EVALUATION OF COMMERCIAL DYED PLASTIC FILM FOR GAMMA-RADIATION DOSIMETRY

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الخلاصـــة :

اهتم هذا البحث بدراسة تأثير أشعة جاما على خواص الاستجابة لرقائق البلاستيك المتوفرة تجارياً بالأسواق والمصبوغة باللون الأحمر وكذلك مدى ثبات تلك الخواص قبل التعرض للإشعاع أو بعده .

وباستخدام تلك الرقائق يمكن قياس جرعات أشعة جاما الممتصة في نطاق كبير يصل (١٠ - ٦٠٠ كيلو جراي) .

وقد وضع برنامج للحاسب الآلي واسُتخدم في دراسة وتقييم مدى الترابط في قيم السماكة وتوزيع صبغة التلوين لكميات ضخمة من تلك الرقائق البلاستيكية . ولقد أثبتت النتائج أن هناك توزيعاً منتظماً ومترابطاً بين العينات سواء في السماكة أو توزيع الصبغة الحمراء .

ومن مزايا استخدام تلك الرقائق كمقياس للجرعات الإشعاعية اضافة إلى حساسيتها للإشعاع هو مرونتها وتحملها للصدمات العنيفة بالإضافة إلى درجة ثبات خواصها عند تخزينها لفترات طويلة سواء قبل التشعيع أو بعده ، وكذلك توافرها بالأسواق التجارية بكميات ضخمة وأسعار زهيدة مما يجعلها مناسبة لتطبيقات قياس الجرعات الإشعاعية المرتفعة الثمن وعمليات المراقبة الدورية للمواد .

ABSTRACT

The radiation response characteristics of a commercially available plastic film tinted with red dye has been investigated, as well as its pre- and post-irradiation stability. By using this film, a wide range of absorbed doses may be measured (10 to 600 kGy). The new film dosimeter is flexible, rugged, and stable on extended storage before and after irradiation.

A computer program has been used for regression analysis of thickness and dye variations in this plastic film. The results indicate a fairly uniform distribution of dye within, and thickness of, the plastic material. This thin dyed plastic dosimeter is widely available in large quantities and inexpensive, which make it suitable for high-dose photon applications as a routine monitor in radiation processing.

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INTRODUCTION

Certain dyed and undyed plastic films and sheets have long been used as high-dose monitors for the routine determination of radiation absorbed doses [1–7]. With the development of radiation processing on a commercial scale in Egypt at the National Center for Radiation Research and Technology (NCRRT) [8], many thin dyed polymeric films, available in the Egyptian market for a variety of purposes, have been evaluated for radiation dosimetry. One "red-tinted" film has shown considerable promise for radiation processing applications. This paper describes the response characteristics of this film in terms of absorption spectrum changes due to irradiation with gamma rays, and studies the response stability.

EXPERIMENTAL

The "red-tinted" plastic films are manufactured by Unit Four Co., Cairo, Egypt. The plastic film is a thin transparent dyed plastic of nominal thickness of 0.03 mm. The sample shape investigated was a small square of 1 cm × 1 cm dimensions, which could be placed before and after irradiation into a specially designed holder fitting reproducibly in the sample beam of the spectrophotometer. A Perkin–Elmer UV/VIS Lambda 3 spectrophotometer was used for measuring all absorption spectra and optical density values at the characteristic peak of the dyed film before and after irradiation.

Irradiations were carried out in Egypt's "Mega-Gamma I" radiation processing facility [9, 10]. The absorbed dose rate in water of this irradiation facility at the central point on the conveyor, at the mid-point perpendicular to the source plaque, was determined using Fricke dosimetry [11]. The dose rate was found to be 19.2 kGy h^{-1}. During irradiation, the red tinted films were sandwiched 4 at a time, between 5.0 mm thick blocks of polystyrene to ensure electronic equilibrium [12]. Data evaluation was performed in the computation centre of the Nuclear Materials Corporation, Cairo, using an IBM/AT computer.

The films were evaluated for suitability in a gamma-radiation dosimeter in terms of thickness and dye uniformity as well as reproducibility of spectrophotometric properties, namely pre- and post-irradiation absorbance at the optical wavelength of the pre-irradiation absorbance band (520 nm). The dosimeter was also evaluated in terms of post-irradiation stability at different storage conditions (temperature and light).

RESULTS AND DISCUSSION

The manufacturing process for commercially available dyed plastic films may lead to considerable variation in thickness and dye concentration across a sheet. Thickness variations clearly represent a problem for thin plastic dosimeters. In order to use such commercially available films for radiation dosimetry, account has to be taken of thickness and dye concentration variations. Considerable uncertainties in dose assessment can arise from these variations.

A regression analysis was carried out in order to evaluate thickness variations and dye distribution within the manufactured sheets of this material. The optical absorbance of unirradiated films (at 520 nm wavelength) depends upon the optical density of the plastic material in addition to that of the dye, and it must be at least an order of magnitude smaller than the optical absorbance of the dye molecules. The measured optical absorbance of the film then depends mainly on the extinction coefficient and concentration of the dye molecules, and the concentration of dye in the plastic host film material can be expressed by the measured values of absorbance for samples having identical thickness.

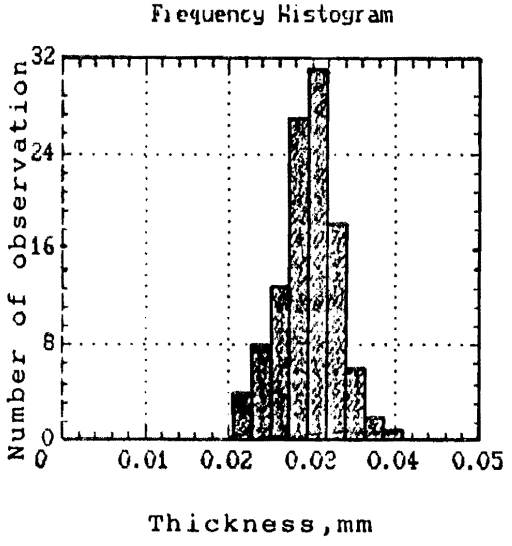
The absorbance (A_o) of 110 samples cut from standard sheets were measured and those samples having identical thickness were grouped together. Two sample sub-sets with thicknesses of 0.030 mm (24 samples) and 0.028 mm (17 samples) were chosen for dye uniformity analysis.

The variation of thickness of the 110 samples is shown in Figure 1. The thickness of these films ranged between 0.021 mm and 0.039 mm (median = 0.03 mm). The majority of samples had a thickness between 0.028 mm and 0.031 (around 50–60% of the standard sheet) and the coefficient of variation (standard deviation/mean) was approximately 6.13%. This indicates a fairly uniform distribution of thickness for commercially available sheets of this material.

Figures 2 & 3 show frequency histograms of the absorbance values for the investigated two sample sub-sets (with thicknesses of 0.03 mm and 0.028 mm). The coefficients of variations were found to be 5.7% and 6.2% for the two sets, respectively, an average value of around 5.95%. These results indicate that the dye is fairly uniformly distributed within the samples. However, when the absorbance values of all samples (thickness ranging from 0.021 mm to 0.039 mm) were taken into consideration, a frequency histogram (Figure 4) was obtained giving a coefficient of variation of about 9%.

EFFECT OF GAMMA RADIATION ON THE "RED-TINTED" PLASTICS

The spectral changes due to gamma-radiation are illustrated in Figure 5. This Figure shows spectrophotometric scans of unirradiated and irradiated films to various absorbed doses ranging from 12 to 580 kGy. It can be seen that gamma-radiation induces a gradual bleaching of the red dye in the film material. The wavelength chosen for spectrophotometry of the film dosimeters is that of maximum induced bleaching ($-\Delta A$) at 520 mm. To investigate quantitatively the effect of increasing doses of

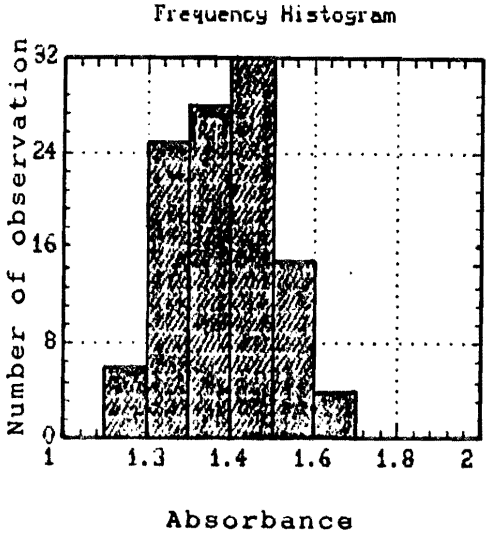


NUMBER OF OBSERVATIONS = 110
SAMPLE AVERAGE = 0.029545
SAMPLE VARIANCE = 1.1902E-5
SAMPLE STANDARD DEVIATION = 3.4499E-3

MINIMUM VALUE = 0.021 MAXIMUM = 0.039
LOWER AND UPPER QUARTILES = 0.028 0.031
INTERQUARTILE RANGE = 3E-3
MEDIAN = 0.03

COEFF. OF SKEWNESS = 0.082455
COEFF. OF KURTOSIS = 3.4247

Figure 1. Frequency Histogram Showing the Variation in Thickness of a Standard Plastic Film Sheet.



NUMBER OF OBSERVATIONS = 110
SAMPLE AVERAGE = 1.3877
SAMPLE VARIANCE = 0.015431
SAMPLE STANDARD DEVIATION = 0.12422

MINIMUM VALUE = 1.14 MAXIMUM = 1.67
LOWER AND UPPER QUARTILES = 1.29 1.48
INTERQUARTILE RANGE = 0.19
MEDIAN = 1.39

COEFF. OF SKEWNESS = -0.088881
COEFF. OF KURTOSIS = 2.2446

Figure 2. Frequency Histogram of Absorbance Values at 520 nm for Samples With Thickness of 0.03 nm.

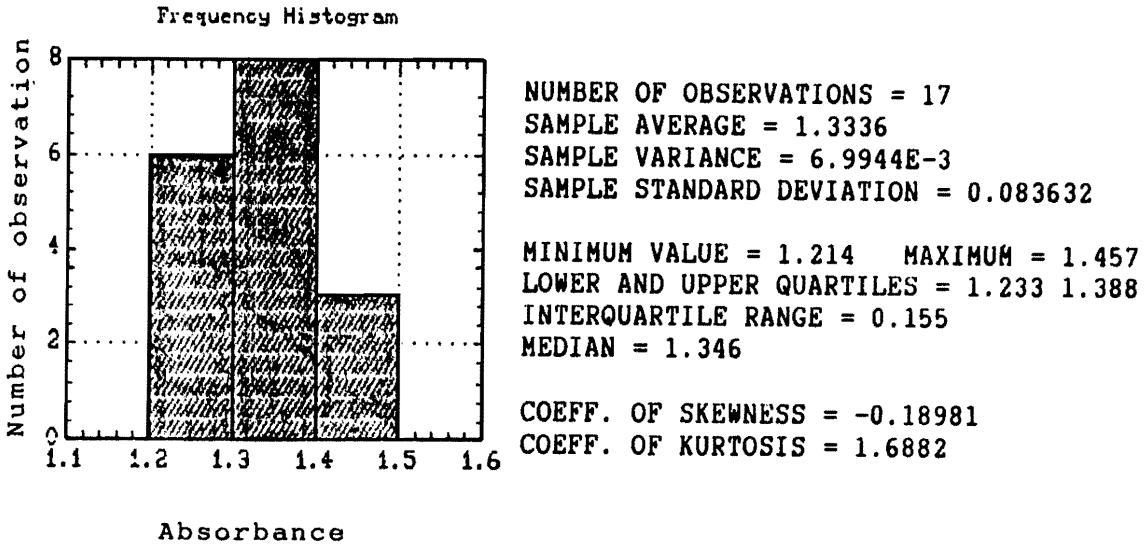


Figure 3. Frequency Histogram of Absorbance Values at 520 nm for Samples With Thickness of 0.028 nm.

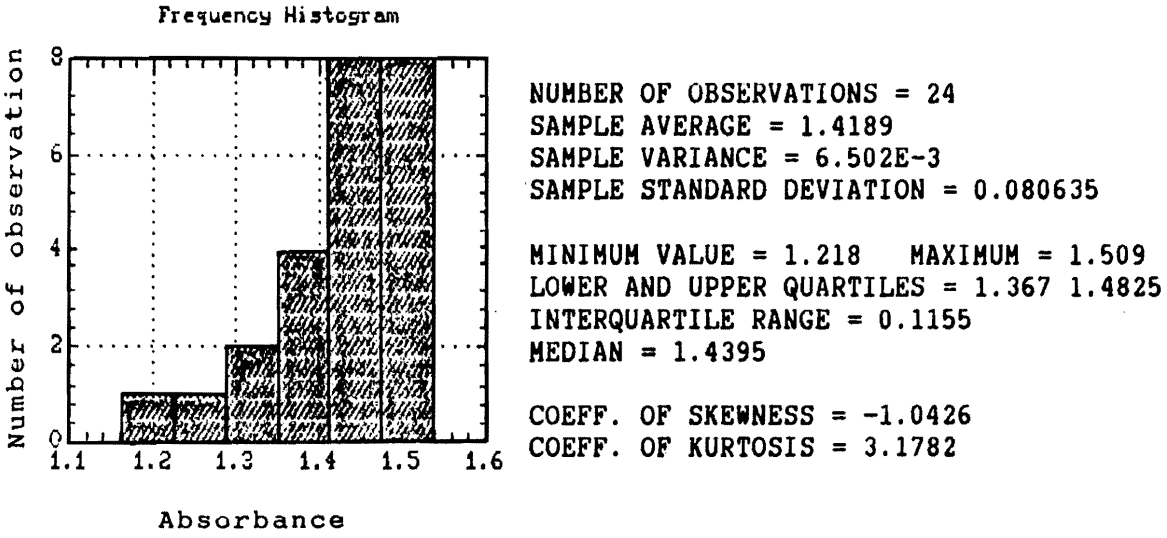


Figure 4. Frequency Histogram Showing the Absorbance Variation for 110 Film Sheet Samples.

gamma-radiation on the absorption spectra of the dosimeter, the change in optical absorbance (average of 4 films for each point) of the dosimeter at 520 nm wavelength was plotted as a function of gamma-ray dose (Figure 6).

It is observed that the response is supra linear up to 600 kGy. The measurement of absorbance at 520 nm in this film therefore presents a dosimetry system for both the sterilization dose region (10–50 kGy) and the material processing region (5–1000 kGy).

IMPROVEMENT OF THE FILM DOSIMETRY PRECISION

The calculation technique described by Uribe *et al.* [13], was used for reducing the errors due to thickness measurements. The percent error for several relevant measurable dosimeter quantities are listed in Table 1, at different adsorbed dose levels. These data show that, rather than using the more conventional value of absorbance change per unit thickness (ΔA/mm) or other variations of this

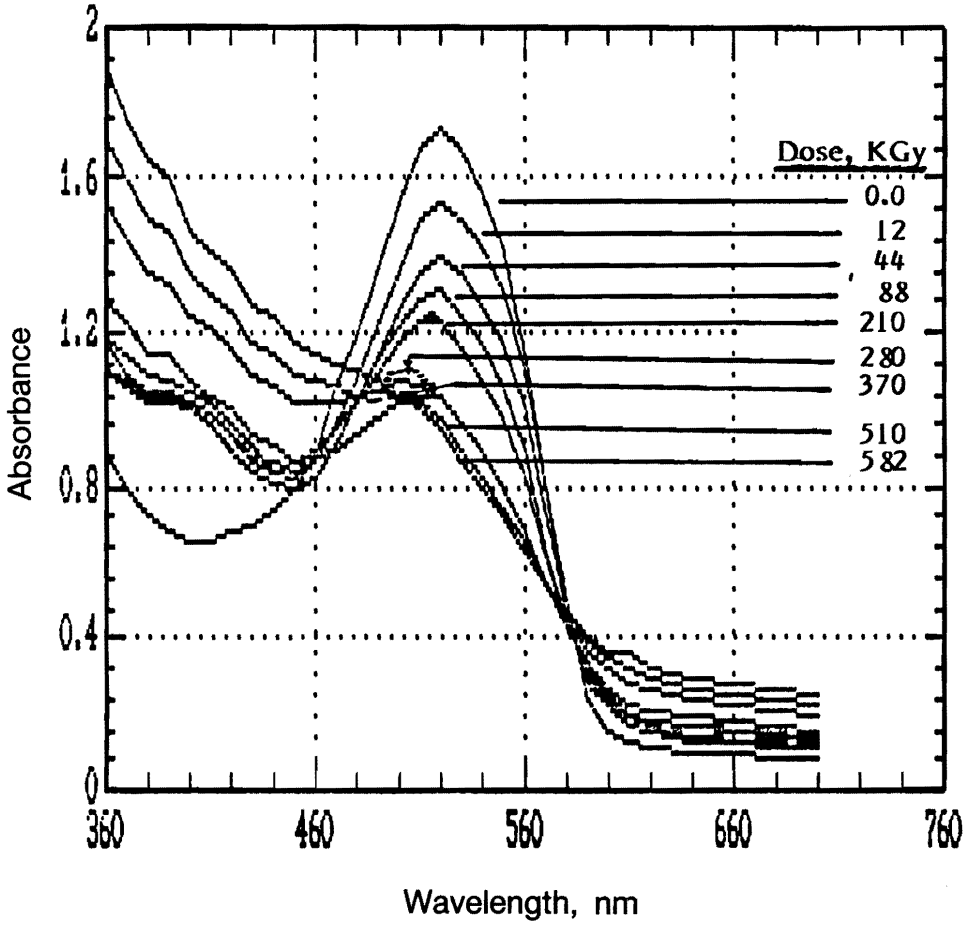


Figure 5. Absorption Spectra for Red-Tinted Films Before and After Irradiation at High Doses (Using Co-60 Gamma-Rays). The suggested wavelength for spectrophotometric analysis for dosimetry is indicated by the vertical arrow.

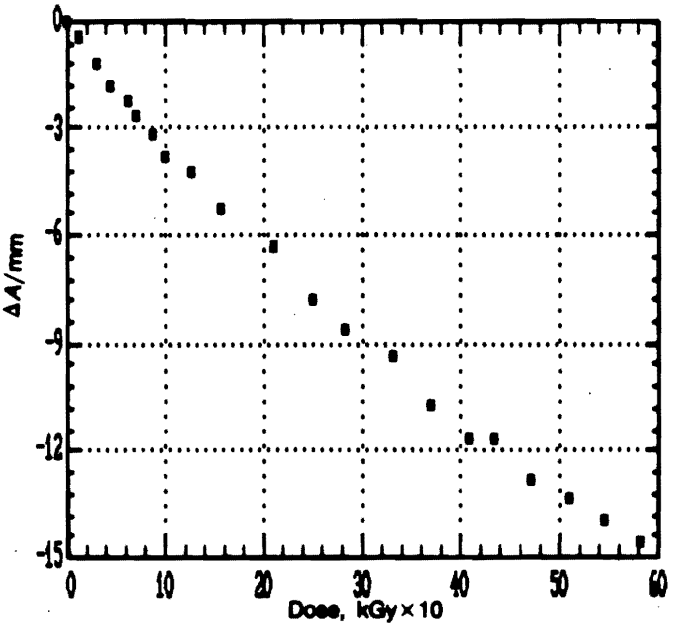


Figure 6. Decrease in Change in Absorbance, at 520 nm Wavelength, as a Function of Absorbed Dose (in Water), When Red-Tinted Plastic Film is Irradiated by Gamma-Rays.

quantity involving film thickness, the best reproducibility for the measure of film response to radiation dose (D) is to use the ratio of absorbance after irradiation (A_i) to that before irradiation (A_o) *versus* dose. The uncertainty reduced considerably from 5.5% to 0.8%. This result is shown to be in close agreement with that previously reported for green plastic films manufactured by the same company [14].

The technique used in this paper provides a simple method for reducing the nominal thickness error, by a factor of six, in addition to eliminating the need for thickness measurements and accounting for film-to-film dye concentration variations.

A linear regression analysis (log A_i/A_o *versus* dose) showed that all the experimental points fitted a straight line to within a correlation coefficient value of 0.999 up to a dose of 600 kGy (Figure 7). Hence, the relation between log A_i/A_o and dose can be described by the following formula:

$$D = \frac{\log A_i/A_o}{0.0050718} - 0.6293426 \qquad \text{for } D \text{ in kGy .}$$

PRE- AND POST-IRRADIATION STABILITY

One of the most important advantages the proposed film dosimeter has over many other types is its insensitivity to ambient light conditions. For example, exposure of unirradiated samples to normal laboratory light (400 Lux) over a six months period resulted in no detectable change in the film color.

Following irradiation, all films were stored at different temperatures at 40–60 percent relative humidity, and some were exposed to cycles of day light and darkness. The optical properties of the films were measured daily up to 40 days, then followed weekly up to 6 months. Figures 8–11 show the stability results in terms of radiation-induced values of ΔA/mm at 520 nm as a function of storage time. Four conditions of storage were investigated, namely: 0°C in the dark; 25°C in the dark; 25°C under white fluorescent light plus indirect day light (400 Lux); and 60°C in the dark.

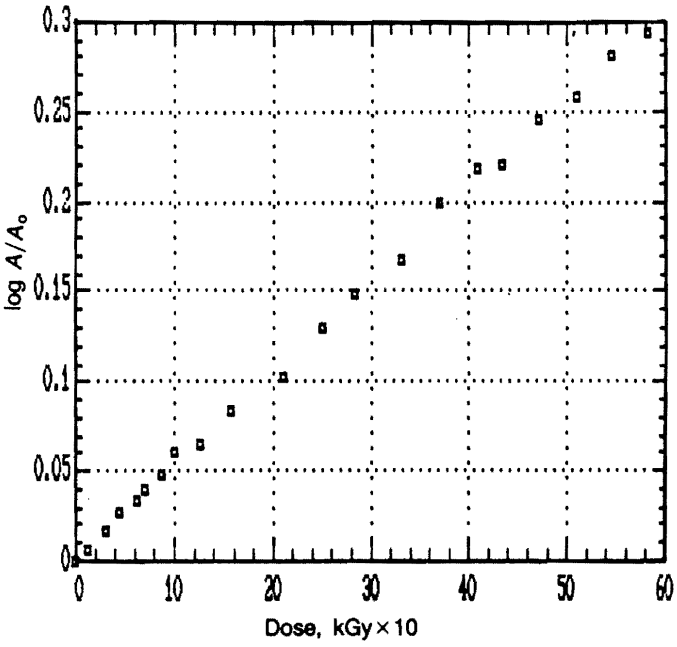


Figure 7. Calibration Curve for the Increase in log A/A_o (at 520 nm Wavelength) as a Function of Gamma Absorbed Dose.

Table 1. Percent Uncertainty (1σ) of Measurement of Red-Tinted Plastic Dosimeter at Different Doses Over the Range 12.5–582.0 kGy (4 Films at Each Dose) Calculated by Different Techniques.

Dose (kGy)	ΔA/mm	$\Delta A/A_o$	$\Delta A/A_o$/mm	$\Delta A_i/A_o$	$(A/A_o)\times$ Avr. A_o
12.5	−21.8124	−21.7385	−21.6314	0.332490	−21.7385
30	−6.56243	−5.06819	−5.62516	0.209210	−5.06819
44	−6.99555	−5.55845	−7.72399	0.363033	−5.55849
63	−17.9435	−16.6868	−15.9192	1.378157	−16.6868
70	−5.53692	−3.62880	−3.57244	0.346172	−3.62880
88	−11.0661	−10.8261	−9.54289	1.289560	−10.8261
100	−4.52075	−3.94398	−2.99800	0.595375	−3.94398
126.5	−3.44575	−2.81586	−4.76373	0.460795	−2.81586
157.5	−3.72710	−4.60958	−3.23858	0.970603	−4.60958
210	−5.80087	−3.20637	−5.55912	0.859503	−3.20637
250	−2.47847	−2.29357	−3.24239	0.793966	−2.29357
284	−3.00636	−0.98464	−4.31706	0.404825	−0.98464
284	−0.68786	−0.81074	−1.77036	0.335176	−0.81074
331	−2.52416	−1.31102	−4.81372	0.614755	−1.31102
370	−1.45960	−2.02734	−1.86463	1.174909	−2.02734
480.5	−2.18016	−1.59734	−4.64350	1.045308	−1.59734
434	−3.59433	−2.92197	−5.05869	1.929163	−2.92197
472	−2.86333	−1.28855	−3.89660	0.982234	−1.28855
510	−2.86656	−0.74229	−4.81126	0.600350	−0.74229
546	−2.54625	−1.29892	−4.91852	1.179835	−1.29892
582	−3.89364	−1.70963	−3.99223	1.650879	−1.70963
Average percent uncertainty	−5.50058	−4.52709	−5.90017	0.834109	−4.52709

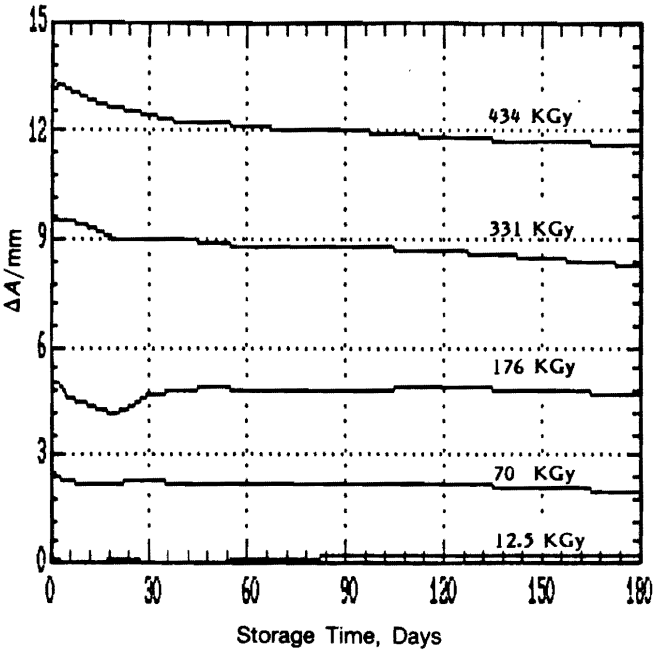


Figure 8. Change in ΔA/mm of Red-Tinted Films After Irradiation as a Function of Storage Time. (At 60°C.)

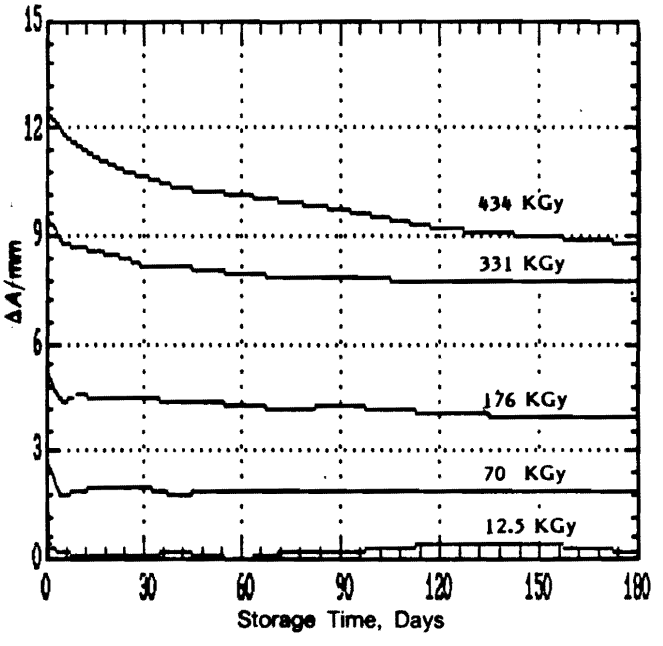


Figure 9. Change in ΔA/mm of Red-Tinted Films After Irradiation as a Function of Storage Time. (At 0°C.)

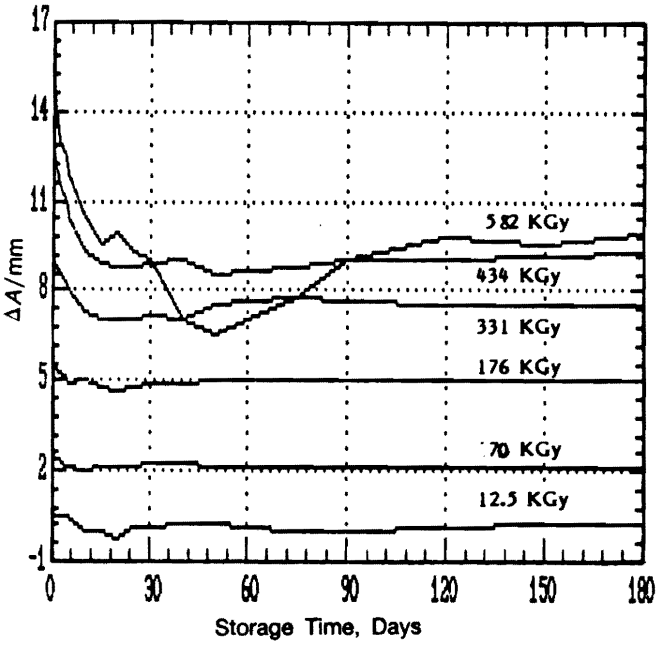


Figure 10. Change in ΔA/mm of Red-Tinted Films After Irradiation as a Function of Storage Time. (In dark, and at room temperature.)

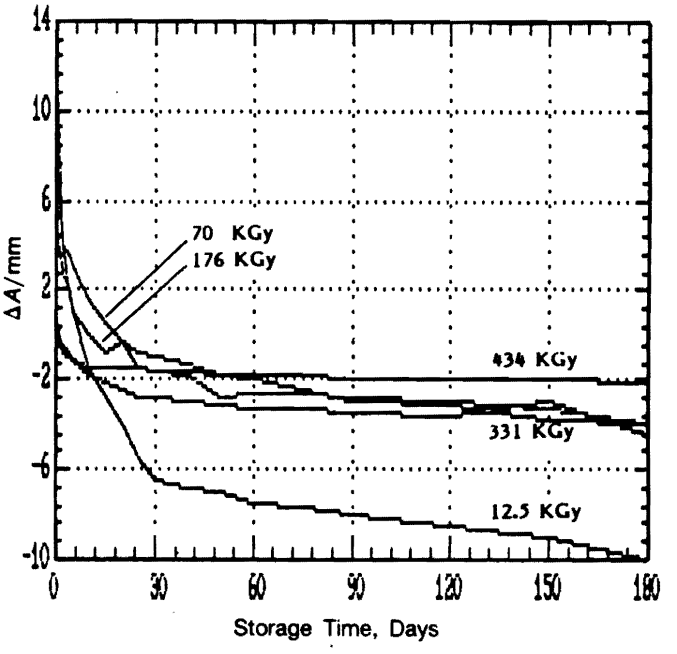


Figure 11. Change in ΔA/mm of Red-Tinted Films After Irradiation as a Function of Storage Time. (In indirect light, and at room temperature.)

The results show that for samples stored for 180 days at 0°C and at room temperature (~25°C) in the dark, the variation in response at higher doses is about 13% and 25% respectively. At low doses (<176 kGy) films stored at 0°C and room temperature in the dark show better stability. Insignificant changes have been observed when films were exposed to light during storage at low doses (<176 kGy), while at high doses irregular changes have been observed (>176 kGy). On storage at 60°C, the films showed a great deal of instability even for low doses. These results indicate that the film dosimeter should not be stored or irradiated at temperatures near 60°C or above.

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