Pergamon

Radiat. Phys. Chem. Vol. 43, No. 6, pp. 569–572, 1994

0969-806X/94 \$6.00 + 0.00

EFFECTS OF TEMPERATURE AND HUMIDITY DURING IRRADIATION ON THE RESPONSE OF RADIACHROMIC FILM DOSIMETERS

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(Received 24 February 1993; accepted 26 May 1993)

Abstract—The effects of temperature and humidity during γ irradiation on the response of two types of film dosimeters (Far West radiachromic and GafChromic films) were studied in the dose range of 0.3–3 kGy. Both films show a significant effect of temperature and humidity and a simple correction function is proposed. This correction is usually between 5 and 10% for the range studied.

For the GafChromic film, a colour change at temperatures above 50°C was observed and, consequently, this system cannot be used at these temperatures. At lower temperatures down to −70°C the sensitivity of both films is reduced and a simple correction is possible. In this study and for the dose ranges used, only a slight dependence on humidity was observed for both films from 0 to 60% r.h. Whereas the GafChromic film at humidities up to 90% r.h. shows only a moderate effect, the Far West film shows a considerable inconsistency for the dose range studied. A simple correction function may be applied for humidity effects, except for the Far West film above 60% r.h. where the effect of humidity is also dose dependent.

INTRODUCTION

Criteria for dose meter selection (Chadwick *et al.*, 1977) include independence on environmental factors as temperature and humidity. Thin plastic films with a radiation sensitive substance incorporated are very suitable for many needs in radiation dosimetry including dose mapping. Such material is easy to handle, yet reliable under conditions of routine applications. It was previously not available in the dose range of food irradiation, i.e. below 10 kGy. A new system, the GafChromic Dosimeter Media became available recently and information on effects of temperature and humidity were lacking.

Usually, dose meters are calibrated under "normal" conditions, i.e. at temperature 22–25°C and humidity 45–50% r.h. It is always assumed that the dose meter is at equilibrium with the environment. In food irradiation and other applications, higher and lower temperatures may prevail. For example, some microorganisms are more sensitive when irradiated at higher temperatures, or deep freezing temperatures are utilized in order to prevent off-flavours in sensitive materials. Many food items are high in water content and a dose meter in contact with the food may absorb humidity. Also during storage of dose meters—before use under ambient conditions—the humidity of the air may be extremely high or low, and dose meter cannot get into equilibrium with the food in contact. In general, it can be assumed that dose meter films are always at equilibrium with the temperature of the goods during the irradiation process; however, equilibrium for humidity will not be achieved due to the slow diffusion of water in such plastic films. In any case, detailed information about the effects of humidity and temperature on the dose meter response is indispensable.

Far West radiachromic film was used for reference with the published data (Levine *et al.*, 1979; Chappas, 1981; McLaughlin *et al.*, 1991; Humpherys *et al.*, 1990). It is a commonly used material for routine dosimetry in radiation processing for sterilization and other high-dose applications.

The GafChromic film has a higher response than the Far West film and is more suitable in the lower dose ranges used in food irradiation. This film became available only recently and the purpose of this study was to provide data on the effects of temperature and humidity on the radiation response of this film.

EXPERIMENTAL

Irradiation

A small Co-60 γ source at a dose rate of about 0.5 kGy/h was used; the dose values were 0.3, 1 and 3 kGy. The films, usually 3–5 per set, were packed in

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small envelopes and the covering plastic film was heat sealed. These sets were kept at reproducible positions during irradiation thus the resulting inaccuracy of the treatment dose was within the expected reproducibility of the films of less than 5%.

Temperature

A double-wall glass container fitting the γ source was used to control the temperature during irradiation. From a thermostat bath, water at 0, 25, 40, 60 and 80°C or ethanol for 0, −20 and −40°C was used as the transfer medium. Addition of dry ice or liquid nitrogen into the thermostat bath was used to support the cooling functions. It was assumed that the presence of the different media would not significantly affect the dose distribution and dose rate at the center of the glass container where the film packets were held in air. For −70°C instead of the container, a beaker filled with a mixture of ethanol and dry ice was used, the film packets were held in the center within a small plastic container. Before irradiation, the setup was always kept for 30 min to allow for temperature equilibrium; no temperature increase was observed during irradiation. Before readout, the samples were stored until the next day at ambient temperature.

Humidity

The humidity of the films was controlled by exposure to known humidities at ambient temperature (22–25°C) in a sealed chamber for 1 week. The humidity adjustment was through silica gel or the saturated solution in water of potassium acetate, magnesium chloride, sodium bromide, strontium chloride, sodium chloride, potassium chloride and barium chloride, the measured equilibrium values were 0, 5, 12, 45, 60, 65, 80 and 90% of relative humidity (r.h.) respectively. The dose meter sets were sealed upon withdrawal from the humidity chamber and opened only immediately before measurement. Before readout, the sealed samples were stored until the next day at ambient temperature.

Optical density

A spectrophotometer was used for readout of optical densities at the wavelengths suitable for the dose range of interest (510 and 605 nm for GafChromic and Far West, respectively). The spectrophotometer was checked for wavelength and absorbance setting (Chadwick *et al.*, 1977). No correction for thickness variations was applied to Far West readings as measured thickness varied only insignificantly; for GafChromic, the measurement of the sensitive layer between other shielding and film supporting materials was not possible.

RESULTS AND DISCUSSION

The observed effects of temperature for the response of the Far West films are in good agreement

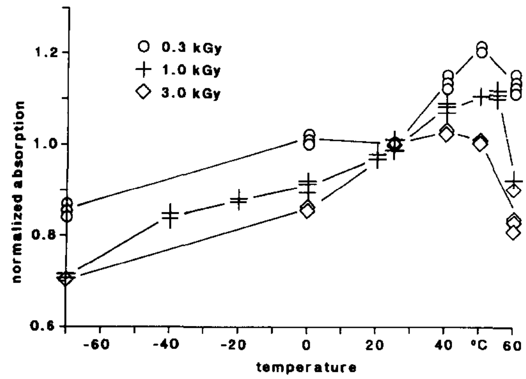

Fig. 1. Temperature effect on the response of the GafChromic dosimetry film; readings at 510 nm, normalized for 25°C at three dose levels.

with published data (McLaughlin *et al.*, 1991); it is essentially an increase with temperature up to 50°C. Similar trends but more pronounced were observed for the GafChromic film (Fig. 1). There was also a slight simultaneous dependence observed on the dose applied. The change of the chemical reaction in the GafChromic film is seen by the drop of the response at about 50–60°C when also the change of colour from blue to red becomes visibly perceptible. This effect was similar also for the other measuring wave lengths 405 and 510 nm recommended by the manufacturer.

The observed effects of relative humidity for the response of the Far West film are in general agreement with the published data (Humpherys *et al.*, 1990); the reason that in our measurement a tendency of reduced response with increased r.h. was observed might be the lower dose ranges applied. In general, from our measurements the effect is small between 0 and 65% r.h. At higher r.h. an increase in response is also dependent on dose level and measuring wavelength which was not yet reported in the literature. The GafChromic films show only marginal influences of r.h. on the response (Fig. 2) over the

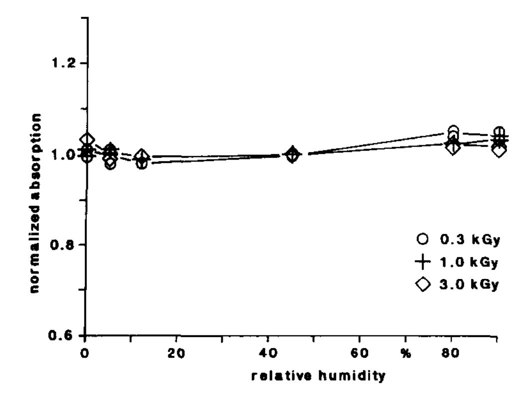

Fig. 2. Humidity effect on the response of the GafChromic dosimetry film; readings at 510 nm, normalized for 45% relative humidity at three dose levels.

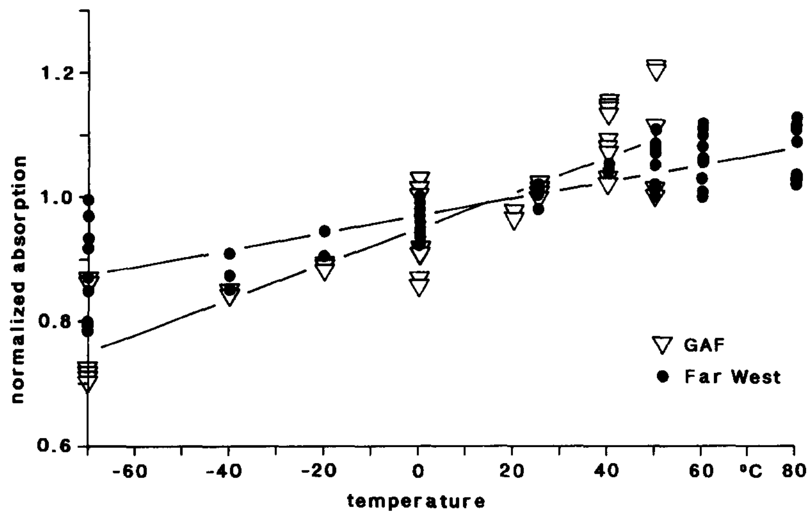

Fig. 3. Comparison of the effect of temperature on the response of Far West and GafChromic dosimetry films: data pooled for the dose range 0.3–3. 0 kGy, readings at 605 and 510 nm, respectively, normalized for 25°C (straight lines from linear regression).

full range of r.h., for this reason additional measurements at several intermediate r.h. values were not made. The observed low sensitivity of GafChromic is in agreement with the claims of the manufacturer.

Comparing both films studied in the dose range below 5 kGy, it is obvious that the effect of temperature and humidity is dose dependent. However, the Far West film is at the lower borderline of its sensitivity and the effect, in consequence, covered by the inherent increased variation of the readings. Linear regression may be used to obtain an easy way to apply correction function. The correction for temperature (Fig. 3) are within 10% of the reading from 0 up to 50°C and for most purposes within the range of accuracy. Below freezing, the behaviour of the Far West film is obviously linear, for the GafChromic shows significant deviation from the straight line. As a consequence, this new film at temperatures below freezing should be applied

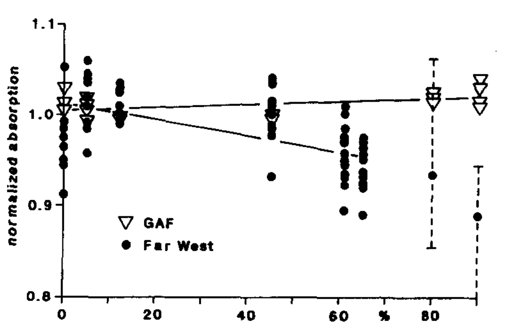

Fig. 4. Comparison of the effect of humidity on the response of Far West and GafChromic dosimetry films: data pooled for the dose range 0.3–3.0 kGy, readings at 510 nm, normalized for 45% r.h. (straight lines from linear regression).

with careful correction for temperature only. The linear regression lines (Fig. 3) show that a simple correction function could be applied with regard to the overall accuracy of the measurements.

The humidity effects for both films are less pronounced; in the dose range up to 3 kGy, the Far West film shows a slight decrease in response, the GafChromic a slight increase. The linear regression applied is within the variation of the measurements, however, because of the increased scatter in the data above 65% r.h. linear regression is not suitable for the Far West film above 65% r.h. (Fig. 4).

In conclusion, the reported study shows that the influence of the extremes of temperature and humidity on the response of dosimetry films might be very significant, up to 30% change of the reading. This effect not only has a considerable variation between makes and batches of films, but at different dose ranges even for the same film, may also cause an unforeseen variation of the response. Careful control of the environmental conditions during the use of such films and a suitable correction are indispensable. However, with regard to the overall variability of the film response to radiation a simple linear correction for temperature and humidity effects may be applied as indicated in Figs 3 and 4. Furthermore, under most practical situations the influence of film humidity can completely be excluded by conditioning the film before use and applying it in a hermetically sealed shield.

Acknowledgements—One of us (T. Ningnoi) is grateful to IAEA for the grant of a fellowship and wishes to thank Professor W. E. L. Spieß, for accepting her to participate in the work of the Institute of Food Engineering. The technical cooperation of Mr M. Knörr during the experiments is gratefully mentioned.

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