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TWO YEARS OF PRACTICAL EXPERIENCE
WITH LR115 AS A HADRON DETECTOR

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ABSTRACT

Following a long series of experiments on the feasibility of using the plastic LR115 as a hadron detector in the stray field around high-energy accelerators, it was decided to run a pilot project issuing the detector for routine use to a selected category of people. Since the official CERN hadron dosimeter, the NTA film, was worn in parallel, an interesting comparison became possible. The results will be described as well as the problems with respect to sensitivity and variation in background of LR115. The behaviour of a so-called thermoluminescence flag, introduced in order to sort out zero-exposure detectors, will be discussed. The final decision to abandon LR115 as a choice for a new hadron dosimeter at CERN was motivated by substantial improvements in the NTA film.

INTRODUCTION

The stray radiation field outside the shielding of a GeV proton accelerator has an extension in energy from thermal neutrons up to primary-energy hadrons. Thus personal neutron dosimeters should be able to detect also those particles contributing to dose, e.g. the NTA neutron film makes it possible to see the high-energy energy protons as long thin tracks. The disadvantages of the nuclear emulsion are, however, the fading of latent information with time and the necessity to scan the tracks with microscopic methods.

The plastic LR115 (a product of Kodak France) has been employed at CERN during a period of two years as an alternative hadron detector on a trial basis, primarily because of the non-fading, even under extreme temperature and humidity conditions (Höfert and Koczynski, 1981). Since latent damage from heavy recoil particles will appear as holes in LR115 after etching, it became possible to use an automatic scanning microscope (Quantimet) for their evaluation. In the following the experience with this detector will be reported as well as the reasons which finally led to abandoning it in routine hadron dosimetry.

USING LR115 AS A DETECTOR; ITS BEHAVIOUR

LR115 consists of a sensitive layer of red-dyed cellulose nitrate with 14 μm of thickness on a transparent plastic base. Latent damage caused by nuclear reactions becomes visible when the foil is etched in a caustic solution. The sensitive layer

is extremely delicate with respect to development conditions. In particular, any mechanical movement of the plastic during treatment or pumping of the solution in order to filter off development products results in unreproducible bulk etching. This makes automatic scanning difficult owing to the necessity of readjusting the basic contrast of the Quantimet for each individual foil at the moment of reading (Dutrannois and co-workers, 1980). Even in cases of many holes per detector, where the stochastic counting error could be neglected, the reproducibility achieved at the beginning was only of the order of 20% for test irradiation with α -rays from a depleted uranium plate.

After many tests, the final development method adopted consisted in etching the LR115 for $2\frac{1}{2}$ h in 2.5N NaOH at 60 °C in a 70 l container. The foils are kept in small holders and are dipped into the solution which is heated thermostatically. The small thermal convection in the vessel is sufficient to ensure homogeneously developed detectors. Etching products stay at the bottom of the container, resulting in clean foils. After development the detectors are rinsed in tap water and dried at room temperature. The reproducibility with this simple technique turned out to be of the order of 5%. Owing to the surplus of etching solution no ageing effect in the latter was detectable for a period of over one year, after which the caustic solution was renewed.

Another problem encountered with LR115 is its background behaviour. After thorough investigation, it was found that background holes are either caused by the radon content in air or by point-like pressure on the sensitive layer when this is kept in contact with various non-plastic surfaces for prolonged periods. Hence, foils freshly cut from the roll show a typical background of 6 holes per cm^2 after development. When foils are kept in free air for about a month their background increases to more than 150 holes per cm^2 . Different materials were tried out inside the badge which housed the LR115 when it was worn by the personnel. The best result is obtained with LR115 being in contact with itself (10 holes per cm^2), while plastic foam still results in about 20 holes per cm^2 . The boron plastic BN1 (Kodak neutron converter) shows values of about 60 holes per cm^2 and per month as typical background.

For the routine procedure foils were always freshly cut from the LR115 roll and mounted in pairs in the badge, in order to reduce the two sources of background to a minimum.

THE USE OF RADIATORS

Any radiator brought into contact with the sensitive layer of the LR115 will induce background holes, owing to its mechanical pressure, as has been mentioned above. This experience was rather marked when a boron layer on a sanded glass surface was employed as a radiator in order to increase the sensitivity of the detector towards low-energy neutrons coming from the (n,α) reaction with ^{10}B . As pointed out above, better results with respect to background are obtained when using the neutron converter screen BN1 provided by Kodak. However, the reproducibility of the results for an individual irradiation was not better than 30% for a negligible stochastic uncertainty. The problem of contact and/or variation in the thickness of the boron layer would be a reason for the poor reproducibility.

It was finally decided to abandon the BN1 boron layer and rather exploit the full field of the LR115 without any radiator. A pair of thermoluminescence dosimeters (TLDs) ($^6\text{LiF}/^7\text{LiF}$) were used instead as a neutron flag. In screening the badges worn by the personnel containing both the LR115 foil and the TLD chips with a cadmium layer towards the outside, it was hoped to detect only thermal albedo neutrons from the body. Since the difference in the thermoluminescence signals from ^6LiF and ^7LiF can be readily obtained, such information would "flag" a possible neutron exposure of a person. With the help of such a signal unexposed LR115 foils could be screened out before evaluating them on the Quantimet.

CALIBRATION

Both the nuclear emulsion and LR115 are threshold detectors. While for the former the lower energy limit is roughly 1 MeV, LR115 has a threshold energy of about 3 MeV, since no recoil protons are registered and only heavy recoil products will lead to etchable holes. Hence, a calibration of both detectors with an isotopic neutron source is not relevant for an interpretation of the results obtained in the stray field around GeV proton accelerators, which is characterized by higher energies. Field calibrations were performed basing the conversion constant holes and tracks per unit area on a measurement of dose equivalent with a multidetector set (Höfert and co-workers, 1976). In Table 1 the calibration figures, as well as other interesting parameters for LR115, are given in comparison with the NTA emulsion.

Table 1

Basic characteristics of nuclear track detectors

	LR115	NTA film
Fluence to dose equivalent conversion factor for Pu-Be neutrons in $\text{cm}^{-2} \text{ Sv}^{-1}$	3.4×10^3	2.0×10^6
Fluence to dose equivalent conversion factor in a stray hadron field (standard interpretation) in $\text{cm}^{-2} \text{ Sv}^{-1}$	1.4×10^4	3.5×10^6
Standard field size read in cm^2	1.44	8.75×10^{-3}
Holes or tracks per mSv in a stray hadron field	20	31
Experimentally determined background in holes or tracks per standard field and its uncertainty	11.6 ± 5.2	1.06 ± 0.87

In the case of a PuBe neutron source the sensitivity of LR115 is only one quarter of that experienced in stray hadron fields. The conversion constant quoted for the latter is actually a typical value, since during the experiments factors ranging from 1×10^4 up to $1.6 \times 10^4 \text{ cm}^{-2} \text{ Sv}^{-1}$ were found, showing an expected dependence on the hardness of the spectrum. In all cases a factor of 1.4×10^4 holes per cm^2 and per sievert was applied as being relevant for the spectral conditions in which the pilot programme took place.

PRACTICAL EXPERIENCE

The LR115 badge containing a $^6\text{LiF}/^7\text{LiF}$ pair was carried, in addition to the official NTA neutron film, by about 30 people during the period starting at the end of 1980

up to the end of 1982. The two dosimeters were worn in an area around the anti-proton accumulator, where, at the start of its operation, dose rates of the order of 100 $\mu\text{Sv/h}$ were encountered. As the shielding situation was steadily improved with time, dose rates decreased by one order of magnitude and the test programme was stopped towards the end of 1982.

In order to check on the conversion constant a couple of badges were fixed to a phantom made from tissue-equivalent plastic which was placed in the area in the vicinity of a radiation monitor. The latter made it possible to check the interpretation of dose equivalent on the LR115 dosimeter for a full operation period, while the NTA film was changed as usual once a month. In Fig. 1 the ratio of dose equivalent for the prototype badges fixed on the phantom to the hadron dose equivalent accumulated by the monitor is plotted as a function of time. During operation up to the third quarter of 1982 the ratio stayed in most cases somewhat lower than one but later the LR115 interpretation led to higher doses than the monitor reading. This can be explained by a hardening of the spectrum in the area, caused by the completion of the concrete shielding around the antiproton ring. This will require a higher calibration factor for the LR115. The hardening of the spectrum is also confirmed by the influence on the result of the neutron flag. As the mean energy of the hadron increases, the thermalization of neutrons in the body decreases; hence equally the albedo effect. The ratio of the ${}^6\text{LiF}/{}^7\text{LiF}$ difference in the luminescence signal expressed in absorbed dose of a ${}^{60}\text{Co}$ calibration irradiation to the hadron dose on the monitor is also plotted in Fig. 1 as a function of the operation period. The decrease in the albedo from the phantom is clearly visible and follows the change in the conversion constant of the LR115.

With respect to the badges worn by the personnel, hadron doses recorded by the LR115 corresponded in many cases rather well with those reported by the NTA film, in particular when dose values were above 1 mSv. Discrepancies found between the two dosimeters were of two kinds. Sometimes the NTA film reading was low compared to the LR115 foil, which was attributed to fading of latent tracks in the emulsion. In other cases the result of the LR115 was found to be excessively high and could not be considered to be real. A check whether the number of holes was caused by irradiation, however, became possible with the help of the TLD flag. Its value expressed in absorbed dose of a ${}^{60}\text{Co}$ photon exposure had to be of the same order of magnitude as the apparent hadron dose. There were cases where this numerical value was higher than the hadron dose on several occasions when additional personnel exposures in stray, low-energy neutron fields had occurred. On the other hand, no explanation of the excessive number of holes found in some of the LR115 foils worn by the personnel can be given. These unexplained high readings plus the inherent high background corresponding to a dose of 0.5 mSv per month are considered to be the greatest obstacles to using LR115 as a hadron dosimeter. In Fig. 2 the standard deviation as a function of dose is given for both LR115 and the NTA emulsion. At high doses the uncertainty is determined by variations in the detector material, in the development, and in the reading. While LR115 and the NTA emulsion behave quite similarly at doses of 5 mSv and higher, a greater standard deviation is encountered with the plastic at small doses owing to its inherent high background signal. Some improvement in the stochastic uncertainties could be obtained in the case of LR115 at lower doses if larger surfaces were scanned. But even in cases where five times the normal surface is used the behaviour of this material at low doses is still worse than that of the NTA film.

From Fig. 3 it is quite obvious that the application of LR115 in fields of lower neutron energies is impossible owing to its high threshold energy, while the NTA emulsion shows only a slight deterioration in behaviour at low doses compared to the stray hadron field.

Fig. 1 Ratios of dose recorded on the LR115 detector to the monitor reading and the signal of the TLD neutron flag to the monitor reading as a function of operation periods of the antiproton accumulator complex.

Fig. 2 Standard deviation for a personnel dose reading in per cent as a function of dose equivalent for an irradiation in high-energy stray fields both for LR115 and NTA film.

Fig. 3 As Fig. 2, but irradiation with Pu-Be source neutrons.

CONCLUSIONS

Two years of practical experience with LR115 as a hadron detector has revealed two major drawbacks. Its low sensitivity is accompanied by a rather high background, which is difficult to control. Hence the uncertainty at low hadron doses becomes unacceptably high. On the other hand, LR115 does not show any fading under normal wearing conditions but this advantage is offset by the necessity to treat the plastic detector with extreme care in order to avoid an uncontrolled increase in background.

Since improvements with respect to fading behaviour and technique of scanning have been made for the NTA emulsion it was finally decided to abandon LR115 as a personnel hadron detector around the CERN proton accelerators (Höfert, 1983).

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