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FILM BADGE RESPONSE IN THE PRESENCE OF PHANTOMS

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ABSTRACT

The personal dosimeter system of CERN based on the film badge must be able to evaluate the irradiation risks in the radiation environment around high energy accelerators.

Over the last few years a critical re-appraisal of the detectors used in the light of the advent of new operational quantities in radiation protection has been made. Of special interest in this context is the comparison between the methods used at present for the evaluation of personal doses from hard photon radiation and the quantities proposed on the one hand by ICRU and on the other hand by a group of experts in Switzerland. In the latter case the detector is exposed on a plexiglass block, a phantom which is preferred to a sphere for the calibration of dosimeters of a certain size. In addition, dose values expressed in this new quantity turn out to be numerically rather close to personal doses received in radiation fields of induced radioactivity and presently evaluated at CERN.

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PLEASE
MAKE A
PHOTOCOPY
or check out as
NORMAL
LOAN

1. INTRODUCTION

Personal doses at CERN are mainly due to two sources of radiation: Exposure to hadrons in the stray field outside the main shield of the proton accelerators during their operation and irradiation by photons from induced radioactivity inside machine and beam transfer tunnels as well as target regions during maintenance and repair work. In addition some beta doses were lately recorded for persons involved in the mounting of hadron calorimeters with plates of depleted uranium.

The personal dosimetry system tailored to the needs at CERN can cope with the radiation risks encountered. Individual doses received in stray fields outside the shielding during accelerator operation are in fact very low, in line with the philosophy that any unnecessary exposures should be avoided by efficiently shielding the sources of radiation. Hence the NTA film, sealed under dry nitrogen and thus reducing its well known fading characteristics, serves for hadrons exclusively as a personal monitor [1].

Table 1 shows the distribution of individual exposures at CERN for the year 1987 [2]. Only 1.1% of the doses exceed 1/10 of the annual limit and no person has reached the CERN reference dose of 15 mSv [3].

All doses higher than 5 mSv/year were recorded on the gamma film and were exclusively received by personnel and outside contractors working in areas with radiation from induced radioactivity.

2. DETERMINATION OF INDIVIDUAL DOSES

Doses received during work in the presence of induced radioactivity are generally followed closely with a direct-reading dosimeter of the quartz fibre type. For a good dose planning it is essential that the reading of the two independent dosimeters worn simultaneously correspond as closely as possible. In addition, those being exposed during their work have the habit of critically comparing both dosimeter results.

In an earlier paper a pragmatic solution to assure the correspondence between the two dose values was presented [4]. Film badges and

quartz fibre dosimeters were exposed in stray fields from induced radioactivity at various places at CERN. Using the pocket dosimeter reading as a reference an algorithm was developed to transform optical densities into individual doses. Such doses are loosely described as the dose equivalent behind 300 mg/cm^2 (the wall thickness of the pocket dosimeter) on the surface of the wearer's body. In the following this "CERN quantity" will be compared with the Individual Dose Equivalent, Penetrating, or rather the calibration quantity of the latter, Directional Dose Equivalent at 10 mm depth, $H'(10)$, in the ICRU sphere [5]. Another quantity that will be considered is $H_{p,f}(13)$ the dose equivalent at a depth of 13 mm in a plexiglass block as proposed in Switzerland [6].

It is of interest in this context to report on the results of three years experience with the CERN approach to individual dosimetry. In Fig. 1 the ratios of exposures recorded by quartz fibre dosimeters over film badge doses are shown for 389 cases where for personal doses of greater than 1 mSv pocket dosimeter results were available. The mean value of the ratio is 0.99 (excluding 4 cases with a ratio of greater than 2.35) with a standard deviation of 6%. Actually 80% of the results lie in the range of $\pm 25\%$, which should be considered as excellent.

3. THE SPECIAL PTB INTERCOMPARISON 1987

During a special PTB intercomparison 1987, dosimeters were irradiated on the ICRU sphere. CERN film badge results are presented in a global form in Fig. 2 [7]. The ratio of experimentally determined dose equivalents over directional dose equivalent at a depth of 10 mm is plotted as a function of the angle of radiation incidence. In all cases shown in the figure experimentally determined values are higher than the calibration quantity $H'(10)$ at zero degrees as actually the films were evaluated knowing their response to exposure free in air. Hence the overestimation for the dose equivalent in 10 mm depth of the ICRU sphere could be expected. The bias at zero degrees poses no problem and the CERN film badge could be correctly calibrated in directional dose equivalent following the experience gained during these experiments.

More important is the observation that the angular dependence of film dosimeters for $H'(10)$ is not flat. Experimentally a decrease in

response with angle is found for high to medium photon energies, while for low energy X-ray spectra the relative response increases with angle. The reason is that at low photon energies the directional dose equivalent drops rapidly as a function of angle whereas the film badge overestimates considerably. Results for the CERN dosimeter are in line with earlier observations and for which a maximum deviation from the correct response of $\pm 38\%$ was considered as acceptable [8].

When further analysing the data of the special PTB intercomparison it was noted in the case of soft X-ray spectra that exposure values calculated on the surface of the sphere using published backscatter factors turned out to be much greater than experimentally determined values. For the radiation quality C30 the discrepancy amounted to more than a factor of two [7].

4. INFLUENCE OF PHANTOM SHAPE ON FILM BADGE RESPONSE

In order to study the response of the CERN dosimeter with respect to $H'(10)$ or $H_{p,f}(13)$ further experiments were performed calibrating film badges both on the ICRU sphere and on the plexiglass phantom proposed in Switzerland. The results are presented in Table 2. Three X-ray qualities were available as well as photons from ^{137}Cs and ^{60}Co sources (column 1). As reference quantity, exposure free in air was chosen (column 2). All doses were expressed in mSv following the German proposal of photon dose equivalent where 100 mR are set to be equal to 1 mSv. Three film badges per experiment were irradiated at the same location (column 3) either free in air (F), on the surface of the ICRU sphere (S), or on the plexiglass block (P).

Knowing the exposure free in air at the place of the phantom surface in the absence of the latter (column 2) it is possible to calculate both $H'(10)$ and $H_{p,f}(13)$ with the help of published conversion factors (column 6) [6,9]. The exposure in the presence of the phantom is increased by the influence of backscatter. As also the backscatter factors have been published for the ICRU sphere and the plexiglass phantom (column 5) it is possible to compare theoretical, i.e. calculated and experimentally determined dose values [10]. As the sphere actually used in the experiments was made from PEAR, a material approaching in its composition tissue equivalent material [10], the

results were corrected for the difference in backscatter for the two materials [11].

Exposures determined experimentally with the film badge are given in column 4 of Table 2, the uncertainty of less than 3% is the standard deviation for the results of three doseimeters.

In the last column finally the ratios between experimentally determined dose quantities over the values calculated by converting the reference dose are given. The first line for each radiation quality simply gives the response of the CERN film badge to exposure free in air. The ratios are rather close to one, as would be expected. With respect to $H'(10)$ and $H_{p,f}(13)$ the measured response of the doseimeter is rather near to the theoretical value for hard photon radiation and still remains so for softer radiation in case of the plexiglass phantom. Ratios lower than one are noticed for the sphere that become smaller as photon energies decrease. This apparent reduction in backscatter is explained by the trivial fact that the rather large flat film badge can only be in close contact with the spherical phantom in one point. Flat phantoms have in addition to their better irradiation geometry the advantage that more than one doseimeter can be exposed at a time.

5. CONCLUSIONS

The introduction of new quantities in personal monitoring will have no great consequences at CERN in routine practice.

As far as personal monitoring for hadrons is concerned nothing will change as there is at present no individual doseimeter available for the use around high energy proton accelerators which could be properly calibrated in any dose quantity [12].

For beta dosimetry of the whole body or rather at the place of the body where the doseimeter is worn the CERN film badge has shown its capabilities considering the recent results of an international intercomparison [13]. In particular it is possible to determine the surface dose for the hard beta radiation from depleted uranium.

With respect to personal dosimetry in radiation fields of induced radioactivity it is essential that the correspondence between the results of the two independent individual doseimeters be maintained. In Fig. 3 the range of ratios of apparent doses behind different filters is presented for which the algorithm developed at CERN will calculate personal doses from optical density. Recent results for ^{137}Cs irradiations on phantoms are just outside the limits of the automatic evaluation. In the lower left hand corner of the rectangle, filter ratios for the hard photon radiation are located. They are typical for routine dose evaluations during the last accelerator shut down. In the direction toward the upper right hand corner one finds filter ratios for softer photon spectra.

An interesting point on the figure is the one marked KKB. This is an irradiation in the framework of the 1986 intercomparison in Switzerland, where doseimeters were exposed on a phantom to photons from activated reactor material. As the optical density pattern clearly showed a predominance of ^{60}Co radiation, the result was evaluated, in the absence of a calibration on a phantom, to be 455 mR in exposure free in air, a value which included the backscatter contribution. The official dose expressed in $H_{p,f}(13)$ was 376 mrem where the CERN algorithm gave 3.65 mSv.

Hence for personal exposures in energetic photon fields typical at CERN it is expected that personal doses expressed in $H_{p,f}(13)$ and likewise in $H'(10)$ will be rather close to doses evaluated using the present approach.

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Table 1

Distribution of annual doses according to different classes for all persons at CERN under individual control present on 31 December 1987

Dose class (mSv)	Number of persons	%	Total dose per class (mSv)
0	2252	50.0	0.0
>0-1	1852	41.1	761.9
>1-5	354	7.8	776.0
>5-15	50	1.1	361.3
>15	0	0	0.0
Total	4508	100	1899.2

Table 2

Results of a calibration of CERN film badges free in air,
on the ICRU sphere, and on a plexiglass phantom

Radiation quality	Reference dose X in mSv	Irradiation geometry *)	H _{exp} in mSv as determined from the results of 3 film badges	Backscatter factor for the phantom [10]	Factor to convert X into H _x , H'(10) [9] and H _{p,f} (13) [6]	Ratio H _{exp} /H _{theo}
C60	0.473	F	0.473 ± 0.004	1	1	1.000 ± 0.008
		S	0.499 ± 0.004	1.40	1.143	0.754 ± 0.001
		P	0.572 ± 0.005	1.61	~1.3	0.751 ± 0.007
A80	0.960	F	0.964 ± 0.010	1	1	1.004 ± 0.010
		S	1.167 ± 0.008	1.57	1.447	0.774 ± 0.005
		P	1.453 ± 0.029	1.66	1.80	0.912 ± 0.018
A200	1.048	F	1.045 ± 0.009	1	1	0.997 ± 0.009
		S	1.090 ± 0.033	1.28	1.273	0.813 ± 0.025
		P	1.450 ± 0.035	1.35	1.40	1.025 ± 0.025
¹³⁷ Cs	4.50	F	4.53 ± 0.06	1	1	1.007 ± 0.013
		S	4.71 ± 0.03	1.07	1.047	0.978 ± 0.006
		P	4.93 ± 0.10	1.08	1.09	1.014 ± 0.021
⁶⁰ Co	4.50	F	4.49 ± 0.01	1	1	0.998 ± 0.001
		S	4.64 ± 0.04	1.03	1.011	1.001 ± 0.009
		P	4.78 ± 0.09	1.04	1.03	1.021 ± 0.019

*) F : free in air
S : on ICRU sphere
P : on plexiglass block.

FIGURE CAPTIONS

- Fig. 1. Distribution of the ratios for doses determined by quartz fibre dosimeters over film dosimeters for 389 cases in the years 1985 to 1987 at CERN.
- Fig. 2. Angular response of the CERN film badge to directional dose equivalent $H'(10)$ for various radiation qualities. In brackets the mean energies of the X-ray qualities A and C are given.
- Fig. 3. Range and limits of ratios of apparent doses behind different filters in the CERN film badge from which personal doses are evaluated automatically according to an empirical algorithm. D_1 , D_5 and D_7 are apparent doses behind an 80 mg/cm^2 plastic, a 1260 mg/cm^2 lead, and a 355 mg/cm^2 plastic filter respectively. Points shown are taken from various experiments, intercomparisons and routine results.

Fig. 1

Fig. 2

Fig. 3