UK EPR	Title: PCSR – Sub-chapter 7.6 – Instrumentation
	UKEPR-0002-075 Issue 04

Total number of pages: 67	Page No.: I / V
Chapter Pilot: B. WORINGER *Name/Initials* B. Woringer *Date* 30-10-2012	
Approved for EDF by: A. MARECHAL *Name/Initials* A.Je.Marechal *Date* 31-10-2012	Approved for AREVA by: G. CRAIG *Name/Initials* G. Craig *Date* 31-10-2012

REVISION HISTORY

Issue	Description	Date
00	First issue for INSA information	14.01.08
01	Integration of technical and co-applicant comments	27.04.08
02	PCSR June 2009 update: - Clarification of text - References added	30.06.09
03	Consolidated Step 4 PCSR update: - Document title updated to Sub-chapter 7.6 - Minor editorial changes - Clarification of text - Update and addition of references - Update of Safety Function Categorisation and SCC Classification to clearly summarise Category A, B, C and Class 1, 2, 3 for I&C scope - Process used for classification of SMART devices - New section 3 added on the Process Instrumentation Pre-processing System (PIPS) Note: This document was previously Sub-chapter 7.5	27.03.11
04	Consolidated PCSR update: - References listed under each numbered section or sub-section heading numbered [Ref-1], [Ref-2], [Ref-3], etc - Minor editorial changes - Update and addition of references - Clarification of text (§0.1, §0.2, §1.1, §2.1, §2.1.3.1, §3.2.1, §3.2.5, §3.2.6, §4.1.1, §10.1) and figures (Section 7.6.3 - Figure 1, Section 7.6.6 - Figures 1 and 2)	31.10.12

Continued on next page

REVISION HISTORY (Cont'd)

Issue	Description	Date
04 cont'd	Consolidated PCSR update (cont'd): - Update of text regarding sensor diversity and smart devices (§1.1, §3.1) - Addition of text regarding the PIPS interface (§3) - Clarification added that the AMS, RPVDT and RPVL instrumentation is Class 2 (§4.1.1, §4.2.3.1, §7.1.2)	

For information address:

AREVA NP SAS
Tour AREVA
92084 Paris La Défense Cedex
France

EDF
Division Ingénierie Nucléaire
Centre National d'Equipement Nucléaire
165-173, avenue Pierre Brossolette
BP900
92542 Montrouge
France

TABLE OF CONTENTS

SUB-CHAPTER 7.6 - INSTRUMENTATION

0. SAFETY REQUIREMENTS

0.1. SAFETY FUNCTIONS

The instrumentation is directly involved in the three main safety functions:

- control of fuel reactivity;
- fuel heat removal;
- confinement of radioactive material;

and must allow the measurement of the parameters:

- required by the process control;
- required to inform the operators about the status of the plant.

0.2. FUNCTIONAL CRITERIA

Control of fuel reactivity: The instrumentation must cover all parameters necessary to establish the neutronic status of the core, i.e.:

- the neutron flux in the power state, intermediate state and shutdown state;
- the position of the control and shutdown rods;
- the concentration of boron in the primary circuit.

Fuel heat removal: The instrumentation must cover all parameters representative of the fuel heat removal. It must allow establishment of:

- the thermo-hydraulic status of the core (primary pressure, primary temperature, primary flow rate, etc.);
- the status of the secondary side (Steam Generator pressure, temperature, feedwater flow rate, etc.).

Confinement of radioactive material: The instrumentation must cover all parameters necessary to establish the status of the plant with respect to containment of radioactive material such as:

- containment pressure and temperature;
- positional state of the containment isolation valves;

- radiological level in the buildings.

Monitoring of the status of the plant: The instrumentation must allow the status of the operational and safeguard systems to be established. The relevant information could be pressure measurements, flow rate measurements, level measurements, temperature, speed and the position of actuators, and other data monitored by special instruments.

0.3. DESIGN REQUIREMENTS

0.3.1. Functional and mechanical classification requirements

The instrumentation must comply with the classification and qualification requirements, the single failure criterion and the periodic test requirements for the functions in which it is involved.

The classification requirements are detailed in Sub-chapter 3.2.

The qualification requirements are detailed in Sub-chapter 3.6.

0.3.2. Safety regulation requirements

For Technical Guidelines, refer to section 2 of Sub-chapter 3.1.

Sub-chapter 7.1 describes the requirements related to Instrumentation and Control (I&C). The requirements applicable to the instrumentation concern:

- the functional classification of the instrumentation;
- the single failure criterion, the preventive maintenance and the physical separation;
- the consequences of internal and external hazards on I&C.

0.3.3. Hazards

Instrumentation equipment must fulfil the same requirements for protection against internal and external hazards as the functions and systems to which it belongs.

0.4. TESTS

Instrumentation must be calibrated and connections must be tested during assembly.

Instrumentation and the functions to which it belongs are tested during both commissioning and in service testing of the systems, otherwise it is self tested, and has to be recalibrated if necessary.

1. CONVENTIONAL PROCESS INSTRUMENTATION

1.1. GENERAL REQUIREMENTS

Conventional process instrumentation must provide plant status and process information in order to support functions:

- for normal operation of the plant;
- for the safety of operating personnel and the general population;
- for safe control of the plant in normal, incident and accident conditions in conjunction with the appropriate nuclear specific and radiological instrumentation.

It is assumed that conventional process instrumentation has to support functions of all functional safety categories.

Typical conventional process instrumentation includes:

- pressure measurements;
- flow measurements;
- temperature measurements;
- liquid level measurements;
- rotational speed measurements;
- voltage measurements;
- frequency measurements;
- positional measurements.

General requirements:

- The output signals will be mostly 4 to 20 mA;
- The devices for safety I&C will be qualified in accordance with the qualification requirements of Sub-chapter 3.6.

Specific requirements for instrumentation apply to:

- **Instrumentation equipment selection:** the instrumentation equipment must be selected in such a manner that the measuring range, the accuracy and other relevant features are consistent with the range and amplitude of the variation expected from the measured process parameters and its intended use.

- **Use of smart devices:** avoidance of smart instrumentation equipment, when used for safety or safety related functions, is preferable. When their use is unavoidable, justification to prove that the smart devices are suitably qualified to meet the designed reliability claims must be provided [Ref-1] to [Ref-3]. When smart devices are use in multiple lines of defence they shall be subject to specific diversity criteria [Ref-4]. The approach is described in Sub-chapter 7.7. Refer to Sub-chapter 8.3 for details of the use of smart devices in the electrical systems.

- **Use of common devices:** redundant instrumentation, belonging to different divisions, must avoid using common devices (such as a common nozzle, common isolation valve, common support, etc.).

- **Calibration:** instrumentation equipment must be designed to facilitate and minimise the need for calibration. Test and verification must ensure that instrumentation is properly calibrated. Provisions must be made to avoid errors during maintenance and calibration.

1.2. DESCRIPTION OF THE SAFETY CLASSIFIED INSTRUMENTATION

1.2.1. Pressure measurement

Pressure (or differential pressure) measurement devices are connected to instrument pressure tappings installed in the pipes of systems and equipment of the primary cooling system, on steam generators and on the pressuriser.

Simple or differential pressure transmitters are connected to pressure tappings installed on pipes or devices (tanks, vessels, steam generators, etc.) downstream of primary isolation valves. The transmitters are installed as close as possible to the pipe or vessel via impulse lines.

An instrumentation valve, installed as close as possible to the sensing element, acts as a secondary isolation valve. A device, installed on the instrumentation line between the secondary isolation valve and the sensing element, is used to flush the line from this point towards the fluid system. This device is also used to carry out tests and to calibrate the transmitter.

The primary isolation valve is generally installed in a way that facilitates its operation (e.g. mounted in a room within the containment and accessible during normal operation).

The instrument lines, for fluid phase systems, are placed with a slope between the instrument tap and the transmitter to allow the instrument line to be degassed towards the main system and to prevent any gas cushion forming upstream of the transmitter.

The transmitters required in accident situations are designed to operate in these situations.

Detectors suitable for pressure measurements operating according to different principles may be used:

- diaphragm cells;

- ceramic cells;

- capacitive probes.

An electric transducer converts the detector output signal into an electrical signal that is proportional to the pressure.

1.2.2. Flow measurement

The flow measurement principles used include the following operating principles:

- Differential pressure measurement at the boundaries of a flow restrictor (standard orifice plates, venturi) relies on measuring the pressure on both sides of a restrictor inserted in a flow line (pipe). The flow in the pipe is proportional to the square root of the differential pressure between these two points.

- Differential pressure measurement between the instrument taps.

- Rota meters, this type of flow detection relies on an impeller being placed in a pipe. The rotation of the impeller is a measure of the rate of flow of the medium in the pipe. The impeller generates pulses which can be converted to electrical signals. This type of measurement is normally used in small pipes.

- Ultrasonic flow meters, this type of flow detection relies on a transmitter T1 upstream of a receiving transducer T2. The time for the sound to travel from T1 to T2 is equal to the distance between T1 and T2 divided by the speed of the sound through the stationary medium plus the velocity of the medium.

- Electromagnetic flow meters, this type of flow detection relies on the fluid being electrically conductive. An external magnetic system transmits a magnetic field through the pipe and the liquid. This magnetic field is at right angles to the flow of the liquid and, in accordance with Faraday’s law of induction, an EMF is generated. The EMF generated is dependent on the velocity of the liquid.

1.2.3. Liquid level measurement

The techniques used to measure liquid levels in the pressuriser and steam generators are mainly differential pressure measurement systems (hydrostatic method using a wet reference column).

Two pressure tap lines are connected to a differential pressure transmitter. One of the two pressure tap lines is connected to the lower section (in the water phase) of the pressuriser or steam generator and the other to the upper section (in the steam space). Suitable design measures must be taken in order to prevent any risk of gaseous blanket formation in the instrumentation lines and to avoid the occurrence of measurement errors related to this phenomenon. The pressure impulse line on the steam space of the pressuriser or steam generator is designed according to the principle of a wet reference column. It is equipped with a condensate pot. The function of the condensate pot is to condense the steam in order to maintain a constant level of liquid in the wet reference column under all operating conditions. The condensate pot must be installed at a high point on the instrumentation line, located above the impulse tap and as near as possible to it. The connecting pipe between the condensate pot and the impulse tap must slope downwards towards the device and must not have any low points in order to avoid the creation of a water plug.

As for the pressure measurement method, the measurement device is connected by impulse lines to the vessel. A primary isolation valve is installed as close as possible to the vessel and a secondary isolation valve is installed as close as possible to the measurement device.

The secondary isolation valve has a device used to carry out tests and to calibrate the transmitter. The primary isolation valve is generally installed in a way that facilitates its operation (e.g. mounted in a room within the containment and accessible during normal operation).

In addition to the hydrostatic method based on differential pressure, liquid level can also be measured by a capacitance method. For this measuring method, a probe in the reservoir or tank acts as a capacitor with the reservoir vessel (or mass tube) and the dielectric properties of the fluid in the vessel (or mass tube). The dielectric properties of the fluid between the two electrodes changes with the level of liquid, as does the resulting high-frequency current circulating through the capacitance. This high-frequency current is converted, by the transmitter, into a direct-current signal proportional to the liquid level.

The following types of level measurement can also be used:

- level measurement with a dry reference column;
- level measurement for an open tank at atmospheric pressure;
- air-bubbler type level measurement;
- level measurement by displacement (with plunger);
- ultrasonic type level measurement.

1.2.4. Temperature measurement

Temperature measurements are performed using either thermocouple type detectors or resistance temperature detectors.

Thermocouples and resistance thermometers, for pressurised fluid systems, must be fitted in thermo-wells so that sensing components can be dismantled for maintenance without having to depressurise the system.

Thermocouples are used for applications requiring very rapid acquisition of temperature data. Their small mass provides a much faster response to temperature variations than is achieved with resistance thermometers.

Resistance thermometers consist of a mineral insulation and a platinum coil and must be designed to withstand vibrations. To ensure the greatest possible accuracy, a four-wire circuit installation is used for resistance thermometers.

1.2.5. Rotating speed measurement

Speed of rotation is measured on the primary pumps by the safety classified I&C systems. A ferromagnetic pole is fitted to the impeller shaft of the reactor cooling pump motor. When the motor shaft rotates, a pulsed signal with a frequency proportional to the shaft rotating speed is generated.

1.2.6. Voltage measurement

For the measurement of AC voltage the input voltage is rectified. An amplifying stage converts the DC voltage to a level proportional to the AC input voltage.

For voltage measurements requiring manipulation of the measuring range, the AC input voltage is fed into an appropriate transformer. The output of the transformer is rectified and input into the amplifier stage.

1.2.7. Frequency measurement

The input frequency is applied to an input stage in the detector. The detector generates a voltage/time output signal that is processed by an amplifier and converted into a DC signal proportional to the frequency.

1.2.8. Position measurement on main steam system safety valve

Position measurement is performed by the inductive method. Detection coils are installed in a detector assembly specially designed for the valve. The detection coils are designed in accordance with the valve service temperatures.

2. ACCIDENT AND SEVERE ACCIDENT INSTRUMENTATION

2.1. ACCIDENT INSTRUMENTATION

2.1.1. Definition

Accident instrumentation provides information about all safety systems involved in the safety of the plant and about environment parameters of the plant in order to perform the required actions and manage the accident.

2.1.2. Functions

The monitoring concept distinguishes between:

- continuous monitoring within the plant using permanently-installed measuring equipment. This equipment provides information for:
  - Monitoring the plant status in normal, incident and accident operating conditions;
  - Documentation of relevant process information and initiation of actions;
  - Alarms for initiating manual actions, when the set limit values are exceeded.
- Intermittent monitoring within the plant by taking samples and by analysing them in a laboratory.

The monitoring functions lead to the following measuring and control tasks:

- provide information about process parameters required to allow control room personnel to take the manual protection actions specified in the accident procedures;
- provide information about process parameters to check that the required safety actions are in progress;
- provide information about process parameters to indicate the potential for degradation or loss of containment barriers against radioactive release;
- provide information about process parameters to indicate the operations of safety systems and the other systems involved in the safety of the facility;
- provide information about parameters required for automatic actuation of safety systems, and of the status of the associated protection signals, to enable manual reinforcement of such actuation if these are not achieved automatically;
- provide information about the continued readiness of other “safety” systems, such as those that may be required at a later stage of the recovery from an accident, to enable suitable action to be taken in due time should their readiness be in doubt.

In addition, equipment for measuring radioactive releases and meteorological conditions provides information that enables an assessment of the radiological status of the plant in normal operation, during and after accident situations, and to assist in determining the magnitude of radioactive release.

2.1.3. Measurement principles and requirements

2.1.3.1. Typical provisions

To accomplish these various tasks, the following typical provisions are applied:

- process monitoring designed to withstand incident and accident conditions in the various areas affected by the accident (e.g. monitoring of temperature, pressure, water level, flow rate, gas and liquid analysis, neutron flux, valve position);
- process monitoring with instrumentation used in normal operation which is not affected by incident or accident conditions, and that remains operable during accident sequences;
- room area monitoring inside and outside the containment (e.g. monitoring of temperature, pressure, radioactivity, gas and liquid analysis);
- area monitoring in the environment close to the power plant (e.g. monitoring for releases of radioactive liquid waste water, gases, airborne particles local dose rate, meteorological parameters).

2.1.3.2. Requirements for probes and sensors

In addition to the general safety requirements linked to classification, single failure criterion, periodic testing and consequences of internal and external hazards (see section 0 of this sub-chapter), specific requirements for probes and sensors are applicable:

- the range, response time and the accuracy of the sensors must meet the requirements defined for normal and accident conditions;
- sensors and probes are mounted in such a manner that they are easily accessible for periodic in-service inspections;
- plug and socket connections are used for cable connections to facilitate maintenance;
- the locations of the sensors must meet the requirements defined for normal and accident conditions.

In addition, for probes and sensors used in areas where severe conditions in normal and/or accident operation can occur:

- probes without electronic components are preferred;
- the consequences of the accident must not impact the required accuracy and the probes' response time;

- the electronic components of the sensors used must meet the requirements of the harsh environmental conditions during and after an accident.

2.1.3.3. Requirements linked to accident procedures

The accident procedures described in Sub-chapter 18.3 provide operational strategies in the framework of the state oriented approach. Consistent with the safety functions in which the instrumentation is directly involved (section 0 of this sub-chapter), a permanent diagnostic of the six state functions evaluates the status of the plant in order to determine the control strategy that is appropriate to the plant status. It is based on the following instrumentation that must be able to perform at least Category B functions.

State function	Instrumentation
Criticality of the core	Intermediate range neutron flux
RCP [RCS] pressure and temperature	Primary pressure Core outlet temperature Core outlet saturation margin
RCP [RCS] water inventory	Reactor vessel water level measurement or Core outlet saturation margin
Steam generators (SG) integrity	Secondary pressure (per SG) Secondary activity (per SG)
Steam generator water inventory	Steam generator water level
Containment integrity	Containment pressure Containment activity

2.2. SEVERE ACCIDENT INSTRUMENTATION

2.2.1. Introduction

In order to evaluate information needed for severe accident management and understand the capabilities of instrumentation used in severe accidents, operational staff (including power station operators, on-site support staff and off-site assistance) require a good understanding of accident management procedures and the processes involved in such accidents. To get an accurate picture of the accident and its progress, a large number of parameters would have to be measured. However, a detailed picture is not necessarily needed to derive an effective severe accident management plan, and a few key parameters only can be sufficient, thereby reducing instrumentation requirements.

The section that follows describes the instrumentation available for use during a severe accident.

2.2.2. Instrumentation required for dedicated actions

2.2.2.1. Depressurisation of the primary system

Core exit temperatures are used to decide when to depressurise the primary system. Depressurisation may be monitored by the operator using indications of the position of the dedicated severe accident valves, i.e. Severe Accident (SA) relief valves (see Sub-chapter 5.4).

2.2.2.2. Injection of water onto the corium after transfer to the spreading area

The retention of the corium is a passive concept (see Sub-chapter 6.2).

The success of the corium transfer to the spreading area may be verified by the detection of reactor vessel failure by the temperature increase detected by thermocouples located in the chimney above the spreading area.

The success of corium retention in the core catcher (including its cooling) may be verified by monitoring the containment pressure and the power extracted by the Containment Heat Removal System (EVU [CHRS]).

Failure of the corium cooling process and loss of the core-catcher geometry would be detected by temperature measurements at the intake of the main core catcher cooling channel.

2.2.2.3. Actuation of the containment residual heat removal system (EVU [CHRS])

In the case of degraded core conditions, particularly when the corium has been transferred to the spreading area, water injection by the EVU [CHRS] (see Sub-chapter 6.2) is the sole method available to remove decay heat without degrading the containment function.

Steam condensation induced by the EVU [CHRS] spray decreases the containment pressure as well as reducing air-borne fission products.

Monitoring of containment pressure is used to determine the condition for actuation of the EVU [CHRS].

In addition, the long operation time of the EVU [CHRS] results in the need for measurements to allow diagnoses of the EVU [CHRS] performance and detection of malfunctions to enable corrective maintenance actions to be initiated. The required measurements are mainly the EVU [CHRS] heat exchanger inlet and outlet temperatures, the flow rates and the water level in the EVU [CHRS] sumps in the protective auxiliary buildings.

2.2.2.4. Hydrogen risk management

The passive autocatalytic recombiner units are efficient under all conditions given there is enough hydrogen and oxygen for recombination. No operator action is therefore required to trigger hydrogen elimination (see Sub-chapter 6.2) and no instrumentation is needed. Monitoring of the hydrogen concentration is not considered to produce additional information of benefit for Severe Accident Management.

Homogenisation of the containment atmosphere is achieved before the occurrence of severe accident conditions by the opening of passives devices (foils and mixing dampers).

2.2.2.5. Control of the radiological releases

In addition to containment isolation, the annulus ventilation system (see Sub-chapter 6.2) and the filtration of releases to the stack play an essential role in limiting fission product releases to the environment. The pressure in the annulus is used to check the annulus ventilation system.

Releases can also be monitored by dose rates measured inside the containment, the annulus, and via the activity in the stack.

The injection of soda into the In-containment Refuelling Water Storage Tank (IRWST) limits the release of airborne radioactive material into the containment during a Loss of Coolant Accident (LOCA) or severe accident. If soda injection has not been done as part of the incident or accident management, then it must be performed in a severe accident.

2.2.3. Final requirements and instrumentation list

The required instrumentation can be broken down into two main categories:

<u>The first category</u> involves the instrumentation needed for the operator to perform the required actions. It includes the following:

- core exit temperature (prior to core melt);
- containment dose rate;
- containment pressure;
- annulus pressure;
- EVU [CHRS] filter clogging detection;
- soda (NaOH) tank level.

The instruments detailed above must be able to perform Category C functions as a minimum.

Satisfactory performance and survivability is needed for all instrumentation in this category (sensors, transducers, etc) in the expected severe accident conditions. Qualification for the severe accident conditions is required (see Sub-chapter 3.6).

<u>The second category</u> involves other instrumentation that could be useful for monitoring the progress of the accident and predicting the environmental consequences.

It may include the following:

- position of the SA relief valves;
- detection of reactor vessel failure;
- temperature in the chimney above the spreading area;
- temperature at the intake of the main core catcher cooling channel;
- temperatures and flow rates in the EVU [CHRS];

- level of the sumps in the EVU [CHRS] rooms outside the containment;
- dose rates at different locations (containment, annulus);
- activity level in the stack.

Most of the information that would be useful in managing severe accidents would be available from the instrumentation designed for use in PCC events, and qualified for such events.

3. PROCESS INSTRUMENTATION PRE-PROCESSING SYSTEM (PIPS)

The PIPS provides an interface between process instrumentation and TELEPERM XS systems that use their signals. Where other I&C systems need to process the same signals then the PIPS also distributes them to these systems. The downstream systems that interface with the PIPS are RPR [PS], SA I&C, RCSL, PAS/SAS, NCSS, MCS [SICS] and Diesel I&C. The PIPS safety requirements are consistent with the highest safety category functions with which they are associated.

The PIPS is implemented using seismic SC1 qualified and Class 1 TELEPERM XS conditioning modules.

3.1. FUNCTION

The function of the PIPS is to provide signal processing for the TELEPERM XS based systems (signal conditioning and/or signal multiplication to different systems) as required for the analogue and binary signals delivered by sensors (which do not require specialised conditioning). It also provides signals to some non TELEPERM XS based systems. It provides isolation between the downstream systems for sensors shared by more than one such system.

The PIPS conditions the analogue and binary signals delivered by sensors in order for these to be suitable to process the safety classified functions in the I&C systems and/or display on the MCS [SICS]. The PIPS performs the following functions:

- Converting the electrical signal delivered by the sensor into a current or voltage signal proportional to the physical value it represents and filtering it if needed;
- Distributing the signals to I&C systems which need them;
- Supplying power to the sensors (if needed);
- Isolation between the downstream systems for shared sensors.

Analysis has been performed to identify the claims on components that may be used by more than one line of protection, taking account of the potential for common cause failure.

Where this analysis determines a requirement for diversity between certain signal paths to meet claimed reliabilities for independent functions, diverse equivalents of the PIPS modules will be provided. These modules will be designed and manufactured in accordance with the defined criteria for diversity [Ref-1] [Ref-2] [Ref-3].

3.2. ARCHITECTURE

3.2.1. Signal conditioning and distribution

The TXS components that provide the signal acquisition and transmission are as follows:

- SAA1 analogue signal conditioning modules;

- SBC1 binary signal conditioning modules;
- SNV1 analogue output multiplier modules;
- STT1 temperature measurement transducers;
- SSC1 speed sensor conditioning module;
- SOBx overvoltage barrier module.

3.2.2. Isolation

The exchanges between PIPS and downstream systems are always done in the same division. In the case of signal exchange between the PIPS and the non-TXS systems, the need for overvoltage protection is considered. Therefore overvoltage barrier modules (SOB1) have to be used for binary exchanges.

Each input and output is independent from other inputs and outputs.

3.2.3. Sensors

The above modules are used to condition different types of sensors (i.e. analogue, temperature, RCP speed measurement and binary).

3.2.4. Installation

The PIPS equipment is distributed across the four divisions. The equipment is installed in the I&C rooms of divisions 1 to 4 in the safeguard buildings.

3.2.5. Interface with other I&C systems

The PIPS exchanges information with the following (refer to Section 7.6.3 - Figure 1):

Sensors

Sensors for Category A, B and C functions are conditioned by the PIPS and distributed to the I&C systems using them.

RPR [PS]

RPR [PS] acquires measurements provided by the PIPS as inputs for the RPR [PS] functions.

RCSL

RCSL acquires measurements provided by the PIPS as inputs for the RCSL functions.

NCSS

NCSS acquires measurements provided by the PIPS as inputs for the NCSS functions. This applies only to sensors that are shared between NCSS and TELEPERM XS systems.

SA I&C

SA I&C acquires measurements provided by the PIPS as inputs for SA I&C functions.

PAS/SAS

PAS/SAS acquires measurements provided by the PIPS as inputs for PAS/SAS functions. This applies only to sensors that are shared between PAS/SAS and TELEPERM XS systems.

MCS [SICS]

MCS [SICS] acquires measurements provided by the PIPS as inputs for MCS [SICS] functions. This applies only to sensors that are shared between MCS [SICS] and TELEPERM XS systems.

Diesel I&C

The Diesel I&C acquires measurements provided by the PIPS as inputs for Diesel I&C functions. This applies only to sensors that are shared between the diesel I&C and TELEPERM XS systems.

3.2.6. Power supply

Principle

Each PIPS cabinet is supplied by two 24V DC converters (double infeed principle): one infeed comes from an AC/DC converter and the other from a DC/DC converter.

Within each PIPS cabinet, the power supply distribution and monitoring is handled by the following TXS modules:

- The cabinet supply unit (SCSU1) which contains all functions and modules for receiving the 24V DC system voltage, e.g. decoupling diodes, and infeed filters in a sub-rack with a height of 3 units;

- The cabinet monitoring unit (SCMU2) which contains all functions and modules for supervising the 24V DC circuits. Additionally all functions for cabinet alarm processing and generation of cabinet alarms are provided;

- The cabinet breaker unit (SCBU2) which contains 30 fuses for protecting the various circuits for distribution of the power supplies.

Electrical bus bars identification

For each PIPS cabinet (except PIPS SA I&C cabinets):

- The AC/DC converter is connected to the 400V AC bus LVF for division 1 (LVG, LVH and LVI for divisions 2, 3 and 4). Each bus is backed-up by 2 hour batteries.

- The DC/DC converter is connected to the 220V DC bus LAA for division 1 (LAB, LAC and LAD for divisions 2, 3 and 4). Each bus is backed-up by 2 hour batteries.

- During normal operation the 400V AC bus and 220V DC bus are supplied by an uninterrupted power supply with 2 hour batteries (the emergency diesel generator is also used as a backup to this supply).

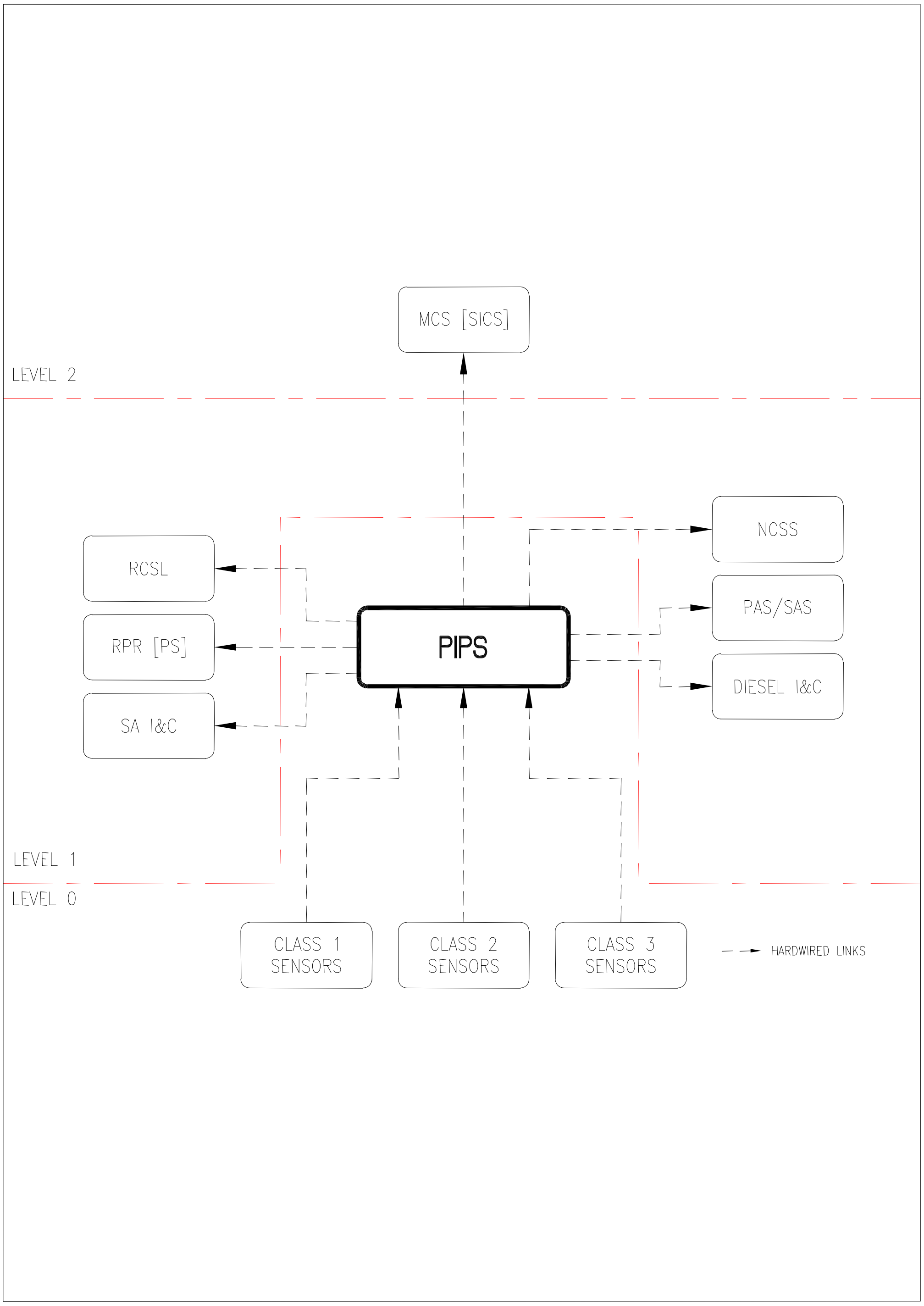
For each PIPS SA I&C cabinet:

- The AC/DC converter is connected to the 400V AC bus LVP for division 1 and LVS for division 4. Each bus is backed-up by 12 hour batteries.
- The DC/DC converter is connected to the 220V DC bus LAA for division 1 and LAD for division 4. Each bus is backed-up by 2 hour batteries.
- The 400V AC bus and 220V DC bus are supplied by an uninterrupted power supply with batteries (the emergency diesel generator is also used as a backup to this supply).

The description of the power supply distribution of the NI is given in Sub-chapter 8.3.

SECTION 7.6.3 - FIGURE 1

PIPS interfaces



4. IN-CORE INSTRUMENTATION

Note: In addition, refer to the quality plans, system specification reports and overall architecture drawings for more detailed information on the In-core Instrumentation [Ref-1] to [Ref-10].

The in-core instrumentation comprises the following systems:

- Flux mapping instrumentation using the Aeroball Measuring System (AMS).
- Fixed in-core instrumentation comprising:
    - 72 fixed Self-Powered Neutron Detectors (SPND) distributed radially and axially over the core;
    - 36 fixed Core Outlet Thermocouples (COT) distributed radially at the core outlet;
    - 5 fixed Reactor Pressure Vessel Dome Thermocouples (RPVDT).

The basic mechanical element of the in-core instrumentation is the instrumentation lance. A yoke, resting on the top plate of the upper core structure between the control assembly guide tubes, supports the guide and protective tubes (fingers). In the tubes are located either an aeroball probe (aeroball finger) or several neutron sensitive self-powered detectors distributed over the core height together with thermocouples installed at the level of the fuel assembly top end piece (in-core detector finger).

Aeroball fingers and in-core detector fingers are grouped together in the instrumentation lance and are located in control assembly guide thimbles of fuel assemblies not occupied by control assemblies. Altogether 12 instrumentation lances are provided. This arrangement is detailed in Section 7.6.4 – Figure 2.

Two out of four Reactor Pressure Vessel Level (RPVL) probes are each fitted with two RPVDT at different elevations in the upper dome. The remaining one of the five fixed RPVDT is called the central RPVDT and uses a single additional reactor pressure vessel head penetration different from the penetrations used by the instrumentation lances and RPVL probes.

4.1. FLUX MAPPING INSTRUMENTATION

4.1.1. Function

The flux mapping instrumentation is operated on demand. Its function is the measurement of the local neutron flux distribution in the reactor core with high resolution. Intermittent measurement of relative local neutron flux in the core is carried out by means of a number of measuring probes distributed radially over the core cross-section and extending axially over the active core height. There is no minimum time interval between two aeroball measurements. As the AMS measurement time is less than 10 minutes, a measurement can be performed every 10 minutes (where a complete flux map involves the measurement of 40 channels). This system delivers information, which is used to construct a 3D image of the core power distribution.

This flux map is then used to calculate the physical core parameter values that are used for the following purposes:

- calibration of the SPND;
- calibration of the ex-core neutron detectors (can additionally be performed if required);
- calibration of the protection thresholds (Protection System (RPR [PS]));
- verification of core conformity, burn-up and behaviour as well as the detection of anomalies;
- validation of the SPND and (if required) ex-core neutron detectors signals.

The AMS is Class 2.

4.1.2. Measurement principle and arrangement

The AMS is an electromechanical, computer-controlled instrumentation system, which is operated on demand. Measurement is performed at 40 fuel assembly positions, which are equipped with aeroball fingers. The indicator material is vanadium contained in stacks of 1.7 mm diameter steel balls. The length of these stacks corresponds to the core height.

A schematic diagram of the AMS is given in Section 7.6.4 – Figure 1.

The radial positions of the aeroball probes are shown in Section 7.6.4 – Figure 2.

The stacks of steel balls are transported pneumatically (by means of nitrogen) into the reactor core where they are activated by neutrons. At the end of the activation period, they are transported to the measuring table room in the containment for measurement of their activity. For this, the activity of an optimised number of sections of each ball stack distributed equally over the length of the ball stack is measured by radiation detectors. The AMS computer uses the resulting activity measurements with various correction factors to derive activation values. These activation values are proportional to the neutron flux level and consequently to the power at the point of activation.

The AMS consists of four subsystems, each with a dedicated valve control system and a separate power supply for each pneumatic transport system. This allows each of the four subsystems to be operated independently.

The mechanical components of the AMS, such as the transport system, valve rack, measuring table with instrumentation equipment as well as the valve control system and solenoid stops of the transport system, are installed inside the containment.

The AMS computer is installed in the safeguard building and performs the following functions:

- sequential control and monitoring of the aeroball measurement process;
- acquisition of the readings of the pulse counters, including attendant information;
- calculation of activation values based on data acquired from aeroball measurement, including correction and plausibility checks of the pulse detector values;

- measurement of the residual activity to update the residual activity data files;
- measurement of the zero rate to check the radiation detectors;
- computer-aided calibration program for the radiation detectors;
- functional testing of the pulse counters including verification of data acquisition and transfer;
- checking of the discrimination threshold setting of all pulse amplifiers;
- monitoring of ball transport time;
- acquisition and evaluation of alarm and status signals;
- switching to the emergency nitrogen supply in the event that the main supply system fails;
- data logging;
- storage of the data records of aeroball measurement sequences on an external storage device.

Taking into account the theoretical calculation model results, as well as other process data, the physical parameters relevant for reactor core monitoring are calculated from the activation values.

4.1.3. Functional characteristics

- Measuring range of the neutron flux: 10^{12} to 5×10^{15} $n.cm^{-2}.s^{-1}$ (total flux).
- Accuracy in the flux range: $\leq 1\%$ of the measured neutron flux value.
- Core γ rays (during irradiation inside the core and after) have no influence on the measurement results.
- Irradiation time: standard is exactly 3 minutes (can be changed if required, e.g. for measurements at power level < 30% Reactor Power).
- Accuracy of the axial position of the measurements: ≤ 1.5 cm.
- No waiting time between 2 flux maps.
- One measurement possible every 10 minutes.

4.1.4. Tests and maintenance

Computer-assisted calibration of the AMS radiation detectors is generally performed with a gamma source during power operation. As AMS measurements are only required every one to two weeks, calibration work can be done easily in-between.

Functional testing of the AMS is generally performed in integrated test programs (some of which are executed automatically at each aeroball measurement) described in section 4.1.2 of this sub-chapter.

Some maintenance operations of the aeroball system require access to the AMS rooms in the reactor building several times per cycle of the power plant. Consequently, the irradiation level in these rooms must be low enough to permit access.

4.2. FIXED IN-CORE INSTRUMENTATION

4.2.1. Fixed self-powered neutron detectors

4.2.1.1. Function

The self-powered neutron detectors (SPND) continuously measure the local neutron flux inside the core and provide signals for the following functions:

- core protection functions;
- core limitation functions;
- core surveillance for maintaining limiting conditions of operation (LCO);
- core control (axial power shape) functions;
- display (core-related monitoring) functions.

The fixed SPND instrumentation supports functions up to Category A. The fixed SPND instrumentation is Class 1.

4.2.1.2. Measurement principle and arrangement

The fixed in-core instrumentation consists of 12 in-core detector fingers distributed radially over the core cross-section as shown in Section 7.6.4 – Figure 2. Each detector finger contains six continuously measuring neutron sensitive self-powered detectors distributed axially over the core height.

The detectors used (n, beta detectors) are SPND with cobalt emitters. The signal provided is an electrical current.

All of the signal-conditioning modules are installed in specific instrumentation cabinets that are located in the four divisions of the safeguard buildings. The purely analogue signal conditioning converts the direct current of the SPND into standard I&C signals. For this purpose, it provides a linear current and compensates for the cable current generated by the radiation in the core and for background noise. The output signal is proportional to the neutron flux at the respective position of each self-powered neutron detector. The modules’ power supply and the electro-mechanical insertion of all modules are monitored and any failure reported.

The signals are transmitted to the downstream I&C systems. Their signal processing allows for the application of calibration factors in physical units of detector current per linear power density.

4.2.1.3. Functional characteristics

- Total flux measuring range: 10^{12} to 5×10^{15} $n \cdot cm^{-2} \cdot s^{-1}$.
- Response time: < 100 ms.
- Signal accuracy of the electronic conditioning equipment: < 1%.

4.2.1.4. Tests and maintenance

The calibration of the SPND is performed at regular intervals (every 15 to 30 days) using a complete flux map. However, if the calibration period is longer, plant safety is always ensured because of the natural increase of the self-powered neutron detector current with burn-up.

The calibration is performed online, during power operation. The AMS supplies activation data, which are a measure of the axial neutron flux distribution at the radial position of each finger. These data and other operational core parameters are acquired by the core computer system that infers 3D maps of linear power density and departure from nucleate boiling ratio. The calibration factors of the SPND are obtained by relating these values to the detector response currents during the same time interval.

The signals are also continuously monitored against maximum and minimum limit values. In the event of abnormal behaviour of the measured data, the signal conditioning equipment can be tested by injecting simulated signals from signal generators.

In addition to the calibration and tests performed during power operation, testing for signal degradation of the self-powered detectors, setting of background noise correction for the instrumentation channels and other tests are performed during refuelling outages. The background noise correction can also be performed during plant operation. Interlocks prevent simultaneous tests of several instrumentation channels.

Necessary replacement of the SPND or thermocouples is performed during refuelling outages.

4.2.2. Fixed core outlet thermocouples

4.2.2.1. Function

The core outlet thermocouples (COT) continuously measure the fuel element outlet temperature and provide signals for the following functions:

- post-accident core monitoring. The core outlet temperatures are used on their own and for the calculation of the core outlet saturation margin;
- information on the radial distribution of core outlet temperatures and on the local thermo-hydraulic conditions.

The fixed COT instrumentation supports functions up to Category B. COT instrumentation is Class 2.

4.2.2.2. Measurement principle and arrangement

A total of 36 COT are distributed over 12 measuring points. Three thermocouples are installed in each in-core detector thimble at the height of the top of the fuel assembly. The temperature of the coolant is acquired at this measuring point above the active zone of the core where the coolant exits from the fuel assembly. The radial position of the thimbles is shown in Section 7.6.4 – Figure 2. The allocation of the thermocouples to the four divisions of the safeguard buildings is the same as those for the SPND of the same in-core detector thimble.

All modules for conditioning of temperature signals are located in the assigned instrumentation cabinets, which are installed in the four divisions of the safeguard buildings. The power supply to the modules and the electro-mechanical insertion of all modules in the I&C sub-racks are monitored and any failure is reported.

The conditioned signals from the thermocouples are transmitted to the downstream I&C systems for further processing.

4.2.2.3. Functional characteristics

- Accuracy (core outlet saturation margin):
  - ≤ 4°C in the range from 0°C to 400°C.
  - ≤ 6°C in the range from 400°C to 800°C.
- Measuring range: 0°C to 650°C at 180 bar.
- Measuring range: 650°C to 1000°C at ambient pressure under post-accident conditions in the reactor building.
- The thermocouples are qualified for the above ranges.
- Response time: < 500 ms (but a response time of 30 seconds is sufficient).
- The thermocouples enable reliable temperature monitoring when the surrounding fluid is water, two phase mixture, or steam up to superheated steam (sub-cooled, saturated or superheated).

4.2.2.4. Tests and maintenance

Measurement signals are checked by comparing redundant measured values. For example, during plant start-up after refuelling outages the measurements can be checked with the reactor under isothermal conditions. In the event of abnormal behaviour of the measured data, the signal conditioning equipment can be tested by injecting simulated signals from signal generators. The thermocouples can be checked by measuring the loop resistance and insulation resistance.

4.2.3. Fixed Reactor Pressure Vessel Dome Thermocouples

4.2.3.1. Function

The water temperature in the reactor pressure vessel dome (RPV-dome) region is measured by thermocouples located in this area.

The temperature of the water in the RPV-dome will be used in the normal operating procedures, to inform the plant operator of the actual thermo-hydraulic status inside the RPV-dome: sub-cooled, saturated, or superheated conditions relative to the reactor coolant system saturation pressure.

The RPVDT safety class is derived consistent with the principles defined in Sub-chapter 3.2. The RPVDT supports non-categorised functions. The RPVDT instrumentation is Class 2.

4.2.3.2. Measurement principle and arrangement

There are 5 RPVDTs arranged as follows:

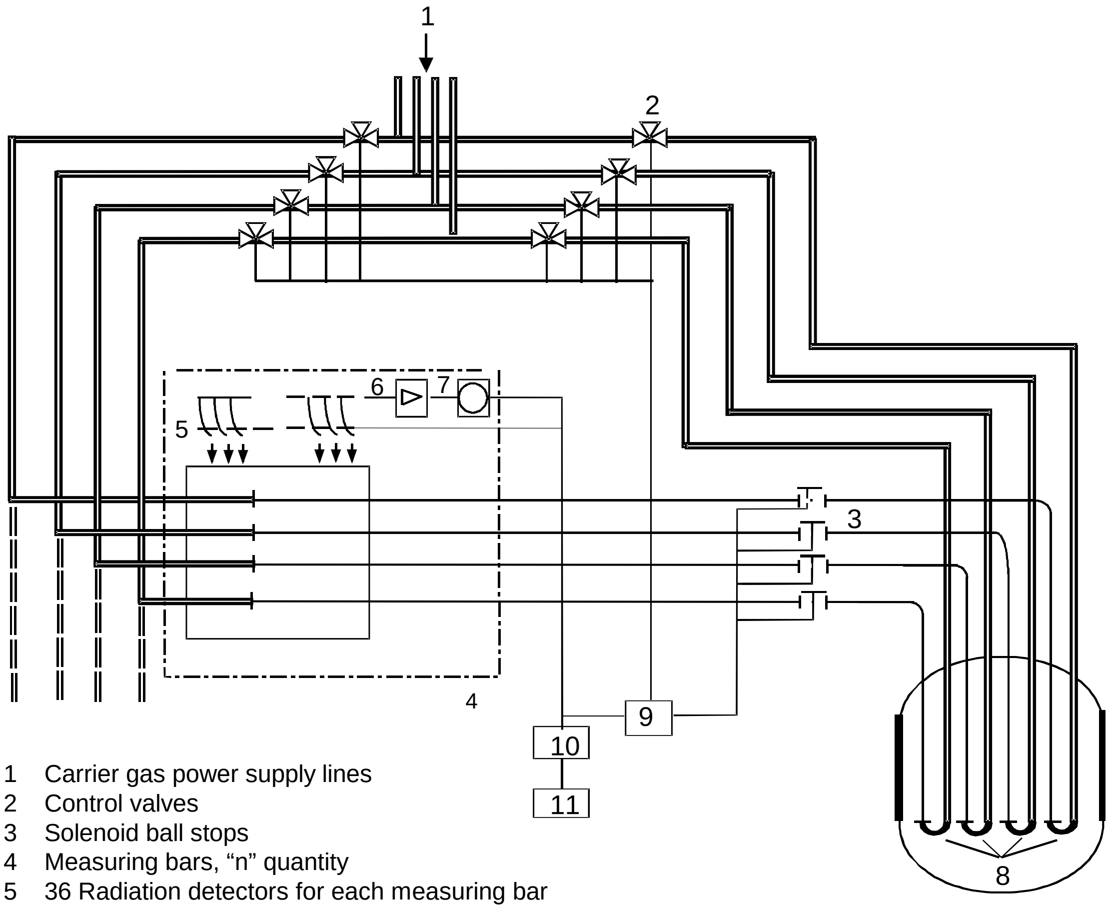
- One thermocouple entering the RPV via a dedicated RVP head penetration and located close to the top of the dome.
- Two thermocouples, in 2 of the 4 RPVL probes, are located at an elevation close to but below the upper section of the control assembly guide tube (flow junction dome/upper plenum).
- Two thermocouples, in 2 of the 4 RPVL probes, are located at an elevation close to the bottom of the dome.

In a horizontal plane, the top dedicated sensor is located near the centre of the RPV-dome; the other sensors are arranged in the RPVL probes further from the centre.

The top dedicated sensor is designed to detect the formation of a steam bubble under natural circulation conditions (hot water at the top). The mid sensor and the bottom sensor are designed to provide information on potential temperature stratification inside the RPV-dome. The bottom sensor may also be used to indicate the temperature at the upper side of the control rod guide tube plate (e.g. for assessment of mechanical behaviour).

SECTION 7.6.4 - FIGURE 1

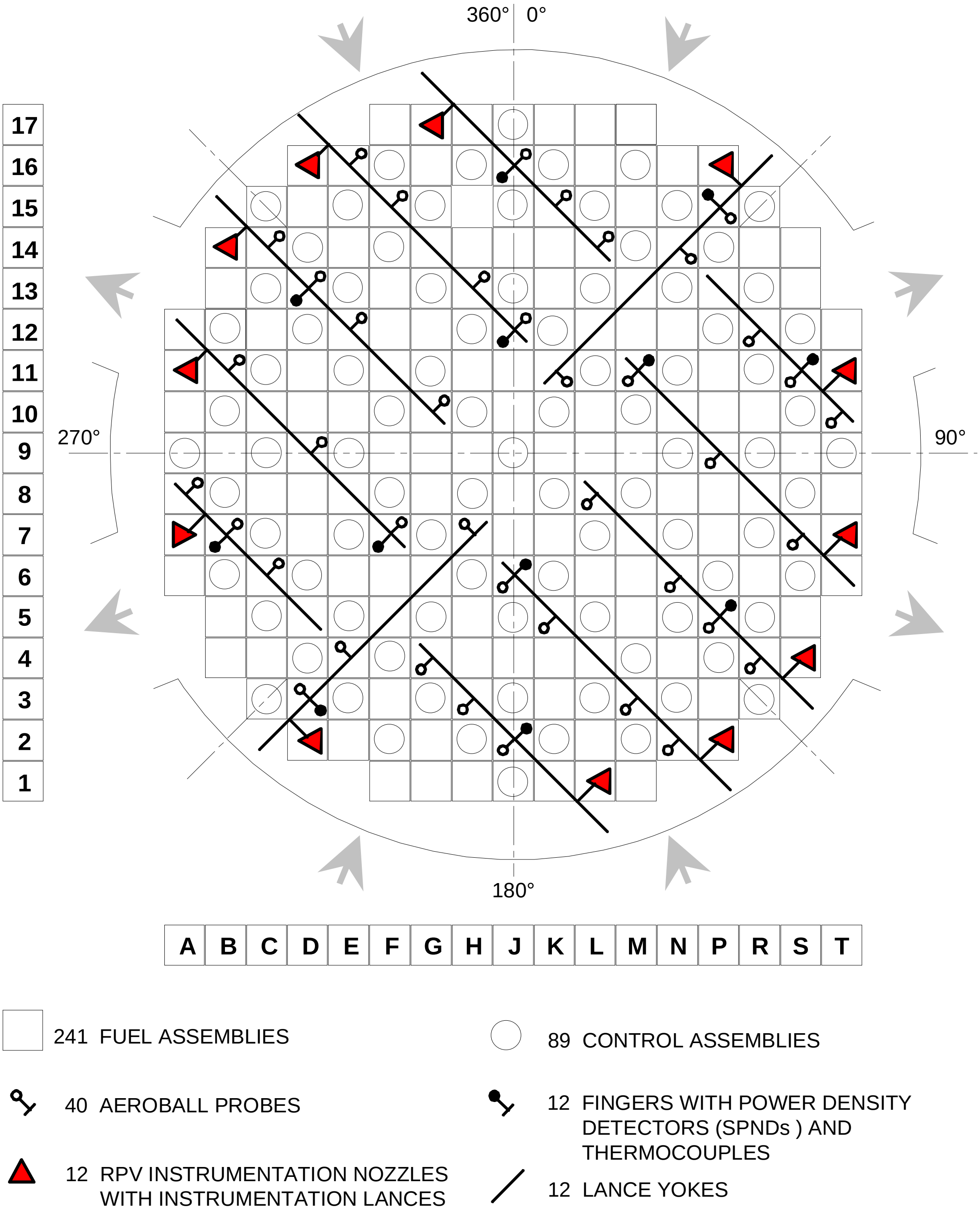
Aeroball measuring system, schematic diagram



1 Carrier gas power supply lines
2 Control valves
3 Solenoid ball stops
4 Measuring bars, “n” quantity
5 36 Radiation detectors for each measuring bar
6 Amplifier
7 Impulse counter
8 Probes, “n x 4"
9 Loading cabinet
10 AMS computer
11 Process information and control system (PICS)

SECTION 7.6.4 - FIGURE 2

Aeroball probes and the fingers with SPNDs and thermocouples



5. EX-CORE INSTRUMENTATION

Note: In addition, refer to the quality plans, system specification reports and overall architecture drawings for more detailed information on the ex-core instrumentation [Ref-1] to [Ref-7].

5.1. FUNCTION

The neutron-sensitive detectors of the ex-core instrumentation are installed outside the reactor pressure vessel, inside the concrete of the biological shield. The ex-core instrumentation provides signals used for core related monitoring, control, surveillance, limitation and protection functions.

The ex-core instrumentation performs the following tasks:

- acquisition of sub-critical neutron pulses during refuelling and shutdown operation;
- acquisition of the neutron flux data to determine the neutron flux level and the rate of increase of neutron flux during approach to criticality and during start-up;
- acquisition of the neutron flux data during load operation to determine the rate of increase of nuclear power and the global axial power shape;
- acquisition of the neutron flux data to determine the nuclear power under accident conditions as part of the post-accident instrumentation function;
- acquisition of the neutron flux data to assist in the monitoring of vibrations of the reactor pressure vessel internals as part of the vibration monitoring system function.

The ex-core instrumentation supports functions up to Category A. The ex-core instrumentation is Class 1.

5.2. MEASUREMENT PRINCIPLE AND ARRANGEMENT

The ex-core instrumentation includes the following instrumentation channels:

- one instrumentation channel group for the source range;
- one instrumentation channel group for the intermediate range;
- one instrumentation channel group for the power range.

Each channel of each group includes a detector and the related signal conditioning equipment.

The total range of the neutron flux to be acquired is approximately 10 to 11 decades up to 150% of the rated reactor power.

The organisation and the overlapping of the measuring ranges required for the source range, intermediate range and power range channels are shown in Section 7.6.5 – Figure 1.

The following measuring techniques are used:

- The source range channels operate in the 6 lower decades of the measuring range. Analysis and calibration of individual detector pulses is performed;

- the intermediate range channels are used in the 7 to 8 upper decades of the measuring range. Ionisation chambers with gamma radiation compensation are used, and the associated conditioning equipment processes the current generated by the detectors;

- the power range channels cover the 3 upper decades of the measuring range. The detectors emit a current that is processed by the conditioning equipment.

The detectors are mounted in movable container chains suspended on steel ropes, which are lowered through guide tubes to their measurement positions alongside the reactor vessel. The guide tubes terminate at their top end in connection boxes, which are accessible during normal operation from rooms located above the closure slab of the reactor well. Section 7.6.5 – Table 1 shows the number of guide tubes provided, the azimuthal distribution around the reactor pressure vessel and the number of container chains associated with the assigned instrumentation channels.

From distribution boxes located in the connection boxes, the detector signals and high voltage supplies to the detectors are transmitted by screened cables to cable penetrations in the containment shell. These screened cables and the penetrations are assigned to the detectors taking account of divisional separation requirements. Outside the containment, the cables are led to the assigned instrumentation cabinets in the appropriate divisions of the safeguard buildings.

The redundant instrumentation channels of the ex-core instrumentation are physically separated. This separation applies to the cable runs, the containment penetrations and the location of the signal conditioning equipment in the four divisions of the safeguard buildings.

The signals are transmitted to the I&C functions that require them.

5.2.1. Source range

The thermal neutron flux in the source range is monitored by three redundant instrumentation channels.

The source range channels are required to monitor the nuclear flux level from sub-critical conditions to critical flux level conditions in the pulse range during refuelling and maintenance shutdown conditions and during cold or hot standard shutdowns.

The source range detectors are boron-lined proportional counters. In power operation, they are de-energised and remain permanently in their measuring position.

For the three source range channels, the detectors in each channel are housed in containers located at the core mid-plane.

Signal conditioning of pulse signals emitted by the detectors mainly perform the following functions:

- provision of a high-voltage power supply to the detectors;

- amplification of pulses;
- suppression of disturbing background signals (noise and gamma signals) using a discriminator;
- calibration of frequency and pulse height of output pulses;
- analogue conversion of detector raw pulses to standard pulse trains suitable for transmission over the required distances. The downstream I&C systems are fitted with input modules to infer count rates from the transmitted pulse trains. The count rate is proportional to the neutron flux at the measuring position. It is derived in physical units applying the appropriate calibration factor to the count rate (to generate a signal “relative rate of change of flux” to detect the rate of increase of neutron flux).

In the event of self-revealing failures (e.g. power supply fault), binary signals are output which generate alarm signals. A test generator is provided for simulation of detector pulses. Interlocking circuits prevent the simultaneous test of several redundant instrumentation channels.

5.2.2. Intermediate range

The thermal neutron flux in the intermediate range is monitored by four redundant measuring channels. The detector of each measuring channel is housed in a container located at the core mid-plane. The intermediate range detectors are installed in the same guide tubes as the power range detectors.

The intermediate range channels are required to monitor the neutron flux level from approximately 10^{-6} % to 50% of rated power. This range corresponds to the start-up range.

The intermediate range channels are able to perform their function in a post-accident situation.

The detectors operate in the current range. The conditioning equipment mainly performs the following functions:

- high voltage power supply for the detectors (measuring high voltage and compensation high voltage);
- analogue conversion of the detector direct current into a standard I&C signal with binary coding of the logarithmic range. This output signal is proportional to the neutron flux at the measurement position and is used by the downstream I&C systems. The neutron flux in physical units is inferred by applying the appropriate calibration factor (this signal is also used downstream to determine the “relative rate of change of flux” used to detect the rate of increase of neutron flux).

In the event of self-revealing failures (e.g. power supply fault), binary signals are output which will generate alarm signals. A test generator is provided for simulation of detector currents. Interlocking circuits prevent the simultaneous test of several redundant instrumentation channels.

5.2.3. Power range

The thermal neutron flux density in the power range is monitored by four redundant instrumentation channels. Each instrumentation channel is equipped with two detectors with one detector assigned to the top half of the core and one detector assigned to the bottom half of the core. The detectors are housed in containers such that they detect approximately the integral reactor power generated in the top or the bottom half of the core. The intermediate range detector is installed between the top half of the core power range detector and the bottom half of the core power range detector.

Uncompensated ionisation chambers are used as detectors. Gamma radiation compensation of the chambers is not required as the ionisation current generated by gamma radiation during power operation is negligible compared to that generated by the neutron flux.

The power range channels are used during reactor power operation and cover a power range from 0.1% to 150% of rated power.

The conditioning of the direct current signals emitted by the uncompensated ionisation chambers mainly performs the following functions:

- high-voltage power supply to the detectors;
- analogue conversion of the detector direct current into a linear standard I&C signal proportional to the neutron flux at the measurement position. This output signal is used by the downstream I&C systems. Neutron flux and/or reactor power in physical units are inferred applying the appropriate calibration factors (this signal is also used in downstream processing to determine the “relative rate of change of flux” used to detect the rate of increase of neutron flux).

The conditioning equipment can also generate signals for vibration monitoring of reactor pressure vessel internals.

In the event of self-revealing failures (e.g. power supply fault), binary signals are output which will generate alarm signals. A test generator is provided for simulation of detector currents. Interlocking circuits prevent the simultaneous test of several redundant instrumentation channels.

5.2.4. Measuring ranges, accuracy, response time

The measuring ranges are defined in sections 5.2.1, 5.2.2 and 5.2.3 of this sub-chapter, and are illustrated in Section 7.6.5 – Figure 1.

The accuracy of the ex-core instrumentation is compatible with the global accuracy of the protection channels. Global accuracy of the source range channel and the intermediate range channel are 10% or less of the signal. The accuracy of the power range instrumentation, including the digital processing, is 1% or less of rated power.

Typical response time of the source range instrumentation, including detector, signal conditioning and processing by the downstream I&C systems, is between 1 second (high flux region) and 100 seconds (low flux region). The response time of the intermediate range and power range instrumentation, also including detector, signal conditioning and processing by the downstream I&C systems, is 300 ms or less.

5.3. TESTS AND MAINTENANCE

The on-line checks consist of a qualitative evaluation of the measured data for the instrumentation channels and their behaviour during power operation. Here the measured data are compared with those from the redundant channels. The monitoring equipment which monitors power supply to the electronic modules, detector high-voltage power supply and which compares the readings from redundant measuring positions, outputs alarm signals in response to any failures, and thereby supports these checks.

Calibration of the power range instrumentation channels is performed at periodic intervals to match the changes in radial power distribution over the burn-up cycle. Calibration is based on reactor thermal power, which is determined by means of a heat balance, and on data provided by aeroball measurements.

Functional testing of the instrumentation channels can be performed at appropriately set intervals by injection of simulated signals from signal generators, recording the detector characteristics and measuring for signal degradation.

If maintenance procedures are necessary, access to instrumentation is possible during plant operation and plant outages without any restrictions.

For the container chains, set down positions are provided in the concrete of the reactor well wall which enable sufficient activity decay for any irradiated container chains housing faulty detectors.

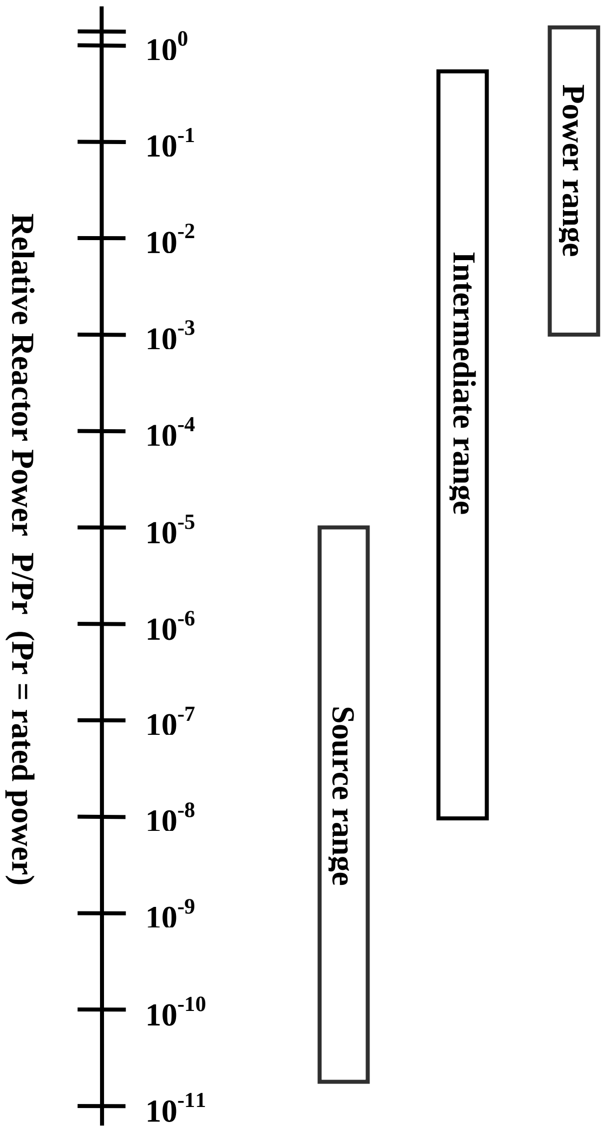
SECTION 7.6.5 - TABLE 1

Ex-core instrumentation - guide tubes, container chains and instrumentation channels

Range	Number of Guide Tubes	Azimuthal Position	Number of Container Chains	Number of Instrument Channels
Source range	3	0°, 90° 270°	3	3
Interm. Range Power range	4	45°, 135°, 225°, 315°	4	4 4

SECTION 7.6.5 - FIGURE 1

Measuring ranges of ex-core instrumentation



6. ROD POSITION MEASUREMENT

6.1. GENERAL

6.1.1. Purpose of the rod position instrumentation

The rod position instrumentation provides the following I&C functions with the measured position of each Rod Control Cluster Assembly (RCCA):

- Protection I&C functions (implemented in the RPR [PS]);
- Limiting condition of operation (LCO) surveillance and limitation functions (implemented in the Reactor Control, Surveillance and Limitation system (RCSL)).

6.1.2. Classification of the rod position instrumentation

The highest category function using the measurements provided by this instrumentation is Category A. Hence, the rod position instrumentation is Class 1.

6.2. INTERFACES AND BOUNDARIES

The rod position measurements are implemented at level 0 of the I&C architecture. Interfaces with the other I&C systems are represented in Section 7.6.6 – Figure 1.

6.3. RULES

6.3.1. Design rules

- Response time:

The response time of the instrumentation must be less than 3 seconds.

- Accuracy:

The accuracy of the measurements must be less than 3% of the core height.

- Redundancy:

The measurement of the individual position of each RCCA is not redundant. Sub-banks of four rods (RCCA) are defined and normally moved together, which constitute a four-fold redundant structure. Therefore, when a group is moving together, the rod position instrumentation is dealt with as four-fold redundant.

6.3.2. Other rules

- Environmental conditions:

The detectors are installed inside the reactor building, above the reactor vessel head. They are designed to withstand the local environmental conditions.

6.4. STRUCTURE

6.4.1. Description of the structure

There are 89 rods (RCCA), comprising 36 control rods and 53 shutdown rods. The rods are assigned to four divisions according to the four sectors of the reactor core to which they belong. Therefore, each division encompasses the position measurements of 22 rods. It is noted that one division also includes the central rod.

The rod position instrumentation consists of a set of four tubular coil measuring circuits for each mechanism associated with each control rod. A measuring circuit consists of:

- the detector consisting of a set of 4 tubular coils;
- the cables and plugs;
- the conditioning module (one for 2 RCCA);
- the digital processing unit (one for all measurements of a division);
- the power supply equipment (per cabinet, i.e. per division).

The rod position measurement detector is made up of a primary coil and a secondary coil covering the height of the thimble and provides an analogue measurement. The magnetic coupling between the primary and secondary coil depends on how far the rod drive shaft is inserted into the tubular coils, i.e. it provides the analogue measurement position of the rod.

Two auxiliary secondary coils located at the extremities of the thimbles are used to validate the highest and lowest positions of the control rod.

The primary coil is supplied by a constant sinusoidal current superimposed with a DC current. The DC offset enables determination of the average temperature of the assembly. Hence, temperature compensation is calculated in the digital processing of the position measurement.

6.4.2. Compliance with design rules

- Redundancy:

The proposed structure complies with the redundancy related design rule for Class 1 and 2 I&C equipment as it provides a four-fold redundancy for a given group.

6.5. INSTALLATION

The reactor core is divided into four sectors numbered from 1 to 4. Each sector has 22 control rods. The central control rod is assigned to sector 4, which therefore has 23 control rods. The general layout and routing principles are illustrated in Section 7.6.6 – Figure 2.

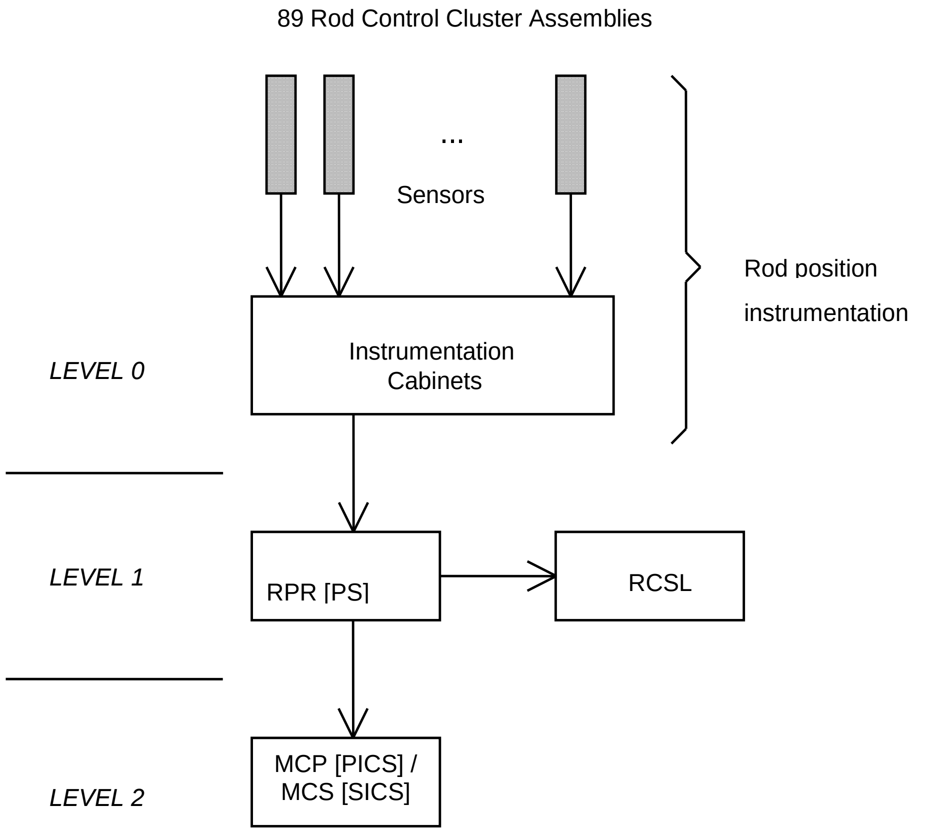
6.6. TESTS

Periodic surveillance tests dedicated exclusively to the analogue rod positions are not anticipated during normal plant operation. Surveillance is provided by the following measures:

- DAD (deviation analogue position versus digital step counter monitoring) is continuously performed;
- The digitalised acquisition unit monitors and indicates each violation of the measuring ranges;
- In the course of plant start-up the analogue rod position is checked, when in the bottom and in the top end position. If needed the corresponding parameters for rod position determination are adjusted.

SECTION 7.6.6 - FIGURE 1

Rod position measurement - interfaces with other I&C systems



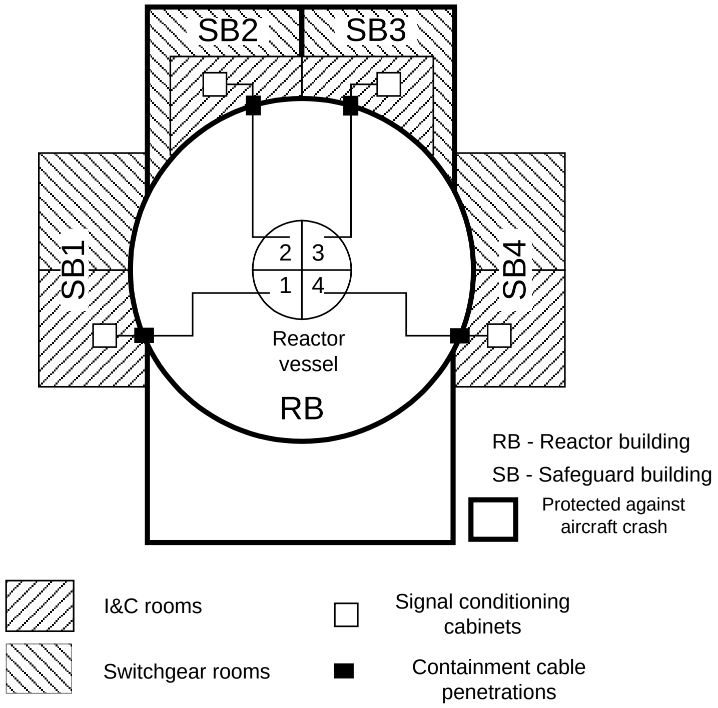
RPR [PS]	:	Protection System
RCSL	:	Reactor Control, Surveillance and Limitation System
MCP [PICS]	:	Process Information and Control System
MCS [SICS]	:	Safety Information and Control System
MCR	:	Main Control Room

This figure only deals with the rod position measurements. The interconnections between other I&C systems do not appear.

This figure is purely functional. No indication is given regarding the hardware of the connections (network, hardwired ...)

SECTION 7.6.6 - FIGURE 2

Rod position measurement - general layout and routing principles



7. REACTOR PRESSURE VESSEL WATER LEVEL MEASUREMENT

Note: In addition, refer to the quality plans, system specification reports and overall architecture drawings for more detailed information on the reactor pressure water level measurement [Ref-1].

7.1. GENERAL

7.1.1. Purpose of the reactor pressure vessel water level measurement

The purpose of the Reactor Pressure Vessel water Level (RPVL) measurement is to provide an indication of the water level in the reactor vessel.

This instrumentation is used during post-accident situations and, together with other post accident instrumentation, it supports the operator's decisions on appropriate mitigation actions.

7.1.2. Reactor vessel water level instrumentation safety classification

The reactor vessel water level instrumentation may participate in the post-accident management. It is safety classified consistent with this purpose and the safety principles defined in Sub-chapter 3.2. The RPVL instrumentation is Class 2.

7.2. INTERFACES AND BOUNDARIES

The RPVL instrumentation is implemented in the level 0 of the I&C architecture and consists of:

- sensors;
- mechanical equipment as the interface between the sensors and the fluid in the pressure vessel;
- signal conditioning and supply equipment;
- cables between the sensors and the signal conditioning and supply equipment;
- supporting structures for the above elements.

The output signal from the conditioning equipment of the RPVL instrumentation is processed in the Safety Automation System (SAS) which indicates the water level to the operator (via the Process Information and Control System (MCP [PICS]) and the Safety Information and Control System (MCS [SICS])).

7.3. RULES

7.3.1. Design rules

- Redundancy and independence:

Due to the importance of the RPVL measurement in diagnosing the plant state in order to allow appropriate mitigating actions to be taken, the RPVL measurement is fourfold redundant.

Each RPVL measurement instrument is electrically independent of the others.

- Information provided by the RPVL instrumentation:

  Three threshold levels must be monitored by the RPVL measuring equipment:

  - the highest threshold corresponding to the top of the reactor coolant system hot leg (THL = Top of hot leg);
  - the lowest threshold corresponding to the bottom of the reactor coolant system hot leg (BHL = Bottom of hot leg);
  - an intermediate threshold located between the top and the bottom of the reactor coolant system hot leg (MHL = Middle of hot leg).

The RPVL instrumentation is required to provide a representative indication of the water level in the liquid phase, in a two-phase mixture or in a steam phase in the upper plenum of the reactor vessel for various operating conditions. The RPVL instrumentation assemblies must withstand high temperatures and high temperature gradients in the vessel:

- Accuracy of the RPVL measurement:

The three threshold levels must be discriminated without ambiguity.

- Response time of the RPVL measuring equipment:

No automatic action is anticipated based on the RPVL measurement as the RPVL measurement supports only manual actions. Therefore, a short response time is not required.

7.3.2. Other rules

- Environmental conditions:

The RPVL instrumentation must withstand the normal, accident and post-accident conditions where they are located.

- Temperature and humidity conditions for the conditioning cabinets:

The conditioning cabinets are located in the I&C rooms of the safeguard buildings. They must withstand the temperature and humidity conditions specified in section 1 of Sub-chapter 9.4.

7.4. STRUCTURE

7.4.1. Architecture

7.4.1.1. General description

The sensor consists of a heated thermocouple, a heating element and an unheated thermocouple. As heat transfer in water is considerably higher than in steam, the heated thermocouple is at a lower temperature and generates a smaller signal when it is immersed in water than when it is surrounded by steam. The difference between the signals of the heated and unheated thermocouples is used to determine the coolant level in the reactor pressure vessel. The coolant level is monitored by thresholds. If the difference in the output signal between heated and unheated thermocouples exceeds a defined threshold, this is an indication that the water level has fallen below the sensor.

There are four level measurement assemblies. Each of the assemblies monitors the water level at three axial measuring points: THL, BHL, MHL (see section 7.3.1 of this sub-chapter). The three sensors are located axially above each other. The level sensor assemblies are fitted in the upper part of the reactor vessel. The probe thimble is inserted into the vessel through the closure head by means of an instrumentation nozzle. It extends from outside the closure head nozzle to a zone located between the bottom of the reactor coolant lines and the upper core plate. The probe thimble is housed in a guide tube (see Section 7.6.7 – Figure 1).

7.4.1.2. Description of the equipment

- Sensor:

The sensor consists of a heated thermocouple, a heating element and an unheated thermocouple located at the same height but housed in separate tubes within the probe thimble.

The thermocouples have good thermal contact to the inner surface of the housing tubes. The heating element directly contacts the heated thermocouple. Both elements are welded to the inner surface of the tube.

- Probe thimble:

Thermocouples and heating elements are inserted into housing tubes fitted in a probe thimble. Each probe thimble incorporates three sensors, which are positioned at three elevations (one sensor per elevation) in order to measure at the top of hot leg (THL), at the bottom of hot leg (BHL) and at an intermediate level (MHL). The probe thimble is perforated with a large number of drilled holes to allow a good circulation of water and steam alongside the housing tubes.

- Guide tube:

Each probe is surrounded by a concentric guide tube, which is located in the region of the upper plenum and extends into the dome region of the RPV. In the region of the upper plenum, the top of the guide tube is attached to the upper support plate and the bottom of the guide tube is connected to the upper core plate. In the dome region, the lower section of the guide tube is attached to the upper support plate. The top of the upper section of the guide tube is equipped with a funnel for travel guidance of the probe during assembly.

The area between the top of the guide tube (where the funnel is located) and the probe tube must be as small as possible, to provide resistance to steam flow from the dome into the probe.

The functions of the guide tube are:

- to locate the probes in their desired positions;
- to protect the probe from the upper plenum flow induced forces.

The guide tube is also designed to ensure defined fluid conditions around the sensors. This is important because in many accident conditions the remaining water is turned into a highly turbulent steam/water mixture, which could prevent the sensor from directly contacting the fluid and hence fail to provide accurate level indication. Consequently, the probe is housed within a protective tube, which is closed over its entire length except at the bottom and at the top where communicating ports are located.

- Cables and connector:

The signals from the thermocouples pass along insulated cables from the thermocouple material to a cold junction box located outside the containment in an area where the temperature is stable and homogeneous and where the temperature compensation for all thermocouple signals takes place. Electrical penetrations, connectors and cables are consequently compatible with the environmental requirement of the thermocouples up to the compensation box. The temperature of the connection point (cold junction) is measured by one resistive thermal device (RTD) element per division.

- Supporting structure:

The probe is located by the instrumentation nozzle on the closure head and by the guide tube in the upper plenum. It is suspended from the head of the instrumentation nozzle, and the nozzle closure performs the pressure retaining function to ensure leak tightness. The cables are routed along the cable bridge above the vessel head and then to the safeguard buildings in appropriate cable trays via reactor building electrical penetrations.

- Conditioning equipment:

The conditioning equipment for the four probes is installed in four separate divisions in the safeguard buildings. The conditioning equipment performs the compensation of the measured temperatures, subtraction of thermocouple signals, and threshold monitoring. The conditioning equipment provides the power supply to the sensors heating element and to the cold junction RTD and conditions the signals received from the thermocouples and RTD. The conditioning equipment is housed in one cabinet per division.

Wire breaks are detected by a surveillance function, which initiates an alarm.

7.4.2. Adherence to design rules

Redundancy and independence:

- The RPVL instrumentation is made up of four probes located in four different areas of the reactor pressure vessel upper plenum.
- Each probe uses a dedicated reactor vessel head instrumentation nozzle.
- Each of the four probes includes three sensors to indicate if water inventory exists at three different RPV threshold levels (THL, MHL, BHL) respectively.

- The conditioning equipment for each probe is installed in a different safeguard building and is supplied by the related independent division.

7.5. INSTALLATION

The conditioning equipment is installed in the I&C rooms of safeguard buildings 1, 2, 3 and 4.

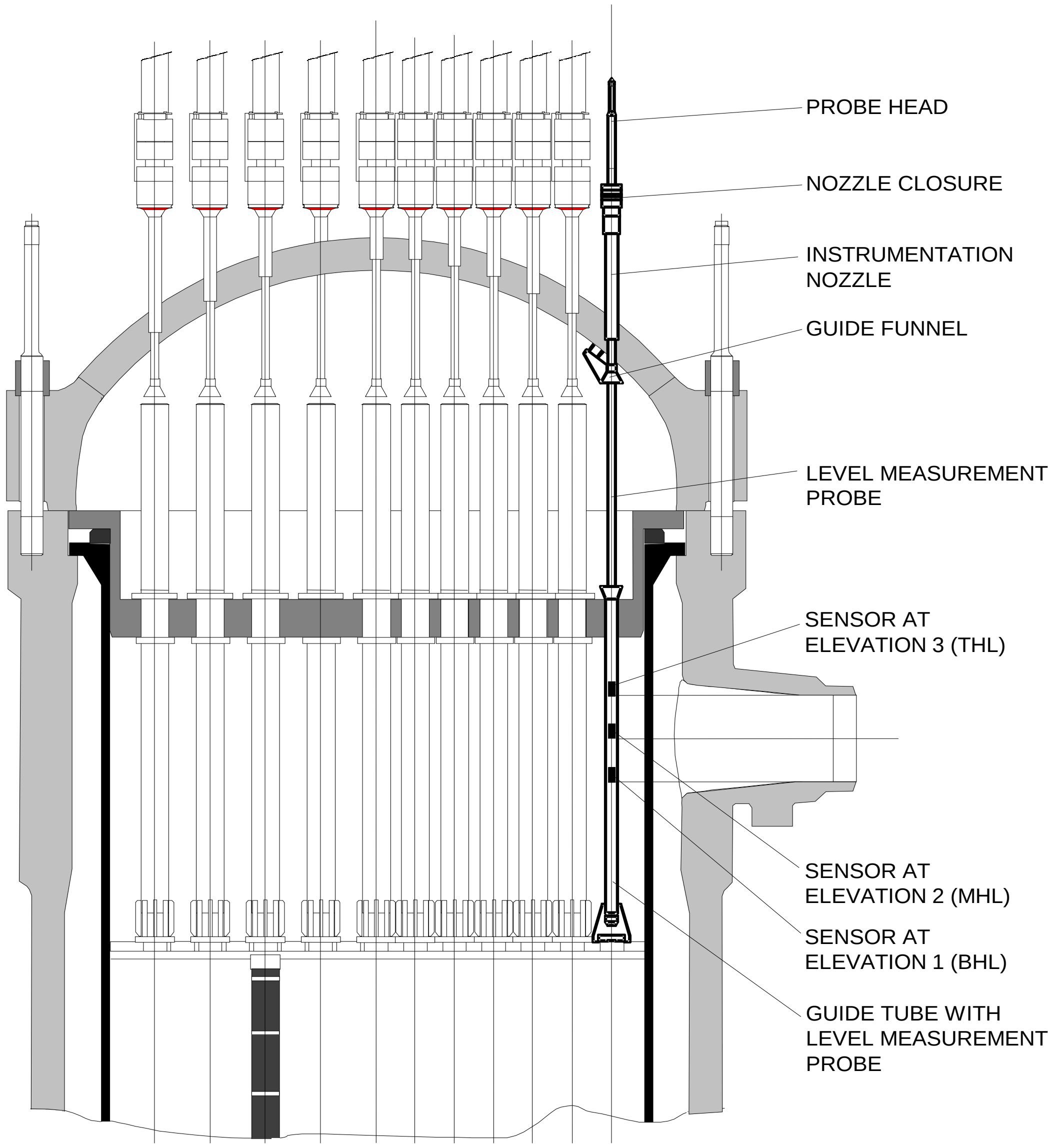
7.6. PERIODIC TESTING AND CALIBRATION

Appropriate periodic testing must be performed during operation to ensure that the information delivered by the reactor pressure vessel water level instrumentation is correct.

Calibration must be performed if signal drifts are detected.

SECTION 7.6.7 - FIGURE 1

RPV water level measurement - General arrangement of water level instrumentation in reactor vessel and vertical arrangement of level measurement sensor



CONTROL RODS, GUIDE FUNNELS AND NOZZLES IN THE BACKGROUND NOT DRAWN

LEVEL MEASUREMENT SENSORS (FOUR PROBES):
- 4 SENSORS AT ELEVATION 1 (BHL)
- 4 SENSORS AT ELEVATION 2 (MHL)
- 4 SENSORS AT ELEVATION 3 (THL)

8. LOOSE PARTS MONITORING AND VIBRATION MONITORING

8.1. INTRODUCTION

Loose parts monitoring and vibration monitoring are performed by non-classified equipment.

The equipment includes measuring channels (from accelerometers) as well as conditioning and signal processing devices.

8.2. LOOSE PARTS MONITORING

Loose parts are elements of the reactor coolant system carried away by the cooling fluid which become trapped in certain areas. Due to the hydraulic recycle, they can impact repetitively on the inside walls of the reactor coolant pressure boundary and its internals and have the potential to cause rapid damage to the reactor coolant system.

The loose parts monitoring system continuously checks the reactor primary circuit. The system uses detectors (e.g. accelerometers) that monitor areas of the primary circuit where the probability of loose parts is the highest.

Loose parts carried by the primary coolant generate noise as a result of impact with the internal walls and structures of the circuit. This is detected by the sensors. The signals are then transmitted through preamplifiers to the signal processing units. The signals sent by the accelerometers are conditioned by load converters in the form of current signals. They are then transmitted to the loose parts detection modules which process and condition the measuring channels.

The loose parts can be identified by examining the RMS value of the noise signals coming from the structure in a predetermined frequency range (acoustics: approximately 1000 Hz – 20 kHz). Threshold levels are defined based on reference measurements and alarms are triggered should they be exceeded. Experience with fully automated monitoring systems has shown that thresholds must be defined at relatively high levels to prevent spurious alarms being triggered due to the stochastic nature of the background noise. Small variations cannot be detected automatically from the noise pattern.

However, these small variations can be selectively identified by the human ear. It is for this reason that it is necessary to augment the automatic monitoring system with subjective monitoring by listening to the noise at regular intervals. The system offers the possibility of an audio mode.

8.3. VIBRATION MONITORING

The purpose of the vibration monitoring system is to identify changes in the vibratory behaviour of some components of the main primary circuit e.g. elasticity characteristics, damping, coupling and excitation forces.

Feedback from the French nuclear plants and current studies on the EPR [Ref-1] to [Ref-3] has indicated that there is a need to install vibration monitoring equipment on the Primary Motor-Driven Pumps. This involves the shaft line and the motor support clamp (the proposed instrumentation is mentioned in section 1 of Sub-chapter 5.4). In addition to the specific methods of detection, such monitoring permits early detection of certain types of anomalies (deterioration of bearings and thrust bearings or of the hydrostatic bearing, erosion of the impeller by cavitation, deterioration of packless seals, etc.).

9. RADIATION MONITORING

9.1. SAFETY OPERATION

As radiation monitoring inside the plant is supported by the Plant Radiation Monitoring System (KRT [PRMS]) (except for personnel radiation monitoring), all the safety functions, functional criteria and design requirements are described in detail in Sub-chapter 12.3 "Radiological Protection Measures". This includes details of the system classification, hazard withstand capability, seismic classification and system architecture applicable to specific radiation monitoring functions.

9.2. FUNCTIONS

The radiation protection instrumentation contributes to the:

- radiation protection of the operating personnel and the surrounding population;
- control of the plant unit in conjunction with conventional, i.e. non-radiological, control measurements, during authorised operation (normal operation and anticipated operational occurrences) and potential accident situations.

The monitoring concept is based on:

- continuous monitoring within the plant by permanently-installed measuring instrumentation, detectors that provide information on the status of the plant in normal, incident and accident circumstances, data recording equipment and, where required, initiation of automatic or manual actions when defined thresholds are exceeded;
- periodic monitoring within the plant by taking samples and their subsequent analysis in a laboratory;
- additional monitoring done by fixed or mobile measuring equipment inside or outside the plant.

These measurements are supplemented by fixed, portable or mobile measuring devices for the purpose of contamination checks and monitoring of personnel and work areas.

These functions are subdivided as follows:

- process monitoring (monitoring of the activity of liquids or gases in systems);
- area monitoring (airborne activity monitoring and local dose rate monitoring);
- radioactive effluent monitoring (liquid and gaseous effluent monitoring);
- personnel monitoring;
- contamination monitoring;

- solid waste monitoring;
- environmental monitoring.

The radiation protection instrumentation supports safety functions up to Category A (see Chapter 12 “Radiological Protection”).

9.3. MEASUREMENT PRINCIPLES AND TYPICAL PROVISIONS

This section describes the measurement principles and typical provisions applicable to the permanently installed radiation instrumentation for process and radioactive effluent monitoring.

The following measurements related to plant management are not considered:

- mobile measuring devices;
- personnel monitoring;
- contamination monitoring;
- solid waste monitoring;
- environmental monitoring;
- radiological laboratories.

Nuclides that emit alpha radiation are rare compared to nuclides that emit beta or gamma radiation, and hence they are not representative of the radioactivity emitted in the plant. In addition, due to its extreme absorption, alpha radiation is not suitable for continuous monitoring of the radioactivity present or released in the plant.

Permanently installed radiation monitoring equipment used in nuclear power stations is based on measurement of beta or gamma radiation.

A limited number of measuring devices are used. When possible, these devices are based on standard components. The variety is limited to the lowest level possible. Whenever possible, suitable off-the-shelf equipment is preferred. This simplified strategy allows for optimisation of the maintenance and the progressive renewal of equipment.

The devices installed permanently for the continuous monitoring of the plant include the following components:

- detector;
- measuring vessel (if required);
- shielding against radiation (if necessary);
- support structure;
- cables and connectors;
- transducer;

- signal processing module;
- test system with a radioactive source.

These permanent devices may be supplemented by devices that continuously sample the monitored medium for periodic analyses in a radiochemical laboratory.

The choice of equipment considers the following:

- radiological aspects e.g. measurement of activities (quantity or concentration) or dose rate;
- medium to be monitored (liquid or gas);
- type of radiation (beta or gamma);
- plant conditions (normal operation, shutdown, incidents, and accidents).

The selection of components to be used is based on the following criteria:

- the accuracy required of the measurement signals with respect to the operating bands and the environmental conditions (e.g. temperature, humidity, pressure, local dose rate, seismic load) during operation;
- the required response time;
- the required measuring range;
- the required detection threshold;
- the specified energy range.

In order to reduce the probability of common mode failure, diverse components have been selected for the redundant measuring channels. The selection criteria for the radiation protection instrumentation components fulfil the relevant quality assurance requirements. The preferred components are those that have been proven in service in nuclear power stations.

9.3.1. Detectors

The following detectors can be used for beta and gamma measurements:

<u>Beta radiation measurements</u>

- Scintillation detectors.
- Proportional counters.
- Beta sensitive Geiger Müller counters.
- Solid-state detectors.

<u>Gamma radiation measurement</u>

- NaI (Tl) scintillation counters (sodium-iodide with thallium).
- Geiger Müller counters.
- Proportional counters.
- High purity Germanium detectors.
- Ionisation chambers.

If necessary, a pre-amplifier for pulse transmission is incorporated or located close to the detector. A power stage is integrated, if not already part of the transducer.

The detectors are located next to or inside a measuring vessel or filter unit or, in the case of dose rate measurement, installed on the building wall, or on the handling crane.

The detectors are mounted so that they are easily accessible for periodic in-service inspections. In the absence of other constraints, the maximum installation height is 1.7 m above the floor or accessible platforms in order to facilitate handling.

Detectors for local dose rate measurement are installed in a way that ensures representative monitoring of the area concerned.

All other detectors are installed, if possible, in areas with very low background radiation (lower than the 2.5 x 10^{-5} Gy/h threshold) in order to preserve the required lower detection limits.

9.3.1.1. Beta radiation measurements

For beta radiation monitoring, detectors with a low spectral response to gamma radiation relative to beta radiation may be used so that the influence of gamma radiation is negligible. In addition, detectors that do not need auxiliary means such as counting gas, as is needed for proportional flow counters, for example, are preferred as follows:

- scintillation counters are chosen because of their low detection threshold;
- proportional counters are used when low concentrations of noble gases must be detected;
- beta sensitive Geiger Müller counters are chosen when environmental conditions (e.g. temperature) do not permit the use of scintillation counters. It is noted that their measuring range and their service life at the highest count rates are limited;
- semiconductor detectors can be manufactured in small sizes and are therefore used to measure high activities or high concentrations.

9.3.1.2. Gamma radiation measurements

Detection of gamma radiation for continuous plant monitoring is particularly important on nuclear sites. It enables the monitoring of radioactive fluids in pipes and tanks by means of gamma detectors that are installed on the outside. Therefore contamination of the detectors or their exposure to high pressure is avoided and their exposure to high temperatures is limited. The following are preferred means of detection:

- NaI (TI) scintillation counters permit the discrimination of the particle incident energy according to a spectrum that corresponds to the sensitivity of the related photomultiplier. They are used to monitor liquids, aerosols and iodine with a low detection limit. In exceptional cases, they can be used to monitor noble gases when gamma measurement is required;

- Geiger Müller counters are chosen when environmental conditions (e.g. temperature) do not allow the use of scintillation counters. It is noted that their measuring range, sensitivity and their service life at the highest count rates are limited;

- high purity Germanium detectors are used to monitor specific nuclides;

- ionisation chambers are mainly used for dose rate measurements. Their robust design means they are capable of withstanding environmental effects (e.g. temperature, humidity, vibrations) and their wide measuring range means they can be used for diverse applications.

9.3.2. Measuring vessels

The use of measuring vessels largely depends on the measuring conditions. Reasons for using a measuring vessel are:

- to avoid contamination of the detector through direct contact with the medium to be monitored (e.g. water);

- the need for space between the detector and the monitored medium, to ensure a constant calibration of this type of measuring equipment;

- to get a defined amount of medium in an exactly defined geometric measuring location near to the detector.

The two possible solutions are: vessels with detectors on the outside and a measurement configuration where the detector is installed in the medium to be monitored.

The following criteria are considered in the measuring vessel design:

- mechanical construction to facilitate handling, installation and replacement;

- compatibility with the materials and conditions of the systems to be monitored;

- minimisation of the radiation absorption in the direction of the detector;

- provisions that facilitate decontamination e.g. smoothness of surfaces and the use of a decontaminable protective coating;

- minimisation of dead flow areas;
- the reduction of contaminated deposits by suitable shaping of the vessel e.g. avoiding burrs and weld seams.

Use of large measuring vessels may improve the overall sensitivity of the measurement. However, dimensions are usually limited, because of the following:

- increasing cost of shielding;
- increasing dependence of measurements on the energy, caused by natural absorption;
- interaction with the medium, causing a delay in the measurement.

For measurements of beta radiation from noble gases, the measuring volume depends on the absorption of medium energy beta particles in air with a saturation thickness of approximately 70 millimetres. The thickness of the protective sheath is limited to reduce absorption to a minimum.

In most cases, the required lower detection limit for radioactive aerosol or iodine concentrations cannot be reached by direct measurement. In these cases, the measuring vessels contain a filter cartridge through which a sample of monitored air passes. The dimensions and material of the filter are appropriate for the task. The activity on the filter is monitored by a detector inside the vessel close to or inside the filter.

Measuring vessels for monitoring liquids are designed in such a manner that deposits and contamination are reduced to a minimum. They are constructed in a way that avoids the occurrence of air bubbles in the monitored volume.

Measuring vessels are not necessary in cases where the monitoring only aims to detect the presence of radioactivity, i.e. if there is no need to process the data to give the specific activity in Bq/m^3. In these cases, the detector is mounted outside the system without a specific measuring vessel.

In addition, no vessel is used for local dose rate measurements.

9.3.3. Shielding against radiation

Depending on the measurement performed, a lead shielding device is used that surrounds the detector and only has one opening between the detector and the volume to be measured.

Lead shielding devices are used where necessary to ensure compliance with the required low detection threshold required under postulated operating conditions. A lead shielding device surrounds both the vessel and the measurement detector, or only the detector. The dimension of the shielding will be such that the required detection limit can be reached, even at the local background radiation.

The design of lead shielding considers:

- the need for in-service inspections and the maintenance of the measuring equipment,

- that easy decontamination is possible by ensuring smooth surfaces and the use of a decontaminable protective coating.

9.3.4. Transducers

The detector signals (pulses or currents) are processed in transducers which are of modular design. The transducers display actual states and measured values.

Depending on the measurement to be performed and on the resulting cable lengths, the transducers are either mounted in individual housings or grouped together in cabinets taking into account the applicable redundancy criteria.

9.3.5. Periodic tests

Faults that do not generate automatic alarms are detected by periodic tests. Periodic tests are defined such that they:

- can be carried out during plant operation;
- do not impact on actions required for safety;
- do not trigger safety actions or disturb normal operation of the plant.

9.3.6. Permanent sampling devices

Independently from the continuous monitoring equipment described above, radiation monitoring principles include periodic monitoring based on samples that are analysed in a radio-chemical laboratory. On request, all or part of these samples can be stored as evidence. Laboratory analysis is performed periodically or on demand.

The samples are either taken intermittently or continuously.

In most cases, continuous sampling devices are placed in a by-pass circuit of the monitored system. The nuclides to be monitored are collected on a suitable filter (e.g. aerosols and iodine) or by a suitable absorber (e.g. Tritium and CO_2 in air) or in bottles (liquids).

9.4. GENERIC REQUIREMENTS FOR RADIOACTIVE AREAS

Materials used must meet the following requirements:

- radiation-resistant;
- suitable external finish to reduce contamination problems as far as possible;
- materials that are difficult to decontaminate must be avoided as far as possible;
- the dose rate during maintenance / replacement should be reduced by component material selection;
- resistance to maximum environmental conditions during operation (humidity, temperature, steam, water, etc.);

- unprotected ferritic materials (in the ventilation systems, air-mixing systems, etc.) must be avoided in applications where detachment and dispersion of oxides can occur;

- materials and coatings that are likely to be contaminated during the plant outages must be easy to decontaminate.

10. BORON INSTRUMENTATION

10.1. INTRODUCTION

The boron instrumentation is used to monitor the boron concentration in the fluid of the Chemical and Volume Control System (RCV [CVCS]), and in the Nuclear Sampling System (REN [NSS]).

The boron meter system is a Class 1 system and is used on the RCV [CVCS] charging line to mitigate the risk of non-uniform dilution.

This boron meter system, which is part of the RCV [CVCS], is described below.

Details of the boron meter systems used in other systems, e.g. REN [NSS] are given in section 1 of Sub-chapter 9.3. These boron meter systems are not classified.

10.2. RCV [CVCS] BORON METER

10.2.1. Function

The RCV [CVCS] boron meter system is required to mitigate the risk of homogeneous and non-homogeneous dilution.

This protection is based on the calculation of the reactor coolant boron concentration via an algorithm using measurements of the flow injected into the reactor coolant and the cold leg temperatures, together with the boron meter.

The functional requirements influence the detailed design of the RCV [CVCS] boron instrumentation channels notably for the following:

- Classification:

The sensors used in the boron meter system are Class 1 as they perform Category A functions.

- Installation:

The RCV [CVCS] boron meter system is installed on the charging line upstream of the reactor coolant pump seal injection line.

- Redundancy:

Four RCV [CVCS] boron instrumentation channels are required.

- Response time and accuracy:

The response time and accuracy of the RCV [CVCS] boron meter system must be compatible with the global accuracy and response time required for the protection channels using the boron concentration measurement.

- Seismic:

Because Category A functions are supported, seismic qualification SC1 is required for the RCV [CVCS] boron meter system.

10.2.2. Measuring principle

The role of the boron meters in the RCV [CVCS] is to provide on-line measurement of the boron concentration and to generate an alarm, or an automatic action, in the case of a limit being exceeded (either fixed or calculated).

The measuring principle used in the boron meter system is based on the absorption of neutrons by the isotope B^{10}, which depends on the boron content of the coolant to be measured.

The measuring principle is as follows (see Section 7.6.10 – Figure 1). A neutron source emits epithermal neutrons. Most of these neutrons are thermalised (i.e. moderated) by water, that forms the main part of the fluid to be analysed. Due to its large cross-section, the B^{10} atoms (included in the fluid to be analysed) absorb a large proportion of these thermalised neutrons. A neutron detector measures the remaining neutron flux resulting from the non-absorbed thermalised neutrons. In order to increase the efficiency of the neutron source, a neutron reflector is added to the equipment, which ensures that the neutrons issued from the source are used efficiently. This reflector also protects the environment from the neutron source. This function is reinforced by a neutron absorber installed on the external barrier of the equipment. The detector characteristics are influenced mainly by the effect of gamma radiation, which leads to a drift of the response of the sensor. Hence, calibration of the sensor is necessary.

The neutron source used is generally an Am/Be type. Am/Be is chosen because it emits relatively low gamma radiation. Its activity must be as low as possible to prevent unacceptable environmental conditions. The minimum activity level depends on the sensitivity of the detector and on the geometry of the sensor. Different types of neutron detectors can be used in order to minimise gamma radiation effects.

10.2.3. Industrial solutions

Different industrial equipment exist that can be installed on pipes, sampling lines or tanks (depending on the functional requirements), with no modifications necessary.

Design features make the equipment highly reliable e.g. use of redundant neutron detectors, monitoring, control of the temperature of the sensor, installation of the associated electronic equipment in non-aggressive environmental conditions, and advanced self-monitoring.

10.2.4. Performance

For all equipment, the accuracy of the measurement depends principally on the duration of the measurement. The longer the measurement lasts; the better the achievable accuracy. Therefore, there will be a compromise between accuracy and response time of the measurement. Existing industrial boron meters are compatible with the functional requirements (see section 1 of Sub-chapter 9.3).

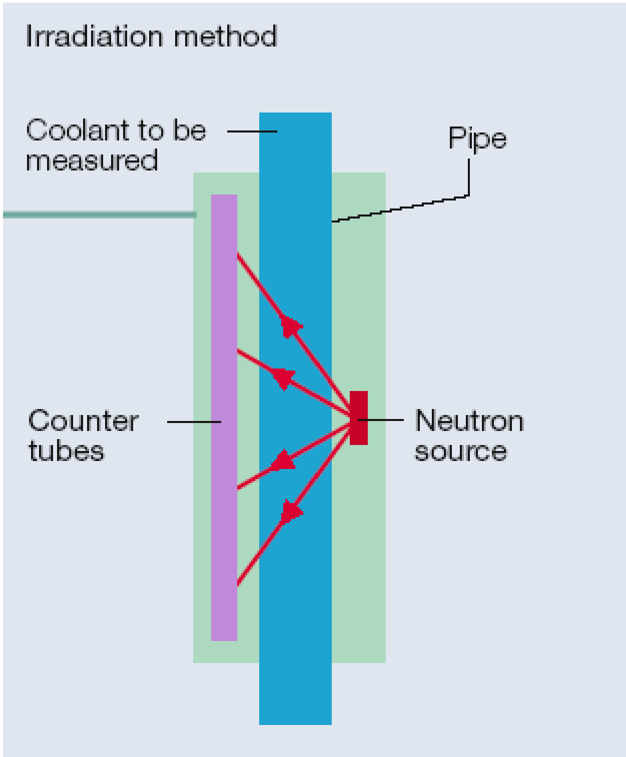
10.2.5. Tests

Periodic tests are performed during power operation to detect signal drift. Signal drift could be due to a loss of neutron detector sensitivity, mechanical changes to the pipe, or modifications to the installed equipment.

It is possible to validate the measurement during particular plant states corresponding to well defined boron concentrations, e.g. from the sampling system.

SECTION 7.6.10 - FIGURE 1

Boron meter measuring principle



SUB-CHAPTER 7.6 – REFERENCES

External references are identified within this sub-chapter by the text [Ref-1], [Ref-2], etc at the appropriate point within the sub-chapter. These references are listed here under the heading of the section or sub-section in which they are quoted.

1. CONVENTIONAL PROCESS INSTRUMENTATION

1.1. GENERAL REQUIREMENTS

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[Ref-2] Justification of smart devices for nuclear safety applications. ENSECC110102 Revision B. EDF. May 2012. (E)

[Ref-3] Lifecycle approach to qualify Smart Devices used in nuclear safety applications. ENSECC110106 Revision B. EDF. March 2012. (E)

[Ref-4] Diversity Criteria for Sensors & Conditioning. PELL-F DC 82 Revision C. AREVA. October 2012. (E)

3. PROCESS INSTRUMENTATION PRE-PROCESSING SYSTEM (PIPS)

3.1. FUNCTION

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[Ref-2] Diversity Implementation plan for sensors & conditioning. PELA-F DC 3 Revision C. AREVA. October 2012. (E)

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4. IN-CORE INSTRUMENTATION

[Ref-1] Fixed Core Outlet Thermocouple Instrumentation System Specification. NLE-F DC 11 Revision E. AREVA. January 2008. (E)

[Ref-2] Self Powered Neutron Flux Detector Instrumentation SPND System Specification. NLE-F DC 15 Revision F. AREVA. December 2009. (E)

[Ref-3] Reactor Pressure Vessel Dome Temperature Measurement System Specification. NLLN-G/2007/en/1020 Revision D. AREVA. November 2008. (E)

[Ref-4] System Design Manual – In-core Instrumentation System (RIC), P1. NLLN-G/2008/en/1087 Revision A. AREVA. July 2008. (E)

[Ref-5] System Design Manual – In-core Instrumentation System (RIC), P2 - System Operation. NLLN-G/2008/en/1088 Revision A. AREVA. August 2008. (E)

[Ref-6] System Design Manual – In-core Instrumentation System (RIC), P3 – System sizing. NLLN-G/2008/en/1089 Revision A. AREVA. August 2008. (E)

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[Ref-8] System Design Manual – In-core Instrumentation System (RIC), P5 – Instrumentation and Control. NLLN-G/2008/en/1091 Revision A. AREVA. August 2008. (E)

[Ref-9] Reactor Pressure Vessel Level Measurement System Specification. NLE-F DC 13 Revision G. AREVA. February 2008. (E)

[Ref-10] System Quality Plan for RIC/RPN Core Instrumentation. NLLN G/2008/en/1006 Revision A. AREVA. February 2010. (E)

5. EX-CORE INSTRUMENTATION

[Ref-1] System Design Manual – Nuclear Instrumentation System (RPN), P1 NLLN-G/2008/en/1092 Revision A. AREVA. July 2008. (E)

[Ref-2] System Design Manual – Nuclear Instrumentation System (RPN), P2 - System Operation. NLLN-G/2008/en/1093 Revision A. AREVA. July 2008. (E)

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7. REACTOR PRESSURE VESSEL WATER LEVEL MEASUREMENT

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8. LOOSE PARTS MONITORING AND VIBRATION MONITORING

8.3. VIBRATION MONITORING

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[Ref-2] R.Chevalier. Additional instrumentation needs for monitoring the EPR electrical rotating machines. HP-1D/05/045 Revision A1. EDF. October 2005. (E)

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