detectors over a fuel cycle
- Mechanical damage of the detector string during the handling of the instrumentation lance
- Problems with the AMS that may have required the replacement of the complete instrumentation lance

[

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During each refueling outage, the following tests will typically be performed for the U.S. EPR SPNDs to ensure their continued functionality:

- Measurement of the cable insulation resistance
- Measurement of the Co-60 background currents
- Compensation for the Co-60 background currents
- SPND instrumentation channel response checks using the test equipment installed in the cabinets

2.1.5 *Defense-in-Depth, Diversity, Redundancy*

The PDDS provides defense against common-mode failures by performing the following:

- SPNDs provide independent input signals to the safety-related PS for the reactor trip echelon
- SPNDs provide isolated inputs to the non-safety related RCSL, which is part of the control system echelon
- SPNDs provide input signals to non-safety related POWERTRAX/E monitoring and indication system
- SPND system is single-failure tolerant

The U.S. EPR Protection System Design report will address PS functions.

SPNDs are to be divided among the four quadrants of the core as shown in Figure 1-1.

AMS is not required to have redundancy because the system is only used only to calibrate the SPNDs. PDDS redundancy and diversity will be addressed in the diversity and defense-in-depth analysis to be performed for the U.S. EPR.

2.1.6 *Seismic Qualification*

Incore Instrumentation System components are required to be seismically qualified in accordance with Institute of Electrical and Electronics Engineers (IEEE) Standard 344-1987 (Reference 3), with the following classifications:

- SPNDs within the reactor pressure vessel (RPV) and the portions of the system, including cabinets, used for a safety-related protection function or qualified display will be seismically qualified
- Instrumentation lances will be seismically qualified
- AMS components within a safety-related building, including cabinets, measuring table, and transport system components will be qualified as Seismic Category II

2.2 *SPND/AMS Lance Shaft, Lance Yoke and Cables*

The incore instrumentation is inserted into the RPV through the closure head. The top-mounted design is based on more than 30 years of incore instrumentation experience Siemens plants. Lance penetrations are subject to normal leakage detection inspections performed during every outage and have accumulated 260 operating years in 16 Siemens plants. Special provisions are provided for safe and easy handling as follows:

- Installing lances and level measurement probes without using specialized equipment to allow for short handing times during the refueling outages and short replacement times
- The tightening system utilizes double seal rings to allow a tightness test on each seal ring before the start up of the plant

The AMS and SPND measurement systems are mounted on the instrumentation lances inside the RPV (shown in Figure 2-1). Instrumentation lances are made of austenitic stainless steel and are moved through the storage pool and the reactor well to above their designated positions in the upper core support structure. By slowly lowering the lance, the lance fingers are inserted into the guide tubes in the upper core support structure with the aid of movable guide funnels of various heights. Once the fingers have been inserted, the lance continues to be lowered until the yoke rests on the upper core support structure. This process ensures that the fingers and the entire lance are correctly positioned. When the closure head is lowered onto the RPV, fixed guide funnels on the lance shaft penetration nozzles ensure that the lance shafts insert into the nozzles. These funnels are the same design as the guide funnels for the drive rods of the control rod drive mechanisms.

Once the closure head is in place, the nozzle closures (shown in Figure 2-4) are installed. A seal ring system is used to make the pressure-tight connection between the lance/probe shaft and the instrumentation nozzle. Following installation of the vessel head equipment, the cables and tubes are connected to the lance head and the plug board.

The AMS tubes and SPND metal-sheathed cables are routed upwards out of the lance fingers, brought together on the lance yoke, and pass up through the lance shaft at one end of the yoke before leaving the reactor through nozzles in the RPV closure head, as shown in Figure 2-5. The Aeroball and gas tubes are brazed to the lance head to provide a pressure-tight connection at the top end of the lance shaft. Similarly, the SPND cables are first brazed into a sheath that is welded to the lance head to provide a pressure-tight connection at the top end of the lance shaft. This pressure-tight cable penetration is integrated into a pipe union at the lance head; however, it can be disconnected, if necessary.

Additional details of the AMS and SPNDs are shown in Figure 2-6.

The lance shaft is used to route the Aeroball, gas tubes, SPND, and cables out of the RPV through special nozzles on the RPV closure head. The lance shaft is basically a robust thimble. At its top end – the lance head – the cables and tubes are routed out of the reactor through pressure-tight penetrations.

2.3 *Aeroball Measurement System*

The AMS is a reference instrumentation system used to determine relative neutron flux density in the core and to calibrate the incore SPND instrumentation.

Moveable probes use Aeroball stacks, in a column length that spans the active core height, to determine the relative neutron flux density in the core. The Aeroballs are steel balls containing vanadium. A nitrogen gas driving medium transports the Aeroball stacks to the core where they become irradiated. After irradiation, the balls leave the core through magnetic stops and pass into the measuring table in the AMS room inside the containment. The mechanical design of the AMS fingers consists of two concentric steel tubes (i.e., the pressure tube and the Aeroball tube) surrounded by an outer protective steel tube.

The magnetic stops are part of the AMS outside the RPV and are mounted on the lower level of the RPV closure head equipment (shown in Figure 2-7). When closed, the magnetic stops retain the Aeroball stacks in a holding position above the reactor. When open, the magnetic stops permit the Aeroballs free passage to the reactor core or to the measuring table.

AMS tubes are routed from the top of the lances over RPV closure head equipment cable bridges through the reactor building to the AMS rooms. These tubes are the transportation device for the Aeroball stacks and propulsion gas. Because the AMS tubes are brazed pressure-tight, the cables are provided with a detachable sealed entry piece that permits the entire finger to be replaced.

The AMS is an electromechanical, computer-controlled, on-line flux mapping measurement system based on movable activation probes. The AMS determines the relative neutron flux density distribution over the entire active core height at 40 fixed fuel assembly positions. A dedicated system computer controls the entire measuring and testing processes, ensures a high accuracy, and calculates the count rates from the received pulses.

Using the measured values provided by the AMS, POWERTRAX/E calculates the 3D measured power distribution in the reactor core.

2.3.1 *Instrumentation Lance*

The core instrumentation lance (shown in Figure 2-5) is the basic mechanical unit of the incore neutron flux measuring system. Instrumentation lances contain the measuring devices for the AMS. There are four types of instrumentation lances that correspond to specific core locations.

The guide tube and protective tubes, containing either an Aeroball probe (AMS finger) or an SPND detector string, are suspended from a yoke resting on the top plate of the upper core structure between the control rod shroud tubes (shown in Figure 2-1). At the lower end of the finger, the Aeroball transport tube in the lance finger ends in a gas permeable Aeroball stop. Concentric to the Aeroball support tube, a gas supply pipe applies counter pressure to eject the Aeroball stacks. During operational conditions, the lance yoke rests upon the top plate of the core structure. The outside diameter of the lance probes is sized to fit into free control rod guide tubes of the fuel assemblies. The shaft extends upwards to where the seal nozzles penetrate the RPV closure head (shown in Figure 2-4). The pressure-tight connection between the lance shafts and the instrumentation nozzle is made by an easily-detachable double seal ring system, which permits leak-tightness tests after nozzle assembly.

2.3.2 *Aeroball Stacks*

[ ] Each Aeroball is 0.067 inch (1.7 mm) in diameter. The Aeroballs are designed to be used for the life of the plant without the need for replacement. When at the rest position (shown in Figure 2-8), the Aeroball stacks are above the solenoid Aeroball stop, which is above the reactor vessel, level with the cable bridge. When the Aeroball stops are opened, the Aeroball stacks move pneumatically (using nitrogen gas) through the 0.079 inch (2 mm) inner diameter Aeroball tube, with 0.020 inch (0.5 mm) wall thickness, to their activation positions in the reactor core. The 40 columns of Aeroball stacks are divided equally into four subsystems; column length is approximately equal to active core height. The activity distribution along the stacks is proportional to the neutron flux density, and thus, to the power density. After a defined irradiation time (shown in Figure 2-9), the Aeroball stacks leave the core, via nitrogen gas through magnetic stops, and pass into the measuring table. In the measuring compartment, the Aeroball transport tubes are connected to a measuring table consisting of several detector beams. The beams are arranged on the measuring table with four Aeroball transport tubes grouped together in parallel under each detector beam to form four subsystems. The 10 Aeroball stacks in one subsystem are measured simultaneously, with individual measurements performed of each stack. During the measurements, the activated Aeroball stacks of the other three subsystems are in the rest position.

The vanadium utilized in the Aeroballs produce a gamma decay signature readily discernable by the measurement software. When exposed to a neutron flux, the V-51 used in the Aeroballs reaches a higher energy state, creating isotope V-52. After a half life of 3.7 minutes, V-52 undergoes a β- decay to Cr-52. Gamma radiation that is given off during this decay can be measured by the AMS. If subsequent measurements are performed immediately following one another, the AMS software factors residual decay energy from previous measurements into the calculations.

2.3.3 *Solenoid Aeroball Stop*

The 40 solenoid Aeroball stops (shown in Figure 2-10) are situated in the Aeroball transport tubes between the lance and the measuring table with the Aeroball stops located close to the lance. The Aeroball stop guide tubes are closed with a piston mounted in a pressure-tight housing that remains permeable to the nitrogen gas. The piston is driven magnetically through the housing wall. The Aeroball stop forms a gateway that can be opened or closed for the Aeroball stack movement. When the stop is open, the Aeroballs can be transported to either the core or to the measuring table. When the stop is closed, a defined wait or rest position is used for the Aeroball stack (shown in Figure 2-11). At the wait position, the Aeroball stack is located below the Aeroball stop, with pressure applied in the direction of the measuring table. In the rest position, the Aeroball stack is located above the Aeroball stop, with pressure applied in the direction of the lance or with no pressure applied.

2.3.4 *Measuring Table*

The 40 Aeroball tubes are grouped into four subsystems of 10 Aeroball tubes in the measuring table (shown in Figure 2-12 and Figure 2-13). Each subsystem has its own valve control for the nitrogen pneumatic transport system that can be operated independently. Each control valve has a redundant voltage supply. Lead shielding strips between the mounting beams shield the detectors from radiation from Aeroball stacks under adjacent mounting beams. The measuring table also contains connections for any required Aeroball stacks replacement.

The driving manifold at the lower end of the measuring table connects the individual Aeroball tubes. Each gas connection supplies the Aeroball tubes of a single system via longitudinal and traverse openings. The end-stop for the Aeroball stacks is attached to the driving medium manifold and protrudes into the Aeroball tubes. The Aeroballs are retained by the end stop while the gas is able to flow through the end stops unimpeded in either direction. If the moisture level in the subsystem is too high, a moisture sensor mounted in the driving medium manifold will shut down the associated system.

The measuring table contains 10 sets of detector bars to measure the decay of the Aeroball stacks that have been irradiated. Each detector beam has 36 tapering ports (shown in Figure 2-14 and Figure 2-15) covered with implanted planar silicon detectors situated at regular intervals along the detector steel beam.

The Aeroball stacks of one subsystem are measured simultaneously; the measurements are performed individually for each stack. During the measurements, the activated Aeroball stacks of the other three subsystems are in the rest position.

[

] Pulse counts acquired for the individual measuring channels are transferred to the AMS computer for further data processing. The AMS computer performs the fully-automatic open-loop control of the AMS. The AMS computer also performs data processing before transferring data to POWERTRAX/E.

2.3.5 *AMS Control Equipment / Valve Rack*

The valve rack is in the AMS control cabinet room next to the AMS measuring table (shown in Figure 2-7). The valve rack consists of the valves necessary for Aeroball transport control. The nitrogen gas pipes leading to the measuring table are routed through this valve rack and laid parallel to the Aeroball transport tubes in the neighboring AMS measuring table compartment.

The nitrogen used to move the Aeroballs is directed to the four pneumatic subsystems via pressure reducers, buffer tanks with pressure indicators and switches, solenoid valves, filters, and branches. Each subsystem is equipped with a separate solenoid valve control system.

In the event of a nitrogen gas pressure drop in the main supply system, the supply line to the main supply system is automatically isolated by a solenoid valve. Aeroball transport is still ensured by using reserve nitrogen from the buffer tanks.

Gas supply piping leading to the individual subsystems branches into two three-way valves. One valve controls the nitrogen gas train leading to the instrumentation lance; the other valve controls the nitrogen gas train leading to the measuring table. The valves are also connected to the common discharge line via an aerosol filter.

Each three-way valve has a solenoid-operated, quick-closing valve mounted upstream on the reactor side. In the event of Aeroball transport system failure (i.e., humidity sensor or pressure switch response), the monitoring modules provide alarm signals to the process automation system and automatically close the solenoid-operated, quick-closing valve. This feature ensures that no Aeroball transport can take place in the subsystems involved until the cause of failure has been identified and removed. Under normal operating conditions, the quick-closing valves are opened by the AMS computer for Aeroball transportation.

2.3.6 *AMS Instrumentation System*

Measurements are initiated from the AMS computer to obtain controlled and activation values of the Aeroball probes. The activation values and any information about corrected or defective probes are compiled into a file that is sent to the POWERTRAX/E computer. The AMS instrumentation system is shown in Figure 2-16.

Once the file is received by the POWERTRAX/E computer, the core simulator calculates the 3D power distributions and DNBR, and performs the adaptation from theoretical to actual measured activation values. Following the adaptation run, the calibration factors are calculated. POWERTRAX/E will automatically evaluate an Aeroball measurement as soon as a file with the activation values has been received by the POWERTRAX/E computer. The Graphic User Interfaces and the computers are separated.

The AMS computer controls the entire measuring and testing processes. It also calculates the adjusted count rates from the measured pulse counts measured by applying correction factors, such as decay of the activity during the measuring procedure, residual activities, and scattering effect.

The AMS operates on dedicated hardware and does not use resources of other systems for control of measurements.

The main technological features of AMS are:

- Near instantaneous survey of core status, with activation times of approximately three minutes, allow for measurements during load ramps
- Shortest time interval between two measurements is 10 minutes
- Start capability from the main control room or operators terminal in the instrumentation and control service room
- Technological function progress and system availability are indicated on the operator’s terminal

To prevent the transport of balls to an identified problem probe, individual solenoid stops can be disabled by the operator.

2.4 *POWERTRAX/E*

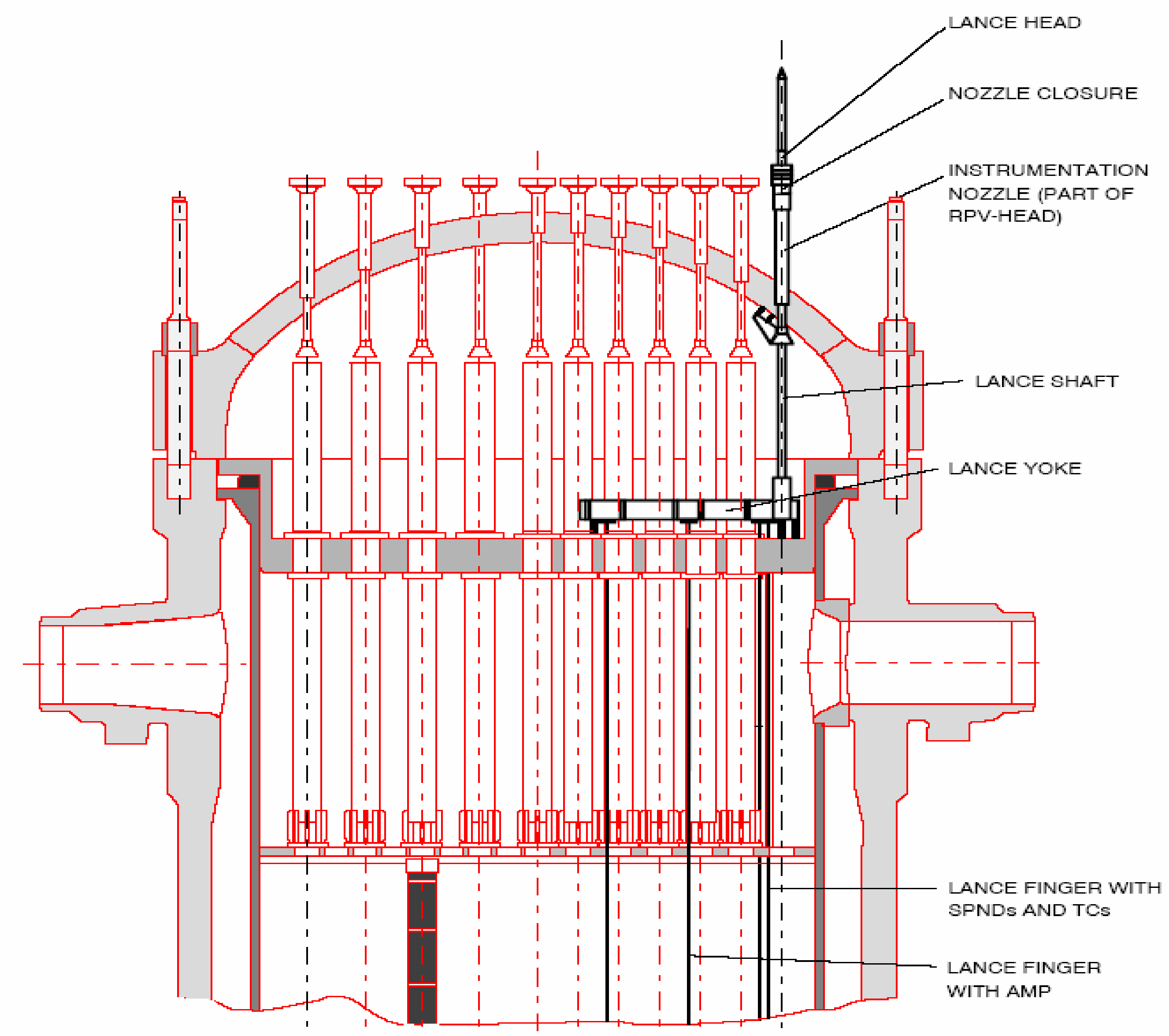
POWERTRAX/E is a state-of-the-art on-line core monitoring software system that performs a wide range of functions related to core monitoring and calculations. POWERTRAX/E uses NRC-approved core neutronics code packages to model the core conditions in core follow mode (i.e., during normal and transient conditions) to generate accurate data about various physics parameters, such as fuel burnups and pin power peaking. POWERTRAX/E generates the detailed power distributions after Aeroball measurements are taken; calculates the corresponding SPND calibration factors; and provides prediction tools to aid the plant operators during planned plant maneuvers. POWERTRAX/E graphically displays a wide range of information about the core conditions obtained from the core neutronics simulations, the plant computer, and the AMS computer.

The details of the methodologies used in the POWERTRAX/E code package will be described in a separate topical report.

[

] This control prevents any illegal access to the POWERTRAX/E computer itself or to other computers in the network. A user identification and password are required to turn on the core-monitoring module, and access rights are defined by the system administrator. Neither the protection system nor any other safety-system is accessible from the POWERTRAX/E system. POWERTRAX/E only receives signals from non-safety systems, and does not provide input signals to other safety or non-safety systems.

Figure 2-1 Instrumentation Lance and Nozzle Arrangement



INSTRUMENTATION LANCE AND NOZZLE ARRANGEMENT DRAWN ROTATED
SOME CONTROL ROD GUIDE ASSEMBLIES AND NOZZLES NOT DRAWN

AMP	AEROBALL MEASURING PROBE
SPND	SELF-POWERED NEUTRON DETECTOR
TC	THERMOCOUPLE

Figure 2-2 Axial Location of SPNDs

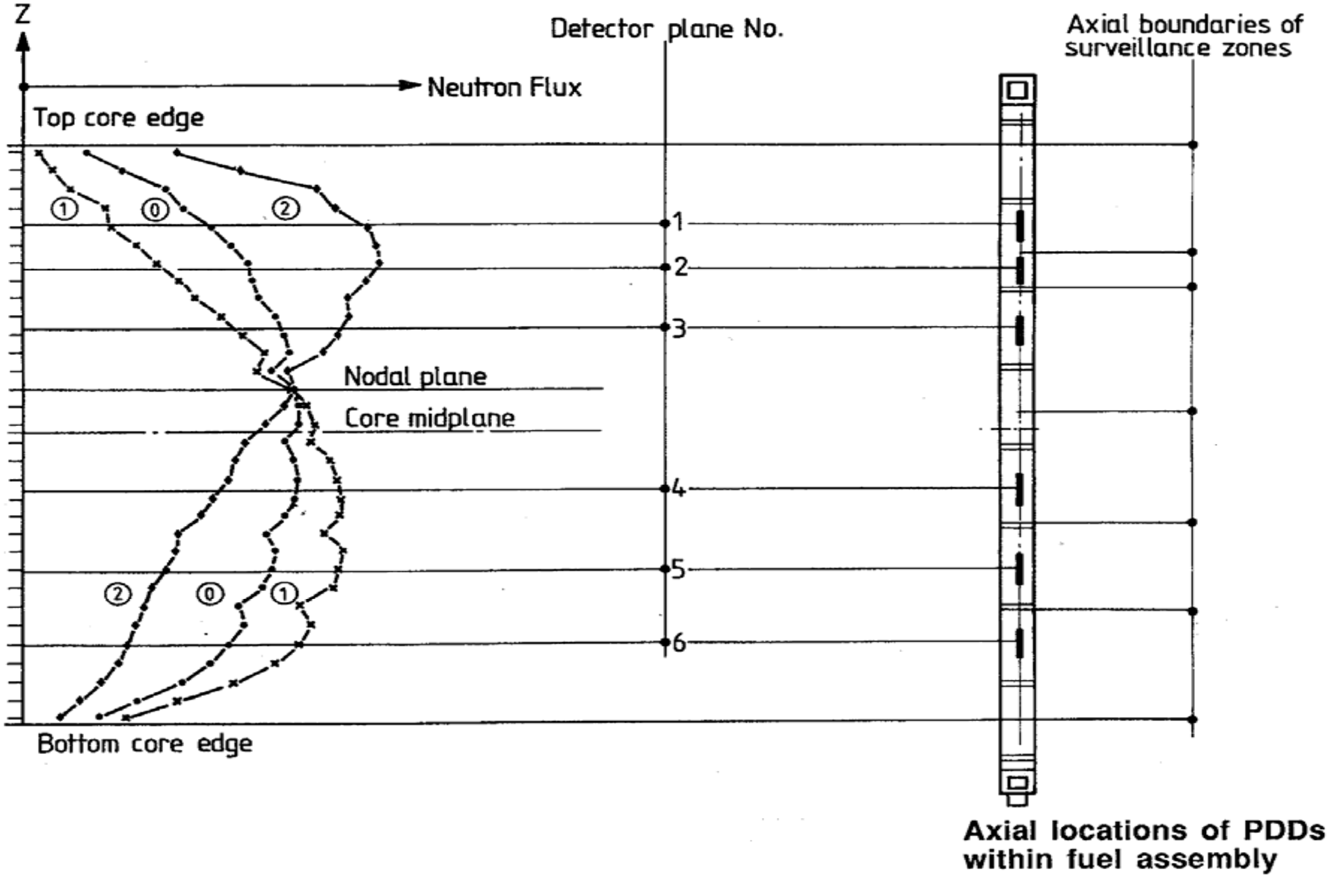


Figure 2-3 ṇ, β Detector and Integrated Connecting Cable

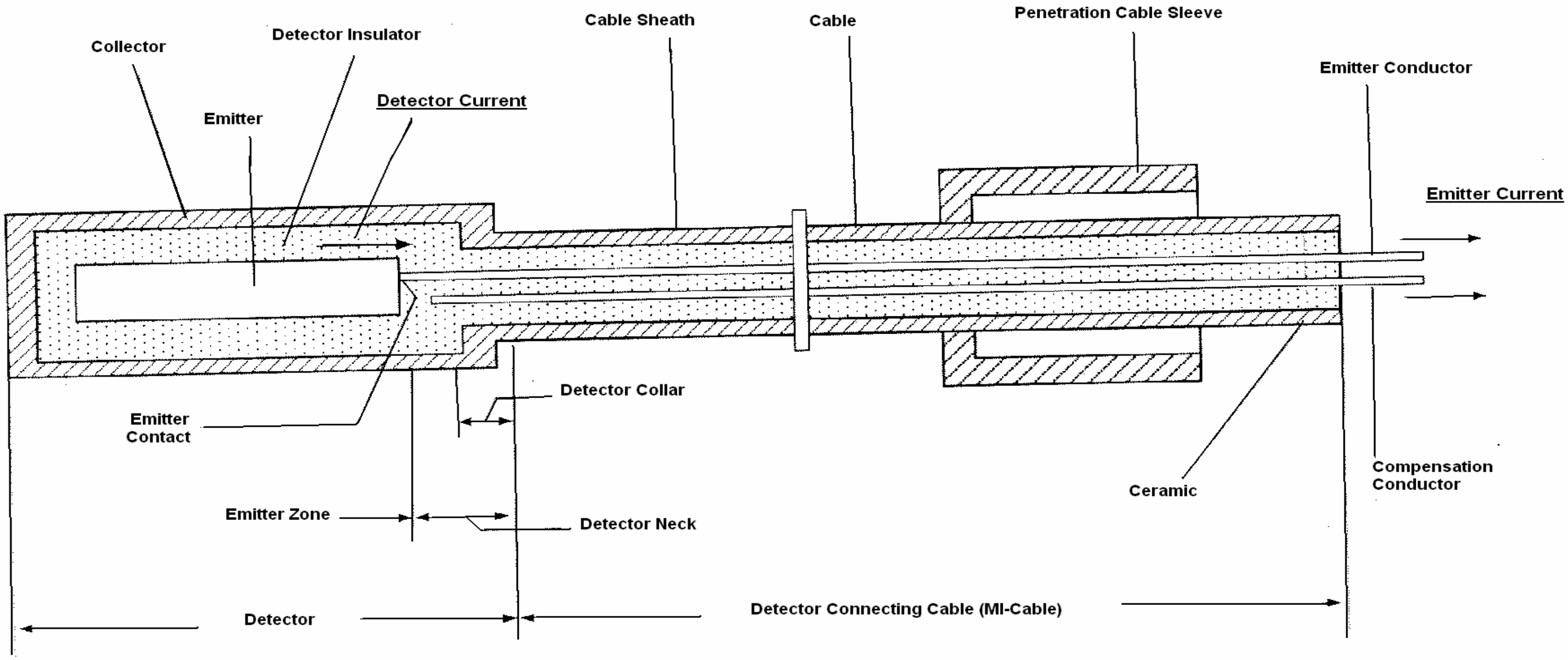


Figure 2-4 Nozzle Closure

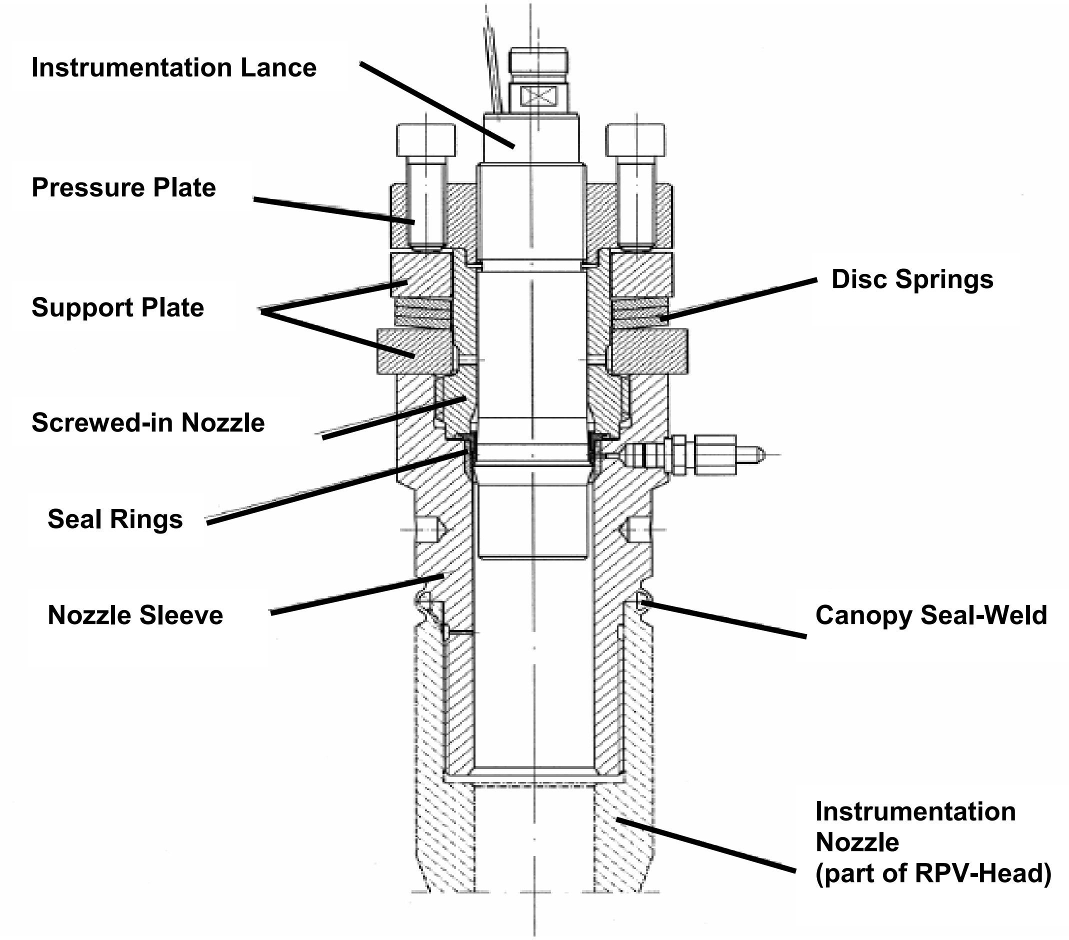


Figure 2-5 Typical Instrumentation Lance

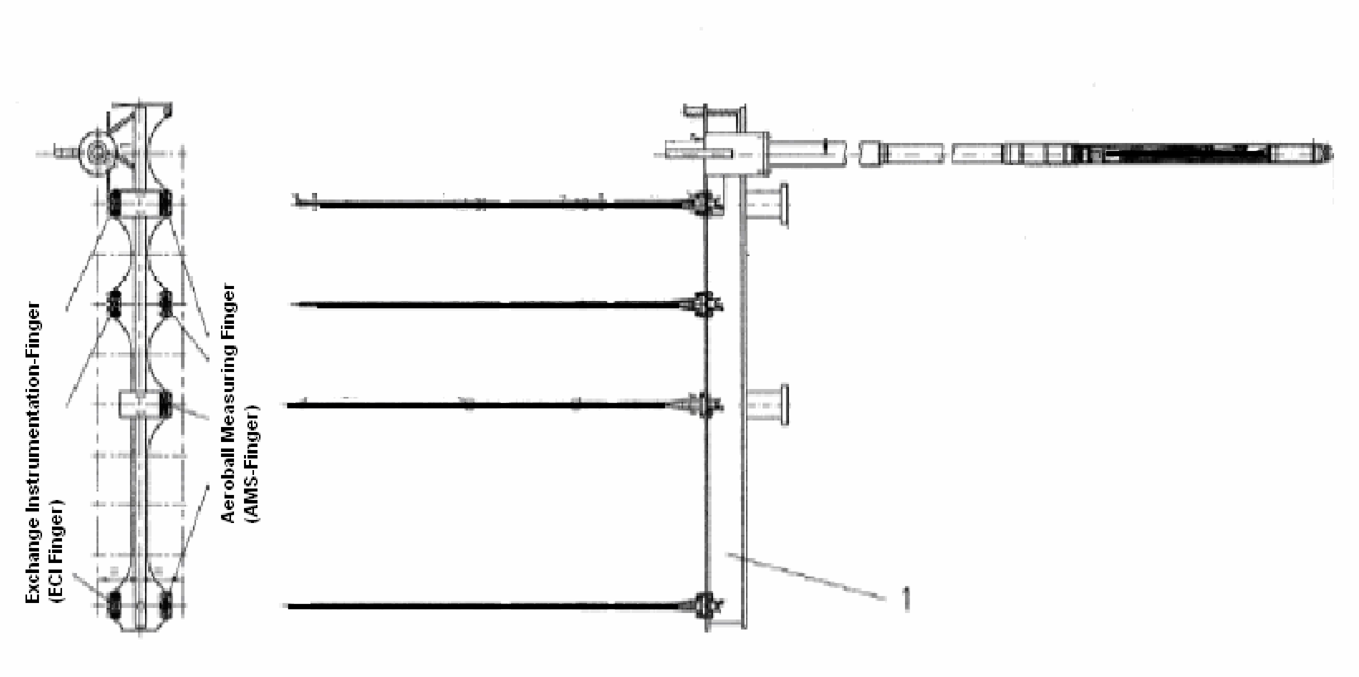


Figure 2-6 Detail of Aeroballs and SPND Probes

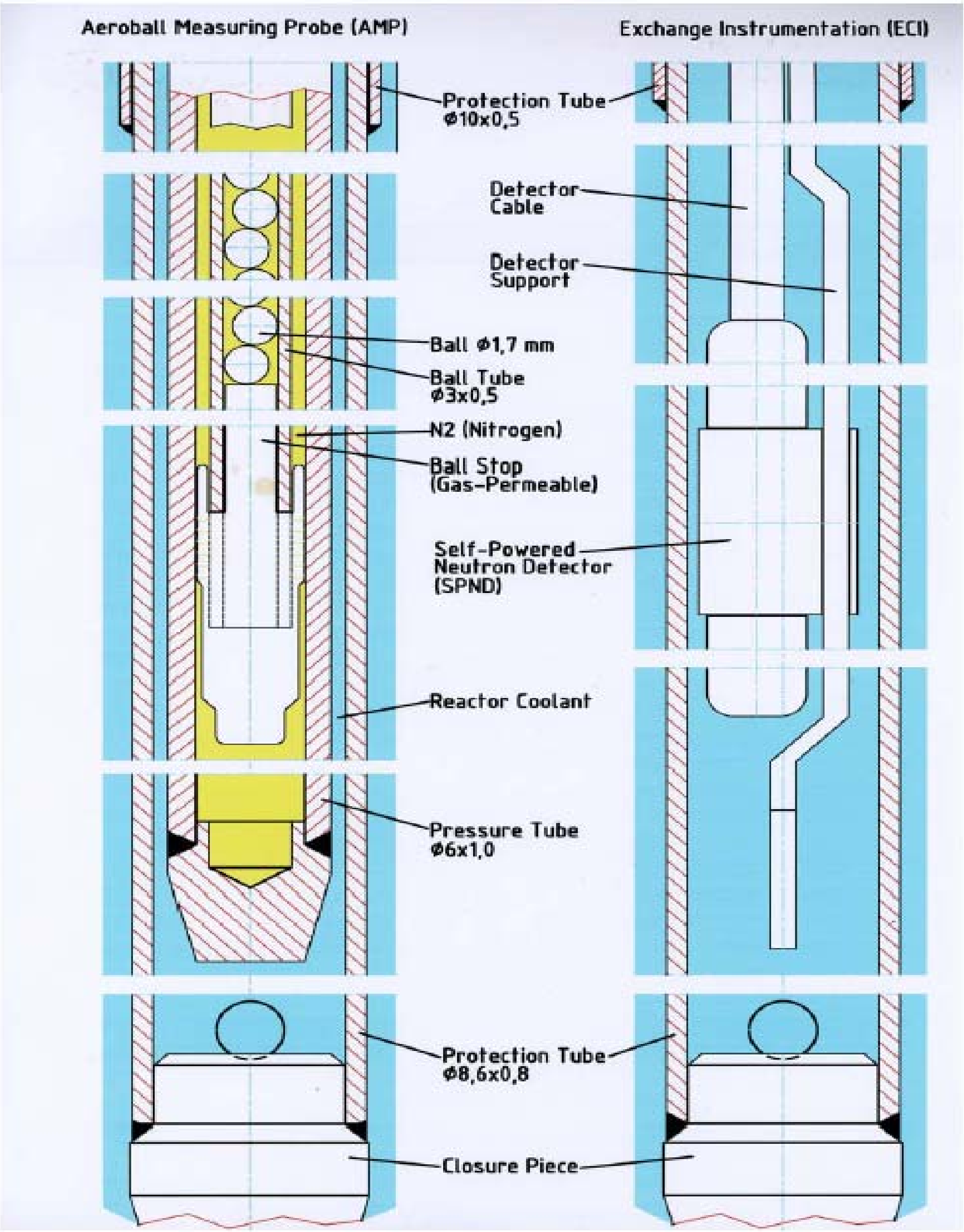


Figure 2-7 AMS Incore Instrumentation Location

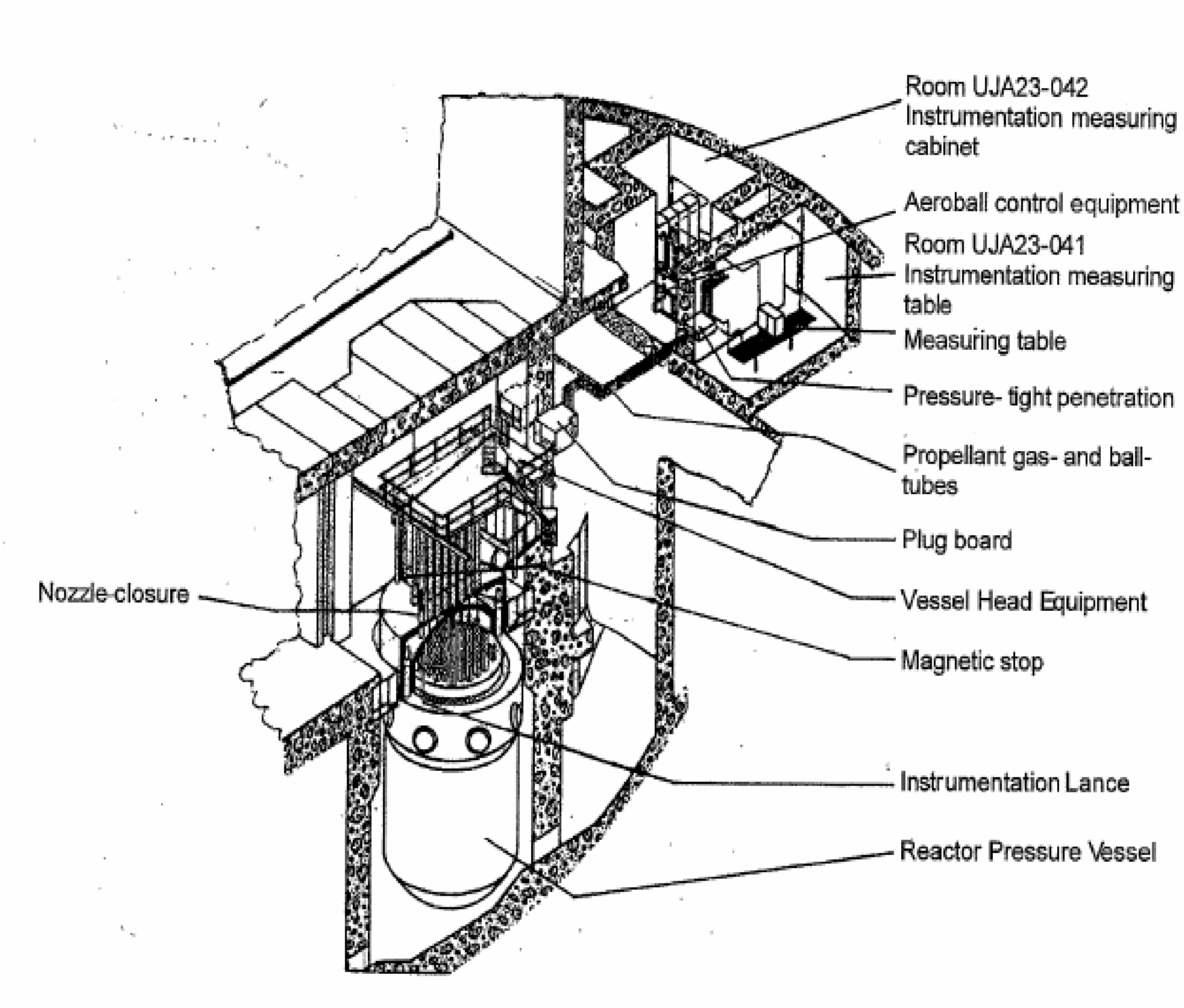


Figure 2-8 AMS Pneumatic Transportation System

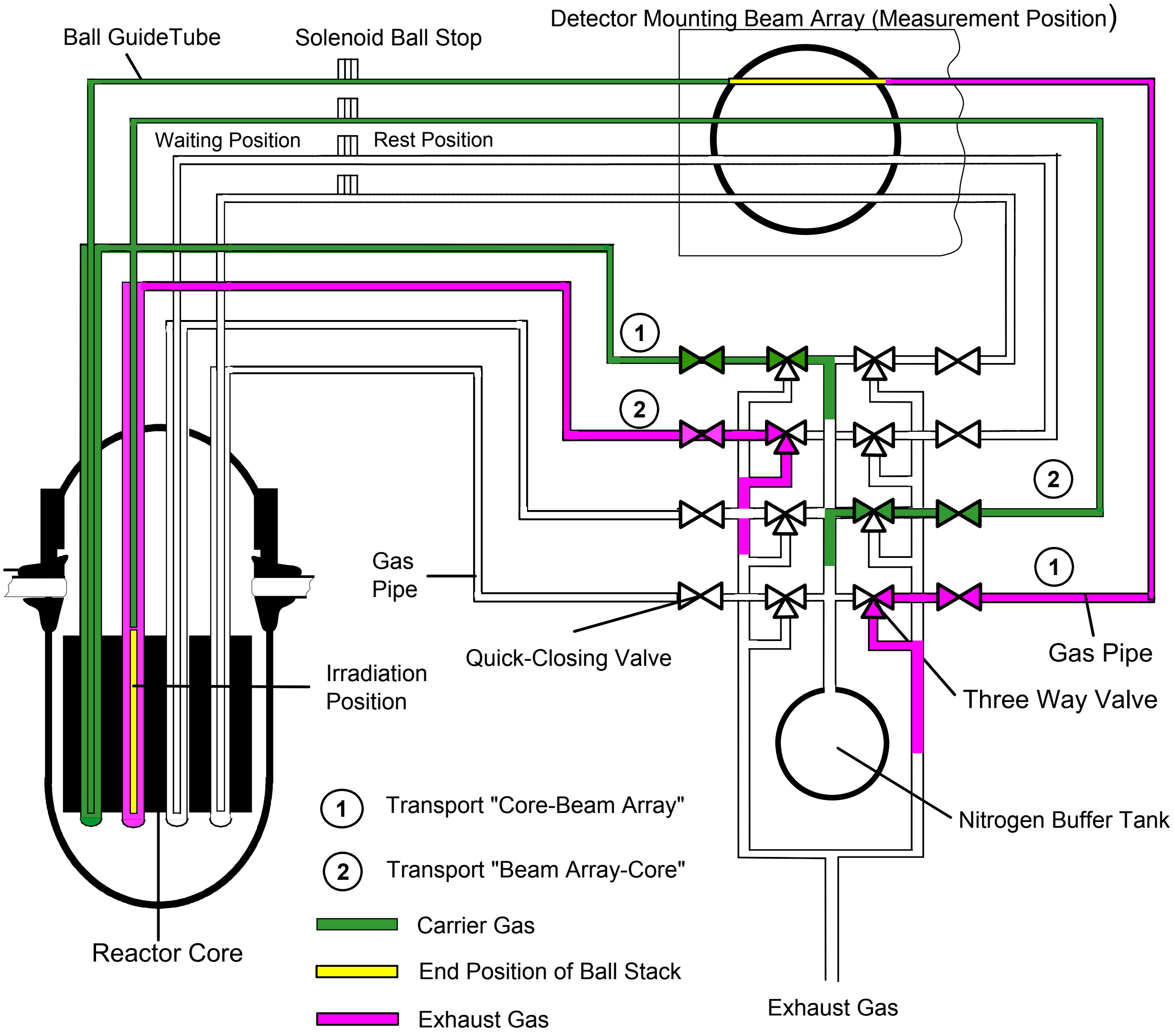


Figure 2-9 Time Schedule of AMS Measuring Process

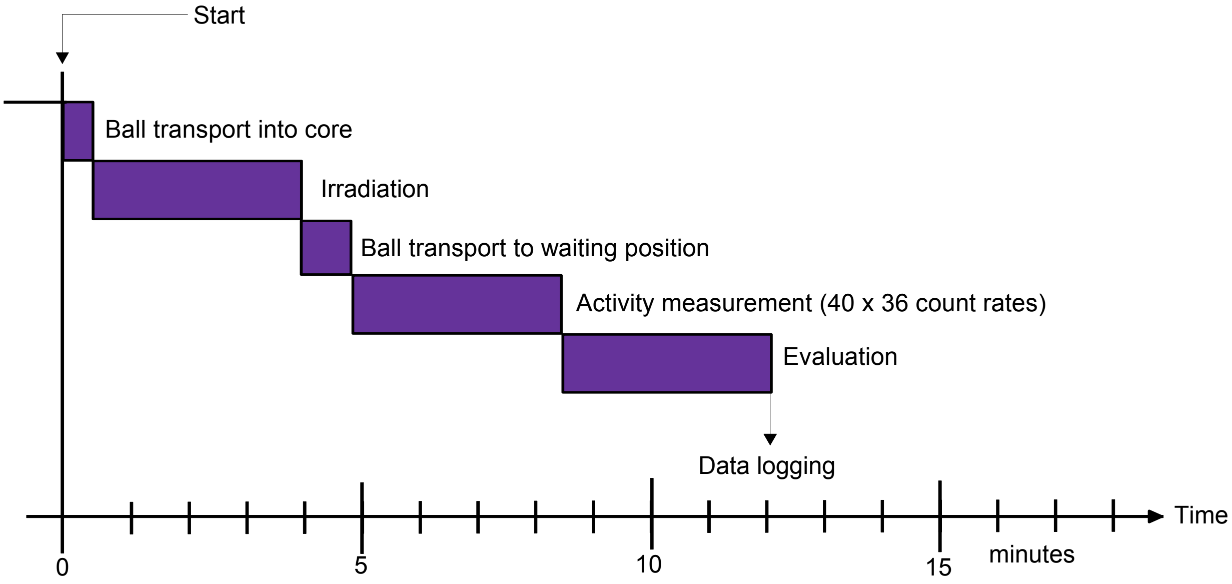


Figure 2-10 Solenoid Aeroball Stop

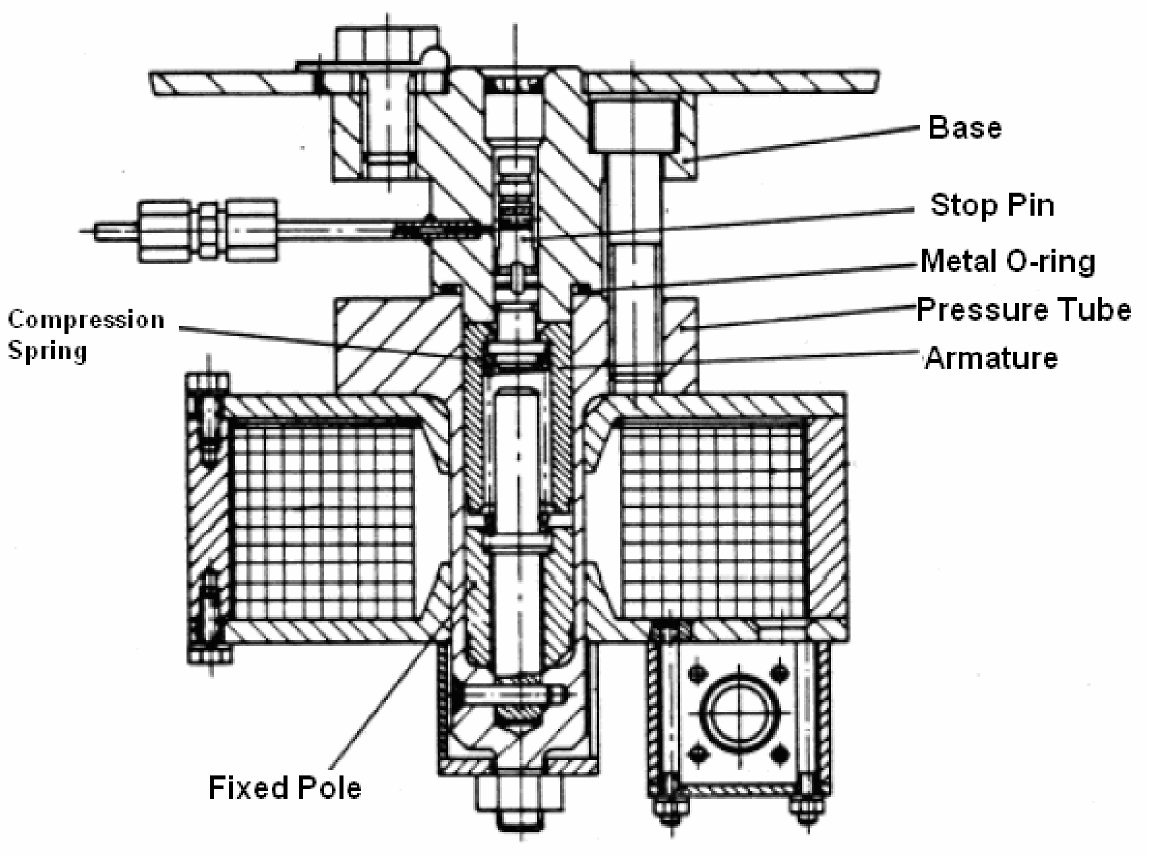
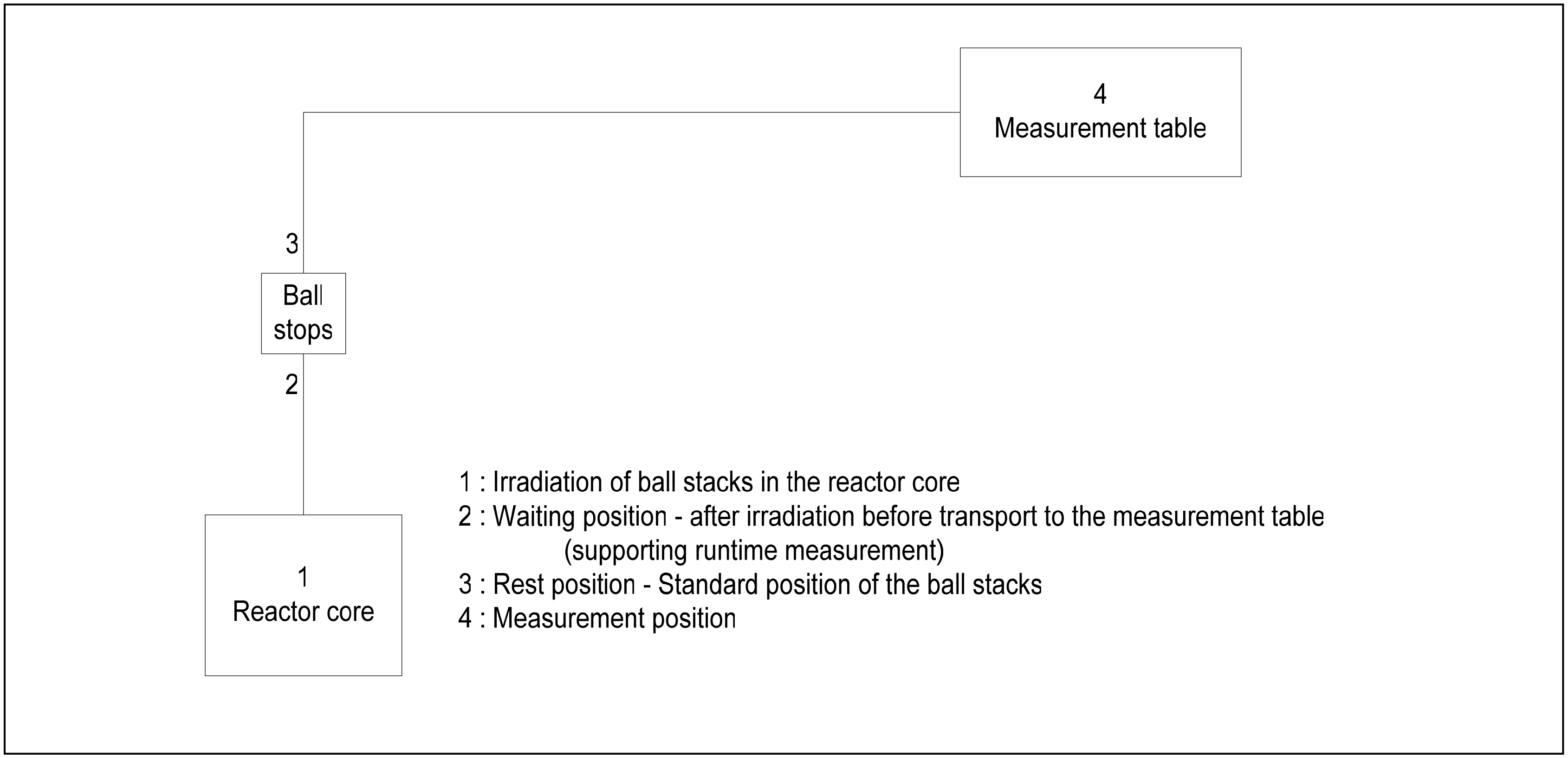


Figure 2-11 Aeroball Stack Position during AMS Operation



1 : Irradiation of ball stacks in the reactor core
2 : Waiting position - after irradiation before transport to the measurement table (supporting runtime measurement)
3 : Rest position - Standard position of the ball stacks
4 : Measurement position

Figure 2-12 AMS Measurement Table

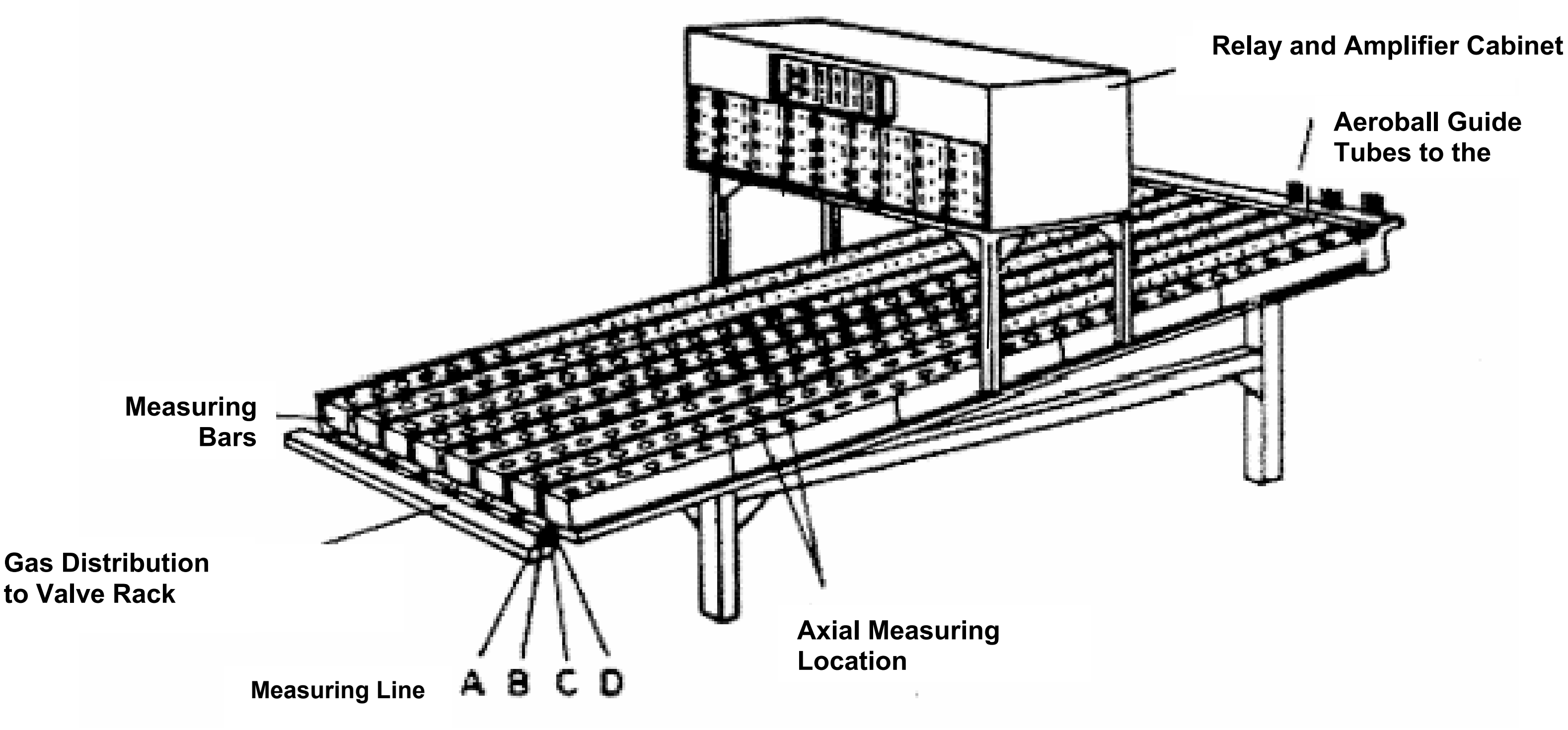


Figure 2-13 AMS Measurement Table Currently in Use for Konvoi-Type Plants

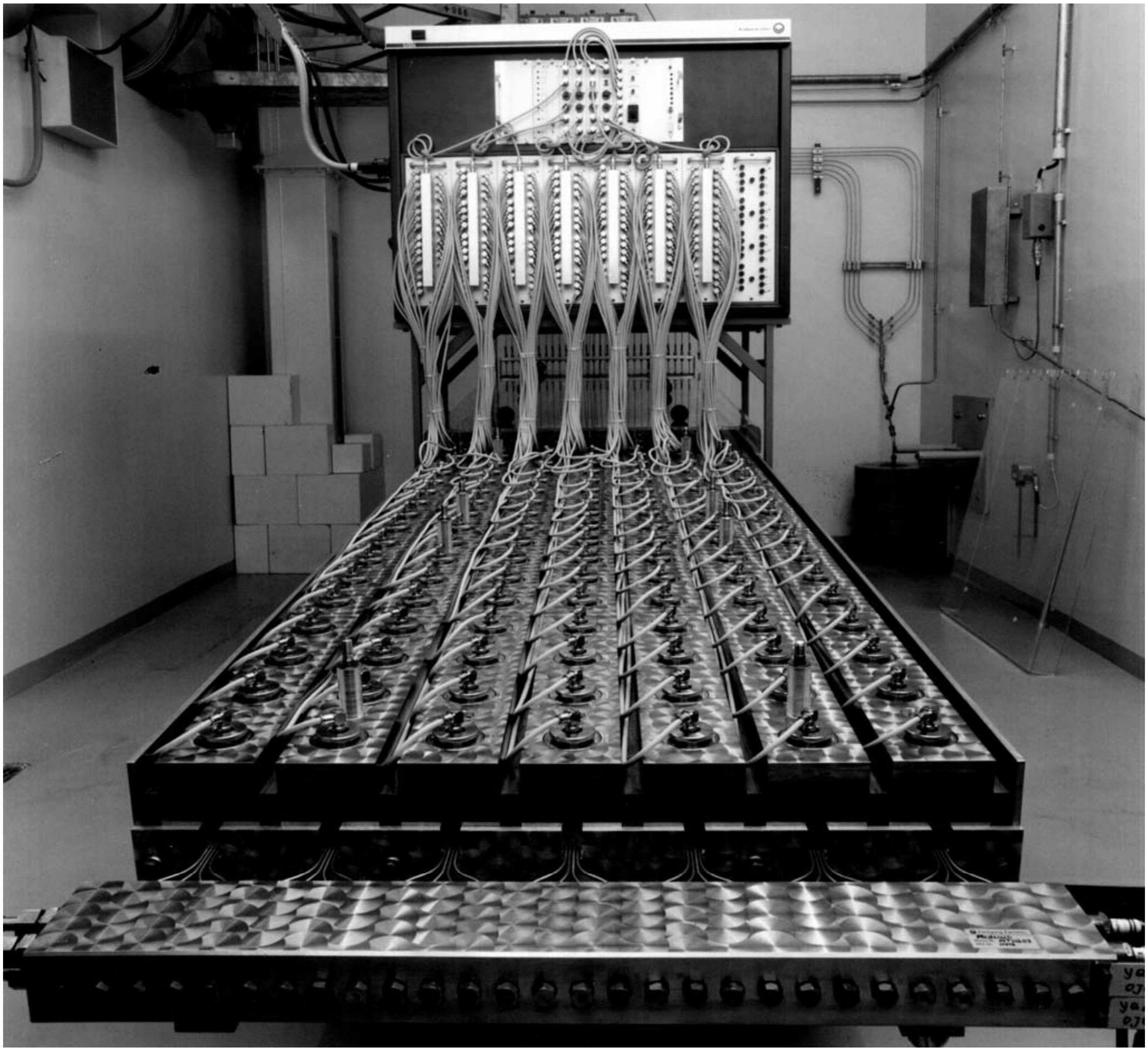


Figure 2-14 Tapering Port with Semiconductor Detector

1. Tapering port
2. Guide pin
3. Ceramic insulation insert
4. Silicon surface barrier detector
5. Knurled screw
6. Locking pin

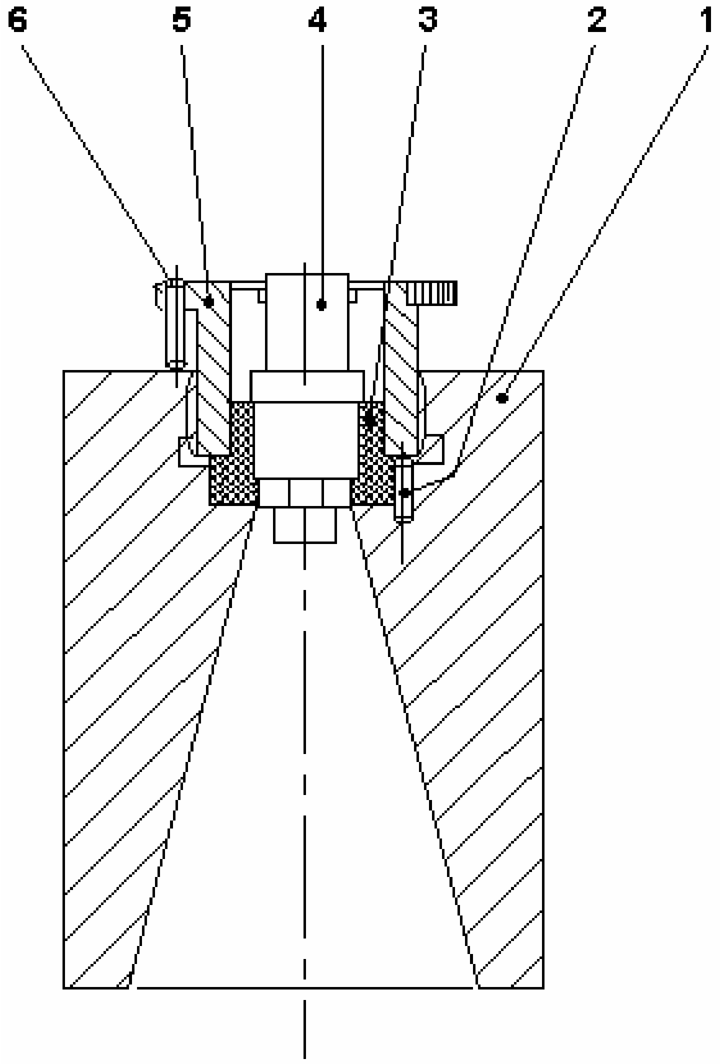


Figure 2-15 Semiconductor Detector Used in AMS Measurement Table

Figure 2-16 AMS Instrumentation System

3.0 OPERATIONAL EXPERIENCE

[

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The AMS currently in service is reliable. Table 3-2 shows Siemens' data of failed Aeroball probes, which was obtained over approximately 30 years of operation for 220 fuel cycles of 12 plants, with each plant having a 12 month fuel cycle, typically with 28 Aeroball probes in each cycle. Table 3-2 shows that the last AMS failure occurred over 15 years ago in 1991. This implies that the lessons learned from the failures reported in Table 3-2, and the subsequent remedies ensured reliable system operation. Furthermore, the only consequence of probe failures is reduced margins, but with no operational restrictions.

The following information applies to the U.S. EPR instrumentation lance AMS probes:

- Based on system design, construction, and operational experience, a probe failure is unlikely
- The 40 ball tubes are grouped into four subsystems of 10 Aeroball tubes each. Each subsystem has its own nitrogen pneumatic transport system capable of independent operation
- To prevent the transport of balls to an identified problem probe, individual solenoid stops can be disabled by the operator

Should the balls become incapable of movement, the irradiated ball isotopes will decay rapidly and will not pose a radiological hazard to personnel.

Table 3-1 Konvoi – Plants A, B, C: Failure of SPNDs

Table 3-2 Abnormal Operational Occurrences Associated with AMS Probes

Plant:	**Biblis A**	**KKP 2**	**KKP 2**	**Other Reactor Plants**
Year:	1975/76	1989/90	1990/91	1975 to Present
Time Since Beginning of Cycle:	Cycle 1 245 EFPD	Cycle 5 70 EFPD	Cycle 6 6 EFPD	See Note 1
Number of Failed Probes:	14 of 32	21 of 28	21 of 28	
Reason:	Wrong lubrication	Excessive residual moisture after N_2 tank hydro test	Subsequent failure of same probes in next cycle	

NOTE 1: Siemens' data for Table 3-2 was obtained over 220 fuel cycles of 12 plants, typically with 28 Aeroball probes in each cycle. No abnormal operation of any AMS probes has been observed for any reactor plants other than those addressed in Table 3-2.

4.0 SUMMARY AND CONCLUSIONS

The core instrumentation concept applied to the U.S. EPR combines two complementary systems:

- A monitoring system employing fixed SPNDs
- A neutron flux mapping system using moveable activation probes called Aeroballs

Since 1974, these core instrumentation systems have been used together in 12 Siemens nuclear plants, each having a 12 month fuel cycle, and have amassed 220 fuel cycles of operation. Siemens plants have documented a failure ratio of 0.018 (number of failures of SPNDs during the cycle divided by the number of SPNDs available at the beginning of cycle). SPNDs have a typical lifespan of six years.

Because both the power-to-signal ratio of an SPND and the reference power distribution change with core burnup, SPND signals are matched to reference signals provided by the AMS approximately every 15 EFPD.

The AMS is a reference instrumentation system for calibration of the incore SPND instrumentation. Tiny steel balls containing vanadium are used to determine the 3D relative neutron flux density in the core. The Aeroballs are designed to be used for the life of the plant without the need for replacement. Siemens' data have been obtained over 220 fuel cycles of 12 plants, typically with 28 Aeroball probes per plant. The AMS has had only minor failures, most recently in 1991. No mechanical failures have ever occurred.

The AMS operates on dedicated hardware and does not use resources of other systems for control of measurements.

5.0 REFERENCES

1. AREVA NP Document, 31-9037142-000, “Prompt Responding Incore Detectors for PWRs, Status Report,” LRC-9005, Babcock & Wilcox, 1971.

2. AREVA NP Document, 31-9037141-000, “Incore Monitoring System Performance,” NPGD IWO-7327-01, Babcock & Wilcox, 1977.”

3. “Recommended Practice for Seismic Qualifications of Class 1E Equipment for Nuclear Power Generating Stations,” IEEE Standard 344-1987.