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# EFFECTS OF GAMMA-IRRADIATION ON THE DYEABILITY, WASH FASTNESS AND STAINING OF IRAQI COTTON FABRICS

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**Abstract**

The effects of $^{60}Co$ source of gamma – irradiation (0.1-1140) kGy on the dyeability, wash fastness and staining of Iraqi cotton fabrics were investigated for the first time, according to our knowledge, in an attempt to improve some characteristics of these fabrics that are used in the General Establishment for Cotton Industries. Color measurement was successfully applied as a tool in a study of the change versus dose, of dye uptake and wash fastness of cotton fabrics. At low doses it was found that the dye uptake initially decreased then increased with increasing dose, after that it increased steadily then rapidly with increasing dose. Staining and wash fastness of cotton fabrics dyed pre or post irradiation were also examined. A computer program was used to estimate changes in the color of the irradiated cotton fabrics as a result of dyeing, washing and staining. The results showed that a dose of 10 kGy favored optimum stain resistance and wash fastness properties for cotton fabrics dyed post irradiation. The overall behavior suggested that cotton fabrics were degraded at high doses (786-1140) kGy, while at low doses, the crosslinking between chains was the predominated process.

**الخلاصة**

تمت في هذا البحث دراسة تأثير أشعة جاما المنبعثة من الكوبالت 60 على أنسجة القطن العراقي من حيث استجابتها للاصباغ وثباتية الصبغة ضد الغسل ومقاومتها للاصطباغ لمدى واسع من الجرع ولحد 1140 كيلو گري ولاول مرة حسب علمنا بغية تحسين بعض خصائص الانسجة القطنية التي تستخدم في المنشأة العامة للصناعات القطنية. استخدم المطياف الضوئي كوسيلة لدراسة الاستجابة للاصباغ وثباتية الصبغة مع تغيير الجرع. عند الجرع القليلة لوحظ أن الاستجابة للاصباغ تقل ثم تزيد مع زيادة الجرع. و عند الجرع المتوسطة تتزايد هذه الخاصية ببطء مع زيادة الجرع ولكنها تزيد باطراد عند الجرع العالية. كذلك تمت دراسة قابلية الاصطباغ وثباتية الصبغة ضد الغسل للانسجة المصبوغة قبل وبعد التشعيع. استخدم لهذا الغرض برنامج حاسوبي بغية تعيين مقدار التغير الحاصل في لون الانسجة المشععة عند صباغتها وغسل المصبوغ منها وقابلية اصطباغ الانسجة غير المصبوغة عند غسلها مع أخرى مصبوغة.

أوضحت الدراسة أن الجرعة 10كيلو گري تزيد من مقاومة الانسجة للاصطباغ وثباتية الصبغة ضد الغسل في حالة الانسجة المصبوغة بعد التشعيع . دل سلوك الخواص المذكورة أعلاه ان الترابطات العرضية هي المتغلبة في الجرع القليلة بينما في الجرع العالية (786-1140) كيلوگري فان عمليات التحطم هي المتغلبة.

## Introduction

The application of ionizing radiation in research industry has occupied a great importance in composites whose properties and structure change largely against small change in their molecules, such as polymers. The basic aim of researches about irradiation of different textiles is to improve their properties, where the radioactive source is available and has long half-life, moreover, the radiation doesn't cause neither shrinkage nor wrinkle, while its effects will not disappear in washing, therefore, its use is better than chemical reagents. The distinct effects which were found in irradiated polymers have encouraged researchers to improve textile properties by irradiation.

Previous studies concerning effects of gamma radiation on cotton textiles have been reviewed by Rutherford [1] and Mahmood [2], including the effects on the mechanical properties [3], alkali solubility [4], and electrical conductivity [5]. Shakra et al. [6] have studied the effect of gamma ray on the wash fastness of Egyptian cotton fabrics (using 6 kinds of direct dye differing in color and chemical structure), their results showed that dyeing of irradiated cotton fabrics exhibited increased wash fastness ,though irradiation decreased the dye uptake.

The aim of the present work is to study the effect of gamma irradiation on the dyeability, wash fastness, and staining of Iraqi cotton fabrics dyed pre or post irradiation, because dyeing process occupies a unique place among the textile industrial stages and it has become valuable to industry. Dye of weak wash fastness was chosen to investigate the effect of gamma ray on color fastness and to determine the dose that gives favorite optimum values.

## Experimental

### 1. Materials

Cotton fabrics were obtained from the General Establishment for Cotton Industries in Baghdad, some cotton samples were dyed post irradiation, others dyed pre irradiation. The dyestuff used was Solar Nawy Blue 6BL - 240%, this dye is a direct dye with weak wash fastness. Standard dyeing process was carried out as that being followed in the Establishment and according to ASTM (American Society for Testing and Materials) [7].

### 2. Irradiation

Irradiation was carried out in Canadian Gamma-Cell 220 $^{60}Co$ radiation facility located at the Agricultural and Biological Research Center / Iraqi Atomic Energy Organization - Baghdad. Cotton fabrics were irradiated in the dry state at room temperature and atmospheric pressure to different doses in the range (0.1-1140) kGy at dose rate (2.7947-2.7041) kGy/ hr, the activity of the source was in the range of $(14.13-13.7) \times 10^{13}$ Bq during the research period.

### 3. Measurements

Diffuse reflectance spectra for Iraqi cotton fabrics were measured for the first time in the wavelength range (400 -700) nm at 10 nm intervals by means of PU 7908/ 24 integrating spheriod [8] fitted to a Philips PU 8800 UV/VIS double beam spectrophotometers [9] with speed 600 nm/min .

Measurements were usually made relative to a white standard plaque consisting of a polytetraflourethylene powder thickly pressed onto a plastic substrate, the sample was mounted on a flat black base. Before each measurement, the zero base line (approximately 0.3%R) and the 100% R line were recorded using standard black plaque and standard white one placed in the sample position respectively.

The output data comprising the reflectance (R %) versus wavelength were fed into an electric computer and were analyzed by using a computer program written in BASIC language performed by Mahmood [10]. The testing and assessment of wash fastness of cotton fabrics (dyed post or pre irradiation ) and the degree of staining were carried out as that being followed in the General Establishment for Cotton Industries and according to the recommendation of ISO (International Organization for Standardization) [11] standard method .

## Results and Discussion

### 1. Diffuse Reflectance Spectra

The spectral reflectance curves of undyed and dyed post and pre irradiation cotton samples are shown in Figs. 1-3 respectively. The undyed samples have a fairly high reflectance at all wavelengths as shown in Fig. 1, as dye is added the reflectance decreases, but certain wavelength have their reflectance decreases more than others depending on the individual dye, as shown in Figs. 2 and 3. For blue dye used in the present work, the decrease in reflectance found to occur in the yellow region, it seems that in the visible region, the dye greatly influenced the optical properties of the fiber and from these Figs. one can see the strong absorption band due to the dye.

Fig. 1 shows that the reflectance of undyed sample decreases with increasing dose especially at short wavelengths, this is due to yellowness of the irradiated fabrics which increases absorption in the blue region, yellowness may be due to chain scission at high doses that gives a new arrangement with smaller volume than that of an unirradiated sample.

Effect of gamma-ray on the reflectance of samples dyed post irradiation is shown in Fig. 2, where it decreases with increasing dose especially at long wavelengths, this insures that great change occurs in the irradiated fiber structure that increases their dyeability at high doses as will be discussed in section 3-2. In case of samples dyed before irradiation the effect found to be less and couldn't be distinguished, as shown in Fig.3. This means that the presence of dye in cotton fabrics hinders the effect of radiation on their structure and no noticeable color change has been observed, this is supported by the fact that benzene ring in the dye molecule offers a considerable degree of radiation protection to molecules of which it forms a part [12].

## 2. Dyeability

Different formulae have been suggested for dyeing strength [13], one which gives the most reliable result is the K/S value in the maximum absorption of the dye [13, 14]. The relative dyeing strength (K/S) was determined using the equation [15, 16]:

$$K/S = (K/S)d - (K/S)o = A.C \qquad (1)$$

Where (K/S)d corresponds to the dyed sample, ( K/S )o corresponds to the same sample before dyeing, C is the dye concentration, and A is a proportionality constant . K/S values were calculated at appropriate wavelength corresponding to maximum absorption in the visible spectrum of the dye (at 600 nm for the blue dye used in this work, Fig. 2).

Fig., 4 shows the variation of K/S vs. dose, where it decreases at low doses attaining a minimum value at 1 kGy, then increases sharply to nearly a constant value (15.2) in the range (97.4 - 786) kGy followed by an increase, up to 1140 kGy. So cotton fabrics dyeability decreases at low doses, while at high doses, it increases with dose, and samples irradiatiated with doses larger than 5 kGy were seen to be deeper than those unirradiated, dyed with the same amount of dye.

The significant decrease in dye accessibility at low doses may be explained as a result of increased crosslinking which leads to a decrease in the number of active groups that regarded as functional centers for the dye molecules. Crosslinking may also hinder the dye molecules from penetrating into the fibers.

The present results are in agreement with those of Shakra et al. [6], where they have observed a decrease in the dyeability of cotton fabrics irradiated with 6 and 13 kGy doses before dyeing with different kinds of direct dye. Furthermore, it has been observed by the author [2] that the dyeability of irradiated wool fibers initially decreased with dose in the range (0 -70) kGy, then it began to increase with dose at higher doses.

Another parameter that describes the relative dyeing strength is the color difference (ΔE) between the irradiated dyed samples and the unirradiated dyed one as reference, ΔE was calculated in CIELAB units according to the following equation [17, 18, 19]:

$$\Delta E = [(\Delta L)^2 + (\Delta A)^2 + (\Delta B)^2]^{1/2} \qquad (2)$$

Where

$$\left.\begin{aligned} L &= 116\,(Y/Yo)^{1/3} - 16 \quad 1 \le Y \le 100 \\ A &= 500\,[(X/Xo)^{1/3} - (Y/Yo)^{1/3}] \\ B &= 200\,[(Y/Yo)^{1/3} - (Z/Zo)^{1/3}] \end{aligned}\right\} \qquad (3)$$

And X, Y, Z are the tristimulus values of the samples, and Xo, Yo, Zo are the tristimulus values of the illuminant used (Yo = 100). Fig. 5 shows the variation of ΔE with dose, which is very similar to K/S in Fig. 4 except at low doses in the range (0 - 1) kGy.

## 3. Wash Fastness

Wash fastness of cotton fabrics is one of the most important characteristics of ready goods. Change in color of the dyed specimen is expressed as the color difference (ΔE) between the washed sample and the unwashed one [20, 21]. Decrease in ΔE values means an increase in wash fastness, as shown in Table 1, which gives the relation between ΔE and change in color [22] .

Fig. 6 shows how ΔE varies with dose for cotton fabrics dyed post irradiation (a) and pre irradiation (b). For sample dyed post irradiation (curve a) ΔE decreases from 15.321 to 4.001 at 10 kGy then begins to increase sharply, then steadly reaching a value 12.5 at 400 kGy. Increase in wash fastness at low doses is believed to be as a result of crosslinking which blockes dye molecules that have diffused in the fiber and prevents water molecules from penetrating into them, as dose increases the degradation processes overcome the crosslinking ones, therefore, the rate of water penetration increases, and as a result, a considerable amount of the dye is removed.

For samples dyed pre irradiation (curve b), improvement in wash fastness is obtained only with doses in the range (10 - 50) kGy, but it is much less than that of samples dyed post irradiation , this can be explained that irradiation has no great effect on dye molecules .

So it can be concluded that irradiation before dye treatment improves wash fastness especially at low doses, and a dose of 10 kGy gives the optimum value.

The present results are in agreement with those of earlier findings [6], where improvement in wash fastness was obtained for cotton fabrics irradiated with doses of 6 and 13 kGy pre direct dye treatment, when the dyed samples were washed with boiling water and soap. In their work, irradiation was not carried out in a wide range, so the optimum value of dose that gives the best result hasn't been reported. As a comparison, wash fastness was tested [2] for wool fibers irradiated with doses in the range(10 - 500) kGy , the best values have been obtained with doses in the range ( 10 - 40 ) kGy especially for samples irradiated after dye treatment with metal complex dye. Difference in the results obtained for cotton fabrics and wool fibers can be attributed to differences in the kind of fibers and kind of dyes used.

### 4. Staining of Cotton Fabrics

Fig. 7 shows the variation of degree of staining (expressed as ΔE between washed and unwashed samples) with dose for white (undyed) irradiated cotton fabrics adjacent to fabrics dyed post and pre irradiation with the same dose (curves a and b respectively). Decrease in ΔE values means decrease in degree of staining, as shown in Table 2 which gives the relation between ΔE and degree of staining [22]. In curve (a) ΔE decreases from 33.375 to 4.516 at 10 kGy then increases steadly with dose, as in the case of wash fastness, a decrease in staining can be obtained by irradiation especially with low doses. In curve (b) ΔE increases sharply then decreases steadily with dose, no improvement in staining is obtained in this case. These results reflect the behavior of both dyeability of white fabrics with dose (see Fig. 4) and the wash fastness of dyed fabrics with dose (see Fig. 6). From the point view of wash fastness and staining, it is desirable to irradiate cotton fabrics with 10 kGy before dye treatment. Actually there are no previous reports dealing with the effect of gamma-ray on staining of white cotton fabrics (neither Iraqi nor others), but similar results have been obtained for wool fibres [2], where staining of white samples increased at high doses and decreased at low doses with minimum value at 10 kGy when undyed irradiated wool fibres washed adjacent to ones dyed pre irradiation.

## Conclusion

Our conclusion from the obtained results is as follows:

1. Dyeability indicates which process is dominated (crosslinking or chain scission) as a result of gamma irradiation.
2. Deeper colors (increased dye concentration) can be obtained by irradiation with doses in the range (40-780) kGy or more, which is economically justified, where one can decrease the amount of the dye used and obtain the desired concentration by irradiation, without adversely affecting other properties.
3. At low doses, an improvement in wash fastness was obtained for cotton fabrics dyed (with weak wash fastness dye) post irradiation, this reflects an economic benefit in cotton industry, also, in this range, the staining of white fabrics decreased, those results have positive effects when washing undyed fabrics with dyed ones, or washing cotton clothes that contain yarns of more than one color, so the dye does not bleed from some yarns to the others, while the white yarns will not stain.
4. From the point view of wash fastness and staining, one can conclude that it is desireable to irradiate cotton fabrics with 10 kGy before dye treatment, so irradiation with this dose can be considered as the optimum condition that gives better properties to the cotton fabrics such as those mentioned above.
5. These findings may oblige to recommend the introduction of continous irradiation in

textile technology, and may open a new horizon in radiation processing of fiber technology. Knowing that gamma-ray with energy less than 10 MeV dose not cause nuclear radiation with matter and dose not produce radiation source inside the irradiated material

6. The present work gives a number of encouraging results, it can be regarded as the starting step for extensive research on Iraqi cotton aiming for the improvement of its properties.

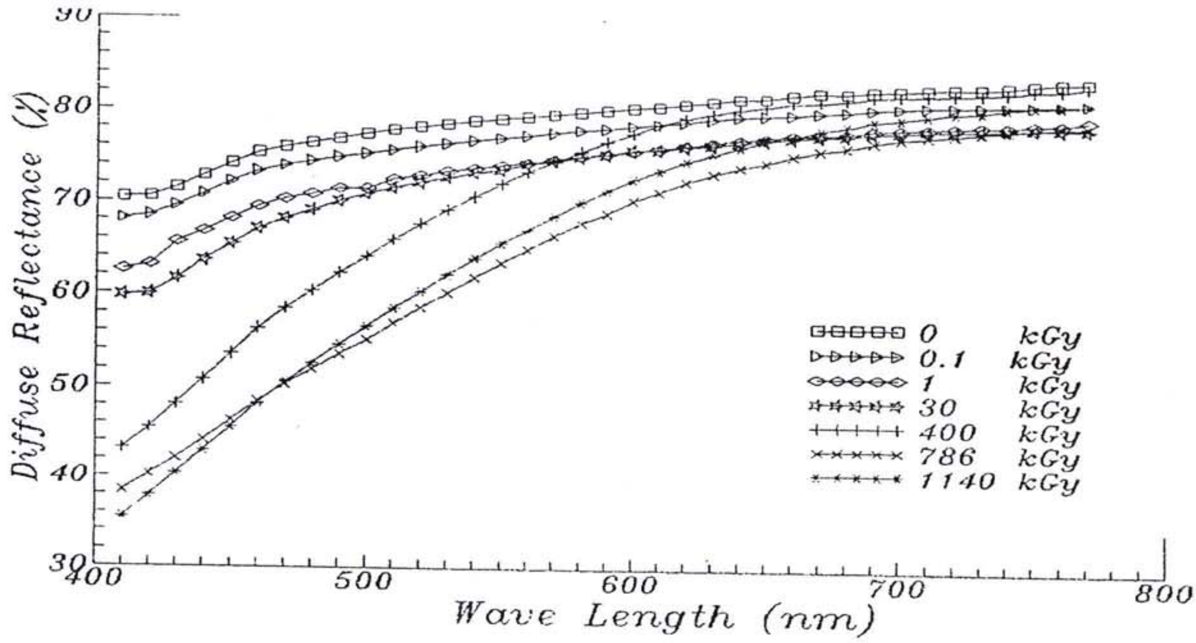


**Figure (1): Spectral reflectance curves of undyed cotton fabrics**

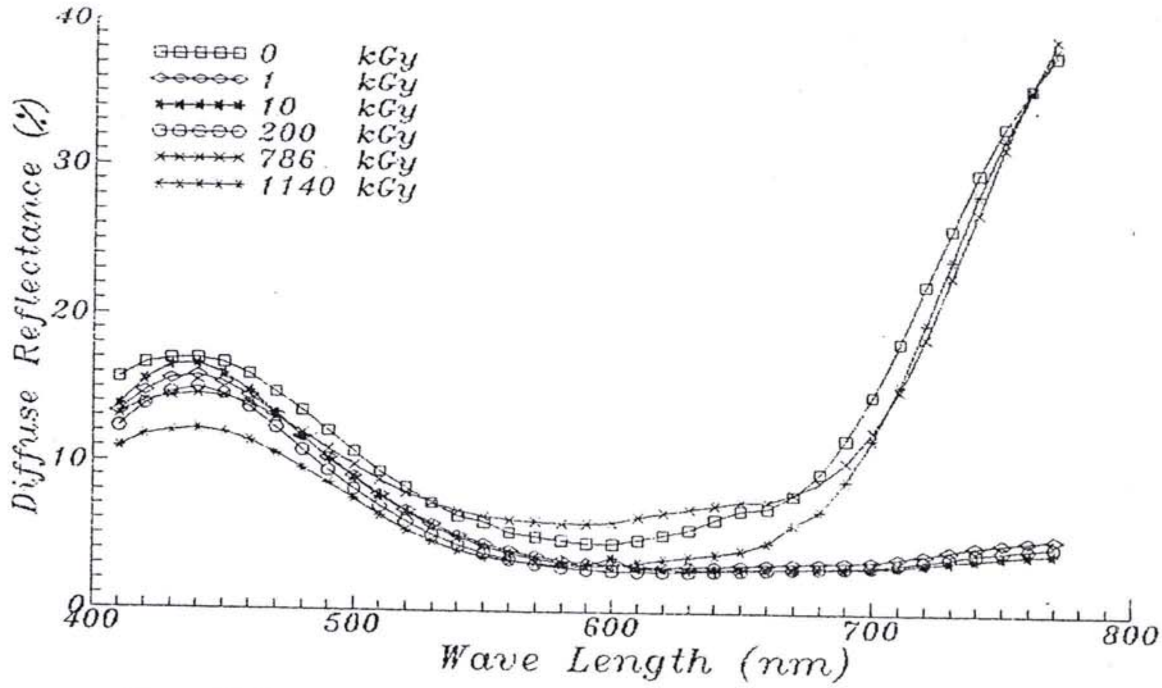


**Figure (2): Spectral reflectance curves of cotton fabrics dyed post irradiation with different doses of gamma rays**

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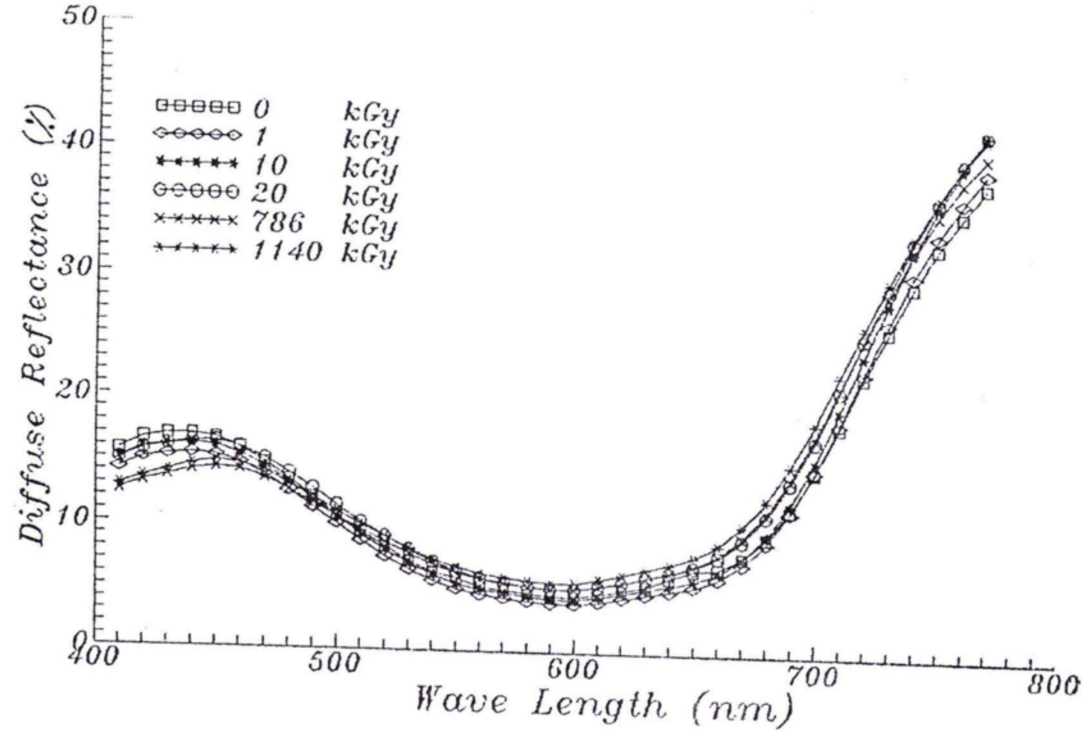


**Figure (3): Spectral reflectance curves of cotton fabrics dyed pre irradiation with different doses of gamma rays.**

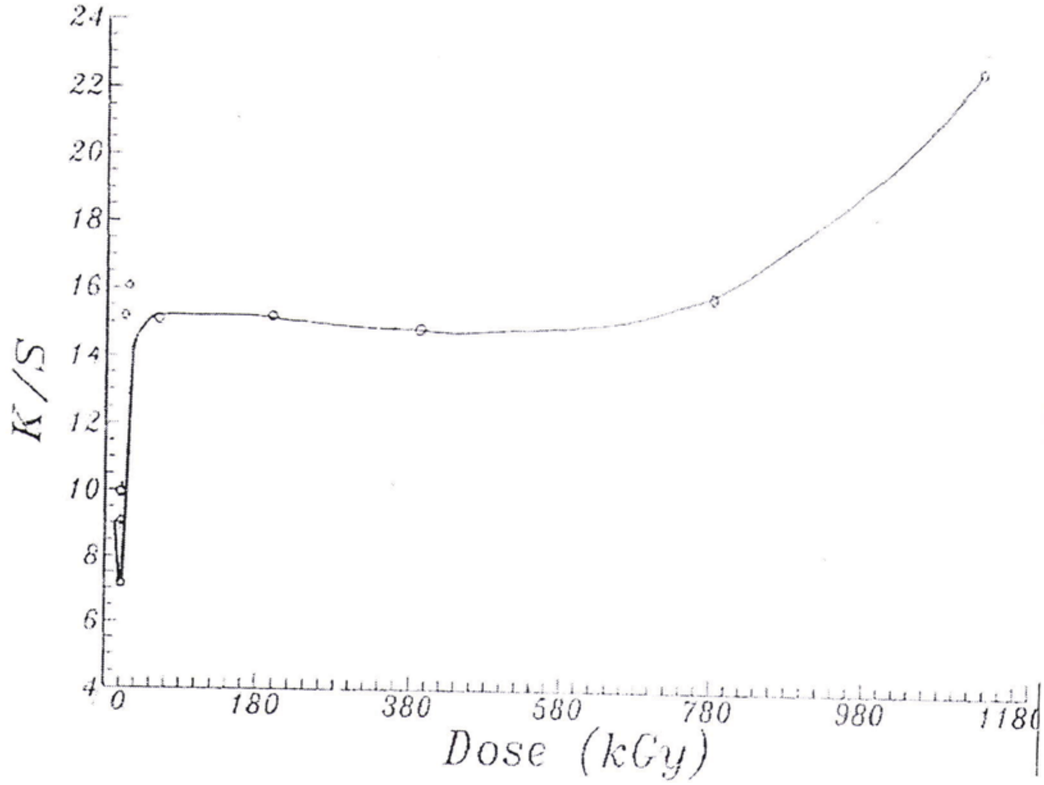


**Figure (4): Variation of color strength K/S with dose, for cotton fabrics dyed post irradiation.**

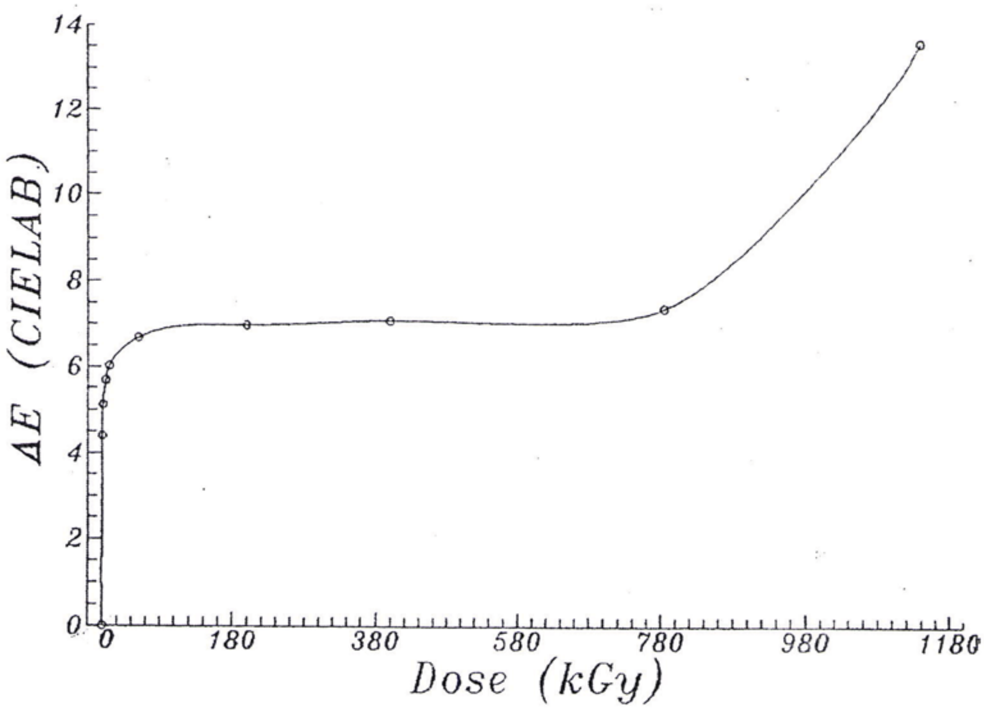


**Figure (5): Variation of color difference (ΔE) with dose, for cotton fabrics dyed post irradiation.**

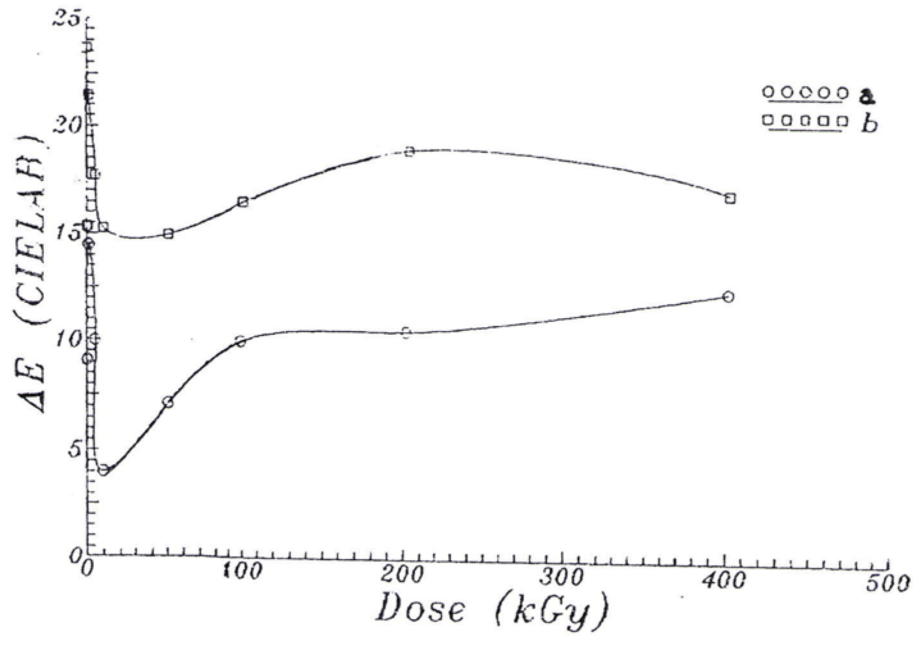


**Figure (6): Variation of color difference (ΔE) with dose, for washed cotton fabrics dyed**
**a) Post irradiation b) Pre irradiation**

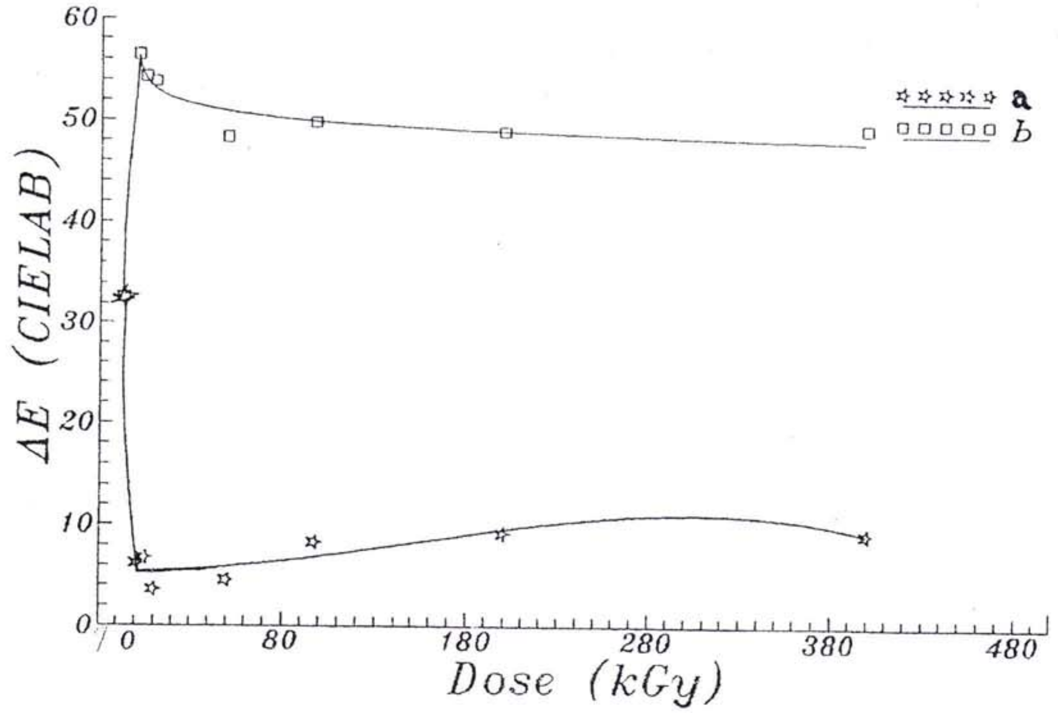


**Figure (7): Variation of staining with dose of undyed irradiated cotton fabrics washed adjacent to fabrics dyed**
**a) Post irradiation b) Pre irradiation**

**Table (1): Relation between ΔE and color change**

| ΔE | Possible Color Change |
|---|---|
| 0.0 ± 0.2 | No change |
| 1.7 ± 0.2 | Little decrease |
| 3.4 ± 0.3 | Decrease or change possibly recognized |
| 6.8 ± 0.6 | Distinct decrease or change |
| 13.6 ± 1.0 | Vast decrease or change |

**Table (2): Relation between ΔE and staining**

| ΔE | Degree of Staining |
|---|---|
| 0.0 ± 0.2 | No staining |
| 4.0 ± 0.3 | Little staining |
| 8.5 ± 0.5 | Possible recognized staining |
| 16.9 ± 1.0 | Deep staining |
| 34.1 ± 2.0 | Vast staining |

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