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PART III

RADIATION PROTECTION ACTIVITIES AROUND THE CERN ACCELERATORS

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1 INTRODUCTION

The staff of the Survey Section of RP working around the CERN accelerators were as usual very busy. The LEP2 programme is now fully on its way, with the installation of additional superconducting RF cavities carried out during both the winter and summer shutdowns. The LEP energy per beam was thus increased to 80.5 GeV in summer and to 86 GeV in autumn.

ACOL and LEAR ended their operational life on 19 December producing, for the last time, antiprotons for the experiments in the South Hall; all experiments will be dismantled in 1997. This programme will be partly replaced by the future Antiproton Decelerator, which was approved by the Research Board in November.

Several experiments also came to their end in the North and West Experimental Areas of the SPS. NA44 (in EHN1) and NA47 (in EHN2) ended this year. All experiments installed in beam lines H1, H3, X1 and X3 in the West Area also terminated, as these beam lines will be dismantled in the course of 1997 to make room for test facilities for the LHC. Several modifications in the West and North Experimental Areas have already been undertaken at the end of the year and will be continued in 1997. Some equipment installed in the West Area will be moved to the North Area.

In addition to routine work, several measurements of synchrotron radiation were made in LEP for the two new energy levels reached in 1996. A number of dedicated measurements were also undertaken in EHN1 (North Area) at the end of the year, during the lead-ion run which closed the physics period. A detailed assessment of releases of radioactivity from the ISOLDE facility was also made.

2 ACCELERATOR OPERATION SCHEDULE

The year started as usual with the long winter shutdown, with major maintenance work on the accelerators and experimental apparatus. The Linac2 and the PS Booster started on 4 March, with first injection into the PS on 7 March; LEAR started on 11 March, and LEAR physics on 12 April. The first protons were sent to the SPS on 25 March; ISOLDE only started on 7 May owing to problems with the robots used for target changing.

In 1996 the SPS fixed-target programme was divided into three periods: period 1 lasted from 3 April to 30 May (for a total of 52 days of scheduled beam time for users), period 2 from 9 June to 26 September (76 days) and period 3 (the lead-ion run) from 16 October to 25 November (40 days), when the 1996/97 winter shutdown began.

The start-up of LEP was delayed by approximately one week because of obstacles found in the vacuum chamber (in the form of two beer bottles). LEP physics was divided into four periods: period 1 ran from 27 June to 1 August and period 2 from 1 August to 19 August, with

LEP running at 80.5 GeV. Period 3 lasted from 10 October to 4 November and period 4 from 6 November to 25 November, with the accelerator operating at 86 GeV. The summer shutdown was used to install additional RF cavities to reach the new energy value.

3 ANNUAL DOSES AROUND THE CERN ACCELERATORS

The annual collective dose for the work performed at the PS complex was 284.8 mSv (168.7 mSv for the PS ring, 67.7 mSv for the Booster, 34.0 mSv for ISOLDE, 12.6 mSv for the antiproton target area and 1.8 mSv for the LEP injectors). Most of this dose was received during the winter shutdown, i.e. 192.6 mSv for the accelerators and 30.3 mSv for ISOLDE. The increase in 1996 compared with the doses accumulated in 1995 is entirely due to higher dose received during work in the PS ring. The annual collective doses for the PS complex are compared with those of previous years in Figs. 1 and 2.

The collective dose in the SPS complex (i.e., the SPS, the target areas, the North and West experimental halls, the neutrino cave and the workshops) was 259.6 mSv for the winter shutdown and 276.1 mSv during machine operation. The total over the year therefore amounts to 535.7 mSv. These values are compared with those of previous years in Fig. 3. Figure 4 summarizes the annual doses (measured by TLDs) at various locations in the BAs in the years 1992–1996. The higher doses are found at BA2 and BA6, i.e. the two extraction regions towards the North and West experimental areas.

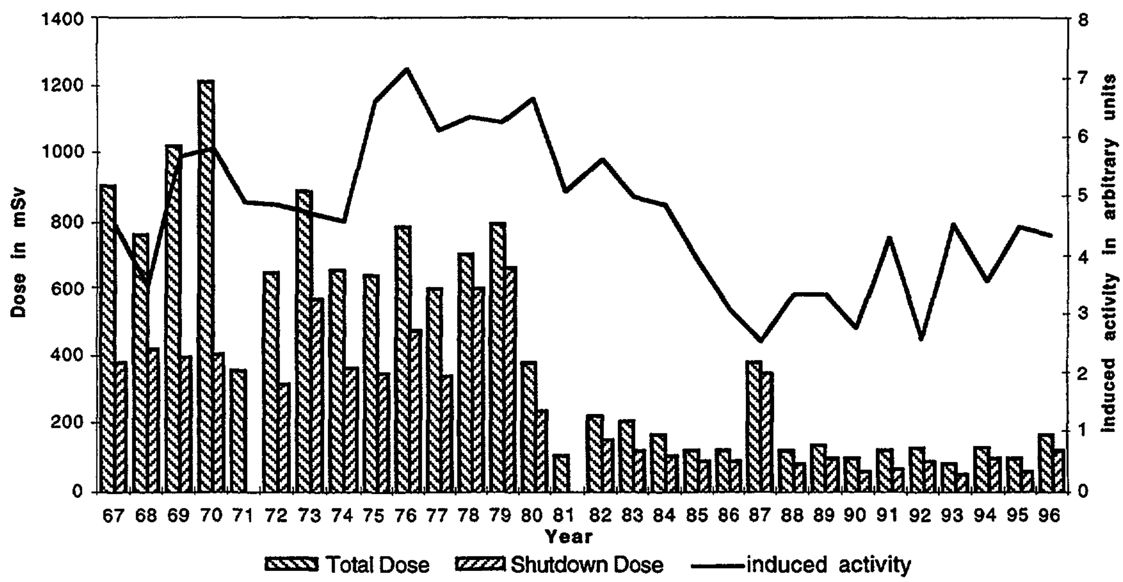


Figure 1: Collective dose for the PS ring. Bars correspond to dose, the line to induced radioactivity

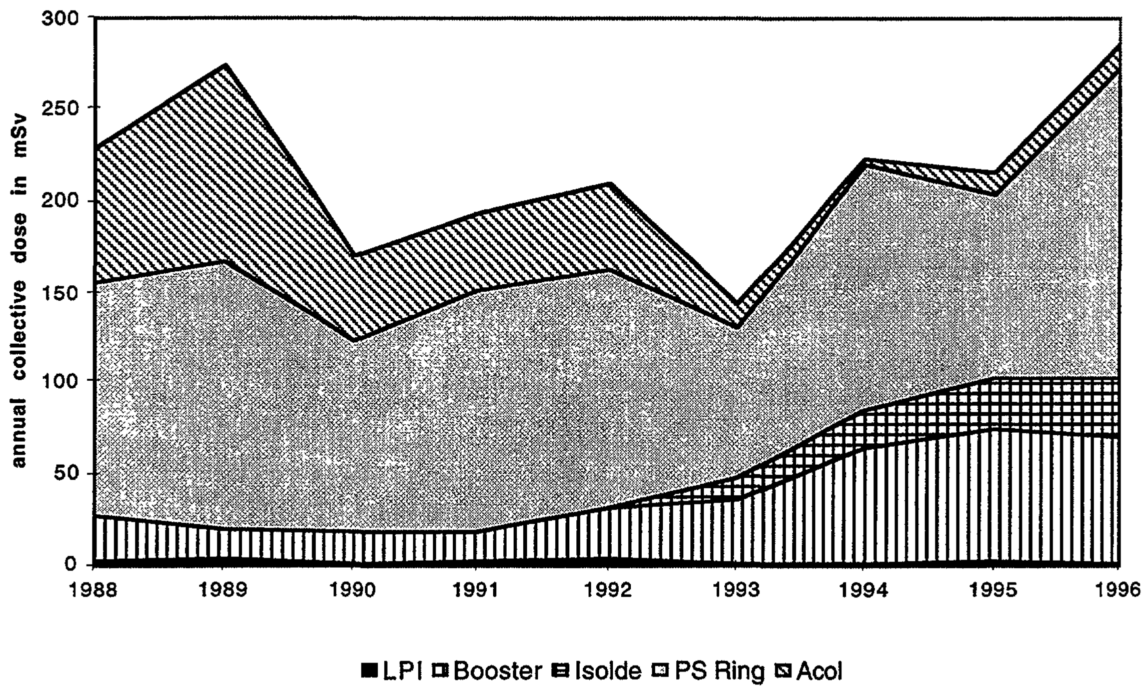


Figure 2: Evolution of the annual collective doses per area within the PS complex

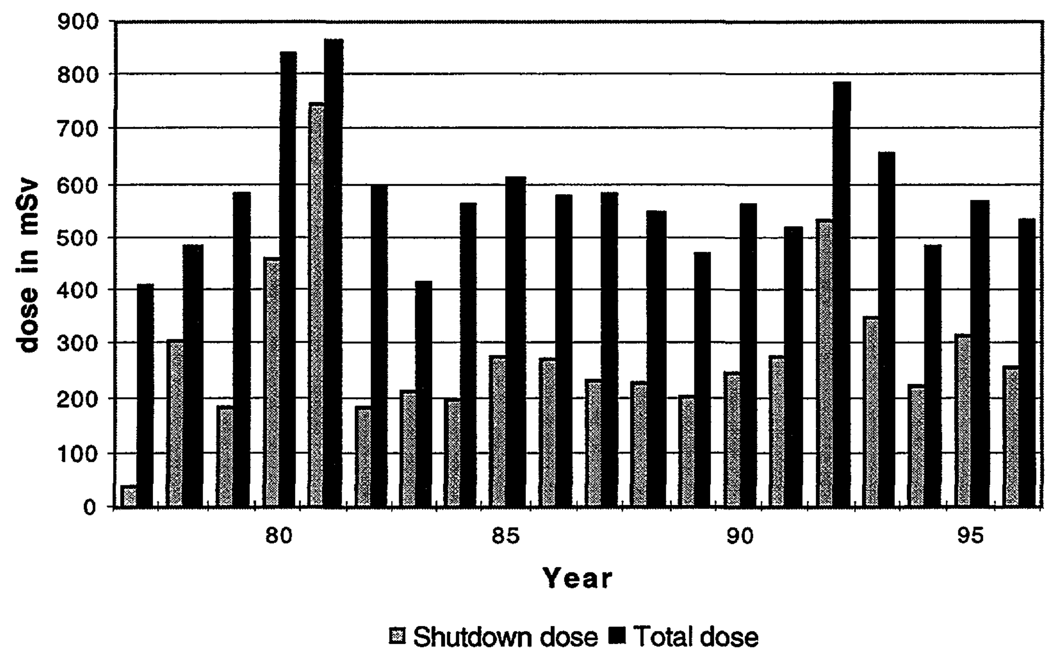


Figure 3: Collective dose for the SPS

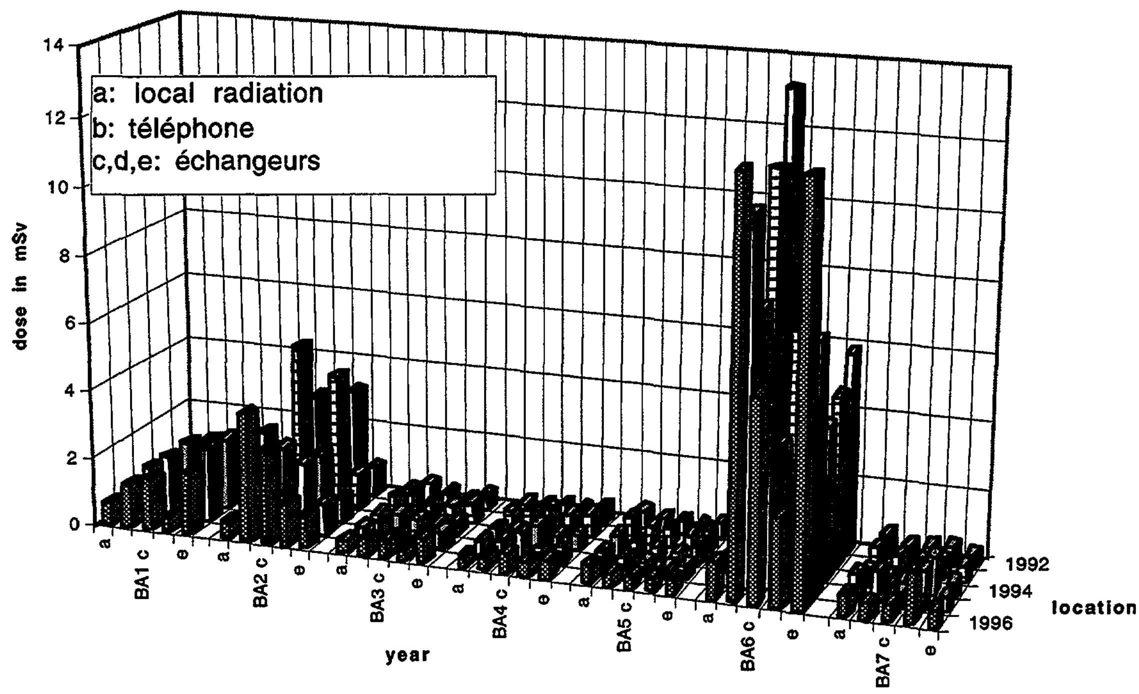


Figure 4: Annual doses in the BAs of SPS

As in the past, the annual doses in the LEP underground areas remained very low, less that one half of the value due to natural background as measured in surface. The annual doses measured in surface around the various access points are not discernible from the background [1].

The major interventions and activities carried out at the CERN accelerators and experimental areas, both during the shutdown period and during machine operation, and the related dose burden are discussed in the following.

4 MACHINE SHUTDOWN

4.1 PS complex

4.1.1 PS ring

The induced activity in the ring measured at the beginning of the 1995/96 winter shutdown was about the same as in previous years; no straight section had to be classified as a high radioactivity area. Beam losses on the vacuum chamber in straight section 1 have decreased by a factor three compared with the past: the measured dose rate was 17 mSv/h in contact and 200 µSv/h at 40 cm. An unusual hot spot was detected in the transfer line from Linac2 to the Booster, giving 60 mSv/h in contact and 700 µSv/h at 40 cm.

During the first day of the shutdown the straight sections 41, 42 and 43 were opened for the installation of the new injection line Booster–PS. The dose rate measured at 40 cm varied between 0.4 and 1.5 mSv/h. The septum 42, removed from the accelerator and stored in the radioactive storage area, gave 7.5 mSv/h in contact and 1 mSv/h at 40 cm. The wiggler dismantled from straight section 41 was also very active, with a maximum dose rate of 60 mSv/h in contact and 4 mSv/h at 40 cm. The cumulative dose for the installation work was about 30 mSv, subdivided among 14 people.

Owing to the heavy workload the total dose for the winter shutdown was 127.1 mSv (more than twice the figure for the shutdown of the previous year), distributed over 169 people. One person had to be stopped from work in radiation areas to prevent him exceeding the limit of 4 mSv per month. The increase of collective dose was practically equally distributed within all sectors. An important role was played by the cabling work (for a total of about 220 km of cables), for which the cumulative dose was a factor 6 higher than in 1995. Although the total dose was higher in 1996 than in 1995 the increased number of people involved in the shutdown work (+65%) has allowed the average individual dose to be kept at a reasonable level.

4.1.2 Booster

A ring survey at the beginning of the shutdown showed that the induced activity was about the same as in the same period of the previous year. The collective dose for the shutdown was 56.6 mSv shared by 66 people.

4.1.3 ISOLDE

A major task in the target area was the setting up of two new robots: to reduce the ambient dose rate, 18 irradiated targets were temporarily stored in the labyrinth of the safety exit, whose access was closed. The collective dose for the work was 7.65 mSv for 5 people. Another intervention of some relevance was the installation of beam monitors in two beam lines, which gave a dose of 12.7 mSv to 21 people. During the cleaning of the front-end of the General Purpose Seperator the following activities were collected: 2 MBq of ^{7}Be, 3 kBq of ^{22}Na and 0.5 kBq of ^{54}Mn.

To assess the radiation resistance of the electronics of the two new robots, activation detectors were exposed in the target area during the last physics period of 1995. The annual dose received by the robots was thus estimated at 1000 Gy.

The collective dose for the shutdown period in ISOLDE amounted to 30.35 mSv for 59 people, 3.5 times the value for the equivalent period of the previous year, for 3 times the number of people. The total dose accumulated over the whole year however remained about the same as last year. The installation of the robots in the target area accounts for about 25% of the total dose.

4.1.4 LEP injectors

A vacuum leak on the second tank of the Linac2 delayed machine start-up. An important beam loss on the graphite ring protecting the vacuum chamber produced a contact dose rate of 200 mSv/h, which called for a two-hour waiting time before intervention, to allow the decrease of ^{11}C activity.

4.1.5 Antiproton Accumulator

In addition to routine maintenance, a number of specific interventions were carried out in the AP target area and in building 232. The first was the removal of 12 screws on the magnetic horn, which had to be done manually (instead of using the robot) since two screws were broken. The dose rate was 12 mSv/h in contact with the horn and 3 mSv/h at 40 cm. The collective dose for the intervention was 2.75 mSv for 4 people. The person who received the highest dose had 1.85 mSv body dose, 8.8 mSv to his right hand and 14 mSv to his left hand. The second intervention was the transfer of several irradiated elements to the radioactive storage area in the ISR, among which three lithium lenses gave 30 mSv/h in contact. The third was the re-installation of a magnetic horn and a lens dismantled several months before; the dose rate in contact with the lens was 110 mSv/h (0.5 mSv/h at 3 m). The collective dose for the shutdown was 8.9 mSv shared by 23 people.

4.2 SPS

4.2.1 SPS ring and transfer tunnels

The most important activity in the SPS during the 1995/96 winter shutdown was the replacement of the radiation-damaged cables in BA6 and BA7. The work was carried out by 25 people of a contract firm, who received a collective dose of 57.8 mSv. Five people lost their film badges in the course of the work; one of them lost it twice and was removed from work. The total dose in LSS6 for the cable replacement, demounting of kickers, and intervention on the vacuum system was 117.4 mSv. In LSS1 repair of beam monitors yielded a total dose of 7 mSv, whilst in LSS2 repair of shutters gave a collective dose of 25 mSv. No significant doses were received in LSS3, LSS4 and LSS5.

Core borings of concrete and the underlying rock were taken from BA4 and TCC6 and analysed by gamma-spectrometry, to assess the level of induced activity in the two areas of the SPS complex where excavation of the transfer tunnels to the LHC will be undertaken [2]. Non-irradiated samples, taken in the region, were also analysed and used as reference. The results of the measurements were compared with data from the literature and with the exemption limits of Switzerland, the European Union and the IAEA. The results showed that the material being removed from the two areas during the excavation of the tunnels will not present any relevant radiation risk and only some precautions will be needed [3].

4.2.2 Neutrino

As soon as the neutrino cave was accessible, a thorough cleaning of the floor was carried out, in order to remove the rust accumulated from oxidation of the crane and avoid any contamination risk. Other relevant interventions were the replacement of beam loss monitors, the installation of a beam monitor at the end of the beam line, the crane maintenance, and modification work on the ventilation system. The total dose accumulated in the shutdown period was 28 mSv (the total over the year was 39.2 mSv, to be compared with 60.45 mSv in 1995).

4.2.3 V_0 cave

A series of measurements was carried out of the residual activity around the dumps and in the access tunnel on 22 February, four months after the neutrino beam was stopped. Dose rates up to several hundred μSv/h were measured around the dump, while in the access tunnel the values varied from 0.3 μSv/h at the access shaft to 100 μSv/h at the bottom of the tunnel (almost in front of the dump).

4.2.4 TCC2, TCC6, TCC8, experimental areas

A radiation survey was carried out in TCC6 40 days after the beginning of the 1995/96 winter shutdown, before the cabling work started. The dose rate varied from 20 to 200 μSv/h, except in the zone between the TAX beam absorbers and the MSN dipoles where the ambient dose rate was 3 mSv/h. The only relevant intervention in TCC8 was the inspection of the ventilation system.

The radiation survey in TCC2 was done 50 days after the beam was stopped. The main interventions in TCC2 during the winter shutdown concerned tests of the emergency stops, tests of the fire detectors (which yielded a dose to one person exceeding 2 mSv), replacement of some magnets, replacement of T4 targets, substitution of a number of rubber hoses of the magnet cooling system (with the connectors treated as radioactive waste). In addition, the entire area was cleaned with the elimination of approximately 6 m^3 of objects of various kinds which had accumulated there over the years. The collective dose over the shutdown was 6.2 mSv, to be compared with a value of 10.4 mSv for the same period in 1995. The total dose in 1996 was 31.3 mSv (44.2 mSv in 1995).

At the end of the year, soon after the accelerators were stopped for the 1996/97 winter shutdown, the dismounting of the H1 beam line (from the SPS to the West area) began. All elements from the splitter before the T1 target were checked and marked with their dose rate. In the North Area, the NA44 experiment reached its conclusion at the end of November (after the lead-ion run) and its dismounting started in December.

4.3 LEP

The winter shutdown for LEP lasted until the end of May, to allow for the installation of 20 superconducting RF modules (each made up of 4 cavities) to scale up the energy to 80.5 GeV from the previous value of 68 GeV. Another long shutdown took place in summer (from 19 August to 11 October) to install 8 additional modules (bringing the total in LEP to 44 modules, i.e. 176 RF superconducting cavities) and increase the energy to 86 GeV in the last run of the year.

As in 1995, the final conditioning of the newly installed RF superconducting cavities was carried out after the modules were moved into the machine tunnel. In order to shield the portion of the LEP tunnel adjacent to the RF straight sections during conditioning, labyrinths (made up of two walls 80 cm thick and spaced by 120 cm) were built at the end of each of the 8 RA straight sections (on either side of interaction points 2, 4, 6 and 8), to separate them from the arcs. This solution allowed work to be carried out in the rest of LEP while the RF cavities were operated. Radiation monitors were interfaced to the klystron safety system, to cut the HV in case a pre-fixed threshold value was exceeded. Measurements made during the RF tests have shown the effectiveness of this solution; the maximum dose rate beyond the labyrinth was 1–2 μSv/h.

In general the RF conditioning is performed with the shutters at both ends of each module closed, to prevent channelling down the beam line of the stray electrons extracted from the cavity walls. However, because of a malfunction, in one case permission was granted to carry out the tests with the shutters opened, all other safety conditions (including collimators closed) being respected. The shutters are usually activated during the tests, with the dose rate largely variable from unit to unit (see Section 6).

The lead/iron shielding walls installed last year in all RB regions to reduce background in the experiments were reinforced. Some of the wave guide ducts connecting the klystron galleries to the LEP tunnels where filled with material both for air-tight and shielding purposes, as they were not used.

As usual, the maintenance work on the four LEP experiments, including that on the uranium calorimeter of L3, did not involve measurable doses to the personnel. With respect to the radiation monitors placed at the base of the detectors, it was decided that the information on radiation alarms, triggered by beam losses which increase radiation in the experimental halls, will still be sent to the control room of the experiment. However, since the radiation levels occurring during a beam loss never exceed a few tens of μSv/h, and are limited to the area at the base of the detector (usually not occupied), the message on the warning panels was changed from ‘leave the area’ to ‘do not loiter’.

5 MACHINE OPERATION

5.1 PS complex

The number of protons and lead ions (in terms of number of charges of Pb^{53+} ions) produced by the Booster during the three physics periods are given in Table 1, while the distribution of particles accelerated in the PS is summarized in Table 2. The record beam intensity in the PS was achieved on 17 August with 2.9×10^{13} protons/pulse, with beam losses kept below 10%.

Table 1: Number of protons and lead ions produced by the Booster in 1996

	Period 1	**Period 2**	**Period 3**	**Total**
Protons	3.63×10^{19}	6.86×10^{19}	2.45×10^{19}	1.29×10^{20}
Charges of Pb^{53+} ions	–	9.6×10^{14}	1.87×10^{16}	1.96×10^{16}

Table 2: Distribution of particle beams in the PS in 1996

Protons	**Positrons**	**Electrons**	**Charges of Pb^{53+} ions**
5.83×10^{19}	9.66×10^{16}	8.85×10^{16}	1.3×10^{14}

5.1.1 PS ring

During a three-day stop in the beginning of June, 16 people had access to the accelerator, receiving a collective dose of 3.2 mSv. Soon after restart, an important beam loss occurred in the beam transfer line Booster–PS because of a blocked sector valve. The dose rate soon after the beam was stopped was 50 mSv/h in contact and 2 mSv/h at 40 cm. The valve was dismantled the following day in an ambient dose rate of 1.3 mSv/h; the 9 people involved in the work received a collective dose of 3.1 mSv.

On 25 July an intervention was required to replace a septum which had a cooling problem. The maximum dose rate in contact with the vacuum chamber was 4.5 mSv/h and in the range 50–100 μSv/h at the place of the intervention. Two days later the spare septum mounted in the ring had in turn to be dismantled and taken to Hall 169 to be tested; it was re-installed in the accelerator on 31 July. The collective dose for these interventions was 3.1 mSv shared by 18 people.

On 29 September, the first day of a scheduled three-day machine stop, a new 40 MHz RF cavity for the LHC was installed in straight section 78. On account of this intervention, the high-intensity beam for the SPS was stopped two days before, so that the collective dose for the cavity installation was limited to 880 μSv for the 18 people involved. The total dose for the routine interventions during the three-day stop was 6.6 mSv for 42 people.

An intervention was required on 31 October on a kicker; the work was carried out in an ambient dose rate of 200 μSv/h and involved a total dose of 1.6 mSv shared by 8 people. The activity measured in the oil was 600 Bq/l of ^{7}Be.

In November a ^{22}Na source of 185 MBq was installed in experiment PS196. A special procedure was set up for safe manipulation of the source. No safety problems were in fact encountered in its use.

The annual collective dose received for maintenance of the PS ring has increased by 67% with respect to the previous year.

5.1.2 Booster

During the three-day technical stop in the beginning of June, routine interventions gave a collective dose of 3 mSv to 11 people. A problem with the ISOLDE beam stopper required a maintenance intervention on the accelerator. Despite the fact that the dose rate at the injection septum was 22 mSv/h, the dose rate at the place of intervention was only 50 μSv/h and no significant doses were involved for the personnel. A three-day stop for maintenance in the beginning of October gave a collective dose of 2.3 mSv shared by 22 people.

Several interventions were needed during operation to replace CCD cameras in the injection line with conventional TV cameras. The overall dose collected by 5 people was less than 1 mSv. A survey made on the injection beam line did not identify significant beam losses which may have caused radiation damage to the CCDs.

During the technical stop of 6 November an important water leak occurred in the Booster; the analysis carried out before releasing the water into the drain showed no radioactivity. The main work performed during the stop was the changing of the water in the septa cooling system: about 2 m^3 were released, after an analysis had shown an activity of 2.5 Bq/l of ^{48}V (compared with an exemption limit of 4 Bq/l).

5.1.3 ISOLDE

Several problems related to the operation of the robots of the General Purpose Spectrometer and the High Resolution Seperator have limited the number of runs and required the cancellation of some runs with heavy targets. Various electronic components of the robots had to be changed several times. The dose received for these interventions could be limited to 650 μSv to 5 people, thanks to a lead shield placed in the GPS pit, between the Faraday cage and the robot.

An assessment of radioactive air release detected 5 MBq of ^{220}Rn and 70 kBq of ^{131}I for the change of a uranium carbide target, and 250 MBq of ^{220}Rn and 12 kBq of ^{131}I for the change of a thorium carbide target. The release of alpha emitter from the latter target was due to problems with the robot. A system designed to prevent the release due to target outgassing was tested with a thorium target; it was estimated that the system could trap up to 2 MBq of ^{126}I (for comparison, the annual release for 1995 was 6.5 MBq).

A number of target tests were carried out on the HRS. With a CaO target bombarded by 3×10^{13} protons per pulse and 6 pulses per supercycle, the maximum dose rate measured in the HV room above the HRS separator was 20 μSv/h. With 3.8×10^{13} protons per pulse and 7 pulses per supercycle, the dose rate reached 41 μSv/h. A second series of tests with a Pb target gave 65 μSv/h in the same room and about 1 mSv/h at 40 cm from the HRS separator.

Because of the above-mentioned problems with the robot, a target could be removed manually from the GPS only after a cooling period of 51 days. The dose rate was 160 mSv/h in contact with the target and 13 mSv/h at 40 cm. However, the cost in terms of individual doses was very limited (a total of 120 μSv for two people) because of the short duration of the intervention. No activity was measured in the ventilation system.

In the course of a run with a Sb target on the HRS, some electronic components placed behind the robots in the target area were irradiated with a dose of about 6 Gy for 7.6×10^{17} protons on target.

Three 'post-mortem' examinations of irradiated targets were carried out in the hot cell: although the maximum dose rates were 110 mSv/h in contact and 8 mSv/h at 40 cm, the maximum dose to the two workers was 100 μSv body dose and 400 μSv to the extremities.

A 185 MBq liquid source of ^{111}Ag was received from PSI (Villigen), to be employed for labelling of molecules; the dose rate measured in contact with the solution was 200 mSv/h.

A quartz window on the GPS magnet had to be changed: a layer of radioisotopes deposited on the window was responsible for a contact dose rate of 120 mSv/h.

The gas retention balloons were emptied five times in the course of the year, yielding a total released activity (after a decay period in the balloons) of 6.6 GBq of equivalent tritium plus 186 MBq of ^{127}Xe. The grand total from the start of the new ISOLDE facility is about 19.6 GBq.

A detailed study of the releases of radioactivity from the ISOLDE facility was performed [4]. Activities and total doses to a critical group from both normal and accidental releases were calculated for several airborne and liquid radioactive effluents of environmental importance. This study demonstrated that the total dose received due to the ISOLDE operation would be low both for single accidental releases and normal annual exposure.

5.1.4 East Hall

The PS211 experiment of C. Rubbia installed on the T7 beam line started on 22 April and continued for the whole year. The zone was transformed into a primary beam area. The maximum dose rate, achieved on the EP3 roof during beam set-up, was 250 μSv/h. Afterwards the dose rate in this zone always stayed below 20 μSv/h and below 5 μSv/h everywhere else around the area. The maximum beam intensity allowable on the T7 target was 10^{10} protons per pulse. On 6 September a 3.7 GBq ^{90}(Sr-Y) source was introduced in the Pb block to be irradiated; this test caused several radiation alarms, with dose rates up to 110 μSv/h, due to bad beam control.

A quadrupole on the T9 line had to be replaced following a short circuit. The contact dose rates measured before the intervention were 1.3 mSv/h at the entrance and 2.1 mSv/h at the exit. The maximum dose rate inside the magnet was 13 mSv/h and approximately 250 μSv/h at 40 cm all around the magnet. The element was sent to the radioactive storage area.

5.1.5 LEP injectors

The installation of the elements for the future CTF2 (which will be classified as 'limited-stay area') continued. Two PMI chambers were installed in the area. Two iron blocks 40 cm thick were installed at the end of the beam line in front of the concrete blocks. Shielding was also installed both around the drive beam and the probe beam.

No particularly high dose rate was detected in the klystron gallery, including the klystrons of the CLIC Test Facility. It was estimated that a person working full time in the gallery for three months would receive 1.2 mSv.

Maintenance work was carried out on one of the spare accelerating sections of LIL. The maximum dose rate measured at one extremity of the section was 4 mSv/h and 100 μSv/h at 40 cm. All along the section the dose rate at 40 cm varied between 5 and 20 μSv/h. A fenced area was set up around the most active point. The collective dose received by five people was 0.74 mSv.

Several sets of optical fibres were irradiated in the EPA with doses varying from 100 kGy to 20 MGy. A gamma spectrometry analysis detected some ^{22}Na, but the activity was sufficiently low to allow transportation outside CERN. The contact dose rate soon after irradiation never exceeded 100 μSv/h.

5.1.6 Antiproton Accumulator

A leak of demineralized water in the AA hall required the intervention of the fire brigade; a gamma spectrometry measurement showed no contamination.

On 17 October a short circuit in the supply line of the magnetic horn called for an intervention in the target area to replace both the cable box and the horn. The dose rate on the horn was 175 mSv/h in contact and 20 mSv/h at 1 m, while it was only 100 μSv/h in contact with the box. The work lasted less than 10 hours and gave a collective dose of 2.6 mSv shared by 10 people.

The dehumidification of the air in the AA target area produced in November an increase of the water level in a collecting tank situated in TT6. The tank was emptied after a gamma spectrometry measurement showed a total activity of 80 Bq/l, mostly due to ^{22}Na (about 40 Bq/l). The same operation was repeated in December.

5.2 SPS

The beam intensity delivered by the SPS to the five production targets (T1, T2, T4, T6 and T9) during the three periods of the fixed-target programme are summarized in Table 3. It can be observed that the beam intensity on the neutrino target was substantially higher than on the other targets. In period 3 the SPS accelerated fully stripped lead ions to an energy of 400 GeV per charge, i.e. 158 GeV/u or 32.8 TeV total beam energy.

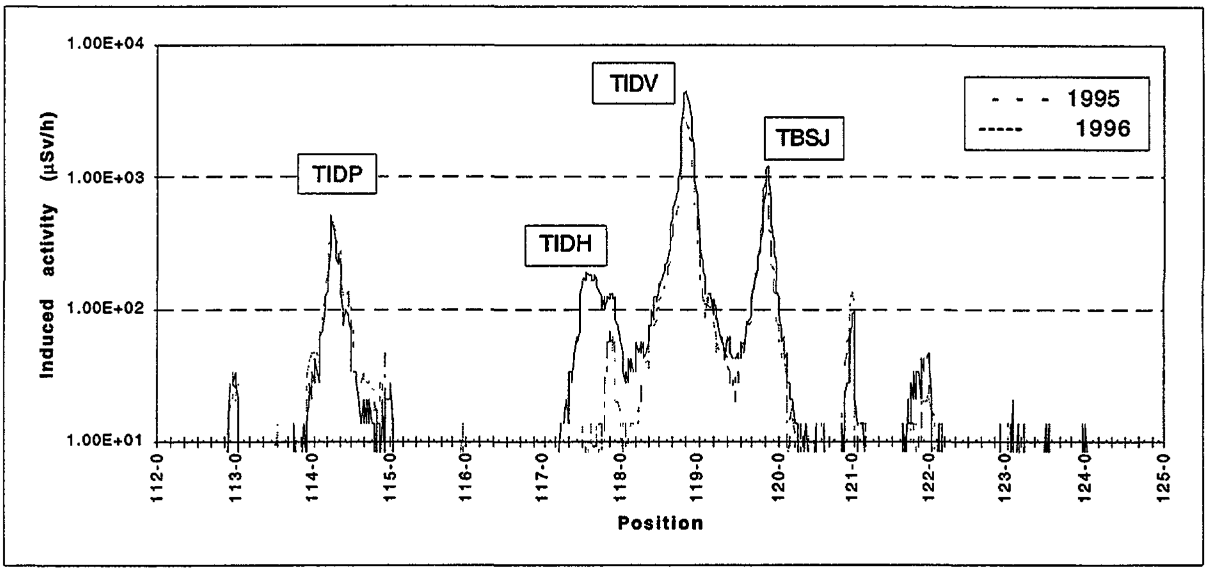
Table 3: Beam intensity on SPS targets. The target T9 (neutrino) was not used during period 3 (the lead ion run)

Period	Beam time(h)	Total number of particles on target					
		T1	T2	T4	T6	T9	Total
1	976.5	5.32×10^{17}	4.32×10^{17}	4.01×10^{17}	1.13×10^{18}	3.79×10^{18}	6.29×10^{18}
2	1919.8	1.04×10^{18}	1.01×10^{18}	1.09×10^{18}	2.36×10^{18}	1.08×10^{19}	1.63×10^{19}
3	844.4	6.15×10^{14}	5.82×10^{14}	8.32×10^{14}	2.91×10^{15}	–	4.94×10^{15}

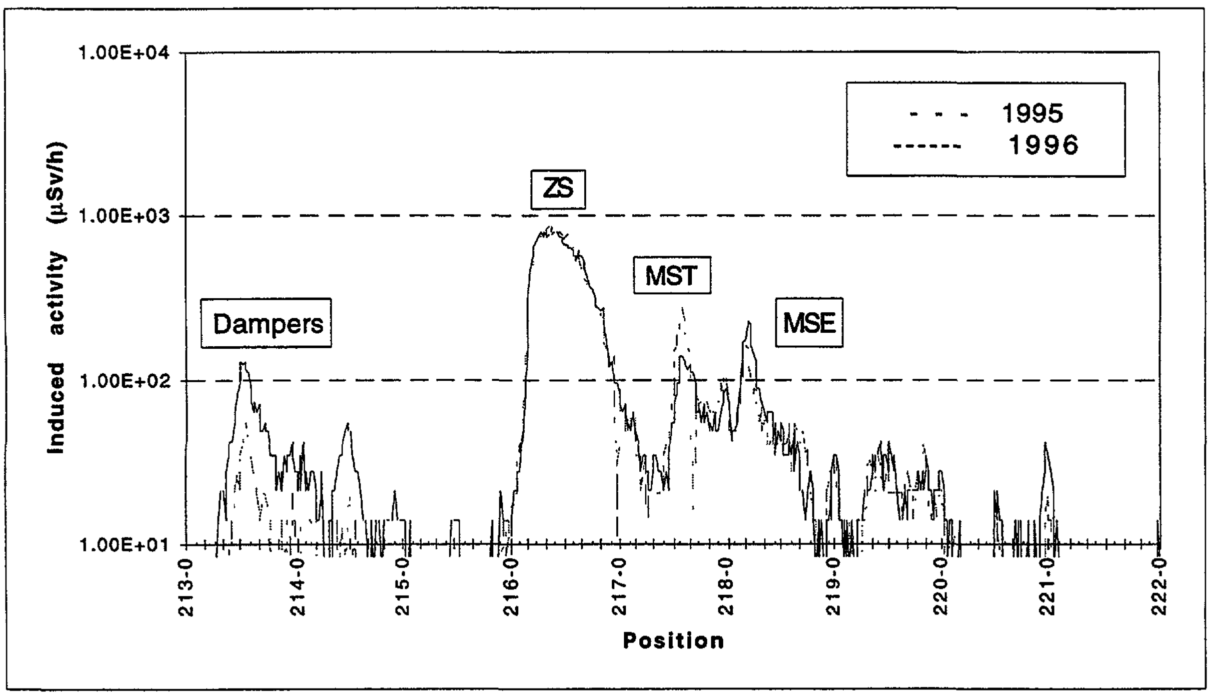
5.2.1 SPS ring

Only a few interventions involved a dose burden of some relevance. The replacement of a MBA magnet in LSS3 was carried out in an ambient dose rate of 150 µSv/h and a maximum of 250 µSv/h on the element, involving a collective dose of 1.2 mSv subdivided amongst 12 people. An intervention in LSS6, needed because of water and vacuum leaks in the MSE sector, gave a collective dose of 560 µSv to 7 people. An intervention on a separator (ZS-2) in LSS6 was carried out in an ambient dose rate of 30 mSv/h; the highest individual dose was 1.15 mSv.

The end-of-year radiation survey of the SPS was carried out on 27 November, after the lead ion run, at the beginning of the 1996/97 winter shutdown. The levels of induced activity in sextants 1, 2 and 6 are given in Figs. 5a–5c, which also show for comparison the result of the survey made in the same period of the previous year. Smear tests were also made in the dump region (BA1) and in the extraction regions (BA2 and BA6); a maximum beta contamination of 3.6 Bq/m^2 was found with no significant alpha contamination. This year the winter maintenance already started in the beginning of December (rather than in January as in previous years): the dismounting of the ZS in LSS6 and their storage in TT60 gave a collective dose of 19 mSv shared by 22 people, with a maximum individual dose of 3.9 mSv. The beginning of work to replace the cables in LSS6 involved for December a collective dose of 30.3 mSv to 18 people.

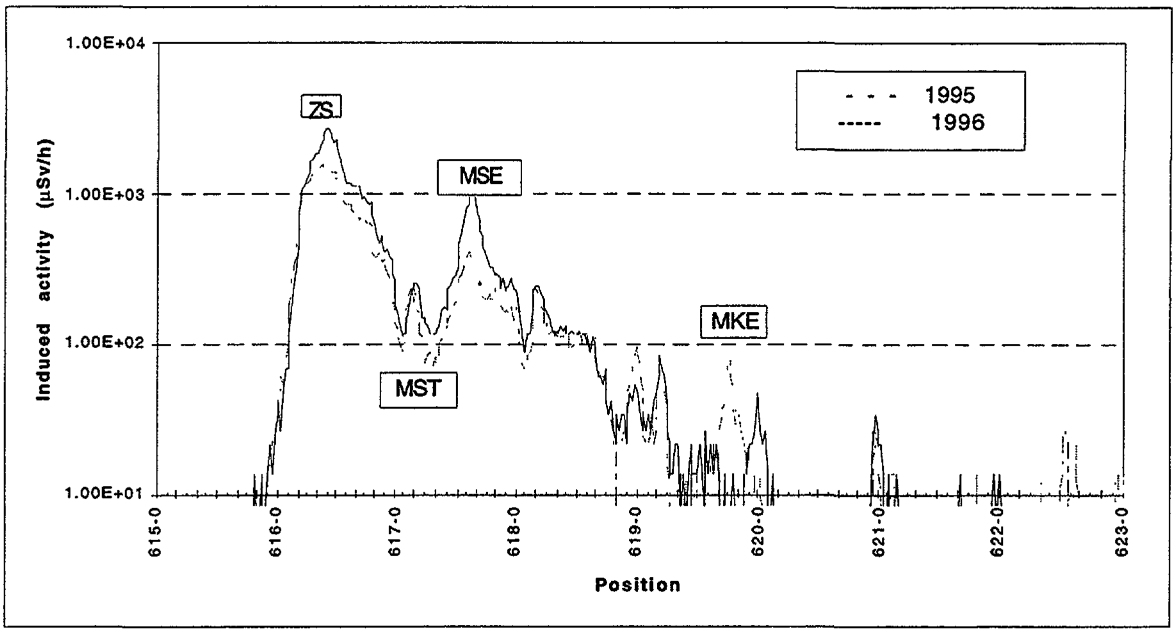


(a)



(b)

Figure 5a,b: Induced radioactivity in sextant 1 and sextant 2 of the SPS



(c)

Figure 5c: Induced radioactivity in sextant 6 of the SPS

5.2.2 TCC2, TCC6, TCC8, experimental areas

The most important intervention in the target areas was the repair of a water leak on a magnet in TCC2, which involved a collective dose of 10.6 mSv for 26 people; one water leak in TCC6 gave a collective dose of 1.19 mSv. TCC8 was chosen to test the new access control system, based on a film badge reader, via a bar code integrated in the film badge case.

In the North and West experimental areas, an investigation was conducted, over a period of three months (from the middle of April to the middle of July), on the wearing of film badges, to enforce the compliance to the rules by CERN staff and visiting scientists. The result of these systematic checks showed that 34% and 62% of people (mostly from the experiments) working in the North and West areas, respectively, were not wearing their film badge at the moment of the check [5]. The result of this investigation was circulated and the situation has apparently improved in the second part of the year.

In September maintenance work was carried out on the roof of EHN1. The surface area right above the beam lines was fenced to prevent workers' access to it. The three people received an individual dose of 180 µSv each for the whole work (17 days).

An extensive campaign of measurements in EHN1 was conducted in November during the lead ion run. The purpose of these measurements was twofold: 1) to obtain a detailed picture of the dose equivalent rate around EHN1, which was found to vary from about 2 μSv/h to 45 μSv/h [6], and 2) to test and intercompare a number of detectors, mainly neutron measuring devices, in the stray field outside the shielding around the experiments. The instrumentation used included different types of Andersson-Braun rem counters, a spherical ^{3}He proportional counter employed with a set of five polyethylene spheres of different diameters, a cylindrical ^{4}He spectrometer, a tissue-equivalent proportional counter (TEPC), a set of superheated drop (bubble) detectors, different ion chambers, and plastic scintillators to detect high-energy hadrons via ^{11}C production. Some activation measurements with ^{32}S pellets — via the $^{32}S(n,p)^{32}P$ reaction — as well as ^{11}C measurements were performed around the NA44 and NA45 experimental apparatus, inside the irradiation caves.

During the lead ion run, in the West area the interlock chain for the H3 beam was modified as in 1995. The improvement of the shielding of the calorimeter in the H3 beam allowed the dose rates to be kept at an acceptable level (less than 15 μSv/h in the barracks and around 35 μSv/h on the roof of the cave housing the calorimeter) despite the increased beam intensity. A one-day experiment (the emulsion run) took place in November, when several people worked very close to the H3 beam just upstream of WA98 to expose various types of emulsions, on a pulse-to-pulse basis, directly in the ion beam. A special monitoring was set up for that day, with ion chambers and rem counters for ambient monitoring and finger dosimeters (in addition to film badges and quartz fibre dosimeters) for individual dosimetry. The maximum personal dose was 580 μSv, the others being in the range 100–200 μSv.

5.2.3 Neutrino

Several tests were carried out on the ventilation system of the neutrino cave, as it seemed that the cave (where the ventilation is closed-circuit) was not air-tight with respect to the access pit. The lock of the door separating the two areas was reinforced to prevent accidental opening.

A few interventions in the neutrino cave requested during the two periods of physics involved a collective dose of 7.3 mSv.

Fifteen TLDs under a 5 inch moderator were placed in the neutrino cave to be exposed during the run from April to June, but they all saturated. The measurement was therefore repeated in the following run (June to September) using alanine dosimeters and the activation of sulphur disks. The integrated dose in period 2 ranged from about 2 Gy near to the access shaft, up to values from 200 to 2000 Gy around the dump (i.e., a maximum dose rate of about 1 Gy/h).

5.2.4 V_0 cave

About 3 m^3 of water are evaporated by the V_0 machine per month. In 1996 seven containers of radioactive chalk were sent to the radioactive storage.

The water pump was replaced and TIS/GS is studying the problem of automation of the evaporator. The water level can now be directly monitored from the ARCON, but the pit still has to be emptied manually when the level approaches overflow.

5.3 LEP

The radiation safety instructions for LEP were updated following the recent modifications in the accelerator, i.e. the installation of new superconducting RF cavities and the subsequent increase in energy of the electron/positron beams [7]. In particular, the straight sections housing the superconducting cavities were classified as controlled areas, because of the presence of a few ‘hot spots’ (on the cavity ends or on some shutters). These spots are most likely the result of activation by high-energy photons produced by stray electrons extracted from the cavity walls and accelerated to an energy of several tens of MeV, and may be residual radioactivity from the conditioning period (see Section 4.3).

Two radiation surveys were made in LEP at the beginning of each shutdown period, the first on 19 August (after the run at 80.5 GeV) and the second at the end of November (after the 86 GeV run), i.e. at the beginning of the winter shutdown. The surveys included all RF zones and the two injection zones. Although radiation levels from induced activity in LEP are much lower than in PS and SPS, a few “hot spots” were found and clearly marked with labels indicating the dose rate. The maximum measured was 480 μSv/h in the injection region and 280 μSv/h in the RF areas RA43 and RA87. The surveys were repeated about two weeks later and the dose rate indications updated, as in most places they have decreased considerably.

A comparison was made of the induced activity measured in the injection region with the results of surveys made the previous years. Accounting for the fact that the radiation levels are influenced by the elapsed time between the end of the run and the survey, by the LEP optics which was not always the same, and by the efficiency of the injection in the days or hours preceding the measurement, one sees that the locations of the activated components and the dose rate values did not change substantially over the years and with LEP energy. This indicates that induced activity is due to beam losses and not to neutrons produced by synchrotron radiation [8]. This was confirmed by gamma-spectrometry measurements made on the vacuum chamber and on one bellow [9].

The measurements of synchrotron radiation in the LEP tunnel, started in 1995, were extended to 80.5 GeV and 86 GeV. The measurements were carried out in the proximity of point 4 to compare the results, wherever possible, with those at 45 GeV and 68 GeV [10]. About 300 alanine dosimeters were placed in the RF straight section, in the arc, at both sides and inside the newly built labyrinth separating the two parts of the tunnel, at both sides and inside the wave guide ducts and in the access maze UJ43. Additional measurements were done at 80 GeV in the region of the polarization wigglers at point 7. At 86 GeV, a number of additional dosimeters were placed under different lead thicknesses to assess the attenuation of the synchrotron radiation spectrum in the arc (where pure synchrotron radiation from dipoles is expected), in the RF zone (most probable presence of higher energy photons emitted by the cavities), and in the injection region (expected high-energy photons generated by beam losses). The results of the measurements at 80.5 GeV [11] show an increase of the radiation levels in the tunnel (with a clear indication of two independent radiation sources in the arc and in the RF zone), but no increase of radiological risk in the areas accessible by personnel during LEP operation. The highest dose rate (25 µSv/h) was detected at the exit of the wave guide ducts at the far end of the klystron gallery, near UJ43. The presence of personnel in this zone (which is classified as controlled area) is very limited. The analysis of the data taken at 86 GeV is not yet complete.

During the run at 80.5 GeV, the increased radiation levels irreparably damaged the electronics of the eight radiation monitors installed in the LEP tunnel at both sides of the four experiments. Since these detectors are deemed useful, as they also allow monitoring during the RF cavity tests, it was decided to replace them by PMI detectors coupled to detached electronics. The installation of the new detectors will be carried out during the 1996/97 winter shutdown.

It also turned out that the increased radiation level perturbed the electronics driving the five automatic gates (GP132, 168, 532, 631 and 732) in the machine tunnel. Such perturbation caused the gates to open thus stopping the beam. For this reason the five doors had to be excluded from the interlock chain during LEP operation.

A GM detector was installed, amongst other instrumentation, on a unit which moves on the monorail (a 'robot') and used to explore the LEP tunnel during operation. This allowed monitoring of radiation levels in the tunnel with the beam on. For the time being the robot only moved in straight section 3; when not in use, it was put into a shielded garage in the tunnel, to minimize radiation damage.

An ozone measurement was made in the arc near interaction point 4 during the run at 86 GeV. The measured concentration of ozone did not exceed 0.01 ppm [12].

6 OTHER AREAS AND ACTIVITIES

The tests of the new superconducting RF cavities for LEP continued in the course of the year in SM18 and in Hall 180. In SM18 the radiation levels were very low and never exceeded 7.5 µSv/h. In Hall 180 no radiation could be detected outside the test bunkers. Measurements of induced activity on the shutters closing both ends of the modules showed values variable from a few µSv/h up to 3–4 mSv/h. It was found that the shutters were deteriorated by heating up caused by the electron bombardment. It was therefore decided to run the tests with the shutters open and placing copper absorbers on the cavity axis. The absorbers get highly activated during the test, but the dose rate then decreases by a factor 10 in about 30 minutes. Seventy hours after the end of the test the dose rate at the extremities of the module is a factor 2 to 3 higher than at the absorber. In building 2250 at LEP point 2 (RF conditioning) and in building 112 (klystron tests) the TLD dosimeters which are permanently in place showed doses of the same order as the natural background.

The two outdoor radioactive storage areas (the one adjacent to the West Area on the Meyrin site and the one at the back of building 917 on the Prévessin site) were cleared of all radioactive pieces and declassified. Following a small incident in EHN1, when an iron block used as support for the hodoscope in the ATLAS H8 beam was found slightly radioactive without being marked, a systematic radiation check of the standard iron blocks used in the experimental areas was undertaken. A large number of these blocks were checked for induced activity, marked and classified according to the dose rate. The classification adopted is given in Table 4. The majority of these blocks are in EHN1 and in the West Hall, but a few of them come from beam lines and target areas. The few blocks producing dose rates at 10 cm above 100 μSv/h were sent to the radioactive storage in the ISR tunnel. All large blocks below 10 μSv/h were sent to LEP point 2, to be used for the weight test of an air-cushion platform for CMS. A summary of the checked blocks (including those removed from the outdoor radioactive storage areas) is given in Table 5.

A radiation survey carried out around the two buildings used for radioactive storage on the Prévessin site (917 and 955) showed that the dose equivalent rate is everywhere below the limit of 2.5 μSv/h which applies to supervised areas. The old V_0 dump which has been stored inside the fenced area adjacent to building 955 since 1982, was transferred to the radioactive storage area in the ISR tunnel.

Table 4: Classification adopted for the standard iron blocks used in the experimental areas according to the level of induced radioactivity

	Non-radioactive	**Slightly radioactive**	**Radioactive**	**Highly radioactive**
Dose rate at 10 cm	≤ 0.1 μSv/h	$0.1 \leq \dot{H} < 10$ μSv/h	$10 \leq \dot{H} < 100$ μSv/h	> 100 μSv/h
Indication	Green point	Yellow trefoil	Yellow trefoil > 10	Yellow trefoil > 100

Table 5: Total number of iron blocks checked for induced radioactivity. The few blocks giving more than 100 μSv/h at 10 cm are not included.

Dimensions (cm^3)	**Green point**	**Yellow trefoil**	**Yellow trefoil > 10 μSv/h**
160 × 80 × 40	–	8	14
160 × 80 × 20	23	28	–
80 × 80 × 40	–	5	–
80 × 80 × 20	220	27	–
80 × 40 × 40	35	11	–
80 × 20 × 20	25 + 6 West	9	–
40 × 40 × 20	21 + 12 West	29	7
Small blocks	700	283	70

Temperature measurements were carried out in hall 169 on the septum magnet dismantled from the PS on 25 July. The dose rate was 1.85 mSv/h in contact with the copper septum and 100 μSv/h at 40 cm. A concrete shield was built to protect the adjacent offices. The collective dose for the work was 0.9 mSv for 5 people. The septum was eventually transferred to the radioactive storage in the north hall.

An overhaul of a kicker removed from the PS in 1989 (substitution of ferrites and cleaning of HV connections) was undertaken. The contact dose rate was 50 μSv/h, but no trace of contamination was revealed by the smear tests.

Overhaul and cabling work were also undertaken on two electrostatic septa from PS straight sections 31 and 23. The measured dose rates were 900 μSv/h (in contact) and 170 μSv/h (at 40 cm), and 200 μSv/h and 40 μSv/h, respectively. The work was carried out in a 'limited-stay area' in building 162.

Nineteen muon chambers formerly used in the UA1 experiment and stocked in BA5 were checked and found not to be radioactive. Permission was therefore granted for their transportation outside CERN.

A fire exercise in a radiation area was carried out on 27 February in BA5, with the participation of the fire brigades of CERN and Geneva.

A first set of a new type of electronic pocket dosimeter, the DMC100, was put into service. These dosimeters, which are meant to replace eventually all quartz fibre dosimeters, will be provided to all people who are regularly working in controlled radiation areas and usually receive a dose exceeding 3–4 mSv/year.

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