CERN–2004–003
5 November 2004

LHC DESIGN REPORT

VOL. II THE LHC INFRASTRUCTURE AND GENERAL SERVICES

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

ISSN 0007-8328
ISBN 92-9083-236-3

CERN-2004-003
5 November 2004

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE

CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

LHC Design Report

Volume II The LHC Infrastructure and General Services

Editorial Board

**O. Brüning, P. Collier, P. Lebrun, S. Myers,
R. Ostojic, J. Poole, P. Proudlock**

GENEVA
2004

CERN – Scientific Information Service – 750 – November 2004

Abstract

The LHC Design Report is presented in three volumes: the first concerns the main ring, the second the infrastructure and general services and the third, the injector chain. The conceptual design was published in 1995 and this report provides a snapshot of the detailed design as it stands at the time of writing – early 2004.

Editorial Note

The editors would like to express their gratitude to the many authors who contributed to this report.

VOLUME II – CONTENTS

CHAPTER 1

INTRODUCTION

The aim of this document is to detail the main modifications that have been made to the existing CERN facilities in order to accommodate the LHC machine and its experiments. Particular attention is given to the infrastructure and the general service requirements including civil engineering, cooling, ventilation and electrical services.

The underground infrastructure of LEP [1] basically consisted of a 26.7 km long ring tunnel lined with concrete and lying in the limestone strata for about 10% of its length and in the molasse for about 90%. It included experimental areas at four points (2, 4, 6 and 8), each incorporating experimental and service caverns, plus an equipment cavern at Point 1 with injection tunnels connected to allow particle transfer from the SPS machine. At points 2 and 6 additional galleries parallel to the main tunnel were used to house klystrons and their power supplies (Fig. 2.1). On the surface a total of 37 buildings housed all the necessary equipment and services for the LEP machine and experimental operations (Fig. 2.2). The LEP-2 upgrade [2] consisted essentially of the addition of two sets of galleries at points 4 and 8, similar to those existing at points 2 and 6, thus allowing a doubling of the number of klystrons and related power supplies.

For the LHC project, the existing LEP tunnel has been re-used after the complete dismantling of the LEP machine. In addition new structures have been added including experimental and service caverns destined to accommodate two new experiments at points 1 and 5, two transfer tunnels of about 2.5 km each in length and beam dump facilities comprising two sets of straight tunnels and caverns each side of Point 6. A total of 32 new surface buildings of various sizes at all points except 3 and 7 have also been constructed.

After about 11 years of LEP operations and subsequent dismantling, the civil engineering infrastructure was generally in good condition and little refurbishment had to be done, with the exception of the headwalls of the experimental caverns at points 4, 6 and 8, which had been damaged by the swelling of the wet molasse rock behind them.

The cooling and ventilation systems rely heavily on the equipment constructed for the LEP machine and subsequently up-graded for the LEP-2 project (e.g. additional cooling towers). The tunnel ventilation systems have, to a large extent, been re-used with up-dates mainly due to the significant increase of thermal load in the tunnel and the addition of the transfer tunnels. New caverns have obviously been equipped with new ventilation systems. The water cooling plants in the technical caverns of the even points will undergo refurbishments to accommodate major changes in the use of demineralised water envisaged for the LHC. This includes the replacement of the stainless steel pipeline in the LHC tunnel. Chilled water plants and cooling towers as well as other hydraulic networks are, to a large extent, left intact.

Systems which are modified for the LHC will automatically receive a technical update. This is, however, not extended to the whole infrastructure. As a result a large part of the technical services equipment will continue to be used after some 20 years of operation and will have to wait until after commissioning of the accelerator for more extensive consolidation.

The power distribution system for LEP, including the 66 kV, 18 kV and 3.3 kV systems as well as the low voltage systems, normal and secured power, will be recuperated for the LHC. The extensions needed for LHC are essentially due to the new large load centres in points 1 and 5, ATLAS and CMS, as well as the new injection tunnels. At the end of LEP operation the power distribution equipment outside the machine tunnel was found to be in generally good condition. The dismantling, the civil engineering works and the fact that the equipment has been partially out of service for a couple of years have however taken their toll and a number of equipment repairs and replacements have been necessary.

The transport and handling equipment such as overhead travelling cranes, lifts and tunnel vehicles that were installed for LEP will form the major part of the logistic chain to install the new material into the tunnel and to allow access. The constant use during the LEP dismantling required a general overhaul of all cranes and lifts in order to re-establish the performance and reliability. A major concern is the conductor line formerly powering the LEP monorail, which will be used for powering the new LHC cryo-magnet tunnel vehicles. The conductor line suffered enormously under the conditions created during the LEP dismantling and the subsequent civil engineering works. The humidity and dust created a mix that damaged large sections of the conductor line, which must now be replaced. This also applies to all electrical equipment for cranes and lifts that could not be removed from the proximity of civil engineering works.

The principles and procedures elaborated for the operation of technical infrastructure during the LEP era will be extended to other services and integrated into a global control room. Particular emphasis will be given to the management of major breakdowns. A technical control room (TCR) will continue to operate on a 24h/365d basis. Its main tasks will be to trigger the intervention of the technical contractors upon reception of technical alarms and to coordinate activities following major breakdowns.

To cope with the new risks of the LHC, fire, flammable gas, oxygen deficiency and evacuation systems will also be installed in the underground areas and surface buildings. The access control systems will also be upgraded.

The aim of this volume of the LHC Design Report is to present the main parameters as well as the status of the numerous varied components concerning the infrastructure and the general services of the project.

REFERENCES

[1] The LEP Design Report, Vol. II: The LEP Main Ring, CERN-LEP/84-1, June 1984.
[2] The LEP Design Report, Vol. III: LEP 2, CERN-AC/96-01 (LEP2), June 1996.

CHAPTER 2

THE SITE, BUILDINGS AND UNDERGROUND STRUCTURES

2.1 INTRODUCTION

In terms of civil engineering, the needs of the LHC machine are, to a large extent, similar to the Large Electron Positron (LEP) machine which was constructed between 1984 and 1989. These needs consist principally of the main beam tunnel, access shafts from the surface to the underground areas together with various underground caverns and other ancillary structures for housing equipment that cannot be located on the surface. Buildings are required on the surface for housing compressors, ventilation equipment, electrical equipment, access control and control electronics.

Great care has been taken to re-use the existing civil engineering infrastructure that was created for LEP as much as possible and all LEP buildings, albeit some with modifications will be re-used for the LHC.

Despite the maximum use of existing facilities, additional infrastructure is required. For the machine, this is primarily for the new injection lines and for the beam dumps. In addition several small caverns are required to house equipment at various locations around the main beam tunnel. At Point 5, the machine requirements have been incorporated within the new infrastructure necessary for the CMS detector, thus eliminating the need for an additional and costly access shaft.

Of the four LHC experimental areas, two have been constructed on almost "green field" sites where there was very little existing infrastructure. As such, two large experimental zones for ATLAS and CMS have had to be constructed at points 1 and 5 respectively. These two new experimental zones are similar in that they both consist of two new large caverns, one for the detector and one for the services, together with various galleries, tunnels and chambers for housing equipment and providing access routes. On the surface an array of buildings are required for offices, cooling and ventilation equipment, cryogenic equipment installations and so on.

For the two smaller experiments (ALICE and LHCb) the existing infrastructure has required only minor modifications to accommodate the new detectors.

At some locations, such as Point 1, the new underground structures were situated very close to the existing LEP ones, which meant special protective measures had to be taken both before and during the LHC works and often entailed repair works afterwards.

Most of the Civil Engineering works for the LHC Project lasted in the region of 4.5 to 5 years with the exception of Point 5 (CMS experimental area) where it took approximately 6.5 years to complete. Work started as scheduled in April 1998 for Point 1 in Switzerland, while the start date was delayed until autumn of the same year for all other Civil Engineering works (on French territory) because of the late signing of the "Déclaration d'Utilité Publique". Until November 2000 when CERN stopped LEP and dismantle the accelerator, the Civil Engineering work had to be carried out with the least possible disturbance to the operation of this machine (for instance all blasting was prohibited for underground excavations, precautions were taken to minimise the infiltration of dust in the LEP areas and movements of the existing LEP underground structures had to be minimized). After November 2000 these precautions could be relaxed, but the constraints from the general LHC programme meant that a lot of work had to be carried out in parallel.

Most of these works were completed and handed over to CERN in the period from the beginning to the middle of 2003, while at Point 5 the bulk of the underground and surface works was finished between April and July 2004 with only the CMS control building to be handed over to CERN later, in early 2005.

2.2 MAIN ASPECTS OF THE ADDITIONAL CIVIL ENGINEERING

2.2.1 Underground Structures

After some minor modifications the main ring tunnel constructed for LEP will be fully re-used for LHC. The tunnel consists of 8 straight sections connected by 8 arcs, the total circumference being some 26.7 km. It was excavated at depths varying between 45 and 170 m and with a horizontal slope of 1.4%, sloping down towards the lake. The position was selected so that most of the tunnel would be situated in the Lemanic

Basin molasse. The beam interaction points are in the centre of the 8 straight sections. Fig. 2.1 shows the underground structures schematically.

The two tunnels that will be used to transfer the proton beams between the SPS and LHC have the same finished internal diameter of 3 m and they are also nearly identical in length (approximately 2.5 km).

The transfer tunnel TI 2 links Point 2 of the LHC to the TT60 tunnel which in turn is connected to the SPS. The shaft in TI 2, located at the western end of the CERN Meyrin site, is the Project's only elliptical shaft. It is through this shaft that most of the magnets for the future machine, in particular the 1232, 15 m long cryo-dipoles, are to be lowered. The longitudinal section of this tunnel had to be modified during the design phase to take account of a dip in the molasse with an inflow of water, under the village of Saint-Genis-Pouilly (F). At the surface, two large buildings have been erected (one on top of the installation shaft and the other one adjacent) to house the transfer, preparation, sorting and some testing of the LHC machine cryo-magnets.

The second transfer tunnel, TI 8, links Point 4 of the SPS accelerator to Point 8 of the LHC. It has the advantage of an access shaft located near the point where it intersects with the SPS. It has a relatively uniform slope of 3.8% and lies within a depth span of approximately 50 m to 100 m.

The structures to be built for the beam dumps are on either side of Point 6, near the village of Versonnex in France. The tangential ejection of the beams and the distance required to disperse them made it necessary to excavate a 20 m long extraction cavern measuring 8 m in diameter, a 330 m long tunnel with a finished diameter of 3 m, and a 25 m long cavern measuring 9 m in diameter, linked to the existing tunnel by a short access/egress gallery on each side. Based on environmental and financial considerations, it was decided that all this work would be done from the existing shafts at Point 6, without creating a new access pit.

The two large experimental areas for the ATLAS and CMS detectors consist of two shafts, which are up to 20 m in diameter and approximately 65 m deep. These provide access to the experimental and service caverns. In the case of the ATLAS detector, the two main caverns are arranged perpendicularly, linked by five L-shaped tunnels. Two smaller caverns either side of the experimental area in the existing tunnel will house the electrical equipment for the LHC machine. This area is located at Point 1, opposite the main entrance to the CERN site at Meyrin in Switzerland. As the upper limit of the molasse rock lies at only 6 or 7 m below ground level, the excavation of the shafts did not pose any particular problems.

For the CMS detector, the two main caverns are arranged side by side to minimise the length of connections to detector. It is essential for the two caverns to be situated not more than 7 m apart, and it was therefore necessary to replace the molasse between them by a concrete "pillar" measuring 50 m long and 28 m high. This work was done in advance, after completion of the excavation of the two shafts and before that of the two large caverns. This area is located close to the French village of Cessy. Unlike the ATLAS experimental area, the level where the moraine meets the molasse is at a depth of more than 50 m, therefore there is only on average 18 m of molasse above the cavern crowns. The excavation of the shafts therefore required the use of a ground freezing technique. As in the case of the ATLAS area, several additional tunnels and caverns, including a complete by-pass tunnel running through the service cavern had to be built.

For experimental areas to house the two other detectors, ALICE and LHCb, the existing underground LEP infrastructure was re-used. The ALICE detector has been designed in such a way that it could fit in the UX25 cavern formerly dedicated to the L3 experiment. Modifications to underground structures included new foundations for a magnet in the UX25 cavern and a new passage called UP25 between this cavern and the LEP US25 chamber.

The LHCb detector will be housed inside the existing UX85 cavern, formally dedicated to the DELPHI experiment. Modifications to the UX85 cavern included the reinforcement of the headwall damaged by the swelling of the molasse rock, the erection of a partly prefabricated concrete shielding wall, and some truncation, or modification, of concrete walls.

2.2.2 Surface Buildings

On the surface, all existing LEP buildings will be re-used for LHC (Fig. 2.2). However, some modifications were needed. This included the construction of a clean room in building SXL2 and a counting room in building SX2. Several new buildings have been built to house new facilities required by the LHC.

At Point 1, a total of 8 new buildings have been erected in order to shelter:

- The shafts on top of the service experimental caverns,
- All services required for the running of the ATLAS detector.

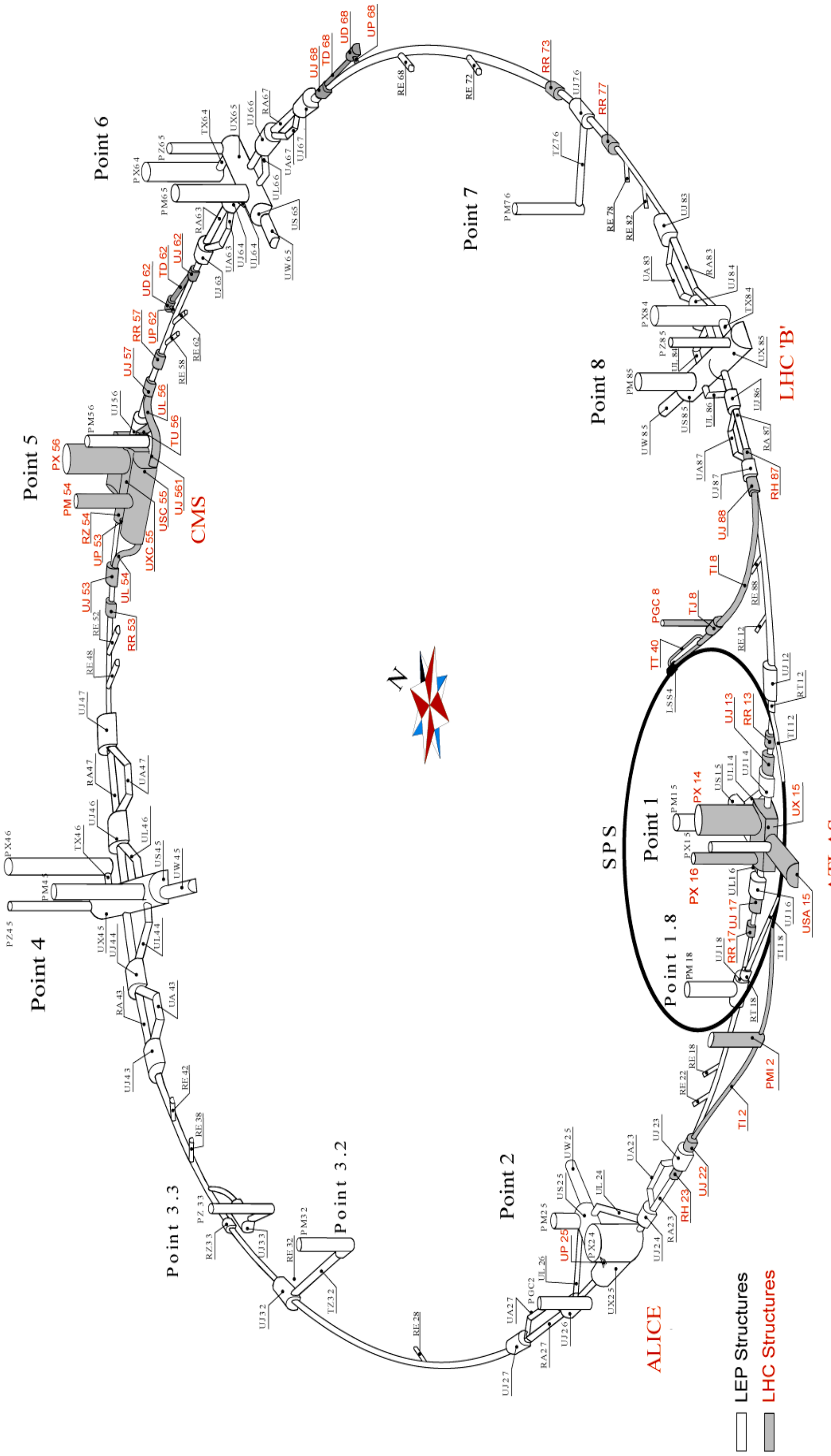


Figure 2.1: LEP and LHC underground structures

At Point 5, a total of 9 new buildings have been erected in order to shelter:

- The two shafts on top of the experimental cavern,
- The single shaft on top of the service cavern,
- All services required for the running of the CMS detector. The SX building was completed very early in the project to allow CMS to start pre-assembly of the detector.

Apart from the surface buildings mentioned above, new ones have been constructed at points 2, 4, 6 and 8 to house the cryogenic compressors for the LHC machine. Three other steel buildings were erected at points 2, 4 and 8 to house cryogenic equipment such as cold boxes. The total number of new buildings erected in the frame of the LHC Project amounts to thirty, representing a total gross surface area of 28 000 m^2.

2.3 GEOLOGY AND ENVIRONMENT

In view of its dimensions, there was no way to avoid locating the main tunnel of LEP in two very different geological zones. Most of the tunnel, i.e. about 23 km, has been excavated in the molasse of the Lemanic basin, which is a tertiary formation of consolidated fluvial and marine deposits of alpine origin. The remainder of the tunnel is situated in the piedmont region of the westernmost Secondary Period (Mesozoic) chain of the Jura.

In the Lemanic plane the molasse does not generally occur at the surface, but lies beneath moraine deposits consisting of gravels, sands and loams which can contain ground water. Such surface rock can pose problems for tunnel excavation since it does not lend itself to mechanised boring methods and is insufficiently stable bedrock for CERN accelerators. The upper limit of the underlying molasse lies at variable depths, ranging from several metres to over a hundred metres following the glacial ridges and furrows. It consists of sub-horizontal lentils of alternating sandstones and marls of variable composition. The nature and geo-mechanical characteristics of these rocks vary considerably, ranging from hard and cemented sandstones to soft marls.

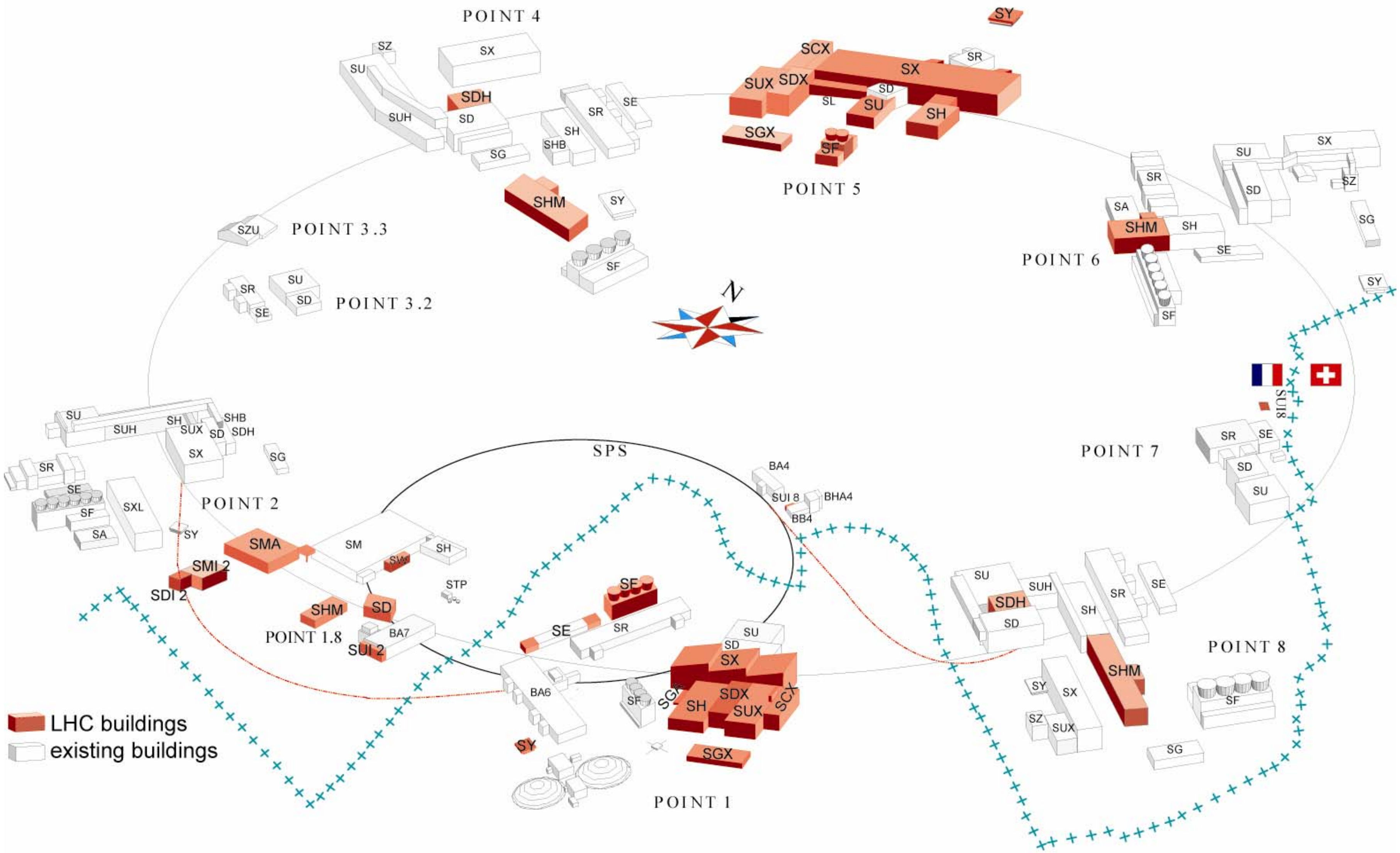
In the piedmont region of the Jura, the tunnel had to pass through the transition and interface zones separating the deposits of the plane from the Jura massif itself before entering the compliant series of Cretaceous and Upper Jurassic rocks consisting of limestone and compact marls. These rocks constitute the anticline fold of the high chain of the Jura.

The whole region has been subjected to severe folding and as a result there are a lot of cracks. The Jura chain has many fissures, either running parallel to its axis, resulting in intense erosion centred on the summit fault or combined in two transverse directions. The massif has thus been segmented into successive blocks separated by faults.

As a result of exploratory test boring, the positioning of LEP was modified to avoid the Jura as much as possible. The final positioning included only 3 km in the piedmont region with a maximum rock cover of 170 m. To avoid a deep depression in the moraine detected in the eastern part of the project near Geneva-Cointrin airport, the main tunnel plane was inclined by 1.42% from the horizontal. This tilting of the tunnel's plane made it possible to optimise the depth of the access shafts, to site the main tunnel at greater depths below the inhabited areas of the plane and, conversely, to reduce the depth of the underground structures under the Jura mountains.

In the same way as for the LEP Project, the implantation of the LHC Project into the local environment required all relevant legal procedures to be followed. This implied firstly the writing of an Environmental Impact Study, which was submitted to the competent authorities and communicated to the general population in the spring of 1997. After this, the application of the normal procedures for reception of construction permits were prepared with the collaboration of external architects and submitted to the regulatory authorities. In following all these different procedures the aim has been to ensure that the LHC Project is integrated into the environment in the best possible way and that the risk of disturbing the population is reduced to a minimum. A number of changes to the original plans have in fact been introduced as a result of the many consultations with the people and authorities concerned.

It was part of the architects' task to ensure the best possible integration of the surface buildings into the environment. Acoustic insulation is of particular importance for installations that could be noisy. The fact that nearby houses are in most cases grouped to one side made it easier to provide suitable screens and plantations as a means to further reduce any residual disturbance.


POINT 1
POINT 1.8
POINT 2
POINT 3.2
POINT 3.3
POINT 4
POINT 5
POINT 6
POINT 7
POINT 8
SPS
N
LHC buildings
existing buildings

Where significant excavation work took place, like in points 1, 5 and 6, these screens were made from "hills" built with the excavation material from the underground works. Later, these mounds were covered with topsoil and planted to match the surrounding landscape.

The finished LEP tunnel in which the LHC Collider is placed is essentially a watertight concrete pipe and hence does not affect the water resources of the area. The only exception to this is in the Jura section of the tunnel, where an ingress of water could not be totally prevented during LEP works because of programme constraints. However, this has a very limited impact on the hydrogeology of this part of the Jura Mountains (see below).

2.4 THE MAIN BEAM TUNNEL

The normal tunnel cross-section (internal diameter of 3.76 m) is divided into two parts:

- The inner side of the ring, which is set aside for handling equipment and for the passage of personnel,
- The outer side, where the machine components and services will be installed – this layout was chosen partly to give free access from the inside of the ring and partly to allow the services to be installed on the same side as the machine.

Excavation of the LEP tunnel was done with full-face boring machines in the molasse. Stability conditions varied considerably in the vicinity of the Allondon fault, where vertical strata displacements of over 100 m were detected. Also, if poor quality and/or permeable rock were encountered, the performance of the required auxiliary operations – such as ground and rock support, grouting, and pilot hole drilling for the detection and delineation of adverse geological conditions – would have been severely hampered by the presence of a full-face machine. Therefore, the more flexible method of using explosives to drive the tunnel through the limestone was preferred.

While the finished internal diameter of the main tunnel is 3.76 m, the excavated diameter was 4.50 m, thus allowing the insertion of firstly a pre-cast concrete segmental lining, grouted to the rock and then a cast in-situ lining. In more detail, the tunnel lining in the molasse initially consisted of a concrete segmental shell, inserted, then contact-grouted to the rock as soon as it was practicable after excavation. This shell supports and preserves the inherent integrity of the rock. A second, cast in-situ lining was poured after the installation of waterproofing and drainage systems. In the molasse, a drainage system, placed between the linings, reduces or eliminates hydrostatic pressure in most cases, the treatment of the construction joints and the inner lining rendering the structure watertight. In the limestone strata, an initial lining consisting of a combination of rock bolting, sprayed concrete, wire mesh and possibly steel arches, has been placed prior to the definitive, cast in-situ concrete lining.

In zones of relatively high water pressure and/or high permeability, which were encountered in the Mesozoic limestone, waterproofing was achieved by a combination of grouting – using chemical and cement-based solutions which solidify within the rock matrix – and the insertion of a waterproof layer between the two linings.

Because problems were anticipated, the Jura section of the LEP tunnel was drilled and blasted, rather than using the full-face tunnelling machine. While being excavated, this region suffered inflows of water under high pressure with up to 200 litres per second, carrying silt and sand with it. These inflows were treated by grouting before the tunnel was lined with shotcrete, waterproofed and given a final concrete lining. Only one remained, with a steady inflow of 23 litres per second throughout the year, which could not be treated for planning reasons during LEP construction. Since then, on two occasions in 1990 and in 1993 pipes and drains were blocked by massive quantities of sand and the LEP machine was flooded, with a deposit of sand on its floor up to 20 cm deep. A number of studies involving external experts and consultants were performed to try and find an efficient solution to this problem, in view of the installation of the LHC machine in the LEP tunnel.

After a "submarine" solution including more than 600 m of heavy steel lining in the concerned area was rejected as too costly, it was finally decided to improve the existing drainage and protection facilities with the following works:

- Demolition and reconstruction of the RE38 alcove (to stand the external hydraulic pressure);
- Improvement of the LEP water drainage system;

- Installation in the LHC tunnel of a new 6 inch stainless steel pipe to carry the (possibly sandy) water to the TZ32 tunnel;
- Fixing of mesh panels in place on the vault of the LHC tunnel to protect personnel and equipment;
- A complete cleaning of the central drain blocked by grouting material in 1991.

On the other hand, it was decided to remove the dams in the TZ32 tunnel and let the flow of loaded water go directly into a pit at the bottom of the PM32 shaft where significantly improved pumps have been installed to take the water up to the existing decantation basins on the surface.

2.5 SURFACE AND UNDERGROUND STRUCTURES AND THEIR FUNCTIONS

Generally speaking all underground and surface structures for ATLAS and CMS experiments situated at points 1 and 5 respectively are new, while those for ALICE and LHCb experiments are those which were erected for the LEP experiments previously situated at points 2 and 8 respectively.

2.5.1 Surface structures

All LEP buildings will be re-used in the frame of the LHC project. On the following axonometric views and layouts, they are indicated as shapes with no fill, while buildings specifically erected for the LHC project are indicated by shapes filled in grey. Together with the axonometric and layout drawings, tables are shown which summarise the new characteristics of the buildings, as well as the lifts and tracking cranes which are available inside them.

At points 1, 2, 5 and 8, where the LHC new experiments are located, the buildings are of two kinds: those related to the need of the LHC machine and those for the detectors. In total 30 buildings have been erected for the LHC project in addition to the existing LEP ones, representing an additional 28 000 m^2 of gross surface area. All buildings housing noisy equipment are built with cast in-situ or prefabricated concrete with internal insulation. The main features of the various building types, together with their functions are summarised below:

LEP buildings

SA (points 2 and 6)
: Steel buildings dedicated to the LEP RF system. They are re-used in a different way for the LHC project. At Point 6, the length of the building was reduced to leave space for erection of the SHM building.

SD
: Steel building on top of PM shaft, giving access to the US caverns. They are used to transfer equipment to service caverns below a use which is unchanged for LHC.

SEE
: Concrete platform at ground level fitted with electrical equipment.

SEM-SES
: Concrete/steel single storey building with false floor used as electrical substations. This building has been extended at Point 1 to cope with the additional local requirements.

SF (points 2, 4, 6, 8)
: Concrete cooling towers to extract the heat loads from machine and former LEP experiment equipments. They are re-used for cooling the LHC machine components.

SG (points 2, 4, 6, 8)
: Concrete/steel buildings housing the equipment for the storage and mixing of gases for the LEP experiments. They will be re-used for storage.

SH (points 2, 4, 6, 8)
: Concrete building housing the cryo-compressors for the LEP experiments. They are re-used for the cooling of the LHC machine components.

SM (Point 1.8) Steel building which was used for various purposes at the time of LEP, mainly to test pieces of equipment. For the LHC, the SM18 building houses a cryogenic plant which serves two major testing facilities, the cryomagnets cold tests benches and the radio-frequency conditioning equipment.

SR Steel building with false floor, which was used to house the power converters of LEP. For the LHC they have been given a variety of new uses including housing clean rooms at Point 1.

SU Concrete building dedicated to the cooling and ventilation of machine areas. Use unchanged for the LHC.

SUH Concrete buildings housing ventilation and cooling equipment for the cryo-compressors.

SUX (Point 2) Concrete building housing the cooling and ventilation equipment for the L3 experiment, to be re-used for ALICE equipment.

SX (points 2, 4, 6, 8)
Steel buildings on top of the PX shafts, giving access to the UX caverns. They were used to transfer experimental equipment to these caverns. Their use will be the same in the frame of the LHC, for Points 2 (ALICE) and 8 (LHCb) while machine components will be transferred through SX4 and SX6.

SY (points 2, 4, 6, 8)
Concrete/steel buildings for access control of the even points of LEP. Their use is the same in the frame of the LHC project. They contain equipment which monitors the access gates to these sites and the safety systems.

SZ (points 4, 6, 8)
Concrete (Point 4) or steel buildings (points 6 and 8) on top of PZ shaft used for personnel access to the underground areas through the UX cavern.

LHC buildings

SCX (Points 1 and 5)
Office buildings required by ATLAS and CMS collaborations. These are 3-story (ATLAS) or 2-story (CMS) buildings of reinforced concrete with partial glass facades. They provide office space, together with the main experimental control room and some technical rooms, mainly for computing facilities.

SD (Point 1.8) Steel building over PM 1.8 shaft giving access to the UJ18 cavern and the LHC tunnel.

SDH (points 4 and 8)
Steel building housing cryogenic equipment for the LHC machine.

SDI (TI2 area, western end of the Meyrin site)
Steel building over the PMI2 shaft and the TI2 transfer tunnel. The building is used to transfer the LHC cryo-magnets from the surface to the TI2 tunnel, on their way to their final position in the LHC tunnel

SDX (points 1 and 5)
Steel buildings on top of the PM shafts for personnel and equipment access to the underground areas through the US caverns.

SF (points 1 and 5)
Concrete cooling towers for the ATLAS and CMS detectors. The SF1 tower also cools SPS BA6 and, to compensate, LHC Point 1.8 is partially cooled by the SPS loop.

SGX (points 1 and 5)
Concrete/steel buildings for the storage and mixing of gases for the ATLAS and CMS detectors. As for the LEP, SG buildings, they have been specially designed so that in the unlikely case of an explosion within the building, the roof will come off, thus releasing the pressure within the building.

SH (points 1 and 5)
Concrete buildings housing the cryogenic compressors and equipment required by the ATLAS and CMS experiments.

SHE (points 1, 1.8, 2, 3.2, 4, 5, 6, 7 and 8)
Steel tanks for storage or recuperation of Helium, placed over two concrete foundations.

SHM (points 1.8, 4, 6 and 8)
Concrete buildings housing cryo-compressors and their equipment for the cooling of the LHC machine.

SMA (Point 1.8) Steel building housing cryo-stating activities of the LHC cryo-dipoles.

SMI (TI2 area, west of the Meyrin site)
Steel building used for storage and sorting of the cryo-dipoles for LHC, prior to their transfer to the TI2 tunnel.

SUI (SUI2 at Point 7 of the SPS, SUI8 at Point 4 of the SPS)
Steel buildings housing the ventilation equipment respectively for TI2 and TI8 transfer tunnels.

SUX (points 1 and 5)
Concrete buildings for housing the cooling and ventilation equipment required for the ATLAS and CMS underground areas.

SW (Point 1.8) Steel building housing cryogenic equipment used for tests in building SM18.

SX (points 1 and 5)
Steel buildings (with wood cladding in the case of SX1) for the transfer and lowering of the ATLAS and CMS detectors components into the experimental caverns.

SY (points 1 and 5)
Concrete/steel buildings for access control and safety monitoring of the ATLAS and CMS surface areas.

All buildings are surrounded by blacktopped access roads and car parks fitted with the necessary drainage facilities including oil separators.

2.5.2 Underground Structures

Except for the upper part of the shafts, all underground structures have been excavated in the molasse rock. After excavation, they all received a temporary lining (Austrian method) with bolts and shotcrete in various thicknesses, a waterproofing membrane (except for some sections of the LEP tunnel) connected to a drainage system and a final lining made of cast in-situ concrete of various thicknesses. On some occasions, halfen channels have been put in the final lining to allow easy fixing of pipes, cable trays and steel structures at a later stage.

LEP structures

PGC shafts (Point 2)
Civil Engineering shaft used to carry out the underground works at Point 2. Now has been partially filled with crushed concrete from demolition works for LHC.

PM shafts (points 1, 1.8, 2, 3.2, 4, 5, 6, 7, 8)
: Access shafts with stairs and lift, containing services and used for the transfer of equipment.

PX shafts (points 1, 2, 4, 6, 8)
: Access shafts to experimental caverns for former LEP and LHC detectors. For the PX15 shaft, repair works, placing of a waterproofing membrane and casting of a concrete lining were carried out in the frame of the LHC project.

PZ shafts (points 3.3, 4, 6, 8)
: Access shafts of underground caverns for personnel only.

RA tunnels (points 2, 4, 6, 8)
: Straight tunnels between UJ caverns for machine equipment each side of even points.

RE Alcoves (16 units around LHC tunnel, 2 on every octant)
: 25 m long small caverns with access from the LHC tunnel, housing electrical distribution, cooling and control equipments.

RT chamber (Point 1.8)
: Tunnel enlargement at Point 1.8 connecting the LEP/LHC tunnel to the UJ cavern at the bottom of the access shaft, housing electrical equipment.

RZ chamber (Point 3.3)
: LEP tunnel enlargement at Point 3.3 used for the transfer of services from UJ33.

TU tunnel (points 4, 6, 7, 8)
: Short bypass tunnels for the installation of ventilation equipment.

TX chamber (points 4, 6, 8)
: Segment of tunnel between the base of the PX shafts and the extremity of the UX caverns, used to transfer equipment.

TZ tunnel (points 3.2, 3.3, 7)
: Horizontal or inclined tunnels providing access from PZ or PM shafts to the nearest UJ cavern.

UA tunnels (points 2, 4, 6, 8)
: Service and access tunnels between US caverns used for klystrons for the LEP machine. Now re-used to house the heavy current power converters of LHC and other electrical equipment.

UJ caverns (points 1, 1.8, 2, 3.2, 3.3, 4, 5, 6, 7, 8)
: Service caverns housing electrical equipment dedicated to former LEP and now LHC machine.

UL tunnels (points 1, 2, 4, 6, 8)
: Junction access tunnels between US and UJ caverns.

UP tunnels (Point 3.3)
: Short access tunnel at Point 3.3 connecting the UJ33 cavern to the LEP/LHC tunnel. Now used to feed some of the services into LHC.

US caverns (points 1, 2, 3.2, 4, 6, 7, 8)
: Service caverns housing electrical, electronic, cooling and cryogenic equipment adjacent to experimental caverns (re-used for ALICE and LHCb equipment in the case of US25 and US85)

UW caverns (points 2, 4, 6, 8)

Caverns directly connected to the US caverns, housing electrical and cooling equipment.

UX caverns (points 2, 4, 6, 8)

Caverns for former LEP detectors and ancillary facilities re-used for ALICE and LHCb detectors in the case of UX25 and UX85.
UX45 is re-used for the RF installation.

LHC structures

PGC shaft (Point 4 of the SPS)

Civil Engineering shaft used to carry out underground works for the TI8 tunnel, which has been sealed close to the surface after completion of the works.

PM shafts (points 1.8, I2, 5)

PM 1.8 shaft was an existing LEP shaft which has received concrete shielding at its base for LHC. PMI2 has no stairs or lift and is only for the passage of equipment unlike the others which are for access as well so they have stairs and lifts. The shafts are used to carry services and for the transfer of equipment.

PX shafts (points 1 and 5)

Access shafts used for the transfer of detector equipment to experimental caverns, fitted with air ducts in certain cases, such as PX14.

RH caverns (points 2 and 8)

Enlargement of RA tunnels close to UJ caverns to house the injected beam line.

RR caverns (points 1, 5, 7)

Service caverns housing power converters and other electrical equipment for LHC machine.

TD tunnels (Point 6)

Tunnels each side of Point 6 housing beam lines for extraction of beams towards UD caverns.

TI tunnels (points 2 and 8)

Tunnels used to transfer beams from the SPS to the LHC machine clockwise and anti-clockwise.

UD caverns (Point 6)

Caverns partially filled with steel blocks and graphite to stop the LHC beam after extraction each side of Point 6.

UJ caverns (points 1, 2, 5, 6, 8)

Service caverns housing electrical equipment for LHC machine and connecting the TI2 and TI8 tunnels to LHC tunnel (UJ22 and UJ88). Also used as enlargements for transport purposes.

US caverns (points 1 and 5)

Service caverns housing electrical, electronic, cooling and cryogenic equipment adjacent to experimental caverns.

UX caverns (points 1 and 5)

Caverns housing the two main LHC detectors ATLAS and CMS and ancillary facilities.

2.6 POINT 1

Models and layouts of surface building and underground structures at Point 1 (Figs. 2.3 to 2.6), as well as tables giving their main characteristics and details of the lifting equipment (Tabs. 2.1 to 2.4) are shown below.

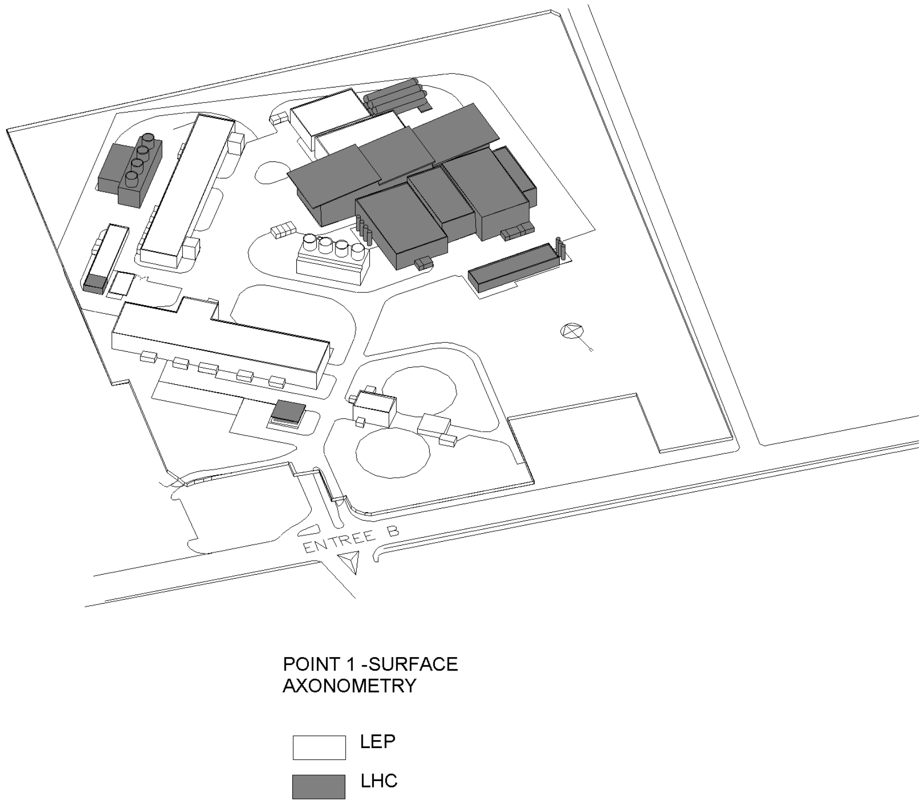


Figure 2.3: Point 1 surface axonometry

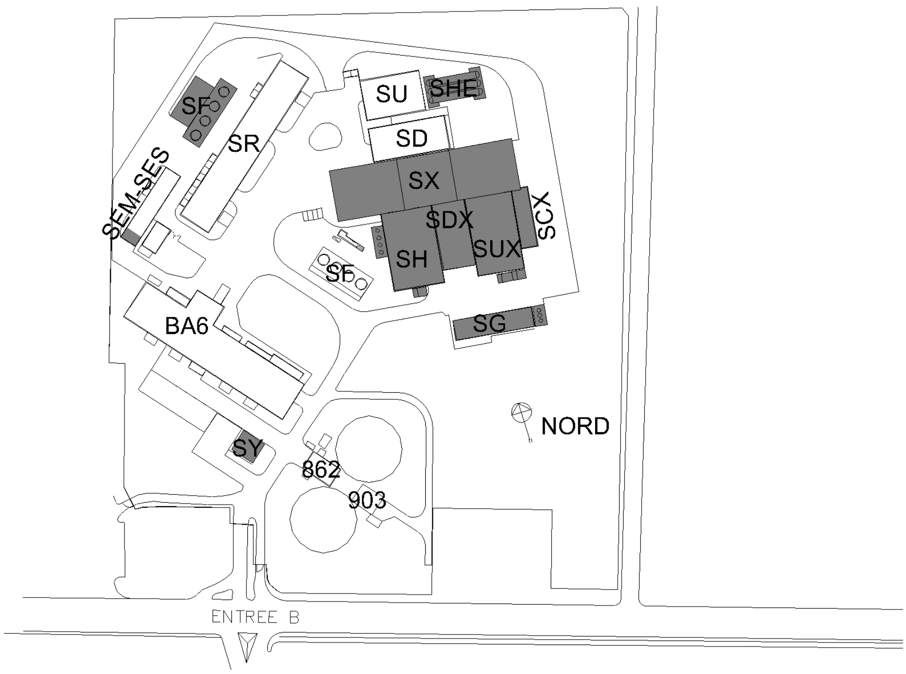


Figure 2.4: Point 1 surface layout

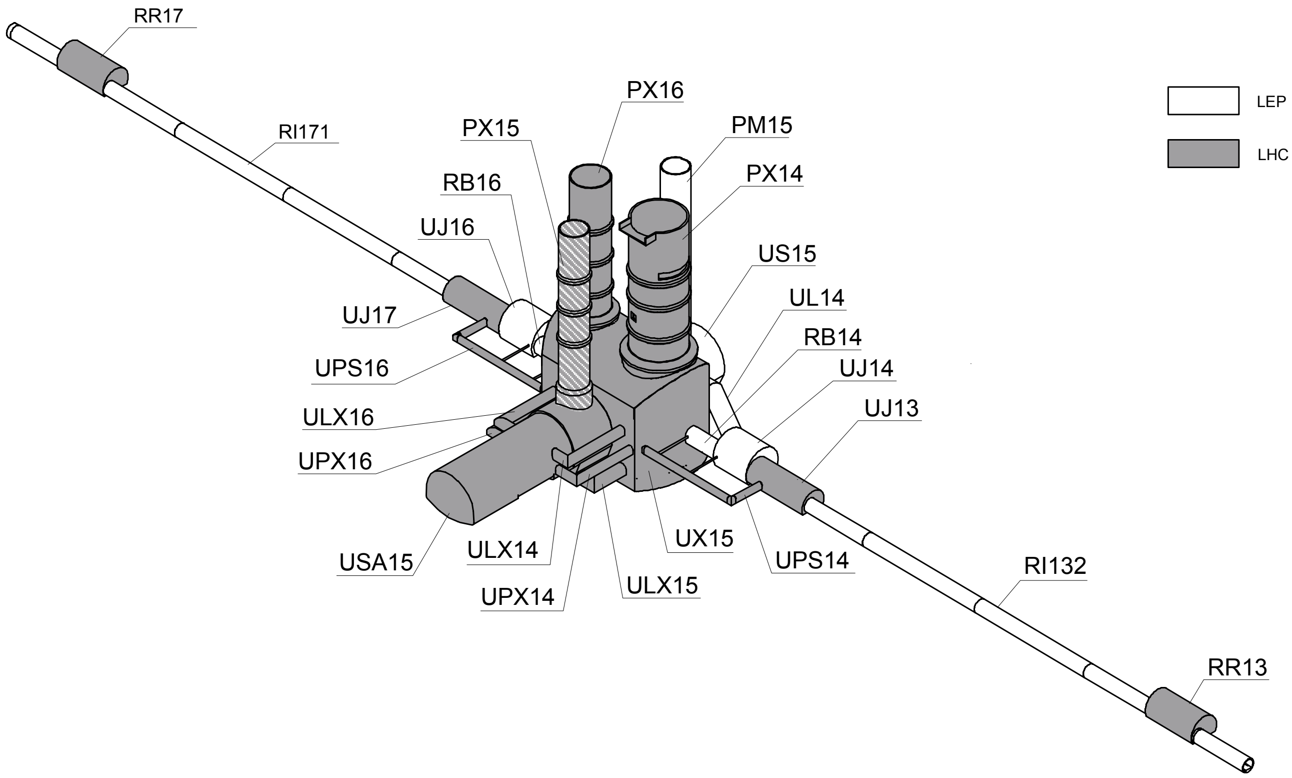


Figure 2.5: Point 1 underground axonometry

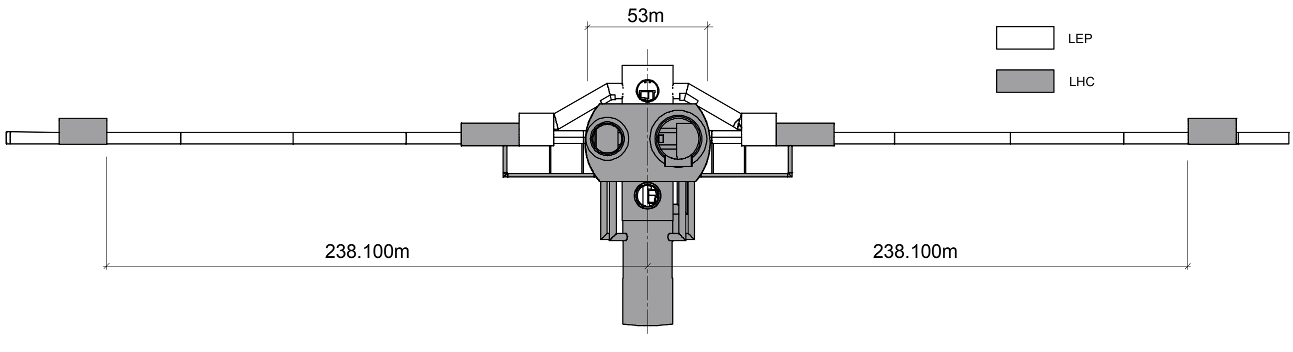


Figure 2.6: Point 1 underground layout

Table 2.1: Point 1 surface buildings

	Length m	Width m	Heigth m	Floor Area m^2	Volume m^3	Motorised Door W(m)xH(m)	Motorised Door W(m)xH(m)
SCX 1	25.00	6.00	9.65	150	1470		
SD 1	18.15	9.15	13.15	166	2185	6.00x6.00	
SDX 1	34.05	17.00	13.60	578	7050	6.00x6.00	
SE 1	50.35	15.60	5.10	785	4006		
SF 1	44.25	23.70	19.50	832	10376	4.00x4.00	
SGA 1	16.00	6.00		96			
SGX 1	40.60	10.40	4.25	422	1794		
SH 1	40.60	26.00	9.15	1055	9678	5.00x5.00	
SHE 1	32.77	16.00		524			
SR 1	93.10	17.15	7.46	1584	14826	3.95x4.00	3.95x4.00
SU 1	30.60	20.60	9.15	630	6205	5.00x5.00	
SUX 1	40.60	24.00	12.20	974	11887	5.00x5.00	
SX 1	84.60	24.00	17.70	2030	35938	(1) 8.00x9.50 (2) 8.00x14.00	5.00x5.00
SY 1	10.70	9.20	3.20	98	315		

Table 2.2: Point 1 underground structures

Structure	Length m	Width m	Height m	Diameter m	Floor Area m^2	Volume m^3
R 11	725.28	3.18	2.88	3.76	2306	6600
RE 12	24.70	4.62	3.45	5.00	101	311
R 12	379.95	3.18	2.88	3.76	1208	3467
RT 12	39.00	4.90	4.00	5.50	191	721
UJ 12	36.00	8.80	5.20	8.90	317	1359
TI 12	536.00	2.94	2.70	3.50	1576	4290
RI 12	206.25	3.62	3.45	4.40	746	2638
RI 13	180.40	3.62	3.45	4.40	653	3640
RR 13	20.00	9.90	6.80	10.40	198	1224
UJ 13	25.00	8.77	5.50	9.00	220	1041
UPS 14	52.52	1.20	2.00	1.20	63	118
UJ 14	14.00	13.30	7.90	13.50	186	1218
RB 14	14.24	3.62	3.45	4.40	51	15
PX 14			53.56	18.00		13628
PM 15			69.15	9.10		4500
PX 15			79.00	9.10		5135
PX 16			54.15	12.60		6751
UL 14	35.00	4.20	5.26	6.10	147	938
UL 16	35.00	4.20	5.26	6.10	147	938
ULX 14	30.60	2.60	2.60	2.60	79	184
UPX 14	52.52	2.20	2.20	2.20	71	140
US 15	20.75	16.20	13.37	21.40	346	4635
USA 15	62.00	19.30	12.60		1197	12951
UX 15	53.00	30.00	34.90		1494	50002
ULX 15	16.30	3.80	3.00	3.80	62	160
UPX 16	32.20	2.20	2.20	2.20	70	139
ULX 16	28.40	2.60	2.60	2.60	74	171
RB 16	13.99	3.62	3.45	4.40	50	106
UJ 16	14.00	13.30	7.90	13.50	186	1218
UPS 16	52.51	1.20	2.00	1.20	63	118
UJ 17	25.00	8.77	5.50	9.00	219	1040
RI 17	180.40	3.62	3.45	4.40	653	1370
RR 17	20.00	9.90	6.80	10.40	198	1223
TI 18	258.00	2.94	2.70	3.50	759	2048
RI 18	206.25	3.62	3.45	4.40	746	2638

Table 2.3: Point 1 gantry cranes

Stucture	Number	Capacity T	Speed m / min	Clearance of Floor m	Hook Travel m	Opening m x m
SD 1	PR 745	20	10	9.00	96.00	8.50x2.00
SR 1	PR 703	5	5	4.50		
SUH 1	PR 718	20	6	5.65		
SX 1	PR 776	140 x 2	3.4	9.30	103.00	
SX 1	PR 777	20	12	6.2	99.00	
SF 1	PR 762	3,2	5	8.55		
SH 1	PR 772	10	6	6.10		
SDX 1	PR 771	16	12.3	9.00	92.00	
SUX 1	PR 766	8	6	9.05		
UD 11	PR 775	30	5.2	10.30		
UX 15	PR 778	65	7.3	24.90		
UX 15	PR 779	65	7.3	24.90		

Table 2.4: Point 1 lifts

Stucture	Lift Number	Capacity kg / pers	Duration min	Cage Size L(m) x H(m)	Door Size W(m) x H(m)
PM 15	AS 714	3000 / 33	1	2.70x1.85	1.85 x 2.10
PX 15	AS 716	3000 / 40	1	2.70x1.85	1.85 x 2.10
UX 15	AS719	320 / 4	0.4	1.00x0.88	0.80x2.00
UX 15	AS 720	320 / 4	0.4	1.00x0.88	0.80x2.00

2.7 POINT 1.8

Models and layouts of surface building and underground structures at Point 1.8 (Figs. 2.7 to 2.10), as well as tables giving their main characteristics and details of the lifting equipment (Tabs. 2.5 to 2.8) are shown below.

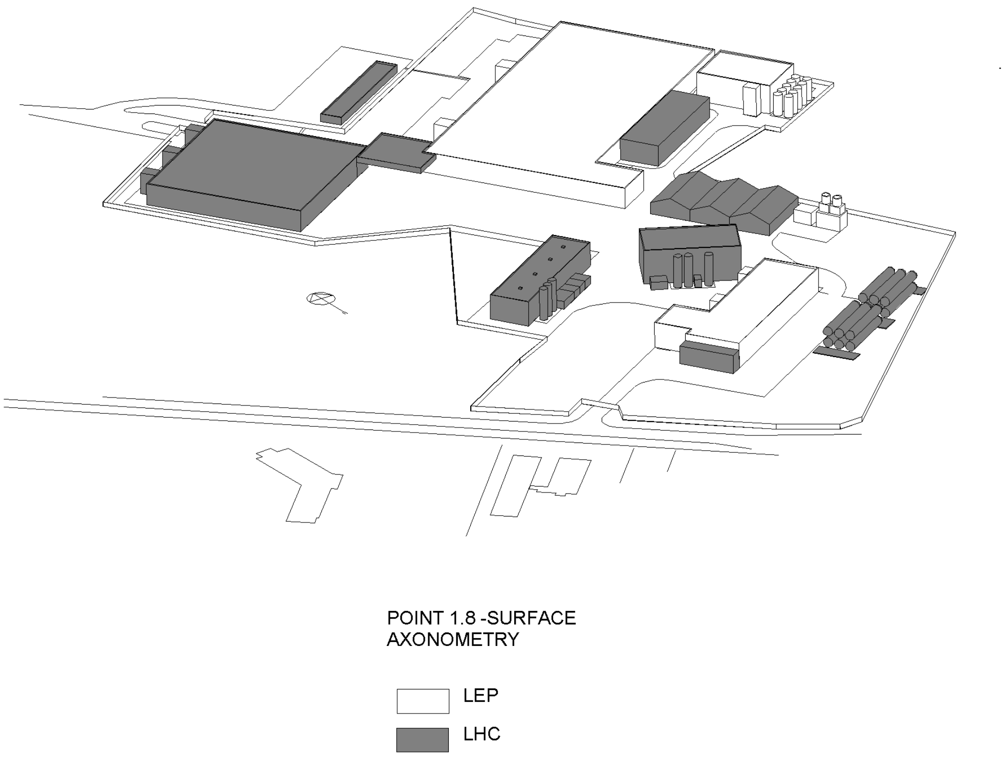


Figure 2.7: Point 1.8 surface axonometry

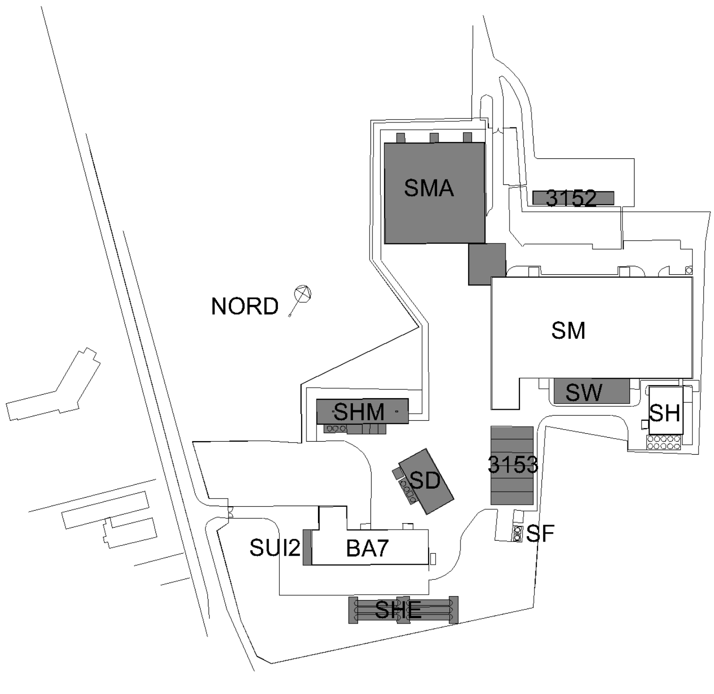


Figure 2.8: Point 1.8 surface layout

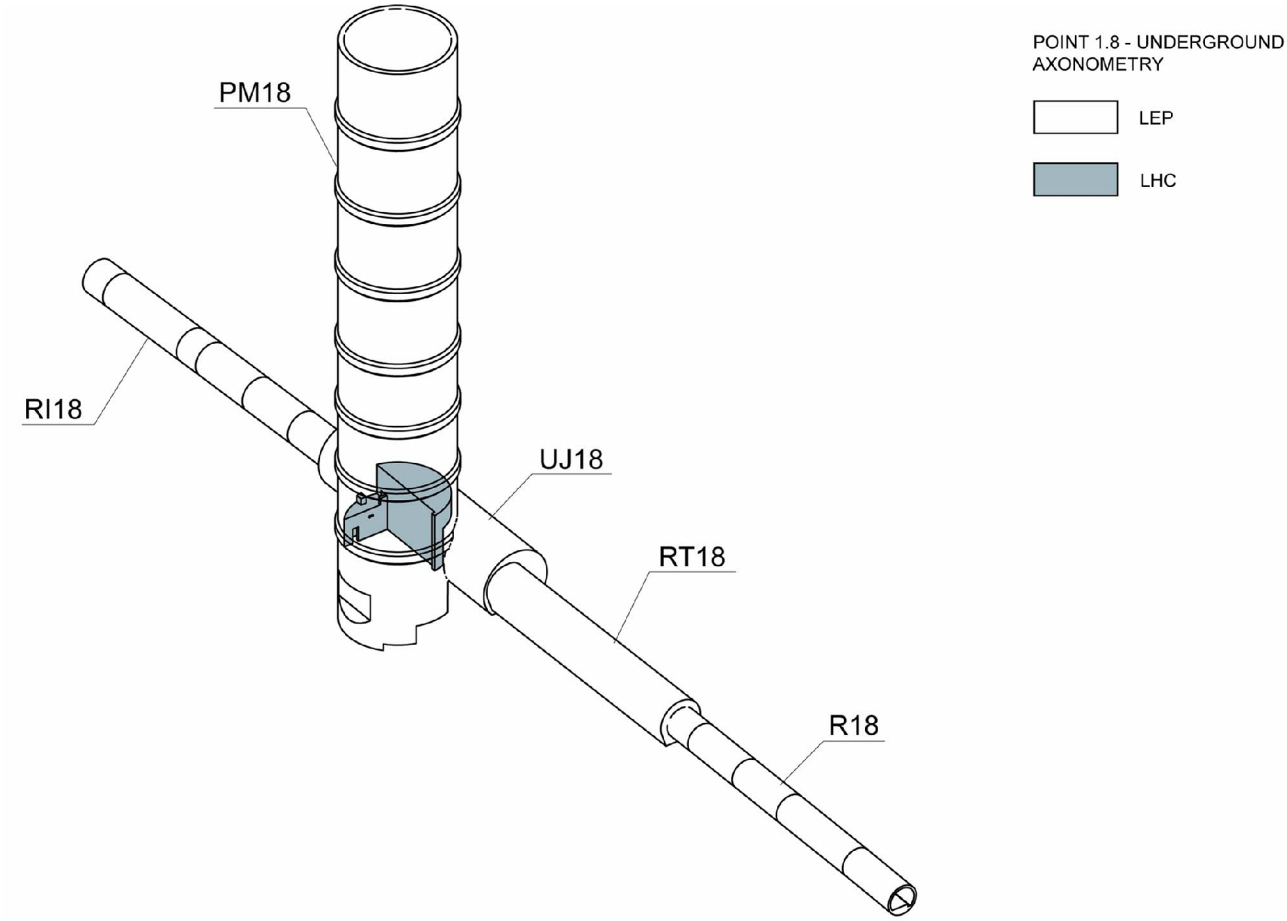


Figure 2.9: Point 1.8 underground axonometry

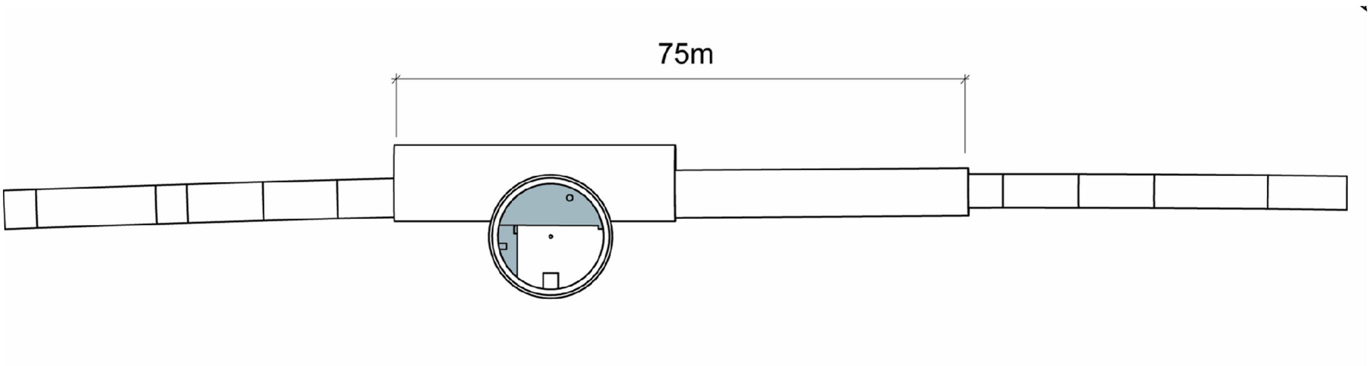


Figure 2.10: Point 1.8 underground layout

Table 2.5: Point 1.8 surface buildings

Structure	Length m	Width m	Height m	Floor Area m^2	Volume m^3	Motorised Door W(m)xh(m)	Motorised Door W(m)xh(m)
SHB 18	34.75	5.65	9.00	195	1138		
SF 18	7.20	6.00	3.85	43	166		
SM 18	120.10	60.10	8.10	7530	61000	4.30x4.30	4.30x4.30
SMA 18	60.00	60.00	8.70	3600	31320	5.00x5.00	
SH 18	28.60	20.60	11.00	590	6490	5.00x5.00	
SD18	34.90	19.00	13.15	662	8710	6.00x6.00	
SHM 18	55.60	15.60	9.50	870	8265	5.00x5.00	4.00x5.00
SW 18	44.55	15.00	9.70	668	6480	3.99x4.02	3.99x4.02

Table 2.6: Point 1.8 underground structures

Structure	Length m	Width m	Height m	Diameter m	Floor Area m^2	Volume m^3
TI 18	258.00	2.94	2.70	3.50	759	2048
UJ 18	36.00	8.80	5.20	8.90	317	1359
PM 18			76.36	14.00	154	11755
RT 18	39.00	4.90	4.00	5.50	191	721
R 18	379.95	3.18	2.88	3.76	1208	3467
RE 18	24.70	4.62	3.45	5.00	101	311
R 19	725.28	3.18	2.88	3.76	2306	6600

Table 2.7: Point 1.8 gantry cranes

Structure	Number	Capacity T	Speed m / min	Clearance of Floor m	Hook Travel m	Opening m x m
SM 18	PR 752	25	4	5.22		
SM18	PR 746	16	5	5.30		
SM18	PR 747	16	5	5.30		
SM18	PR 748	16	5	5.30		
SM18	PR 749	8	5	5.40		
SM18	PR 750	8	5	5.40		
SH18	PR 753	10	6	5.70		
SD18	PR 764	13	10	9.30	100.00	2.20x11.00
SHM 18	PR 763	20	6	5.70		

Table 2.8: Point 1.8 lifts

Stucture	Lift Number	Capacity kg / pers	Duration min	Cage Size L(m) x H(m)	Door Size W(m) x H(m)
PM 1.8	AS 701	1000 Kg 13 Pers	1.4	130x200	1.27x200

2.8 POINT I2

Models and layouts of surface building and underground structures at Point I2 (Figs. 2.11 to 2.14), as well as tables giving their main characteristics and details of the lifting equipment (Tabs. 2.9 to 2.11) are shown below.

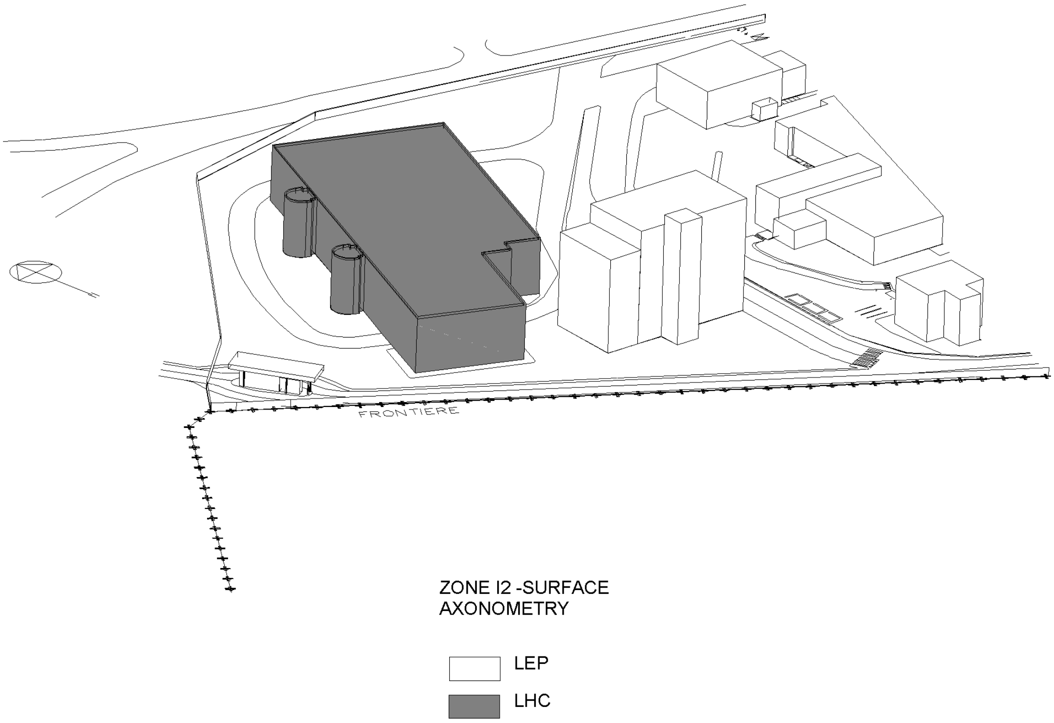


Figure 2.11: Point I2 surface axonometry

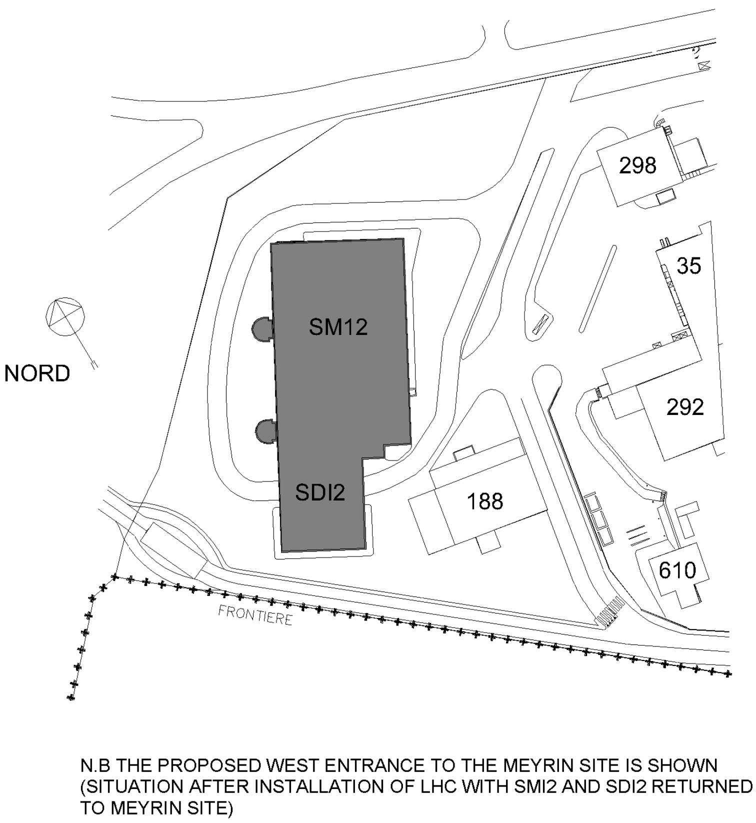


Figure 2.12: Point I2 surface layout

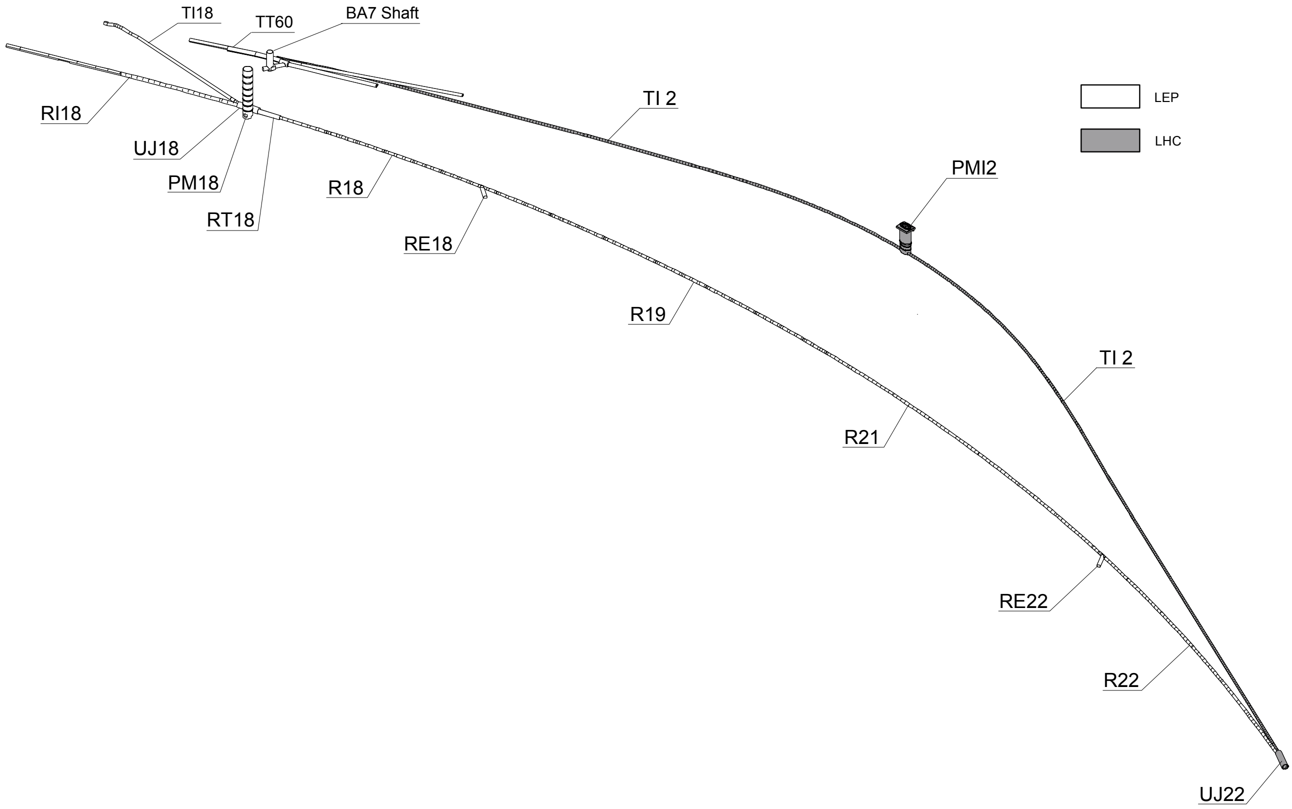


Figure 2.13: TI2 underground axonometry

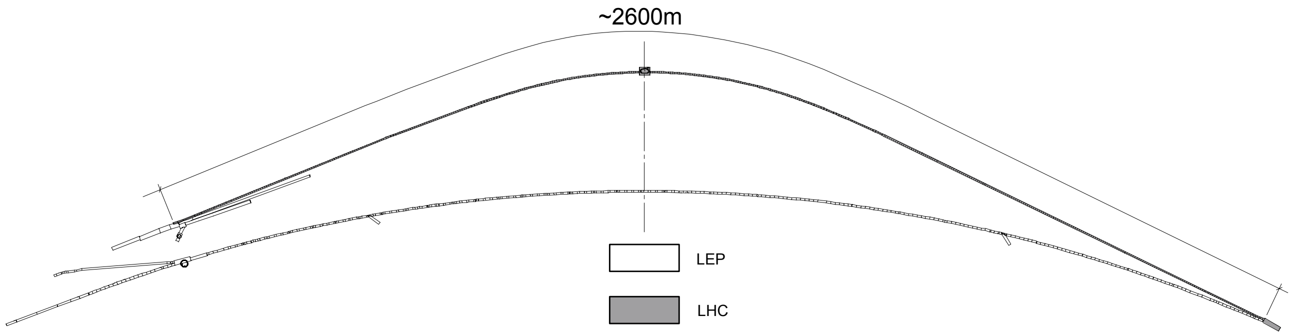


Figure 2.14: TI2 underground layout

Table 2.9: Point I2 surface buildings

Structure	Length m	Width m	Height m	Floor Area m^2	Volume m^3	Motorised Door W(m)xH(m)	Motorised Door W(m)xH(m)
SMI 2	54.46	35.16	12.00	1915	22980	5.00x5.00	5.00x5.00
SDI 2	27.20	22.16	12.00	603	7233	5.00x5.00	5.00x5.00
SUI 2 *	21.10	6.10	7.10	129	1050	1.90x3.50	

* See Figs. 2.7 and 2.8 (Point 1.8)

Table 2.10: Point I2 underground structures

Structure	Length m	Width m	Height m	Diameter m	Floor Area m^2	Volume m^3
PMI 2	18.80	12.80	47.03	18x12		8888
TI 2	2648.25	2.24	2.50	3.00	5922	13708
UJ 22	40.18	7.91	6.65	9.00	311	1690

Table 2.11: Point I2 gantry cranes

Structure	Number	Capacity T	Speed m / min	Clearance of Floor m	Hook Travel m	Opening m x m
SMI 2	222	8	6	8.00		
SDI 2/ SMI 2	223	40	10	7.00	54.00	18x9

2.9 POINT 2

Models and layouts of surface building and underground structures at Point 2 (Figs. 2.15 to 2.18), as well as tables giving their main characteristics and details of the lifting equipment (Tabs. 2.12 to 2.15) are shown below.

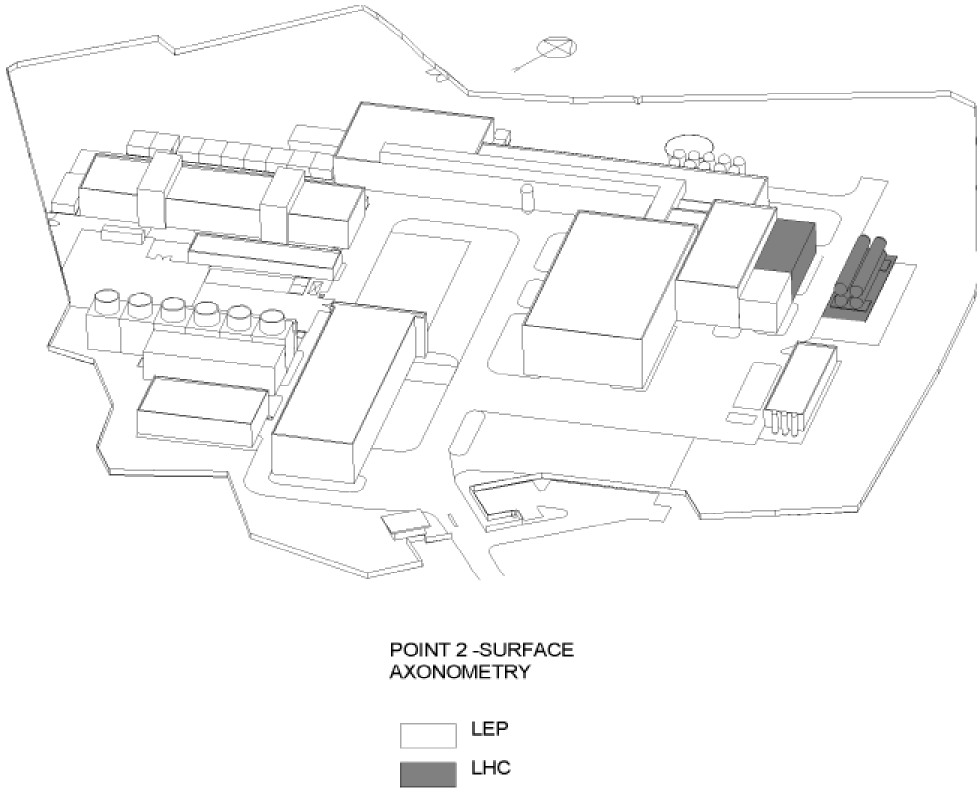


Figure 2.15: Point 2 surface axonometry

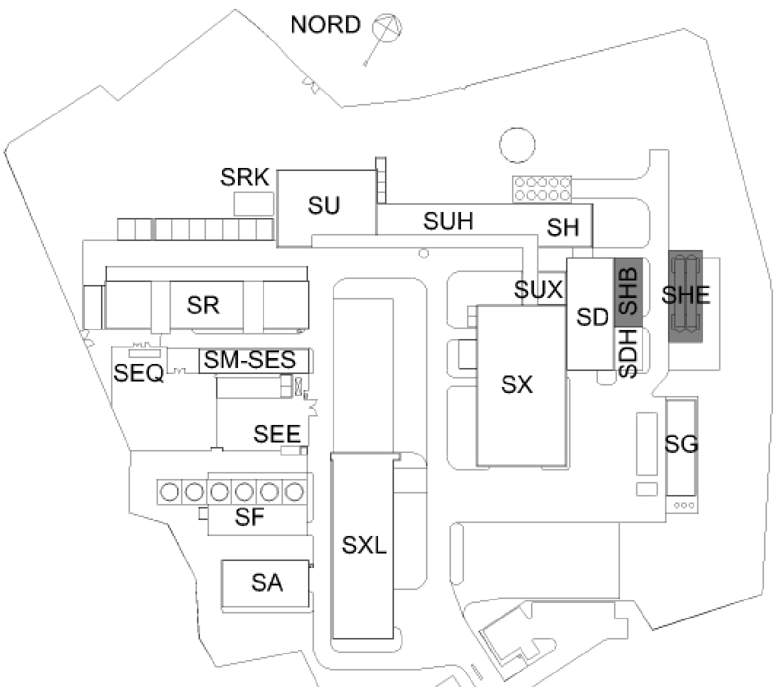


Figure 2.16: Point 2 surface layout

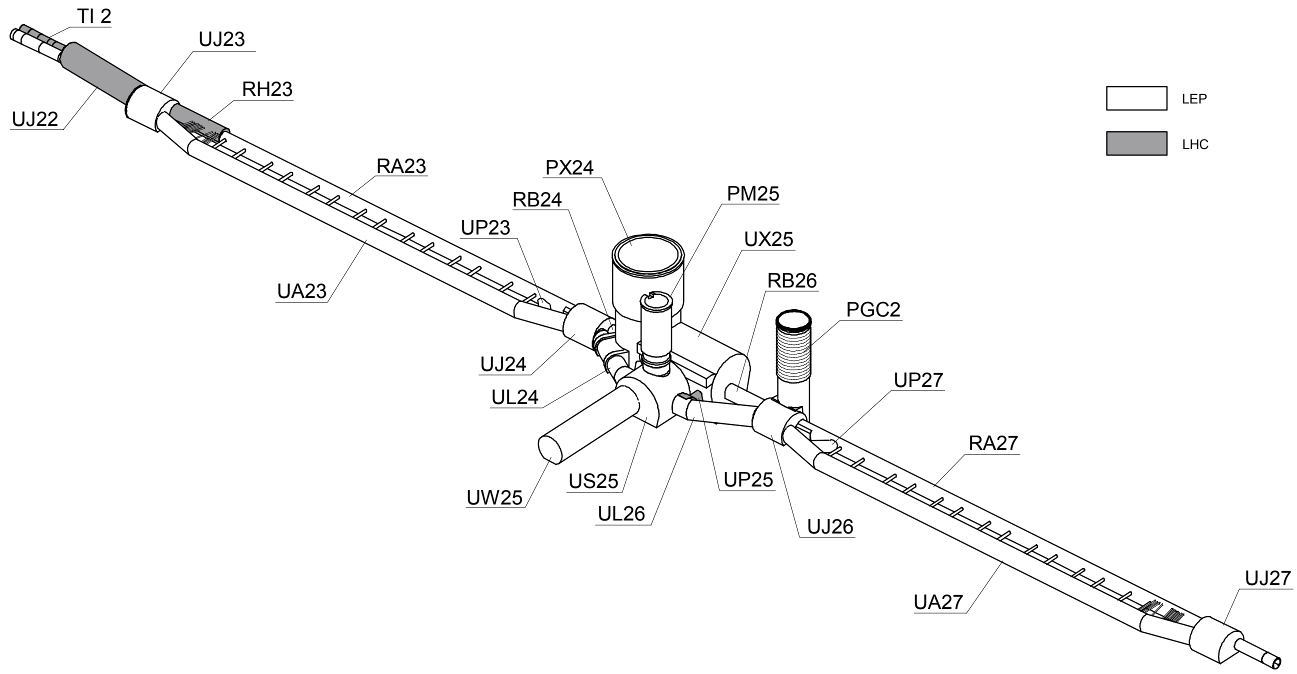


Figure 2.17: Point 2 underground axonometry

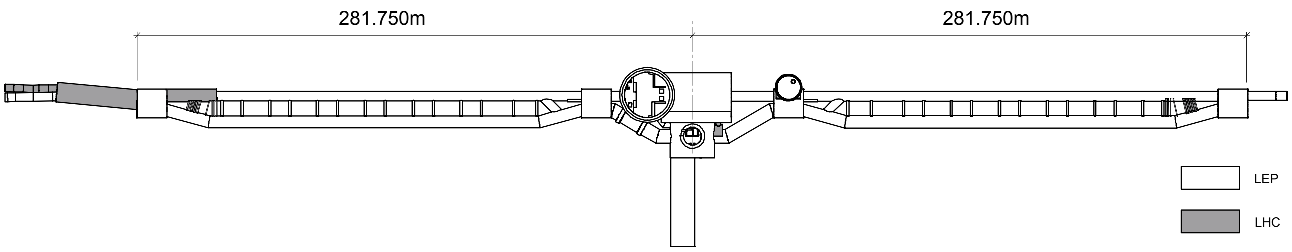


Figure 2.18: Point 2 underground layout

Table 2.12: Point 2 surface buildings

Structure	Length m	Width m	Height m	Floor Area m^2	Volume m^3	Motorised Door W(m)xH(m)	Motorised Door W(m)xH(m)
SA 2	30.50	16.80	7.40	512	4583	4.95x4.95	
SHB 2	24.50	10.15	13.15	190	2500	3.00x3.00	
SXL 2	67.50	21.70	12.80	1465	18748	20.15x11.90	10.00x5.00
SR 2	50.35	15.60	9.60	785	7540	4.00x3.95	
SD 2	40.15	17.20	13.20	615	8249	6.00x5.95	
SDH 2	15.40	10.15	9.60	155	1442	3.00x3.00	
SE 2	39.00	9.00	3.85	864	3862		
SF 2	53.25	22.60	15.00	780	8355	4.00x4.00	
SG 2	34.20	10.60	4.80	345	2257		
SU 2	45.70	27.75	9.35	1136	10416	5.00x5.00	
SUH 2	38.20	15.60	9.35	593	6050	4.00x3.00	
SUX 2	15.60	12.15	12.05	190	2575	5.00x5.00	
SH 2	29.00	15.60	9.35	640	12862	5.00x5.00	
SX 2	57.30	31.20	16.00	1800	28880	9.00X8.00	
SY 2	10.50	8.60	3.10	89	562		

Table 2.13: Point 2 underground structures

Structure	Length m	Width m	Height m	Diameter m	Floor Area m^2	Volume m^3
R 21	721.18	3.18	2.88	3.76	2293	6563
RE 22	24.70	4.62	3.45	5.00	101	311
R 22	661.20	3.18	2.88	3.76	2103	6017
UJ 23	14.00	13.30	7.90	13.50	186	1218
RA 23	159.90	3.39	3.60	4.40	718	2821
UA 23	213.42	4.24	4.50	5.50	905	4439
UJ24	14.00	13.30	7.90	13.50	186	1218
UL 24	34.68	4.20	5.26	6.10	146	929
RB 24	7.38	3.39	3.60	4.40	25	98
PX 24			28.64	23.00	415	11900
PM 25			31.97	9.10	65	2078
US 25	21.40	16.20	13.37	0.00	346	4635
UX 25	53.50	15.50	22.70	21.40	829	21667
UP 25	5.70	1.90	2.45	1.90	10	24.500
RB 26	22.88	3.39	3.60	4.40	77	304
UL 26	34.68	4.20	5.26	6.10	146	929
UJ 26	14.00	13.30	7.90	13.50	186	1218
RA 27	211.87	3.39	3.60	4.40	718	2821
UA 27	213.42	4.24	4.50	5.50	905	4439
UJ 27	14.00	13.30	7.90	13.50	186	1218
R 28	661.20	3.18	2.88	3.76	2103	6017
RE 28	24.70	4.62	3.45	5.00	101	311
R 29	721.18	3.18	2.88	3.76	2293	6563
RH 23	25.50	4.24	4.50	5.50	108	1995

Table 2.14: Point 2 gantry cranes

Structure	Number	Capacity T	Speed m / min	Clearance of Floor m	Hook Travel m	Opening m x m
SD 2	PR 707	10	10	8.80	47.20	10.00x2.20
SR 2	PR 754	10	5	4.57		
SR 2	PR 726	5	5	4.50		
SA 2	PR 727	5	5	4.50		
SX 2	PR 709	63	10	8.10	54.30	14.00x20.00
SLX 2	PR 706	63	10	7.70		
SF 2	PR 728	3,2	5	8.00		
SH 2	PR 757	20	6	5.70		
SDH 2	PR 773	5	6	10.30		
UW 25	PR 729	3.2	5	5.94		
UX 25	PR 774	80	10	18.00		
UJ 22	PA ---	20		4.05		

Table 2.15: Point 2 lifts

Stucture	Lift Number	Capacity kg /n pers	Duration min	Cage Size L(m) x H(m)
PM 25	AS 702	3000/33	0.7	2.70x1.85
PX 24	AS 703	630/8	0.4	1.40x1.10
PX 24	AS 715	1000/13	0.4	2.10x1.10

2.10 POINT 3

Models and layouts of surface building and underground structures at Point 3 divided into Point 3.2 and Point 3.3 (Figs. 2.19 to 2.24), as well as tables giving their main characteristics and details of the lifting equipment (Tabs. 2.16 to 2.19) are shown below.

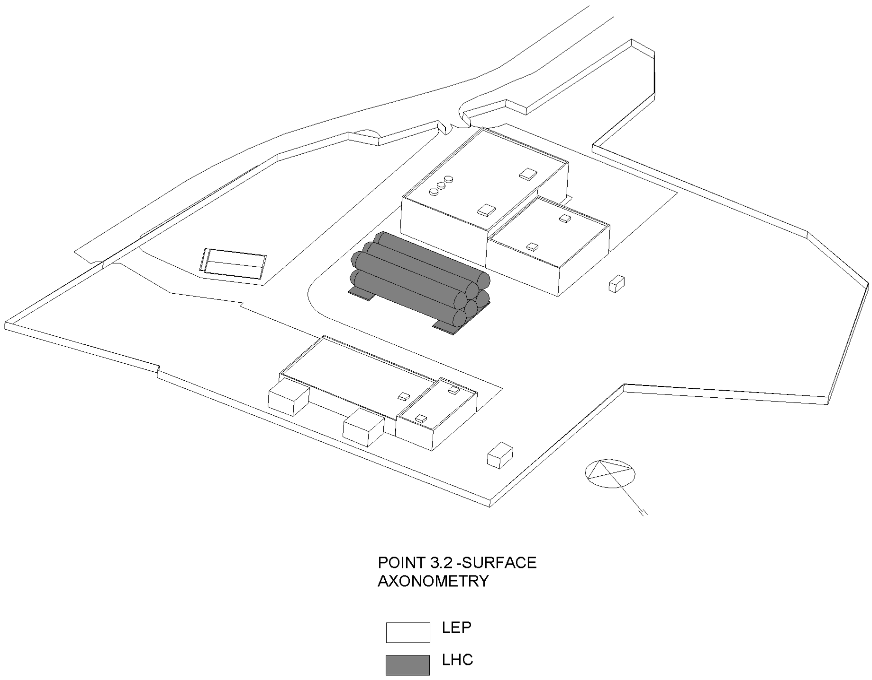


Figure 2.19: Point 3.2 surface axonometry

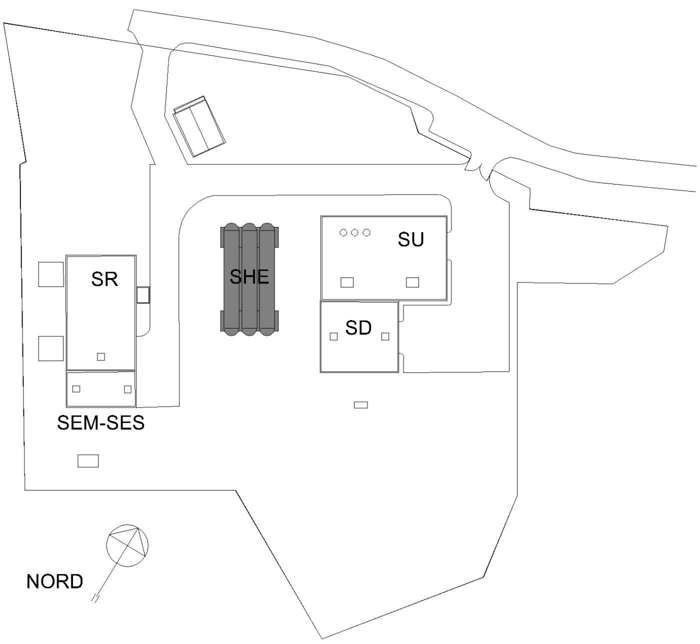


Figure 2.20: Point 3.2 surface layout

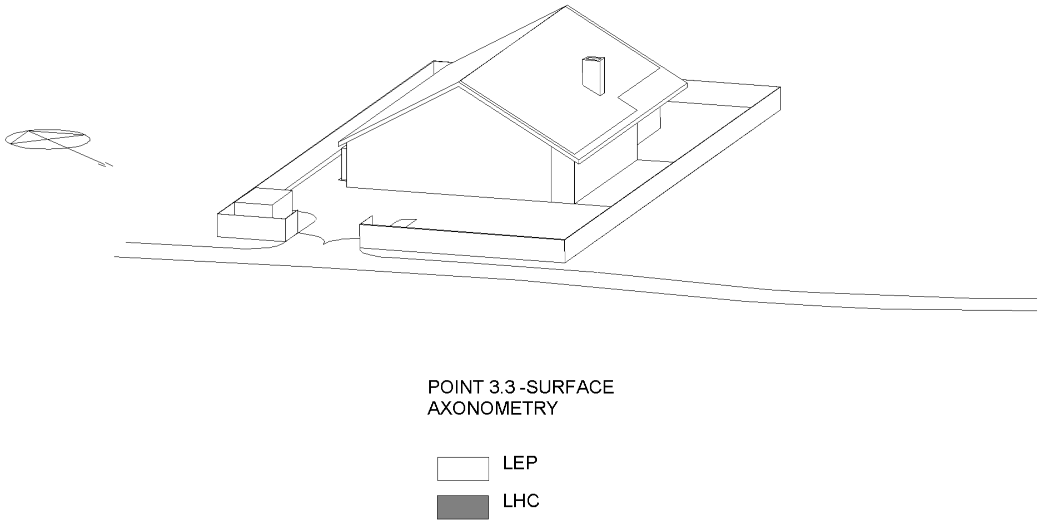


Figure 2.21: Point 3.3 surface axonometry

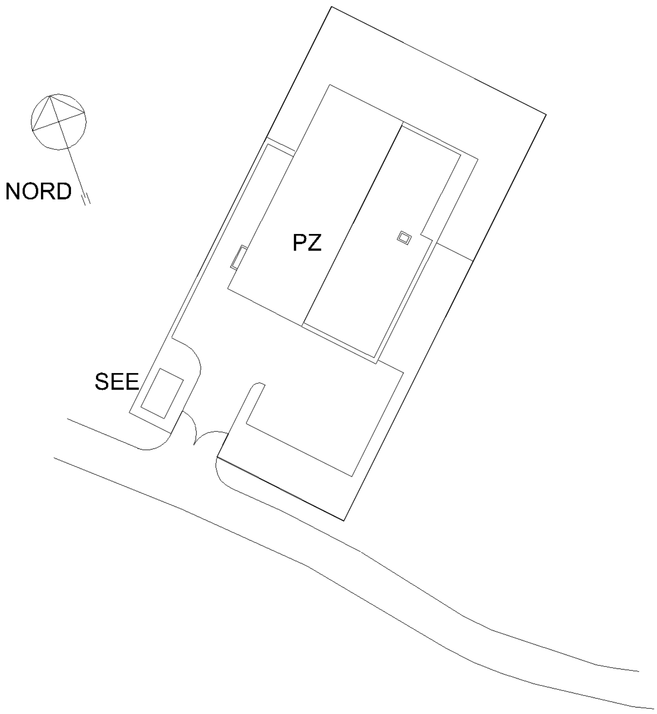


Figure 2.22: Point 3.3 surface layout

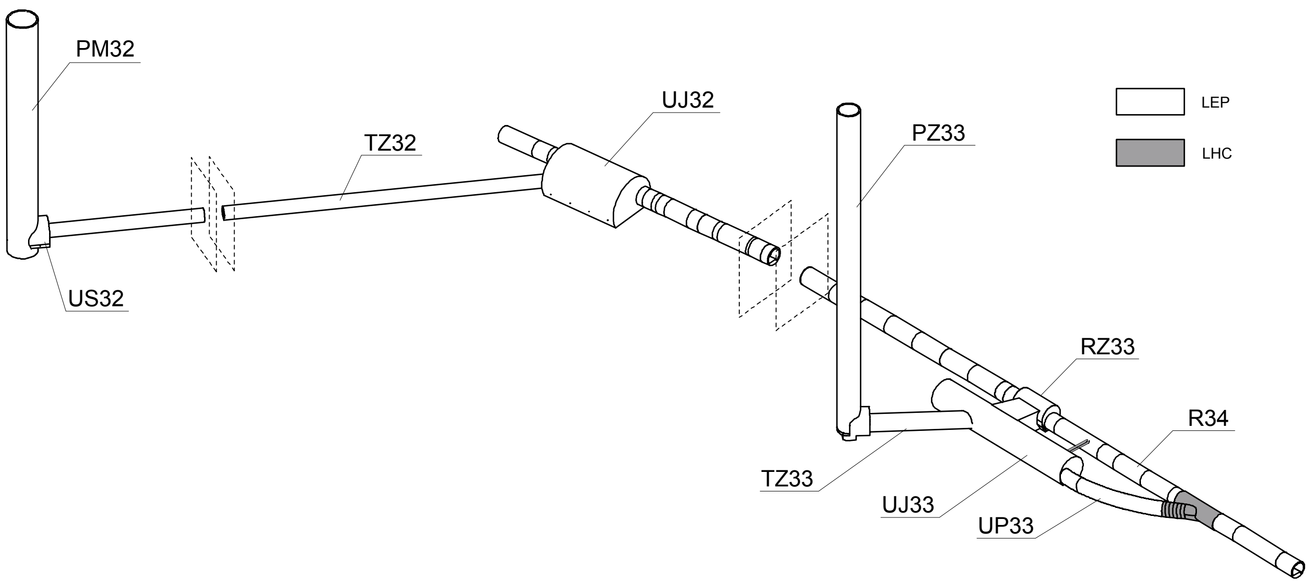


Figure 2.23: Point 3.2 and Point 3.3 underground axonomy

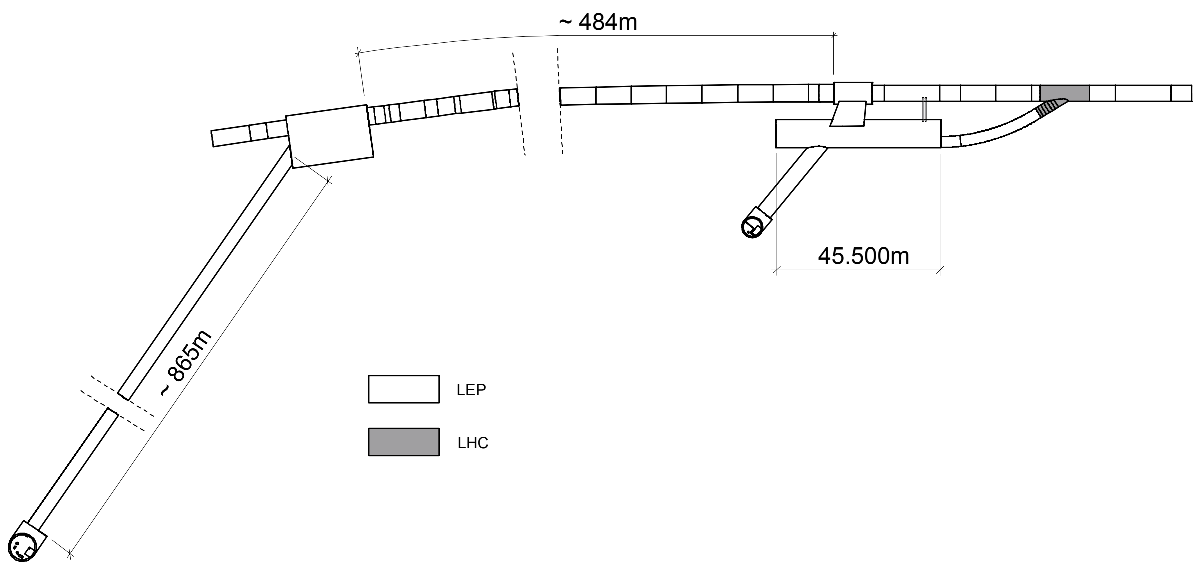


Figure 2.24: Point 3.2 and Point 3.3 underground layout

Table 2.16: Point 3 surface buildings

Structure	Length m	Width m	Height m	Floor Area m^2	Volume m^3	Motorised Door W(m)xH(m)	Motorised Door W(m)xH(m)
SD 3	19.00	17.30	7.25	329	2878	4.00x3.95	
SU 3	30.60	20.60	8.90	630	6552	5.00x5.00	
SE 3	17.40	9.10	5.00	151	981	2.20x2.50	2.20x2.50
SR 3	28.30	17.15	3.85	526	2525	4.00x3.95	
SZ 33	18.4	9.60	8.70	516	3414		

Table 2.17: Point 3 underground structures

Structure	Length m	Width m	Height m	Diameter m	Floor Area m^2	Volume m^3
R31	721.18	3.18	2.88	3.76	2293	6563
R32	163.45	3.18	2.88	3.76	520	1487
UJ 32	22.00	13.34	8.70	13.50	293	2145
TZ32	869.00	2.37	2.55	3.10	2059	5735
R33	484.45	3.36	3.36	4.20	1628	5765
UJ33	45.50	6.71	4.50	7.00	305	1188
TZ33	19.67	3.18	2.88	3.76	63	179
US33	7.60	5.10	5.05		36	168
PZ33			93.00	5.10	20	1860
UP33	40.34	1.80	2.45	2.40	73	190
R34	267.15	3.18	2.88	3.76	850	2431
PM32			62.25	7.10	40	2490
US32	9.55	7.10	5.00	7.00	46	281
R36	281.75	3.18	2.88	3.76	896	2564
R37	479.85	3.18	2.88	3.76	1526	4367
R38	181.35	3.18	2.88	3.76	577	1650
RE38	24.70	4.62	3.45	5.00	101	311
R39	725.28	3.18	2.88	3.76	2306	6600

Table 2.18: Point 3 gantry cranes

Structure	Number	Capacity T	Speed m / min	Clearance of Floor m	Hook Travel m	Opening m x m
SR 3	PR 730	5	5	4.50		
SD 3	PA 1135	2	5	5.80		2.50x4.50

Table 2.19: Point 3 lifts

Stucture	Lift Number	Capacity kg / pers	Duration min	Cage Size L(m) x H(m)	Door Size W(m) x H(m)
PM 32	AS 704	1120 13	0.6	130 x 200	1.27 x 200
PZ 33	AS 705	1000 13	1.4	1.10x2.10	0.90x2.10

2.11 POINT 4

Models and layouts of surface building and underground structures at Point 4 (Figs. 2.25 to 2.28), as well as tables giving their main characteristics and details of the lifting equipment (Tabs. 2.20 to 2.23) are shown below.

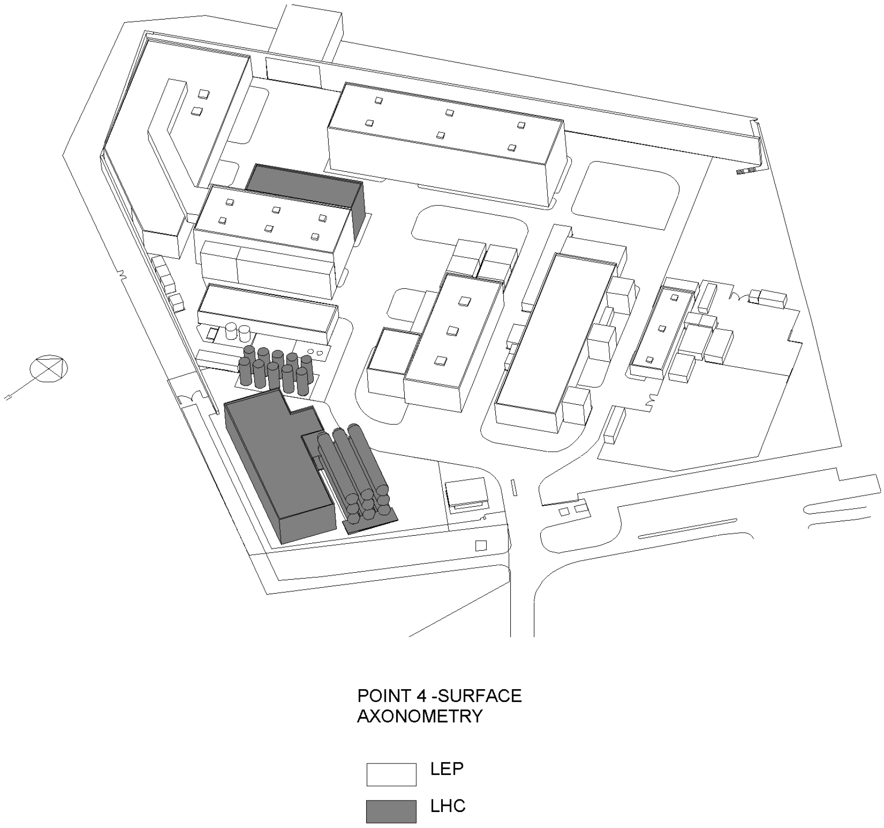


Figure 2.25: Point 4 surface axonometry

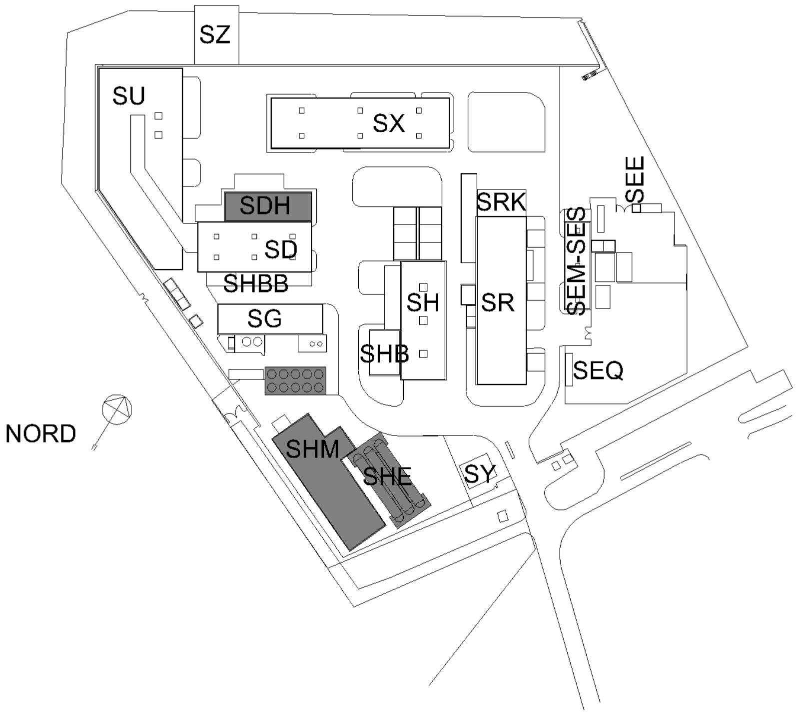


Figure 2.26: Point 4 surface layout

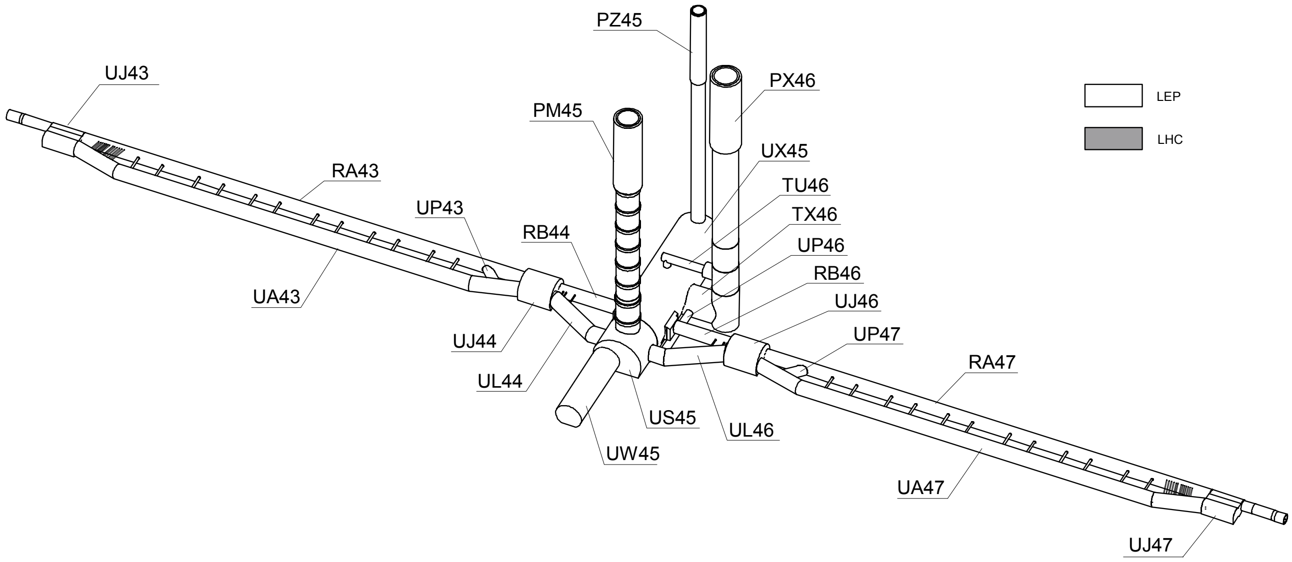


Figure 2.27: Point 4 underground axonometry

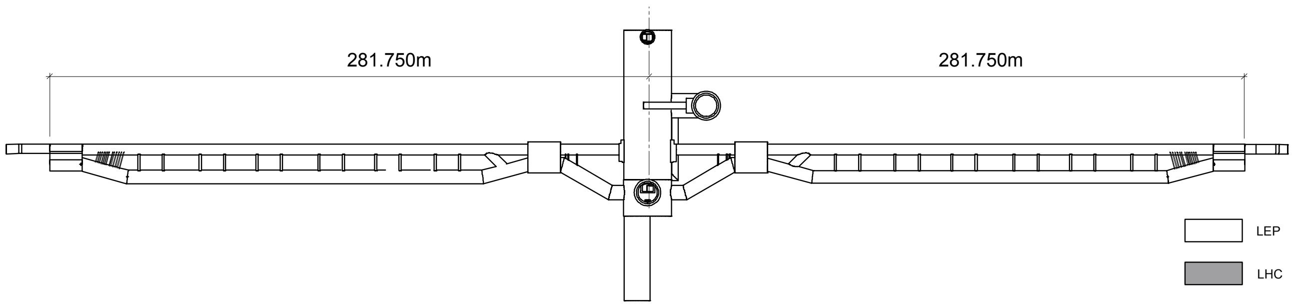


Figure 2.28: Point 4 underground layout

Table 2.20: Point 4 surface buildings

Structure	Length m	Width m	Height m	Floor Area m^2	Volume m^3	Motorised Door	Motorised Door
SHB 41	37.60	10.60	9.65	398.00	3470		
SDH 4	18.15	9.15	13.15	166.00	2185		
SHE 4	32.75	15.00		492.00			
SHM 4	50.35	15.60	9.60	785.50	7540	4.00x5.00	
SHB 4	37.20	10.60	9.00	163.00	1404	3.00x3.00	
SD 4	39.20	17.20	13.15	665.00	9742	6.00x5.95	
SE 4	34.80	9.00	3.85	271.00	2722		
SF 4	44.30	23.60	15.00	325.00	3306	4.00x4.00	
SG 4	36.20	10.60	4.66	532.00	2587		
SHBB	26.10	4.60	9.60	123.00	1365		
SR 4	57.30	17.15	7.36	910.00	6698	3.90x4.00	
SU 4	59.90	28.90	9.10	1325.00	11853	5.00x5.00	
SUH 4	28.80	15.60	9.30	415.00	4482	4.00x3.00	
SH 4	40.60	15.60	9.10	450.00	4095	5.00x5.00	
SX 4	61.15	17.20	16.00	1036.00	18130	6.00x4.00	7.60x8.00
SY 4	10.60	8.60	3.10	89.00	562		
SZ 4	20.95	15.90	8.40	334.00	3307		

Table 2.21: Point 4 underground structures

Structure	Length m	Width m	Height m	Diameter m	Floor Area m^2	Volume m^3
R 41	721.18	3.18	2.88	3.76	2293	6563
RE 42	24.70	4.62	3.45	5.00	101	311
R 42	661.20	3.18	2.88	3.76	2103	6017
UJ 43	14.00	11.20	4.50	5.50	156	326
RA 43	211.90	3.39	3.60	4.40	766	2981
UA 43	213.50	4.24	4.50	5.50	905	4439
UJ 44	14.00	13.30	7.90	13.50	186	1218
UL 44	34.70	4.20	5.26	6.10	146	930
RB 44	31.18	3.39	3.60	4.40	106	414
PM 45			124.60	9.10		8099
US 45	16.50	20.70	13.37	21.40	342	3897
UX 45	70.00	16.60	18.50	21.40	1162	23170
UW 45	45.00	9.30	8.40	11.00	418	3128
PZ 45			143.60	5.10		2480
PX 46			133.00	10.10		10640
TX 46	22.05	7.00	10.05	10.10	154	1808
UP 46	34.00	1.50	2.20	2.20	51	133
TU 46	22.65			2.50		111
RB 46	31.18	3.39	3.60	4.40	106	412
UL 46	34.70	4.20	5.26	6.10	146	930
UJ 46	14.00	13.30	7.90	13.50	186	1218
RA 47	225.87	3.39	3.60	4.40	766	2981
UA 47	213.50	4.24	4.50	5.50	905	4439
UJ 47	14.00	11.20	4.50	5.50	156	380
R 48	661.20	3.18	2.88	3.76	2103	6017
RE 48	24.70	4.62	3.45	5.00	100	311
R 49	721.18	3.18	2.88	3.76	2293	6563

Table 2.22: Point 4 gantry cranes

Stucture	Number	Capacity T	Speed m /min	Clearance of Floor m	Hook Travel m	Opening m x m
SD 4	PR 712	10 T	10	8.85	145.50	9.50x2.00
SR 4	PR 732	5 T	5	6.65		
SUH 4	PR 713	20 T	5	5.65		
SX 4	PR 714	80 T	6	9.85	153.45	Diameter 10.10
SF 4	PR 733	3,2 T	5	8.00		
SH 4	PR 755	20 T	6	6.10		
SHM 4	PR 769	20 T	6	5.70		
SDH 4	PR 770	5 T	6	10.30		
UW 25	PR 734	3.2 T	5	10.30		
UX 45	PR 710	40 T	10	13.50		
UX 45	PR 711	80 T	10	13.50		

Table 2.23: Point 4 lifts

Stucture	Lift Number	Capacity kg / pers	Duration min	Cage Size L(m) x H(m)	Door Size W(m) x H(m)
PM 45	AS 706	3000 33	1.4	2.70x1.85	1.85x2.10
PZ 45	AS 707	1000 13	0.8	2.10x1.10	0.90x2.10

2.12 POINT 5

Models and layouts of surface building and underground structures at Point 5 phases 1 and 2 (Figs. 2.29 to 2.34), as well as tables giving their main characteristics and details of the lifting equipment (Tabs. 2.24 to 2.27) are shown below.

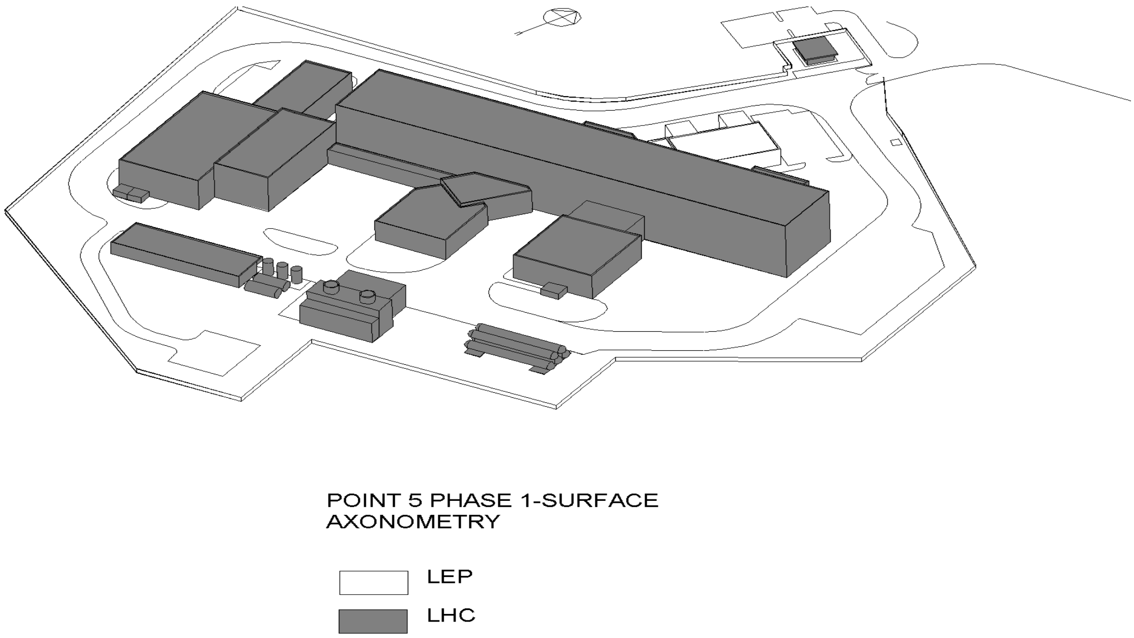


Figure 2.29: Point 5 Phase I surface axonometry

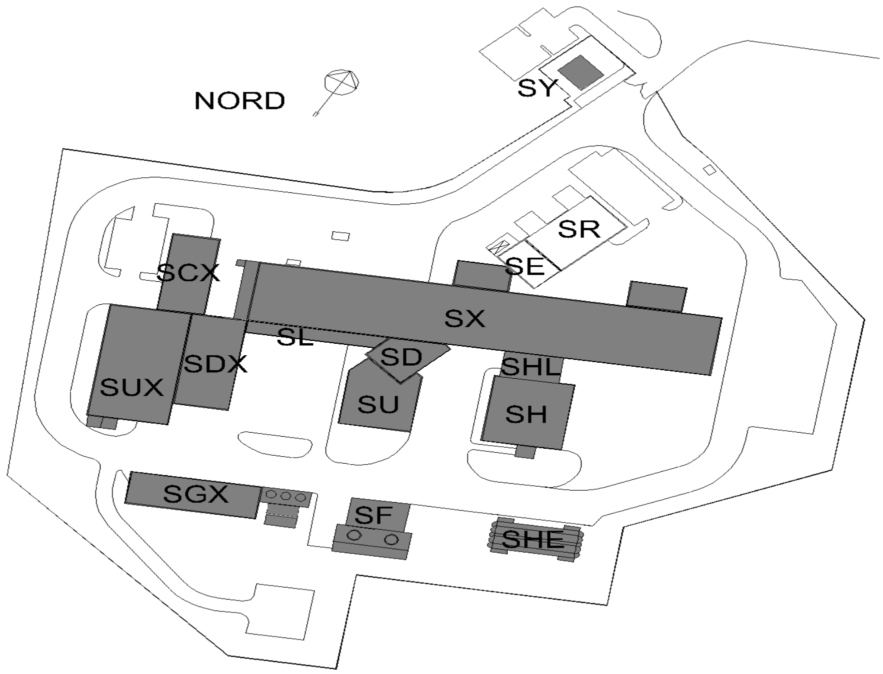


Figure 2.30: Point 5 Phase I surface layout

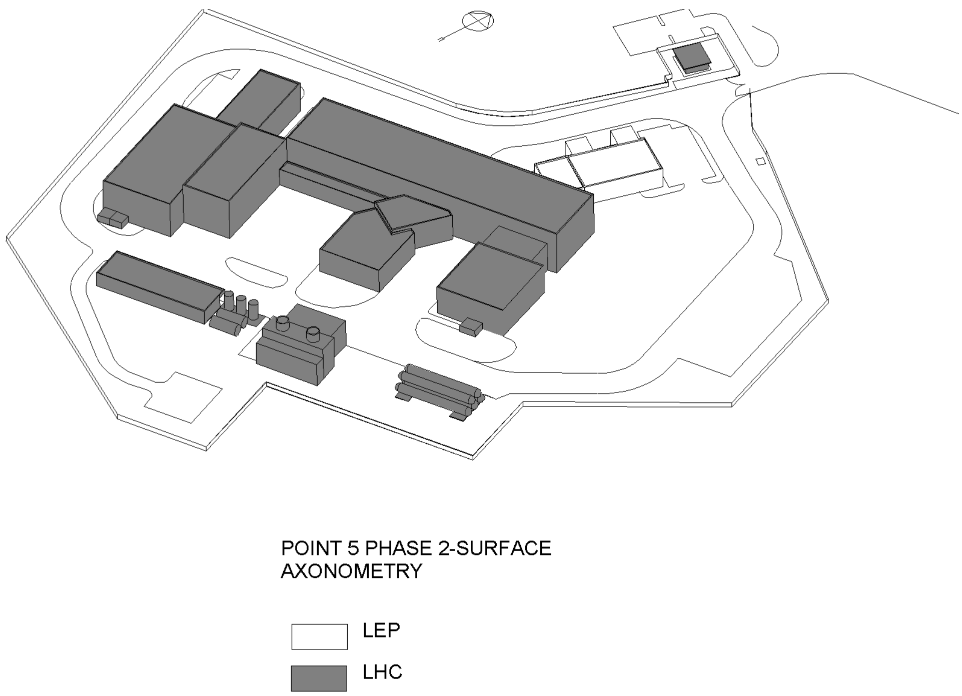


Figure 2.31: Point 5 Phase II surface axonometry

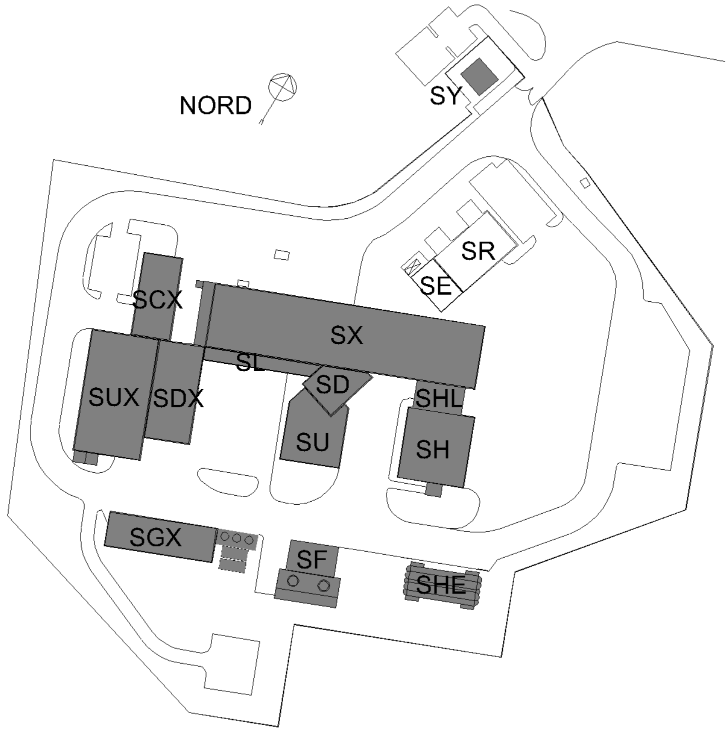


Figure 2.32: Point 5 Phase II surface layout

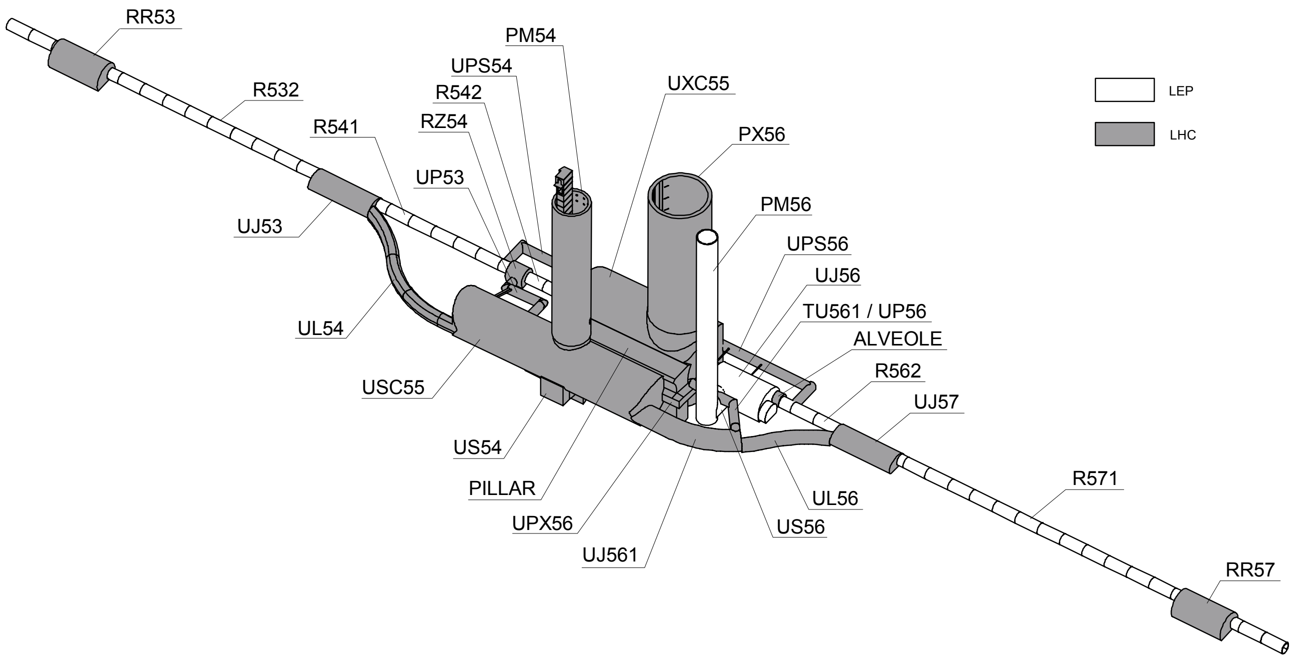


Figure 2.33: Point 5underground axonomy

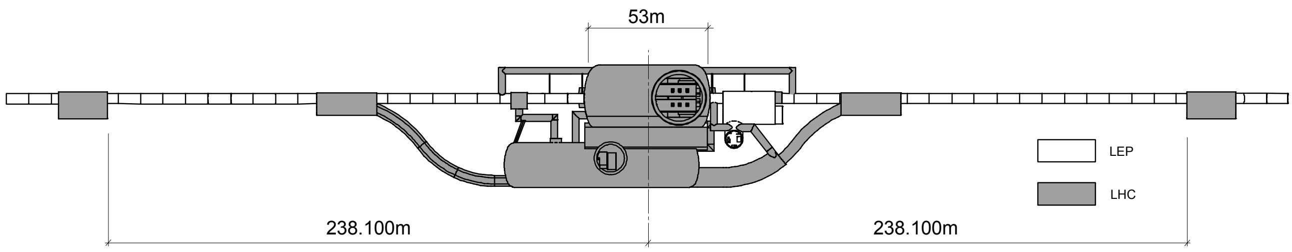


Figure 2.34: Point 5 underground layout

Table 2.24: Point 5 surface buildings

Building	Length m	Width m	Heigth m	Floor Area m^2	Volume m^3	Motorised Door W(m)xH(m)	Motorised Door W(m)xH(m)
SD 5	16.60*	15.60	10.00	330	3305		
SE 5	17.40	9.10	5.00	151	980		
SR 5	28.50	17.00	3.85	526	2814		
SHL 5	10.00	18.50	10.00	185	18500		
SCX 5	30.60	14.60	12.69	447	5402		
SHE 5	32.00	15.00					
SF 5	24.45	22.60	17.60	500	2766		
SGX 5	40.00	13.00	5.32	520	2766		
SDX 5	36.00	17.00	15.51	612	9492		
SU 5	22.55	22.10	8.90	498	4435		
SUX 5	44.94	24.80	14.65	1115	16114		
SH 5	26.40	24.67	10.75	651	7001		
SX 5 (1)	141.00	23.90	23.30	3313	77867	6.80x8.00x3	5.00x5.00x2
SX 5 (2)	102.00	23.50	16.00				
SHL 5	18.42	10.02	10.75	185	1984		
SY 5	10.70	9.20	3.29	98	323		

Table 2.25: Point 5 underground structures

Structure	Length m	Width m	Height m	Diameter m	Floor Area m^2	Volume m^3
PM 54			67.80	12.10	115	7796
PM 56			85.00	7.10	40	3400
PX 56			62.50	20.50	330	20629
R 51	725.30	3.20	2.90	3.80	2306	6600
R 52	651.20	3.20	2.90	3.80	2071	5926
R 53	142.40	3.20	2.90	3.80	600	2125
R 54	84.17	3.20	2.90	3.80	302	1070
R 56	31.64	3.20	2.90	3.80	928	2655
R 57	190.80	3.20	2.90	3.80	750	2122
R 58	651.20	3.20	2.90	3.80	2071	5926
R 59	725.30	3.20	2.90	3.80	2306	6600
RE 52	24.70	4.60	3.50	5.00	101	311
RE 58	24.70	4.60	3.50	5.00	101	311
RR 53	20.00	9.96	6.65	10.40	199	1217
RR 57	20.00	9.96	6.65	10.40	199	1217
RZ 54	6.10	4.20	4.89	6.20	25	158
TU 56	16.00			2.00		64
TU 561	24.67	2.30	2.25	2.30	56	114
UJ 53	25.10	7.28	3.96	8.60	182	715
UJ 56	22.00	13.40	7.80	13.50	294	1870
UJ 561	38.91	6.36	4.89	7.51	247	1198
UJ 57	25.10	7.28	3.96	8.60	182	715
UL 54	68.11	3.35	2.95	3.90	228	660
UL 55	84.10	3.85	3.61	3.90	323	1168
UL 551	10.25	2.40	3.00		24	149
UL 56	35.60	3.35	2.95	3.90	119	345
UP 53	28.99	1.62	2.25	2.30	47	126
UP 531	2.50	3.21	3.05	3.90	8	32
UP 541	3.10	4.60	2.73	4.70	14	32
UP 55	34.53	1.62	2.25	2.30	56	150
UP 56	56.11	2.30		2.30	117	455
UPS 54	50.33	2.20	2.25	2.20	110	222
UPX 56	22.59	2.30	2.40		51	124
US 54	18.21	9.85	7.51		180	1357
US 56	10.60	7.10	5.00	7.10	64	314
USC 55	84.10	17.71	11.73	18.10	970	15856
UXC 55	53.10	26.66	24.22	26.60	920	29007
UL 552	10.25	2.40	3.00		24	201
UL 553	10.25	2.40	3.00		24	149

Table 2.26: Point 5 gantry cranes

Stucture	Number	Capacity T	Speed m /min	Clearance of Floor m	Hook Travel m	Opening m x m
SX 5	PR 758	80	5.95	18.30	115.30	Diameter 10.25
SX 5	PR 759	80	5.95	18.30	115.30	
SUX 5	PR 765	8	6	9.20		
SF 5	PR 767	3.2	5	8.15		
SDX 5	PR 759	80	5.95	10.00	106.90	Diameter 12.10
SR 5	PR 735	5	5.95	4.50		
SH 5	PR 761	10	6	6.30		
USC 55	PR 780	10	5	8.50		
UXC 55	PR 760	20	9.8	18.30		

Table 2.27: Point 5 lifts

Stucture	Lift Number	Capacity kg / pers	Duration min	Cage Size L(m) x H(m)	Door Size W(m) x H(m)
PM 56	AS 7--	1000 13	0.7	2.10x1.10	2.10x0.90
PM54	AS717	3000 33	1.1	2.70x1.85	1.85x2.10

2.13 POINT 6

Models and layouts of surface building and underground structures at Point 6 (Figs. 2.35 to 2.38), as well as tables giving their main characteristics and details of the lifting equipment (Tabs. 2.28 to 2.31) are shown below.

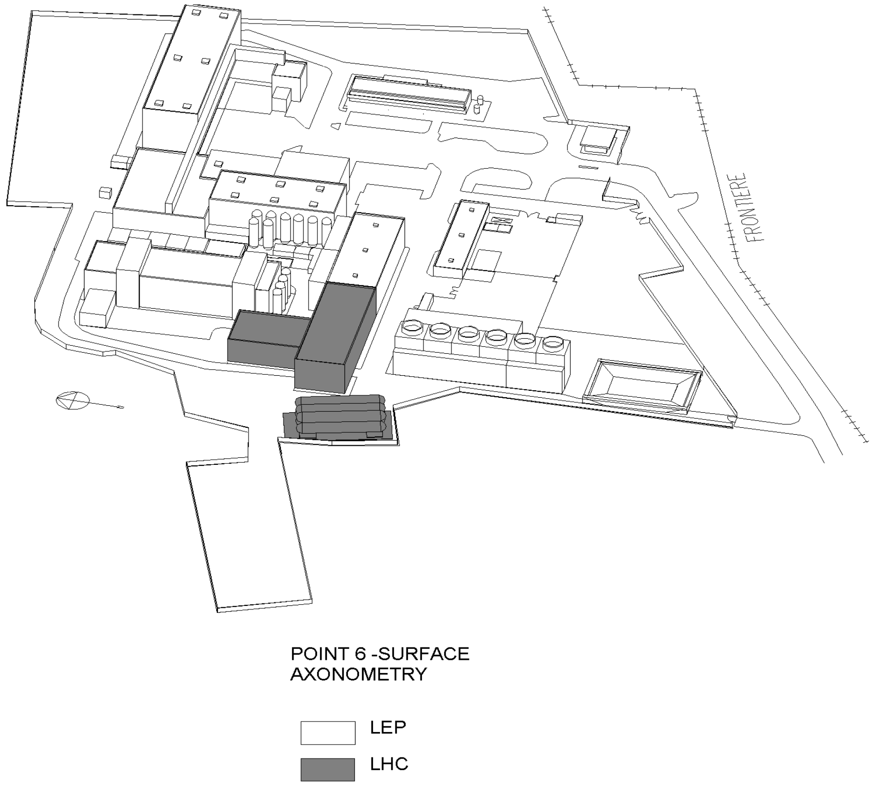


Figure 2.35: Point 6 surface axonometry

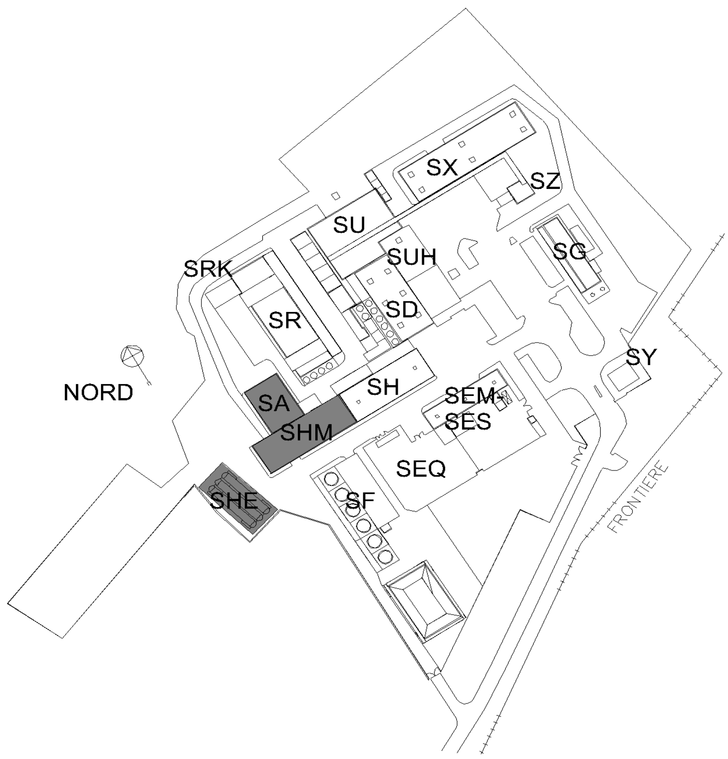


Figure 2.36: Point 6 surface layout

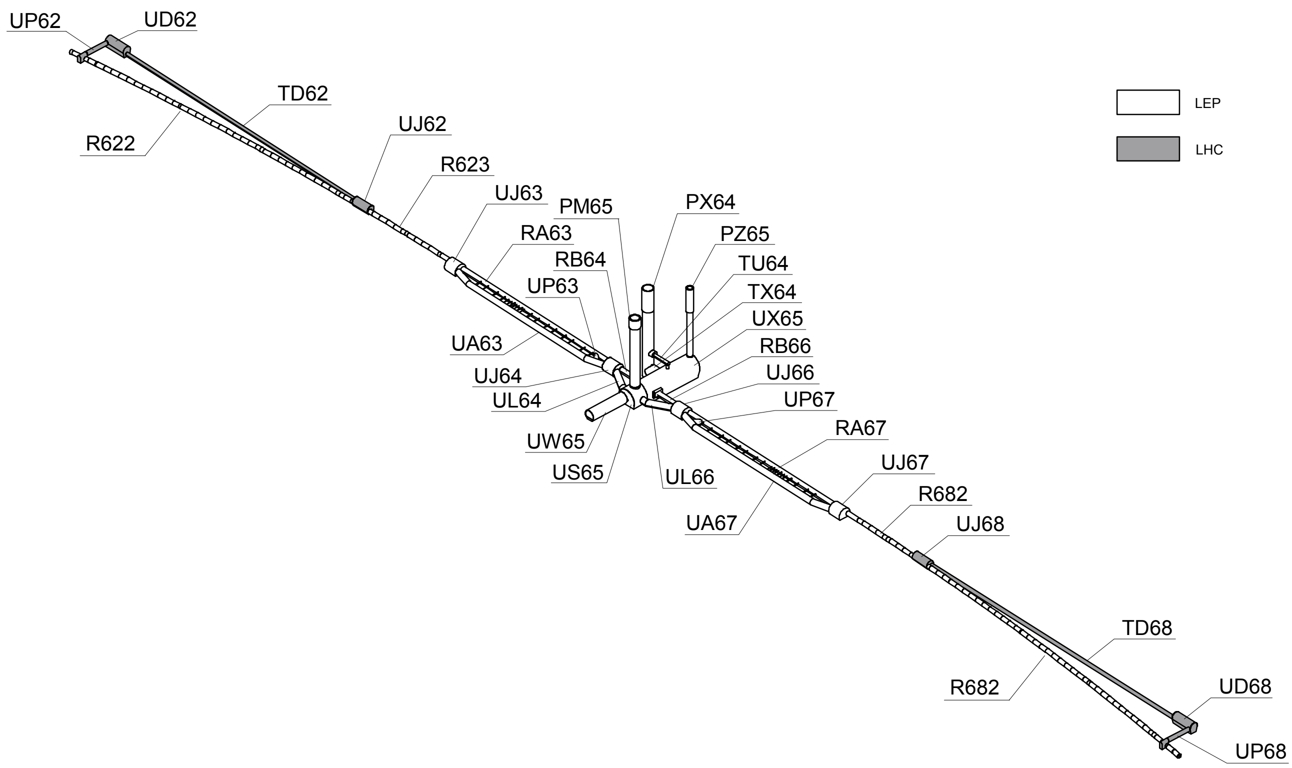


Figure 2.37: Point 6 underground axonometry

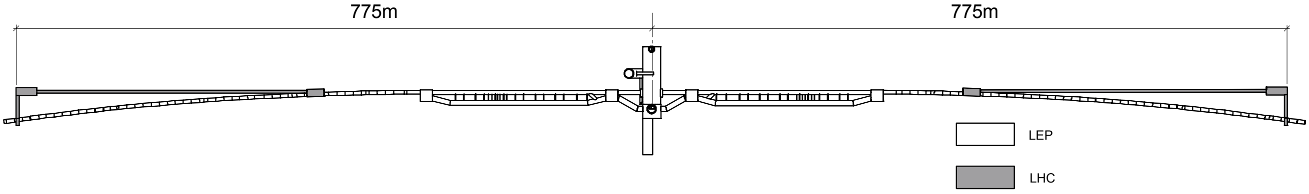


Figure 2.38: Point 6 underground layout

Table 2.28: Point 6 surface buildings

Structure	Length m	Width m	Height m	Floor Area m^2	Volume m^3	Motorised Door W(m)xH(m)	Motorised Door W(m)xH(m)
SHB 61	25.00	6.00	9.65	150.00	1470.00		
SDH 6	18.15	9.15	13.15	166.00	2185.00		
SHE 6	32.75	15.00		491.00			
SHM 6	50.35	15.60	9.60	785.00	7540.00	4.00x5.00	
SA 6	23.35	17.00	6.81	475.00	3250.00	5.2x4.95	
SHB 6	40.90	5.50	11.70	225.00	2177.00	3.00x3.00	
SD 6	39.40	21.75	13.15	723.00	10592.00	6.00x6.00	
SE 6	39.05	9.00	3.85	834.00	3700.00		
SF 6	53.00	22.60	12.27	997.00	4620.00	4.00x4.00	
SG 6	36.20	11.60	4.66	501.00	2540.00		
SHBB 6	25.80	4.65	9.50	131.00	1276.00		
SR 6	57.20	16.90	12.30	1834.00	13345.00	3.9x4.00	
SU 6	35.60	28.60	9.30	1305.00	15183.00	5.00x5.00	
SUH 6	43.05	15.70	9.30	668.00	7610.00	4.00x3.00	
SH 6	40.60	15.50	11.70	733.00	7068.00	5.00x5.00	
SX 6	61.10	17.20	16.05	1058.00	18560.00	5.95x3.95	7.60x7.90
SY 6	10.70	9.20	3.25	97.00	603.00		
SZ 6	15.70	8.80	9.40	107.00	1006.00		

Table 2.29: Point 6 underground structures

Structure	Length m	Width m	Height m	Diameter m	Floor Area m^2	Volume m^3
R61	715.15	3.18	2.88	3.76	2274	6508
RE62	24.70	4.62	3.45	5.00	101	311
R62	641.20	3.18	2.88	3.76	2103	6017
UJ63	14.00	13.30	7.90	13.50	186	1218
RA63	211.85	3.39	3.60	4.40	718	2817
UA63	211.87	4.24	4.50	5.50	898	4407
UJ64	14.00	13.30	7.90	13.50	186	1218
UL64	34.60	4.20	5.26	6.10	145	923
RB64	31.48	3.39	3.60	4.40	107	418
PX64			90.90	10.10	93	7274
TX64	22.05	7.00	10.05	10.10	159	1808
UP64	37.90	1.50	2.20	2.20	57	148
PM65			81.42	9.10	65	5292
US65	16.20	20.72	13.37	21.40	335	3828
UX65	70.00	16.50	18.57	21.40	1155	23170
UW65	45.00	9.30	8.40	11.00	418	3106
PZ65			82.40	5.10	20	1683
TU64	22.65	0.00	0.00	2.50		111
RB66	31.55	3.39	3.60	4.40	107	418
UL66	34.60	4.20	5.26	6.10	145	923
UJ66	14.00	13.30	7.90	13.50	186	1218
RA67	211.85	3.39	3.60	4.40	718	2817
UA67	211.87	4.24	4.50	5.50	898	4343
UJ67	14.00	13.30	7.90	13.50	186	1218
R68	641.20	3.18	2.88	3.76	2103	6017
RE68	24.70	4.62	3.45	5.00	101	311
R69	715.15	3.18	2.88	3.76	2274	6508

Table 2.30: Point 6 gantry cranes

Structure	Number	Capacity T	Speed m/min	Clearance of Floor m	Hook Travel m	Opening m x m
SD 6	PR 717	10	10	8.85	107.50	8.90x2.10
SR 6	PR 737	5	5	6.65		
SUH 6	PR 718	20	5	5.65		
SX 6	PR 719	80	6	9.85	110.80	Diameter 10.10
SF 6	PR 739	3,2	5	8.00		
SH 6	PR 756	20	6	6.10		
SDH 6	PR 773	5	5	10.30		
UW 65	PR 756	20	5	6.10		
UD 62	PR 781	30	5	10.30		
UD 68	PR 775	30	5	10.30		
UX 65	PR 715	80	10	13.50		
UX 65	PR 716	40	10	13.50		

Table 2.31: Point 6 lifts

Stucture	Lift Number	Capacity kg/pers	Duration min	Cage Size L(m)xW(m)	Door Size W(m)xH(m)
PM 65	AS 709	3000 33	1	2.70x1.85	1.85x2.10
PZ 65	AS710	1000 13	0.6	2.10x1.10	0.90x2.10

2.14 POINT 7

Models and layouts of surface building and underground structures at Point 7 (Figs. 2.39 to 2.42), as well as tables giving their main characteristics and details of the lifting equipment (Tabs. 2.32 to 2.35) are shown below.

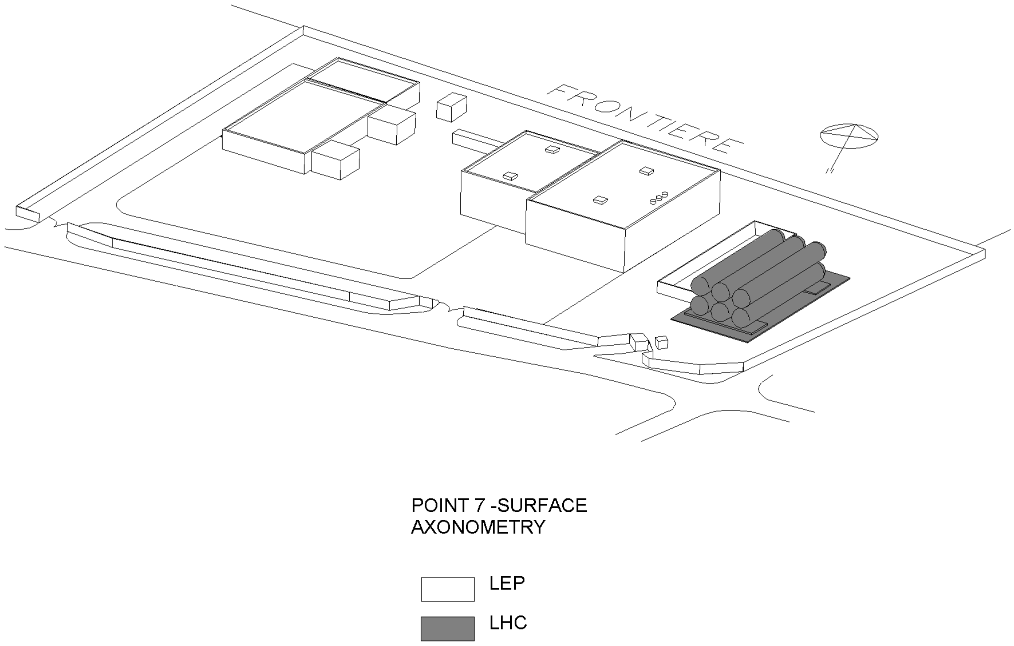


Figure 2.39: Point 7 surface axonometry

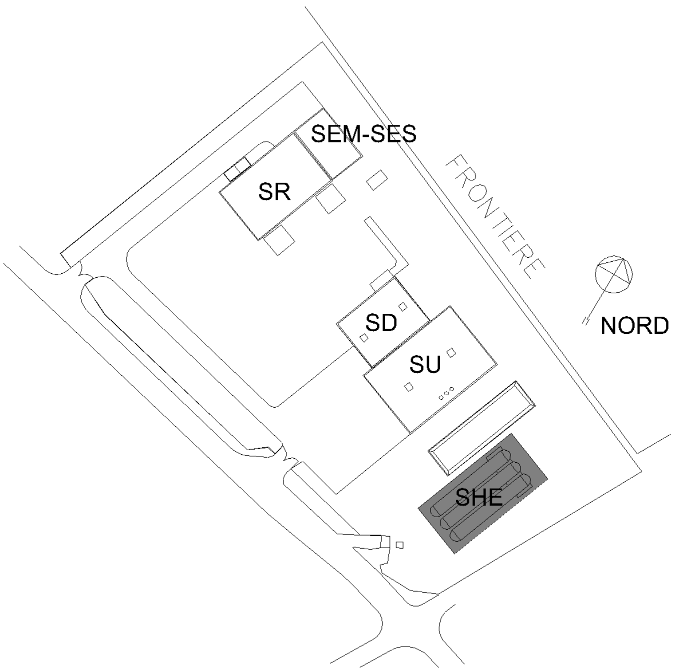


Figure 2.40: Point 7 surface layout

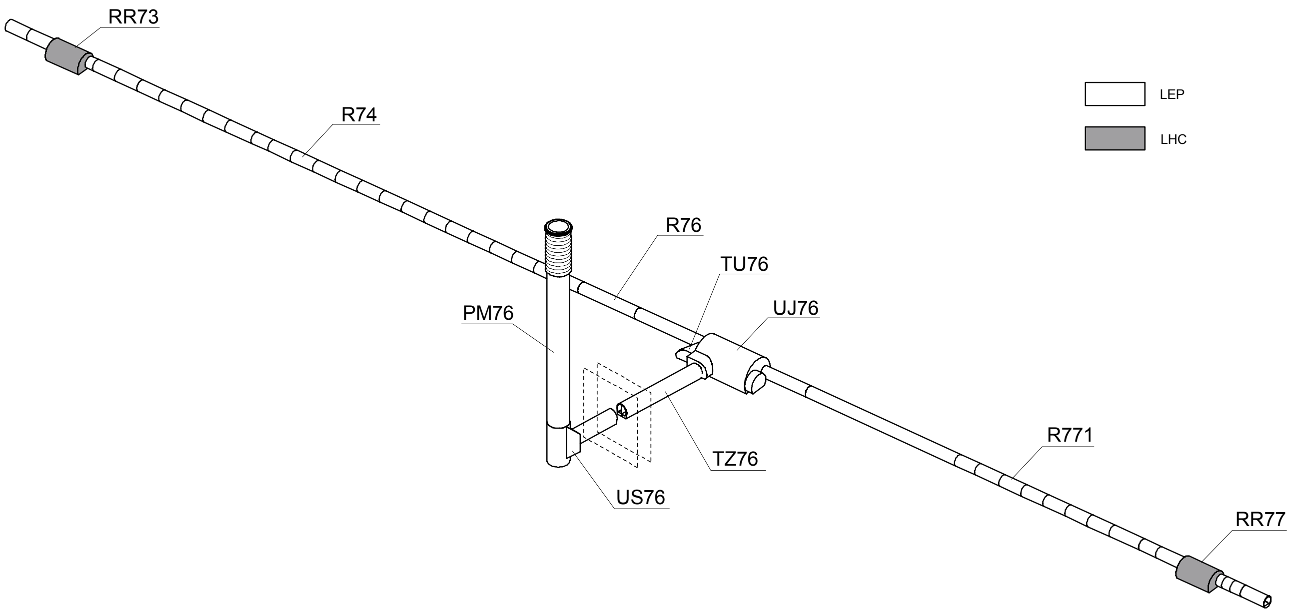


Figure 2.41: Point 7 underground axonometry

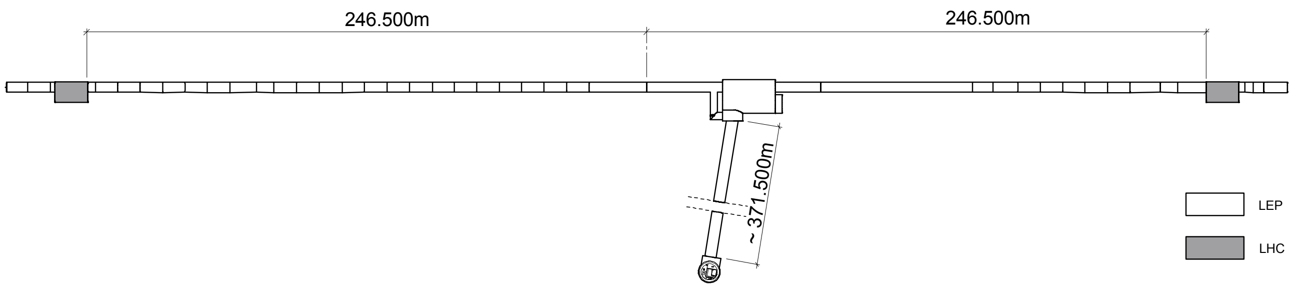


Figure 2.42: Point 7 underground layout

Table 2.32: Point 7 surface buildings

Structure	Length m	Width m	Height m	Floor Area m^2	Volume m^3	Motorised Door W(m)xH(m)	Motorised Door W(m)xH(m)
SHE 7	32.75	11.70					
SD7	20.60	15.60	8.50	332.00	2184	4.00x3.95	
SE7	17.40	9.15	3.85	157.00	1018	2.20x2.50	2.20x2.50
SR7	28.30	17.15	3.85	526.00	2025		
SU7	30.60	20.60	8.50	630.00	6320	5.00x5.00	

Table 2.33: Point 7 underground structures

Structure	Length m	Width m	Height m	Diameter m	Floor Area m^2	Volume m^3
RR 73	13.30	7.75	5.00	8.00	93.00	32
R 71	725.27	3.18	2.88	3.76	2306	6600
RE 72	24.70	4.62	3.45	5.00	101	311
R 72	651.19	3.18	2.88	3.76	2071	5926
R 73	187.50	3.18	2.88	3.76	600	2125
R 74	94.30	3.18	2.88	3.76	302	1070
PM 76			91.41	7.10	39	3565
US 76	9.60	7.10	5.00	0.00	63	313
TU 76	15.30			2.20		56
R 76	55.88	3.18	2.88	3.76	181	503
UJ 76	22.00	13.35	7.75	13.50	294	1870
R 77	225.87	3.18	2.88	3.76	732	2033
TZ 76	372.05	3.39	3.80	4.40	1262	5171
R 78	651.19	3.18	2.88	3.76	2071	5926
RE 78	24.70	4.62	3.45	5.00	101	311
RR 77	13.30	7.75	5.00	8.00	93	32.500
R 79	725.27	3.18	2.88	3.76	2306	6600

Table 2.34: Point 7 gantry cranes

Structure	Number	Capacity T	Speed m/min	Clearance of Floor m	Hook Travel m	Opening m x m
SR 7	PR 741	5 T	5	4.70		

Table 2.35: Point 7 lifts

Stucture	Lift Number	Capacity kg/pers	Duration min	Cage Size L(m)xW(m)	Door Size W(m)xH(m)
PM 76	AS 709	1000 13	0.6	2.10x1.10	2.10x.90

2.15 POINT 8

Models and layouts of surface building and underground structures at Point 8 (Figs. 2.43 to 2.46), as well as tables giving their main characteristics and details of the lifting equipment (Tabs. 2.36 to 2.38) are shown below.

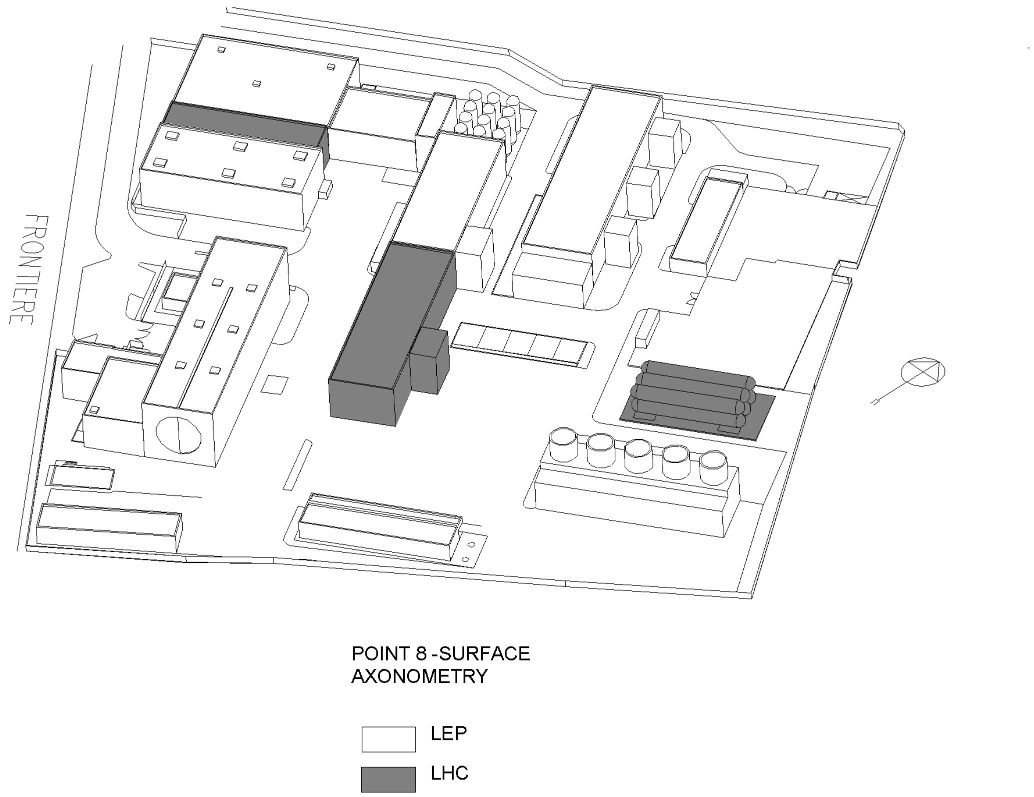


Figure 2.43: Point 8 surface axonometry

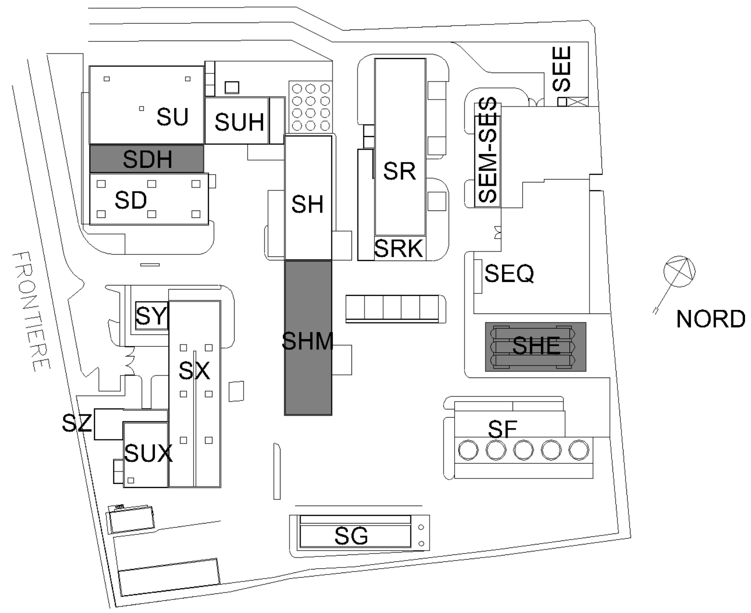


Figure 2.44: Point 8 surface layout

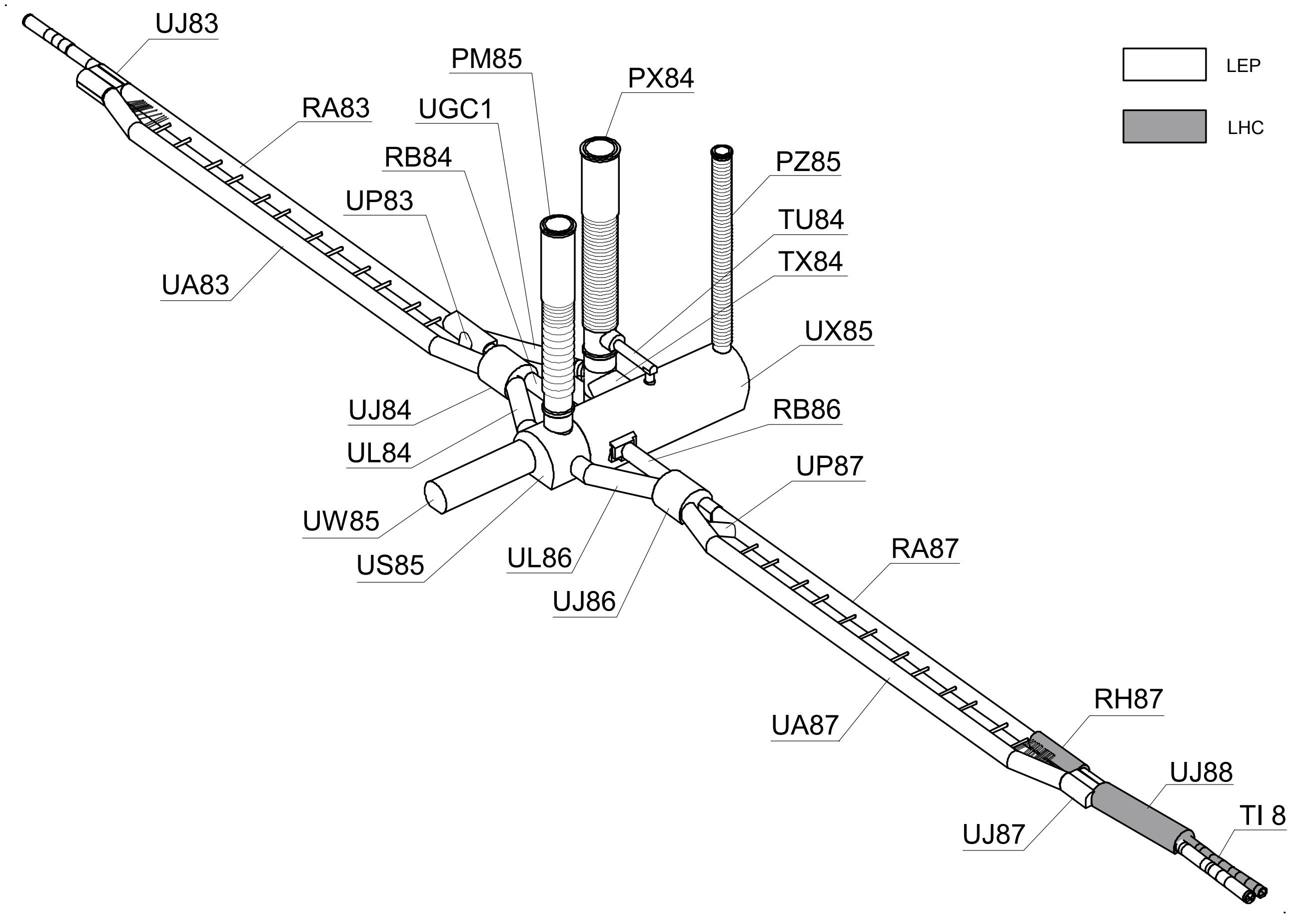


Figure 2.45: Point 8 underground axonometry

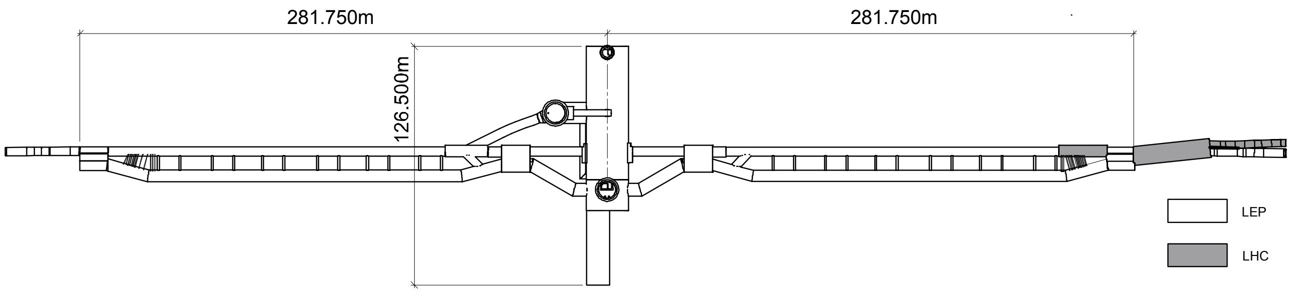


Figure 2.46: Point 8 underground layout

Table 2.36: Point 8 underground structures

Structure	Length m	Width m	Height m	Diameter m	Floor Area m^2	Volume m^3
R81	721.18	3.18	2.88	3.76	2293	6563
RE82	24.70	4.62	3.45	5.00	101	311
R82	661.20	3.18	2.90	3.76	2103	6017
UJ83	14.00	11.20	4.50	5.50	156	326
RA83	211.90	3.39	3.60	4.40	766	2981
UA83	213.50	4.24	4.50	5.50	905	4483
UJ84	14.00	13.30	7.90	13.50	186	1218
UL84	34.60	4.20	5.26	6.10	145	927
RB84	31.18	3.39	3.60	4.40	106	415
PX84			93.24	10.10		7459
TX84	22.05	7.00	10.05	10.10	154	1808
UP84	33.95	1.50	2.20	2.20	51	131
PM85			86.21	9.10		5604
US85	16.50	20.72	13.37	21.40	342	3899
UX85	70.00	16.50	18.57	21.40	1155	23170
UW85	40.00	9.30	8.40	11.00	418	2720
PZ85			85.17	5.10		1703
TU84	22.65			2.50		111
RB86	31.18	3.39	3.60	4.40	106	415
UL86	34.60	4.20	5.26	6.10	145	927
UJ86	14.00	13.30	7.90	13.50	186	1218
RA87	200.87	3.39	3.60	4.40	612	2361
UA87	213.50	4.24	4.50	5.50	905	4483
UJ87	14.00	11.20	4.50	5.50	156	326
R88	661.20	3.18	2.88	3.76	2103	6017
RE88	24.70	4.62	3.45	5.00	100	311
R89	721.18	3.18	2.88	3.76	2293	6563
R 89	721.18	3.18	2.88	3.76	2293	6563
RH 87	25.00	6.15	4.50	6.60	153	618.750

Table 2.37: Point 8 gantry cranes

Structure	Number	Capacity T	Speed m/min	Clearance of Floor m	Hook Travel m	Opening m x m
SD 8	PR 722	10	10	8.85	108.45	8.50x2.00
SR 8	PR 723	5	5	6.65		
SUH 8	PR 724	20	5	5.65		
SX 8	PR 725	80	6	9.85	113.15	Diameter 10.10
SF 8	PR 743	3,2	5	8.00		
SH 8	PR 757	20	6	6.10		
SDH 8	PR 773	5	5	10.30		
UX 85	PR 720	80	10	13.50		
UX 85	PR 721	80	10	13.50		

Table 2.38 : Point 8 lifts

Stucture	Lift Number	Capacity Kg / pers	Duration min	Cage Size L(m) x H(m)	Door Size W(m) x H(m)
PM 85	AS 712	3000 33	0.9	2.70x1.85	1.85x2.10
PZ 85	AS713	1000 13	0.5	2.70x1.10	0.90x2.1

2.16 POINT I8

Models and layouts of surface building and underground structures at Point I8 (Figs. 2.47 to 2.50), as well as tables giving their main characteristics and details of the lifting equipment (Tabs. 2.39 to 2.40) are shown below.

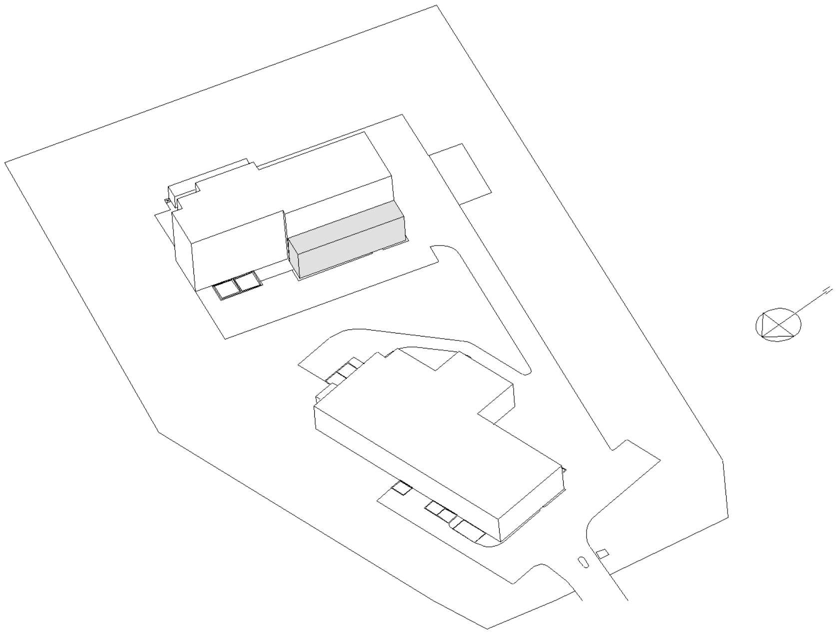


Figure 2.47: Point 4 SPS surface axonometry

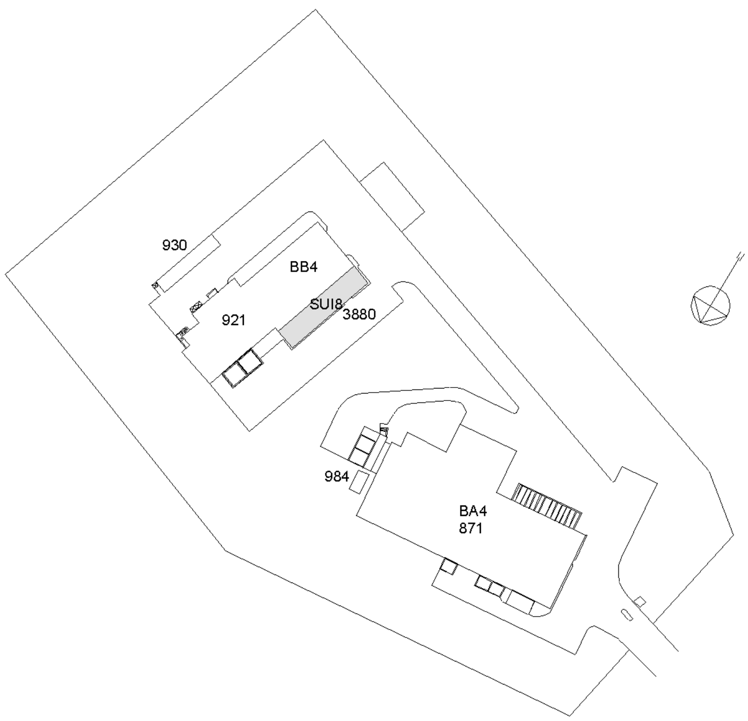


Figure 2.48: Point 4 SPS surface layout

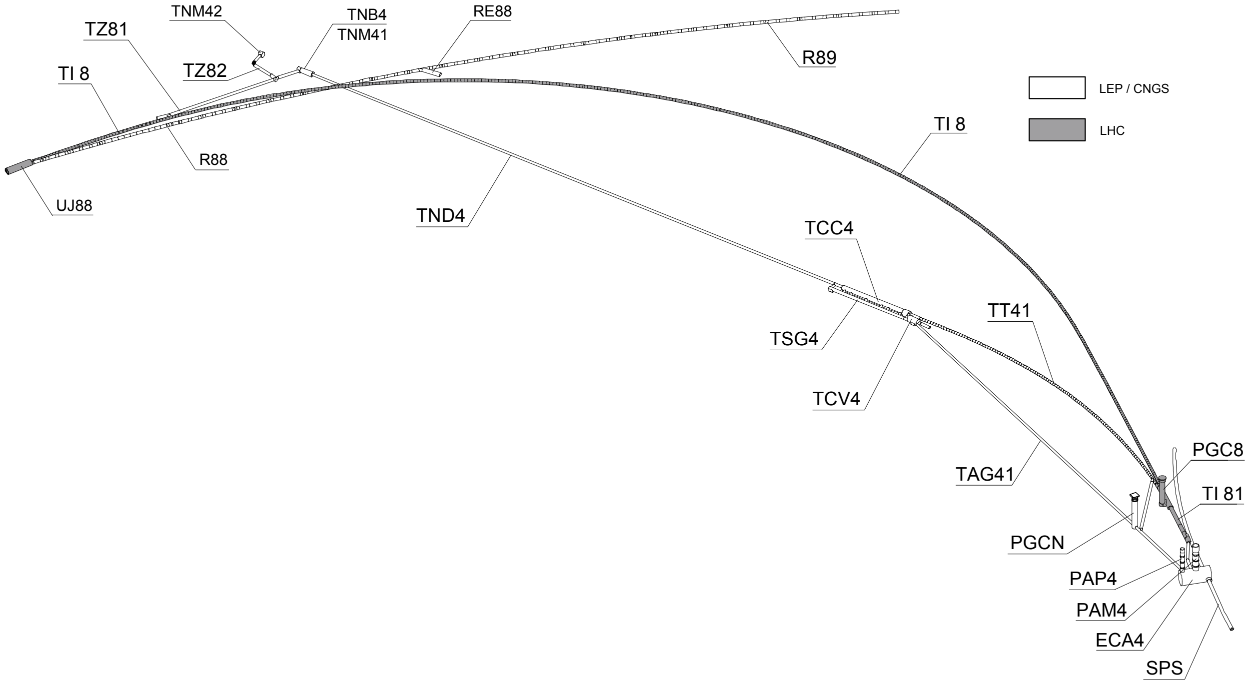


Figure 2.49: TI 8 underground axonomy

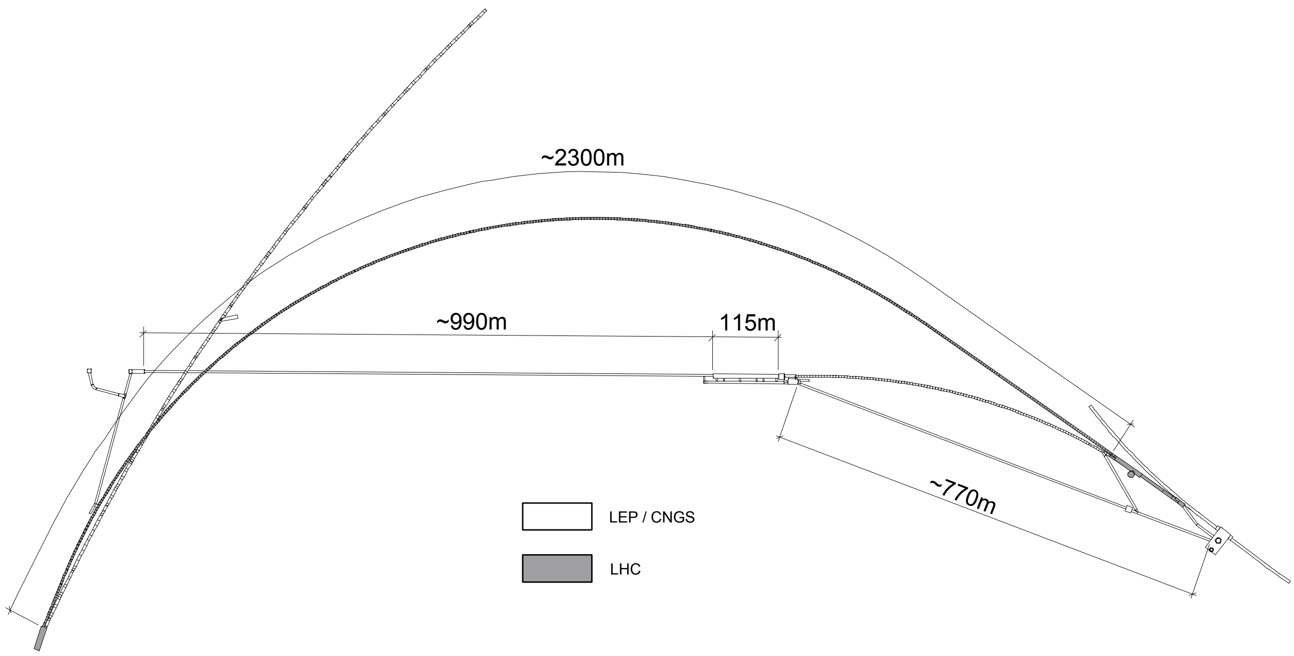


Figure 2.50: TI 8 underground layout

Table 2.39: Point I8 surface buildings

Structure	Length m	Width m	Height m	Floor Area m^2	Volume m^3	Motorised Door W(m)xH(m)	Motorised Door W(m)xH(m)
SUI8	26.00	5.57	7.50	145.00	1088	1.90x3.00	

Table 2.40: Point I8 underground structures

Structure	Length m	Width m	Height m	Diameter m	Floor Area m^2	Volume m^3
TJ 8	53.00	5.86	4.65	6.50	310	1335
TT40	90.65	4.40	3.60	4.40	400	1197
TZ40	77.70	2.24	2.50	3.00	175	478
PGC8			46.80 / 42.15	3.00		330
TI8	2285.00	2.24	2.50	3.00	5120	14050

2.17 PROPOSED NEW CONTROL CENTRE

As part of the restructuring to improve operational efficiency and to meet the needs of the LHC Project, the necessity for a single Accelerator Control Centre to replace the existing control rooms has emerged. This centre will also include the Cryogenics and Technical Control Rooms, which will be transferred from their present locations. It is essential that the new control centre is operational by February 2006.

In January 2004, the CERN Management decided that the location of this facility, named CCC for "CERN Control Centre", would be on the Prévessin Site, integrated on the side of the building currently housing the Prévessin Control Room (PCR). The new building, which will house the common control room itself, will have an area of 625 m^2 (25 m × 25 m), with an internal height of about 6 m.

The existing building will be totally refurbished and will house:

- Conference rooms
- Rest facilities for operators
- Toilets and showers
- Service rooms (including a maintenance laboratory, server and racks rooms)
- Technical rooms (for telecom, cooling and ventilation installations)

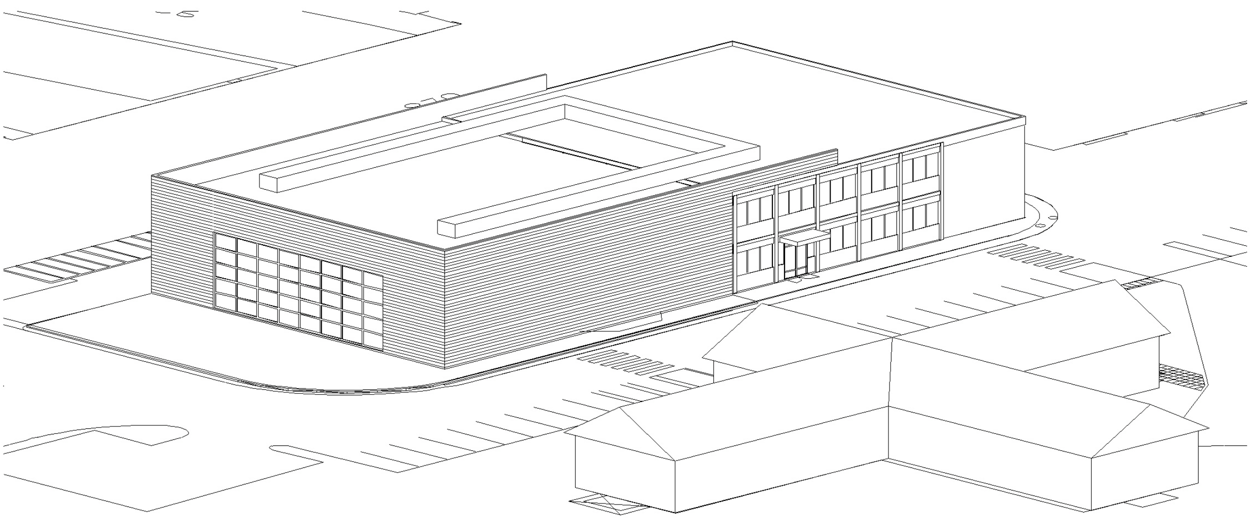
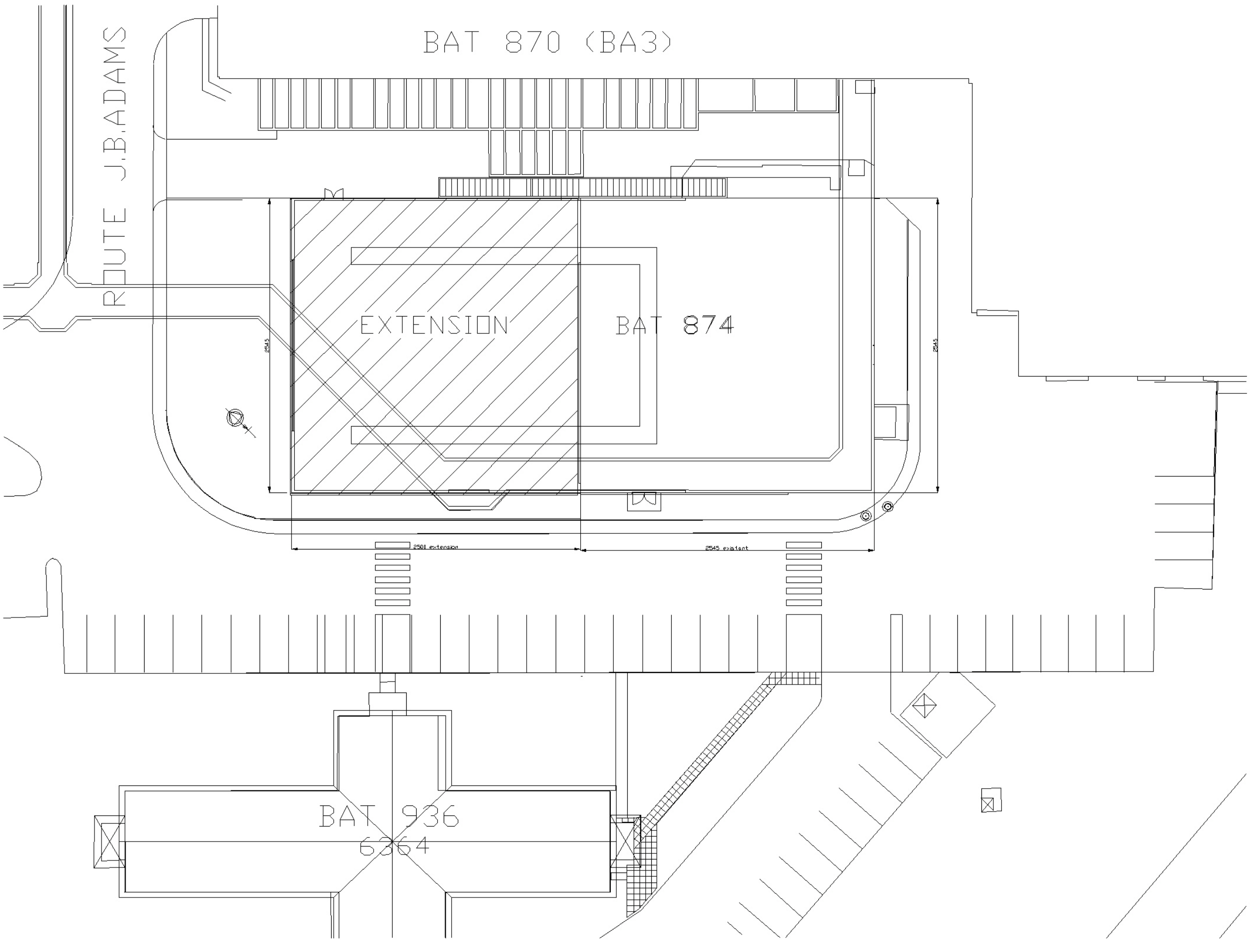


Figure 2.51: CERN Control Centre project axonometry



BAT 870 (BA3)
ROUTE J.B.ADAMS
EXTENSION
BAT 874
2545
2545
2500 extension
2545 existant
BAT 936
6364

CHAPTER 3

SAFETY ISSUES

3.1 GENERAL SAFETY INFRASTRUCTURE

3.1.1 Risks

The analysis of the dangers present in the LHC domain has shown that they are similar to those around any other big accelerator facility, with the exception of the omnipresence of helium (He) in the underground areas during operation. The risk analyses performed concerning the latter have demonstrated that serious oxygen deficiency could occur if there is an accidental release of a significant quantity of He in closed areas such as the underground tunnels, tunnel junction chambers or even surface galleries.

In the LHC installations, potential hazardous conditions [1] are associated with:

- Ionising radiation,
- The fact that persons are unfamiliar with the premises and necessary precautions (e.g. visitors),
- Cryogenic liquids in the machine tunnel, technical and experimental caverns,
- Isolation of workers underground in a long and extended tunnel system,
- Limitation to the number of evacuation paths in case of an accident and confinement of volumes underground,
- Space limitation in the safe zones,
- The presence of water in a "mining" environment,
- Flammable or asphyxiating gases in the physics detectors or emanating from cryogenic installations,
- Large amounts of combustible materials,
- Falling objects in high caverns and pits as well as personnel working at height,
- Work in the presence of magnetic fields,
- Electrical risks,
- Laser radiation,
- Pressurized installations and lifting equipment.

Once the LHC is operational most of these risks will be permanently present. The radiation issues are treated in the next chapter.

Preventive Measures

Preventive measures [2] aim to reduce the frequency or the probability of an accident. CERN has its own regulatory documents for safety which establish the rules to follow for the construction, installation and utilization any equipment in order to protect people and equipment from the risks listed above. These documents are based on European and host state regulations. They are mainly in the form of Safety Codes, Safety Instructions and Safety Notes and translate the CERN safety policy into rules applicable for specific domains such as chemicals, radiation, flammable gas, fire prevention, electricity, lifting devices, pressurized vessels and so on. All of the details concerning the preventive measures for the LHC machine and premises can be found in [3] and [4].

Protective Measures

Protective measures may be applied collectively or individually and aim to reduce the gravity of an accident as much as possible. Automated safety systems reduce human intervention to a minimum and therefore they ensure collective protection in an autonomous and reliable way.

Training and Information

Training is mandatory before access to a zone which has safety risks. The skills and techniques learned during the mandatory training sessions and evacuation drill exercises have to be refreshed regularly and access permission is withdrawn from personnel who have not followed the refresher training.

Information is provided on panels at relevant places like access points to the underground installations to inform people about the risks, the individual protection systems which they need, the state of the equipment, alarms and other information relevant to safety.

3.1.2 Alarms

LHC safety alarms are classified in three levels according to their importance:

Level-3: These are generated in the case of an accident or a serious abnormal situation. They warn of danger to human life, property or to the environment. These alarms trigger an immediate response by the Fire and Rescue service.

Level-2: These are generated in the case of incorrect operation of equipment or an abnormal situation. They trigger an immediate intervention by the technical service concerned.

Level-1: These are generated by an equipment or installation fault. They trigger an intervention by the technical service concerned.

The CERN safety alarm monitoring system (CSAM) transmits the level-3 alarms with high priority though redundant pathways which use differing transmission methods to the safety control room for immediate intervention by the CERN Fire Brigade (FB). The quality and the precision of information which is transmitted are crucial to ensure fast and efficient interventions. This information is also sent to the accelerator and technical control rooms.

3.1.3 Safety Systems which Generate Level-3 Alarms

Level-3 alarms are generated by the following systems:

- Smoke (fire) detectors,
- Flammable or toxic gas detectors signalling serious leaks,
- Emergency calling system,
- Emergency stop button (electrical power),
- Oxygen deficiency detection system,
- Water leak (flooding) detectors,
- Activation of evacuation signals,
- Call from a lift (trapped occupants),
- “dead man” devices.

The important features of these systems are described in the following paragraphs.

Smoke (fire) detection

The LHC automatic fire detection system (AFD) is composed of detectors located in strategic areas and uses detectors of various kinds chosen for the most efficient fire detection. Theses detectors are connected to control systems which are located in service areas where their status can be monitored. A repeater screen is installed in the SY surface building of the site.

The AFD system’s main functions are to:

- Generate Level-3 alarms when smoke or fire is detected and transmit them via CSAM to the Fire Brigade for immediate action,
- Notify the Technical Control Room (TCR), via the CSAM, of any internal faults that might occur, so that corrective action can be undertaken,
- Trigger any necessary ancillary equipment or safety actions like activate buzzers or cut the power.

In the arcs of the LHC there is no need for a fire detection system since the fire risk in these regions is negligible. The control chassis which are located under the cryostats might have been considered as potential fire hazards, but they have lateral panels which limit thermal propagation to the adjacent chassis, appropriate electrical protection and are also thermally protected if the installed power is greater than 500W. A fire detection system is installed in the underground zones where electrical equipment is concentrated (for example the UJ, UA, RR, RE, US, RF zones together with the experimental areas).

In the surface buildings, fire detection is installed if the group responsible for the building and/or the Safety Commission has requested such a system to protect equipment and/or people.

Flammable gas detection system

An automatic alarm system, known as a *sniffer*, which uses air sampling through perforated or branched tubes detects the presence of flammable gases. It provides an analogue value corresponding to the gas concentrations and the appropriate pre-alarms and alarms are generated accordingly.

There is no gas detection system in the main tunnel as there are no flammable gases in these regions. However, a gas detection system is installed in the experimental caverns where flammable gases are used in the experimental detectors.

Flammable gas detectors are also installed in all gas buildings (SG, SGX), located at the different access points of the LHC where gases for use in the experiments are stored.

Oxygen deficiency detection system

The LHC oxygen deficiency alarm system (ODH) is composed of numerous detectors, located in selected areas to detect low oxygen levels. These detectors are connected to control racks located in service areas where their status can be monitored. The system will transmit alarms if low oxygen levels are detected. If the machine is in access mode the system will trigger the LHC emergency evacuation system in the relevant zones. A repeater screen is installed in the SY surface building of the site.

Oxygen deficiency detectors are installed in the upper part of each enlargement or alcove, including the experimental caverns. Flashing panels are installed in these areas to provide a visual warning to personnel. In the curved part of the tunnel an ODH detector is mounted every 285m on the ceiling. The addition of a flashing light to these detectors is still under discussion. In surface areas ODH detectors are installed in the galleries linking the SD and SH/SHM buildings.

Flood detection system

Water level detectors are installed in the retention pits which concentrate all drainage flow at the lowest points of the different LHC sites before pumping it up to the surface. In normal conditions, only one pump is running. When the second pump starts to run, a level-2 alarm is generated. When the 2 pumps are running at full speed, a level-3 alarm is generated and sent to the Fire Brigade indicating a risk of flooding. Finally, a level-3 alarm is generated when the float indicates a high water level in the sump.

The LEP flood warning infrastructure has been extended to cope with the new underground caverns. Retention pits are located at each even point and at the lowest point in the tunnel.

Emergency phone system

The «red telephone» system installed for the LEP machine has been kept and upgraded. When off the hook, the red telephone allows vocal communication with the rescue service and at the same time identifies the place of origin of the call. A telephone is installed every 280m in the tunnel. Red telephones are also installed in the experimental caverns and in the non pressurized part of the accessible pits. Certain areas, such as the lift shaft and emergency staircases have an air pressure which is slightly higher than the other areas so that smoke cannot infiltrate. These can be used as a "safe haven" in the event of fire.

Evacuation System

The evacuation system consists of push buttons and warning sirens, fixed at 1.5 m above the floor. It takes the form of a "manual call-point" of break-glass type set either surrounded by the standard CERN square plate with the inscription "Evacuation" or near the corresponding evacuation pictogram. The action of breaking the glass triggers the sirens of the corresponding areas.

The role of this emergency evacuation system is twofold: to warn people of a serious situation that could put their lives in danger (emergency evacuation) and to serve as the last reminder to rapidly evacuate the area before injection of high energy particle beams (beam imminent warning). Two different and identifiable signals, 10dB over the ambient noise, are produced. All occupants of the underground areas will have been to the safety training sessions where it was explained what to do when they hear them.

The push buttons and sirens can be found all around the facility, in the machine and transfer tunnels, in the technical galleries, experimental caverns, and in some surface buildings. About 300 emergency evacuation buttons and 400 sirens are installed underground.

Emergency stop system (AUG)

The emergency stop system is usually known by its French acronym AUG, which stands for Arrêt d'Urgence Générale. The system allows someone to cut electrical power in a given area during emergencies. Two different systems exist: general and local emergency stops. The general emergency stop only generates a level-3 alarm when activated. The activation of a general or local emergency stop (red panel, break the glass type) cuts off all power sources except those related to safety installations which are clearly marked. In relevant places, it kills the circulating beams and prevents any injection of beams.

The electric network is organized in sectors which generally cover a building or a precisely delimited underground area. A network of general emergency stops equips each of these sectors.

3.2 PROTECTION OF PERSONNEL IN THE TUNNEL

3.2.1 Equipment Needed to Access Underground

In some cases, collective protection systems cannot provide all the necessary guarantees for safety and have to be reinforced by individual protection measures and/or extra means of prevention. Training and safety information panels provide all the relevant information about the way to behave when accessing the different zones.

People who wish to access the tunnel must wear a reliable mobile communication system and have an oxygen mask. They must also wear a personal radiation dosimeter (film-badge), an operational dosimeter, an access card, a token in case of supervised access. The operational dosimeter will provide immediate readout of the radiation dose whereas the dosimeter is usually only read after several weeks.

To access the experimental zones, the same equipment is necessary but a safety helmet is mandatory. The oxygen masks will be provided on a self service basis in the experimental caverns, unlike the tunnel where individuals have their own.

Safety information is generally given at the entrance doors to the surface buildings or galleries. This information varies according to the specific dangers, for example, noise protection is required for compressor buildings, or ODH monitors for galleries where helium is present.

3.2.2 Escape Routes

Pictograms showing the directions and distances to the nearest exits to be used for evacuation are available every 50 m in the machine tunnel, in the caverns and galleries around the access pits and in the experimental areas.

REFERENCES

[1] Memorandum TIS/GS/WW-ac (2001-10) and Annex, *"Safety requirements for LHC underground works-Access conditions"*, July 16, 2001

[2] Systèmes généraux de sécurité du LHC, EDMS 346512

[3] Rapport définitif de sûreté du LEP, édition 1994

[4] Rapport préliminaire de sûreté du LHC, 1999

CHAPTER 4

RADIATION PROTECTION AND SHIELDING

4.1 INTRODUCTION

This chapter describes the radiation protection aspects of the LHC Project including the pre-injectors for protons (LINAC II, PS-Booster) and ions (LINAC III, LEIR), the two injectors PS and SPS, the LHC main ring and the LHC experimental areas. It gives an account of the expected radiological situation and the provisions made to minimise the radiological consequences for those working with LHC, or living in its vicinity. These precautions include adequate shielding where necessary and a state-of-the-art radiation monitoring and alarm system as well as a rigorous access control system to protect personnel.

In the assessment of possible radiological risks, due account is taken of the maximum possible performance and utilisation of the LHC installations. In the calculations and estimates, reasonable safety factors are applied with respect to the production of prompt radiation, radioactivity and to their respective attenuation, decay and decomposition.

4.2 REGULATORY BASIS FOR RADIATION PROTECTION AT CERN

CERN's standards for the protection of the environment and the workers are based on the European Council Directive 96/29/EURATOM [1]*, together with the French and the Swiss National Legislations on Radiation Protection [3][4][5][6][7]. CERN's Radiation Protection Manual [8] meets the legal radiation protection requirements of the two host states by following the most advanced regulations of the two. As all member states of the European Union (EU) committed themselves to include the EURATOM recommendations into their national legislations, France acted accordingly by releasing the Décret No 2002-460 du 4 avril 2002 « relatif à la Protection générale des personnes contre les dangers des rayonnement ionisants » [4] and the Decret No 2003-296 du 31 mars 2003 « relatif à la protection des travailleurs contre les dangers des rayonnement ionisants » [5]. Although Switzerland does not belong to the EU, the Swiss radiation protection legislation [6] is compatible with the European Directive. With the latest developments in France and Switzerland, CERN decided to revise its Radiation Protection Manual [8] and the release of the up-dated version is planned for 2004 [9].

4.2.1 Basic Rules of Radiation Protection

State of the art radiation protection is based on three principles: **Justification**, **Limitation** and **Optimisation** of any personal and collective dose.

Justification

A practice involving the exposure to ionising radiation is only considered as justified when the economic, social or other benefits clearly outweigh the health detriment it may cause.

Limitation

Yearly dose limits, expressed in terms of effective dose† received by a person are laid down in the EU, the Swiss and the French legislation. The effective dose to members of the public should not exceed 1 mSv per year. All persons who risk exceeding this limit during their professional activity have to be classified as radiation workers.

---

* The European Directive 96/29/Euratom takes into account the latest recommendations of international bodies like the International Commission on Radiological Protection ICRP [2]

† The quantity effective dose (Sievert) takes into account that

a) the biological consequences depend on the type of radiation
b) some tissues and organs are more sensitive to ionising radiation than others.

The equivalent dose of energy (Gray) deposited in an organ is therefore weighted by a radiation weighting factor and a specific risk factor for each tissue or organ to give the effective dose (Sievert). The total effective dose is the sum of the weighted equivalent doses given to the various tissues or organs.

Within the EU radiation workers are classified according to the professional risk involved in their job and are sub-divided into Category B workers (< 6 mSv/year) and Category A workers (< 20 mSv/year)[‡].

CERN's future RP Safety Manual [9] will adapt to the classification of workers which is already common practice in France and within the EU. Tab. 4.1 gives an overview of these limits.

Table 4.1: Annual limits for personal effective doses as laid down in European legislations

	Public	Radiation Workers	
		B	**A**
EU-Directive	< 1 mSv	< 6 mSv	< 20 mSv
France	< 1 mSv	< 6 mSv	< 20 mSv
Switzerland	< 1 mSv	< 20 mSv	
CERN from 2004	< 0.3 mSv	< 6 mSv	< 20 mSv
CERN until 2004	*< 0.3 mSv*	*< 20 mSv*	

CERN's annual effective dose limit for the public of 300 μSv has to be understood as a source related dose limit. CERN is following the Suisse Directive HSK-R-11 of the "Hauptabteilung für die Sicherheit in Kernanlagen" (HSK). This one is based on the recommendation of the "International Commission on Radiological Protection" (ICRP) [2]. Respecting a limit of 300 μSv/year permits the coexistence of several installations that might potentially contribute to the effective dose of the same critical group of members of the public.

Optimisation

Any justified job is considered as optimised when:

- Different appropriate solutions have been evaluated and judged against each other from the radiation protection viewpoint,
- The decision process leading to the chosen solution can be reconstructed at any time,
- The risk of failure and the elimination of radioactive sources have been taken into account.

Optimisation can be considered as respected if the activity never gives rise to an annual dose of more than 100 μSv for persons professionally exposed or 10 μSv for members of the public [6].

4.2.2 Consequences of Implementing the Regulatory Requirements at CERN

As society judges High Energy Physics in general and CERN's research in particular as beneficial, the consequences of radiation doses given to individuals by these activities have to be considered as justified. In order to keep the exposure low, CERN strives to respect internal guide line limits that are well below the legal ones.

Public

The effective dose resulting from CERN's activities and received by any person living or working outside the Organization's boundaries must not exceed 300 μSv per year. This limit includes both external and internal exposure to ionizing radiation. The internal exposure results from the intake of radioactive nuclides that are released from CERN's installations into the environment. Its contribution to the annual effective dose for persons living outside the Organization's boundaries must be limited so that it does not exceed 200 μSv per year.

‡ In Switzerland only one category of radiation workers exists (< 20 mSv/year).

Non-radiation worker

The effective dose resulting from CERN's activities received by any person working at CERN without being professionally exposed should be kept below the same limits as for the public.

Radiation worker

From 2004 it is envisaged to use internal limits for the effective dose of CERN's radiation workers as presented in Tab. 4.2 [9]. The responsible persons for CERN staff or contractor's staff should make an effort to arrange the work in such a way that an effective dose of 6 mSv per year and per person will be not exceeded.

Table 4.2: CERN's internal guide line limits for the effective dose of radiation workers

	Effective Dose
per week	< 1 mSv
per month	< 2 mSv
per year	< 6 mSv

Table 4.3: CERN's classification of areas and guideline limits for ambient dose equivalent rate as valid from beginning of 2004[§]

Type of Area	Guide line value for ambient dose rate equivalent in µSv/h	Legal limit for annual effective dose in mSv/ year	Conditions of access and work
Public area (outside CERN fence)	<0.1 (permanently occupied) <0.5 (temporarily occupied)	<1	Free access
Supervised area (inside CERN premises)	<0.5 (permanent working place) <2.5 (temporary stay)	<1	Free access
Controlled area	<10 (without special restrictions) <25 (temporary stay)		Persons working in these areas have to be classified as radiation workers and their effective dose has to be individually monitored.
Limited stay area	<2000	<20	Persons working in these areas have to be classified as radiation workers and their effective doses have to be individually monitored by passive and active dosimetry. The access is strictly controlled.
High radiation area	$<10^5$	<20	Persons working in these areas have to be classified as radiation workers and their effective doses have to be individually monitored by passive and active dosimetry. The access is strictly controlled.
Prohibited Areas	$>10^5$	< 20	No access

[§] CERN's classification of areas is presently based on the Swiss radiation protection legislation [6, 7], the corresponding classification in France is still less restrictive. The revised version of the Safety Code F will take into account the newest developments in France.

All radiation workers at CERN need medical clearance and appropriate training. They will be supplied with passive dosimeters and, where necessary, with active dosimeters. The decision on the latter depends on the risk the person is exposed to during his professional activity.

Classification of Areas at CERN

In order to fulfil its legal obligation to keep exposure of persons to ionizing radiation as low as reasonably achievable (ALARA) and in particular below legal limits, CERN is obliged to regularly monitor the ambient dose equivalent and the ambient dose equivalent rate in the various areas in and around CERN. These include the areas outside CERN's fences, the total of its premises and in particular the working places of CERN's radiation workers. Guideline values for the ambient dose equivalent rate and the classification of areas according to these limits are practical means for the operational radiation and environmental protection to guarantee that legal requirements are respected.

4.2.3 LHC Design Limits for Doses and Dose Rates

When dose and dose rate design limits for the LHC were fixed, legal requirements and in particular the optimisation principle had to be taken into account [10-14].

Design Limits for occupied areas

The specifications of LHC shielding parameters are either derived from analysis based on the consequences of a full beam loss or on continuous loss processes during normal operation. In the case of a full beam loss the following limits for effective doses are set: 20 mSv maximum for persons working in the LHC underground areas, 1 mSv for persons working within CERN's premises and 300 μSv for the persons living outside CERN's fences. The limits for ambient dose equivalent rates are based on continuous losses and should not exceed 10 μSv/h for a controlled area, 1 μSv/h for a public area within CERN and 0.1 μSv/h for a public area outside CERN. The choice of these limits is justified by:

1) The legal limits for effective doses will be not exceeded, even in the case of a full beam loss.
2) The dose rate of 10 μSv/h is the upper limit for a simple controlled area according to the Swiss legislation [7]. Taking into account that the results of Monte Carlo calculations include considerable safety margins and that the decision making is always based on the results for the worst case (loss close to the shielding wall), a reasonably low ambient dose equivalent rate can be expected for the fixed working places in these types of area.

Design Limits for Maintenance

For LHC it is sensible to plan maintenance operations with a design limit for the annual effective dose of less than 2 mSv. Based on the optimisation principle all work in radiation areas must be planned and expected doses estimated. If this estimate exceeds 100 μSv for an activity per year, an optimisation must be made, balancing the doses against the cost of protection measures (time, shielding, distance and remote handling). A more detailed list of basic principles concerning job planning and optimisation can be found in [14]. Long term experience in high-energy accelerators has proved the usefulness of the dose rate guide line values as listed in Tab. 4.4.

Table 4.4: Maintenance constraints as function of the ambient dose rate level

Ambient dose rate reference level	**Maintenance Constraints**
> 100 μSv/h	All work must be carefully planned and optimised
> 2 mSv/h	All work must be carefully planned, the intervention time in the zone must be severely limited, remote handling of the components shall be seriously envisaged. French legislation: Workers of French firms holding only a temporary contract with the firm are not permitted to intervene in such CERN areas [15].
> 20 mSv/h	In regions where dose rates are above this value, no work is allowed since dose limits would be too easily exceeded. Remote handling of objects is essential.

In case an item under repair has to be taken out of the LHC it must be immediately transferred into a properly equipped and radiologically classified workshop. Obviously, transport as well as the workshop activities has to be optimised. The legal requirements for a radioactive workshop depend strongly on the type of job and on the radionuclide inventory of the accelerator component [7]).

4.3 EVALUATION OF RADIOLOGICAL RISKS

The particles of a hadron beam interact with matter via various processes such as beam-gas, beam-beam, beam-collimator, beam-target or beam-dump interactions. The high energy nuclear reaction between the beam particles and the target atoms will result in:

- The in-situ production of ionising radiation fields (prompt, mixed radiation fields),
- The production of radioactive nuclei inside the target material (induced activity).

Prompt Radiation Fields

The so-called prompt, mixed radiation fields are composed of charged hadrons (protons, pions, kaons, etc.), neutrons, leptons (e.g. muons) and photons. The composition of the fields at a given point in or outside the LHC tunnel strongly depends on its position with respect to the beam loss and the kind of shielding in between. As a general rule radiation fields around high energy accelerators are very similar to cosmic radiation fields.

Induced Radioactivity

Radioactive isotopes are produced in the accelerator components and the accelerator tunnel structure during the nuclear reactions between a high energy primary or secondary particle with the nucleus of target atoms. The radioactive ("unstable") isotopes decay, mainly by emitting betas and gammas, until they reach the "Valley of Stability". Since the half-lives of the radioactive isotopes range from fractions of seconds to years and beyond, the radiation fields will always be present in the machine once it becomes operational and are the source for the remanent dose rates.

4.3.1. Radiological Studies by Monte Carlo Techniques

The radiological studies discussed in this Chapter are based on Monte-Carlo (MC) simulations of the particle interactions and transport in matter. Most of these calculations were performed with the FLUKA code [16][17]. FLUKA is a multi-purpose Monte Carlo code which is capable of simulating all components of hadronic and electromagnetic cascades from TeV-energies down to that of thermal neutrons. Its predictive power has been confirmed by a large number of benchmarking studies, comparing FLUKA results against experimental data [18]. The code has its roots in the field of radiation physics and is thus the most appropriate choice for LHC Radiation Protection studies. In the following, a brief summary is given of the methods used with FLUKA for the evaluation of radiological risks.

Dose equivalent

Dose equivalent can be estimated from the physical quantities obtained with FLUKA by one of the following methods:

- Multiplication of dose (energy deposition) with an average quality factor,
- Multiplication of the density of inelastic interactions with energies above a certain threshold, typically 50 MeV ("stars"), with pre-determined factors
- Folding particle fluence with particle type and energy dependent conversion factors.

For LHC studies the third method is used most frequently. In particular, fluence to effective dose and fluence to ambient dose equivalent conversion factors [19] are used. These have been calculated with the FLUKA code and are based on recommendations of the International Commission of Radiation Protection (ICRP).

Induced radioactivity

Three methods exist for the calculation of the specific activity induced by hadronic interactions in beam line, shielding components and in the environment (air, rock, water, etc.). These are:

1) Multiplication of star density with pre-determined factors,
2) Folding of particle fluence with energy-dependent cross sections for the production of certain isotopes,
3) Direct calculation of isotope production with FLUKA.

Each method has its advantages and limitations and is used correspondingly for LHC studies. The first approach allows easy implementation and fast estimates, but is limited to high-energy reactions. Furthermore, the factors have been determined for a certain radiation environment (particle composition and spectra) and are therefore only valid for similar conditions. The second method is considered to be most reliable if experimental cross sections are available. In addition, it is the only option for the estimation of activities in regions of low density (e.g. air). Finally, the prediction of isotope production with FLUKA provides the most universal and problem-independent method although its reliability is strongly dependent on the quality of the hadronic interaction models in FLUKA.

Remnant dose rates

Methods for the calculation of remanent dose rates are either based on the so-called omega factor approach or on an explicit simulation of the production of radioactive isotopes and the transport of radiation from radioactive decay. Using the omega-factor approximation means to determine the surface dose rate by multiplying the number of inelastic interactions ("stars") produced in a material with pre-determined factors that are characteristic for a specific material. This technique allows estimations of dose rates on the surface of extended, uniformly activated objects. The results depend strongly on the particle environment as well as on irradiation and cooling time. Although the omega factor approach is rather limited in its range of application, it is considered to be reliable if used appropriately. The explicit simulation method has, in principle, no limitations with regard to the geometry or complexity of the problem. However, it is more time-consuming and depends on the quality of the prediction of isotope production with FLUKA. It has only recently been used for estimating remnant dose rates around the LHC machine.

Interaction rates and loss assumptions

Radiological assessments of environmental parameters and shielding use ultimate parameters for the LHC proton beam current (850 mA, 4.7×10^{14} protons/ring) and luminosity (2.5×10^{34} $cm^{-2}s^{-1}$) whereas nominal parameters (536 mA, 1.0×10^{34} $cm^{-2}s^{-1}$) are applied in assessments of radiation damage and induced radioactivity in the accelerator [10][20]. The studies assume an annual operation cycle of three 60-day periods separated by 10 days of shutdown and having two daily fill scenarios, one fill of 20 hours duration or two fills each of 8 hours duration, respectively. Environmental assessments are therefore based on the following intensities [10][20]:

- Inelastic proton-proton interaction rate at the high-luminosity insertions: 1.6×10^{16} y^{-1} (1.0×10^{9} s^{-1}),
- Total number of dumped protons: 1.0×10^{17} y^{-1},
- Total proton loss rate per LHC beam in the beam cleaning insertions: 4.0×10^{16} y^{-1} (2.5×10^{9} s^{-1}),
- Total proton loss rate per LHC beam in the Main Ring: 3.4×10^{15} y^{-1} (2.2×10^{8} s^{-1}).

Further details as well as the intensities for internal assessments can be found in [10]

Heavy-ion operation

The radiological importance of ion operation at the LHC has been found to be generally lower than that of proton operation [21]. The estimate is based on LHC performance parameters as given in the Conceptual Design Report of the LHC [22] and the Technical Proposal for the ALICE experiment [23].

4.4 THE INJECTOR CHAIN

As already indicated the radiological concerns for the LHC injector concentrate on two issues:

- The operation with ions and its consequences in particular for LINAC3 and LEIR.
- Operation of the SPS with the LHC beam and in particular the ejection of the proton beam into the LHC.

4.4.1 Ions in the Injector Chain

As the radiation protection aspects of LHC ion beams in LINAC3 and LEIR are already discussed in detail in Volume III of the LHC Design Report [24], only a short summary will be given here.

LINAC3

Three radiation sources have to be taken into account: neutrons, X-rays from the ion source and X-rays from the LINAC3 itself.

When the beam intensity is increased by two orders of magnitude, additional shielding will be required around the dump for neutrons. The improvement of the present 100 μA current to the potential 500 μA with the ECR source means an increase of the X-ray dose rate at the ion source by a factor of three. Additional shielding of 1 cm lead or 10 cm concrete will be sufficient. The X-ray dose rate around LINAC3 is expected to increase by a factor five and consequently some extra shielding of 2 mm lead or about 10 cm concrete are recommended.

LEIR

Given the expected beam intensity in LEIR, the 1.6 m thick concrete walls enclosing the accelerator will be sufficient to shield LEIR sideways and to allow access to the rest of the South Hall during operation. The gangway can remain accessible during operation of LEIR with Pb ions (10^{+9} $^{208}Pb^{54+}$ ions at 72 MeV/u every 3.6 seconds) – providing that special precautions are taken (e.g. fast beam abort) in case of accidental conditions. The decision on top-shielding for LEIR will be taken as soon as more experimental data become available. This data is needed to verify the theoretical models.

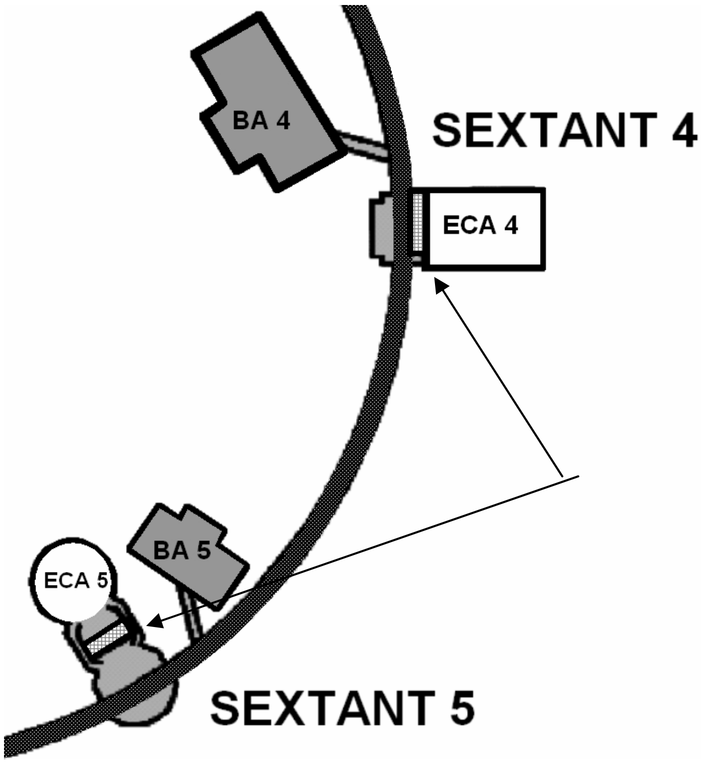


Figure 4.1: Schematic lay-out of ECA 4 and EC5 of the SPS, the arrows point to the mobile shielding walls.

4.4.2 Protons in the Injector Chain

Whereas the LHC beam in LINAC, Booster and PS will not cause major radiation protection problems, the present shielding in the ECA4 and ECA5 areas of the SPS will have to be redesigned.

SPS

In the late 1970s two caverns were excavated in point 4 and point 5 of the SPS to house the detectors of UA1 and UA2. The former assembly areas of UA1 and UA2 (ECA5 and ECA4) are shielded towards the SPS machine by mobile concrete walls, up to 5 m thick (see Fig. 4.1) and are presently classified as simple controlled areas [8]. Nowadays, they are used for various purposes: ECA5 as a storage area for accelerator components and ECA4 for the installation of power supplies and various control equipment for the SPS machine.

The radiation level in ECA4 will increase during the ejection of the beam into LHC and CNGS when compared to "normal" SPS operation. This is because the ejection will be initiated by kicker and septum magnets installed in LSS4 to direct the beam into TT40. Monte-Carlo studies were performed to evaluate the radiological risks in ECA4 under LHC and CNGS beam conditions [25][26][27].

Two scenarios were calculated: beam losses in the septum magnets [25] and in the spoiler protection unit installed in ECX4 [26]. Assuming loss rates under normal operation of 10^{-3} at the spoiler and 10^{-4} at the magnets, the losses at the spoiler determine the upgrade of the shielding of the concrete wall between ECA4 and ECX4. The calculations give dose rates of the order of some tens of μSv/h for the present shielding wall. Adding additional shielding will reduce the dose rate but not sufficiently low to classify ECA4 as a radiation controlled area during LHC and CNGS operation. In case it turns out that the loss factor at the spoiler is really as high as assumed (10^{-3}), the shielding of the wall or around the spoiler has to be re-enforced as much as possible and the area classified as a limited stay area with many consequences (strict access control, job planning, passive and active dosimetry).

The first results on dose rate calculations for ECA5 show similar tendencies [28].

4.5 LHC UNDERGROUND AREAS

With circulating beam, the radiation doses in the LHC underground areas reach high levels and therefore access during beam operation has to be prohibited for the major part of the underground structure. However, access during beam operation is required for a few underground areas (USA15, upper part of PX24, USC55, part of UX85) and therefore extensive shielding calculations had to be performed.

4.5.1 Shielding Design

A summary of design values of doses and dose rates outside the shielding of the LHC is given in Ref. [11]. Three loss conditions have to be considered in the shield design:

1) A full loss of a circulating LHC beam of 4.7×10^{14} protons at a point,
2) Proton-proton interactions at an intensity of 10^{9} s^{-1},
3) A continuous loss of the injected beam of 450 GeV at a maximum rate of 4×10^{12} s^{-1}.

ATLAS and CMS

Shield design in the areas around the ATLAS and CMS experiments is determined by stray radiation from the collimators protecting the first superconducting low-beta quadrupole magnet. Each collimator absorbs approximately 2 TeV of the colliding 7 TeV protons. It can be shown that the attenuation provided by the shield must be better than 10^{-5} pSv per 7 TeV proton [10]. Results of detailed FLUKA simulations are available [11] and demonstrate that the design is adequate to meet the requirements for the classification of the experimental service caverns as Controlled Areas.

ALICE and LHC-b

Because of the lower luminosity, shield design in the ALICE and LHC-b areas is dominated by a full beam loss or a continuous loss during injection. Both scenarios require the same attenuation of about 10^{-4} pSv per

7 TeV proton [11]. As an example, Fig. 4.2 shows the total dose equivalent per lost proton for a vertical longitudinal section through the PX24 shaft at Point 2 [29]. The loss point was assumed to be at the bottom of the shaft in the first quadrupole magnet of the low-beta insertion. The values shown on the contour plot have to be multiplied by 4.7×10^{14} protons in order to obtain the total dose for a full beam loss. The design constraints for the upper part of PX24 which houses the ALICE counting rooms (Controlled Area) are fulfilled.

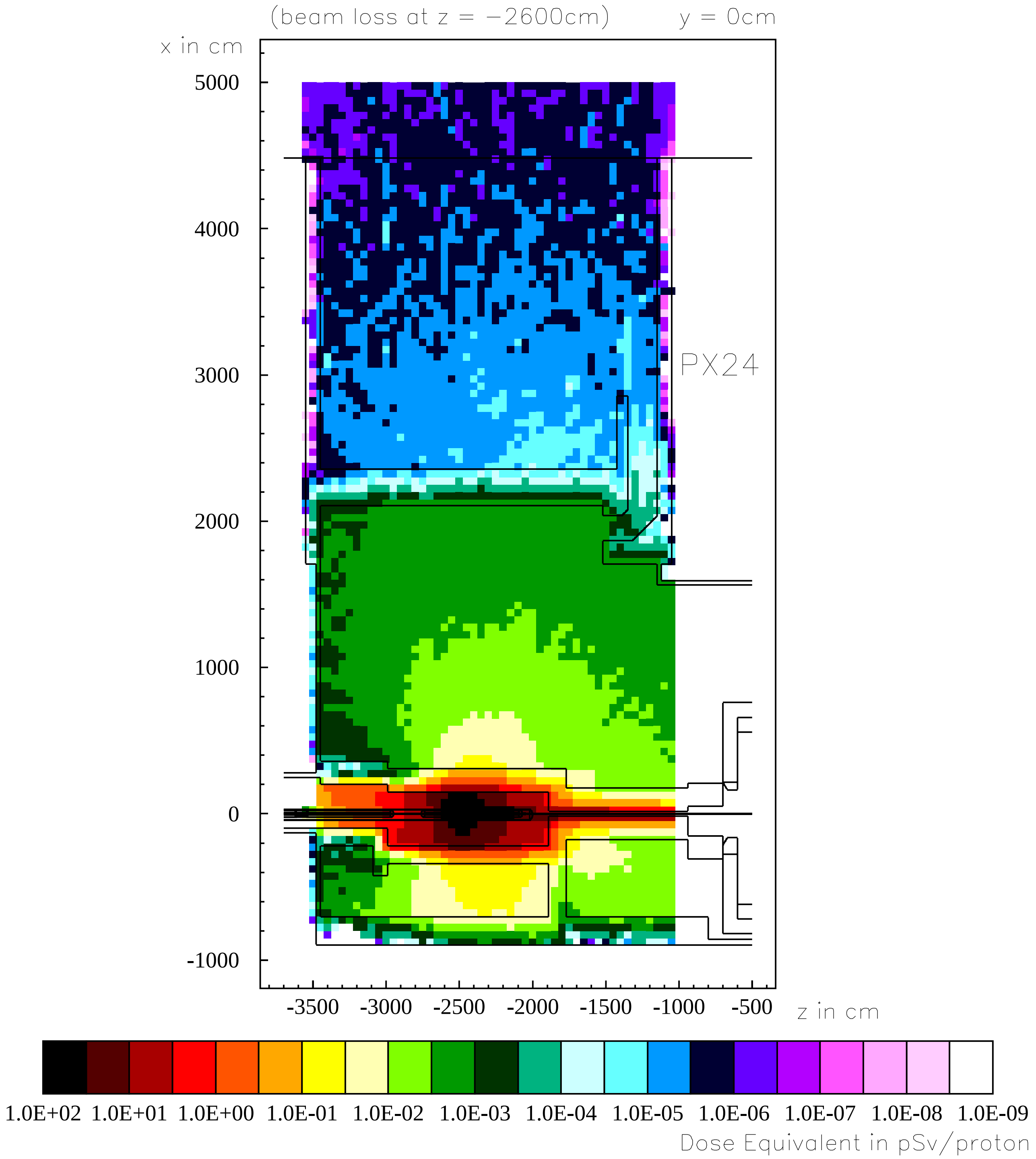


Figure 4.2: Dose equivalent per lost proton in the PX24 shaft.

The shield wall in the UX85-cavern at Point 8 separates the counting rooms from the LHC-b detector area. The wall consists of a large movable central part of about 3 m thickness covering the access opening, a fixed part (~4 m thick) on either side of this opening and a thinner top part. A complex system of ducts allows the passage of cables and pipes through the wall. At the UX floor level a labyrinth provides access to the detector. Among other considerations, the final design of this wall has been optimised with respect to a minimisation of dose equivalent in the counting room area based on detailed FLUKA calculations [30].

Point 4 – LHC RF cavities

The LHC superconducting RF cavities will be installed in Point 4. Whereas the access into these underground areas will be prohibited during beam operation, people may be present in UX45 and US45 during the conditioning of the cavities. A study of the radiological risk caused by the high energetic bremsstrahlung was necessary to design the shielding. For this, experimental results measured during the conditioning of 2, LHC modules in the SM18 test facility were combined with detailed Monte Carlo simulations [31]. According to the study a roof shield as well as a second, 80 cm thick shielding wall towards UX45 is required. With these in place, access will be possible to the US cavern and to the ground floor of UX45 during RF cavity conditioning. The access to the upper floors in UX45 will be restricted.

4.5.2 Remnant Dose Rates and Maintenance

In general, all equipment installed in the LHC tunnel will become radioactive as a result of particle showers induced by interactions of the beam with the residual gas in the vacuum chamber. In addition to these distributed losses there are localised areas which will become radioactive as a result of interactions of the beam with accelerator components. In the following the most affected areas will be addressed.

TAS Collimators

Calculated residual dose rates for the TAS collimator can be found in [32][33]. Close to the beam pipe dose rates may reach tens of mSv/h and require careful job planning and the provision of some means of remote or easy handling for maintenance operations. The dependence of the residual dose rate - averaged over the IP-side surface of the collimator - on irradiation and cooling time is shown in Fig. 4.3 [33]. Except for very short irradiation times, dose rates are comparable within a factor of two up to one day of cooling and within an order of magnitude for several months of cooling. Even after one week of cooling time the dose rates are of the order of several mSv/h.

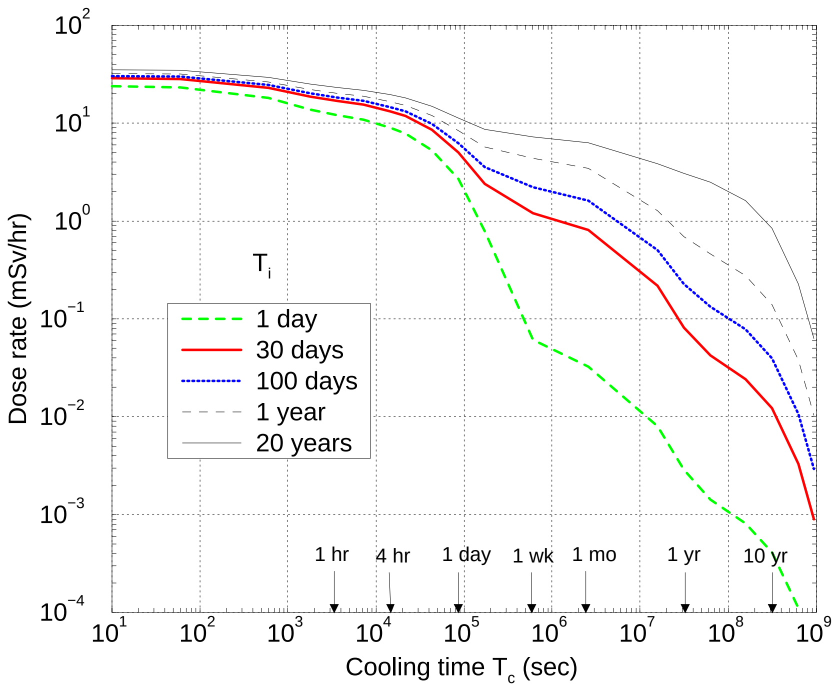


Figure 4.3: Residual dose rate averaged over the IP-side surface of the TAS for various irradiation and cooling times [33].

Low-β Insertions and TAN Absorbers

As for the TAS the magnets of the low-β insertions at IP1 and IP5 together with all the vacuum equipment and the TAN absorber will become highly radioactive from secondary particles emerging from the interaction point. Estimates of residual dose rates at the IP5 inner triplet vacuum vessel [33] are shown in Fig. 4.4. It should be noted that these values are valid for the outside of the vessel, whereas dose rates close to the vacuum pipe will reach several tens of mSv/h [33].

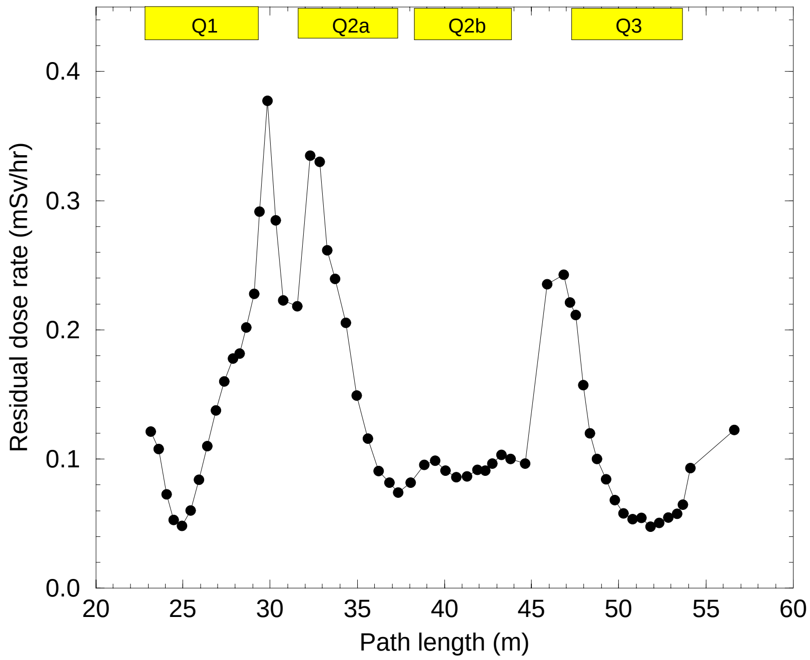


Figure 4.4: Residual dose rate on the outside of the IP5 inner triplet vacuum vessel after 30 days of irradiation and 1 day of cooling [33].

Momentum and Betatron Cleaning Insertions

Apart from the beam absorbers in IR6 the cleaning insertions will become the most radioactive zones of the LHC. For radiation studies it is assumed that about 30% of all stored LHC protons will be lost in the cleaning insertions at points 3 and 7. Expected dose rates depend strongly on various factors, such as the collimation layout, local shielding, the materials chosen and the cooling time. The question of whether and where to implement shielding is still a matter for further studies.

First detailed studies related to contact dose rates on the surface of a possible iron shield and magnets in the momentum cleaning section (IP3) were obtained with the omega-factor approach (see above). The simulations [34] are based on machine layout version 6.2 (one primary aluminium collimator, six secondary copper collimators and local thick iron shielding). The results are normalised to 10^9 protons per second and per ring, interacting in the momentum cleaning insertion and refer to 30 days of irradiation and 1 day of cooling.

Fig. 4.5 shows contact dose rates on the outer surface of the iron shield and magnets as a function of the longitudinal position for both rings. The contact dose rate reaches a maximum value of 3 mSv/h near the first secondary collimator TCS1 and near the bare coil ends of the dipole and orbit corrector magnets. In most of the regions the dose rates significantly exceed the reference value of 100 µSv/h (Tab. 4.4) therefore work must be carefully planned and optimised. In case the shielding has to be removed for maintenance of the vacuum components, the dose rates from induced radioactivity in the collimator jaws, the front bare coils and the beam pipes will exceed 100 mSv/h [34].

As a result of the new collimation layout in the cleaning insertions and ongoing design work (in particular with respect to shielding) the first generic studies have been performed to estimate the induced activity for different proposed collimator materials [35]. Possible candidates for low-Z materials have been identified as beryllium and carbon composites; copper is kept in the generic study for comparison with results of earlier simulations. Dose rates have been estimated by two different approaches; the omega-factor approach and the explicit method of calculating and transporting the radioactive decay products (see Sec. 4.3.1). It has to be noted, that the omega-approach could include rather large uncertainties in the case of the very thin beam pipe or the tunnel wall. The dose rates as calculated clearly exceed 20 mSv/h near the copper collimator, whereas beryllium and carbon composite give dose rates of few mSv/h. In all cases values are reached which require dose optimisation in design and maintenance of the beam cleaning insertions.

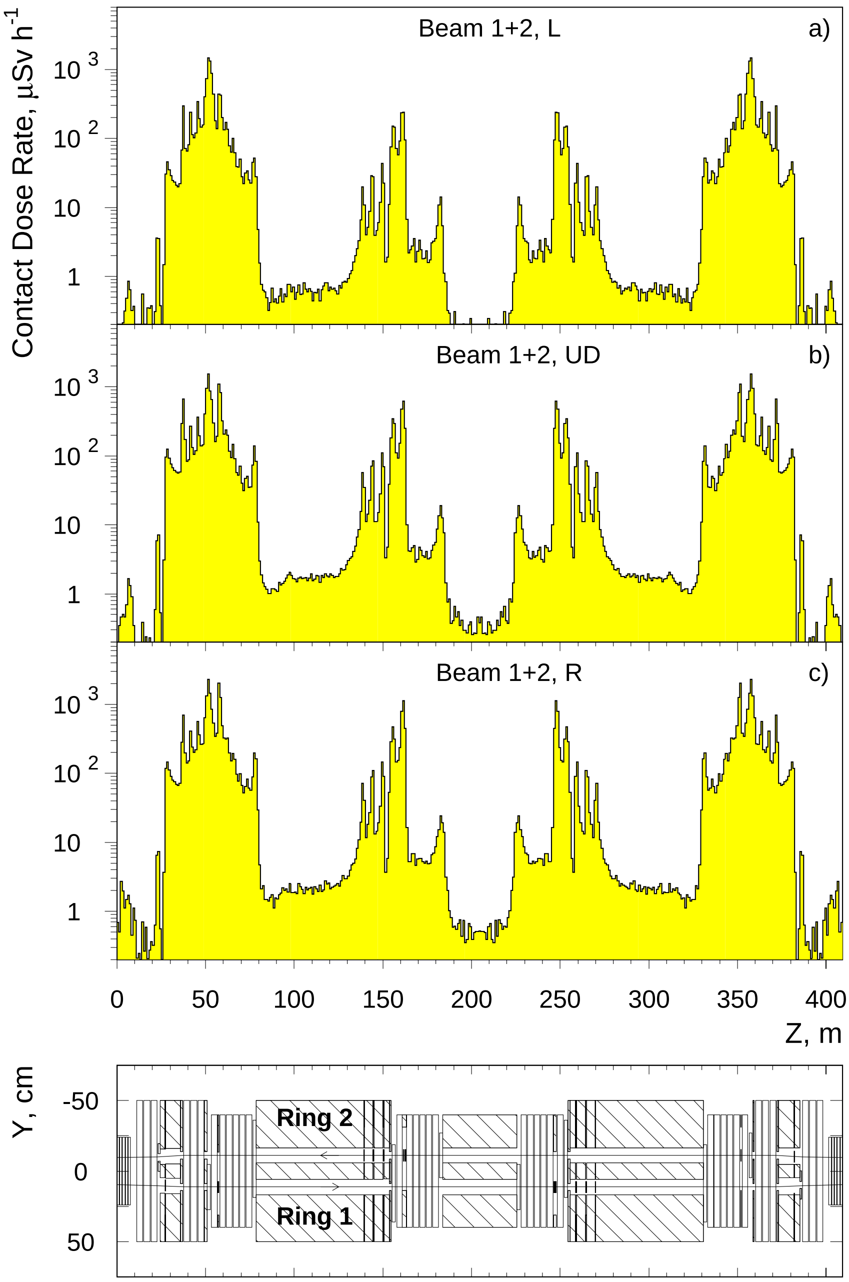


Figure 4.5: Contact dose rates on the surface of the iron shield and magnets in the momentum cleaning sections: a) left surface L; b) up-down surface UD; c) right surface R [34].

Generic Monte Carlo simulation studies were performed to compare different choices of material and to study the effect of shielding. Fig. 4.6 shows results comprising a very simplified geometrical model, which was used to obtain fast first estimates for dose rate distributions: the residual activation can be significant, thus imposing restrictions on human interventions [36]. In the case where the collimators are shielded, high dose rates in the order of several tens of mSv/h are to be expected on the inside of the iron shield after 180 days of operation and one day of cooling. The situation is much more relaxed in the unshielded scenario, where dose rates reach values of several mSv/h. The results are normalised to 10^9 protons per second and per ring and refer to a full beam loss at a single collimator.

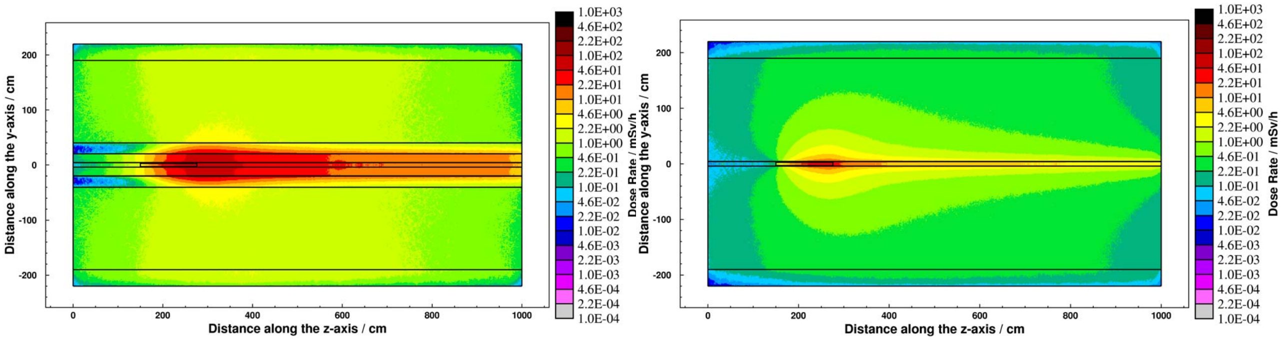


Figure 4.6: Spatial dose rate distribution after 180 days of operation and one day of cooling for the shielded (left) and unshielded (right) configuration of a carbon composite collimator.

Any kind of intervention in this kind of radiation area requires a detailed job and dose planning. The results strongly depend on the particle losses at the particular collimator, the collimator material and the surrounding local shielding [37]. More detailed calculations will have to be performed in order to optimise the final layout of the collimators and its implication on collective doses (see [38] and Fig. 4.7).

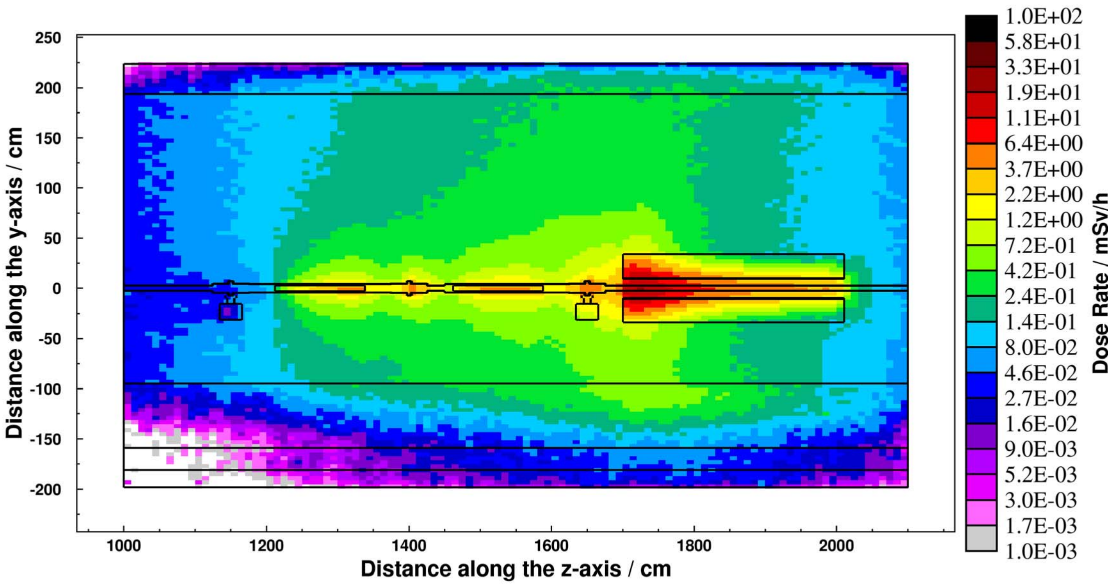


Figure 4.7: Spatial dose rate distribution for a vertical projection of the collimator geometry for 180 days of irradiation and 1 hour of cooling [38].

Beam Dump Caverns

Photon dose rates coming from the graphite, aluminium and concrete of the dump have been estimated for various locations in the dump cavern (see Fig. 4.8) [39]. Assuming a total number of $4.5\times10^{+16}$ protons dumped per year, the dose rate will reach a maximum value of 84 μSv/h after one hour of cooling at position 4 above the dump. Since it is possible that the top shielding blocks will have to be removed to allow a core-sleeve assembly or a base-plate to be exchanged, dose rates have also been estimated for this case. The dose rates range from 380 μSv/h at position 4 (see Fig. 4.8) to 1 μSv/h at position 1 after one day of cooling. After one month cooling values ranging from 100 μSv/h to 0.4 μSv/h are reached.

Beam Dump Assembly

Details of the dump and shielding have been reproduced to the nearest millimetre; details of the cavern walls, floor, tunnels etc. to the nearest centimetre. The beam-dump comprises the cylindrical graphite core (length 700cm and diameter 70cm), surrounded by the aluminium sleeve (outer dimensions 94×94×700 cm). This core ensemble, along with the aluminium end-block (100×110×100 cm), sits on a 16 cm thick aluminium base plate. The densities of the graphite and aluminium are 1.85 g/cm^3 and 2.7 g/cm^3 respectively. The shielding for the dump is made from decommissioned magnet-yokes, partially filled with concrete, and an outer 20 cm layer of concrete. The densities of the iron and concrete are 7.88 g/cm^3 and 2.35 g/cm^3 respectively. The cavern ceiling, walls and floor are composed of the same concrete; the ceiling and wall thickness is taken to be 60 cm while the floor is 200 cm deep. In order to speed up the calculations the volume of the cavern is assumed to contain a vacuum. The rock (molasse) with a density 2.40 g/cm^3 surrounds the cavern-concrete.

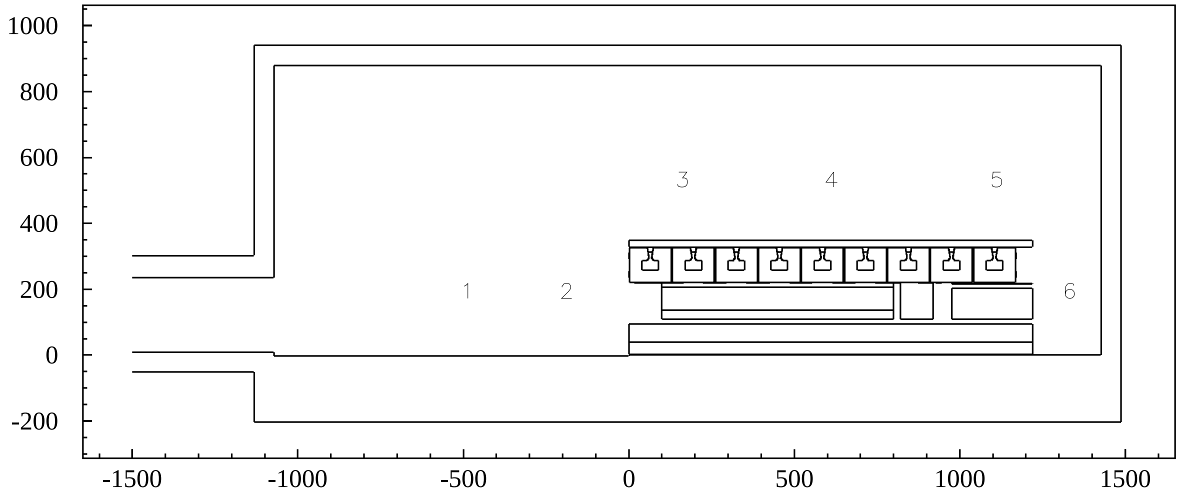


Figure 4.8: Vertical slice through the centre of the dump. The positions where dose has been determined are indicated. Dimensions are in cm.

Dispersion Suppressor Regions

No explicit calculations exist for remanent dose rates around the dispersion suppressor (DS) regions at Points 1 and 5. However, a rough estimate of the remanent dose rates in these areas can be obtained by scaling the results for dose rates from beam-gas interactions in the arcs [40] to the proton loss density in the DS region [41]. The latter loss densities were calculated based on optics Version 6.2 and an interaction rate at the IP of 3.5×10^8 s^{-1}. The dose rates depend strongly on the amount of self-shielding provided by the beamline elements and may reach several mSv/h at isolated spots.

4.6 RADIATION DAMAGE TO ELECTRONIC EQUIPMENT

4.6.1 Electronic Equipment in the LHC Tunnel

The LHC is technically more complex than any of the previous accelerators built at CERN and the physics operation margins are very tight. This has had a clear impact on the design and the integration of the controls electronics for the machine.

A large amount of low-level controls electronics is located close to the beampipe to improve the signal quality, to reduce cabling costs and to reduce ohmic losses in the power cables. In total, there will be around 10 000 crates installed under the cryostats of the main magnets and containing the low level electronics for beam instrumentation (BPMs, BLMs), quench protection, cryogenics, power converters (orbit correctors), vacuum and magnet position surveying. Other electronic systems such as junction boxes or local control electronics will be attached to the cable trays.

There are some trends in the selection and use of microelectronics for the LHC machine components that have raised questions concerning the radiation tolerance of this equipment:

- Most systems use complex programmable devices such as ASICs (Application Specific ICs), Memory (EEPROM) based CPLDs (Complex Programmable Logic Devices), SRAM based microprocessors or devices with flash memory. Although this gives more flexibility and allows easy switching between operational modes (calibration, proton run, ion run), it is difficult to predict how an error may propagate through the whole system.

- There is a preference for using complete commercial off-the-shelf systems (COTS) whenever possible. Complete COTS systems eliminate the need for a specific custom development and may lead to overall reduction of costs. For example, the use of PLCs (Programmable Logic Controllers) in combination with digital or analogue remote I/O modules is presently envisaged for the cooling and ventilation system, the electrical distribution system, interlocks, vacuum and the RF system.
- Modern designs use the latest technology that has the highest performance, meaning a high density of bits and low power supply voltage.

The scale of the LHC project excludes the use of specific radiation-hard components such as those used in space or military applications. Instead radiation tolerance of electronic equipment is ensured at the system level, using multiple identical circuit paths, error correction codes, current protection and radiation tolerant power supplies.

4.6.2 Radiation Damage to Electronic Equipment

In the complex radiation field of the LHC machine, electronics will degrade via 3 different damage mechanisms [42]:

- Surface damage caused by ionizing radiation (in the tunnel mainly gamma rays and electrons) proportional to the total absorbed dose in the device.
- Displacement damage caused by energetic particles (in the tunnel mainly neutrons) that create damage in the bulk of electronic devices and that is proportional to the number of particles incident on the device per unit of surface.
- Single Event Errors caused by hadrons (mainly neutrons in the LHC tunnel) with energy above 10 MeV. This number of these errors is proportional to the number of particles incident on the device per unit surface.

Surface and displacement damage are cumulative effects. It is not expected that electronics will degrade significantly from cumulative effects during the first years of LHC operation. Single Event Errors (SEE), however, are caused by individual ionizing particles and will appear as soon as there is a circulating beam.

4.6.3 Radiation Spectra and Shielding

The "radiation map" of the LHC has been constructed over the last 10 years or so and results have been obtained with various simulation codes, optics versions, assumptions about the proton-proton collision rate, beam gas densities, beam life times and proton loss rates [44][45][46][47][48]. The evolution of the parameters over the years has relatively little impact on the radiation levels in the arcs where the magnetic lattice is regular. In the dispersion suppressor (DS) regions however, radiations levels may be higher, which is why safety factors are used in all radiation tests of electronics.

Most electronic equipment is located under the cryostats in the regular arcs of the machine. To compute the radiation levels in the arcs, it was assumed that the machine is operating at nominal conditions and that there is a loss rate of 1.65×10^{11} protons $m^{-1}y^{-1}$ for the 2 beams [44]. To compute the radiation levels close to the interaction regions, the point loss distribution from [45] was taken.

To estimate the radiation damage to electronics, it is very useful to have an idea of the highest hadron energy that can be expected in the tunnel. This is because hadrons at very high energies (>1 GeV) may cause destructive (hard) single event errors in the machine electronics. Fig. 4.9 shows that the spectra in the DS regions have more high energetic hadrons than those in the arc. This is due to the fact that some of the beam pipes in the DS are not shielded with a magnet core. The maximum hadron energy in the dispersion suppressor regions reaches several hundred GeV.

Fig. 4.9 also gives an impression on the effect of shielding which leads to a reduction in the number of protons and charged pions at high energy. However, many more neutrons appear in the MeV energy range. A proposal to shield the electronic equipment in the RRs around Point 1 and Point 5 is described in [46].

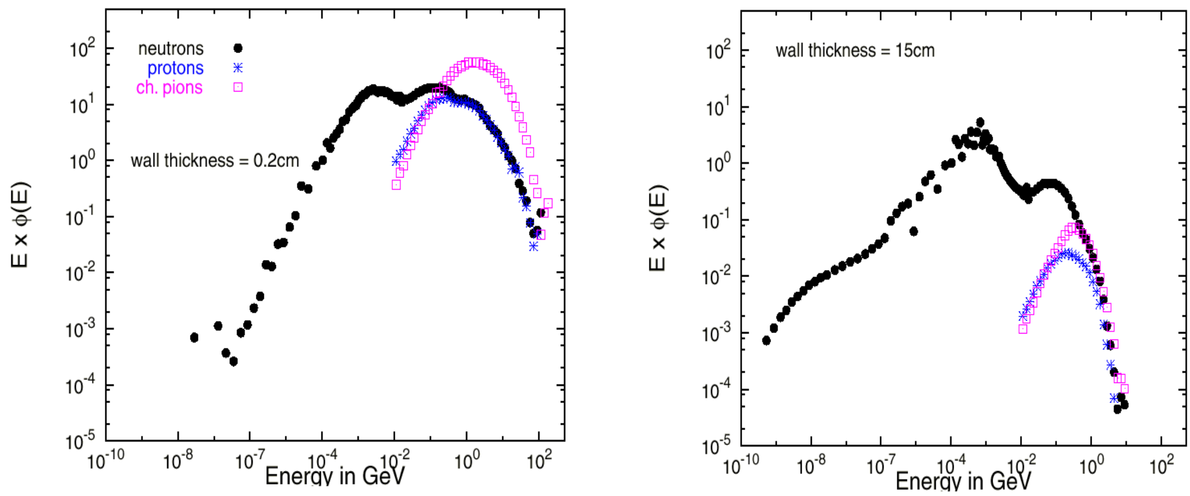


Figure 4.9: Simulated particle spectra for the LHC tunnel (left: DS region, right: regular arc).

4.6.4 Ensuring Radiation Tolerance of LHC Machine Electronics

All electronic devices installed in the LHC tunnel must be tested for their radiation tolerance. Because of the relatively short time available and the quantity and volume of the items to test, it has not been possible to adopt the standard radiation hardness assurance methods as used in space and military applications as well as for the LHC detectors. Instead, a method has been developed based on testing components and systems in a radiation facility (the LHC radiation test facility) in the SPS North area. This region has a complex radiation field similar to that expected in the LHC tunnel but with much higher dose rates [48][49]. During the selection phase, a trial and error method was used to determine whether the use of COTS (commercial off the shelf) components can be envisaged. In the second stage, irradiation tests in calibrated facilities outside the laboratory are conducted using proton beams, neutrons sources or Cobalt irradiation. Such tests are needed to determine the radiation tolerance of specific components in detail and to define the tolerance limits with sufficiently high precision. More than 90% of the radiation tests outside CERN are dedicated to solving Single Event Errors. The remainder concern cumulative damage effects (TID and displacement damage).

Final prototypes and randomly picked samples of completed pre-series systems are also tested in the complex field of the LHC radiation facility. If the radiation tolerance is consistent with observations in earlier experiments, series production and installation can be started.

4.6.5 Dosimetry for the LHC Machine Electronics

Any method to ensure radiation tolerance can only provide a reduction of the risk of inducing radiation damage to electronics: it cannot completely eliminate it. In order to monitor the degradation of electronics and materials in the tunnel, an on-line radiation-monitoring system will be used. The aim of the system is:

- To monitor the total dose (the 1 MeV equivalent neutron fluence and the hadron (E>20 MeV) fluence) on line at locations underground where electronics are located,
- To compare measured radiation levels to simulated radiation levels,
- To predict long term radiation induced failure from cumulative damage and hence anticipate replacement,
- To distinguish between radiation induced Single Event Errors and normal MTBF failure,
- To provide radiation tolerance requirements for new electronic designs,
- To evaluate the efficiency of the shielding and to assess the possibility of staged implementation,
- To provide feedback to LHC operations on the beam confinement.

The system is composed of 125 radiation monitors distributed around the ring. There are approximately 200 junction boxes and 125 dosimeters which make it possible to position dosimeters at various locations. In the areas that are cabled, there is one junction box per half cell and the default location of the junction box in the half cell is next to the Beam Loss Monitor station. The local cable length is 15 m, which means that the radiation monitors can be placed at virtually any location in the half cell. A maximum of 32 monitors per half cell can be obtained if the devices are connected in series from a junction box.

The monitors are based on 3 extremely sensitive semiconductor electronic components that measure the three radiation damage parameters:

- The RADFET, which is a special MOSFET, sensitive to the ionizing radiation component of the mixed radiation field. The change in threshold voltage of the transistor can be calibrated in terms of the total absorbed dose in Silicon, in units of Gray.
- The PIN (p+/n/n+) diode that is sensitive to displacement damage in Silicon. The forward voltage over the diode is calibrated in terms of the 1 MeV equivalent neutron fluence.
- SRAM memory that is sensitive to Single Event Errors. The number of corrupted bits can be calibrated in terms of the hadron fluence with energy above 20 MeV (Fig. 4.10).

The dosimeter components have been calibrated in dedicated test facilities. A small-scale system test is currently installed in the SPS North experimental area.

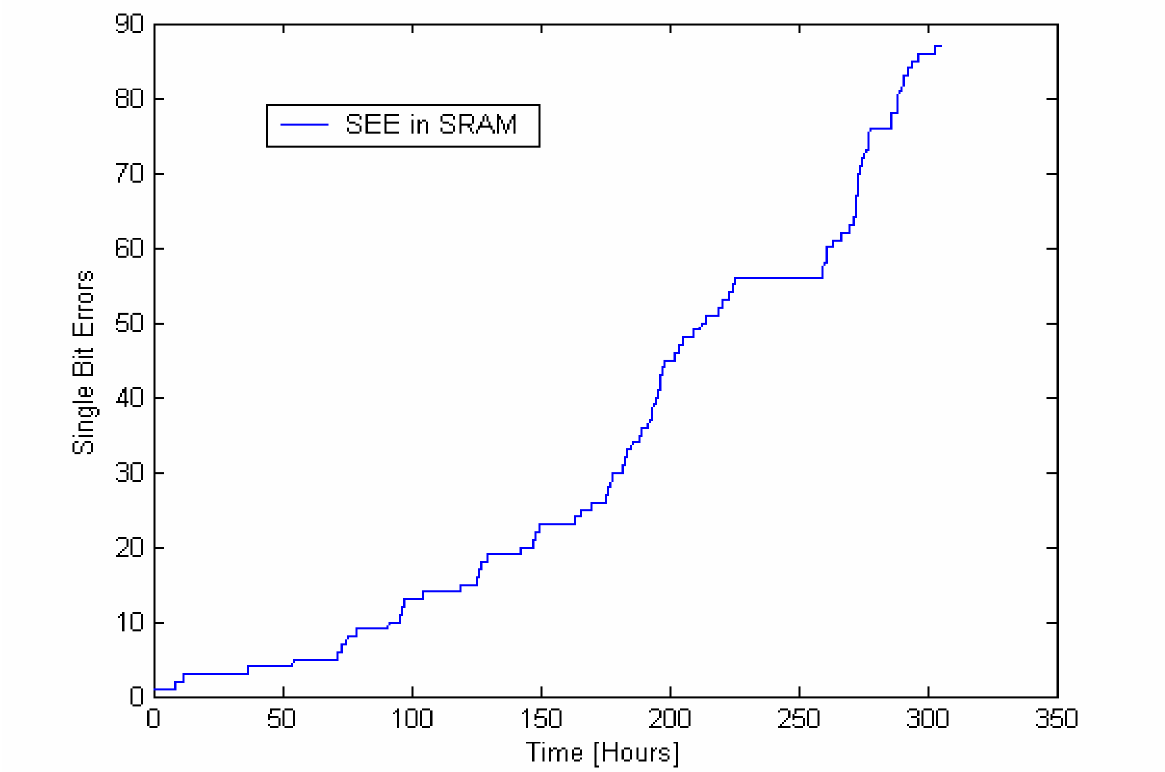


Figure 4.10: On-line observation of Single Event Upsets in standard SRAM memory as observed in the LHC radiation test facility (TCC2).

4.7 ENVIRONMENTAL MONITORING PROGRAMME

The objective of the environmental monitoring programme is to prove that the facility complies with the regulatory limits in force and to provide early warning if violation of these limits is imminent. The programme can be divided into three parts: (1) monitoring of radioactivity in released fluids (air, water) – the source term, (2) monitoring and measurements of dose rate levels in the environment and measurement of activity densities in various environmental matrices – the receptor term, and (3) evaluation of the effective dose to critical groups of the population – the radiological impact.

The crucial technical infrastructure required to meet the above-mentioned objectives is formed by the instrumentation and the data acquisition system included in the RAMSES system [50] (see Sect. 4.8).

4.7.1 Monitoring of Radioactivity in Air

Each air extraction duct likely to contain radioactivity produced in the facility will be equipped with a ventilation monitoring station. Each station consists of an on-line real-time monitor of short-lived radioactive gases together with an aerosol sampler. Whilst the readings of the monitor will be stored in a database, the aerosol filters will be replaced twice a month and analyzed in an off-line laboratory for longer-lived beta and gamma activity. Alarm thresholds will be set for the activity density of the short-lived radioactive gases. Tritium in ventilation ducts will not be measured on-line but conservatively estimated on the basis of sporadic measurements. Such measurements will be carried out especially after upgrades in the facility. The very low radiological impact of Tritium justifies such a simplified approach. There will be 5 stations for the LHC machine (PA1, PA3, PA5, PA6, PA7), 2 stations for the transfer tunnels (TI-2 and TI-8), and 11 stations for the experiments (4 in ATLAS, 3 in ALICE, 3 in CMS, 1 in LHC-b).

4.7.2 Monitoring of Radioactivity in Water

All water discharge points likely to receive water containing radioactivity produced in the facility will be equipped with water monitoring stations. In a similar configuration to the ventilation monitoring stations, each water monitoring station will consist of a radioactivity monitor with on-line alarm functions (positron emitters, ^{7}Be, ^{24}Na) and an automatic water sampler. Monthly samples will be analysed in the laboratory for tritium, total beta activity and gamma activity. There will be one station dedicated to the outlet of the LHC cooling water loop (PA1) and 8 stations located at the end of the drainage networks covering the 8 main LHC sites. The water monitoring stations will also include probes for pH, temperature, conductivity and turbidity of discharged water with alarm functions ensuring a quick detection of potential conventional pollution.

The radioactivity monitors will work with a time resolution adjustable from 10 to 60 minutes. The monitors of the physical and chemical parameters of the released water will work with a time resolution of 1 minute. The detection limits will be low enough to recognise any releases to be considered as radioactive (Ventilation: short-lived radioactive gases: <5 kBq/m^3, total beta: <0.03 mBq/m^3, gamma radionuclides: <0.1 mBq/m^3; Discharged water: short-lived positron emitters: <400 Bq/l, ^{3}H: <2 Bq/l, total beta: <0.02 Bq/l, ^{22}Na: <0.3 Bq/l, ^{24}Na: <20 Bq/l.).

Combined with the records of released fluid amounts, balance sheets of activity released into the environment will be compiled on a monthly basis. These will be used in the evaluation of the effective doses to the public due to the releases of radioactive substances into the environment.

4.7.3 Monitoring of Stray Radiation

The dose rate and doses in the environment will be monitored and measured with environmental stray radiation monitoring stations, located either at critical, or, at representative places. Each station will consist of a pressurised ionisation chamber (photons, penetrating charged particles) and a rem-counter (neutrons). These work as on-line monitors with a time resolution adjustable from 10 to 60 minutes. The sensitivity is better than 10 nSv/h for the ionisation chambers and better than 5 nSv/h for the rem-counters. The environmental monitoring stations generate alarms when dose-rate thresholds are exceeded. Twelve stray radiation monitoring stations will be dedicated to the LHC, placed around the LHC sites and at reference places. To obtain even more detailed spatial information about the dose levels on and around the LHC sites, up to 100 thermo-luminescence dosimeters will be placed in the environment and evaluated annually.

4.7.4 Sampling Programme

To check the environmental impact of releases of radioactive substances from the LHC facilities, an extensive sampling programme will be carried out. Aerosol samples will be taken at three critical places and at two reference places by using aerosol sampling stations. Exposed aerosol filters will be analysed off-line in the laboratory for total beta activity and gamma activity. Four stations will be needed to reach the same detection limits as for the ventilation aerosol samplers to be reached (see above). A high-volume aerosol sampling station, which will be alternatively placed at PA5 and PA7, will allow detection limits of fractions of µBq/m^3.

The deposition of aerosol-bound radioactivity on the ground will be checked by analysing grass and/or soil samples for gamma radionuclides. The samples will be collected downwind from the ventilation outlets close to all main LHC sites once per year. The detection limits will be several Bq/kg of dried matter.

The impact on the aquatic environment will be controlled by analysing samples of water, sediment and bryophytes taken annually in all watercourses receiving water from the LHC facilities. All samples will be analysed for gamma activity and water samples will be analysed for tritium and total beta activity in addition. The detection limits will be between 1 and 10 Bq/l or Bq/kg, depending on the sample type and the radionuclide in question.

The LHC-specific environmental monitoring programme will be complemented by the CERN-wide environmental monitoring programme including analyses of reference samples of all types, precipitation samples (2 sites), samples of agricultural products, and groundwater samples (5 wells). Detection limits will be low enough to clearly recognise any pollution with radioactive substances.

4.7.5 Monitoring of Wind and Atmospheric Turbulence

In order to make use of atmospheric dispersion models needed for calculations of the effective dose to the population (see below), site-specific wind and atmospheric turbulence data must be collected. Five ultrasonic anemometers will be installed around the LHC sites. Two of them, in Maisonnex (downwind from PA1 and the CERN Meyrin site) and close to PA5, will be synoptic and measure the 10-minute averages of the wind speed, wind direction and turbulence parameters necessary for assignment of the atmospheric stability class. They will be installed on dedicated 10-metre high masts. Three anemometers installed on roofs of buildings at the sites PA3, PA7, and BA4 (TI-8 + CNGS) will measure 10-minute averages of the wind speed and wind direction. This arrangement will generate a suitable data set for the large LHC area whilst keeping the number of anemometers reasonably small.

4.7.6 Monitoring of Noxious Gases

There will be two emission monitoring stations for nitrogen oxides and ozone, which may be produced in the accelerator and released from the ventilation outlets. One station will be located in Maisonnex, downwind from PA1, and the second in Cessy. The station in Cessy will serve as a background station, as it is located far away or crosswind of all accelerator ventilation outlets. Experience with LEP and hadron accelerators confirmed that emissions of noxious gases from accelerator facilities are well below any regulatory concern and their environmental impact, if any, is negligible. Therefore, only sporadic controls of levels of these gases will be carried out in the ventilation ducts, mostly after major changes in the facility.

4.7.7 Effective Dose to the Population

The effective dose to critical groups of the population will be estimated annually from the readings of the stray radiation monitors and from the activity of radioactive substances released from the LHC facilities with air and water. For the latter exposure pathway, methodology is available [51], which is based on widely accepted environmental and radiological models [52][53].

4.8 THE RADIATION MONITORING SYSTEM (RAMSES)

The Radiation Monitoring System for the Environment and Safety (RAMSES) for LHC will be a new, state of the art system that at a later stage will replace the ARCON (Area Control System) currently used at CERN. RAMSES will take into account the latest legal requirements, international standards, the results of the preliminary hazard analysis [54], the latest technical developments and in particular the specific requirements at CERN such as the time structure or the special composition of the radiation fields.

RAMSES provides continuous measurements of the ambient dose equivalent and the ambient dose rate equivalent in the LHC underground areas together with the surface areas inside and outside the CERN perimeter. If preset radiation levels are exceeded within radiation controlled areas, an alarm will be triggered for the evacuation of personnel. RAMSES generates operational interlocks (e.g. in case of the LHC injection or the LHC RF system during tests) and transmits remote alarms to the CERN control rooms. It will permanently monitor the level of radioactivity in water and air released from the LHC installations. For radiation protection purposes RAMSES will also include hand-foot monitors, site gate monitors, tools and material monitors. In total 350 monitors of 15 types will be installed for LHC, a major part, i.e. about 150 plastic ionisation chambers will be installed inside the machine tunnel to allow remote dose rate measurements necessary for job and dose planning and subsequent decisions on access.

RAMSES provides remote supervision, long term database storage and off-line data analysis. A more detailed description of RAMSES' functions and engineering specifications can be found in [40][45]. A synoptic of RAMSES is given in Fig. 4.11 and examples for the installation are given in Figs. 4.12 and 4.13. As others might be interested in the data, the system is kept open and the data will be accessible for clients via the WEB.

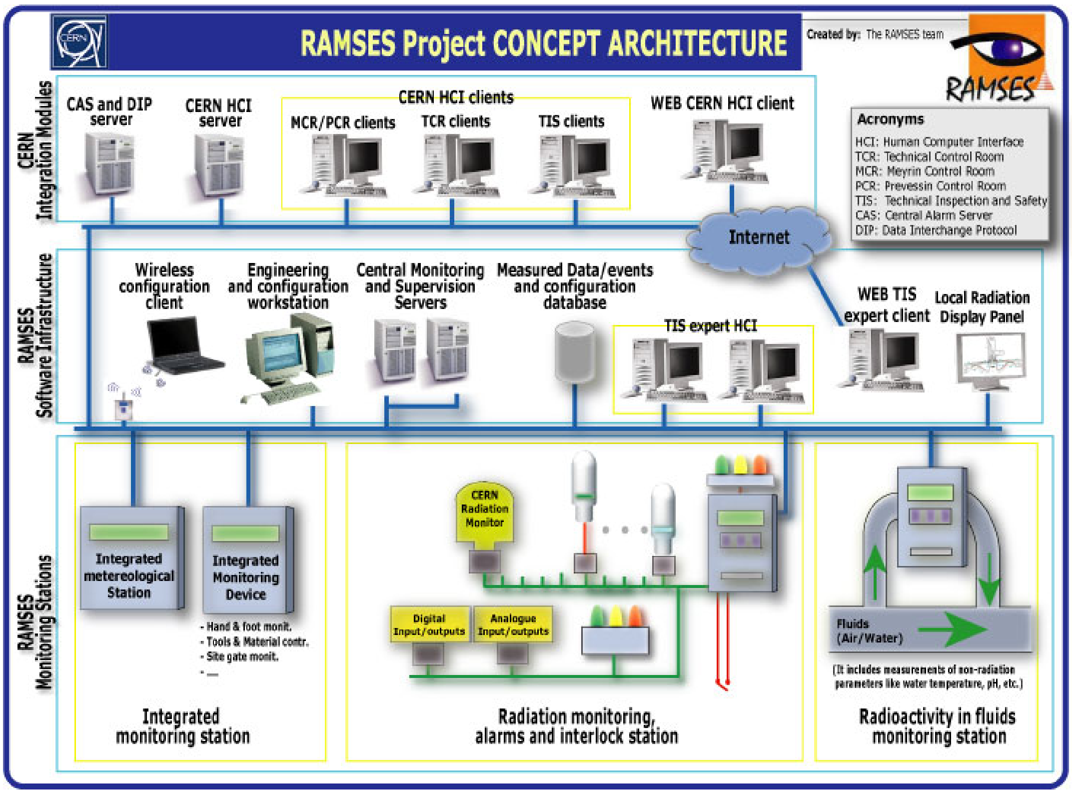


Figure 4.11: Ramses Project Concept Architecture

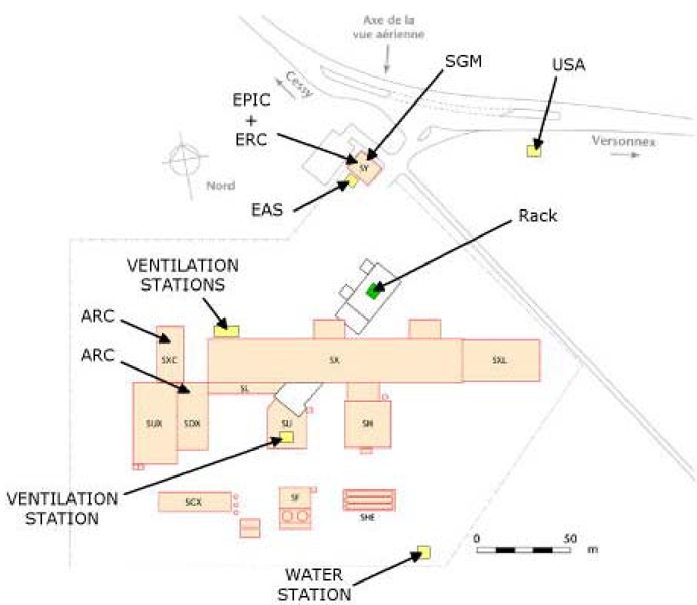


Figure 4.12: LHC point 5 surface buildings

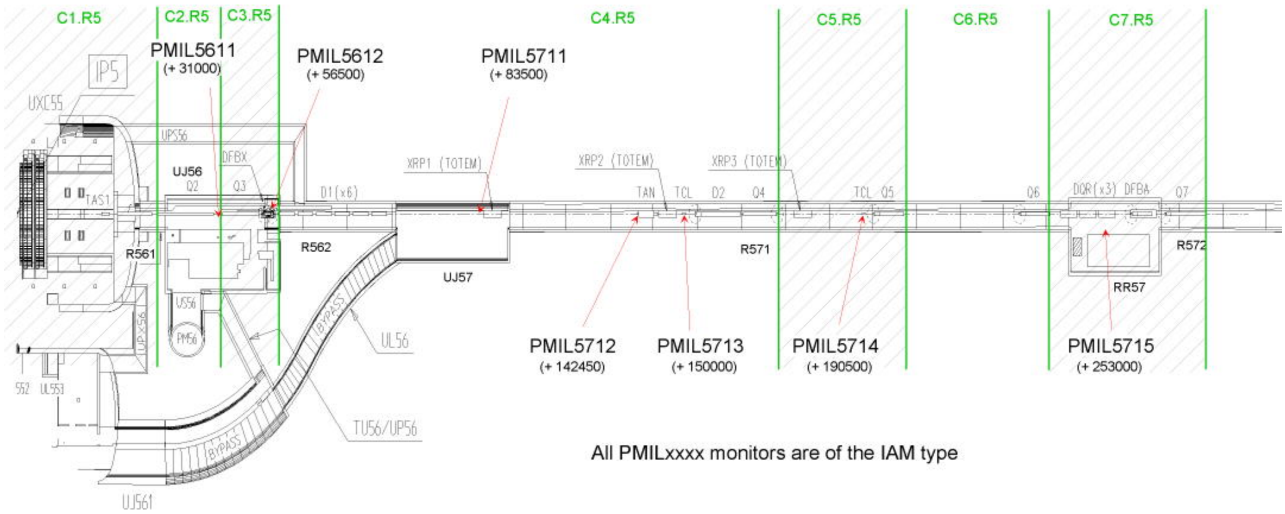


Figure 4.13: LHC point 5 underground tunnel

4.9 MANAGEMENT OF RADIOACTIVE MATERIAL AND RADIOACTIVE WASTE

Radioactive accelerator components as well as radioactive items from general services will be a product of the operation of the LHC and of the chain of injector accelerators. As a result of the interaction of the particle beams with matter, various nuclear processes will develop and in consequence, parts of the accelerator structure and its surroundings will become radioactive.

4.9.1 Classification of Radioactive Items

Radioactive material leaving the accelerator tunnel and injection lines will fall into two categories:

- Accelerator components which are meant to be reused for future re-installation in LHC (e.g. after repair) or in other CERN installations. In this context the category will be named “radioactive material”.
- Radioactive items that will be considered as radioactive waste.

4.9.2 Radioactive Material

All items that belong to the category of radioactive material remain under the responsibility of the relevant department. The radiation protection group classifies the material radiologically, gives advice on the transport and where to store the material properly and safely. The RP group also performs radiological checks of the storage centres. However, the management of the stored radioactive material remains the responsibility of the owner department.

4.9.3 Radioactive Waste

Components that are considered as radioactive waste are handed over to the RP group which has full responsibility for treatment, temporary storage and, eventually, elimination of this material. In the case of massive or strongly radioactive items with dose rates above the 100 μSv/h at 10 cm, the components are directly transferred from the accelerators to the central Radioactive Temporary Storage Facility. Whereas in the case of lower dose rates, the material is sorted and separated as far as possible into radioactive and non-radioactive components, before it is sent to the central Temporary Storage Facility.

4.9.4 Management of Radioactive Waste

With respect to radioactive waste management, CERN must comply with the relative legislations of the two Host-States (France and Switzerland) [7][56]. The legal requirements that are common to the two national legislations can be summarised as follows:

- The temporary storage of radioactive material in safe conditions,
- The establishment of a radionuclide inventory (qualitative and quantitative specification of the radionuclide content in each object),
- An update of a register (book-keeping) of the information related to the radioactive waste temporarily stored in CERN.

Typical treatment procedures that will be performed on LHC radioactive waste comprise separating the materials of different natures, a reduction in volume and temporary storage in appropriate containers.

As required by the legislation radioactive waste will be disposed of by sending it to the long-term repositories for low and intermediate level radioactive waste of the host states.

4.9.5 Precautions for Dismantling

The Specific Activity of the radioactive components coming from of the LHC tunnel will vary considerably. This depends on the material composition, the location of the material with respect to beam losses, the irradiation history and on the elapsed decay time. The RP group assesses the radionuclide inventory of each item in the machine. Most of the radioactive waste will be metallic. In addition, specific estimates for the non-metallic solid waste (insulation of power and signal cables, electronic components, etc.) will be performed. As long as machining and corrosion are avoided, all this material can be considered non-contaminating.

Liquid waste (oils, water etc.) will be classified and treated according to the specific risks.

REFERENCES

[1] Council Directive 96/29/EURATOM of 13 May 1996, Office Journal of the European Communities, Vol. 39 (1996), L159

[2] *"1990 Recommendations of the International Commission on Radiological Protection"* ICRP Publication 60, Annals of the ICRP 21, 1-3, Pergamon Press (1991)

[3] *"Protection contre le rayonnement ionisants"*, J.O. de Republique francaise no 1420, edition mise a jour 31 aout 2000

[4] Decret No 2002-460 du 4 avril 2002 « *relatif à la Protection generale des personnes contre les dangers des rayonnement ionisants* », J.O. de la Republique francaise no 81, du 6 avril 2002

[5] Decret No 2003-296 du 31 mars 2003 « r*elatif a la protection des travailleurs contre les dangers des rayonnement ionisants* », J.O. de la Republique francaise no 78, du 2 avril 2003

[6] Ordonnance sur la radioprotection (ORaP) du 22 juin 1994 (Etat le 4 avril 2000) 814.501

[7] Ordonnance sur l'utilisation des sources radioactives non-scellées du 21 Novembre 1997 (Etat 23 Decembre 1997), 814.554

[8] Safety Code F, *Protection against Ionising Radiations*, Radiation Safety Manual, Rev. 1996, CERN.

[9] Safety Code, to be released in 2004

[10] M. Höfert, K. Potter, G.R. Stevenson, "*Summary of Design Values, Dose Limits, Interaction Rates etc. for use in estimating Radiological Quantities associated with LHC Operation"*, CERN/TIS-RP/IR/95-19.1, (1995)

[11] G.R. Stevenson, *"Design values of doses and dose rates outside the shielding of the LHC"*, CERN/TIS-RP/IR/99-28, (1999)

[12] G.R. Stevenson, *"Dose Limits for Shielding Estimation at the LHC"*, CERN-TIS-2003-003-RP-TN, (2003)

[13] G.R. Stevenson, *"Dose and Dose-rate Guidelines for LHC Maintenance Operations"*, CERN-TIS-2003-004-RP-TN, (2003)

[14] M. Brugger, D. Forkel-Wirth, S. Roesler, G.R. Stevenson, "*Constraints from induced radioactivity on design and maintenance"*, Proc. LHC Performance Workshop, Chamonix XIII, 2003, page 360.

[15] Arrete du 12 mai 1998 modifiant l'arrete du 8 octobre 1990 modifie fixant la liste des travaux pour lesquels il ne peut etre fait appel aux salaries sous contract de travail a duree determinee ou aux salairies des enterprises de travail temporaire, J.O. de la Republique francaise No. 118, du 23 Mai 1998, page 7849

[16] A. Fassó, A. Ferrari and P. R. Sala, "*Electron-photon transport in FLUKA: status"*, in: A. Kling, et al. (Eds.), Proceedings of the International Conference on Advanced Monte Carlo for Radiation Physics, Particle Transport Simulation and Applications, Monte Carlo 2000, Lisbon, Portugal, October 2000, Springer-Verlag Berlin, Heidelberg, pp. 159-164 (2001).
[17] A. Fassó, A. Ferrari, J. Ranft and P. R. Sala, *"FLUKA: Status and Prospective for Hadronic Applications"*, in: A. Kling, et al. (Eds.), Proceedings of the International Conference on Advanced Monte Carlo for Radiation Physics, Particle Transport Simulation and Applications, Monte Carlo 2000, Lisbon, Portugal, October 2000, Springer-Verlag Berlin, Heidelberg, pp. 955-960 (2001).
[18] A. Ferrari and P. R. Sala, *"Physics of showers induced by accelerator beams"*, Lecture given at the 1995 "Frederic Joliot" Summer School in Reactor Physics, Cadarache, France (1995).
[19] M. Pelliccioni, *"Overview of fluence-to-effective dose and fluence-to-ambient dose equivalent conversion coefficients for high energy radiation calculated using the code"*, Radiat. Prot. Dosim. 88, pp. 279-297 (2000).
[20] Y. Baconnier, G. Brianti, P. Lebrun, A. Mathewson and R. Perin (Eds.), *"LHC: The Large Hadron Collider Project"*, CERN/AC/93-03(LHC) (1993).
[21] S. Roesler and G. R. Stevenson, *"Simple estimates of the radiological importance of heavy-ion operation at the LHC"*, CERN/TIS-RP/IR/98-30 (1998).
[22] P. Lefèvre and T. Petterson (Eds.), *"The Large Hadron Collider - Conceptual Design"*, CERN/AC/95-05(LHC) (1995).
[23] ALICE Collaboration, *"ALICE: Technical Proposal for A Large Ion Collider Experiment at the CERN LHC"*, CERN/LHCC/97-51 (1995).
[24] LHC design report Vol. III chapter 34 and 35, CERN 2004
[25] H. Vincke, G.R. Stevenson, D. Forkel-Wirth, *"Radiation Levels in ECA4 caused by beam losses in the septum magnets to be installed in ECX4"*, CERN-TIS-2002-025-RP-TN, (2002)
[26] H. Vinkce, G.R. Stevenson, D. Forkel-Wirth, *"Radiation in ECA4 caused by beam losses in the dummy protection unit installed in ECX4"*, CERN-TIS-2002-026-RP-TN, 2002
[27] G.R. Stevenson, H. Vincke, *"Studies of the Dose Rate in ECA4 due to Beam Losses in TT40"*, CERN-TIS-2002-034-RP-TN, (2002)
[28] M.J. Muller, G.R. Stevenson, *"Radiation Levels in ECA5 due to proton losses in ECX5"*, CERN/TIS/2003/020/RP/TN (2003)
[29] S. Roesler and G. R. Stevenson, *"The radiation environment at the LHC Insertion Point 2 (ALICE) in beam loss situations"*, CERN/TIS-RP/IR/98-10 (1998).
[30] S. Roesler and G. R. Stevenson, *"Radiation studies for LHC Point 8"*, CERN/TIS-RP/IR/99-22 (1999).
[31] S. Roesler, I. Brunner, presentation to the LHC-TCC, 14 June 2002, to be published
[32] I. Dawson and G.R. Stevenson, *"Radiation Studies in the Collimator Region of the ATLAS Experimental Area"*, CERN/TIS-RP/IR/98-01 (1998)
[33] N.V. Mokhov, I.L. Rakhno, J.S. Kerby and J.B. Strait *"Protecting LHC IP1/IP5 Components against Radiation Resulting from Colliding Beam Interactions"*, Fermilab (2003)
[34] I. I. Azhgirey et al., *"Towards a Shielding Design for the Momentum Cleaning Insertion of the LHC"*, LHC Project Note 297 (2002).
[35] M. Brugger, S. Roesler and G. R. Stevenson, *"Constraints to handling of collimators, shielding and vacuum installation"*, in Minutes of Meeting on Status of Collimation Insertion (6.12.2002).
[36] M. Brugger. Proposal to the AB LHC Technical Committee (LTC) on June 25th, 2003.
[37] M. Brugger, S. Roesler, *"Remanent Dose Rates in the LHC Beam Cleaning Insertions"*, CERN-TIS-2003-026-RP-TN, 2003.
[38] M. Brugger, S. Roesler, *"Accumulated Doses during Interventions on the Vacuum System in the LHC Beam Cleaning Insertions"*, CERN-TIS-2003-027-RP-TN, 2003.
[39] I. Dawson and G. R. Stevenson, *"Radiological Impact of the LHC Beam Dumps"*, CERN/TIS-RP/IR/98-27 (1998).
[40] G. R. Stevenson, A. Fassó and J. M. Zazula, *"The Estimation of Parameters of Radiological Interest for the LHC Main Ring*", CERN/TIS-RP/IR/92-08 (1992)
[41] I. Baichev, *"Proton Losses in the Dispersion Suppressors of IR1 and IR5 of LHC"*, LHC Project Note 240 (2000).
[42] G. Messenger, M. Ash, *"The effects of Radiation on Electronic Systems"*, Van Nostrand Reinhold Company New York, 1986.

[43] C. Fynbo, G. Stevenson, *“Radiation environment in the main ring of the LHC”*, LHC project seminar, Nov. 2001 http://cern.ch/LHC-radwg/LHC_Radiation_Studies/Radiation_in_the_LHC_main_ring.pdf
[44] K. Potter, H. Schönbacher and G.R. Stevenson, *“Estimates of dose to components in the arcs of the LHC due to beam-loss and beam-gas interactions”*, LHC Project Note 18 1995.
[45] I. Baishev, J.B. Jeanneret and G.R. Stevenson, *“Beam losses far downstream of the high luminosity interaction points of LHC - intermediate results”*, LHC Project Note 208 1999.
[46] I. Baishev, *“Radiation Levels in the LHC RRs at point 1 and 5”* http://cern.ch/LHC-radwg/LHC_Radiation_Studies/RR_IB1404.pdf
[47] http://cern.ch/SL/HRFgroup/LHC_RF_Mtgs/LHCRF_030910.htm
[48] A. Tsoulou et al., *“Monte Carlo Simulaions of the TCC2 test facility at CERN”*, LHC project note 317, June 2003.
[49] T. Wijnands et al., *“Large Scale Radiation Tolerance Assurance for LHC machine electronics”*, 7th European RADECS conference, Noordwijk, The Netherlands, September 2003.
[50] D. Forkel-Wirth, D. Perrin, L. Scibile, G. Segura and P. Vojtyla, *“RAMSES Technical Requirements”*, LHC-P-CI-0002.00, CERN/TIS-ST, Geneva (2003).
[51] P. Vojtyla, *“Models for assessment of environmental impact of radioactive releases from CERN facilities”*, CERN-TIS-2002-013-TE.
[52] *“Berechnung der Strahlenexposition in der Umgebung aufgrund von Emissionen radioaktiver Stoffe aus Kernanlagen”*, HSK-R-41/d, Hauptabteilung für die Sicherheit der Kernanlagen, Villigen (1997).
[53] *“Generic Models for Use in Assesing the Impact of Discharges of Radioactive Substances to the Environment”*, Safety Reports Series No. 19, IAEA, Vienna (2001)
[54] Preliminary Hazard Analysis, EDMS No: 361934
[55] Functional specification *“Radiation Monitoring System for the Environment and Safety”,* LHC-P-ES-003.00
[56] Arrêté du 31-12-1999 fixant la reglementation technique generale destinée à prévenir et limiter les nuisances et les risques externes résultant de l’exploitation des installation nucléaires de base.

CHAPTER 5

ACCESS SYSTEMS

5.1 INTRODUCTION

The LHC access systems are two complementary systems dedicated to personnel protection inside the LHC interlocked areas, which are all located within the underground installations of LHC. These two systems are the LHC access safety system (LASS) [1] and the LHC access control system (LACS) [2].

During machine operation, the LHC access safety system ensures the protection of all personnel from the hazards arising from the operation of the accelerator and from the injection and circulation of the beams. It acts on specific equipment identified as important safety elements (ISE). By interlocking these elements, it is possible to establish the accelerator and equipment conditions in order to allow access to authorised personnel in the underground installations and vice versa, to allow the restart of the equipment and the accelerator when the access is finished.

When the accelerator is not operating with beam and the LHC is in the access mode of operation, the LHC access control system allows the operation of access equipment which must positively identify the person requesting access and check that the pre-requisites (safety training) and authorisations (access rights) of this person are valid. Access can then be granted through the release of some access equipment serving as a door. The LHC access control system is also designed to limit, for operational or safety reasons, the number of users simultaneously present in the interlocked areas. The LHC access systems do not directly protect against fire, explosive gas, oxygen deficiency hazards, beam losses or high radiation levels, however links to these systems are often used to establish if conditions are correct for safe access or operation. In addition, the system cannot protect against malicious intent to defeat or circumvent the access systems.

In designing the access systems, experience has been particularly sought in the fields of operations (LEP and SPS, both from users and operators), radiation safety, the rules and regulations in the host states, the current CERN practice, as well as the most current practice in laboratories with similar installations in France and in the USA.

The first section of this chapter reviews the access sectorisation of the LHC underground areas and defines the different types of access zones. The next section concentrates on the access safety system including the definition of the interlocked elements and the principle of the interlocking mechanism. Finally the access control system is detailed.

5.2 ACCESS SECTORISATION

The sectorisation of the LHC for access results from several considerations: the accessibility of the different zones from a radiological standpoint, the segmentation of the larger zones into smaller and more manageable sectors and the limitation of the occupancy of certain sectors.

5.2.1 Radiological Classification

On the basis of theoretical studies, simulations and calculations of radioactivity dose rates [3] associated with the injection, circulation and dumping of the beams, as well as beam losses in both normal and abnormal situations, the Radiation Protection group has determined an ensemble of zones classified as exclusion zones according to the CERN radiation protection code [4]. These zones need to be interlocked for access, and personnel are not allowed in these zones when the LHC is running.

Other zones where shielding is sufficient to lower the dose rates to an acceptable level have been classified as simple controlled zones. No access interlock needs to be provided, however people accessing these zones must carry a personal dosimeter.

This radiological classification, which is summarised in [5], is the basis for the definition of the interlocked and non-interlocked areas of the LHC as detailed below.

5.2.2 Non-interlocked Areas

Access to LHC surface buildings is not interlocked with the presence of beam or other hazards arising from the running of the accelerator. Wherever some hazards arise from the presence of specific equipment in the surface buildings, local protection is provided, including local interlocks and local emergency stop systems.

Some LHC underground installations are also accessible for authorised personnel irrespective of the machine conditions because adequate shielding from beam hazards has been provided and no other significant hazard is present; the installations concerned are:

- Point 1: PX15 and USA15,
- Point 2: Upper part of PX24, above the shielding plug,
- Point 3: PM32 and US32,
- Point 5: PM54 and USC55,
- Point 8: PZ85 and the shielded part of UX85.

If a zone is not interlocked with the presence of beams or other hazards, it does not mean that it is freely accessible. General safety or operational requirements might require access restrictions to non-interlocked zones. In particular all underground installations at CERN are under access control.

5.2.3 Interlocked Areas

The interlocked areas of the LHC are those areas of the LHC installations that must contain no personnel when the accelerator is operating with beam, is ready to start beam operation or is running equipment tests which present significant hazards.

The LHC access safety system provides the personnel protection and interlocking mechanism for the interlocked areas of the LHC installations. The interlocked areas are further divided into beam zones and service zones which are defined below.

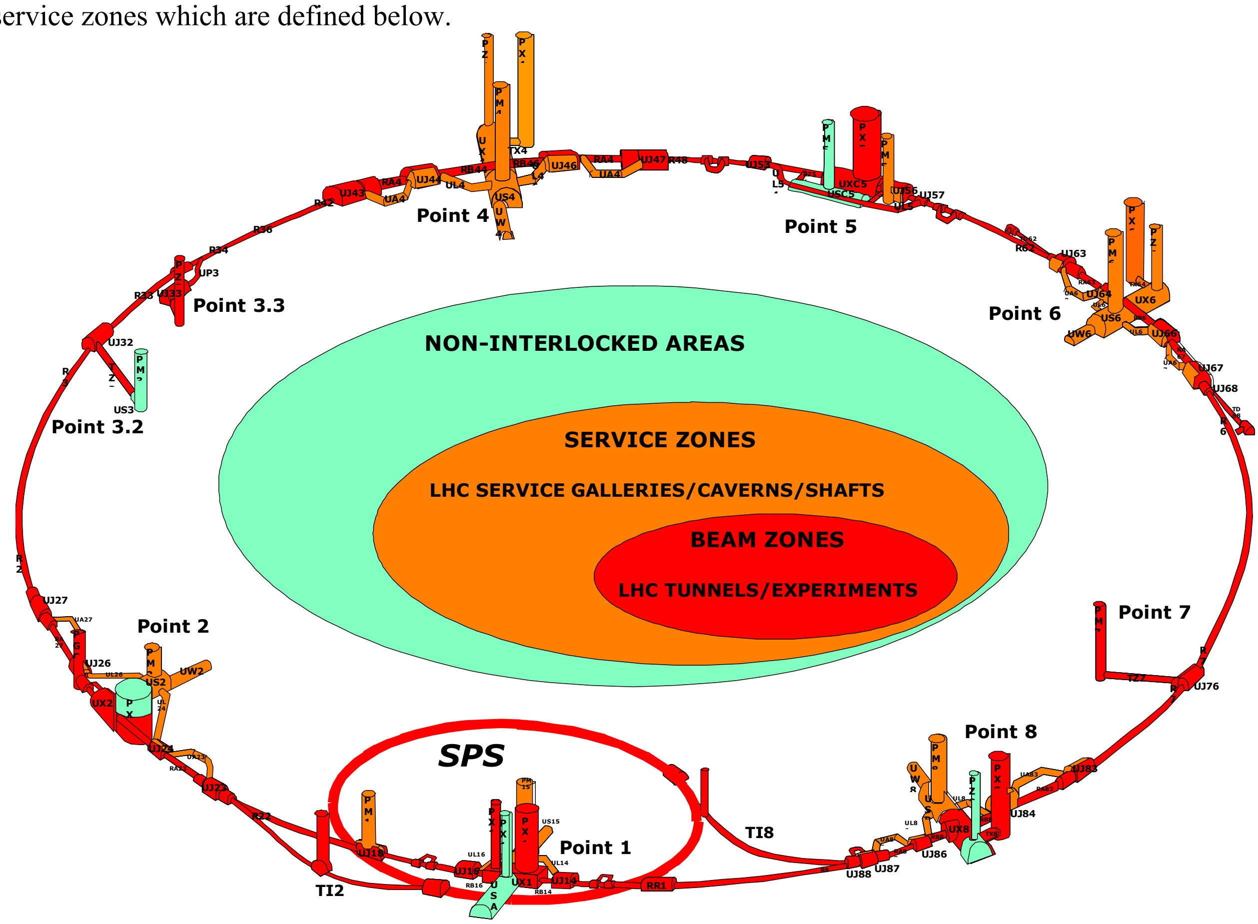


Figure 1: LHC underground areas classification.

Beam zones

Beam zones are those zones where beam could be present or which could be directly affected by the presence of circulating or injected beams during normal operation. Beam zones include the accelerator tunnel, all stub tunnels and enlargements, transfer line tunnels, the experimental caverns and the pits directly leading to the LHC ring tunnel and experimental caverns.

Service zones

Service zones are underground areas principally used to house service equipment of the LHC. They are normally not directly affected by the presence of beams. In these zones, the only hazard associated with beam operation could arise from an abnormal and significant beam loss in an adjacent beam zone that would induce a prompt radiation level higher than acceptable for human presence. Since in many cases the installation of additional shielding is not practical, or is too expensive and since one cannot exclude such cases of abnormal beam losses, the Service zones are not accessible during beam operation of the LHC.

The separation of the interlocked areas of the LHC into service zones and beam zones is a topology constraint for the access systems, which must take into account a two layer model with beam zones embedded within service zones and often accessible only through the service zones. This constraint has many consequences on the number of access points, their locations and the access procedures to be followed. The complexity of the access systems stems in part from this topological constraint.

5.2.4 Constraints for Access Sectorisation

Access sectorisation is the subdivision of the access zones into smaller and more manageable areas. Access sectorisation is driven by different needs which are detailed below:

Experimental Areas

The experimental areas of the LHC contain the four large experimental detectors and the associated electronics and ancillary equipment. The experimental detectors are owned by experimental collaborations and are under their responsibility. It follows that the collaborations want to control and restrict the occupancy of the experimental areas to their collaborators and the CERN support personnel.

Because the equipment in the LHC accelerator tunnel and in the experimental areas will be very different, together with the people entering these different areas and the risks attached to the equipment in these areas being different, it has been decided to physically separate access to the LHC accelerator from access to the LHC experimental areas. Passages are nevertheless provided for emergency exit in both directions. In most cases (ALICE, ATLAS, LHCb), the access shafts used by experimental collaborations are different from the shafts used to access the accelerator.

Patrols

Access sectorisation is primarily needed to help with the Patrol procedure - which is a search and secure procedure to ensure that no personnel are left in the interlocked areas when the accelerator is about to restart for beam operation or equipment tests. The Patrol is also intended to check that the interlocked areas are in a safe state to restart beam operation or equipment tests, for example that no work area is still active and that all tools and other equipment have been safely removed.

Because the topology of the LHC underground installations is complex and in order to limit the number of persons and the time required to patrol the accelerator, the interlocked areas must be sectorised into topologically more simple patrol sectors.

Equipment Tests

It must be possible to perform equipment tests in the accelerator tunnel while the LHC is not running with beam and is generally in the access mode of operation. Some equipment tests generate significant hazards from which the personnel must be protected. This equipment is normally located in well defined areas such as the RF zone in the long straight section in Point 4. To help with the closure of zones for equipment tests while allowing access in adjacent zones, the equipment test areas are enclosed within an LHC access sector.

5.2.5 Access Sectorisation.

The access sectorisation [6] of the interlocked areas of the LHC has been derived from the different constraints above after several iterations with the equipment groups concerned, the accelerator operations group and representatives of the collaborations for the experiments. The result is necessarily a compromise which can be revised at a later stage. Wherever possible the sectorisation has been kept to a minimum, while still allowing evolution of the system.

The sectorisation as presently approved in the LHC baseline comprises a total of 74 access sectors, separated by 39 sector doors and gates and 63 end zone doors. Access into the LHC is possible through 6 access points leading into a service zone, 11 access points leading from a service zone into a beam zone, and 11 access points leading directly from a non-interlocked area into a beam zone.

5.3 LHC ACCESS SAFETY SYSTEM

5.3.1 Rules for Access Safety

The interlocked areas of the LHC must be completely empty of personnel and access forbidden when the accelerator is running with beams, or is ready to start beam operation.

When the accelerator is operating with beam or for equipment tests, any access violation of the interlocked areas of the LHC must automatically and systematically stop the circulation of beams and prevent the injection of new beams into the LHC as well as to stop or limit the powering of some specific equipment of the accelerator.

On the other hand when the accelerator is stopped and access has been granted to an interlocked area of the LHC, any starting up of dangerous equipment must be forbidden and any situation presenting a risk for the health or safety of persons must trigger the immediate evacuation of the concerned areas.

5.3.2 Important Safety Elements

Host state regulations define the concept of important safety elements (ISE) which applies to equipment or systems involved in the protection of personnel. The ISE can be either elements generating a specific risk, or elements designed to help prevent or limit the exposure to risks. In both cases these elements must be interlocked under certain conditions.

All ISE are identified on the schematics of the interlocked areas of the LHC per site, in a separate document [6]. Each ISE in the LHC is identified on an ISE identification sheet, which contains all the information relevant to this ISE and in particular its name, function, exact location and the detailed definition of all safety signals to and from this element, including the clear definition of the SAFE and UNSAFE status of the element. As an example, the SAFE status of a sector door is returned when the redundant detectors on the door indicate that it is “closed” and “not open”. Alternatively a door for which the detectors indicate that it is at the same time “closed” and “open” – indicating a detector or communication fault – would be UNSAFE. All such combinations must figure on the ISE identification sheet.

Three classes of important safety elements are defined: ISE-access, ISE-beam and ISE-machine.

ISE–access

The equipment dedicated to the access into the LHC and which can trigger the stop of the accelerator are classified as important safety elements for access (ISE-access). This equipment forms the boundary of the interlocked areas of the LHC. The following have been classified as ISE-access:

- Personnel access device and material access device: these are key elements of the access points belonging to the LHC access control system, but will be monitored by the LHC access safety system as physical barriers that can prevent entry into the interlocked areas.
- Sector doors and grids: these separate two access sectors in the interlocked areas and are equipped with electro-mechanical locks including an emergency passage mechanism from both sides. Sector doors usually act as ventilation barriers as well, while sectors grids are used where the ventilation flow must be maintained.

- End zone doors and grids: these separate two sectors or zones where passage is not allowed except in emergency conditions. They are equipped with locks providing only an emergency passage mechanism from both sides. The only way to open an end zone door or grid is to force open the lock mechanism for an emergency passage. In a limited number of special cases all related to the geometrical survey of the accelerator around the experiments, some end zone doors will be equipped with an additional lock to allow limited passage without triggering the emergency passage.
- Patrol box: these are located close to the access points and serve to validate the patrol procedure of the relevant access sectors.
- Safety key: these elements are linked to a key rack located at each access point. The safety key is liberated from the rack by the LHC access control system. The number of safety keys is limited in order to limit the number of persons present at the same time in a given access zone. The presence of all safety keys on a rack or the absence of at least one safety key from the rack is monitored by the access safety system.
- Fixed grids, mobile shielding walls etc.: any physical obstacle that can be used to block a passage to guarantee that no one can go through this passage and therefore ensure the "tightness" of the interlocked areas.

ISE-beam

The equipment of the LHC accelerator which are concerned with the protection of personnel from the risks associated with the circulation or injection of beams into the LHC are known as important safety elements for beam operation (ISE-beam). Further a distinction is made between the ISE-beam for circulating beam and the ISE-beam for injected beam.

The list of ISE-beam element is in the process of being finalised. In drawing up this list care has been taken to choose elements for which the SAFE and UNSAFE status can be readily and clearly defined. The chosen elements must also be able to fulfil their safety function in isolation and not require being in conjunction with other elements. In particular, each of the ISE-beam for circulating beam must be able to eliminate the circulating beam from the accelerator independently of the other elements.

ISE-machine

The equipment of the LHC accelerator which are concerned with the protection of personnel against risks other than the presence of beam are called important safety elements for machine operation (ISE-machine). The ISE-machine must be stopped and interlocked before access can be granted to certain zones of the LHC interlocked areas. At the time of writing, the list of ISE-machine is in the process of being finalised.

5.3.3 INTERLOCK CHAINS

An interlock chain is composed of an ensemble of ISE which, together and through the actions of the LHC access safety system, ensure the protection of the personnel in a given zone. The smallest zone to be covered is an access sector; the largest is the ensemble of the interlocked areas of the LHC.

As a minimum, an interlock chain contains all the ISE-access forming the envelope of the zone to be protected. The other ISE-access elements belonging to this zone are, in most cases, also part of the interlock chain. The ISE-beam or ISE-machine associated with the danger from which protection is required will also form part of the chain.

The following rules have been used to establish the interlock chains:

- A given ISE-access can belong to several interlock chains.
- A given ISE-machine can in principle belong to several interlock chains but as much as possible, a given ISE-machine should belong to only one interlock chain.
- An ISE-beam and an ISE-machine cannot belong to the same interlock chain.
- All ISE-beam belong to one and only one interlock chain. This chain is known as the principal interlock chain.
- The interlock chains containing an ISE-machine are called Local Interlock Chains.

Principal Interlock Chain

This chain contains all ISE-beam including those for injected beam as well as those for circulating beam. The principal interlock chain also contains all the ISE-access elements of the LHC and not just the ISE-access elements which form the envelope of the installation. This chain is always active independent of the status of the LASS or the access modes applied to the access points.

Local Interlock Chains

These chains contain all of the ISE-access elements and all of the ISE-machine for a given sector or ensemble of sectors delimiting an access zone. This chain is active unless a local interlock chain for test purposes has been enabled for the zone in the LASS and, in addition, the access mode for this zone is the test mode.

Local Interlock Chains for Tests

These chains contain a subset of the ISE-access elements. Each one should contain at least all of the ISE-access elements which make the envelope of the sector to which it belongs, with the possible exception of the personnel access device of the sector access point. In addition, each chain will contain a subset of the ISE-machine elements belonging to a sector, or ensemble of sectors, which delimit a test zone. Excluding an ISE-machine from the interlock chain will allow the operation of this equipment for test while access is given under special conditions (test mode). Conversely, excluding an ISE-access (for example the personnel access device of the access point) from the interlock chain will allow, under special conditions (i.e. test mode), the access to the zone while the equipment is under operation in that zone. A chain of this type is only active when it has been enabled for a zone in the LASS and the access mode for this zone is the test mode.

Interlock chain documentation

Each interlock chain is identified in a configuration data sheet which contains all the information about the interlock chain, including its type, function and an exhaustive list of the associated ISE with reference to the corresponding ISE identification sheets. A list covering all interlock chains together with their corresponding configuration data sheets is grouped in a single document. At the time of writing the list of all interlock chains for the LHC is in progress.

5.3.4 Principle of Interlocking Mechanism

Access safety is ensured by applying a mutual locking or interlocking mechanism between an ISE-access element and the ISE-machine, or ISE-beam element of an interlock chain. This mechanism follows the following rules:

1) All ISE-access elements in an interlock chain must be in a safe position in order for an operator to manually remove the inhibition commands on the ISE-machine or ISE-beam element.
   In order to manually (by action of an operator) remove the inhibit commands which maintain the ISE-machine or ISE-beam element of an interlock chain in a safe position, all ISE-access elements of the same interlock chain must be in a safe position.
   In other words, the access sector where the ISE-machine or ISE-beam elements are located must be closed and empty of all personnel. Once the inhibit commands have been manually removed the ISE-machine or ISE-beam element can be activated.
2) The unsafe position of at least one ISE-machine or ISE-beam of an interlock chain automatically and systematically generates an inhibit command on the access control equipment (e.g. identifier readers) associated with the ISE-access elements of the same interlock chain.
3) The unsafe position of at least one ISE-access element in an interlock chain automatically and systematically generates an inhibit command on all ISE-machine or ISE-beam elements of the same interlock chain.
4) All ISE-machine or ISE-beam elements of an interlock chain must be in a safe position in order for an operator to manually remove the inhibition commands on the ISE-access, thereby allowing the operation of access control equipment.

5.3.5 Main functions of the LHC Access Safety System

The complete list of all safety functions of the LHC access safety system is in the process of being defined. However, the main functions are outlined below:

Monitoring the interlocked areas when operating with beam.

When the accelerator is operating with beam, i.e. when the machine equipment is powered and the beams are either circulating or about to circulate, the LHC access safety system monitors the integrity of both the envelope and the internal sectorisation of the zones where access is prohibited. Any loss of integrity, such as an intrusion, triggering of an emergency stop (AUG), uncertain or incoherent state of a door, gate or other access element is detected by the LHC access safety system which automatically and systematically triggers an inhibit on the equipment presenting a danger for the personnel and hence stops the accelerator. Moreover, the information about the loss of integrity is transmitted to the beam interlock system (part of the LHC machine protection system), which protects the sensitive components of the accelerator against hardware failures. This link between the LHC access safety system and the beam interlock system is a redundant path for stopping the circulating beams in case of loss of integrity of the access envelope of the LHC.

Establishing conditions for access operation.

In order to establish conditions for access operation, the operators first stop the accelerator equipment from the operation consoles using the LHC control system. Through the LHC access safety system the operators then stop and inhibit the restart of the equipment involved in personnel safety (ISE-beam and ISE-machine). Once these conditions are met the operators can lift the inhibit on the operation of the access control equipment (ISE-access) and can then operate these elements via the LHC access control system.

Monitoring the interlocked areas when operating with access.

When the accelerator is operating for access, i.e. when the access equipment is actually operated or can be operated, the LHC access safety system monitors the equipment involved in personnel protection (ISE-beam and ISE-machine) and prevents any abnormal situation that could present a danger for the persons present inside the interlocked areas. In the case of abnormal situations, the LHC access safety system must inhibit the operation of the LHC access control system, thereby preventing access into the areas concerned. In addition, if necessary the evacuation of the areas will be triggered via the emergency evacuation system.

Establishing conditions for beam operation.

Prior to establishing conditions for beam operation, the zones that have been accessed may have to be patrolled by a team according to a search and secure procedure that ensures that no personnel are present in the interlocked areas, that the equipment and the areas are in a safe state for beam operation and that all ISE-access equipment are in a safe state. Once all ISE-access elements of the LHC are in a safe position the operators can lock the doors and access points and inhibit the operation of the LHC access control system via the LHC access safety system.

Prior to removing the inhibit signals on the ISE-machine and ISE-beam elements which would authorise the operation of the LHC with beam, an audible signal emitted by the sirens used for the emergency evacuation system is activated for a preset time duration. This signal acts to warn anyone still be within the interlocked areas of the accelerator of the imminent arrival of beam. When the LHC access safety system receives confirmation that the sirens have been sounded for the preset time, the inhibit signals on the ISE-machine and ISE-beam are removed and the operation of the LHC with beam becomes possible.

5.4 LHC ACCESS CONTROL SYSTEM

5.4.1 Introduction

The LHC access control system allows the operation of access equipment to manage the access and egress of personnel and material in the interlocked areas of the LHC. The LHC access control system is designed as a complementary system to the LHC access safety system and must be simple, reliable and highly available.

The LHC access control system will be the most visible part of the access systems for the users and it should not limit the operational time for beam in the LHC nor should it unduly prevent authorised users from accessing in the interlocked areas when safety conditions are met. The LHC access control system must be active and ready, when required, 24 h per day and all year-round. Preventive maintenance and upgrades must not impact on this availability. In order to be immune to potential network unavailability, or saturation, the LHC access control system does not permanently rely on networks or remote databases.

For the purpose of access control, each sector of the interlocked areas controlled by one or more access points is generally independent from the others, while for safety aspects the interdependencies are handled by the access safety systems through cabled links.

Because access control to the LHC must also be maintained during the annual long shutdowns, when the control room is not staffed on a 24 hour basis, the LHC access control system is designed to function automatically and autonomously and to not generally require personnel for its operation except when human supervision of the process is specifically foreseen (see access modes below). When necessary, human supervision of access will be performed remotely from a control room with data, video and audio communication between the access point and the control room.

Access to all interlocked areas of the LHC is always controlled by the LHC access control system. No passage can be left open and unattended. The LHC access control system remains available in the event of a power cut in order to allow the evacuation of all personnel under safe conditions. The LHC access control system must timestamp and log all events. Timestamping must be made according to standards set by the LHC logging system.

The LHC access control system hardware that will be located close to the beam path is likely to be subject to electronic upsets and other effects coming from prompt radiation when beam is present. To minimize the impact of beam operation on the LHC access control system it must also be possible (without degrading the safety level) to switch off sensitive equipment when the LHC is not in access mode and might be operating with beams.

The LHC access control system is designed and will be built in an extendable and scalable way to allow possible add-ons or a reconfiguration of access equipment or zones at a later stage and to allow future implementation of the same system on other CERN accelerators such as the SPS and the PS, or other CERN installations.

The LHC access control system is described in detail in a Functional Specification [2].

5.4.2 Access Modes

The access mode determines the conditions under which access can be granted in an access zone. Different access modes can be assigned to an access zone. There are three main access modes (Closed, Restricted and General) and two additional specialised modes (Test and Patrol). Each mode is described below.

Closed mode

No access is allowed. Beam or other hazards could be present in this mode and the safety conditions are handled by the LHC access safety system. Alternatively, when safety conditions for access are met, this mode can be set for operational reasons in order to prevent anyone from entering into the zone. This mode, set for all access points of the LHC, is a prerequisite to LHC beam operation.

Test mode

This mode is used when equipment which is undergoing tests in the access zone generates equipment specific and significant hazards. These hazards might mean either no entry at all while the tests are ongoing, or only entry by specially trained personnel. Access is therefore allowed but is restricted to a list of registered specialists with a special authorization. There is no remote supervision from the control rooms. The safety is ensured by the access safety system. In this mode all personnel accessing must take their own safety token (see below) at the access point.

Restricted mode

This mode is used when there are operational constraints on access duration, the type of work to be performed, or when the occupancy of the zone must be limited. Access is allowed after approval by a control room operator. This supervision by a control room operator is only needed for operational aspects (duration and time limits, type of work to be performed, optimisation of accelerator beam time) and is not required for safety reasons. In this mode all personnel accessing must take their own safety token at the access point.

Patrol mode

This mode is used during the period when a patrol is being conducted in the zone. This walk-through procedure by a patrolling team is intended to check that no personnel is present in the zone that the installation is safe before powering or activating equipment and before injecting beam into the accelerator. Access is allowed after approval by a control room operator. The patrol itself is under the responsibility of the patrolling team. In this mode all personnel accessing the zone must take their own safety token at the access point.

General mode

This mode is used when there are no operational constraints on access such as duration or type of work to be performed. Access is allowed without prior approval by the control rooms. In this mode a safety token is not delivered at the access point. Any access in this mode implies a patrol before equipment test, test mode, or beam operation can resume.

Access modes can only be applied or changed when the LHC access safety system is in a state that authorizes access operation. Access modes can only be applied or changed manually from the accelerator control room, via the LHC access control system. Access modes are not changed automatically, in particular a fault in the system, an intrusion or the starting up of dangerous equipment does not change the access mode. All mode transitions are allowed through the LHC access control system and the consequences for safety are handled by the LHC access safety system.

5.4.3. Main Functions

When the accelerator is stopped and the safety conditions for access are met (absence of an access veto from LASS) the LHC access control system positively identifies the person who wants to access, checks the relevant authorizations and related safety training and finally controls the access equipment according to pre-established procedures triggered by the user at the access point. The LHC access control system also limits the occupancy of the interlocked areas and helps with the evacuation of the zones before the restart of the accelerator.

When the safety conditions are not met (presence of an access veto from LASS), the LHC access control system acts as a physical barrier preventing access to the interlocked areas of the LHC.

5.4.4 Personnel Access

The LHC Access Control System ensures that only one, positively identified and fully authorised, person enters into a zone for each access granted:

Identification

Access into an interlocked area of the LHC is subject to prior identification of the person. The identification is encoded on an identification chip. In order to reasonably ensure that everyone accessing into a controlled area of the LHC wears their personal dosemeter, while only requiring a single object to be checked at the access point, the personal dosemeter casing supplied by CERN is used as the support of the identifier chip and both are tightly bound together. The identifier is read remotely, without contact or manipulation by the user.

Authorization

Access into an interlocked area of the LHC is subject to a prior authorisation which is checked by the LHC access control system at the access point. Access authorisations can be valid for a specific access zone or an ensemble of access zones, for specific access modes where necessary (see Test mode above), for a defined work schedule (daily, weekly, annual), and until an expiration date is reached (e.g. end of contract or end of shutdown work). Authorisations are stored in a central database and mirrored at each access point.

Safety Training

Access into an interlocked area of the LHC is subject to having successfully completed the appropriate safety courses which are checked, together with associated expiration dates, at the access point. Information on safety courses and expiration dates are stored in a central database and mirrored at each access point.

Positive Identification

Access into an interlocked area of the LHC is subject to positive identification by means of a biometric verification of the identity of the person. The biometric method chosen is the iris pattern recognition. The biometric data of the user, acquired by the LHC access control system at the access point, is compared to fiducial biometric data. The biometric reader to acquire the live data of the user is installed within the personnel access device and the data acquisition will be made without contact and will be non-invasive. The fiducial biometric data is kept in an encoded format in a central database and mirrored at each access point.

Airlock

Personnel access will be physically done through an airlock to ensure that only one person at a time can enter into the interlocked areas of the LHC. This personnel access device is based on industrial equipment for which CERN already has considerable experience. It allows the passage of one person at a time but does not trap the person inside the mechanism through the simultaneous movement of the sliding doors on both sides. In case of emergency the system can be forced open to allow unrestricted passage e.g. for interventions of the fire-brigade or the passage of a stretcher.

Counters

The LHC access control system keeps a record of the number of persons present in a zone, their identities, the date and time of entry and the duration of the access. This data is displayed at the access point and available in the accelerator control room and the experimental control rooms for their respective zones. A maximum number of persons that can simultaneously be present in each access zone will be defined for safety reasons. When the maximum number of persons in an access zone is reached, the LHC access control system inhibits the entry procedure until the number of persons in the zone is again below the maximum. At this stage, the access procedure for entry is re-enabled.

Time Constants

In General access mode, the complete procedure to access into an interlocked area of the LHC will take less than ten seconds. In Test mode the access time is slightly increased because of the additional token delivery process, but should take less than 12 seconds. In Patrol or Restricted mode, the access time is further increased because of the interaction with a control room and this time (queuing of access requests and dialogue with the operator) can hardly be quantified.

The complete procedure to exit from an interlocked area of the LHC will take less than ten seconds.

5.4.5 Material Access

The LHC access control system allows the passage of material in both directions through a dedicated airlock device which is distinct from the personnel access device. The material is introduced on one side of the lock-chamber through the first door and is later extracted from the lock-chamber through the second door which can only be opened when the first door is closed. Not all access points will be fitted with a material access device, which will only be placed in certain key locations [6].

In rare cases where the dimensions of the material or equipment is larger than the internal dimensions of the material access device, the closest end-zone door or sliding shielding wall (“bouchon”) will be opened. This can only be done on request and under strict supervision by a person who will be responsible for limiting the duration of this opening and making sure that no personnel uses this opening to access into the interlocked areas instead of using the personnel airlock.

5.4.6 Additional Access Point Equipment

At each access point, one display attached to the access point controller presents the information relevant to the operation of the access point (in graphical and/or textual form). A set of visible indicator lights indicates the access mode of the access point and if necessary the presence of an access veto from the LHC access safety system. Different audible and visible signals are used to help the users at the access point and indicate failures in the procedures or alarms requiring attention. The visible signals will be labelled with the relevant information.

The LHC access control system is fitted with a full-duplex intercom system between each access point and the access consoles in the control room. Video supervision of the access point with displays in the relevant control rooms is also provided.

In Restricted, Patrol or Test access modes, anyone accessing must take a personal safety token at the access point and carry it with them during the whole access. The token must be returned to the same access point from which it was taken as soon as the access is finished. The number of safety tokens at each access point will be between 8 and 48 depending on the access point.

Hardware test or beam operation cannot resume unless all safety tokens are returned to the access point from which they were taken; this is ensured by the LHC Access Safety System.

5.4.7 Delegation of the Supervision

The interlocked areas of the LHC include the four large experimental caverns (UX15, UX25, UXC55 and UX85 in part) housing the four experimental detectors.

Because the hazards, personnel concerned and operational constraints in experimental areas are very different from those found on the accelerator side, it might be difficult for an operator in the accelerator control room to make an educated decision to allow or deny access to experimental areas during Restricted or Patrol modes.

The experimental control rooms will be able to manage the supervision of access control to their respective experimental areas in Restricted or Patrol Modes. Each of the four experiments control rooms will be equipped with an access console with functionality limited to this supervision process.

REFERENCES

[1] Système de Sûreté d'Accès du LHC, LHC-Y-ES-0005-10-00 – EDMS 362437

[2] The LHC Access Control System, LHC-Y-ES-006-10-00 – EDMS 386759

[3] Calculation of radioactivity dose rates…

[4] Radiation Safety Manual (Safety Code F)

[5] Accessibilité des Zones Verrouillées du LHC en Fonction de la Classification Radiologique – LHC-Y-ES-0001-10-00 – EDMS 352114

[6] Sectorisation Accès des zones verrouillées du LHC, – LHC-Y-ES-0002-10-00 – EDMS 344410

[7] Systèmes généraux de sécurité du LHC, – LHC-P-ES-0002-10-10 – EDMS 346512

CHAPTER 6

COMMUNICATION NETWORKS

6.1 INTRODUCTION

The majority of the active computing and control devices which will be used during the installation, commissioning and operation of LHC will be remotely accessible from one of the control rooms and from the commissioning stands. Industrial control devices will mostly be accessible via field-bus attachments, other devices will be connected to one of the CERN communication networks. The computers in the accelerator will also have network access to the CERN internal computing services and resources, in particular to databases and file storage.

A comprehensive network infrastructure which provides IP/Ethernet connectivity in most areas of the accelerator is being installed to support the communication services. The exceptions are in areas where the radiation levels expected are too high for active networking components to work reliably. Connections to the high capacity network are specifically possible in the surface service areas, in the underground service galleries and the alcoves.

The Technical Network will not be available for connections along the accelerator in the main accelerator tunnel because of the high radiation levels expected. During the installation and commissioning phases, a medium capacity VDSL cabled network distribution will be available there, with a connection point every 106 m along the beam pipe. The VDSL installation cannot be used while the accelerator is running because of the radiation levels, but the passive components will remain in place and can be re-activated at no cost should the need arise again later in the life cycle of the accelerator.

The data communication network for the LHC will be integrated into a new infrastructure, broadly known as the Technical Network. When the LHC enters the commissioning phase, the Technical Network will comprise the controls network for the PS and SPS accelerators as well as the network used for monitoring and control of the technical infrastructure at CERN. This network will not have direct access to the Internet, but can access the services on the CERN general network, i.e. the campus network.

The interconnection switches between the technical and general networks are located at two separate locations, CCR and PCR. In order to isolate the Technical Network and protect the operation of the technical installations, it is possible to open these interconnections. Recent operational experience, however, has shown that this protection mechanism is insufficient to protect the site from malicious intruders. The current policies, presently under review, will be strengthened and refined, so that by the time of LHC commissioning, more powerful monitoring tools and more efficient controls will be available for the protection of the CERN networks.

It is expected that several hundred people will be working underground during the installation and commissioning phase of the LHC. To provide voice communication between the members of the teams and between the teams and the external world, the coverage area of the CERN GSM portable telephone will be extended into the LHC underground areas. The distribution of the GSM signals will also facilitate wireless GPRS connectivity on portable devices wherever there is GSM coverage.

The general installation of fixed telephones will be limited to safety systems. Usage of such telephones will provide immediate voice communication to the control centre of the fire-brigade. In addition, a Level-3 alarm will be raised when the hand-set of an emergency phone is un-hooked.

An underground VHF radio diffusion system will provide the CERN fire-brigade with portable radio communication identical to the one they have on the surface. No dedicated portable equipment is needed for the underground areas. The emergency service will therefore be able to use a single portable communication system on all CERN sites.

6.2 PASSIVE NETWORK INFRASTRUCTURE

A significant passive infrastructure is needed to support the communication network. A cabled, as opposed to a wireless infrastructure, has been chosen for the data network in order to reach a sufficient level of electromagnetic compatibility (EMC) between communication equipment and the accelerator components.

The cabled network infrastructure will ensure the highest capacity at a predictable performance level of the communication network.

It is important to minimise the time needed for fault isolation and repair. The duration of such interventions represents down-time for the accelerator and must be contained. A carefully planned and executed installation of the passive infrastructure is vital for efficient maintenance of the network and hence, for the operation of the accelerator.

The installation of the cable infrastructure for the communication systems, optical fibres and copper cables, is described in Chap. 7.

6.2.1 Optical Fibre

Optical fibres will be used to support the backbone of the data communication networks in the LHC. In addition, they will be used in the local network distribution as determined by cost, distance and capacity considerations. The optical fibres are installed in mini-tubes, which may contain up to 70 fibres each. The mini-tubes are inserted in protective ducts which can be directly buried in surface trenches or laid on cable trays, where such infrastructure is available. Fibre "blowing" technology is used wherever possible in order to facilitate fibre maintenance and future extensions. The installation of the optical fibres is described in Sec. 7.8 of this report.

The cables situated in the machine tunnel will be subject to radiation, which will damage the fibre over time. It is expected that the light transmission capability of the fibre will deteriorate so much that it must be replaced in the most exposed zones of the machine after every 3-5 years of operation at nominal beam intensity. The installation technique, using mini-tubes contained in ducts, lends itself to rapid replacement of defective fibres. The optical characteristics of the fibres in the main fibre paths will be continuously monitored as described in Sec. 7.8.4. Based on trend analysis from the monitoring system, the replacement of defective fibres can be planned within the normal maintenance windows during machine operation.

Optical fibres are also used to interconnect the many GSM Base Transceiver Stations (BTS) on the site. These optical fibres share the installation paths with the data communication fibres. CERN only provides the passive infrastructure of these interconnections, i.e. the installed, terminated and tested optical fibre, while the GSM operator is responsible for the transmission system.

Fig. 6.1 illustrates the paths and endpoints of the optical fibre installation. The surface trenches cross private and public land, which constrains CERN for access for installation and maintenance. Not shown are the many man-holes dug in the ground at branch-off points.

Tab. 6.1 shows the lengths of the fibre paths passing through the machine tunnel. The trench crossing the land between LHC Point 1 and Point 8 is 3.8 km long. Tab. 6.2 shows the lengths of the fibre paths on the surface.

Table 6.1: Distances in kilometres between the eight LHC Service (SR) buildings, measured along the cable ducts of the optical fibre installation.

	SR1	**SR2**	**SR3**	**SR4**	**SR5**	**SR6**	**SR7**	**SR8**
SR1		4.2						4.2
SR2	4.2		5					
SR3		5		5				
SR4			5		4.2			
SR5				4.2		4.2		
SR6					4.2		4.4	
SR7						4.4		4.4
SR8	4.2						4.4	

Table 6.2: Distances in kilometres between the Prévessin Control Room (PCR) and the eight LHC Service (SR) buildings, measured along the cable ducts of the optical fibre installation.

	SR1	**SR2**	**SR3**	**SR4**	**SR5**	**SR6**	**SR7**	**SR8**
PCR	3.8	5.4	9.2	9.5	10.1	6.5	7.7	4.6

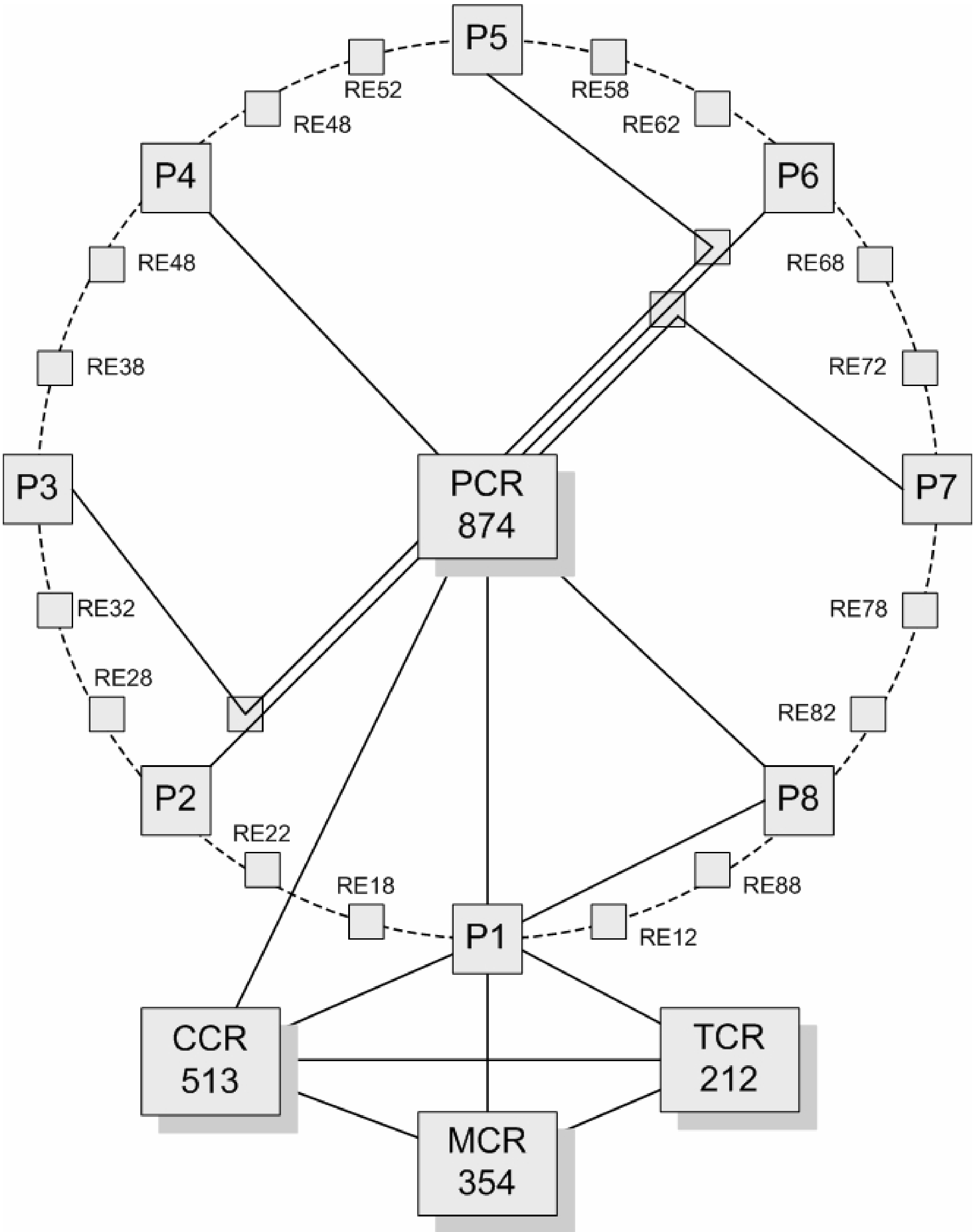


Figure 6.1: Installation paths for the optical fibres in LHC. The full lines show the surface trenches and the dotted lines show the ducts installed in the tunnel sectors.

6.2.2 The Leaky Feeder Antenna Cable

It has been specified that two voice communication systems must be available everywhere in the LHC underground areas [1]. The two systems are:

- The bi-directional VHF radio of the fire brigade,
- The GSM portable telephone system.

The goal is to unify and simplify the communication between personnel wherever they may be situated. The underground installation extends the coverage of the existing GSM and radio communication systems used on the CERN surface sites. In order to satisfy the requirement of universal coverage, segments of the leaky feeder antenna cable have to be present in all underground areas. These segments are interconnected by broadband splitters/combiners, which are passive components with a cut-off frequency at 2 GHz.

The GSM and the VHF communication systems use this omnipresent longitudinal antenna in diplex operation. A total of 49 km of antenna cable will be installed in the main LHC machine tunnel, the service and the access galleries, the experimental caverns and in the two transfer lines from the SPS. Most of the SPS machine is already equipped with such a system.

6.2.3 Copper Cables

The local network distribution is primarily based on structured cabling with telecommunication cable of category 5e terminated on standard RJ-45 connectors. Compliant cable installations reach up to 100 meters, measured along the cable path at 100 Mbit/s.

The VDSL network in the LHC tunnel is wired in a point-to-point configuration where the individual lines emanate from the underground service areas and the alcoves and are distributed along the beam line of the accelerator. Telecommunication cables of category 5e wires will be used for this installation.

It is possible that telecommunication cable of category 5e will become obsolete and that it will be replaced by a superior category 6 type before the LHC is brought into operation.

6.3 ACTIVE NETWORK INFRASTRUCTURE

The passive network infrastructure interconnects the active networking devices. Such devices are active in the sense that their operation requires the continuous supply of electrical power. This is a sensitive factor because an outage of the electricity supply will directly cause downtime of the communication network. Several precautions have been made to minimise the risk and consequences of such situations, see also Sec. 6.4.

6.3.1 Switching and Routing Equipment

There are two conceptual levels in the network: the backbone and the edge. The backbone is built of a number of powerful and complex IP/Ethernet switched network routers. The routers feed the edge devices where the user equipment is connected. The edge is built of much simpler devices: IP/Ethernet network switches.

The selected router models have been used at CERN for many years, their characteristics are well known and they have proven to be reliable in our environment. The backbone routers are designed for redundancy and have a modularised construction which allows hot-swap of the line interface modules. The redundant structure also incorporates duplicated switching fabric and power supplies which can be replaced without service interruption. The software is able to identify redundant paths to other networking devices and react intelligently when a broken path is detected.

The network switches are less complex and less specialised equipment. Several brands will be used in order to match the specific needs of the technical environment in terms of the number of outlets, power requirements and interface options for the interconnections to the backbone routers.

The routers support modules with transmission rates of 10, 100 or 1000 Mbit/s and modules exist with ports for both copper wire and optical fibre. Both multi-mode and single-mode optical interfaces are available. Gigabit ports on optical fibre are used almost exclusively in the links between the backbone routers. In the local distribution to the edge devices, the transmission rate will be determined as required by the number of connections and the expected performance of the end-user equipment.

In the Technical Network for the LHC, the complex components of the network have been lifted out of the underground areas and installed in the surface service buildings. What remain underground are essentially the edge switches, the optical fibre and the copper cable interconnections. There are several reasons for this decision: surface space is available at much lower cost and the accessibility for maintenance is much easier. In addition, the environmental conditions, i.e. radiation, humidity and temperature, can be kept under much stricter control in the surface buildings. The backbone routers of the LHC Technical Network are installed in the service building (SR) at each of the eight LHC intersection points, near the Prévessin Control Room (PCR) in building 874 and in the Computer Centre (CCR) in building 513 (Fig. 6.3).

The active networking devices honour quality of service options (QoS) in the TCP/IP protocol suite. The data communication network will therefore be well prepared to support latency and jitter-sensitive applications like real-time control, voice and video transmission.

6.3.2 Support for Mobile Telephones

The radio signals of the GSM telephone system are exchanged between the portable phones and the Base Transceiver Station (BTS) by means of the leaky feeder antenna cable. The installation of this passive component is described in Sec. 6.2.2. When the network is fully deployed, there will be two typical configurations of the BTS installations in the LHC:

- One BTS with its aerial is installed in each of the eight surface service buildings. It covers the surface area, and it feeds the leaky feeder antenna segment which descends the vertical shaft to the tunnel floor. There, a broadband splitter/combiner feeds the antenna segments in the relevant service and access galleries. The same splitter/combiner also feeds the antenna segments in the left and right direction of the adjacent long straight sections of the machine tunnel.
- One small BTS is installed in each of the 16 alcoves. It feeds the leaky feeder antenna cable going up to the mid-arc point of the machine tunnel. This BTS also feeds the antenna segment in the direction of the adjacent intersection point where it will join the other segment described above.

Each BTS will be connected by optical fibre to the Base Station Controller (BSC) of the GSM operator. The BSC will be situated on the premises of the operator, together with the Mobile Switching Centre (MSC) where the CERN communication traffic is inserted into the GSM operator's global communication networks. The network configuration, with BTS units distributed around the tunnel, will make it possible to implement a future personnel search facility on the existing infrastructure should the need arise.

The GSM infrastructure supports the 900 MHz band. Use of the higher GSM frequencies would have required installation of a more expensive and unwieldy antenna cable, and/or the installation of additional electronics in areas with significant radiation exposure from the circulating hadron beams.

The GSM operator also supports wireless GPRS data communication with access to the CERN computer networks. This will conveniently provide a data communication facility wherever there is GSM coverage, albeit at a modest speed of up to 50 kbit/s.

6.3.3 Support for the Radio of the Fire Brigade

The portable bi-directional VHF (~160 MHz) radio is the main communication equipment used by the fire-brigade during their interventions. The authorities of the host states have authorised one VHF radio channel for exclusive use by the CERN fire-brigade. Two other channels are available to allow communication with auxiliary rescue services in the two CERN host states.

The transmission of the radio signals shares the leaky feeder antenna cable with the GSM system in diplex operation. The VHF signal is picked up by an aerial at each of the eight intersection points. It is inserted onto the cable by means of a passive combiner device. In each alcove, a passive VHF by-pass device ensures VHF transmission continuity across the opposite antenna cable segments all the way to the mid-arc point of the tunnel. Fig. 6.2 illustrates how the major components are interconnected in a typical LHC Sector.

6.4 NON-INTERRUPTED OPERATION

The communication infrastructure will support voice and data communication without interruption during the normal operational cycles of the accelerator: commissioning, operation and maintenance. Both of these systems rely on the optical fibre infrastructure.

Cable trenches and ducts pass across private land to reach the remote sites of the LHC, which means that there is always a risk that someone gains access to the cable itself or to the man-holes at the cable junctions. Whether by accident or design, the cable may be damaged and transmission interrupted. Protecting the installation under lock and key is a precaution which may not be sufficient to deter an intruder. Sec. 6.4.2 describes how the Technical Network for the LHC is prepared to deal with this eventuality by providing redundant signal paths.

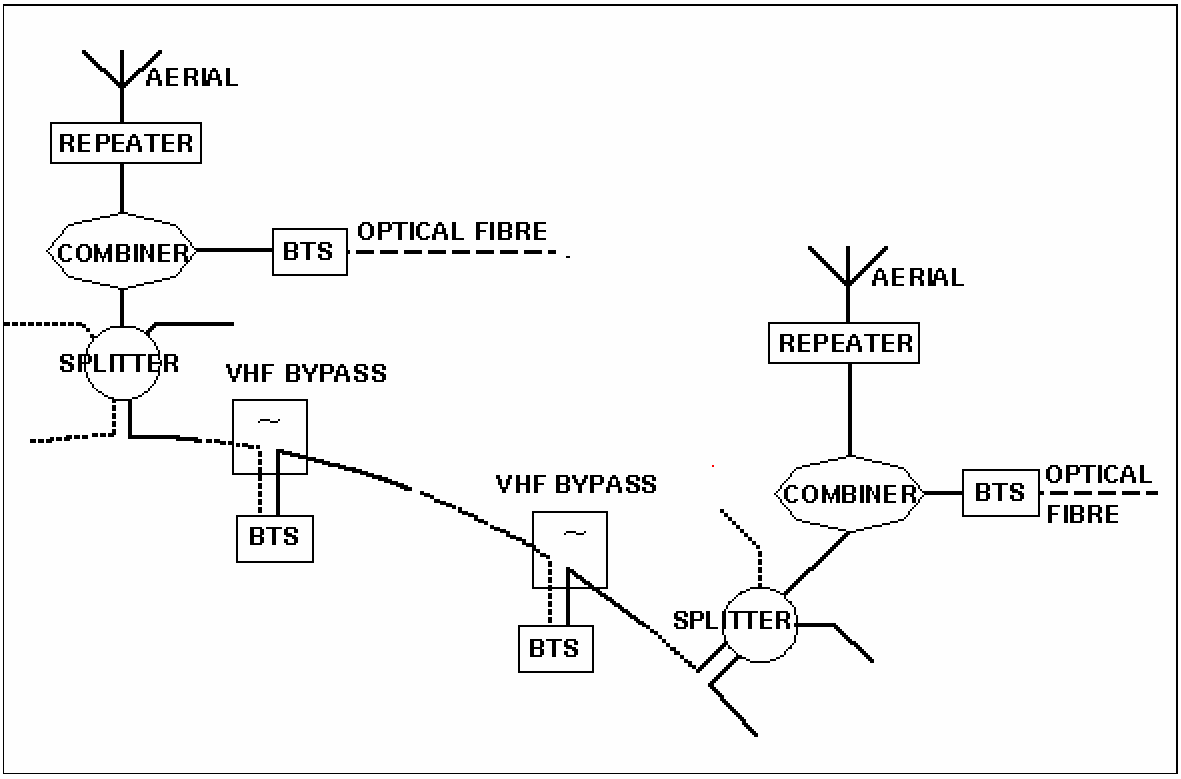


Figure 6.2: Schematic illustration of the leaky feeder antenna with the supporting components in an LHC sector.

Environmental perturbations may also occur during operation. It is important to minimise the impact such events will have on the availability and performance of the communication services. Risks are related to the reliability of the equipment and also to possible interference with the physical components of the installation: cables, connectors and active devices. Additional risk factors include the stability of the electrical power supply and the environmental conditions: i.e. the radiation level, the ambient temperature, the humidity and settling dust brought by the air flow due to the ventilation.

The primary voice communication system is the portable GSM telephone infrastructure covering the CERN sites in the two host states. The extended coverage underground is ensured by the optical fibres, the leaky feeder antennas and active BTS equipment which are installed both in the service areas on the surface and in the alcoves underground. The reliability of the GSM service relies both on the operational quality level of the service provider and on the availability of the CERN specific installation.

Data communication will be provided by the Technical Network. This is an IP/Ethernet network running on the cabled infrastructure using active routers and switches. These components are installed both in the surface service areas and in the underground galleries. Fig. 6.3 depicts the backbone routers and indicates their interconnections. The technical network alone does not offer the resiliency required to transport vital alarm information to the control rooms (TCR and SCR) in the sense laid down in the earlier alarm recommendation [2]. It has, however, been qualified as one out of the two diversely redundant transmission paths which are required for the transport of vital alarm information.

The equipment chosen to support the backbone of the technical network for the LHC has already been deployed on a large scale at CERN. The switched routers have been in operation for several years, first in the CERN campus network and then in the technical network to support controls for the PS and the SPS accelerators and for the support of the site-wide monitoring of the technical services. As a result of this experience, the network support team is already familiar with the equipment. Hence, the maintenance and service interventions will be executed efficiently and with confidence from the start.

6.4.1 Supporting Services

Experience of network support gathered from the operation of SPS and LEP, shows that the supply of electrical power is the most critical factor affecting network availability. With active components in the system, the availability of the communication network can never surpass the availability of the electrical power. Reliable, non-interrupted supply of power is mandatory in order for the data communication network to be useful for post-mortem data collection and transport of alarm information. For this reason, the supply of un-interrupted electrical power has been requested for technical network.

The situation is similar for the voice communication systems. Handling of fault and alarm situations in the accelerator often implies interventions in the underground by equipment specialists or the fire-brigade. Voice communication is vital for the experts to be able to work efficiently and to coordinate the actions between them and the control rooms. For this reason, the active components of the voice communication system need to be supplied with electrical power from an un-interrupted supply.

Electronic equipment is usually specified to operate in an ambient temperature of up to 40 °C. The ambient air temperature in many of the technical areas of the LHC can only be contained at that level by artificial cooling and ventilation. In the case of a break-down of these services there is a risk of service interruptions, caused by over-heating of the equipment, these failures may be transient or permanent. Operation can only be restored when the supporting services have been restored. If the equipment has been damaged by over-heating, it must be replaced which will incur additional cost and down-time.

6.4.2 Redundancy

The guiding principle for the design of the backbone of the data communication infrastructure is to avoid a single point of failure. In order to achieve this, at least two separate transmission paths between every node (router) in the backbone of the network are required. The paths are preferably chosen such that they do not share cable ducts which pass through the same physical area. The redundant paths traverse separate nodes, while the termination ports of the redundant paths reside on separate modules in the routers. By this design, a single failure, whether it is a broken fibre, a faulty termination port or a faulty module, will not be sufficient to completely isolate a router from all of its neighbours.

The optical fibre installation for the data communication in the LHC is rich enough to satisfy this requirement. Multiple interconnections between the backbone nodes of the communication network are possible by exploiting the fibre ducts in the surface trenches and in the underground tunnels. The backbone router in each of the eight LHC service buildings is connected to the PCR and also the CCR routers by the surface link and also through the two neighbouring service buildings through the left and right underground sectors. Fig. 6.3 shows the routers in the LHC backbone of the technical network and the redundant optical fibre paths which interconnect the routers.

If a broken link is detected, the router will activate the selection procedure of one of the back-up links. The choice will be based on the router’s perception of the links relative performance. It is worth noting that this mechanism will also make the communication system much less susceptible to service interruptions during maintenance phases of the accelerator.

The equipment which is the source of the LHC alarm messages is situated on the surface in each of the intersection points, where both the technical and the general networks are present. The alarm equipment will be connected to both networks by separate interfaces and ports, and the transmission of the messages will follow separate paths to the alarm servers for processing. The configuration eliminates a possible communication failure in the event that a single port or connection cable should fail.

The lines for the GSM service provider are terminated in building 513. From this location an SDH dual ring interconnects the major nodes in the GSM terrestrial backbone. The base stations, which are situated on the surface of each of the LHC intersection points and in the underground alcoves, are fed by point-to-point links from these nodes. This arrangement does not provide end-to-end redundancy, but a damaged optical fibre will only have a limited adverse impact on the local service.

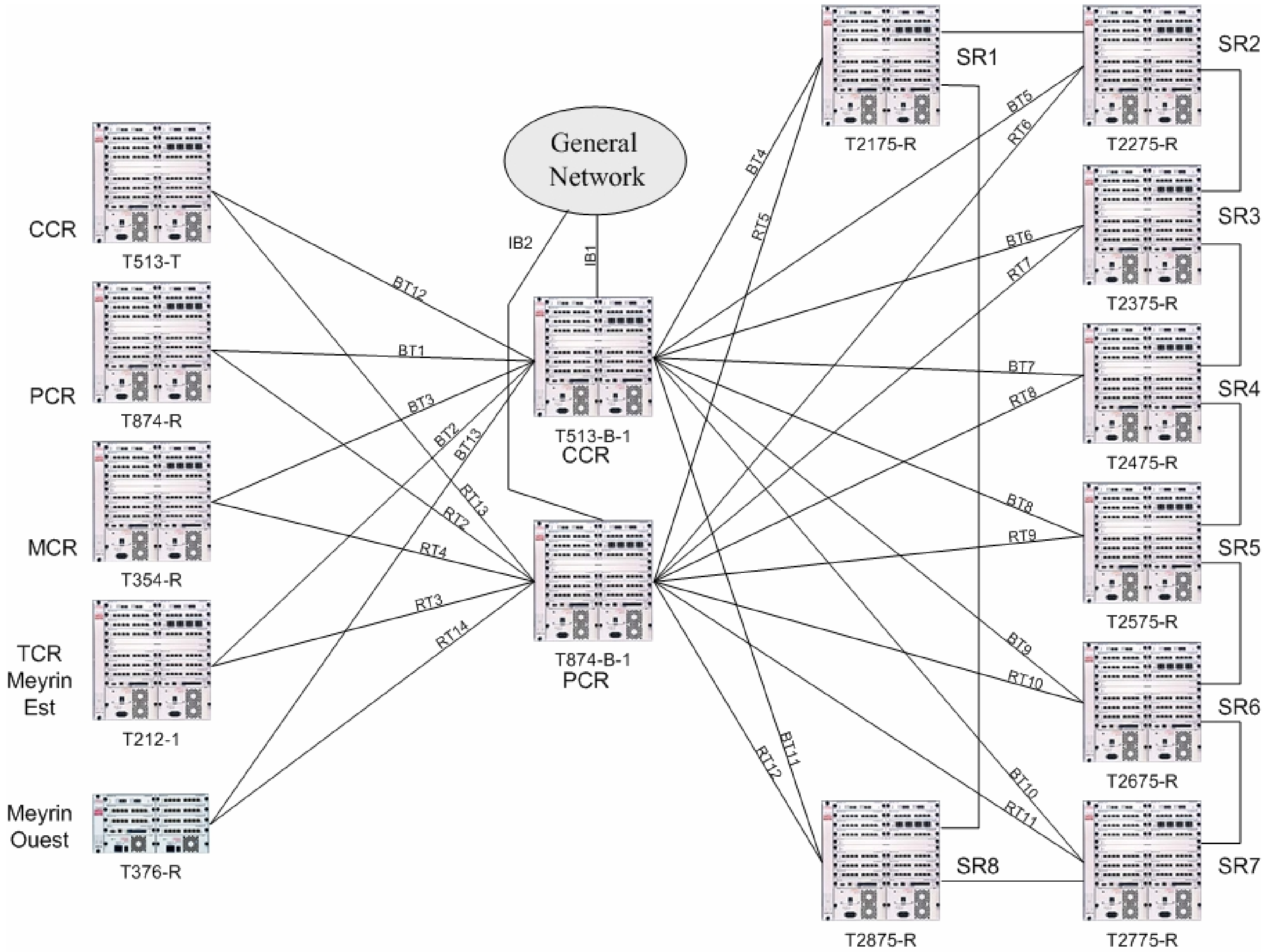


Figure 6.3: The principal routers in the backbone of the Technical Network and the redundant optical fibre paths.

REFERENCES

[1]. LHC Engineering Specification “VOICE AND DATA COMMUNICATIONS IN THE LHC UNDERGROUND AREAS” (LHC-C-ES-0002.00 rev 1.0)

[2]. Recommendations for the LHC Safety Alarm System (DG/DI/LE/jf/98-57)

CHAPTER 7

POWER DISTRIBUTION, SIGNAL CABLING AND OPTICAL FIBRE INSTALLATION

7.1 INTRODUCTION

The general design criteria laid down as a basis for the power distribution system of LHC are to a large extent taken from LEP. The equipment and installation specifications are those of the blanket order contracts for the electrical service. This ensures that LHC will be inscribed in the logic of maintenance and operation of the CERN power network.

The main 400 kV power supply line for LHC is from the Electricite de France (EDF) Bois-Tollot substation. The capacity of about 1000 MVA will be ample for the LHC and its injectors, which together will demand about 240 MW.

The main transformers for the LHC are the two 110 MVA, 400/66 kV units (EHT 4 and EHT 5) installed for LEP. No changes have been made to this part of the 400 kV substation for LHC. Although the LHC project does not require extensions to the substation, the older part, feeding the SPS and the North Area, was extensively renovated during the SPS shutdown between November 2000 and June 2001.

The energy transport system to the main load centres is the 66 kV cable system installed for LEP. For the LHC it has been extended by the addition of a 66 kV link to the substation SE 1 at Point 1. To feed this link, the Prevessin 66 kV substation was extended by a 66 kV feeder, identical to those installed for the links to the even Points of LEP. Calculations showed that the power needs for the machine systems in Point 5 could be covered by an 18 kV cable link. This represented a considerable saving, as the 66 kV link and the 66/18 kV substation, including its transformer, could be replaced by an 18 kV cable link from the substation SE 6 in Point 6.

The 18 kV power distribution system for LHC is similar to the system developed and installed for LEP and all the basic design features are maintained. The power consumption of LHC will be comparable to that of LEP, but the load distribution will be different. Due to the vastly extended sites for ATLAS and CMS the 18 kV substations SE 1 and SE 5 have been transformed into substations similar to those in the even points which are equipped with some switchboards dedicated to machine equipment and others dedicated to the general service systems.

The engineering principles for the 3.3 kV systems, the different low voltage systems and the safety systems have also been reused from LEP. Due to the many critical elements of the LHC, un-interruptible power supply (UPS) systems will be installed in all underground areas.

The technology of the general emergency stop system is retained but the logic is being adapted to the new machine.

The electrical engineering group covers two other activities: cabling and optical fibre installation. The cabling activity can be subdivided into signal cabling and high current D.C. power cable links. The latter has considerable importance for the LHC, as it covers all the warm links between the power converters and the cryogenic feed boxes. The optical fibre installation is an activity entirely contracted out to a specialised company. The technology and the specialized installation equipment is provided by the company; the system design, including equipment specification, the installation studies and lay-out has been made by CERN.

7.1.1 The situation After the Dismantling of LEP.

The dismantling of the LEP machine was mainly concentrated in the machine tunnel. Most of the LEP electrical infrastructure outside the tunnel was in a good state and could be recuperated for LHC without problems. As most equipment was installed between 1984 and 1988 it had seen about 14 years of operation. When LHC goes into service in 2007 there should still be 10 to 15 years of operational life in this equipment.

A considerable reconfiguration of the high and low voltage distribution systems is necessary, but a very high percentage of the equipment will be recuperated. Whenever possible the general service systems in the tunnel were not dismantled. In the zones of the tunnel where there were LHC civil engineering works all equipment was removed. An effort was made to prepare the LHC installation by modifications of the support structures left in the tunnel, but the high density of equipment and ducting in the tunnel has made considerable changes to the support infrastructure necessary.

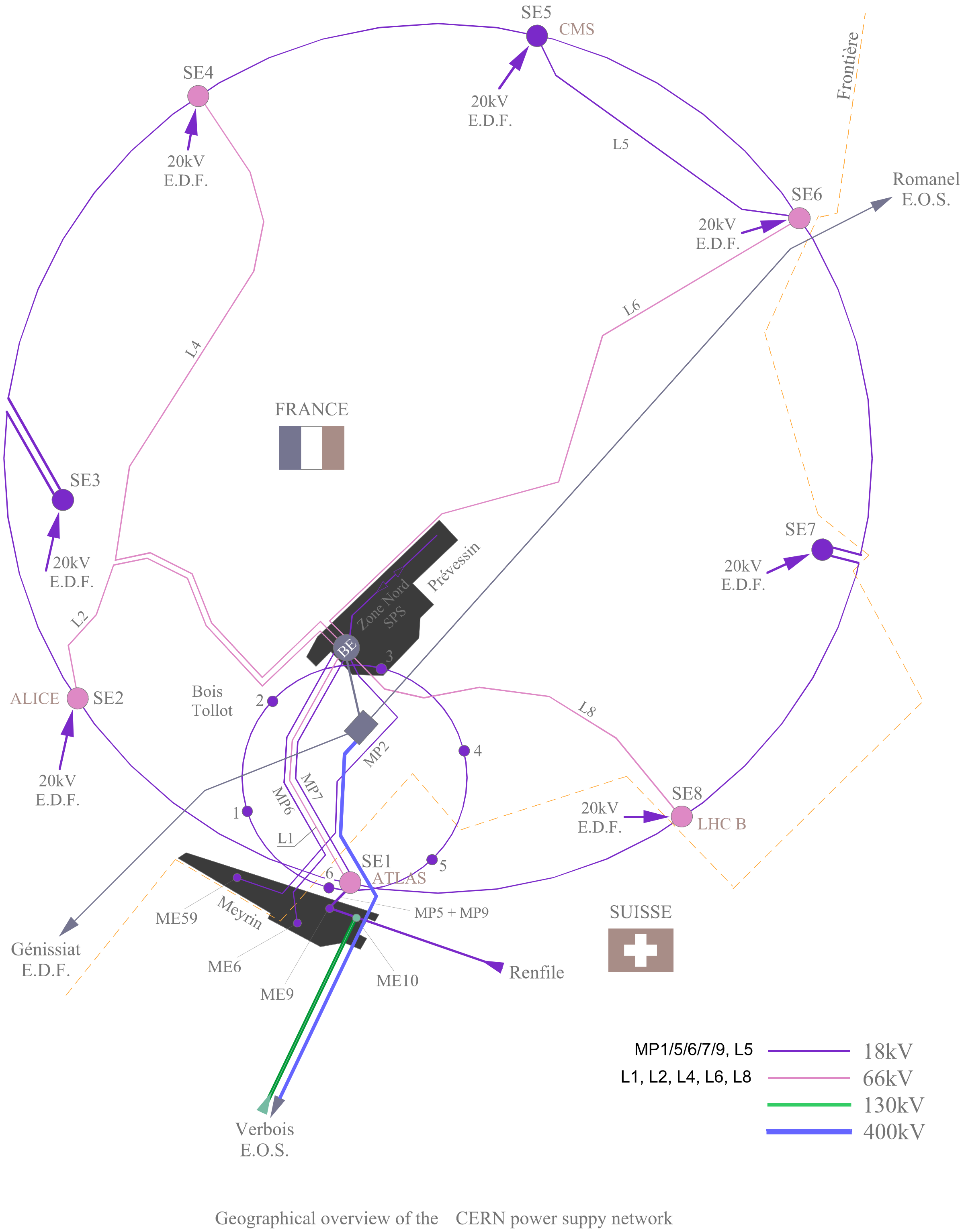


Figure 7.1: General lay-out of the CERN power network

7.2 POWER DISTRIBUTION

The following voltage levels are found in the LHC energy transport and power distribution systems:

400 kV EDF incomer, Prevessin main substation
130 kV EOS incomer, Meyrin main substation
66 kV Energy transport system, Prevessin main substation to main load centres.
18 kV Power distribution system, CERN wide.
3.3 kV Power distribution system, dedicated to large motor-compressor sets.
0.4 kV Power distribution, general service and dedicated services.

The design of the power distribution network is to a large extent determined by the load to supply. Tab. 7.1 shows an overview of the loads of the machine systems. The values given represent the power consumed in MVA.

Table 7.1. The main loads of the LHC.

MVA	Point 1	Point 18	Point 2	Point 3	Point 4	Point 5	Point 6	Point 7	Point 8	Total
Power converters										
Steady state	2.2		3.2	2.7	2.9	2.2	3.8	2.5	3.1	22.6
Peak	2.3		9.8	2.7	9.5	2.3	10.4	2.5	9.8	49.3
Machine cryogenics										
3.3kV and 0.4kV	0	8.0	8.5		14.5	0	14.5	0	15	60.5
Cooling and ventilation										
Chilled water	1.8		1.3	0	0.9	1.8	0.9	0	1.3	8.0
Other water	1.3		3	0	2.4	2..3	2.7	2.4	1.2	15.3
Air handling										
Winter	1.7		3.5	0.9	3.1	1.4	3.1	0.7	3.3	17.7
Summer	0.5		1.1	0.3	1.1	0.9	1.1	0.3	1.1	6.4
R.F. systems										
					22.4					22.4
Beam dump										
							0.4			0.4
Other machine systems										
	0.2	0.2	0.2	0.2	0.3	0.1	0.3	0.2	0.3	2.0
Experiments										
ATLAS	7									7
CMS						7				7
ALICE			7.8							5.8
LHC-B									7.5	7.5
Machine systems and experiments, total, steady state										
MVA	13.0	8.2	25.1	4.1	44.5	14.3	23.7	5.4	29.5	166.9
MW	10.0	7.0	20	2.5	31.2	11.2	20.4	4.1	24	130.4
MVAr			15.2		31.7	8.9	12.1		17.1	
Comp. MVAr	0	0	24	0	24	0	24	0	24	
Compensated MVA	13.1	8.2	20	4.1	32.2	11.2	20.5	5.4	24	138.7
Machine systems and experiments, total, peak										
MVA	13.1	8.2	31.7	4.1	51.1	14.4	30.3	5.4	36.2	194.5
MW	10.1	7.0	24.7	2.5	35.9	11.3	24.9	4.1	28.7	149.2
MVAr			19.8		36.6	8.9	17.3		22.1	
Comp. MVAr	0	0	24	0	24	0	24	0	24	
Compensated MVA	13.1	8.2	24.7	4.1	38	11.3	24.9	5.4	28.7	158.3
General services										
MVA	3	1	2	1	2	3	2	1	2	17

7.2.1 High Voltage Systems

This section lists the different systems comprising the high voltage installations, i.e. systems with a rated voltage above 1000 V.

400 kV EDF incomer, Prevessin main substation

The CERN Prevessin main sub station is fed from the EDF Bois-Tollot substation. This substation is integrated in the French-Swiss national inter-connection and is therefore connected to both EDF in Genissiat and to the Energie Ouest Suisse (EOS). At Present the upstream configuration of the Swiss 400 kV network does not allow machine operation supplied to be by EOS. However, studies are underway to allow the possibility in the future. The Prevessin substation is composed of six bays: one incomer and five transformer bays. The substation as designed for LEP will be adequate for the LHC.

The incomer is only equipped with an isolating switch and not with a circuit breaker. The function as breaker to the line is fulfilled by the EDF breaker in the Bois-Tollot substation. It is at the other end of the 600 m long 400 kV line between CERN Prevessin and Bois-Tollot. This breaker receives trip orders from CERN in case of faults. This agreement has allowed CERN to economise on a set of three single phase 400 kV breakers.

Of the five transformer bays, three were installed for the SPS and the North Area and they continue to assure the supply to these installations. These 400/18 kV units, each rated at 90 MVA, are used to power the pulsed loads of the SPS. They cannot be used for the LHC because of the cyclical distortions in the 18 kV mains, which would affect the stability of the LHC beams.

The last two transformer units were installed to supply LEP. They each have a rated power of 110 MVA and have a 400 kV primary and a 66 kV secondary voltage. Both units are equipped with an equalizing winding with a rating of 15 MVA. They will cover the entire power demand for the LHC and the general service requirements of the other parts of the laboratory.

130 kV EOS incomer, Meyrin main substation

The 130 kV sub-station is operated by SIG (Service Industrielle de Geneve). This substation is used for the supply of the laboratory outside the period of machine operation. It allows a maximum load of 60 MVA, limited by the cable links to the Meyrin dispatching substation 9 (Jura). This power limit could be increased to 75 MVA, but then no reserve cable link would be available in case of a fault.

Automatic source transfer

An automatic source transfer exists between the two 400 kV and 130 kV incomers. In the case of a mains fault on the bus-bar in service, the load is automatically transferred to the other source. In case of a transfer from the 400 kV to the 130 kV supply only certain loads continue to be supplied due to the power limits. Machine operation on the 130 kV supply is not possible. The automatic source transfer procedure causes a break of about 11 seconds.

66 kV Energy Transport System.

In view of the increased power demands in LHC Point 1 the original 18 kV line from Prevessin was not sufficient. The energy transport system has therefore been extended with an additional 66 kV line to LHC Point 1. In 1998 the SEM12 66/18 kV dispatching substation was extended and supplied by a 66 kV link from Prevessin. The link terminates in a 66/18 kV substation with a 70 MVA, 66/18 kV transformer. The 66 kV cables were laid in trenches like those supplying the substations SE 2, SE 4, SE 6 and SE 8.

In the case of LHC Point 5, where the CMS experiment is located, the additional power demands could be met by an 18 kV cross country cable link from SE 6.

The 66 kV lines operate at a voltage varying between 63 and 69 kV, the rated voltage therefore being 62/72.5 kV. They are of the single-core aluminium type, XLPE-insulated, with a waterproof metal sheath and laid in trenches on public property, in accordance with EDF rules. These trenches are also used for fibre-optic data links.

The secondary neutrals of the two 400/66 kV transformers are each earthed via an 80 ohm resistor, limiting the fault current to less than 500 A. The 66 kV system thus obtained is of the resistive neutral type, tripped at the first fault.

Table 7.2: Load on 66 kV substations.

	Steady State		**Peak**	
	Load / MVA	**% of transformer rating**	**Load/ MVA**	**% of transformer rating**
SE 1*	40	57	40	57
SE 2**	20	26	24.7	32.5
SE 4	32.2	85	38	100
SE 6***	31.7	84	36.2	95
SE 8	24	63	28.7	76

* LHC Point 1, ATLAS and the Meyrin site
** Two 38 MVA units are installed in Point 2
*** Sum of loads in LHC Points 5 and 6

The load of the 66 kV substations is shown in Tab. 7.2. The load of the 38 MVA transformer in Point 6, which also feeds machine equipment in Point 5, will be about 32 MW, or 84 % of its rated power in steady state operation.

When operating at peak load, the transformers in Points 4 and 6 will need reactive power compensation in order to avoid overloading of the transformer. The existing compensation equipment will take care of this.

18 kV Power distribution system.

All LHC sites, apart from Points 3 and 7 will have large 18 kV substations installed in utility buildings (SE1 to SE8). There is a mini-substation (SE33) in the building at the top of the emergency shaft PZ33. Compact substations, in the form of 18 kV ring main units, are installed underground in the 16 stub-tunnel alcoves. All 18 kV substations, apart from SE3 and SE7, have two sets of 18 kV bus-bars:

- One set of bus-bars, referred to as the machine network, is fed from the 66 kV system.
- The other set is fed from an 18 kV loop, starting in Point 1 and connected upstream to both the Prevessin main station and the Meyrin dispatching station. This second set is referred to as the general service network.

The 18 kV loop as laid in the machine tunnel and its shafts is shown in Fig. 7.4. The18 kV loop is brought to the surface at each access Point. The loop starts at Point 1 in substation SEM 12. This station, and thus the loop, has three supplies:

- The normal supply is via an 18 kV cable link from Prevision, arriving in substation SEM 12. The power rating of this link is 30 MVA.
- The automatic emergency supply is via an 18 kV cable link from the Meyrin site (Electricité Ouest Suisse). This link will be automatically energized if there is a fault on the normal supply. The power rating of this link is 60 MVA. Although the emergency requirements of the LHC ring are limited to 17 MVA, the capacity of this link will be 60MVA, so that in the event of an emergency the whole of the Meyrin system can be powered from SEM12.
- A manual emergency supply is formed using an 18 kV link from the SPS stable network in building BA6. This short link provides a bi-directional back-up supply between the LHC and SPS systems. The power rating of this link is 15 MVA.

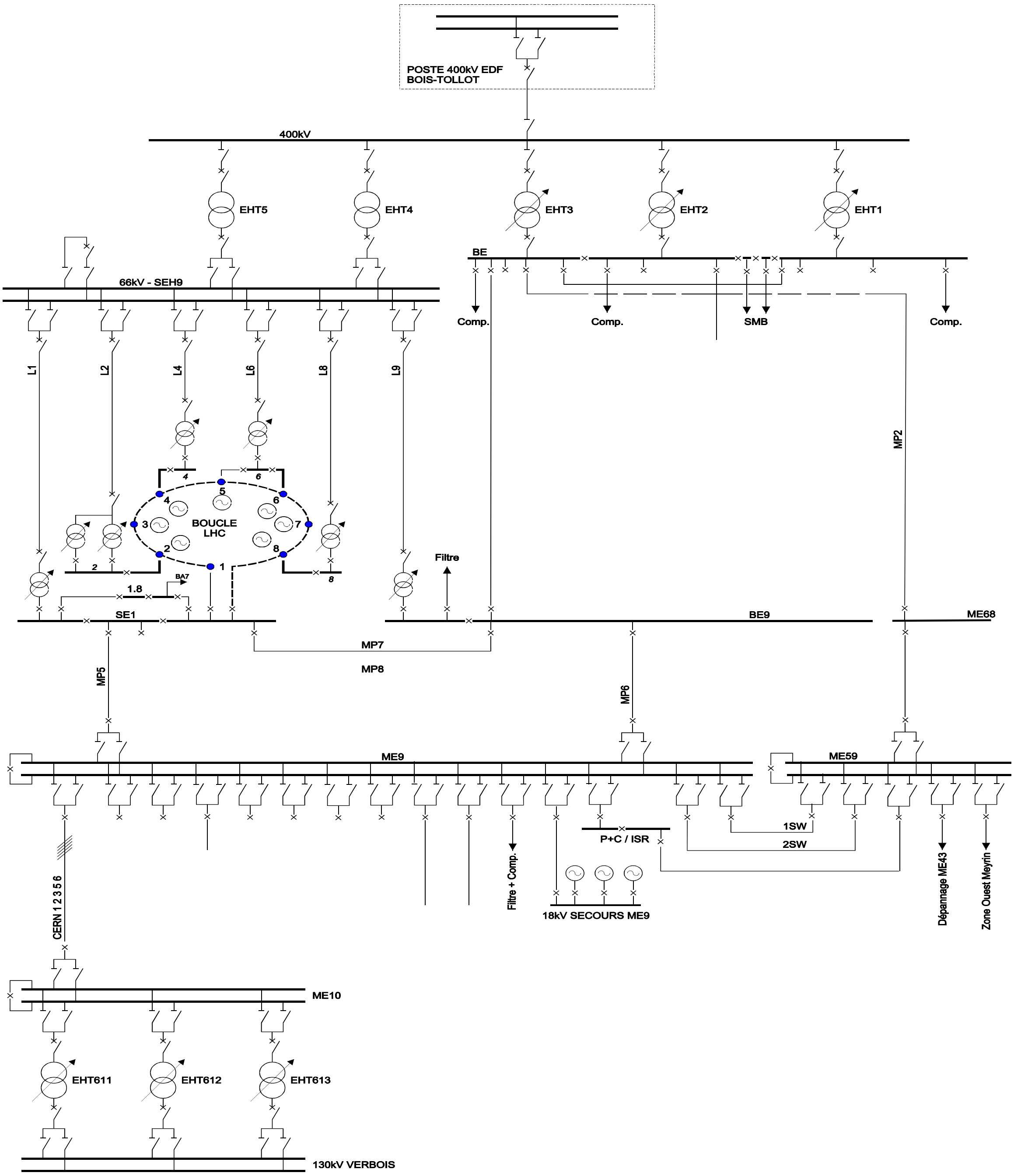


Figure 7.2 Schematic layout of the 400 kV, 130 kV, 66 kV and main 18 kV sub-stations

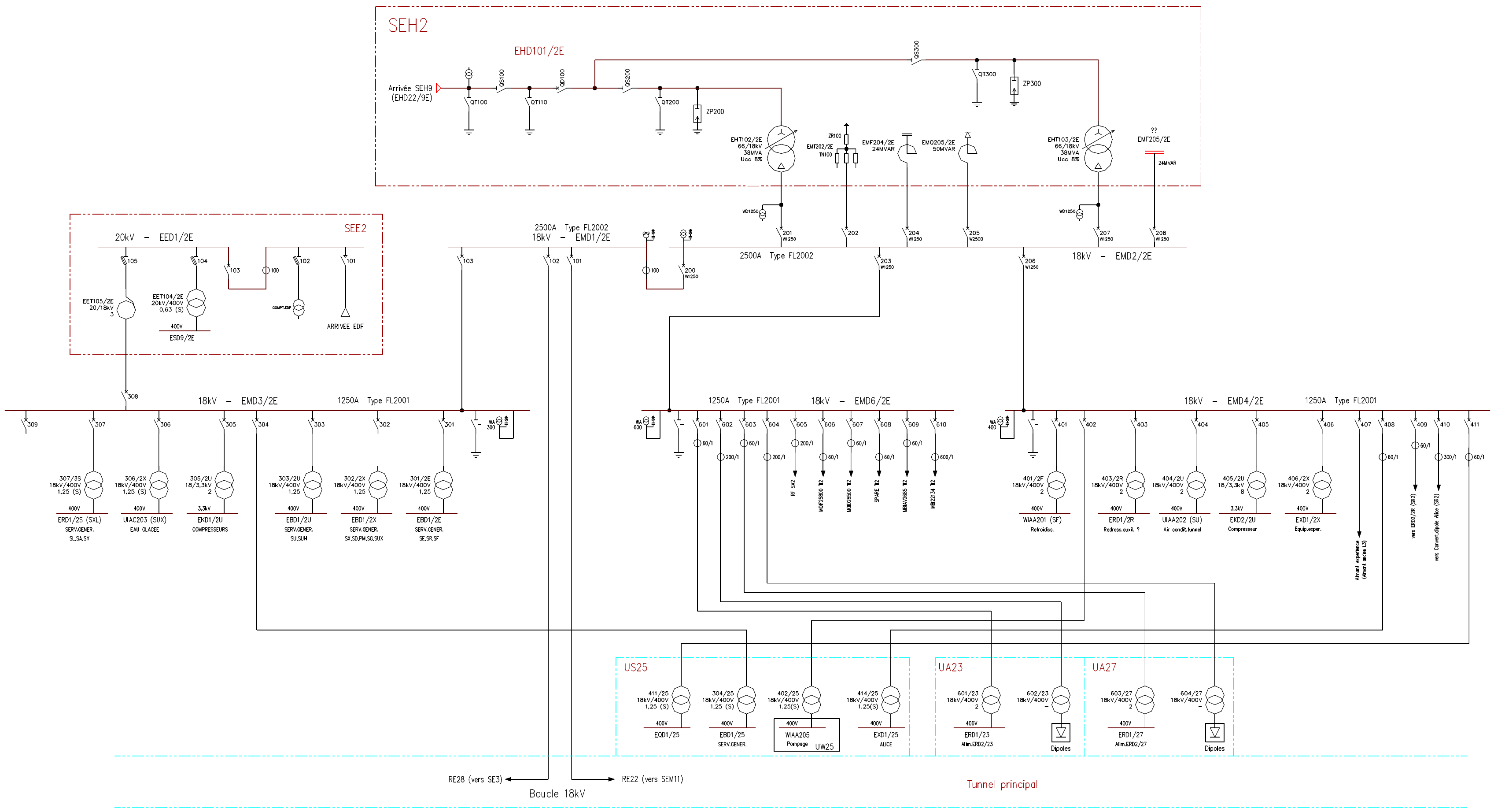
The bus-bars fed by the loop are connected to the local French 20 kV network in the LHC points in France (points 2, 3, 4, 5, 6 and 7) as secondary back-up.

A coupling exists in each station between the two sets of bus-bars. This structure ensures maximum flexibility and back-up possibilities and it allows a clear separation of systems.

Substations SE3 and SE7 are simple: they will only be supplied by the 18 kV loop, and no dedicated 18 kV switchboard will be provided for splitting into accelerator and services loads.

Each 18 kV substation in the underground alcoves is fitted with a compact 24 kV ring-main unit housed in a tank completely filled with SF_6, a cast resin 18 kV/LV, 630 kVA transformer and a standard LV distribution cubicle. Fig. 7.5 shows one of these alcove substations.

The earth fault current of the 18 kV network will be limited to 1000 A via a neutral Point coil, earthed by a resistor. Thus the whole 18 kV network on the French site will remain of the resistive neutral type, tripped at the first fault.



SEH2
EHD101/2E
Arrivée SEH9 (EHD22/9E)
SEE2
20kV - EED1/2E
ARRIVEE EDF
2500A Type FL2002
18kV - EMD1/2E
2500A Type FL2002
18kV - EMD2/2E
18kV - EMD3/2E
1250A Type FL2001
1250A Type FL2001
18kV - EMD6/2E
18kV - EMD4/2E
1250A Type FL2001
US25
UA23
UA27
UW25
RE28 (vers SE3)
RE22 (vers SEM11)
Boucle 18kV
Tunnel principal

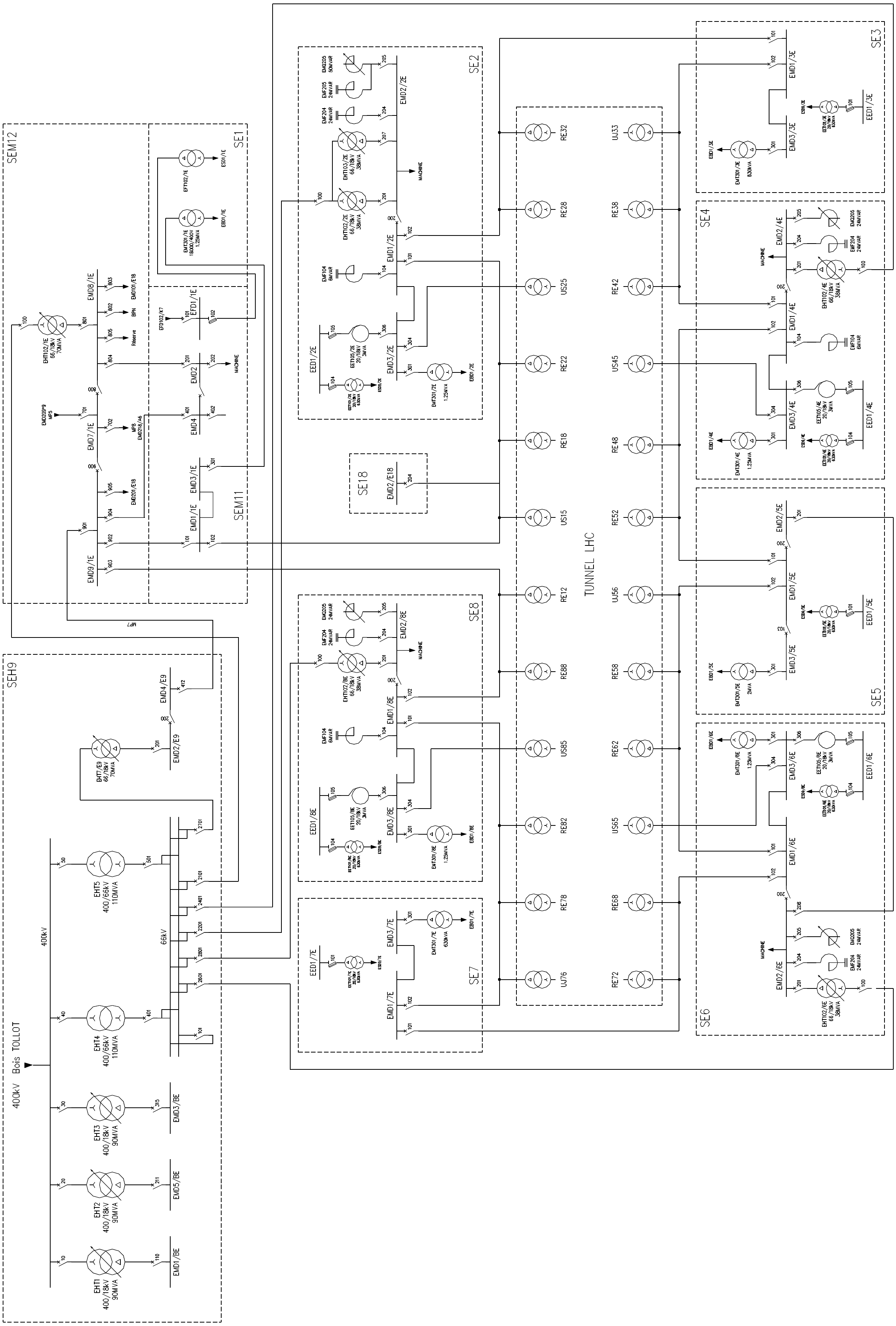
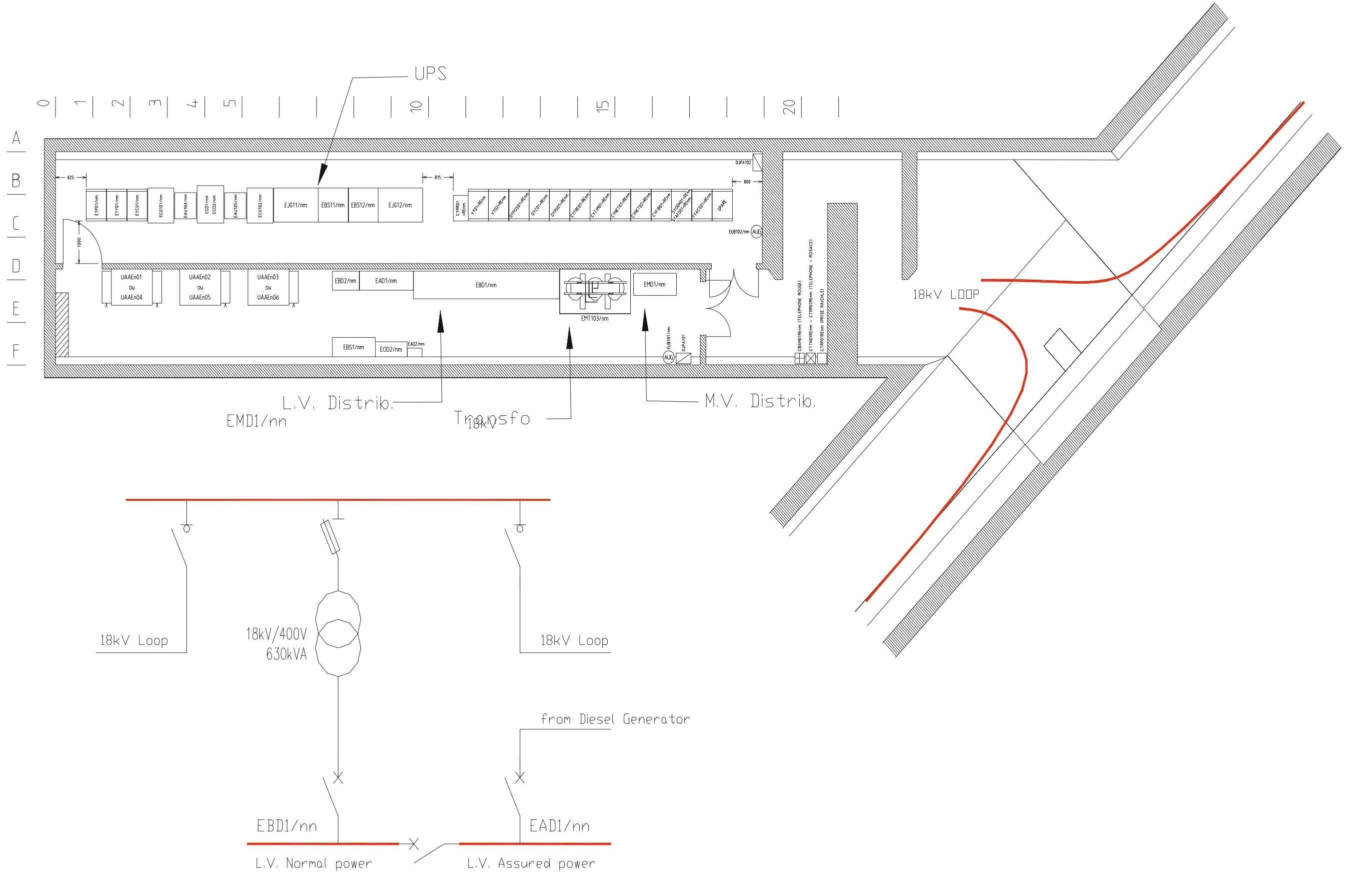


Figure 7.4: Single line diagram showing the LHC distribution. Note the general service loop following the tunnel.


UPS
A
B
C
D
E
F
0
1
2
3
4
5
10
15
20
18kV LOOP
L.V. Distrib.
EMD1/nn
Transfo
18kV
M.V. Distrib.
18kV Loop
18kV/400V
630kVA
18kV Loop
from Diesel Generator
EBD1/nn
EAD1/nn
L.V. Normal power
L.V. Assured power

with power losses, operation and maintenance. This however, will only be done once sufficient operational experience with LHC has proved compensation to be unnecessary.

For LEP the machine network was fitted with a high voltage filter to remove any risk of interference between the rectifiers due to harmonic voltage distortion and in order to decrease the high reactance upstream of the network for the thyristor commutation, which would otherwise increase the reactive power of the rectifiers.

These filters consist of four circuits tuned to the fifth, seventh, eleventh, and thirteenth harmonics, a 100/150 Hz transient trap and an HF circuit. 24 MVAr filters and reactive power compensators were sufficient to eliminate voltage fluctuations on the machine network, in spite of the periodic load change of the LEP during operation. Each compensator is rated to balance the capacitative power of the adjacent filter during the injection or shutdown period of the accelerator and operates on the principal of current regulation in linear inductors via an HV thyristor controller. The regulation is carried out directly at the 18 kV level.

The reduction of short-circuit power along the loop as the distance from Point 1 increases, causes similar but more modest interference than that mentioned for the machine network (480 MVA in SEM12, falling to 180 MVA in SE6). Two 6 MVAr capacitor banks are fitted on the ring in SE4 and SE8 to limit the voltage drop and the harmonic distortion to less than 2%. They are associated with inductors and resistors to form a damped HF filter.

The compensation equipment has the additional advantage of virtually eliminating the transfer of reactive power into the transmission system, with considerable benefits with regard to losses, transformer rating, and the cross-section of the conductors.

Injection tunnels

In terms of power distribution the injection tunnels are essentially extensions of the SPS. Most of the 18 kV power equipment of TI 8 is situated near the BA4 building and supplied from the BE 18 kV substation. The TI 2 tunnel has a number of its power converters still at SR 2 in Point 2. The power distribution of BA7 is only used for general services in the tunnel. A small substation, using existing equipment, near the SMI 2 building at the end of the Meyrin site feeds part of the general services of TI 2.

3.3 kV system.

A part of the installations for the cryogenic systems are powerful motor-compressor sets with a rated power of several hundred kW. Similar sets are used for production of chilled water. These systems cannot be fed from the low voltage systems, as their inrush current would create a too high voltage drop across the impedance of the network. Dedicated 3.3 kV substations have been created to feed these sets. These substations are powered from the 66 kV machine network. A part of the installation can be maintained on the general services loop in case of a failure on the 400 kV system.

During the last years of LEP an upgrade of the supply systems for the motor-compressor sets was made. The remaining installations to be made for the LHC were the four 3.3 kV SHM substations: SHM 4, 6, 8 and 18. These substations were made according to the same model as the 3.3 kV substations built for LEP. In particular they have their own 0.4 MVA, 3.3/0.4 kV transformer for their auxiliaries.

7.2.2 General Service Installations

The description of the general service installations falls under the 400/230 V system description, although (as described above) a part of the 18 kV distribution system is oriented to the general service installations. Most users, however, will interface to the general service part of the power distribution system at the 400/230 V level.

Low-voltage electricity distribution

The low-voltage distribution system s is designed to facilitate a load-shedding schedule with a hierarchy of four networks; these are listed below, from the least to the most secure:

- A machine network, divided into dedicated LV sectors powering each main technical system at the accelerator.

- A general-services network, the total power for LHC being 17 MVA. This is divided into LV sub-distribution systems serving different sectors of the area in question;
- A `guaranteed´ LV network, backed up by the diesel-generator set, divided into as many sub-distribution systems as there are `general-services´ systems, except in the small buildings, where single feeders will suffice.
- A safe supply, forming the part of the guaranteed network which is maintained in operation in the event of an emergency stop. The whole of this network is supplied from the SE safety switchboard. The cables are routed in separate ducts which provide protection from fire and other hazards.

The design of the low voltage system makes it possible to set up a selective emergency stop system. For this purpose each area is divided into sectors, where an emergency stop is required to cut off any voltage above 50 V. The exception to this is where a supply is needed for a safety system. These will have to be fully protected and marked. The following LV machine networks will be fed by their own 18 kV transformer:

- Cooling and pumping equipment,
- The main cryogenic plant,
- RF auxiliaries.

Underground lighting

The lighting system designed for the underground areas is composed of two systems:

- A global lighting system supplied from the guaranteed LV network. The lighting can be switched off remotely when the machine is in operation.
- A safety lighting system designed to illuminate escape routes in case of equipment break down of the guaranteed lighting. The safety lights are powered from 48V D.C./ 230V A.C. inverters in the SE substations. This system is fire resistant, and will remain energized in the event of an emergency stop

7.3 SECURED POWER SYSTEMS

A safe room is provided in each substation to supply equipment that must remain operational in the event of an emergency stop or mains failure. The latter includes the 48 V D.C. control supply, the network control equipment, protection equipment and emergency distribution switchboards.

All the surface substations are fitted with an LV diesel generator set which starts automatically if the substation suffers a mains fault. These generators will power all the guaranteed circuits in the area. Part of this guaranteed distribution forms the safety network, which will be maintained in the event of an emergency stop. The underground substations are supplied with assured power through feeders originating from these diesel sets.

7.3.1 Diesel Generator Based Systems.

Some systems are required for personnel safety: lifts, smoke extraction etc. These are supplied from switchboards which are backed by diesel generator sets. The safety systems must accept a short break of about 20 to 30 seconds, which is the time required for the diesel generators to take over the load. For LEP, all even points were equipped with a 750 kVA diesel generator, points 3, 5 and 7 were equipped with 285 kVA generator sets and Point 1 was supplied from the Meyrin emergency supply generators. The LHC requires a 750 kVA generator in Point 5 in replacement of the existing 285 kVA unit.

7.3.2 Un-interrupted Static Power Systems.

A certain number of technical systems including cryogenics, cryogenic instrumentation and power converter control systems require uninterrupted power supplies. In the case of a mains fault, static systems with battery back up will maintain the supply; the power failure will not be seen by the user. These un-interruptible power supplies (UPS) generally have battery autonomy of 10 minutes. Certain have diesel generator back up, so that not only will the fault not be seen, but a prolonged power outage can be covered by the safe power system.

Table 7.3 List of UPS systems per access Point. All systems with 10" autonomy

POINT	BUILDING	RATING	SYSTEM BACK-UP	AREAS TO FEED
Point 1	US15	2x120kVA		2xRR, TUNNEL, USA,US,UJ
Point 18	US18	2x20kVA	Diesel generator back-up	UX(Cryo)
Point 3	UJ33	2x80kVA		TUNNEL, UJ
Point 5	UJ56	2x120kVA		2xRR,TUNNEL, USC,UJ
Point 7	UJ76	2x80kVA		TUNNEL, UJ
Point 2	US25	2x20kVA		TUNNEL, US
Point 2	UA23	2x80kVA		UA23
Point 2	UA27	2x80kVA		UA27
Point 2	UX25	2x20kVA	Diesel generator back-up	UX(Cryo)
Point 4	US45	2x20kVA		TUNNEL, US
Point 4	UA43	2x80kVA		UA43
Point 4	UA47	2x80kVA		UA47
Point 4	UX45	1x120kVA		HRF
Point 4	UX45	2x20kVA	Diesel generator back-up	UX(Cryo)
Point 6	US65	2x20kVA		TUNNEL, US
Point 6	UA63	2x80kVA		UA63
Point 6	UA67	2x80kVA		UA67
Point 6	UX65	2x20kVA	Diesel generator back-up	UX(Cryo)
Point 8	US85	2x20kVA		TUNNEL, US
Point 8	UA83	2x80kVA		UA83
Point 8	UA87	2x80kVA		UA87
Point 8	UX85	2x20kVA	Diesel generator back-up	UX(Cryo)
16 Alcoves	RE's	2X80kVA		RE, Tunnel

All systems should be 100% redundant which means that each of the two systems can maintain the load alone and that there is an automatic commutation which is not seen by the user.

The systems backed up by a diesel generator set will have practically unlimited autonomy. The number of UPS systems of various types and power ratings is:

Number of 80kVA UPS systems:	52
Number of 20kVA UPS systems:	8
Number of 20kVA Diesel backed-up UPS systems:	10
Number of 120kVA UPS systems:	5

The autonomy for a simple unit loaded at 100% is 10 minutes. This same UPS system loaded at 50% will have a battery autonomy of 20 minutes.

7.4 SAFETY SYSTEMS

7.4.1 The Emergency Stop System.

The general emergency stop system is installed, commissioned, operated and tested by the electrical service. The system logic is determined both by the power distribution system design and by the operational and interlock requirements of the machine. The logic has been defined by a working group with machine, safety and electrical service representatives. The technical system to be used is that of LEP. It is modified to cover the new emergency stop zones and will be organised to allow reset without access to the underground areas.

7.4.2 The 48 V D.C. Safe Supply

The electrical service powers all its essential auxiliaries from a 48 V D.C. system with battery back up. It also supplies emergency lighting systems both on the surface and underground. LEP equipment has been re-used with additional systems added for the new requirements of LHC.

7.5 POWER DISTRIBUTION NETWORK SCADA SYSTEM

The electrical equipment of the CERN Power Distribution Network is interfaced with a SCADA system, which provides the Technical Control Room (TCR) and the electrical operation personnel with remote monitoring and control facilities. This system manages almost all the equipment located in the CERN electrical substations, in surface and underground areas, as well as other buildings throughout the site. The equipment supervised in these installations spans all voltage levels, from 48V DC battery chargers to 400 kV transformers. Since the distribution network involves different generations of technology, the SCADA system includes many heterogeneous hardware and software interfaces that offer different methods of integration.

Altogether, the system manages about 100 000 input channels. These are mainly simple status signals (including alarms), however there are a significant number of analogue measurements and counters. A limited number of control output channels are available for remote operation of specialized substation equipment such as battery chargers and UPS systems. For safety reasons these facilities are not used for manoeuvring high-voltage switch-gear.

Fig. 7.6 illustrates in a schematic manner the architecture of the supervision system and the different levels or "layers" between the applications in the TCR and the equipment in the electrical substations.

The first layer of the SCADA infrastructure is responsible for the physical interface with the equipment. In the case of electrical equipment without software-based communication facilities, the supervision is based on specialized digital I/O modules or in some cases general-purpose industrial PLCs. In addition, important legacy equipment (e.g. medium-voltage switch-gear initially installed for LEP and without built-in measurement capabilities) is equipped with devices dedicated to electrical measurements such as active power, reactive power and energy.

Modern generations of equipment (such as protection devices based on micro-processor technology) offer easier integration using a serial communication interface over RS-232 or RS-485 bus systems. This allows extensive supervision facilities via software modules that implement transmission of status signals, measurements and remote controls. Although the majority of such equipment uses standardized data exchange protocols, nevertheless about 20 different software drivers are required

At this level of equipment supervision, simple user interfaces have been installed in critical areas using touch-screens connected to PLCs. These screens offer high-availability for alarms and state visualization, as well as command functions. They also act as a backup to other, higher-level, supervision systems in the case where these are unavailable. The experiment rack control system is a particular example of autonomous PLC systems: the PLCs implemented in the experimental zones interface with the low-voltage distribution system for electronic racks and concentrate all states, alarms and measurement relevant to the electricity supply. Control facilities of individual feeders are also provided. The local PLC systems are integrated with both the general experimental detector control system (DCS) via a dedicated Ethernet communication link and the power network SCADA system.

The second level of the supervision infrastructure is a small "local" PC-based SDADA system located in the 20 major high- and medium-voltage electrical substations. This system acquires data from the electrical equipment and presents the information collected in the form of single-line synoptic diagrams, alarms lists or event histories. The implementation is "stand-alone" in the sense that it remains fully operational even if the external informatics infrastructure is unavailable. Under normal conditions, the system transmits all data to the central SCADA servers in the Technical Control Room; since events are also stored on the PC, the local system provides redundancy in the case of server or network failure. If required, this SCADA system includes facilities to implement any type of automation procedure via industry standard PC programming tools. This can be used to perform tasks normally implemented via dedicated PLCs but without installing such extra hardware.

All events and measurements acquired from the electrical equipment in the field are received by the central Unix-based SCADA servers that are dedicated to the supervision of the power network. This system is to a large extent based on industrial hardware and software which is also installed outside CERN for the supervision of public power distribution networks. The CERN-specific modules are principally limited to drivers for the equipment unique to CERN. To facilitate the development of these modules, *de-facto* or official standards are applied whenever possible (e.g. IEC-defined communication protocols). Some specialized software is installed for Web-based energy consumption supervision and real-time calculations of the network state. The system includes extensive facilities for archiving and logging, which allow for long-term storage of all events and measurements. This can be used when analysing and diagnosing disturbances and network transients. Data extraction tools are available to consult the logging database, which can also be accessed from other applications over the network using standard database communication protocols.

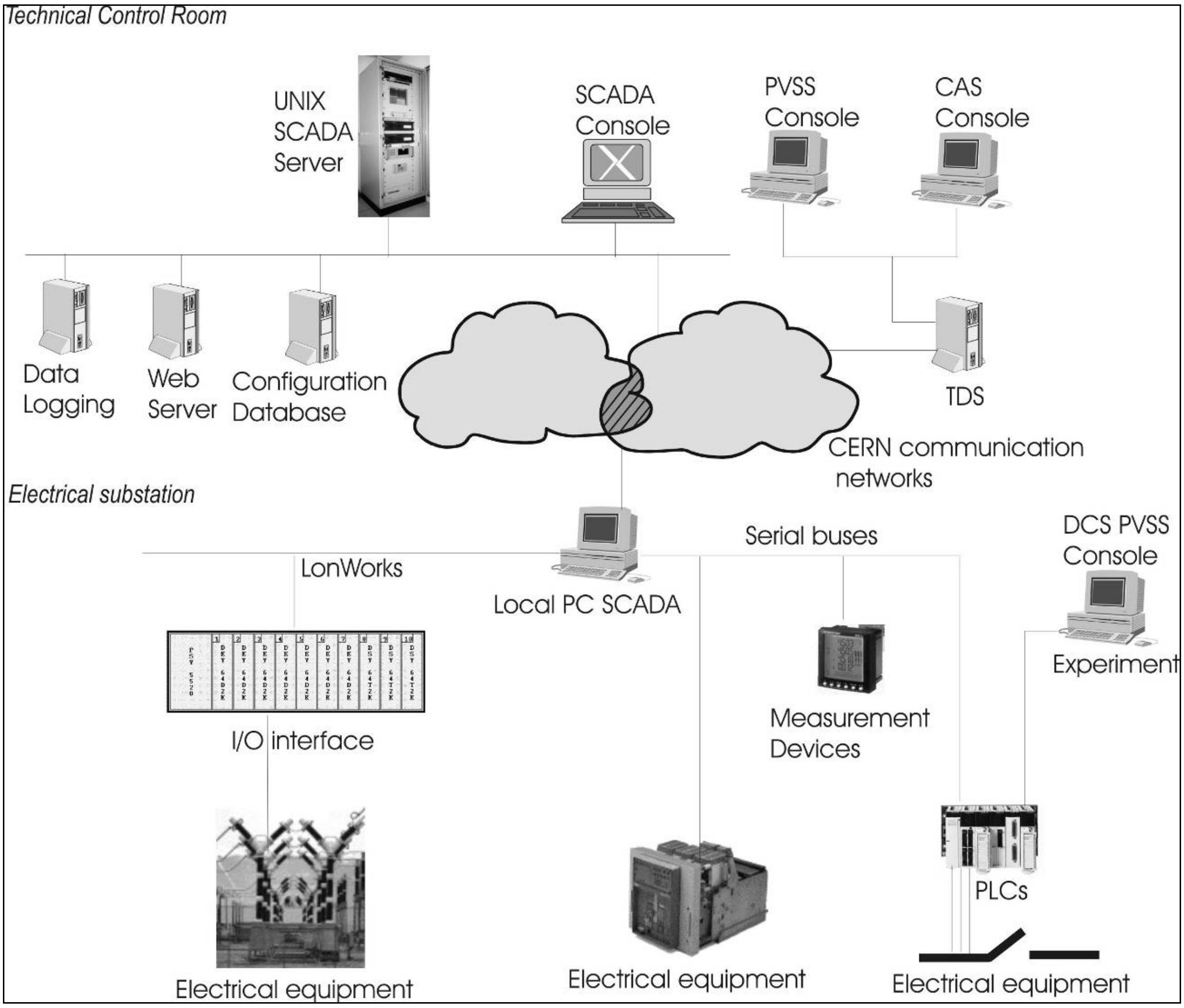


Figure 7.6: Control System Architecture

Limited data from the power network is transmitted to other applications in the TCR to provide the operators with views integrating information from different technical systems such as cryogenics, cooling and ventilation. This information is managed via the standard Technical Data Server (TDS) middle-ware application from where it is available to PVSS applications and the CERN alarm server (CAS). Chap. 13 describes in more detail the top-level monitoring of general service equipment.

The maintenance of the SCADA infrastructure is to a large extent performed by industrial suppliers or through dedicated service contracts. CERN personnel are mainly involved with installation and configuration issues and to some extent with the software integration of special equipment not supported by the standard SCADA system.

The installation of the new control system started in the year 2000 and will follow the electrical installation work for the LHC, with the aim of supervising the installations as they are made operational. In parallel with this activity, the system has been deployed in the SPS and the main power stations at CERN.

7.6 SIGNAL CABLING

The most important part of the cabling activity groups the signal cables which includes:

- Field buses,
- Interlocks,
- Equipment protection,
- High voltage cables used for vacuum equipments and beam control,
- Low loss cables,
- Security cables for the loss of oxygen and fire detection,
- Cables for radiation monitoring equipment.

Table 7.4: Quantities of Cables Requested by the Users.

Groups	**Number of cables**	**Cable Quantities / km (as of 2002)**
Survey	1400	75
Vacuum	3600	405
Magnet Protection	2400	215
Cryogenics	3100	190
Controls	1000	36
Beam Transfer	1200	27
Beam Instrumentation	1850	495
Power Converters	2500	42
Radio Frequency System	1300	85
Electrical Systems	3200	180
Warm magnets	300	74
Access System	1700	307
Level 3 Alarms	0	0
Safety Systems	64	31
Radioprotection	400	66
Total :	24014	2228

7.6.1 Cable Pulling Programmes

The installation of the conventional signal cables is organised in a series of cabling programmes to optimise the price and the working time in the tunnel. Cables are installed in the tunnel before the great majority of the equipment. The exact position is given by the LHC reference database. All cables included in the programme are pulled and fixed on the cable trays. The requested connectors are mounted at each end and then protected from dust. For each LHC sector, four cabling programmes are scheduled to allow for the constraints of the commissioning of the different equipment.

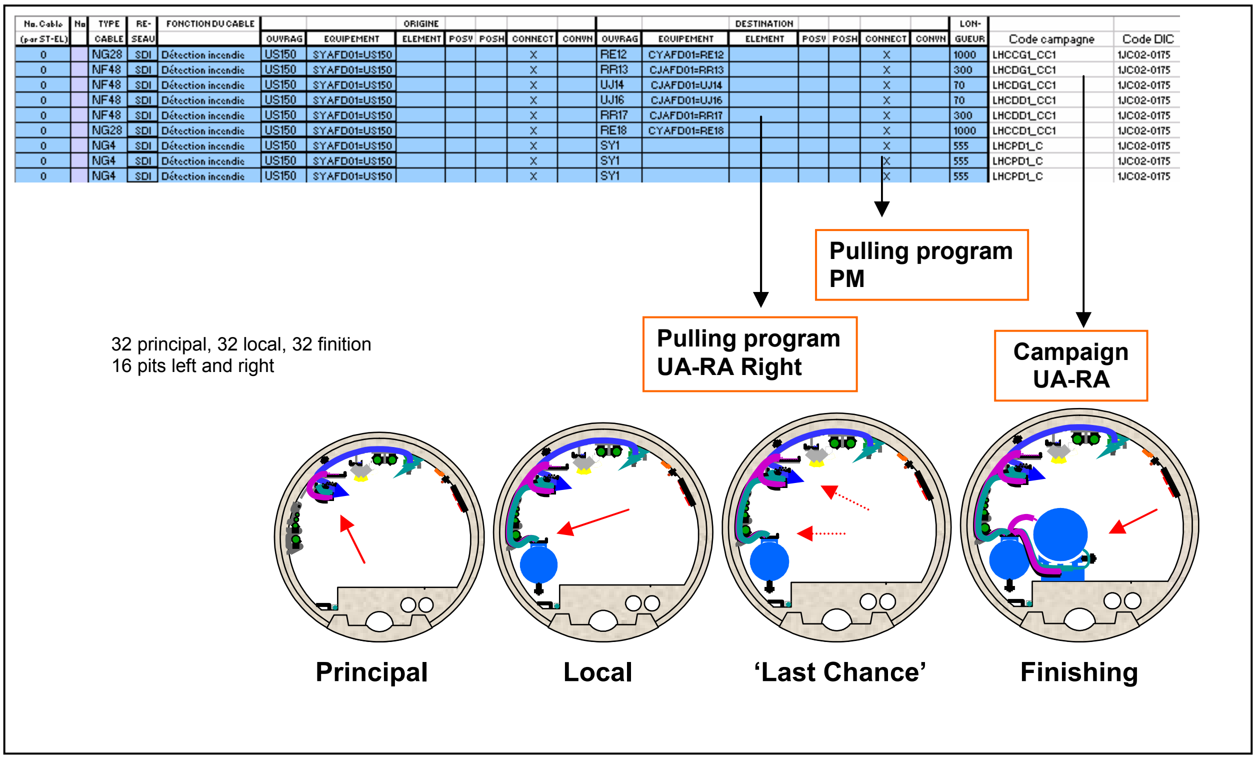
Each installed cable is visually checked and tested for insulation and continuity and the wiring convention is verified.

7.7 HIGH CURRENT DC CABLE SYSTEM

High current D.C. cables are used between power converters and electrical feed box (DFB) or between power converters and warm magnets. The power cables are either conventional, or water cooled depending on the current requirements.

7.7.1 Conventional D.C. Cable Systems

The cross section of the conventional D.C. cables is defined in the reference database. The installation is included in the cabling programmes. The connection to the power converters and energy extraction systems is planned for later, along with the local cabling, when the equipment has been installed.



No. Cable (par ST-EL)	No	TYPE CABLE	RE-SEAU	FONCTION DU CABLE	ORIGINE OUVRAG	EQUIPEMENT	ELEMENT	POSV	POSH	CONNECT	CONVN	DESTINATION OUVRAG	EQUIPEMENT	ELEMENT	POSV	POSH	CONNECT	CONVN	LONGUEUR	Code campagne	Code DIC
0		NG28	SDI	Détection incendie	US150	SYAFD01=US150				X		RE12	CYAFD01=RE12				X		1000	LHCCG1_CC1	1JC02-0175
0		NF48	SDI	Détection incendie	US150	SYAFD01=US150				X		RR13	CJAFD01=RR13				X		300	LHCDG1_CC1	1JC02-0175
0		NF48	SDI	Détection incendie	US150	SYAFD01=US150				X		UJ14	CJAFD01=UJ14				X		70	LHCDG1_CC1	1JC02-0175
0		NF48	SDI	Détection incendie	US150	SYAFD01=US150				X		UJ16	CJAFD01=UJ16				X		70	LHCDD1_CC1	1JC02-0175
0		NF48	SDI	Détection incendie	US150	SYAFD01=US150				X		RR17	CJAFD01=RR17				X		300	LHCDD1_CC1	1JC02-0175
0		NG28	SDI	Détection incendie	US150	SYAFD01=US150				X		RE18	CYAFD01=RE18				X		1000	LHCCD1_CC1	1JC02-0175
0		NG4	SDI	Détection incendie	US150	SYAFD01=US150				X		SY1					X		555	LHCPD1_C	1JC02-0175
0		NG4	SDI	Détection incendie	US150	SYAFD01=US150				X		SY1					X		555	LHCPD1_C	1JC02-0175
0		NG4	SDI	Détection incendie	US150	SYAFD01=US150				X		SY1					X		555	LHCPD1_C	1JC02-0175

Figure 7.7: Organization of the pulling program

7.7.2 Water Cooled D.C. Cable Systems

The cables and tubes will be used for high current D.C. interconnections between power converters and superconducting current leads, located in various parts of the LHC tunnel (mainly UA, RR and UJ). Fig. 7.8 shows an example of a lay-out in a UA gallery. An electrical feed box (DFB) may receive between 2 and 21 current leads.

The cross-sections of the copper cables are 500, 800, 1000, 1300 and 2000 mm^2 and the cross-section of the tube is approximately 2550 mm^2.

The main dipole and main quadrupole circuits will be composed of water cooled cables and water cooled tubes and will be installed between the power converters, the energy extraction systems and the current leads to the cryostat. Tubes will only be used in the linear parts of the circuits.

The auxiliary quadrupole circuits will be composed of 500, 800, 1000 or 1300 mm^2 water cooled cables installed between the power converters and the current leads.

The quantities for the LHC are approximately:

- 8400 m of cable with cross-section of 500, 800, 1000, 1300 and 2000 mm^2
- 2400 m of tubes with cross-section of 2550 mm^2.

The bending radius of the cables is approximately 8 times the external diameter (80 cm for 2000mm^2). The space required for the links has been reserved in the integration database. The supports of the cables located above power converters and the DFBs have to be designed carefully to avoid stress on equipment and connectors.

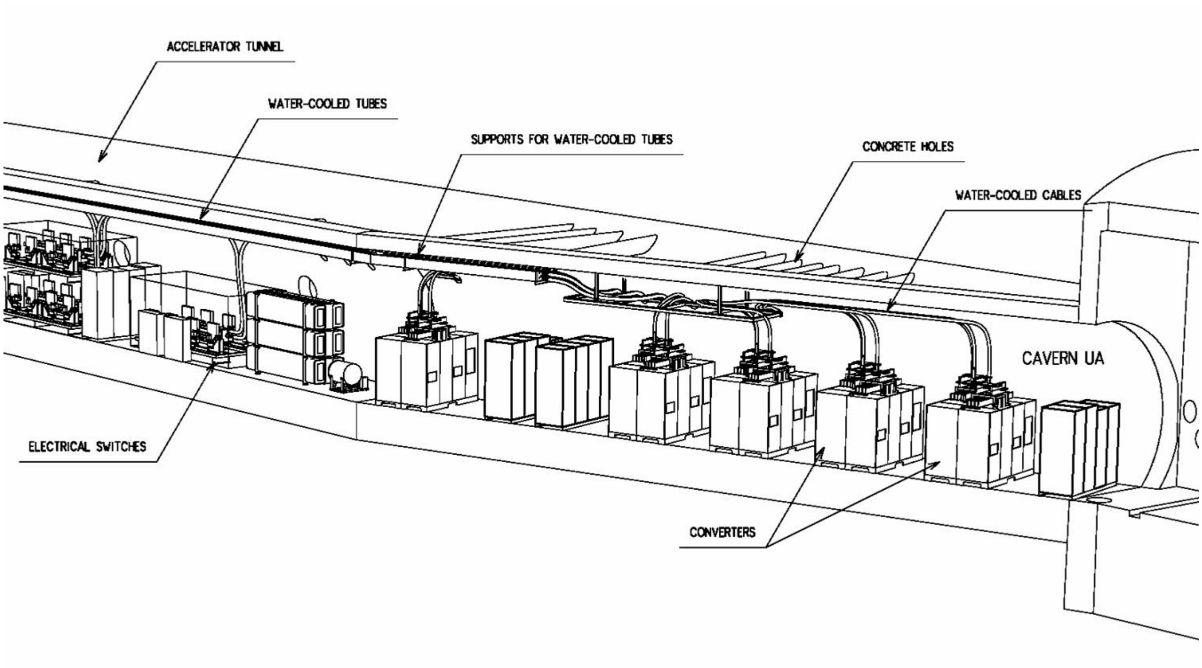


Figure 7.8 Example of a lay-out for the installation of D.C. cable systems.

7.8 OPTICAL FIBRE INSTALLATION

Optical fibres play a vital role in the communications, machine controls, instrumentation and safety systems in the LHC complex. CERN will have over 25,000 km of fibre installed by LHC commissioning and more than 40,000 optical terminations.

This section describes the technology that will be used to provide the LHC with its surface and underground optical fibre infrastructure. The optical fibre network must be extremely reliable and have redundant loops to avoid single points of failure. The laser power used at the transmitter rarely exceeds 1 mW and hence optical connections must be of high quality to keep optical reflections and attenuation within acceptable limits. The long distance surface optical fibres (in ducts) may suffer from mechanical stress and will therefore be permanently monitored by an autonomous system using optical time domain reflectometry. The optical fibres in the LHC tunnel will be subject to irradiation and will therefore darken, increasing their attenuation. This process will be closely monitored, in order to trigger a replacement of these fibres when necessary.

7.8.1 Surface Optical Cabling

Optical cables to the LHC surface points are installed in trenches in HDPE[1] ducts along with the 18 or 66 kV high voltage cables. LHC points 1, 5, 6, 7 and 8 have been equipped with classical loose tube optical cables, specified by CERN with respect to fibre types, cable construction etc. High fibre densities with up to 216 fibres have been installed on certain links. LHC points 2, 32, 33 and 4 will be equipped using a new technology with mini tubes and mini optical cables.

This technology is based on individual mini tubes running through protective ducts. In these mini tubes small, mini optical cables can be installed without any splice by using a technique known as ‘blowing’. This is a completely new and economical solution for laying optical fibre networks, which avoids the limitations of the former technologies and which introduces a great deal of flexibility for future upgrading.

Two types of mini tubes will be used: 7 mm tube and a 10 mm tube. The 7 mm tube can hold mini optical cables with up to 24 fibres and the 10 mm tube can hold mini optical cables with up to 72 fibres

The mini optical cables are similar in construction to the classical jelly-filled loose-tube cable construction. The jelly avoids humidity penetration and acts also as a protective mechanical buffer. The cables can either

[1] HDPE High Density Poly Ethylene

be made with a stainless steel protection covered by a polyethylene sheath or be completely metal free. CERN will use the metal free type for protection from electrical hazards.

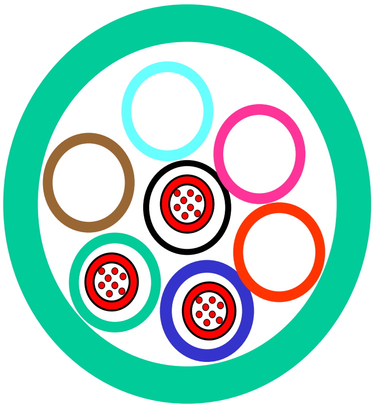


Figure 7.9 Combination of tube, mini tubes and mini cables.

The guide tubes can be blown with a Superjet[2] system at low air pressure (3 to 4 Bar). The Superjet is proven technology for the installation of optical cables and has been adapted to blow up to 10 mini tubes simultaneously. The mini tubes will be interconnected with simple, waterproof connection pieces. This technology is ideal for the upgrading of fragile ducts, as short sections can be installed and connected afterwards.

Once the mini tubes are in place, the mini optical cables can be blown using a Microjet. The Microjet is a small blowing unit (air pressure up to 14 bar), which can blow mini optical cables with lengths exceeding 2.5 km. If necessary, several Microjets can be cascaded to achieve longer installation lengths with an uninterrupted cable.

The mini tube concept with the use of mini optical fibre cables allows parallel and serial upgrades. When new installations are planned, final requirements are often not known. For example a 25 mm duct allows installation of 7x7 mm mini tubes with 24 fibres per mini tube, giving a total fibre count of 168 fibres. The mini tubes may be filled with different fibre types; a cable on the other hand has a rigid structure, once it is in place the structure cannot be modified.

7.8.2 LHC Pit and Tunnel Installations

Optical fibre links for communications and machine reference signals are required in the pits and all around the LHC tunnel including partial stops at the stub tunnel alcoves. These links are part of the redundant optical fibre network for LHC communications and machine control. A 40 mm duct with ten 7 mm mini tubes will be installed in the pits and on the tunnel wall under the leaky feeder cable.

Optical fibres for the beam position monitoring system will be installed between each pair of Beam Position Monitors (BPM) and the corresponding instrumentation in the SR building. It is foreseen to equip each BPM pair with 6 or 8 single-mode fibres.

About 35 positions at each side of a machine octant will be connected to 25 mm ducts, which are pre-equipped with seven 7 mm mini tubes. In this way each 350 m sector can be serviced from the duct, with an outlet approximately every 50 m.

The pre-equipped tubes will be installed during the control cabling installation phase and before the installation of the QRL and Cryostats. Only once a machine sector has been installed, can the mini optical fibre cables be blown and terminated. The fibres have to be blown in one go from the SR to the BPM (longest distance about 3500 m) and cascading techniques using an extra Microjet at the bottom of the shaft or between sections will be needed.

[2] High precision machine to blow cables.

7.8.3 Optical Fibre Types

Two main optical fibre types will be used:

- Graded index multimode fibres (ITU G-651; 50/125 μm) and
- Single-mode fibres (ITU G-652.B; 9/125 μm)

For LEP, special temperature compensated single-mode optical fibres were used for the complex radio-frequency reference phase shift compensation. These fibres have a temperature coefficient of better than 14 times that of normal single-mode fibres. The basic fibre is the same, but the coatings, with a negative temperature coefficient, are different. Instead of the fibre becoming longer as temperature increases, it becomes mainly thicker giving better phase behaviour for high frequencies. These fibres have been maintained between the PCR and Point 4, and will be re-used for the 400 MHz radio frequency reference signals.

7.8.4 Optical Connectors

The choice of the optical connectors is very important. Not only must the connector be perfectly aligned and mated with other connectors in order to keep losses in the region of some tenths of a dB, but they must also have an acceptable reflection coefficient, to avoid perturbation of the laser source. Laser sources are extremely sensitive to nearby reflections, whilst the output power only ranges from about 0 to –10 dBm (0 dBm = 1 mW).

The E-2000/APC connector was selected for single-mode applications in LHC. This connector has an angled polished end face, which has the advantage of a high return loss figure of better than –55dB. The connector has also a dust and laser protection cap.

For multimode applications the widely available ST connector will be used.

7.8.5 Optical Fibre Monitoring

The optical fibres in the ducts in surface trenches may be subject to mechanical stress. In addition, the fibres installed in the LHC machine will be subject to radiation. In each case the fibres must be closely monitored in order to raise an alarm as soon as the attenuation and/or reflection exceed preset threshold levels.

Extensive radiation measurements have been done in the TCC2 radiation test facility and measurements are continuing with different conditions and different types of optical fibres and optical cables. The radiation environment in the radiation test facility is supposed to reflect the type of radiation, which can be expected in the LHC, but for similar integrated doses, a much shorter time scale is obtained as the radiation levels in the radiation test facility are higher than LHC.

Multimode fibres contain dopants, which disintegrate with radiation dose and darken the silica thus increasing the attenuation values. Single-mode fibres have hardly any dopants and resist a radiation environment much better. Fig. 7.10 shows the measurement results over a period of 6 months and a total integrated dose of 500 Gy.

It is clear that multimode fibres should not be used in the LHC tunnel. In agreement with the Communications Infrastructure Working Group (CIWG) and the Tunnel Electronics Working Group (TEWG), it has been decided to use only single-mode fibres in the tunnel. Multimode fibres can however be used around the LHC detectors in the experimental areas, as distances are usually short here.

An optical fibre monitoring system has been put into service for monitoring CERN's main optical trunks and tunnel fibres. The system has 24 optical test ports, largely sufficient for the whole CERN complex, as each port can test an optical link with a total length of up to 200 km.

The system is based on a Remote Test Unit (RTU) with a powerful optical time domain reflectometer which operates at a wavelength of 1550 nm in order to be able to detect any micro bending (the longer the wavelength, the better). Micro bending might occur when fibres are under mechanical stress (for example in the surface ducts). One fibre per trunk cable is dedicated to the monitoring system.

Ports 1 to 8 will be used for the corresponding 8 octants of the LHC and the surface links from the PCR to these octants. Four other ports will be used for main optical trunks, leaving 12 spare ports for possible future use.

A fibre is tested during a certain time and the measured OTDR trace results are averaged and then compared to an initial reference measurement. If the results of the measurements do not correspond to the reference measurement (minus a programmable offset) the system will raise an alarm.

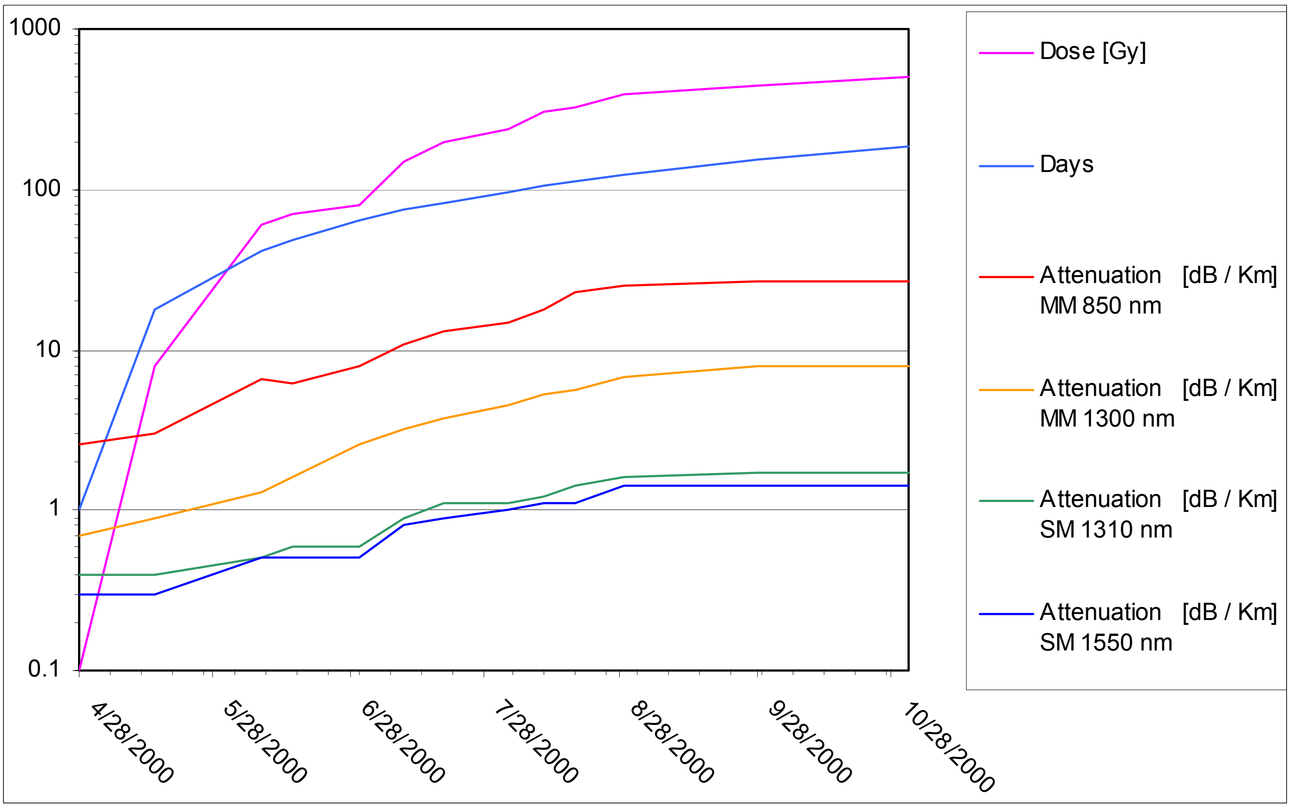


Figure 7.10 Results of radiation tests of fibres.

CHAPTER 8

COOLING AND VENTILATION

8.1 INTRODUCTION

In this chapter the cooling and ventilation equipment for the LHC-machine and experimental areas are explained system by system. In many areas, the cooling and ventilation systems in use for the LEP machine have been extensively re-used, thus limiting the investment needed for LHC. All cooling and ventilation systems are controlled by PLC-systems and a local (SCADA) supervision system. Alarms are transmitted via an Ethernet communication network to central servers, presently installed in the TCR.

8.2 PRIMARY WATER SYSTEMS

A typical layout of a primary water circuit is shown in Fig. 8.1.

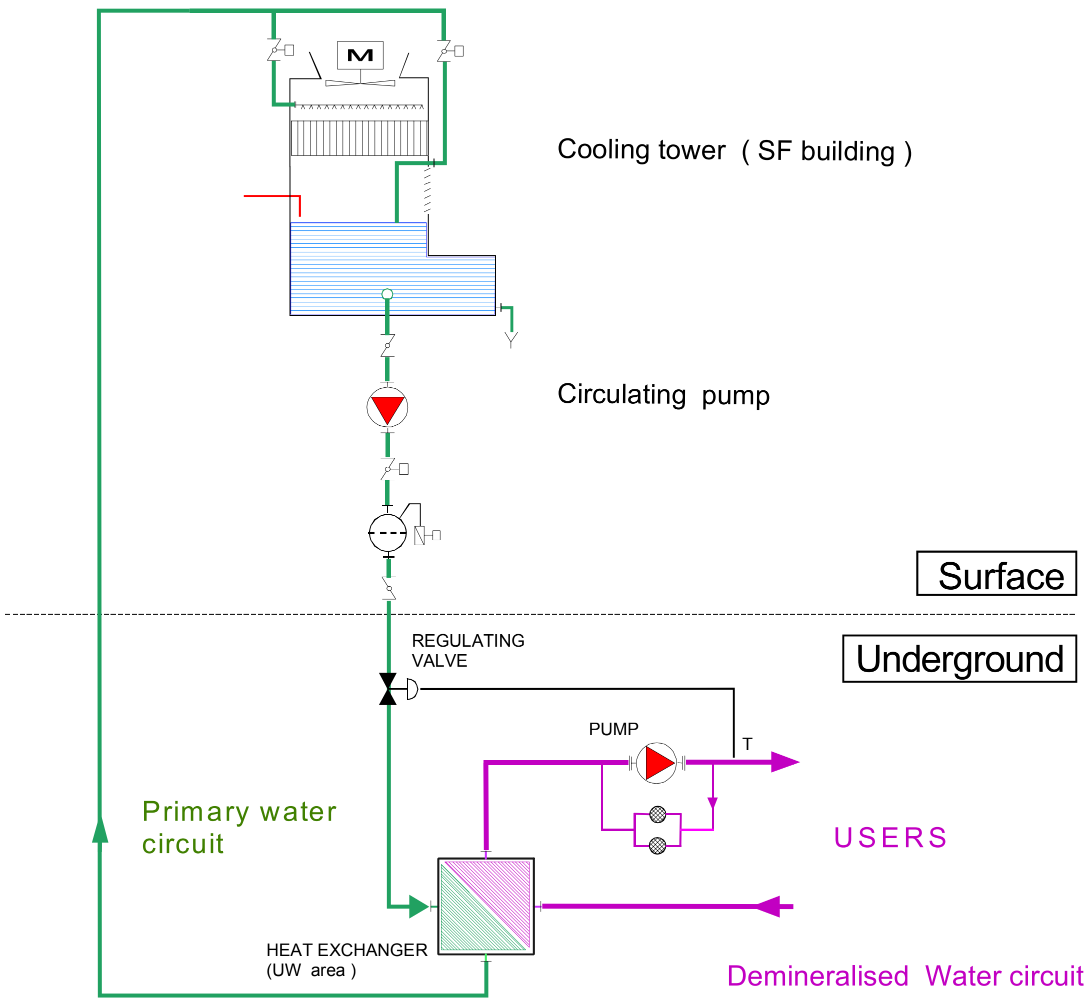


Figure 8.1: Primary Water System layout

The primary water is supplied from the LHC cooling towers and principally provides a heat sink for the following users:

- Cryogenic components, such as compressors, cold boxes etc.,
- The demineralised water circuits serving the underground areas,
- The condensers of chillers located in the surface buildings.

Each primary water loop is an open circuit. The water is cooled by cooling towers and distributed to users by pumps installed in pumping stations. The cooling towers are of an open atmospheric type, built as modular concrete structures, with each one having a cooling capacity of 10 MW. The pumping stations are directly attached to the cooling tower structure and are also constructed in reinforced concrete. The choice of this structure was determined by the need to limit the noise to the environment in the neighbourhood around CERN. The water temperature of the primary water at the cooling tower has been set as follows:

Inlet	34 ºC (tolerance ±1 ºC)
Outlet	24 ºC

These figures, taken together with the normal atmospheric conditions in the Geneva area (maximum 21°C wet bulb temperature and 32°C outside temperature) corresponds to dimensioning data for the primary cooling system. The available pressure difference, on the user side is typically 3 bar. The maximum cooling power capacity per point is shown in Tab. 8.1.

Table 8.1: Maximum Primary Cooling Power Capacity per LHC Point

POINT	AREA	BUILDING	FLOW RATE [m^3/h]	COOLING CAPACITY [MW]
1	Cryogenics	SH	344	4.0
	ATLAS	USA	86	1.0
	Air-Conditioning	SUX	1050	12.3
18	Cryogenics *	BA7	20	0.23
		SHM	630	7.32
		PM	20	0.23
2	Demineralised Water	UW	1385	16.1
	Cryogenics	SH	540	6.3
		SD	10	0.1
		US	30	0.35
	Air-Conditioning	SU	475	5.5
4	Demineralised Water	UW	2150	25.0
	Cryogenics	SHM	540	6.3
		SH	540	6.3
		SD	30	0.35
		US, UX	40	0.47
	Air-Conditioning	SU	475	5.5
5	Cryogenics	SH	175	2.0
	CMS	USC	215	2.9
	Air-Conditioning	SUX	1050	12.2
6	Demineralised Water	UW	400	4.6
	Cryogenics	SHM	540	6.3
		SH	540	6.3
		SD	30	0.35
		US, UX	40	0.47
	Air-Conditioning	SU	475	5.5
8	Demineralised Water	UW	1085	12.6
	Cryogenics	SHM	540	6.3
		SH	540	6.3
		SD	30	0.35
		US, UX	40	0.47
	Air-Conditioning	SU	475	5.5

* This circuit is cooled by the SPS cooling loop

Each pumping station is equipped with an auxiliary circuit for filtering the water in the basins. The filters are self cleaning and of the sand-bed variety. The circuit is also fitted with a heater and circulation pumps for frost protection.

Each distribution circuit is designed for two pumps; one in use and one as stand-by. For the first phase of LHC, the stand-by pump will not be installed, but some spare pumps will be stored at CERN, in order to limit the repair time to a maximum of two days in case of a breakdown.

8.3 DEMINERALISED WATER SYSTEMS

Demineralised water is used in underground areas to cool:

- Power converters, cables, warm magnets and auxiliary equipment in the LHC tunnel (Machine circuit),
- The ATLAS, CMS, ALICE and LHC-B Experiments,
- The radio frequency system at point 4,
- The injection tunnels and magnets installed in TI 2 and TI 8.

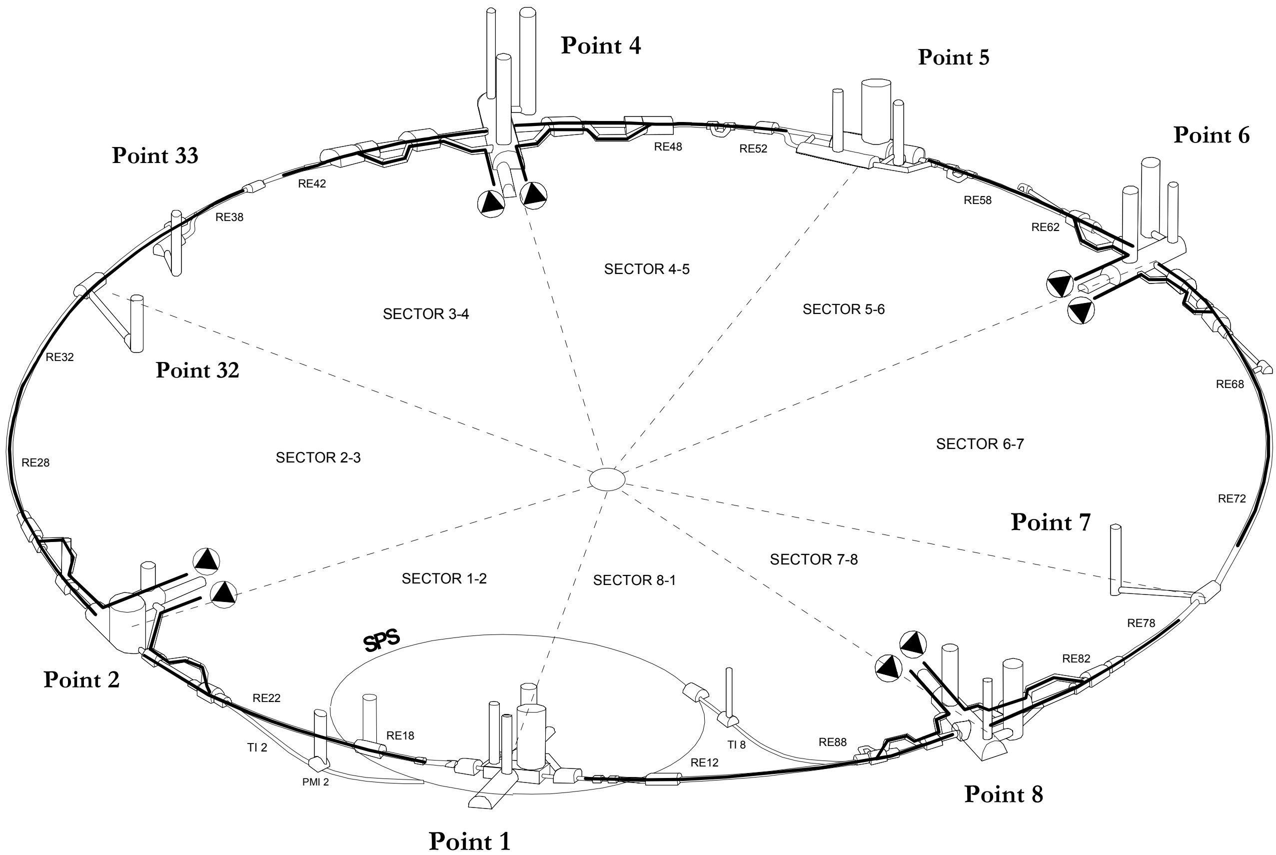


Figure 8.2: “Machine circuit” of demineralised water of the LHC

Each demineralised water system is a closed circuit and equipped with a pump, heat exchanger, expansion vessel, filter, ion cartridge (demineraliser) and all the necessary control and regulating devices. This equipment is installed in the UW caverns at LHC Points 2, 4, 6 and 8. The thermal load of the demineralised water network is extracted to the primary water system. The main characteristics of the demineralised water system are as follows:

Inlet design temperature	27 ºC (tolerance ±1 ºC)
Set point	26 ºC
Design pressure	16 bar
Conductivity	<0.5 µS/cm

Tab. 8.2 gives the demineralised water cooling capacity in the different parts of the LHC accelerator, divided into the cooling stations in the technical caverns (UW-caverns) in Points 2, 4, 6 and 8.

The layout of the machine circuit of the demineralised water is shown schematically in Fig. 8.2. From each UW-cavern, the demineralised water is distributed to the adjacent sectors of the machine. For example, the station in point 4 (UW 45) supplies water to sector 3-4 and to sector 4-5. Moreover, the transfer tunnel (warm magnets) TI 2, is supplied from point 2, while TI 8 is supplied from Point 8. The detailed heat-load by user and by sector of the LHC machine has been described elsewhere [2].

Table 8.2 Demineralised water cooling capacities

POINT	**COOLING LOAD IN UW AREAS [MW]**
2	13.95
4	23.8
6	4.6
8	12.6

Table 8.3: Cooling capacities, chilled water in the LHC Points

POINT	**AREA**	**BUILDING**	**FLOW RATE [m^3/h]**	**COOLING CAPACITY [kW]**
1	Ventilation	SU	101	710
		SR	150	1050
	Electrical Racks for Power Converters	UJ14	0.4	3
		UJ16	0.4	3
1 ATLAS	Ventilation	SCX-SGX-SH	150	1050
		SX-SD-SU	258	1806
		SUX	243	1701
	Heat Exchangers	USA	206	1442
2 ALICE	Ventilation	SU	395	2765
		SR	0	0
		UA23	17	120
		UA27	17	120
	Heat Exchangers	PM-PX	387	2709
	Electrical Racks for Power Converters	UA23	1	7
		UA27	1	7
32	Ventilation	SU	4	28
		SR	60	420
33	Ventilation	SU	16	112
	Ventilation	PM-PX	43	301
4	Ventilation	SU	440	3080
		SR	0	0
		SX	0	0
		UX45	17	120
		UA43	17	120
		UA47	17	120
	Heat Exchangers	PM-PX	57	399
	Electrical Racks for Power Converters	UA43	0.6	4
		UA47	0.6	4

POINT	AREA	BUILDING	FLOW RATE [m^3/h]	COOLING CAPACITY [kW]
5 CMS	Ventilation	UA47	0.6	4
		SR-SH-SGX	134	938
	Heat Exchangers	SUX-SX	345	2415
	Electrical Racks for Power Converters	USC	72	504
		USC	0.4	3
6	Ventilation	SU	362	2534
		SR	0	0
		SX	0	0
		UA63	17	120
		UA67	17	120
	Heat Exchangers	PM-PX	57	399
	Electrical Racks for Power Converters	UA63	0.6	4
		UA67	0.6	4
7	Ventilation	SU	47	330
		SR	38	266
	Heat Exchangers	PM-PX	14	98
8 LHC-B	Ventilation	SU	220	1540
		SR	0	0
		SUX	151	1057
		UA83	19	135
		UA87	19	135
	Heat Exchangers	PM-PX	345	2415
	Electrical Racks for Power Converters	UA83	1	7
		UA87	1	7

8.4 CHILLED AND MIXED WATER SYSTEMS

Chilled and mixed water are produced in the LHC surface buildings in water-chillers, using the primary water from the cooling towers as a cooling source. The chilled and mixed water is used in the LHC surface buildings in air handling units and in underground areas of UW and US in the heat exchangers. Chilled water is produced at the temperature of 5±0.5°C. Mixed water is produced at 13±0.5°C. The cooling capacities of the chilled water (Δt= 6°C) in different LHC points are shown in Tab. 8.3 while the mixed water cooling capacities (Δt= 5°C) in the different LHC points are shown in Tab. 8.4.

Table 8.4: Cooling capacities for mixed water in the different LHC Points

POINT	BUILDING / CAVERN	FLOW RATE [m^3/h]	COOLING CAPACITY [kW]
1	USA	600	3500
2	Experiments and underground areas	172	1000
5	SCX	54	315
	USC	388	2263
8	Experiments and underground areas	215	1500

The four experiments are also large consumers of chilled and mixed water.

8.5 FIRE FIGHTING WATER SYSTEMS

The LHC fire fighting system includes the water distribution pipes inside the tunnel access areas and LHC experiment caverns. The distribution circuit has to provide water at 7 bar to the RIA (Robinet d'Incendie Armée) fire fighting hose-wheel. Fig. 8.3 presents a schematic view of a typical fire fighting circuit installation.

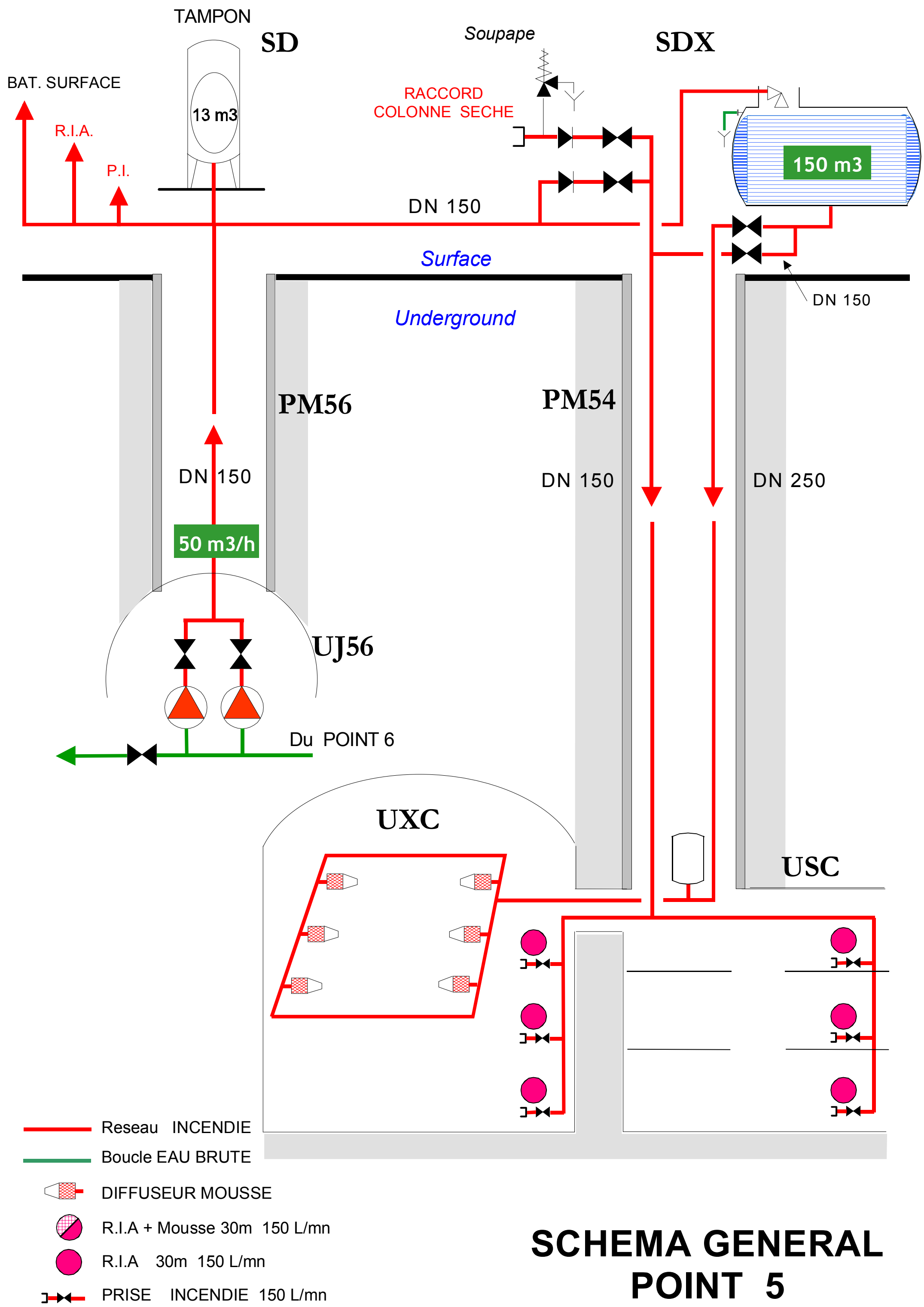


Figure 8.3: Schematic view of a fire fighting water installation

8.6 COMPRESSED AIR SYSTEMS

The main distribution locations for the compressed air are at points 1, 2, 4, 6 and 8 of LHC. There are additional compressed air plants at Point 1.8 and at Point 5. From each plant, the compressed air is passed around the LHC sectors as illustrated in Fig 8.4. The main consumers of the compressed air are the LHC cryogenics and vacuum systems. On the experimental sites the detector groups also use compressed air.

Table 8.5 Compressed air demand at each LHC point

	Cryogenics	**CV**	**EXPERIMENTS**	**TOTAL**
Point	**Flow rate [m^3/h]**	**Flow rate [m^3/h]**	**Flow rate [m^3/h]**	**Flow rate [m^3/h]**
1 (ATLAS)	USA15 : 159 UX15 : 57 SH1 : 40	SU1: 30		286
1.8	BA7: 40 PM18: 70 SD18: 60 SHM18: 40			210
2 (ALICE)	SD2: 20 SH2: 30 US1: 110 Sector 1-2: 285 Sector 2-3: 285	SU2: 30	UX: 10	770
4	SD4: 20 SDH4: 60 SH4: 30 SHM4: 30 US: 40 UX: 90 Sector 3-4 : 285 Sector 4-5 : 285	SU4: 30		870
5 (CMS)	SH: 5 SHL: 15 SX5: 2 USC55: 15 UXC55: 2			39
6	SD6: 20 SH6: 30 SHM6: 30 SUH6: 60 US: 40 UX: 90 Sector 5-6 : 285 Sector 6-7 : 285	SU6: 30		870
8 (LHCb)	SD8: 20 SDH8: 60 SH8: 30 SHM8: 30 US: 40 UX: 90 Sector 7-8 : 285 Sector 8-1 : 285	SU8:30		870
TOTAL:	**3755**	**150**	**10**	**4005**

The compressed air plants are located either in SU- (points 2, 4, 6, 8), SH- (points 1 and 5) and SHM- and SW- buildings (Point 18). The total demand of compressed air is distributed across the different points of LHC as shown in Tab. 8.5.

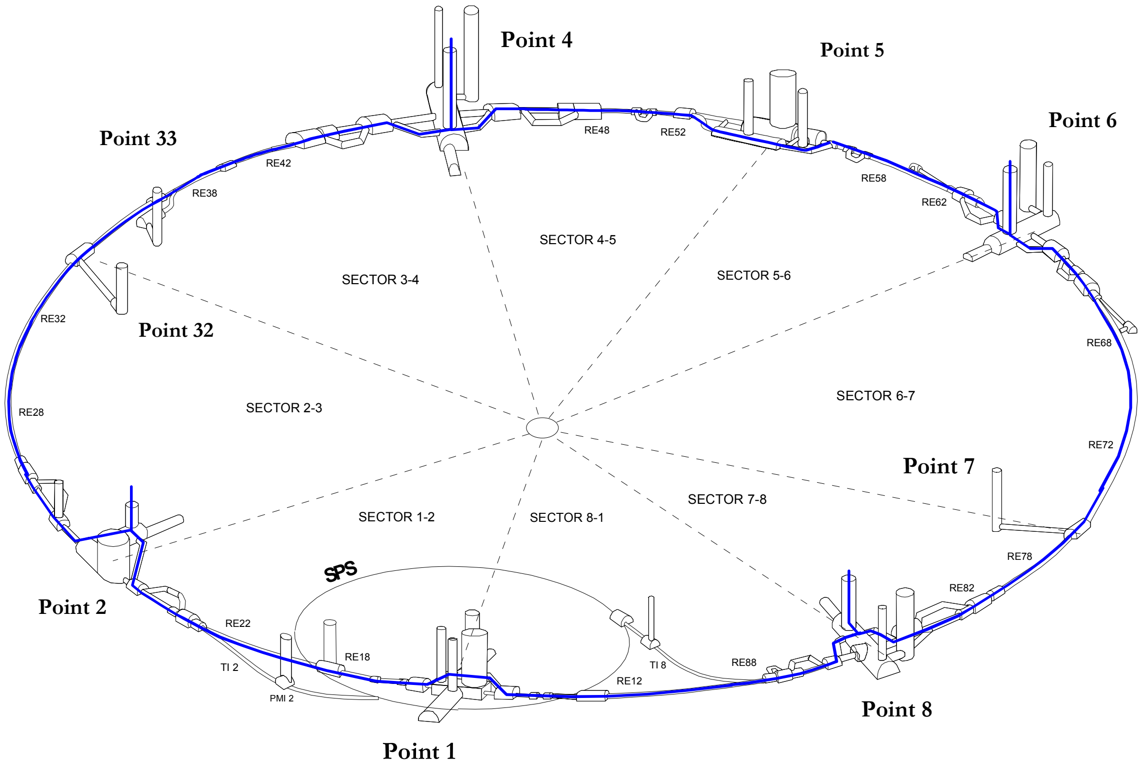


Figure 8.4: The LHC compressed air plants

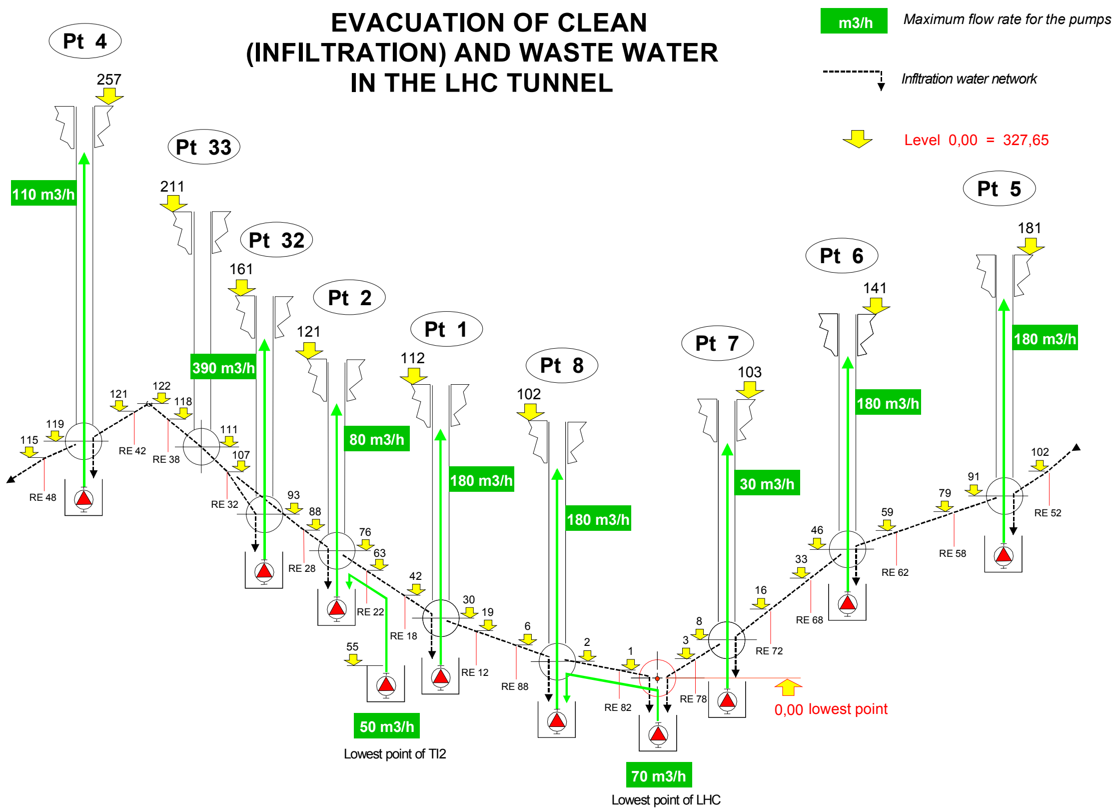


Figure 8.5: LHC pumping stations for clean and waste water

8.7 CLEAN AND WASTE WATER SYSTEMS

The clean water is mainly ground water which comes from the stub tunnels, by infiltration through the tunnel walls and occasionally from leaking pipes. Such water is calcareous and may carry traces of hydrocarbons. It flows in the machine tunnel drain to a sump at the next lower LHC access point.

The waste water comes from lavatories (with waste grinders), urinals and wash basins. It is collected in sumps, diluted and pumped up to the surface, then discharged to the communal waste water network. In order to ensure that surface water does not leave the CERN sites carrying dirt and oil, water treatment plants have been installed. These include flocculation, neutralisation, settling and oil removing tanks/systems. Should a change in pH be detected, the electronic monitors trigger an alarm in the Technical Control Room.

Fig. 8.5 presents the locations of the clean and waste water pumping stations, while Fig. 8.6 presents a typical installation schema.

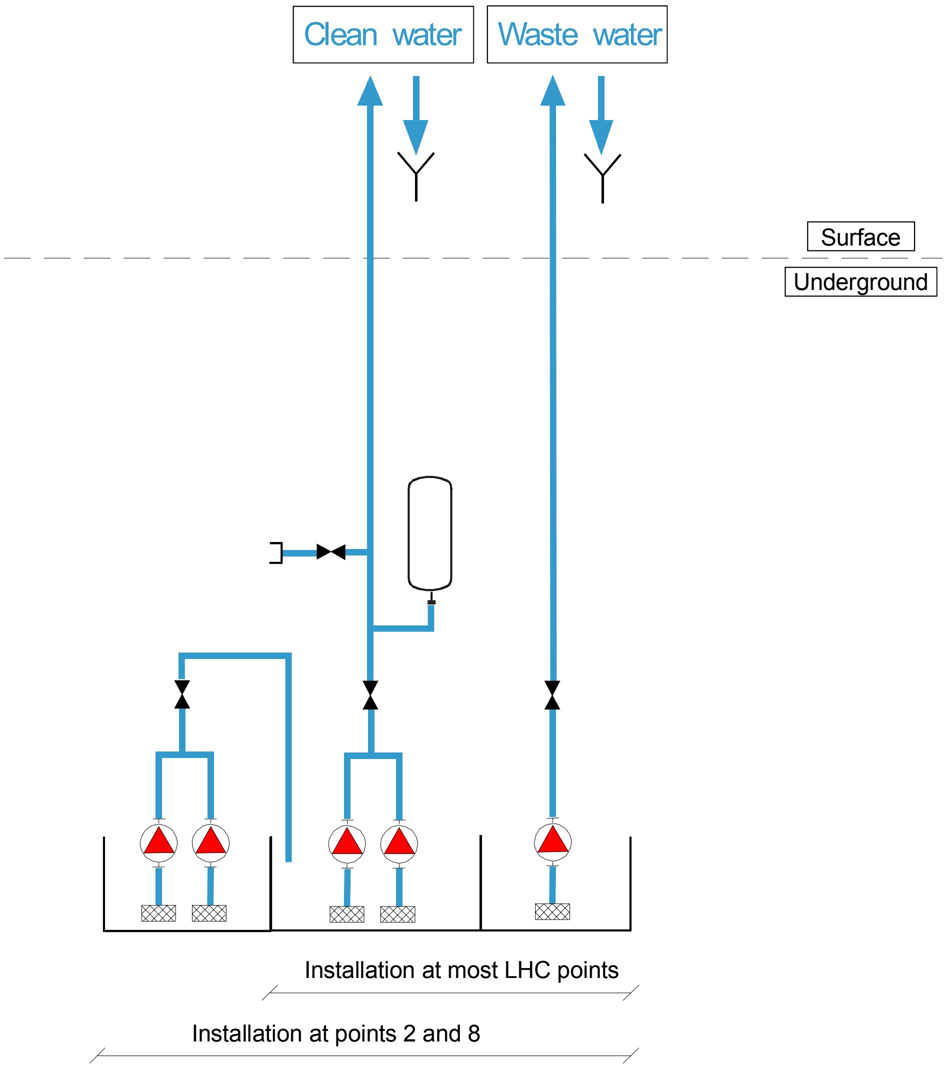


Figure 8.6 Schematic of the principal clean and waste water equipment of the LHC

8.8 VENTILATION OF THE LHC TUNNEL AND ITS TECHNICAL AREAS

This section concerns the ventilation system of the LHC tunnel itself, with associated technical underground areas: the RR caverns, the beam-dump region and the RE alcoves. In addition, the UA caverns, as well as the UX45 cavern which will house the machine radio frequency equipment.

The main tunnel is divided into eight independent volumes, called sectors which are treated separately. Two air handling units supply air at each even point of a sector, while two extraction units remove air at the odd points of the corresponding sector. The generalised air flow is shown schematically in Fig. 8.7.

The air is supplied via air handling units located in the surface buildings SU2, SU4, SU6 and SU8. The treated air is transported by air ducts, via PM25, PM45, PM65 and PM85 shafts down to the UJ24, UJ26, UJ44, UJ46, UJ64, UJ66, UJ84 and UJ86 junction chambers. The air is pulsed into the tunnel on the machine side of these junction chambers. The exhaust air is extracted from the odd points via the UJ14, UJ16, UJ32, UJ561, UP56, and UJ76 junction chambers. In UJ32, UP56 and UJ76, partitions separate the airflows coming from points 2 and 4, points 4 and 6, and points 6 and 8.

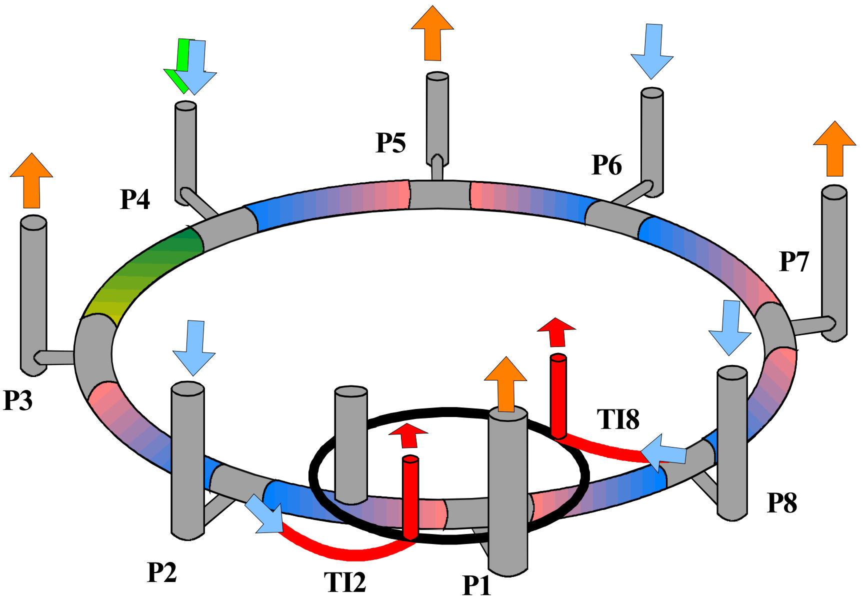


Figure 8.7: Schematic layout of the air-flows in the LHC tunnel.

In the design of the air handling installations, one of the most important aspects is the heat load which can only be evacuated via the ventilation air. As a general rule the maximum possible heat generated by equipment should be removed by water cooling. The remainder comes from such sources as warm cabling, and the heated surface of equipment. In addition to the heat load, many other functions must also be taken into account:

- Supply fresh air for people,
- Provide heating and ventilation,
- De-Stratify the air and maintain a suitable temperature of the equipment,
- Dehumidify to prevent condensation,
- Permit cold smoke extraction,
- Purge the air in the tunnel before access,
- Filter the exhaust air,
- Attenuate sound emissions associated with the exhaust air.

In each sector of the tunnel, four operating modes are provided. With the corresponding air flow rates shown in Tab. 8.6.

The cooling capacity of the ventilation system is partially determined by the inlet air parameters. The remaining heat load is cooled by local air-conditioning units, connected to the chilled water network in the various technical areas. Components which dissipate heat to underground air are: magnets (warm), cables, transformers, orbit correctors, electronic cells, electronic racks and powers converters. Indoor conditions as well as the total heat dissipation in all the sectors are shown in Tab. 8.7.

It can be seen from Tab. 8.7 that there is a gradient of the temperature and humidity along each sector, in the direction of the air flow. With a dew point < 10 °C the absolute humidity is 8.2 g/kg, whereas with a dew point < 5°C the absolute humidity will be 5.1 g/kg. A more precise breakdown of how much each component contributes to the total heat balance is available [3].

Table 8.6: Air flow rate per tunnel sector

Tunnel sector	Reduced Consumption mode [m³/h]	Tunnel Accessible mode[1] [m³/h]	Tunnel Not Accessible mode [m³/h]	Emergency Sector mode [m³/h]
1-2	9 000	18 000	36 000 22 500[2]	64 000
2-3	9 000	18 000	36 000	64 000
3-4 [3]	9 000	18 000	45 000	64 000
4-5	9 000	18 000	36 000	64 000
5-6	9 000	18 000	36 000	64 000
6-7	9 000	18 000	36 000	64 000
7-8	9 000	18 000	36 000	64 000
8-1	9 000	18 000	36 000 22 500[2]	64 000

Table 8.7: Indoor conditions per tunnel sector

Tunnel sector	Total heat Dissipation [kW]	Dry bulb temperature, even input [°C]	Dew point at the even input [°C]	Dry bulb temperature odd output[4] [°C]
1-2	125	18 ±1	< 10	23 ±6
2-UJ32	41	18 ±1	< 10	20 ±2
UJ32-4	233	18 ±1	< 5	25 ±7
4-5	111	18 ±1	< 10	22 ±6
5-6	118	18 ±1	< 10	23 ±6
6-7	117	18 ±1	< 10	23 ±6
7-8	109	18 ±1	< 10	22 ±4
8-1	117	18 ±1	< 10	22 ±6

UA Galleries

The UA galleries are ventilated with a supply overpressure in the gallery compared to the tunnel volume while a separate circuit provides cold smoke extraction in case of emergency. The local heat dissipation in the gallery is treated by additional local air handling units cooled using chilled water.

---

1 *This air flow rate may be chosen between 9000m³/h and 18 000 m³/h per sector.*
2 *Reduced air flow rate in the adjacent sector when the injection lines, TI2 and TI 8 are operating.*
3 *The air flow rates are different from those proposed in the "Rapport Préliminaire du Sûreté LHC". The higher air flow rate is needed to cope with the heat dissipation.*
4 *The calculation of the resulting temperature is based on an adiabatic tunnel. The maximum temperature will be reached when there is maximum heat dissipation.*

Beam dumps

The beam dump caverns (UP, UD) are ventilated via relay fans. As a result the heat loads generated in these areas are taken into account as part of the ventilation of the main tunnel.

Alcoves

The 16 alcoves are ventilated and air-cooled by three air-handling units in each one. As there is no chilled water available in the alcoves, these air handling units each contain a refrigeration compressor unit, in which the condenser is cooled by demineralised water.

Outdoor conditions

The following extreme outdoor atmospheric conditions have been considered when dimensioning the air handling equipment:

- Summer: Dry bulb temperature: 32 °C
  Relative humidity: 40 %
- Winter: Dry bulb temperature: -12 °C
  Relative humidity: 90 %

8.9 VENTILATION OF THE LHC TRANSFER TUNNELS

During the beam injection from SPS to LHC, the TI2 and TI8 injection tunnels are in operation. A fraction of the air flow available in sectors 1-2 and 1-8 will be deviated to the injection tunnels via dedicated extraction units. An extraction plant located in SUI2, composed of two extraction units, one for normal extraction with filters, and a second for emergency and cold smoke extraction, will provide extraction at the end of the TI2 tunnel. The same principle will apply for TI8, for which the extraction plant is located in building SUI8. In each injection tunnel, the ventilation system will run in four operating modes, as shown in Tab. 8.8.

Table 8.8: Air flow rate per injection tunnel

Injection Tunnel	Reduced consumption mode [m^3/h]	Accessible mode [m^3/h]	Non Accessible mode [m^3/h]	Emergency mode [m^3/h]
TI2	7 500	9 000	22 500	45 000
TI8	7 500	9 000	22 500	45 000

8.10 VENTILATION OF THE EXPERIMENTAL CAVERNS

This section describes the heating, ventilation and air conditioning of the detector caverns and their associated services and the operation modes, design values and corresponding ventilation parameters. The ventilation functionalities listed in the previous chapter are also valid for the ventilation of the detector and service caverns. In general, the ventilation works on the principle of an air displacement system for the supply and a central extraction duct with grills distributed on the ceiling of the cavern. In general, the extraction systems for the experimental areas are fitted with absolute filters.

8.10.1 Point 1: ATLAS

The experimental cavern UX15

The design values for the experimental cavern UX15 are as follows:

	Temperature (°C)	Dew point temperature (°C)	Thermal load (kW)	Air volume (m^3)	Surface at floor level (m^2)
UX15	18-30	<12	<180	47 000	1 590

The UX15 cavern is air conditioned and ventilated by a mechanical supply and extraction of air, it also has dedicated smoke, Argon and gas extraction systems. As the gas extraction system works continuously, the UX15 cavern is always at a lower atmospheric pressure than the adjacent USA15 cavern. The main air extraction is done at the upper levels by means of extraction plenums. The air handling units for UX15 are housed in the surface building SUX1. Ducts in the PX14 shaft link the units to the supply and extraction points in the cavern. The surface and underground arrangement is illustrated in Fig. 8.8. The air flow values in the different networks and for the different operation modes are listed in Tab. 8.9.

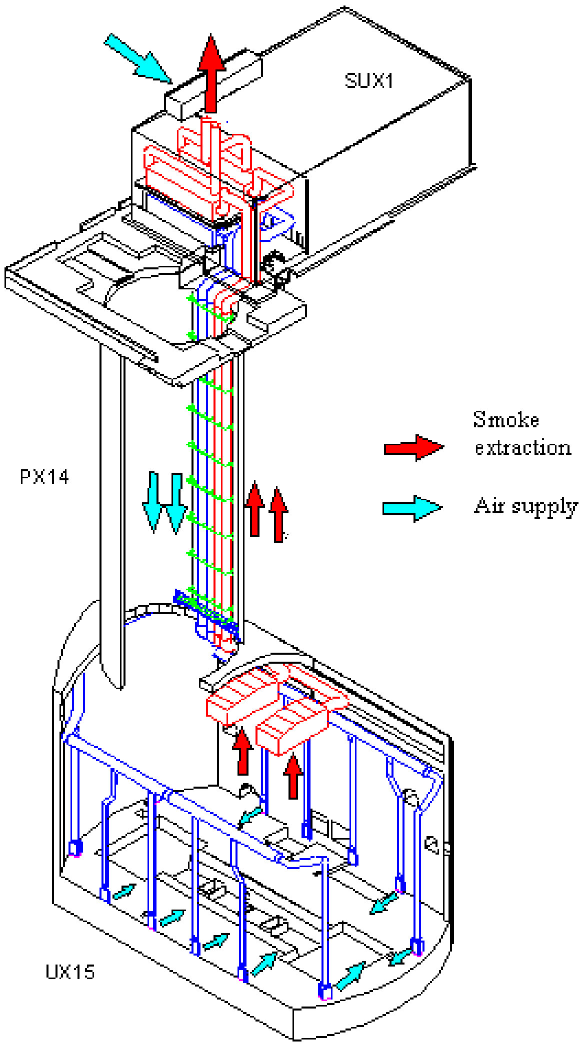


Figure 8.8: Ventilation of UX15

Table 8.9: Air flow values in different networks and different operation modes

	Air supply (m^3/h)	**Air extraction (m^3/h)**	**Smoke extraction (m^3/h)**	**Gas extraction (m^3/h)**	**Argon extraction (m^3/h)**
Access mode	60 000	60 000	0	5 000	8 000
No access mode	60 000	60 000	0	5 000	8 000
In case of fire in UX15	120 000	0	120 000	5 000	16 000
In case of Argon leak	120 000	0	120 000	5 000	32 000

The USA15 technical cavern

As well as the main ventilation system, the USA15 cavern has dedicated air conditioning systems for the transformer, cryogenics and electronic racks areas. Moreover, a smoke extraction network, fitted with dampers to target particular zones, takes care of the different areas. The ventilation systems for USA15 are shown in Fig. 8.9.

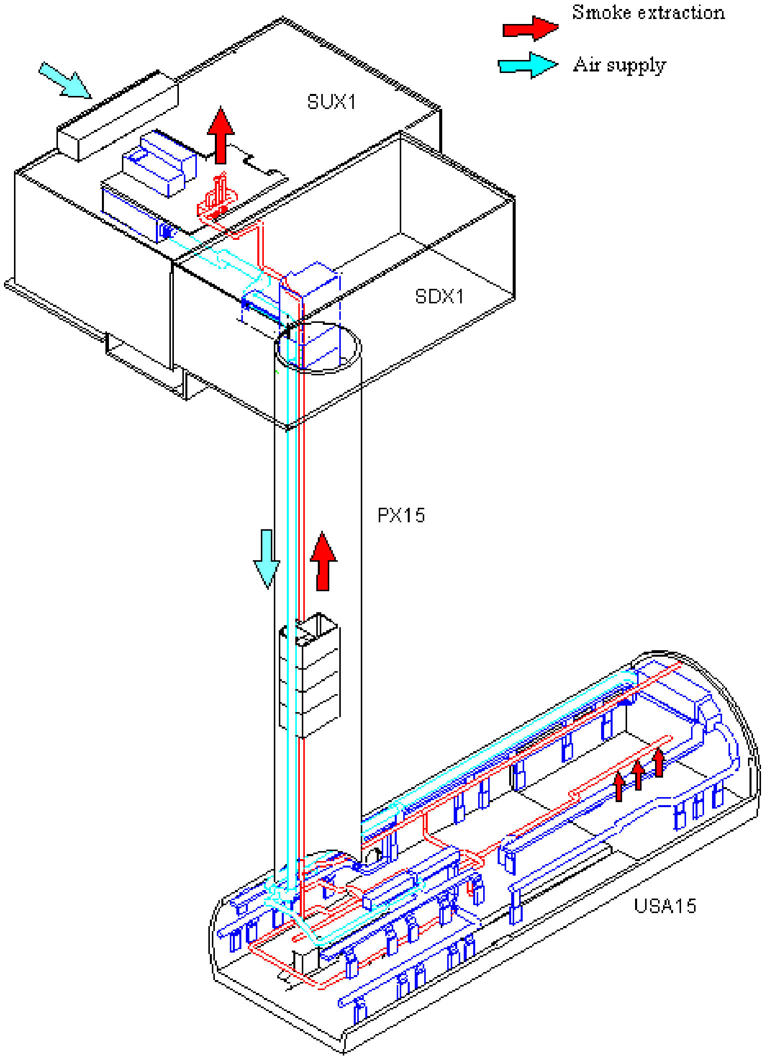


Figure 8.9: Ventilation of USA15

Table 8.10: Design values for USA15

AREA	Temperature (°C)		Dew point temperature (°C)	Thermal load (kW)	Air supply and extraction (m^3/h)
	Winter	Summer			
USA15 Electronic racks room	19 ±1	26 ±1	<12	125	4 x 10 000
USA15 Service area	19 ±1	26 ±1	<12	120	40 000
USA15 Safe room	19 ±1	26 ±1	<12	5	500
USA15 Transformers room	19 ±1	30 ±1	<12	<80	26 000
PX15	19 ±1	22 ±1	-	0	0

In the event of a fire, the ventilation is automatically stopped in the affected zone. The smoke extraction system is manually switched on, once the personnel have been evacuated and the fire controlled. For this purpose, priority manual commands for the fire brigade are installed both on the surface and underground.

The access galleries UPX14 and UPX16 and the service corridor are used as escape passages towards the UX15 cavern, they are therefore over pressurised with respect to USA15. The concrete modules in PX15 will also be pressurised because they are safe zones in case of fire.

The design values for the USA15 and the air flow rate for the particular air-conditioning systems are given in Tab. 8.10.

The main ventilation system in USA15 has the only mechanical supply. The extraction occurs as a result of the pressure difference between USA15 and the surface building SDX1 and between USA15 and UX15. The main ventilation parameters are presented in Tab. 8.11

Table 8.11: Air flow rates for the USA15 cavern

	Main air supply (m^3/h)	**Gas mixture extraction (m^3/h)**	**Smoke extraction (m^3/h)**
Access mode	26 000	5 000	0
In case of fire in USA15	26 000	5 000	10 000

8.10.2 Point 2 : ALICE

The experimental cavern UX25

The experimental cavern UX25 has the following thermal requirements:

	Air Temperature (°C)	
	Dry bulb	Dew point
Supply	17	<10
Extraction	<27	<12

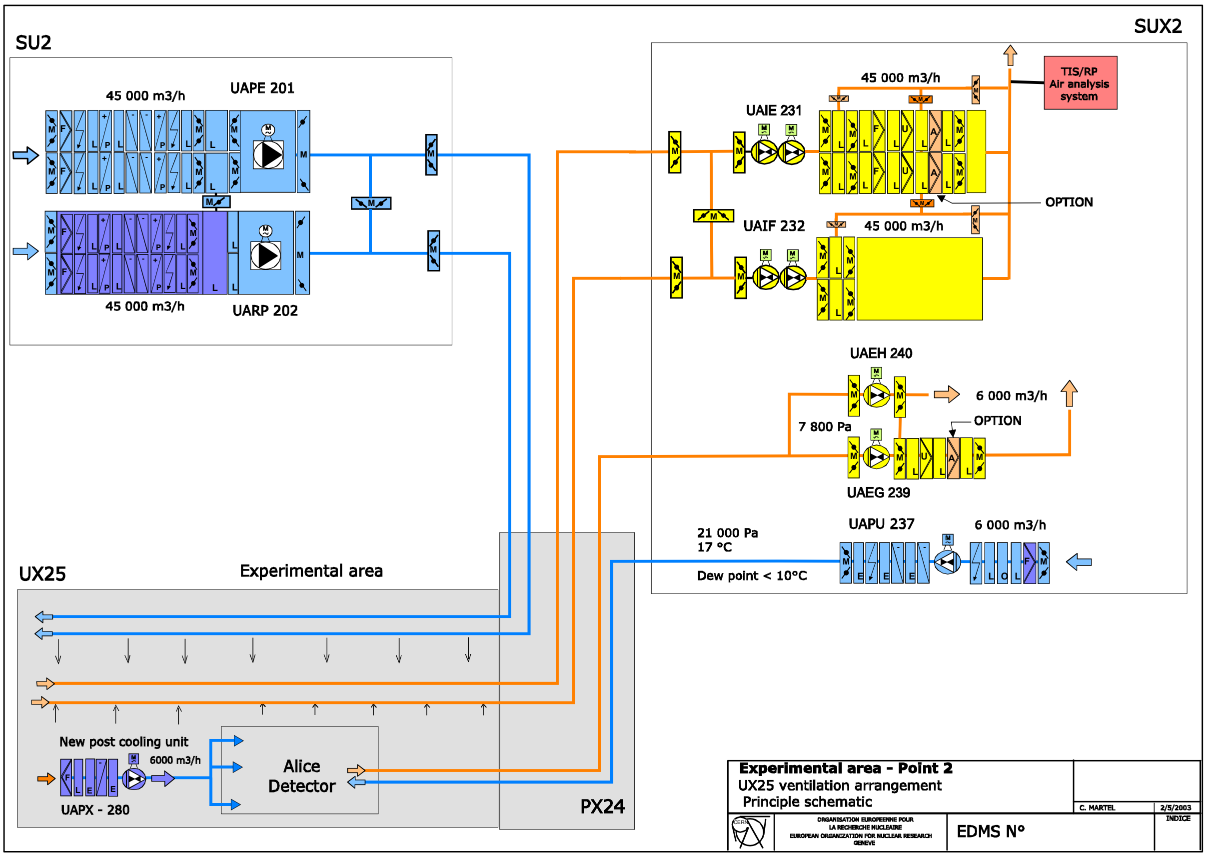


Figure 8.10: Ventilation of UX25

The maximum capacity for heat dissipation to the cavern is 100kW. The main ventilation system has two supply units located in building SU2 which are connected to the UX25 cavern through ducts traversing SUH2 and the PX24 shaft. The extraction units are in building SUX2 and the link with the cavern is also done through PX24. The arrangement is illustrated schematically in Fig. 8.10.

The air extraction system will also be used for smoke extraction. The filters in the experimental area air extraction system can be by-passed in order to avoid clogging and to ensure good operation during smoke extraction. The air supply and extraction is 45 000 m^3/h during normal operation which will be doubled in the event of a fire.

The shaft PX24

There are 3 air handling units located in the SU2 building serving the PX24 shaft. An air handling unit provides air conditioning in the PX24 hut where the air flow rate is 15 000 m^3/h. Another unit pressurises the concrete modules to permit access to the hut and has an air flow rate of 12 000 m^3/h. A third unit pressurises the stairs and lift with an air flow rate of 8 000 m^3/h. The 2 pressurization units are backed up by a fourth unit.

8.10.3 Point 5: CMS

The experimental cavern UXC55

The design values for the experimental cavern UXC55 are as follows:

	Temperature (°C)	Dew point temperature (°C)	Thermal load (kW)	Air volume (m^3)	Surface at floor level (m^2)
UXC55	18-30	<12	<100	28 000	1300

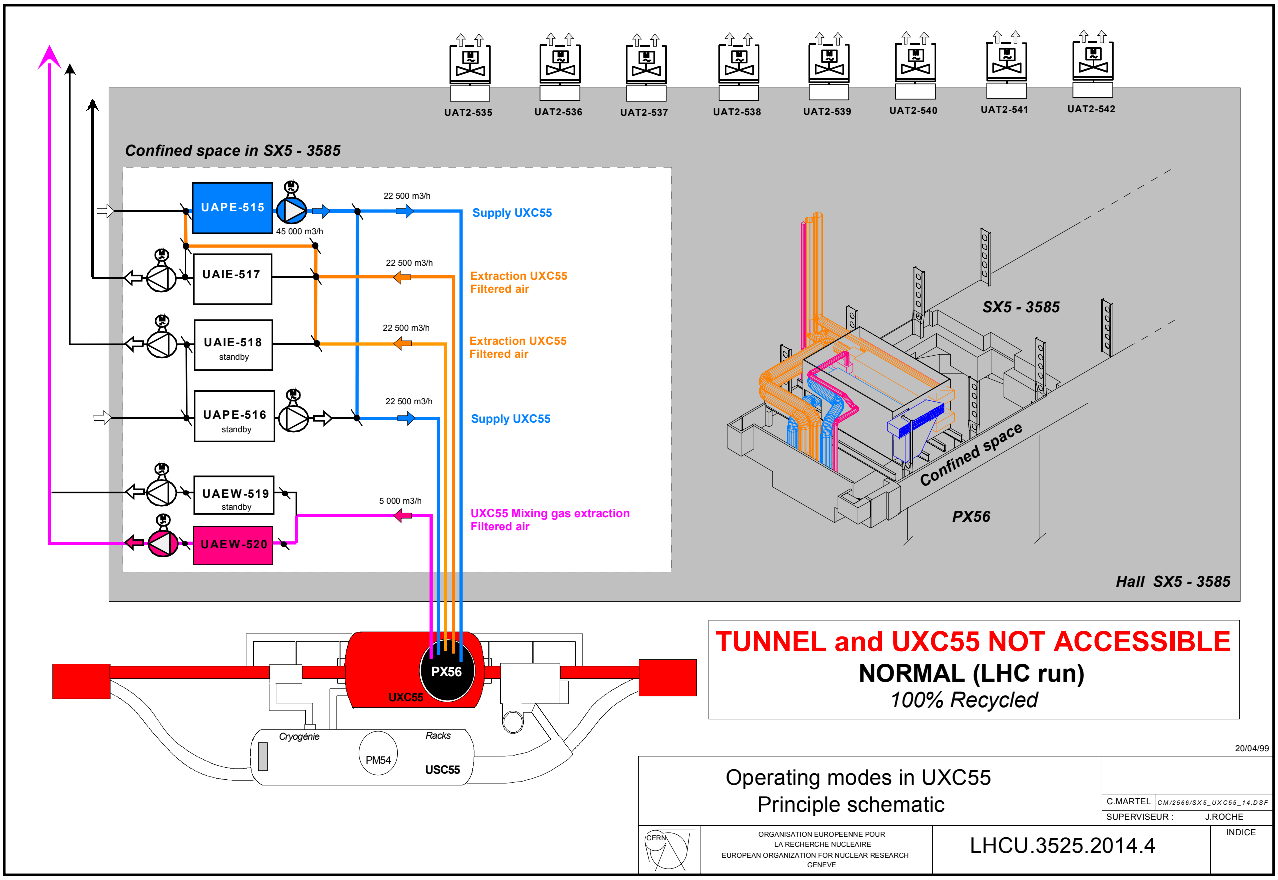


Figure 8.11: Ventilation of UXC55

The UXC55 cavern is air conditioned and ventilated by a mechanical supply and extraction of air as with UX15, the UXC55 cavern has dedicated smoke, Argon and gas extraction systems. The gas extraction system works continuously and because of this, the UXC55 cavern is always at a lower atmospheric pressure than the adjacent USC55 cavern. The main air extraction is done at the upper levels by means of extraction plenums. The air handling units for UXC55 are housed in the surface building SX5. Ducts in the PX56 shaft link the units to the supply and extraction points in the cavern.

The surface and underground arrangement is illustrated in Fig. 8.11. The air flow values in the different networks and for the different operation modes are listed in Tab. 8.12.

Table 8.12: Air flow values in different networks and different operation modes

	Air supply (m^3/h)	**Air extraction (m^3/h)**	**Smoke extraction (m^3/h)**	**Gas extraction (m^3/h)**
Access mode	45 000	45 000	0	5 000
No access mode	45 000	45 000	0	5 000
In case of fire or gas leakage in UXC55	90 000	0	90 000	5 000

The technical cavern USC55

As well as the main ventilation system, the USC55 cavern has dedicated air conditioning systems for the transformer, cryogenics and electronic racks areas. Moreover, a smoke extraction network, fitted with dampers to target particular zones, takes care of the different areas.

In the event of a fire, the ventilation is automatically stopped in the affected zone. The smoke extraction system is manually switched on, once the personnel have been evacuated and the fire controlled. For this purpose, priority manual commands for the fire brigade are installed both on the surface and underground. The access galleries and access shafts PM54 and PM56 are used as escape passages towards the UXC55 cavern. They are therefore over pressurised with respect to USC55. The concrete modules in PM54 will also be pressurised as they are considered a safe zone in case of fire. The design values for the USC55 and the air flow rate for the particular air-conditioning systems are given in Tab. 8.13.

Table 8.13: Design values for the USC55 Ventilation System

AREA	**Temperature (°C)**		**Dew point temperature (°C)**	**Thermal load (kW)**	**Air supply and extraction (m^3/h)**
	Winter	**Summer**			
USC55 Electronic racks rooms	19 ±1	26 ±1	<12	125	2 x 20 000
USC55 Service area	19 ±1	26 ±1	<12	100	40 000
USC55 Safe room	19 ±1	26 ±1	<12	8	500
USC55 Transformers room	19 ±1	30 ±1	<12	<80	26 000
PM54	19 ±1	22 ±1	-	0	12 000

The main ventilation system in USC55 has the only mechanical supply. The extraction occurs by pressure differences between USC55 and the surface building SDX5 and between USC55 and UXC55. The main ventilation parameters are presented in Tab. 8.14.

Table 8.14: Air flow rates for the USC55cavern

	Main air supply (m^3/h)	**Gas mixture extraction (m^3/h)**	**Smoke extraction (m^3/h)**
Access mode	12 000	5 000	0
In case of fire in USC55	12 000	5 000	10 000

8.10.4 Point 8: LHC-b

The experimental cavern UX85 is physically divided into two separate volumes each of which needs its own ventilation system. These volumes are:

- An experimental area which will house the LHCb detector,
- A protected area for the LHCb counting rooms and the Delphi barrel exhibition which is always accessible.

The design parameters are similar to those for the UX25 cavern and are as follows:

	Air Temperature (°C)	
	Dry bulb	Dew point
Supply	17	<10
Extraction	<27	<12

The maximum heat dissipation in each of the areas is 50 kW. The supply units for both areas are located in building SUX8 and the extraction unit for the protected area is also located in SUX8. See Fig. 8.12.

The extraction duct is placed below the cavern ceiling and is divided in two parts for the two different zones. For the experimental area, the extraction is done by fans located in the technical gallery TU84 which extract the air from the cavern to the PX84 shaft. At the same time, fans in SX8 which have a filtration section, extract the air from the PX84 shaft to the outside. The air extraction system will also be used for smoke extraction. The filters in air extraction for the experimental area can be by-passed in order to avoid clogging and to ensure good operation during the smoke extraction. In both areas the air supply and extraction is 22500m^3/h in normal operation and is doubled in the event of a fire.

Both areas are equipped with a gas extraction network and ducts from both parts of the cavern are connected to gas extraction units placed in TU84 gallery. The units blow the gasses to the PX84 shaft and the main extraction system blows them outside. The gas flow rate is 5 000m^3/h.

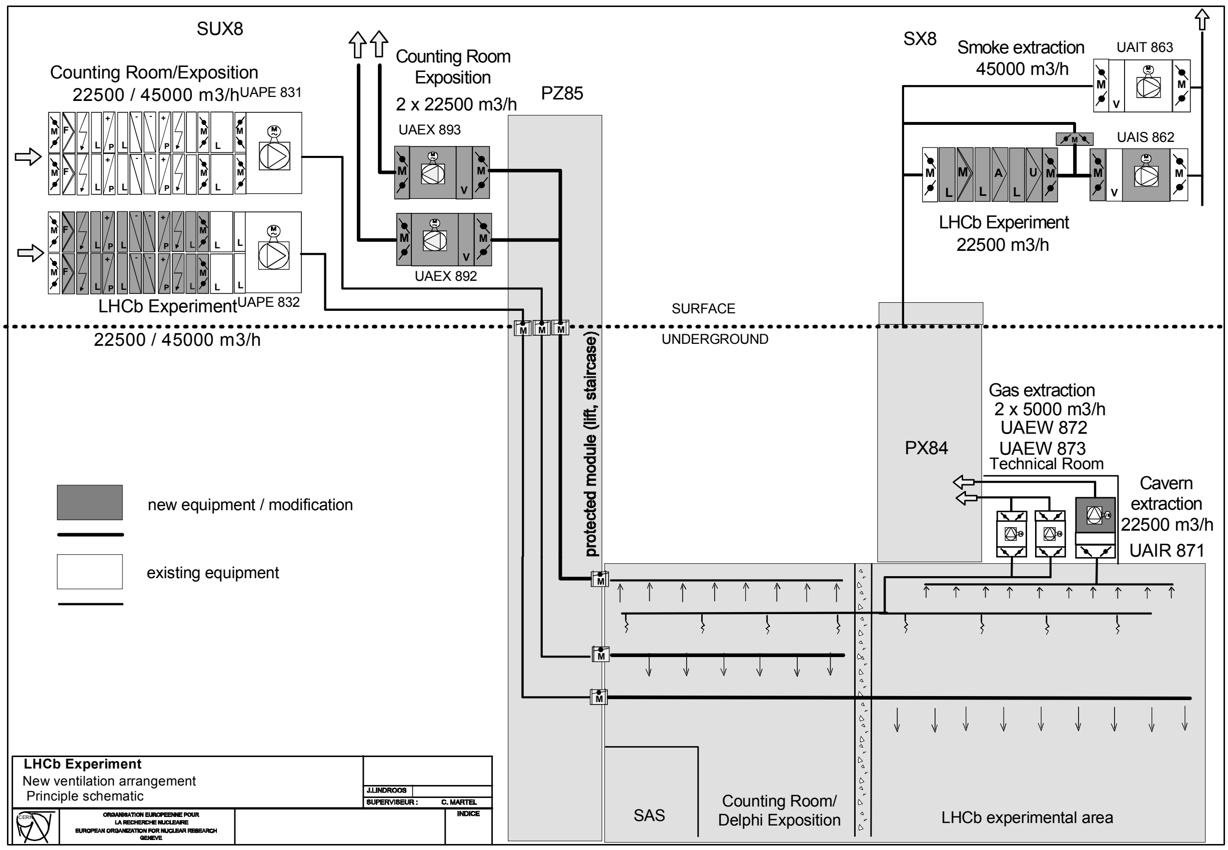


Figure 8.12: The ventilation system of UX 85

8.11 HEATING, VENTILATION AND AIR-CONDITIONING FOR THE SURFACE BUILDINGS

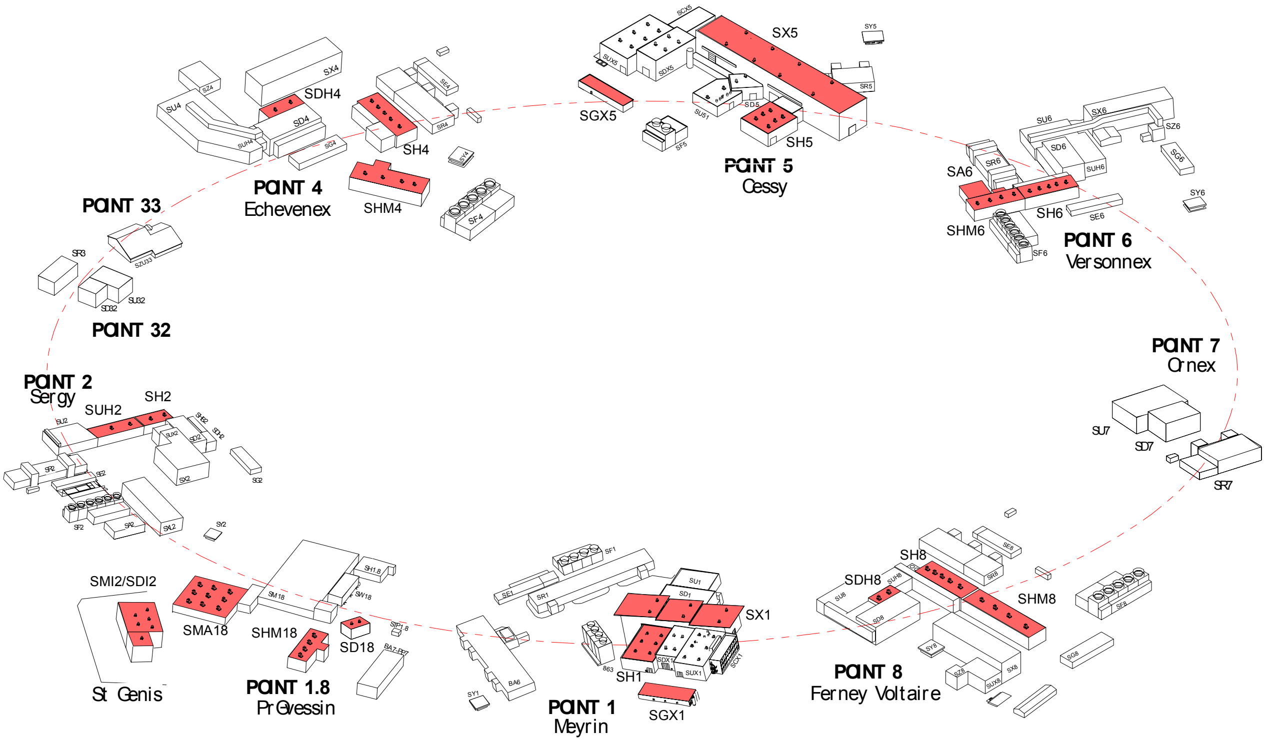


Figure 8.13: LHC Surface buildings

Table 8.15: Heating, ventilation and air-conditioning equipment by building

LHC buildings	HVAC equipment
SA (Points 2 and 6)	Heating and Ventilation
SD (Points 1-8)	Heating, ventilation and smoke extraction
SD (Point 1.8)	Heating, ventilation, smoke extraction and PM18 pressurisation
SDH (Points 4 and 8)	Heating, ventilation and passive smoke evacuation
SDX (Points 1 and 5)	Heating, ventilation and smoke extraction
SEM-SES	Heating, ventilation and cooling
SF (Points 1, 2, 4, 5, 6, 8)	Heating, ventilation and passive smoke evacuation
SG (Points 2, 4, 6, 8)	Heating, ventilation, cooling, gas extraction and heat recovery
SH (Points 1, 2, 4, 5, 6, 8)	Heating, ventilation and smoke extraction
SHM (Points 1.8, 4, 6, 8)	Heating, ventilation and smoke extraction
SR (Points 1-8)	Heating, ventilation, cooling and smoke extraction
SU (Points 1-8)	Heating, ventilation and passive smoke evacuation
SUH (Points 2, 4, 6, 8)	Heating, ventilation and passive smoke evacuation
SUX (Point 1, 2, 5)	Heating, ventilation and passive smoke evacuation
SX (Points 1, 2, 4, 5, 6, 8)	Heating, ventilation and smoke extraction
SY (Points 1, 2, 4, 5, 6, 8)	Heating, ventilation and smoke extraction
SZ (Points 4, 6, 8)	Heating, ventilation and smoke extraction
SCX (Points 1 and 5)	Heating, ventilation and air-conditioning
SGX (Points 1 and 5)	Heating, ventilation, cooling, gas extraction and heat recovery
SMA (Point 1.8)	Heating, ventilation and passive smoke evacuation
SW (Point 1.8)	Heating, ventilation and smoke extraction

There are 118 surface buildings at the LHC sites as illustrated in Fig 8.13. A total of twenty buildings (indicated by shaded roofs) were constructed specifically for the LHC project and the others were from LEP. They are all equipped with various types of air handling equipment. A total of 80 buildings only have a heating and ventilation system, whereas the remainder are equipped with a more sophisticated air-conditioning system. All buildings have electric heating, except building SMA 18 which is heated by hot water from the central heating system at the Meyrin site. Where applicable, the cooling media is chilled water. According to the contents of the buildings, some are equipped with active (mechanical) or passive (air-louvers) smoke evacuation devices. Under winter conditions, the general set point for the indoor temperature is 17°C. A summary of how the various types of buildings are equipped is presented in Tab. 8.15. More details on the purpose and volume of each of those buildings may be found in chapter 2.

REFERENCES

[1] L. Annila, *'LHC Primary Water Circuit'*, LHC-FB-ES-0001, EDMS No. 335023.
[2] L. Annila, *'LHC Demineralised Water Circuit'*, LHC-FW-ES-0001, EDMS No. 335008.
[3] C. Martel, *'Air Handling of the LHC Tunnel and its underground areas'*, LHC-UA-ES-0001, EDMS No. 344211.
[4] J. Inigo-Golfin & C. Martel, *'Air conditioning systems for the ATLAS experimental and technical caverns UX15 and USA15'*, LHC-UA15-ES-0001, EDMS No. 313039.
[5] J. Lindroos & C. Martel, '*Primary air handling of the experimental area at point 2 of the LHC'*, LHC-UA-ES-0004, EDMS No. 386351.
[6] J. Lindroos & C. Martel, *'Air conditioning of the LHCb experimental and protected areas'*, LHC-UA-ES-0003, EDMS No. 351740.
[7] C. Martel, *'Ventilation et securite incendie d'une zone experimental'*, CERN–ST-2000-055, 2000.

CHAPTER 9

INTEGRATION AND OVERALL MACHINE EQUIPMENT LAYOUT

9.1 INTRODUCTION

Integrating the large and complex LHC machine into the existing LEP tunnel is a major challenge. Space was less of a problem when integrating LEP into its tunnel. However, the LHC cryostats are much larger than the LEP quadrupoles and the external cryogenic line fills even more of the tunnel. Space problems here lead to small clearances. Conflicts, at least the most penalising ones, must be solved beforehand in order to avoid unacceptable delays and extra costs during the installation. These conflicts can arise between the different equipment elements to be installed or with space required for transport.

This chapter presents the study work done to prepare for a smooth installation including the related data management and the tools provided to the teams procuring and operating the equipment.

9.2 INTEGRATION STUDIES

The difficulties to integrate the LHC machine into the existing tunnel are due to dimensional problems of two types. Firstly the machine is very long and the precise longitudinal positioning of the numerous elements is essential. Secondly, the transverse dimensions of the machine and its services must fit into the tunnel.

It was already a challenge to integrate the LEP machine in the tunnel, the quadrupoles were the widest elements, having a transverse section of about 0.7 m^2, but the LHC cryostats and the cryogenics line occupy four times more transverse space.

When space inside the tunnel is a problem clearances become a major concern, especially since the tunnel dimensions do not have the same precision as the mechanical parts of the accelerator. The tunnel is itself a very large piece of civil engineering with offsets of centimetres or even decimetres with respect to its theoretical position and dimensions.

Given these space constraints, an in depth study had to be carried-out to ensure that all the equipment would fit in the available space and that no interference between components would be encountered not only during installation but also during handling and transport. After a feasibility study, the overall integration work started in mid 2001[1]. Three working groups were created and each was given the task of studying a particular part of the collider: the underground service areas, the tunnel and the shafts. At the beginning of 2003, the integration work was entrusted to the Installation Coordination group (TS-IC) together with the LHC Reference Database [2][3] and the configuration management.

9.2.1 Methodology

Experience with LEP showed the advantages that computer-aided engineering (CAE) software could provide for integration. Because LHC integration is much more complex, the use of CAE software is essential. Specific tools, based on the CAE software, have been developed in the two dimensional domain for the longitudinal positioning of elements and in the three-dimensional domain for the complete digital mock-up (DMU) of the LHC.

The integration study required the creation of 3-D computer models of all the major components (cold and warm magnets, electrical feedboxes, dump resistors, racks, electronics crates, transformers, etc.), the services (cable trays, cables, pipes, metallic structures, etc.) as well as the civil engineering works (as-built models).

Each group was asked to provide the 3-D models of the equipment they designed and the installation they were procuring. These were introduced in a library of "standard" models which were made available to all those involved in integration studies. Since the studies strongly rely on the quality of the models, a lot of effort was put in maintaining the coherence of the models whilst the design and integration studies progressed, often in parallel.

The integration process relies on the DMU and the LHC reference database to position the models in the tunnel or the service areas. Two specific parts of the underground areas are treated by the DMU: the periodic part consisting of the "standard" tunnel sections and the repetitive cells of the machine and are automatically generated and the non-periodic part, typically underground service areas. The shafts have been integrated manually.

As a result of this effort, 3-D representations of any part of LHC can be produced. Priority has been given to the most crowded areas and major difficulties were encountered in some specific zones where civil engineering modifications were deemed necessary. However, in most of these cases, a thorough integration study confirmed that civil engineering could be avoided, albeit at the expense of a very dense and complex installation.

The 3-D views produced through DMU are very thorough representations, but sometimes difficult to use by non-specialists. In order to satisfy the requirements from users groups, two types of coherent and consistent documents have been prepared on the basis of the 3-D views: standard tunnel cross-sections and 2-D dimensioned drawings. The 2-D dimensional drawings are produced with each layout version but the latest changes are available on-line and equipment layouts can be produced on-the-fly for installation [4].

9.2.2 Quality Assurance

The integration studies are only useful if they are reliable, meaning that quality control is essential. The first step is the quality of the "standard" models under the responsibility of the groups. The second step is the quality of the integration itself which is the responsibility of the integration team: no model must be forgotten and all elements must be at their correct position. Finally, the third step is the quality of the installation itself.

The standard models should correspond to the equipment installed and only the relevant groups have a thorough knowledge of this.

The quality of the integration is enforced by meetings with the parties preparing equipment for installation (on a weekly basis). When the studies converge, i.e. when it is shown that the equipment can be installed without interfering with other installations or the tunnel boundaries, a folder containing 3-D drawings, plans and other documents is submitted for approval to all parties involved.

The underground installation of equipment has started. After each installation phase, measurements are taken to verify that the equipment was installed as planned by the integration studies. The survey is done either visually or, when needed, with sophisticated techniques such as laser scanning. Any anomaly is checked against the next layer of equipment. This quality assurance procedure ensures the feasibility of the installation of the next phase. In conjunction with this, non-conformity reports are issued and followed-up until all are either resolved or accepted as-is with technically bearable consequences.

9.2.3 Documentation

The integration working groups have created a web site [5] where all the relevant information can be viewed. The documentation includes about 3500 standard models, the status of the studies, approval folders, about 110 3-D integration models and a large series of pictures of the underground areas.

A total of 70 standard tunnel cross-sections and 514, 2-D installation drawings are accessible in the CERN Drawing Directory [6]. Equipment layouts can also be produced on the fly for each system or any combination of systems.

Some examples of documentation taken from these two repositories is shown in Sec. 9.4.

9.3 NAMING OF UNDERGROUND STRUCTURES

To localise equipment or a place is quite often a burden in such a large site as the LHC. In order to speak the same simple language, an abbreviation system [3] has been put in place. In fact, the abbreviation system used for the LEP underground works has been kept for LHC. New works are identified according to this system, while existing installations kept their LEP name, even if their usage for LHC is different.

9.3.1 Definition of Abbreviations

Each name is made of up to six alphanumeric characters, split in two groups of three. The first group is alphabetic and defines the works type and the second the works number. This convention totally conforms to the Naming conventions for LEP buildings and Civil Engineering [7].

9.3.2 WORKS TYPE

First Character

The first character of the works type determines the kind of Civil Engineering works, according to the following list:

P = Pit (Shaft)
R = Ring underground works on the beam path
S = Surface buildings
T = Tunnels and underground galleries
U = Tunnel enlargements, experimental caverns, other underground works which are not directly on the beam path.

Second Character

This indicates the main usage of the building and underground work, with the following list:

A = Acceleration and Radio-frequency equipment
B = Equipment for Low Beta section
C = Controls and Communications
D = Material unloading
E = Electricity
F = Fluids
G = Gas for detectors
H = Cryogenics
I = Injection
J = Junction caverns
L = Liaison galleries
M = Magnets and other machine equipment
P = Personnel Protection and Fire Brigade
R = Power Converters
S = Services
T = Beam transfer
U = Ventilation
W = Water
X = Experiments
Y = Access control
Z = Access

Third Character

This character is optional and is used either to be more precise about the usage of the works concerned or to distinguish between different specific parts of that works or to distinguish two works having a similar usage.

A web page [8] gives the list of civil engineering works abbreviations actually in use.

9.3.3 WORKS NUMBERING

Up to three digits follow the works type and are used to localise the works concerned. The first numeric character is the octant number defined as the LEP access point. The digit 0 is used to designate the whole LHC site, while 9 is used for zones outside the CERN domain. The second digit allows more precise localisation with respect to the middle of the octant: this point (the former LEP collision point) is given the number 5 and the octant is split in equal parts, numbered from 1 to 9 clockwise. The last and optional digit can be used for specifying the floor number of a building or for distinguishing between two neighbouring works.

9.4 TYPICAL DOCUMENTATION

9.4.1 Tunnel Cross-Sections

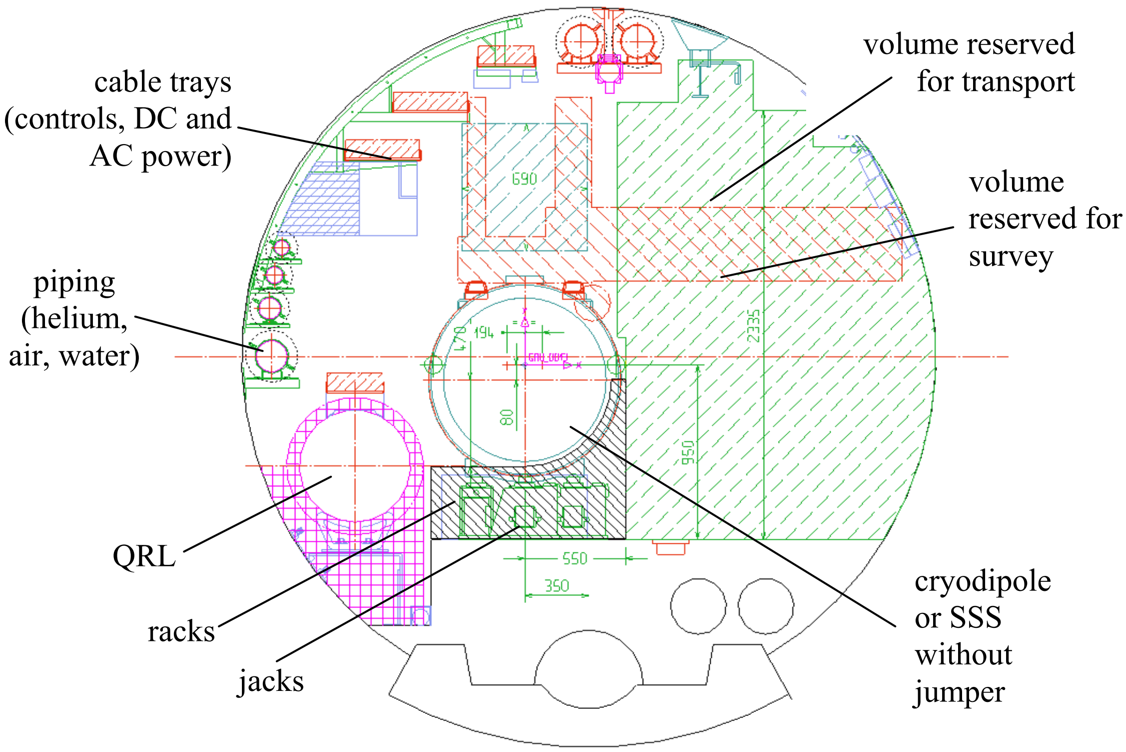


Figure 9.1: Standard Tunnel Cross section

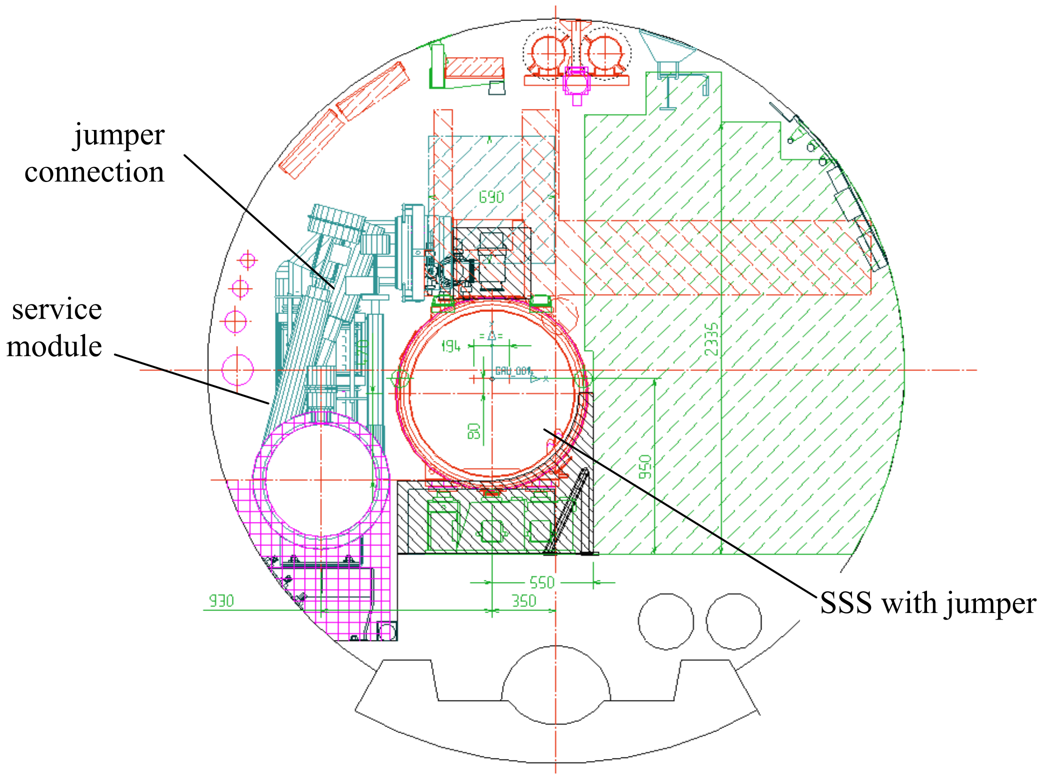
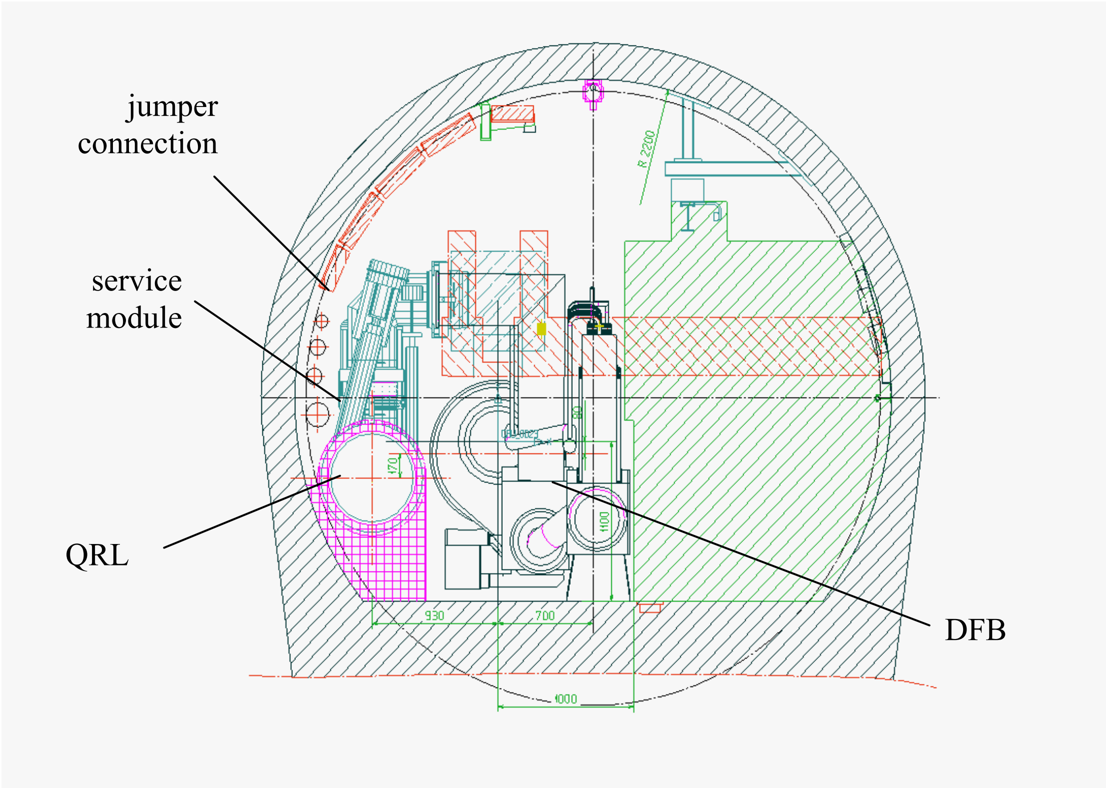
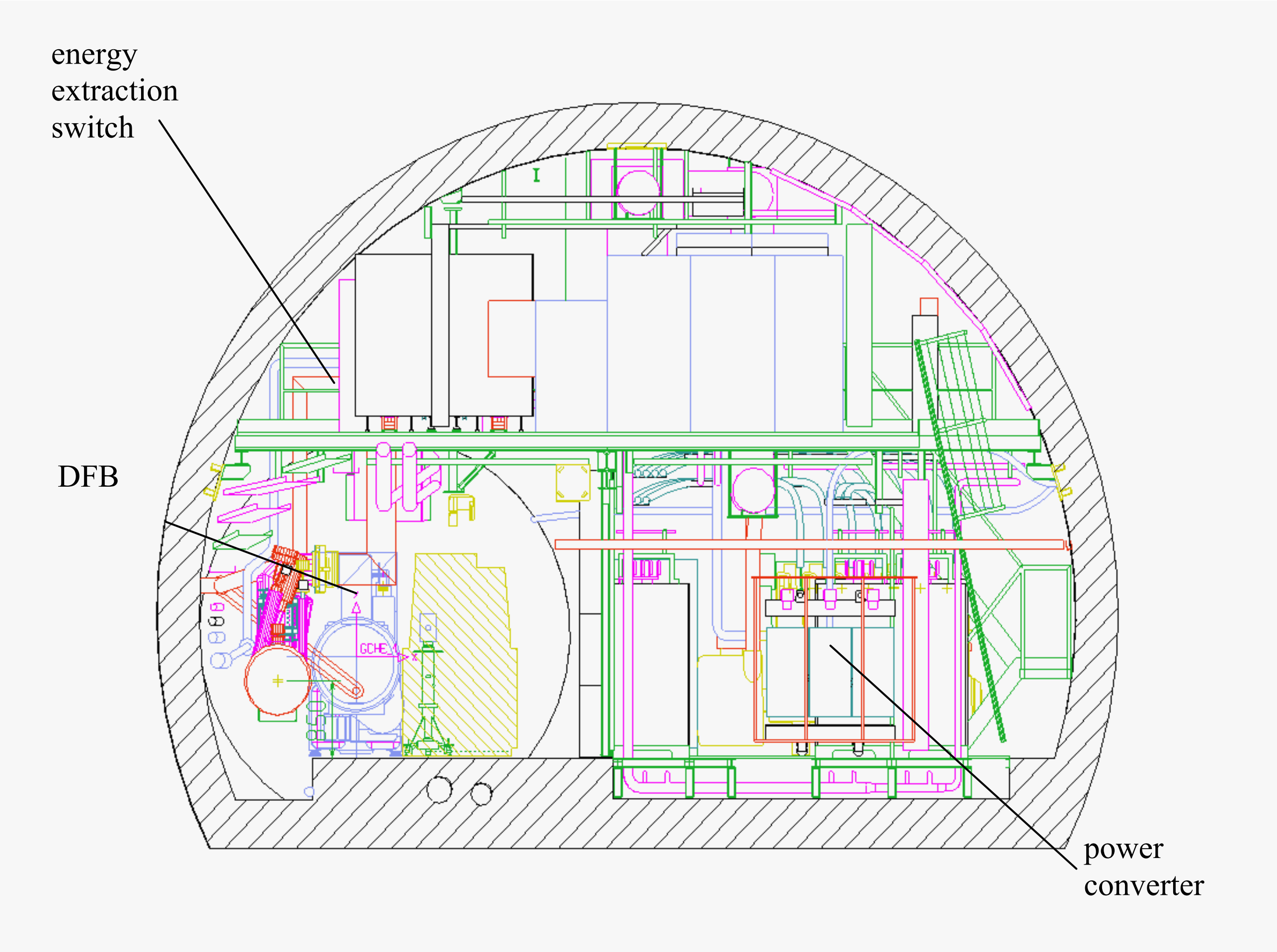


Figure 9.2: Standard tunnel cross section with jumper connection to the QRL


jumper connection
service module
QRL
DFB
R 2200
930
700
1000
1100
170


energy
extraction
switch
DFB
power
converter

9.4.2 3-D Views

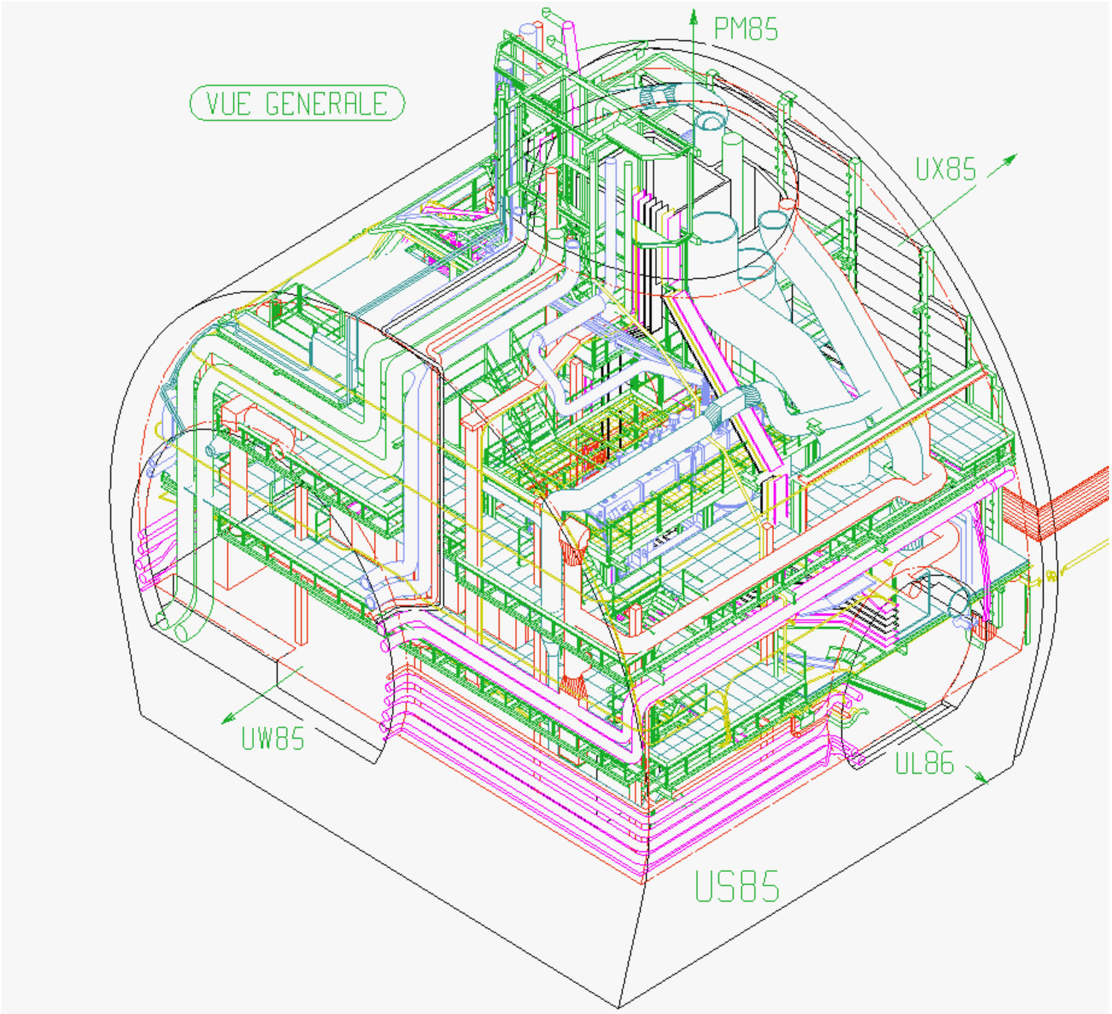


Figure 9.6: Service Areas – US85

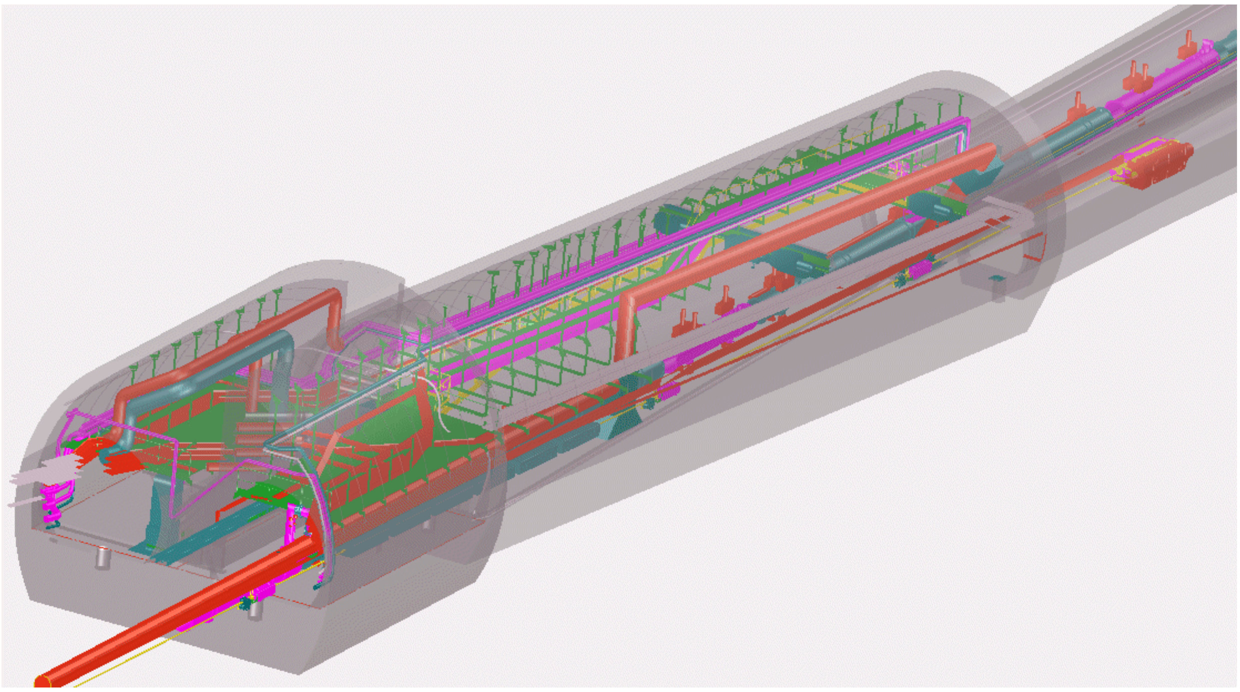


Figure 9.7: Junction with the TI2 Injection Tunnel – UJ22

9.4.3 2-D Installation Drawings

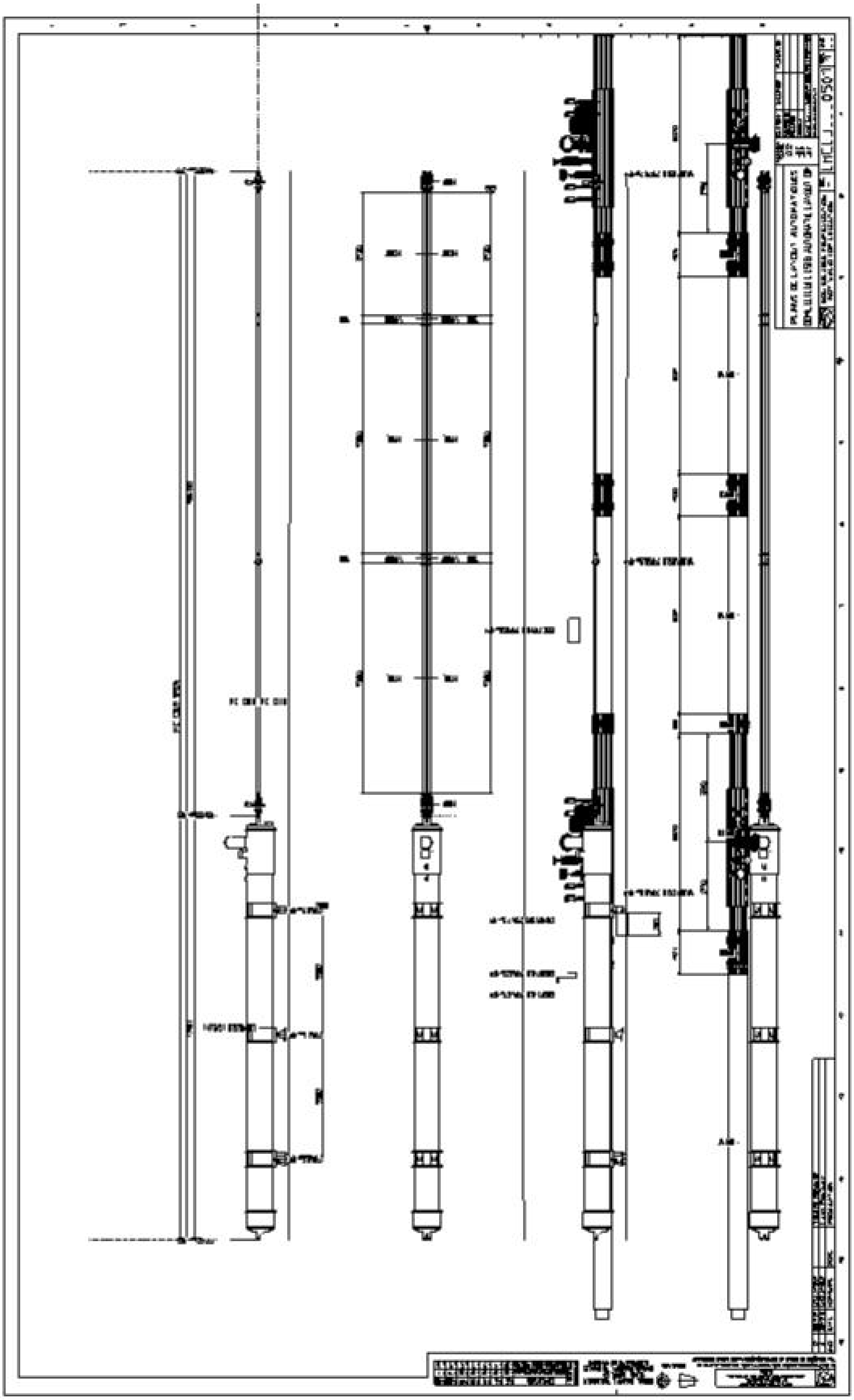


Figure 9.8: Example of an automatically generated 2-D drawing of a half-cell

REFERENCES

[1] Chemli S. et al., *'A Virtual CAD Model of the LHC*', EPAC 2000, Vienna, Austria, June 2000.
[2] Section 14.6, LHC Design Report Vol. I: The LHC Main Ring, CERN-2004-003, June 2004.
[3] Le Roux P. et al., *'LHC Reference Database; Towards a Mechanical, Optical and Electronic Layout Database',* EPAC 2004, Lucerne, Switzerland, July 2004.
[4] Chemli S. et al.,*'Layout Drawings of the LHC Collider'*, EPAC 2004, Lucerne, Switzerland, July 2004.
[5] http://cern.ch/ts-dep-ic/IN/index.html
[6] https://edms.cern.ch/cdd/plsql/c4w.get_in
[7] *'Naming Conventions for Buildings and Civil Engineering Works'*, LHC-PM-QA-207, EDMS: 107398.
[8] http://cern.ch/st-div/Groups/ce/lhc/ListeStruc.htm

CHAPTER 10

EXPERIMENTAL AREAS

10.1 INTRODUCTION

As already described the initial experimental programme at the LHC consists of five experiments installed in four experimental areas located at IR1, IR2, IR5 and IR8. Two new underground caverns and associated surface facilities have been built for the ATLAS experiment at IR1 and the CMS experiment at IR5. These zones were designed around each experiment, but also had to take into account the existing local structures. The layout and construction of the caverns and surface buildings are described above in Chap. 2. The experiments at IR2 (ALICE) and at IR8 (LHCb) will reuse the existing caverns built for the LEP experiments. In both cases only minor modifications to the underground caverns and buildings have been necessary. However, a major rearrangement of the infrastructure is needed and the consolidation of the existing infrastructure left from LEP is also an important consideration. The fifth experiment of the initial programme is TOTEM which will be installed at IR5 together with CMS.

ATLAS is a very large volume experiment which will have to be assembled for the first time in the underground cavern, as there is no hall at CERN large enough to make a pre-assembly. This has been taken into account as far as possible in the design of the new experimental area at Point 1. When considering the experimental area for the CMS detector, the main constraints are given by the construction and the installation of the magnet and the necessity to provide adequate and safe working conditions during the fabrication, assembly and installation periods. Unlike ATLAS the experiment can be almost completely assembled and tested in the surface hall and will be lowered 100 m to the underground cavern in large elements of up to 2000 tonnes each.

ALICE will not only reuse the experimental area at Point 2, but also the large solenoid magnet built for the LEP experiment L3. In addition, ALICE is building a large dipole spectrometer magnet (weight ~1000 tonnes) with a room temperature water-cooled coil, which will be assembled in the UX25 cavern and finally installed alongside the L3 solenoid. LHCb is a smaller experiment similar to those installed at LEP, but it is also based on a ~1000 tonne spectrometer magnet of a similar size and design to that being built by ALICE. This magnet will also be assembled and tested underground for the first time in the UX85 cavern.

10.2 NEW EXPERIMENTAL AREA AT POINT 1 FOR ATLAS

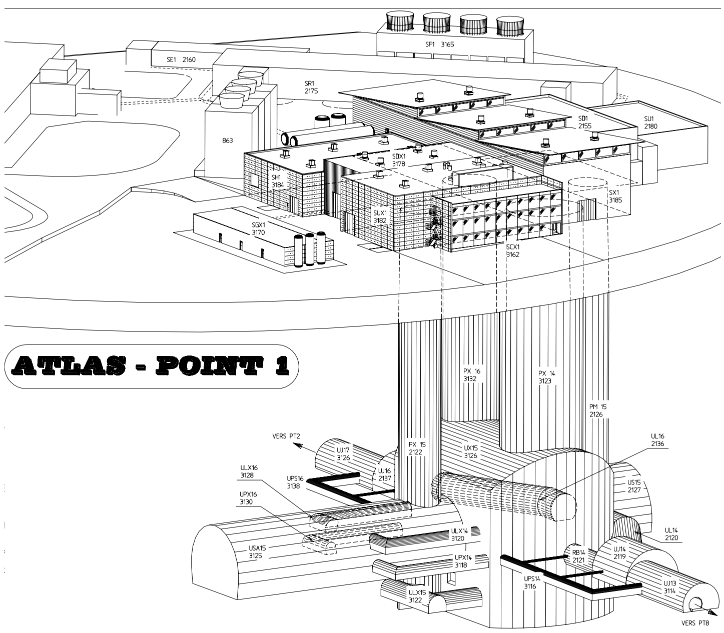


Figure 10.1: The ATLAS experimental Area at Point 1

10.2.1 Underground Caverns and Equipment

Experimental cavern UX15

The UX15 experimental cavern is located below the SX15 building, and linked to it via the PX14 and PX16 shafts. It has its axis parallel to the beam tunnel, between the previously existing US15 cavern on one side and the PX15 shaft and new technical cavern USA15 on the other side.

The UX15 cavern has a maximum internal length of 53 m, an internal width of 30 m and a maximum internal height of 34.9 m. It has an inner lining of reinforced concrete, comprising plain vertical sidewalls of 2 m thickness, curved vertical end-walls of 1 m thickness and a curved roof of 1.3 m thickness. The floor of the cavern consists of a 5 m thick slab of reinforced concrete, but has several trenches and channels cast into it, mainly for the collection of a possible large volume spill of liquid argon from the ATLAS detector. The floor slab is horizontal, thus the foundations for the detector feet will be inclined via the so called "bed-plates" in order to follow the slope of the beam.

The top of the vertical sidewalls include continuous concrete beams to support the crane rails for two 65 tonne capacity overhead cranes. At either end of the cavern, at the entrances of the beam tunnel, concrete elements of the low beta shielding have been cast integrally with the end-walls and are supported by concrete columns from the cavern floor.

The ULX15 liaison gallery provide personnel and equipment access into the UX15 cavern between the bottom of the PX15 shaft at ground floor level of UX15. The gallery is a 3.8 m wide by 3 m high horseshoe shaped tunnel and is provided with a 0.3 m thick inner lining of reinforced concrete.

Figure 10.2: The UX15 cavern for the ATLAS experiment shortly after reception by CERN from the civil engineering contractor

Service cavern USA15

The USA15 service cavern is located below the pre-existing PX15 shaft, with its axis perpendicular to the beam tunnel, adjacent to the new UX15 cavern. The cavern has a diameter of 20 m, a height of 13.5 m and a length of 62 m. The cavern has an inner lining of reinforced concrete of 0.6 m thickness. The invert of the cavern is curved and is filled with reinforced concrete to create a floor slab of a maximum thickness of 2.5 m.

The rear part of the cavern is equipped with an internal mezzanine floor of reinforced concrete, supported on the cavern sidewalls and on two rows of reinforced concrete columns. A 1 m wide by 2.2 m high personnel passage was constructed to provide an emergency escape passage from the rear end of the cavern to the access point of the UPX16 personnel access gallery. A crane beam for a 10 tonne capacity crane is installed in the apex of the cavern, running from the intersection with the PX15 shaft back to the rear end of the cavern.

The floor of the front part of the cavern is lowered in order to take the bottom of the PX15 shaft to the floor level of the UX15 cavern. Sumps for clean and waste water have been constructed at the low point of the underground complex, and water is pumped up the PX15 shaft to the surface. In addition, two cable galleries, named TE 14 and 16, run out of the floor of the USA15 cavern and into the UX15 cavern at low level. Each has a chicane for radiation protection purposes.

The wall between UX15 and USA15 is 2 m thick. It incorporates nine holes with diameters between 200 and 300 mm to permit short routing of trigger cables from the ATLAS detector to the acquisition racks located close to this wall in USA15. The UPX14 and UPX16 access galleries provide personnel access between the UX15 cavern and the USA15 cavern at the ground floor level of USA15. The galleries are 2.2 m wide by 2.2 m high horseshoe shaped tunnels.

The ULX14 and ULX16 liaison galleries provide connections for services between the UX15 cavern and the USA15 cavern at intermediate floor level of USA15. The galleries are 2.6 m wide by 2.6 m high horseshoe shaped tunnels and are provided with a 0.25 m thick inner lining of reinforced concrete.

Given the thickness of the walls and the geometry of the linking galleries, the radiation level has been estimated to be low enough (below 10 μSv/h) in order to allow access to the USA15 cavern during LHC runs up to the ultimate energy and luminosity [1].

Service cavern US15

The previously existing US15 cavern is shared with the LHC machine. The 2nd floor will be partially occupied by ATLAS to locate 60 racks [2], mainly for inner detector power supplies. The ground floor also houses the soap tank for the foam fire extinguishing system. The US15 service cavern is a non shielded zone and therefore not accessible during LHC operation with beam.

10.2.2 Electronic Racks

The UX15 experimental cavern where the ATLAS detector is installed constitutes a hostile environment where standard and non-standard racks and crates will be installed around the muon spectrometer. These racks will not be accessible during the operation of the LHC and will have very limited access during the short shutdowns.

It is planned to install some 100 racks of various dimensions for a variety of components either related to the control of the detector or to safety systems. The USA15 technical cavern will accommodate approximately 245 standard racks on two-levels, while the US15 technical cavern will house 60 racks for ATLAS. The SDX1 building on top of the PX15 shaft will provide space for up to 100 standard racks over two levels.

10.2.3 Cabling Infrastructure

To transmit all the information ATLAS will be handling, some 50 000 cm^2 of cable section and 10 km of cable trays will be needed. The cables for the transmission and acquisition of data will be of five types: multi-fibre optics, multi-conductor signal cable, multi-coax signal cable, multi-coax high-voltage cable and multi-conductor low-voltage cable for the supply of the electronics. The total section of cable linking the detector to the USA15 racks is estimated to be around 37 000 cm^2, with an average length of 130 m. Those linking the detector to the racks in the UX15 cavern will have an aggregate section of some 10 000 cm^2 (50 m long), and the cables for the trigger will need some 3 000 cm^2 of section (60 m long).

10.2.4 Detector Gas Infrastructure

The provision of gas for the detector is organized with the following infrastructure:

SGX1 gas building

This building has been conceived specifically for the storage, distribution, and mixing of inert and flammable gases in accordance with CERN regulations.

The ceiling of this building is divided into 16 separate sections; in such a way that each of the sections can act as deflagration vents. This type of construction reduces the risk of injuries to personnel working inside the building should deflagration or explosions occur. In addition to this, the building is divided into six different rooms in order to minimize the risks of flammable gas leaks.

A bundle of 34 pipes of various dimensions runs between the SGX1 and SDX1 buildings. These pipes will be extended down the PX15 shaft, into the gas room on the second floor of the USA15 cavern. From there, another 54 pipe bundle goes to manifolds on the walls of the UX15 cavern and finally the gas racks of the detectors.

All distribution pipelines are made in stainless steel. In accordance with TIS prescriptions for gas piping and pressurized pipes, all the welds are X-rayed and pressure-tested. In total, approximately 16 km of tube (all sizes) will be installed.

10.2.5 Cryogenic Infrastructure

The ATLAS detector includes two independent systems requiring cryogenic technologies: the superconducting magnets and the liquid argon calorimeters.

ATLAS magnet system

The ATLAS experiment houses three different magnet systems; a barrel toroid, consisting of eight coils housed in individual vacuum tanks, two end-cap toroids, each consisting of eight coils housed in a common vacuum tank and a central solenoid. A summary of the main parameters for each of the magnet systems is given in Tab. 10.1.

The central solenoid is cooled via the thermal siphoning method similar to that used for the CMS solenoid, while the three toroid systems are cooled by forced flow indirect cooling.

Table 10.1: Main cryogenic parameters of ATLAS magnets

	Cold mass (tons)	**Stored energy (MJ)**	**Static heat load (W @ 4.5 K)**	**Dynamic heat load (W @ 4.5 K)**
Barrel Toroid	370	1080	660	350
End-Cap Toroids	160	206	180	110
Solenoid	5.4	38	80	80

For the three toroid magnets the liquid helium to be circulated is taken from the bottom of a phase separator dewar by a liquid helium pump (1.2 kg/s at 400 mbar). This helium is then distributed over 10 parallel cooling circuits and passed through heat exchangers which are placed in contact with the cold masses of the magnets. The helium gas / liquid mixture coming from the heat exchangers is returned to the phase separator dewar. A 6 kW (at 4.5 K equivalent) refrigerator re-liquefies the gas from the phase separator and sends it to an 11 000 litre buffer. The liquid from this buffer is used to regulate the liquid level in the phase separator. The intermediate dewar provides a two hour cooling capacity, sufficient for a slow ramp-down of the magnets. To guarantee the functioning of this system there is a back-up pump and a no-break power supply.

The thermal shields of the magnets are cooled by a separate 20 kW (40-80K) helium refrigerator, which will also be used for the cool down of the cold masses. This delivers 60 kW of cooling power when boosted by liquid nitrogen.

After surface tests, the magnets will be assembled in the experimental cavern, where the first functional test of the complete ATLAS magnet system has been planned for 2006.

ATLAS calorimeter system

The ATLAS liquid argon calorimeter is housed in three independent cryostats: one barrel cryostat and two end cap cryostats. The main parameters of the cryostats are given in Tab. 10.2.

Table 10.2: Main cryogenic parameters ATLAS Calorimeter Cryostats

	Cold vessel volume (m3)	**Weight of full cryostat (tons)**	**Number of signal wires**	**Static Load (kW)**
Barrel	58	203	130000	1.8
End Cap	43	269	50000	2.5

Each of the argon baths of the three calorimeter cryostats is connected to an expansion vessel which is placed away from the cryostat at a higher level. The temperature in this expansion vessel and in the cryostat itself is regulated to be 87.3 K, creating an argon bath which is sub-cooled by 5 to 8 K. This sub-cooling is needed to avoid the formation of argon gas since bubbles would have fatal consequences for the high voltage system present in the cryostat. The argon baths are cooled by forced flow liquid nitrogen passing through heat exchangers placed in the baths. The liquid nitrogen is taken from a phase separator by a nitrogen pump which circulates the nitrogen through the heat exchangers. The mass flow and pressure of the nitrogen can be regulated for each heat exchanger individually. The nitrogen mixture coming from the heat exchangers is returned to the phase separator from where the gaseous nitrogen is sent to a nitrogen refrigerator (20 kW at 84 K equivalent).

The calorimeter cryogenic system has to function continuously over the complete lifetime of the ATLAS experiment. To guarantee this uninterrupted operation the nitrogen refrigerator has been backed-up by two 50 000 litre nitrogen storage tanks, which will supply the necessary cooling power in case of non-availability of the nitrogen refrigerator, and the nitrogen circulation is assured by two back-up pumps.

The three calorimeter cryostats will be tested individually before being lowered into the ATLAS experimental cavern. The complete system should be operational in the underground area by the end of 2005.

10.2.6 Surface Buildings and Equipment for ATLAS

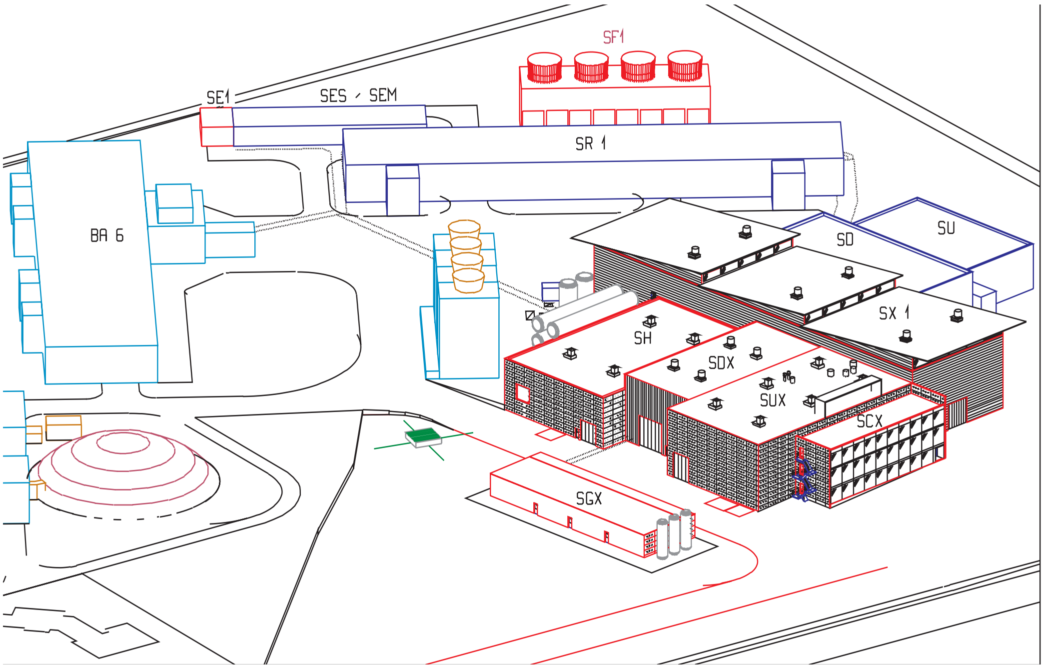


Figure 10.3: Layout of the surface buildings at Point 1

Assembly building SX1

The SX1 assembly hall is a steel-framed building comprising main columns (9 m centre to centre) supporting the crane girders, the roof and the side sheeting, together with secondary columns (4.5 m centre to centre) supporting roof and side sheeting. The roof structure is in lattice frames and the building is clad in steel profiled roof sheeting and timber wall panelling.

The main dimensions of the building are an internal length of 84 m, a width between the internal faces of the main columns of 20 m, with an internal height of 14.5 m to the lower eaves and 17.5 m to the higher eaves. The building is located over the PX14 and PX16 shafts.

The building is equipped with CERN's highest capacity overhead crane having two 140 tonne capacity hoists installed, each with a hook height of 9.3 m. The secondary crane, with 20 tonne capacity hoist, has a height under the hook of 6.2 m.

Special features of the building include a removable roof section and concrete beams over the PX14 and PX16 shafts.

Building for the collaboration and control room SCX1

The SCX1 control room building is a three-storey concrete and steel-framed structure. The main dimensions of the building are an internal length of 30 m, an internal width of 8.8 m and an internal height of 10.9 m. The front wall facing the Alps is made of glass panels. The building is equipped with an internal lift and staircase as well as exits from each floor to an external emergency staircase. The ground floor is intended to be the control room proper, but until 2006 it will be used as a CAD room for the ATLAS Technical Coordination. The first and second floors are to be used as offices.

The SUX1 ventilation building

The SUX1 ventilation equipment hall is a concrete box with two compartments and is constructed with reinforced concrete walls. The building houses ventilation equipment in the bigger of the two rooms and plant for chilled water production in the smaller room. The main dimensions of the building are an internal length of 40 m, an internal width of 23 m and a maximum internal height of 13.75 m from the lowest floor level to the underside of the roof. An 8 tonne capacity overhead crane is installed in the smaller of the two rooms, with a height under the hook of 9.6 m. The capacity of this crane had to be reduced to 4.5 tonne as a result of late modifications to the supporting wall, where large holes for cooling pipes and electrical services have been added.

Access building SDX1

The SDX1 access building to the USA15 cavern is situated on top of the PX15 shaft. The main dimensions of this building are an internal length of 34 m, an internal width of 17 m and an internal height of 12.3 m from floor level to the underside of the roof. The building provides personnel and services access to the underground area via the PX15 shaft. A 16 tonne capacity overhead crane is installed in the building with a height under the hook of 9 m.

Helium compressor building SH1

The SH1 cryogenic equipment hall is a concrete box, constructed with reinforced concrete walls. The main dimensions of the building are an internal length of 40 m, an internal width of 25 m and an internal height of 9.4 m from floor level to the underside of the roof. A 10 tonne capacity overhead crane is installed in the building with a height under the hook of 6 m.

Gas for experiment building SGX1

The SGX1 gas supply building has been constructed with reinforced concrete walls. The main dimensions of the building are an internal length of 40 m, an internal width of 10 m and an internal height of 4.5 m to the underside of the roof. The building comprises various rooms for storing, mixing, and controlling the supply of gas to the underground areas. The roof sections above the mixing room and the flammable gas room are designed to allow release of blast force in the event of an explosion.

Access control building SY1

The SY1 security control building is located at the entrance of the site to control site access. The main dimensions of the building are an internal length of 10.5 m, an internal width of 9 m and an internal height of 2.5 m. The main structure is in structural steel. The roof is made of lightweight, sandwiched, insulated steel sheeting, and the perimeter walls are of proprietary insulated panels with double glazed windows. This building is similar to existing LEP security control buildings.

Local computer building

The racks containing the computer for DAQ are planned to be installed in a two storey metallic structure, to be housed in the SDX1 building. Up to 100 racks can be accommodated there, with appropriate cooling and ventilation.

10.2.7 Safety at Point 1

Radiation shielding

The dominant source of the radiation in ATLAS comes from the proton-proton collisions at the interaction point. Other sources such as beam halo and beam-gas interactions are very small in comparison. Most of the collision products are absorbed in the calorimeters or in the copper absorber protecting the first machine quadrupoles. Gaps between calorimeters are the dominant source of the radiation field in certain regions. Careful consideration has been given to background rates, and activation of material. Steps have been taken to minimize them. The residual radiation in the adjacent building structures has been simulated using realistic wall thicknesses and openings for cable ducts.

In the surface building SX15, with the access shafts covered with a shielding consisting of concrete beams, 120 cm high over both shafts, the dose level will be substantially below the limit of 1μSv/h in a surveyed area. This building will therefore be accessible at all times [1]. The dose outside the building at the site fence will be below the 0.1μSv/h required for a public area, even at ultimate LHC performance.

The layout of the passages between the experimental cavern UX15 and the lateral equipment cavern USA15 gives sufficient attenuation factors such that the dose rate in the most disadvantaged part will remain below the limit of 10μSv/h as required for a controlled area. This means that this technical cavern will be accessible for authorised and monitored personnel at all times [1].

The lateral cavern US15 is shared with the machine. As it is connected to open passages towards the machine this cavern is only accessible with no beam in the machine. Since there will be no activation in this area, access can be granted immediately after a beam dump and declaration of the appropriate access conditions.

Ventilation

The concept, size and mode of operation of the air-conditioning systems for the ATLAS experiment proper, and its underground and surface auxiliary buildings, have been designed taking into account the interconnections amongst the underground structures and their required accessibility. The air-conditioning systems will perform the heating, ventilation, air cooling, and the safety functionalities (smoke control and gas extraction) related to the occupation and usage planned for each particular building. Various emergency scenarios have been considered, and the corresponding operation modes have been implemented. For example, in the event of a gas leak, or detection of smoke, the flow of air in the UX15 cavern can be increased from 45 000 m^3/h to 90 000 m^3/h, while gas extraction systems continue to remove 21 000 m^3/h from the lowest part of the cavern. Similar scenarios exist for the USA15 cavern.

10.3 THE NEW EXPERIMENTAL AREA AT POINT 5 FOR THE CMS EXPERIMENT

10.3.1 Introduction

The CMS experiment will be housed at the LHC Point 5 area located at Cessy in France [3][4]. When considering the experimental area for the CMS detector, the main constraints are given by the construction and the installation of the magnet and the necessity of providing adequate and safe working conditions during the fabrication, assembly and installation periods. Great effort has been made to balance the necessity and the convenience of a large experimental hall with the overall cost and with the basic limitations set by the LHC machine elements as well as the already existing LEP installations. Since the design of the experimental area for CMS was completed a second much smaller experiment TOTEM has been approved and will be installed in the same area. No additions or modifications to the infrastructure are needed.

The design of CMS is based on a large superconducting solenoid surrounded by an iron muon spectrometer. The 4 T field of the solenoid acts directly on the steel disks, which form the forward part of the iron yoke, thus creating a large magnetic pressure. To resist this force, only assembly based on 600 mm thick plates has been found to provide a satisfactory solution. The design of the barrel yoke consists of three layers built up of steel plates. The thickness of the inner layer is 295 mm, the middle and the outer layers being 630 mm thick each, weighing up to 40 tonnes per unit piece, which must be assembled to create the five rings of the muon spectrometer barrel. The coil, which will be built as a single unit weighing 220 tonnes, has to be inserted in the horizontal position into the central barrel ring of the yoke, YB0. The vacuum tank is then welded around the coil.

Carrying out this heavy assembly work in the underground cavern was excluded for the following reasons. It would require a very large cavern with one additional large access pit and two 80 tonne cranes, one at each end of the cavern, since large pieces cannot be transferred over the detector unless the height of the cavern is substantially increased. Even if these requirements were met, the detector construction work would have to proceed in series, because of the limited length of the cavern along the beam line, and the fact that most of this work is not compatible with the cleanliness required for the assembly of the superconducting coil. The duration of the construction of the magnet in the underground area was estimated to take at least a year longer compared for assembly on the surface. Furthermore, the duration of this activity would have to be counted from the finishing date of the underground area. Only then could the assembly and completion of the sub-detectors be performed. Such a scenario proved to be unacceptable. Finally, the safety risk for personnel and equipment would inevitably be greater.

The alternative solution is to carry out as much detector assembly work on the surface; this could be done in parallel with LEP operation and during the construction of the underground cavern after the LEP closure. Several sub-detectors, such as the barrel and end-cap muon chambers and part of the calorimetry, will be installed in the yoke at the surface, saving additional time in the underground area. Moreover, assembling and testing the CMS detector on the surface provides the additional advantage of rehearsing the risky operations on the surface and being able to cope with the unplanned spread of sub-detector delivery. However, a larger surface hall is required temporarily, together with the hiring of heavy lifting equipment at some point in time.

The CMS experimental area at Point 5, both surface buildings and underground caverns, is shown schematically in Fig. 10.4.

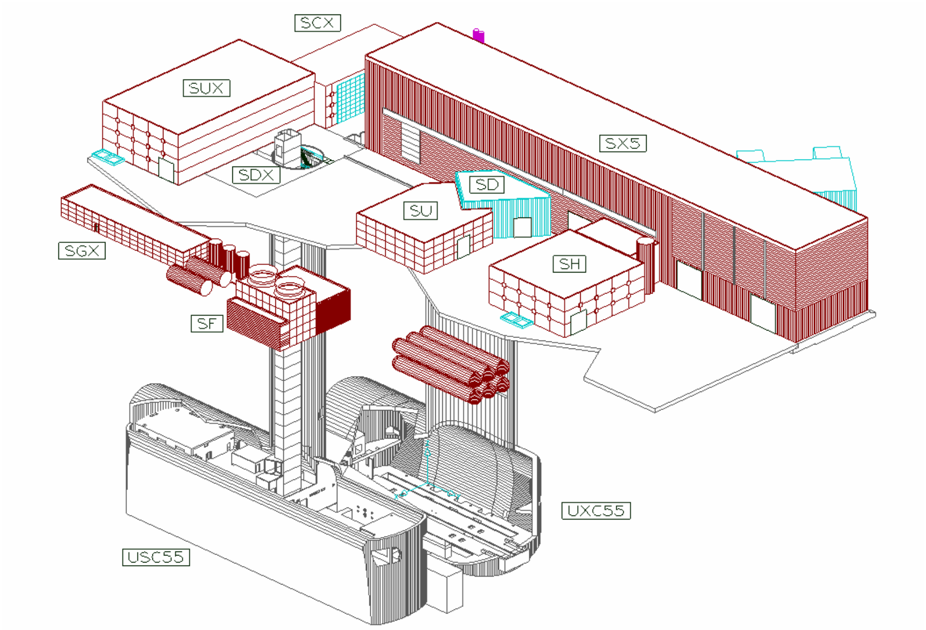


Figure 10.4: The CMS experimental area

10.3.2 Surface Buildings

Building dimensions

The surface building requirements of CMS are dominated by the need to carry out a complete assembly and test of the magnet on the surface, which requires a minimum height of 18.3 m under the crane hook. This implies a 23.5 m high building. The construction of the magnet sub-assemblies, too large to transport by road, requires a 100 m long, 23.5 m wide assembly hall (SX5), which will be linked to the main access shaft (PX56) for installation underground after testing. In order to allow changing of the relative position of the large sub-assemblies inside the hall, two alcoves have been added, which locally increase the effective width of the hall. The hall is equipped with two 80 tonne overhead cranes and a heating and ventilation system, but has no general temperature stabilisation. Furthermore, the main assembly hall is complemented by a temporary appendix (SXL5) needed for the in-situ reinforcement of the conductor for the superconducting coil. The layout extends outside the Point 5 border established for LEP. In addition one of the existing LEP buildings (SU5) had to be moved.

Environmental impact

The CMS collaboration, together with CERN, was concerned about the environmental impact of the proposed assembly hall. The preparation of several of the sub-detector units is being made in existing CERN assembly halls. Road transport sets a strict limit to the size and weight of objects that can be transported. However, after the completion of the manufacturing, assembly and testing of detector components on the surface and their lowering to the cavern, the alcoves and the appendix SXL5 will be demolished and the height and the length of the assembly hall will be reduced to 16 m and 100 m respectively from its most extended dimensions of 23.5 m and 141 m.

10.3.3 Underground Caverns

General considerations

The basic design criteria for the integration of the CMS experimental cavern at Point 5, where the beam level is situated at a depth of 90 m, are:

- A longitudinally oriented cavern (UXC55) providing space for the withdrawal of the end-cap sections,
- One access shaft (PX56), centred on the beam line, permitting successive installation of the large detector pieces from one side of the cavern,
- A separate cavern (USC55), placed parallel to the main cavern and integrated with the LHC machine by-pass tunnel, housing the counting room (at a radiation-safe distance while allowing the shortest possible routing of the cables) and the technical services (cryogenics, gas, power supplies, cooling and ventilation),
- One personnel access shaft (PM54) serving both caverns USC55 and UXC55, thus avoiding a dead-end in the latter,
- The preservation and use of the existing LEP installations, as far as possible.

The absence of existing major underground structures at Point 5 gave a certain freedom in the design of the overall layout of the experimental cavern. However, the unfavourable underground geological rock structure (compared to Point 1) and the location of the deep underground water layers had to be carefully examined prior to the final design. In particular, this resulted in choice of a 7 m thick separation wall between the two caverns (as compared to the minimum 3 m required for the radiation shielding). However, as a result, the service cavern will be permanently accessible, as a radiation controlled area.

Additional reduction of radiation doses will be provided by the intrinsic shielding offered by heavy objects such as the calorimeters and the magnet yoke and the use of mobile shielding around the beam line. The main access shaft is centred on the LHC beam line and must, therefore, have a mobile shielding plug of 2 m thick concrete, which will be situated at the surface level flush with the floor of the assembly hall. A 3 m thick shielding door will separate the access from the bottom the shaft PM54 to the floor of the main cavern.

It was essential that the design of the experimental area also include facilities to provide for safe and efficient working conditions during the installation and maintenance periods. The chosen scheme, in which all detector units and the magnet are fully assembled and tested on the surface and brought down into the experimental cavern with a minimum of further assembly work, has resulted in reduced dimensions of the underground cavern. An incorporation of a de-mountable platform into the main access shaft will separate the ventilation systems and will provide mechanical protection from falling objects. This platform is installed at the level of the ceiling of the cavern. A three level gangway system fixed to the cavern walls provides for unobstructed circulation and easy access to the two independent exits from the underground caverns.

Layout of the underground caverns

The main cavern UXC55, 26.5 m in diameter and 53 m long, is comparable in size and volume to the ex-LEP cavern at Point 2. The auxiliary cavern housing the counting room and the technical services as well as the LHC machine by-pass tunnel has an overall diameter of 18 m and a total length of 85 m. It is aligned parallel with the main cavern and separated by a 7 m thick wall. The thickness is primarily dictated by the required civil engineering structures and it largely offers appropriate radiation shielding. Two access tunnels, one from the auxiliary cavern (UP56) and one from the bottom of the shaft PM54 (UP55), join the main cavern at different levels. In addition, at the height of the beam, two smaller survey galleries interconnect the main cavern with the machine tunnel.

The main access shaft PX56 to the UXC55, 20.4 m in diameter, provides a net 14 m x 19.5 m opening for the installation of the magnet and the detector units. A second access shaft PM54, 9 m in diameter, provides lateral installation access at the floor level to the other end of the detector. This is necessary, since the limited crane clearance over the detector does not allow large objects to be transported between the two end-cap regions. Metal plates are embedded in the concrete floor inclined by 1.23% and thus running parallel to the slope of the beam line. In the central part of the cavern the floor level is lowered by 3 m in order to provide access under the detector for services. This volume is also connected to the counting room in the auxiliary cavern via three labyrinth tunnels to run cables and services.

The low-β quadrupoles, which penetrate into the experimental hall, are placed on a solid concrete platform in order to provide a stable foundation for the intersection elements. This concrete structure also serves as a radiation shielded alcove for the HF detectors, when the main end-cap sections are withdrawn for access.

The existing underground structures at Point 5, the access shaft PM56 and the junction UJ57 serving the LHC machine proper, have not been modified, since they are outside the boundaries of the new structures.

10.3.4 Infrastructure

Main UXC5 Cavern

Although the bulk of the heat load produced by the detector units will be removed by dedicated cooling arrangements, the environment in the experimental hall will play an important role in the long term stability of the detector. The ambient air in the cavern must be kept at a low humidity level (dew point 9 °C ± 1) and with a high degree of temperature stability (18 °C ± 1). In order to achieve this, a system of distributed ducts for the injection of air into the cavern has been designed to fit the walls behind the gangways. The gangways are arranged on three levels and aligned with the rack platforms attached to the detector. A series of stairs make it possible to access the protection platform in the main shaft PX56. The cavern is equipped with a 20 tonne crane having an effective hook-span of 17 m.

Auxiliary Cavern USC55

The auxiliary cavern USC55, which is horizontal (not aligned with the slope of the main cavern), is essentially divided into two sections: one for the counting room and the gas distribution system and one for the general detector services. In addition, the latter section will house the power supplies for the low-β LHC machine quadrupoles. The two sections, which are nearly identical in size, will be separated by the common access shaft PM54 and the personnel safe room.

The counting room, which is longitudinally centred with respect to the detector in the main cavern, has been designed to house approximately 250 electronics racks installed on a two-floor structure with separation walls. This cavern section also houses the gas distribution system. The 9 m diameter shaft (PM54) will give access to the two floors of the counting room, as well as to the floor level of the main cavern via a dedicated large shielding door in the separation wall. The access shaft is equipped with a fire protected 3 tonne lift and a staircase system, which will ease the installation of all counting room equipment and provide direct installation access to the main cavern floor level. The limited size of the access shaft does not allow installation of large prefabricated counting room modules. This is, however, not regarded as necessary since the cavern itself will constitute the 'housing structure' and will also allow the centralisation of the cooling, ventilation and power arrangements.

The other half of the auxiliary cavern will house the power supply and the cryogenic system for the magnet, part of the magnet quench protection system, the cooling and ventilation distribution systems as well as a few racks for the low-β LHC machine power supplies.

10.3.5 Cryogenic Infrastructure

The solenoid magnet of CMS has a cold mass of 225 tons and a nominal field of 4 T. The stored energy in the magnet is 2.6 GJ. The static heat load is estimated as 160 W at 4.5 K and the dynamic load as 365 W at 4.5 K. The heat load on the thermal screens (temperature 60-80 K) is expected to be 3 kW, while the current leads will need a liquid helium flow of 3 g/s. The magnet is cooled by the thermal siphoning principle; liquid helium is taken from a phase separator placed on top of the experiment to the bottom of the solenoid, from where it is distributed over heat exchangers placed in contact with the cold mass. The thermal load will create helium gas in the heat exchangers and the hydrostatic pressure difference creates a driving force circulating the helium through the heat exchangers back to the phase separator.

A 1.5 kW at 4.5 K equivalent helium refrigerator then re-liquefies the gas and sends it to a 6 000 litre intermediate storage dewar which provides a buffer volume guaranteeing a five hour cooling period. This is sufficient for the slow ramp down of the magnet, even in case of refrigerator failure.

The refrigerator system installation has been planned to cool-down the solenoid for the surface tests early in 2005 and, once the magnet has been lowered and reconnected, to provide cooling for cold tests in the underground experimental area which are planned for 2006.

10.3.6 Safety

The design of the experimental area has incorporated several specific safety aspects, such as:

- Fixed gangways and staircases for easy access at all levels in the underground caverns,
- Emergency escape routes at each end of the main cavern,
- Smoke extraction, in case of fire,
- Fixed and mobile radiation shielding surrounding the low-β quadrupoles and absorbers,
- A hard cover (removable platform), providing protection beneath the main access shaft.

The large capital investment and the unique nature of the CMS detector imply that a first class fire prevention and fire fighting system must be installed in the CMS experimental area. The global fire prevention in the experimental area is based on the correct choice of material, application of intumescent paint and the installation of permanent inertion and sniffer systems, all based around PLC architecture. The fire fighting system consists of hydrants / portable fire extinguishers, a water mist system and a high expansion foam system.

10.3.7 Other Surface Facilities

During the construction phase of the magnet and during the assembly phase in the surface hall other hall surfaces will be required on a temporary basis elsewhere on the CERN site for the storage, preassembly, and testing of the sub-detectors. Some of these sub-detectors require clean (e.g. Electromagnetic Calorimeter and Forward Hadronic Calorimeter) or very clean areas (e.g. for the tracker).

10.4 RE-USE OF THE POINT 2 EXPERIMENTAL AREA BY THE ALICE EXPERIMENT

10.4.1. The UX25 Underground Cavern

The ALICE detector will be installed at Point 2 of the LHC. This area was designed for the LEP, L3 experiment, but is ideally suited for the ALICE detector. Only very minor modifications are needed to the experimental cavern or the surface zone. The main access shaft (PX24) is 23 m in diameter and provides a 15 x 7 m^2 opening for the installation passage and space for counting rooms. The counting rooms are separated from the experimental area by a concrete shielding plug as shown in Fig. 10.5. The PX24 shaft is equipped with an 800 kg capacity lift and a separate staircase. The experimental cavern (UX25) is 21.4 m in diameter and was initially equipped with a 40 tonne crane, having a limited clearance over the L3 magnet.

The experimental area is dominated by the presence of the L3 magnet, which provides an 11.6 m long and 11.2 m diameter 0.5 T solenoidal field. The end-caps have a door-like construction. The magnet has an octagonal shaped yoke with the lower three octants embedded into the UX25 hall foundation. The door frames will support large beams traversing the L3 magnet, which will be used to support the ALICE central detectors.

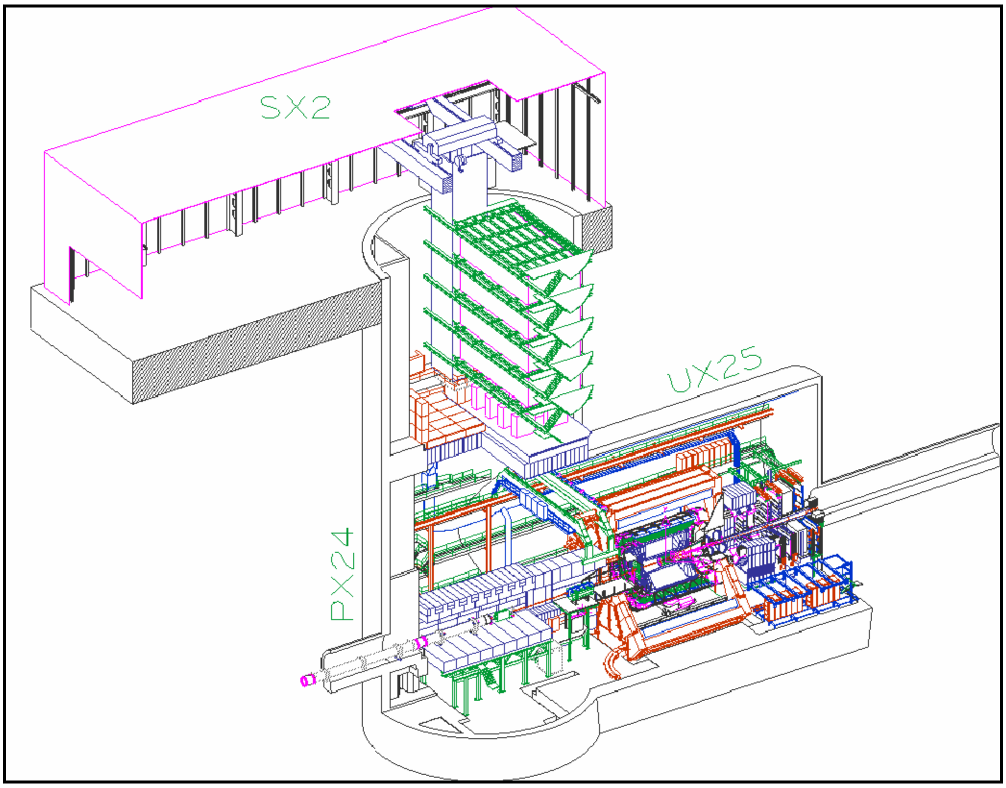


Figure 10.5: Basic layout of the underground structures at Point 2.

10.4.2. The Point 2 Surface Zone

The existing surface zone at Point 2 includes sufficient assembly hall space and storage areas (the 1350 m^2 SXL2 assembly hall and the SXS storage platform) to meet the essential requirements of the ALICE experiment and no new hall constructions will be necessary. The surface zone and existing buildings are shown in Fig. 10.6. The main access shaft (PX24) is covered by a 1790 m^2 building (SX2), equipped with a 63 tonne gantry crane. The existing gas distribution building (SGX2) can be used without any modification by the ALICE experiment. The Point 2 site has no specific office building, but instead a number of building-site barracks have been installed in a semi-permanent manner

10.4.3. Modifications to Point 2

The existing capacity of the infrastructure installations at Point 2, such as cranes, power, cooling and ventilation systems all meet the requirements of the ALICE experiment. However, an extensive repair and maintenance programme is necessary in order to consolidate the existing infrastructure and guarantee a further 15 year operation.

Initially, it was proposed to construct a second access shaft for the UX25 underground cavern. However this has been avoided by sharing the PM25 shaft for access to the LHC tunnel and the UX25. This has, furthermore, been facilitated by enlarging the chicane between the US25 and UX25 caverns. In addition, a new 2 x 20 tonne crane has been installed in the UX25 cavern, with a clearance of 3 m over the L3 magnet. This permits the PX24 shaft to be used to transport large items to the RB26 side of the L3 magnet.

On the surface the construction of a roof between the SA and SF buildings has created a 250 m^2 cold storage area, which avoids using the SXL2 and SX2 assembly halls for storage. In agreement with the LHC project, the ALICE collaboration can also use half of the SA building for temporary storage.

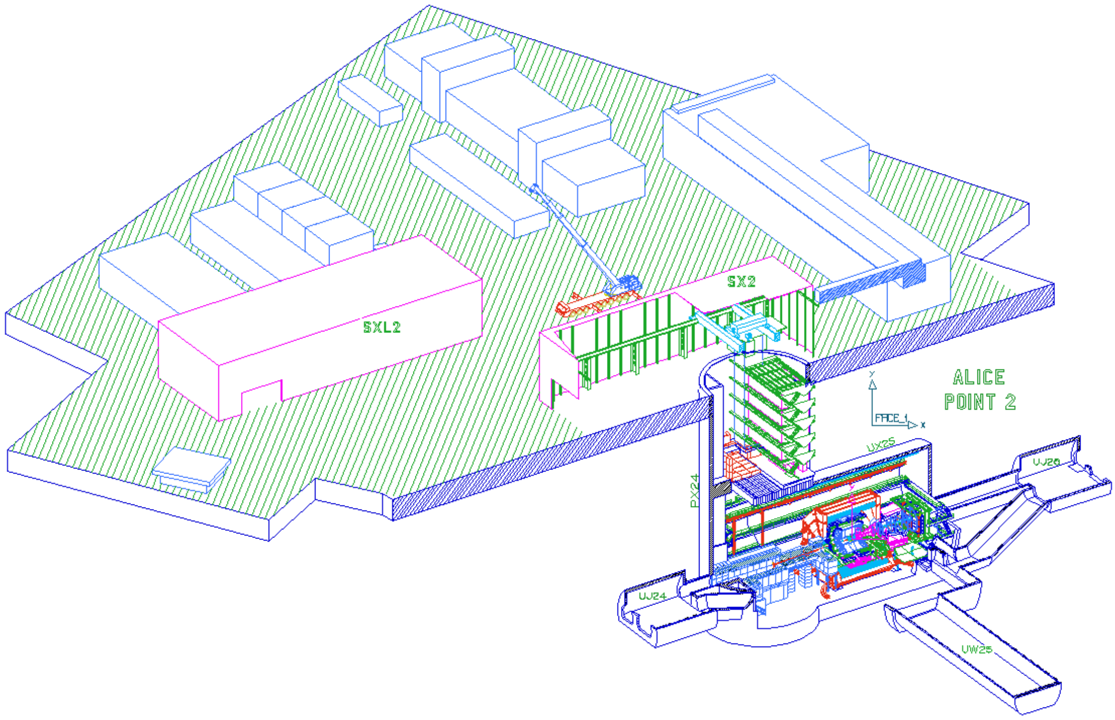


Figure 10.6: The Point 2 surface zone indicating the main assembly halls SXL2 and SX2.

10.4.4. Radiation Shielding

The more severe radiation environment of LHC compared to LEP will require reinforced radiation shielding and changes to the present access. The reinforcement of the shielding is not related to the ALICE experiment, since even without any experimental installation at Point 2 the shielding would have to be upgraded to LHC standards. The integration of the additional shielding is the dominant complication in the conversion of the Point 2 experimental area and does impose a number of constraints on the layout of the Alice detector.

Extensive simulations [5] have shown that additional shielding of the beam line on the RB24 side and the reinforcement of the shielding plug in the PX24 shaft, are necessary in order to provide a satisfactory shielding situation at Point 2. The beam line penetrating into the UX25 will be surrounded by a minimum of 1.6 m of concrete as shown in Fig. 10.7.

10.4.5. Infrastructure for Services

The four counting room levels in the PX24 access shaft provide space for a maximum of 120 racks (see Fig. 10.8). Each counting room is equipped with water cooling circuits and an air cooling capacity of 50 KW. The different levels can be reached by a dedicated lift installation and two independent staircases. The false floor of each level is directly connected to a vertical service shaft, which permits easy access for installation of cables. Fig. 10.8 also shows the routing of the services.

The shielding plug separating the public area from the radiation controlled cavern, also serve as a convenient area for the gas distribution racks. All services enter the experimental area via two chicane arrangements incorporated at the circumference of the shielding plug. The UX25 cavern has a system of fixed cable trays covering the entire length of the cavern and the part of the PX24 access shaft below the shielding plug.

The main control room ACR (ALICE control room) is situated in the SX2 hall and provides a 150 m^2 working area, divided into two different sections; control room area and a computing room.

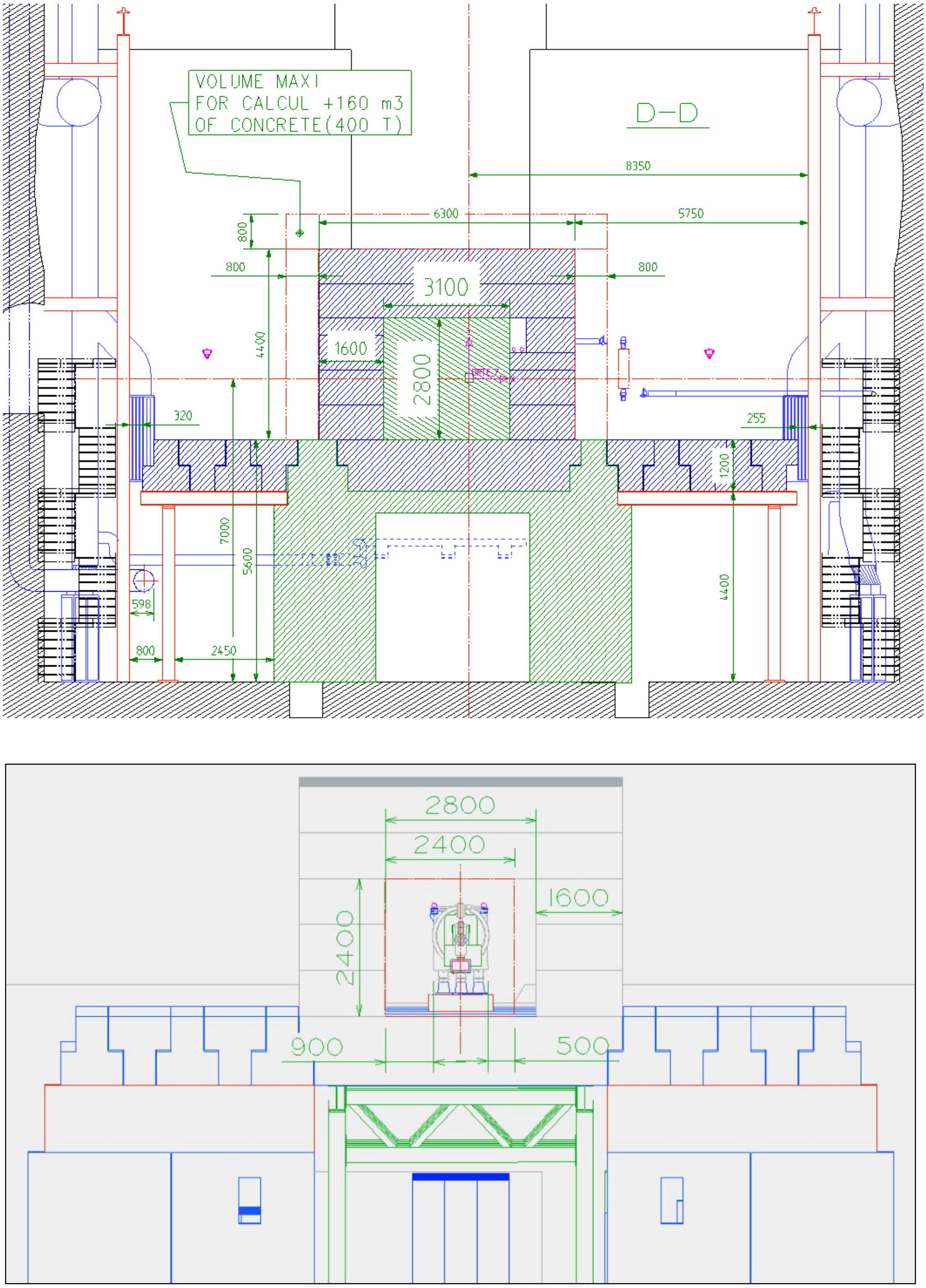


Figure 10.7: Shielding arrangement for the beam line in UX25.

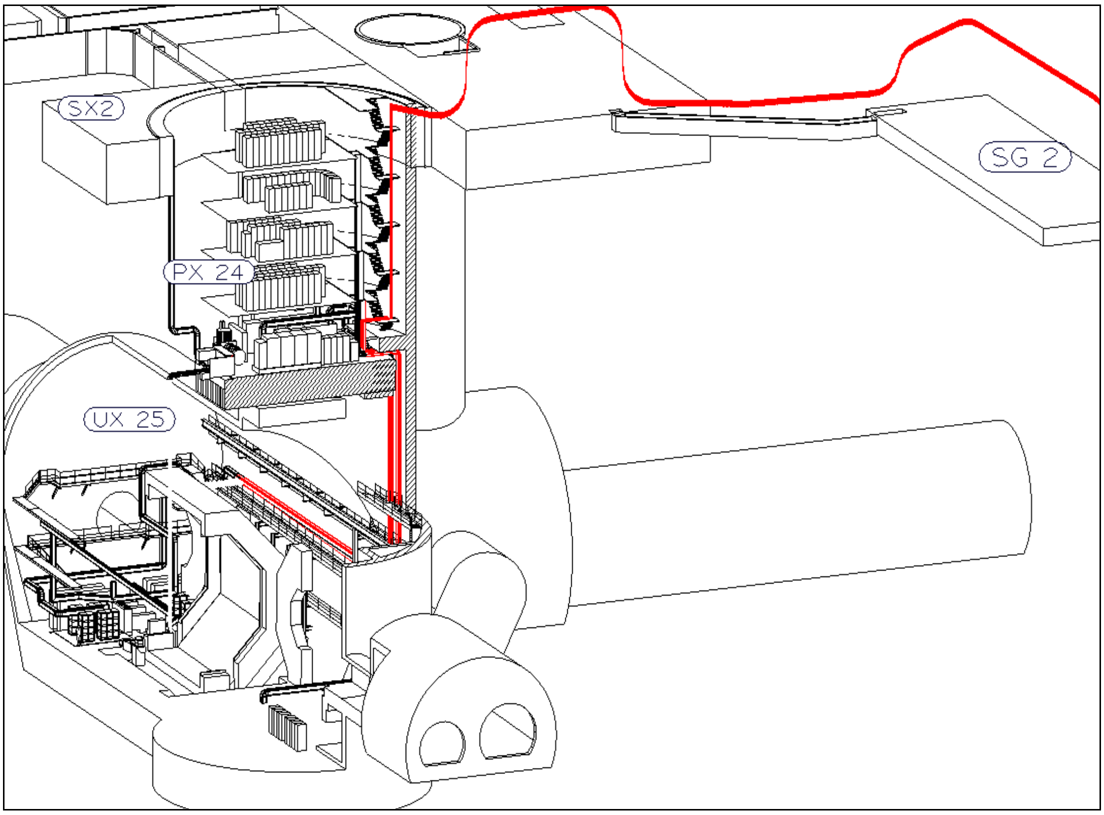


Figure 10.8: Routing of services in the Point 2 experimental area

10.4.6. Safety Installations

The area safety installations are designed to give global protection of the surface and underground areas independently of the dedicated safety installations needed for the experimental installations.

The surface assembly halls (SX2 and SXL2) are equipped with smoke detector systems placed near the roof and general emergency stops. Depending on the nature of the activities inside the halls, local detection systems or emergency stops are added as a complement to the general facilities.

The general safety arrangements in the underground cavern UX25 reflect the restrictions set by the underground environment. In addition to general smoke detector systems and general emergency stops the cavern is equipped with an emergency evacuation alarm. Two independent escape routes are available; via the lift/staircase system in the PX24 shaft or via the lift/staircase system in PM25. Special panels indicate the escape routes, which stay visible even during limited visibility.

The underground cavern is also equipped with a water flooding detection placed at the bottom of the PX24 lift shaft.

10.5 RE-USE OF THE POINT 8 EXPERIMENTAL AREA BY THE LHCb EXPERIMENT

10.5.1 Introduction

The Large Hadron Collider Beauty Experiment (LHCb) for precision measurements of CP–violation and rare decays [6][7], is to be installed at the existing experimental area at LHC Point 8.

The LHCb Detector is a single-arm spectrometer motivated by the production of the beauty particles and anti-particles in the same forward or backward cone. Fig. 10.9 is a side view of the LHCb detector in the y-z plane. Where the LHCb coordinate system is a right handed coordinate system with z-axis pointing from the interaction point towards the muon chambers along the beam-line. The y-axis is pointing upwards. The x-axis is pointing towards the outside of the LHC ring.

The detector covers the angular region from 10 mrad to 300 mrad in the horizontal (x-z) plane and from 10 mrad to 250 mrad in the vertical plane (y-z) plane. The detailed description of the sub detectors are presented in the LHCb technical design reports submitted to the LHCC.

Interaction Point

The characteristics important for the layout of the experimental equipment around IP8 [8] are summarised in Tab. 10.3.

Table 10.3: IP8 characteristics

Displacement from the centre of cavern towards Point 7	11 220 mm
Tilt angle of the beam-line – Lowest point towards Point 7	3.6 mrad
Beam crossing angle	± 285 μrad
Beam crossing plane	Horizontal
IP beta	1 → 35 m
Design Luminosity (mean)	2×10^{32} cm^{-2} s^{-1}

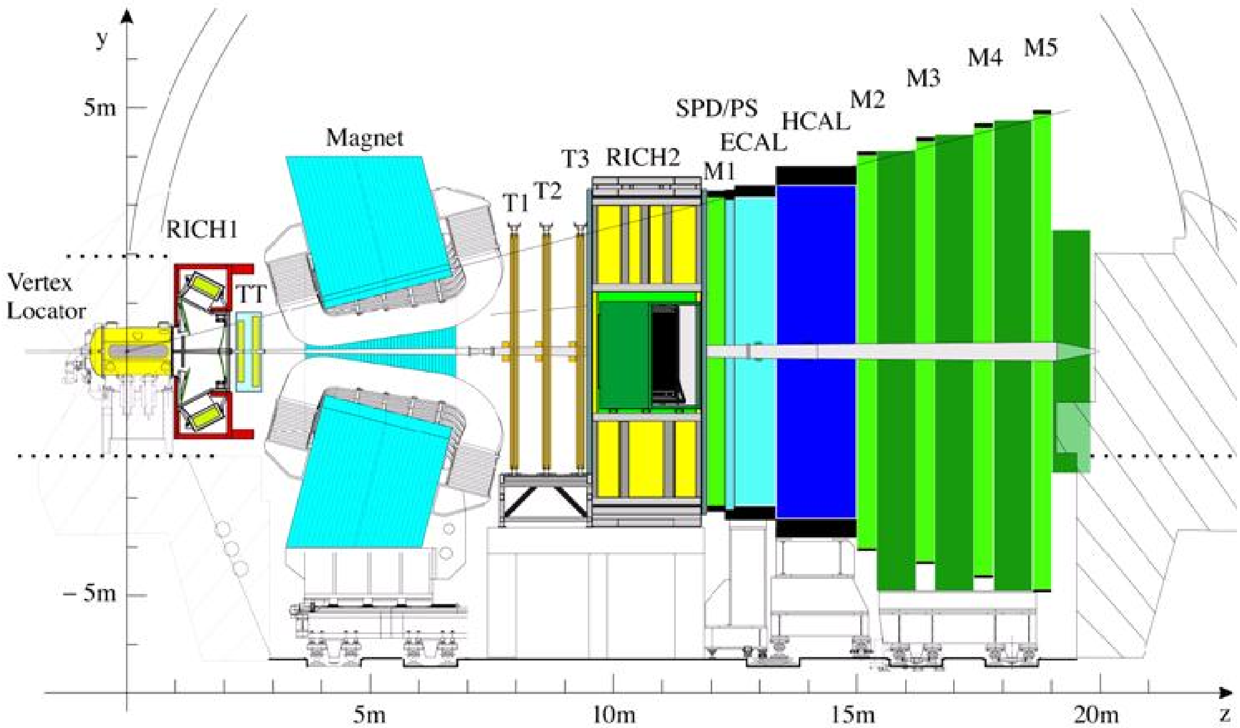


Figure 10.9**:** Side view of the LHCb detector in the y-z plane.

.

10.5.2 The UX85 Underground Cavern and Modifications

The existing UX85 cavern at Point 8 is located at a depth of 110 m below the surface. Fig. 10.10 is an axonometric view showing the underground areas.

Personnel access is via the PZ shaft, while for lowering the equipment the 10 m diameter PX shaft is used. The existing cranes include an 80 tonne hook at the PX shaft and a 40 tonne and 2x40 tonne hooks in the UX85 area are all reused.

All of the existing infrastructure equipment and facilities, originally provided for the LEP experiment DELPHI are re-used by the LHCb experiment. However, a few major modifications were required. The most important concerns the head wall at the PZ end, which has required major consolidation work using a concrete structure to replace the original metallic structures.

In addition, in order to allow access to the mobile counting rooms which have been withdrawn to the PZ end of the cavern, the UX85 cavern has been divided into two distinct areas: a detector area and a protected area where the counting rooms and all the control racks are located. The protected area will be accessible when the LHC is operating. The third major modification concerns the installation of a cryogenic unit for the LHC machine at the end of the UX85 cavern beside the LHCb detector.

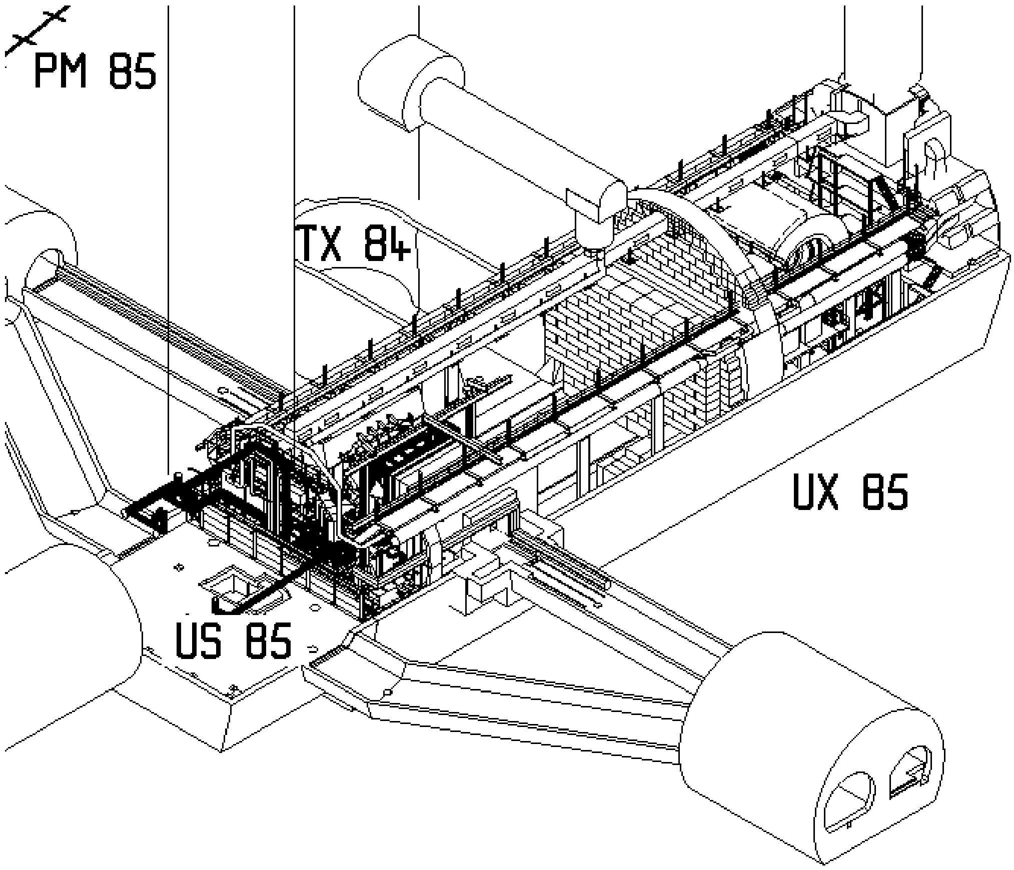


Figure 10.10: Axonometric view of the underground areas at Point 8

Layout

Fig. 10.11 shows the layout of the LHCb detector and LHC cryogenic units as they will be installed in the cavern. The first major component of LHCb in the cavern is the warm dipole magnet [9], which will be assembled in the underground cavern during the transport and the transfer of the LHC components for the sectors 7-8 and 8-1. This requires a temporary bridge across the experimental area. The installation of the rest of the LHCb detectors will follow and the global commissioning is planned from September 2006 until March 2007.

The main radiation shield

The UX85 cavern is divided into two distinct areas, a protected area and a detector area. A large radiation shielding wall [10] is required for that purpose in order to ensure that access to the protected area will be possible under all LHC operating conditions. Radiation simulations [11] using FLUKA code show that a concrete wall 3 m thick is needed as a minimum radiation protection against the total loss of a maximum intensity LHC beam. These simulations are very conservative, not only because the total loss of every proton in the LHC beam is very unlikely but also because it is assumed that the loss occurs on an 'ideal' target in which every proton can interact, but which provides no lateral shielding.

A modular shield consisting of a total in the order of 3 000 tonnes of concrete has been designed [12], which consists of both fixed and removable parts made using concrete blocks. The erection is scheduled in various steps. On both sides of the front door is a protected slit having an aperture of 4000 x 350 mm. This is provided for the passage of the general services, the detector services and cabling.

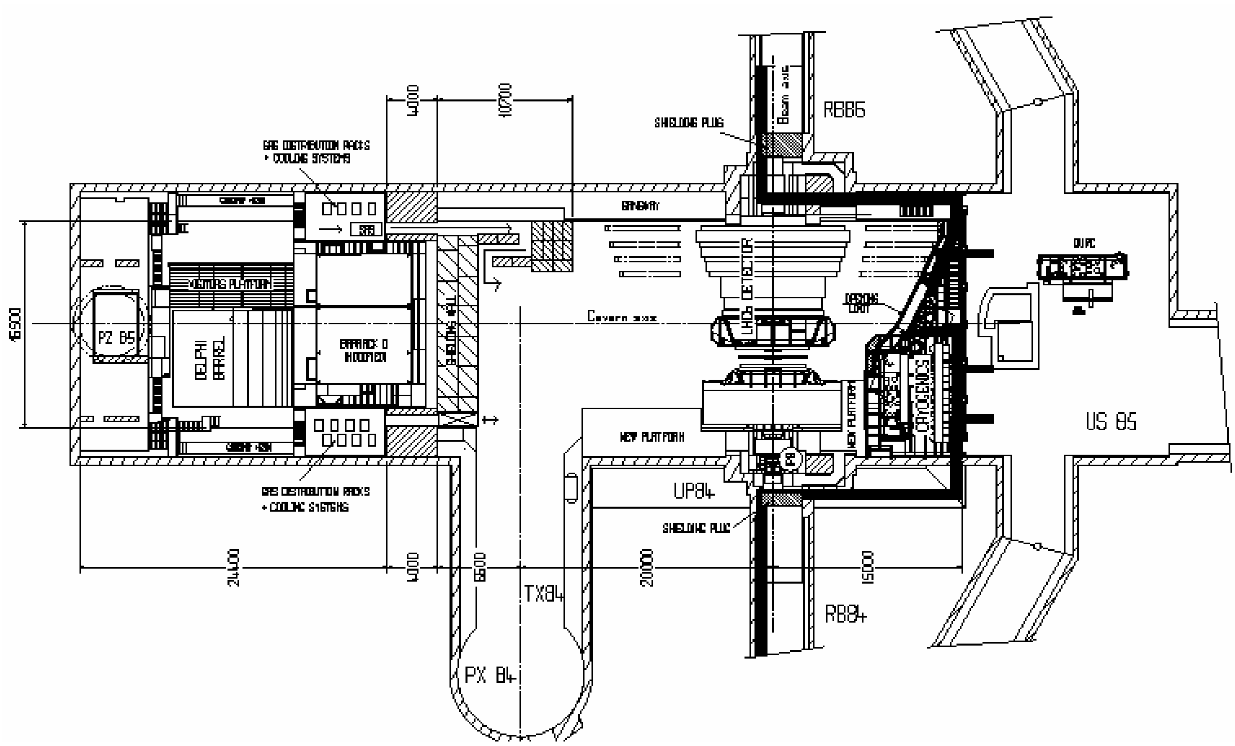


Figure 10.11: Layout of the LHCb Experiment in the UX85 cavern

Sharing space with the LHC Cryogenics

Two large cryogenic components, the QUI interconnection box and the QURCA cold box for the octant 8 are located at the end of the UX85 close to the US85 machine service area. The QURCB cold box is installed in the US85 area. The implementation in the UX85 respects the space required for the maintenance of the muon chambers. Fig. 10.12 shows the cryogenics region at the end of the UX85 area.

The space needed for accessing to the inner part of the vertex tank is Z = -2200 mm in front of IP8. The position of the last muon filter is at Z = +19900 mm. Two radiation shielding plugs made of concrete/iron blocks similar to the LEP plugs are foreseen to be installed in both RB areas [13]. A fence delimits the cryogenics region from the LHCb detector area. Appropriate exit doors are available as emergency escape routes.

10.5.3 Primary Services

The global power distribution requirement for LHCb in the UX85 cavern is about 7 MW. The warm dipole magnet requires 5 MW, the rest of detector 2 MW. The refrigeration power needed is 5 MW using de-mineralized water for cooling the magnet [14], and 2 MW using mixed and chilled water for the rest of the experiment [15].

The existing ventilation system is re-useable, however a few adaptations and modifications were required in order to have two independent air systems for the detector and the protected areas, with a slight over-pressure in the protected area [16].

10.5.4 Access & Safety

The protected area is accessible via the PZ shaft when the LHC operates. The main LHCb access checking point is located in the UX85 protected area at the entrance of the chicane which passes through the shield in order to reach the detector area for maintenance when the LHC is not in operation, such as during technical stops or regular shut-downs.

No specific safety requirements are to be mentioned except the use of a large amount of Be metal. Three segments of the vacuum beam pipe [17] are made of Be metal. The presence of large quantity of CF_4 gas in the RICH2 detector also requires appropriate safety devices to be locally installed, such as an oxygen deficiency detector in the tunnel beneath the RICH2 which would trigger an alarm in case of a serious leaks of large volumes of gas.

Figure 10.12: Picture of the QUI interconnection box in its final position

REFERENCES

[1] ATLAS Technical Coordination TDR, 1999, ISBN 92-9083-137-5, p. 370

[2] CERN Drawing directory, drawing number LHCLJ1G_0009

[3] CMS Technical Proposal CERN/LHCC 94-38, LHCC/P1, December 1994

[4] The CMS Magnet Project Technical Design Report, CERN/LHCC 97-10, CMS TDR 1, May 1997

[5] CERN/TIS-RP/IR/98-10

[6] LHCb Technical Proposal - CERN/LHCC 98-04 LHCC/P4, February 1998.

[7] *Re-optimized LHCb Detector – Design & Performance*, LHCb TDR 9, CERN/LHCC/2003-030, Sept. 2003.

[8] *Measurement of the relative luminosity at the LHC*, EDMS no. 347396.

[9] LHCb Magnet , TDR, LHCb TDR 1, CERN/LHCC 1999-0037 (1999)

[10] *Radiation Shield for LHCb Experiment at Point 8*, EDMS no. 111020

[11] S. Roesler & G. Stevenson, *Radiation Studies for the design of the Main Shielding Wall of the LHCb Experiment*, CERN/TIS-RP/IR/97-31, 1997.

[12] *Radiation Shielding Wall – Technical Specification* , EDMS no. 406875.

[13] *Radiation Shielding plugs- LHCb Requirements*, EDMS no.380839.

[14] *LHC Demineralized Water Circuit*, EDMS no. 335008.

[15] *LHC Chilled and Mixed Water*, EDMS no. 346936.

[16] *Air handling of the LHC tunnel and its underground areas*, EDMS no. 344211.

[17] J.Knaster, EDMS no. 382798.

CHAPTER 11

THE ALIGNMENT OF LHC COMPONENTS

11.1 THE GEODETIC REFERENCE NETWORK

The geodetic reference network provides a three dimensional framework and is needed for the first positioning of components. In addition, it allows the accelerator to be installed correctly with respect to the injection system, particularly with the SPS.

The reference network has to take into account all of the geodetic parameters which are required due to the size and location of the accelerator: geoidal undulations and deviation of the vertical (vertical geodetic reference surface), ellipsoidal reference surface for the earth (horizontal geodetic reference surface), geodetic coordinates, etc. Throughout the work to update the CERN vertical datum (geodetic reference surface) and to establish a geocentric set of horizontal datum position parameters for the CNGS project [1], the topocentric set of datum position parameters established for LEP [2] have been maintained for LHC [3]. The geoid determined for LEP will also be used to determine the height of LHC elements.

Table 11.1: Geodetic Parameters for LHC

XCERN P0	2000.00000
YCERN P0	2097.79265
ZCERN P0	2000.00079
Latitude at P0 (gon)	51.36920
Longitude at P0 (gon)	6.72124
Height of P0 (m)	433.65921
Azimuth of CERN Y-axis: Azyc (gon)	37.77864
GRS80 ellipsoid semi-major axis (m)	6378137.0
GRS80 ellipsoid first eccentricity: e^2	0.0066943800229
GRS80 ellipsoid second eccentricity: $(e')^2$	0.0067394967755
Radius of curvature in the Meridian at P0: RP0 (m)	6368761.40
Radius of curvature in the Prime Vertical at P0: NP0 (m)	6389299.67

11.1.1 Connection with LEP Network

The best reference geometry in the tunnel was provided by the position of the LEP quadrupole alignment targets. These points were accurately positioned from the surface and underground networks during the construction of the LEP machine and their radial and vertical position was checked periodically during the machine lifetime. The absolute shape of the machine as well as the relative position of the quadrupoles was proved by the quality of the beam orbit. In addition, the length of the orbit measured geometrically fitted very well with the RF measurements, within an accuracy of 2×10^{-7}.

The underground geodetic reference network is based on the position of the LEP quadrupoles. Before their removal, a last refinement of their absolute radial position was carried out by injecting accurate gyroscopic measurements into the data set.

11.1.2 The New Reference Points

Layout

The new geodetic reference network is defined by a set of 580 new points sealed in the floor of the tunnel, in the passage area. In the arcs, they are installed at 53.45 m intervals, in front of the middle of the first cryo-dipole of each half-cell. In the LSS, the distance between two consecutive points is shortened, to provide flexibility for component alignment [4].

Derivation

The reference points have been determined by angle, distance, wire-offset and gyroscopic measurements with respect to the LEP quadrupoles and to the reference pillars located at the bottom of each pit (previously linked to the surface network). Both measurements on the new points and those carried out on LEP before its removal (wire offsets and gyroscopic measurements) are fitted together by using least square adjustment assuming, as a basic hypothesis, that the pillars are fixed. They provide a set of co-ordinates in the global CERN co-ordinate system, for the new points as well as for the LEP quadrupole targets.

In the vertical plane, the heights are determined by direct optical levelling. This levelling is also connected to the LEP quadrupoles - which were surveyed and realigned every year since 1992. The accuracy of the measurements is 0.4 mm per km (r.m.s.).

One special levelling reference has been sealed deep under the floor of the enlarged part of the tunnel at Points 2, 3, 4, 6, 7 and 8. Two more of these are also installed around the ATLAS and CMS experimental caverns to enable checking of their stability. All these deep reference points are included in the levelling traverses, and will be considered as fixed, to allow future checks of parts of the machine.

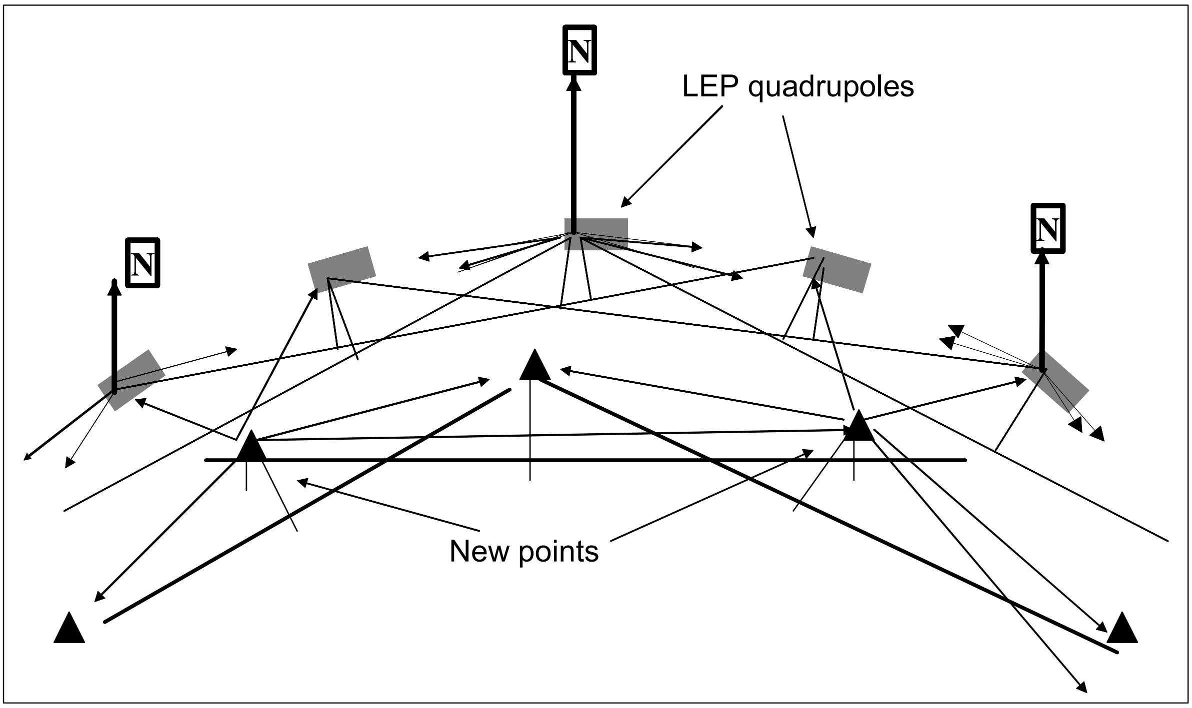


Figure 11.1: Layout of the Measurements

TI2 and TI8

The geometrical link between the SPS and the LHC is made by measuring the reference network of these two lines in a similar way to the LHC and by forcing the orientations in the SPS and the LHC to stay unchanged in the adjustment process.

11.2 THEORETICAL ABSOLUTE POSITION OF THE LHC

The LHC ring is contained in a plane parallel to and 300 mm above, the LEP plane. The interaction points IP1 to IP7 are located on the normal (orthogonal vector) to this plane in each corresponding point of LEP [5].

The co-ordinates of the IP's are defined in the global CERN reference frame, and the parameters of the mean beam line at the origin for MAD input are given in the Tab 11.2, below.

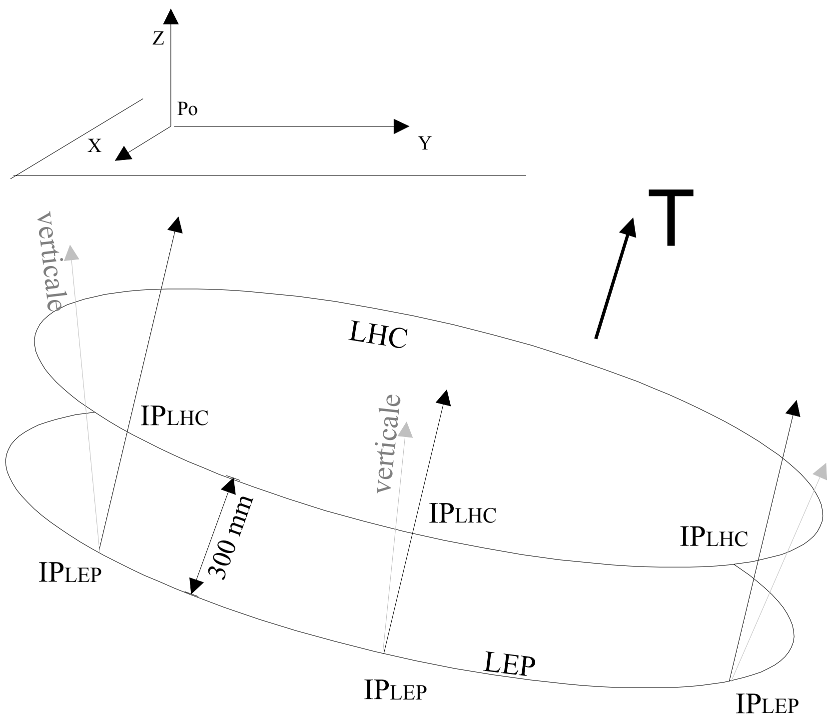


Figure 11.2 : Position of LHC with respect to LEP

Table 11.2 : Parameters for MAD SURVEY

X0	-2202.21027
Z0	2710.63882
Y0	2359.00656
THETA0	-4.315508007
PHI0	0.0124279564
PSI0	-0.0065309236

11.3 INTERNAL METROLOGY OF THE CRYO-MAGNETS

11.3.1 The Cryo-Dipoles of the Arcs

Layout of the Fiducials

Each element to be aligned in the tunnel is equipped with (at least) two reference alignment targets and a reference for the control of the transverse tilt. These references are called fiducials [6].

These are located on the cryostat in a very favourable position with respect to the adjustment jacks, in order to minimise the lever arm effects and so facilitate the alignment process of the magnets.

The cryo-magnets of the arcs and DS are equipped with four fiducials. Two transverse fiducials S and T are used to control the tilt. Due to the possible thermal vertical deformations of the cryostat, a dedicated central jack is needed to adjust the vertical sag. The central fiducial M is used to control this sag [7].

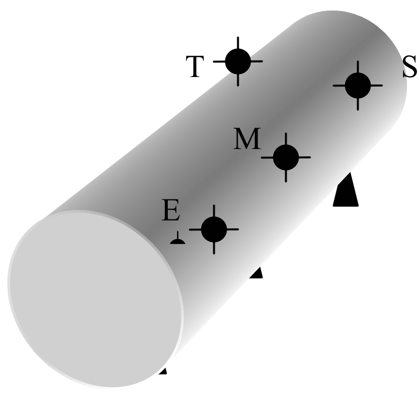


Figure 11.3: Layout of the fiducials on the cryo-dipole

The design of the fiducials allows instruments to be set up for the direct measurements carried out on them during the smoothing phases (see Sec. 11.6.2).

Determination of the Fiducials

The determination of the fiducials with respect to the mechanical plane and geometric axis is performed after the cold tests of the cryo-magnet. In this process, the geometric axis is defined as the best fit of a series of points located in the centre of each cold bore tube (with an auto-centring device going through it) and measured with a laser tracker from the two ends, assuming that the mean axis has the theoretical radius.

This operation, called "Fiducialisation", gives an accuracy of the position of the fiducials to better than 0.1 mm at 1σ [8].

As the measurements are performed at room temperature, a correlation factor is established during the cold tests in order to validate the position of the fiducials with respect to the cold mass, thus ensuring that warm magnets positioned in the tunnel reach their theoretical position when cold. In the same process, the central cold post is adjusted and blocked in order to force the shape of the cold mass to that measured in industry.

The oval deformation of the cryostat under vacuum in the sections containing the fiducials has been checked on prototypes and since it is always below 0.05 mm, it can be considered as negligible [9].

Additional Measurements

At the hand-over of the dipole cold masses at CERN, the shape of the magnet is checked by measuring a set of points inside the cold bore tubes using a laser tracker. This shape is compared to the theoretical one. The operation will be done on 10% of the dipole magnets.

The cartography of the tubes at the ends of each cryo-dipole is performed at the same time as the fiducialisation process. It consists of measuring the position of the flanges of several pipes and critical elements, in order to control the feasibility of the interconnection between two consecutive magnets. When the beam screen is inserted in the cold bore tube just before going down in the tunnel, the position of the end of the beam screen is also verified.

11.3.2 The SSS

The Fiducials

Three fiducials are installed on the cryostat of the SSS, similar to those of the cryo-dipoles. As no central jack is needed, no central fiducial is required.

The fiducials are determined by the survey group with respect to the magnetic axis of the cold mass, during the magnetic measurements under ambient conditions.

Additional Measurements

The mechanical position of the BPM is measured with the laser tracker with respect to the fiducials, in the same process as the adjustment of the extremity of the drift tubes for the lines V1 and V2 and the cartography of the ends. This gives good knowledge of the real position of the BPMs when the SSS is aligned in the tunnel and facilitates the interconnection between magnets.

11.3.3 Other Magnets

The separation magnets are equipped with six fiducials and the fiducialisation is done at BNL. On arrival at CERN, the position of the magnet with respect to its fiducials is checked, as well as the position of several tubes at the ends. For the inner triplets, the same kind of measurements will be done.

11.4 MEASUREMENTS FOR INSTALLATION

In order to facilitate the integration of the equipment in the tunnels, the real shape and position of the tunnel in the CERN global reference frame are used. The information is provided by the civil engineering department for the new caverns and tunnels.

The profiles of the LEP tunnel measured every 10m during the construction have been re-calculated with the new geometry for the existing tunnels. In addition, new measurements have been carried out at critical points, on the floor and the ceiling, mainly for the cryo-line and the transport vehicle passage.

Due to the lack of space in the tunnels, 'as built' measurements will be done at different steps of the installation of the machine to prevent topological problems between the various components. These are carried out using a laser scanner, which is the most efficient tool for collecting the data, reconstructing 3D models and studying their compatibility with the theoretical CAD models for integration.

A typical example of as built measurements is the check of the position of the jumpers of the QRL after their installation [10].

11.5 PREPARATORY WORKS

A series of tasks are performed prior to the alignment of the magnets in order to help during the final installation.

11.5.1 Marking on the Floor

This work consists of marking the vertical projection of the geometrical mean of the dual beam line, the position of the elements in the long straight sections (LSS), the interconnection points and the vertical projection of the head of the jacks in the arcs on the floor. In the transfer lines, the beam line is drawn in the straight parts of the lines, as well as the position of all the elements defined by BEATCH file, completed with the position of their supports. This work provides clear positioning for anybody working in the tunnels and is performed prior to the installation of the general services. The accuracy of the marks is ± 2 mm (r.m.s.) [11].

11.5.2 Positioning of the Jacks

The jacks of the magnets have an adjustment range of ±10 mm in radial and ±20 mm in vertical position. This is needed for compensating the errors of the floor, the errors in their own positioning, cryostat construction errors and ground motion during the life of LHC [12]. Because of this very limited range, the heads of the jacks are positioned within ±2 mm before the installation of the cryomagnets, with the adjustment screws in their mid position. 5 mm of the range of the vertical screw can be used to compensate the errors of the floor but for larger deviations of the floor, shimming or grinding is needed. After their accurate positioning, the jacks are sealed and fixed on the floor and then their position is checked again [13].

11.6 ALIGNMENT OF THE MAGNETS

The alignment of the magnets is performed in two phases: the first positioning and the final one, called smoothing.

11.6.1 First Positioning

This phase takes place once the magnets are installed on their jacks. It consists of independently aligning each magnet with the reference geodetic network and a magnet is considered to be aligned once its fiducials have reached their theoretical position. At the same time, a small local smoothing from magnet to magnet is done in order to obtain a relative alignment precision of ± 0.25 mm (r.m.s.) in radial and vertical for each magnet, and 0.5 mm (r.m.s.) axially, over a distance of 110 m. This smoothing decreases the influence of the small relative errors between the points of the reference network. The transverse tilt is adjusted within 0.15 mrad (r.m.s.) and the absolute precision in radial and vertical can be considered equivalent to that of the reference network.

This operation is performed when the magnets are not yet connected and the interconnection can only start at the end of this process [14, 15].

11.6.2 Smoothing of the Magnets

This phase is the final alignment of the magnets. Unlike LEP or the SPS, for the LHC the final alignment must be applied to all quadrupoles and dipoles - which have nearly the same sensitivity to misalignments. The process can only start once the magnets are connected, under vacuum and are cooled down, so that all the mechanical forces are taken into account.

The objective is to obtain a relative radial and vertical accuracy of 0.15 mm over a distance of 150 m [16]. As with the first alignment, the accuracy mentioned is applied at the fiducials. The vertical smoothing is performed with direct optical levelling measurements whilst the radial one is done by wire offset measurements. For this latter operation, access to the tunnel is required with the ventilation system adjusted to give minimum air-flow and certainly not exceeding 8000 $m^3 h^{-1}$.

This smoothing process initially corrects both residual errors in the pre-alignment and ground motion. As various geo-mechanical and structural forces are acting on the tunnel, the reference network mainly tends to move vertically, but magnets may also become tilted by a transverse component of this motion and by the deformation of the floor - thus also generating a radial displacement. Repeated measurements of the network are very expensive and in fact useless if, on the other hand, tilt, radial and vertical measurements are made directly on the magnets and then processed with respect to a local trend curve within a sliding window along the machine [17]. This efficient method allows an optimal and minimal detection of the magnets which need to be realigned.

At the end of the process, the misaligned magnets are moved, while keeping a contingency for relative movement (within the tolerance) at interconnection level [18].

An additional 1 mm offset can be made in the interconnections during the realignment process. This value is included in the maximum offset acceptable for the bellows of the interconnects.

11.7 ALIGNMENT OF THE INSERTION ELEMENTS

11.7.1 The Inner Triplets and TAS

Three points can be mentioned from the experience of LEP:

- The repeated surveys of the underground reference networks, in a recent and consequently not yet stable tunnel, with no link to the experiments, made it difficult to have a good geometrical relationship between the machine and the experiments;
- It was impossible to align the low-beta sections within the requested accuracy with classical methods, and that generated many demands for re-alignments;
- The subsequent monitoring of low-beta magnets with very accurate (a few μm r.m.s.) hydrostatic levelling systems was very effective in improving the orbit quality.

Table 11.3 : Requested Alignment Accuracy

Functionality	Function	Accuracy (r.m.s.)
Alignment of one triplet w.r.t. the other magnets of the same arc.	F1	0.1 mm
Alignment of the experiment w.r.t. the machine.	F2	See § 11.7.2
Alignment of one triplet w.r.t. the other triplet (left vs. right)	F3	0.3 mm
Alignment of Q1 vs. Q2 vs. Q3 for one triplet	F4	0.1 mm Few μm for short term stability
Alignment of the TAS	F5	0.33 mm

The requirements on the accuracy for the alignment of the inner triplets are given in Tab. 11.3 [19]. The situation for LHC is very different to that of LEP. The tunnel was finished sixteen years ago, the experiments at points 2 and 8 have been dismantled, no major civil engineering works have been undertaken there, and dedicated UPS galleries have been built for the geometry around ATLAS and CMS. The LHC geometry can be better related to the experimental caverns, thus minimizing the changes with respect to the experiment during the construction [20].

Each cryo-magnet Q1 or Q3 is equipped with 6 targets for the alignment F1. Three targets would have been sufficient but due to the symmetry of the installation with respect to the IP, the number of fiducials has been doubled to allow the installation anywhere. The Q2 has two additional targets in its centre, due to the additional central jack. The alignment F1 is performed with classical methods: optical levelling and wire offset measurements.

Each cryo-magnet is also equipped with additional targets dedicated to the permanent monitoring of their position. For the radial alignment, the equipment is as follows:

- A wire stretched along each triplet allows the function F4;
- A wire stretched through the two UPS galleries and the UX cavern allows the function F2, and F3.

The positions of the elements are detected with wire positioning sensors (WPS). The resolution of such sensors is 5 μm. For ALICE and LHC-b, where the stability is not altered by new heavy civil engineering works, no UPS gallery has been designed, and no stretched wire will be installed through the experiment. The radial link between left to right is made using the reference network of the tunnel, determined directly where the experiments do not obscure the lines of sight.

The vertical positioning is performed with hydrostatic levelling systems (HLS) installed from one triplet to the other one, through the UPS galleries and the UX cavern. These systems allow the functions F2 to F4 to be satisfied.

At the four intersection points, the cryostats are installed on motorised jacks to allow initial and maintenance alignments in these confined and (later on) radioactive areas.

Due to the high level of radiation which is expected, all the electronics are installed in less critical areas, UPS galleries at points 1 and 5 and UL galleries at point 2 and 8.

The TAS will be aligned from the network of the experiment.

Table 11.4: Installations for the Four Experiments

Function	ATLAS and CMS	ALICE and LHC-b
F3	Left to right vertical link (HLS)	Left to right vertical link (HLS)
F1	Two permanent levelling reference	One permanent levelling reference
F3	Left to right radial link (WPS) via UPS galleries	Left to right radial link via network
F4	Radial and vertical control of one triplet (WPS and HLS)	Radial control of one triplet (WPS)
F1	Link with the machine network	Link with the machine network
F2	Radial link with the experience (WPS via UPS galleries)	Radial link with the experience via network
F2	Vertical link with the experience (HLS)	Vertical link with the experience (HLS)

11.7.2 The Experiments

The Geometrical Links with the Machine

Each LHC experiment will be surrounded by a reference network that will be linked to the machine geometry either via the UPS galleries for ATLAS and CMS or via direct views for ALICE and LHC-b since there are no WPS systems traversing these two experiments. The reference networks are in the form of plug-in and foldable brackets on walls and metallic structures and the configuration is adapted to the needs for the detectors.

Two hydrostatic stations are installed in the four experimental caverns for the vertical link with the machine.

Accuracy

An error budget at 1 σ has been estimated for the ATLAS and CMS configurations from the machine itself to the reference network in the cavern and then to any other detector points.

That exercise has to be divided into the different steps of the geometrical process to link the machine geometry to any fiducial mark on the detector and to the locations of the reference points in the cavern, namely:

- Survey galleries reference line (UPS geometry) versus machine geometry : radial 0.1/0.2 mm, levelling 0.1/0.3 mm.
- Cavern reference points directly linked to the UPS geometry versus that geometry : radial 0.2/0.4 mm, levelling 0.1/0.2 mm. This is also the error budget of any fiducial mark directly measured from those reference points.
- Cavern reference points NOT directly linked to the UPS geometry versus cavern reference points directly linked to the UPS geometry: 0.5 mm in the three directions.
- Any detector fiducial mark versus cavern reference points NOT directly linked to the UPS geometry: 0.3 / 0.7 mm in the three directions.

Thus the global range of the three dimensional uncertainty at 1σ of any reference point in the cavern versus the nominal beam line is from 0.3 mm up to 0.6 mm, the global range of the three dimensional uncertainty at 1σ of any fiducial mark versus the nominal beam line being from 0.5 mm up to 1.2 mm.

The Stability of ATLAS

Due to very limited possibilities for vertical mechanical re-adjustments, tracing the vertical movements is critical [20].

Estimations for the ATLAS cavern floor stability show the following:

- Initial settlement due to cement contraction : about -2 mm from the time the concrete is poured to the time ATLAS gets possession of the cavern (4 to 5 months);
- Experiment weight : an additional adiabatic move over about 6 months of -5.5 mm due to the weight of ATLAS;
- Heave to hydrostatic pressure : about +1 mm per year, up to 20 mm over 20 years in the worse case.

According to the results of a-priori analysis, it would seem that stable conditions in ATLAS cavern within less than 1 mm per year might not happen in the first 15 years of its lifetime.

The main problem for ATLAS is the ability to precisely monitor and react to any movement in the floor level relative to the LHC beam. A permanent hydrostatic levelling system will be installed on the detector and linked to the main network specifically in order to monitor the relative movements of the feet at better than 50 μm.

Possibilities of beam adjustments have been studied for ATLAS in order to compensate the vertical motion of the cavern and its detector. An 'immediate' adjustment of less than 1 mm could be achieved by changing the magnetic field in the last magnet in the LSS, a 'short term' adjustment of about 1 mm could be achieved by adjusting jacks under the last triplet and a 'long term' adjustment of several mm's will imply a re-alignment of a string of magnets in the tunnel.

The Stability of CMS

Even if the mechanical configuration of CMS permits easier re-adjustments, a hydrostatic system has been also proposed to monitor the central wheel (YB0) of the CMS yoke. The layout and its integration enable it to be linked directly and easily to the hydrostatic tube traversing the CMS cavern in such a way that YB0, containing the barrel and the central detectors, can be inspected vertically via the entire machine hydrostatic system in the UPS and the radial tubes in the tunnel up to the inner triplets. An uncertainty of less than 0.5 mm with respect to the inner triplets is estimated.

The Stability of ALICE and LHC-b

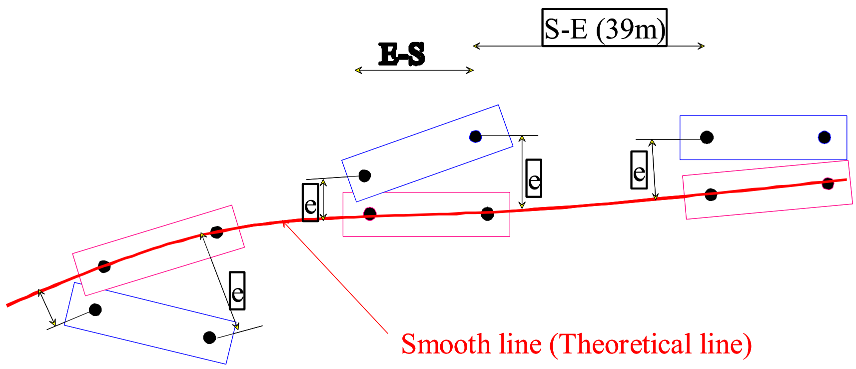
No direct links via WPS or HLS on any detectors in ALICE and LHC-b have been proposed yet. Only the periodic checks of the reference network and links with the machine will provide information about the stability of the detector.

11.8 ALIGNMENT OF THE TRANSFER LINES

As for the ring, the elements of the transfer lines are aligned with respect to the reference geodetic network and then smoothed into the SPS and the LHC through the elements concerned at the ends of the lines. The accuracy of the final alignment of the quadrupoles is 0.15 mm. The BPMs fixed on the quadrupoles are aligned in the workshop with respect to these quadrupoles, and only surveyed when installed in the tunnel [21].

11.9 MAINTENANCE OF THE ALIGNMENT

From 1992 to 2000, the vertical position of all LEP quadrupoles was surveyed annually. These measurements gave a very good knowledge of the tunnel stability and the hypothesis of the degradation of the alignment of the LHC was based on the results of these measurements [22]. Fig. 11.4 gives average statistics of misalignment around the trend curve of the smoothing process.



Polynome	92	93	94	95	96	97	98	99
max	0.00408	0.00105	0.0013	0.0008	0.0007	0.00067	0.0007	0.0007
min	-0.00216	-0.00145	-0.00073	-0.0009	-0.00068	-0.0009	-0.0008	-0.0008
rms	0.00060	0.00031	0.00019	0.00020	0.00020	0.00018	0.00018	0.00024

E-S (3 m)	92	93	94	95	96	97	98	99
max	0.0006	0.0006	0.0004	0.0004	0.0006	0.0006	0.0005	0.0005
min	-0.0008	-0.0004	-0.0004	-0.0006	-0.0004	-0.0004	-0.0003	-0.0003
rms	0.00017	0.00014	0.00014	0.00014	0.00014	0.00014	0.00012	0.00011

Figure 11.4: Deformation of LEP between 1992 and 1999

The table shows that after the first three years which were needed to recover correct alignment, the accuracy of successive alignments stabilised around 0.2 mm (r.m.s.) per year.

About 100 quadrupoles where re-aligned using the smoothing method each year in order to recover an alignment within 0.15 mm (r.m.s.).

Therefore, the precision of the alignment will be as follows:

- After one year 0.2 mm in vertical, 0.2 mm in radial, mainly due to tilt deviations, so 0.28 mm transversally to the beam,
- 0.50 mm in the interconnection plane due to lever arm effects and amplification errors.

About 350 cryo-magnets will therefore have to be re-aligned annually.

At the lowest point, a subsidence of about 2 mm per year is still active and affects 600 m of tunnel in a gradual way (Fig. 11.5).

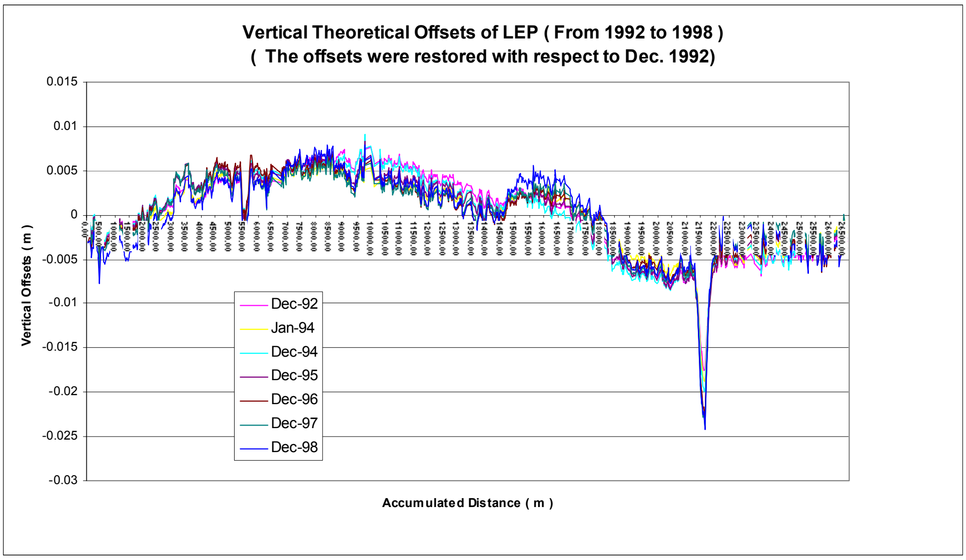


Figure 11.5: Vertical theoretical offsets of LEP from 92 to 98

This will have a serious impact on the range of the jacks of the cryo-magnets and the jumper connections with the QRL in this area. In order to delay the effect on these elements, an anticipation of the motion over four years will be taken into account for the installation of the jacks and the QRL.

In order to prevent movements beyond tolerances for bellows, a permanent geometric control of the interconnections will be set up. A sensor will send a warning to the control room when the critical limit in the relative movement of two consecutive magnets is reached. Initially, half of the interconnections will be equipped – these have been chosen according after analysis of movements observed on LEP.

11.10 QUALITY ASSURANCE

The successive phases of the alignment process are describes in detail [23], including the conditions needed for performing the work, and the procedures determine the role of the contractors and CERN in the quality control process.

All the geometrical data are stored in a dedicated database [24]. This database manages the following data:

- The theoretical 3D positions of all the elements, the orbit points provided by MAD and the fiducials,
- The measurements carried out for the metrological works (networks control, alignments, smoothing),
- The calibration parameters of the instruments,
- The results of the works, the real position of the elements.

For elements such as BPMs and correctors which are parts of the cryo-magnets, their real position is deduced from the position of the main components taking the assembly errors contained in the MTF into account.

REFERENCES

[1] Jones M., Mayoud M., Wiart A., *"Geodetic Parameterisation of the CNGS Project"*. https://edms.cern.ch/file/362348/1/CNGS_IWAA2002.pdf, IWAA 2002, Spring-8, Japan, November 2002.

[2] Mayoud M., *"Géométrie théorique du LEP »*, http://doc.cern.ch/tmp/convert_SCAN-0008124.pdf, LEP Note 456, Juin 1983.

[3] Jones M., *"Geodetic Definition (Datum Parameters) of the CERN Coordinate System"*, EST-SU Internal Note, https://edms.cern.ch/file/107981/1/cerndatums.pdf, November 1999.

[4] Naegely P., «*Le Réseau Métrologique - Présentation Générale* », EDMS No. 111391, June 2000.
[5] Lasseur C., Mayoud M., Missiaen D., Quesnel J.-P., « *Géométrie du LHC: Points caractéristiques, Formules de Transformation* ». https://edms.cern.ch/file/108124/1/geometrie_lhc_coordonnees.pdf, LHC Project Note 95.
[6] Quesnel J.-P., « *Alignment Targets* », https://edms.cern.ch/file/90314/1.0/LHC-GI-ES-0001-00-10.pdf, March 1999.
[7] Chambardon M, Missiaen D, Naegely A.V., Naegely P., Quesnel J.-P. , Scandale W., "*The Metrology of the LHC Project : What News*", https://edms.cern.ch/file/308645/1/jpque99.pdf, IWAA, Grenoble, 1999.
[8] Missiaen D., Quesnel J.-P., "*Fiducialisation of the LHC Cryo-Dipole Magnets*", https://edms.cern.ch/file/110632/1.1/LHC-GI-ES-0002-00-11.pdf , June 2000.
[9] Dupont M., Missiaen D., Peguiron L., "*3-D Metrology applied to Superconducting Dipole Magnets for LHC*", https://edms.cern.ch/file/308647/1/dmiss99.pdf, IWAA, Grenoble, 1999.
[10] Dobers T., "*Positioning of the Service Modules of the Cryogenic Distribution Line (QRL)*", https://edms.cern.ch/file/112011/2/LHC-G-ES-0015-00-20.pdf, August 2000.
[11] Quesnel J.-P., Schmitt J., *"Marking on the Floor in the LHC and Transfer Tunnels (TI2 & TI8)"* – Interface specification, https://edms.cern.ch/file/311753/1.1/lhc-g-es-0006-10-10.PDF, November 2001.
[12] Quesnel J.-P., "*Alignment Requirements for the Jacks of the Cryomagnets"*, https://edms.cern.ch/file/109520/2.1/LHC-G-ES-0007-00-21.pdf, December 2000.
[13] Quesnel J.-P., « Positioning of the Jacks of the Cryomagnets », https://edms.cern.ch/file/311752/2.0/lhc-g-es-0008-20-00.pdf, March 2002.
[14] Quesnel J.-P., « Alignment Requirements for the Jacks of the Cryomagnets », https://edms.cern.ch/file/109520/2.1/LHC-G-ES-0007-00-21.pdf, December 2000.
[15] Quesnel J.-P., « The First Positioning of the LHC Cryomagnets (Arcs and DS), https://edms.cern.ch/file/311755/1.1/lhc-g-es-0009-10-10.PDF, November 2001.
[16] Jeanneret J.-B., Quesnel J.-P., Scandale W., Verdier A., *"Report on the Mini Workshop on the LHC Alignment*", http://doc.cern.ch//archive/electronic/cern/others/LHC/Note/project-note-247.pdf, February 2001.
[17] Woodhouse N., *"Plane, a Tool for Smoothing Accelerators"*, October 1995.
[18] Podevin C., « *The Smoothing of the Magnets of the LHC Ring – Final Positioning* », https://edms.cern.ch/file/311768/1.0/lhc-g-es-0010-10-00.PDF, January 2002.
[19] Mainaud Durand H., *"Alignment requirements for the LHC low beta triplets"*, https://edms.cern.ch/file/344496/1.0/LHC-G-ES-0016-10-00.pdf, August 2002.
[20] Hatch C., Lasseur C., Lissauer D., *"Alignment of the ATLAS Experiment with the LHC Beam*", https://edms.cern.ch/file/320043/1/ATLAS_beam_alignment1.doc , May 2001.
[21] Mathieu A., *« Alignment of the Elements of the LSS of the LHC Machine,* https://edms.cern.ch/file/311782/1.0/lhc-g-es-0013-10-00.PDF, December 2001.
[22] Jin F., Mayoud M., *"Deformation Analysis of LEP"*, https://edms.cern.ch/file/308644/1/mmayo99.pdf, IWAA, Grenoble, 1999.
[23] Quesnel J.-P., *"Alignment of the LHC Components – Organisation of Work Packages"*, https://edms.cern.ch/file/334671/1.0/LHC-G-IP-0001-10-00.pdf, April 2002.
[24] Bhattacharjee T., Missiaen D., *"Case Design and Implementation of a Geodetic Database for CERN Accelerators"*, IWAA, Annecy, 1993.

CHAPTER 12

LOGISTICS AND INSTALLATION

12.1 INTRODUCTION

The size and the complexity of the LHC project call for a strong coordination of all installation activities. More than 2000 tasks have been identified and about 80 000 tons of materials have to be transported and installed in the tunnel

The coordination of the installation is carried out by the Installation Coordination (IC) Group which was created for this purpose. The planning, installation and logistics issues and methods are described in the following sections. There is also a section is devoted to the cryomagnets.

An Installation Day was organised in order to provide all of the Project Engineers with reference documentation [1].

12.2 PLANNING

The total time allocated for underground installation is about 5 years, excluding civil engineering. The sequencing of the various installations has been studied in great detail in order to minimise interferences and consequently the amount of time lost [2].

12.2.1 Multi-level Planning

In order to limit the risk of delays, a multi-level scheduling process has been chosen for the project:

- ***The Master Schedule*** reviews the strategic goals and major milestones of the project. It gives a schematic plan for the different phases of the installation, indicates the main dates and shows the sequence of work in the different sectors of the LHC.
- ***The General Co-ordination Schedule*** is issued by the planning team of IC and aims to implement and control the flow of installation that is most effective in term of resources and time. It also has to respect the main milestones of the Master Schedule, such as injection tests in TI8, tests of sector 7-8 with beam, closing of the machine and the end of installation. It is endorsed by the Project Leader.
- ***The Detailed Installation Planning*** derives from the details of the installation scenario and the knowledge of each individual installation work unit (activities, boundary conditions, resources, etc.). It is maintained with the MS-Project software package, which automatically updates all the chronological relations between the different activities whenever a schedule change or a new task is introduced. It also provides a resource levelling function that is very useful to assess the feasibility of a new scenario.

12.2.2 Installation Phases

The installation of LHC is subdivided into twelve steps occurring at different times in each sector. At the time of writing a detailed study for the installation of the arcs and injection lines has been prepared. The installation sequences for the other sections of the machine (RF, extraction, cleaning, etc.) remain to be defined. The installation sequence for the arcs is given below together with a short description of the operations carried-out.

Phase 1: General services

- Step 1: The marking of the floor and its preparation
    - The theoretical position of the axis of the jack head is marked on the floor together with the name of the cryomagnet.
    - The half-cell boundaries are also marked on the floor.
    - The height of the floor is adjusted

- Step 2: The installation of the general services
  - The position of the cable trays is modified
  - The AC cables are pulled
  - The position of the lighting is modified
  - The leaky feeder used for communication is installed
- Step 3: The piping work
  - The two demineralised water pipes are installed in the centre of the ceiling
  - The helium ring and recovery lines are installed
  - A compressed air line is installed
- Step 4: Cabling campaign #1
  - The power cables
  - The signal cables
  - The optical fibres
  - The connectors
  - The junction boxes

Phase 2: Cryogenic line

- Step 5: The installation of the QRL
  - The QRL supports
  - The QRL elements (pipe, service and return modules)
  - The helium pipes are welded
  - The vacuum vessel is welded
  - Leak tests
- Step 6: Cabling Campaign #2
  - The local cables
  - The connectors
- Step 7: The commissioning of the QRL
  - The connection to the QUI
  - The pump down
  - The cool down
  - The commissioning
  - The warm up

Phase 3: Machine

- Step 8 : The installation of the jacks
  - The positioning of the jacks
  - The bolting to the floor
  - The pre-alignment of the jacks
  - Activities left over from the general services phase: e.g. The painting of the optical guidance strip - the signal cables (last campaign)- the connectors (last campaign)
- Step 9: The transport and the installation of the cryomagnets on the jacks
  - The cryomagnets are lowered via PMI2
  - The transport to the final destination
  - The transfer onto the jacks
  - The pre-alignment of the cryomagnets

- Step 10: The interconnection of the cryomagnets
    - The interconnection of the bus-bars
    - The welding of the beam and helium vessel pipes
    - The connection to the QRL in the jumper
    - The closing of the external bellows
    - The leak tests
- Step 11: The installation and the connection of the electronics under the magnets
    - The mounting of the connectors
    - The installation of the crates under the cryomagnets
    - The pre-commissioning

Phase 4: Hardware commissioning

- Step 12: The Hardware commissioning
    - The pump down
    - The pressure tests
    - The insulation tests
    - The cool down
    - The cold commissioning of systems
    - The powering of all circuits at nominal current

The installation of the hardware in a sector is expected to be completed in three years. A schematic drawing of the installation phases for an LHC arc is shown in Fig. 12.1.

12.2.3 Update and Rescheduling

The installation activities have to adapt through continuous feedback from the production sites and from the field. To this end, the detailed installation planning is regularly reviewed. Short Term Planning Meetings, are held every 4 weeks, with the aim of confirming the activities to be carried out over the coming three months. In this forum, early warnings of potential delays may come up. These can include situations such as:

- Interfaces between groups have not been identified,
- The task sequencing is incorrect,
- Components or team are not available,
- Preparation work or integration is not ready,
- The time required for a given task wrongly calculated
- Unexpected technical difficulties are encountered.

It is essential to limit the impact of such problems and rescheduling of activities or redeployment of staff to optimise the usage of resources might be considered. In the decision making process, solutions with no consequences on other work units (co-activity if possible) are initially studied; then, at a second stage, those with no consequences on work units under the responsibility of sub-contractors or vendors, are considered. Rescheduling can be accepted rapidly if the impact is limited to the domain of activity of the project engineers present or represented at the Short Term Planning Meeting and if the dates of the General Co-ordination Schedule are respected. A revised Detailed Installation Plan, taking into account the current component production and installation contracts as well as the progress of installation is issued periodically.

Such direct rescheduling can be a hazardous exercise. Particular care must be taken with the logistics of the supply of the different work sites since activity in a shaft (cabling, piping or installation of cryogenics lines) forbids lowering material through this shaft for the duration of the work. All safety aspects must also be taken into account: safety rules have to be strictly enforced and the procedures must be studied and documented in detail. This is an essential step in the assessment of the feasibility of the new scenario.

If it appears that the change cannot be considered locally and that it has implication on the installation of other equipment occurring at different times and locations, the rescheduling must be published and accepted by all parties involved. This is achieved by publishing a Schedule Change Request (SCR).

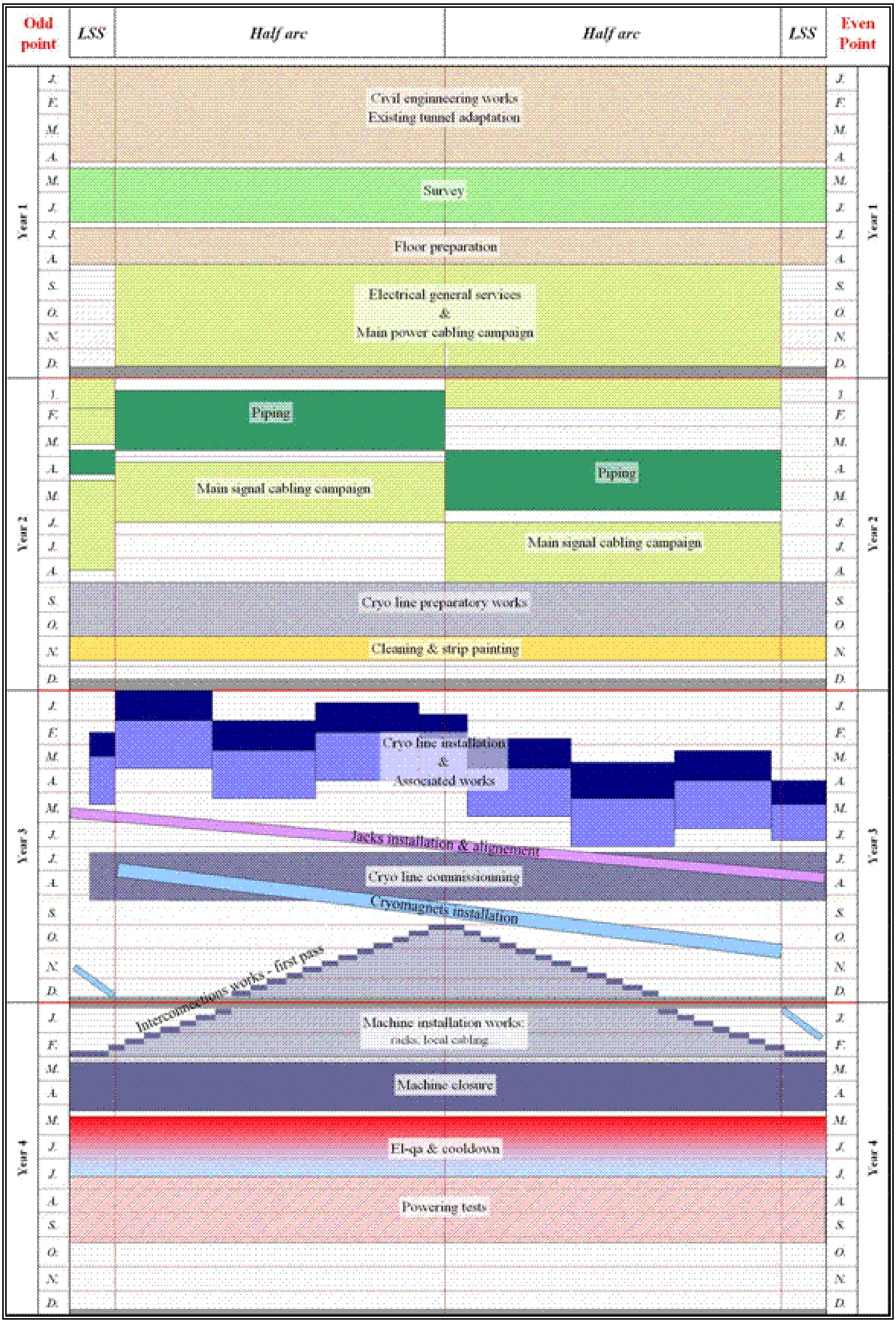


Figure 12.1: The LHC installation schedule for a sector

Significant rescheduling of the installation, in particular if it concerns a complete phase or even a period, can have major consequences and will certainly involve many parties. To obtain authorisation for such a schedule change, a Schedule Change Request is circulated to all the Group Leaders involved in the LHC Project for them to evaluate any eventual implications on the installation of their equipment and on their contracts. Once approved, the document is declared as being a Schedule Change Order by the Project Leader and all the Project Engineers are informed.

12.3 INSTALLATION

The machine and service equipment is provided by different groups working closely together during the installation and with a tight coupling of their activities. The planning details the installation scenarios, however the large number of actors and the addition of any unforeseen activities will inevitably lead to interferences. In order to allow rapid reaction and minimise the impact a strict and knowledgeable coordination in the field has to be put in place.

12.3.1 Organisation of the Installation of LHC

Due to the number of protagonists both from CERN and from contracting companies, it is important at the beginning of the project to give details about the general organisation of the installation and the decision-making bodies. All the information is gathered in the document "Organisation of the Installation of the LHC and its Experiments" [3]. It describes:

- The specific measures related to the installation: work packages, etc.
- The operational coordination, detailing the role of the group leaders, the TSO (territorial safety officers), the safety coordinators, the site managers, and the operators of transport and handling equipment,
- The working hours and days,
- The access to the sites and to the underground works,
- The barracks and parking on surface,
- The storage issue,
- The handling and transport issues,
- The underground transport of staff to worksites,
- The waste management,
- The utilities, energies and worksite services.

12.3.2 Description of Work Packages

Several protagonists may intervene in the same zone simultaneously leading to a need to check the compatibility of all the activities. This requires an overall view of what needs to be done, which is only possible if the information is coherent across the installation of the whole project. For that very reason, the installation of services and machine components has been broken down in Work Packages which cover a given period of the installation and a specific part of the underground areas.

This means that a punctual delay or a hazard may propagate onto a chain of activities within a given Work Package, thus resulting in additional delays and potential cost over-runs. The role of IC is to limit the impact of such incidents whenever decisions can be taken in the field and to give assistance with minor interventions when this can unblock the situation.

The Work Package documents contribute to the quality assurance process of the LHC project. They are linked with the detailed installation planning. In addition to a summary description of the different tasks to be carried out, these documents give precise information about:

- Human and material resources required, including contact persons,
- Specific logistics needs and means,
- Specific access conditions,

- Installation of surface barracks and storage areas,
- Protective measures to implement if required,
- Field utilities available over the work package time span,
- A Description of the initial environmental conditions if necessary.

The description of an installation Work Package is prepared together with the scheduling process, with the assistance of the Zone Coordinators. It is checked by those involved in the field and approved by the Group Leaders concerned and Heads of Department.

12.3.3 Co-ordination in the Field

Co-ordination in the field [4] requires a very good knowledge of the situation in each worksite and of the possibility of co-activities and of the transport conditions in the underground areas. The LHC ring and its injection tunnels are subdivided into three main zones as shown in Fig. 12.2. Each zone is supervised by a Zone Coordinator who ensures that the installation activities are carried-out as specified in the Work Package description, according to the defined strategy and in conformity to safety rules and regulations of CERN and Hosts States. The aim is to stay aware of the advancement of every work site and to rapidly react to any problems. In order to fulfil this mission, IC provides assistance to installation and carries minor tasks ranging from quick repairs to preparation of masonry, steel structures, electricity, etc. This allows work which is sitting on the borderline of well identified responsibilities (so called orphan activities) to be handled and the unblocking of problematic situations in the field.

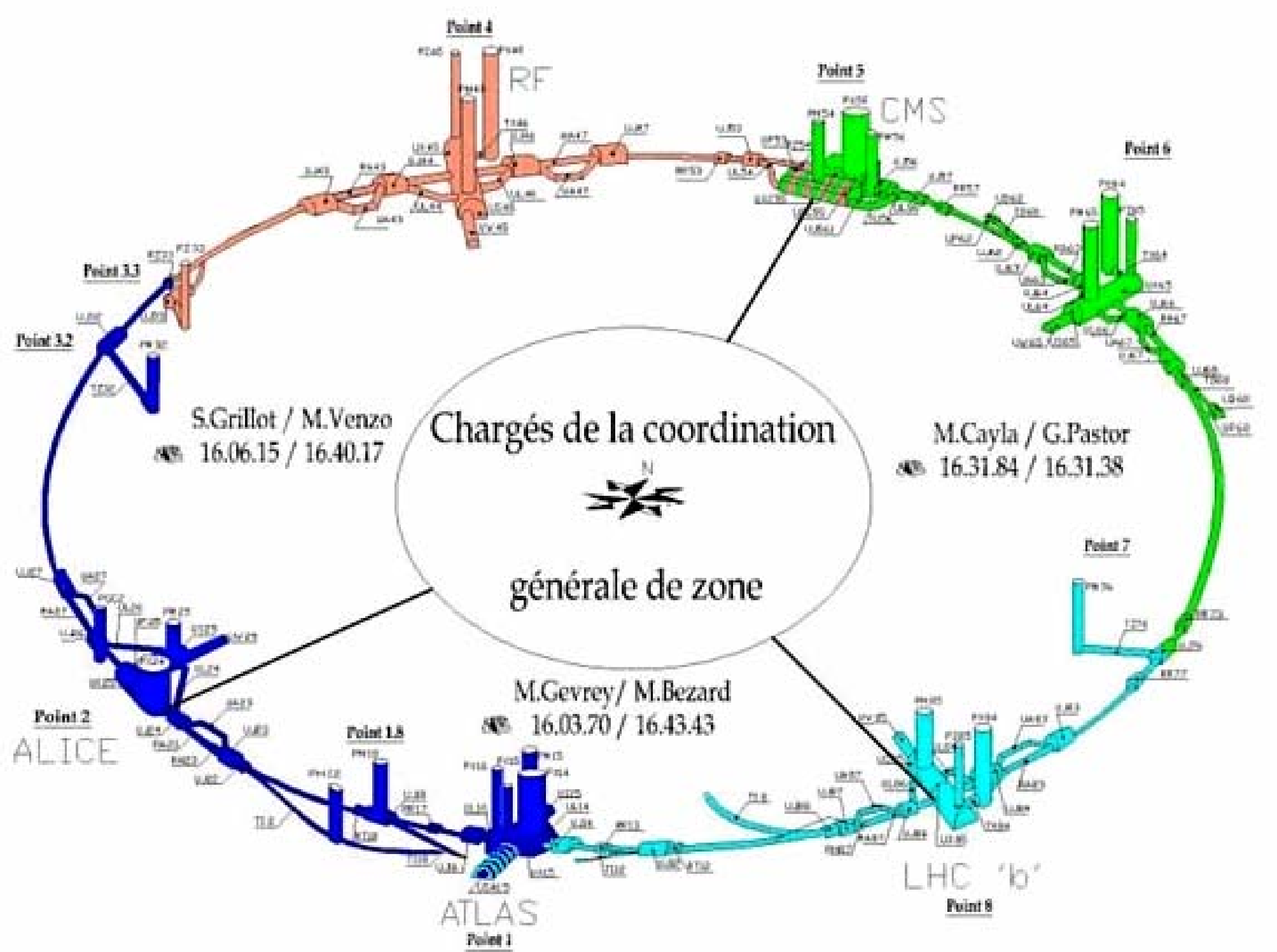


Figure 12.2: LHC installation zones and zone coordinators

12.3.4 Monitoring of Installation Progress

The Zone Coordinators organise weekly meetings in the field with the aim of following the progress of all installation activities, identifying potential problems and proposing corrective measures if necessary. The list of actions is included in the minutes of the meetings. The Work Supervisors of the groups involved, the Site Managers and the Safety Inspector participate to these meetings. Ad-hoc meetings are also organised with the teams involved in specific areas to study the details of a delicate installation scenario.

The Zone Coordinators report to the Installation Follow-up Meeting that takes place every four weeks: this is a forum for the sharing of experience and to check the homogeneity of the installation procedures on the different work sites. The Zone Coordinators also participate in the Short Term Planning Meeting described earlier: the project engineers in charge of the current work, the Safety Coordinators and the members of the IC group thus get an updated and coherent view of the situation of the installation every two weeks. A synthesis of the Installation Follow-up Meeting and of the Short Term Planning Meeting is presented at each Technical Coordination Committee meeting and covers the following points:

- The work which has been achieved in the period elapsed since the previous report,
- The problems which have been encountered during that period and the corrective action taken and any repercussions expected on other activities,
- The actual status of the project versus the planning presented in the form of a broken line on the General Co-ordination Schedule.

The advancement of the installation versus the planning is published once a month on the LHC Project home page [5].

12.3.5 Reception of a Work Package and the Treatment of Non-conformities

In addition to the formal hand over meeting with the contractor (organised by the group responsible for the equipment installed), a visit is always organised by IC to identify any non-conformities with respect to the Work Package definition and to ensure that the zone is acceptable for the next installation phase.

In some cases, for example the general services, when a group subcontracts the installation of equipment to another group, who in turn subcontracts this work to an external firm, IC also ensures that the equipment has been installed in conformity with the original technical specification. To this effect, a meeting is organised with the two groups involved in order to identify non-conformities and, if possible, have them resolved before the formal hand over.

Any non-conformities of a Work Package are documented and the Installation Coordination Team follows-up their resolution, according to the LHC quality assurance plan. Experience shows that the majority of non-conformities involve either poor workmanship, deviance from installation drawings, integration errors or missing equipment. In many cases, non-conformities can be detected by visual inspection and documented using photographs. However, problems such as bad positioning may need confirmation by an accurate survey. In addition to the standard techniques, this verification can also be made through a laser scanning of the elements installed. This scan can then be checked against the 3-D views produced by DMU [6].

12.3.6 Site Management

The general management of all the LHC sites has been placed under the responsibility of the IC group. The mission of the Site Managers consists of assisting all the people working on site. It includes:

- The organisation of repair work when there are technical problems with the infrastructure,
- The daily management of site access conditions assisted by the site guards,
- The management of the so-called shared spaces and facilities.

The site managers are also the territorial safety officers (TSO) for the site and thus have the mandate to make sure that the rules in matters of health, safety and environmental protection are applied. In the framework of LHC installation work, they take care of the correct application of the measures specified in the work package documents. Site managers are present at each of the points 1, 2, 4, 5, 6 and 8 of the LHC and on-call at points 1.8, 3, 7 and I2.

12.3.7 Safety during Installation

During the installation and commissioning, safety is a top priority. Specific measures related to installation activities are enforced in addition to those described in the LHC Design Report Vol II, Chap. 3 [7].

The implementation of the safety rules is both a matter of organisation and a matter of application in the field. The organisation includes all the rules and regulations defined by CERN, but also all those coming from the Host States (France and Switzerland). A Project Safety Officer (PSO) has been appointed for all the installation activities. The PSO organises the activities of the Safety Coordinators and supervises the Territorial Safety Officers (TSO) responsible for safety matters in given areas.

The safety coordinators are appointed by the LHC project leader according to French law. They have the mandate to take care of the application of all the measures necessary for safety at all stages of the project. They have complete freedom to send their remarks to all the protagonists of the project. They take care of the application of the French regulations and the associated actions and documentation. This documentation includes a '*Plan Général de Coordination en matière de Sécurité et de Protection de la Santé'* (PGCSPS) and a '*Plan Particulier en matière de Sécurité et de Protection de la Santé'* (PPSPS) which includes a Task Description for each work site. Finally there is a '*Visite d'Inspection Commune*' (VIC) before the start of any activity in the field.

The responsibility in matters of safety is a hierarchical one. Group leaders and their representatives in matters of safety are responsible for the safety of their own equipment, from their conception to their installation in the tunnel.

12.4 TRANSPORT ARRANGEMENTS

The tight schedule and the large quantity of items to be transported require fully integrated logistics on the surface and even more stringent co-ordination underground. The general means of transport and handling of equipment, together with the organisation necessary to bring the equipment to its final destination, are described below. However, the specific case of the cryomagnets is treated in Sec. 12.5. The reliability of all the transport and handling equipment is extremely important as faults, or breakdowns can quickly lead to logistical problems. A very effective maintenance programme has been put in place for the vehicle park and handling equipment. The computer simulation of transport scenarios is very important to identify bottlenecks and resource limitations, as well as to finalize schedules and compute transport durations.

12.4.1 Items to be Installed

The quantity and variety of equipment in the LHC is huge. The total weight to be lowered down into the tunnel for the machine is estimated to be about 80'000 tons. This equipment can be categorised as follows:

- Standard equipment for services:
  Electrical equipment such as cable ladders and drums, transformers, distribution boards, etc.
  Piping and miscellaneous equipment for the cooling circuitries,
  Metallic structures,
- Cryogenic equipment,
- Cryomagnets (see Sec. 12.5),
- Electrical distribution feed boxes,
- RF equipment,
- Warm magnets,
- Jacks,
- Vacuum chambers and vacuum equipment,
- Power boxes and electronic crates.

Each category of equipment has specific properties (dimensions, weight and fragility) and has to be treated individually in terms of transport means and procedures.

12.4.2 Surface Transport and Handling

Depending on the agreement reached with the supplier, on the requirements of customs formalities or on the assembly processes, equipment will be transported to assembly halls, storage areas or tunnel access points either directly or more usually via the Meyrin and Prévessin laboratory sites. All transport between the different points is carried out using the CERN fleet of vehicles. Of note are the special heavy trailers required for large, heavy and cumbersome loads. Transport over distances of up to 18 km using public roads will be required. Host States regulations apply for public roads, in particular for exceptional loads.

Most standard types of handling equipment are available at CERN including overhead cranes and mobile cranes which can commonly handle objects having a weight of tens of tons.

12.4.3 Access Shafts and Cranes

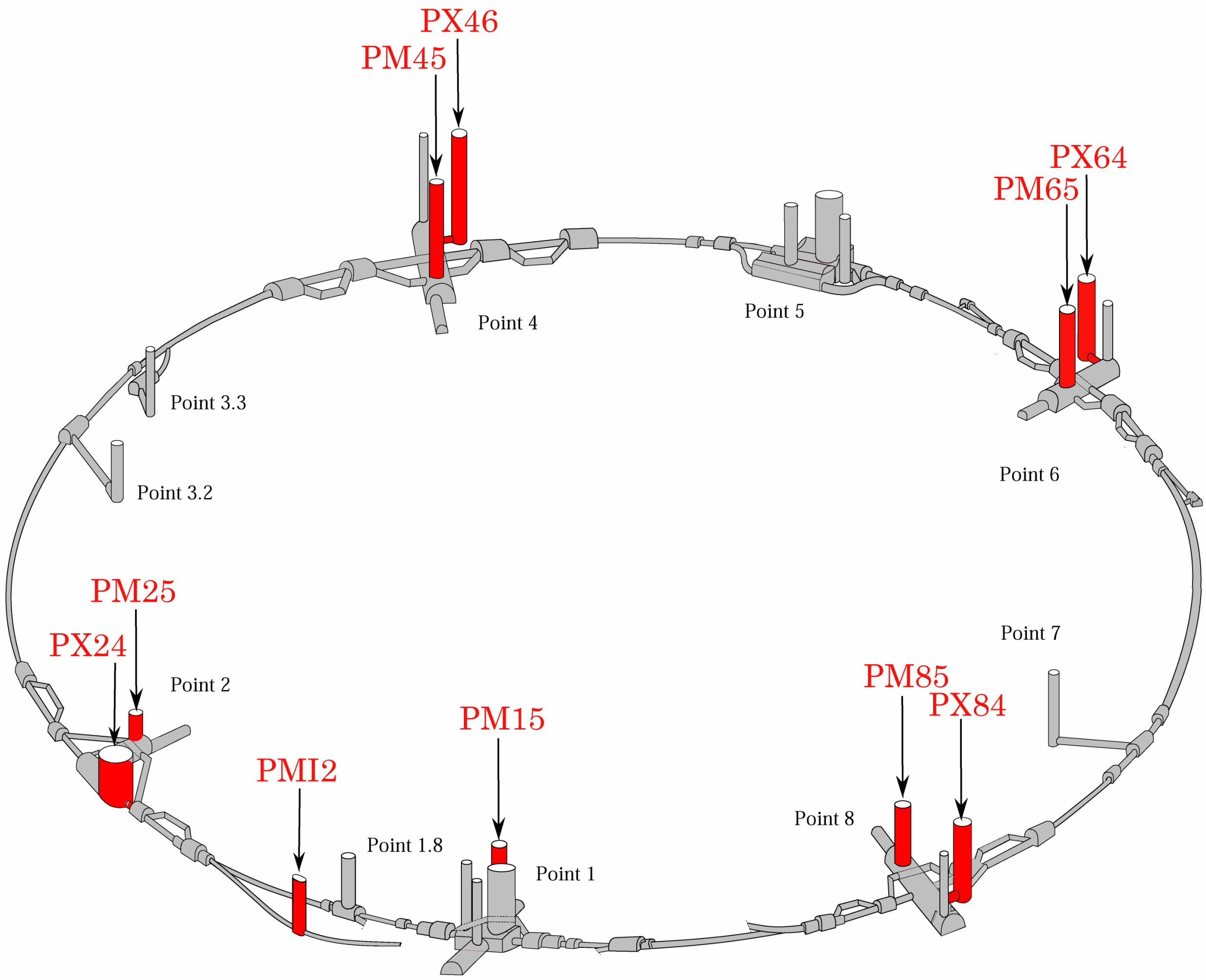


Figure 12.3: The access shafts used for the LHC installation

The access points for the equipment down to the tunnel are eight shafts located all around the machine as shown in Fig. 12.3. These shafts have the following particularities:

- Five shafts (PM15, PM25, PM45, PM65, PM85) reach the service caverns. They are equipped with cranes of 10 t capacity or more.
- Two shafts (PX46, PX64) each equipped with an 80 t crane reach the two LEP experimental caverns which are now dedicated to the machine.
- A further shaft (PMI2), equipped with a 40 t crane reaches the TI2 injection tunnel. This allows the larger machine components, like the cryodipoles to be lowered, but the TI2 cross-section is smaller than the main tunnel cross-section, prohibiting transport of high objects.

In addition, two shafts (PX24, PX84), can be used occasionally for specific cases (e.g. abnormal dimensions of the equipment, practicality of access) to reach the LHC experimental caverns. The transport arrangement in the shafts described above is summarised in Tab. 12.1.

Lifts for personnel are available at all access points, except Point I2. These lifts can also be used to take relatively small and mobile equipment down into the tunnel. The capacities of these lifts are given in Tab. 12.2.

Table 12.1: Main overhead travelling cranes

Location	Capacity (t)	Height Hook (m)	Lifting Height (m)	Hopper (m)		Speed (m/min)	
				Length	Width	High	Low
SD1/PM15	20	8.8	92	5.7	1.9	30	10 (> 1 t)
SDI2/PMI2	40	6.7	52.5	17	3	20	10 (> 10 t)
SD2/PM25	10	8.8	54	5.7	1.9	30	10 (> 1 t)
SX2/PX24	65	8.1	59	14	7.2	10	5 (> 5 t)
SD4/PM45	10	8.8	147	5.7	1.9	30	10 (> 1 t)
SX4/PX46	80	9.8	153	∅ 10.1		10	5 (> 5 t)
SD6/PM65	10	8.8	105	5.7	1.9	30	10 (> 1 t)
SX6/PX64	80	9.8	110	∅ 10.1		10	5 (> 5 t)
SD8/PM85	10	8.8	108	5.7	1.9	30	10 (> 1 t)
SX8/PX84	80	9.8	113	∅ 10.1		10	5 (> 5 t)

Table 12.2: Main lifts to be used for lowering of equipment

Location	Capacity (kg)	Cabin dimensions (m)			Door width (m)	Speed (m/s)
		Length	Width	Height		
SD1/PM15	3000	2.70	1.85	2.70	1.85	1.6
SD2/PM25	3000	2.70	1.85	2.70	1.85	1.6
SD4/PM45	3000	2.70	1.85	2.70	1.85	1.6
SD6/PM65	3000	2.70	1.85	2.70	1.85	1.6
SD8/PM85	3000	2.70	1.85	2.70	1.85	1.6
SDX1/PX15	3000	2.70	1.85	2.70	1.85	1.6
SDX5/PM54	3000	2.70	1.85	2.70	1.85	1.6

12.4.4 Underground Transport and Handling

The efficiency with which equipment and personnel can be transported underground has a major influence on the installation planning. The length and narrowness of the tunnel strongly influence the rate of transport of the equipment. The floor width, initially around 2.5 meters, will narrow down to 1.35 meters when the machine is installed. Crossing of vehicles transporting equipment becomes impossible over lengths of 3 km.

During the first phase of the installation, the general services, tractors and trailers, developed for underground use, are the standard means of transport. For the cryogenic line, trailers provided by the contractor are pulled by the same tractors. However, for the last phase, the equipment and methods used to transport each piece of machine equipment should be specifically selected. In particular, the warm magnets will be transported with the so-called buggies: the automatically guided vehicles developed for the injection tunnel magnet installation [8].

Personnel are transported by tractors towing personnel trailers, but there is no restriction on the use of bicycles complying with the safety rules.

12.4.5 Organisation of Transport Operations

All the constraints already mentioned lead to strictly organised logistics. Most of the information is stored in a database, extracted partly from the reference database [9][10], a documented pre-warning is requested months in advance and all the transport requests are issued via an electronic procedure (EDH). This allows definition of handling methods and preparation of associated tools. On the surface, standard CERN transport procedures are used, but underground a transport schedule linked in real-time with the co-ordination schedule is issued. For this, all oversized and/or heavy components are transported by IC.

12.5 CRYOMAGNETS HANDLING AND TRANSPORT

The presence of fragile components, like the composite support posts, makes the long and heavy cryomagnets difficult to handle and transport. Furthermore, keeping their geometry unchanged in the specified range of ±0.1 mm throughout the various transport and handling operations is essential. During the preparatory phase of the project, analyses and tests showed that long-distance transport is not advisable. Therefore, most of the cryomagnets are assembled on the CERN site. In order to reduce the cold mass displacements in the vacuum vessel, they are equipped with transport end restraints during the whole sequence of transport and handling on the surface, except for the activities around Point 1.8.

During movements each cryomagnet is monitored to ensure that the acceleration limits, in the range of 3-7 m/s^2 for frequencies up to 50 Hz, are not exceeded. A tri-axial acceleration-monitoring device is placed on each cryomagnet at one extremity of the cold mass.

After storage, the cryomagnets are lowered into the tunnel and installed at their final position.

12.5.1 Assembly and Preparation

The dipole, short straight section or quadrupole cold mass assemblies [11] are inserted into their cryostat on their support posts, fitted with the thermal shield, the multi-layer insulation and the instrumentation feed through at Point 1.8 (building SMA18) or at the Prévessin site (building 904).

They are then cold tested at Point 1.8 (building SM18) and, once the tests are completed these elements are conditioned in the tunnel configuration again at Point 1.8 (building SMA18) or on the Prévessin site (building 904). This consists in stripping the interfaces, tubes and short circuits necessary for the cold tests and configuring the mechanical interfaces for installation and connections in the tunnel.

The last operations before the lowering of the cryomagnets through the PMI2 shaft are the cleaning of the cold bore tubes and fitting the beam screen followed by the associated quality assurance operations. This takes place in the building SMI2, right on top of the PMI2 shaft.

Figure 12.4: The Point 1.8 Straddle Carrier handling a Cryodipole

12.5.2 Surface Transport and Handling

Articulated vehicles with hydraulic suspension are used for the road transport. The cryodipole is placed on rigid blocks at both extremity supporting points. In order to damp the vertical modes as much as possible during transport, a third support, made of a damping material and ensuring a static load of about 20 kN, is placed under the cryodipole central cradle. The transport speed is limited to a maximum of 20 km/h.

The activities at Point 1.8 are shared between two buildings (SM18 and SMA18). Unfortunately, the buildings configuration [12] prevents the use of standard overhead cranes. Therefore a specific vehicle has been designed to transport cryomagnets between the two buildings. This straddle carrier is illustrated in Fig. 12.4 [13]. It can accurately install and remove cold masses and cryomagnets onto/from the assembly and test benches with low accelerations, allowing transport without end restraints.

12.5.3 Storage

The different contracts, which constrain the production and installation of the cryomagnets, have been initially rated according to the baseline schedule and based on a just-in-time scheme. However the complexity of the construction and the time needed to fully test the cryomagnets required the decoupling of contracts and this, in turn lead to the requirement for temporary storage between the different assembly and test activities. To assist in optimizing the activities a tool simulating the logistics over the whole duration of the project was created to determine the number of cryomagnets which have to be stored at the various stages of production. The evolution of the different activities is entered twice a month in the simulation tool in order to follow the storage area evolution. The simulation performed so far shows that hundreds of cryodipoles will have to be stored [14].

Storage areas located on the Prevessin site and near Point 1.8, receive cryomagnets on their way between the assembly and testing areas and the shaft to the tunnel. The following measures are taken to preserve the integrity of the cryomagnets stored outdoors:

- Cold masses are filled with nitrogen at atmospheric pressure and plugs are placed in the extremities of all open lines,
- Desiccant bags are placed inside the cryostats and end covers are mounted to protect the cryomagnets from rain, snow and dust,
- Cryomagnets are placed on wooden blocks at the extremity supporting points without support under the central cradle,
- Transport end restraints should not been removed during storage.

12.5.4 Installation

Most of the cryomagnets will be lowered in the underground area down shaft PMI2 by the 40 t overhead crane [15]. The transport vehicle will receive the cryomagnet at the bottom of the shaft. Once the cryomagnet has been loaded, the vehicle will enter and travel along the injection tunnel TI2 to junction gallery UJ22 where it meets the LHC tunnel. The vehicle will then enter the LHC ring and travel either clockwise or anticlockwise depending on the destination (see Fig. 12.5). The 250 m of TI2 tunnel upstream of PMI2 will be used for parking of the waiting vehicles.

On arrival at the installation point, the vehicle will stop and the magnet will be unloaded and transferred to pre-aligned jacks.

Since the distance between the entry point and the final position can be large (up to 15 km), the time needed for the underground transport of a cryomagnet could be up to 6 hours for a one way journey. This, combined with the impossibility of vehicles passing each other inside the main tunnel and the long unloading time, imposes a strict organisation of the logistics to keep the cycle time of a cryomagnet installation below 24 hours. Computer simulations of these transport scenarios are systematically run with any new version of the installation planning.

12.5.5 Underground Transport and Handling Equipment

The following main items of equipment will be used:

- Cryomagnet transport vehicles, each consisting of a cryomagnet transport unit and two operator transport units[16],
- Unloading equipment, to unload the magnet from the vehicle and support the magnet; allowing the vehicle to be withdrawn. A set of unloading equipment is carried on the operator transport units of each vehicle,
- Transfer equipment, to transfer the magnet from the unloading equipment in the transport passage and onto the jacks [17].

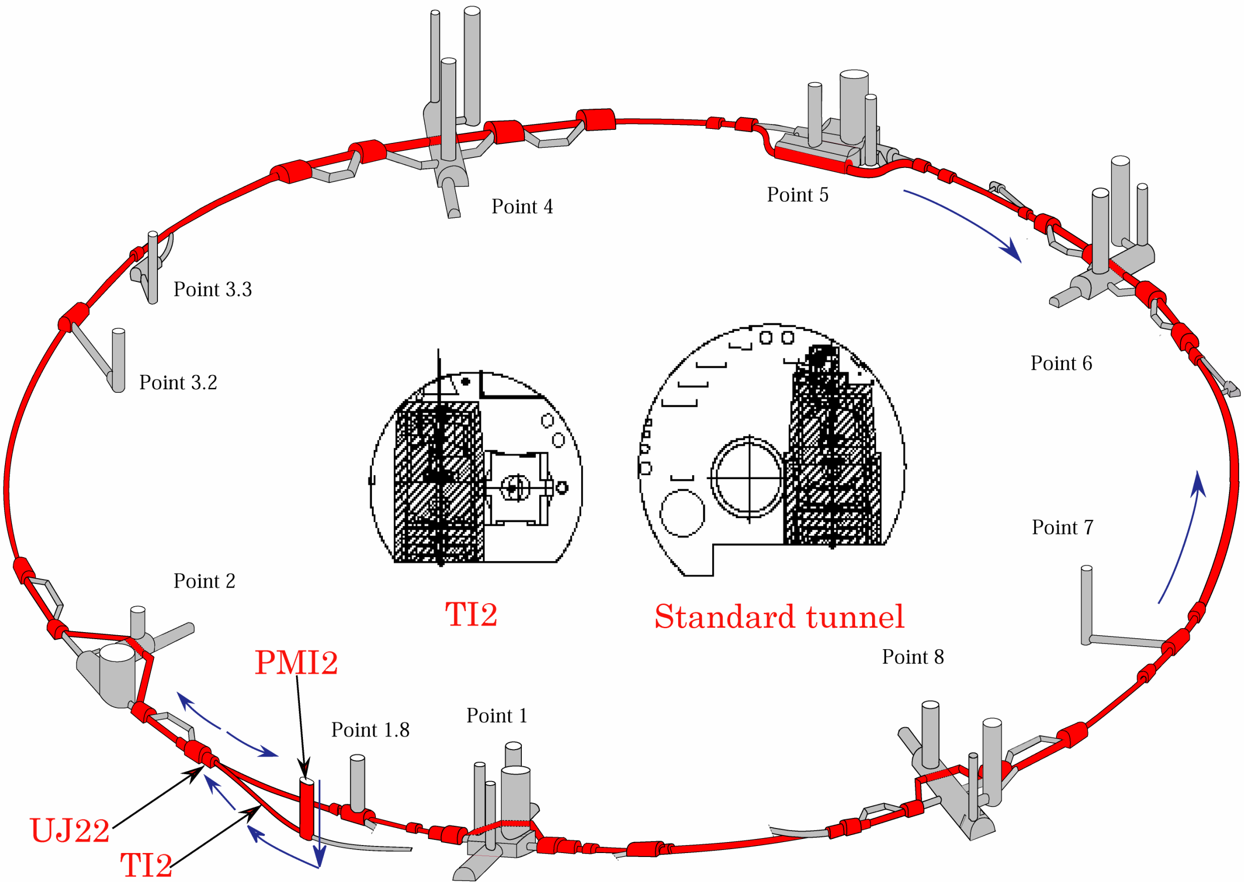


Figure 12.5: Underground travel of the cryomagnets

The major design requirements for the underground transport and handling equipment are:

- The ability to operate in limited space available in the tunnel,
- The need to respect vibration, acceleration and tilt limits,
- The need to respect a precise trajectory during transfer onto the jacks in order not to damage overlapping interconnection elements.

To meet these requirements the vehicles and equipment are designed to be as compact as possible and are equipped with hydraulic suspension and automatic guidance; all lifting cylinders on the vehicles and handling equipment are electronically controlled and synchronised.

When preparing the transport operations, the reservation of the necessary volumes for vehicle passage have been studied and included in the integration studies for LHC (see Fig. 12.6).

Special care was taken in integrating certain key points in the regions passing by the experimental caverns. In some regions the tunnel walls had to be modified to allow the passage of the 27 meter long convoys and the speed in this regions is reduced to just 1 km/h. The vehicles normally travel at 3 km/h when loaded and at 4 km/h when unloaded. Three types of convoys are available to transport the standard Short Straight Sections (SSS), the cryodipoles and all the different types of cryomagnets such as special short straight sections and stand-alone quadrupoles. A typical magnet convoy is shown in Fig. 12.7.

Figure 12.6: An SSS trailer passing by an "installed" cryodipole

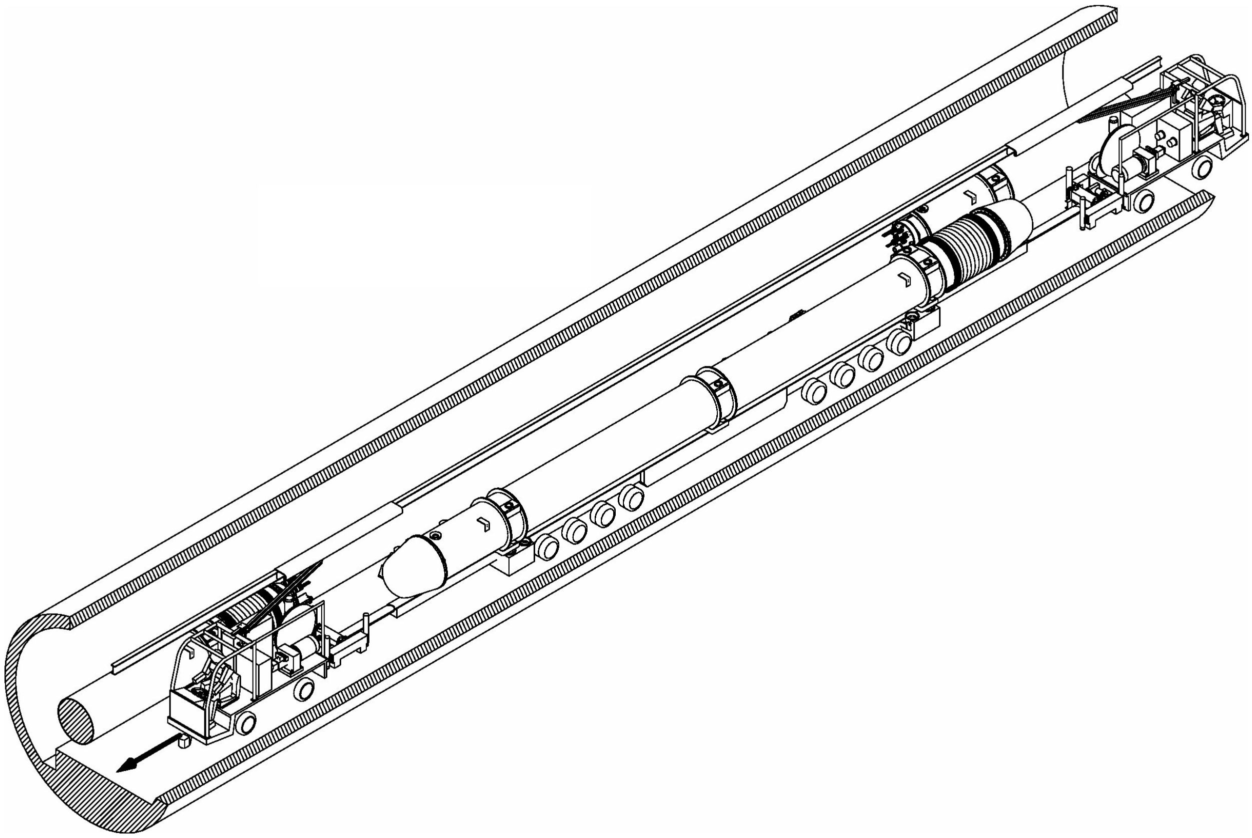


Figure 12.7: Cryodipole on its trailer

In order to provide the vehicles with power, the LEP monorail's I-section rail and its electrical sliding contact rail have been refurbished. Four kilometres of these rails have been re-installed after the civil engineering works to complete the full 27 km of the LHC main ring. This rail is also used for unloading the transfer tables from their trailers after moving between installation sites. New power rails have been installed in the injection tunnels.

The lack of space meant that the vehicle suspension could not guarantee isolation of cryomagnets from shocks induced by floor irregularities. To minimize this, the tunnel floor has therefore been carefully prepared to smooth out such features. In addition, a high reflectivity guidance line is painted on a black background on the floor to guide the vehicles in the restricted space available in the LHC ring and through galleries round the experiments.

The precision transfer equipment set has a load capacity up to 370 kN, a lift height range up to 150 mm, the capability of manoeuvring a cryomagnet with six degrees of freedom and an accuracy ~0.5 mm. The restricted space below a cryomagnet necessitated a very compact design since the height available for the equipment is only 300 mm. The tables can be operated under normal control or with an automated mode which computes the necessary movements from electronic theolodolite measurements of the exact positions of the jacks' heads and the cryomagnet's initial position on the unloading equipment. The transfer equipment is shown in Fig. 12.8.

The cryomagnets in the interactions regions will be transported and installed with essentially the same equipment. However, some modifications have been prepared to take account of their special dimensions [18].

The final focusing elements will be installed in very confined areas (dead-end tunnels), through and/or inside radiation shielding walls. Their longitudinal transfer will be done on gantry rails using motorised bogies.

Figure 12.8: The last step of a cryodipole installation: transfer onto the jacks.

12.5.6 Exchange in the Case of Failure

This major intervention is a lengthy one but it is also considered as an exceptional one. It requires the warming-up and the venting to atmosphere of the continuous cryostat. The faulty cryomagnet can then be disconnected from its neighbours. The removal of a cryomagnet is essentially a sequence inverse to that of its installation:

- Take the cryomagnet off the jacks and transfer it on the unloading equipment in the transport passage with the transfer equipment
- Insert precisely the transport trailer below the cryomagnet and load the cryomagnet on it (this is a very delicate operation due to the required precision and the lack of space)

- Evacuate the faulty cryomagnet and install the new one already waiting near-by.

The time required for this exchange is mainly driven by the cryogenic transients and the disconnection/connection activities which last for many days. The replacement of a cryomagnet itself is performed in some hours. The preparation of the logistics, in particular the removal of the shielding blocks at the bottom of the PMI2 shaft, will be done in the shadow of the other activities.

REFERENCES

[1] LHC Installation Day 11th November 2003, EDMS 410801

[2] K. Foraz, *Scheduling the Installation of the Large Hadron Collider*, EPAC 2004, Lucerne, Switzerland, July 2004

[3] P. Bonnal, M. Vitasse, "*Organisation of the installation work of LHC and its experiments*" August 2002, EDMS 323972

[4] R. Saban, *L'Installation du LHC - La Coordination sur le Terrain,* August 2003 EDMS 369821

[5] http://sylvainw.home.cern.ch/sylvainw/planning-follow-up/Schedule.pdf

[6] LHC Design Report Vol II Ch. 9, CERN-2004-003

[7] LHC Design Report Vol II Ch. 3, CERN-2004-003

[8] LHC Design Report Vol III Section 30.2, CERN-2004-003

[9] LHC Design Report Vol I Section 14.6, CERN-2004-003

[10] P. Le Roux et al., "*LHC Reference Database; Towards a Mechanical, Optical and Electronic Layout Database*", EPAC 2004, Lucerne, Switzerland, July 2004.

[11] LHC Design Report Vol I Section 7.4

[12] Etude d'Impact LHC Chap. 4.2.2 1997

[13] K. Kershaw, *Supply of Cryomagnet Transport Vehicles for the Point 1.8 Area*, IT-2501/EST/LHC, EDMS: 103116

[14] K. Foraz, *Logistics of LHC Cryodipoles: from simulation to storage management*, EPAC 2004, Lucerne, Switzerland, July 2004

[15] K. Artoos, *Transport and Installation of Cryo-magnets in CERN's Large Hadron Collider tunnel*, EPAC 2004, Lucerne, Switzerland, July 2004

[16] K. Kershaw, *Supply of Cryomagnet Transport Vehicles and Unloading Equipment for the LHC Tunnel,* IT-2803/EST/LHC, EDMS: 111918

[17] S. La Terza, *Transfer Equipment Set for LHC Cryomagnet Installation*, IT-2952/EST/LHC, EDMS: 335628

[18] S. Bartolome Jimenez, *Installation of the LHC Experimental Insertions*, EPAC 2004, Lucerne, Switzerland, July 2004

CHAPTER 13

MONITORING AND OPERATION OF GENERAL SERVICES

13.1 INTRODUCTION

The availability of the LHC technical infrastructure (general services) has an important impact on LHC operation. Most accelerator components rely on it either directly, or indirectly, both during LHC beam operation and during shutdown. Therefore the technical infrastructure monitoring and operation has to be guaranteed 24 hours a day and 365 days per year, especially for the correct functioning of the LHC safety systems. In this context the general services consist of the following systems located on the surface or underground installations as well as in the LHC experiments:

- Electrical distribution systems
- Cooling and ventilation
- Fire, gas, oxygen deficiency detection and evacuation systems
- Access safety system.

This chapter describes the concept of the monitoring and operation of the general services for the LHC. It focuses on 24 hour operation, maintenance activities and the operation from the control room. In addition the technical infrastructure monitoring (TIM) control system and the computer aided maintenance management system (CAMMS – MP5) are described.

13. 2 MAINTENANCE & OPERATION

13.2.1 General Services Maintenance

The general services operation is shared amongst a number of equipment groups. The operation of theses different systems depends on control systems which are, themselves, considered to be part of the LHC technical infrastructure. Figure 13.1 shows the main general services systems.

Table 13.1: General Services Systems

General Services Systems	Description
Safety systems	Fire, gas, oxygen deficiency detection and evacuation systems, access safety
Cooling and ventilation	Pumping stations, fluid distribution networks, cooling water, air-conditioning, ventilation, heating, reject water
Electrical distribution	Electricity high, medium, low tension, normal and secured supplies, emergency stops
Communication, control and monitoring infrastructure	Control hardware, front ends, servers for TS general service equipment only

Operation activities can be categorised as follows:

- System/accelerator start-up,
- Full/partial shutdown for maintenance,
- Normal/steady state operation,
- Breakdown and emergency scenarios.

Start-up and shutdown periods are used for preventive maintenance, process optimisation and upgrades. These activities are planned and co-ordinated by the equipment groups in close collaboration with the users. The control room has only a support role for the teams in the field.

The entire general services' equipment is itemised in a Computer Aided Maintenance Management System (CAMMS – MP5), see Sec. 13.4. This is used to plan ahead preventive equipment maintenance during the entire equipment lifecycle. MP5 is also used for extensive fault and breakdown reporting to improve process availability and reliability.

The operation and maintenance of the technical infrastructure relies to a considerable extent on industrial support contracts. These contracts ensure the maintenance and repair interventions both during normal working hours and out of working hours (stand-by service). CERN staff is available to provide assistance to the contract personnel, in particular during breakdowns when the competence of the stand-by service may be insufficient. Tab. 13.2 summarises the intervention teams and their obligations.

Table 13.2: Intervention Teams and Obligations

System	Industrial Support Contract	Time Limit	Contract Coverage	CERN Staff
Fire, gas, oxygen detection and evacuation systems	Schrack – Soteb	2 hours	24 h/365 d	First person found basis
Access control and safety radiation zones	None	None	accelerator run	CERN stand-by service
Site access control	GTD-Cégélec	4 hours	24 h/365 d	First person found basis
Cooling and Ventilation	ENDEL	30 minutes	24 h/365 d	First person found basis
Electrical Distribution	E065/ST	30 minutes to be on-site 15 minutes diagnostic	24 h/365 d	First person found basis
Diesel generators	E072/ST	360	24 h/365 d	First person found basis

13.2.2 Technical Control Room (TCR) Operation

Introduction

The TCR is a CERN-wide 24 hour service that is available for any technical related monitoring and operation task that fits its workload and skills profile. The TCR is manned with two operators on shift all year round. They have a higher technical diploma in domains such as electricity, cooling and ventilation, process control, mechanics or computing. Depending on the shift roster additional operators may be available during CERN opening hours, to reinforce the team on duty, e.g. during breakdowns.

The state of the systems under control in the TCR is monitored continuously by the monitoring and control systems. Each equipment group provides this information using their proprietary system and the information relevant to the TCR work is transmitted remotely to the control room using TIM, see Sec. 13.3. The TCR services can be split into two main categories:

- As a site facility call centre (Service 72201)
- For technical infrastructure, monitoring and operation.

It is estimated that on average the workload is shared equally between these categories and depending on the operation mode the workload varies considerably. Tab. 13.3 summarises the TCR services related to the general services.

Table 13.3: TCR Services for LHC General Services

TCR Service	Description
General services monitoring	24 hours, 365 days
On-site & remote interventions	Mainly outside normal working hours
Co-ordination and follow-up of troubleshooting activities	Comprising control rooms of water and electricity suppliers (SIG, EDF)
Optimise restart after breakdowns	See chap. 13.2.3
Incident analysis and reporting	Anytime
Energy monitoring	24 hours, 365 days

Site Facility Call Centre

The site facility call centre registers and dispatches faults in CERN's technical site facilities, such as office buildings, restaurants etc. This activity is provided in collaboration with the Facilities Management Group (FM) and its industrial support contractor. In addition, any request for repair or technical assistance that is not part of standard procedures and contracts, is processed in the TCR to provide a pragmatic solution with minimum delay.

The workload of this service varies considerably and can be in conflict with the workload necessary for the LHC general services operation, due to the available TCR resources. Once LHC exploitation has started, priorities and resources will be reviewed.

Technical Infrastructure Monitoring and Operation

The remote monitoring and operation of CERN's technical infrastructure and in particular of the LHC general services, is centralised in the TCR. This makes the TCR a main actor during normal operation and breakdown of the general services, where it is in charge of the co-ordination of intervening teams of the TS equipment groups. In addition, during normal operation one of the two TCR operators on shift carries out first-line on-site repair interventions. These interventions are a rapid way to achieve a first fault diagnosis and so improve the setting-up of the appropriate compensatory measures, in many cases allowing fault recovery without the intervention of a specialist or stand-by service [1]. These interventions are, in general, not possible during breakdowns because the workload requires a minimum of two operators in the control room. This is due to the fact that several thousand fault signals have to be handled and co-ordination and communication between the intervening teams has to be managed.

As a consequence of an alarm or any other notification of a malfunction, the TCR makes an impact and cause analysis before triggering the appropriate corrective intervention. Operator help systems and procedures are established to assure reliable situation assessment. Fast and effective interventions are important to reduce LHC downtime and keep the necessary level of safety.

All interventions related to general services' equipment are traced using MP5. It is also used to generate work orders for CERN staff or the related industrial service contractor. During normal working hours the team responsible receives the work orders directly via MP5 and takes it in charge automatically. Out of normal working hours the stand-by services are called in by the TCR operator manually. Control room operations not related to a particular installation or equipment are documented in an electronic logbook.

Other TCR Services

In addition to the general services monitoring and operation, the 24 hour monitoring of some systems that are part of the accelerator infrastructure has been delegated to the TCR, e.g. the SPS beam vacuum. This is motivated by the qualification of the TCR operators, which is well adapted to these tasks and to the fact that the accelerator control rooms are only manned during beam operation. For LHC exploitation it is proposed to delegate similar tasks to the TCR. Some additional areas under discussion are shown in Tab. 13.4.

Table.13.4: Future TCR Services Related to Accelerator Infrastructure and Future Services

TCR Services Today	**Description**
SPS beam vacuum monitoring	Pumps, pressure, controls
Cryogenic installations: backup calling	Backup for automatic alarm messaging system
Monitoring of communication, control and monitoring infrastructure	E.g. controls network, vacuum servers
Future TCR Services	**Description**
513 control room operation	Transfer of computer centre operation team to TCR
LHC experiment system monitoring	During the shutdown when experiment operation is not available, during the run to be defined
Vacuum	Extension to include PS, LHC & QRL considered

With the integration of the TCR in the new CERN Common Control Centre (CCC), the service structure of the TCR has to be reviewed. This will be a way to create synergies and more flexibility with the operation teams that carry out tasks requiring similar qualifications and operator skills. Appropriate structures need to be set-up to handle management differences arising from the difference between industry-like, round-the-clock operation of the TCR as opposed to the accelerator operation. By adapting man power and workload profiles, the TCR can evolve its services quickly and flexibly to future needs of the LHC.

13.2.3 Major Breakdowns

General

In the context of the restarting of accelerators and experiments after major breakdowns, such as a major power outage, the impact analysis becomes a complex task. To achieve a quick recovery of beam or experiment operation additional aid for the analysis and decision making processes in the control rooms and for field operators and equipment groups has to be provided.

This aid must be based on the optimal restart sequences as seen from the accelerator operations point of view. These sequences are different for different operation scenarios and have to take into account the LHC injectors, too. Operation scenarios might be SPS proton beam for fixed target physics or SPS proton beam for LHC injection. These restart sequences are established and validated by operation teams and the equipment groups of ST and AB divisions. In consequence, the progress of the restart activities is made available and transparent to all the operation teams involved (control rooms, CERN equipment specialists, stand-by services and contractors). During major breakdowns the control rooms co-ordinate all interventions and activities following these sequences. Moreover, re-scheduling becomes possible taking into consideration the availability of accelerators for concurrent modes of operation.

Tools

Prototypes of monitoring applications based on the above-mentioned principles are available for the PS complex and the SPS. Status and fault information of the accelerator equipment and the related general services are synthesised in one single application available to all control rooms, named GTPM [2][3]. Their usage resulted in considerable progress in co-ordination and restart time reduction. As a side effect these applications are an excellent tool for operator training. Operation teams, general services and LHC equipment groups, as well as the associated control and monitoring teams will have to collaborate to achieve the extension of this concept to the LHC.

Event Reports

Faults in the general services resulting in an interruption of accelerator or experiment exploitation are documented in Major Event Report [4]. This report contains a detailed analysis of the event, its causes and consequences. All the involved parties contribute to this analysis, including the accelerator and experiment control rooms. Improvement issues, either technical or organisational, are identified and proactive measures are taken to reduce fault impacts and recovery time [5].

13. 3 TECHNICAL INFRASTRUCTURE MONITORING (TIM)

13.3.1 Introduction

The monitoring of the general services from the TCR will be made through the Technical Infrastructure Monitoring (TIM) system [6-8]. This system will replace the present TCR data acquisition and transmission system: the Technical Data Server (TDS). The TIM system has to be fully operational 24 hours per day, 365 days per year. In order to facilitate control room operation as much as possible it integrates data from various heterogeneous data sources of the general services and the LHC and its injectors.

It provides a homogeneous monitoring environment to the TCR following design standards, see Sec. 13.3.3. The accelerator control rooms use human computer interfaces of the TIM system such as the restart applications after breakdowns (GTPM) and specific process applications for fault assessment, which still need to be specified.

The TIM system has to provide the following functionalities:

- Data acquisition from approximately 100 different data sources,
- Human computer interfaces in the form of process monitoring applications,
- Data logging system and trending utility,
- Alarm Display,
- Alarm notification through automatic telephone calls using the Alarm Notification System (ANS).

For cost and efficiency reasons some of these elements will be developed as common tools for use by all the control room operators. The implementation of the complete operational TIM system will be ready for the LHC start up in 2007. However, most of the components have to be used earlier in test environments such as the QRL commissioning and thus have to be ready before 2007. The aim is to have a partial TIM system implementation as of 2004. The final system is planned to be implemented in 3 phases:

- Replacement of the existing human computer interfaces,
- Integration of common tools such as alarm screens and data logging utilities,
- Replacement of the existing TCR data acquisition and transmission system by the TIM system.

13.3.2 Architecture

The TIM system is based on industrial hardware such as Siemens PLC's and HP or Sun server machines for the operational platforms, however, it will also use standard off-the-shelf hardware for test and development environments. This has the advantage of ensuring support for the operational platform and low cost for test and development platforms.

Standard software packages will be used wherever possible. It is planned to use Linux (Red Hat Advanced Server version) for the servers and Windows (standard CERN configuration) for the operator consoles. This gives access to the complete CERN office infrastructure in parallel to the monitoring tools. Existing UNIX or OSF/Motif applications can be run using X-terminal emulation software such as Exceed during the transition from the present system to the TIM system.

Hardware Architecture

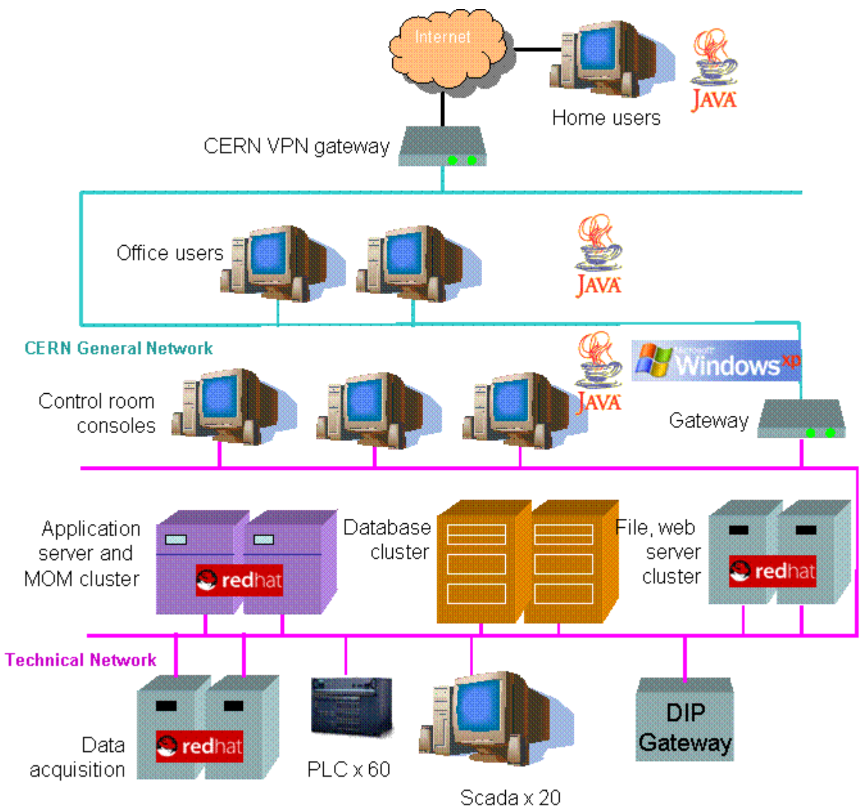


Figure 13.1: TIM Hardware Architecture

The monitoring system will rely on redundant hardware deployed in two separate locations for maximum safety and availability; one location being the current TCR building (212) and the other being the future CCC, see Tab. 13.5. The servers need air-conditioned rooms and uninterruptible power supplies. Fig. 13.1 shows the TIM hardware architecture in more detail:

Table 13.5: TI Hardware Locations

Hardware Purpose	Hardware Type	CCC	TCR - 212	IT - 513
Data Acquisition server	HP ProLiant	1	2	
Application server	HP ProLiant	1	1	
File server	HP ProLiant	1	1	
DB server off-line	Sun Solaris			1
DB server on-line	Sun Solaris	1	1	

Software Architecture

The TIM system will use component-based software architecture with standard data acquisition components, a middleware component and a set of user interface components, see fig. 13.3. Process information enters the TIM system through dedicated equipment drivers. There are two main categories of data: TS general services' equipment data and data from other domains (e.g. accelerator data, vacuum, cryogenics etc).

General services equipment is interfaced to the TIM through a PLC driver (Dsec) and the Standard Data Acquisition Library (Ddal). The Dsec is a Java application acquiring data from PLC's and updating the application server through the message oriented middleware (MOM) SonicMQ. The Ddal is also the ST-MA standard component to communicate with SCADA systems. The TIM system will provide a version of Ddal connecting to SonicMQ replacing the version now used to connect to the TDS. Thus existing applications need not be modified, only restarted using a new version of the library. This is a big advantage as most of these applications have been developed by contractors, which would make each modification time-consuming and costly.

The Oracle9i Application Server and the SonicMQ JMS-brokers will be used for the middleware, both for data acquisition and data distribution. The Oracle9i Application Server covers the business logic, persistence, configuration etc. The SonicMQ brokers handle data communication from data sources and to data clients. The data clients or user interface components connect to the middleware receiving current data and updates as they occur. Sec. 13.3.3 describes the human computer interface components in more detail.

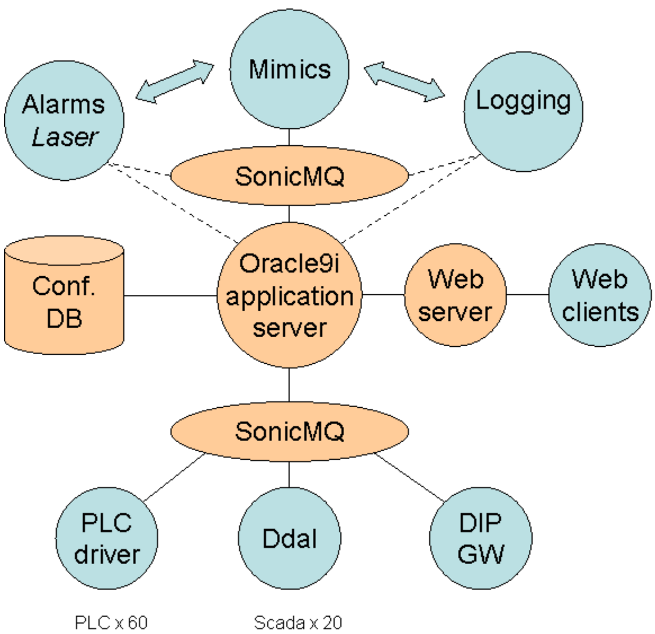


Figure 13.2: TIM Software Architecture

Data acquisition from non general services systems and data publication to external users will use the Data Interchange Protocol (DIP) gateway [9]. The DIP protocol is a standard protocol being implemented by the LHC Data Interchange Working Group (LDIWG), mandated by the CERN Controls Board to supply a protocol for inter-domain data exchange. A first version of the DIP is requested for the QRL tests in sector 7-8. The file servers host application files (human computer interfaces etc.) and the web server provides an operation portal for system administration.

Configuration

The TIM system will use an Oracle database for configuration and data persistence: the Technical Data Reference Database (TDrefDB). The data will be extracted by configuration tools for the configuration of the different layers and modules of the TIM system. This has the advantage of using a single data source and to achieve a coherent configuration for the complete monitoring chain. At the time of writing only TDS components are configured from the TdrefDB and for the TIM systems the configuration will also include the connected external components.

The reconfiguration or update of system parameters will be possible without stopping the operational system (online configuration). Similarly the configuration of one part of the system will not unduly perturb the proper functioning of another. The configuration tools must always be available and a complete reconfiguration of any operational part must be possible by any trained person (i.e. stand-by service or TCR operator). The operational operating system version and all software will be burned on a bootable CD to assure an identical environment in case of a system restart.

All software modules will be kept in the Software Configuration and Management System (SCaMS) and with this tool all installation and version changes can be traced.

Technical Network

TIM data clients access the application or file servers via the Technical Network. All applications and administrations tools will be available to specialists connected to the general CERN network. On-call specialists may connect to the system through the CERN VPN. The TIM system completely relies on the network availability but a network failure may stop the monitoring.

The new CERN technical network will be used to ensure high availability and reliable data transfer. It has to be verified that all critical network paths are either redundant or that uninterrupted service can be assured otherwise. Recent events have again shown that it is absolutely vital that network maintenance is carried out without interrupting the network. The necessary maintenance procedures must be established and approved.

13.3.3 Human Computer Interfaces

Process Diagrams

At the time of writing there are 32 monitoring applications, totalling some 700 process diagrams. These diagrams mainly concern the three domains: electricity, safety and cooling and ventilation.

The equipment groups responsible for these domains are currently implementing proprietary control systems in the form of SCADA systems. These include:

- The Electrical Network Supervisor (ENS) [10] for electrical distribution equipment
- PcVue for safety equipment (CSAM [11], RAMSES [12], LHC Access Control [13])
- Wizcon for cooling and ventilation.

These systems all offer remote access to their proprietary human computer interfaces. Wherever possible these applications will be used in the TCR, providing that they can be integrated with the other tools on the TCR operator consoles. Previously, these views were developed by the TCR and used by both the TCR and the equipment groups, re-using the SCADA tools will lower development costs and ease maintenance.

However, homogeneous operator interfaces have to be provided. One way of achieving this is by using web interfaces and hyperlinks and by respecting the TCR human computer interface conventions [14]. It is planned that at least 26 of the current 32 monitoring applications will be replaced by web access to SCADA systems.

The only exception will be the CSAM systems. The fire brigade Safety Control Room (SCR) will be equipped with the control system provided by the CSAM project. The TCR is the backup location for the SCR in case of SCR breakdown and will be equipped with the full SCADA solution for safety applications. Web interfaces are not sufficient and, in addition, technical alarms from the safety equipment (e.g. detector faults) will be transmitted to the TCR through the TIM system.

The TIM system will offer overview process diagrams, displaying systems from all these different data sources in a single application, such as the GTPM views. The TIM system also offers the possibility for operators to develop detailed views for equipment not monitored by the SCADA systems.

Data Logging

The data logging functionality is divided in two parts: data acquisition and data display. The data acquisition is currently made in an event driven way or by polling equipment periodically with special logging processes. In both cases the acquired data is written to an external Oracle logging database. Data display is performed by the "JavaGuils" client, a tool produced and used by both TS and AB departments. At present there are around 850 analogue measurements being logged and this number will increase in the future.

The LHC Logging Project [15] is setting up a new LHC data logging facility both for logging data to a database and retrieving data in a user interface. The TIM project will use identical facilities to allow cross-system correlation.

Alarms

Approximately 15 000 alarms are defined in the TDS and this number will significantly increase in the future as equipment will be supervised by the use of more detailed information. The TIM system aims for a common alarm display to be used by all services, such as the PCR, TCR, SCR and other control rooms. The LHC Alarm Service project (LASER) [16] is preparing the successor to the Central Alarm System (CAS). The TIM will use the LASER product as its main alarm screen. By doing this, the TCR will have access to any alarm through a single user interface, whether the alarm is generated by the TIM system or by a dedicated equipment control system, e.g. for the cryogenics.

13.3.4 Alarm Notification System (ANS)

The Alarm Notification System (ANS), was designed in 1998 to replace the obsolete Automatic Paging System, which had been used at CERN to automatically inform support personnel about alarm occurrences in systems under their responsibility. The ANS supports Short Message Service (SMS) paging to GSM displays and interactive voice notification. Users of the ANS are able to set their individual settings independently via a dedicated administration interface available on the NICE network.

SMS Paging to GSM

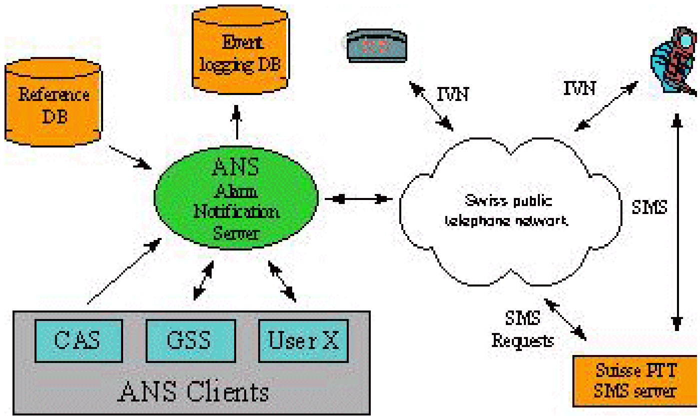
SMS is a service provided by the Swiss service provider. The ANS can send a user defined message to the SMS server when an alarm is received. The reception of a new message is indicated by an acoustic signal from the GSM. The message can be downloaded to the GSM display from the SMS server.

Interactive Voice Notification

Due to the necessity of immediate and reliable automatic notification, interactive voice notification was introduced. A user can define up to three phone numbers to be contacted in case of an alarm. These numbers are contacted by the ANS in a sequential order. The notification chain stops when a message has been acknowledged by the user. The ANS includes a speech synthesiser to handle voice communication.

Operational Environment

The ANS is an automatic extension of any monitoring system which will be updated in 2004 and will be integrated in the TIM system of redundant hardware deployment, see Fig. 13.3



Event logging DB
Reference DB
ANS
Alarm Notification Server
IVN
IVN
Swiss public telephone network
SMS
SMS Requests
Suisse PTT SMS server
CAS
GSS
User X
ANS Clients

13.4 COMPUTER AIDED MAINTENANCE MANAGEMENT SYSTEM (CAMMS)

Since 1999 CERN uses MP5, developed by DATASTREAM, to manage CERN equipment or assets. The MP5 software is widely used at CERN:

- For the management of manufacturing processes of LHC assets by the EST division
- And for Computer Aided Maintenance Management (CAMMS) for technical infrastructure assets.

Tab. 13.8 details the functionalities available at CERN. The current version of MP5 is running in the standard NICE environment with Oracle tools. The ST/MA & EST/ISS MP5 support teams currently prepare this tool for the LHC. A single database for CERN in multi organisation mode with a web interface will be put in place (D7i).

Table 13.8: MP5 Functionalities available at CERN

Module	Function
Base	Functions as the prerequisite for all other modules.
	Security & administrative controls
Asset Management	Identify, track, locate, and analyzes physical assets.
	Associates documents, permits, and other data with assets.
	Establish & control relationships between assets and the associated business processes.
Work Management	Control work orders for routine maintenance, response maintenance and periodic preventive maintenance.
	Store material and task lists in a library for easy reference and retrieval.
	Determine cause and effect relationships and provides a full range of diagnostic tests.
	Generate invoices for work performed on "third-party" assets.
	Expedite work order entry.
Project Management	Allow large projects to be sub-divided.
	Compute actual costs, committed costs, and planned costs of projects.
	Include individual budget setup and management for each project and allow linking of projects.
Inspection Management	Manage condition-based maintenance by defining inspection points.
	Execute inspection jobs, triggered by time frequency and/or meters based on previous inspection results
Materials Management	Streamline parts and materials management by constantly monitoring inventory online.
	Maximise an efficient quantity on hand of store room parts (EOQ Analysis).
	Allocate materials to work orders and automatically generate pick lists for materials.
	Identify items to be requisitioned based on existing stock, forecasts, and reservations.
	Classify parts based on their percentage of total inventory value (ABC Analysis).
	Individual inventory pricing methods
Purchasing Management	Compute the cost of services using either fixed prices or time and materials.
	Control purchase order and invoicing for stocked materials, direct materials, hired labour, and services.
	Register standard contracts and register blanket orders with vendors, along with financial agreements and conditions.
	Allow vendor rankings to facilitate the purchasing process.
	Monitor the progress of quotations for materials and services.
	Maintain a library of standard ISO clauses.
Budget Management	Automate the process of setting up budgets
	Provide a link between the financial, organisational and physical structures
	Calculate a variety of financial and performance indicators.
Reports	Allow users to select pre-defined reports to track the performance of assets.

REFERENCES

[1] ST Operation Report – CERN ST 2003

[2] *Towards a common monitoring system for the accelerator and technical control rooms at CERN*, Arduini, G; Arimatea, C; Batz, M; Carron de la Morinais, J M; Manglunki, D; Priestnall, K; Robin, G; Ruette, M; Sollander, P, CERN-SL-2002-012; CERN-PS-2002-010; CERN-ST-2002-001.- Geneva : CERN, 1 Feb 2001

[3] *Engineering Process Monitoring for Control Room Operation*, Batz, M, CERN-ST-2001-037; Geneva: CERN, 1 Feb 2001

[4] *ST Major Event Report Operation Procedure*, M. Batz, CERN July 2001, EDMS 317999

[5] *The first Year of the ST Operation Committee – Is there a Future?*, N. Bangert, M. Batz, G. Cumer, N. Dos Santos, U. Epting, P. Ninin, R. Nunes, J. Pedersen, P. Pepinster, S. Poulsen, T. Riesco, M. Wilhelmsson, CERN ST Workshop 2003

[6] *CERN LHC Technical Infrastructure Monitoring (TIM)*, Epting, U; Ninin, P; Martini, R; Sollander, P; Bartolomé, R; Vercoutter, B; Morodo-Testa, M C, CERN-ST-2000-018; Geneva : CERN, 25 Jan 2000

[7] *Integrating industrial control systems into the control environment of the technical infrastructure at CERN*, Sollander, P; Blanc, D; Swift, A, CERN-ST-95-04 MC; Geneva: CERN, 25 Oct 1995

[8] *Feasibility study: Technical Infrastructure Monitoring, Migrating the TIM system to J2EE*, P. Sollander, R. Martini, J. Stowisek – EDMS No 344549

[9] LHC Data Interchange Working Group - LDIWG (Wayne Salter)

[10] *An Industrial Control System for the Supervision of the CERN Electrical Distribution Network*, Poulsen, S, CERN-ST-2000-017; Geneva: CERN, 25 Jan 2000

[11] *CERN Safety Alarm Monitoring System – CSAM*, Luigi Scibile - http://st-proj-csam.web.cern.ch/st-proj-csam/

[12] *Radiation Monitoring System for the Environment and Safety (RAMSES)*, http://proj-ramses.web.cern.ch/proj-ramses/

[13] LHC Access Systems Project – P. Ninin - http://lhc-proj-access.web.cern.ch/lhc-proj-access/

[14] TCR Human Computer Interface standards (EDMS document number 116087)

[15] LHC Logging Project - http://lhc-logging.web.cern.ch/lhc-logging/

[16] LHC Alarm Service (LASER) project Web page : http://proj-laser.web.cern.ch/proj-laser/