


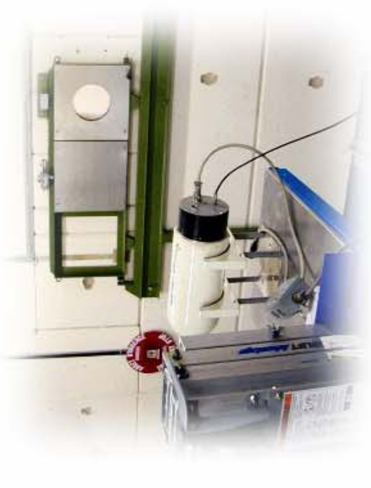

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Safety Commission

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RADIATION PROTECTION GROUP ANNUAL REPORT 2003

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RP ANNUAL REPORT 2003

Executive summary

The RP Annual Report summarises the activities carried out by CERN's Radiation Protection Group in the year 2003. It includes contribution from the EN section of the TIS/IE Group on environmental monitoring. Chapter 1 reports on the measurements and estimations of the impact on the environment and public exposure due to the Organisation's activities. Chapter 2 provides the results of the monitoring of CERN's staff, users and contractors to occupational exposure. Chapter 3 deals with operational radiation protection around the accelerators and in the experimental areas. Chapter 4 reports on RP design studies for the LHC and CNGS projects. Chapter 5 addresses the various services provided by the RP Group to other Groups and Divisions at CERN, which include managing radioactive waste, high-level dosimetry, lending radioactive test sources and shipping radioactive materials. Chapter 6 describes activities other than the routine and service tasks, i.e. development work in the field of instrumentation and research and support activities for future CERN projects or in RP-related domains.

A few changes in the group organisational structure have taken place in 2003. The group organisational chart shown on page 4 reflects the situation on 1 November 2003, soon after G.R. Stevenson retired after more than 30 years of successful work for CERN. The high-level dosimetry service was transferred from the TIS/IE group to the TIS/RP group in the beginning of the year.

Releases of short-lived radioactive gases and of long-lived beta/gamma radionuclides attached to aerosol as well as of tritium, gaseous alpha activity and of radioactive iodine were monitored at the ventilation outlets of CERN's accelerator facilities. In 2003, these releases caused an effective dose to members of the public of less than 3.5 µSv. The radioactive substances discharged into the rivers Nant d'Avril and Le Lion were predominantly tritium and long-lived gamma radionuclides, mainly ^{22}Na. However, their impact on the environment was negligible. The corresponding dose to members of the public was less than 0.05 µSv. In the majority of the environmental samples collected in the frame of the Organization's routine environmental monitoring programme no CERN-made radionuclides were identified. In the samples in which such radionuclides were measured, their activity densities remained well below the Swiss immission limits by less than a factor of 2×10^{-3}. The total effective doses to members of the critical groups of the population from stray radiation and releases were assessed to be less than 25 µSv in 2003, which is about 8% of the annual limit of 300 µSv. Out of these 25 µSv, 21 µSv are due to stray radiation emitted from CERN's accelerator facilities and the remaining 4 µSv come from all releases of radioactive substances into the environment. For the CERN Meyrin site, 86% of the effective dose was due to stray radiation, 13% was due to emissions of short-lived radioactive gases and only 0.7% originated from other released radionuclides. It should be noted that 97% of the effective dose is due to external exposure, which is monitored on-line and in real time. The proportion of the external exposure was similar for the CERN Prévessin site (98%). Hence, thanks to the active monitoring, corrective measures could be taken rapidly if necessary.

The Individual Dosimetry Service has been monitoring about 5500 staff, users and contractors with personal dosimeters for gamma/beta and neutron radiation in 2003. As observed in preceding years, collective gamma/beta dose equivalents depend critically on the level of work activity at CERN. The experimental programme is still reduced during the preparation of the LHC, but increased accelerator maintenance and urgent repair interventions brought the collective dose equivalent to 544.4 person-mSv, more than twice the value observed in 2002 when maintenance work was at a minimum.

The radiation levels in the controlled areas at the accelerators, experimental areas and at the borders of the CERN site are monitored continuously by fixed monitors over the entire year. In addition, radiation protection technicians have to regularly carry out manual monitoring during routine procedures, in particular during the shutdown and maintenance periods. In 2003 the frequency of such interventions during the operation of the accelerators increased markedly. Urgent maintenance and repair work, in particular due to vacuum and water leaks in the TDC2/TCC2 area required optimised working plans and close supervision in view of the relatively high local dose rates. The coils of all dipole magnets in the PS accelerator will have to be replaced in the coming years. The first two magnets were serviced in 2003. This operation was closely monitored and the data obtained will enable realistic dose planning and job optimisation to be made for the exchange of the other 50 dipole magnet coils.

Experiments at the n-TOF facility required special attention due to the use of highly radiotoxic substances in the experimental setups. Radiation and general safety procedures, in accordance with Host State regulations, were established in collaboration with TIS/GS and with the Swiss authorities and their implementation was closely monitored.

In the framework of the ISOLDE consolidation programme, plans for an upgrade of the target handling facilities were finalised. Once realised, the facilities will be in line with Host State regulations for the handling of unsealed radioactive sources with very high activity.

The existing fixed radiation monitoring system has to be regularly maintained and modified or extended. The system was extended for, and used during, the LHC extraction tests in TT40. Other modifications and installations were carried out in BA4 and ECA4, SUI8 and in the TCC8-ECN3 and EHN1 areas. The dosimetry system for the on-line radiation damage tests for LHC components in TCC2 was improved.

The ongoing TIS/RP studies of radiation safety and protection issues for the LHC and CNGS are important input into the final design of the facilities and will provide essential information into the preparation of the reports to be submitted to French authorities according the INB convention. Computational simulations using the FLUKA code were carried out for the two beam cleaning sections of LHC where the highest irradiation and activation of materials has to be expected. The results of these ongoing simulations are important for the final design of these collimation regions. For CNGS, remanent dose rates around the future target station were calculated using the FLUKA code. Other simulations focused on the simulations of the shielding at ECX4/ECA4 where protons from the SPS are extracted into TT40 to be routed into TI8 (for LHC) or TT41 (CNGS). Other simulations included shielding studies for SPS point 5, for the extraction test in TT40 and for investigations on the response of radiation protection monitors to high-energy, mixed radiation fields. A study was conducted to assess the radiological implications on the use, storage and elimination of the irradiated Xe gas of the ATLAS Inner Detector

Computational studies for the SPL project (Superconducting 2 GeV Proton Linac with a beam power of 4 MW) were pursued to compare the expected induced radioactivity in mercury and tantalum targets, as well as in the decay tunnel, the magnetic horn and the surrounding rock. A preliminary Monte Carlo study was also conducted to evaluate the induced activity and the environmental impact for a beta-beam decay ring. Studies for the CTF3 facility also continued.

The project of the RAdiation Monitoring System for the Environment and Safety (RAMSES) for LHC progressed significantly in collaboration with the TIS/TE Group and the ST Division. Following the establishment of the technical specification based on the preceding market survey and own studies, the call for tender was successfully completed and adjudication of the contract was achieved. The installation of cables for radiation monitors has started in 2003 and the integration of monitors in the underground and surface areas has continued.

As for the management of radioactive waste, in 2003 a total volume of 150 m^3 of waste was received from the CERN installations and treated (separation of components, volume reduction, etc.) in the CERN waste treatment centre, before storage in the interim storage centre (ISR tunnel). Most items were in the category of low level activity waste, but some were classified as medium level waste. About 600 kg of solid, non-burnable waste were eliminated in collaboration with PSI (Paul Scherrer Institute) and following the requirements of the Swiss *Office Fédéral de la Santé Publique* (OFSP).

The French *Direction Générale de la Sûreté Nucléaire et de la Radioprotection* (DGSNR) inspected the CERN temporary storage areas for radioactive waste located within the INB perimeter. The result of the inspection was a positive judgment of the management of the radioactive waste and on the correct application of the current legislation.

The implementation of the new policy for radioactive waste management, launched in 2002, progressed in 2003 with various activities. The bases for new consultancy contracts for the inventory of all radioactive waste currently stored at CERN and for the planning of a new treatment centre have been laid down. At the end of the year, ISRAM, a new information system including a database for the book-keeping of the CERN radioactive waste, was successfully put in place.

The RP group provides a range of services to other groups and divisions at CERN that include the shipping of radioactive material (total of 49 consignments in 2003), gamma spectrometry of samples (1420 measurements), the administration and supply of radioactive test sources and thermo-luminescence dosimeters (12,000 measurements in 2003).

The high-level dosimetry was included in the range of services provided by the RP Group. The procedures used previously were evaluated and where necessary modified.

The CERF facility (which simulates the cosmic radiation field at flight altitudes) was operated for two measurement periods of one week each and used by researchers from several European and non-European institutes. A benchmark experiment was performed in which samples of different materials used for the LHC were irradiated at CERF to the stray radiation field. Results were compared to detailed FLUKA simulations.

Group Leader **H.G. Menzel**
Deputy Group Leader **M. Silari**
Secretary **J. Madden**

Radiation Survey and Control

SPS and experiments, LHC, CNGS, High level dosimetry	Meyrin Site, LHC Experiments	PS Accelerator complex, Dosimetry service, Calibration	Radioactive waste management	Instrumentation, Logistics
D. Forkel-Wirth	**M. Silari**	**Th. Otto**	**C. Lamberet**	**D. Perrin**
I. Brunner	G. Bertuol	P. Carbonez	D. Alberto	N. Aguilar
N. Conan	Y. Donjoux	A. Dorsival	G. Dumont	H. Müller
J.C. Gaborit	J. Wolf	A. Müller	M. Lemaître	M. Noldin
G. Grobon		M. Rettig	Th. Nguyen	M. Pangallo
S. Roesler		Dosimetry	L. Ulrici	M. Renou
H. Vincke		E. Kotamaki		
		J. Lavanchy		
		H. Soubeyran		

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Fellows
S. Mayer

1 Environmental impact and public exposure

Pavol Vojtyla and Dietlinde Wittekind

1.1 Introduction

Operation of accelerators leads to generation of radiation, which may penetrate the environment. In addition radioactive substances are produced, which may be transported into the environment with fluids such as ventilation air or discharged water.

The regulations applicable to radiation emissions and releases of radioactive substances into the environment are laid down in the CERN Radiation Safety Manual (1). The effective dose resulting from activities carried out on the CERN sites and received by any person living or working outside the Organization's boundaries must not exceed 0.3 mSv per year. This limit includes both the external and internal exposures, the latter resulting from an intake of radioactive substances. Releases of radioactive substances must be limited in such a way that the annual effective dose due to such releases for persons residing outside the Organization's boundaries does not exceed 0.2 mSv per year. The values of ambient dose equivalent due to ionizing radiation and radioactivity emitted by CERN beyond boundaries of its sites must not exceed 1.5 mSv per year. For persons working on the CERN sites but not belonging to the category of those exposed in the exercise of their profession, the annual effective dose limit is 1 mSv per year (1).

To prove the compliance with the above-mentioned regulations, the Organization carries out a radiological environmental monitoring programme that consists of:

- monitoring of stray radiation around accelerators and experimental areas, including places on the CERN sites accessible by the general public, at fences, and outside close to CERN premises. Some monitoring stations are placed far from any source of radiation to measure the natural background in the region;
- monitoring of radioactivity in air and water released from the facilities on the CERN sites and evaluation of the activity of radioactive substances released into the environment on a monthly basis;
- measurements of activity densities (2) in various environmental compartments at places, which are likely to be influenced by the releases of radioactive substances, and at reference places. This part of the programme is aimed at verifying that immission limits have not been exceeded and that the environmental dispersion models in use do not underestimate;
- evaluation of the radiological impact of the stray radiation and releases of radioactive substances on the population living in the vicinity of the Organization. This includes calculations of the effective doses to the critical groups of the population according to widely accepted environmental dispersion models.

1.2 Monitoring programme in 2003

The CERN environmental monitoring programme covered the CERN Meyrin and Prévessin sites, the seven isolated islands (BA1–BA7) along the Super Proton Synchrotron (SPS) main ring and the testing area SM18.

An outline programme listing the instruments and methods used for measuring radioactivity is summarized in Tables 1.1 and 1.2. The distribution of the environmental monitors and sampling places on the CERN Meyrin site and its vicinity, and on the CERN Prévessin site is shown in Figures 1.1 and 1.2, respectively. The location of the monitors and sampling places outside the two main CERN sites is presented in Figure 1.3.

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(1) CERN Radiation Safety Manual, Edition 1996.
(2) Terminology according to the ICRU Report 65, Quantities, Units and Terms In Radioecology, Journal of the ICRU, Vol. 1 (2001).

Table 1.1 Environmental monitoring programme on the CERN sites – emissions and effluents.

Monitored subject	**Radioactivity**	**Type and frequency of sampling and measurements**	**Number of points**	**Locations**
Air/aerosol	Total beta Gamma Total alpha	*Glass-fibre filters changed 2x/ month;* large-area proportional counter HPGe gamma spectrometry proportional counter (PMV170 only)	8	PMV11, 31, 51, 170, 172, 173, 174, 801
Air/gas	Total beta	*Continuous;* differential ionization chamber	9	PMVG11, 31, 51, 126 170, 172, 173, 174, 801
Release (surface) water	Total gamma	*Continuous;* NaI(Tl) crystal immersed in water tank	5	PMW21, 62, 101, 102, 103
	Dissolved total beta Gamma Tritium	*Sampling 2 ml/173 sec for the whole month;* large-area proportional counter HPGe gamma spectrometry liquid scintillation counting	6	PMWS21, 62, 101, 102, 103, 104*

*) Instantaneous manual sampling

Table 1.2 Environmental monitoring programme on the CERN sites and in the CERN environment – stray radiation and environmental samples.

Monitored subject	Radiation, radioactivity	Type and frequency of sampling and measurements	Number of points	Locations
Stray radiation	Total gamma dose rate Total neutron dose rate	*Continuous;* argon filled ionization chamber moderated BF_3 counter	40	24 near fences or outside 16 inside the sites
Air/aerosol	Total beta Gamma Total alpha	*Glass-fibre filters change 2x/r month;* large-area proportional counter HPGe gamma spectrometry proportional counter (PSA911, 951 only)	9	PSA71, 100, 126, 805, 821, 832, 911, 951 PSA 973 (gamma only)
Grass, soil	Total beta in soil Gamma in g. and s.	*Once per year;* large-area proportional counter HPGe gamma spectrometry	4	GR(SO)-nTOF, MSW, P801, VG
Precipitation	Dissolved total beta Gamma Tritium	*Sampling time: 1 month, funnel: 1* m^2*;* large-area proportional counter HPGe gamma spectrometry liquid scintillation counting	2	Roof of Bldg. 24 (PSP-M) Roof of Bldg. 865 SPS (PSP-P)
Rivers/ water, sediment, moss	Total beta in w. and s. Gamma in w., s. and m. Tritium in water	*Once per year;* large-area proportional counter HPGe gamma spectrometry liquid scintillation counting	6	RW(S, M)-LL1, LL2, LL3, LL4, NA, VE
Groundwater and tap water	Dissolved total beta Gamma Tritium	*Once per year;* large-area proportional counter HPGe gamma spectrometry liquid scintillation counting	5+2	GW-201, BO, FL, GR, PG TW-M, P
Agricultural products	Gamma	*Once per year at harvest time;* HPGe gamma spectrometry		Surrounding fields

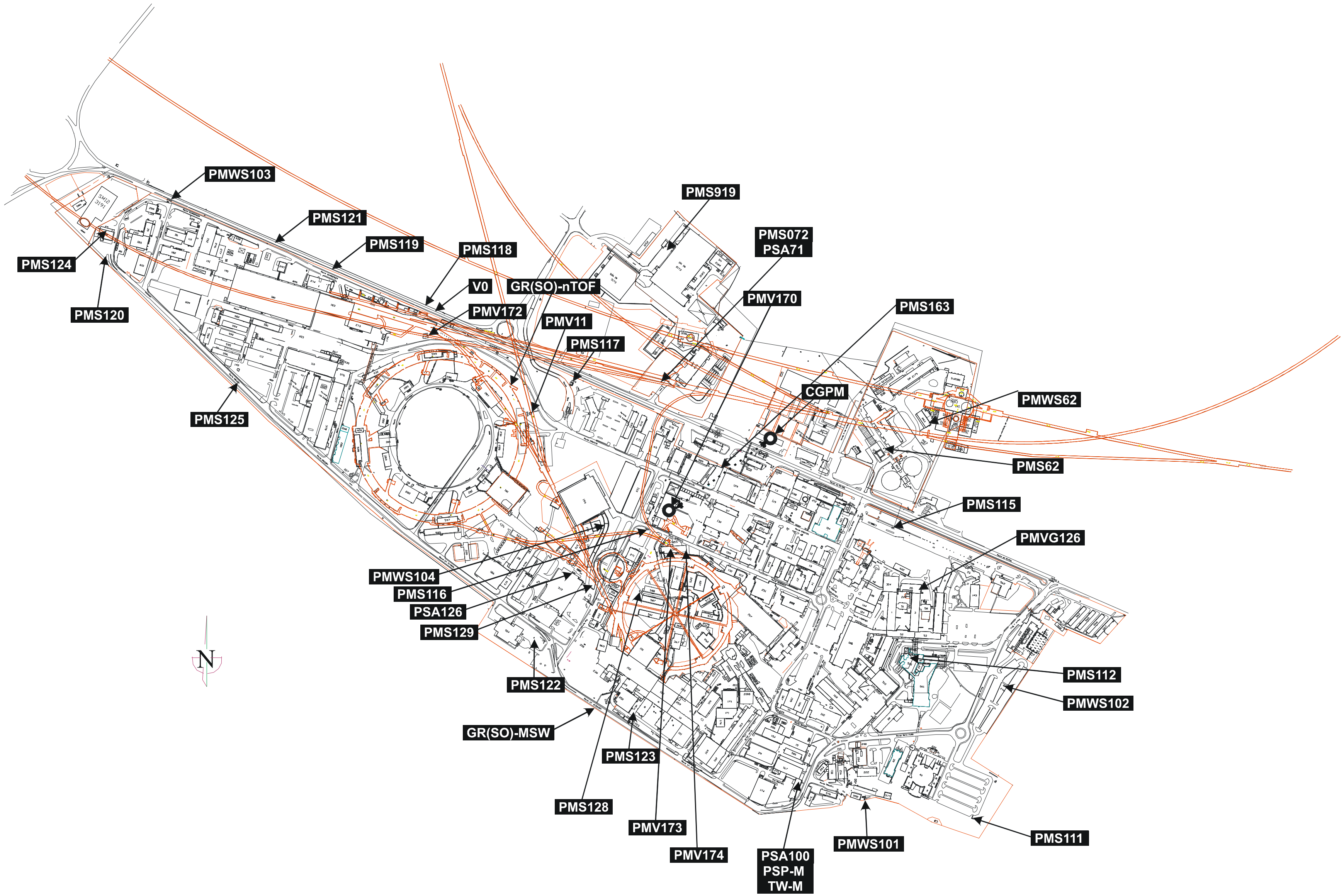

Figure 1.1 Location of monitoring stations and sampling places on the CERN Meyrin site, at BA6, BA7, PA1 and SM18.

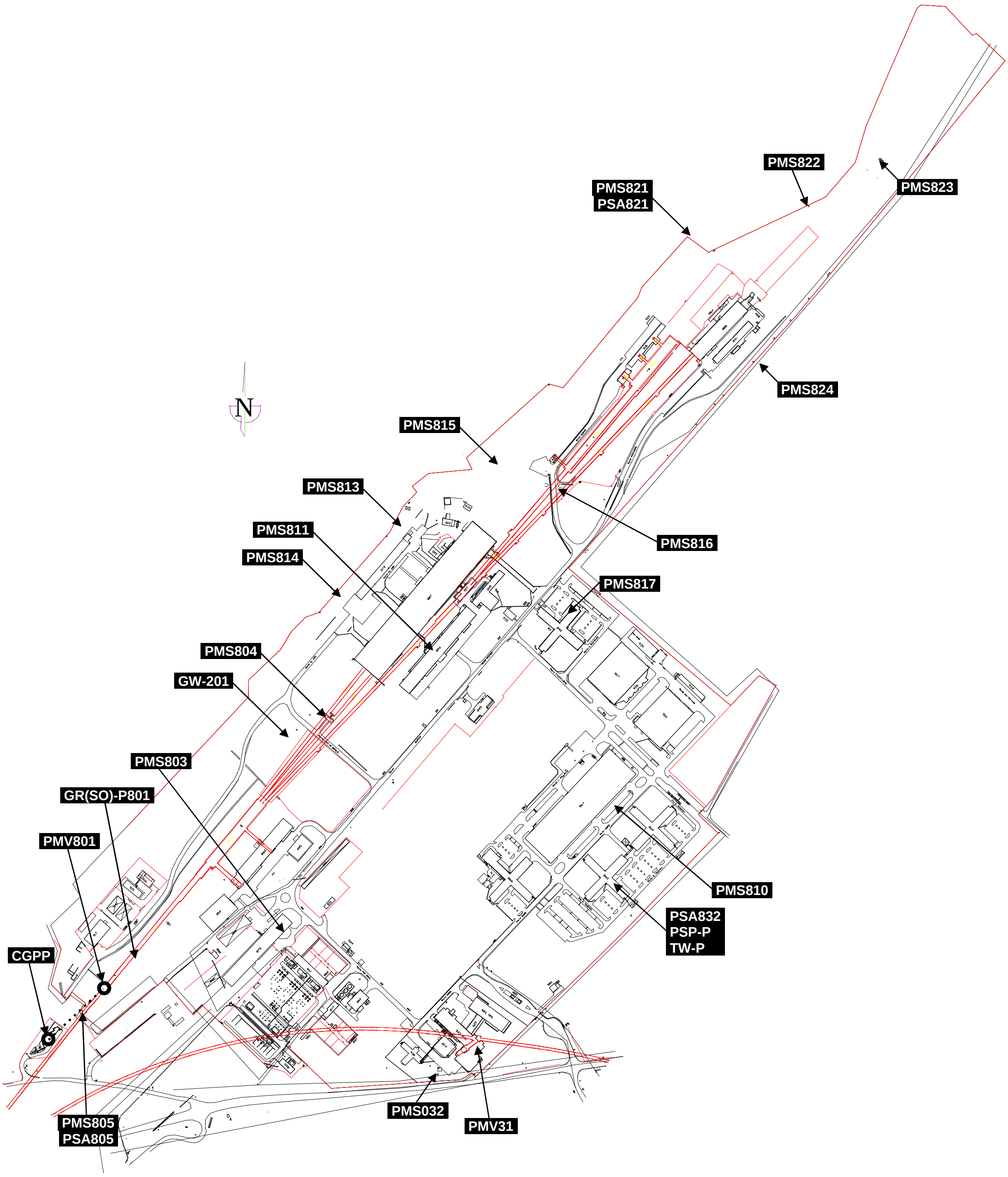

Figure 1.2 Location of monitoring stations and sampling places on the CERN Prévessin site.

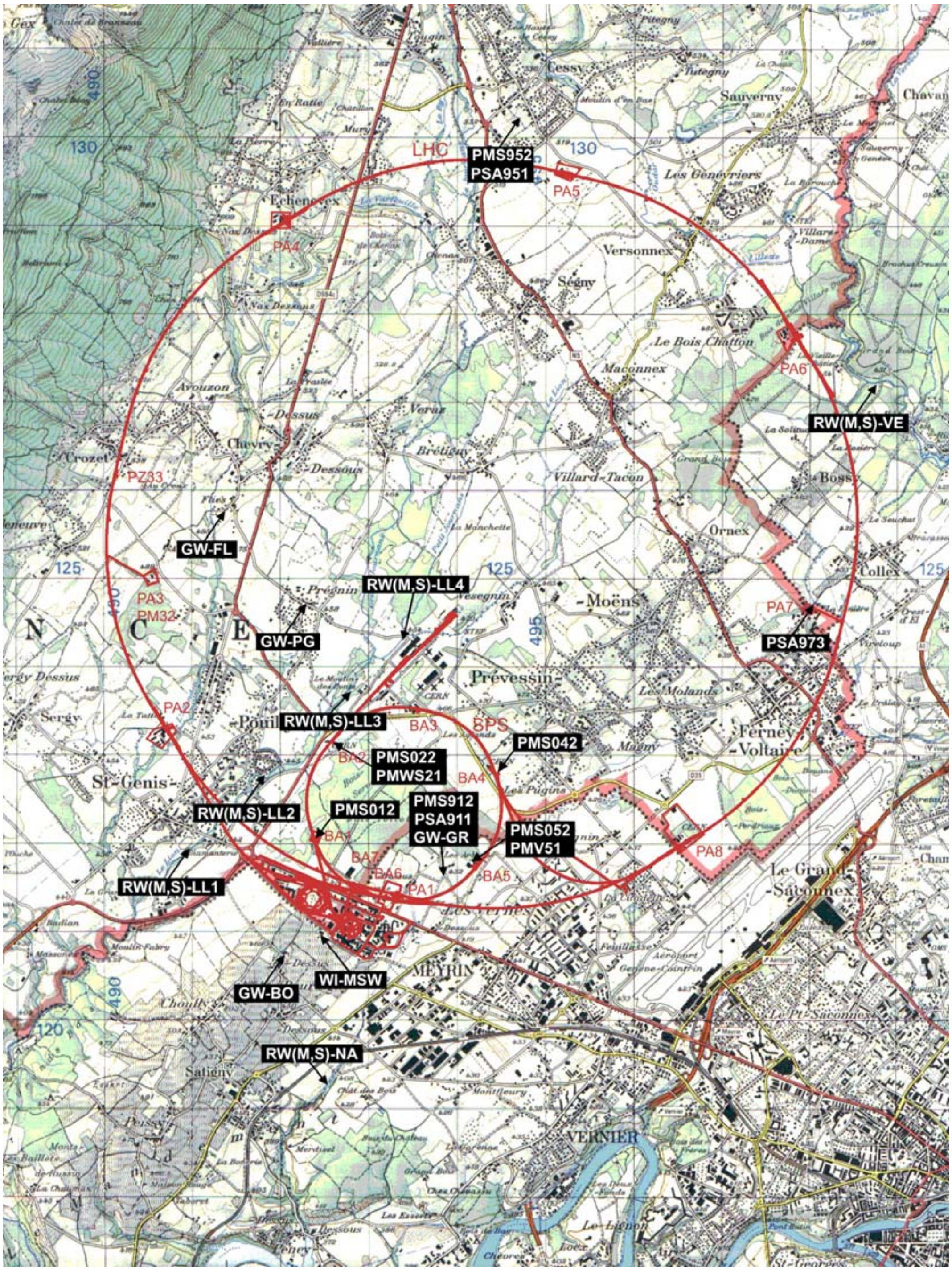

Figure 1.3 Location of monitoring stations and sampling places outside the two CERN main sites.

Legend to Figures 1.1–1.3

GR(SO) Grass (soil) sampling place
GW Groundwater sampling place
PMS Stray radiation monitoring station
PMV Ventilation monitoring station
PMWS Release water monitoring station
RW(M,S) River water (moss, sediment) sampling place
PSA Environmental aerosol sampler
PSP Precipitation sampling station
TW Tap water sampling place
WI Collecting place for wine grapes
CGPM(P) Critical group of the population for the Meyrin (Prévessin) site

1.2.1 Stray radiation

A stray radiation monitoring station (PMS in Figures 1.1–1.3) consists of an argon-filled pressurised ionization chamber and a rem-counter. The ionization chamber serves for monitoring of the dose rate from energetic photons and penetrating charged particles such as muons, whilst the rem-counter measures the neutron dose rate. Monitors of both types are calibrated for the ambient dose equivalent $H^*(10)$. Stray radiation monitoring stations are located at the boundaries or inside the CERN sites where radiation surveys have indicated measurable radiation levels caused by the operation of the various CERN facilities. Several stations are installed at some distance from CERN premises and far from any sources of ionizing radiation.

To obtain more detailed spatial information about the annual dose, dose-integrating ^{6}LiF/^{7}LiF thermo-luminescence dosimeters (TLD) put inside 12.5 cm diameter by 12.5 cm long polyethylene cylinders are positioned on the CERN sites at about 160 places and exposed for one year. Further some dosimeters are put at distant places to measure the background dose and its spatial variations. The TLDs are calibrated in the stray radiation field itself by placing some TLD detectors also in the stray radiation monitoring stations. All detectors are calibrated individually in a ^{137}Cs gamma-radiation field after their readout and annealing procedure.

1.2.2 Radioactive substances in released air

The activity of radioactive substances in discharged air (emissions) is monitored in ventilation monitoring stations (PMV in Figures 1.1–1.3) that are installed at all air extraction points from which such substances are likely to be released. These comprise the main accelerator rings of the Proton Synchrotron (PS), SPS, beam transfer tunnels, and some experimental areas.

Radioactive gases produced in air during operation of high-energy accelerators are mainly short-lived positron-emitting radionuclides ^{11}C, ^{13}N, ^{14}O, and ^{15}O, and the short-lived β^- emitter ^{41}Ar. Their total activity densities are measured continuously by flow-through differential ionization chambers installed in exhaust sampling lines.

The fraction of radioactivity, which is attached to aerosol, is collected on aerosol-sampling filters that are replaced twice per month. Total beta activity and activities of gamma radionuclides collected on the filters are measured in a laboratory. The exhaust air usually contains ^{7}Be and other gamma-emitting radionuclides like ^{22}Na, ^{24}Na, ^{46}Sc, ^{48}V, ^{51}Cr, ^{52}Mn, ^{54}Mn, ^{56}Co, ^{57}Co, ^{58}Co, ^{59}Fe, ^{65}Zn, ^{121}Te, ^{124}Sb, and ^{139}Ce, activity densities of which are typically much lower than that of ^{7}Be.

Activities of released tritium are estimated from the total amounts of released air and the maximum activity densities found in the emissions during a special study. Although a significant fraction of tritium may be in the form of hydrogen gas, all tritium is assumed to be in water vapour for which the dose conversion factor is higher than for hydrogen gas. The small radiological importance of this radionuclide fully justifies such a simplified approach, which is very conservative in addition. Another source of airborne tritium is the evaporator at the pit V0, which collects infiltration water from a former beam dump region in the western part of the Meyrin site. The water from the pit is evaporated and ventilated into the ambient air. Water samples from the pit are analyzed monthly and activities of released tritium are estimated from the known amounts of evaporated water and the measured tritium activity densities.

Unlike the other installations, the emissions from the On-Line Isotope Mass Separator (ISOLDE) may contain artificial alpha radioactivity and radioactive iodine, which are radiologically important. Therefore also the total alpha activity is measured on the aerosol filters from the ventilation monitoring station of this facility. Special attention is paid to changing of uranium and thorium carbide targets at ISOLDE. During these short-term operations iodine radioisotopes (^{124}I, ^{125}I, ^{126}I, and ^{131}I) and alpha radionuclides – almost exclusively ^{220}Rn and its progenies – are released. Gaseous alpha activity is measured in a Lucas cell and the prevailing alpha radionuclide is identified in a decay-curve analysis. Another operation leading to short-term emissions of radioactive substances from ISOLDE is emptying reservoirs, which collect gas from ISOLDE vacuum pumps. Rests of gaseous and volatile radioactive substances containing long or medium half-life radionuclides such as ^{3}H, ^{42}Ar, ^{72}Se, ^{75}Se, ^{85}Kr, ^{125}I, ^{127}Xe, and ^{129m}Xe are usually present in the reservoirs but only tritium and noble gases are released, which cannot be trapped on filters. The content of the reservoirs is analyzed before each release.

Total beta activity density, activity density of ^{7}Be and total alpha activity density, which have been measured at a background environmental aerosol-sampling station in Cessy, are subtracted from activity densities measured in the ventilation outlets to correct for the natural background.

1.2.3 Radioactive substances in released water

Each water release point where radioactive substances are likely to be released is equipped with a water monitoring station consisting of two instruments: a water monitor and an automatic water sampler. The water monitor is a NaI(Tl) scintillation probe immersed in a tank through which a sample of the monitored water flows continuously. It is intended for on-line indication of short-lived radionuclides in effluents such as ^{11}C, ^{13}N and ^{24}Na. The water sampler takes representative samples of the released water, which are analyzed monthly in the laboratory for long-lived activity. The analyses include tritium, total beta activity in suspension or dissolved in water, and gamma radionuclides.

Water samples are also taken on the spot close to the Antiproton Decelerator (AD) at the sampling point PMWS104 (pit DP62 in Bldg. 193) every month. The pit DP62 collects water, which percolates through the ground around the AD installation where it leaches out radionuclides produced by secondary particles in the earth shield around the target. Unlike the other water release points from which effluents are released to the local rivers Nant d'Avril and Le Lion, the water from the pit DP62 is pumped to the sewage treatment plant in Peney and finally released into the Rhone River.

1.2.4 Environmental samples

To check the presence of CERN-made radioactive contamination in the environment, samples are taken in all environmental compartments and analyzed in the laboratory.

Environmental ***aerosol*** samplers (PSA in Figures 1.1–1.3) have a design similar to the aerosol samplers in the ventilation monitoring stations and their filters are processed in the same way. The samplers are placed in cabins, which are located downwind of the main air extraction points, that is in areas where radioactivity attached to aerosol is expected, but also far from any artificial sources of radioactive aerosols to measure the natural background. A high-volume aerosol sampling station ASS 500 is installed at the LHC site PA7 close to the municipality Collex-Bossy (PSA973). The high-volume aerosol sampling station is operated with a flow rate of 650 m^3/hour and its filters are exposed for one week and subsequently analyzed for gamma radionuclides.

The ***deposition*** of radioactivity ***from the ambient air*** on the ground is surveyed by analyzing once per year grass (GR) or the upper 5 cm layer of uncultivated soil (SO), if grass is not available. There are three sampling points close to CERN installations and one reference sampling point at a distant place in Le Vengeron.

There are two ***precipitation*** collectors, one on the CERN Meyrin site (PSP-M, roof of Bldg. 24) and one on the CERN Prévessin site (PSP-P, roof of Bldg. 865), from which samples are analyzed monthly.

The aquatic environment is checked annually in the rivers Nant d’Avril and Le Lion, which receive water from the two main CERN sites and in the river Versoix, which is a reference river. Samples of ***river water*** (RW), ***river bryophytes*** (RM) and ***river sediment*** (RS) are taken at places downstream of the CERN water outlets once per year and analyzed in the laboratory. CERN effluents from the CERN Meyrin site, BA6 and PA1 into the river Nant d’Avril are brought together in covered drainage and arrive already mixed into the natural flow of the river. Therefore there is only one sampling point in this river (R*x*-NA). The river Le Lion receives water from the western part of the CERN Meyrin site through an outlet in the commune St Genis (R*x*-LL1); from the SPS underground areas and meteoric water from the greater part of the CERN Prévessin site through an outlet in Bugnon (R*x*-LL2); and from two other outlets of the surface drainage on the CERN Prévessin site (meteoric water). An outlet is located opposite to Bldg. 917, where some activated material is stored, and it drains meteoric water from around that building and from the northwest side of the Experimental Hall North 1 (EHN1). The sampling place R*x*-LL3 is specific to this water discharge point. Three other drainage outlets of meteoric water from the northeast part of the CERN Prévessin site are covered with the sampling place R*x*-LL4.

Leaching of radioactive substances into ***groundwater*** is checked by analyzing water samples from one drilling on the Prévessin site (GW-201) and from public fountains supplied from groundwater sources. The ***tap water*** samples from the CERN Meyrin and Prévessin sites are analyzed as well. All samples are taken once per year except GW-201, which is collected more frequently – at least in spring and in autumn.

Gamma radioactivity of ***agricultural products*** from the surrounding farms is analyzed annually. The nature of samples depends on their seasonal availability. In 2003 asparagus, soybeans, sunflower and wheat grains were collected from the farm Grunder. Sample of wine of 2002 and 2003 (preceding year, WI-MSW), which had been produced from grapes collected in vineyards southwest of the PS (farm Graber) were analyzed for gamma radionuclides and tritium in 2003.

More details on the monitoring programme can be found elsewhere [(3)].

1.3 Results of monitoring in 2003

The complete collection of results obtained in 2003 can be found in a separate report [(4)]. An extensive summary is given in the present section.

1.3.1 Stray radiation

Natural radiation in the environment

The total mean annual dose due to natural radiation in the environment around CERN sites in 2003 was established from readings of the stray radiation monitors during the shutdown period of the accelerators. This figure has been stable over the years and in 2003 the average reading of the gamma and charged particle monitors was 753 µSv with a standard deviation of 80 µSv. This can be compared with a ten-year average of 728 (61) µSv (the standard deviation is given in parentheses). The average reading of the neutron monitors during 2003 was 67 (9) µSv, compared with a ten-year average of 66 (8) µSv.

The annual ambient dose equivalent due to the natural radiation was also measured in some municipalities far from CERN accelerator installations by using thermo-luminescence dosimeters. The results for 2003 are listed in Table 1.3. The average values of 689 (94) µSv and 73 (17) µSv were obtained for the gamma and charged-particle dose, and the neutron dose, respectively. These values agree within their standard deviations with the results based on readings of the stray radiation monitors. Note that the standard deviations given in parentheses reflect not only measurement uncertainties but the spatial variations of the natural radiation as well.

Table 1.3 The annual ambient dose equivalent measured by thermo-luminescence dosimeters placed in various municipalities far from CERN accelerator installations (in µSv, standard deviations are given in parentheses).

Position	Municipality	Gamma + charged	Neutron	Total
273	Sauverny	679	67	746
274	Prévessin	723	95	819
275	Sergy	662	54	716
276	Thoiry	519	57	576
277	St Jean	817	73	890
279	Collex-Bossy	758	67	825
280	Meyrin city	668	95	762
Average		**689 (94)**	**73 (17)**	**762 (101)**

[(3)] P. Vojtyla, Environmental monitoring plan, CERN-TIS-2002-031-TE-TN (2002).
[(4)] P. Vojtyla (ed.), Results of the environmental monitoring at CERN, January – December 2003, CERN-SC-2004-001-IE-SN (2004).

Dose measurements at the CERN boundaries and outside

The annual net values of ambient dose equivalent measured by the stray radiation monitoring stations placed at the CERN site boundaries and outside the CERN sites are shown in Figure 1.4. The net doses were calculated by subtracting the individual background of each monitor. Contributions from photons and penetrating charged particles, and from neutrons are indicated separately.

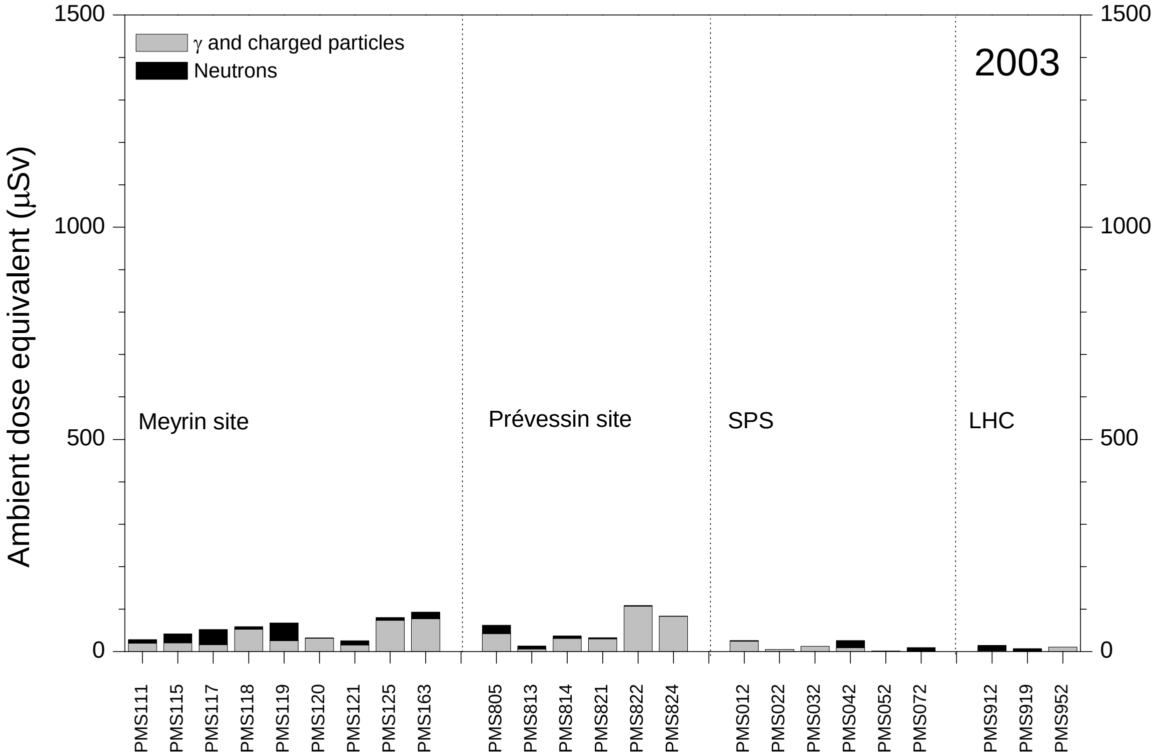

Figure 1.4 Results of dose measurements by the CERN stray-radiation monitoring stations at boundaries of the CERN sites and outside (natural background subtracted).

The values measured at the monitoring stations located on the SPS sites vary insignificantly around the natural background. This is due to the underground location of all radiation sources of this facility. Higher net doses occur systematically only around installations where the radiation sources are at the ground level. This concerns mainly Experimental Hall West 1 (PMS118, 119, 121, 125) with a clear neutron contribution, the ISOLDE area (PMS163) on the CERN Meyrin site, and some fence monitors placed around the experimental halls on the CERN Prévessin site. The stations PMS813, 814, 821 and 824 measure the radiation doses in lateral direction to particle beams whilst the station PMS822 is located in the down-beam direction. The station PMS805 is placed above the transfer tunnel TT20 through which particles from the SPS are extracted to the target areas on the CERN Prévessin site.

The annual limit of 1.5 mSv per year, which is defined in the CERN Radiation Safety Manual [(1)] for areas at the CERN fences and outside, was not exceeded anywhere. In fact, the highest measured value amounted to 7% of this limit.

Dose measurements inside the CERN boundaries

Scope of the environmental monitoring programme is also area monitoring inside the CERN boundaries at places, which are accessible to persons without individual dosimetric control, including the personnel of the Organization who are not exposed in the exercise of their profession and visitors. Figure 1.5 shows the annual net values of ambient dose equivalent measured by the CERN stray radiation monitoring stations located inside the CERN sites in 2003. Contributions from photons and penetrating charged particles, and from neutrons are indicated separately.

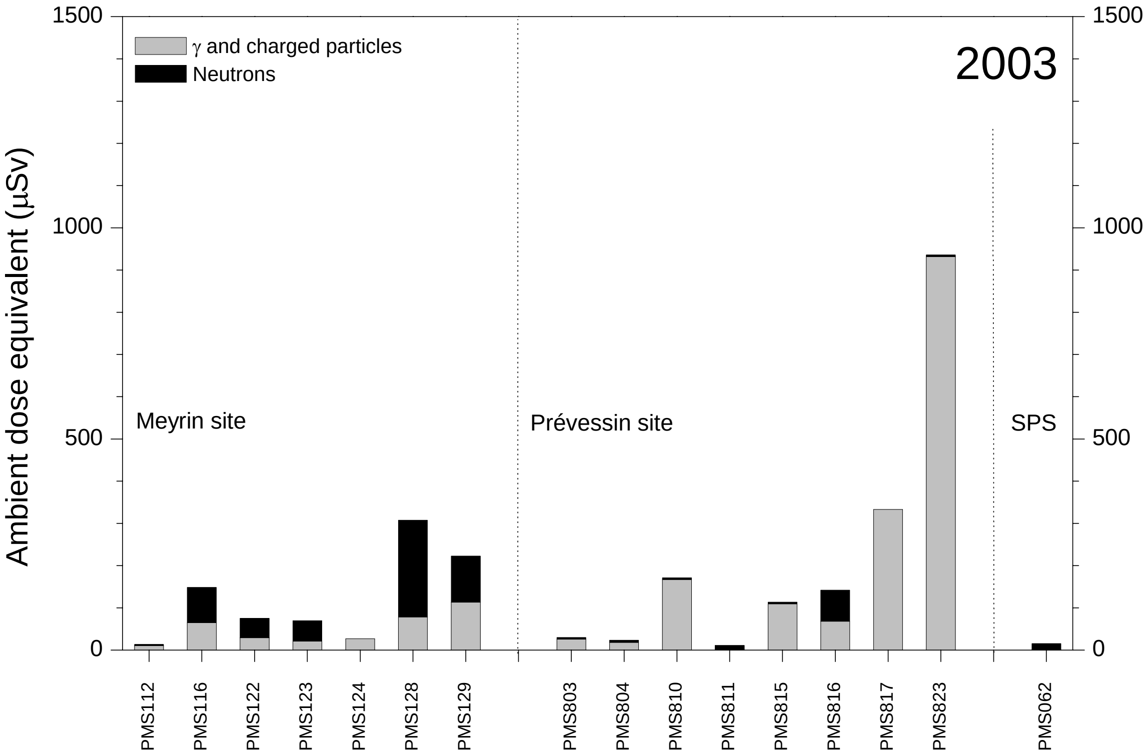

Figure 1.5 Results of dose measurements with the CERN stray-radiation monitoring stations inside the CERN sites (natural background subtracted).

On the CERN Meyrin site, one can clearly recognize the impact of the PS main ring (PMS116, PMS128) and of the Proton Synchrotron Booster (PMS129) with high neutron contributions. Both these facilities are placed at the ground level.

On the CERN Prévessin site, the station PMS823, which is located downstream of the Experimental Hall North 2 (EHN2), measured the highest net dose (936 µSv). The dose was caused by a scattered muon beam from the experiment COMPASS. The station is located almost exactly at the place where the ambient dose due to the COMPASS muon beam reaches its maximum. This is a remote area where no persons reside and it is used only for cattle and sheep pasture. According to Monte Carlo simulations, the doses at the fences should be much lower than this maximum dose, which was confirmed by the fact that none of the TLDs located in the area measured a dose of this magnitude (see Table 1.4). The second highest dose was measured inside Bldg. 892 (PMS817); however, this dose did not originate from direct radiation from the experimental areas on the site (EHN1 in this case) but was rather caused by slightly radioactive concrete placed close to the building. A clearly measurable dose was recorded also by the station PMS810, which is placed close to Bldg. 867, where activated items from accelerator facilities are temporarily stored and machined. The stations PMS815 and PMS816 (hadron stopper) reflected the radiation generated in EHN1 and around. The net dose measured by the station PMS062, which is specific to SPS site BA6 and the LHC site PA1, fluctuated insignificantly around the natural background.

Dose measurements by thermo-luminescence dosimeters on the CERN sites

Values of the annual ambient dose equivalent measured by thermo-luminescence dosimeters (TLD) on the CERN sites in 2003 are listed in Table 1.4 (natural background included). Only the TLD results are reported for which the annual readings exceeded the average natural background with its two standard deviations added (964 µSv). Hence only significant values are discussed further on. The positions of these dosimeters on the CERN Meyrin and Prévessin sites are shown in Figures 1.6 and 1.7, respectively.

Table 1.4 The annual ambient dose equivalent measured by thermo-luminescence dosimeters at selected positions on the CERN Meyrin and Prévessin sites (in µSv, natural background included).

CERN Meyrin site				**CERN Prévessin site**			
Position	Photons + charged p.	Neutrons	Total	Position	Photons + charged p.	Neutrons	Total
40	547	504	1051	224	738	231	969
58	884	764	1648	227	762	267	1029
59	697	680	1377	230	941	343	1284
61	719	489	1208	231	788	255	1043
62	636	687	1324	260	885	183	1068
63	821	235	1057	264	847	122	969
64	724	272	997				
66	852	273	1125				
93	565	457	1022				

On the CERN Meyrin site, significant doses were measured only around the PS Complex and at the position 40 close to the West Experimental Hall, all inside the site. One can observe strong neutron contributions. On the CERN Prévessin site, doses well above the natural background were measured only above the transfer tunnel TT20 and the target area TCC2 (positions 224 and 227, respectively), laterally from the beam in the experimental hall EHN1 (positions 230 and 231), above the beam line to the target area TCC8 (position 264), and close to the experimental hall EHN2.

The highest measured value was 1648 µSv. If one assumes an average natural background value of 762 µSv, one can conclude that a net ambient dose equivalent above the regulatory limit of 1500 µSv [(1)] was not exceeded at any position.

1.3.2 Activity released with air

The detailed breakdown per site, per ventilation outlet and per radionuclide category of activity released with air is given in Table 1.5. Not included in Table 1.5 are alpha and radioiodine activities released with air from ISOLDE.

In 2003, 11.0 TBq of short-lived gaseous radionuclides were released from the CERN ventilation outlets – the prevailing part from the Meyrin site (9.6 TBq), mainly from the transfer tunnel TT10 and from ISOLDE. The released long-lived radioactive substances attached to aerosol consisted mostly of ^{7}Be (313 MBq). The total beta activity discharged into the atmosphere was about thirty times lower (10.7 MBq). Also for the two latter radionuclide categories, the prevailing part of the activity was released from the CERN Meyrin site with dominating contributions from TT10 and ISOLDE. The released tritium activity was smaller than about 191 GBq out of which 174 GBq were discharged from the ventilation outlets on the CERN Meyrin site. The contribution of the V0 evaporator was negligible. These figures are roughly the same as those of the previous years.

During the normal operation of ISOLDE no excessive alpha activity was released. The released activities of iodine radioisotopes remained small: 0.39 MBq of ^{124}I, 0.64 MBq of ^{126}I, 2.59 MBq of ^{131}I. Uranium carbide and thorium carbide targets were exchanged 8 times at ISOLDE in 2003. During these operations 9.3 MBq of ^{220}Rn and 1.2 MBq of ^{212}Pb were released. The released radioiodine activities amounted to: 0.91 MBq of ^{124}I, 0.81 MBq of ^{126}I and 3.42 MBq of ^{131}I. The total alpha and radioiodine activities released from ISOLDE in 2003 were 10.5 MBq and 8.8 MBq, respectively. The reservoirs collecting gas from ISOLDE vacuum pumps were emptied three times in 2003. During these operations 10.3 GBq of tritium (included in Table 1.5), 1.2 MBq of ^{42}Ar, 63 MBq of ^{85}Kr, 0.69 GBq of ^{127}Xe, 0.34 GBq of ^{129m}Xe, 0.46 GBq of ^{131m}Xe, and 1.6 GBq of ^{133}Xe were released. The activities of these noble gases are negligible compared with the total activity of short-lived radioactive gases released from ISOLDE (see Table 1.5).

Figure 1.6 Positions on the CERN Meyrin site of the thermo-luminescence dosimeters listed in Table 1.4.

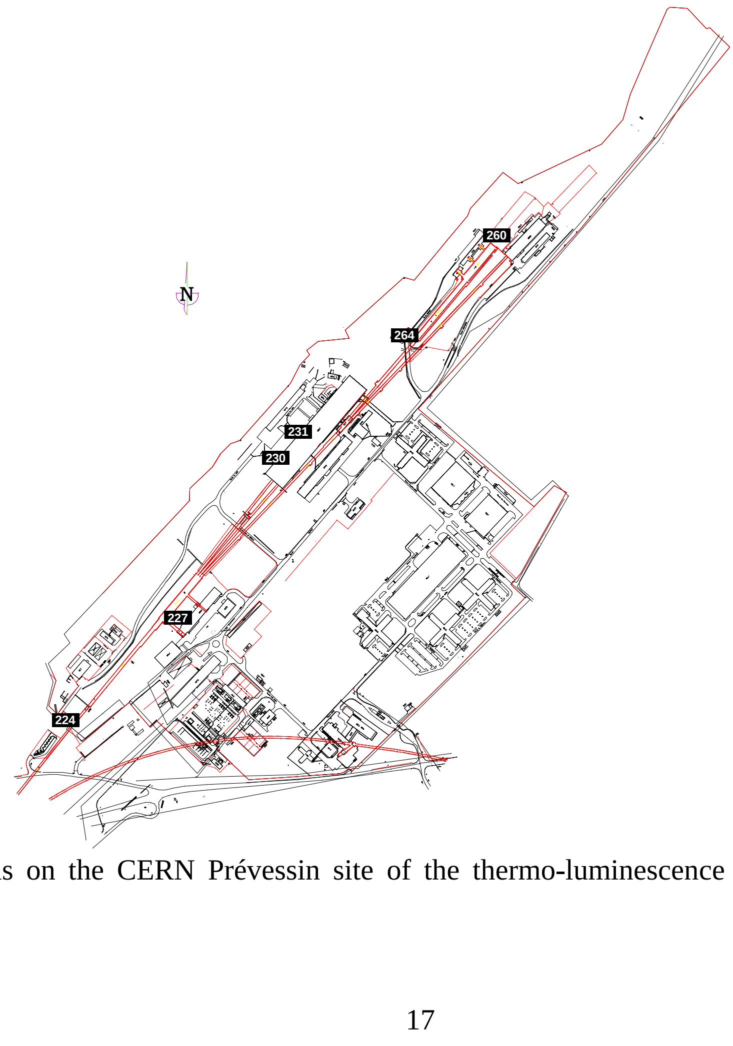

Figure 1.7 Positions on the CERN Prévessin site of the thermo-luminescence dosimeters listed in Table 1.4.

Table 1.5 Breakdown of activity released with air in 2003.

Origin	**Station**	**Air released** 10^6 m^3	**Short-lived gas** TBq	^{7}**Be aerosol** MBq	**Beta aerosol** MBq	**Tritium** GBq
PS Main Ring	PMV174	265	1.10	40	1.5	2.1
TT10 Extraction North	PMV11	292	3.7	112	3.8	11.3
TT60 Extraction West	PMV172	60	0.19	1.6	0.042	73
TT70 Transfer PS-SPS	PMV173	106	0.28	0.04	0.000	83
ISOLDE	PMV170	93	4.3	142	4.58	3.3
Evaporator V0	V0	–	–	–	–	1.23
Subtotal Meyrin		*815*	*9.6*	*295*	*10.0*	*174*
SPS Main Ring BA3	PMV31	292	0.66	0.48	0.000	4.6
SPS Main Ring BA5	PMV51	286	0.60	1.2	0.000	4.5
TT20 Extraction North	PMV801	68	0.12	15.8	0.73	7.9
Subtotal Prévessin		*645*	*1.4*	*17.4*	*0.73*	*17.0*
Total CERN		**1460**	**11.0**	**313**	**10.7**	**191**

1.3.3 Activity released with water

Activity densities measured in released water were low. For tritium, the highest average monthly activity density of 820 Bq/l was measured in September 2003 in the water outlet from BA2 (PMWS21) where water from the CERN Prévessin site and the SPS tunnel is collected and released into the river Le Lion. This value can be compared with the Swiss immission limit for tritium of 12 kBq/l (5). The monthly average activity density of tritium did not exceed 8 Bq/l in any other water outlet.

No beta-gamma radionuclide of CERN origin was detected in gamma spectrometry analyses of monthly released water samples, except the September sample from BA2 in which 0.24 ± 0.15 Bq/l of ^{22}Na was measured. Total beta activity densities measured in large-area proportional counters were low as well and did not exceed 0.5 Bq/l (the September sample from BA2). One can assume that the natural beta activity (^{40}K, U and Th decay series) in the water samples is around 0.1 Bq/l and the remaining maximum activity density of 0.4 Bq/l is exclusively due to ^{22}Na. Such maximum activity density makes only 0.7% of the Swiss immission limit of 60 Bq/l valid for this radionuclide (5).

In the calculation of the activities released with water, it was assumed that the tritium baseline was 1.5 Bq/l (the present average in water from the Lake of Geneva) and that all total beta activity measured above 0.1 Bq/l could be ascribed to ^{22}Na produced at CERN. The detailed breakdown per radionuclide category, per water release outlet and per receiving river is given in Table 1.6.

It is estimated that 6.3 GBq of tritium was released into the river Nant d’Avril and 38 GBq of tritium was discharged into the river Le Lion. The estimated activities of presumably ^{22}Na released into the rivers Nant d’Avril and Le Lion were 41 MBq and 53 MBq, respectively.

1.3.4 Environmental samples

Total beta activity in the aerosol fraction of the ambient air

The total beta activity densities in the aerosol fraction of air collected on the CERN Meyrin site and in its vicinity, on the CERN Prévessin site and at a true-background station in Cessy, France, are shown in Figures 1.8 and 1.9. The data series follow patterns very similar to that of the Cessy station PSA951. This confirms that the natural total beta activity (^{40}K, U and Th decay series) dominated and that any possible effect of CERN air releases on the total beta activity in aerosol was negligible. The temporal variations of the total beta activity mainly followed the aerosol contents in

(5) Swiss Ordinance on Radiological Protection 814.501 of 22 June 1994, state of 29 December 2001.

the ambient air, which depended on the origin of air masses and on varying wet and dry deposition and resuspension. The radon emanation rate played an important role as well.

Table 1.6 Breakdown of activity release with water in 2003.

Origin	**Station**	**Water released** 10^6 m^3	**Tritium** GBq	**β/γ (^{22}Na)** GBq	**River**
Cooling loop of the SPS SE of the Meyrin site NE of the Meyrin site AD infiltration	PMW62 PMW101 PMW102 PMW104	0.15 2.1 0.44 0.031	0.17 5.8 0.20 0.088	0.0129 0.024 0.00079 0.0030	Nant d'Avril Nant d'Avril Nant d'Avril STEP Peney (*)
Subtotal Nant d'Avril		*2.7*	*6.3*	*0.041*	
Prévessin site, SPS West of the Meyrin site	PMW21 PMW103	0.31 0.131	38 0.16	0.052 0.00098	Le Lion Le Lion
Subtotal Le Lion		*0.44*	*38*	*0.053*	
Total CERN 2003		**3.2**	**44**	**0.090**	**Nant d'Avril, Le Lion, STEP Peney**

(*) Sewage treatment plant; STEP = *Station d'Épuration*.

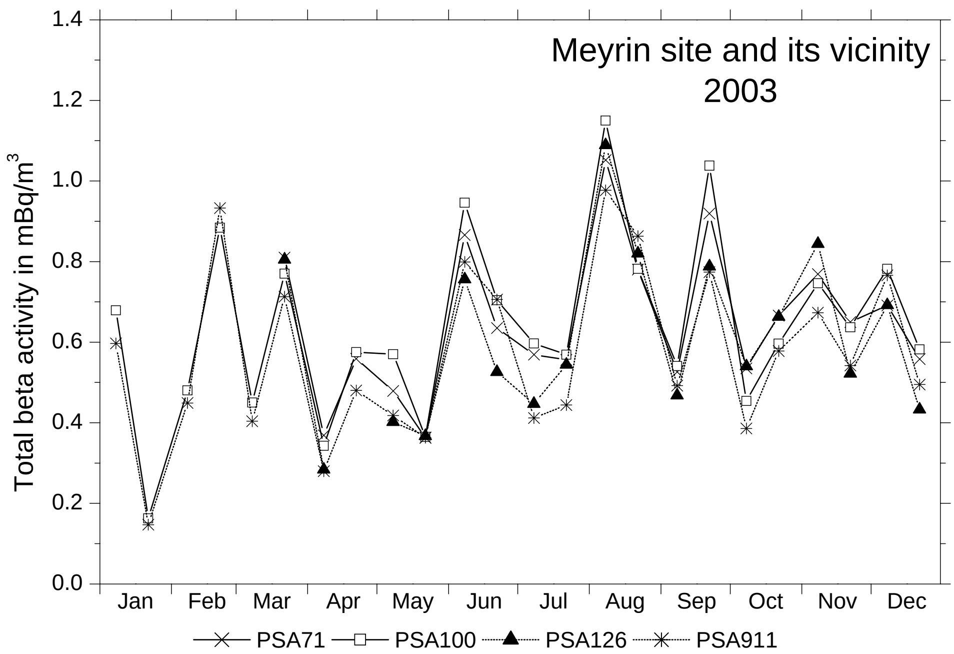

Figure 1.8 Total beta activity densities in the aerosol fraction of the air collected on and near the CERN Meyrin site.

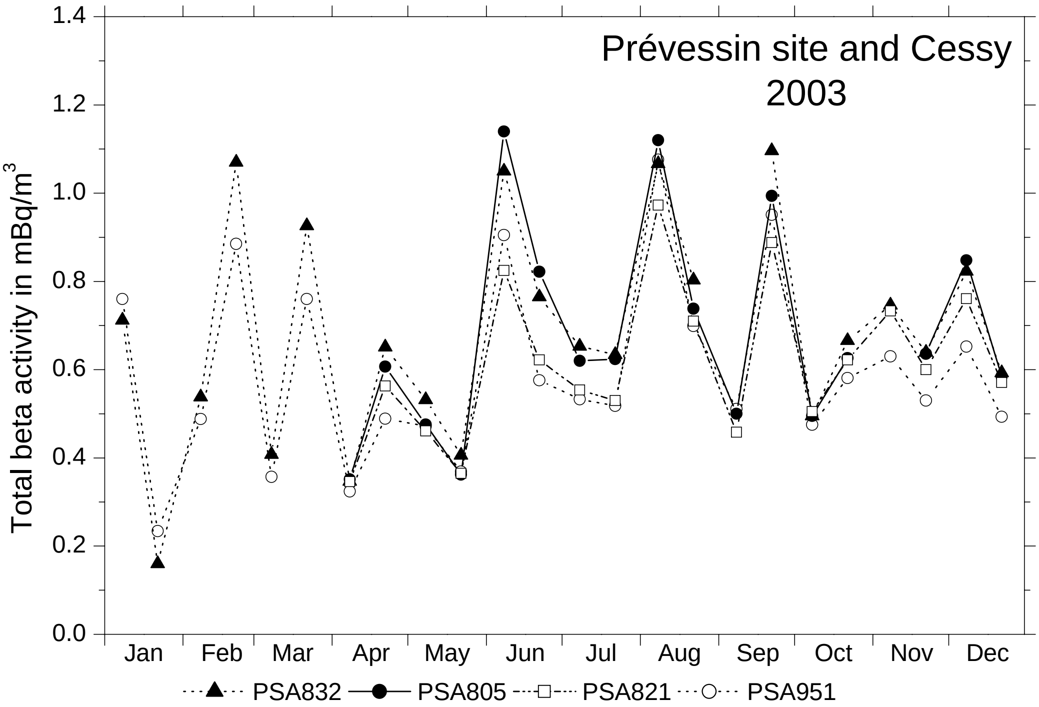

Figure 1.9 Total beta activity densities in the aerosol fraction of the air collected on the CERN Prévessin site and in Cessy.

Gamma activity in the aerosol fraction of the ambient air

The majority of the gamma activity attached to aerosol, which is released from the ventilation of CERN accelerator facilities, consists of ^{7}Be (see Table 1.5). Therefore ^{7}Be can serve as an indicator of the environmental impact of the air releases from CERN facilities. Beryllium-7 is also produced naturally in the atmosphere in spallation reactions of cosmic rays with nuclei in the air. It attaches quickly on aerosol particles after its creation. The ground-level activity density of ^{7}Be in the air is subject to natural seasonal variations with maxima in summer and minima in winter. This variation is controlled by the dynamics of the air exchange between the stratosphere, where most of the cosmogenic ^{7}Be is produced, and the troposphere. In middle latitudes, the tropopause separating the two atmospheric compartments breaks in early summer, which leads to injection of the stratospheric air rich in ^{7}Be into the troposphere.

Figure 1.10 shows the average monthly activity densities of ^{7}Be in the air collected at the aerosol sampling stations on the CERN Meyrin site and in its vicinity. Results from two sampling stations, which belong to regulatory authorities of the CERN Host States Switzerland and France, are included in Figure 1.10 as well [(6,7)]. The French station 612PRE operated by the *Institut de Radioprotection et Sûreté Nucléaire* is located at the French border guard stand on the Swiss-French border close to the site main entrance. The Swiss station HVS Meyrin is a high-volume aerosol sampler run by the *Office Fédéral de la Santé Publique*. It is placed in the southeast corner of the CERN Meyrin site near the stray radiation monitoring station PMS111 (Figure 1.1).

Figure 1.11 shows the monthly activity densities of ^{7}Be in the air collected at the aerosol sampling stations on the CERN Prévessin site and at distant places – Cessy (PSA951), LHC PA7 close

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[(6)] H. Völkle et al., Zusammenstellung der Messergebnisse 2003, Bundesamt für Gesundheit, Abteilung Strahlenschutz, Sektion Überwachung der Radioaktivität, Fribourg (2004).
[(7)] Institut de Radioprotection et de Sûreté Nucléaire, Tableaux mensuels des mesures, janvier 2003 – juillet 2003, Le Vésinet (2003–2004).

to the commune Collex-Bossy (PSA973). Included in Figure 1.11 are results from a high-volume aerosol sampling station, which belongs to the *Office Fédéral de la Santé Publique* and which is located in Güttingen, Switzerland (canton Thurgau). The three latter stations, which are placed far from any artificial sources of ^{7}Be, can serve as reference stations.

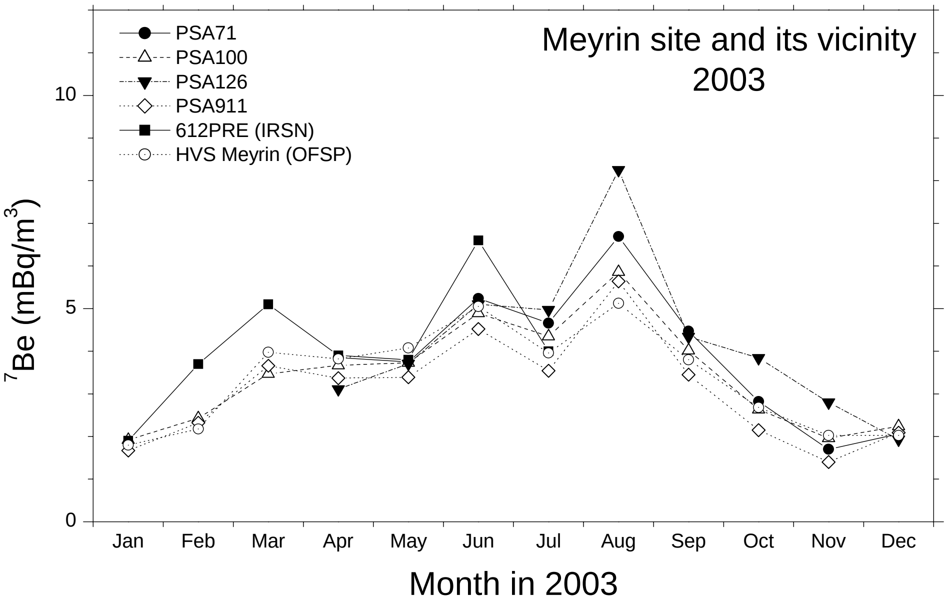

Figure 1.10 Monthly activity densities of ^{7}Be in air collected on the CERN Meyrin site and in its vicinity.

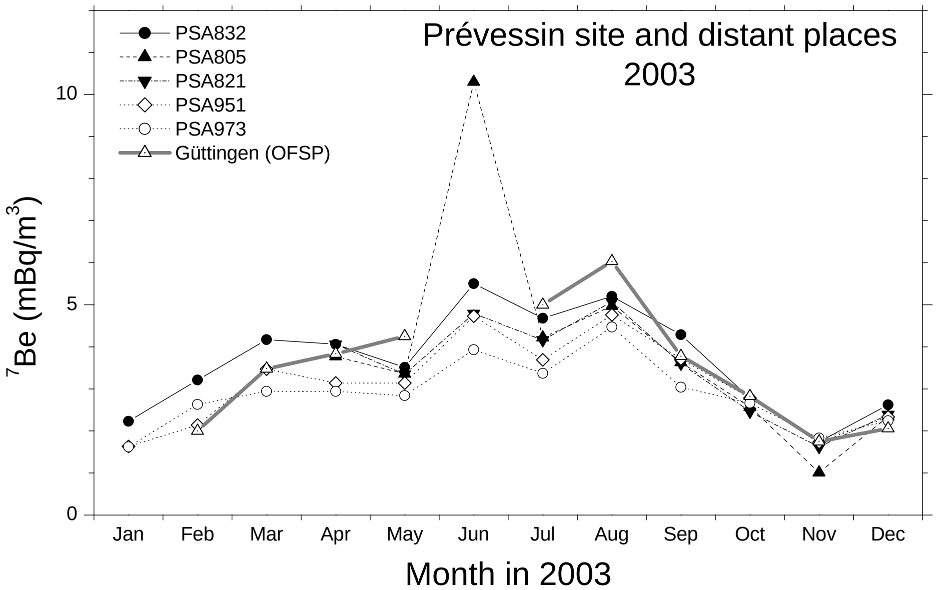

Figure 1.11 Monthly activity densities of ^{7}Be in air collected on the CERN Prévessin site and at three distant places.

Except for the stations PSA126, PSA805 and 612PRE, it is difficult to recognize any impact of the CERN air releases by comparing the ^{7}Be records from the stations located near the ventilation outlets of the accelerator facilities (PSA71, 100, 911, 832, 821, HVS Meyrin) with those from the remote places (PSA951, 973, Güttingen). As can be seen in Figures 1.10 and 1.11, possible contributions of ^{7}Be from CERN releases are hidden in natural spatial variations.

The activity densities of ^{7}Be, which were measured at the stations PSA126 and PSA805 during the operating period of the accelerators, are clearly above the values measured at the other stations. However, the increase does not exceed 7 mBq/m^3. Here the local impact of the air releases from the PS Complex and the transfer tunnel TT20 in the vicinity of which the stations are located can be observed.

Even the maximum possible activity density of ^{7}Be of 7 mBq/m^3, which could be attributed to releases from CERN facilities and which was measured in the ground-level air, is radiologically insignificant: the Swiss immission limit for ^{7}Be in ambient air (5) is 3.3×10^5 mBq/m^3. The slightly higher values observed at the station 612PRE in February and March are hard to explain because the CERN accelerators were shut down. Very likely, enhanced resuspension of the natural ^{7}Be deposited on the ground is the cause, as the station is located in the middle of a road with a lot of traffic.

The only other artificial gamma radionuclides attached to aerosol, which were identified in the CERN routine environmental monitoring programme in 2003, were ^{137}Cs (in several samples, up to 5.7 µBq/m^3) and ^{22}Na in the August sample from the station PSA126. Detection limits for the prevailing gamma radionuclides present in CERN air releases, such as ^{22}Na, ^{54}Mn or ^{60}Co, were always below 5 µBq/m^3. Caesium-137 originated in resuspension of soil particles contaminated during the atmospheric nuclear weapon tests and the Chernobyl accident. Sodium-22 at the station PSA126 was measured just above the detection limit: 30 ± 20 µBq/m^3 but it clearly originated in the airborne releases from the PS Complex because activity densities of the naturally produced ^{22}Na may reach only several µBq/m^3, as observed at the background high-volume aerosol-sampling station PSA973 at the LHC PA7 site. However, the above-mentioned value appears radiologically insignificant when compared with the Swiss immission limit of 13 Bq/m^3 valid for ^{22}Na in ambient air (5).

Total alpha activity in the aerosol fraction of the ambient air

Screening measurements of total longer-lived alpha activity in the aerosol fraction were carried out on monthly samples from two environmental aerosol sampling stations: PSA911 in Maisonnex – downwind of the CERN Meyrin site, and PSA951 in Cessy – true background. The results are shown in Figure 1.12 in comparison with total alpha activity densities in the aerosol fraction of the air collected in the ISOLDE ventilation stack (PMV170).

The data series from both the environmental stations follow the same pattern confirming that the measured alpha activity was of natural origin. In addition, the total alpha activity densities in aerosol fraction of the air collected in the ventilation stack of ISOLDE were lower than those in the environment. This was a consequence of an efficient aerosol filtration in the ISOLDE air extraction plant, which removed also the natural alpha radionuclides introduced into the facility from the environment by its ventilation system. Apparently, there could not be any measurable impact on the environment of the alpha activity released from the ISOLDE after its dispersion in the atmosphere.

Deposition on ground

Because of the unusually hot and dry summer in 2003, grass samples were not available at the places foreseen in the monitoring plan and soil samples were taken instead. Only radionuclides of natural origin and the omnipresent ^{137}C were identified in the samples. Table 1.7 gives the results for ^{7}Be, ^{40}K and ^{137}Cs. The detection limits for other radionuclides produced at CERN were as follows (all in Bq/kg of dry weight): ^{22}Na, ^{54}Mn, $^{56, 57, 58, 60}$Co: <0.4, ^{51}Cr, ^{52}Mn: <3.3, ^{59}Fe: <0.8.

The results show a high degree of coherence for the total beta and ^{40}K activity densities and partially also for the omnipresent ^{137}Cs. The values for ^{7}Be are close to the detection limits and can hardly reveal any extra input from the CERN facilities when compared with the reference sample from Le Vengeron (SO-VG). This proves that the environmental impact of the air releases was negligible as already expected from the results discussed in the previous section.

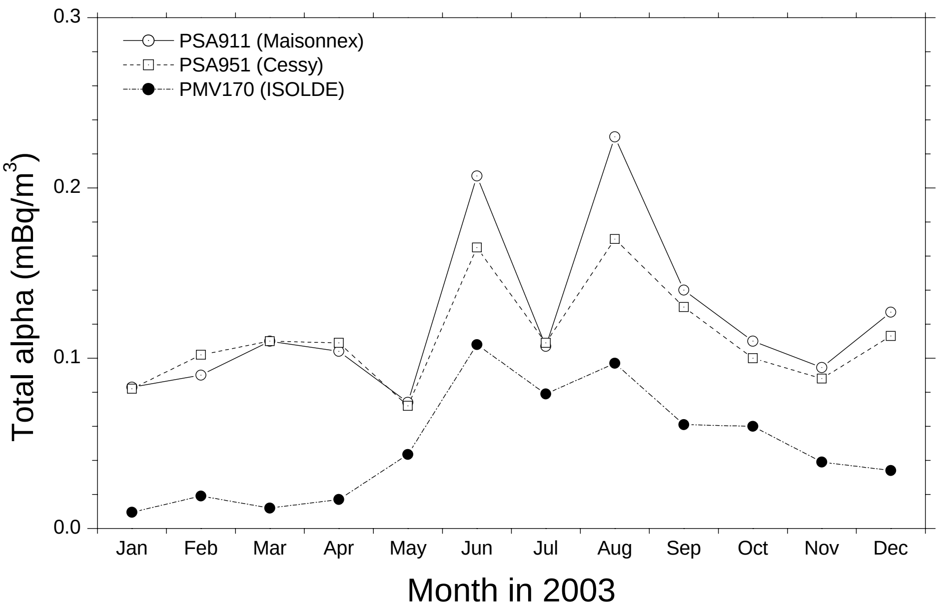

Figure 1.12 Monthly total alpha activity densities of the aerosol fraction in the air collected at the stations PSA911, PSA951 and in the ISOLDE ventilation stack.

Table 1.7 Results of beta and gamma analyses of soil samples.

Code	**Date**	**Total beta**	**^{7}Be**	**^{40}K**	**^{137}Cs**	**Remark**
		Bq/kg dry weight				
SO-nTOF	25 Aug 2003	650 ± 20	3.0 ± 1.0	435 ± 13	18 ± 1	Close to the target area of the nTOF experiment
SO-MSW	25 Aug 2003	630 ± 30	3.6 ± 3.0	414 ± 12	6.2 ± 0.2	Downwind of the PS Complex
SO-P801	26 Aug 2003	650 ± 20	<4.3	402 ± 12	20 ± 1	Downwind of the ventilation outlet of TT20
SO-VG	26 Aug 2003	700 ± 30	<3.1	398 ± 12	20 ± 1	Reference sample from the municipality Le Vengeron

Precipitation

Precipitation was collected on a monthly basis at two sampling stations: on the CERN Meyrin site (PSP-M) and on the CERN Prévessin site (PSP-P). The total annual precipitation reached values unusually low for the region: 682 l/m^2 on the CERN Meyrin site and 781 l/m^2 on the CERN Prévessin site (the usual figure is around 1000 l/m^2). In addition, the precipitation was unevenly distributed with heavy rainfalls in autumn.

Figures 1.13 and 1.14 show the total beta and tritium activity densities in monthly precipitation samples, and the monthly precipitation rates for the stations PSP-M and PSP-P, respectively. No gamma radionuclide was identified in any of the precipitation samples. Detection limits were smaller than 4 Bq/l for ^{7}Be and smaller than 0.4 Bq/l for other artificial radionuclides possibly present in rainwater (e.g. ^{22}Na, ^{60}Co, ^{137}Cs).

The total beta activity measured in the samples was of natural origin (^{40}K, U and Th decay series). Activity densities remained below 0.2 Bq/l. The highest values were measured in March and April at the station on the CERN Meyrin site, probably due to pollens from the trees nearby.

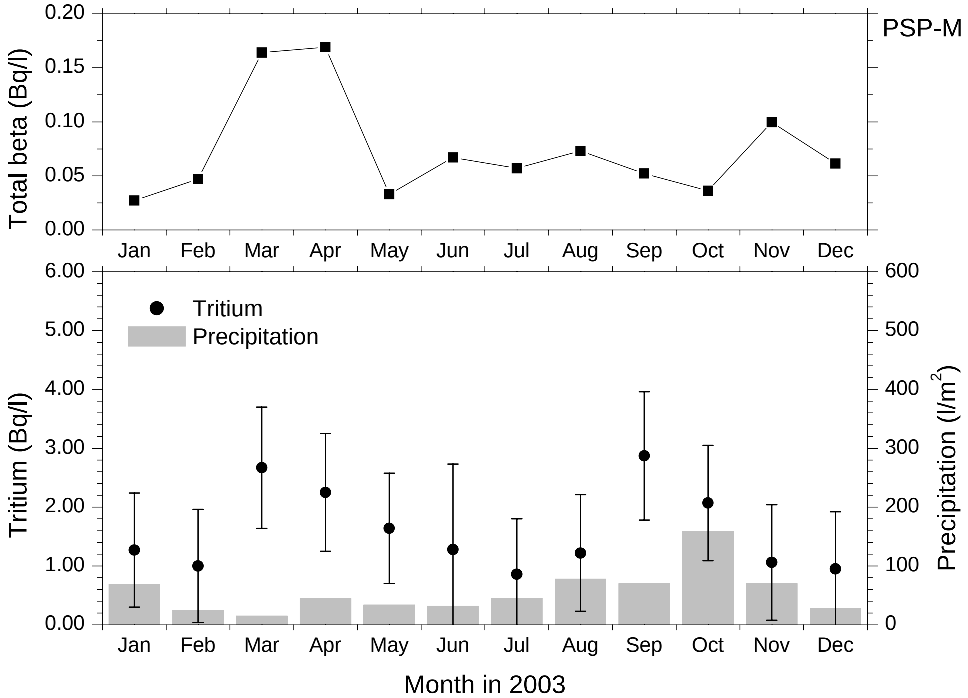

Figure 1.13 Total-beta activity density, tritium activity density and monthly precipitation quantity for samples collected on the CERN Meyrin site.

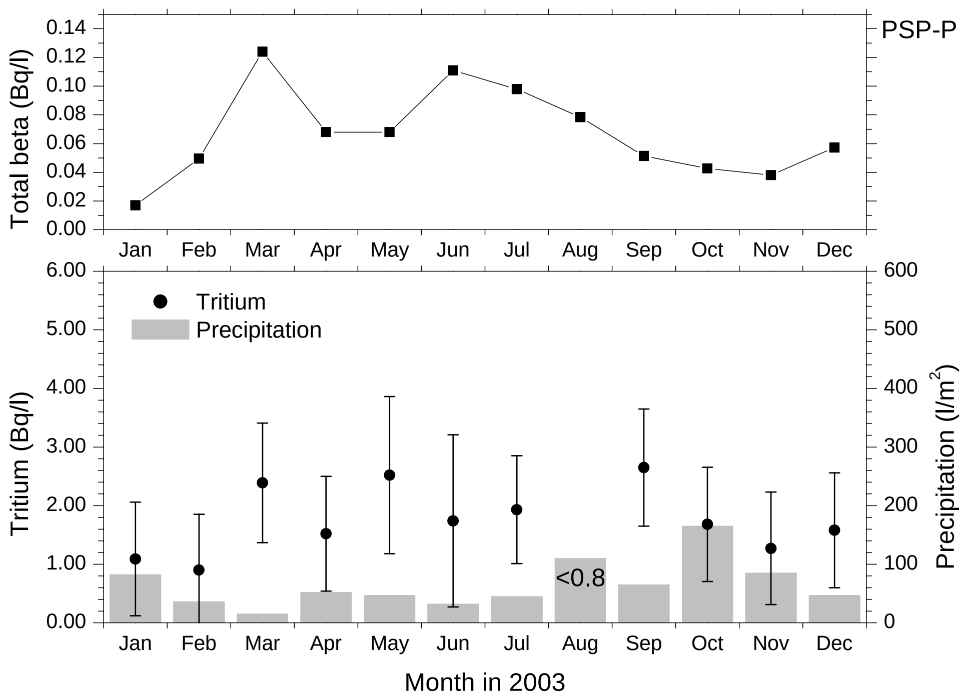

Figure 1.14 Total beta activity density, tritium activity density and monthly precipitation quantity for samples collected on the CERN Prévessin site.

The tritium activity densities in the rainwater do not show any effect of tritium releases from the CERN accelerator facilities. Most of the time their values varied randomly around a mean value of 1.5 Bq/l, which is typical for the European continental surface waters.

Rivers receiving water from CERN

In September 2003, samples of water, sediment and bryophytes were taken from the two rivers into which CERN discharges water likely to contain CERN-made radionuclides and in the reference river Versoix. No gamma radionuclides were identified in any river water sample. The detection limits were roughly the same as for the precipitation samples (see the previous section). Table 1.8 gives results of total beta and tritium activity measurements.

Table 1.8 Total beta and tritium activity densities in river water samples.

Code	Date	Total beta	^{3}H	Remark
		Bq/l		
RW-LL1	19 Sep 2003	0.118 ± 0.008	18.3 ± 1.5	Le Lion, municipality St Genis, Meyrin site (West)
RW-LL2	18 Sep 2003	0.188 ± 0.009	3.3 ± 1.0	Le Lion, Bugnon, SPS, Prévessin site
RW-LL3	18 Sep 2003	0.123 ± 0.006	<0.8	Le Lion, surface drainage of the Prévessin site
RW-LL4	19 Sep 2003	0.336 ± 0.013	<0.8	Le Lion, surface drainage of the Prévessin site
RW-NA	18 Sep 2003	0.163 ± 0.008	2.9 ± 1.0	Nant d'Avril, Meyrin site (East)
RW-VE	18 Sep 2003	0.048 ± 0.005	1.2 ± 1.0	Versoix – reference sample

The instantaneous water samples had total beta activity densities ranging from 0.05 Bq/l to 0.34 Bq/l corresponding to the normal natural levels. However, the tritium analyses revealed an impact of the water releases from the CERN sites. In the sample RW-LL1 taken from the river Le Lion in St Genis, France, 18.3 ± 1.5 Bq/l were measured, clearly above the value of 1.2 ± 1.0 Bq/l measured in the reference river La Versoix. The tritium activity originated in the water released from BA2 (SPS and the CERN Prévessin site). A sample taken from the river at the place close to the BA2 outlet one day before showed only 3.3 ± 1.0 Bq/l. The Swiss immission limit for tritium in water is 12 kBq/l as weakly average (5).

Tables 1.9 and 1.10 give activity densities of radionuclides, which are not of natural origin exclusively, as measured in sediment and bryophyte samples, respectively. Cesium-137 does not originate from CERN; it was included in the tables as a tracer for soil-erosion particles in the samples. The natural ^{7}Be gets into sediment and bryophytes through particles, which were deposited on the surface and washed out by rain into the river water. This process depends strongly on the conditions of the basin and hence large variability of activity densities may occur. However, the variability observed for ^{7}Be is much greater than the one observed for ^{137}Cs, and the samples from the river Le Lion contain more ^{7}Be than expected. A relatively high activity density of ^{7}Be was found also in the bryophyte sample RM-LL1. A contribution from CERN water releases is therefore likely for this river. Further, traces of ^{54}Mn were found in sediment from Le Lion collected close to the water outlet at BA2, and well measurable activities of this radionuclide were present in the bryophyte samples taken downstream of the outlet. In addition, ^{60}Co was identified clearly in the bryophyte sample RM-LL2. Manganese-54 and ^{60}Co are corrosion products from activated metallic accelerator parts but they are produced also in earth and concrete and get into the river with fine earth and concrete particles. The measured activity densities remain, however, well below the Swiss exemption limits (^{7}Be: 400 kBq/kg, ^{54}Mn: 10 kBq/kg, ^{60}Co: 1 kBq/kg (5)) and their radiological importance is negligible (<1% of LE).

Table 1.9 Activity densities in river sediment (RS).

Code	**Date**	**Total beta**	**^{7}Be**	**^{40}K**	**^{54}Mn**	**^{137}Cs**
		Bq/kg dry weight				
RS-LL1	19 Sep 2003	660 ± 20	130 ± 7	253 ± 13	<0.24	6.8 ± 0.3
RS-LL2	18 Sep 2003	482 ± 14	52 ± 4	253 ± 10	0.8 ± 0.3	6.7 ± 0.5
RS-LL3	18 Sep 2003	430 ± 20	24 ± 4	340 ± 20	<0.3	1.9 ± 0.4
RS-LL4	18 Sep 2003	413 ± 12	27 ± 3	260 ± 20	<0.4	3.3 ± 0.4
RS-NA	18 Sep 2003	620 ± 30	25 ± 2	323 ± 10	<0.3	2.0 ± 0.1
RS-VE	18 Sep 2003	500 ± 20	4 ± 2	440 ± 20	<0.3	1.1 ± 0.4

Table 1.10 Activity densities in river bryophyte (RM).

Code	**Date**	**^{7}Be**	**^{40}K**	**^{54}Mn**	**^{60}Co**	**^{137}Cs**
		Bq/kg dry weight				
RM-LL1	19 Sep 2003	1470 ± 70	480 ± 20	12 ± 1	<1.0	17 ± 0.8
RM-LL2	18 Sep 2003	300 ± 20	230 ± 20	97 ± 3	2.1 ± 0.6	11 ± 2
RM-LL3	18 Sep 2003	340 ± 20	360 ± 20	<0.5	<0.6	7.1 ± 0.8
RM-LL4	18 Sep 2003	180 ± 30	310 ± 60	<3.1	<4	8 ± 4
RM-NA	18 Sep 2003	280 ± 20	370 ± 30	<2.1	<1.4	14 ± 2
RM-VE	18 Sep 2003	380 ± 30	260 ± 40	<1.5	<1.5	6 ± 2

The total beta activity densities in the sediment samples range from 413 Bq/kg to 660 Bq/kg with the activity density in the sediment from the reference river Versoix of 500 Bq/kg. No impact of water releases from CERN can be recognized.

Groundwater and tap water

In 2003 seven groundwater samples and two tap water samples were collected and analyzed for tritium, total beta activity and gamma radionuclides. Results for total beta activity densities, for tritium activity densities, and detection limits for ^{22}Na are given in Table 1.11. Detection limits for other radionuclides were roughly the same as those for rainwater.

Table 1.11 Results of analyses of groundwater and tap water samples.

Code	**Date**	**Total beta**	**^{3}H**	**^{22}Na**	**Remark**
		Bq/l			
GW-201	2 May 2003		<0.8	<0.2	Drilling on the Prévessin site – spring
GW-201	3 Nov 2003		1.2 ± 1.0	<0.2	Drilling on the Prévessin site - autumn
GW-201	2 Dec 2003	0.17 ± 0.01	1.8 ± 1.0	<0.2	Drilling on the Prévessin site – winter
GW-BO	7 Nov 2003	0.19 ± 0.01	<0.8	<0.2	Municipality Bourdigny
GW-FL	7 Nov 2003	0.15 ± 0.01	<0.8	<0.4	Municipality Flies
GW-GR	7 Nov 2003	0.093 ± 0.006	1.4 ± 1.0	<0.2	Grunder farm
GW-PG	7 Nov 2003	0.091 ± 0.006	<0.8	<0.4	Municipality Pregnin
TW-M	7 Nov 2003	0.11 ± 0.006	1.4 ± 1.0	<0.3	Tap water from the CERN Meyrin site
TW-P	7 Nov 2003	0.079 ± 0.005	1.6 ± 1.0	<0.3	Tap water from the CERN Prévessin site

The low tritium activity densities, not exceeding 2 Bq/l and often below the decision threshold of 0.8 Bq/l, proved that there was no contamination due to infiltration water from around CERN facilities. The total beta activity densities remained below 0.2 Bq/l corresponding to the natural water with more mineral content.

Agricultural products

In 2003 asparagus, wheat grains, sunflower grains and soybeans grown on the farm Grunder located northeasterly of the CERN Meyrin site as well as wine from grapes cultivated on the farm Graber positioned southwesterly of the CERN Meyrin site in 2002 (Côté Soleil) were analyzed. Both farms are located in the main wind directions from the principal accelerator ventilation outlets. All samples contained the natural ^{40}K and in the sunflower grains some ^{7}Be just above the detection limit could be found. The results are summarized in Table 1.12.

The wine of 2002 contained insignificant 2.9 ± 1.0 Bq/l of tritium and 23 ± 3 Bq/l of ^{40}K. Till the time of writing this report also a 2003 wine from the same wine-producer of the same mark could be collected and analyzed. It contained only tritium and ^{40}K with activity densities very similar to those from 2002: ^{3}H: 2.0 ± 1.0 Bq/l; ^{40}K: 22 ± 2 Bq/l. Detection limits for other radionuclides were roughly the same as those for the water samples discussed above.

Table 1.12 Activity densities of radionuclides in agricultural products from the farm Grunder.

Sample	**Date**	**^{7}Be**	**^{40}K**
		Bq/kg fresh weight	
Asparagus	30 Apr 2003	<0.2	59 ± 2
Wheat grains	17 Sep 2003	<2	169 ± 8
Sunflower grains	22 Sep 2003	4.3 ± 2.2	237 ± 12
Soybeans	19 Sep 2003	<2	550 ± 20

CERN-made radionuclides could not be clearly identified in most environmental samples. In the cases when activity densities of such radionuclides could be measured, their values remained well below the applicable limits. Hence the environmental impact of releases from the CERN sites remained negligible as in the previous years.

1.4 Radiological impact

The radiological impact on the public of activities carried out on the CERN sites is expressed in terms of effective doses received by individual members of the population. An effective dose is composed of an external dose due to the stray radiation and an effective dose due to releases of radioactive substances into the environment. Whilst the former component can be estimated directly from readings of the stray radiation monitors, the latter can only be evaluated by using environmental models. The models used at CERN [(8,9)] are based on the Swiss directive HSK-R-41 [(10)] and on the IAEA Safety Report No. 19 [(11)].

For the sake of simplicity only effective doses to members of the critical groups of the population are examined. The critical groups of the population consist of people who reside at places, which are most exposed to the stray radiation and to the emissions of radioactive substances.

[(8)] P. Vojtyla, Calculation of the effective dose to the public due to releases from the CERN Meyrin site implementing the Swiss Directive HSK-R-41, CERN/TIS-TE/98-20 (1998).
[(9)] P. Vojtyla, Models for assessment of the environmental impact of radioactive releases from CERN facilities, CERN-TIS-2002-013-TE (2002).
[(10)] Berechnung der Strahlenexposition in der Umgebung aufgrund von Emissionen radioaktiver Stoffe aus Kernanlagen, HSK-R-41/d, Hauptabteilung für die Sicherheit der Kernanlagen (HSK), Villigen (1997).
[(11)] Generic models for use in assessing the impact of discharges of radioactive substances to the environment, Safety Reports Series No. 19, IAEA, Vienna (2001).

1.4.1 Critical groups of the population

The critical group for the CERN Meyrin site is formed of border guards working at and living close to the Swiss-French border near the main entrance to the site (CGPM in Figure 1.1). The principal ventilation outlet for this group is the ISOLDE ventilation stack. The critical group of the population for the CERN Prévessin site consists of persons working in a waste dump adjacent to the southwest end of the site (CGPP in Figure 1.2). The principal ventilation outlet for this group is the ventilation stack of the air extraction from the transfer tunnel TT20 [(8)].

For releases of radioactive substances to watercourses, a general critical group of the population was identified. It consists of members of the public from Pays de Gex and the neighbouring Geneva region who may use water of the rivers Nant d'Avril and Le Lion [(8)]. Members of the critical groups defined in the previous paragraph belong also to the general critical group for water releases.

1.4.2 Effective doses due to the stray radiation

The monitoring station PMS163, which is located in the vicinity of the border guard stands, recorded an annual net ambient dose equivalent of 93 μSv. The border guards spend in this area their working time, whilst the rest of their time they reside away from the site borders where the exposure due to the direct radiation is negligible (e.g. in their houses). Hence an occupancy factor of 0.23 corresponding to 2000 working hours per year can be assumed. This leads to the annual effective dose of less than 21 μSv. The widely accepted assumption was made that the ambient dose equivalent estimates the effective dose due to external exposure conservatively.

Similarly, for the critical group specific to the CERN Prévessin site, an exposure only during the working hours is considered. The annual ambient dose equivalent measured by the station PMS805, which is located at the fence of the waste dump, was 62 μSv. An upper estimate of the effective dose due to stray radiation of 14 μSv is obtained for this critical group following the same reasoning as in the previous paragraph.

1.4.3 Effective doses due to the releases of air and water

Table 1.13 presents effective doses per unit released activity (Sv/Bq) to the above-mentioned critical groups of the population for various radionuclide categories. It further gives, for each radionuclide category, the total activity released and the corresponding effective doses. To simplify the calculation, all activities released from the CERN Meyrin site were added together and considered as released from the ISOLDE ventilation stack. This approach is conservative because the effect of releases from ISOLDE on the given critical group is at greatest [(8)]. Radionuclide categories are represented by critical radionuclides, which are given in parentheses and to which the quoted effective doses per unit released activity apply. A similar approach was taken also for the critical group of the population specific to the CERN Prévessin site and SPS. Activities released from the SPS sites were added to those released from the ventilation of TT20.

The effective doses due to releases of radioactive substances into the environment are about one order of magnitude lower than those due to the stray radiation. The effective dose from releases of short-lived radioactive gases clearly predominates in the total effective dose caused by releases of radioactive substances (>88%). In addition, more than 80% of this effective dose component is because of an external exposure (radioactive plume), which is detected also by the stray radiation monitors, and hence, at least a part of it is taken into account two times in Table 1.13. The effective doses resulting from discharges of radioactive substances into the rivers Nant d'Avril and Le Lion were roughly the same and negligible. The higher value of 41 nSv, which is valid for the river Le Lion, was assumed for the critical groups specific to both the CERN Meyrin and Prévessin sites, as it is impossible to identify the river from which members of the two groups may use water.

In 2003 nobody from the public received an effective dose due to activities carried out on the CERN sites, which would be greater than 25 μSv. This value makes 8% of the regulatory limit defined in the CERN Radiation Safety Manual [(1)].

Table 1.13 Breakdown of effective doses received by the critical groups of the population in 2003 (*R* – activity released, *D* – dose per unit released activity, *E* – effective dose).

Radionuclide category	**CERN Meyrin site / Nant d'Avril**			**CERN Prévessin site / Le Lion**		
	R (GBq)	*D* (Sv/Bq)	*E* (μSv)	*R* (GBq)	*D* (Sv/Bq)	*E* (μSv)
Emissions						
Tritium (water vapour)	170	5.7×10^{-20}	0.0097	17.0	3.8×10^{-19}	0.0065
^{7}Be	0.30	1.9×10^{-17}	0.0056	0.017	1.6×10^{-16}	0.0028
Short-lived gases (^{11}C)	9600	3.4×10^{-19}	3.3	1380	5.5×10^{-19}	0.76
Other β/γ (^{60}Co)	0.0100	1.5×10^{-14}	0.15	0.00073	1.2×10^{-13}	0.088
Radioactive iodine (^{126}I)	0.0088	5.6×10^{-16}	0.0049	–	–	–
Alpha emitters (^{212}Pb)	0.0105	4.3×10^{-16}	0.0045	–	–	–
Total from emissions			**3.4**			**0.86**
Water releases						
Tritium (HTO)	6.3	9.5×10^{-20}	0.0006	38	9.5×10^{-20}	0.0036
Other β/γ (^{22}Na)	0.041	7.1×10^{-16}	0.029	0.053	7.1×10^{-16}	0.037
Total from water releases			**0.030**			**0.041**
Stray radiation			**21**			**14**
Total from all sources			**25**			**15**

2 Occupational exposure

Thomas Otto

2.1 Introduction

The Individual Dosimetry Service of the RP group is monitoring the exposure to ionising radiation of persons working at CERN with passive dosimeters. Every person working in controlled radiation areas at CERN, irrespective of his category (Table 2.1) must wear a dosimeter issued by this service. Category "Staff" comprises only CERN staff members with employment contracts of at least 3 years duration. Users (i.e. visiting scientists), unpaid associates, fellows, doctoral students, technical students, summer students, etc. are summarised in category "Users/Temporary". Contractor's personnel finally is summarised in category "Contractor".

Table 2.1 Category of people working in CERN controlled radiation areas.

Category	Definition
Staff	CERN Staff members with contracts of at least 3 years duration
User/Temporary	Users, unpaid Associates and Fellows, Doctoral Students, Technical Students, Summer Students
Contractor	Personnel of contractors working for CERN

According to laws in the Host States, persons working in a controlled radiation area need a specific authorisation; they have to present a medical fitness certificate, proving that no medical reasons speak against an exposure to ionising radiation. At CERN, receiving a passive dosimeter constitutes a de-facto authorisation to work in a controlled radiation area. Indispensable requirements for obtaining a dosimeter are therefore a valid contract with CERN and a recent medical fitness certificate. The strict application of these rules has led to an important reduction in the numbers of monitored personnel and distributed dosimeters (see section 2.2)

2.2 Statistics

Table 2.2 and Figure 2.1 show the number of individuals monitored with at least one dosimeter in the report year in comparison to the regularly monitored persons, i.e. persons receiving periodically a new dosimeter. The difference between the two figures is a measure of the fluctuations in monitored personnel. The number of monitored personnel has decreased by 6% due to a reduced research activity at CERN during the construction of the LHC.

The number of dosimeters distributed during 2003 follows approximately the trend of monitored personnel with 11264 neutron dosimeters and 27103 gamma dosimeters. Many users with irregular, short stays at CERN do no longer receive periodically a passive dosimeter but they fetch a one-off dosimeter under the short-term visitor status. Figure 2.2 shows the number of dosimeters distributed annually as of 1991.

The collective dose of personnel working at CERN has more than doubled with respect to 2002. It amounts to 544.4 person-mSv during 2003. This rise is due to an increase in the scheduled maintenance programme of the accelerators, but also to dose-intensive interventions for urgent repairs in some of the installations (see chapter 3). Out of the collective dose, 1480 monitored CERN staff members received 215 person-mSv, 3215 users of collaborating institutes 137.9 person-mSv and 951 employees from firms working on the CERN premises 191.5 person-mSv. The collective dose equivalents for the years 1991-2003 are listed in Table 2.3 and plotted in Figure 2.3.

The neutron dose has been reduced to zero by using a dosimeter that is not biased by a high background effect. With hindsight one can conclude that a large fraction of the neutron dose equivalents recorded in the past were false positives provoked by background.

Usually, collective dose equivalent is used as an indicator for the effectiveness of the radiation protection programme in an organisation. However, this requires that the activities of the organisation are stable or repetitive every year. This is not the case at CERN and collective dose equivalent mainly reflects the level of workload in controlled radiation areas, which varies depending on the experimental programme and on the maintenance schedule of the accelerators.

Table 2.2 Personnel monitored during the year and on 31 December of every year. The difference between numbers is a measure of personnel fluctuations.

Year	**Personnel**	**Regulars (End-of-Year)**
1991	6101	4914
1992	6456	5303
1993	6492	5351
1994	6948	5174
1995	6800	5269
1996	7220	5155
1997	6736	4967
1998	7039	5028
1999	7048	5000
2000	7195	4958
2001	7080	3661
2002	5977	3764
2003	5646	3372

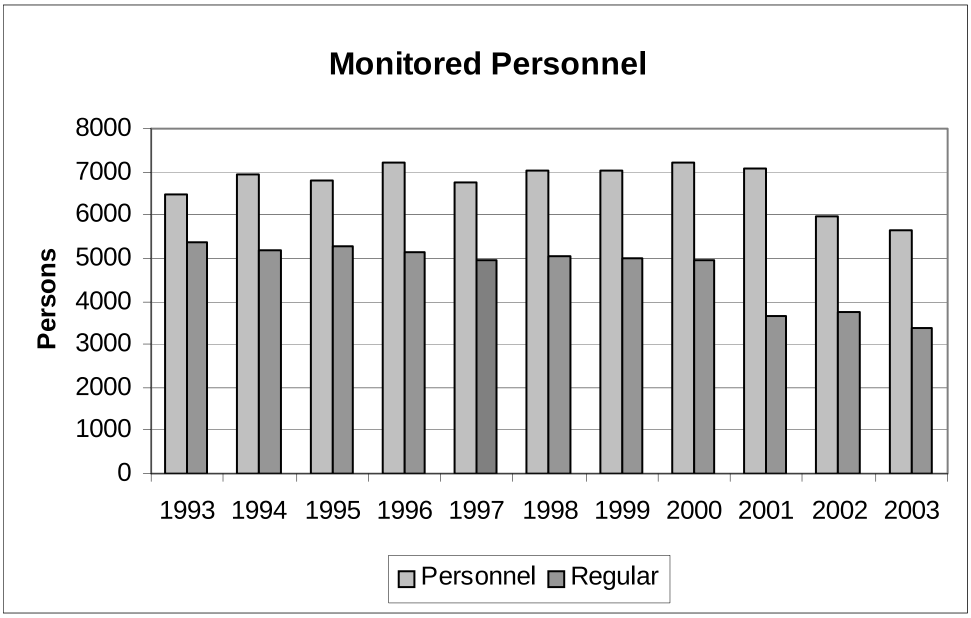

Figure 2.1 Evolution of monitored personnel and monitored personnel with a regular distribution of dosimeters present on 31 December of the report year. The difference is a measure of the fluctuations of the number of monitored personnel.

Personal dose equivalent can be classified in intervals, as required for the Swiss National Register of Occupational Doses. Table 2.4 shows that the vast majority of monitored personnel were exposed to less than the detection limit (0.2 mSv for both dosimeter types) in any monitoring period. A further, large group of personnel received dose equivalents under 1.0 mSv. This further supports the observations made on the reduction of collective dose. These data are represented in graphical form in Figure 2.4.

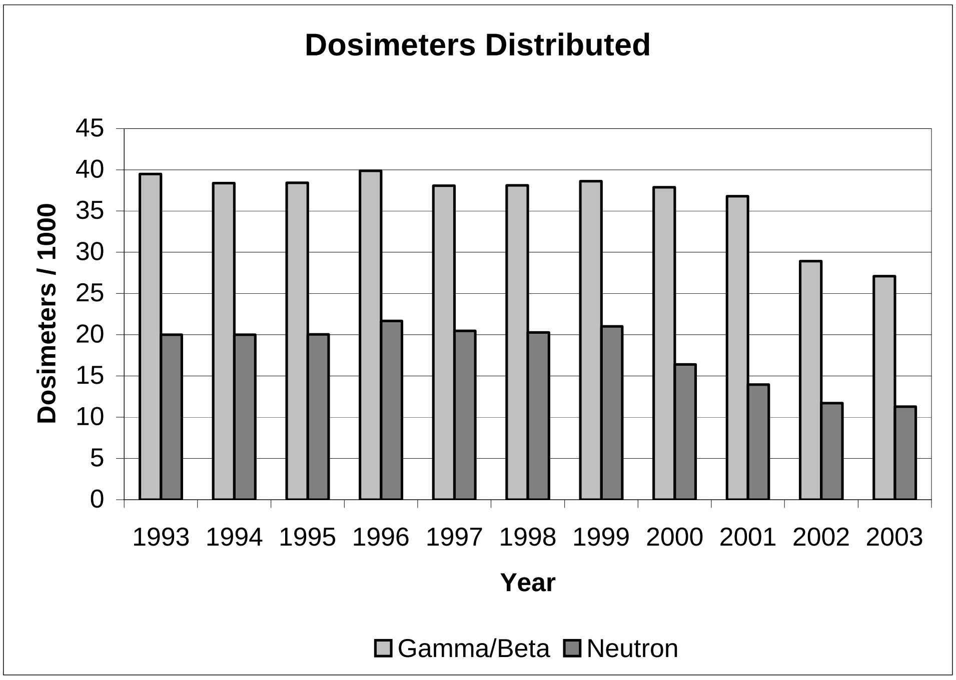

Figure 2.2 Number of dosimeters distributed throughout the report year.

Table 2.3 Collective dose equivalent for personnel monitored in the report year in person-mSv.

Year	Total (person-mSv)	Gamma/Beta (person-mSv)	Neutron (person-mSv)
1991	1587	1252	335
1992	1976.5	1558.9	417.6
1993	1259	919	340
1994	1232	834	398
1995	1378.2	893.3	484.9
1996	1452	1183	269
1997	1327	900	427
1998	1266	684	582
1999	857	634	223
2000	942.9	729.3	213.6
2001	468.5	430.6	37.9
2002	241	241	0
2003	544.4	544.4	0

Only two persons are left who received a lifetime dose equivalent in excess of 200 mSv. One, aged 54, received a total of 238.8 mSv, the other, aged 64, 236 mSv over their career. Exposures leading to such levels of lifetime dose do no longer routinely occur at CERN and these persons are the last highly exposed individuals still active at CERN.

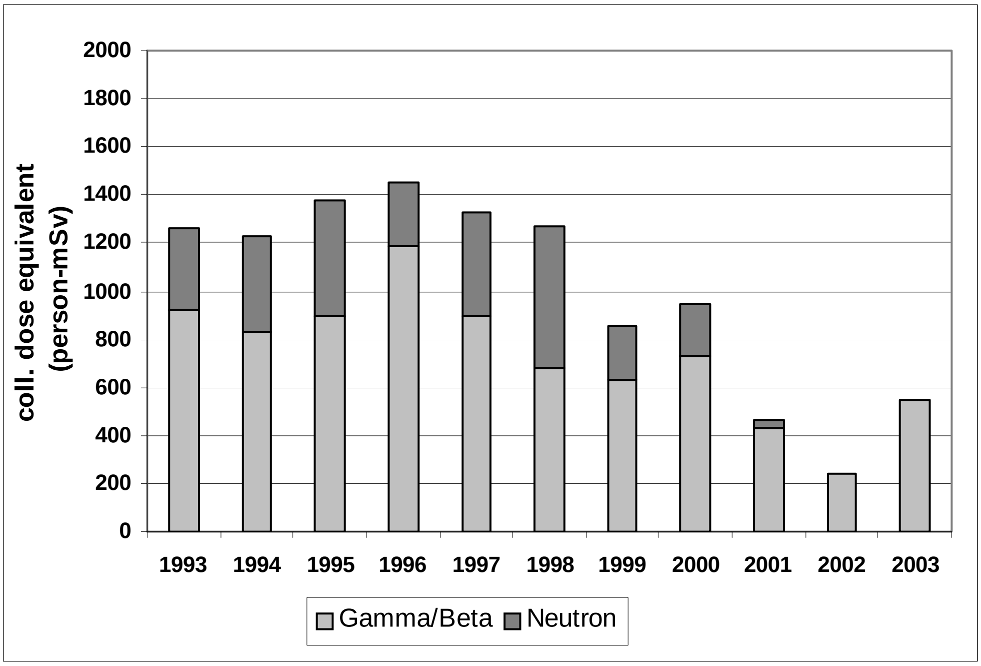

Figure 2.3 Evolution of collective dose equivalent for personnel monitored in the report year in person-mSv. The decrease of collective neutron dose equivalent is due to the subtraction of natural background (1999) and to the introduction of a technically more advanced dosimeter (2001). The collective gamma dose reflects the level of work activities in controlled radiation areas.

Table 2.4 Distribution of personal annual dose equivalent as of year 2000 in intervals of increasing dose.

Dose interval (mSv)	Number of individuals (2000)	Number of individuals (2001)	Number of individuals (2002)	Number of individuals (2003)
0.0	5502	6328	5842	4495
0.2-0.9	1428	511	343	899
1.0-1.9	79	64	41	45
2.0-2.9	33	32	8	20
3.0-3.9	18	10	4	14
4.0-4.9	17	7	0	7
5.0-5.9	6	5	0	0
6.0-6.9	8	1	2	1
7.0-7.9	3	0	0	1
8.0-8.9	1	1	0	1
9.0-9.9	0	0	0	0
10.0-10.9	1	0	0	1
11.0-11.9	0	0	0	0
12.0-12.9	0	0	0	1
>13.0	0	0	0	0

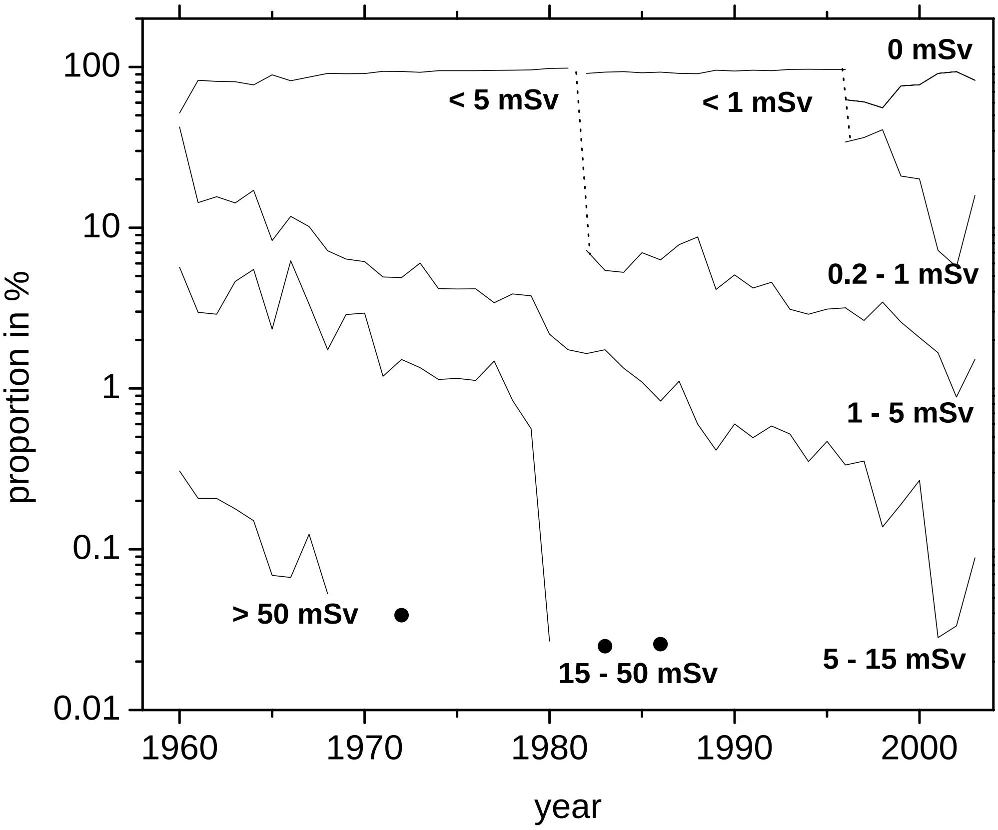

Figure 2.4 Proportion of monitored personnel in annual personal dose equivalent intervals. The lowest interval was subdivided from 1982 respectively 1996 on to provide better legibility.

3 Operational radiation protection at accelerators and in experimental areas

Doris Forkel-Wirth, Jean-Claude Gaborit and Thomas Otto

3.1 Introduction

Monitoring of radiation levels on the CERN sites and of the doses received by individuals is carried out routinely both during accelerator operation and during shutdown periods. This chapter summarises the major interventions that involved some doses to individuals and the induced radioactivity in the CERN accelerators measured during the ring surveys. Several planned interventions foreseen during the shutdown 2002/03 were deferred to a later date in order to make financial economies.

The ISOLDE consolidation project, which included an improvement of operational radiation protection, has continued with the active involvement of RP. The plans for upgrading the present target production and handling facilities have been completed and received approval from the Swiss authorities. The installation is due to start in February 2004.

Some experiments at the n-TOF facility included the use of actinide targets within a neutron detector. The RP group assisted in defining the strict safety measures required in order to obtain several exceptional authorisations from the Swiss authorities for the use and handling of such targets. The targets for one detector were imported from Russia and mounted at PSI into a sealed detector for use at CERN.

The CTF3 preliminary phase was terminated and the following one (called CTF3 initial phase) started. The whole 350 MeV CTF3 linac and part of the combiner ring were dismantled in the course of 2002. The 2002/2003 winter shutdown saw the start of the installation of the CTF3 injector, which was tested up to an energy of 66 MeV during 2003. Due to the high beam current, voluminous beam dumps were required for this accelerator and numerous radiological controls in the accessible areas around the installation were performed during operation.

Like every year, the target area TDC2/TCC2 of the SPS complex required special attention. The major shutdown jobs included the exchange of the TAX on the H6 beam line and the exchange of the fire detection system. During the physics period many interventions due to water and vacuum leaks became necessary. Consequently, the Accelerator and Beam Department (AB) established a consolidation project for this area. Parts of the necessary maintenance jobs have already started or are under preparation.

A major milestone for the LHC, the ejection of the SPS beam into TT40, was achieved. These tests required profound theoretical RP calculations and numerous technical RP precautions. The RP measurements during and after the tests clearly demonstrated that the tests were carefully planned and performed. They were optimised with respect to potential radiological risks and consequently no radiological problem intervened.

3.2. PS accelerator and injectors

3.2.1 Shutdown work and interventions in 2003

During the 2002/2003 shutdown, two highly activated septa (in sections 57 and 58) and the internal dump (in section 48) were replaced. In an attempt of cost reduction, only minor maintenance work was performed during this shutdown.

At the end of the shutdown it was detected that two PS magnets (the so-called “main units”) were defective, as their electric insulation had become brittle after nearly 45 years of service. Two spare magnets could replace them, but it became clear that a magnet revision programme had to be envisaged with the aim of replacing the coils of all 100 PS main units. The revision programme will start in the long PS shutdown from November 2004 to April 2006 with the successive renovation of 40 main units; the remaining units will be refurbished in the following years.

The ring survey, a mapping of dose equivalent in 40 cm distance from the two ends of every main unit, is of help in planning such interventions. The survey provides a first estimate of the expected dose equivalent rates and job doses for a particular intervention in the PS or in the PS Booster.

The result of the ring surveys performed during the last shutdown (2003/04) is shown in Figure 3.1. The black area between the data from the beginning and the end of the shutdown demonstrates how much dose can be saved by performing a task towards the end of the shutdown rather than at its start. Every year, the highest dose rates are observed in the injection regions (around sections 42), close to the ejection septa to the East Hall (section 58) and to the SPS (sections 31 and 16). Here additional induced radioactivity is produced every year. Consequently, the activity decreases by an important factor during the shutdown, up to a factor of 2. In other sections of the PS rather long-lived isotopes contribute to the activity and the reduction in dose rate over the duration of a shutdown is less important.

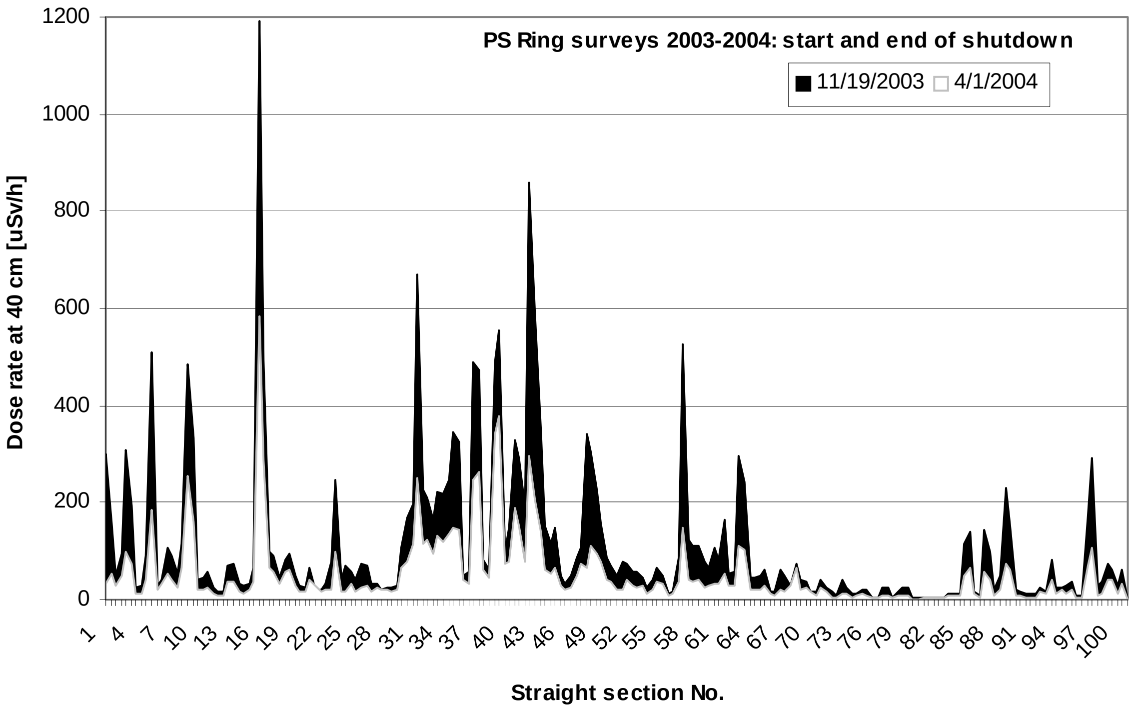

Figure 3.1 Results of the two dose equivalent rate surveys in the PS ring at the beginning and at the end of the 2003/04 shutdown. The dose rate decreased by up to a factor of two over the duration of the shutdown.

3.2.2 Operational dosimetry

An overview of the most important interventions in the year 2003 is given in Table 3.1. Figure 3.2 shows the distribution of operational doses, measured with electronic dosimeters of types DMC 100 and DMC 2000 S, in the PS complex including ISOLDE.

While operational doses accumulated in the PS accelerator, in the Booster, in the LINACs and in other areas were smaller by 5% to 40% than in the previous year, owing to the reduced maintenance schedule, the operational dose at ISOLDE has nearly doubled and the total for the PS complex is approximately 10 % higher than in 2002 (Table 3.2).

Table 3.1 Summary of the most important interventions in the accelerator, target areas and accelerator areas of the PS complex in 2003.

Area	Intervention	Date	Number of persons involved	Collective dose equivalent (person-μSv)	Protective equipment
PS	Removal of septa 57 and 58	9.1	n.a.	n.a.	
ISOLDE	Exchange of faraday cup in GPS	28.1	3	16	
PS	Repair of internal dump	15.1 – 30.1		n.a.	
ISOLDE	Production of Th-C and U-C targets	February	2		Overall and mask
ISOLDE	Exchange of a turbo molecular pump on GPS	10.2	5	417	Overall and mask
ISOLDE	Repair of a shutter on GPS	27.2	2	103	
ISOLDE	Repair of a valve on HRS	7.3	2	178	
ISOLDE	Cleaning of Faraday cages	12.3	12	1033	Overall
PS	Radiological measurement of two main units in view of their removal	21.3	1	n.a.	
ISOLDE	Transport of spent targets to ISR	27.3	7	147	
ISOLDE	Repair of door to GPS Faraday cage	7./8.4	2	318	
ISOLDE	Test of extraction electrodes	16.4	3	356	Overall and mask
ISOLDE	Diagnosis of HV leaks on HRS front-end, including its removal, dismounting and reinstallation	May-September	15	6570	Overall and mask when required
EAST	Cooling problems on magnet T10.QDE01	9.7	6	400	
PS	Leak detection and repair in sections 80-89	17.7	6	186	
TT2	Change of CCD cameras	17.7	2	n.a.	
EAST	Cooling problems on magnet T10.QDE1	20.8	1	100	
EAST	Short circuit on magnet FT61S.BHZ01	28.8	5	579	
n-TOF	Mounting of targets in FIC-0 detector	8./9.9	3	-	Overall
n-TOF	Mounting of FIC-0 and PPAC detectors in beam line	18.9	5	-	
n-TOF	Reception of additional targets for PPAC detector, contamination incident	16.10	2	400 (internal dose)	
n-TOF	Mounting of new targets in PPAC detector	20.10/30.10	3	-	
n-TOF	Mounting of FIC-1 detector in beam line	31.10	3	-	

3.3 ISOLDE

3.3.1 Work during the 2002/2003 shutdown

During the annual shutdown, different types of routine maintenance work were performed. These interventions included the exchange of contaminated roughing pump oil, the exchange of extraction electrodes and Faraday cups on the separators and the cleaning of the Faraday cages

At the end of the shutdown, 14 spent isotope production targets were transported to the intermediate storage area in the former ISR tunnel. The capacity of this storage will be exhausted with the spent targets from operation in 2004. A new storage area, complying with technical requirements for the storage of unsealed radioactive sources has to be prepared before irradiating targets in 2005.

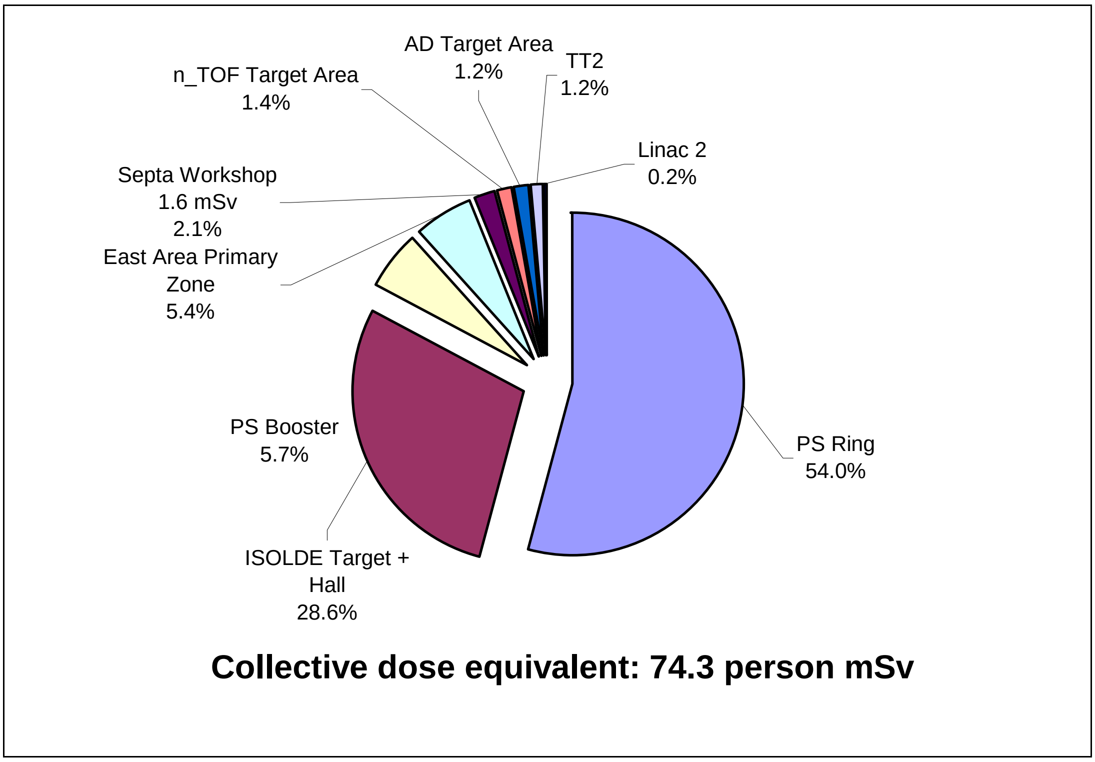

Figure 3.2 Collective dose equivalent in the PS complex during 2003.

Table 3.2 Development of collective dose equivalent (measured by operational dosimetry) in various areas of the PS complex.

Area	Collective dose 2002 (person-mSv)	Collective Dose 2003 (person-mSv)
PS ring	42.4	40.1
PS Booster	7.1	4.2
Linac 2,3	-	0.2
East Area	5.0	4.0
AD target area	1.2	0.9
n-TOF target area	1.2	1.0
Transfer tunnels	-	0.9
Workshops	-	1.6
ISOLDE	11.9	21.3
Total	**68.8**	**74.3**

3.3.2 Interventions during ISOLDE operation

Immediately after taking up operation with proton beam in May 2003, front-end #3 on the HRS separator showed signs of high voltage leaks. Owing to the small number of protons on target at that moment, the ambient dose equivalent rate at the front end was only moderately higher than at the end of the shutdown and the ISOLDE technical group AB/ATB decided to perform a fault analysis and to attempt a repair. For this purpose, the front end was removed from the separator and brought into a workshop, which had been prepared with contamination barriers. The fault analysis and repair attempts resulted in a collective dose equivalent of 6.57 person-mSv, exceeding the projected dose by nearly 50% due to a number of complications arising during the repair. After re-installation of the front end, it became obvious that the source of the high voltage leaks was not related to the front end itself but to its cooling water connections, located in an area with insignificant dose rates. With hindsight one has to say that a more careful analysis of the possible faults could have resulted in a significantly lower dose for all participants in the intervention.

During an experimental run with the REX-ISOLDE post accelerator, large quantities of the radioactive isotope ^{88}Kr ($t_{1/2}$= 2.84 h) were produced and streamed from the target into the beam line system. The gas was not ionised and a significant amount of it was pumped by the vacuum system. The RP group became aware of this fact by observing an increased dose rate on a radiation monitor close to REX-ISOLDE. A dose rate measurement at the roughing pump of REX-ISOLDE revealed a contact dose rate of 35 mSv/h. The access to the roughing pump and to the passageways in its vicinity were fenced off as a “limited stay area” until the dose rate had decreased to acceptable values. The activity trapped in the pump oil was estimated to 3.4 GBq, but an unknown quantity may have been released into the experimental hall. The RP group recommended connecting the roughing pump to the ventilation system in order to prevent future accidental releases of radioactive gas into the experimental hall.

3.3.3 Radioactive releases, operational dosimetry

Releases of radioactive aerosols and gases are measured with a ventilation monitor coupled to a flow meter. The ventilation monitor is calibrated for the activity concentration of tritium gas (^{3}H). Multiplication of the sampled concentration with the total flow yields the total accounted radioactive release from ISOLDE. Gamma spectrometry analysis of air samples from the ventilation gives additional information on the real isotopic composition of the releases. ISOLDE is equipped with a stack, which is too low to assure laminar flow conditions, indispensable for accurate flow measurement and representative sampling of releases. A measurement of the geometrical distribution of air flow in the stack demonstrated that the flow is very inhomogeneous and that neither the flow meter nor the sampling point are situated at representative positions. A series of independent measurements of activity concentration in the ventilation ducts showed that the releases might be higher than presently accounted for. Possible improvements have been recommended to the AB department, including a prolongation of the stack to assure laminar airflow and the exchange of the particulate filters with a type with higher retention capability.

Due to a vacuum leak in one of the front ends, large amounts of air were pumped into the retention balloons. It was decided to release the contents of one of the balloons prematurely a few days after this incident, leading to a radioactive release of 24.3 GBq of ^{3}H-equivalent, a number which has to be compared to the typical 10 GBq ^{3}H-equivalent which are normally released from the retention tanks after 6 months of operation and 6 months of radioactive decay.

In 2003, operational dosimetry was performed with electronic dosimeters for every intervention at ISOLDE. The collective dose is 21 person-mSv, divided equally between the shutdown and the operational period (Figure 3.3). For comparison, the operational period 2002 led to a collective dose of 2.4 person-mSv (out of the total of 11.9 mSv shown in Table 3.2); the excess can be attributed to the attempted repair of the HRS front-end #3. The dose equivalent is concentrated on a few specialised operators, the person with the highest exposure having received 4.5 mSv during 2003. A recommendation to AB suggests training more operators in order to share the dose equivalent more equally.

3.3.4 ISOLDE consolidation programme

The consolidation programme for ISOLDE includes an extension of the target handling area in building 179 in order to accommodate all manipulations with new and irradiated targets in appropriate work sectors. In 2003, the plans for the building were finalised in agreement with specialists from the *Office Fédéral de la Santé Publique* (OFSP), the Swiss authority in radiation protection matters. Construction work was supposed to start late in 2002, but it was delayed due to administrative problems. The tentative schedule foresees termination of the building by February 2005, allowing the removal of all radioactive workshops from buildings 3 and 26.

During the 2002/03 shutdown the experimental hall (Bldg 170) was equipped with an access control system. From now on, only authorised personnel have access to the ISOLDE hall. Proper authorisation requires a valid registration at CERN, an access request approved by the ISOLDE coordinator and a valid personal dosimeter. An access control to the ISOLDE hall is justified by certain experimental activities: the collection and manipulation of radioactive samples is causing a permanent contamination hazard and the operation of the separator and the beam transport system is frequently at the origin of areas with increased dose rates in the experimental hall.

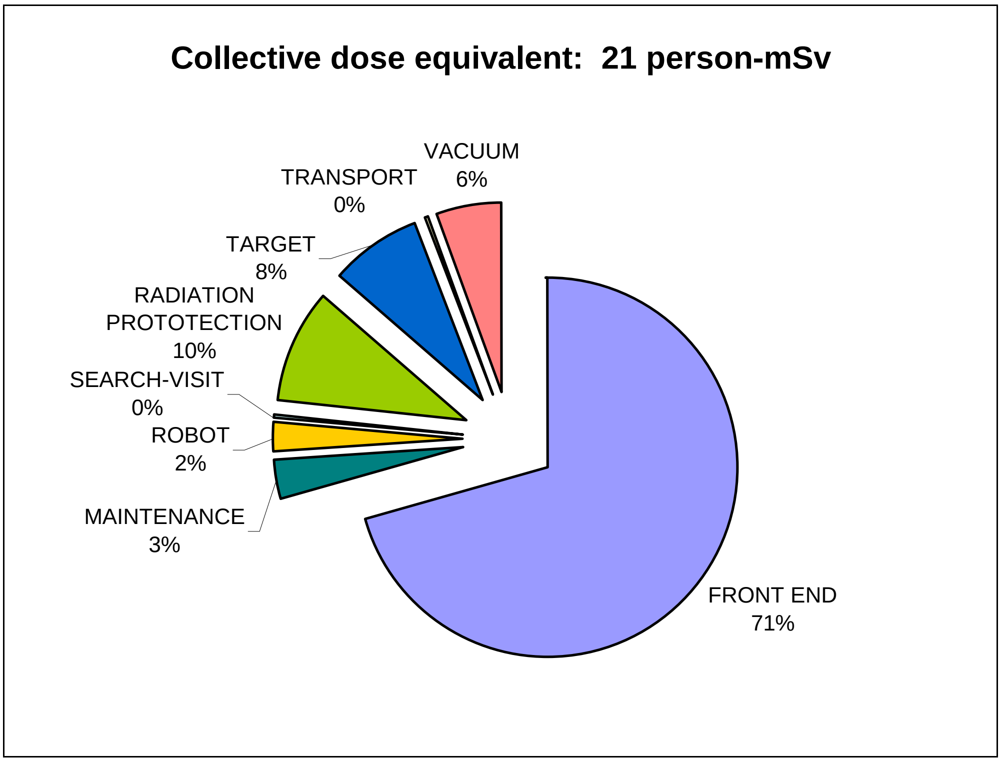

Figure 3.3 Collective dose received for various tasks during the ISOLDE annual shutdown and operation in 2003. The diagram covers the period 1 January 2003 to 31 December 2003

3.4 n-TOF

The experimental programme of n-TOF focuses on the determination of neutron capture and fission cross sections of interest for future scenarios of nuclear energy generation or nuclear waste management. The isotopes of interest are either actinides or transuranium elements, alpha emitters with very high radiotoxicity. Isotopic targets for neutron capture experiments can be prepared as sealed radioactive sources [(1)], but this is not possible for fission measurement targets.

In a first series of experiments in 2002, targets with an activity exceeding the authorisation limit by a factor of 15000 were mounted in a specifically arranged work sector into a detector presenting some protection against loss of confinement. In 2003, the projected activity of the isotopic

(1) International Standard ISO 2919, Radiation Protection - Sealed radioactive sources, Geneva (1999).

targets exceeded the authorisation limit by a factor of more than 10^6. In agreement with the OFSP, a detector body corresponding to the technical requirements of the international standard was constructed. CERN is not equipped with laboratories where such an amount of unsealed activity could be handled. The detector body and the sources were transported to the Paul Scherrer Institute (PSI) in Villigen, Switzerland, where the detector was assembled, under the control of the Swiss nuclear authority, in a workshop normally reserved for handling irradiated nuclear fuel. In this configuration, the experiment could be conducted at the end of the measurement period 2003.

A second experiment received targets for fission cross section measurements with a smaller radiotoxicity for mounting at CERN. The transport to CERN was performed as an "exempted package", meaning that no specific danger should result from the radioactive contents of the package. Upon opening the package, two RP staff realised that the radioactive target material was attached very loosely to the supporting foils. An external contamination measurement of their hands and clothes showed a positive result. After repacking and securing the targets and thoroughly cleaning and controlling the laboratory, involving two further staff, it was decided to perform an internal dose measurement on the two persons involved in the incident. The radiological analysis of urine samples by the personal dosimetry service of the PSI in Villigen, showed a committed dose of E_{50} = 0.4 mSv respectively 0.1 mSv from inhalation of ^{233}U.

3.5 CLIC test facility

The CLIC Test Facility 3 (CTF-3) consists at the moment of a linear accelerator for electrons with end energy of 150 MeV. The facility will be extended in the next years by a delay loop, a combiner ring and an experimental area. The aim of the project is to demonstrate the feasibility of an acceleration mechanism for electrons using a low-energy, high intensity "drive beam" of electrons to transmit energy to a low intensity, high energy "pilot beam". The facility is constructed in the surface buildings of LIL and EPA, the former electron/positron injector and storage rings for LEP. The buildings have been sufficiently shielded for the assumed electron beam losses of LIL and EPA, with a power amounting to a few watts. Loss estimates for the 7.7 kW CTF-3 range in the hundreds of watts. Luckily, LIL and EPA have been constructed with a large safety margin of at least one order of magnitude. In spite of this, additional shielding estimates for CTF-3 are required to either show that the existing constructions offer enough protection or to request shielding upgrades or power limitations. In 2003, the size of a beam dump, absorbing the full beam power of 7.7 kW, was estimated with Monte Carlo radiation transport methods. The design criterion was that the klystron gallery on top of the accelerator building should remain accessible as a simple controlled radiation area. The dump was dimensioned such that estimated dose equivalent rates in the klystron gallery would not exceed 1 $\mu Sv\ h^{-1}$, providing sufficient safety margin to account for simplifications in the simulation model.

During 2003, the injector of CTF-3 and the first stages of the linear accelerator worked with a maximum energy of 66 MeV. The passages for RF wave guides, representing weak points in the roof shielding to the klystron gallery were identified, were filled with sand bags and reinforced with lead bricks where necessary.

3.6 SPS and experimental areas

3.6.1 Doses and major interventions

In 2003 the collective dose in the SPS complex (which includes the SPS, the target areas, the North and West experimental areas, the neutrino cave and the workshops) amounted to 123.39 mSv for 531 persons (to be compared to 261 mSv for 470 persons in 2001 and to 120.86 mSv for 370 persons in 2002). A large fraction of the doses was received during the 2002/2003 winter shutdown (from November 2002 to April 2003), that is 71.26 mSv (to be compared with 92.07 mSv in the 2001/2002 shutdown and 224.6 mSv in the 2000/2001 shutdown), with a maximum individual dose of 4.41 mSv. During the physics period of the North Area major interventions in the target area TDC2/TCC2 became necessary. The repair of numerous water and vacuum leaks caused a collective dose of 35.3 mSv with a maximum individual dose of 2.4 mSv. The Accelerator and Beams

Department (AB) reacted accordingly by establishing a consolidation project for this area. The main jobs within this project were either already performed during the shutdown 2003/2004 (continuation of the removal of PVC tubes, cleaning of the drains) or are scheduled for the long shutdown in 2005 (replacement of cables).

The collective dose is compared to those of previous years in Figure 3.4. Figure 3.5 shows the repartition of the collective dose in the various areas: the different zones of the SPS (BAs), the target areas (BDW, TDC2/TCC2 and TCC8). The breakdown of individual doses that were received around the SPS is shown in Figure 3.6. The most important interventions in the SPS ring, target areas and experimental areas are summarised in Table 3.3. When the collective dose for a given intervention was negligible, the number of people involved was usually not recorded.

3.6.2 Radiation surveys

In year 2003 the ring survey of the SPS was carried out on 11th November, as usual about 30 hours after the accelerator ended its operation with ion beams. Figure 3.7 gives a comparison with the results of 2002. As in the past, the most active areas were sextants 1, 2 and 6 (injection, extraction towards the North Experimental Area and extraction towards the West Experimental Area, respectively). The highest dose rate in LSS1, at about 1 m distance from the machine, was around 1 mSv/h in proximity of the injection elements, with a peak of about 8 mSv/h close to the internal dump (TIDV).

The radiation survey of the target areas was carried out on 10th December 2003, 30 days after the end of operation with indium ions and 80 days after the end of the proton run. The maximum dose rates were 1.3 mSv/h measured near the T1 target in TCC6 (11th November), 170 mSv/h between T6 and TCX in TCC2 and 17.5 mSv/h near the splitters in TDC2. In November the maximum dose rate measured in TCC8 was 1.1 mSv/h near the T10 target (60 days after the end of the proton run).

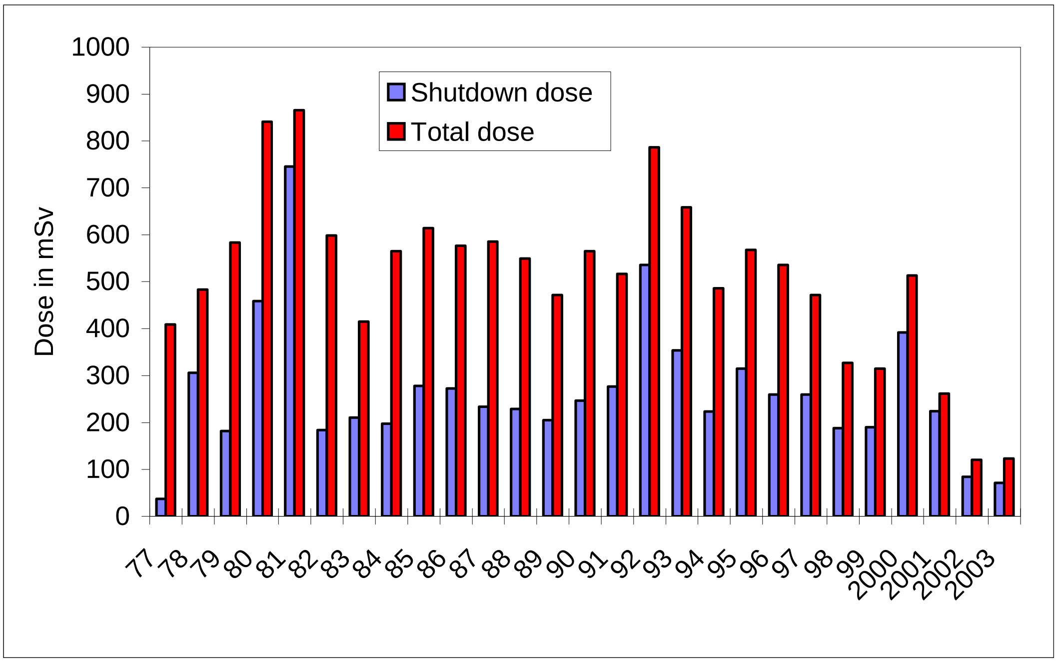

Figure 3.4 Collective dose for the SPS complex in the years 1977-2003.

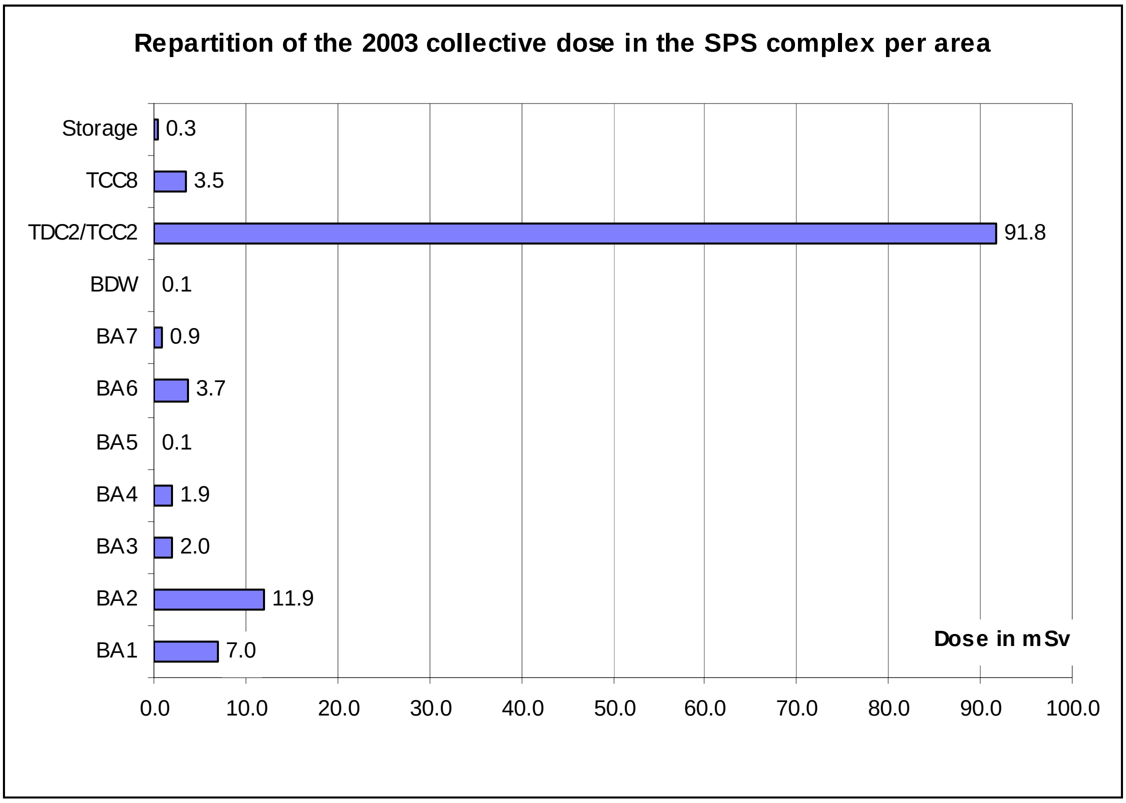

Figure 3.5 Repartition of the collective dose in the SPS complex per area in 2003.

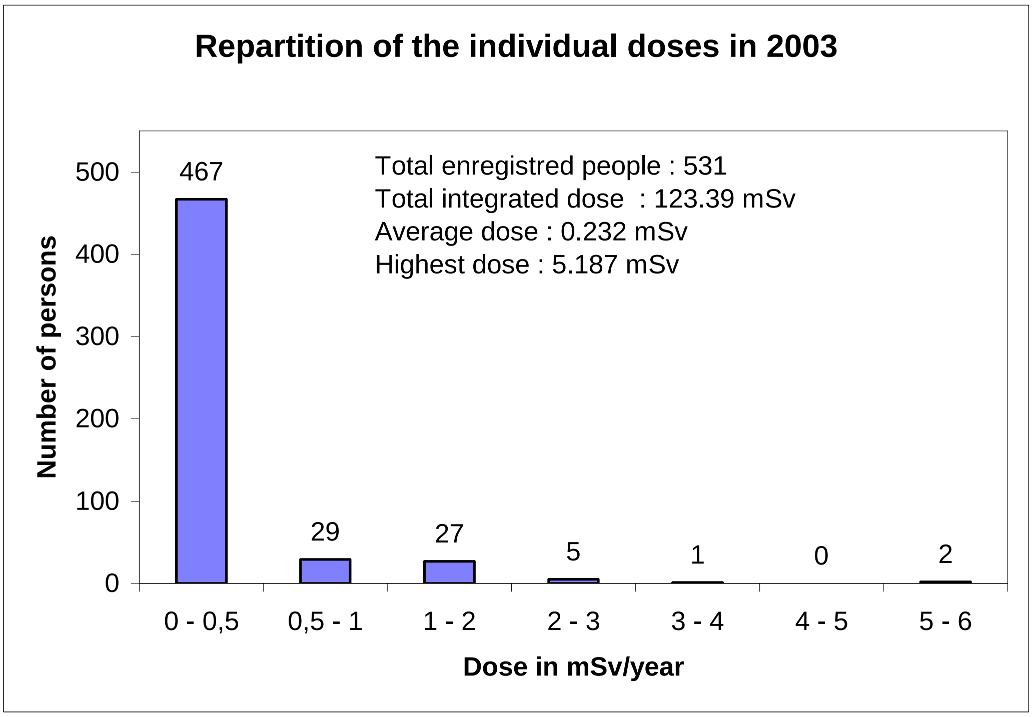

Figure 3.6 Breakdown of individual doses received at the SPS complex in year 2003.

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Table 3.3 Summary of the most important interventions and observations in the accelerator, target areas and experimental areas of the SPS complex in 2003.

Intervention	Description	Remarks	Collective dose
SPS	Short release of slightly radioactive air in BA1 during a MD dedicated to LHC tests	Reason: high intensity beam was stopped on TIDV in LSS1	
	General survey in experimental areas (west and north).	Radiation levels measured: natural background with exception of storage areas	
EHW1	Installation of 30 purity monitors containing each an ^{241}Am and a ^{207}Bi source in the ATLAS liquid argon detector	^{241}Am $\rightarrow$ 500 Bq ^{207}Bi $\rightarrow$ 18,5 Bq	
	Radiation field study next to beam line X5 (ATLAS clean room)	Improvement of shielding performed	
EHW2	Radiological control of 325 iron shielding blocks	152 blocks classified as non-radioactive, the rest remains classified as radioactive.	
EHN1	Contamination measurements campaign	No contamination detected	
	New layout for H8 beam line	Radiation protection measure-ments confirmed that the shielding layout of the beam line meets the radiation protection requirements	
TCC2/TDC2	Exchange TAX in H6 beam	Maximum in contact with TAX : 1.2 Sv/h	34 workers = 29.1 mSv max. individual 4.4 mSv
	Intervention on T6 target box	Exchange of switches and cables	4 workers = 2.58 mSv max individual 1.1 mSv
	Exchange of the fire detection system in TDC2	Reason: PVC tube is the source of corrosion on vacuum chambers	6 workers = 0.71 mSv max individual 219 µSv
	Water leaks in TDC2 and TCC2	Interventions of the fire brigade and RP	6.198 mSv max individual 831 µSv
	Vacuum leak in TDC2	13 to 22 mSv/h - hot spot between splitters and collimator	67 workers = 29.1 mSv max individual 2.4 mSv
TCC2/TDC2	Radiation damage tests for LHC equipments	21 accesses into TCC2 by RADWG	59 workers = 7.23 mSv max individual 724 µSv
TCC8	Installation of K12 beam line		Collective dose 3.5 mSv
TT40	Extraction tests		
Bldg 954	Control of contamination	Radioactive storage	
Bldg 867	Survey of the assembly hall	Survey of maintenance of radioactive equipments	
LHC	Control of material from the LHC tunnel (LEP material that has to be removed)	Regular radiological controls with the gate monitor	
Miscella-neous	Non destructive controls of material with radiography sources or X-rays	About 238 « avis de tirs » (around 200 days of radiography activities)	

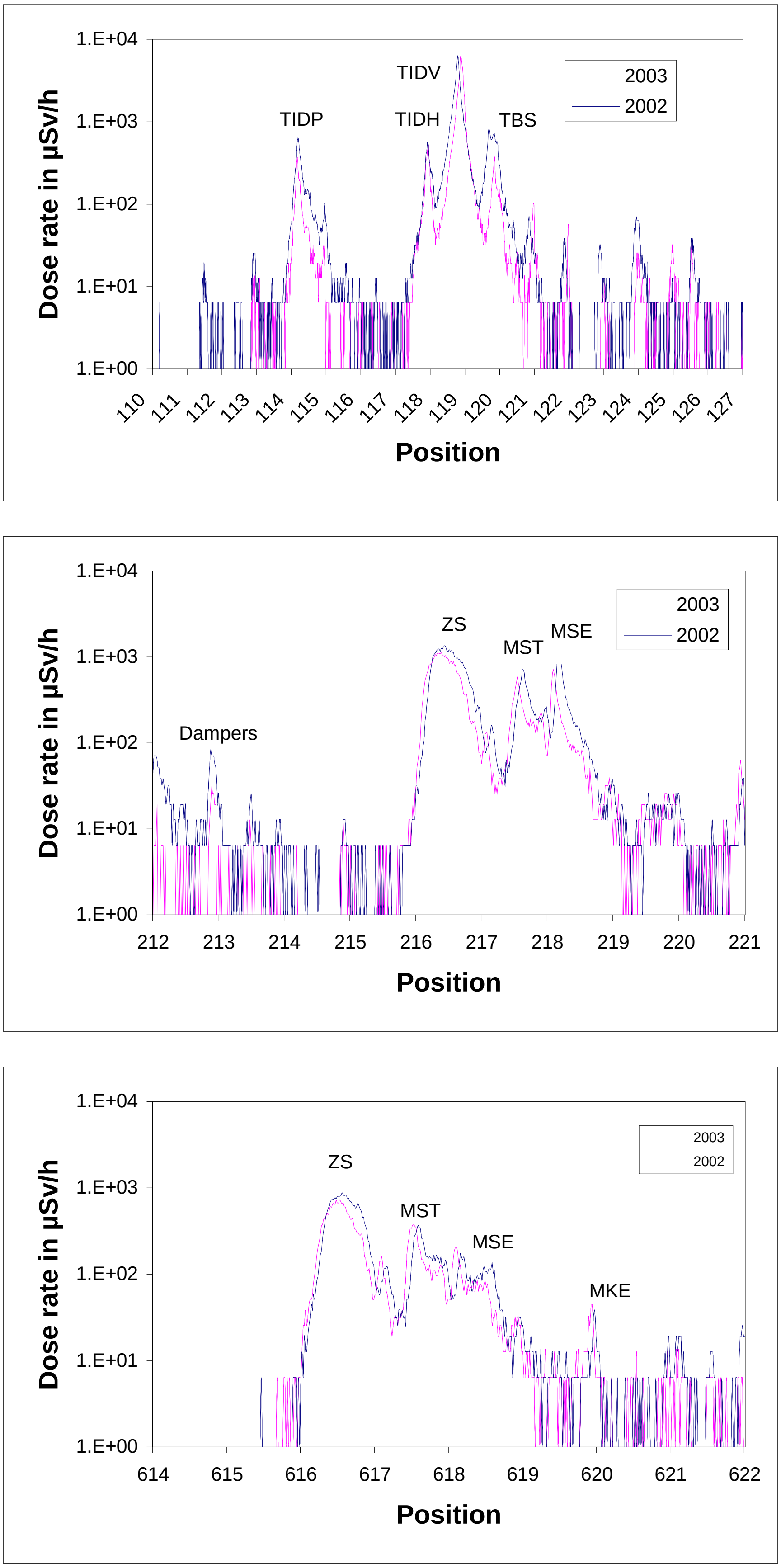

Figure 3.7 Induced radioactivity in sextants 1 (top), 2 (middle) and 6 (bottom) of the SPS in the years 2002-2003.

3.6.3 Ejection tests from SPS into TT40

In 2003 the ejection of the SPS proton beam into the transfer tunnel TT40 was tested for the first time. The transfer tunnel TT40 connects the SPS with the SPS-LHC transfer tunnel TI8 and the SPS-CNGS transfer tunnel TT41. The ejection tests took place on 8 to 9 September and on 8 to 9 October 2003. A proton beam with energy of 450 GeV and intensity of 5 to 10×10^9 particles per extraction was sent on the external beam dump TED 400354 in TT40. The total number of protons during these tests was 1.3×10^{13} for the September run and 1.4×10^{14} for the October run.

Careful radiation protection measurements were performed before, during and after the tests. The controls comprised dose rate measurements, TLD measurements with ^{6}Li and ^{7}Li, activation measurements of gold foils and of concrete samples. Since the tests were carefully prepared and optimized with respect to doses and dose rates present during and after the tests, the radiological consequences were minimal. No radiological problem was detected. Figure 3.8 shows the results of the dose rate measurements.

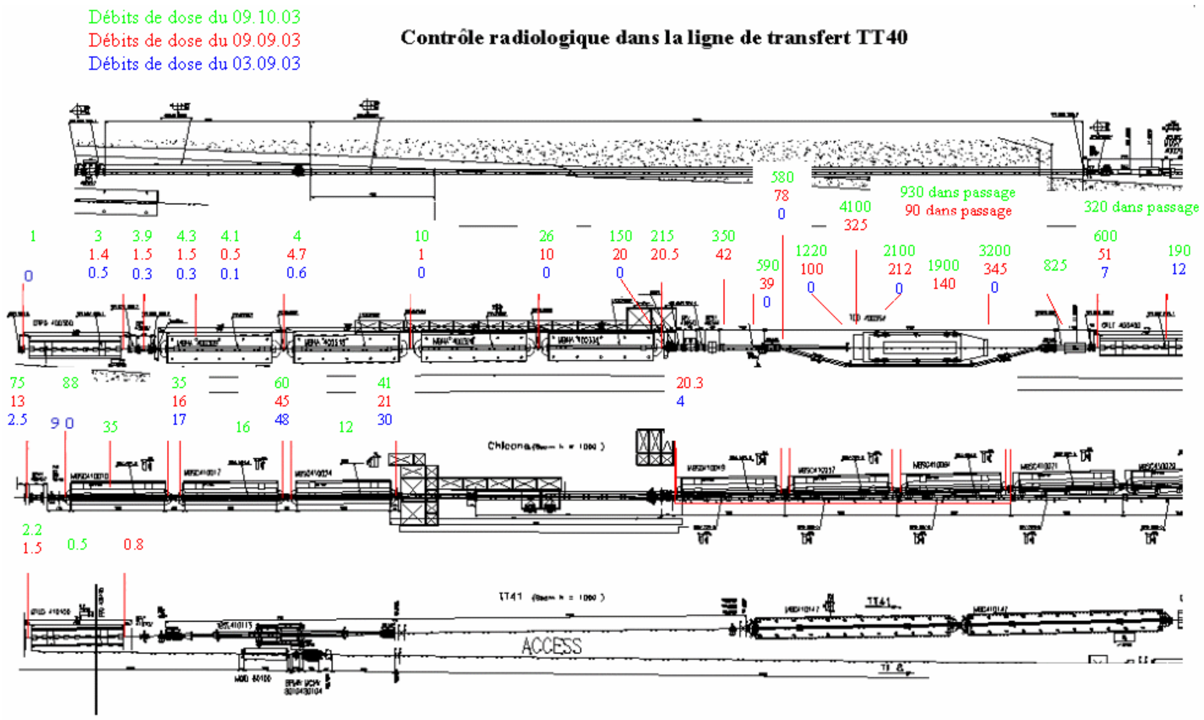

Figure 3.8 Results of the dose rate measurements before (3 September 2003) and after the two ejection tests SPS-TT40 in 2003.

4 LHC and CNGS projects

M. Brugger, D. Perrin, S. Roesler, M. Silari and H. Vincke

4.1 Introduction

The Radiation Protection group is heavily involved in several radiological studies for both the LHC and the CNGS projects. In year 2003 the main involvement in the LHC was the RAMSES project, but the group also contributed to the radiological impact studies for the LHC beam cleaning system and for beam losses on the TCDS diluter. A study was also performed on the radiological aspects of the use of Xe gas in the ATLAS inner detector. For CNGS, the remanent dose rates around the target station were assessed. Several radiological studies were also performed for the SPS/LHC-CNGS beam transfer lines, and an assessment was made for the shielding of LEIR, which will be part of the LHC injection chain for ion operation. The RP group also contributed to the LHC design report.

4.2 LHC

4.2.1 Radiological impact studies for the beam cleaning system

The LHC will require an extremely powerful and unprecedented collimation system. As about 30% of the LHC beam is lost in the cleaning insertions they will become one of the most radioactive locations around the entire LHC ring. Radiation protection forms a critical part of the design, especially for areas close to the collimators where interventions will become necessary. Thus, remanent dose rates to be expected at the intervention locations are considered already in the design phase.

As a consequence, the beam cleaning insertions form a unique test bed for a recently developed approach to calculate remanent dose rates [Brug03a, Roe03a]. A set of simulations, different in complexity, was used in order to evaluate methods for the estimation of remanent dose rates [Brug03d]. The scope as well as the restrictions of the omega-factor method was shown and compared to the explicit simulation approach (1). The latter was then used to calculate remanent dose rates in the beam cleaning insertions and include a representative example for maintenance and dose planning [Brug03e]. The latter included a complex and detailed geometry as shown together with a longitudinal dose rate distribution in Figure 4.1.

In addition, the completion of the collimation design and fundamental changes with respect to previous layouts require detailed studies of airborne radiation. Accurate estimates are of particular importance as at the locations of both cleaning insertions air is released into the environment, moreover, at one of them into a densely populated area. Estimates existed so far only for old designs of the accelerator, hence it was essential to revise these results and study carefully the radiological impact so to consider possible provisions.

It was shown that a simplified geometric model of the beam cleaning insertions can be used in order to calculate airborne radioactivity [Brug03c] (1). This is due to the fact that activation of air is mainly determined by the collimator itself and by the layout of the nearby shielding and downstream beamline elements. Other beamline components, usually located at rather large distance, are shadowed by those close to the collimator and therefore give only minimal contributions to the air activation. In an extensive comparison [Brug03c] (1) two collimator materials were studied, copper and beryllium, as well as two different total collimator lengths with respect to the cleaning insertions. For each configuration two simulations were performed, with and without a longitudinal iron shield of 20 cm thickness. In addition all scenarios were studied for different ventilation speeds, accounting for possible design adaptations.

Depending on the assumed configuration the total release of radioactive air would increase by a significant factor when compared to earlier calculations. Therefore, these new simulations and their dependence on changes in the layout of the beam cleaning insertion served as a basis for ongoing

(1) M. Brugger, The radiological situation in the beam-cleaning sections of the CERN Large Hadron Collider (LHC), Thesis, TU-Graz (2003).

environmental simulations, i.e. for calculations of annual effective dose to the critical group in the vicinity of the respective release point.

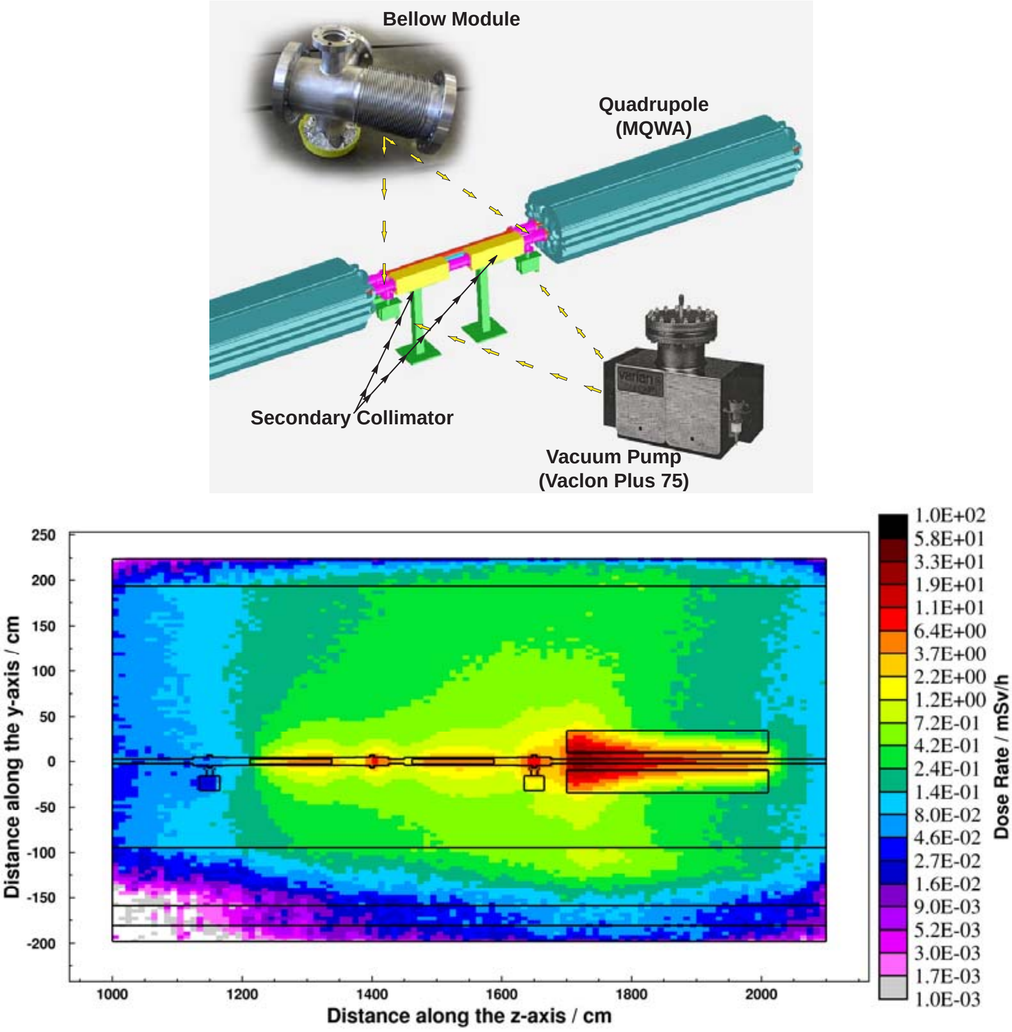

Figure 4.1 Three-dimensional representation of the region considered in this study together with the according remanent dose rate distribution after 180 days of continuous operation and one hour of cooling period. The latter is shown for a vertical section through the beam line containing the two collimators and vacuum pumps.

4.2.2 Radiological aspects of the use of Xe-gas in the ATLAS inner detector

The ATLAS experiment will use Xe gas (about 20 kg or 4 m^3) in its inner detector. The gas will be circulated during operation and 40% will be outside the active volume of the detector (about 2.4 m^3) at any given time (in pipes, racks, buffer volume and the recuperation system), in areas accessible by personnel. The ATLAS collaboration has performed an estimate of the induced radioactivity in the Xe and the RP group has assessed the radiation protection issues for the use, storage and elimination of the irradiated gas, has evaluated the radiological impact of the release of the entire gas volume in the ATLAS cavern and in the SGX1 building, as well as the potential exposure of the population in case of a full release in the external environment [Sil03d].

Some local shielding around the 60 l container, the buffer and the recuperation system will be needed to reduce exposure of personnel. In particular, 1 cm of lead will be necessary to shield the gas recuperation system, i.e. the bottle containing the 20 kg of Xe during the recovery operation.

Releasing the entire volume of radioactive gas in the ATLAS cavern and assuming that people will breathe the radioactive air for one hour will cause a total effective dose of about 5 µSv to an individual present in the cavern. As for a similar accidental condition in the SGX1 building, the committed dose will be about 60 µSv.

It has been estimated that the activation of xenon will not pose a serious radiological hazard to the public. In the unlikely event of an accidental release under the most adverse dispersion conditions, the total effective dose to any member of the public would not exceed 30 µSv. If such an accident would happen, the Safety Commission will check the vegetation around PA1 for contamination with ^{125}I, which dominates the dose, in order to confirm the prediction of the models used.

As most of the dose to the personnel and to the public would come from ^{125}I, the Safety Commission has recommended to include in the gas circuit, preferably behind the outlet from the detector, a permanent iodine absorber. This absorber would remove iodine from the gas circuit immediately after its production. In this way iodine contamination of the rest of the system would be avoided and the radiological impact of any leak or accidental release would be substantially minimized.

The iodine absorber will become contaminated because of the trapped ^{125}I. Under the assumption that the entire volume of gas would pass through it and that the total amount of ^{125}I (74 MBq) would be trapped, the dose rate at 10 cm distance from the absorber will be of the order of 10 µSv/h. No special precautions will be needed for handling the absorber. After its use the iodine absorber should be closed and kept for about one year before disposal (or reutilisation) to let ^{125}I decay.

A controlled release of the activated xenon gas to the outer atmosphere can be performed through any ventilation system available. The outlet of the gas system must be equipped with an iodine absorber during such operation.

4.2.3 Radiological aspects due to beam losses on the TCDS diluter

The LHC beam dumping system consists of a set of fast-pulsed kicker magnets, horizontally deflecting the beam into Lambertson septum magnets (MSD), which deflects the beam vertically to the dump absorber block. A fixed collimator block (TCDS) will be installed immediately upstream of the MSD magnets in order to protect them from destruction in the event of an asynchronous firing of the kicker magnets.

The system will be subject to irradiation by protons or heavy ions due to losses arising from secondary particles from proton-proton collisions in the LHC experiments or scattering from collimators. Remanent dose rates at 30 cm distance to the beam axis have been calculated for three different cooling times using the Monte Carlo code FLUKA. The results have shown that an intervention after a few hours of cooling time would require detailed dose planning as dose rates may reach several mSv/h. Later interventions can possibly be performed with fewer precautions depending on their duration and other related factors (time needed to reach the intervention place, number of people, etc.).

4.2.4 The RAMSES project

The RAMSES project (**RA**diation **M**onitoring **S**ystem for the **E**nvironment and **S**afety) will provide the LHC with a state-of-the-art radiation monitoring and alarm system. The main purpose of RAMSES is area monitoring, which is related to monitoring occupational exposure and the release of radioactivity into the environment in order to assess the effective dose to the population. The Safety Commission will exploit this system for the LHC in order to assess the radiological risks around the accelerator and experimental areas, to optimise radiation protection in all working conditions, and to control stray radiation and release of radioactivity into the environment (air, water). The requirements of the system are derived from CERN’s own safety standards (CERN’s Radiation Protection Manual, SAPOCO), which are based on those of CERN’s two Host States (from the European Directive 96/29/Euratom and from European standards). RAMSES will be integrated into CERN’s control infrastructure (control rooms of the LHC accelerator and experiments).

The radiation levels around the LHC, its supporting facilities and in the environment need to be monitored continuously; about 350 monitors of 15 different types will be installed Monitors will be connected to local control units to form monitoring stations depending on the radiation to be monitored at a given location.

For the environment, three main types of monitoring stations are foreseen:

- stray radiation monitoring station (gamma monitor, neutrons monitor);
- ventilation monitoring station (aerosol sampler and gas monitor);
- water monitoring station (release water sampler and release water monitor);

These monitoring stations are supplemented with:

- meteorological monitoring station (wind parameters and atmospheric stability class);
- environmental aerosol sampler (EAS);
- physical and chemical water parameters (pH, temperature, conductivity, turbidity);
- non-ionising radiation monitoring station (electromagnetic field).

For radiation protection purposes the ambient dose equivalent rate H*(10) has to be measured at various workplaces around the LHC machine and the LHC experiments. The monitoring stations will be equipped with one or more of the following monitor types:

- area rem-counter (ARC);
- area gamma monitor (AGM, TGM);
- area mixed field monitor (AMF, TMF);
- X-rays monitor (XRM);
- induced activity monitor (IAM).

The monitoring stations are supplemented with:

- hand and foot monitor (HFM);
- site gate monitor (SGM);
- tools and material monitor (PCM);
- alarm display unit (visual and audible alarm).

The RAMSES functional diagram is illustrated in Figure 4.2. The core of RAMSES is the Radiation Instrumentation (1). It represents the radiation detectors and radiation monitoring equipment that are capable of measuring the dose rate due to the ionizing radiation of various types occurring around the LHC. The Data Acquisition and Processing (2) is the brain of the system. It gathers data from the Radiation Instrumentation, processes these data and generates local and remote alarms. It is a distributed system with a central supervision. Local control units need to work independently of each other and of the central supervision for safety reasons. The local control unit can generate visible Local Alarms (3). Remote alarms are generated in the CERN Central Alarm Server (7) via the central supervision. The data need to be acquired in different formats according to the detector type. However, all data are standardized at the central supervision level. The central supervision shall be capable of interfacing to the present radiation monitoring system. Another function of the system is to provide an interlock with the Access System and Interlocks (6) for systems that present high radiation risks (i.e. RF systems).

To carry out off-line analyses, RAMSES needs to store the Radiation Data in a database (9). In addition, to achieve the required homogeneity and to avoid data incoherence between different local control units, the system shall also store its own configuration data, such as alarms, equipment addresses or interfaces, in the database. The system shall also store in the database events, like alarm information, change of settings, etc., for post-mortem and historic analysis.

A global Supervision manager (5) monitors various parts of the system for diagnostic coverage and ensures that they work correctly. RAMSES shall provide a user-friendly Human Computer Interface (8) for handling and analysing the data under various conditions. It shall also provide means to carry out tests, maintenance and calibration of the detectors. Finally, data are exchanged with all control rooms through the Data Interchange Protocol (10).

For the sake of simplicity, the functional diagram only covers the radiation protection functions of the system. The non-radiation data shall be handled in a similar way.

The definition of the RAMSES architecture (Figure 4.3) has been derived from the functional requirements based on an analysis of the present system, the ArCon (Area Controller), and of the safety requirements for the LHC.

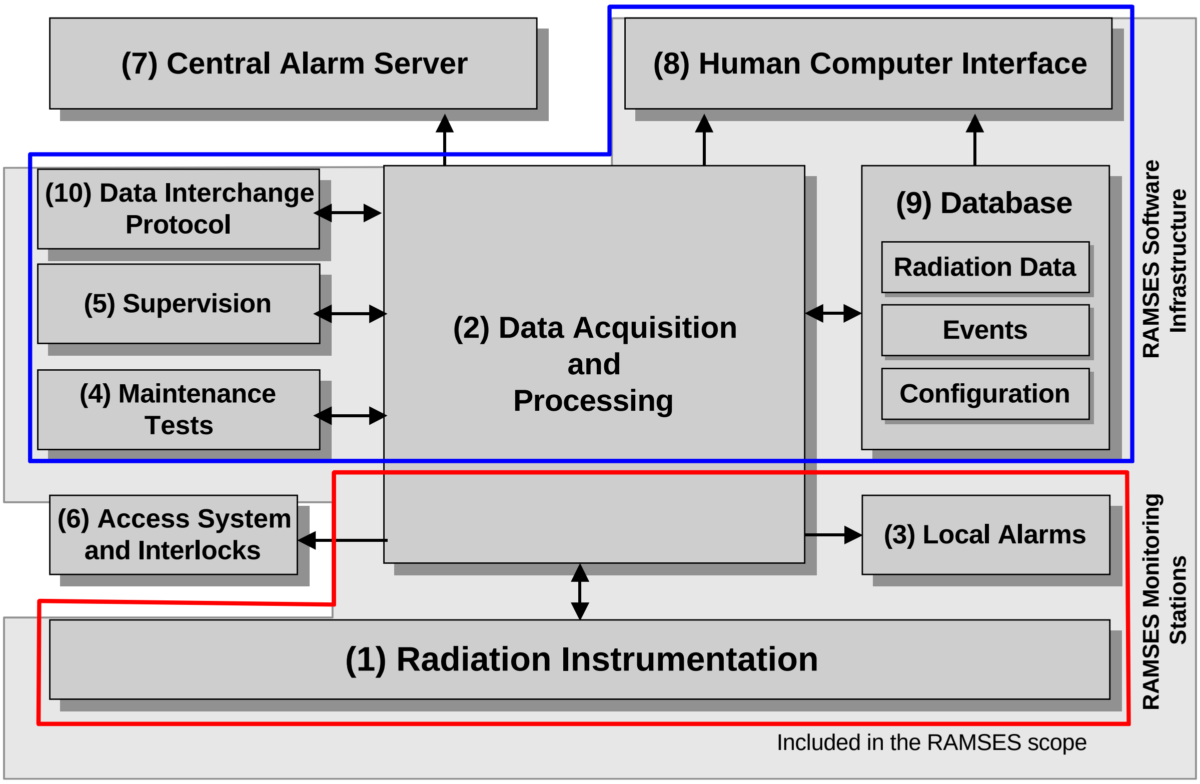

Figure 4.2 RAMSES functional diagram.

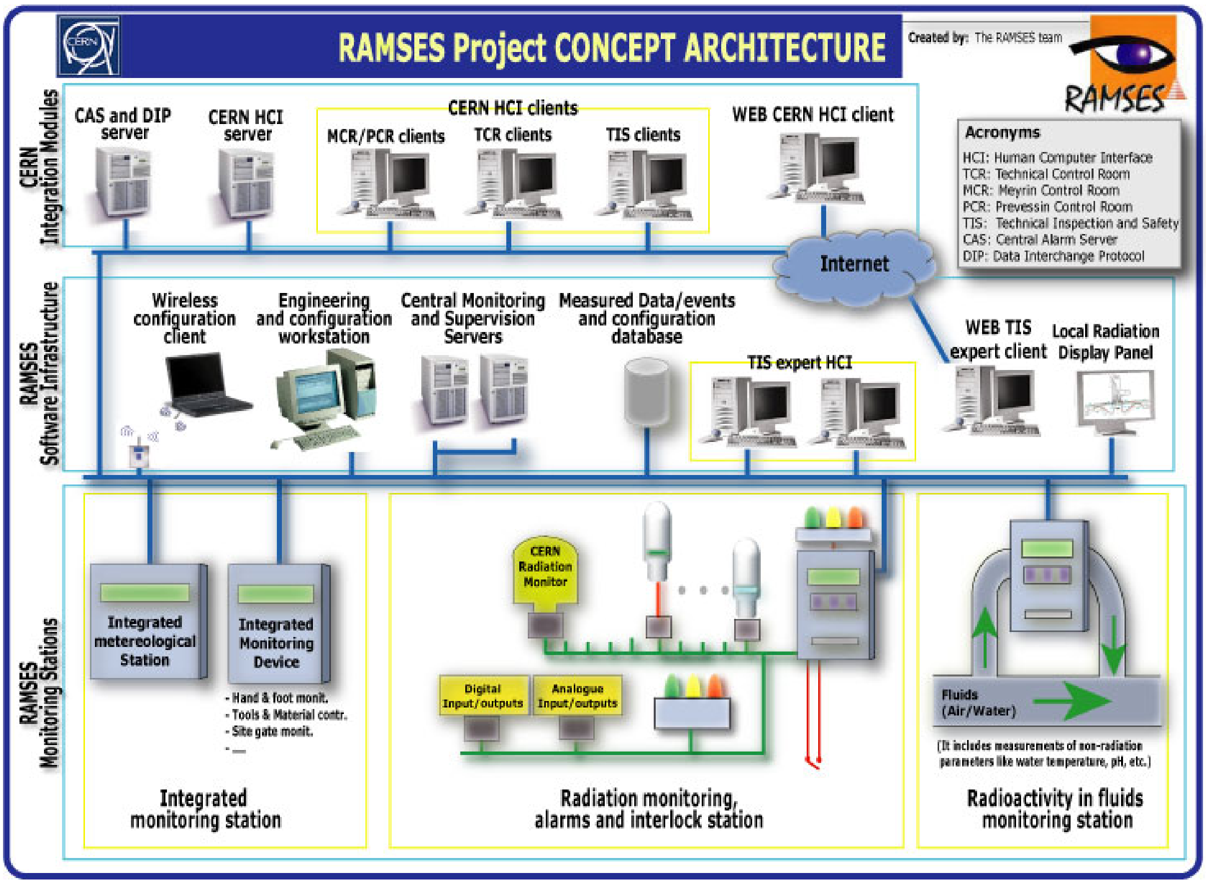

Figure 4.3 RAMSES conceptual architecture.

The RAMSES project, launched in October 2001, is under the responsibility of a project team whose mandate covers the system specification, prototyping, tendering, integration and installation of radiation monitors and control equipment for safety systems (Figure 4.4). In the framework of the LHC project to plan and implement the RAMSES and following the market survey for a fully integrated system dated 25 July 2002, an invitation to tender was launched in July 2003 for the supply, installation and maintenance of the radiation monitoring system for the LHC. The major European companies and manufacturers of radiation monitors having been consulted and having shown their interest in the project have been qualified for the invitation to tender. The adjudication of the contract took place in December 2003 followed by the preparation of the contract signature foreseen for the second quarter of 2004.

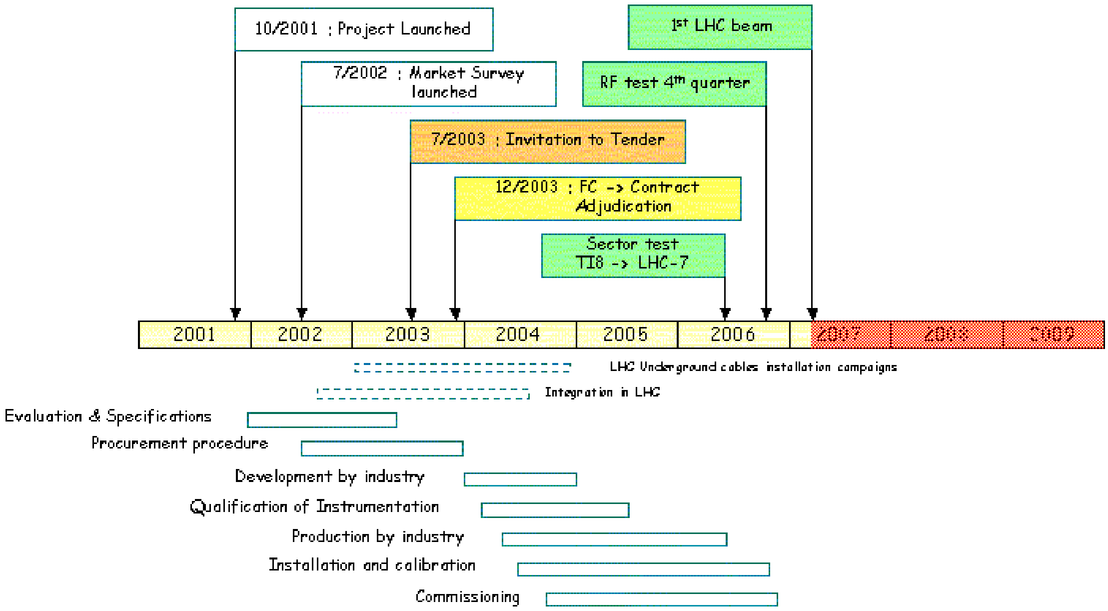

Figure 4.4 RAMSES schedule.

Several types of the radiation detectors needed for a range of purposes were experimentally tested in high-energy radiation fields and their response was simulated in Monte Carlo studies (see section 6.10). The information obtained was used to define the technical specification of the detectors for the complex radiation fields at the LHC.

The integration of various equipments in the underground areas of the LHC continued in 2003 and the reservation of spaces in the surface buildings was undertaken. The first special cables for the radiation monitors that will be installed in the LHC tunnel were pulled. As an example, the locations of monitoring stations at LHC point 5 are shown in Figure 4.5, both for the surface installation and for the underground installation service cavern and galleries.

4.3 CNGS

4.3.1 Remanent dose rates around the target station

The target station will become one of the most radioactive areas of the CNGS facility. The station consists of the target magazine containing five target units as well as supports and alignment equipment surrounded by a thick iron shielding. In order to lower the remanent dose rate in the passage next to the target station a layer of marble will be added to the iron shield.

Although the target magazine can be exchanged remotely, interventions will include work to be performed close to the target station, e.g. the disconnection of motorization shafts or the alignment of the target unit. Therefore, the remanent dose rate around the target station was calculated with the

FLUKA Monte Carlo code for one year of operation and various cooling times. As an example Figure 4.6 shows the results for one day of cooling. As can be seen, dose rates may reach several mSv/h close to the shielding and any intervention will require detailed dose planning. The latter can be performed on the basis of the simulation results.

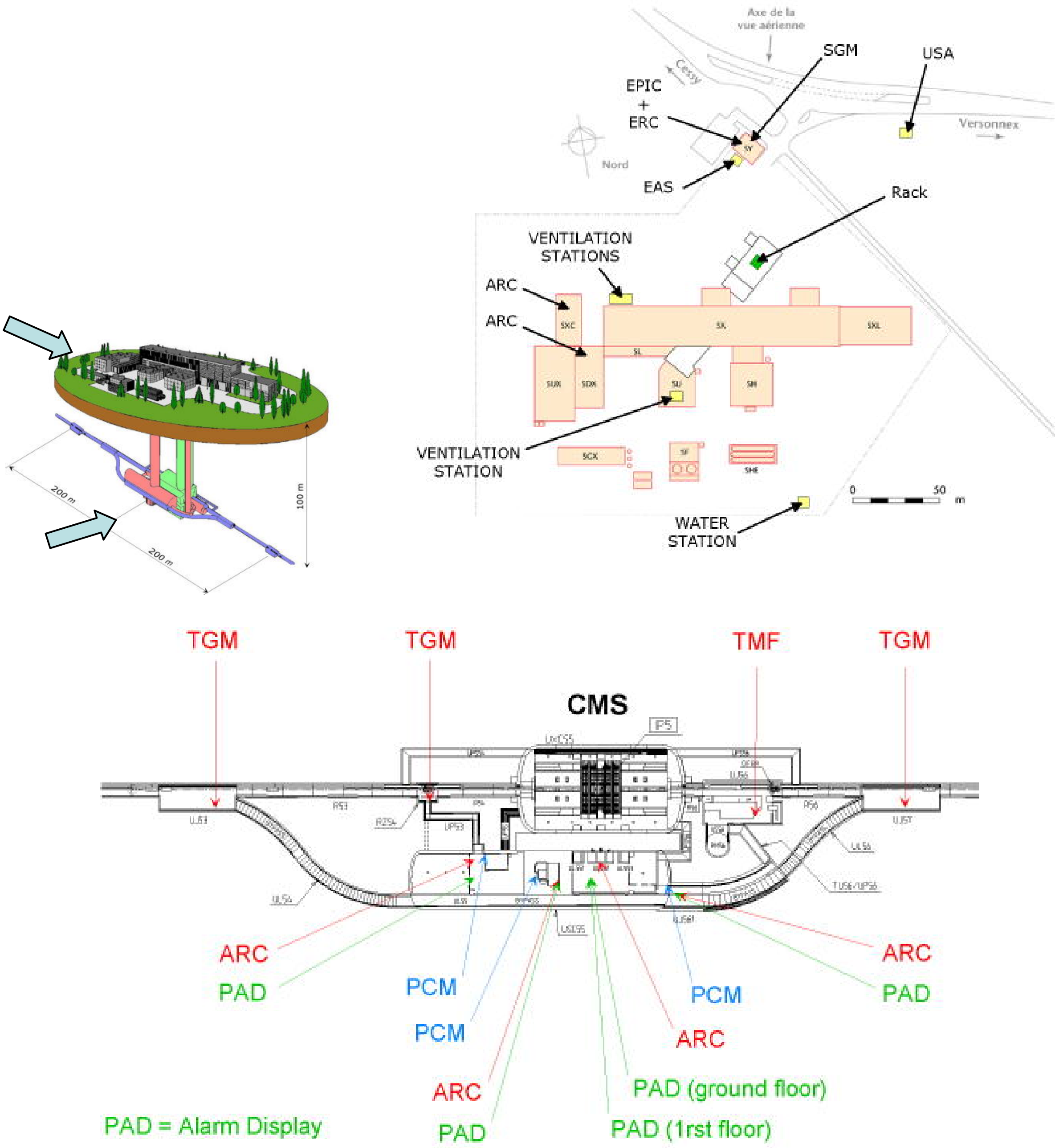

Figure 4.5 Surface buildings and underground service cavern and galleries at LHC point 5.

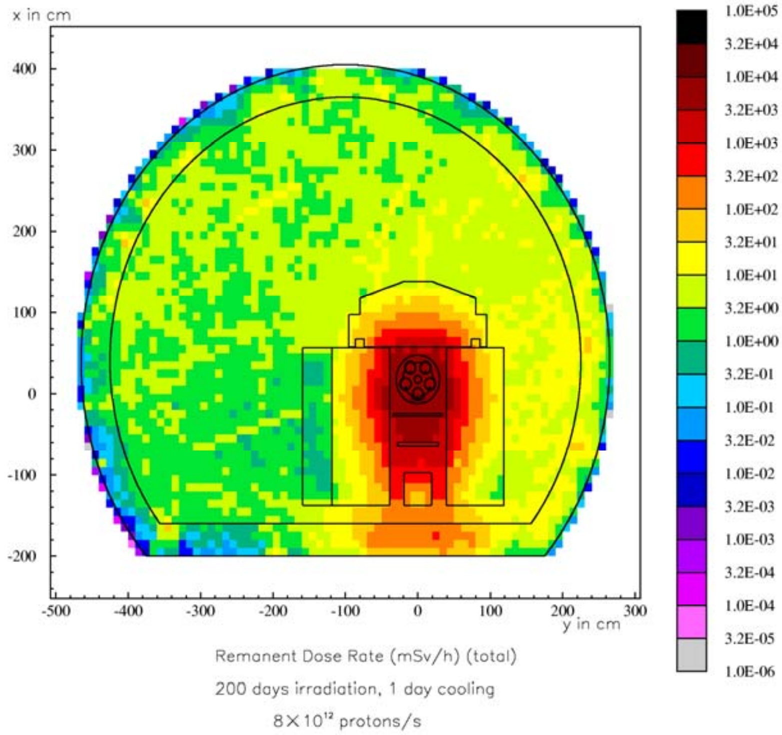

Figure 4.6 Remanent dose rates around the CNGS target station after 200 days of operation and one day of cooling.

4.4 SPS/LHC-CNGS beam transfer

4.4.1 Radiation levels in LHC points 2 and 8 due to beam dumping on the TEDs at the bottom of TI2 and TI8

A series of FLUKA simulations were performed in order to evaluate the radiation levels in US25 and UX25 when the injected beam for the LHC is dumped on to the TED at the bottom of TI2, and the radiation levels in US85 and UX85 when the beam is dumped on to the TED at the bottom of TI8 [Vin03b]. The tunnel systems of these areas are shown in Figure 4.7. During the setting-up of beam for injection into the LHC, dose rates on the RB tunnel axes should be of minor radiological significance but they could be important for muon chambers placed close to the beam axis in the experimental caverns. The maximum dose rate in the US caverns is high enough to impose working restrictions, but it is about a factor of 6 lower than the present maximum value allowed in an area which is not interlocked. The dose rates both on the tunnel axis and in the US at point 8 with the intensities planned for the TI8 beam tests in 2004 should not give rise to any radiological concern.

4.4.2 Radiation levels in TI2 and TI8 due to LHC beam losses in the UJ22 and UJ88 areas

This study evaluated the propagation of secondary radiation from losses of the LHC proton beam at 7 TeV in UJ22 and UJ88 through the injection tunnels TI2 and TI8 (for geometry details see Figure 4.7) [Vin03c]. Simulations made using the FLUKA program showed that access can be safely allowed to the upper part of TI8 on the TJ8 side of the present gate when there is a circulating beam in the LHC. For TI2, it would be prudent to prohibit access to the LHC side of the pump pit (825 m from the UJ22 junction) during LHC operation.

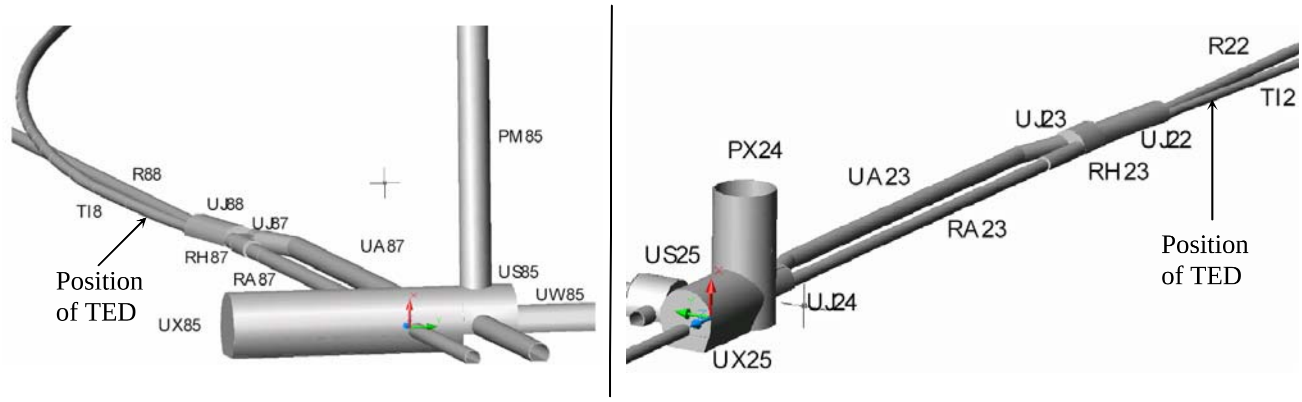

Figure 4.7 Tunnel systems in the area of point 8 (left) and point 2 (right).

4.4.3 Remanent dose rates in the area of a TCDI collimator after 200 days of normal operation and after an accidental beam loss

TCDI collimators will be installed in the LHC transfer tunnels, the LHC injection areas and the LHC ring in order to protect equipment located further downstream from being seriously damaged. However, beam losses in these collimator units might cause radiological hazards in the area close to the beam loss point. The aim of this study was to evaluate the remanent dose rate in the region of a TCDI collimator [(2)]. FLUKA calculations were performed dealing on the one hand with the remanent dose rate produced after 200 days of normal operation and on the other hand with the radiological consequences caused by an accidental beam loss. The simulation geometry used to calculate the effect of the two types of beam impact is shown in Figure 4.8. The beam particles are protons with a momentum of 450 GeV/c. For this study a new simulation method was used which allows to calculate the remanent dose rate in all locations in the simulated area. Table 4.1 resumes the two remanent dose rate schemes for five cooling times. The maximum value reflects the highest dose rate in the accessible part of the collimator container. The value between the beam line and the wall is the one alongside the collimator, half way between beam axis and wall.

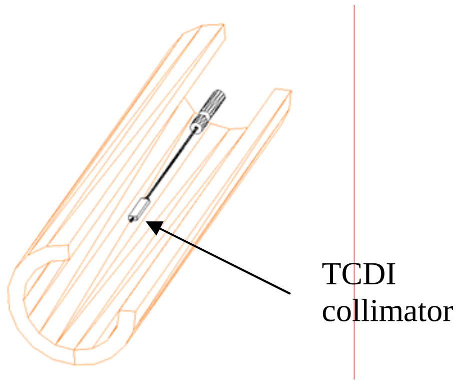

Figure 4.8 FLUKA simulation geometry of the TCDI collimator mounted in a simplified tunnel geometry.

4.4.4 Calculations of the remanent dose rates after beam dump operation in the area around the TED

Detailed FLUKA calculations of the induced radioactivity caused in and around the Target External Dump (TED) were performed. The TED is mainly used in SPS/LHC transfer areas in order to stop the protons during beam alignment operation and for protecting personnel and equipment in

[(2)] H. Vincke, Remanent dose rates in the area of a TCDI collimator after 200 days of normal operation and after an accidental beam loss, Technical Note CERN-SC-2004-018-RP-TN (2004).

tunnel areas located further downstream. The simulations were based on a beam intensity of 6.25 10^9 protons/s. The irradiation time was assumed to be 24 hours and the duration of the subsequent cooling period varied between one day and one month. A new simulation method was used which allows to calculate the remanent dose rate in all locations in the simulated area. The remanent contact dose rate alongside the TED was found to be 1 mSv/h after a cooling period of one day, 100 µSv/h after one week and 25 µSv/h after one month. Based on these simulations simple calculations were performed in order to extrapolate the given results to different intensities and cooling times. It was also found that the shielding strength of the TED is insufficient to prevent activation of equipment located further downstream. Therefore, a secondary dump was designed which reduces significantly the high-energy hadron component emerging from the end face of the TED.

Table 4.1 Remanent dose rate occurring in the TCDI area after a full beam loss and after normal operation for five cooling times.

	Full loss scenario		**Normal operation of 200 days**	
Cooling time	**Wall - beam line**	**Maximum value**	**Wall - beam line**	**Maximum value**
1 hour	4 mSv/h	200 mSv/h	20 µSv/h	800 µSv/h
12 hours	300 µSv/h	10 mSv/h	15 µSv/h	600 µSv/h
1 day	100 µSv/h	2.2 mSv/h	12 µSv/h	500 µSv/h
1 week	10 µSv/h	500 µSv/h	7 µSv/h	300 µSv/h
1 month	4 µSv/h	100 µSv/h	5 µSv/h	150 µSv/h

4.5 Shielding of LEIR as LHC injector

LEIR (Low Energy Ion Ring), which is part of the PS complex, will be used in the LHC injection chain for ions. Given the expected beam intensity in LEIR, the present 1.6 m thick concrete walls are sufficient to shield the accelerator sideways and allow access to the rest of the East Hall during operation. The issue that had to be investigated [Sil03c] is whether or not a top shielding is required and whether or not the gangway (which is at a distance of approximately 5-6 m from the closest section of the machine) from which LEIR can be viewed by visitors could be made accessible during acceleration and extraction. This depends on the rate and localisation of beam losses.

Losses at the injection energy of 4.2 MeV/u will pose no major radiation problems. The estimate of the dose equivalent rate previously made for the dump at the end of linac 3 indicates that, even if 50% of the beam is lost at injection, the radiation level will remain below a few µSv/h. Under these conditions the gangway can remain accessible.

LEIR will extract about 10^9 $^{208}Pb^{54+}$ ions at 72 MeV/u every 3.6 s. No significant losses are expected in the course of the acceleration process during normal operation. Thus the only case which was considered is an accidental scenario with loss of the entire beam at maximum energy. Two cases were investigated: 1) 10^9 Pb-ions lost at 72 MeV/u every 3.6 s in a single, unshielded point in the extraction region, at a distance of approximately 25 m from the gangway; 2) 10^9 Pb-ions lost at 72 MeV/u every 3.6 s uniformly around the ring. In this case losses occurring in the fraction of the machine closest to the gangway (approximately 5 m distance) are the major concern. Losses can occur in a straight section (where no shielding is provided by the machine) or inside a magnet (where some shielding is provided by the magnet yoke).

Estimates of the expected dose equivalent rate at the gangway indicated that a maximum dose equivalent rate of a few tens of µSv/h can be expected under accidental conditions. Cutting the beam within – say – ten machine pulses will give an integral dose of the order of 1 µSv. If this beam abort time can be guaranteed, no special precautions need to be taken.

During the commissioning phase it is planned to operate LEIR with $^{16}O^{4+}$ ions at 67 MeV/u at a higher intensity than with $^{208}Pb^{54+}$ ions, i.e. extracting $2x10^{10}$ ions every 2.4 s. With such a beam and under the same accidental conditions as above, a full beam loss may induce a dose equivalent rate at the gangway of the order of 1 mSv/h. Cutting the beam within ten pulses will give an integral dose of the order of 10 µSv (a few tens of µSv maximum). A radiation monitor providing a local alarm will most likely suffice, but it might nonetheless be safer to prevent access to the gangway by visitors during the commissioning phase.

5 Services

C. Lamberet, D. Perrin, M. Silari, L. Ulrici and H. Vincke

5.1 Introduction

The Radiation Protection group provides a range of services to other groups and divisions at CERN that include the management of radioactive waste from all CERN accelerators and experimental areas, the shipping of radioactive material (mainly for ISOLDE and electronic equipment irradiated for testing), gamma spectrometry of samples, the administration and supply of radioactive test sources. In 2003 the responsibility for high level dosimetry was transferred from the TIS/TE group to the RP group, whilst laser safety was transferred from the RP group to the TIS/GS group. The RP group maintains, repairs, tests, modifies and, where necessary, expands the radiation monitors installed at CERN that are controlled by a central system (ArCon).

5.2 Radioactive waste management

The yearly campaign for the elimination of radioactive waste towards PSI in Switzerland took place following the requirements of the *Office Fédéral de la Santé Publique* (the Swiss Federal Office for Public Health, OFSP). A total of 7 drums of 200 liters of not-burnable wastes (limestone), contaminated by β and γ emitters, were eliminated (see Table 5.1). The total activity was measured by gamma spectrometry.

Table 5.1 Summary of the 2003 waste elimination campaign.

Number	**Volume (m^3)**	**Mass (kg)**	**Radionuclide**	**Total β,γ activity (MBq)**
7	1.4	605	^{22}Na	138.8

In 2003 the CERN radioactive waste treatment centre located in the centre of the PS ring received, controlled and conditioned about 131 m^3 of radioactive waste of different origin. Most of the waste consists of solid components (steel, aluminium, cables, etc.) irradiated in the various CERN accelerators. Figure 5.1 gives the total amount of radioactive waste accumulated and treated since 1981. The total amount of waste cited above does not include radioactive waste originated in the SPS (which is now classified as *Installation Nucléaire de Base*, INB) that was received, reconditioned and temporary stored in the octant I6 of the ISR (Intersecting Storage Ring). Being declared within the INB perimeter, this area is used for the temporary storage of solid waste according to the requirements of the French nuclear authority (*Direction Générale de Sûreté Nucléaire et Radioprotection*, DGSNR). An inspection of I6 by DGSNR in 2003 resulted in very positive remarks on the organization and management of the waste. The temporary storage in this area is organised in three zones, corresponding to the level of induced radioactivity: TTFA (*très très faiblement actif*, extremely low level waste), TFA (very low level waste) and FA (low level waste). This last zone is equipped with a remotely controlled overhead crane. In 2003 only TTFA and TFA waste were received from the SPS (see Tables 5.2 and 5.3).

A total of 6.99 tons of non radioactive scrap, resulting from the separation of active from non-active material, was released in 2003. Moreover 36 tons of non-radioactive scrap, coming from the dismantling of electrical switches, was eliminated, but these are not accounted for in the data for 2003 given in Figure 5.2.

The annual inspection by TIS of the installations for handling and storage of radioactive waste showed good general safety of the working conditions. Nonetheless, some refurbishment (infrastructures, lights, etc) on aged buildings was carried out.

The collective dose for the RP personnel working on the treatment and storage of radioactive waste was 0.3 mSv for 5 people. As for the previous years, this value is low if one considers the total volume of radioactive waste handled and the related activities.

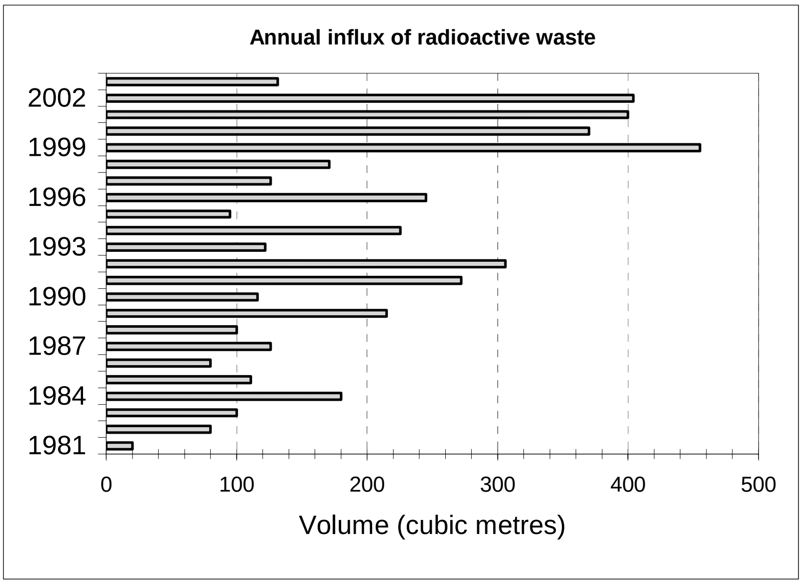

Figure 5.1 Annual influx of radioactive waste since 1981.

Table 5.2 Amount of radioactive waste received from the SPS in 2003.

Classification of radioactive waste		**Specific activity (Bq g^{-1})**	**Dose rate (μSv h^{-1})**	**Mass (tons)**	**Volume (m^3)**
TTFA	Extremely low level waste	Natural radionuclides (α,β,γ emitters)	< 1	0.085 **	1
TFA	Very low level waste	Between 1 and 100 (β,γ emitters)	≤ 50	2.2	3

** Ceramic. Content in natural radioactivity: 973 kBq for the Uranium chain and 239 kBq for the Thorium chain.

Table 5.3 Total amount of radioactive waste stored in the INB area (ISR I6) of SPS origin.

Classification of radioactive waste		**Specific activity (Bq g^{-1})**	**Dose rate (μSv h^{-1})**	**Mass (tons)**	**Volume (m^3)**
TTFA	Extremely low level waste	Natural radionuclides (α,β,γ emitters)	< 1	12.795 * 0.085 **	181
TFA	Very low level waste	Between 1 and 100 (β,γ emitters)	≤ 50	108.7	199
FA	Low level waste	> 100 (β,γ emitters)	> 50	308.2	98.353

* Insulators in electrical switches. Total α, β, γ activity: 32.2 MBq (^{226}Ra: 2.35 Bq g^{-1}, ^{232}Th: 0.3 Bq g^{-1} and ^{238}U: 1.34 Bq g^{-1})

** Ceramic (see above)

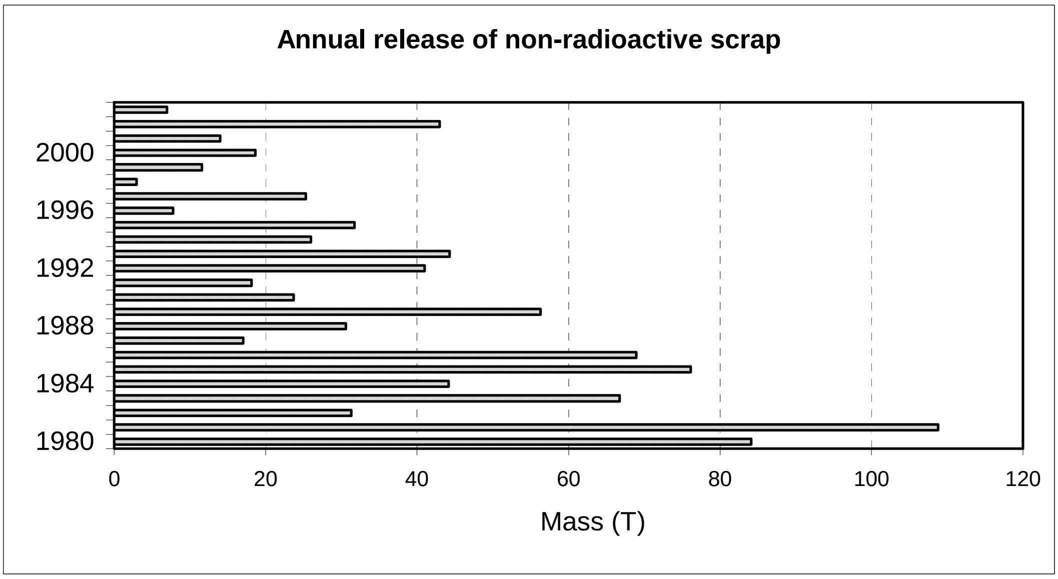

Figure 5.2 Annual release of non-radioactive scrap.

5.2.1 The new project for the management of radioactive waste at CERN

A new project for the management of the radioactive waste at CERN was launched in 2002 and developed in 2003. The following achievements were reached in 2003:

- a contract was established with a company (NAGRA) for the full inventory of the radioactive waste currently stored at CERN. The study will last 2 years (2004 and 2005) and the results will include proposals on the temporary storage and possible elimination pathways for the different types of radioactive waste;
- following the allocation by the CERN directorate of the ISR as future centre for the temporary storage of pre-conditioned radioactive waste at CERN, a detailed analysis of the status of the octant I7 of the ISR was started. I7 will be the first octant to become available, once the conventional LEP components temporary stored there will be moved to another CERN location;
- the evaluation of the needs in the field of databases for the book-keeping of the radioactive waste led to the identification of ISRAM (Information System for Radioactive Materials) as the best tool. ISRAM is widely used in Switzerland for the documentation and book-keeping of radioactive waste generated, handled and stored in Switzerland, and its structure will allow its adaptation to the French "traceability" system. The ISRAM system was purchased in 2003 and its full integration in the routine use is planned for 2004;
- side projects were started in 2003, and will be continued in 2004, concerning the identification of new elimination pathways for the radioactive waste and for the free release of waste, the radionuclide content of which has decayed below the national clearance values. An important step in this direction was done in 2003 with the choice of the In Situ Object Counting System (ISOCS) from Canberra. This detector will allow the performance of in situ gamma spectrometry on a wide variety of objects. Extended investigations, tests and benchmark studies on this system proved its suitability for clearance measurements that will be developed in 2004.

A major effort was made in collecting the material compositions of several LHC components. These data, together with the results of irradiation tests at the CERF facility discussed in section 6.9, are a fundamental step towards the establishment of a radionuclide inventory for the LHC machine and experiments.

5.3 Instrumentation and logistics

5.3.1 Installed monitoring systems

The Instrumentation and Logistics service of the RP group maintains, repairs, tests, modifies and, where necessary, expands the radiation monitors installed at CERN that are controlled by a central data acquisition system (ArCon).

The radiation monitoring system for the extraction tests in TT40 (LHC project) was commissioned and operational for the tests that took place in September and October 2003. As planned the radiation monitoring system was entirely modified and moved from BA4 to ECA4 during the 2002/2003 machine shutdown to cope with the additional necessary measuring channels. The monitoring system for the extraction tests was complemented with the installation of a ventilation monitor in the SUI8 building.

A study was started for the installation of the radiation monitoring system to be set up for the LHC injection tests foreseen in TI8 in September 2004. All relevant requests for the necessary infrastructure were prepared and the necessary equipment was ordered. An additional area controller will be temporarily installed at LHC point 8 to monitor the tests.

A preventive maintenance program was established for the CERN site gate monitors. The first stage within this program was the production of the technical specifications for the consolidation of the electronics of the gate monitors. The new electronics module will be installed and commissioned in 2004.

The dosimetry system for the on-line radiation damage tests of the LHC components located in the TCC2 target region was adapted for the 2003 irradiation period. The cabling of the radiation monitoring system in BA81 was modified in order to permit the transmission and storage of data from twelve induced activity monitor channels to the ArCon. The corresponding electronics has been designed and its construction has started in order to be installed in 2003.

The construction of a new release water monitor to be installed in BA2 water monitoring station during the 2003/2004 shutdown period has been undertaken.

5.3.2 Projects and developments

A mobile acquisition system was designed, constructed and commissioned to perform tests of CERN radiation monitors at the CERF facility during beam time in July and August 2003 (see section 6.10). The system is based on a personal computer running a Labview application and an electronic interface for up to 14 channels for PTW plastic chambers, Centronic IG5 ionisation chambers and other CERN monitors. This mobile system was also used (in parallel to the fixed monitoring system) for the extraction tests in TT40.

In the continuous process of improvement of the monitoring of radiation due to activation of accelerator components or material in experimental areas, work continued on the development of a new integrated cable to connect plastic ionisation chambers to their remote electronics. Based on the good results obtained in 2002, the technical specifications of the integrated cable were produced in 2003 to launch its procurement. In parallel the design and construction of the test bench for the acceptance tests of the integrated cable was carried out.

5.3.3 Instrument calibration

The calibration service is calibrating radiation protection monitors and dosimeters with radiation from gamma and neutron sources. Large surface alpha and beta sources are used to calibrate contamination monitors. An evaluation of the work procedures revealed that at present, 0.3 full time equivalent of a technical engineer are necessary for legally required routine calibrations. Additional resources would become necessary if significantly more monitors or dosimeters had to be calibrated, e.g. for LHC and CNGS or from a generalised operational dosimetry system.

The service personnel completed the quality assurance manual early in 2002. All routine calibrations are described in detail and an estimation of calibration uncertainty is made for every measurement. The manual has been thoroughly tested and, after last amendments, will be submitted to the Swiss Accreditation Service in order to receive an accreditation as Calibration Service according to International Standard ISO 17025.

5.4 Control of basic nuclear material (MNB)

The MNB (*matériel nucléaire de base*, nuclear basic material) remaining at CERN is now grouped in a single building on the Meyrin site, except for that used by the ISOLDE experimental groups, which is stored in a dedicated place, and for one of the calibration sources of the RP group. The annual IAEA inspection took place on 9 March 2003 and found everything in order. Only 1841 kg of depleted uranium are still used in an experimental area on the Prévessin site. This material as well as the approximately 2 g of ^{6}Li used for TLD dosimetry (see section 5.9) were inspected by the French IRSN (*Institut de Radioprotection et de Sûreté Nucléaire*) on 4 December 2003 without any remark being formulated.

5.5 Management of radioactive sources

The RP group maintains a stock of radioactive sources for various uses. The group is in charge of the purchase and loan of the sources, holders and shielding, as well as of the registration and updating of the radioactive source database. The group also performs periodic inspections on the sources in use on the CERN premises. In 2003 a new web site was set up providing advice to the users on procedure for loaning sources and on safety measures (http://cern.ch/rp-sources). An area with access restricted to RP staff was also created, where the certificates of all sources and the associated drawings are stored.

The number of radioactive sources registered in the RP database on 31 December 2003 was 2435, 976 of which are considered as 'active sources' for loan: 394 are in stock and 582 are on loan to 123 users.

In year 2003, 7 new sources were registered whilst 5 were taken out of the source record for the following reasons:

- 3 sources were removed from the database, to be eliminated towards PSI in Villigen, Switzerland (their activity was below the authorisation limit, LA);
- 1 source used for industrial radiography was returned to the owner;
- 1 source from ISOLDE was shipped to Germany.

A study was continued for the possible use in the RP group of a Geographical Information System (GIS) linked to the source database.

An effort was undertaken to clean the laboratory, which is close to the entrance of building 24, where the radioactive sources are handled. The aim is to recuperate some space and create an area for the reception, handling and packing of radioactive material and sealed sources (control on arrival).

5.6 Transport of radioactive material

The RP group provides all necessary support for shipping radioactive materials by air, road, sea and train. The group supplies packaging and shipping documents and provides information on transport rules. In 2003 a web site was set up providing all necessary information for shipping and importing radioactive material into CERN (http://cern.ch/rp-shipping).

In year 2003, 49 radioactive packages were shipped from CERN. Of these, 46 were « Excepted Packages » (UN 2910) and 3 were « Type A » packages. Two out of these three were classified UN 2915: one was sent to Germany and the other to Switzerland. The last one, classified UN 2911, was sent to Germany.

5.7 Gamma spectrometry

In the course of year 2003, the gamma spectrometry laboratory performed a total of 1420 gamma spectrometry analyses, using mainly two LabSOCS-characterised, high-purity

Ge-detectors. The analyses were mainly done for the RP survey sections, but several were also performed for the LHC activation studies discussed in section 6.9. The laboratory is equipped with four Ge-detectors, two of which were LabSOCS-characterised in 2003. Unfortunately they were both affected by a problem which obliged the RP group to return them to Canberra for repair after only 4 months of operation. One was affected by a vacuum leak due to a too high nitrogen filling pressure, problem which obliged to change the filling system of the dewars. The other one showed an inaccuracy in the LabSOCS modelling.

The laboratory participated in the set-up of ISOCS (see section 5.2.1) purchased from Canberra in 2003. This detector will allow realizing in situ gamma spectrometry on a wide variety of objects; it will mainly be used for the characterisation of radioactive waste. However, the wide range of applications of this system is testified by the many pilot measurements performed both for RP purposes and for other applications at CERN. Test and calibration measurements pointed out an anomalous behaviour of the electronics (which was returned to the manufacturer for repair) and more recently a decreasing performance in the resolution. The set up of an automatic liquid nitrogen filling system is in progress.

A large effort went into making uniform the measurement and data analysis procedures of the Meyrin and Prévessin gamma spectrometry laboratories of the RP group. The quality control of the detectors was pursued with the weekly monitoring of several parameters. This approach has assured a good accuracy of the results and has allowed detecting various problems in advance, some of which would otherwise have lead to a much larger unavailability of the detectors. Following a request by TIS/GS, an oxygen monitoring system was installed to monitor a possible oxygen deficiency caused by nitrogen leak. A new ventilation and air conditioning system was also put in place. The ventilation system raised some electromagnetic compatibility problems, solved by the removal of the dimmer.

With a view to the future, a small study was undertaken to replace the present software (the Canberra Genie-2000) by a more advanced analysis software linked to the Apex database, also by Canberra. Information was transmitted to Canberra in view of a future upgrade of their system.

5.8 High-level dosimetry

The main task of the High-Level Dosimetry (HLD) service is to perform dose measurements on accelerator and beam transfer line elements, in order to predict radiation-induced damage to materials and accelerator components. For this purpose about 1800 dosimeters, radio photo luminescence (RPL) and alanine, are installed around CERN's accelerators. The results of the 2002 HLD campaign can be found in [Fre03a]. Besides the machine monitoring, the HLD service also provided several hundred dosimeters to various CERN groups.

In order to improve the reliability of the dosimetry system, a series of calibrations with gamma radiation in the dose range between 0.1 Gy and 1 MGy were performed. The build-up and fading effects of the two types of dosimeter were studied and a new analysis procedure was implemented, which reduces the RPL signal read-out uncertainty to about 2%. Moreover, three possible base materials for the production of new alanine dosimeters were studied. Details about the calibration work and the aforementioned studies are given in a diploma thesis [(1)].

In parallel to the CERF activation studies (see section 6.9), calibration measurements in high-energy radiation fields were performed. These measurements will be used to investigate the response of alanine and RPL to the different radiation fields encountered around the various CERN accelerators.

Besides the routine dosimetric measurements, the service carries out radiation induced material damage tests of cable insulating materials. The results are published in various material test reports.

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(1) I. Floret, Calibration, characterization and application of CERN's high level dosimetry systems, diploma thesis, Ecole d'Ingénieur de Genève (2003).

5.9 TLD monitoring

The TLD (thermo-luminescent dosimetry) service routinely provides dosimeters for ambient monitoring around the accelerators, in the experimental areas and in the environment. In 2003 the service has provided TLDs for approximately 211 gamma measurement locations (implying 1688 TLD reading) and for 442 locations for gamma/neutron measurements (10608 TLD reading).

5.10 Other activities

The RP group carried out a number of other tasks in addition to those described above, mainly:

- management of EDMS (Engineering Data Management Service) for the entire TIS Division and of DFS (Distributed File System) for the RP group, with an increasing use of both systems;
- maintenance and improvement of the group web site (http://cern.ch/radiation). Several new functionalities were implemented such as data libraries, computing tools for calculations of ADR and of exemption limits.

6 Supporting and research activities

M. Brugger, S. Roesler, M. Silari and H. Vincke

6.1 Introduction

This chapter describes activities other than the routine and service tasks carried out by the RP group, i.e. development work in the field of instrumentation, research and support activities for future CERN projects or in RP-related domains and irradiation tests of LHC materials in view of establishing a radionuclide inventory for future disposal of radioactive waste as well as benchmarking new FLUKA capabilities.

6.2 The radiological situation at SPS point 5

Areas in sextant 5 of the SPS accelerator were reassessed in order to check the radiation protection conditions given there, not using estimation methods as done in the past, but rather using modern Monte Carlo particle transport techniques. The complete area was reconstructed as a computer model (Figure 6.1) for FLUKA simulations, on the foundation of old plans from the late ’70s and countless discussions with senior engineers and technicians who were once involved during the construction phase of this region.

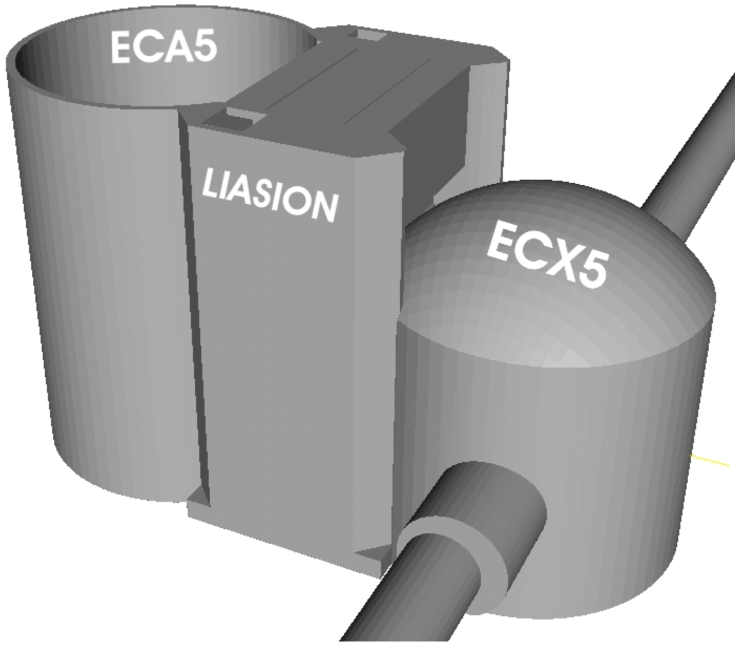

Figure 6.1 The SPS5 underground constructions consist of the assembly area ECA5, the experimental area ECX5 and the liaison area including 20 crossing zones.

The calculations carried out with FLUKA using worst case proton loss scenarios for selected loss points along the beam line [Mue03a] [1,2] have proved that the recently used area classification was not sufficiently safe. It was thus recommended that areas currently classified as “Supervised Areas” be changed to “Simple Controlled Areas”, and that the present “Simple Controlled Areas” (all

[1] M. J. Mueller, G.R. Stevenson, C. Theis, 3D visualization for FLUKA Monte-Carlo simulation at the CERN-SPS-accelerator point *5*, poster presented at the International Conference on supercomputing in Nuclear Applications SNA'2003, 22-24 September 2003, Paris, France, Technical Note CERN-SC-2004-021-RP-TN (2004).
[2] M.J. Mueller, G.R. Stevenson, Shielding design of an underground experimental area at point 5 of the CERN Super Proton Synchrotron (SPS), presented at the 10th International Conference on Radiation Protection (ICRP10), 9-14 May 2004, Madeira (Portugal).

the underground constructions) be upgraded to "Areas with controlled Access". The 2003 beam line setup is shown in Figure 6.2.

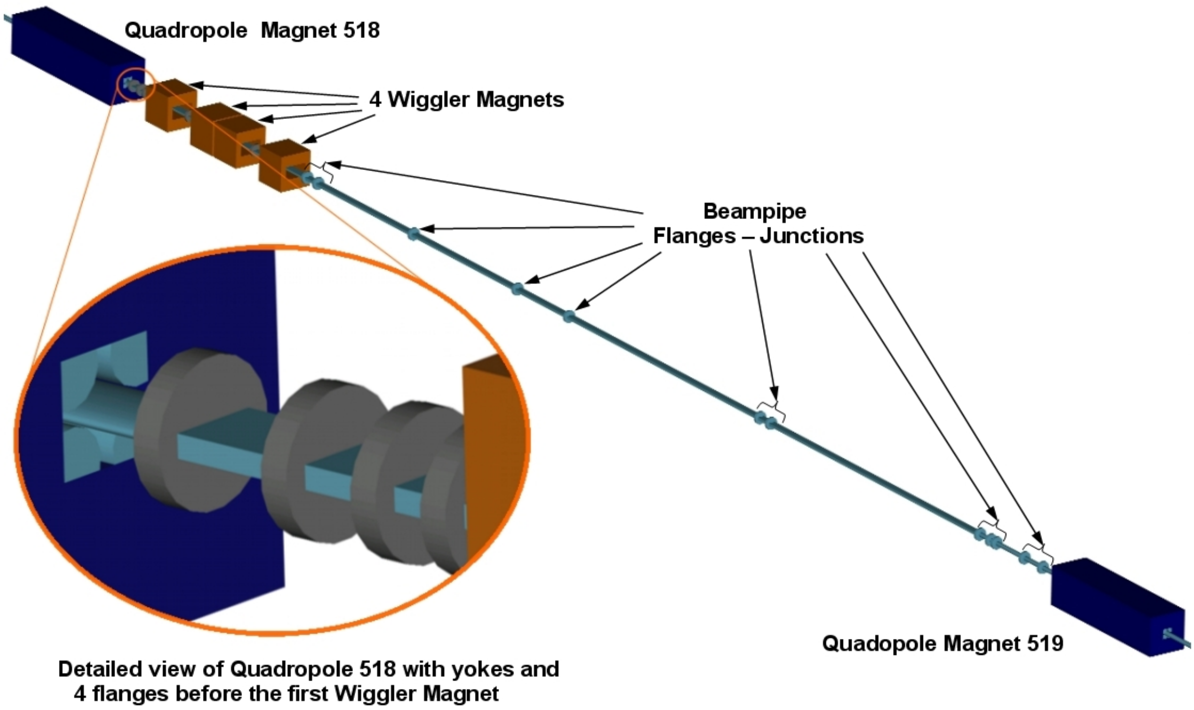

Figure 6.2 Beam line in the 2003 set up with two quadrupole magnets, 4 wiggler magnets and 23 flanges interconnecting the beam pipe segments.

6.3 Radiation protection estimates for a 3 MeV test facility

A 3 MeV H^- facility in the PS South Hall has recently been approved. Its purpose is threefold: 1) to validate the chopper functioning and the beam optics design of the line, 2) to serve as first stage of a novel injector for the Proton Synchrotron Booster (PSB), and 3) to demonstrate the technical feasibility of the first section of a front-end for the Superconducting Proton Linac (SPL). The RP group participated in the design of the two dumps which are an essential part of the facility, by estimating the induced radioactivity and evaluating the prompt radiation generated during operation [(3)]. Both of these aspects are to be considered in the choice of the dump material. Because of the short range of 3 MeV protons, the induced radioactivity in a copper dump can be strongly reduced by coating its surface with a thin (0.01 cm) layer of Ni or C. The ambient dose equivalent rate due to ^{65}Zn in copper, expected after one month of continuous irradiation at 1 cm distance from the dump is 650 µSv/h. This value does not vary significantly after one month waiting time, because of the relatively long life of ^{65}Zn. In the case of a copper dump with a layer of Ni, the ambient dose equivalent rate is 80 µSv/h at 1 cm distance, 11 µSv/h at 10 cm and 0.3 µSv/h at one metre. Very low remanent dose rates are expected close to a dump coated with a carbon layer, 5 µSv/h at one metre distance. The fraction of the incoming protons scattered out of the dump as a function of material was also calculated, as this information was necessary to define the position of a downstream beam monitor. The prompt dose rate during operation is mainly due to photons and it is 1 µSv h^{-1} at one metre for nickel and about 10 µSv/h for carbon.

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(3) L. Bruno, M. Magistris, M. Silari, Conceptual design and radiological issues of a dump for the 3 MeV test facility, Technical Note CERN-SC-2004-008-RP-TN (2004).

6.4 The 4 MW target project

The Superconducting Proton Linac (SPL) is one of future CERN's projects. This accelerator will provide a 2.2 GeV, 4 MW proton beam to feed facilities like, for example, a future neutrino factory or a neutrino super-beam. The material activation in such facilities is an important aspect that has to be taken into account at an early design stage. In particular, the choice of the target has consequences on the induced radioactivity and dose rates in the target station and its surroundings. The radiological aspects of a stationary target made up of Ta pellets were compared to those of a free-surface jet of mercury. An estimation of the hadronic inelastic interactions and the production of residual nuclei in the target, the two magnetic horns, the decay tunnel, the surrounding rock and a downstream dump were performed for both targets with the FLUKA code [Ago03a, Mag03a]. The aim was to assess the dose equivalent rate to be expected during maintenance work and to evaluate the amount of residual radioactivity, which will have to be disposed of after the facility has ceased operation.

The induced radioactivity in mercury and tantalum after 10 years of operation is plotted in Figure 6.3, as a function of decay time. The induced activity in the magnetic horns is shown in Figure 6.4, whilst that expected in a typical layer of rock is plotted in Figure 6.5, where the specific activity is also expressed as a fraction of Swiss exemption limits for a mixture of radionuclides.

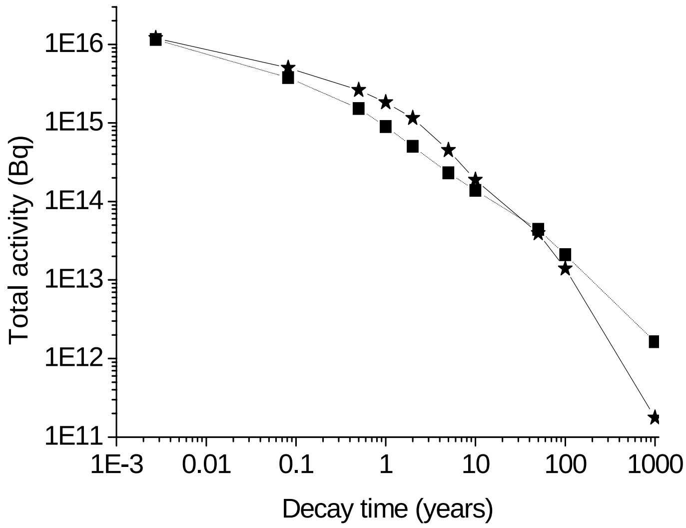

Figure 6.3 Induced radioactivity in Hg (squares) and Ta (stars) after 10 years of operation, as a function of decay time.

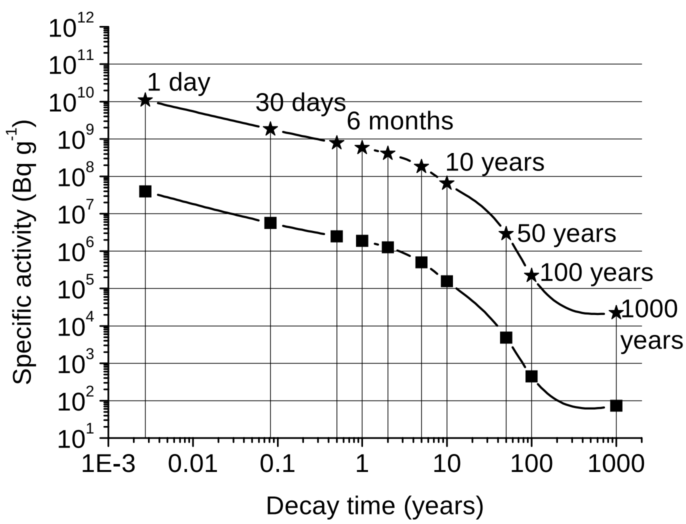

Figure 6.4 Specific activity of the most (stars) and least (squares) radioactive parts of the magnetic horns after 6 weeks of irradiation, as a function of decay time.

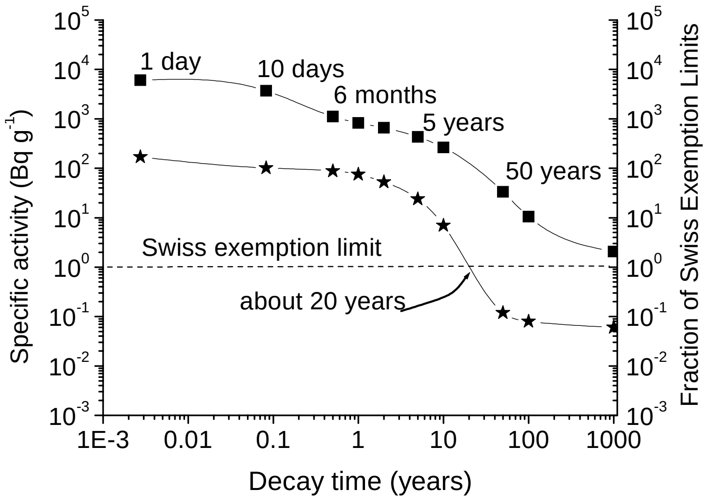

Figure 6.5 Specific activity (squares) and fraction of Swiss exemption limit for a mixture of radionuclides (stars) averaged in a 2 m deep, 1 m thick layer of rock at 10 m distance from the target, after 10 years of operation, as a function of decay time.

The ambient dose equivalent rate expected at 1 m from the entire set of 40 Ta targets irradiated in 10 years of operation, after 1-year waiting time is 30 Sv h^{-1}. In case of a Hg target, if after the shutdown of the facility all mercury is stored in a spherical tank, after 10 years of operation and 1 year of decay the H*(10) expected at 1 m from the tank surface is 1.1 Sv h^{-1}. Such a much lower dose rate for almost the same induced radioactivity is mainly due to the phenomenon of self-absorption in the target, which is much more effective in mercury (~7 tons) then in the tantalum targets (~100 kg). However, due to their comparatively small size, the tantalum targets can be easily shielded. For the same volume (waste + shield), the dose rates expected at a given distance from the tantalum targets would be lower than from the irradiated mercury.

The dose equivalent rate expected at one metre from the horns after six weeks of irradiation and 1-day waiting time is 10 Sv h^{-1}. The dose equivalent rate expected in the centre of the decay tunnel after 10 years of operation and 1-month waiting time is 3.5 Sv h^{-1}.

One of the major advantages of the solid target is that the amount of irradiated material is considerably reduced and it can be stored after the shutdown of the facility without the need of reprocessing. The storage of liquid radioactive waste may be subjected to severe restrictions from a regulatory point of view. Mercury may thus require being solidified in-situ with a special treatment when becoming waste: it may be transformed into mercury sulphide (HgS), which is almost insoluble and has a higher melting point (641 K). Although the process of solidification of non-radioactive mercury, in spite of its chemical toxicity, is technically feasible, the high induced radioactivity will impose strict constraints on the handling of the large amounts required.

6.5 Development of an extended-range Bonner sphere spectrometer

Work continued on the characterisation of a Bonner sphere neutron spectrometer (BSS) with response extended to energies above 20 MeV. After calibration with monoenergetic neutron beams at PTB (Braunschweig, Germany) in 2001 and 2002, a measurement with nearly monoenergetic 33 and 60 MeV neutrons was performed at UCL (Louvain-la-Neuve, Belgium) in 2003. Unfortunately a malfunctioning of the electronics did not allow deriving reliable experimental data to be compared with previous Monte Carlo simulations.

In completing the data analysis of an experiment performed in 2001, where the BSS was employed for measuring the neutron yield and spectral fluence from semi-thick targets bombarded by a mixed proton/pion beam with 40 GeV/c momentum [(4)], it became evident that, under certain circumstances, the use of lead-enriched moderators may present a problem. These detectors were found to have a significant response to the charged hadron component accompanying the neutrons emitted from the target. Conventional polyethylene moderators show a similar behaviour but less pronounced. These secondary hadrons interact with the moderator and generate neutrons, which are in turn detected by the counter. To investigate this effect and determine a correction factor to be applied to the unfolding procedure, a series of Monte Carlo simulations were performed with the FLUKA code. These simulations aimed at determining the response of the BSS to charged hadrons under the specific experimental situation. Following these results, a complete response matrix of the extended BSS to charged pions and protons was calculated with FLUKA. An experimental verification was carried out with a 120 GeV/c hadron beam at the CERF facility at CERN [Ago03c]. The results were used to correct the experimental data of the 2001 measurements.

6.6 Shielding data for low-energy ion accelerators

Data on transmission in concrete of neutrons generated by heavy ions of intermediate energies (typically up to a few hundreds of MeV per nucleon) are of interest for the shielding design of accelerators for use in both the medical and the research field, and in particular for the transformation of the former Low Energy Antiproton Ring (LEAR) at CERN into a Low Energy Ion Ring (LEIR) for the LHC injector chain. Systematic measurements of yield and energy distribution in the angular range 0º – 90º of neutrons produced by the interaction with various targets of ion beams from carbon to xenon with energy of up to 800 MeV per nucleon, recently published in the literature, were used as input data for Monte Carlo simulations – to extend work started in 2002 – to determine source terms and attenuation lengths in ordinary concrete [Ago03b]. Calculations were performed for 100 MeV/u helium ions on a Cu target, 100 MeV/u carbon ions on C, Al, Cu and Pb, 100 MeV/u neon ions on Cu and Pb, 400 MeV/u carbon ions on C, Al, Cu and Pb, 400 MeV/u neon ions on Cu, 400 MeV/u Ar ions on Cu, 400 MeV/u Fe ions on Cu and 400 MeV/u Xe ions on Cu. The results include the contributions of all secondaries. It turned out that some of the resulting attenuation curves are best fitted by a double-exponential function rather than the usual single-exponential. A comparison was made with shielding data for protons scaled with the ion mass number. A comparison was also made with a simple analytical model in use at GANIL, which was eventually employed in the calculations for LEIR discussed in section 4.5.

6.7 Radiation issues in a radioactive ion decay ring

CERN has studied the conceptual design of a future beta-beam facility. In such a facility a pure beam of electron neutrinos or their antiparticles would be produced through the decay of fully stripped radioactive ions (^{6}He and ^{18}Ne) circulating in a storage ring. Since the beam is not extracted from the ring, all the particles will eventually be lost somewhere in the machine and thus activate the machine components and the surrounding concrete and rock. In particular, as nuclei change their charge in beta-decay, a large part of the particles will be lost in the arcs of the decay ring and mainly irradiate the magnets. The density of inelastic interactions of hadrons in the magnets, concrete and rock and the track-length distribution of secondary hadrons were calculated with FLUKA. These values were used to estimate the induced radioactivity in the facility, the dose rates expected in the decay ring and the consequences for the environment [Mag03b].

This very preliminary study has shown that after 10 years of operation and 10-year waiting time, magnets and vacuum chambers in the arcs will still show a level of induced radioactivity exceeding the Swiss exemption limits. The dose rate in contact with magnets in the arcs after 30-day operation and 1-day cooling will be 2.5 mSv h^{-1}. The dose rate in contact with magnets and vacuum chambers in the straight sections after 30-day operation and 1-day cooling will be lower than 0.5 µSv h^{-1}. After 10 years of operation and 1-month decay time, the highest dose rate expected in the ring from magnets, vacuum chambers and concrete wall is 0.8 mSv h^{-1}. After the final shutdown

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[(4)] S. Agosteo, C. Birattari, E. Dimovasili, A. Foglio Para, M. Silari, L. Ulrici, H. Vincke, Neutron production from 40 GeV/c mixed proton/pion beam on copper, silver and lead targets in the angular range 30º – 135º, submitted for publication in Nuclear Instruments and Methods B.

of the facility, the induced radioactivity in a 1.5 m thick layer of concrete and rock will be above the Swiss exemption limits.

6.8 Experiments at CERF

Two experimental runs took place at CERF (CERN-EU high-energy Reference Field) facility [(5)] set up at the H6 beam in the North Experimental Area on the Prévessin site), in the periods 16 – 23 July and 28 August – 3 September 2003. As in the past years, the beam was 120 GeV/c positive particles. Several research teams from the following institutions participated in the experiment: the Agenzia Nazionale per la Protezione dell'Ambiente (ANPA), Rome (Italy), the National Radiological Protection Board, Didcot (U.K.), the Nuclear Physics Institute of Prague (Czech Republic), GSI Darmstadt (Germany), the University of Kiel (Germany), the Austrian Research Center Seibersdorf (Austria), CIEMAT (Spain), INFN and University of Torino (Italy), the Istituto di Cristallografia of CNR in Torino (Italy), INP Krakow (Poland), IRSN Paris (France), the Royal Military College of Canada, Kingston (Canada), EADS Nucletudes, Paris (France), KFKI, Budapest (Hungary) and PSI, Villigen, (Switzerland). Various types of passive and active detectors were tested: radon dosimeters, TEPCs, GM-counters, ionisation chambers, different types of rem counters, bubble detectors, scintillator based dose-rate meters, Si-diodes, TLDs, films, nuclear track detectors, a Bonner sphere spectrometer, the DOSTEL detector, the NEUDOS detector, the LIULIN Si-detector, a neutron spectrometer designed to measure the atmospheric neutron flux. A group also measured biological samples (algae of different types and rat cells) and a biodevice (instrument based on biological substances),

As usual, the CERN Radiation Protection group took care of the schedule and co-ordination among the various users, provided the monitoring of the primary beam as well as that of the neutron field. The beam monitoring at H6 is performed by a 1-litre volume Precision Ionisation Chamber (PIC) and since 2002 by a second chamber of the same type but 3-litre volume (BIG PIC). The number of beam particles is also recorded by a scintillation counter; a check of its operation is performed every year before the start of each CERF run. The efficiency curve of the scintillation counter was measured in August 2003. An inter-comparison between the PIC and the BIG PIC was also performed, along with an inter-comparison between two scintillators counting the muons downstream of the CERF area and the PIC [Dim03a].

6.9 Activation and dose rate benchmark measurements at CERF

Samples of materials, which will be used in the LHC machine as well as for shielding and construction components, were irradiated in the stray radiation field at CERF. The materials included various types of steel, copper, titanium, concrete, marble as well as light materials such as carbon composites and boron nitride. Emphasis was put on an accurate recording of the irradiation conditions, such as irradiation profile and intensity, and on a detailed determination of the elemental composition of the samples. After the irradiation the specific activity induced in the samples as well as the remanent dose rate was measured at different cooling times ranging from about twenty minutes to two months.

Furthermore, the irradiation experiment was simulated with the FLUKA code and specific activities as well as dose rates calculated. The latter was based on a new method simulating the production of the various isotopes and the electromagnetic cascade induced by the radioactive decay at a certain cooling time. In general good agreement (see for example Figure 6.6) was found giving confidence in the predictive power of the applied codes and tools for the estimation of the radioactive nuclide inventory of the LHC machine as well as the calculation of remanent doses to personnel during interventions [Brug03a, Roe03a].

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(5) A. Mitaroff and M. Silari**,** *The CERN-EU high-energy Reference Field (CERF) facility for dosimetry at commercial flight altitudes and in space*, Radiation Protection Dosimetry 102, 7- 22 (2002).

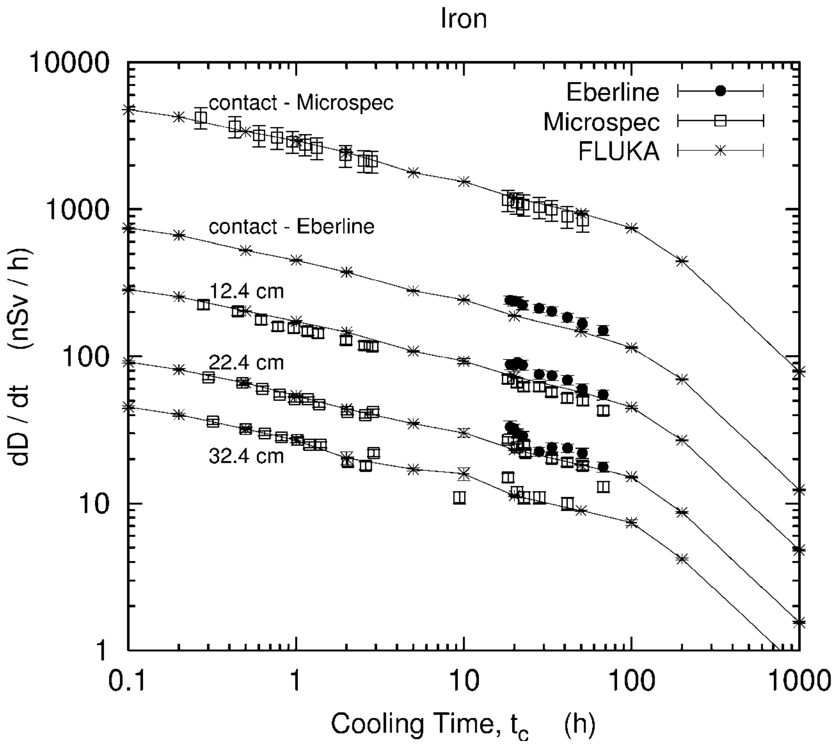

Figure 6.6 Dose equivalent rate as a function of cooling time for the aluminium sample measured with the Microspec and the Eberline instruments and calculated with FLUKA at different distances between the surface of the sample and the effective centre of the detector.

6.10 Simulation and measurements of response functions of ionization chambers

6.10.1 Hydrogen- and argon-filled ionization chambers (IG5)

Ionization chambers of type IG5 by Centronic Ltd. were characterized by simulating their response functions (for photons, electrons, pions, muons, protons and neutrons) with detailed FLUKA calculations as well as by calibration measurements for photons at the PSI and neutrons at fixed energies at the PTB. The latter results were used to obtain a better understanding and validation of the FLUKA simulations. During July and August 2003 tests were also conducted at the CERF facility in order to compare the results with accompanying simulations of the response in such a mixed radiation field.

It was demonstrated that the Monte Carlo code FLUKA can be used successfully to simulate the response of hydrogen-filled high-pressure ionization chambers to mixed radiation fields (Figures 6.7 and 6.8). In the case of argon-filled chambers the results for mixed radiation fields look promising. However, further investigations are required as the experimental benchmarking of their calculated response to low-energy neutrons showed discrepancies that are not yet fully understood (Figure 6.8). In the most relevant cases (outside shielding) the difference between measured and calculated value is less than 20% for both monitor types. Consequently, FLUKA simulations can be used to determine the field quality factors of the mixed fields at high-energy accelerators to obtain correct results for the ambient dose equivalent. The study confirmed that high-pressure ionization chambers, in particular the hydrogen-filled monitors, might fulfill the task of measuring ambient dose equivalent in the mixed radiation fields of the LHC. The study will be extended to other gas types like nitrogen or methane.

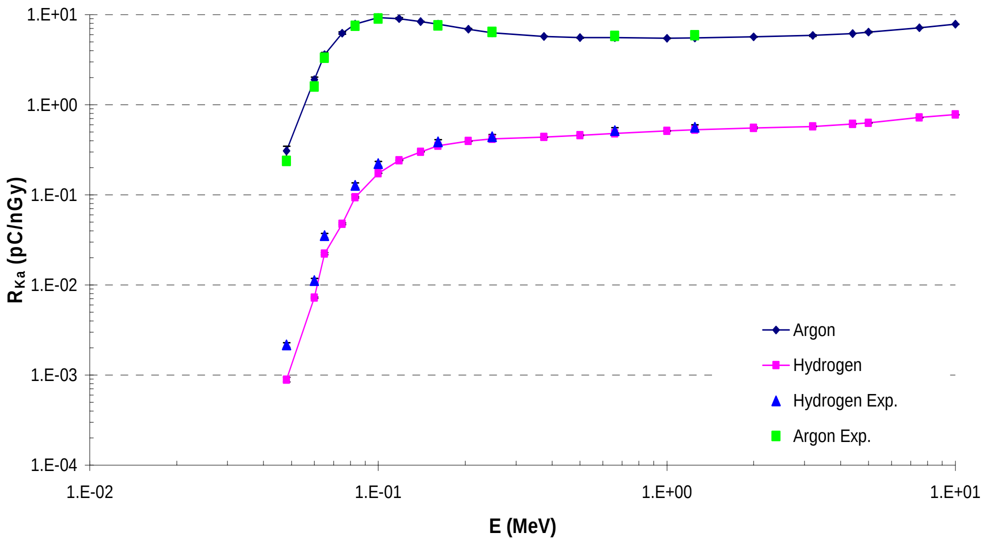

Figure 6.7 Calculated and measured response to photons expressed in terms of created charge per energy released in matter for argon- and hydrogen-filled IG5 chambers.

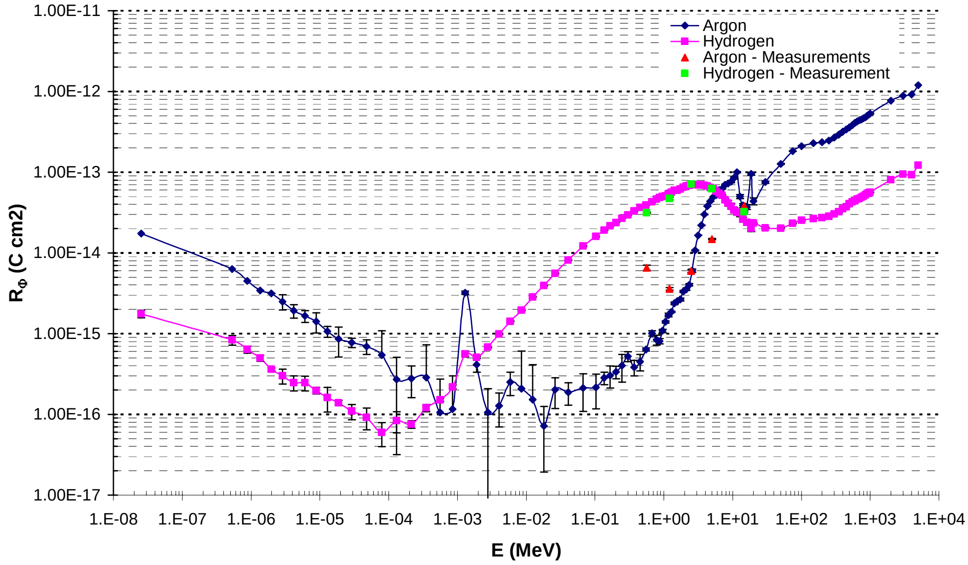

Figure 6.8 Calculated and measured response to neutrons expressed in terms of created charge per unit fluence for argon- and hydrogen-filled IG5 chambers.

6.10.2 Measurements and simulations of the PMI chamber response to the radiation field inside the CERF target area

The PMI detector is an air ionization chamber which is operated under atmospheric pressure. Its main use at CERN is to monitor photon radiation in beam areas during beam-off conditions. The aim of this study was to extent the use of this detector to measure the energy deposition in air produced by all radiation components occurring in a mixed high-energy radiation field [(6)]. To this purpose measurements in the CERF target area were performed, exposing six chambers to different mixed particle fields generated by a 120 GeV/c hadron beam impacting on a copper target. Figure 6.9 shows the detector arrangement in the experimental set-up. The detector positions were chosen as

[(6)] H. Vincke et al., Measurements and simulations of the PMI chamber response to the radiation field inside the CERF target area, Technical Note CERN-SC-2004-025-RP-TN (2004).

such that the mean energy seen by the various chambers is different in the six locations. The measurement results were backed up by FLUKA simulations in order to study the influences of the various radiation components on the final detector response. The comparisons between the simulation and the measurement showed very good agreement at all positions. The influence of the detector hull on the counting rate was up to 20%. This study has showed that FLUKA is capable to predict the PMI detector response to various high-energy radiation fields.

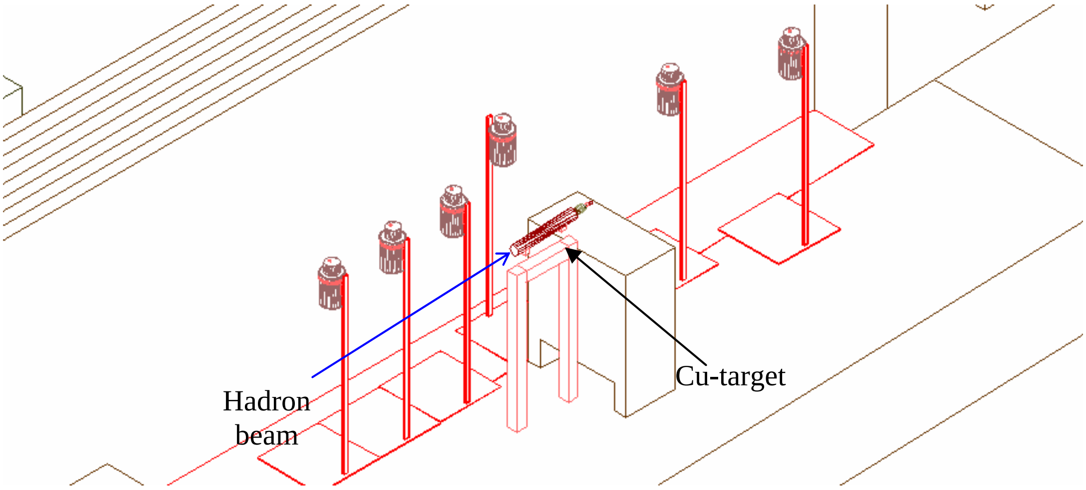

Figure 6.9 Experimental set up showing the arrangement of the 6 PMI chambers around the copper target at CERF irradiated by a 120 GeV/c mixed hadron beam.

6.11 Measurements of the response of solid state detectors

In parallel to the CERF activation studies, measurements with alanine and RPL dosimeters in the secondary high-energy radiation field at the surface of the copper target were performed. For this purpose several sets of alanine and RPL dosimeters were mounted on the target irradiated by hadrons with a momentum of 120 GeV/c. These measurements will be used to better understand the response of alanine and RPL dosimeters to radiation occurring in the area of CERN's accelerators.

6.12 Seminar programme

Six seminars and lectures were given in 2003, one by a fellow in the TIS/RP group and five by visitors from foreign laboratories.

Date	Title	Lecturer
28.04	Introduction of personal monitoring system by glass badge	Norimichi Juto, Chyoda Technol Corporation, Japan
12.06	Natural radioactive concentration of rocks coming from the tunnel where the Large Hadron Collider will be set up at CERN	Prof. Gilles Triscone, University of Geneva
17.07	Dose reconstruction in the case of radiological accident	Jean-François Bottollier-Depois, IRSN, Fontenay – Aux – Roses, France
03.09	Radiation monitoring on the International Space Station	Tad Shelfer, Johnson Space Center, Houston, USA
25.09	Dose equivalent measurements in mixed and time varying radiation fields around high-energy accelerators	Sabine Mayer, TIS/RP fellow
20.10	Cosmic rays in the solar system	Keran O'Brien, University of Arizona, Flagstaff

7 Publications

7.1 Published papers, contribution to conferences and divisional reports

[Ago03a] S. Agosteo, M. Magistris, Th. Otto, M. Silari, *Induced radioactivity in a 4 MW target and its surroundings*, Divisional Report CERN-TIS-2003-003-RP-CF (2003), Proceedings of the Sixth International Topical Meeting on Nuclear Applications of Accelerator Technology, AccApp'03, 1 – 5 June 2003, San Diego, California, U.S.A. (in press).

[Ago03b] S. Agosteo. T. Nakamura, M. Silari, Z. Zaiacova, *Attenuation curves in concrete of neutrons from 100-400 MeV per nucleon He, C, Ne, Ar, Fe and Xe ions on various targets*, Divisional Report CERN-TIS-2003-008-RP-PP (2003), Nuclear Instruments and Methods B 217, 221-236 (2004).

[Ago03c] S. Agosteo, E. Dimovasili, A. Fassò, M. Silari, *The response of a Bonner Sphere Spectrometer to charged hadrons*, Divisional Report CERN-TIS-2003-010-RP-PP (2003), Radiation Protection Dosimetry (in press).

[Brug03a] M. Brugger, Y. Donjoux, A. Mitaroff, S. Roesler, *Measurement and simulation of induced activity at the CERN-EU high-energy reference field facility*, Proceedings of the Sixth International Topical Meeting on Nuclear Applications of Accelerator Technology, AccApp'03, 1 – 5 June 2003, San Diego, California, U.S.A. (in press).

[Brug03b] M. Brugger, D. Forkel-Wirth, S. Roesler, G.R. Stevenson, *Constraints from induced radioactivity on design and maintenance*, Proceedings of the LHC Performance Workshop, Chamonix XII, page 360 (2003).

[Fre03a] E. Freret, M. Noldin, M. Tavlet, *High-level dosimetry results for the CERN high-energy accelerators*, Divisional Report CERN-TIS-2003-006-RP (2003).

[Roe03a] S. Roesler, M. Brugger, Y. Donjoux, A. Mitaroff, *Simulation of remanent dose rates and benchmark measurements at the CERN-EU high-energy reference field facility*, Proceedings of the Sixth International Topical Meeting on Nuclear Applications of Accelerator Technology, AccApp'03, 1 – 5 June 2003, San Diego, California, U.S.A. (in press).

[Sil03a] M. Silari, H.-G. Menzel (Editors), *Radiation protection group annual report 2002*, Divisional Report CERN-TIS-2003-007-RP (2003).

[Vin03a] H. Vincke, G.R. Stevenson, *Calculations of dose attenuation in slowly curving tunnel geometries at a high-energy proton accelerator*, Proceedings of the Sixth International Topical Meeting on Nuclear Applications of Accelerator Technology, AccApp'03, 1 – 5 June 2003, San Diego, California, U.S.A. (in press).

7.2 Technical notes

[Brug03c] M. Brugger, S. Roesler, *Parametric study of air activation at the LHC beam cleaning insertions*, Technical Note CERN-TIS-2003-023-RP-TN (2003).

[Brug03d] M. Brugger, S. Roesler, *Remanent dose rates in the LHC beam cleaning insertions,* Technical Note CERN-TIS-2003-026-RP-TN (2003).

[Brug03e] M. Brugger, S. Roesler, *Accumulated doses during interventions on the vacuum system in the LHC beam cleaning insertions,* Technical Note CERN-TIS-2003-027-RP-TN (2003).

[Brun03a] I. Brunner, D. Pérez-Sánchez, Y. Donjoux, *Résultats de spectrométrie gamma: irradiation TT40, faisceau pilote LHC sur TED 400354*, Technical Note CERN-TIS-2003-018-RP-TN (2003).

[Con03a] N. Conan, *Procédure d'évacuation des déblaies issus du nettoyage du drain central du LEP point 4,* Technical Note CERN-TIS-2003-008-RP-TN (2003).

[Dim03a] E. Dimovasili, M. Magistris, M. Silari, *Inter-comparison of the CERF beam monitors,* Technical Note TIS-2003-016-RP-TN (2003).

[Don03a] Y. Donjoux, G. Dumont, D. Pérez-Sánchez, *Assurance qualité pour les détecteurs de spectrométrie gamma HPGe,* Technical Note CERN-TIS-2003-005-RP-TN (2003).

[Don03b] Y. Donjoux, *Recalibration of HPGe detector using a quality assurance measurement,* Technical Note CERN-TIS-2003-006-RP-TN (2003).

[Don03c] Y. Donjoux, *Logiciel MicroShield - Utilisation des grandeurs dosimétriques appropriées,* Technical Note CERN-TIS-2003-007-RP-TN (2003).

[Don03d] Y. Donjoux, G. Dumont, D. Pérez-Sánchez, *Procédure pour la mise en service et la calibration d'une chaîne de spectrométrie gamma HPGe,* Technical Note CERN-TIS-2003-014-RP TN (2003).

[Don03e] Y. Donjoux, D. Pérez-Sanchez, *Recherche du coefficient d'atténuation linéaire d'un matériau inconnu,* Technical Note CERN-TIS-2003-025-RP-TN (2003).

[Don03f] Y. Donjoux, G. Dumont, D. Pérez-Sánchez, *Résultats de spectrométrie gamma: 2ème irradiation TT40, faisceau pilote LHC sur TED 400354,* Technical Note CERN-TIS-2003-029-RP-TN (2003).

[Kou03a] I.A. Kourotchkine, *The calculation of the effective dose to the public due to the air releases from the LHC facilities*, Technical Note CERN-TIS-2003-001-RP-TN (2003).

[Lam03a] C. Lamberet, L. Ulrici, *L'observatoire national des déchets radioactifs ANDRA/France,* Technical Note CERN-TIS-2003-012-RP-TN (2003).

[Lam03b] C. Lamberet, L. Ulrici, *Fusion des déchets radioactifs métalliques, étude et caractérisation d'un projet d'élimination,* Technical Note CERN-TIS-2003-015-RP-TN (2003).

[Mag03a] M. Magistris, M. Silari, *A comparison between Hg and Ta as material for a high power target from a radiation protection point of view*, Technical Note CERN-TIS-2003-011-RP-TN (2003).

[Mag03b] M. Magistris, M. Silari, *Parameters of radiological interest for a beta-beam decay ring,* Technical Note CERN-TIS-2003-017-RP-TN (2003).

[Mue03a] M.J. Mueller, G.R. Stevenson, *Radiation levels in ECA5 due to proton losses in ECX5,* Technical Note CERN-TIS-2003-020-RP-TN (2003).

[Mul03a] A. Muller, *Contamination of the ISOLDE vacuum system*, Technical Note CERN-TIS-2003-009-RP-TN (2003).

[Ott03a] Th. Otto, *Improved SQL-script to retrieve personal dose information,* Technical Note CERN-TIS-2003-010-RP-TN (2003).

[Sil03b] M. Silari, H. Vincke, *Shielding proposal for the SPL Front End*, Technical Note CERN-TIS-2003-002-RP-TN (2003).

[Sil03c] M. Silari, *Shielding requirements for LEIR as LHC injector,* Technical Note TIS-2003-022-RP-TN (2003).

[Sil03d] M. Silari., P. Vojtyla, *Radiological and environmental aspects of the use, storage and release of activated Xe gas of the ATLAS inner detector*, Technical Note TIS-2003-028-RP-TN (2003).

[Ste03a] G.R. Stevenson, *Dose limits for shielding estimation at the LHC*, Technical Note CERN-TIS-2003-003-RP-TN (2003).

[Ste03b] G.R. Stevenson, *Dose and dose-rate guidelines for LHC maintenance operations*, Technical Note CERN-TIS-2003-004-RP-TN (2003).

[The03a] C. Theis, N. Aguilar, M. Pangallo**,** D. Perrin, M. Renou, S. Roesler, H. Vincke, *Centronic high-pressure ionisation chamber measurements in the mixed radiation field of the CERF facility*, Technical Note CERN-TIS-2003-024-RP-TN (2003).

[Vin03b] H. Vincke, G.R. Stevenson, *Radiation Levels in LHC Points 2 and 8 due to beam dumping on the TEDs at the bottom of TI2 and TI8* , Technical Note CERN-TIS-2003-013-RP-TN (2003).

[Vin03c] H. Vincke, G.R. Stevenson, *Radiation Levels in TI2 and TI8 due to beam losses in the LHC in UJ22 and UJ88*, Technical Note CERN-TIS-2003-021-RP-TN (2003).