# Radiological Work Management at CNE Cernavoda NPP: Radiation Monitoring System (RMS)

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## 1.0 INTRODUCTION

Cernavoda Nuclear Power Station is a two-unit plant with pressurized heavy water reactors, CANDU 6 type designed by AECL Canada, 700 MW electrical each.
The main mission of the company is the industrial production of electricity and heat, by using nuclear power, in terms of maximum safety, reliability and respect towards the environment.

Commercial operation of Unit #1 started in December 1996. The operation has been fairly smooth since the beginning and annual gross capacity factor of 91,37% in 2006 ranked the Cernavoda NPP-Unit 1 in a leading position in the nuclear power plants top worldwide. Unit 2 commercial operation started in November 2007 therefore CNE Cernavoda now generates about 17 – 18% of the overall electricity production of Romania.
CNE Cernavoda management is committed to continuously improve the safety standards in order to protect environment, population and personnel.
A new system - Radiation Monitoring System (RMS) was implemented at Cernavoda U2, with commercial operation in the fall of 2007. The purpose of this improvement is to connect the on-line radiation monitoring equipment to a computerized interface system that allows remote monitoring, limited remote control capability and maintaining integrated short and long-term database. Thus the collective dose of the operating personnel will decrease (by avoiding the entrance in high radiation hazard areas) and a better radiation hazard control will be improved for the normal operation of the plant (where real time radiation hazard information will be available).

## 2.0 THE RADIATION MONITORING SYSTEMS NETWORK (RMS)

The RMS integrates all fixed and portable radiation monitoring equipment, a local area network (LAN) and dedicated components and software to control the field equipment, store and display the measured or processed data, trends.
RMS interface with the following systems: Fixed Gamma Area Monitoring, Fixed Contamination Monitoring, Portable Radiation Monitors, Fixed Tritium in Air Monitoring, Liquid Effluent Monitor, Gaseous Effluent Monitor and Post Accident Air Sampling and Monitoring.
Information is transferred in real time using standard communication protocols and commercial computers.
The RMS is only having a support function for the radiation monitoring equipment, which are stand-alone devices being able to operate independently. All the RMS components are located in accessible areas or in mild environmental conditions.

The RMS functions are:

- **Monitoring** – allows operator to survey the radiation hazards (gamma radiation fields, level of tritium emissions, radiation levels of liquid and gaseous effluents, radiation levels of post accident air sampling and monitoring system) generated by the normal operation of the plant and annunciate high (dangerous) levels in Radiation Control Service (RCS) room and Main Control Room (MCR); survey the working status of the measuring loops;
- **Control** – to establish the set-up parameters for the automatic operation of the channel; to operate manually the measuring loop for non-routine measurements / calibrations; to configure the network database;
- **Maintainability** – equipment and system failures are annunciate in RCS and MCR rooms;

- **Data storage –** every event is stored in a data file that can be read and backed up or printed; alarms, acknowledgements system events or parameter changes are recorded in this file and exported into a spreadsheet allowing filtering, statistical analysis and publishing of the archived data; integrated short and long term databases can be kept;
- **Operator interface –** provide customer reports, detailed display of historical events, remote interactive control functions for the field radiation monitoring equipment, including the display of the commands and the response to these ones.

All the RMS systems shall be operated online 24h per day.

**2.1 RMS Portable Area Monitors**

RMS portable equipments interface consists of 26 junction boxes wired to a special designed network, where portable monitors can be connected.
Thus, portable radiation monitors can be placed in different locations in Reactor Building and Service Building which are not covered by other fixed monitors or, they can be used as back-up solutions in case of failure of fixed monitors measuring loops.

Portable equipment that can be use in this way is:
- Semi-portable area alarming gamma monitors;
- Continuous air (radioactive particulate) monitors.

**2.2 Fixed Area Gamma Monitors System (FAGM)**

This system is intended for the protection of personnel working in those areas of the Reactor Building and Service Building where high gamma radiation fields are expected.
The system consists of 34 loops connected to a Central panel through redundant network line. The panel includes one industrial PC used to provide means for remote control of the system and interface with the operator and other LANs in the plant (RMS - Radiation Monitoring Systems Network).
Each loop consists of a gamma detector and a processing / alarming unit.

The system is designed to accomplish the following functions:
a) **Monitor** the level of gamma radiation in those areas of the station where high radiation fields are expected.
b) Provide a continuous and centralized **display of the radiation level** in each of the monitored areas. The displays are in equivalent dose rate - mSv/hr.
c) Provide a **visual and audible alarm** in each monitored area.
d) Allows to the control room operator to **check at any time the radiation level** and alarm conditions in each of the monitored areas.
e) **Alert** the control room operator about the alarm conditions (high radiation or equipment failure) that occur in the monitored areas.
f) Provide a **permanent record of parameters**, on the industrial computer and on the control room computer (DCC).

Extension with one loop and improvement (replacement of silicium detectors with ionization chamber) of Fixed Area Gamma Monitors (FAGM) system is in progress at both units. At the end of this program there will be 35 operational loops per unit.
During Unit 2, planned outage in 2009 four loops were improved and one loop was improved in running.
During Unit 1 planned outage in 2010, the last 3 loops will be improved.

**2.3 Fixed Contamination Monitors System (FCM)**

The primary aim of contamination control is to minimize internal exposure by preventing the spread of contamination within the Radiation Controlled Area (RCA) and outside of it.
To reduce the spread of contamination, the movement of personnel is controlled by establishing traffic routes and fixed monitoring stations at the transitions boundaries between radiological zones and at the exit from the RCA. To attain such control the radiological zone is divided into three zones according to the potential contamination in each area.
Control of personnel contamination is achieved by placing monitors at the transition boundaries, thus individuals passing between zones can monitor hands, feet and clothes.
These zones are defined as:

**Zone 1** is a controlled area and contains radioactive systems, equipment and materials that may be source of contamination or significant radiation exposure. Normally frequented areas should have no detectable loose contamination.
Two Full Body Pre-monitors and one Exit Tools Monitor are provided for the persons leaving the Reactor Building through equipment airlock.
Hand, foot and clothes monitors are placed in the Service Building (S/B) at the exits point from those rooms considered Zone 1.

**Zone 2** contains no radioactive systems, and is normally free of contamination but is subject to infrequent cross-contamination as a result of people and equipment traffic.
Hand, foot and clothing monitors are placed in other rooms in the Service Building, the Solid Radwaste Management Facility and the Spent Fuel Dry Storage Facility, and the Mechanical Office Complex.
Also hand, foot and clothing monitors are placed in key traffic place in the Service Building.
There are 43 contamination monitors all connected to the Radiation Monitoring System PC server, to indicate high radiation alarms and monitor failures.
A laundry monitor is placed in the laundry room and it is used to detect residual radioactive contamination of the radiation protection clothing after decontamination into washing machines.

**Zone 3** A clean zone where absolutely no contamination is permitted. (Turbine Building).

Four Full Body Monitors are located at the main exit from the RCA, so that personnel leaving this area must make a final check at this point. Also, two Exit Tool Monitors (Small Article Monitors – SAMs) are provided in the same location to check the tools and small personal objects. At Unit 2, these monitors are connected to Radiation Monitoring System (RMS) network, to remotely indicate high radiation alarms and monitor failures.
Due to the fixed contamination monitors obsoleteness at Unit 1, 65% of the monitors were replaced starting from 2003 and the program will be finalised in 2012.

### 2.4 Fixed Tritium in Air Monitoring System (TAM)

CANDU reactors are both moderated and cooled by heavy water ($D_2O$). Tritium is produced in CANDU reactors by neutron reactions with deuterium, boron, and lithium and by ternary fission. Most of the tritium present in CANDU reactors is in the form of tritiated heavy water – DTO.
The leaks from tritiated heavy water systems (moderator and primary heat transport) or their auxiliaries are the main sources of tritium in the reactor building air atmosphere. Despite all protective measures (design, procedures and rules), operating experience to date of CANDU reactors has indicated that DTO is the major contributor to the internal dose of professionally exposed workers.
At Cernavoda Unit 1, after three consecutive years (2004, 2005 and 2006) of major concern on individual and collective internal doses, due to the increase of tritiated water vapours concentration in the Reactor Building, corrective and preventive actions and recommendations, aiming both work

planning (exposure control) and technical aspects, worked efficiently and at the end 2007 internal dose contribution to the total collective dose was reduced to 30.7%.
Before the commercial operation, in Unit 2 the "Tritium in Air Monitoring" was operational and integrated in the Radiation Monitoring System.
Tritiated water vapour is a health hazard and its early detection in nuclear plants is important because it has all the characteristics of water vapour in atmosphere. By detecting tritiated vapour, the monitoring system serves the following purposes:

- detects heavy water leakages;
- indicates levels of tritium in radiological area;
- Decreases the exposure of plant personnel by preventing the entrance in those areas where tritium dose rates unexpectedly increased and reducing time spent by radiation control staff for air sampling.

The Tritium in Air Monitoring System contains 8 fixed Local Monitoring Units (LMU). Each LMU is sampling air from 4 locations with a potential tritium hazard.
The LMU is controlled either locally or remotely, through the Radiation Monitoring Systems (RMS) network and by a software application dedicated to this system.

The system performs the following functions:

- Continuous sampling of the air from various locations in Reactor Building and Service Building where high-level of tritium is expected.
- Performs tritium concentration measurements on the continuous samples and compare the measurement results with a preset value (set point) established by operator.
- Displays tritium concentration activity (Bq/m3) or on request, equivalent dose rate (Sv/h).
- When the set point is exceeded or a failure occurs, the system alarms remotely in the Main Control Room through DCC, throughout the RMS network and to Radiation Control Service, by visual and acoustic signal.
- Performs "non-routine" tritium concentration measurement using the temporary sampling lines and semi-portable Tritium Monitors.

Tritium Monitors provide compensation for other radioisotopes, including all reactor gases as well as radon.
Even the tritium concentration in Unit 2 systems is still low the TAM system already proved its efficiency by prompt detection of increased level of tritiated water vapour in the air of some rooms in the Reactor Building and Service Building.
A similar Tritium in Air Monitoring System was installed at Unit 1, system which contains 4 fixed Local Monitoring Units. Each LMU is sampling air from a specific area (5 to 11 separate locations). In order to improve the system efficiency, will be implemented one supplementary Local Monitoring Unit, so the system will contain 5 Local Monitoring Units.

## 2.5 Liquid Effluent Monitor (LEM)

The national regulatory body, CNCAN, established the maximum allowable radiation dose to be received annually by a member of the general public at the site boundary. In its day-to-day operation, a nuclear power plant must restrict its radioactive waste release levels such that any person (hypothetical or otherwise) who drank water at the outfall, and who breathed air in the vicinity of the plant, could not ingest sufficient quantities of radioactive substances such that the maximum permissible dose criteria were exceeded.

To facilitate the provision of acceptable release levels, all the crucial released radionuclides are limited to specific maximum concentrations (in air and water) called "Derived Emission Limits" (DELs). The maximum concentration allowed for each radionuclide is a function of that substance's potential for accumulated radiation dose to an exposed individual.

All active (or potentially active) liquid waste of the nuclear power station is collected in the hold-up storage tanks of the liquid waste management system. The contents of each one of the five tanks are permanently agitated to ensure homogeneity, and samples are taken for radio-chemical analysis. When half full, the contents of any one particular tank judged to have a sufficiently low activity concentration, are discharged to the station Condenser Cooling Water Duct (CCWD) where the activity is reduced by dilution to an acceptable level before release to public waters.

The role of the Liquid Effluent Monitor (LEM) system is to:
- continuously monitor any liquid waste as it is being discharged to the CCWD;
- provides a permanent record of the concentration of radioactivity in the discharge as a function of time;
- provides by integration with respect to flow and time, the daily and monthly total activity released;
- alarms in the Main Control Room and automatically terminates the discharge if the concentration level or the totalized activity (daily or monthly) of the liquid effluent exceeds present limits. An automatic discharge termination will also occur for any malfunction of the LEM. In each case, proper local and remote annunciation will alert operators.

The LEM system consists of the following:
- liquid sampler
- sample delivery system
- NaI scintillation detector, preamplifier and a control console.

At the end of 2007, at Unit 1 was finalised the improvement of the LEM system, which consist in installation of two redundant subsystems: LEM OLM and LEM OFM.
The On-Line Leak Monitor (LEM OLM) is designed to measure the gamma volumetric activity of a leak stream in a pipe. The monitor displays the measured volumetric activity and can alarms whenever the pre-set threshold levels are exceeded.
In order to control their released activities, an OFF-LINE Monitor (LEM OFM) is used to take a sample from this pipe to a bucket. This bucket is located on the top of a NaI scintillation detector used to control the gamma volumetric activity. The measurement is correlated with the bucket volume by using a weigher based on a strain gauge sensor technology.
The samples collected by the LEM over a day are taken to the station Health Physics laboratory for detailed radionuclide analysis. The results of this analysis constitute the official release results for the station.

### 2.6 Gaseous Effluent Monitor (Stack Monitor - GEM)

To ensure that the limits of permissible release of radioactive gases and particulates are not exceeded, a stack monitor, called Gaseous Effluent Monitor (GEM) is used to measure particulate, iodine and noble gases activity and to alarm when these release levels are exceeded. The activities measured are recorded by the station control computers which initiate alarms for any high instantaneous release and high 24-hour total release. The monitors are designed to initiate fail-safe alarms for such conditions as loss of power, high radiation level and air flow disturbance.
The GEM system consists of a multi-entrance izokinetic nozzle (in order to provide a representative sample), a sample line and a monitor. The nozzle is located in the ventilation exhaust stack and allows a draw of representative air sample through the sampling line.

The Gaseous Effluent Monitor consists of:
- a particulate monitor;
- an iodine monitor;
- a noble gases monitor;
- two tritium samplers and two 14C samplers for further laboratory analysis.

The alarms signals which are displayed on a monitor in the Main Control Room are:

- stack air flow unbalanced (high or low);
- high activity alarm for cumulative releases and instant release rates for each monitor;
- equipment test;
- Equipments failure (measurement system and sampling pump failure).

In order to solve the "components obsoleteness" problems of the GEM's system at Unit 1, at the end of 2008 were finalised the first two steps of improvement, so it were installed a redundant particulate, iodine and noble gases loop and two passive collectors (tritium and $^{14}C$ samplers) similar with the new equipments installed at Unit 2 (same manufacturer). The third step is to install a new noble gases spectrometric loop by the end of 2009, in order to evaluate the individual radioactive isotopes releases. The GEM spectrometric noble gases project will be extended in the next year at Unit 2.

**2.7 Post Accident Air Sampling and Monitor System (PAASM)**

At Unit 2, a new Post-Accident Air Sampling and Monitoring (PAASM) system obtains samples of air from the Reactor Building (R/B), detects and quantifies iodine, noble gases activity and tritium expected to be present in the Reactor Building atmosphere under accident conditions and perform routine monitoring of the contamination with Noble Gases of the atmosphere in the R/B basement under normal operating conditions.

The PAASM is an independent system that consists of a permanently-installed monitor with a sampling system attached to it, and it is capable of:

- draw air samples from R/B basement under normal operating conditions to monitor the Noble Gases contamination;
- draw air sample from the Reactor Building Boilers' Room upon operator's request;
- monitor and measure the gross gamma and beta activity for iodine, noble gases activity and tritium (grab sampling), under accident conditions (LOCA – Loss Of Cooling Agent);

Measured values of activity concentrations for iodine and for Noble Gases are displayed on the RMS computer and on the CRT in the Main Control Room on operator's request.

Post Accident Air Sampling and Monitoring system and Gaseous Effluent Monitors proved their efficiency soon after commercial operation of Unit 2 started, during the discharges of defective fuel bundles, and doses to the public were considerably reduced (reactor building containment isolation due to the high level of air contamination). Also, on line indications of Fixed Area Gamma Monitors helped / allowed the identification of defective fuel bundles and prevented unexpected exposure of workers which might enter in those rooms (normally with free access) of the reactor building where radiation fields significantly increasing during defective fuel discharges. (Figure 1)

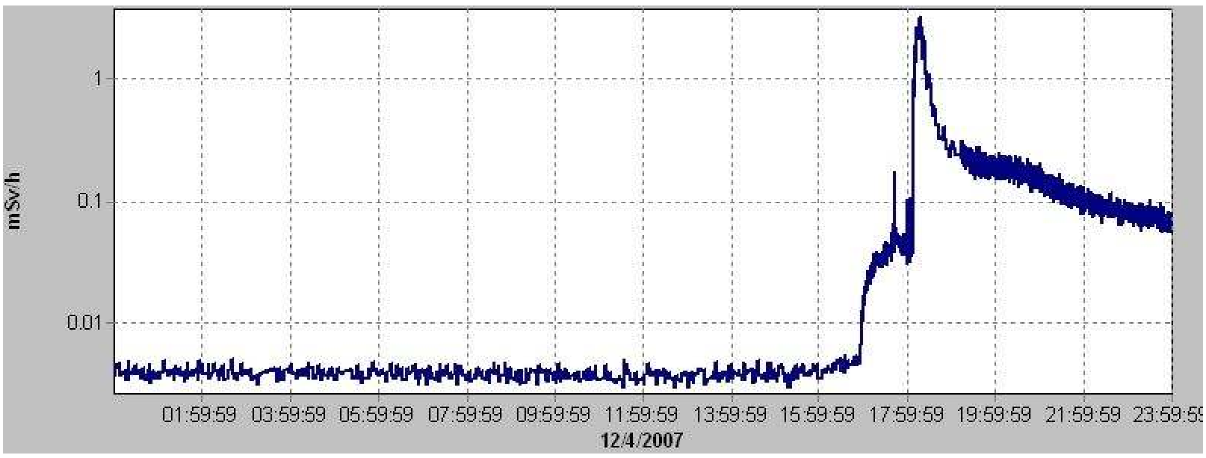

Figure 1 Fixed Area Gamma Monitors indication during defective fuel discharge

In Unit 1, what we call Post Accident Air Sampling consists just of a set of pipes and valves sampling air from Reactor Building. In order to determine the dose rate in these rooms further lab analysis of the air samples are performed.

## 3.0 MODERNIZATION OF RADIATION MONITORING SYSTEMS IN UNIT 1

The project of Radiation Monitoring System chosen for Cernavoda Unit 2 was intended to prevent the problems encountered in Unit 1 with similar equipment, most of them due to their obsoleteness, and so far it was proved to be a right decision.

Further implementation of radiation protection systems modification leading to personnel and public exposure optimization represents a top priority for the plant management and health physics department staff.

At Cernavoda Unit 1, in the next years it's intended to install a new Post-Accident Air Sampling and Monitoring (PAASM) system similar with Unit 2 design and extension of the RMS network from Unit 2 to Unit 1, in order to integrate the radiation monitoring systems: Fixed Gamma Area Monitoring, Fixed Contamination Monitoring, Portable Radiation Monitors, Fixed Tritium in Air Monitoring, Liquid Effluent Monitor and Gaseous Effluent Monitor under a common network Unit 1 and Unit 2.

References:


- 82-67873 Fixed Area Monitors Design Manual
- 82-67874 Fixed Contamination Monitors Design Manual
- 82-67878 Tritium in Air Monitoring System Design Manual
- 82-67800 – Radiation Monitoring System Design Manual
- 82-67883 Gaseous Effluent Monitor Design Manual
- 82-67882 Liquid Effluent Monitor Design Manual
- 82-67885 Post Accident Air Sampling and Monitoring System Design Manual