EDMS No. 347165

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
EUROPEAN LABORATORY FOR PARTICLE PHYSICS

Technical Note
TIS-RP/TN/2002-020

HANDI TEPC measurements during the 1999, 2000 and 2001 CERF runs

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Abstract

This note provides the results of measurements of dose equivalent obtained with the HANDI TEPC in the 48 exposure locations at the CERF (CERN-EC high-energy Reference Field) facility, on top and on side of the two target positions. The measurements were performed during the runs in the years 1999, 2000 and 2001. In 2001 the experiments were carried out only at a few positions on the concrete top and on the concrete side. A complete mapping of the whole exposure area was instead performed in 2000. In 1999 the dose equivalent was measured only for the most frequently used positions on the concrete top, iron top, concrete side and iron side. The results of the 1997 run are also presented for the purpose of comparison, along with the FLUKA reference values for the neutron component.

CERN, 1211 Geneva 23, Switzerland
5 June 2002

1. Introduction

This report presents the results of measurements carried out with the CERN HANDI TEPC at the CERN-EC high-energy Reference Field (CERF) facility [1-3]. The measurements were performed during three runs in 1999 (May, June and August), two runs in 2000 (May and July) and two runs in 2001 (August and October). For comparison the results of the 1997 measurements [4] are also listed, along with the FLUKA reference values for the neutron component. As usual, a beam of positively charged hadrons (a mixture of about 2/3 pions and 1/3 protons, with a few percent kaons) with a momentum p=120 GeV/c was supplied to the users in different intensities.

2. Experimental set-up

Measurements of the dose equivalent at CERF were performed with the HANDI TEPC. The HANDI instrument, developed at the Universität des Saarlandes in Homburg, is based on a low-pressure tissue-equivalent proportional counter (TEPC). The spherical TEPC is filled with propane based tissue-equivalent gas simulating a density of 1 g/cm^3 and a diameter of about 2 µm. In 1999, 2000 and 2001, before the start of each beam time period, the HANDI was calibrated in the CERN calibration laboratory with a ^{60}Co source.

A 3-D view of the CERF facility is shown in Fig. 1. There are 16 reference exposure locations on top of the 80 cm thick concrete roof-shield (*Concrete Top*) and 16 on top of the 40 cm thick iron roof-shield (*Iron Top*), as shown in Fig. 2. They are arranged in a grid of 2 x 2 m^2 (Fig. 3). Each reference location is a square of 50 x 50 cm^2. Additional measurement positions are available alongside the lateral-shield of the irradiation cave (Fig. 2). Shielding is 80 cm concrete when the target is placed under the concrete-roof shield (*Concrete Side*) or 160 cm concrete when the target is placed under the iron-roof shield (*Iron Side*). At both positions 8 additional exposure locations (arranged in 2 x 4 grids made up of the same 50 x 50 cm^2 elements) are provided. At each reference position the spectra is well known by Monte Carlo simulations performed with the FLUKA code [5, 6].

The measurements were performed in the centre of the 50 x 50 cm^2 reference exposure positions at approximately 25 cm above floor on the concrete top and iron top, and at the beam height on the lateral positions.

The beam intensity in the H6 beam is monitored with an air-filled Precision Ionisation Chamber (PIC). One PIC–count corresponds to 2.3x10^4 incident particles within a statistical uncertainty of 4% [7]. The intensity was varied by means of the collimators C3 and C5 (see ref. 4 and Appendix B in ref. 8). The beam cycle and the energy of the primary beam in the SPS changed

between 1997 and 2001 due to an upgrade of the SPS for the future LHC (Table 1). The secondary beam in the H6 line was always 120 GeV/c positive particles.

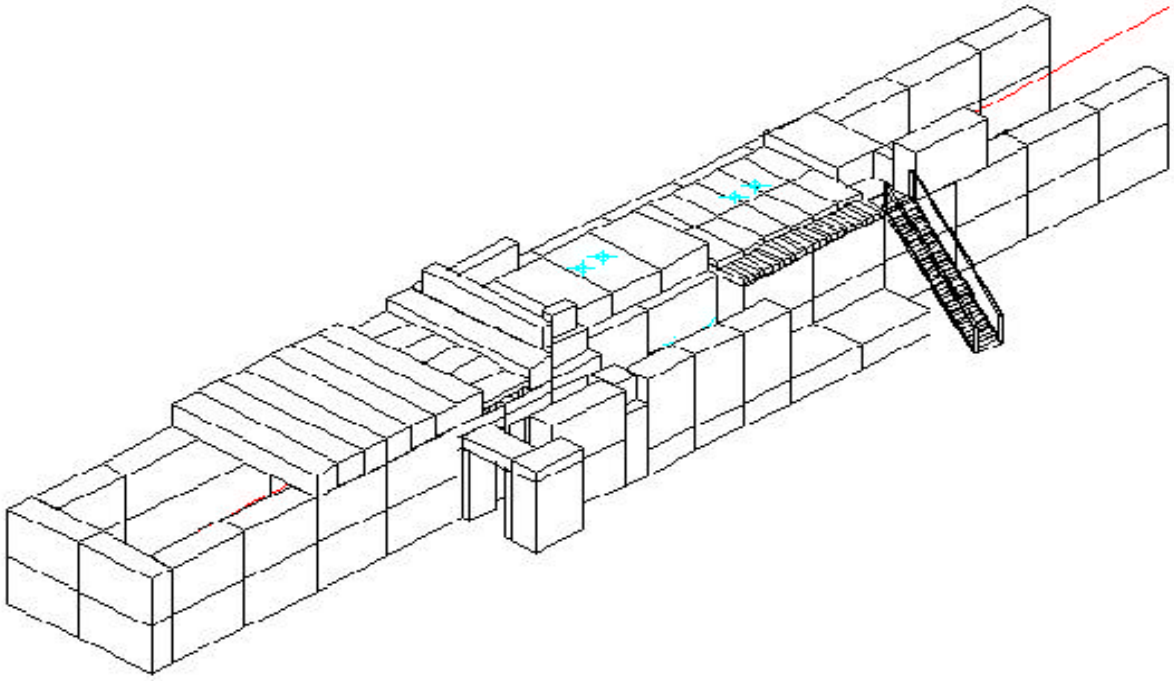

Fig. 1. Axonometric view of the CERF facility in the experimental hall EHN1 on the Prévessin site of CERN.

Table 1. Beam cycle parameters and proton momentum of the SPS during the runs in the years 1997, 1999, 2000 and 2001.

Year	**SPS – p^+ momentum** [GeV/c]	**Cycle length** [s]	**Spill length** [s]
1997	450	14.4	2.37
1999	450	14.4	2.37
2000 until 13 July	450	14.4	2.37
2000 after 13 July	400	14.4	3.2
2001	400	16.8	5.2

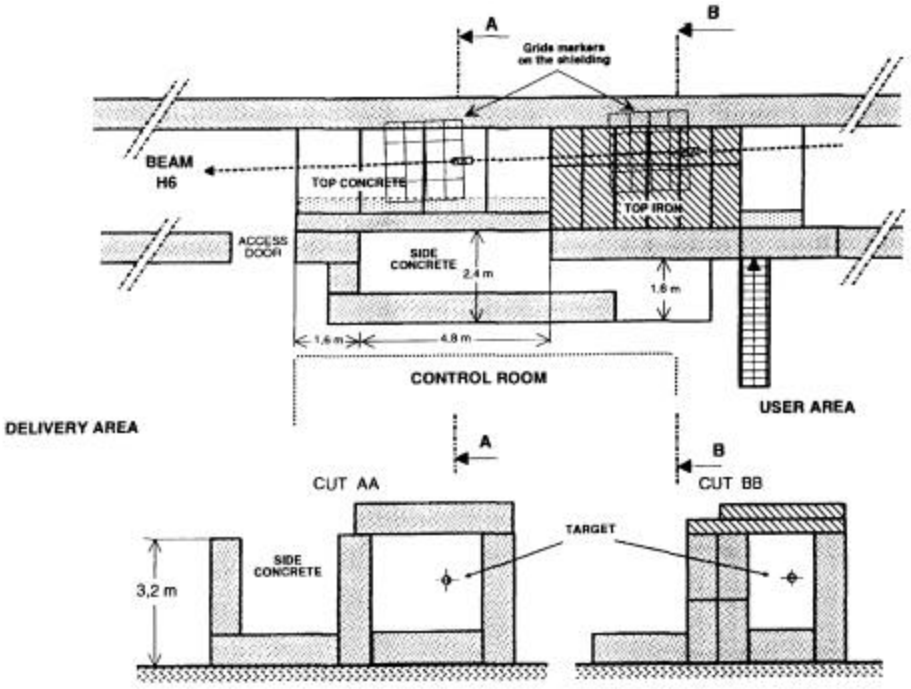

Fig. 2. Plan and sectional views of the CERF facility.

T 1	**T 5**	**T 9**	**T 13**
T 2	**T 6**	**T 10**	**T 14**
T 3	**T 7**	**T 11**	**T 15**
T 4	**T 8**	**T 12**	**T 16**

Fig. 3. The reference grid with the 16 exposure locations used on the concrete and iron roof-shields. The target (in grey) and the beam direction (arrow) are shown. Each square in the grid is 50 ´ 50 cm^2.

In 1999 the measurements were made in several squares on the concrete top, iron top, concrete side and iron side. A complete mapping of the dose equivalent rate (normalised to PIC-count) at the 48 reference locations was carried out in the runs of 2000. In the 2001 runs only a few positions on the concrete top and on the concrete side were measured.

3. Results

The measured dose equivalent values at the reference positions of CERF are given in Tables 2-5 for each year and for different beam intensities. The tables show the total dose equivalent, the low LET (< 6 keV/µm) and the high LET (> 6 keV/µm) components, evaluated from the absorbed dose by the Q(L) relationship of ICRP60, with the evaluation program of Sannikov [9]. Repetitive measurements of the same year are averaged if they refer to the same beam intensity. All values are normalised to one PIC-count. As can be seen from the tables, the low LET component and thus the total dose equivalent vary strongly with the beam intensity. This is due to a low LET background component that is independent of the beam intensity in H6, but it is rather due to muons coming from upstream in the beam line as well as from adjacent beam lines [1]. This background appears as a non-linearity of the detector response as a function of beam intensity. For this reason an average over different beam intensities is given only for the high LET component. The results of the 1997 run and the FLUKA simulations, as given in refs. 1 and 4, are also listed for the purpose of comparison. The 1997 measurements were performed with beam intensities in the range 3500 – 5000 PIC-counts per spill for the concrete top and concrete side, in the range 1000 – 2200 PIC-counts per spill for the iron top, and in the range 1000 – 9000 PIC-counts per spill for the iron side. The values of the neutron ambient dose equivalent from the simulations were obtained by folding the neutron spectral fluence calculated by FLUKA at each reference position with the fluence-to-ambient dose equivalent conversion coefficients of ICRP74 [10] and of Ferrari and Pelliccioni [11]. These values are also normalised to one unit of the beam monitor (PIC-count). They are listed in the column “FLUKA” and are to be compared with the “HIGH LET” values of the experimental data.

The agreement between measurements of different years is in general very good. For the concrete top and side, roughly 75% of the values show an agreement within 1s uncertainty, while 25% show an agreement within 2s uncertainty. At the iron side the situation is similar: 60% of the measurements agree within an uncertainty of 1s, 40% with an uncertainty of 2s. On the iron top the values of 1997 and 1999 are in perfect agreement and slightly lower than the FLUKA values: 83% of the values agree within 1s, 17% within 2s. On the other hand, the results of the measurements of 2000 on the iron top show a tendency of being significantly higher, by a factor of 1.15 to 1.40, in comparison with those obtained in the other years. This fact is not fully explained yet, since the measuring conditions did not change from one year to the other. Data for concrete top, concrete side and iron side are also usually slightly higher for 2000

with respect to both the results of measurements in the other years and the FLUKA values (Fig. 4).

A graphical representation of the high LET values from Tables 2-5 is shown in Figures 4 and 5 for positions 4 and 6 on the concrete top for the years 1999, 2000 and 2001. Figure 6 shows the stability of the high LET component in the CERF field through the runs of one year. The data are from the runs in 2000 on the iron top.

4. Conclusions

The comparison of the HANDI measurements performed in the CERF facility during the runs 1999 – 2001 has shown good agreement with the results of the 1997 run, in particular for the neutron dose equivalent rates (HIGH LET). There is also a good agreement between the neutron dose equivalent rates measured by the TEPC and those calculated by FLUKA.

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Table 2. Dose equivalent rates on top of the concrete roof-shield (Concrete Top). The values are in 10^{-10} Sv /PIC-count. The FLUKA values are high-LET.

	2001				2000				1999				1997			FLUKA
Pos	**PIC/ spill**	**TOTAL**	**HIGH LET**	**LOW LET**	**PIC/ spill**	**TOTAL**	**HIGH LET**	**LOW LET**	**PIC/ spill**	**TOTAL**	**HIGH LET**	**LOW LET**	**TOTAL**	**HIGH LET**	**LOW LET**	
CT1					3000	2.95 ± 0.20	2.40 ± 0.18	0.55 ± 0.03	4800	2.76 ± 0.19	2.28 ± 0.17	0.48 ± 0.02	2.51 ± 0.23	2.11 ± 0.22	0.40 ± 0.02	**2.16**
CT2					3000	3.43 ± 0.23	2.88 ± 0.21	0.55 ± 0.03	3900	3.11 ± 0.21	2.53 ± 0.19	0.58 ± 0.03	2.62 ± 0.24	2.26 ± 0.22	0.36 ± 0.02	**2.25**
CT3					3000	3.10 ± 0.21	2.58 ± 0.20	0.52 ± 0.03					2.69 ± 0.23	2.33 ± 0.21	0.36 ± 0.02	**2.13**
CT4	1000	2.77 ± 0.22	1.77 ± 0.20	1.00 ± 0.05												
	2000	1.91 ± 0.14	1.34 ± 0.12	0.57 ± 0.03												
	2700	2.33 ± 0.13	1.84 ± 0.11	0.49 ± 0.02												
	3700	2.21 ± 0.12	1.84 ± 0.10	0.37 ± 0.02												
	4000	1.87 ± 0.12	1.48 ± 0.11	0.39 ± 0.02												
	5000	2.22 ± 0.12	1.81 ± 0.10	0.41 ± 0.02												
	6000	2.21 ± 0.10	1.84 ± 0.07	0.37 ± 0.01												
	6100	1.96 ± 0.12	1.62 ± 0.10	0.34 ± 0.02	1500	2.59 ± 0.21	2.23 ± 0.20	0.36 ± 0.02								
	7500	2.27 ± 0.10	1.90 ± 0.10	0.37 ± 0.01	2600	2.36 ± 0.15	1.95 ± 0.14	0.41 ± 0.02								
	7800	1.82 ± 0.11	1.50 ± 0.10	0.32 ± 0.02	3000	2.80 ± 0.20	2.34 ± 0.18	0.46 ± 0.02					1.98 ± 0.18	1.71 ± 0.17	0.27 ± 0.02	**1.85**
Aver.			**1.81 ± 0.36**				**2.17 ± 0.30**									
CT5					3000	4.25 ± 0.27	3.44 ± 0.24	0.81 ± 0.04					3.12 ± 0.30	2.62 ± 0.27	0.50 ± 0.03	**2.54**
CT6	2200	3.71 ± 0.22	2.63 ± 0.18	1.08 ± 0.05					1400	4.57 ± 0.26	3.06 ± 0.20	1.51 ± 0.08				
	4000	3.20 ± 0.13	2.45 ± 0.11	0.75 ± 0.03	2600	4.11 ± 0.37	3.32 ± 0.30	0.79 ± 0.07	3500	3.24 ± 0.20	2.57 ± 0.18	0.67 ± 0.03				
	6000	3.35 ± 0.11	2.71 ± 0.08	0.64 ± 0.02	2800	4.26 ± 0.35	3.46 ± 0.31	0.80 ± 0.06	4100	3.48 ± 0.20	2.72 ± 0.17	0.76 ± 0.04				
	7500	4.02 ± 0.11	3.11 ± 0.33	0.91 ± 0.08	3000	4.75 ± 0.45	3.94 ± 0.41	0.81 ± 0.06	7500	3.42 ± 0.21	2.89 ± 0.19	0.53 ± 0.03	3.23 ± 0.30	2.73 ± 0.27	0.50 ± 0.03	**2.70**
Aver.			**2.66 ± 0.40**				**3.57± 0.60**				**2.81 ± 0.37**					
CT7					3000	3.95 ± 0.25	3.21 ± 0.22	0.74 ± 0.04	3200	3.32 ± 0.21	2.68 ± 0.19	0.64 ± 0.03	3.64 ± 0.31	3.20 ± 0.30	0.44 ± 0.03	**2.67**
CT8					1400	3.18 ± 0.24	2.70 ± 0.21	0.48 ± 0.03								
	6000	2.92 ± 0.11	2.37 ± 0.10	0.55 ± 0.02	2800	3.23 ± 0.21	2.57 ± 0.18	0.66 ± 0.03								
	7000	2.77 ± 0.10	2.25 ± 0.08	0.52 ± 0.01	3000	3.19 ± 0.17	2.62 ± 0.14	0.57 ± 0.03					2.78 ± 0.25	2.41 ± 0.24	0.37 ± 0.02	**2.23**
Aver.			**2.31 ± 0.13**				**2.63 ± 0.31**									
CT9					2900	4.10 ± 0.26	3.28 ± 0.22	0.82 ± 0.04					3.49 ± 0.32	2.95 ± 0.30	0.54 ± 0.03	**2.53**

Table 2 (continued).

	2001				2000				1999				1997			FLUKA
Pos.	**PIC/ spill**	**TOTAL**	**HIGH LET**	**LOW LET**	**PIC/ spill**	**TOTAL**	**HIGH LET**	**LOW LET**	**PIC/ spill**	**TOTAL**	**HIGH LET**	**LOW LET**	**TOTAL**	**HIGH LET**	**LOW LET**	
CT10	2300	3.32 ± 0.21	2.22 ± 0.16	1.10 ± 0.06												
	4000	3.03 ± 0.17	2.28 ± 0.14	0.75 ± 0.04												
	6000	3.87 ± 0.20	3.20 ± 0.17	0.67 ± 0.03					1400	4.46 ± 0.27	3.22 ± 0.23	1.24 ± 0.06				
	7500	2.97 ± 0.11	2.43 ± 0.10	0.54 ± 0.02	2900	4.13 ± 0.26	3.29 ± 0.22	0.84 ± 0 .04	4000	3.31 ± 0.21	2.67 ± 0.19	0.64 ± 0.03	3.51 ± 0.30	3.00 ± 0.28	0.51 ± 0.03	**2.70**
Aver.			**2.53 ± 0.29**								**2.95 ± 0.15**					
CT11									1500	3.72 ± 0.19	2.68 ± 0.16	1.04 ± 0.04				
									2100	3.70 ± 0.18	2.84 ± 0.16	0.86 ± 0.03				
									3600	3.30 ± 0.10	2.64 ± 0.09	0.66 ± 0.02				
									4000	3.59 ± 0.21	2.89 ± 0.19	0.70 ± 0.03				
									4700	3.26 ± 0.15	2.68 ± 0.13	0.58 ± 0.02				
					3000	3.97 ± 0.26	3.17 ± 0.23	0.80 ± 0.04	5700	3.37 ± 0.22	2.84 ± 0.20	0.53 ± 0.03	3.61 ± 0.31	3.14 ± 0.28	0.47 ± 0.03	**2.65**
Aver.											**2.76 ± 0.39**					
CT12					1400	3.23± 0.28	2.74± 0.26	0.49 ± 0.03								
					2800	3.71 ± 0.24	2.98 ± 0.21	0.73 ± 0.04								
	6000	3.09 ± 0.17	2.51 ± 0.14	0.58 ± 0.03	4000	3.42 ±0.22	2.79 ± 0.20	0.63 ± 0.03	4100	3.66 ± 0.18	2.54 ± 0.15	1.12 ± 0.04				
	7000	3.05 ± 0.10	2.50 ± 0.10	0.55 ± 0.02	4600	3.18 ± 0.16	2.60 ± 0.13	0.58 ± 0.03	5900	3.00 ± 0.19	2.47 ± 0.17	0.53 ± 0.03	3.06 ± 0.27	2.66 ± 0.25	0.40 ± 0.03	**2.21**
Aver.			**2.51 ± 0.17**				**2.78 ± 0.41**				**2.50 ± 0.23**					
CT13					3000	3.46 ± 0.23	2.67 ± 0.20	0.79 ± 0.04					2.84 ± 0.25	2.37 ± 0.23	0.47 ± 0.03	**2.07**
CT14					3000	3.55 ± 0.23	2.75 ± 0.21	0.80 ± 0.04					3.09 ± 0.27	2.62 ± 0.24	0.47 ± 0.03	**2.22**
CT15					3000	3.59 ± 0.23	2.80 ± 0.20	0.79 ± 0.04	3900	3.12 ± 0.20	2.37 ± 0.18	0.74 ± 0.04	3.17 ± 0.30	2.74 ± 0.27	0.43 ± 0.03	**2.07**
CT16					2800	3.05 ± 0.02	2.34 ± 0.18	0.71 ± 0.04								
					3500	3.42 ± 0.18	2.81 ± 0.16	0.61 ± 0.03	4000	2.37 ± 0.13	1.90 ± 0.10	0.47 ± 0.02	2.48 ± 0.22	2.11 ± 0.20	0.37 ± 0.02	**1.82**
Aver.							**2.57 ± 0.24**									

Table 3. Dose equivalent rates on top of the iron roof-shield (Iron Top). The values are in 10^{-10} Sv/PIC-count. The FLUKA values are high-LET.

	2000				1999				1997			FLUKA
Pos.	**PIC/ spill**	**TOTAL**	**HIGH LET**	**LOW LET**	**PIC/ spill**	**TOTAL**	**HIGH LET**	**LOW LET**	**TOTAL**	**HIGH LET**	**LOW LET**	
IT1	1250	12.07 ± 0.73	11.30 ± 0.70	0.77 ± 0.04	3500	9.21 ± 0.49	8.66 ± 0.46	0.55 ± 0.03	9.52 ± 0.67	8.96 ± 0.67	0.56 ± 0.04	**10.41**
IT2	1250	14.67 ± 0.84	13.30 ± 0.80	1.37 ± 0.07					10.28 ± 0.68	9.82 ± 0.65	0.46 ± 0.03	**11.70**
IT3	1250	14.69 ± 0.87	13.90 ± 0.83	0.79 ± 0.04					11.90 ± 0.83	11.43 ± 0.82	0.47 ± 0.03	**12.38**
IT4	1250	13.87 ± 1.46	13.10 ± 1.40	0.77 ± 0.07	4800	10.70 ± 0.56	10.40 ± 0.55	0.30 ± 0.01	11.00 ± 0.70	10.58 ± 0.70	0.42 ± 0.03	**11.37**
IT5	1250	14.91 ± 0.86	13.60 ± 0.81	1.31 ± 0.07	4000	11.57 ± 0.64	11.10 ± 0.62	0.47 ± 0.02	12.14 ± 0.84	11.47 ± 0.80	0.67 ± 0.04	**12.86**
IT6	1250	17.47 ± 0.45	16.10 ± 0.26	1.37 ± 0.04								
	2400	17.33 ± 0.10	16.00 ± 1.04	1.33 ± 0.10	4100	14.02 ± 0.76	13.40 ± 0.73	0.62 ± 0.03				
	2500	16.65 ± 0.96	15.80 ± 1.03	0.85 ± 0.06	4500	14.45 ± 0.77	13.70 ± 0.73	0.75 ± 0.04	14.37 ± 0.94	13.67 ± 0.92	0.70 ± 0.04	**14.90**
			15.97 ± 1.49				**13.55 ± 1.03**					
IT7	1250	20.05 ± 1.08	18.10 ± 0.10	1.95 ± 0.10	4200	15.39 ± 0.83	14.80 ± 0.80	0.59 ± 0.03	15.46 ± 0.10	14.78 ± 0.94	0.68 ± 0.04	**16.02**
IT8	1250	18.58 ± 1.05	17.30 ± 0.10	1.28 ± 0.06					13.01 ± 0.88	12.40 ± 0.85	0.61 ± 0.04	**14.93**
IT9	1250	14.50 ± 0.81	13.20 ± 0.75	1.30 ± 0.07					11.05 ± 0.75	10.18 ± 0.70	0.87 ± 1.07	**12.03**
IT10					1000	15.42 ± 0.98	14.10 ± 0.92	1.32 ± 0.07				
					1500	15.48 ± 0.88	14.50 ± 0.84	0.98 ± 0.05				
					2100	15.08 ± 0.86	14.30 ± 0.83	0.78 ± 0.04				
					2900	14.57 ± 0.84	13.90 ± 0.81	0.67 ± 0.03				
					4800	14.41 ± 0.80	13.90 ± 0.78	0.51 ± 0.03				
	1250	18.06 ± 1.03	16.70 ± 0.10	1.36 ± 0.07	5800	14.46 ± 0.82	14.00 ± 0.80	0.46 ± 0.02	14.30 ± 0.10	13.60 ± 0.95	0.70 ± 0.04	**14.54**
Aver							**14.12 ± 2.03**					
IT11	1250	19.95 ± 1.12	18.60 ± 1.06	1.35 ± 0.26	4100	16.31 ± 0.87	15.70 ± 0.84	0.61 ± 0.03	16.35 ± 1.02	15.67 ± 1.00	0.68 ± 0.04	**15.96**
IT12	1250	18.51 ± 1.05	17.20 ± 0.10	1.31 ± 0.07	4200	14.53 ± 0.76	14.00 ± 0.73	0.53 ± 0.03	14.57 ± 0.10	13.95 ± 0.93	0.62 ± 0.04	**14.71**
IT13	1250	10.52 ± 0.63	9.04 ± 0.60	1.48 ± 0.07	4000	6.96 ± 0.40	6.53 ± 0.38	0.43 ± 0.02	8.30 ± 0.61	7.54 ± 0.57	0.76 ± 0.05	**7.32**
IT14	1200	12.89 ± 0.74	11.30 ± 0.70	1.59 ± 0.10	4100	9.85 ± 0.55	9.38 ± 0.53	0.47 ± 0.02	11.00 ± 0.81	10.20 ± 0.77	0.80 ± 0.05	**10.02**
IT15					2000	12.13 ± 0.61	11.10 ± 0.56	1.03 ± 0.05				
	1200	14.13 ± 0.81	12.40 ± 0.74	1.73 ± 0.10	3900	10.98 ± 0.61	10.30 ± 0.58	0.68 ± 0.03	12.53 ± 0.83	11.72 ± 0.82	0.81 ± 0.05	**10.99**
Aver							**10.70 ± 2.31**					
IT16	1250	14.17 ± 0.82	12.40 ± 0.74	1.77 ± 0.10	4100	10.16 ± 0.56	9.70 ± 0.54	0.46 ± 0.02	11.99 ± 0.75	11.16 ± 0.73	0.83 ± 0.06	**10.05**

Table 4. Dose equivalent rates alongside the 80 cm concrete side-shield, i.e. with the target placed under the concrete roof-shield (Concrete Side). The values are in 10^{-10} Sv/PIC-count.

	2001				2000				1999				1997		
Pos.	**PIC/ spill**	**TOTAL**	**HIGH LET**	**LOW LET**	**PIC/ spill**	**TOTAL**	**HIGH LET**	**LOW LET**	**PIC/ spill**	**TOTAL**	**HIGH LET**	**LOW LET**	**TOTAL**	**HIGH LET**	**LOW LET**
CS1					2800	5.00 ± 0.31	4.33 ± 0.28	0.67 ± 0.03	3800	4.25 ± 0.22	3.66 ± 0.19	0.59 ± 0.03	4.40 ± 0.40	3.80 ± 0.36	0.60 ± 0.03
CS2					2800	5.12 ± 0.16	4.45 ± 0.14	0.67 ± 0.02	2100	4.68 ± 0.20	4.06 ± 0.19	0.62 ± 0.02	4.56 ± 0.40	3.96 ± 0.35	0.60 ± 0.03
CS3	1500	4.39 ± 0.22	3.83 ± 0.20	0.56 ± 0.04											
	6000	4.28 ± 0.22	3.73 ± 0.20	0.55 ± 0.04	2850	4.98 ± 0.31	4.39 ± 0.30	0.59 ± 0.05					4.47 ± 0.41	3.95 ± 0.40	0.52 ± 0.03
Aver.			**3.78 ± 0.28**												
CS4	2200	2.86 ± 0.14	2.51 ± 0.13	0.35 ± 0.02											
	4000	3.78 ± 0.20	3.32 ± 0.17	0.46 ± 0.03											
	6000	3.32 ± 0.17	2.96 ± 0.15	0.36 ± 0.02	2900	4.32 ± 0.30	3.86 ± 0.26	0.46 ± 0.02	2200	4.14 ± 0.16	3.62 ± 0.15	0.52 ± 0.02	3.63 ± 0.31	3.23 ± 0.30	0.40 ± 0.02
Aver.			**2.93 ± 0.26**												
CS5					2900	3.75 ± 0.25	3.28 ± 0.23	0.47 ± 0.44					3.75 ± 0.32	3.31 ± 0.30	0.44 ± 0.03
CS6					2800	3.94 ± 0.26	3.48 ± 0.24	0.46 ± 0.02					3.44 ± 0.30	3.02 ± 0.26	0.42 ± 0.02
CS7					2800	3.26 ± 0.22	2.85 ± 0.20	0.41 ± 0.02					3.12 ± 0.30	2.76 ± 0.26	0.36 ± 0.02
CS8					2800	3.06 ± 0.21	2.74 ± 0.14	0.32 ± 0.02					2.90 ± 0.25	2.60 ± 0.24	0.30 ± 0.02

Table 5. Dose equivalent rates alongside the 160 cm concrete side-shield, i.e. with the target placed under the iron roof-shield (Iron Side). The values are in 10^{-11} Sv/PIC-count. Position 5 is not available for measurements.

	2000				1999				1997		
Pos.	**PIC/ spill**	**TOTAL**	**HIGH LET**	**LOW LET**	**PIC/ spill**	**TOTAL**	**HIGH LET**	**LOW LET**	**TOTAL**	**HIGH LET**	**LOW LET**
IS1	1310	5.08 ± 0.60	4.31 ± 0.58	0.77 ± 0.04	3500	4.37 ± 0.34	3.88 ± 0.33	0.49 ± 0.02	5.09 ± 0.40	4.72 ± 0.40	0.37 ± 0.02
IS2	1310	5.49 ± 0.72	4.65 ± 0.70	0.84 ± 0.04	5400	3.47 ± 0.25	3.13 ± 0.23	0.34 ± 0.02	4.38 ± 0.31	4.03 ± 0.30	0.35 ± 0.02
IS3	1385	5.05 ± 0.61	4.35 ± 0.60	0.70 ± 0.03	4100	3.17 ± 0.30	2.88 ± 0.29	0.29 ± 0.01	3.64 ± 0.25	3.34 ± 0.24	0.30 ± 0.02
IS4	1250	3.37 ± 0.75	3.00 ± 0.74	0.37 ± 0.00					2.84 ± 0.24	2.60 ± 0.23	0.24 ± 0.01
IS5											
IS6	1250	4.51 ± 0.64	4.10 ± 0.64	0.41 ± 0.22	4000	3.01 ± 0.21	2.72 ± 0.20	0.29 ± 0.01	3.44 ± 0.3	3.18 ± 0.30	0.26 ± 0.01
IS7	1250	3.92 ± 0.54	3.58 ± 0.54	0.34 ± 0.02					3.70 ± 0.27	3.28 ± 0.25	0.42 ± 0.03
IS8	1250	3.30 ± 0.60	3.00 ± 0.58	0.30 ± 0.02	5000	2.03 ± 0.16	1.83 ± 0.15	0.20 ± 0.01	2.65 ± 0.20	2.45 ± 0.20	0.20 ± 0.01

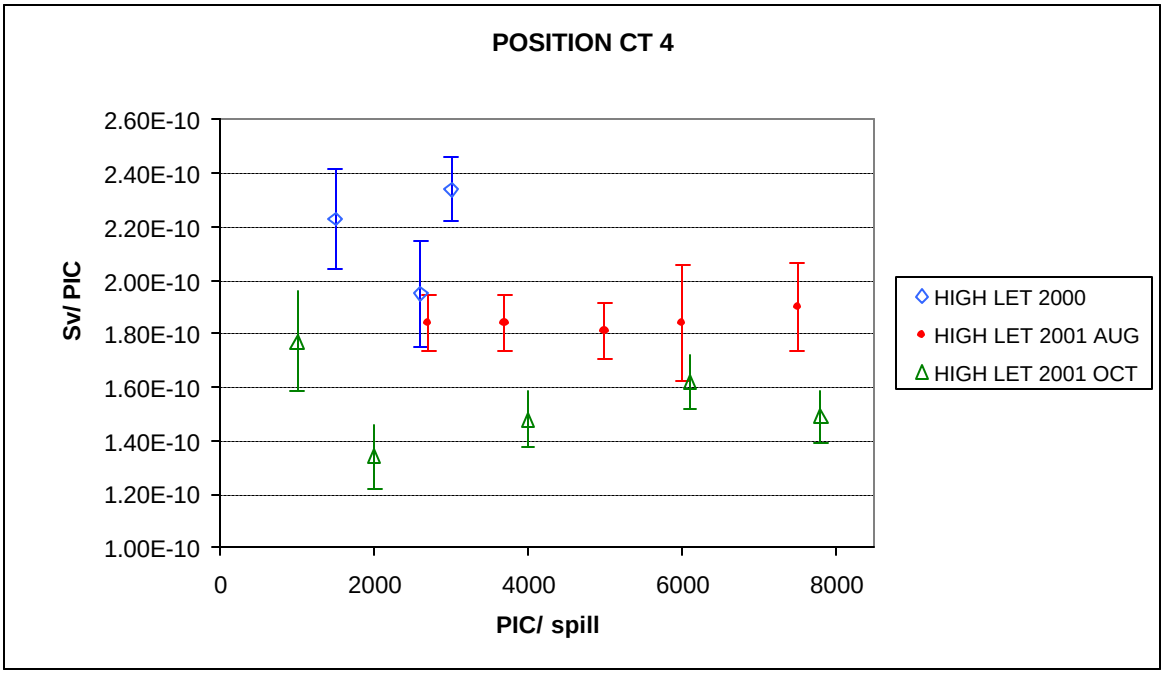

Fig. 4. The high LET component as measured for position 4 on concrete top in the 2000 and 2001 runs for several beam intensities.

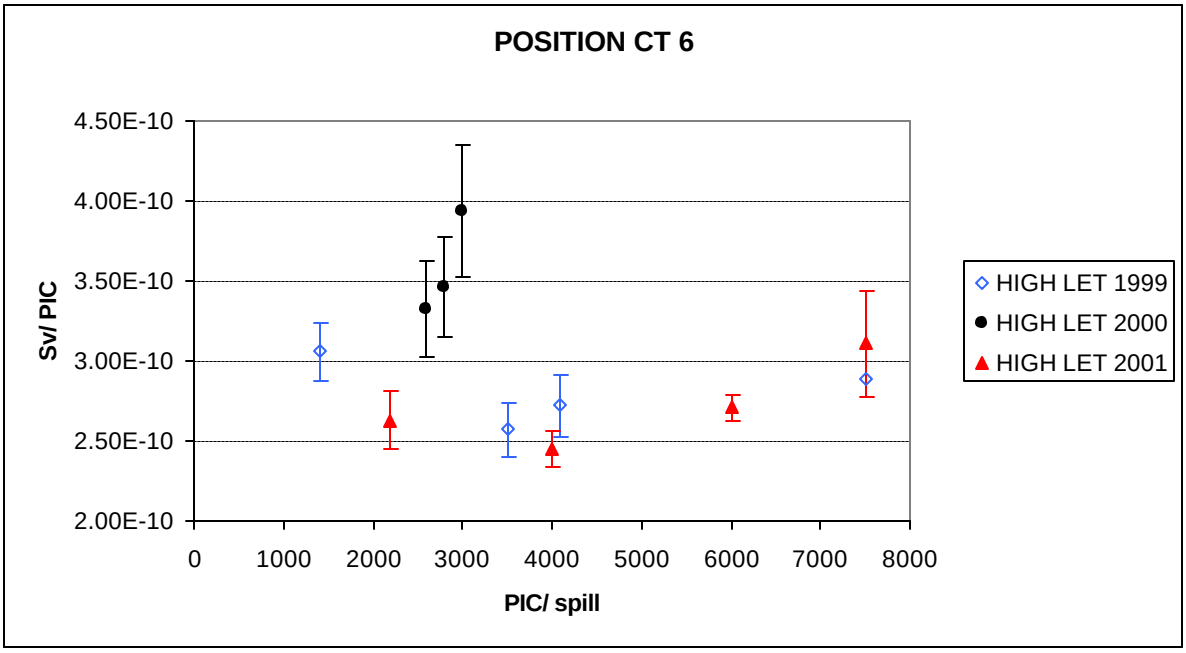

Fig. 5. The high LET component as measured for position 6 on the concrete top in the 1999, 2000 and 2001 runs.

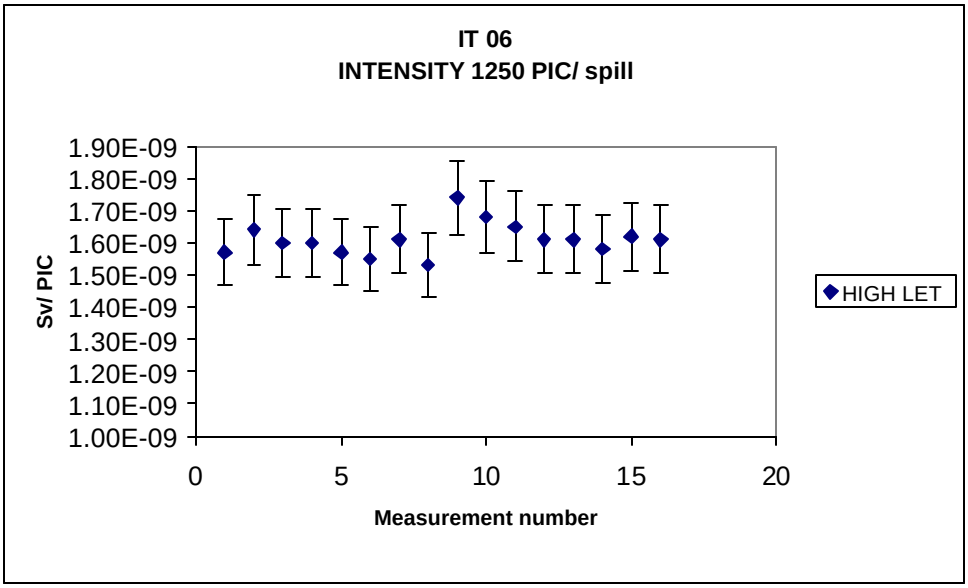

Fig. 6. Reproducibility of the high LET in a position on the iron top (measurements in 2000).

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