ENVIRONMENTAL MONITORING AT CERN: PRESENT STATUS AND FUTURE PLANS FOR THE LARGE HADRON COLLIDER (LHC)

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1. Introduction

The operation of particle accelerators is usually accompanied by the generation of stray radiation and the production of induced radioactivity. This occurs as a result of beam losses either in the machine itself, in beam transfers lines, or in production targets. The environment may be affected depending on the design of the machine and its supporting systems, and on the type and the energy of the accelerated particles. Hence, environmental monitoring of the accelerator installations must be performed to ensure compliance with laws regulating the protection of the staff and public against stray radiation and radioactivity.

CERN – the largest accelerator complex in the world – has a well established environmental monitoring programme. Presently the Electron-Positron Collider (LEP), the Super Proton Synchrotron (SPS), the Proton Synchrotron (PS), and the Isotope Separator on Line installation (ISOLDE) are the major sources of stray radiation and induced radioactivity. In 2005 the Large Hadron Collider (LHC) will start its operation. As a proton machine with a beam energy of up to 7 TeV, the LHC will have a greater potential for producing induced radioactivity than the existing LEP machine presently housed in the same tunnel. Therefore, the environmental programme of CERN will have to be enhanced.

2. Present status

A detailed description of the present status of the environmental monitoring at CERN is given in Ref. [1].

All emissions of radioactivity in airborne and aqueous forms released from the CERN installations are monitored. There are 14 differential ionisation chambers and 15 aerosol filters installed at the ventilation outlets. The ionisation chambers measure mostly short-lived airborne radionuclides (^{11}C, ^{13}N, ^{14}O, ^{15}O, ^{41}Ar, etc.) directly and continuously whilst the aerosol filters collecting the radioactivity bound to aerosols are analysed off-line in the environmental laboratory for beta and gamma radioactivity (mostly ^{7}Be). Releases of ^{3}H in airborne form are assessed from the ^{7}Be releases with an assumption that the ratio between the concentrations of ^{3}H and ^{7}Be is not greater than ten.

Discharge water from six CERN water release points is checked continuously using NaI crystals immersed in water tanks. Seven automatic samplers collect water samples integrated during a whole month. The samples are analysed for total dissolved beta radioactivity, tritium, and gamma activity (usually ^{22}Na and ^{24}Na) in the environmental laboratory.

The monitors operating continuously are connected to a centralised system surveying the current releases and detecting possible problems. For a more detailed information, in particular for long-lived radionuclides, the results of the laboratory analyses are used.

Stray radiation is monitored using 30 monitors placed near the CERN fences and 13 monitors placed on the CERN sites. Argon-air filled ionisation chambers and moderated BF_3 proportional counters are used for gamma and neutron dose rate measurements, respectively. The monitors are connected to the centralised system as well and can be read out on-line.

To check the environmental impact, samples from the environment around CERN are taken regularly and analysed in the environmental laboratory for ^{3}H, beta, and gamma radioactivity. There are 8 aerosol sampling points, 2 points for precipitation, 11 points for river water, sediments, moss and water plants, 4 points for tap and well water, and 9 points for grass and soil. Agricultural products are analysed as well. In 1996 the environmental laboratory processed 1489 samples.

The results of the measurements are expressed in ambient dose equivalent for stray radiation and the release of activity for various radionuclides. The actual figures in μSv and in GBq at CERN in 1996 and the corresponding effective dose in μSv to the critical group of the population living in the vicinity of the CERN Meyrin site (Swiss part) are given in Table 1 [1]. The effective dose was determined from the release and reference values calculated on the basis of the Swiss Richtlinie HSK-R-41/d [2–4]. A high degree of conservatism was included in each step of the calculation such that the actual effective dose is much smaller.

Table 1. Ambient dose equivalent of stray radiation in μSv and release of radionuclides in GBq from CERN in 1996 and the corresponding effective dose in μSv to the critical group of the population living in the vicinity of the Organisation.

	Release in 1996	Effective dose in μSv
Stray radiation in μSv:*	64	14
Air releases in GBq:		
Tritium (as gaseous HTO)†	19	< 0.001
^{7}Be (as aerosol)	0.62	0.004
Beta/gamma activities (T<1 day)	18000	0.95
Other beta/gamma emitters (T>1 day)	0.019	0.095
Radioactive iodine	0.000082	< 0.001
Alpha emitters (as aerosol)	0.26	14
Liquid effluents in GBq:		
Tritium (as HTO)	42	< 0.001
^{7}Be	–	–
Beta/gamma activities (T<1 day)	–	–
Other beta/gamma emitters (T>1 day)	0.13	0.09
Alpha emitters	–	–
Total		**29**

* Ambient dose equivalent wit 21% occupation time assumed.
† All ^{3}H is assumed to be released as water vapour for which the dose factor is the highest.

The prevailing part of the total effective dose of 29 μSv originated from stray radiation and releases of alpha activity from ISOLDE. The largest CERN installation, LEP, contributed only negligibly. The radiological impact of CERN on its environment in 1996 and in previous years was exceedingly small.

3. Plans for the LHC

Following the phase of the important physics results obtained with LEP, the natural extension of the CERN experimental programme is the construction of the Large Hadron Collider (LHC) in the existing underground LEP tunnel. It is planned that the LHC will start its operation after 2005. Several studies of its environmental impact have been done. The most recent one is described in Ref. [5].

To distinguish between the future impact of the LHC, the natural radiation and radioactivity, and the impact of the other installations, a study of the original radiological situation was performed. It was based on a similar study for the LEP, on the results of the routine monitoring as well as on special measurements done mostly around the future LHC pits. Though, in general, the radiological impact of CERN is negligible comparing to the natural background in the region (≈780 μSv/a) [1], there are several parameters which might exceed the natural levels in the future and which will have to be followed carefully. As the natural level of the neutron background is very small (≈60 μSv/a) [1], even minute contributions from the accelerator operation can be detected. It is not excluded that slightly elevated concentrations of ^{7}Be in the air (up to ≈20 mBq/m^{3}) and in river sediments (up to ≈20 Bq/kg) at some places might be a consequence of the CERN activities. Another radionuclide typical for the operation of accelerators, which might be detectable in the future, is tritium [5].

The LHC will have two proton beams, each max. 4.7×10^{14} of 7 TeV protons, circulating in opposite directions within a tunnel of 27 km in circumference placed 50–100 m underground. In a later phase heavy ions up to Pb will be accelerated. The LHC ring will be divided into eight octants with eight points that will contain important components of the complex. Experiments (ATLAS, CMS, ALICE, LHC-B) will be placed at the Points 1, 2, 5, and 8, respectively. The Octant 4 is reserved for RF cavities, the Octant 6 for beam dumps, and the Points 3 and 7 for collimators cleaning the beam. More details can be found in Refs. [5, 6].

The layers of rock and soil above the tunnel will ensure sufficient shielding against stray radiation. The only path for the penetration of stray radiation and induced radioactivity to the surface will be through the access pits placed in the vicinity of the eight points.

The starting point of calculations concerning the environmental impact of the LHC was the estimation of the beam losses during its operation. For the machine operating 180 days per year, the number of protons lost in its main components per year was estimated as follows [5]: 1.6×10^{16} in each experiment, 4×10^{16} in the collimators, 10^{17} in the beam dumps, and 3.4×10^{15} around the collider ring during the machine operation.

The stray radiation and induced radioactivity were estimated in Monte Carlo simulations using the codes FLUKA for simulations of hadronic and electromagnetic showers and MARS for detailed simulations of muons [5]. To keep the level of stray radiation low enough so that the surface sites could have free access, some pits will have to be equipped with additional shielding. This concerns the pits which will have a direct sight at the beams, that is the pits of the experiments ATLAS (PX14), ALICE (PX24), and CMS (PX56), and the machine pit PM18. The pits leading to the collimator regions will have elbow-like access tunnels and no extra shielding will be necessary. There will be no access pits to the beam dump caves. Although muons are much more penetrating than hadrons, they will not contribute to the surface dose as they will be emitted mostly in horizontal direction.

Most of the induced radioactivity will be confined in the construction parts of the machine and the experiments but some will be produced also in the surrounding rock and groundwater. During ten years of the LHC operation with two experiments it has been estimated that about 144 GBq of induced radioactivity (^{3}H, ^{22}Na, ^{7}Be, ^{54}Mn, etc.) could accumulate in the rock mostly around the collimators and the experiments [5]. This figure is comparable to the natural radioactivity of the rock excavated from the tunnels. The radionuclides possibly found in groundwater due to the LHC operation will be ^{3}H and ^{22}Na. Their annual production is estimated as 72 GBq and 15 GBq, respectively [5]. However, this radioactivity remains immobile as there is no water exchange between the groundwater in 80 to 150 metre depth and the water table just below the surface.

Induced radioactivity in technological water will consist mostly of ^{3}H, ^{7}Be, and short-lived products of oxygen spallation. However, the total radioactivity drained per year calculated as 0.052 GBq of ^{3}H, 1.2 GBq of ^{7}Be, and 750 GBq of short-lived radionuclides [5] will be negligible. About 68% of the total ^{3}H and ^{7}Be release in aqueous form could be discharged into the river Nant d'Avril from the LHC Point 1 whilst 31% might be drained out of the Point 3 (PM32, collimator). On the other hand, the short-lived radionuclides in aqueous form may be discharged mostly from the Point 3 (93%) whilst the Point 1 will add only 5%. The contributions of the other points will be negligible.

Induced radioactivity released in airborne form will comprise a number of radionuclides produced in spallation reactions and neutron capture reactions on nuclei contained in the air of the underground tunnels and halls. The annual release of the short-lived radionuclides could be about 50 TBq mostly from the Points 1 and 5 (experiments, 35% each), and 3 (collimator, 20%). About 3.7 GBq of long-lived radionuclides, in particular ^{7}Be, might be released per year, mainly from Points 3 (67%), 5 (12%), and 1 (10%) [5].

The present environmental monitoring programme at CERN will be enhanced to cope with the future number of potential release points for radioactivity and stray radiation. Ventilation outlets of the experiments and the machine will be equipped with aerosol filters and differential chambers to monitor airborne radioactivity. A filter installation will be put at each point to check the immissions of airborne aerosol-bound radioactivity including the air from the beam dumps (Octant 6) which are ventilated from the main machine tunnel. A mobile high-volume aerosol sampler with a high monitoring sensitivity will complement these filter measurements. The existing installations for checking the discharge water will be completed so that there will be a water sampler at each major release point and continuous water monitors at the Points 1 and 3 (PM32). There will be at least one stray radiation monitor at each point including the Point 6. Two of them will be installed at the two islands PZ33 and PM32 of the Point 3. Considerably more environmental samples from the vicinity of the Organisation will be analysed. The present sample throughput of the environmental laboratory will be substantially increased mainly performing gamma spectroscopy and tritium counting.

4. Conclusions

The present radiological impact of CERN on the environment is negligible. It is estimated that this will also be the case for the LHC starting operation in 2005. Nevertheless, the environmental monitoring programme at CERN will be further extended. It is important to demonstrate to the public living in the vicinity that the Organisation fully complies with the standards and limits for the environmental impact of nuclear installations as set up by the authorities in the CERN's host countries.

5. References

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