# THE LHC RADIATION MONITORING SYSTEM FOR THE ENVIRONMENT AND SAFETY: FROM DESIGN TO OPERATION

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*Abstract*

The RAdiation Monitoring System for the Environment and Safety (RAMSES) [1] has been installed and successfully commissioned. The system was originally designed in 2003 for the Large Hadron Collider (LHC), it was extended to the CERN Neutrinos to the Gran Sasso (CNGS) experiment in 2005 and it is also planned to extend it further to the rest of the CERN accelerators. This state-of-the-art radiation monitoring and alarm system provides continuously ambient dose equivalent rates and ambient dose equivalent measurements in underground areas as well as on the surface inside and outside the CERN perimeter. It monitors continuously air and water released from the LHC and CNGS installations; it incorporates also conventional environmental measurements such as physicochemical parameters of released water, as well as meteorological parameters.

The paper illustrates the experience gained during the various project phases outlining the problems encountered and the solutions implemented. In addition, it gives a first outline on the operational experience gained with the operation of CNGS and the tests of the LHC beam transfer injection lines.

## INTRODUCTION

The Large Hadron Collider (LHC) at CERN is being commissioned in 2007-2008 and it is planned to be ready for operation with beam in the second half of 2008. The monitoring of ionising radiation around high-energy accelerators like the LHC and its injectors represents a major technical and metrological challenge, in particular, due to the complex composition of the radiation field and the time structure of the pulsed particle beams. RAMSES is an essential component to enable CERN to run the LHC and its related experiments, fulfilling CERN's radiation protection requirements and other legal constraints. RAMSES will also be extensively used during the LHC beam commissioning, providing an integrated system for the LHC machine and experiment operators. RAMSES generates local radiation warnings, local alarms as well as remote alarms. It generates operational interlocks, allows remote supervision of all measured variables as well as data logging and safe, long-term archiving for off-line data analysis and reporting.

## ARCHITECTURE

RAMSES system architecture as presented in Figure 1 is organised in three layers: *Monitoring Stations layer, Software Infrastructure for supervision, and CERN Integration Modules.*

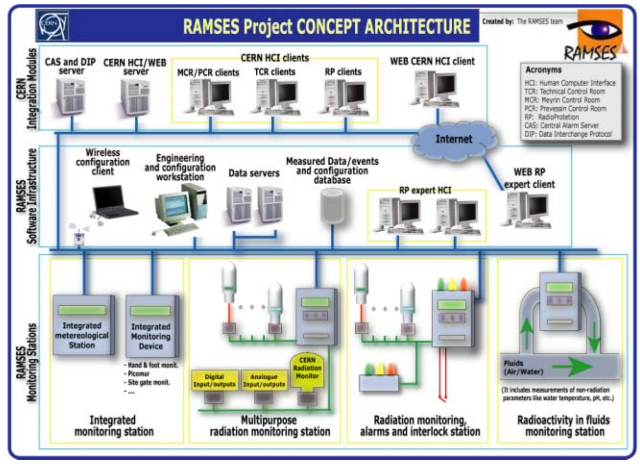

Figure 1 - LHC RAMSES architecture overview

***The Monitoring Stations layer*** is composed of 112 monitoring stations of 9 different types controlling 358 monitors of 18 types. The monitoring stations provide data at very different frequencies depending on the type of monitor ranging from 0.25 mHz to 10 Hz. The values are provided 24 hours a day 365 days per year. Most of the monitoring stations share the same architecture controlling a group of up to 8 detectors and/or measurement devices, some of them equipped with alarm unit devices to alert personnel to evacuate accessible areas in case radiation levels exceed predefined radiation alarm thresholds.

***The Software Infrastructure for supervision*** enables the connection of all the monitoring stations to the RAMSES servers by mean of a TCP/IP network. Central servers are in charge of collecting measured values, radiation alarms, system faults and other status variables from the monitoring stations. RAMSES provides software tools to display and analyse data as well as export capabilities. All data are stored in the RAMSES database for off-line analysis and reporting. This database is also the central repository for system configuration and maintenance. RAMSES provides users with a set of synoptic views of the LHC underground and surface areas. Each view is animated with live radiation values and alarms at the place where they are measured (see Figure 2). Users can analyse measurements using plots or tables. The user interface provides functionalities for remote configuration of the monitoring stations, monitors and associated alarms and a set of diagnostic tools.

***CERN Integration Modules*** enable RAMSES to integrate the LHC control infrastructure by exchanging data with other systems and in particular with the CERN Central Control room (CCC). Two interfaces are available for data exchange: an interface to the LHC Alarm SERvice [2] to inject radiation and technical alarms and an interface via the CERN data interchange protocol.

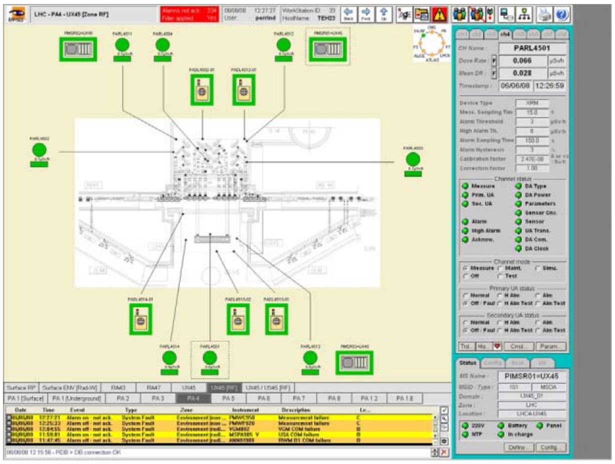

Figure 2: RAMSES supervision

## RAMSES MAIN ISSUES

RAMSES is a complex project which has required considerable effort to overcome a variety of managerial and technical challenges from its design to its operation.

***Monitoring of pulsed, mixed radiation fields:*** Performance requirements for monitoring pulsed, mixed radiation fields around high energy accelerators [3] is one of the most challenging task. Comprehensive studies were performed to evaluate the suitability of different existing monitors for radiation protection measurements in such specific radiation fields [4]. An optimised read-out electronic for ionisation chambers has been successfully designed and tested. The new read-out electronic enables the accurate and stable measurement of both, very low currents ($10^{-14}$ A) at natural background level and high currents at high radiation dose levels equivalent ($10^{-5}$ A). Preliminary tests have shown that this electronic is capable of measuring charge pulses of up to 300 nC / pulse (with 50 % of the charge collected in 2 ms).

***Remote monitoring of radiation dose rate due to material activation:*** The operation of accelerators inevitably results in the production of ionising radiation and radioactivity due to interactions of high-energy beam particles with matter. In order to withstand the high radiation doses during beam operation, the electronics of monitors must be detached from the detectors. This required the use of a reliable and accurate cabling. An integrated cable has been developed [5] and successfully validated for distances up to 800 metres between the detector and its associated read-out electronic for measurement of current as low as -0.1 pA.

***Electro Magnetic Compatibility (EMC) issues***

During the first acceptance tests campaign, instabilities were detected on certain channels, see Figure 3. These stations were equipped with remote monitors to measure radiation dose rates in the LHC tunnel. Two causes were identified. One was linked to the use of ionisation chambers with metal walls. Their metallic supports were fixed to the tunnel wall with metal fixings which were in contact with the steel within the reinforced concrete or installed on metal cable trays connected to the local earth. This situation increased the magnetic susceptibility of the corresponding measurement channels generating induced eddy currents. This was confirmed by tests with the strong pulsed currents (12 kA, rise time 2s, fall time 1s) generated by power converters feeding the magnets of the LHC injections beam lines. The problem was solved by installing special isolators between the ionisation chamber support and the wall of the tunnel.

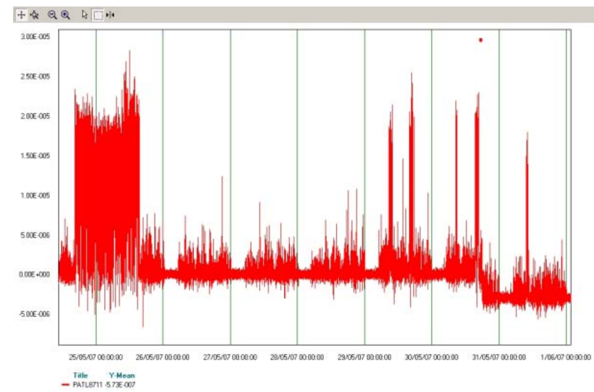

Figure 3: Interferences due to current pulses of power converters of LHC beam transfer line magnets.

Due to its intermittent nature, the second cause was difficult to isolate and identify. The problem was linked to the assembly of special connectors for very low current cables and inadequate tightening of certain elements not adhering to the torque value recommended by the manufacturer to guarantee the correct connection to the signal coaxial cable. During cabling manipulation this weakness resulted in a capacitive coupling of the signal coaxial shielding which highly increased the magnetic susceptibility of the corresponding measuring chain to external perturbations.

***Monitoring channels synchronisation***

A synchronisation mechanism had to be improved to facilitate the comparison of measurements separated by large distances up to more than 8 km. Even if monitoring stations are able to work independently of the system, their local clocks are regularly synchronised with the CERN time servers. After that, each radiation monitor connected to a monitoring station is also synchronised in order to ensure a difference of no more than 10 ms.

## PROJECT MANAGEMENT ISSUES

The management of the RAMSES project was a major challenge due to the complexity of the system, issues of the radiation protection regulation, applicable standards for radiation protection instrumentation, safety matters and integration in the LHC project. The resources were drawn from different CERN Departments and with the participation of external companies. The overall project was setup following closely the international standard IEC 61508 [6]. As such, a Project Management Plan [7] was established in order to define the roles and responsibilities of the participants. A Preliminary Hazard Analysis [8] was carried out to identify the required levels of reliability, availability, maintainability and safety. Finally, these were fixed by assigning a Safety Integrity Levels (SIL) to the safety functions carried out by the system: the alarm and interlock functions have been classified as SIL2 and the monitoring functions related to radiation protection have been classified as SIL1.

All along the RAMSES project, the LHC quality assurance plan was followed, and much effort was made to accurately integrate the system in the overall LHC project coordination for machine and experiments integration, installation, hardware commissioning and finally for the LHC operation. Figure 4 shows one of the RAMSES detectors in the LHC tunnel.

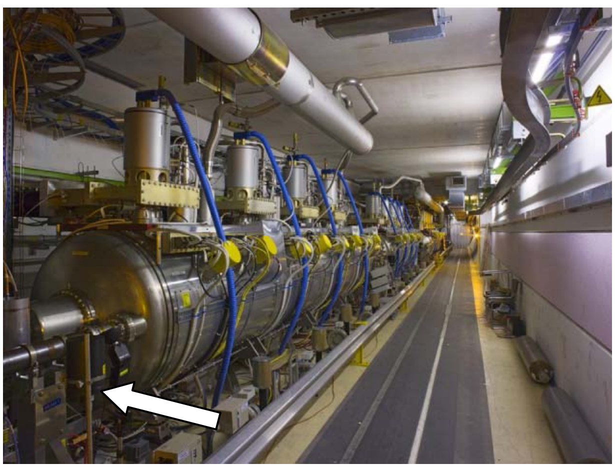

Figure 4: RAMSES monitor in LHC tunnel.

Web based tools were used to manage the project baseline and to allow an efficient form to disseminate information. Although CERN made the global and detailed technical design, the actual integration and installation of RAMSES was outsourced to a consortium with the overall responsibility for engineering the integration of the subcomponents into a homogenous, coherent and maintainable radiation monitoring system.

## COMMISSIONING

The commissioning of RAMSES started with the factory acceptance test and followed by tests on-site for each first of series. The first commissioning with a particle beam took place in 2006 at CNGS, where detailed acceptance tests were carried out and documented (see Figure 5). Exhaustive test campaigns on all LHC sites were completed in early January 2008. All measuring chains were tested both individually and system-wide. The result of the RAMSES commissioning was very positive: a number of minor issues were detected and only one major EMC problem was identified and solved.

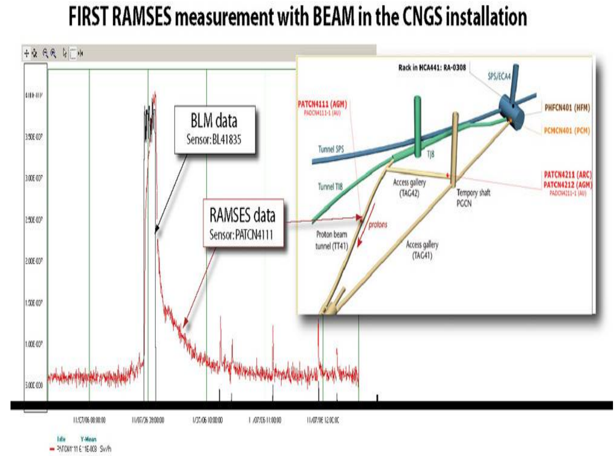


Figure 5: RAMSES first measurement in CNGS

## INITIAL OPERATIONAL EXPERIENCE

The experience gained since the first operation at CNGS in 2006 has been very positive; most of the issues arisen so far are considered to be part of the phase-in period. Fine tuning of measuring monitors parameters has been carried out and actions are underway to improve the user interface as well as the system's response time to operator requests.

## CONCLUSIONS

The RAMSES system has been successfully commissioned at LHC after more than 5 years of intensive work. The rigorous definition and follow-up of the detailed project plan, which was defined well in advance, with precise milestones and deliverables including an extensive documentation, were key elements for accomplishing the project's objectives fully. The project team has managed to deliver the complex system successfully and in time for the LHC start-up.

## REFERENCES

[1] L. Scibile et al., *"The LHC Radiation Monitoring System for the Environment and Safety"*, Proc. EPAC (2004).
[2] LASER: LHC Alarm SERvice
[3] D. Forkel-Wirth et al., *"Performance requirements for monitoring pulsed, mixed radiation fields around high-energy accelerators"* EPAC (2004).
[4] D. Forkel-Wirth et al., *"Radiation monitoring around high energy accelerators – a challenging task"* CERN-SC-2005-121-RP-TN
[5] CERN SPA6 cable for remote monitoring. Annual report *"CERN technology transfers to industry and society"*, ISBN 92-9083-240-1, 2005, CERN
[6] International standard IEC 61508 *"Functional safety of* E/E/PE *safety-related systems*".
[7] RAMSES Project Management Plan, EDMS: No 458348.
[8] RAMSES Preliminary Hazard Analysis, CERN report, EDMS No: 361934.