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HIGH-LEVEL DOSIMETRY RESULTS FOR THE CERN HIGH-ENERGY ACCELERATORS

Part 3 : The LEP Machine (at 94.5 GeV) 1998

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Abstract

This year, for the second time, the high-level dosimetry results are presented in three separate reports : Part 1 gives the doses in the PS complex, Part 2 in the SPS complex. This Part 3 gives the doses in the LEP machine. The results are presented in the form of graphs. The aim of these reports is to provide a dose estimate for the various components of the accelerator, and to draw attention to possible radiation damage.

Results show that, in general, no major radiation damage is to be expected for the operation of LEP until the end of the year 2000, but that some components will have to be looked carefully, and some will have to be replaced.

1. Introduction

Integrated radiation dose measurements at selected points in high-dose-level areas have given reliable information on radiation ageing of accelerator components, and have provided an indication of their projected lifetime. We do not, however, keep track of the movement and exchange of equipment, although this need to be taken into account for the determination of the total integrated dose of individual components.

Since the LEP start-up in 1989, more than 800 alanine dosimeters have been installed at standard positions in the tunnel for the measurement of the radiation doses absorbed by magnet coils and electrical cables. Figs 1 and 2 show the standard positions of the dosimeters. Dosimeters have also been installed on RF modules, on and near the (mini-) wiggler magnets, in injection tunnels and around interactions points [1]. Table 1 gives the list of the standard dosimeter positions in the main ring and in the transfer tunnels. The mini-wigglers magnets area and the interaction points were not equipped in 1998 but results for previous years can be found in Reference [2]

The results obtained at standard points (quadrupole and dipole coils) are published every year [2]. Some special experiments have also been done to measure the radial and longitudinal dose distributions, and the effect of the lead shielding [3, 4, 5, 6, 10].

With the increase of the beam energy, more and more dosimeters have been installed close to the most sensitive components such as electronics. Results have already been presented after the 68 GeV, the 80 GeV, the 86 GeV and the 94.5 GeV runs [7, 8, 9, 10]. More measurements have also been carried out for the purpose of radiation protection [11, 12, 13].

In 1998, LEP operated mainly at 94.5 GeV; the integrated current was 6.7 Ah. This report gives the results of the absorbed-dose measurements, compares them with the preceding ones and gives estimates for the operation at 2x100 GeV.

2. Dosimetry Method

For the measurement of the absorbed doses due to synchrotron radiation, polymer-alanine dosimeters (PAD) have been found to be well adapted because their response is independent on the X-ray energy in the range of 500 keV up to several MeV. Stable free radicals are created in alanine by ionizing radiation. The unpaired electron comes from the breaking of a carbon covalent bond, and is detected by the electron spin resonance (ESR) technique. Although a sophisticated readout apparatus is required, ESR spectroscopy has the advantages of high precision and high stability [14, 15, 16].

For the 1998 operation, hydrogen pressure dosimeters (HPD) were also installed in "position 3" on the vacuum chamber between dipoles together with the PAD dosimeters to avoid saturation problems of the alanine with the increase of dose in the machine. For the HPD, the pressure of hydrogen released by polyethylene under irradiation conditions is measured by means of a small vacuum chamber and a pressure-sensor device [14, 17].

The dosimeters are calibrated with cobalt source. This means that all doses reported here are those that would be needed in order to produce the same signal, by a ^{60}Co gamma irradiation, in a $(CH2)_n$-type material. This dosimetry method is sufficiently reliable, as can be seen from dosimeter comparison experiments in accelerator environments, and from our experience of radiation damage in polymeric materials [15, 16]. The behaviour of alanine dosimeters at cryogenic temperatures has also been investigated [18].

3. Results for 1998 and Discussion

The production of synchrotron radiation increases with the fourth power of the beam energy. As the energy of the x-rays also increases, they become more penetrating, and the result is that the absorbed-dose-rate in the tunnel increases approximately with the ninth power of the beam energy [11]. This appears in the three first rows of Table 2 which shows the dose-rates seen by the various components of the machine, and their increase with energy. These dose rates have been calculated by taking the mean recorded values in several cells, divided by the integrated current.

The increase of the normalised dose rates is clearly shown on Fig. 11 for various components. It appears that the increase is lower than expected from the theoretical calculations. The reason for this may be the improvement of the beam shielding along the years.

3.1. Magnet coils

Figs 3 and 5 give, in the form of bar-graphs, the absorbed doses in 1998, respectively on dipole coils (identification "position 3") and on quadrupole coils. The doses were measured by means of HPD dosimeters in "position 3", and by means of PAD dosimeters as previous years in quadrupole positions.

Figs 4 and 6 give, for dipoles and quadrupoles, the integrated radiation doses from the start-up of LEP in 1989. The dipole position in HC 163 does not appear on the graph of Fig. 4, but the integrated radiation dose since the start-up in 1989 is already greater than 10 MGy, mainly due to the 1998 operation (see Fig. 3).

As already discussed in [8], the apparent dose level is still 10 times lower at the quadrupole compared to the dipoles, but this may be due to the measuring position which is a bit further away from the beam axis, and which is partially shielded in the case of the quadrupoles (see Fig. 1). The maximum dose absorbed by the quadrupole coil insulation is probably of the same order as for the dipole coils.

3.2. Cables

Fig. 7 gives, in the form of bar-graphs, the absorbed doses in 1998 for the rubber cables powering the quadrupoles (identification "position 1"). The weaker shielding and the higher synchrotron radiation level (because of double-field magnets) along the injection sectors is clearly visible. Fig. 8 gives the integrated doses from the start-up of LEP in 1989. The evolution from 1997 to 1998 is somewhat lower at the injection than in the rest of the measured positions.

Dose distribution measurements on some control cables in HC 216, both on side and on top cable tray were carried out for the period May-June 1998. The results are published in [10]. These measurements, with the same distribution, in the same positions, will be repeated in 1999.

The insulation of some cables which come close to the beam pipe start to crumble, in particular, in connectors, where the protection against oxidative degradation is weaker than under the sheath. Samples of insulating materials have been taken out and tested [19].

3.3. Other components

Dosimeters have been installed in RF areas (points 2-4-6-8) on the different modules (2 dosimeters by module, one at each extremity). Table 3 gives the absorbed dose in 1998. In some positions, saturation of alanine dosimeters was reached meaning that the absorbed dose is greater than 500 kGy.

Figs. 9 and 10 show the absorbed doses in 1998 in the Wiggler magnets areas in HC532 and 568. The integrated doses on the magnets coils since LEP start-up are far below any radiation damage level (maximum value :160 kGy in HC 568).

Some measurements were carried out on shielded electronics. For 1998, there is a average attenuation factor of 200 between the outside dosimeters and the dosimeters under shielding but in the injection area, the maximum absorbed dose below the shielding reaches 2 kGy.

Measurements were also carried out by the RP group on the optical fibres installed in the central drain of the tunnel. At some points, doses above 10 Gy have been observed [20]; some lengths of the fibre had to be replaced.

4. Conclusion

Table 4 shows the integrated doses over the years. Because the maximum energy was limited to 94.6 GeV instead of 96 GeV in 1998, and because the foreseen integrated currents for 1999 and 2000 have been reduced by a factor of two compared to the values given in [9], the expected absorbed doses for the following years, as well as the total integrated doses, are also reduced by almost a factor of two.

Therefore, in general, no major radiation damage is to be expected for the operation of LEP at 2x100 GeV until the end of the year 2000.

Nevertheless, as the beam energy will still increase in 1999, some components will have to be looked at carefully (the critical doses appear in italic in Table 4), and some will have to be replaced :

- The insulating resin of the dipole in cell 163 has integrated a dose above 10 MGy. Samples of this resin have been tested in 1998 and revealed an unexpected dose-rate effect [19].

- The k-modulation windings (made of polyolefin-insulated cables), around the coils of D-quadrupoles, are already severely damaged. It will be necessary to take them out at the end of 1999 [19, 21].

- It will also be necessary to cut the open ends of the control cables to suppress the damaged part of the insulations, and to remount the connectors.

More samples will be taken and tested to follow up the degradation.

References

1. F. Coninckx : Dosimétrie à haut niveau dans le LEP. TIS–CFM/TM/89–10

2. F. Coninckx, J-J. Farey and M. Tavlet : High-level dosimetry results for the CERN high-energy accelerators. TIS–CFM/90–22, /91–10, /92–10, /93–11, /94–11, /95–12, /96–09, /97–22, and /98–02.

3. F. Coninckx and M. Tavlet : Dose measurements in LEP, with and without lead shielding around the vacuum chamber. TIS–CFM/TM/91–16

4. F. Coninckx : Dose measurements for electronic equipment in LEP position H.C. 159. TIS–CFM/TM/91–17

5. F. Coninckx et M. Tavlet : Mesures de dosimétrie en DC 143, 144 et 159 du LEP, en 1992. TIS–CFM/MT/93–01

6. M. Silari and L. Ulrici : The effect of the polarisation wigglers on radiation levels in the LEP tunnel. TIS–RP/IR/97–30

7. F. Coninckx, H. Schönbacher and M. Tavlet : Dose measurements in LEP at 68 GeV, and estimate of radiation damage for LEP 200. TIS–CFM/IR/96–02

8. F. Coninckx, J-J. Farey, A. Fontaine et M. Tavlet : Mesures de doses dans le LEP à 80 GeV et estimation des dégats radiatifs pour LEP 200. TIS–CFM/MT/96–10

9. C. Chevalier, F. Coninckx, J-J. Farey, A. Fontaine and M. Tavlet : Dose measurements in LEP at 86 GeV, and estimate of radiation damage for LEP 200. TIS–TE/IR/97–13

10. V. Coste, J-J. Farey, A. Fontaine et M. Tavlet : Mesures de doses dans le LEP à 94.5 GeV et estimation des dégats radiatifs pour LEP 200. TIS–TE/IR/98–05

11. A. Fasso et al.: Mesures du rayonnement synchrotron effectuées dans le LEP TIS–RP/IR/96–06

12. P. Fattibene et al.: Mesures de rayonnement synchrotron dans le LEP à 86 GeV. TIS–RP/IR/97–15

13. F. Pirotte, M. Silari and L. Ulrici : Mesures de rayonnement synchrotron dans le LEP à 94.5 GeV. TIS–RP/IR/98–18

14. F. Coninckx et al.: Alanine dosimetry as the reference dosimetric system in accelerator environments. Appl. Radiat. Isot. Vol. 40, No.10–12, 1989

15. F. Coninckx and H. Schönbacher : Experience with a new polymer-alanine dosimeter in a high-energy particle accelerator environment. Appl. Radiat. Isot. Vol. 44, No.1/2, 1993

16. F. Coninckx et al.: Comparison of high-dose dosimetry systems for radiation damage studies in collider detectors and accelerators. CERN/TIS–CFM/92–12/PP (1992);. Nucl. Instrum. & Methods in Phys. Res. B 83 (1993) 181–188

17. J.T. Morgan, R. Sheldon, G.B. Stapleton and G. Wilkinson, A continuous reading and a single measurement dosimeter for the range 104 – 109 rad, RPP/E14, Rutherford High Energy Laboratory (April 1980)

18. F. Coninckx et al.: Response of Alanine dosimeters to irradiations at cryogenic temperatures, CERN/TIS–CFM/95–09/cf (1995);
Appl. Radiat. Isot. 47, No 11/12 (1996) pp. 1223–1229

19. C. Chevalier et al.: Observation of radiation degradation of electrical insulators in the CERN particle accelerators. TIS–TE/IR/98–10, + NIM–B 151(1–4) 438–443

20. F. Pirotte : Doses intégrées sur la fibre optique du LEP de 1995 à 1998. TIS–RP/RSR/SL/99–06

21. R. Bailey et al.: Synchrotron radiation effects at LEP. EPAC '98

Tables

Figure captions

Table 1. Localisation of dosimeters.

Area	Localisation	Dosimeters	Results in Figure :
HC 170 to 200	On vacuum chambers between dipoles	PAD and HPD	3 and 4
	On quadrupole coils	PAD	5 and 6
	On cable trays	PAD	7 and 8
HC 532 and 568	On wiggler magnets	PAD	9 and 10
Mini-wiggler	On magnets	PAD	Not equipped in 1998.
Interaction points	On equipment and cable trays	PAD	Not equipped in 1998.
Injection tunnels TI12 , TI18	On magnets coils	PAD	Not measured this year
HC 240 to 242 HC 259 to 261	In RF zones On radiosensitive items	PAD	Not equipped in 1998.
In RF zone	On RF module	PAD	Tab. 2

Table 2 : Normalized absorbed dose rates (kGy/Ah)

	45 GeV	68 GeV	80.5 GeV	86 GeV	91.5 GeV	94.5GeV	96 GeV	100 GeV	100 GeV
Energy factor (power 4)	1	5.2	10.2	13.3	17.1	19.4	20.7	24.4	
Penetration factor from [14]	1	17.3	24	27	38	42	44	52	
Total multiplication factor	1	90	245	360	650	823	911	1268	Maxi (1)
Dipole coils	**1.100**	**64**	**130**	**185**	**230**	**274**	430	600	2000
Quadrupole coils	**0.065**	**5.1**	**12**	**24**	**31**	**37**	53	73	800
Magnet power cables	**0.001**	**0.060**	**0.18**	**0.22**	**0.63**	**0.70**	0.92	1.30	15
Cables on side	**0.002**	**0.050**	**0.09**	**0.20**	**0.23**	**0.38 (7)**	0.51	0.70	7
Cables on top	**0.007 (2)**	0.140	**0.15**	**0.25**	**0.40**	**0.62 (7)**	0.80	1.00	7
Ancilary equip. in tunnel			**0.2 - 0.5**						
Electronics under magnets	**0.008 (3)**				**3.0 (5)**		5.0	6.0	
Electronics under shielding	**0.0005 (4)**		**0.23 (4)**	**0.50 (4)**	**0.03 (6)**	**0.05 (6)**	0.1	0.1	2

values in bold are measured values

(1) maximum kGy/Ah in some positions
(2) measured in 1991 above an inter-magnet gap
(3) on "normaliseurs" below dipoles, no shielding
(4) with shielding (6 cm lead bricks), below dipole 170
(5) in some beam monitors
(6) below dipole, 10 mm shielding
(7) from 11/05/98 to 15/06/98

Table 3 : Doses on RF modules in 1998.

2 dosimeters on each module
A : left extremety, viewing the module from the pathway.
D : rigth extremety

H.C.	Module	Dose in Gy A	D
232	Ansaldo 1014	>5 E5	2.20E+05
	Ansaldo 1013	2.11E+05	1.04E+04
	Siemens 3016	2.42E+05	3.03E+04
	Siemens 3017	2.48E+05	9.59E+03
233	Cerca 2014	4.92E+04	1.95E+04
	Cerca 2012	6.54E+04	3.31E+04
	Siemens 3007	4.16E+05	3.01E+04
	Cerca 2005	1.66E+05	4.02E+04
272	Ansaldo 2016	3.02E+05	8.24E+04
	Cerca 2020	7.48E+04	5.21E+04
	Ansaldo 1017	4.71E+04	6.59E+04
	Cerca 2017	3.73E+04	5.19E+04
273	Cerca 5	3.90E+03	4.13E+04
	Cerca 4	2.86E+04	1.36E+05
	Cerca 5	4.90E+03	7.55E+04
	Cerca 6	9.39E+03	3.53E+04
431	Ansaldo 1008	5.93E+04	9.43E+03
	Siemens 3015	4.21E+04	3.57E+04
432	Cerca 2007	1.68E+05	2.57E+05
	Siemens 3009	3.47E+04	2.02E+04
	Cerca 2008	6.18E+04	2.75E+04
	Siemens 3010	1.90E+05	6.81E+03
433	Ansaldo 1009	6.16E+04	2.75E+04
	Ansaldo 1010	7.82E+04	3.03E+04
	Ansaldo 1011	9.23E+04	2.29E+04
471	Cerca 2018	1.24E+04	1.68E+04
	Cerca 2013	2.60E+04	3.27E+04
472	Cerca 2009	>5 E5	1.14E+05
	Ansaldo 1005	>5 E5	2.32E+05
	Siemens 3006	1.83E+04	6.33E+04
	Ansaldo 1004	2.98E+04	1.27E+05
473	Ansaldo1007	4.90E+05	6.40E+04
	Cerca2015	4.32E+05	5.28E+04
	Cerca2016	3.16E+04	1.35E+05

H.C.	Module	Dose in Gy A	D
632	Ansaldo 1020	4.14E+05	4.97E+04
	Ansaldo 1021	1.77E+05	3.00E+04
	Siemens 3019	1.89E+05	1.96E+04
	Siemens 3020	9.74E+04	1.15E+04
633	Siemens 3001	7.88E+04	1.97E+05
	Ansaldo 1002	7.85E+04	1.21E+05
	Cerca 2002		7.61E+04
	Cerca 2003	3.12E+05	8.28E+04
672	Ansaldo 1018	>5 E5	6.14E+04
	Ansaldo 1019	6.72E+04	3.68E+04
	Cerca 2022	5.86E+04	3.16E+05
	Cerca 2023	6.97E+04	7.28E+04
673	Ansaldo 1001	3.34E+05	1.55E+05
	Siemens 3002	1.15E+05	1.91E+05
	Cerca 2004	7.67E+05	2.52E+05
	Cerca 2001	7.13E+05	3.11E+05
831	Siemens 3018	9.48E+04	2.21E+04
	Ansaldo 1015	1.57E+05	6.03E+03
832	Siemens 3011	7.47E+04	2.61E+04
	Siemens 3014	2.55E+04	7.95E+03
	Siemens 3008	5.53E+04	2.81E+04
	Cerca 2006	1.24E+05	1.30E+04
833	Siemens 3012	1.12E+05	3.48E+04
	Siemens 3013	1.29E+05	1.65E+04
	Ansaldo 1012	4.27E+03	
871	Cerca 2019	1.08E+04	3.13E+04
	Cerca 2021	1.17E+04	1.89E+04
872	Siemens 3005	8.27E+04	1.82E+05
	Ansaldo 1003	3.32E+04	8.41E+04
	Ansaldo 1006	8.92E+04	2.25E+05
	Cerca 2010	6.51E+04	1.22E+05
873	Siemens 3004	3.41E+04	1.10E+05
	Siemens 3003	8.54E+04	8.27E+04
	Cerca 2011	5.11E+04	1.66E+05

Table 4: Yearly absorbed doses (Gy) in LEP tunnel on specific components (1)

Components / Material	1989-1995 45 + 68 GeV 36 + 0.55 Ah	1996 80 + 86 GeV 1.2 + 0.7 Ah	1997 92 GeV 3 Ah	1998 94.5 GeV 7 Ah	1999 96 GeV 8 Ah	2000 100 GeV 8 Ah	**Total dose (Gy)** Mean	 Max	Dose limit (Gy)
Dipole coils / Epoxy + G.F.	**7.5E+4**	**2.9E+5**	**7.0E+05**	**2.0E+06**	3.5E+06	4.7E+06	1.1E+7	3.5E+7	5.0E+7
Quadrupole coils / Epoxy + G.F.	**5.1E+3**	**3.2E+4**	**9.3E+04**	**2.0E+05**	4.2E+05	5.7E+05	1.3E+6	1.5E+7	5.0E+7
Magnet power cables / rubber sheath	**90**	**400**	**2.0E+03**	**3.0E+03**	7.4E+03	1.0E+04	2.3E+4	*7.0E+5*	5.0E+5
I&C Cables on side / polyolefins	**120**	**170**	**7.0E+02**	2.0E+03	4.1E+03	6.0E+03	1.3E+4	1.8E+5	2.0E+5
I&C Cables on top / polyolefins	**270**	**265**	**1.2E+03**	3.0E+03	6.3E+03	8.0E+03	1.9E+4	*2.5E+5*	2.0E+5
Pick-up Cables / polyolefins	**5.5E+3**	**3.2E+4**	**1.0E+05**	**2.0E+05**	*4.2E+05*	*6.0E+05*	*1.4E+6*		2.0E+5
Electronics under magnets	**160 (2)**	**530**	***1.6E+03***	***2.0E+03***	*3.0E+03*	*5.0E+03*			1E2 - 1E4
Electronics (with shielding)	**25 (3)**	**250 (4)**	1.0E+02	**1.2E+02**	*6.0E+02*	*7.0E+02*	*2E+3*	*6E+3*	1E2 - 1E4
Ancilary equip. in tunnel	**250**	**750**	**9.0E+03**	3.0E+03	5.0E+03	8.0E+03	3E+4	*5E+5*	1E5 - 1E6

(1) the given figures correspond to mean values; some components may be 3 to 30 times higher
Values in bolt are measured values. *Values in italic indicate where and when radiation damage is to be expected.*
(2) measured outside the shielding of the "normaliseurs" below dipoles
(3) with Pb shielding made of 10 cm bricks, below the steel support, in DC 143 and 144
(4) with Pb shielding made of 6 cm bricks, below the dipole, in cell 170

Fig.1 DOSIMETER POSITION ON DIPOLE AND QUADRIPOLE COILS

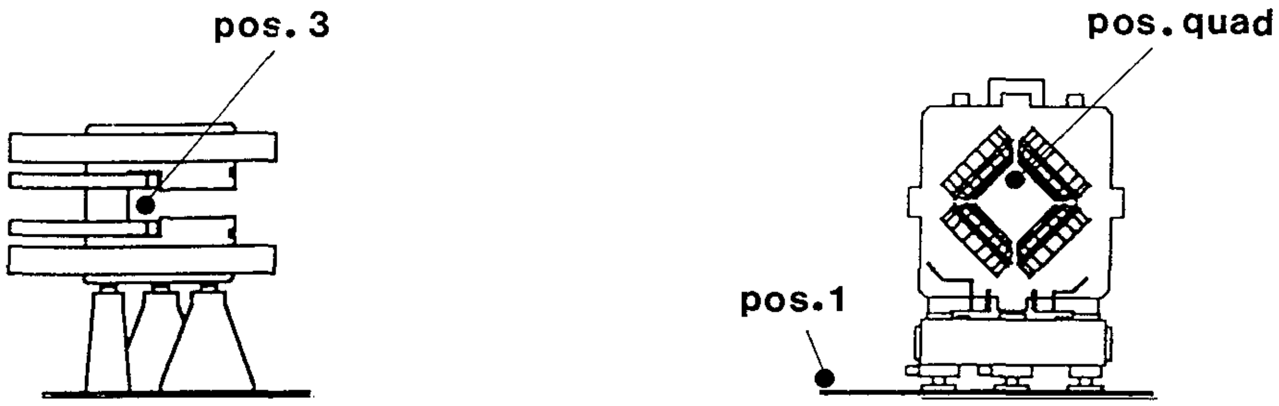
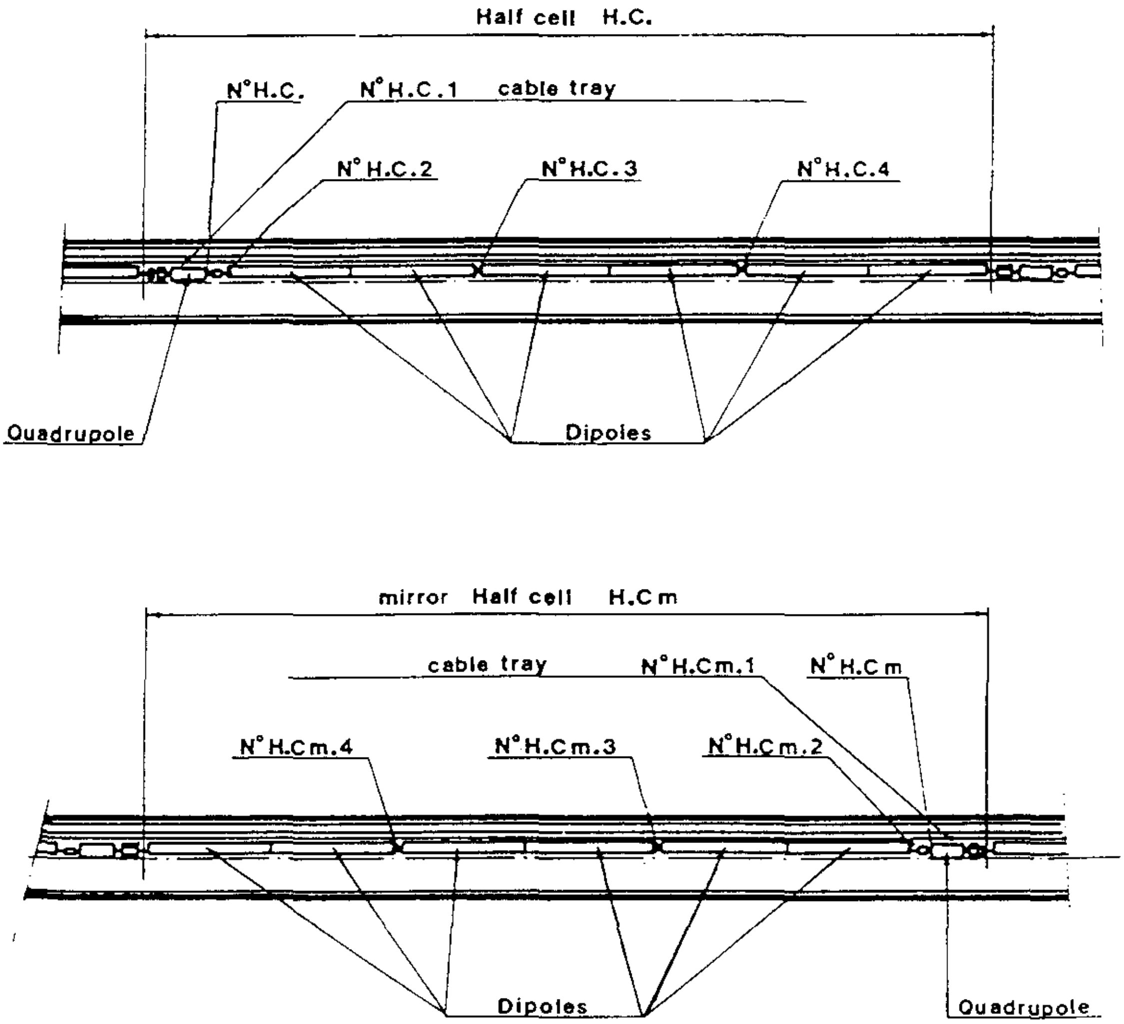
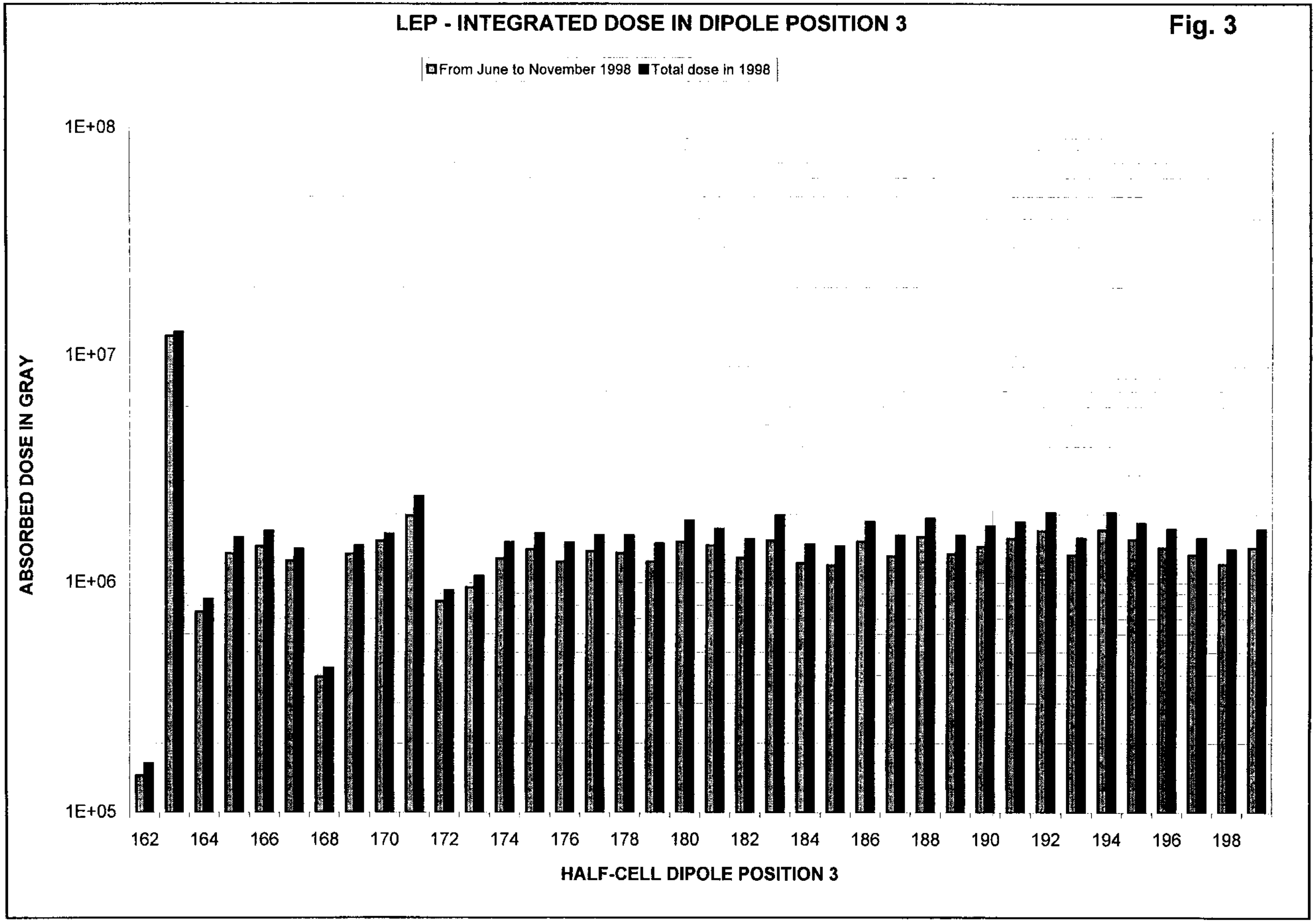


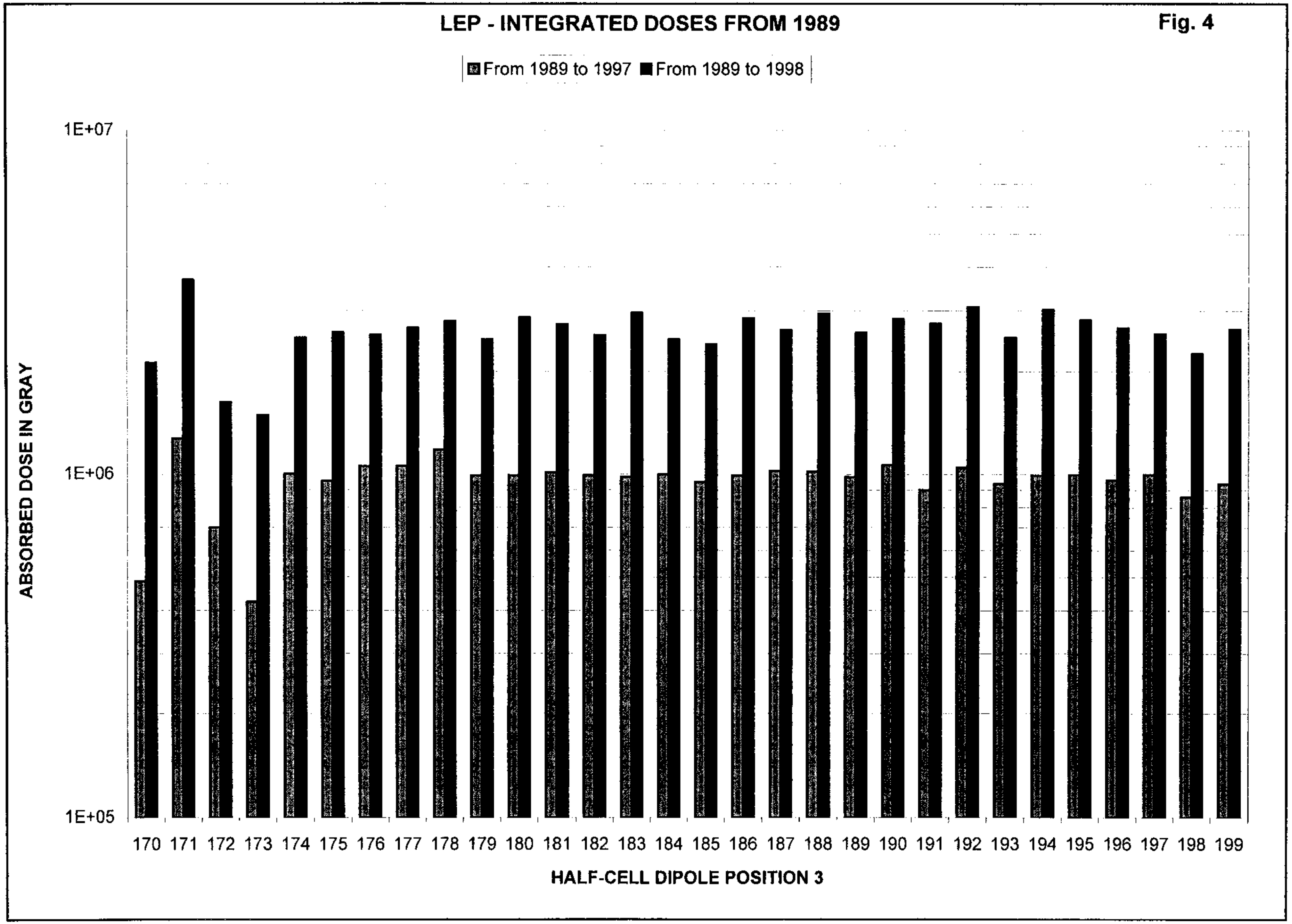
Fig. 2 STANDARD POSITIONS IN HALF CELLS





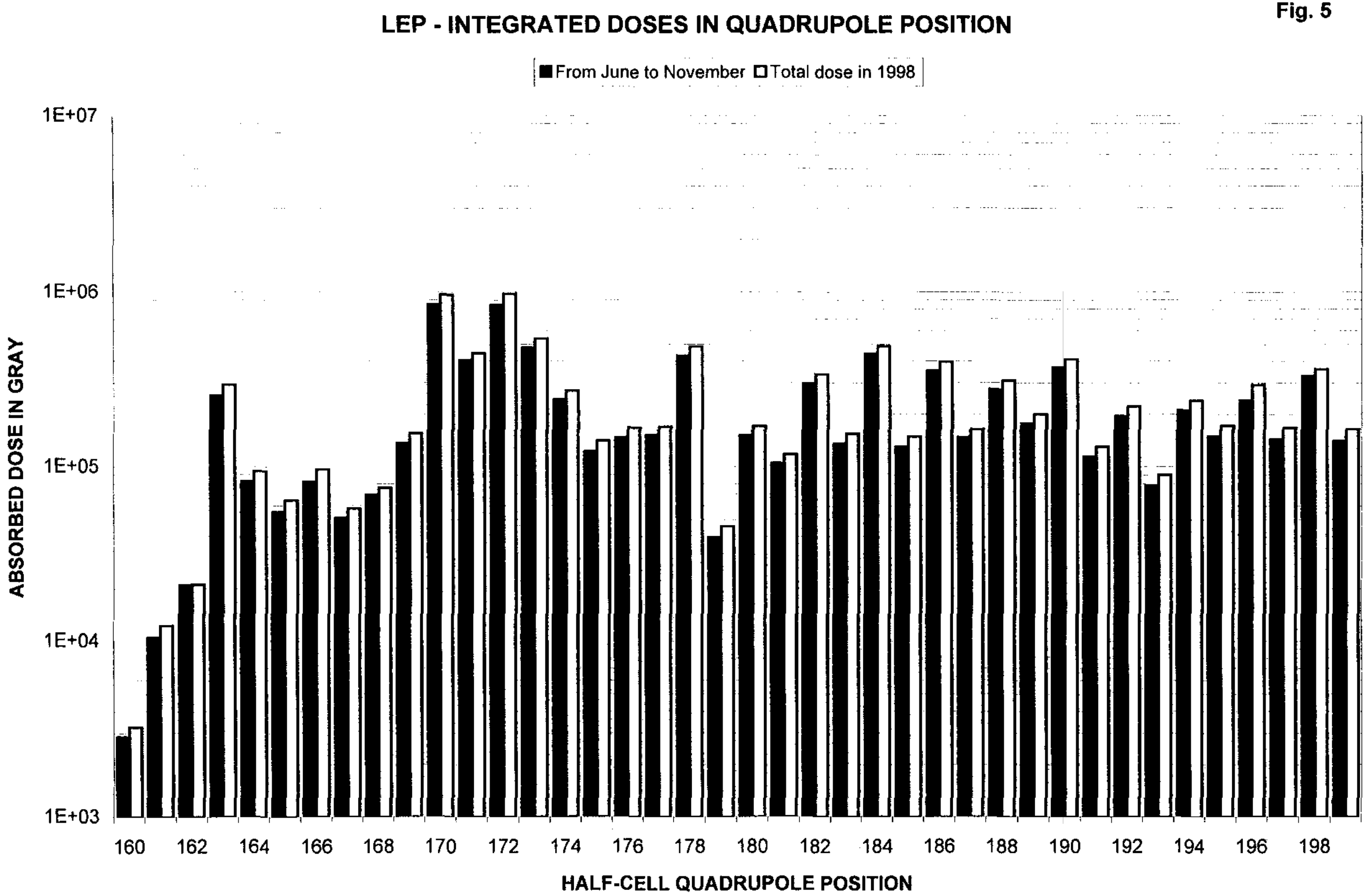
LEP - INTEGRATED DOSE IN DIPOLE POSITION 3
From June to November 1998
Total dose in 1998
1E+08
1E+07
1E+06
1E+05
ABSORBED DOSE IN GRAY
162
164
166
168
170
172
174
176
178
180
182
184
186
188
190
192
194
196
198
HALF-CELL DIPOLE POSITION 3

Fig. 3



LEP - INTEGRATED DOSES FROM 1989
Fig. 4
From 1989 to 1997
From 1989 to 1998
1E+07
1E+06
1E+05
ABSORBED DOSE IN GRAY
170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199
HALF-CELL DIPOLE POSITION 3

Fig. 5



LEP - INTEGRATED DOSES IN QUADRUPOLE POSITION
From June to November
Total dose in 1998
1E+07
1E+06
1E+05
1E+04
1E+03
ABSORBED DOSE IN GRAY
160
162
164
166
168
170
172
174
176
178
180
182
184
186
188
190
192
194
196
198
HALF-CELL QUADRUPOLE POSITION

Fig. 6

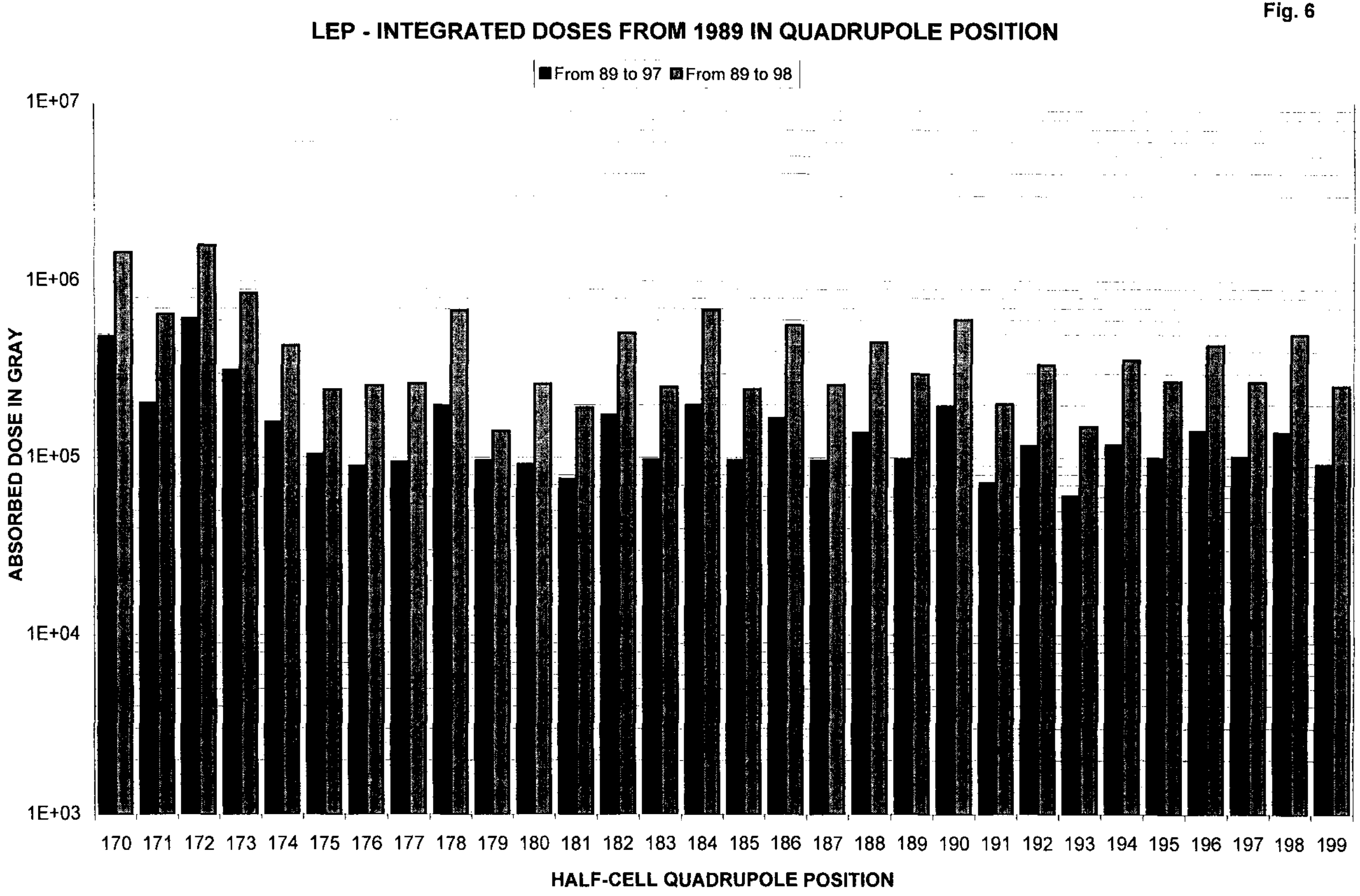
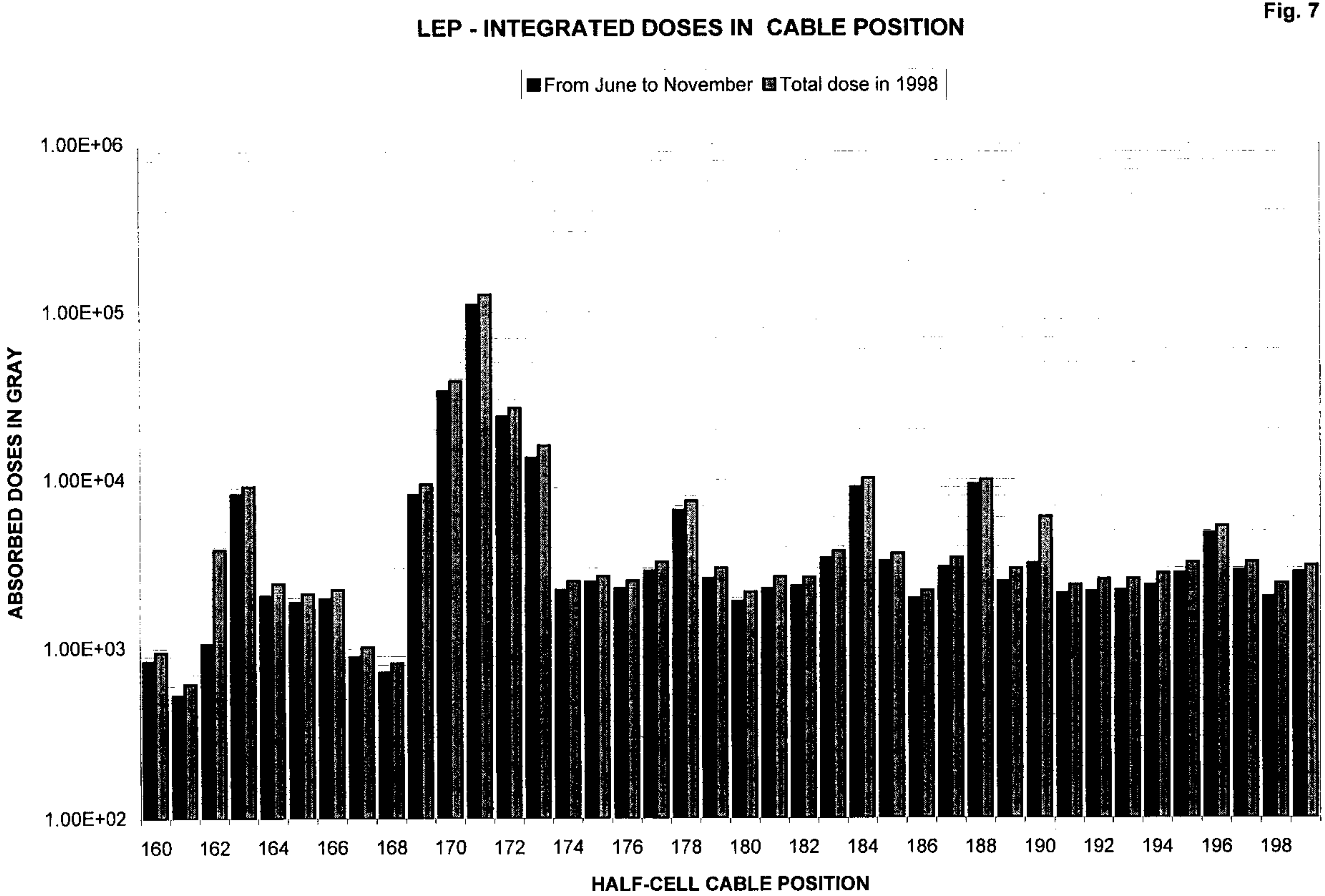

LEP - INTEGRATED DOSES FROM 1989 IN QUADRUPOLE POSITION
From 89 to 97
From 89 to 98
1E+07
1E+06
1E+05
1E+04
1E+03
ABSORBED DOSE IN GRAY
170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199
HALF-CELL QUADRUPOLE POSITION

Fig. 7



LEP - INTEGRATED DOSES IN CABLE POSITION
From June to November
Total dose in 1998
ABSORBED DOSES IN GRAY
1.00E+06
1.00E+05
1.00E+04
1.00E+03
1.00E+02
160
162
164
166
168
170
172
174
176
178
180
182
184
186
188
190
192
194
196
198
HALF-CELL CABLE POSITION

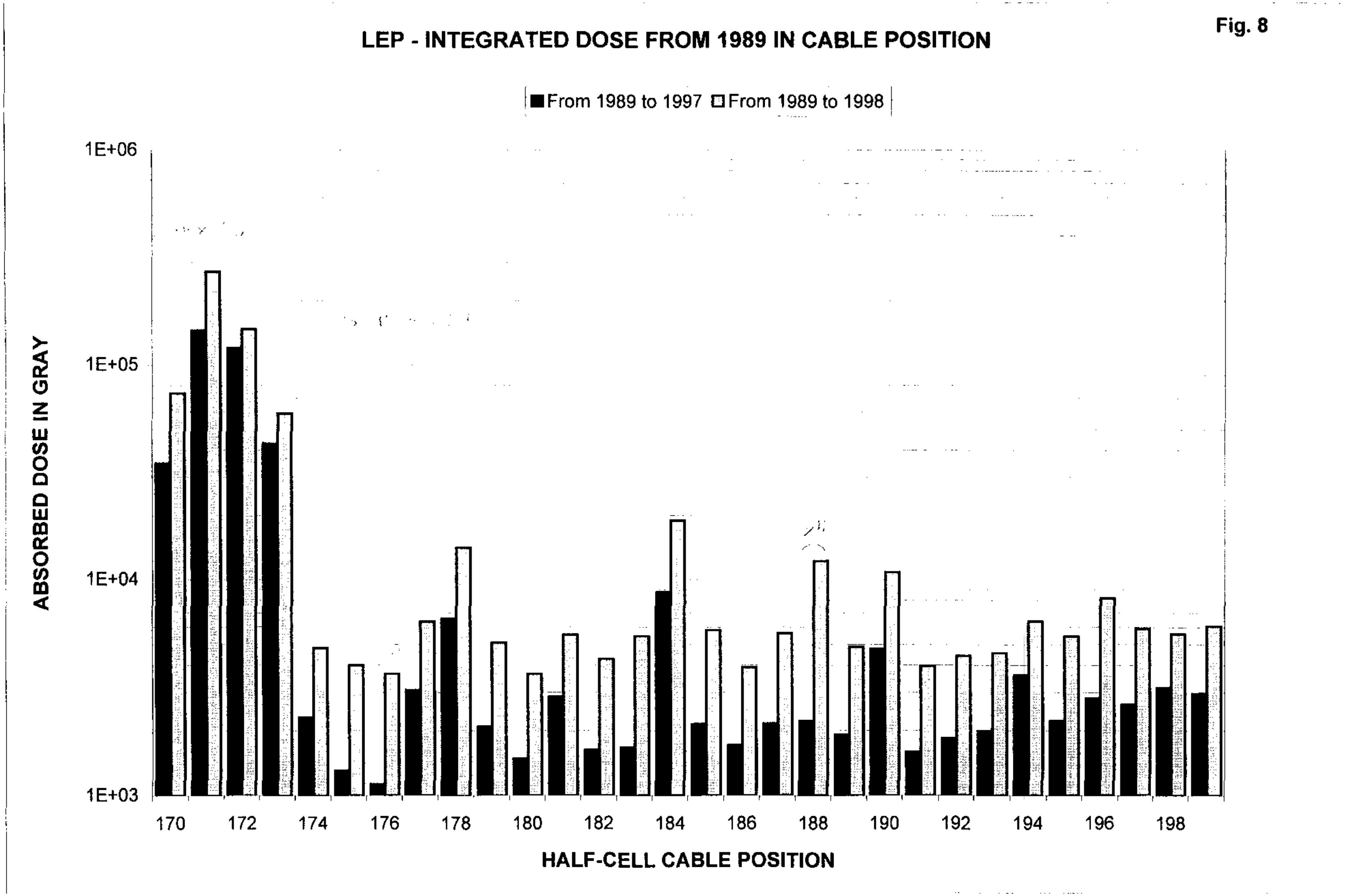
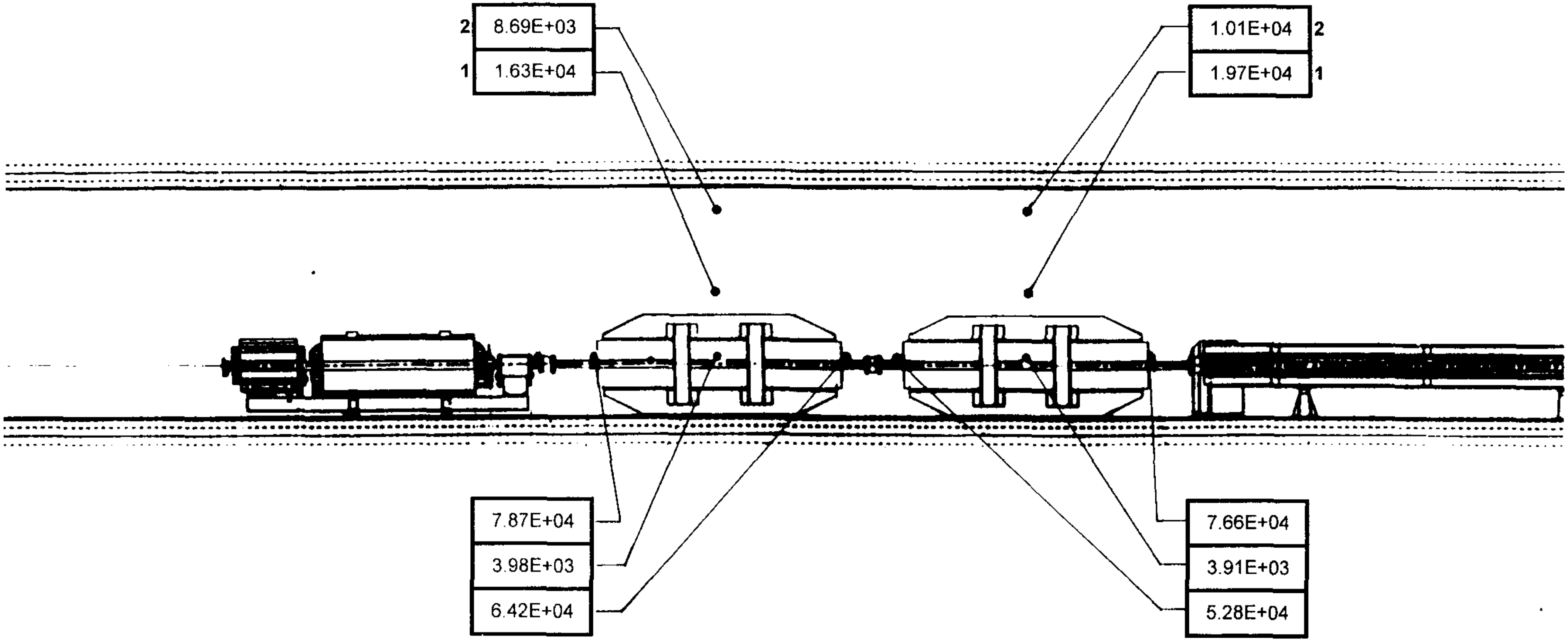


Fig. 8
LEP - INTEGRATED DOSE FROM 1989 IN CABLE POSITION
From 1989 to 1997
From 1989 to 1998
ABSORBED DOSE IN GRAY
1E+06
1E+05
1E+04
1E+03
170
172
174
176
178
180
182
184
186
188
190
192
194
196
198
HALF-CELL CABLE POSITION



Wigglers 532

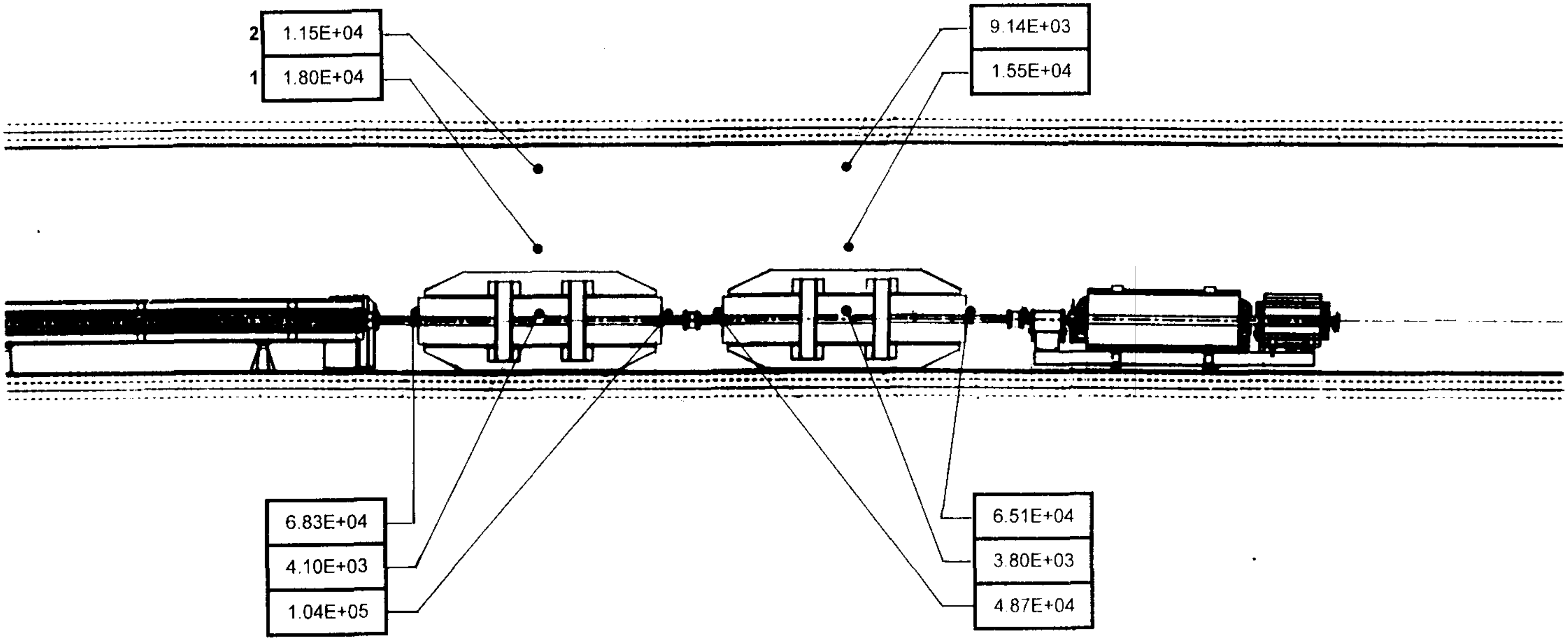
INTEGRATED DOSES IN GRAY

from May to November 1998.

1 : on side cables tray

2 : on top cables tray

Fig. 9



Wigglers 568

INTEGRATED DOSES IN GRAY

from May to November 1998.

1 : on side cables tray

2 : on top cables tray

Fig. 10

Fig. 11 : Absorbed dose rates in LEP octants