SUB CHAPTER G.5 INSTRUMENTATION

0. SAFETY REQUIREMENTS

0.1. SAFETY FUNCTIONS

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

- Reactivity control,
- Residual heat removal,
- Containment of radioactive substances

and must allow the measurement:

- of parameters used as input data in automatic processes,
- of parameters used to give information to the operator about the status of the plant.

0.2. FUNCTIONAL CRITERIA

Reactivity control: The instrumentation must cover all parameters necessary to establish the neutronic core status, i.e.:

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

Residual heat removal: The instrumentation must cover all parameters representative of the residual heat removal function. 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 (SG pressure, SG temperature, feedwater flow rate, etc.)

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

- containment pressure and temperature,
- position of containment isolation valves,
- activity level in the buildings

- Monitoring of the status of the plant: instrumentation must allow the status of the plant and systems to be established. Required measurements include pressure measurements, flow rate measurements, level measurements and indications of the status of actuators.

0.3. DESIGN REQUIREMENTS

0.3.1. Functional and mechanical classification requirements

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

The classification requirements are detailed in Chapter C.2.

The qualification requirements are detailed in Chapter C.7.

0.3.2. Safety regulation requirements

Basic Safety Rules

There are no specific Basic Safety Rule applicable to EPR instrumentation at present.

Technical Guidelines (see Chapter C.1.2)

Paragraph G3 – Design of instrumentation and control

This paragraph describes the requirements related to instrumentation and 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.

EPR specific texts

There is no specific text applicable to EPR instrumentation.

0.3.3. Hazards

Instrumentation equipment must fulfil the same requirements for the 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 must also be tested during tests of systems and functions to which it belongs, and must be recalibrated if necessary.

1. CONVENTIONAL PROCESS INSTRUMENTATION

1.1. FUNCTIONAL REQUIREMENTS

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

- normal operation of the plant,
- the safety of operating personnel and the general population,
- 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 classes.

Most typical conventional process instrumentation includes:

- pressure measurements,
- flow measurements,
- temperature measurements,
- rotational speed measurements,
- voltage measurements,
- frequency measurements,
- position measurements.

Specific requirements for instrumentation concern:

- 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 common devices: the installation of redundant instrumentation, belonging to different divisions must avoid using shared devices (such as shared nozzle, shared isolation valve, shared support, etc.)
- calibration: instrumentation equipment must be designed to facilitate and reduce the need for calibration and must be installed to facilitate maintenance. 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 measurement devices are connected to all fluid systems. The measurement principles described below mainly apply to pressure measurements on 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 the pressure taps installed on systems' pipes or devices (tanks, vessels, steam generators, etc.) 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 measurements operating according to different principles may be used:

- absolute pressure measurement: for example, diaphragm cells or ceramic cells
- relative pressure measurement: for example, capacitance cells or bourdon tube mechanisms
- differential pressure measurement: for example, diaphragm cells. These cells consist of two sensitive diaphragms, whose displacement is converted into an electrical signal.

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

1.2.2. Flow measurement

The measurement principles used include the following methods:

- differential pressure measurement at the boundaries of a flow restrictor (standard orifice plates, venturi).
- differential pressure measurement between the instrument taps located in the concave and convex sides of a bend,
- rotameters
- ultrasonic flowmeters,
- inductive meters.

The output signal from the differential pressure transmitters, derived by extracting the square root, gives an electrical signal which is proportional to the flowrate.

1.2.3. Liquid level measurement

The techniques used to measure liquid levels in the pressuriser and steam generators are mainly differential pressure measurements (hydrostatic method using 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 phase). 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 that phenomenon. The pressure tap line on the steam phase 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 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 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.

In addition to the hydrostatic method based on differential pressure, the liquid level is also measured by a capacitance method. For this measuring method, a probe in the reservoir or tank acts as a capacitance with the reservoir 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 are also used:

- level measurement with dry reference column
- level measurement for tank at atmospheric pressure
- air-bubbler type level measurement
- level measurement by displacement (with plunger)

1.2.4. Temperature measurement

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

Thermocouples and resistance thermometers, for pressurized fluid systems, must be fitted in thimbles so that sensitive components can be dismantled for maintenance without having to depressurize the system.

Thermocouples are used for applications requiring very rapid acquisition of the measured 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

Rotating speed is measured on the primary pumps by the safety classified instrumentation and control system. 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's rotating speed is generated.

1.2.6. Voltage measurement

Alternating-current (AC) voltage measurement sensing elements operate on the rectifier principle. The sensing element's input and output signals are electrically insulated from each other. An amplifying stage converts the resulting voltage signal into a direct current (DC) signal.

Other voltage measurement methods consist of transforming the signal into a low voltage signal using a transformer. The resulting signal is then acquired by a computer, and the amplitude and the root mean square (r.m.s.) value of the AC voltage are determined by digital means.

1.2.7. Frequency measurement

The input variable is applied to a tripping 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. IN-CORE INSTRUMENTATION

The in-core instrumentation consists of the following systems:

- Flux mapping instrumentation consisting of an Aeroball Measuring System (AMS),
- Fixed in-core instrumentation consisting of:
    - 72 fixed Self-Powered Neutron Detectors (SPND) distributed radially and axially over the core,
    - 36 fixed Core Outlet Thermocouples (COTC) distributed radially at the core outlet,
    - 3 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 which 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 G.5 FIG 2.

One of the fixed RPVDT uses a single additional reactor pressure vessel head penetration different from the penetrations used by the instrumentation lances.

2.1. FLUX MAPPING INSTRUMENTATION

2.1.1. 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. The minimum time interval between two aeroball measurements (40 channel complete flux mapping) is approximately 10 minutes. 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 parameters values that are used for the following purposes:

- calibration of the self-powered neutron detectors,
- calibration of the excore neutron detectors,
- calibration of the protection thresholds (protection system),
- verification of core conformity, burn-up and behaviour as well as the detection of anomalies,
- validation of the self-powered neutron detectors and excore neutron detectors signals.

The flux mapping instrumentation is not safety classified (NC).

2.1.2. Measurement principle and arrangement

The aeroball measuring system 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 G.5 FIG 1.

The radial positions of the aeroball probes are shown in G.5 FIG 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 optimized 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 values 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 aeroball measuring system 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 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:

- 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 case the main supply system fails,
- data logging,
- saving 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

2.1.3. 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: ≤ 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: about 3 minutes,
- Accuracy of the axial position of the measurements: ≤ 1.5 cm.
- Preparation time of a full flux map: ≤ 15 minutes
- Minimum time between 2 flux maps: 10 minutes

2.1.4. Tests and maintenance

Computer-assisted calibration of the AMS radiation detectors is generally performed with a gamma source during refuelling outages.

Functional testing of the AMS is generally performed by integrated test programs (some of which are executed automatically at each aeroball measurement) described in section G.5.2.1.2.

Some maintenance operations of the aeroball system require access to the AMS rooms of 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.

2.2. FIXED IN-CORE INSTRUMENTATION

2.2.1. Fixed self-powered neutron detectors

2.2.1.1. Function

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

- monitoring of representative core parameters,
- control of axial power shape,
- core surveillance for maintaining limiting conditions of operation.
- core protection.

The fixed self-powered neutron detector instrumentation support functions up to safety class F1A. Hence the fixed self-powered neutron detector measurement is F1A safety classified and the fixed self-powered neutron detector equipment is E1A safety classified.

2.2.1.2. 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 G.5 FIG 2. Each detector finger contains 6 continuously measuring neutron sensitive self-powered detectors distributed axially over the core height.

The detectors used (n, beta detectors) are self-powered neutron detectors 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 4 divisions of the safeguard buildings. The signal conditioning provides a linear current and compensates for the cable current generated by the radiation in the core and for background noise. Signal calibration is performed with the aeroball measurement system. The modules' power supply and the status of all modules are monitored and any failure reported.

The signals are transmitted to the I&C system for further signal processing.

2.2.1.3. Functional characteristics

- Total flux measuring range: 10^{10} to 5.10^{15} $n.cm^{-2}.s^{-1}$,
- Response time: < 100 ms,
- Signal accuracy of the electronic conditioning equipment: < 1%

2.2.1.4. Tests and maintenance

The calibration of the self-powered neutron detectors is performed at regular intervals (every 15 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 on line, during power operation, by comparing the latest calibration factors for the detector signals with the reference calibration factors evaluated from the values measured by the aeroball system.

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 of insulation resistance 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 self-powered neutron detectors or thermocouples is performed during refuelling outages.

2.2.2. Fixed core outlet thermocouples

2.2.2.1. Function

The core outlet thermocouples 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 core outlet thermocouple instrumentation support functions up to the safety class F1B. Hence the fixed core outlet thermocouple measurement is F1B safety classified and the fixed core outlet thermocouple equipment is E1B safety classified.

2.2.2.2. Measurement principle and arrangement

A total of 36 core outlet thermocouples are distributed over 12 measuring points. Three thermocouples are installed in each incore 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 G.5 FIG 2. The allocation of the thermocouples to the 4 divisions of the safeguard buildings is the same as those for the self-powered neutron detectors of the same incore detector thimble.

All modules for conditioning of temperature signals are located in the assigned instrumentation cabinets which are installed in the 4 divisions of the safeguard buildings. The power supply to the modules and the status of all modules in the I&C subracks are monitored and any failure is reported.

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

2.2.2.3. 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 1000°C.
- Response time: < 500 ms (but a response time of 30s is sufficient).
- The thermocouples give a reliable temperature when the surrounding fluid is water, two phase mixture, or steam up to superheated steam.
- The thermocouples are qualified up to 180 bars.

2.2.2.4 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.

2.2.3. Fixed Reactor Pressure Vessel Dome Thermocouples

2.2.3.1. 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 post-accident operating procedures, and can be also used in the normal operating procedures, to inform the plant operator of the actual thermohydraulic status inside the RPV-dome: subcooled, saturated, or superheated conditions relative to the RCS saturation pressure.

The RPV-dome thermocouples (RPVDT) are non safety classified (NC).

2.2.3.2. Measurement principle and arrangement

There are 3 fixed RPV-dome thermocouples entering the reactor pressure vessel via a single dedicated RPV head penetration. The arrangement of these RPVDT is as follows:

- 1 detector located close to the top of the dome.
- 1 detector located close to but below the upper part of the RCCA guide tube (flow junction dome/upper plenum).
- 1 detector located close to the bottom of the dome.

In a horizontal plane, each sensor is located near the centre of the RPV-dome.

The top 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).

3. EX-CORE INSTRUMENTATION

3.1. FUNCTIONS

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 (LCO), limitation and protection functions.

The ex-core instrumentation performs the following tasks:

- acquisition of subcritical neutron pulses (source range) during refuelling and shutdown operation,
- acquisition of the neutron flux 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 during load operation to determine the rate of increase of nuclear power and the global axial power shape,

- acquisition of the neutron flux to determine the nuclear power under accident conditions as part of the post-accident instrumentation,

- acquisition of the neutron flux to assist in the monitoring of vibrations of the reactor pressure vessel internals as part of the vibration monitoring system.

The ex-core instrumentation supports functions up to F1A safety class. Hence, the ex-core measurement is F1A safety classified and the excore instrumentation equipment is E1A safety classified.

3.2. 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.

Two principles can be retained for the intermediate range detector which can be either an ionization chamber with gamma ray compensation or a fission chamber (very low sensitivity).

The total range of the neutron flux to be acquired is approximately 10 to 11 decades up to 150% 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 G.5 FIG 3.

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,

- intermediate range channels are used for measurement in the upper 7 to 8 upper decades of the measuring range. If the fission chambers are implemented, the measuring is made by means of two separate signal conditioning equipment which process the signal from the same detector cable: pulse processing and fluctuation measuring. If the ionization chambers with gamma ray compensation are implemented, the conditioning equipment processes the current supplied 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. From the connection boxes the detectors are led down inside the guide tubes through the reactor well wall and then at the height of the reactor core in the concrete of the biological shield down to the measuring positions.

Table G.5 TAB 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, which 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 4 divisions of the safeguard buildings.

The signals are transmitted to the instrumentation and control functions that require them.

3.2.1. 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 subcritical conditions to critical flux level conditions in the pulse range during refuelling and maintenance shutdown conditions and during cold or hot standard shutdowns.

At this stage of the design, the source range detectors are boron-lined proportional counters. In power operation, they are de-energized and stay permanently in their measuring position. This design choice is to be confirmed by further studies. In case these studies demonstrate that higher detector sensitivity is required, BF_3 counter tubes surrounded at measuring position by a lead shielding to enable proper operation could be used. At start of power operation, the BF_3 counter tubes are withdrawn from their measuring position to avoid radiation damages.

The further studies are also required to confirm the number of source range channels and the location of source range detectors with regard to the surveillance during core reload phases.

Signal conditioning of pulse signals emitted by the chambers mainly performs 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 output pulses,

- pulse rate counting proportional to the neutron flux at the measuring position (to generate a signal “relative rate of change of flux” to detect the rate of increase of neutron flux).

In the event of self-annunciating failures (e.g. power supply fault) binary signals are outputs 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.

3.2.2. 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 middle 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 % 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 current range. The conditioning equipment mainly performs the following functions:

- high voltage power supply for the detectors (measuring high voltage and compensation high voltage),

- detector current processing and generation of an output signal proportional to the neutron flux at the measurement position (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 case fission chambers are implemented, the detectors operate in pulse range and in fluctuation range. Signal conditioning is then processed by two separate pieces of conditioning equipment.

In the pulse range, the signal conditioning mainly performs the following functions:

- provision of high voltage supply to detectors,

- amplification of pulses,

- discrimination and suppression of background signals (noise, alpha and gamma signals),

- calibration of output pulses,

- pulse rate counting proportional to neutron flux at measuring position (which is afterwards used to elaborate a "relative rate of change of flux" for detection of the relative neutron flux increase rate).

In the fluctuation range, the signal conditioning mainly performs the following functions:

- provision of high voltage supply to detectors,

- decoupling of the d.c. signal part from the detector signal and filtering,

- amplification of the remaining fluctuant component of the signal,
- formation of the variance of the amplified signal to obtain a signal proportional to the neutron flux at measuring position (according to the Campbell theorem). (This signal is also used downstream to elaborate the "relative rate of change of flux" for detection of the relative neutron flux increase rate).

In case of self-annunciating 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.

3.2.3. Power range

The thermal neutron flux density in the power range is monitored by four redundant instrumentation channels. Each instrumentation channel is equipped with 2 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 acquire 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% 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,
- detector current processing and generation of an output signal proportional to the neutron flux at the measurement position (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 case of self-annunciating 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.

3.2.4. Measuring ranges, accuracy, response time

The measuring ranges are defined in sections G.5.3.2.1, G.5.3.2.2 and G.5.3.2.3 and are illustrated in G.5 FIG 3.

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 the detector, the signal conditioning and digital processing, is between 1 s (high flux part) and 100 s (low flux part). The response time of the intermediate range and power range instrumentation, also including the detector, the signal conditioning and the digital processing, is 300 ms or less.

3.3. TESTS AND MAINTENANCE

The on-line checks consist of a qualitative evaluation of the indicator readings 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 annunciation 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 burnup 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 appropriate set intervals by injection of simulated signals from signal generators, recording the detector characteristics and measuring insulation resistance.

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 a sufficient activity decay for any irradiated container chains housing faulty detectors.

4. ROD POSITION MEASUREMENTS

4.1. GENERAL

4.1.1. 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 Protection System).
- Limiting condition of operation (LCO) surveillance and limitation functions (implemented in the Reactor Control, Surveillance and Limitation system).

4.1.2. Classification of the rod position instrumentation

The highest safety classified function using the measurements provided by this instrumentation is F1A classified. Hence the rod position instrumentation is therefore E1A classified.

4.2. 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 G.5 FIG 4.

4.3. RULES

4.3.1. Design rules

- Response time:

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

- Accuracy:

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

- Redundancy:

The measurement of the individual position of each control rod is not redundant. Sub-banks of four rods (RCCAs) 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 four-fold redundant.

4.3.2. 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

4.4. STRUCTURE

4.4.1. Description of the structure

There are 89 control rods and the structure of a RCCA group is four-fold redundant. Therefore, each redundant group encompasses the position measurement of 22 rods. It is noted that one group also includes the central rod.

The rod position instrumentation has one measuring circuit for each mechanism associated to each RCCA. A measuring circuit consists of:

- the detector,
- the power supply module,
- the processing module,
- the cables,
- the power supply equipment.

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.

The magnetic coupling between the primary and secondary coil provides the analogue measurement position of the control rod.

The current generator provides a constant sinusoidal current. An offset is added to ensure a positive current. The direct current component is used to determine the resistance of the primary coil which is representative of the average temperature along the detector. The secondary voltage depends on the position of the drive shaft. The secondary voltage, corrected according to the resistance of the primary coil, provides the measurement.

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

4.4.2. Compliance with design rules

- Redundancy:

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

4.5. 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 G.5 FIG 5.

4.6. TESTS

A periodic test is performed on each measuring circuit which entails checking a sufficient number of positions (low, high and intermediate).

5. REACTOR PRESSURE VESSEL WATER LEVEL MEASUREMENT

5.1. GENERAL

5.1.1. Purpose of the reactor pressure vessel water level measurement

The purpose of the reactor pressure vessel water level (RPVL) measurement is to provide a permanent indication of the water level in the reactor vessel.

This instrumentation is used in post-accident situations. It enables the operator to identify the correct actions to maintain the water inventory.

5.1.2. Reactor pressure vessel water level instrumentation safety classification

- Functional classification: the reactor pressure vessel water level instrumentation is F1B classified.
- Mechanical classification: the lance heads of the reactor vessel water level measurement are RCC-M class 1
- I&C classification: the reactor pressure vessel water level instrumentation equipment is E1B classified.
- Seismic classification: the reactor pressure vessel water level instrumentation equipment is seismic class 1.

5.2. INTERFACES AND BOUNDARIES

The reactor pressure vessel water level instrumentation is implemented in the level 0 of the I&C architecture and consists of:

- detectors,
- interface equipment between the detectors and the fluid in the pressure vessel,
- signal conditioning and supply equipment,
- cables between the detectors and the signal conditioning and supply equipment,
- supporting structures for the above elements.

The output signal from the conditioning equipment of the reactor pressure vessel water level instrumentation is processed in the SAS (Safety Automation System) which indicates the water level to the operator.

The interfaces and relations with other systems of level 1 and 2 are represented on G.5 FIG 6.

5.3. RULES

5.3.1. Design rules

- Redundancy and independence:

Due to the importance of the reactor pressure vessel water level measurement in diagnosing the plant state in order to allow appropriate mitigating actions to be taken, the reactor pressure vessel water level measurement is fourfold redundant.

Each reactor pressure vessel water level measurement instrument is electrically independent of the others.

- Information provided by the reactor pressure vessel water level instrumentation:

Three threshold levels must be monitored by the reactor vessel water level 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 reactor vessel water level measuring equipment must provide a representative indication of the vessel water inventory under various operating conditions. The reactor vessel water level measurement equipment must:

- provide an appropriate response with zero, one, two, three or four primary pumps in service,
- provide an appropriate response in the liquid phase, in a two-phase mixture and in the steam phase.
- provide an appropriate response with a void fraction in the upper plenum at constant pressure,
- provide an appropriate response with a void fraction in the upper plenum and a decreasing pressure, particularly in the case of an APRP (LOCA) with small, intermediate or large breach.
- withstand temperatures as high as 800°C above the upper plate of the core in such a manner that the measuring equipment remains usable after the temperature has dropped (after reflooding the core, for example).
- withstand high temperature ramp rates (of approximately +1°C/s).
- provide an appropriate response at pressures that up to 180 bars,
- be compatible with vessel water chemistry, in particular with high boron concentrations (up to 4,000 ppm).:

- Accuracy of the reactor pressure vessel water level measurement

An accuracy of +/- 10 cm is required for the detection of each threshold..

- Response time of the reactor pressure vessel water level measuring equipment

A 30-second response time is enough, given that only manual actions are implemented based on the water level measurement..

5.3.2. 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 I.4.1.

5.4. STRUCTURE

5.4.1. Architecture

5.4.1.1. General description

The heat transfer measurements indicate whether the level of liquid water that surrounds a sensor is below or above a fixed threshold. The number of thresholds that are monitored depends on the number of sensors that are installed in the reactor vessel. The heat transfer measurements are performed in the reactor vessel upper plenum.

A heating element heated at a constant power will reach a substantially lower excess temperature in water than when it is surrounded by steam. A resistance thermometer wire incorporated in the heating element reacts to the temperature of the element: if the element is immersed in water, the temperature excess is lower than when it is surrounded by steam. In order to become independent of the absolute temperature of the water or steam, the sensor also contains an unheated resistance thermometer wire which provides a reference.

These two measurement resistances are interconnected with two constant compensating resistances (outside the reactor pressure vessel) to form a Wheatstone bridge (see G.5 FIG 7). The voltage across the bridge diagonal is therefore a measure of the different temperatures of the instrument wires: when the sensor is immersed in water, the voltage is low; when it is surrounded by steam, the voltage is far higher. The voltage is compared to a voltage threshold.

The measurement is local to the sensor and depends on the fluid conditions surrounding the sensor itself.

The sensors are installed within a probe thimble which is fitted in the upper part of the reactor vessel. The probe thimble is inserted inside the vessel through the closure head by the 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 (see G.5 FIG 8).

In the upper plenum, the probe thimble is inserted in a guide tube..

5.4.1.2. Description of the equipment

- Sensors

The sensitive element consists in a heated coil and an unheated coil close together; both coils are resistance thermometers.

Each probe thimble incorporates in total three sensors which are positioned at three elevations (one sensor per elevation) in order to measure the THL, BHL and MHL water levels (see G.5 FIG 8). The thermal influence of the heated coil on the unheated coil is acceptable in terms of accuracy.

- Probe thimble

The sensors and their cables are inserted in a probe thimble which is the mechanical resistant part of the probe.

The zones of the probe thimble surrounding the location of the sensors are drilled with a large amount of holes. This allows a good circulation of water, steam or steam water mixture on the sensor coils themselves.

- Guide tube

Each probe is surrounded by a concentric guide tube which is limited to the region of the upper plenum. The top and bottom ends of the guide tube are attached to the top plate and to the upper core plate..

The functions of the guide tube are:

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

Another purpose is to ensure fluid defined conditions around the sensors. The reason is that in many accident conditions the remaining water is turned to a highly turbulent steam/water mixture which would not enable a sensor directly in contact with the mixture to provide a significant indication. Consequently, the probe is inserted in a protection guide tube which is closed over its entire length except at the top and bottom ends where communication ports are made.

- Cables and connector

Each probe includes three sensors and each sensor is connected to a sheathed cable of six wires within the probe (four for the Wheatstone bridge, two for the heating element). Each probe requires eighteen wires.

Each of the three cables within the probe includes heating and measurement wires of one sensor.

The cables of one probe are terminated to one electrical connector.

It is possible to disconnect the cables from the cable layer running up to the safeguard building in order to allow the removal of the vessel closure head without withdrawing the probe from the reactor vessel.

- Supporting structure

The probe is guided by the means of the instrumentation nozzle on the closure head and the guide tube in the upper plenum. It is hung up on the head of the instrumentation nozzle in the zone of the sealing devices.

Top and bottom ends of the guide tube are attached to the top plate and to the upper core plate.

The cables are connected on the cable bridge above the vessel head and run up to the safeguard buildings using appropriate cable trays.

The mechanical design is suitable to prevent water entering the guide tube from the closure head plenum.

- Conditioning equipment

The conditioning equipment is installed in the safeguard buildings. The conditioning equipment has the functions to ensure the current supply of the heating element of the sensors, the current supply of the Wheatstone bridges and the conditioning of the signal received from each bridge.

Wire breaks in the heating circuit are detected by a surveillance function which initiates an alarm.

5.4.2. Compliance with design rules

Redundancy and independence:

- The reactor pressure vessel water level instrumentation is made 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 measure three different water 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.

5.5. INSTALLATION

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

5.6. PERIODIC TESTING AND CALIBRATION

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

The function and the information given by the sensors arranged above mid-loop level is checked while the reactor coolant system is filled during every plant unit start-up sequence after refuelling shutdown. A comparison with the readings of the loop level measurements is performed.

Compensation of a possible drift of the signal voltage is required at most once a year. Independently of that, the evolution of the distance between the signal voltage and the threshold value is monitored during normal operation so that a signal drift can be compensated in time.

6. LOOSE PARTS MONITORING AND VIBRATION MONITORING

6.1. INTRODUCTION

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

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

6.2. LOOSE PARTS MONITORING

The loose parts monitoring system continuously checks the reactor primary circuit. The device uses detectors (e.g.: accelerometers, acoustic detectors) 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 detectors. 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 r.m.s value of the noise signals coming from the structure in a predetermined frequency range (acoustics: approximately 1000 Hz – 15 kHz). Threshold levels are defined based on reference measurements and alarms are triggered should they be exceeded. The experience of 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 selectively be identified by the human ear. It is for this reason that it is necessary to correlate the automatic monitoring system to a subjective monitoring by listening to the noise at regular intervals. The system offers this possibility in audio mode.

6.3. 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 fleet of nuclear stations and current studies on the EPR, has indicated the 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 Chapter E.4.1). 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 seal, etc.). The value of monitoring the vessel’s internals is still under consideration by the designers and the manufacturers.

7. RADIATION MONITORING

7.1. SAFETY MISSIONS

As radiation monitoring is supported by the KRT [PRMS] system inside the plant, all the safety functions, functional criteria and design requirements are described in detail in Chapter L.3.5.

7.2. 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, if 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,
- generic 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 class F1A (see Chapter L.3.5)

7.3. 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.

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

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.

A limited number of diverse measuring devices are used, these based to the extent possible on standard components. The variety is limited to the lowest level possible. Whenever possible and suitable, off-the-shelf equipment is preferred. This strategy simplifies and hence allows optimisation of the maintenance and 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 measuring points are 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, disturbances, accidents).

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 received good feedback in nuclear power stations.

7.3.1. Detectors

The following detectors are used for beta and gamma measurements:

Beta radiation measurements

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

Gamma radiation measurement

- NaI (TI) scintillation counters (sodium-iodine 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 it is 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.

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 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.

7.3.1.1. Beta radiation measurements

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

- scintillation counters are chosen because of their low detection threshold,
- proportional counters are used when low concentrations of noble gasses 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.

7.3.1.2. Gamma radiation measurements

Detection of gamma radiation for the 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:

- 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 are used to monitor noble gasses 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; their use is limited because they require cooling with liquid nitrogen,

- 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.

7.3.2. Measuring vessels

The use of measuring vessels largely depends on 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.

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 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 and

- 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:

- 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.

7.3.3. 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 thickness of the shielding permits a low level of detection given the local background radiation, and is at least 5 centimetres thick.

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.

7.3.4. 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 resulting cable lengths, the transducers are either mounted in individual housings or grouped together in cabinets taking due account of the applicable redundancy criteria.

7.3.5. Periodic tests

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

- can be executed during plant operation,
- do not impact on actions required for safety,

- do not trigger safety actions or disturb normal operation of the plant.

7.3.6. 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 the 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).

7.4. 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 choice of materials for the components requiring dismantling or replacement must be made to reduce the dose rate during maintenance/replacement.
- resistance to maximum environmental conditions during operation (humidity, temperature, steam, water, etc.),
- unprotected ferretic 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 easily decontaminable.

8. ACCIDENT INSTRUMENTATION

8.1. 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.

8.2. 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 analyzing them in 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,

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.

8.3. MEASUREMENT PRINCIPLES AND REQUIREMENTS

8.3.1. 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. 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. temperature, pressure, radioactivity, gas and liquid analysis)
- area monitoring in the environment close to the power plant (e.g. releases of radioactive liquid waste water, gases, airborne particles local dose rate, meteorological parameters).

8.3.2. 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 G.5.0 and Technical Directives G.3), specific requirements for probes and sensors are applicable:

- the 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,
- connection plugs are used for cable connections to facilitate maintenance.

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 sensors are used if their electronic components must meet the requirements of the harsh environment conditions during and after an accident.

8.3.3. Requirements linked to accident procedures

The accident procedures described in sub-chapter M.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 G.5.0.1), 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 at least F1B safety class.

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

9. BORON INSTRUMENTATION

9.1. INTRODUCTION

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

Further to the analysis of the EPR safety requirements, it is proposed to install a F1A classified boron meter system on the RCV[CVCS] charging line to mitigate the risk of non-uniform dilution..

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

Details of the boron meter system used in REN[NSS] are given in section I.3.1.

9.2. RCV[CVCS] BORON METER

9.2.1. 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:

- Classification.

The use of a boron meter system in the Protection System in order to mitigate the risk of homogeneous and non-homogeneous dilution leads to require a F1A classification for the protection functions using these sensors, and for the sensors themselves.

- Location.

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

- Redundancy.

4 RCV[CVCS] boron instrumentation channels are required.

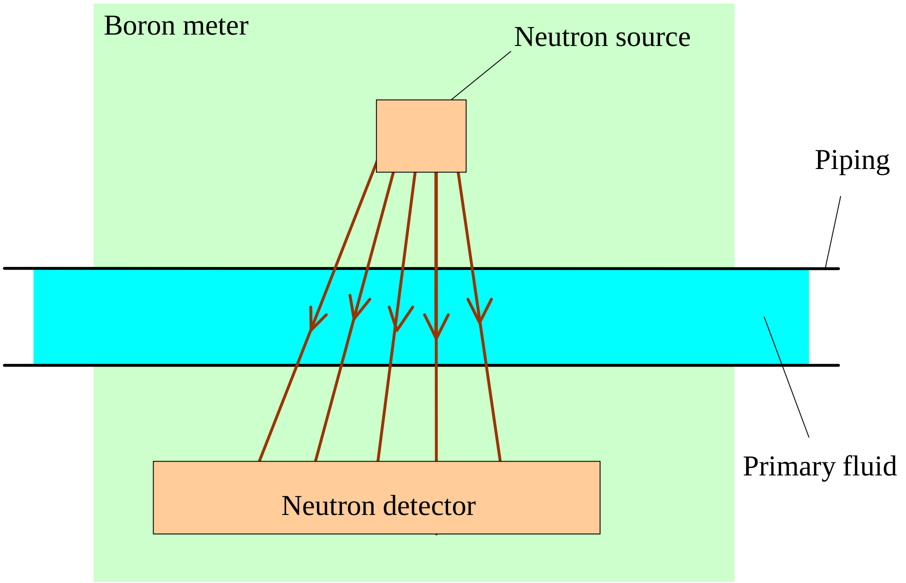
- Response time and accuracy.

The response time of the RCV[CVCS] boron meter system must be as short as possible. However increasing the update rate of the signal decreases the accuracy of the measurement and vice versa. The functional requirement is therefore a compromise between accuracy and response time.

- Seismic classification.

Because FA1 functions are supported, seismic qualification SC1 is required for the RCV[CVCS] boron meter system.

9.2.2. 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 case of exceedance of a limit which may be either fixed or calculated.

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

The measuring principle is as follows. 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 ^{10}B 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. The 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 levels of 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 minimize gamma radiation effects.

9.2.3. Industrial solutions

Industrial equipment is available that uses the principles described in the previous section and can be installed on pipes, sampling lines or tanks (depending on the functional requirements) without need for modification.

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

9.2.4. Performance

For all equipment the accuracy of a measurement depends principally on the duration of the measurement. The longer the measurement takes, the better is the achievable accuracy. Therefore there is a compromise between the measurement accuracy and response time.. Existing industrial boron meters are compatible with the functional requirements (see Chapter I.2.1).

9.2.5. Tests

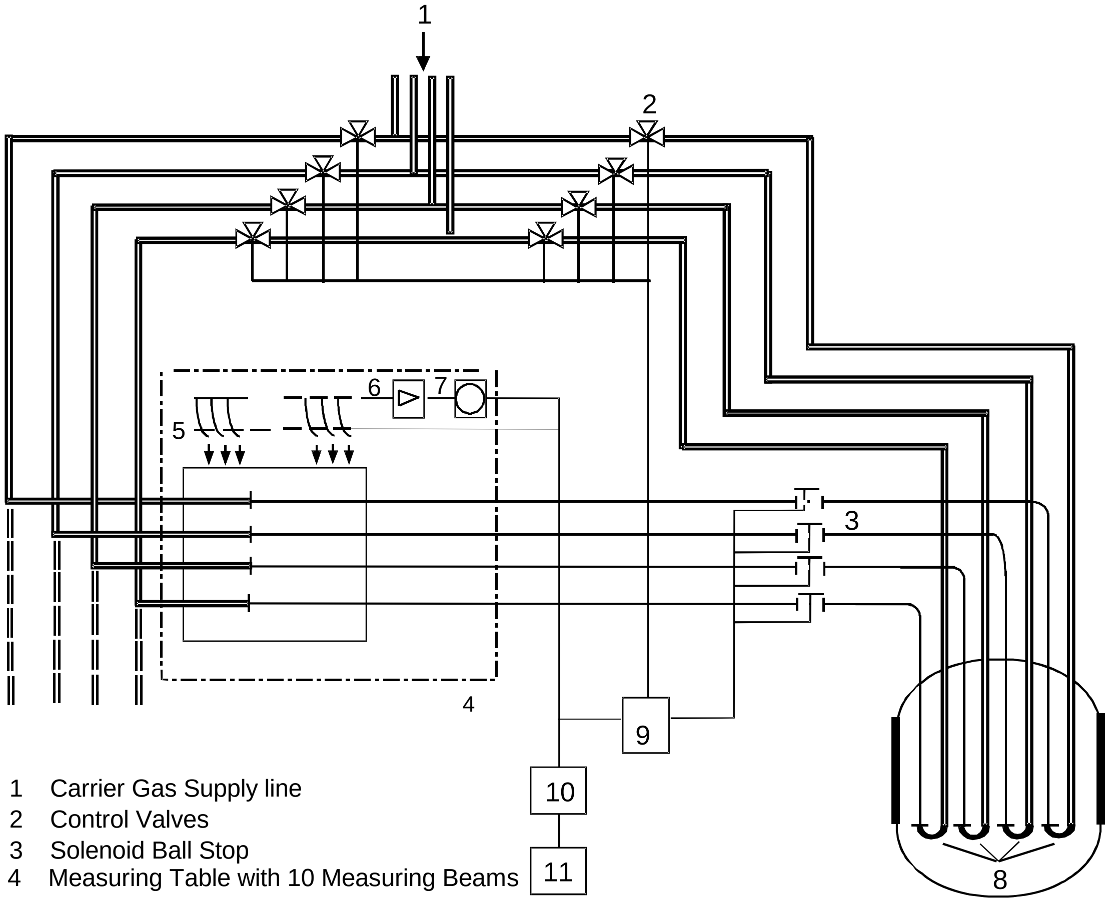
Tests are performed to detect signal drift due to a loss of sensitivity of the neutron detectors or mechanical changes to the tube or the installed equipment.

As the equipment is mounted directly on a pipe, it is possible to validate the measurement during particular plant states corresponding to well defined boron concentrations.

G.5 TAB 1: EXCORE INSTRUMENTATION - GUIDE TUBES, CONTAINER CHAINS AND INSTRUMENTATION CHANNELS

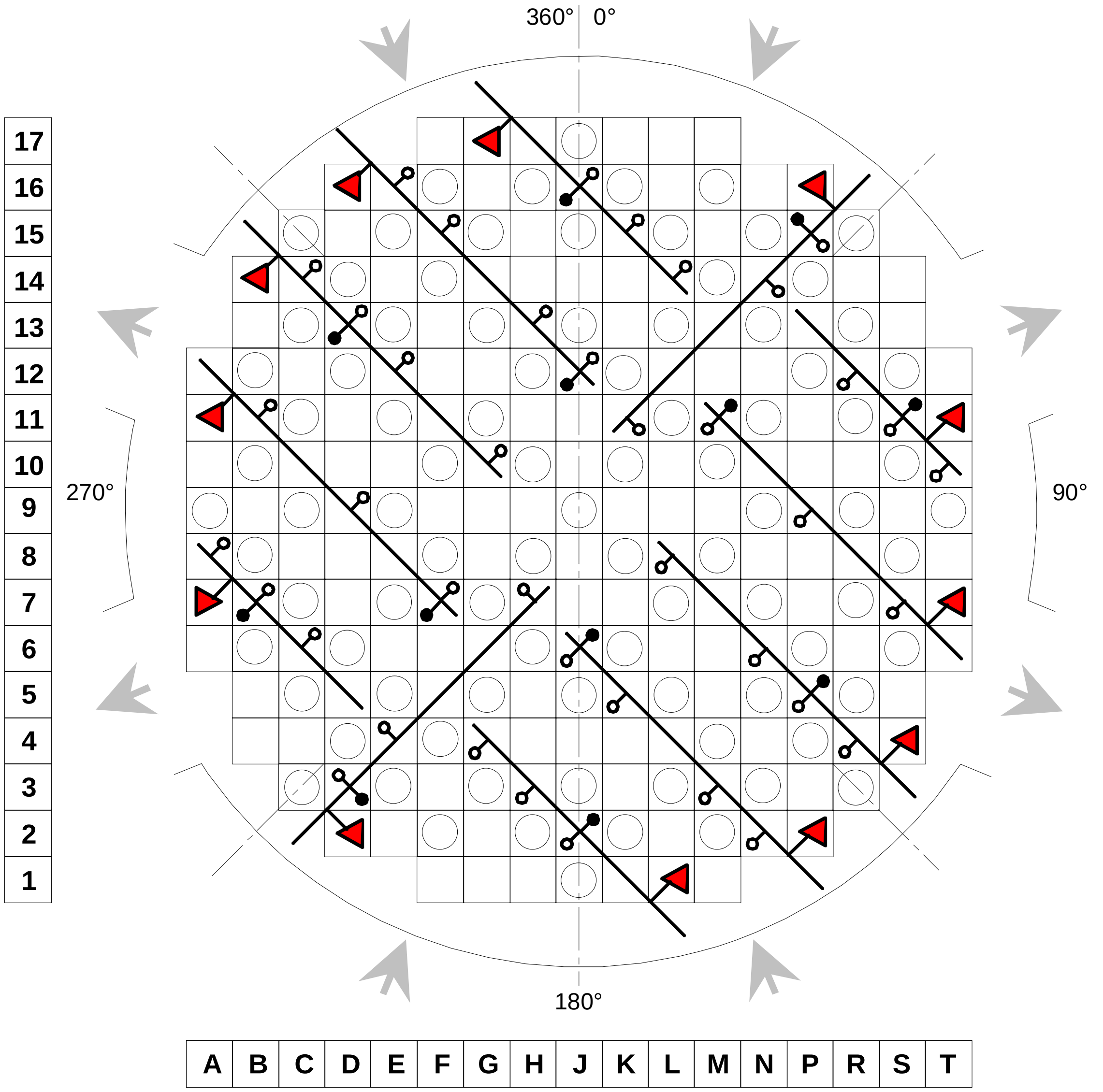
Range	Number of Guide Tubes	Azimuthal Position	Number of Cont. Chains	Number of Instrument. Channels
Source range	3	0°, 90° 270°	3	3
Interm. Range	4 (Interm. Range and Power range)	45°, 135°, 225°, 315° (Interm. Range and Power range)	4 (Interm. Range and Power range)	4
Power range				4

G.5 FIG 1: AEROBALL MEASURING SYSTEM, SCHEMATIC DIAGRAM



1 Carrier Gas Supply line
2 Control Valves
3 Solenoid Ball Stop
4 Measuring Table with 10 Measuring Beams
5 Radiation Detectors for each Measuring Beam
6 Amplifier
7 Pulse Counter
8 Probes, "10 x 4" Thimbles
9 Load Cabinet
10 AMS Control Computer
11 Process Information and Control System (PICS)

G.5 FIG 2: AEROBALL MEASURING SYSTEM - RADIAL POSITIONS OF THE AEROBALL PROBES AND THE FINGERS WITH SPNDS AND THERMOCOUPLES



241 FUEL ASSEMBLIES

89 CONTROL ASSEMBLIES

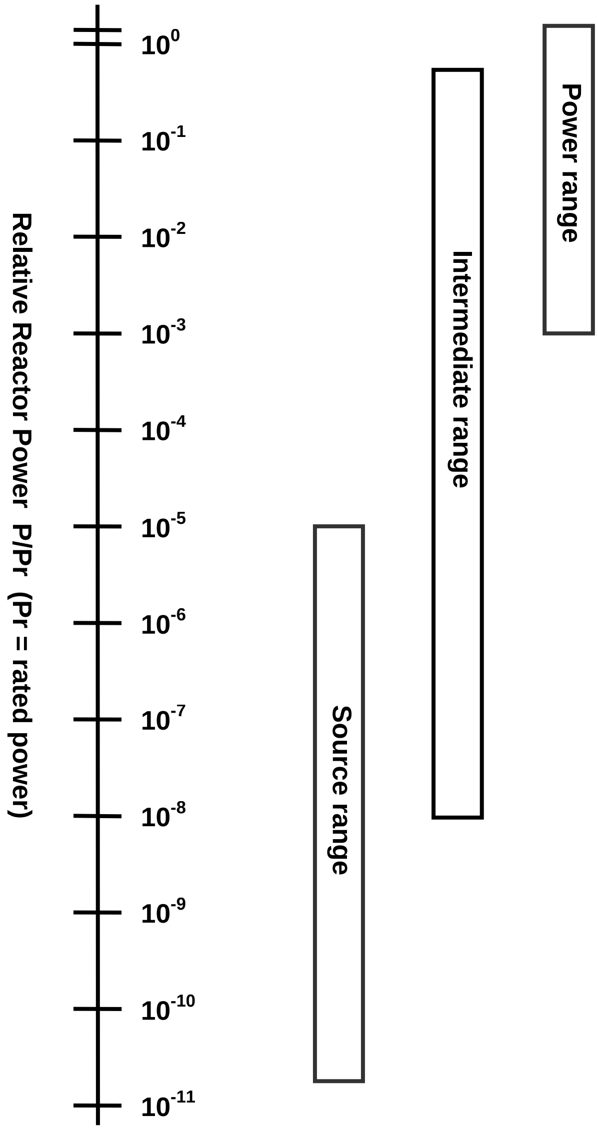
40 AEROBALL PROBES

12 FINGERS WITH POWER DENSITY DETECTORS (SPNDs) AND THERMOCOUPLES

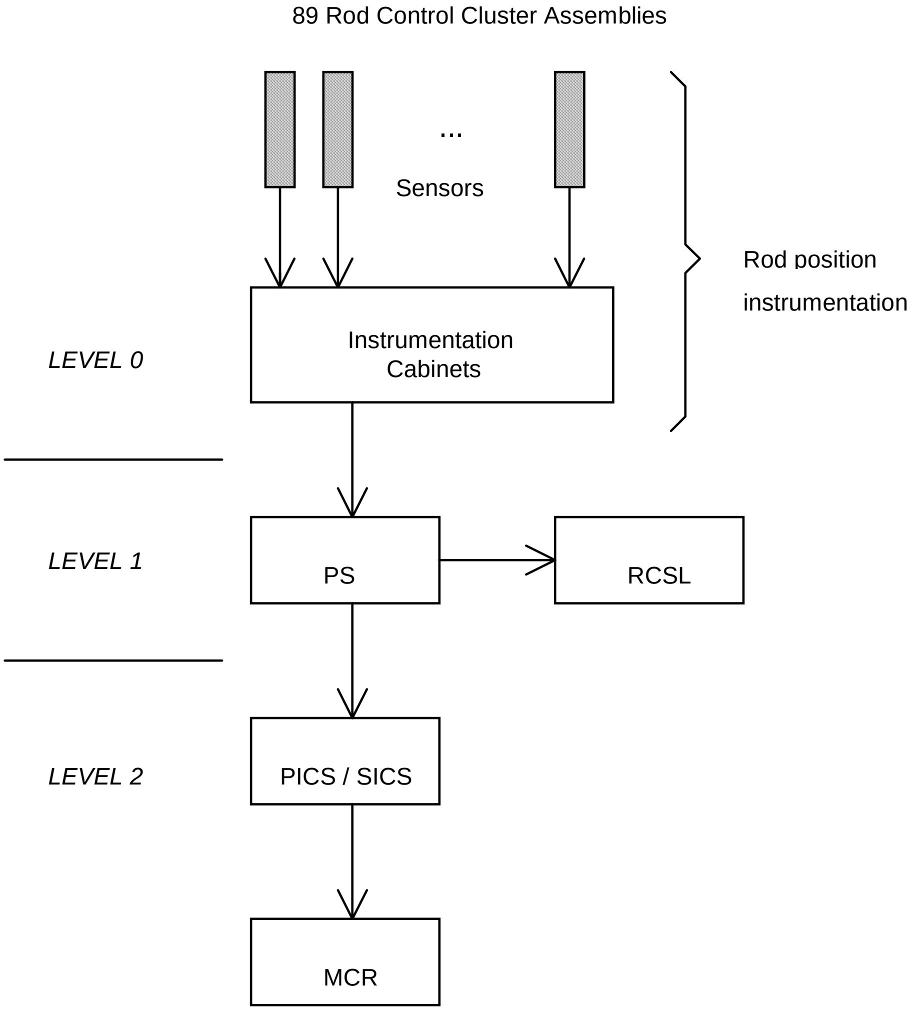
12 RPV INSTRUMENTATION NOZZLES WITH INSTRUMENTATION LANCES

12 LANCE YOKES

G.5 FIG 3: MEASURING RANGES OF EXCORE INSTRUMENTATION



G.5 FIG 4: ROD POSITION MEASUREMENT - INTERFACES WITH OTHER I&C SYSTEMS

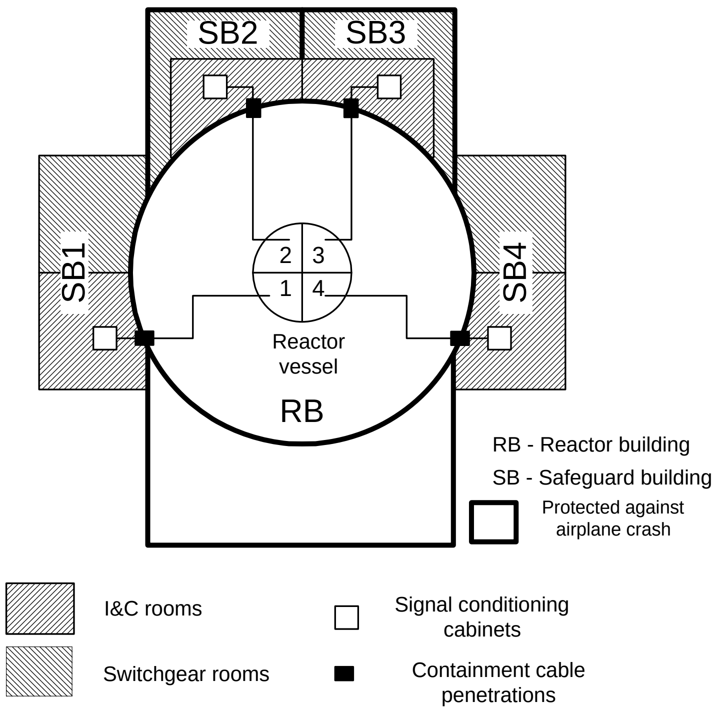


PS	:	Protection System
RCSL	:	Reactor Control, Surveillance and Limitation System
PICS	:	Process Information and Control System
SICS	:	Safety Information and Control System
MCR	:	Main Control Room

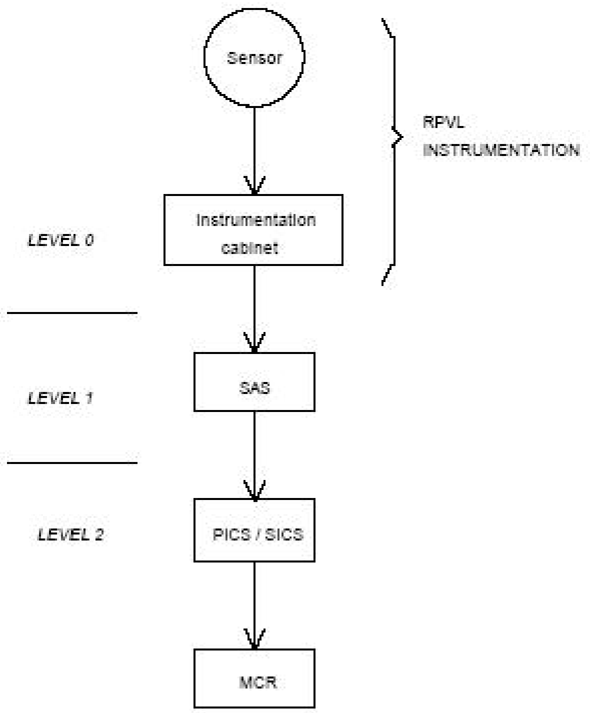
This figure only deals with the rod position measurements. The interconnections between other I&C systems do not appear.

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

G.5 FIG 5: ROD POSITION MEASUREMENT - GENERAL LAYOUT AND ROUTING PRINCIPLES



G.5 FIG 6: INTERFACES AND RELATIONS BETWEEN REACTOR PRESSURE VESSEL WATER LEVEL INSTRUMENTATION AND OTHER SYSTEMS OF LEVEL 1 AND 2

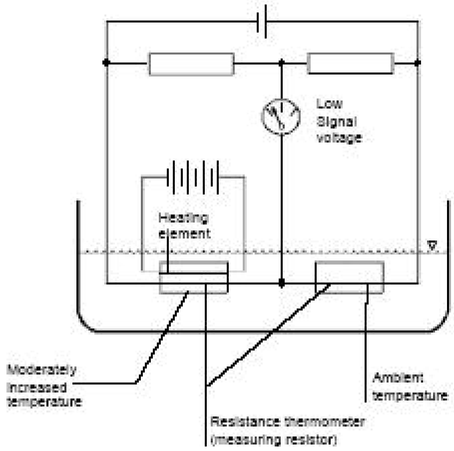


SAS : Safety Automation System
PICS : Process Information and Control System
SICS : Safety Information and Control System
MCR : Main Control Room

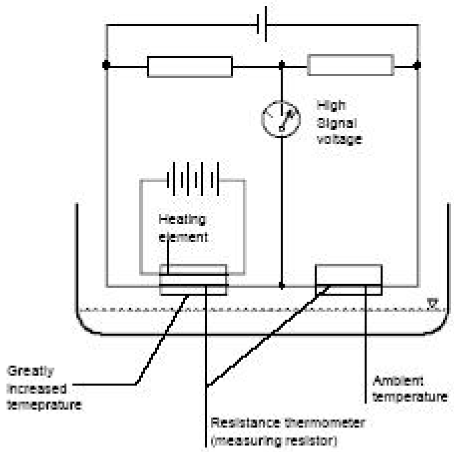
This figure only deals with the reactor pressure vessel water level measurement. The interconnections between other I and C systems do not appear.

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

G.5 FIG 7: HEAT TRANSFER – OPERATING PRINCIPLE OF LEVEL PROBE HEATED AND UNHEATED RESISTANCE THERMOMETERS IN WHEATSTONE BRIDGE CIRCUIT

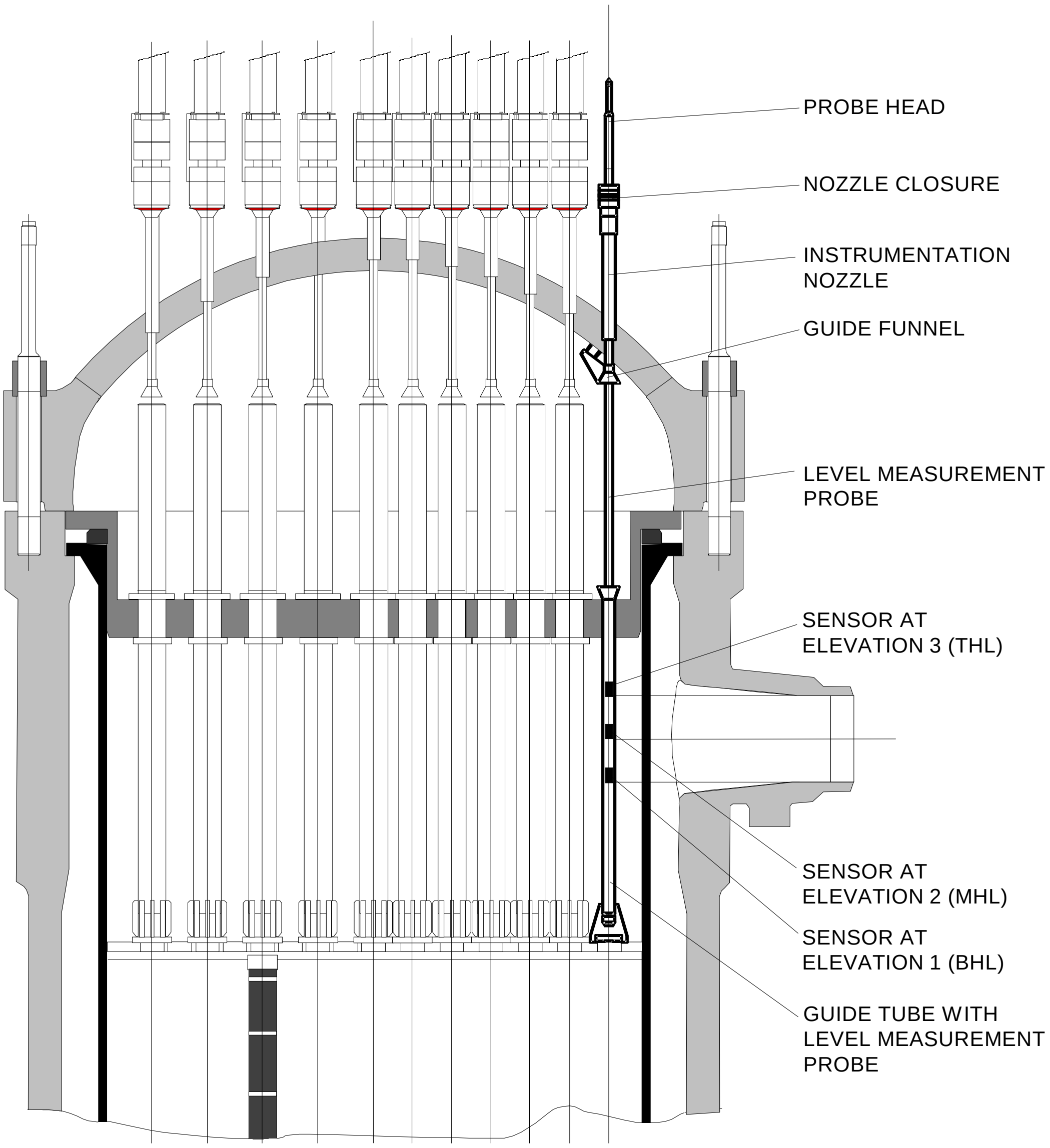


a) Level above sensor



b) Level below sensor

G.5 FIG 8: 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)