GAMMA RADIATION MONITORING IN THE PRIMARY HEAT TRANSPORT CIRCUIT

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Abstract

Heavy water contamination with fission products in the Primary Heat Transport Circuit (PHTC) of a nuclear power plant (NPP), due to the cladding failure of the fuel element, leads to an unsafe operation of the plant from the point of view of protection of personnel, population and environment. The resulting radioactive waste also makes the use of nuclear energy a sensitive subject. Therefore, these problems must be analysed and treated objectively, in order to choose the best solutions from a technological point of view that will allow a sustainable development of this form of energy. Based on these considerations, the paper addresses the issue of gamma radiation monitoring in PHTC based on gamma spectrometric analysis. The system presented in the paper was successfully implemented in Cernavoda NPP and was developed by the specialists of the Institute for Nuclear Research Pitesti.

Keywords: *Monitoring, Fission products, Spectrometer analysis*

Introduction

Following the fission reactions, the radioactive fission products are accumulating in the fuel element. Moreover, due to the chemical reactions and mechanical stresses to which the fuel element is subjected (high temperature and pressure), the corrosion and deformation processes appear, and, in time, could lead to possible fuel element damages.
The damage of the fuel element, through the cladding failure, leads to the release of radioactive fission products which represent the main source of contamination for the Primary Heat Transport Circuit (PHTC) in a CANDU type nuclear power plant (NPP).

Generally, during the fission reactions the transition from one fission product to another is done by means of β, γ disintegrations or by neutron capture. In this particular case, the nuclear reactions of interest are those leading to obtain the following radioisotopes: $_{36}Kr^{88}$, $_{53}I^{131}$, $_{54}Xe^{133}$ and $_{54}Xe^{135}$, respectively.

PHTC also contains other isotopes of Iodine, Xenon and Krypton, so the energy spectrum of gamma radiation tends to 2.5 MeV, occasionally up to 6 MeV energies.

Radioisotopes can be present over a wide range of energies, depending on fuel parameters and reactor power history. The range of the energy domain of the monitored fission products, for the detection of failed nuclear fuel, covers the interval (80 ÷ 400) keV, the rest of the energy range up to 6 MeV contributing to the creation of the induced gamma background, *Compton background*, and implicitly to the increase of global gamma rate.

The gamma spectrometric system that monitors fission products results: ^{133}Xe, ^{135}Xe, ^{88}Kr and ^{131}I radioisotope for the detection of failed nuclear fuel must cope with a global gamma rate over 100,000 imp./s.

For the simultaneous monitoring of the entire PHTC, from the two hydraulic loops, separate lines are used for continuous sampling. When an increase in PHTC activity is detected, the operator monitors either loop 1 or loop 2 to determine the affected circuit.

Structure of the gaseous fission products monitoring system

In principle, the spectrometric chain specific to the monitoring system of gaseous fission products (see Fig. 1) consists of the detector-preamplifier assembly, amplifier, multichannel buffer (MCB) and a process computer [1, 2].
The multichannel analyser (MCA) consists of a MCB and the suitable software.

ADCAM MCA concept (Analogue to Digital Converter And Memory) implemented by ORTEC, implies separation of the MCA functionality, as follows:
- data acquisition and storage in a hardware component, known as multichannel buffer (MCB);
- control and display, software component, often referred to as MCA emulation software.

In a MCB, the purpose of the analogue-to-digital converter (CAD) is to convert maximum of the analogue pulse into a numerical quantity, and for the microprocessor to manage data to be stored in memory in the form of a histogram. Finally, after a certain acquisition period, this histogram (see Fig. 2) shown on the display will represent the shape of the energy spectrum of the radionuclides monitored by the detector system associated with the given application.

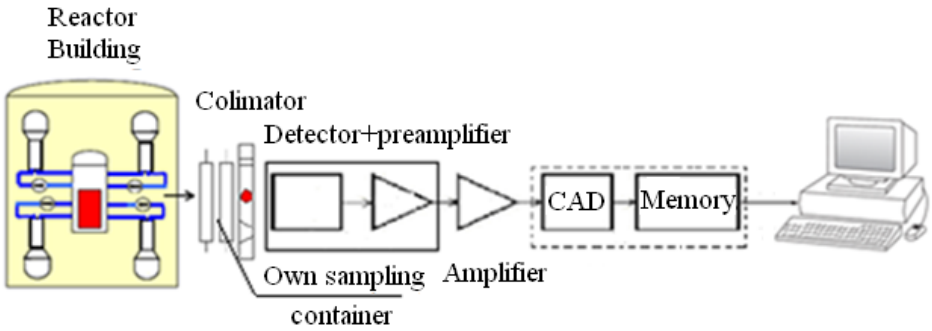


Fig.1. Gaseous fission products monitoring system

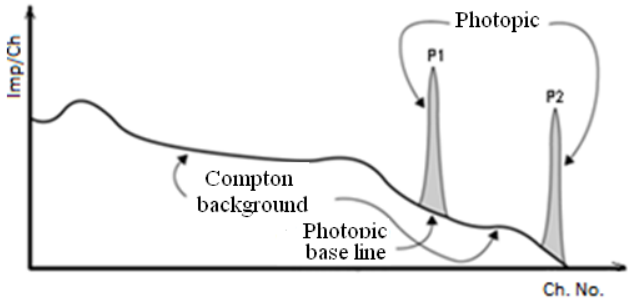


Fig.2. Multi-energy gamma spectrum

The five main outputs of the gas fission monitoring system are of the 4-20 mA current loop type and represent the mass/volume concentrations of monitored radionuclides activities: ^{133}Xe, ^{135}Xe, ^{88}Kr, ^{131}I and the global gamma rate, respectively.

In addition to these outputs, the systems have two more relay contact outputs. Through these outputs the protection of the detector is ensured and the operation of the system itself is monitored; low liquid nitrogen level alarm and system failure alarm are provided. The system failure is monitored by programming the watchdog on the computer motherboard.

The monitoring system for gaseous fission products consists of sampling containers and the detector-collimator subassembly. The sampling containers and the detector are facing each other, in a well-defined source-detector-collimator geometry, and the samples from the two PHTC loops are directed to the two sampling containers using a hydraulic system that selects the point of origin of the samples by means of a system of pneumatic valves.

The detector-collimator subassembly contains an HPGe type semiconductor detector, a collimator provided with two slots for blocking the gamma radiation flow and a calibration source (^{133}Ba) in the spectrometric chain energy.

The energy calibration source must be a long-lived radionuclide, it should have at least 4-5 well-defined peaks in the interested energy field and the activity must allow calibration in a reasonable period of time (5-10 minutes).

The detector is encapsulated in a PopTop type capsule, and its sensitive area with the "front-end" electronics of the preamplifier and the temperature sensor are placed in a vacuum enclosure and maintained at cryogenic temperatures (80 ÷ 100 K).

The detector must be optimized for the following energy peaks of interest:

Fission product	Photon energy
Xe^{133}	81.0 KeV
Kr^{88}	196.1 KeV
Xe^{135}	249.6 KeV
I^{131}	364.5 KeV

The collimator is made of lead with two slots (SA -Small Aperture, LA -Large Aperture), and the walls are plated with tungsten alloy, to avoid formation of secondary X-rays, which would interfere with the primary gamma radiation.

Such a system includes also the detector supply and protection system, consisting of high voltage (HV) module and liquid nitrogen level (LNL) module which monitors the liquid nitrogen level in the Dewar vessel (see Fig. 3). When the liquid nitrogen level falls below a certain threshold, LNL module generates a local acoustic-optical signal and a TTL pulse, which is afterwards processed.

The software generates a message: "Low liquid nitrogen level" and it transmits the information to the central computer through a relay contact.

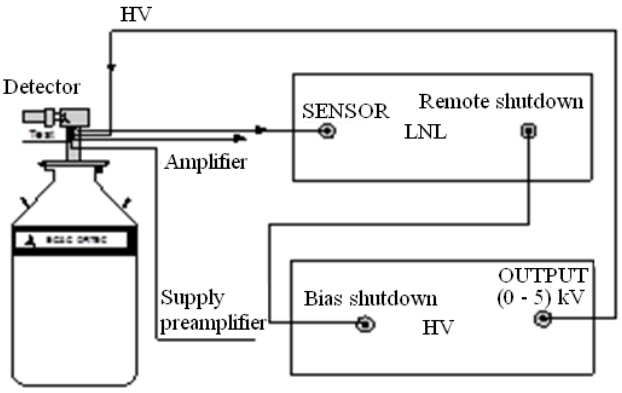


Fig. 3. Block diagram of the detector power supply system

By interposing the SA aperture between the detector and the radioactive source, gamma radiation flow attenuation is achieved, which assures an opening that allows the overall counting rate reduction by a factor of 100. The collimator movement to one of the positions: LA, SA or energy calibration is performed using a kinematic mechanism screw-nut allowing the collimator to slide along a ball rail.

Since the reproducibility error of the collimator position must be within ± 0.1 mm, the collimator drive system must be provided with a relative absolute encoder. The presence of the encoder allows the establishment of a working algorithm so that in case of incorrect positioning of the collimator (for various reasons) a new repositioning command having as positioning parameter the difference between the final position and the new position obtained, to be launched. This cycle can be repeated many times, avoiding as much as possible the shutdown of the system and the loss of a number of spectrometric data acquisition cycles. To ensure a fixed mark (origin) the collimator command-control system is provided with three switches: left stroke head, right stroke head and origin.

The collimator command-control system is a system consisting of: stepper motor, command-control card, power driver, encoder and computer interface.

The position control is performed by a system in which the encoder sends the relative position of the collimator to the encoder interface, and through the controller system this value (number of steps) is compared with actual value of the position (number of steps between two successive positions).

The preamplifier (PopTop) - supplied with the HPGe detector in a PopTop type capsule, is mounted in the vacuum chamber, behind the detector. The pulse from the detector is an electrical signal whose amplitude is proportional to the energy of the incident gamma photon.

The load preamplifier provide as output a voltage signal with rise and fall times of the order of nanoseconds, or microseconds, respectively, given by the expression:

$$V_{out} = \frac{Q}{C} \cdot \exp\left(\frac{-t}{RC}\right)$$

The amplifier forms and amplifies the signal from the preamplifier. The signal formation process must not lead to a change in the pulse height (amplitude), because the signal amplitude is proportional to the energy of the incident gamma radiation (γ). The output of the amplifier (Gaussian form) is sent simultaneously to the input of the MCB and of the level discriminator (SCA - Single Channel Analyzer).

The level discriminator produces a logic output signal only if the input signal exceeds a preset threshold level of 50 KeV. The output pulses are sent to the ratmeter.

The Lin/Log Ratmeter displays the global gamma rate: linear or logarithmic and generates an analog output in the range 0-10 V. This voltage signal is proportional to the logarithm of the measured rate.

The multichannel buffer is either a plug-in card or a plug and play device, which contains data processor, CAD, program memory and data memory with the main function of acquisition and storage. The stored gamma spectrum is then transferred to the control and data processing system (process computer).

The calibration of the gamma spectrometric chain specific to such a system is a calibration in energy, shape and efficiency. The calibration in energy and form is performed with a solid source of ^{133}Ba, the calibration in efficiency being performed with a liquid source of ^{133}Ba, with the geometry of the sampling containers.

Hardware and software configuration of the monitoring system

The monitoring system shows the four fission products concentrations evolution over time, the overall rate, times (real, live and dead), collimator position (LA, SA and calibration), history of the four fission products activities, local warnings (system fault and low LNL, etc.) [3, 4].

There is the possibility to perform gamma spectrometric analysis: calibration in energy, calibration in efficiency, identification of radioisotopes, calculation of the activities of these radioisotopes, etc. The system requires a single operation to effectively calibrate the spectrometric chain for both source-detector geometries: LA and SA.

The activities of gaseous fission products: ^{133}Xe, ^{135}Xe, ^{88}Kr and ^{131}I together with the global gamma rate can be displayed locally and remotely to the main computer. Remote data transmission is performed by unified signal, 4-20 mA and displayed at the operator's request. The gas fission monitoring system block diagram is shown in Fig. 4.

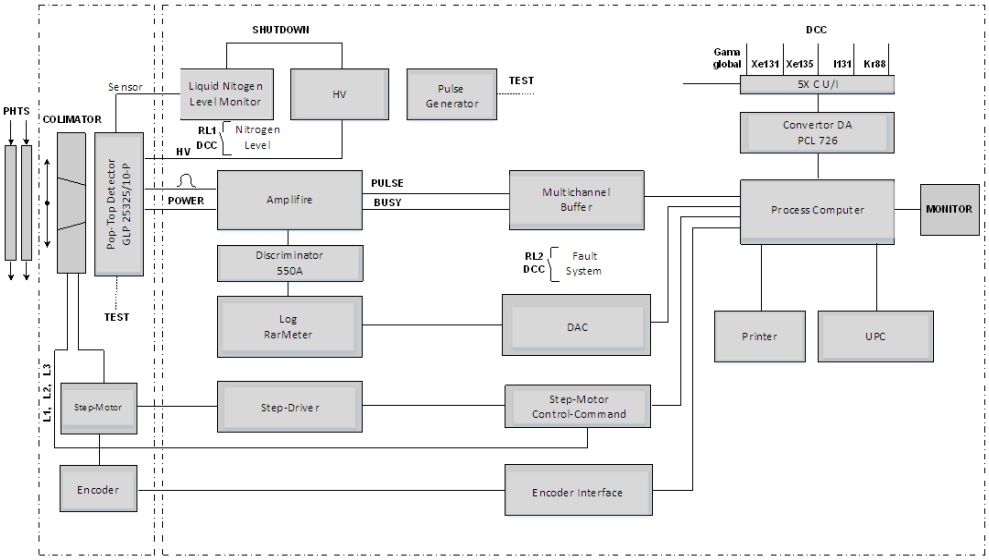


Fig.4. Block diagram of the gas fission monitoring system

The gamma radiation monitoring system in the primary heat transport circuit was developed, based on the accumulated knowledge and a vast experience gained in many years of research, through the interdisciplinary contribution of specialists from the Institute for Nuclear Research Pitesti. This system is in operation at Units 1 and 2 of Cernavoda NPP, being used successfully since its commissioning.

Conclusions

The PHTC heavy water radioactivity monitoring system is part of the auxiliary safety systems of a CANDU nuclear power plant.

The irradiated fuel element is subjected to chemical reactions and mechanical stresses that can lead to corrosion and deformation. Thus, the mechanical strength of the irradiated fuel element is important in terms of efficiency, protection of personnel, population and the environment.

The gaseous fission monitoring system is an online system that continuously monitors PHTC to detect the presence or absence of ^{133}Xe, ^{135}Xe, ^{88}Kr and ^{131}I radioisotopes.

Based on the time-evolution of these radionuclides and the gamma spectral analysis performed, the defect amplitude can be determined: pore, crack (heavy water enters the fuel element) and major defect (fuel element cladding rupture).

After analysing the information received from this system, in case of a major failure of the fuel element, the operator can decide to shutdown the plant.

References

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