RADIATION ZONING FOR VACUUM EQUIPMENT OF THE CERN LARGE HADRON COLLIDER

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Abstract

Beam losses in high-energy particle accelerators are responsible for beam lifetime degradation. In the LHC beam losses will create a shower of particles while interacting with materials from the beam pipes and surroundings, resulting in a partial activation of material in the tunnel. Efforts have been made during the accelerator design to monitor and to reduce the activation induced by beam losses. Traceability for all vacuum components has been established providing a tool to follow-up individually each component or subcomponents installed in the tunnel, regardless of their future destination *e.g.* recycling or disposal. In the latter case, the history of vacuum components will allow calculating the beam-induced activation and permit comparisons with in-situ and ex-situ measurements. This zoning will also help to reduce collective and individual radiation doses to personnel during interventions. The paper presents the vacuum system layout and describes the LHC vacuum zoning and its implementation using an ORACLE© database.

INTRODUCTION

CERN is operating a variety of accelerators to provide high-energy hadron beams to physics experiments. In 2008, the Large Hadron Collider (LHC) had been added to the chain of accelerators. The LHC consists of a pair of superconducting storage rings, with a circumference of 26.7 km, installed in the tunnel of the former Large Electron-Positron collider (LEP). The LHC is a quasi-ring with 8 bending sections (arcs) containing superconducting magnets and eight long straight sections (LSS) housing the LHC experiments, accelerating cavities, insertions with collimators for beam cleaning, beam diagnostics, injection and extraction to the beam dumps. The collider is built to accelerate protons up to 7 TeV and lead ions up to 2.76 TeV/u. The LHC will exceed existing accelerators in many aspects. On one hand, LHC will allow the search for new physics by colliding beams of energies never reached before, on the other hand its operation and maintenance requires utmost care to keep the risk of health detriments for personnel and of damage to material as low as possible. With this in mind, a radiation zoning was developed for LHC vacuum equipment which aims to minimize the risk of undue dose to personnel and the uncontrolled dispersion of radioactive material, and to facilitate future LHC interventions for maintenance and consolidation.

LHC VACUUM SYSTEM OVERVIEW

The LHC comprises the world largest ensemble of vacuum system, which was commissioned in 2008 [1]. It contains very different vacuum systems covering a wide range of pressures and technologies, *i.e.* 54 km of ultrahigh vacuum (UHV) for the circulating particle beams (protons, heavy ions) and 50 km of insulation vacuum around the cryogenic magnets and the liquid helium transfer lines. In total, 48 km of beam vacuum are at cryogenic temperature (1.9 K). The remaining 6 km are at ambient temperature and uses non-evaporable getter (NEG) coated vacuum chambers, which need to be baked for NEG activation. The pumping scheme is completed by using 780 sputter ion pumps and turbo molecular pumping groups, the latter ones are either mobile or permanently installed. Ion pumps are necessary for the pumping of noble gases, not pumped by the NEG, and to provide interlocks to sector valves. The pressure monitoring is ensured by 170 Bayard-Alpert hot-cathode gauges and 1084 Pirani and cold-cathode Penning gauges, which are distributed around the LHC machine.

Such a huge and complex beam vacuum system requires to carefully separate the cold from the ambient temperature part of the machine, to create vacuum sectors in long or fragile zones, to allow the installation of machine components, which need an *ex situ* conditioning, and to ensure reasonable intervention times if necessary. Therefore, 303 sector valves have been installed, 70% of them separate a cold sector from an ambient temperature one. For the insulation vacuum, a sectorisation is made at three different levels: 104 vacuum barriers between the magnets, 64 for the cryogenic transfer line (QRL), and 272 for so-called "jumpers" *i.e.* the link between cryogenic magnets and the QRL.

The two high-intensity and high-energy proton beams circulate in opposite directions and collide in ATLAS and CMS (high-luminosity experiments), in ALICE (heavy-ion experiment) and LHCb (B-physics experiment). The 8 LSS contain some symmetries: LSS1 and LSS5 house the ATLAS and CMS detectors, LSS2 and LSS8 the ALICE and LHCb detectors as well as the two injection points from the SPS (Super Proton Synchrotron). LSS3 and LSS7 contain the collimators (betatron and momentum cleaning), LSS4 the radiofrequency and beam instrumentation components (accelerating cavities, dampers, gas profile monitors), and LSS6 the two beam dump systems.

RADIATION PROTECTION ISSUES

Loss Regions

The beam losses and hence the activation of components will not be equally distributed around the LHC. After several years of LHC operation, the arcs, which correspond to about 20 km of the LHC, will be only slightly activated due to beam gas scattering. Other regions like the dump caverns, the injection regions, the cleaning insertions, the inner triplets, and the LHC experiments will certainly experience higher beam losses and a higher activation of material. In particular the betatron cleaning insertion of Point 7 will see the highest annual particle losses of all LHC areas. Figure 1 shows the machine areas of high and low beam losses.

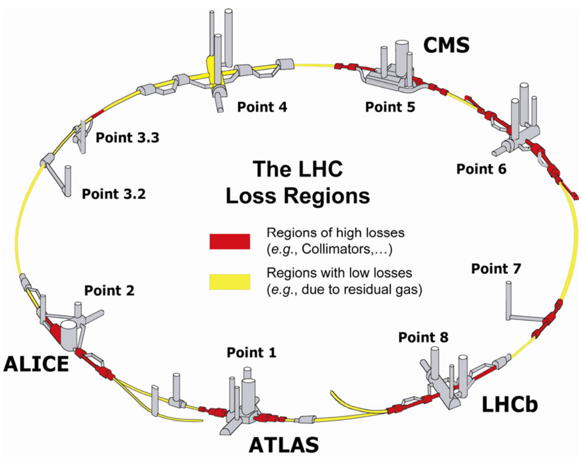

Figure 1: Distribution of high (red) and low (yellow) loss regions around the LHC [2].

Waste Zoning

All material and waste leaving LHC underground areas must be subject to a radiological control, which is under the responsibility of the CERN Radiation Protection (RP) Group. Subsequent handling procedures for LHC equipment depends on the radiological classification of the material and the so-called "waste zoning". This zoning falls into 3 categories: radioactive zones (ZDR), conventional zones (ZDC), and operational zones (ZDO). A detailed description of these zones as well as the procedures concerning the removal of equipment and waste can be found in Ref. [3]. The purpose of this waste zoning was to predict the nature and amount of radioactive waste at the time of dismantling of the facility under the assumption of 10 years nominal LHC operation followed by 100 days "cooldown" for the accelerator and two years for the experiments. However, this waste zoning was targeted for the final LHC dismantling only and is therefore not adequate for operational issues like the annual maintenance and consolidation of major LHC machine components such as the entire vacuum system. To cope with that, a radiation zoning for vacuum equipment in the LHC was developed and is described below.

RADIATION ZONING FOR LHC VACUUM EQUIPMENT

Long Straight Sections

The LHC vacuum system next to the ATLAS experiment, namely the region C1R1 to C7R1, has been chosen for a first vacuum zoning study. As a starting point, the installed machine elements between Q4 and Q5 were investigated, a picture of this area is shown in Fig. 2. Typical LSS vacuum assembly modules of this region were used to elaborate on the LHC vacuum zoning.

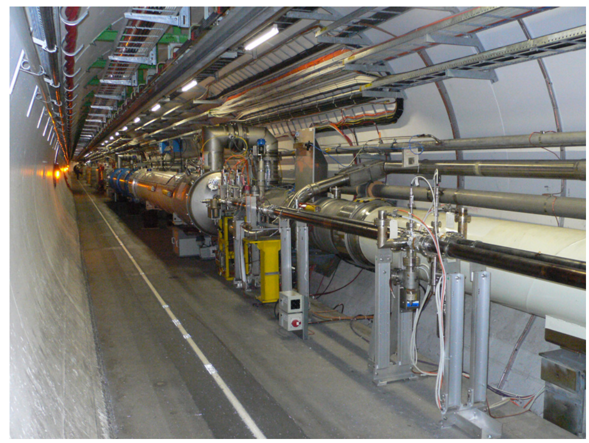

Figure 2: Picture of LHC machine elements in sector 1-2.

Zoning Classifications and Motivation

The basic idea of a detailed radiation zoning of LHC vacuum components is to classify the equipment into different areas which will be most likely activated to a different level by low-intensity proton operation starting in 2009. The safety procedures, handling and follow-up of vacuum components, from the LHC tunnel to surface buildings and their eventual return, can be adapted to their classification level. Although the procedures to be applied will depend on the activation level as measured *in-situ* by RP specialists, the zoning classification will be used to define, plan and optimize tunnel interventions in accordance with ALARA principles. Component classification will evolve year by year with integrated dose. The suggested radiation zonings for LHC vacuum equipment installed in the LSS, the arcs, and the experiments are summarized below:

LHC LSS

- Zone 1: the LSS beam line vacuum chambers with its flanges comprising all other vacuum equipment (sector valves, bellows, RF shields, etc.) on the main beam line. It also contains the vacuum chamber support elements which are in direct contact with the beam pipe.
  Specific machine equipment like the collimators, absorbers (TAS, TAN), Septa, Kicker, and the beam dumps are also classified as zone 1, with the addition

that all adjacent accelerator components fall in the same class, namely: the QRL, the upstream and downstream beam pipes with all attached vacuum equipment.
- Zone 2: all vacuum equipment that is not part of the main beam line but connected to it, *e.g.* gauges, pumps, valves, elbows, and reduction pieces. It includes all vacuum chamber supports and any other vacuum equipment, *e.g.* control units etc.

One important point is the visualization of the zoning. Due to the complexity of the installed vacuum equipment, both zones were colour coded: zone 1 in "red" and zone 2 in "orange" (Fig. 3).

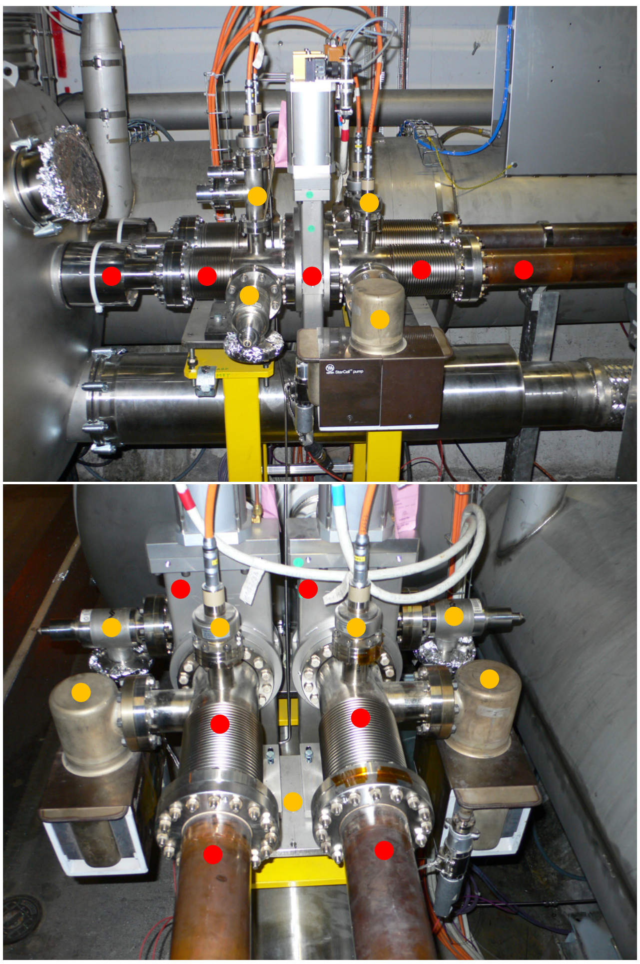

Figure 3: Vacuum modules, installed in LHC sector 1-2, with superimposed colour coding indicating the radiation zoning for vacuum equipment, zone 1 in "red" and zone 2 in "orange".

LHC Arcs

- Zone 1: all components inside the cryostats, *i.e.* beam pipes with beam screens, plug-in modules, beam position monitors etc.
- Zone 2: all instrumentation outside the cryostats, *i.e.* pumps, valves, gauges, etc.

LHC Experiments

- Zone 1: all vacuum equipment in the experimental caverns, installed between Q1 (left) and Q1 (right).
- Zone 2: is not attributed.

Database Implementation, Data Entering Methodology, and Zone Displaying

In 2008, the LHC Configuration Database has been populated with these vacuum classification data. To do so, the database has been modified to include a tag associated to each slot, the tag values being either "red" or "orange". The value of the tag is a combination of several simple rules and factors. A slot in the layout database contains a reference to an object type and belongs to an object class. The primary approach is to qualify the slot using its type and its class, mainly using the transverse location of classes of equipments in the tunnel cross section. The property associated to the object class and the object type is then propagated to all the instances of the object, using an Oracle script. Then this cross section information is overwritten with the longitudinal location of the equipment. The layout database allows the definition of regions associated to slot locations. Internal regions have then been defined around special equipments, and all the vacuum equipments within the defined area have seen their tag changed, independently from the class or type information.

The web interface of the layout database has also been modified to visually show the information concerning the zoning classification. Users can navigate in a dedicated tree through the vacuum sectors and subsectors, and display the list of slots contained in the area. The color associated to each slot is immediately displayed in the web page.

CONCLUSIONS

The classification of all LHC vacuum equipment into two zones appears as a reasonable approach for the first one or two years of LHC operation with probably rather low proton intensities. Future interventions in the LHC can be planned and optimized using the Configuration Database information. As a general rule, all machine interventions will be accompanied with measurement from the RP Group prior to any work on LHC vacuum equipment and all other devices.

REFERENCES

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