Electronic Components and Systems for the Control of the LHC Machine

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Abstract

The present estimation of the LHC underground control electronics gives a total of 10.400 crates of which some 4.400 will be connected to the machine control network. Electronic equipment will be housed under the cryostats, along the tunnel, in the alcoves and in the galleries parallel to the machine tunnel.

In the regular arcs and in the dispersion suppressers areas the radiation level is expected to be relatively low. But, despite this low radiation level, radiation tests results obtained in previous years demonstrate that all electronic equipment needs to be qualified in a test facility providing an LHC like radiation environment. The radiation qualification of all tunnel electronics will be essential in order to guaranty a reliable operation over the lifetime of the machine.

The object of this paper is to give a review of the various electronic systems as they are planned today and to provide simulation results concerning the radiation environment of the CERN on-line test facility used for qualification of electronic components and systems. This paper is an update and an extension of the presentation made at the 5th Workshop on Electronics for LHC Experiments held in Snowmass, in September 1999 [1].

I. ELECTRONIC SYSTEMS

The underground electronic systems planned to control the LHC machine are being discussed, developed and some prototypes are already being tested; only a few final decisions have been taken at this stage. The results, of the radiation tests currently conducted on many components and systems, are important factors that will influence the final decisions. The radiation test results will impact on the type of electronic to be used and on its final position either in the tunnel or in a protected area. We already know that intelligent sensor interfaces are radiation sensitive and that simplified fieldbus interfaces will have to be preferred. These results will have a direct consequence on the number of cables that will be required to connect tunnel equipment to its controller located in the closest alcove.

In the following subsections the various underground electronic systems are briefly described and the current options taken are presented. The final solution may be different once the radiation test results will have been taken into account or in the case of a different technical proposal.

A. Beam Instrumentation

Six years before the scheduled commissioning of the LHC a complete list of beam instruments has been established, giving a detailed overview of the basic requirements and specifications of all beam instrumentation foreseen for the transfer lines and for the main rings [2].

Around the LHC ring and underneath the superconducting dipoles the annual radiation dose will be as low as 1 Gy. This is due to the extremely effective beam halo cleaning system necessary to prevent magnet quenches. For Beam instrumentation that means the front-end electronics can be spread around the circumference, avoiding long and expensive cables.

For distributed monitors like Beam Position (BPM) and Beam Loss (BLM) data collection will be done through 240 Beam Instrumentation (BI) crates located under the middle cryostat of each alternate half-cell, at 30m from the monitors.

The beam position information generated by the 988 BPMs will be pre-processed in these 240 BI crates. Each crate will be connected to three networks: an Ethernet segment, a Beam Synchronous Timing (BST) and a WorldFIP fieldbus dedicated to beam instrumentation. Every 100ms, the BPM real-time information will be sent to the central control room via the WorldFIP and a high-speed transmission channel for computation [3].

In a previous layout, the beam loss information was intended to be pre-processed in these 240 BI crates. But, in order to ensure the closest possible coupling between the beam loss system and the beam interlock system, it has been decided recently to house both systems together in each of the 16 alcoves and at the bottom of the 8 pits. This implies now to carry the BLM signals, via some 120 additional cables, into each alcove and pit.

In addition to the BLM and BPM systems, which are distributed all around the machine, there is more specialised beam instrumentation required. Most of this specialised BI equipment will be located in point 4 and at the two beam injection areas in point 1 and 2.

B. Power Converters

The LHC machine will use some 1700 power converters of about 14 different types ranging from 8V/50A for the closed orbit correctors and up to 12V/12.5kA for the main quadrupole circuits [4].

964 power converters will be housed in the klystron galleries and in some surface buildings while 736 power converters will be installed under the cryostats in the machine tunnel and will be subject to radiations.

An unprecedented precision of about 1ppm (of 13kA) in terms of resolution, stability and reproducibility is required. This represents an improvement over current practice of approximately a factor of ten. In addition, the very large electrical time constants presented by super-conducting magnets, coupled with the need to remove dynamic errors required a new approach. In order to meet this challenge a number of studies and practical tests have taken place over the last few years aimed at proving that such an increased performance can be obtained reliably [5,6].

The strategy to obtain such improvement is:

- Employ digital regulation methods rather than analogue methods.
- Apply digital corrections of known errors.
- Employ real-time feedback mechanisms (both magnetic and beam related).
- Incorporate in-situ calibration techniques.

The aim of the ongoing development is to improve all-round performance of the power converter system by using closed loop control in the converter and all over the machine, by enhancing the remote control and diagnostic as well as the reliability. Measurements with a precision of a few ppm to 13kA require the improvement of the overall accuracy of the DCCTs and the ADCs. The power parts of the converters have an equally stringent performance requirement and development in this area is going on as well.

C. Real-Time Control

Real-time control is needed for the LHC because of the non-reproducibility of magnet field errors, of the demanding beam parameter limits and of a very low tolerance of the machine to beam losses.

A real-time system has a deterministic behaviour but does not necessarily have to be fast. In the case of LHC we need a bounded response time for repetition rates of about 1 Hz (max. 10 Hz for some systems).

The real-time control of the 1700 power converters will use both beam related (BPMs) and magnetic parameters as well as an ultra-sure site-wide timing for synchronisation and time stamping.

Three key issues for power converter control are to be considered: ramps, trims and real-time control. The ramp provides a synchronous change in current in most magnets, the trim is a synchronous adjustment in current in a small group of magnets and the real-time control insures a continuous adjustment in current in any combination of magnets [7].

The real-time system architecture is composed of three layers: the central server, the gateway and the digital controller and also of two networks: the WorldFIP fieldbus and the LHC RT network [8].

The system architecture shows that the controller and the voltage source are intimately linked to make a complete power converter. The analogue measurements of the current are supplied directly to the controller so that digital regulation of current can be performed. Each digital controller has two interfaces, one is a serial port for local diagnostics and the other an interface to the WorldFIP fieldbus for remote operation.

The real-time data path from the top to the bottom can be seen as a permanently open data channel capable of transporting one value per digital controller and per 10ms from a real-time top level server to each digital controller at the bottom level. This transport channel must be guaranteed to have a certain maximum latency for a certain proportion of the values sent in a given time period.

Real-time data will also flow in the other direction from bottom to top. This will include analogue measurements and the status of the power converter and its controller.

The fieldbus of choice for the real-time control and for the distribution of timing and synchronisation of all power converters is the WorldFIP. *(See below).*

The real-time data flow implies a certain performance from all three layers in the system as well as from both networks. The real-time control software will be a standard function in each power converter, thus offering a great flexibility to the LHC control system.

D. Magnet Protection System

The magnet protection system continuously monitors the proper operation, within their superconducting state, of the following superconducting elements: magnets, current leads and bus bars [9].

The main function of the magnet protection system is to detect the resistive transitions (quenches). In the case of a quench the protection system undertakes the corresponding actions internally to the system by firing heaters and recording signals. It provokes elsewhere the necessary actions: switches off power converters, opens dump switches aborts the beam through the power abort and beam abort systems. It sends alarms during operation to the control room and it receives requests for information in test mode and on-line mode [10].

In case of a quench detected, different actions are envisaged depending on the type of the quenching magnet:

- For main dipoles and quadrupoles operating at about 12 kA: to fire quench heaters power supplies, to fire the cold by-pass diodes and to activate dump switches and resistors.

- For quadrupoles magnets in the insertion regions the protection is achieved with quench heaters.

- In all cases the corresponding power converters must be immediately switched off.

For security reasons the quench detection electronics provides redundancy with at least two independent circuits and, in order to avoid false detection, validation signals are needed. The quench detection electronics provides the necessary signals to allow remote monitoring and post mortem analysis from the control room. It sends local trigger signals to the heater discharge supplies and to the power abort system located far away.

The hart of the magnet protection system is the Acquisition and Monitoring Controller (AMC). The AMC acquires and stores data of a list of signals. On request from the control room it transmits data on all signals (time, analogue, logic). The AMC synchronises and time stamps the signals, in case of a quench trigger it locks the data acquisition (keeps “x” sec of data and continues to acquire “y” sec of data). On request it sends snapshots of the present values.

The AMC’s communication with the control room is implemented on WorldFIP fieldbuses and on the control network via PLC bridges.

E. *Cryogenics System*

The superconducting magnets will operate in superfluid helium below 2K. At the surface of each even point (2, 4, 6, 8) there will be one complete cryogenic plant comprising the compressors and the cold boxes for 4.5K and 1.8K refrigerators as well as the necessary storage for gaseous helium and liquid nitrogen [11].

At the level of the underground caverns there are the cold boxes for the 4.5K and 1.8K refrigerators and the interconnection boxes to the Cryogenic Distribution Lines (QRL). Each of the 8 sectors, with a length of some 3.3km, has its own self-standing cryogenic system. The cryogen provided by a refrigeration plant of 18 kW at 4.5 K equivalent power, is distributed at different temperatures and pressures via the QRLs to the LHC magnet cryostats.

From the controls point of view the cryogenic system represents some 12.000 digital I/O channels and 23.000 analogue I/O channels. In addition to the overall supervision of the LHC cryogenic system from the central control room a local supervision at each of the cryogenic plants will be available for local monitoring, intervention and maintenance [12].

As the operation reliability of each cryogenic plant is of utmost importance the local supervision, monitoring and control must not depend on the overall network backbone operation. To provide a certain degree of autonomy to each cryogenic plant is essential.

The local field network will be based on Ethernet with the TCP/IP protocol interconnecting the Programmable Logic Controllers (PLC) located in the surface control room, in the underground caverns and in the alcoves. Redundancy of the field network will be provided based on re-configurable network hubs. Each local cryogenic control network will be synchronised to the CERN wide timing system with a resolution of 10 milliseconds. The same time resolution is required for the synchronisation of the field equipment interfaces with the control network.

The cryogenics control system is fully based on standard industrial hardware and software. The PLCs will be from SCHNEIDER PREMIUM family and the fieldbuses will be of both Profibus and WorldFIP standard. All communication over the local cryogenic field network and the global site-wide network will be implemented with TCP/IP protocol. Access to real-time information in the supervision layer will be done with a “client/server” mechanism, including subscription-based access, like the one provided by the OPC industrial standard.

A test facility for 3 QRL pre-series units has been implemented at CERN along with the cryogenic control system and associated instrumentation [13].

For this QRL test facility, the process automation has been based on PLCs from the SIEMENS S7 family implementing more than 30 control loops, alarm handling, interlock and the overall process management. More than 160 sensors and actuators are distributed over 150m on a Profibus DP/PA network. Parameterisation, calibration and diagnostics are remotely available through the Profibus.

Temperature sensors, fulfilling the LHC stringent specification requirements, have been studied and developed at CERN. They provide industrial robustness in terms of thermal drift, galvanic protection, compact packaging and cost to performance ratio. Future developments will include Application Specific Integrated Circuit versions, fieldbus interfacing and a radiation tolerant redesign [14].

Considering the diversity, amount and geographical distribution of the instrumentation involved, this QRL test facility is a representative approach of the cryogenic controls for the LHC machine.

F. *Vacuum System*

In LHC one can identify three vacuum systems: the beam vacuum for both rings (< 10^{-11} mbar), the insulation vacuum for the cryostats and for the cryolines (< 10^{-6} mbar) in the cold state.

These three vacuum systems require some 200 sector valves, 500 roughing valves, 200 fixed and 40 mobile pumping groups, 800 gauges and 1300 ion pumps.

Based on previous experience, the control of the LHC vacuum system will use extensively industrial PLCs, the Profibus fieldbus and distributed I/O equipment [15].

For the vacuum control in each octant it is planned to install 3 master PLCs per alcove and to connect all vacuum devices to Profibus fieldbuses. One of the master PLCs would be dedicated to the control and monitoring of the QRL lines and cryostat vacuum equipment, the second for beam vacuum equipment and the third for mobile pumping stations [16].

Depending on the results obtained from ongoing radiation tests on intelligent local controllers it may be necessary to consider electronic equipment to be installed in the alcoves with the necessity in this case to draw additional cables to these alcoves.

G. *Radiation Protection & Monitoring*

The Radiation Protection Monitoring will consist of 150 Induced Activity Monitors (PMI) with remote read-out located around the experiments and where the highest levels of radiation are expected, typically in the Long Straight Sections of the tunnel. Area Monitors (PAX) will be used in areas accessible during beam operation, such as counting rooms. Specialised Monitors will be installed in specific areas of the tunnel such as around the RF sections [17].

At the major exit points from LHC, a total of 18 self-service radioactivity monitors (PCM) will be installed to detect the level of induced radioactivity in any equipment leaving the controlled areas. Sensitive Site Monitors (PMS) will be placed in and around the surface buildings as well as at the top of the pits and ventilation shafts. A total of 77 site monitors will be needed.

The radiation protection and monitoring system will entirely use industrial equipment for data collection, analysis and communication over the CERN wide networks. All the radiation monitors will be connected to industrial PLCs in a redundant architecture. Two PLCs will drive a WorldFIP fieldbus to which the radiation monitors are connected. In case of failure of one of the PLCs, WorldFIP has the necessary feature to allow an automatic control take-over by the PLC which is in standby mode [18].

H. Other Electronic Systems

In the tunnel and alcoves additional electronic systems are foreseen for installation. The following systems are not yet completely defined, options are under discussion or have still to be proposed.

The *Machine Interlock and Protection System* will be housed in the 16 alcoves and 8 intersection points. In these 24 locations, this system will receive information from the Beam Loss Monitors, the Magnet Protection, the Vacuum and the Cryogenics and will, according to predefined conditions, activate a beam dump link.

The *Personnel Access System* will allow people to enter into selected areas of the tunnel provided that certain security conditions are met. There will be three security interlock chains: the main security chain will stop the beam, local chains will stop specific equipment only and test chains will provide limited access to a test zone with particular security conditions.

I. Industrial Systems

For the controls of the LHC it is anticipated that Programmable Logic Controllers (PLCs) will be used extensively for most electronic systems. Industry offers a vast choice of PLCs. The PLCs are used for the cryogenics process control, the magnet protection system, for the vacuum system, the power distribution, the machine access system, the radiation protection, the cooling and the ventilation systems.

Recently PLCs have also been used for typical accelerator systems such as beam transfer equipment, beam extraction systems, beam target electronics and radio-frequency power generators.

VME crates and modules or ad-hoc assemblies will remain the best choice for fast beam instrumentation and for special systems.

In order to limit the diversity of PLC equipment in LHC a study of the industrial offer has been made by a PLC Working Group and a CERN recommendation for their use has been published [19].

Following an official market survey two contracts have been signed with SCHNEIDER (F) and with SIEMENS (D) for the supply of PLCs and fieldbus equipment.

Industry offers also a large diversity of input/output modules for analogue and digital acquisition and control, for steeping motor control and for sensor interfaces. Additionally, some special modules may have to be developed if they are not commercially available.

The mounting of these I/O modules is usually done on rails, conforming to the DIN standard, which can be housed under the dipoles or even be fixed under the control cable tray and close to the sensors.

J. Fieldbuses

Following the recommendation of the CERN Fieldbus Working Group only three types of fieldbuses will be used for LHC. Profibus and WorldFIP are preferred for the control of the machine for reasons of long distance transmission capability, while CAN is the choice for the experiments [20].

Conceptually Profibus is a Command/Response fieldbus; like the MIL-1553-B that has been used extensively over the past 10 years for the control of CERN accelerators.

Profibus is an industrial fieldbus well supported by a large number of manufacturers. Many interfaces exist for analogue and digital input/output modules, for stepping motor controllers, for sensors and actuators. Industrial PLCs of various performance level are available, they provide all the necessary Profibus drivers and the development software facilities required are provided by the manufacturers.

WorldFIP is also an industrial fieldbus well supported by manufacturers, but to a less extend than Profibus. WorldFIP will be used for control applications where the real-time performance is required, for the distribution of universal time or for precise synchronisation of accelerator equipment to machine events.

WorldFIP implements a Producer/Consumer concept in which a single command can be recognised and executed simultaneously by a variable number of consumers. This Producer/Consumer concept, associated with deterministic bus arbitration, allows WorldFIP to offer real-time control capabilities.

One of the most demanding applications of WorldFIP is the real-time control of the corrector power converters [7]. In this application 2.5 Mbit/s WorldFIP transmission will be used over a high quality shielded twisted pair cable. Up to 32 nodes can be connected per bus over a distance of 500m without repeater. Electronic repeaters allow for more nodes and longer distances. Broadcast of synchronised timing from GPS is supported with a jitter of <10 µs. Each digital controller contains a WorldFIP chip (called µFIP) which supports fixed length variables (8-64 bytes), variable length messages (1-122 bytes), broadcast and point to point addressing as well as periodic and aperiodic transmission.

For this application a lightweight communication protocol has been devised to support: the secure transport of broadcast/multicast, individual commands and command/response, as well as remote login to digital controllers. On every 10 ms cycle a 4 byte value is delivered to each digital controller via a broadcast message over the WorldFIP containing real-time correction data. Every 10 ms cycle each digital controller produces a WorldFIP variable containing status information. In addition, the time remaining in every cycle is available for point to point messages.

K. Timing and Synchronisation

A Timing Working Group has been given the mandate to make a detailed inventory of the requirements for timing and synchronisation for the various systems in the accelerator and to establish a clear philosophy for timing associated with LHC [21].

Timing and synchronisation includes domains such as:

1) Beam synchronous timing for injection and extraction, experiments, radio frequency and beam instrumentation,

2) Cycle timing for synchronisation of settings for distributed machine components,

3) Synchronisation of data acquisition systems for post mortem analysis after a beam dump or equipment fault,

4) Timing references for archiving and data tagging.

The LHC machine equipment requires precise timing information. A precise universal time reference (Universal Time Co-ordinates, UTC) is required to synchronise all CPU clocks to better than a millisecond. To this purpose each of the 8 LHC access points plus the central control room are equipped with GPS antennas and reception equipment. The universal time reference is received and conditioned in commercially available VME and PLC modules and is locally distributed to all systems which need this time reference [22].

From each intersection point the GPS time is propagated both sides to the adjacent alcoves, distant of 943 m, via the Inter-Range Instrumentation Group (IRIG-B) standard transmission cable. In alcoves the IRIG-B signal is available to time-stamp local data acquisition and to synchronise the control of equipment.

Time stamping will be used for the magnet quench protection system. This system will have over 4000 possible inputs to the beam dump trigger system. In order to perform meaningful post mortem analysis, all related systems actions would have to be time stamped. Due to the uniform distribution of the major systems throughout the LHC complex, it will be essential to use the GPS as the unique source of time reference.

Amongst others, a Beam Synchronous Timing (BST) distribution is required by beam instrumentation equipment to identify particle bunches. This BST information will be derived from the 40 MHz bunch clock, from the 11 kHz turn clock and from the machine events. The BST information will be available in 24 stations (16 alcoves and 8 IPs) and is distributed to all the beam instrumentation crates installed in the tunnel. The BST signal may be an updated LEP type or the Timing Trigger and Control (TTC) system developed for LHC physics experiments, if deemed suitable for the machine beam instrumentation [23].

The overall TTC system architecture provides for the distribution of synchronous timing, level-1 trigger, broadcast and individually addressed control signals, to electronic controllers with the appropriate phase relative to the LHC bunch structure, taking account of the different delays due to particle time-of-flight and signal propagation.

L. Communication Networks

In view of the LHC construction a Communication Infrastructure Working Group (CIWG) has been created in order to study the overall communication requirements. The CIWG has presented the results of its investigation and made a recommendation to the LHC Technical Coordination Committee [24].

The communication infrastructure will cover the needs for machine beam control, detector’s control, transport of physics data, technical services, transport of safety information, personnel access as well as voice, video and telephones, cabled and wireless.

Today optical fibre is the media of choice for networking. Optical wavelength multiplexing utilises the fibre efficiently by inserting many wavelengths on the fibre. In addition, by adopting a fibre optical ring configuration, redundancy and continuity of service can be guaranteed in case of fibre damage.

The fibre optic transport provides: fibre and wavelength management, performance monitoring and alarm generation, automatic recovery on the redundant path in case of fault, bit stream transparent optical add/drop, Gigabit Ethernet, fast point to point links and more.

During the LHC construction period fibre optic transport is intended to be installed and operated on a sector by sector basis. To this end, the existing fibre optic infrastructure needs to be strengthened in particular to LHC point 2, 3 and 4. As optical fibres are sensitive to radiation care must be taken in the tunnel.

IP/Ethernet connections are expected to be available in all alcoves, pit floors, surface buildings and the experimenters counting rooms. IP connections will tie together the equipment control with the facilities of the control centres for monitoring, storage archival and operator control.

All IP needs for controls can be met with a Gigabit Ethernet backbone infrastructure much like the one that is deployed at CERN today. But, if it would be decided to transport video over IP then the bandwidth requirements would increase significantly.

Fast and low jitter transport of beam measurements to the control centre will require point to point links for closed-loop beam control, with a reserved bandwidth.

During the construction, the installation and commissioning of equipment will require portable phone and data access in the tunnel; this type of communication will probably be implemented by means of a leaky feeder system. The site surveillance, equipment control and beam observation need also a controlled video transmission and the fire brigade will require a radio communication system in all underground areas.

II. UNDERGROUND INSTALLATION OF ELECTRONIC EQUIPMENT

Electronic equipment will be housed under the cryostats, along the tunnel, in the alcoves, in the galleries parallel to the machine tunnel, klystron galleries and in dedicated areas located at the bottom of each pit (USs).

A. Dipoles and Quadrupoles

Taking into account the necessary room for accessing the support jacks and the space required for the cryostat interconnection, up to 13 standard Eurocrates can be placed under each 14,56 m long dipole. A standard Eurocrate has a total height of 8U, including a 2U ventilation unit. To simplify the installation of some systems, for example in the case of the corrector power converters, four or five crates may be regrouped into a single box. The cooling air is aspired from the rear side of the crates, it flows through the electronics and is blown out at the bottom level to the front side of the crates and towards the transport area of the tunnel. This ventilation method has been chosen following a thermal analysis of possible heating effects on cryostats and on the cryogenic helium feeder lines (QRL) due to the Beam Instrumentation crates which are expected to dissipate locally up to 900 Watts [25].

B. Control Cables and Fieldbuses

Four cable trays are foreseen in the LHC tunnel: three of them are fixed on the wall and one is fixed on the top of the QRL. The highest near the ceiling of the tunnel is dedicated to general services, the second is reserved for power cables, the third will carry all control cables and the fourth cable tray is reserved for the local interconnection cables, inside a full-cell. This fourth cable tray is necessarily interrupted at each QRL jumper location.

According to the general LHC construction planning the QRLs will be amongst the first systems to be installed and serviced. In order to commission these QRLs as soon as they are installed it will be necessary to gradually control and to monitor the vacuum in these QRLs. All vacuum control and monitoring cables will be laid in the third cable tray and their associated electronic boxes will be fixed under that cable tray.

A standard cabling methodology for Profibus and WorldFIP fieldbuses has been proposed, standard fieldbus cables are now available in CERN stores and a list of recommended fieldbus components, for both Profibus and WorldFIP, has been agreed to [26].

If required, electronic and opto-electronic repeaters for fieldbuses and networks as well as electronic boxes for other systems will be fixed under this third cable tray.

C. Alcoves

Around the LHC tunnel there are 16 alcoves (RE12 - RE88) housing the electrical distribution, a 120 kVA redundant non-interruptible power supply, the cooling and ventilation installation and the front-end equipment for the various electronic systems, mounted in a raw of racks.

As far the radiation level and equipment hardness permit, electronic crates will be installed in the tunnel under the cryostats and electronic boxes will be fixed along the third cable tray. Radiation sensitive systems will be housed in alcoves where the radiation level is low.

Taking into account the space required for the electricity distribution equipment and for the cooling and ventilation system only 15 racks (38U-height) remain available for electronic equipment. If this space would prove to be insufficient it would be possible to put up a row of slim racks along the existing separation wall situated in the middle of the alcoves.

D. Galleries and USs

In the LHC straight sections the radiation level precludes installation of electronic crates in the tunnel itself. Parallel to the long straight sections, on both sides of an intersection point, there are galleries (UAs or Uls) which will house these electronic crates as closely as possible to the equipment they control.

Electronics that does not require to be close to its equipment will be installed in the US areas located on the bottom of the pits. In USs one will find the fibre optic terminals linking each pit to the control centre, the communication and network equipment, the fieldbus controllers of the electronics located in the galleries, the timing and the synchronisation systems.

II. RADIATION QUALIFICATION

Before installation in the LHC tunnel, electronic components and systems must be fully tested and be qualified for standing the radiation levels to which they will be exposed, during the life of the LHC machine.

The absorbed dose levels have been calculated at a distance of 700 mm from the proton beams. This is the distance between the beams and the location of the electronic racks under the cryostats. The results of these calculations give an annual dose level of the order of 1 Gy under the middle dipole of a regular half-cell and of 12 Gy under the Short Straight Section (SSS) quadrupole. At such dose levels, no major radiation-damage problems are to be expected, and designers plan to use Commercial Off The Shelf (COTS) electronic components and systems [27, 28].

While the radiation dose level is low, significant numbers or high energy neutrons and hadrons could be a worse problem than doses.

As a consequence and despite this low level doses, it is essential to check that COTS equipment does not contain radiation sensitive components, is not subject to Single Event Upsets (SEU) and to latch-up phenomenon.

A. CERN On-Line Radiation Test Facility

The radiation test facility has been described at the last LEB Workshop [1]. In view of the year 2000 test campaign the facility has been improved during the last SPS winter shutdown according to the wishes of the experimenters.

In particular a zone, protected from radiation, is now available for installation of electronic responder modules, reference equipment, power supplies and some measurement instruments. This has been possible inside a gallery perpendicular to the present beam lines. Continuous measurements during this year have shown that in the protected area the radiation dose is in the order of 150 times lower than in the active zone.

B. *Qualification of the Test Facility*

It is essential to qualify the TCC2 radiation test zone and to check if it provides a radiation environment similar to the one that will exist in the LHC tunnel during operation of the machine.

The validity of all our component and system tests to radiation depends entirely on this qualification.

In addition, for a better understanding of the test results, experimenters need to know the particle composition in this area, the energy spectrum of the particles, the geographical in-homogeneity of the radiation level and the reliability of the absolute calibration of the radiation measurements.

An in-depth study of the radiation environment of the TCC2 test area and a comparison with the LHC tunnel environment have been done during this year 2000 and the results have been published recently [29].

Based on the FLUKA simulation program the results of the calculation demonstrate that:

- The ratio of the Fluence/Dose shows very little longitudinal and radial dependencies.

- The radiation environments in the LHC and in the TCC2 experimental area are the same for particle fluences > 1 MeV.

- For fluences above the low energy cut-offs (e.g. neutrons > 100 keV) the TCC2 has a higher Neutron/Dose ratio than the LHC radiation environment.

- As SEUs are caused by hadrons > 20 MeV, the TCC2 test area will provide the same radiation environment as the LHC for testing electronics.

The conclusion of the radiation simulation study is that the CERN On-Line Radiation Test Facility is qualified for the test of electronic components and systems in a radiation environment similar to the one that will exist in the LHC tunnel during operation.

III. CONCLUSION

The definition of the major electronic systems for underground installation, in the tunnel, in alcoves and at bottom of the pits is well advanced. Some systems have to be finalised and several decisions will depend on the radiation hardness of their components.

The On-Line Radiation Test Facility is now qualified and further experiments on electronic components and systems can now proceed with confidence and with the insurance that the results obtained are valid.

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