ASSESSMENT OF OCCUPATIONAL EXPOSURES AROUND HIGH-ENERGY PROTON ACCELERATORS

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INTRODUCTION

At CERN, the European Laboratory for Particle Physics, three high-energy proton accelerators are in operation: a 600 MeV Synchro-cyclotron (SC), a 28 GeV Proton Synchrotron (PS) and the 450 GeV Super Proton Synchrotron (SPS).

At present the Large Electron Positron (LEP) accelerator is under construction and will start in 1989 initially operating at 51 GeV. In the meantime the 31 GeV Intersecting Storage Rings (ISR) for protons have been decommissioned (1984). In conjunction with the accelerators mentioned above occupational exposures to various types of radiation are of concern. As around nuclear reactors, the main source of radiation causing personal exposures is gamma radiation from activated accelerator components during accelerator shutdown periods. During operation of the accelerators, exposures to hadrons (mainly neutrons), covering a wide energy range in experimental areas, and to high-energy muons downstream of primary proton beam targets have to be considered. Outside controlled radiation areas occupational exposures are derived from a system of passive thermoluminescence detectors (TLD) used for area monitoring, while inside controlled radiation areas individual dosimeters are worn. This paper describes the systems used at CERN for monitoring of exposures.

INDIVIDUAL MONITORING

Personal monitoring at CERN is still based on films. For gamma, beta, thermal neutron and muon monitoring the double-coated Kodak RM type 2 film is used. For evaluating the different radiation components, the CERN film badge contains the following filter combination: (1) plastic 80 mg/cm^2, (2) plastic and aluminium 89 mg/cm^2, (3) open window, (4) tin 1070 mg/cm^2, (5) lead 1260 mg/cm^2, (6) cadmium 1150 mg/cm^2 and (7) plastic 355 mg/cm^2. While the exposure free-in -air of a ^{137}Cs source serves as a reference for the calibration, the interpretation of the optical density pattern behind the various filters, as a result of a irradiation in the photon field of induced radioactivity, takes the backscatter from the wearer's body into consideration. Hence, a good match of dose results between the film badge and the pocket dosemeter is assured [1].

The presence of beta radiation or thermal neutrons is checked by comparing the optical densities behind the two thin plastic and aluminium filters or behind the cadmium and tin filters, respectively. Thermal neutrons are of no concern for personal exposures at CERN, while beta doses mainly occur during the assembly of large high-energy physics experiments containing depleted uranium.

Muons cause a blackening of the gamma film about 20% lower than expected from a ^{137}Cs exposure for the same dose equivalent [2]. Personal exposures to muons are only occurring in limited quantities.

Personal dosimetry of hadrons (mainly neutrons) is still carried out with the Kodak NTA nuclear emulsion, since the stray radiation field outside the shielding of the CERN accelerators is composed of a broad spectrum of hadrons (up to the energy of the protons accelerated). Calibrations in such fields are carried out as a routine. Fading of latent tracks in the NTA film sealed by the NRPB under nitrogen is sufficiently low to enable the use of the nuclear emulsion during two-month periods. A two-monthly distribution period is further justified by the low personal neutron doses normally encountered at CERN [3]. The (conservative) conversion factor used is 14 tracks per mSv and mm^2.

Attempts to replace the NTA film by solid-state nuclear track detectors like LR115 and CR39, to overcome e.g. the fading problem, have been made since 1972 [4,5,6]. High background and poor reproducibility did discourage routine use at CERN.

AREA MONITORING WITH PASSIVE DETECTORS

The dose distribution outside controlled radiation areas is determined with a TLD system having a high neutron-to-gamma sensitivity. The system used consists of ^6LiF and ^7LiF (Harshaw TLD-600 and TLD-700 chips) inside a cylindrical polyethylene moderator of 12.5 cm Ø x 12.5 cm, so that the neutrons after slowing down are detected by the $^6Li(n,\alpha)^3He$ reaction. The read-out of the ^6LiF detector is corrected for gamma and charged particle background using the read out of the ^7LiF detector, almost insensitive to thermal neutrons.

A network of 178 TL monitors of this type is in use at present on both CERN sites on an annual read-out basis. The detectors are calibrated in the stray field itself using Andersson and Braun neutron rem counters and argon-air filled high-pressure ionization chambers at 13 different positions as reference detectors. The ^6LiF calibration factor for stray neutrons is about five times higher per mSv than for gamma radiation. The system is in use since 1973. The two pairs of ^6LiF and ^7LiF detectors have so far been read out using a Harshaw Atlas reader. The same detectors will be evaluated from 1988 onwards, using the Alnor hot nitrogen Dosacus reader and corresponding detector holders.

The neutron energy dependence of the response of such a small moderator system is not ideal with respect to dose equivalent measurements, but the system can still be used since the stray neutron spectrum below 10 MeV does not show too strong variations at sufficiently large distances (>100 m) from the shielding of primary proton beams [7].

EVALUATED OCCUPATIONAL EXPOSURES

Occupational exposures, as determined by both systems for the CERN population of 7363 persons (4791 under film-badge control) at the end of 1986, are summarized in Table 1. The collective dose for both CERN personnel and outside contractor staff under film badge control is given, together with the collective dose derived from isodose distributions as measured by the TLD system outside controlled radiation areas. An example of such an isodose distribution measured on the CERN Meyrin site is presented in Fig. 1. The collective dose derived assumes a presence of 21% of the time on the CERN site with no corrections applied for working indoors, so that a considerable overestimation may be present.

The collective dose as given in Table 1 for the film badge results contains a contribution of neutrons (for CERN staff an average of 12%), while for the collective dose due to stray radiation, as measured with the TLD system, the average neutron contribution is about 83%. Table 1 shows that although the main source of occupational exposure is work on activated accelerator components inside controlled radiation areas (target and primary beam areas), the collective dose due to stray radiation, as determined by the TLD area monitoring system, is not negligible. The total detriment due to CERN operation, expressed in terms of total collective dose (film badge + area monitoring results), could be compared to the total number of protons accelerated annually at CERN by the PS. This accelerator has been the principal source of protons at CERN during the periods considered, whereby it supplied protons to ISR and SPS as well. The collective dose per accelerated proton, as given in Table 2, diminished between 1976 and 1986 by a factor of about 7, partly due to improved accelerator design and maintenance practices, as well as accelerator shielding.

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Table 1

Year	Film-badge results		TLD area monitoring	
	Collective dose (man.Sv)[1]	Average individual dose (mSv)[2]	Collective dose[3] (man.Sv)	Average[3] individual dose (mSv)
1976	4.16		0.81	0.16
1977	4.62	1.06	0.83	0.17
1978	3.65	0.77	0.80	0.16
1979	4.06	0.84	0.70	0.14
1980	3.08	0.52	0.46	0.09
1981	2.08	0.41	1.30	0.24
1982	1.83	0.34	1.47	0.22
1983	1.68	0.29	0.63	0.09
1984	1.59	0.27	0.79	0.10
1985	1.67	0.30	0.61	0.08
1986	1.52	0.27	0.38	0.05

1) CERN personnel and outside contractors
2) CERN staff only
3) Total CERN population outside controlled radiation areas

Table 2
Collective dose versus number
of accelerated protons

Year	Total collective[1] dose (man.Sv)	PS accelerated protons (x 10^{19})	Dose in Sv per proton (x 10^{-19})
1976	4.97	2.76	1.80
1977	5.45	3.66	1.49
1978	4.45	6.18	0.72
1979	4.76	6.99	0.68
1980	3.64	5.86	0.60
1981	3.38	5.08	0.66
1982	3.30	8.27	0.40
1983	2.31	9.68	0.24
1984	2.38	10.93	0.22
1985	2.28	9.78	0.23
1986	1.90	7.15	0.27

1) Film badge + TLD area monitoring.

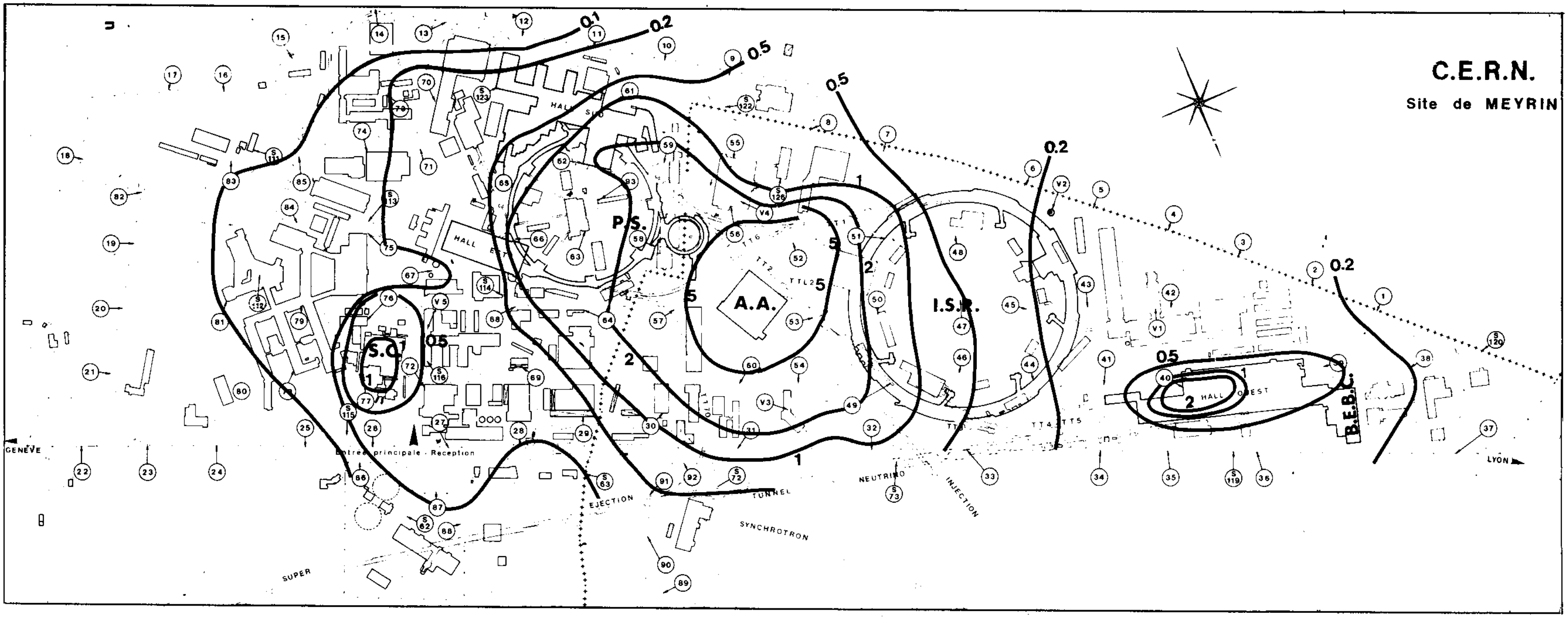

Fig. 1 Isodose distribution for 1985 (total dose in mSv) CERN Meyrin site