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Post Accident Monitoring in PFBR—Safety in Nuclear Power Plant

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Abstract

In 500 MWe Prototype fast breeder reactor (PFBR), instrumentation for Post Accident Monitoring (PAM) is provided for monitoring the status of core and Reactor Containment Building (RCB) in case of Core Disruptive Accident (CDA). The instrumentation for PAM provides the operator with the necessary information by monitoring and displaying critical parameters. This paper details the parameters and how they are monitored.

Keywords: accident, pressure, sodium, activity, neutron

1. Introduction

Energy is a vital component for development of economy and providing high quality of life to the citizens. In view of growing concerns on availability of resources, climate change and energy security, nuclear is a preferred option for providing sustainable energy. Among many nuclear energy systems, Fast Reactors (FRs) are the most efficient energy system for the effective utilization of uranium resources.

In order to demonstrate the techno-economic viability of SFRs for the commercial exploitation, a 500 MWe Prototype Fast Breeder Reactor (PFBR) has been designed and developed. PFBR is under construction at Kalpakkam. The reactor is provided with two shutdown systems having diverse design features.

2. Scope

Normal process upsets and Design Basis Events (DBE) such as transient over power are not considered as design basis events for the design of PAM. In addition, common mode events such as fire and flooding are not treated as PAM events. When there is mismatch of power produced and power removed from the reactor, with shutdown systems failing to respond to the demand, certain parameters such as temperature, pressure and gamma activity in the core raise, causing CDA. This leads to sodium boiling, core melting and pressure bubble formation in the main vessel. This results in sodium entry into RCB, raising the pressure, temperature and gamma activity in RCB. In case of anticipated plant occurrences, initial protection and mitigating actions are taken automatically by the plant protection systems. Instruments for PAM have ranges to cover the maximum values that can attain under worst-case conditions (i.e. under CDA, which is a beyond design basis event).

The instruments are also qualified to survive the conditions associated with CDA, such as temperature, pressure and radiation level. When CDA occurs, parameters such as core neutron power, main vessel surface temperature, RCB sodium activity, RCB air temperature, RCB air pressure and gamma field inside RCB may rise to considerably higher levels. The role of Post Accident Monitoring System (PAMS) is to acquire the above parameters signals, compare the acquired signals with the threshold values and transmit the processed information & parameters values through Safety Class-2 data highway and generate alarms in control room.

3. Salient Features

- The signal processing channels are located outside RCB.
- The equipments (sensors and cables) are qualified for the extreme conditions expected in their lifetime and during CDA.
- The electronic instrument channels are qualified as per the applicable specifications for environmental and EMI/EMC conditions.
- Periodic surveillance is under taken on the instruments to keep them in healthy and calibrated condition.
- In order to know the instrument's healthiness, "Good Operation Trip (GOT)" is provided.

- Hardwired outputs are brought to control room for indication and annunciation.
- All the parameters are isolated and fed to Safety Class II data highway for centralized display and logging.
- Galvanic Isolation is provided between the channels input and outputs and display in control room.
- Redundant instrument channels are powered with independent bus of Class II Uninterrupted Power Supply (UPS)
- Safety Classification: These instrument channels are classified as Safety Class II.
- Seismic Categorization: These channels are categorized as Seismic Category I.

4. Parameters and Instrumentation

The instrumentation for Post Accident Monitoring (PAM) provides the operator with the necessary information during CDA, by monitoring and displaying critical parameters such as Core neutron flux, pressure, temperature, gamma and sodium presence in RCB air after CDA.

The input signals (both analog and digital), terminated at cabinets located in Control building (CB) Local Control Centre (LCC) LCC 1 and CB LCC 2, and processed by separate Real time computer (RTC) systems. The parameters such as core neutron power, RCB sodium activity and gamma field inside RCB, main vessel surface temperature, RCB air temperature and RCB air pressure are processed by separate hardware processing units and signal conditioning modules. Each RTC acquires the above signals in the electrical range of 0.5V-9.5V & 0V-5V. The system compares the acquired signals with the threshold values entered from the process computer and generates alarms in the form of potential free contact outputs whenever the parameter crosses the set threshold value. Similarly analog outputs are generated to display the parameter physical value on recorder units located in control room (CR) Panel. Thereafter each RTC system sends the input signals, parameter values, alarms and health status of RTC system to SC-2 data highway. Table 1 details the parameters, ranges and their location.

Table 1. Parameters monitored in post accident monitoring

Parameter	Range	Type of the detector	Location of the detector
Core neutronic power	1% Pn to 200 Pn	Two Fission Chambers	Below the safety vessel
Main vessel temperature (hot pool)	373 K to 1273 K (100 ^oC to 1000 ^oC)	Two, 2 mm surface mounted K type thermocouples	At the hot pool elevation EL 23520
Main vessel temperature (core catcher)	373 K to 1273 K (100 ^oC to 1000 ^oC)	Two, 2 mm surface mounted K type thermocouples	At the core catcher elevation EL15401
RCB temperature	288 K to 373 K (15 ^oC to 100 ^oC)	3 wire RTD (PT 100)	Inside RCB at EL 35600 and EL35700
Gamma field inside RCB	0.1 mR/h to 10^5 R/h (1µSv/h to 10^3Sv/h)	Two Ionization chambers	Inside RCB at EL35600 and EL35700
Sodium presence inside RCB	10 Bq/cc to 10000 Bq/cc	Two scintillators with sample intake from RCB	Outside RCB in CB at EL35600 and EL35700
RCB Pressure	70 kPa (abs) to 130 kPa (abs)	Two pressure transmitters	Outside RCB in CB at EL35600 and EL35700

4.1 Core Neutron Flux Monitoring

Measurement range is 10^3 n/cm^2/s (nv) to 2x10^7 nv (12.5 MWt to ~ 200% of nominal power Pn). Two fission chambers with a sensitivity of 0.1 cps/nv are located under the safety vessel. Mineral insulated cables from these detectors are connected to the super screened cables (carrying signal over +HV). These cables are routed to CB-LCC where the instrument channels are located.

4.2 Main Vessel Temperature Monitoring

Measurement range: 373 K to 1273 K (100 ^oC to 1000 ^oC). The main vessel temperature monitoring system consists of 2 mm dia surface mounted K type thermocouples (T/C), two each, located at the elevation of hot pool and core catcher. The thermocouples are terminated in a junction box on the roof slab. T/C extension cables are used from the junction box upto the RCB penetration and from the other side of penetration to CB LCC where signal processing units are located.

4.3 RCB Air Temperature Monitoring

Measurement range is 288 K to 373 K (15 ^{o}C to 100 ^{o}C). The RCB air temperature monitoring system consists of Platinum RTDs (two no.). The signals are routed to CB LCC where signal processing units are located.

4.4 RCB Gamma Monitoring

Gamma field inside RCB may go upto a maximum of 10^5 R/h during CDA. Two gamma monitors are provided. Measurement range is 0.1 mR/h to 10^5 R/h (1 µSv/h to 1000 Sv/h). The Channel for gamma monitoring consists of Ionization Chamber with a sensitivity of 10^{-11} A/(R/h) and two super-screened cables (carrying signal and HV) coming from the ionization chamber to the instrument channel in CB LCC.

4.5 Detection of the Presence of Sodium in RCB

During CDA, active sodium enters RCB atmosphere. Sensors and electronics are provided to monitor the presence of active sodium (Na^{24} activity) in RCB air from 10 Bq/cc to 10,000 Bq/cc. Air sample is drawn from RCB at two locations in CB through 25 mm OD SS tubing by means of Dry Carbon type vacuum pump and brought to the detector. Sampled air is returned back to RCB. Gamma channel with Scintillator detector of sensitivity 1 cps/(Bq/cc) with preamplifier is located in the sampling line. Cables (one for signal and other for power supplies/ control signals) coming from the preamplifier are connected to the instrument channel in CB LCC. Sampling arrangement is shown in Fig. 1.

During and after CDA, an abnormal increase in Sodium concentration is expected in the air within the RCB. A sample of air from RCB is drawn at by means of a sampling pump and a sampling pipeline. The air sample is passed continuously through a gas chamber of the monitor, in which detector is placed to detect the activity due to sodium concentration.

The Electronics Processing and Display Unit of the monitor is located in CB-LCC1/CB-LCC2. The monitor provides instantaneous Sodium Aerosol gamma activity concentration display on front panel and analog signal output for display / paperless recorder in control room. The monitor provides relay contact output for the alarm conditions of the signal and also Good Operation Trip contact output for annunciation in control room.

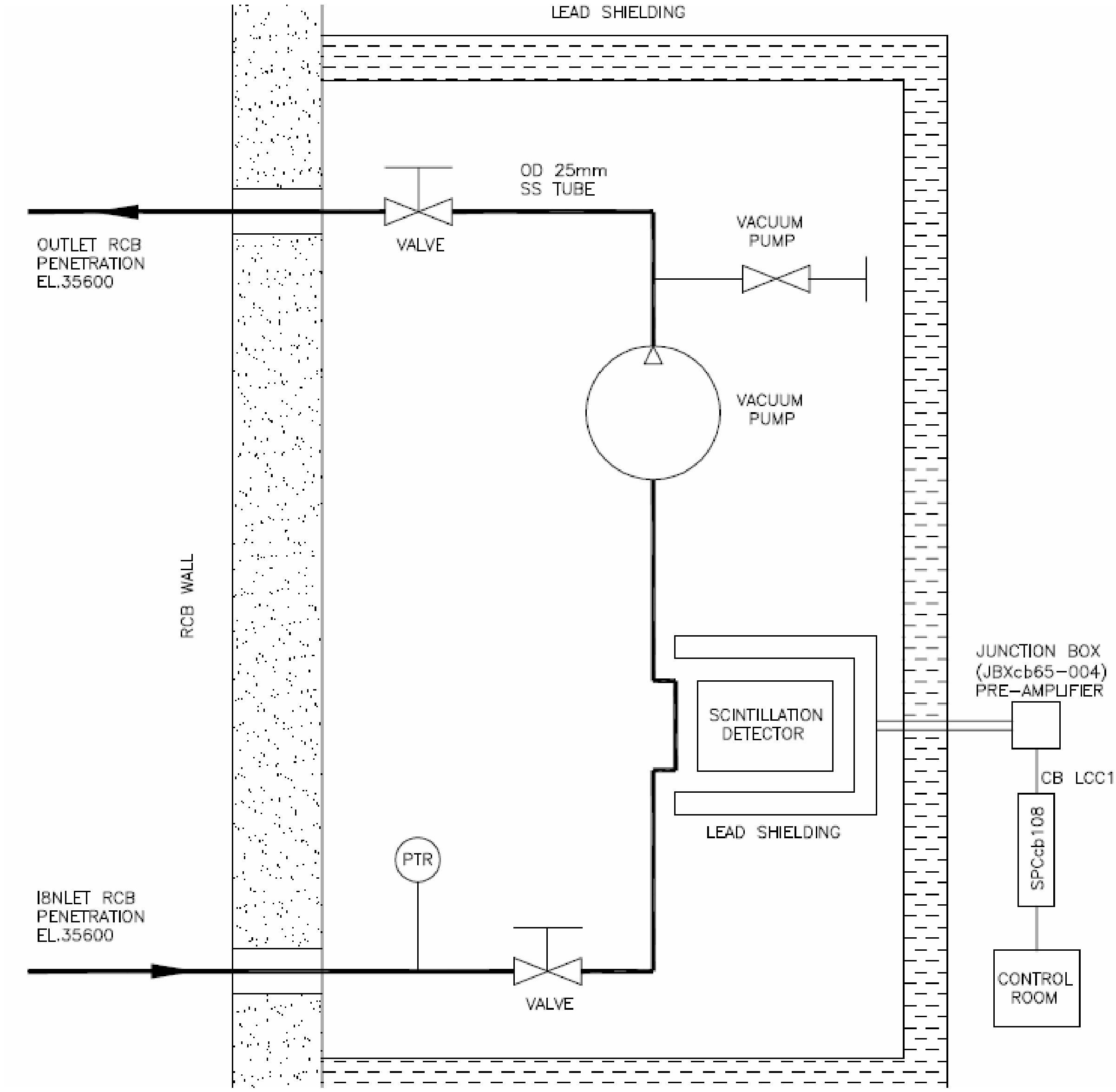

Figure 1. Sampling & monitoring system of "sodium in RCB"

4.6 RCB Pressure Monitoring

Absolute pressure transmitters are connected to the sample intake point, provided for monitoring the presence of sodium and the signal processing electronics are located in CB LCC. Each sampling line is provided with pressure transmitters.

5. Safety Analysis

- Healthiness of the instrument channels of PAMS is a pre-requisite for reactor start-up. Provision is made for monitoring healthiness continuously.
- Dual sensors are provided for each parameter.
- Redundant instrument channels are fed from independent divisions of Class II UPS, 240 V AC.
- System is designed in such a way that no active components of post accident monitoring instrumentation (solid state electronics) are present inside RCB, which are expected and required to be qualified to work during and after CDA.

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