FF

12 DEC. 1989

CERN-TIS-CFM 89-14
C2

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/TIS-CFM/89-14

1.11.1989

COLOUR DOSEMETERS FOR HIGH-LEVEL RADIATION DOSIMETRY

H. SCHÖNBACHER, F. CONINCKX, CERN, Geneva, Switzerland

A. MILLER, RISØ National Laboratory, Roskilde, Denmark

G. KRUSKA, I. WULF, SCE, Hombrechtikon, Switzerland

CERN LIBRARIES, GENEVA

ABSTRACT

P00030816

Development work was undertaken in order to produce a visual dosimeter system for measurement of radiation levels around the present and future high-energy particle accelerators. This dosimeter should exhibit radiation induced colours in the visible part of the spectrum leading to a visual dose interpretation or a dose measurement with a simple instrument such as a portable reflecting densitometer in the range of 10^3 to 10^6 Gy.

Two projects were investigated: A thin plastic film with a self adhesive tape containing a radiochromic dye which induces a colour change when exposed to ionizing radiation and a paint containing a base substance and a pigment.

Calibration of the dosimeters was made with a ^{60}Co source up to 10^6 Gy.

The paint dosimeter remained unaffected by irradiation up to 3×10^4 Gy while the film dosimeter showed a measurable colour change from 10^4 Gy to 5×10^5 Gy. Above 10^6 Gy the film dosimeter is destroyed by radiation. Samples of paint and film dosimeters were installed in the 450 GeV Super Proton Synchrotron (SPS) at CERN and irradiated during operation for more than two years. Within the useful range of the dosimeters, dose comparisons with other dosimeter types gave satisfactory results. Application in other fields such as commercial irradiation facilities is envisaged.

Paper to be presented at 9th International
Conference on Solid State Dosimetry, Vienna, 6-10 Nov. 1989

1. INTRODUCTION

At the European Organization for Nuclear Research (CERN) the application of a new type of high-level dosimeter system was investigated for the 450 GeV Super Proton Synchrotron (SPS) with later possible application at the Large Electron Positron Collider (LEP). This dosimeter should exhibit radiation induced colours in the visible part of the spectrum which lead to a visual dose interpretation in the range of 10 kGy to 1 MGy. This might be obtained by a paint or a tape which could be applied to the accelerator components making it possible to estimate the order of magnitude of absorbed dose.

The characteristics required for such a dosimeter system are following:

1. Clear change in colour in a broad dose range (i.e. it must remain unaffected by radiation up to 10^4 Gy, show a clear change of colour between 10^4 and 10^5 Gy and another change of colour between 10^5 and 10^6 Gy).
2. Insensitivity to ozone, oxygen and humidity in the air.
3. No pronounced colour changes or bleaching effects from normal ageing.
4. Insensitivity to ordinary room light.
5. Commercial availability.
6. Ease of application (e.g. by spray or tape) on organic materials (epoxy resins) and metals (stainless steel, aluminium, lead).

Two types of colour dosimeters were tested at CERN. The first was a thin plastic film on a self adhesive tape containing a radiochromic dye showing a colour change when exposed to ionizing radiation. The second was a paint containing an acryl-styrol dispersion with a certain amount of radiation sensitive pigment.

The aim of such a dosimeter was that, applied on different accelerator components, it can be read with a simple instrument. The order of magnitude of the dose can also be estimated by comparing the colour with the colour of a calibration chart.

The investigation of the film/tape dosimeter was based on development of a dosimeter for use in radiation processing (1, 2, 3), while there was no previous experience on paint dosimeters. Twelve different compounds were tested before a prototype paint was selected.

Here we describe the results obtained during preliminary tests with one selected paint and a dye film dosimeter and when irradiated at various positions at CERN. The dye film was also included in an intercomparison of high-dose dosimeters in accelerator fields in the framework of a collaboration between the Technical Inspection and Safety Commission at CERN and the Laboratorio di Fisica at the Istituto Superiore di Sanità (ISS) in Rome (4).

2. DESCRIPTION OF THE DOSEMETERS

2.1. Paint dosimeter

Surface-Protection Consult Engineering (SCE) provided 12 different systems, painted on aluminium plates of 40 mm x 80 mm. Out of these systems one was selected for further investigations, which yielded the most satisfactory response with regard to radiation-induced colour changes and the influence of temperature and fluorescence light exposures. The plates were entirely painted with an acryl-styrol dispersion (Prozink 2000) containing TiO_2 and a coreagens, and partly repainted with the same acryl-styrol dispersion but containing less TiO_2 , with a pergaskript pigment added.

The basis of the pergaskript pigment is a crystallized violet lactone (CVL) and a benzoyl-leucomethylene blue (BLMB). The development of colour of these two products is shown below:

The colourless left side product (CVL) turns to blue-violet by separation of the carboxyl-groups from the binder which is an acryl-styrol dispersion. In order to reduce the temperature sensitivity of the above reaction a coreagens was included which resulted in a colour change to brown instead of blue.

2.2. Radiochromic dye thin film

RISØ National Laboratory provided one series of dosemeter samples which may be regarded as an early prototype for a commercial tape dosemeter. It consists of a thin plastic film containing a radiochromic dye which induces intense permanent colours when exposed to ionizing radiation. The dosemeters are sensitive to exposure of UV-light, but they are protected by a UV-absorbing layer.

This thin film radiochromic dye dosemeter contains a leucocyanide which is transformed into a coloured state, a dye, by absorption of energy from ionizing radiation. The leucocyanide belongs to the family of tri-methananes, which like cyanides are colourless. Upon irradiation the cyanide bond is broken and the positive carbonium ion becomes coloured:

At present, RISØ has developed procedures for a synthesis of pararosanine cyanide based on pararosanine chloride, and is able to produce the cyanide in suitable amounts at a reasonably price. The dosemeter films are made by dissolution of polyvinyl butyral (PVB) and of the dye in a suitable solvent and by casting on a pilot film casting and dying line at Beiersdorf AG, Hamburg, Federal Republic of Germany (3).

3. RESPONSE CHARACTERISTICS

The response of the dosimeters was checked by irradiation from 10^3 up to 10^6 Gy at Conservatome in Dagneux-Montluel, France. The irradiation source at Dagneux is part of an industrial radiation facility. The ^{60}Co source has an activity of 5550 TBq on 1.2.84. The approximate dose rate, 10^4 Gy/h, was calculated from the activity of the source and measured by red Perspex dosimeters. Proper calibration of the dye film was carried out during the cited comparison with ISS (4) and at RISØ (3).

The reflected optical density of each sample was measured with a portable reflection densitometer GRETAG, type D152. A blue, green and red filter is respectively used for the measurement of the density of the yellow, magenta and cyan pigments in the test sample.

Figure 1a shows the response curves for the dye film dosimeter, and figure 1b for the paint dosimeter.

Earlier measurements with the dosimeter film with a dye content of 2% irradiated with Cobalt-60 gamma rays showed that the absorbance saturated at a level of approximately 2 for doses above 100-200 kGy. Irradiations with 10 MeV electrons showed a response which is within 5% of the gamma-ray response (3).

4. INFLUENCE OF ENVIRONMENT

No significant colour change for the paint and the film where observed when exposed to daylight or fluorescence light for three months. Long term exposure of 2.5 years to daylight of the irradiated dosimeters shows a significant fading of the film above $2 \cdot 10^5$ Gy; no fading is observed on the same film when stored for the same period in dark (see Fig. 1a).

The paint showed significant darkening at doses below 2×10^5 Gy and fading above, when exposed to daylight for 2.5 years (see Fig. 1b). Samples which were kept in dark show the same effect but much less intensive ($< 10\%$).

Fig. 2 shows the behaviour of the irradiated film dosimeter when heated up to 200°C . After a first increase of the optical density up to 50°C the decrease becomes significant after 100°C .

The film dosimeters have been tested for the influence of temperature, humidity and prolonged storage (3). These measurements showed that the film dosimeter should be used with some caution. Although the stability at room temperature was excellent, elevated temperature ($> 60^{\circ}\text{C}$) caused the response to fade during a storage time of 1-2 years. It was also found that the influence of the irradiation temperature was different at different doses, and that temperatures exceeding 60°C should be avoided.

5. IRRADIATION AND RESULTS AT CERN

An intercomparison was made with Radiophotoluminescent (RPL) dosimeters, which are used in CERN routine high dose dosimetry (5); the dosimeters were placed at different positions at the CERN accelerators (4). The dose readings of both types of dosimeters are given in Table 1. The results show in general very good agreement. At the PS and a few other positions the threshold dose was not reached. At position 20, e.g. downstream SPS target 6, the film dosimeter was destroyed. The reason for this could be the high dose and/or the relative high temperature of the collimator.

Paint and film dosimeters were installed in 1986 and 1987 at various positions in the SPS accelerator at CERN and irradiated during fixed target operation. The results showed that only at a few points the threshold dose was exceeded and hence no colour change was observed, neither on the paints nor on the films. This, however, is also an important result because it shows that the dosimeters are not influenced with time and by the environment. At points where the threshold dose was exceeded the comparison of dye films with RPL dosimeters gave very satisfactory results (Fig. 3).

A new serie of paint dosimeters was installed in 1988 in the SPS. Cobalt 60 gamma irradiation showed that this was much less radiation-sensitive than the samples from a previous serie. The reason for this was, that the new batch of the pergaskript pigment was of higher purity; this yielded in crystallization and prevented the change of colour by radiation.

6. CONCLUSIONS

- 1) Both selected systems - paint and film - fulfil the requirement laid down in the specification as this programme was started, e.g. they remain unaffected by irradiation up to 10^4 Gy; they show a clear colour change between 10^4 and 10^5 and another clear colour change between 10^5 and 10^6 Gy.
- 2) Field experience gained with colour changes of the film in the different radiation fields of the PS Booster, the SPS ring and target areas, is very positive up to 10^6 Gy. Above that dose dosimeter film will be destroyed, due to radiation damage.
- 3) With the paint, experience in colour change could only be gained from the calibration irradiations, since in "life" exposures the threshold dose was not reached.
The UV-stability and reproducibility from batch to batch needs to be improved.

Acknowledgements

The advice and comments by W.L. McLaughlin during the development of the film dosimeter is highly appreciated. The production and the development of the tape version of the film dosimeter would not have been possible without help and active participation of Dr. W. Karman, Beiersdorf AG, Hamburg, FRG.

REFERENCES

1. McLaughlin W.L., Miller A., Fidan S., Pejtersen K., Radiochromic plastic films for accurate measurement of radiation absorbed dose and dose distributions, Radiat. Phys. Chem. 1977, Vol. 10, pp. 119-127.
2. Miller A. and McLaughlin W.L.: On a radiochromic dye dose meter, RISØ National Laboratory Report, RISØ-M-2254 (1980).
3. Miller A., W. Batsberg and Karman W.: A new radiochromic thin-film dosimeter system, Int. J. Radiat. Appl. Instrum. Part C., Vol. 31, pp 491-496.
4. Coche M., Coninckx F. and Schönbacher H., CERN; Bartolotta A., Onori S. and Rosati A., Istituto Superiore di Sanità: Comparison of high-dose dosimetry systems in accelerator radiation environment, CERN-TIS-RP/205 (1988).
5. Coninckx F., Schönbacher H., High-level dosimetry results for the CERN high-energy accelerators, CERN TIS Commission Report, TIS-CFM/89-08 (1989).

TABLE 1

Integrated doses in gray at selected positions
at the CERN accelerators

No	Description of position	Film		RPL
		magenta	yellow	
	450 GeV Super Proton Synchrotron (SPS)			
1	Coil: 2.17.01	6.2 10 ⁴	5.5 10 ⁴	6.4 10 ⁴
2	Coil: 3.14.01			1.0 10 ²
3	BLM: 2.18.01	1.9 10 ⁴	9.0 10 ³	1.9 10 ⁴
4	BLM: 3.14.01			1.5 10 ²
5	Cable tray: 6.16.54	1.5 10 ⁵	5.0 10 ⁵	4.3 10 ⁵
6	Cable tray: 4.14.05			1.1 10 ⁰
	26 GeV Proton Synchrotron (PS)			
7	Vacuum chamber: pos. 37			3.0 10 ³
8	Vacuum chamber: pos. 23			2.7 10 ²
9	Vacuum chamber: pos. 67			7.1 10 ²
10	Vacuum chamber: pos. 80			2.8 10 ¹
	800 MeV-PS Booster			
11	Position: BR3.BHZ82.U	5.0 10 ⁴	6.0 10 ⁴	1.9 10 ⁵
12	Position: BR3.BHZ72.U	2.1 10 ⁴	1.3 10 ⁴	1.5 10 ⁴
13	Position: BR3.BHZ72.D			4.1 10 ²
14	Position: BR3.QF072.U			1.6 10 ²
	SPS Transfer tunnel (TT20)			
15	Position: MBE211415.U	1.9 10 ⁴	1.5 10 ⁴	1.7 10 ⁴
16	Position: MBE211427.U			1.7 10 ³
17	Position: Cable tray (MBB211368)			4.5 10 ³
	SPS Target area (TCC2)			
18	Target 2: MTN 02 0003 U	4.5 10 ⁴	5.5 10 ⁴	5.7 10 ⁴
19	Target 4: MTN 04 0003 U	1.2 10 ⁵	3.8 10 ⁵	2.2 10 ⁵
20	Target 6: QNL 025 U	*	*	1.8 10 ⁶

* destroyed

Fig. 1 Reflected optical density as a function of absorbed dose after irradiation and storage in dark (full line) and effect of 2.5 years exposure to daylight (dashed line) a) Dye film, b) Paint.

Fig. 2 Temperature response of dye film dosimeter irradiated to 10^5 Gy.

Fig. 3 Comparison of dye film dose with Radiophotoluminescent dosimeters irradiated at the CERN SPS for 10 months.