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RADIATION LEVELS IN LEP, 1989-1995

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Abstract

This paper discusses the radiation levels monitored in and around the LEP tunnel and the underground experimental areas and in the environment on the surface, following the first six years of operation where the collider has mostly been working at 45 GeV (LEP phase I). At the end of 1995 the LEP II program was started, with an energy increase to 68 GeV. The radiation levels in the underground areas accessible during LEP operation are very low and on the surface the values of dose equivalent are not discernable from the background.

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1. Introduction

The Large Electron Positron collider (LEP) [1] at CERN started operation in 1989. The accelerator, installed underground at a depth between 50 and 170 m, has an eightfold symmetry, with eight arcs and eight long straight sections, for a circumference of 26,658 m. The four experiments, L3, ALEPH, OPAL and DELPHI, are located at the interaction points in the centre of straight sections 2, 4, 6 and 8, respectively. Injection of e^+/e^- from the SPS takes place in the octant centred at point 1, while the beam dumps are installed at point 5. Electrostatic separators are located at each of the eight interaction points, while the RF cavities are installed at both sides of the four experiments. The klystrons are placed in auxiliary tunnels running parallel to the main tunnel at these four locations. These auxiliary tunnels are 210 m long and are shielded by 8 m of rock from the LEP tunnel; ducts for the waveguides connect these two tunnels every 10 m. Nineteen pits, with a diameter ranging from 5.10 m to 23.0 m, connect the surface to the underground areas, for the access of personnel and materials.

Until 1995 LEP was operated at an energy of 45 GeV, with four bunches per beam. A number of upgradings were made in the course of 1995, namely: 1) the injection energy has been increased from 20 GeV to 22 GeV; 2) to increase luminosity, the mode of operation has first been changed to the acceleration of two bunch trains (4 x 2) per beam, then to 4 x 3 bunches and finally to 4 x 4 bunches per beam; 3) towards the end of the year, the collider energy was increased to 68 GeV. This is the first energy upgrade in the LEP II program, which envisages a final operation at a maximum energy of 97.6 GeV per beam in May 1998. The energy increase is obtained following the installation of superconducting RF cavities. The integrated luminosities in the years 1990-1995 are summarised in Table 1.

The impact of LEP from the point of view of radiation protection has been carefully assessed before its construction [2,3]. The radiological (as well as conventional) risks are prevented by the safety system and procedures described in refs. [4,5]. An extensive radiation survey program is carried out routinely to ensure that the dose levels inside and around the installation are within the imposed limits (LEP is classified as French *Installation Nucléaire de Base*, INB). The aim of this paper is to provide a summary of the radiation levels monitored in and around the LEP tunnel, the experimental areas and the surroundings, following the first six years, when the collider has mostly been operated at 45 GeV (LEP phase I), and at 68 GeV towards the end of this period (beginning of LEP II program). A brief description is first given in section 2 of the radiation monitoring system and survey procedures. Section 3 overviews the dose levels in the LEP tunnel and in the areas which can only be accessed by authorised personnel. Finally, section 4 discusses the doses recorded at the surface, both at the access points and at some reference areas in the French and Swiss countryside. Specific problems that are to be encountered in the course of the LEP II program are also addressed.

2. The LEP radiation monitoring system

Radiation survey at LEP is based on both passive dosimetry (films and ^{6}LiF/^{7}LiF thermoluminescents (TLDs) under a 5 inch polyethylene moderator, to evaluate dose equivalent values integrated over a given period of time), and on-line monitoring using three types of ionization chambers (either plastic, hydrogen-filled or argon-filled). The read-out of these chambers is sent to the RP's central data acquisition system. From a console one can view the location and status of each monitor, check and reset alarm levels, display and print (either in tabular or graphical form) the values of dose equivalent recorded over the past 72 hours (integrated over one hour period), or over any given period over the preceding two months. At present 86 ionization chambers are connected to the system. These are installed in the LEP tunnel, in the experimental halls, in the service halls (US), in the klystron tunnels (UA), in the junction halls (UJ, connecting the auxiliary tunnels to the LEP tunnel or the LEP tunnel to the two transfer tunnels housing the beam transport for e^{+}/e^{-} from the SPS) and at the mazes giving access to the LEP tunnel (UP). The gates of the four sites giving access to the experiments are equipped with detectors provided with large area plastic scintillators, to monitor the passage of radioactive materials. The read-out of these detectors is also sent to the central data acquisition system.

3. Radiation levels in the LEP tunnel and experimental areas

A general view of the underground areas of the LEP complex is shown in Fig. 1. In LEP most of the dose is due to synchrotron radiation emitted by the circulating e^+/e^-. The annual gamma doses measured with TLDs are shown in Fig. 2 for the auxiliary areas adjacent to the four experiments. A comparison between the doses recorded outside the shielding in the halls UJ in the years 1994 and 1995 shows a general increase in the dose levels, particularly evident at points 4 and 8 (Fig. 3). This increase is due to the operation of LEP at 68 GeV at the end of 1995. Although the active detectors at points 4 and 8 recorded an increase of a factor 6 to 7 in dose rate at 68 GeV compared with an operation at 45 GeV, the total dose integrated over the year 1995 has increased less than a factor 2 because of the short duration of this first 68 GeV run (see Table 1).

Additional measurements with passive detectors are routinely made to monitor radiation levels in the areas occupied by physicists during data acquisition, for ALEPH, OPAL and DELPHI. The results, listed in Tables 2 and 3, show that the annual doses are usually just above the local natural background, which at this depth is about 0.2 - 0.3 mSv per year, or approximately one third of the value on the surface. The annual doses in the klystron galleries are also usually below 0.5 mSv. However, future operation of LEP at energies higher that 68 GeV requires shielding of the waveguides ducts, if this gallery needs access while LEP is running. Another way to achieve this is by installing shielding walls (in the form of a maze) in the LEP tunnel, as discussed below. The doses are about a factor 2 higher at the end of the gallery, corresponding to results of measurements in the access mazes to the LEP tunnel, where in 1995 neutrons were detected for the first time. It is likely that these neutrons are produced by (γ,n) reactions in the shutters which close both ends of the newly installed RF superconducting cavities during their conditioning (see below). This means that neutron doses are in fact accumulated when LEP is not in operation. This part of the tunnel remains locked during the RF tests. At one point annual dose equivalents of 1.28 mSv for gammas and 2.69 mSv for neutrons were recorded, in all other locations the total annual dose equivalent being usually lower than 1 mSv.

Measurements were also performed inside the largest of the access pits connecting the surface to the underground areas, PM18 near point 1 (Fig. 1). This pit is 81 m deep and 14.10 m in diameter. Measurements were performed with ^{7}LiF TLD both at 45 and 68 GeV, to evaluate the dose attenuation in the pit. The results shown in Fig. 4 indicate that there is no variation in the photon attenuation with increasing

e^+/e^- beam energy, and that the curve is very close to that calculated for a neutron plane source [6].

A study has also been undertaken on the propagation of synchrotron radiation in both the arcs and the straight sections of the LEP tunnel. The attenuation of the photon radiation in the waveguide ducts and in the access mazes connecting the service tunnels to the LEP tunnel has also been investigated. Preliminary measurements have been made at 45 and 68 GeV with different types of dosimeters, TLD LiF, alanine, radiophotoluminescent (RPL) and film, near point 4 (ALEPH). This first study has shown an increase by a factor 90 of the dose due to synchrotron radiation propagating in the tunnel when the beam energy is increased from 45 to 68 GeV [7], in accordance with the predictions [4]. The 8 mm lead layer covering the vacuum chamber is effective at 45 GeV, but has almost no shielding effect at 68 GeV. This is due to the increased penetration because of the higher critical energy of the photon spectrum; the photon intensity is also much larger. The yoke of dipoles and quadrupoles provide a much better shielding in the arcs, although the dipoles are of C-type and there is therefore no shielding on one side of these magnets.

Further measurements will be carried out with increasing LEP energy, to understand better the propagation and attenuation of synchrotron radiation in the tunnel, ducts and access mazes, including a full assessment of the average energy of the scattered radiation as a function of LEP energy; the complete results will be the subject of a future paper. Some conclusion can already be drawn on the propagation through the waveguide ducts. At 68 GeV the dose transmitted through these ducts is 200 to 500 times the value measured at 45 GeV. To reduce the dose equivalent levels at the exit of these ducts and allow occupancy of the klystron tunnel during LEP operation, mazes made up of two walls, each 80 cm thick and spaced by 120 cm, have been built in the LEP tunnel in the straight sections at both sides of the four experiments. These local shieldings are expected to reduce substantially the synchrotron radiation propagating into the straight sections.

A good indication of the dose rate due to synchrotron radiation is also given by the ion chambers located in the accelerator tunnel, such as those placed in the straight sections, as shown in Fig. 5. The effect due to the increase of beam energy is clearly visible. For a circulating current which is half that at 45 GeV, the dose rate at 68 GeV is about 50 times higher, in accordance with data provided by passive dosimetry.

On the other hand, LEP poses almost no problems from the point of view of induced activity. Doses are only detectable at the injection points and on the RF cavities. A slight increase has been noticed in 1995 with respect to the previous year, due to the operation at 68 GeV, but the dose rates near the machine components in the injection zones are always below 100 μSv/hour.

A different type of problem is posed by the conditioning of the superconducting RF cavities in the tunnel during shutdown. These tests require preventing access to the given section of the tunnel, as radiation levels produced by electrons accelerated in the cavities and striking the structure are very intense. Dose rates due to induced activity up to about 200 μSv/hour have been measured at 10 cm from the cavities several hours after they have been switched off. Adequate protection is provided by the mazes installed for shielding synchrotron radiation during LEP operation, as discussed above.

4. Site measurements

Routine monitoring is also performed at ground surface on various sites around the LEP ring, with both active and passive detectors. Active gamma and neutron monitors are installed at points 1, 2, 4, 6 and 8. Fig. 6 shows the annual gamma doses recorded by these monitors in 1995, compared with those measured by TLDs in a 5 inch thick polyethylene moderator. Fig. 7 summarises the annual doses measured by TLDs in the years 1989-1995. The average annual doses measured by TLDs under moderator in the French countryside (Pays de Gex) around LEP are shown in Table 4. The dose values are due to natural background. They are in agreement with the data provided by the environmental monitoring system. As an example, the average dose rate recorded over the years at two representative sites, one in Switzerland (Meyrin) and one in France (Cessy), is shown in Fig. 8.

5. Conclusions

The data discussed in the present paper show that the radiation levels in the underground areas accessible during LEP operation are very low. On the surface, LEP does not produce radiation doses discernable from the background.

The major problem that is going to be faced with increasing the LEP energy is that of radiation damage of materials in the accelerator tunnel due to synchrotron radiation, as well as scattered photons streaming through the waveguides ducts into the klystron gallery. The former will possibly require shielding of some cable trays; the latter has already been solved with the installation of the mazes as discussed above; if needed, some local shielding may be added at the opening of the waveguide ducts. Further measurements will be undertaken in the accelerator tunnel and in the access mazes between the service tunnels and the accelerator tunnel when the LEP energy is increased, starting at 80 GeV in summer of 1996. Measurements are also planned in the same period to study the production of ozone.

References

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Table 1. Integrated luminosity for the years 1990-1995.

Year	Energy (GeV)	Integrated luminosity (nb^{-1})
1990	44.12 - 47.12	12053
1991	44.25 - 46.87	18919
1992	45.62	28619
1993	44.69 - 46.48	39948
1994	45.57	64454
1995	44.67 - 46.44	39851
	65	3122
	68	3103
	70	51

Table 2. Annual dose equivalent measured by TLDs in the areas occupied by physicists in the experimental halls of ALEPH, OPAL and DELPHI.

	Annual dose equivalent (mSv)		
Year	ALEPH	OPAL	DELPHI
1990	0.08 - 0.32	0.11 - 0.40	0.11 - 0.41
1991	0.17 - 0.32	0.21 - 0.40	0.08 - 0.41
1992	0.26 - 0.43	0.16 - 0.30	0.08 - 0.94
1993	0.29 - 0.46	0.26 - 0.37	0.15 - 0.36
1994	0.17 - 0.34	0.19 - 0.32	0.10 - 0.98
1995	0.17 - 0.40	0.18 - 0.30	0.14 - 0.33

Table 3. Annual dose equivalent measured by TLDs at the bottom of the access pits PX of ALEPH, OPAL and DELPHI.

	Annual dose equivalent (mSv)		
Year	ALEPH PX46	OPAL PX64	DELPHI PX84
1990	0.40	0.40	0.41
1991	0.48	0.51	0.49
1992	0.46	0.44	0.41
1993	0.55	0.52	0.52
1994	0.41	0.37	0.39
1995	0.45	0.47	0.46

Table 4. Average annual dose equivalent in the French countryside around LEP (Pays de Gex).

	Annual dose equivalent (mSv)	
Year	Gamma	Neutron
1989	0.83	0.049
1990	0.75	0.050
1991	0.82	0.047
1992	0.83	0.072
1993	0.85	0.043
1994	0.77	0.060
1995	0.88	0.062

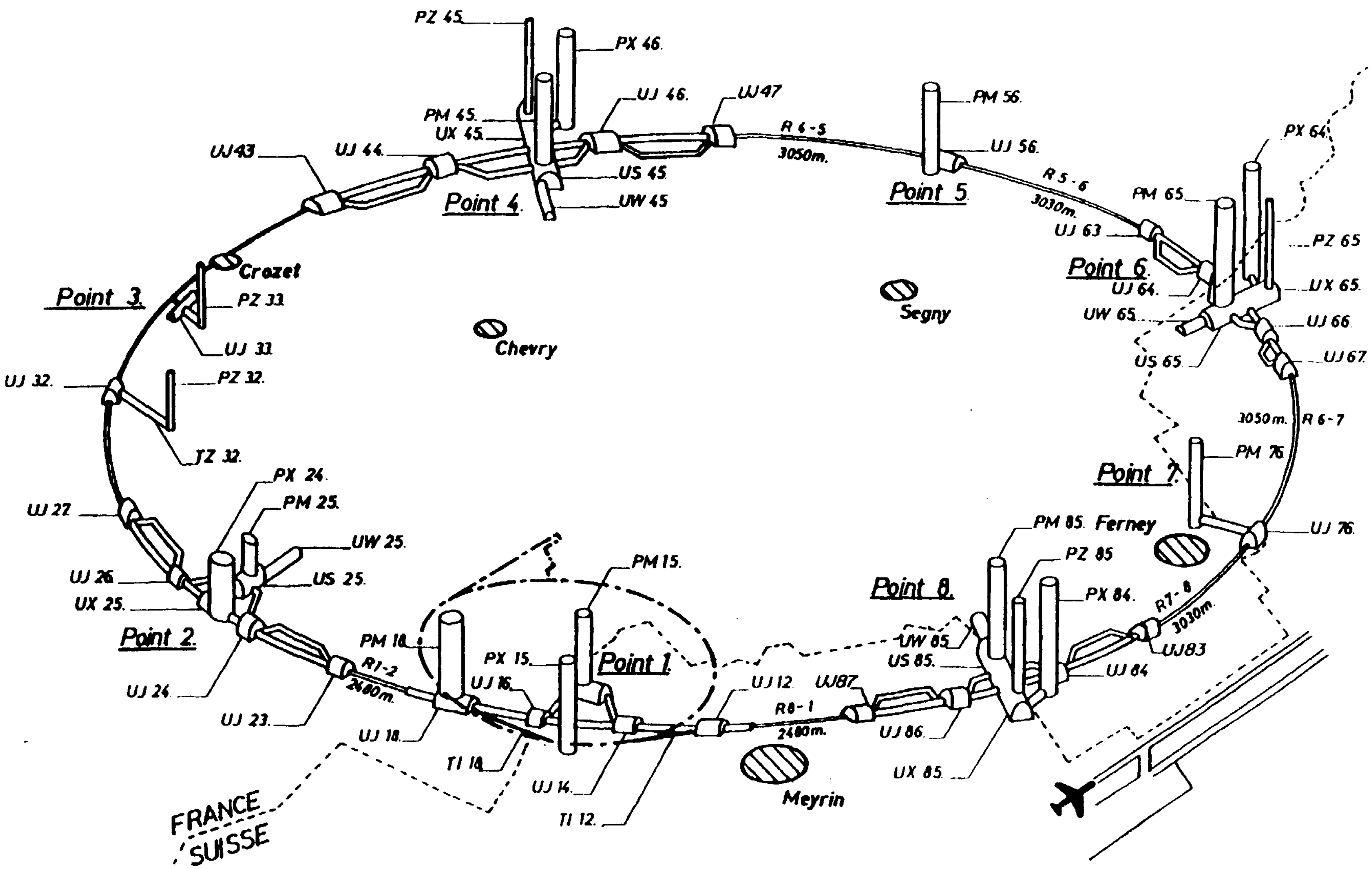


Fig. 1. The underground areas of LEP.

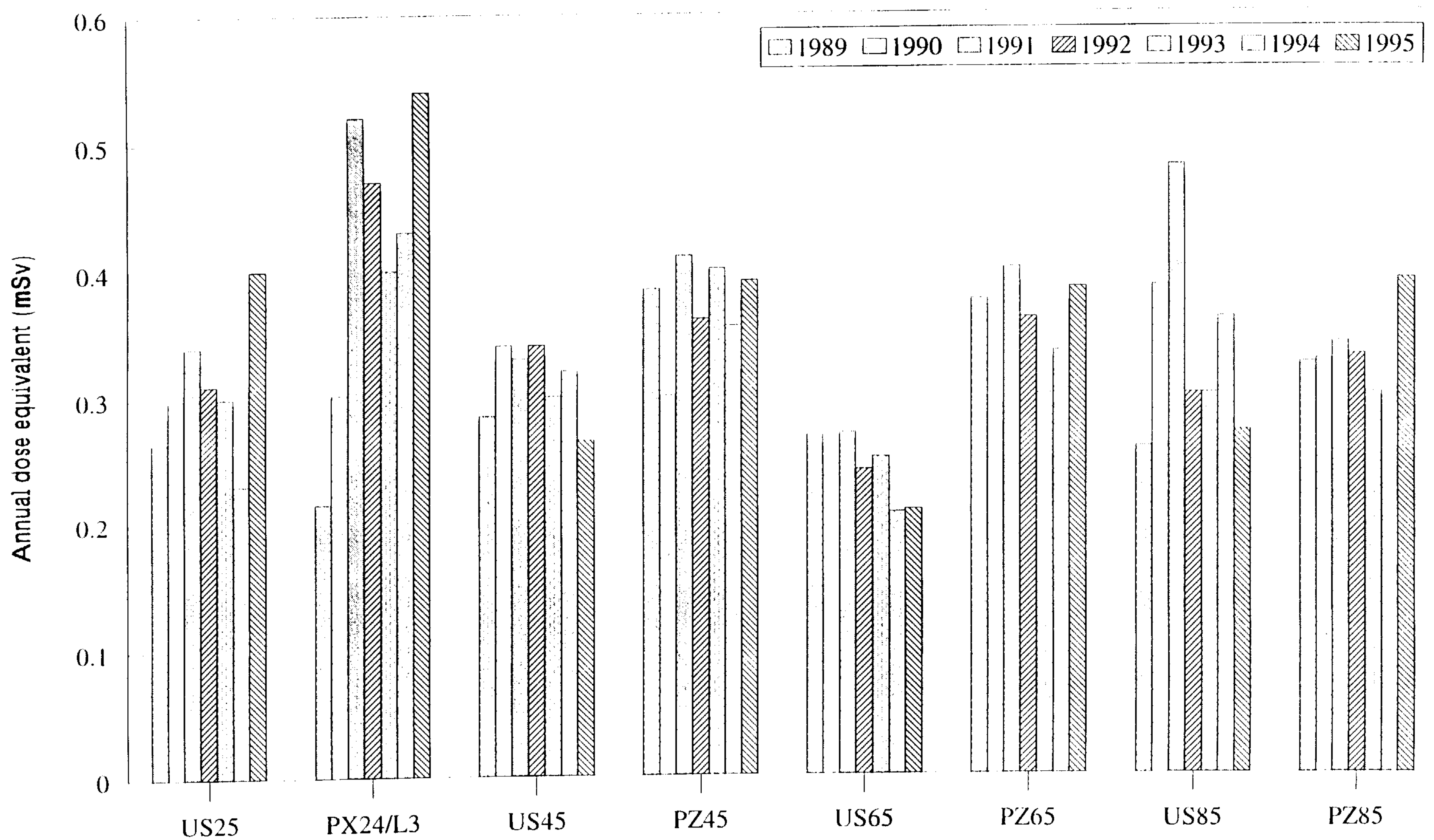


Fig. 2. Annual gamma doses in the underground areas.

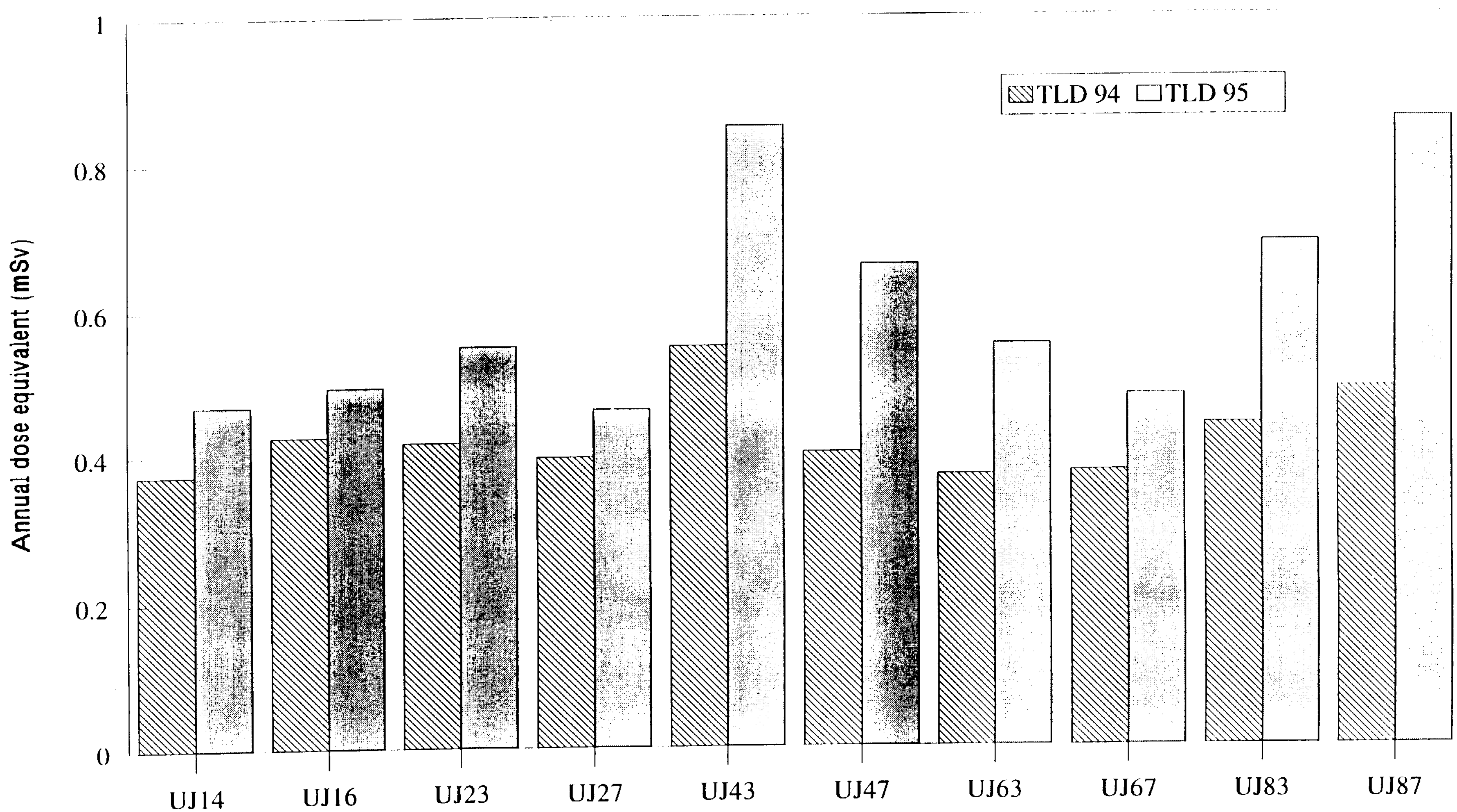
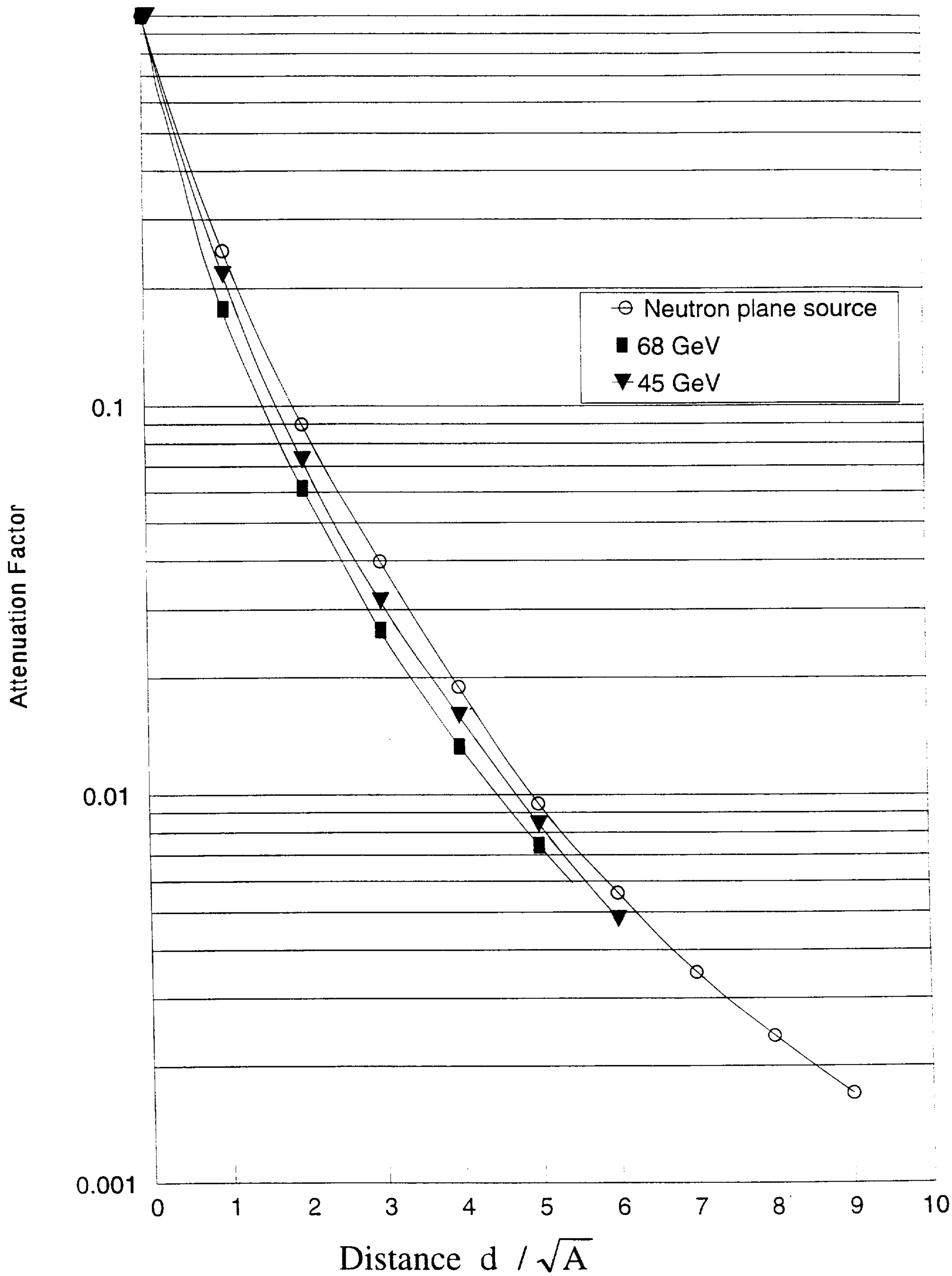


Fig. 3. **Comparison of gamma doses recorded in the years 1994 - 1995 in the junction halls UJ.**

Fig. 4. Attenuation of gamma radiation in the access pit PM18 (14.10 m in diameter and 81 m in depth). The uncertainty on the measurements is only slightly larger that the symbol used to plot the data. The attenuation for a neutron plane source is shown for comparison.



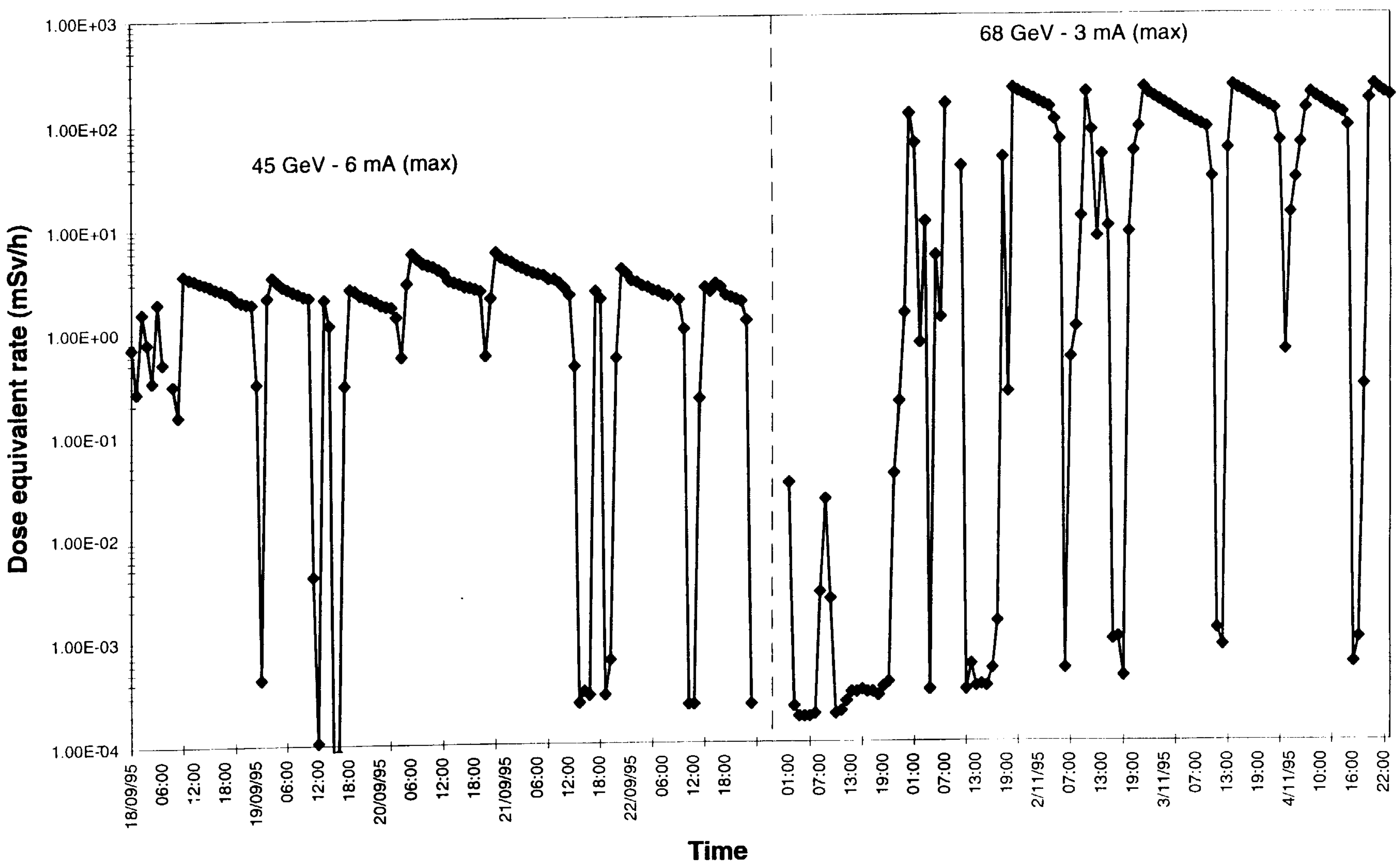


Fig. 5. Instantaneous dose rate in the LEP tunnel at the end of one of the straight sections, at 45 GeV (6 mA total beam current) and at 68 GeV (3 mA).

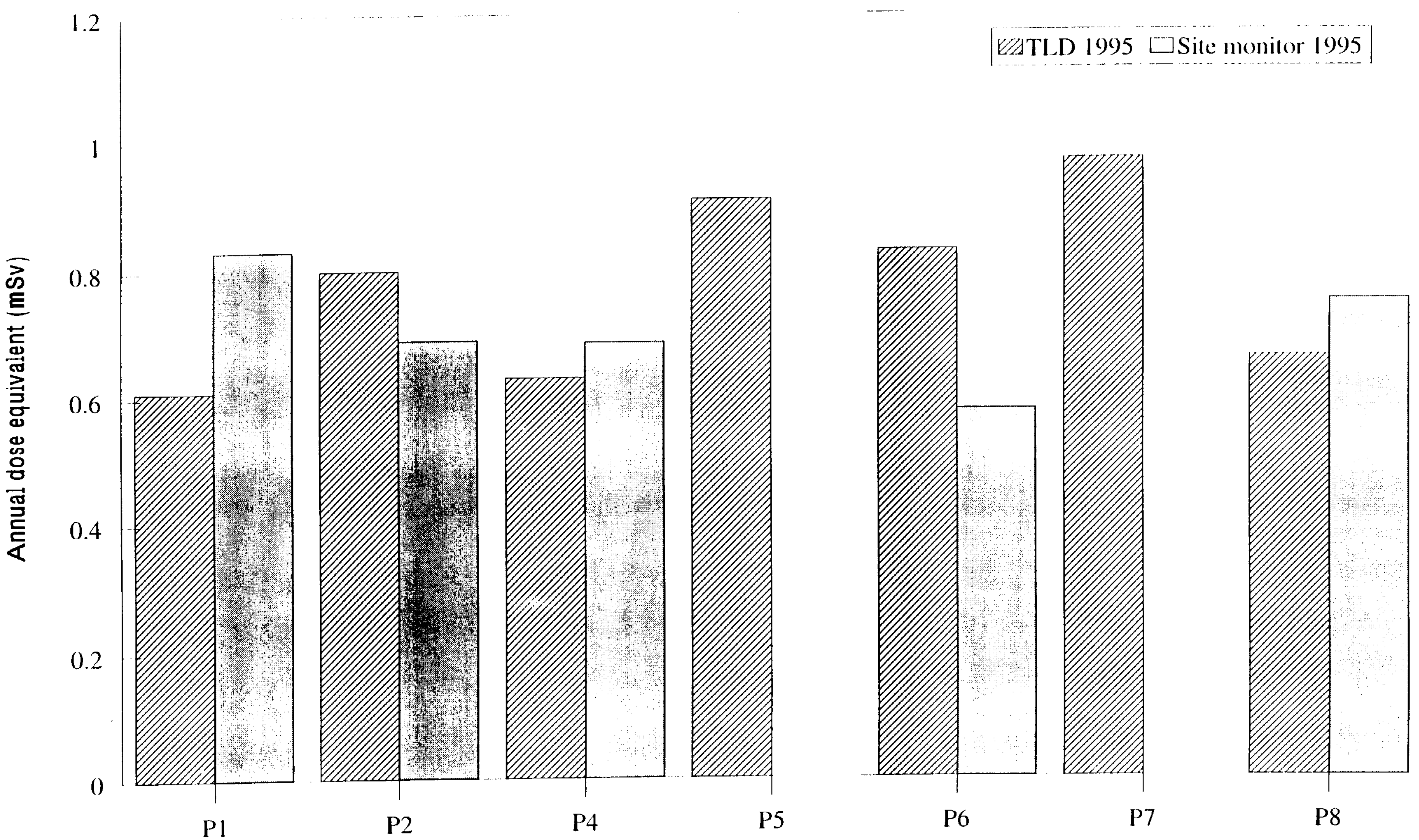


Fig. 6. Comparison of gamma doses at the eight access points in surface integrated in 1995 by active monitors and TLDs.

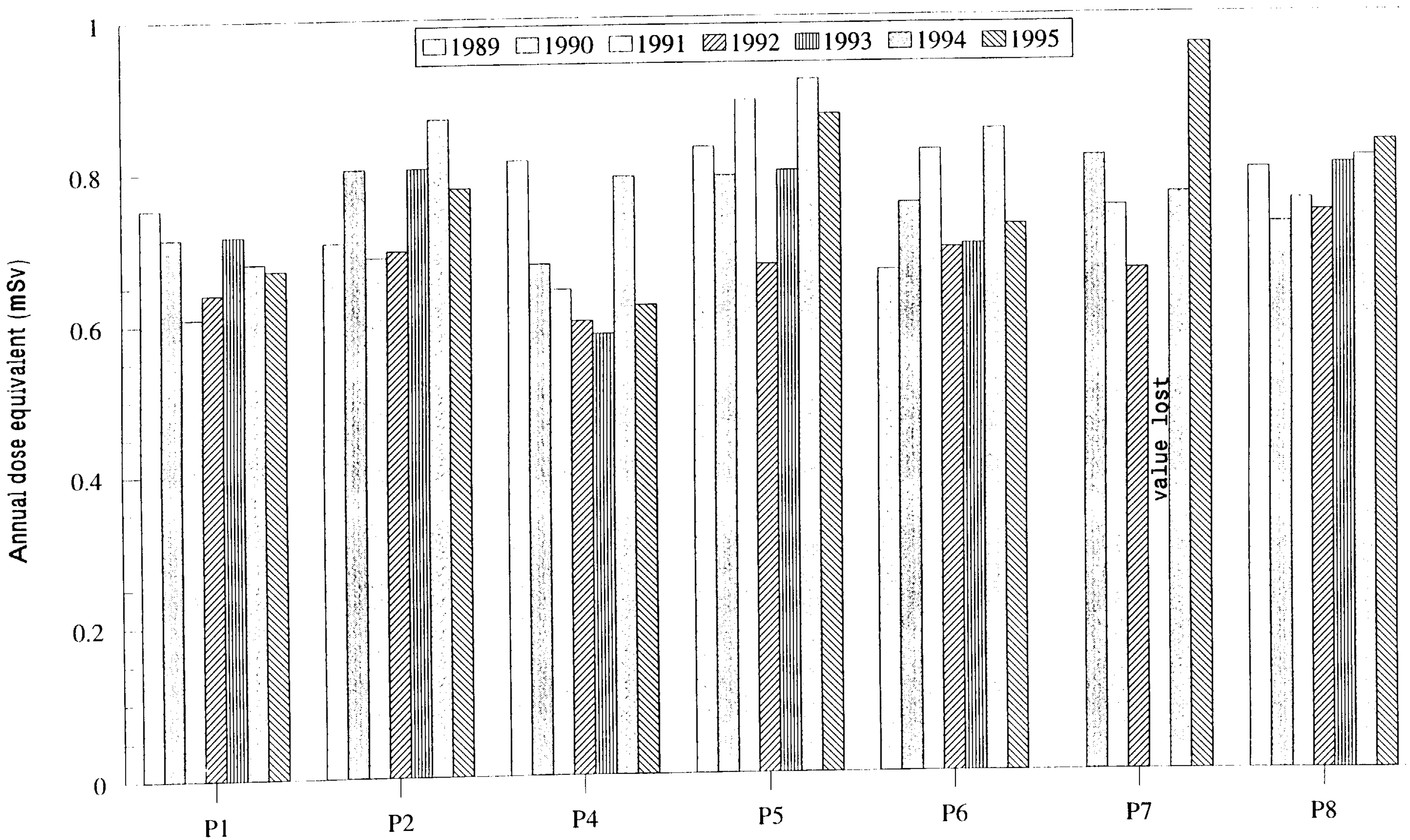


Fig. 7. Annual doses in the years 1989-1995 measured by TLDs.

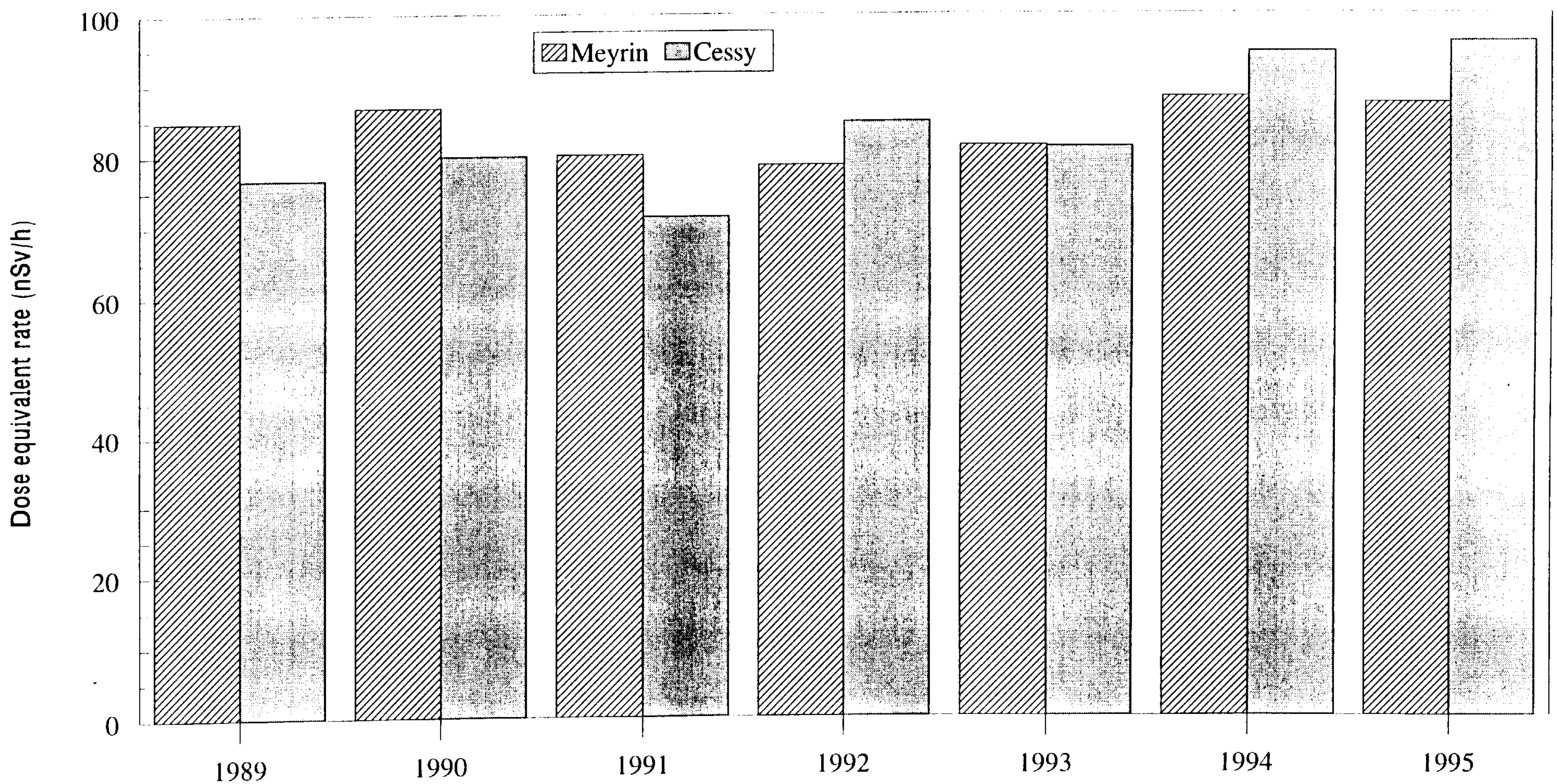


Fig. 8. Average dose rate (nSv/h) measured at two representative sites on surface around LEP, in the years 1989-1995.