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The Influence of Temperature and Humidity on the Stability of the Response of Different Thermoluminescent Detectors

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Fading results are presented for thermoluminescent detectors for temperatures of 20, 35 and 50°C and for relative humidities of 50 and 90% during storage periods of up to 30 days. The thermoluminescent detectors investigated were LiF:Mg,Ti(TLD-100 and TLD-700), CaF_2:Dy(TLD-200) and $Li_2B_4O_7$:Mn,Si. These detectors are very commonly used in personnel monitoring.

1. Introduction

With the ever increasing use of nuclear energy, particularly for power production, there is more and more need for radiation detection and dose assessment for a variety of purposes. One of these is personnel absorbed dose determination. This type of measurement is essential for ensuring the radiological safety of individual radiation workers. Additionally it may have great importance in legal aspects of nuclear energy.

Many radiation detectors and measuring devices have been developed over the last few decades and some are being used routinely for personnel dose control. One of them is the thermoluminescent (TL) solid state detector. This detector emits light when heated after exposure to radiation. It is widely used to determine the dose in personnel and environmental monitoring for radiation protection purposes, for instance in the field of nuclear power production, medicine and research. Loss of information during application (fading) is a limiting factor for a long-term application, especially where temperature and humidity conditions are changing significantly during the accumulation period.

The band model is used to explain some phenomena of thermoluminescence. During exposure to ionizing radiation, electrons or holes are filled in discrete local energy levels in the forbidden region between the valence and conduction band, the so-called traps. The release of electrons, or holes, and consequent recombination is a statistical phenomenon, the probability of which is a function of temperature. But even the number of traps created can be influenced by temperature treatment of thermoluminescent material. Hence, temperature is normally responsible for the fading, but other factors such as humidity can also influence the loss of latent information in the TL material, especially if the material shows hygroscopic properties. In thermal fading, the shallow traps fade more rapidly than deep ones due to a larger transition probability. In order to avoid fading, the shallow traps can be emptied intentionally by a post-irradiation heat treatment, which will, when applicable, increase the stability of the latent information, even over very long periods.

In the past, different authors investigated the fading of various TL materials.[1-13] However, for practical use, some of these results are not applicable in routine monitoring because:

—In some cases, the materials were studied in powder form. In general in this form, the detectors exhibit a higher fading. There are also practical reasons for this form of material not being of interest in routine monitoring.
—Reported fading results are often too high for practical application because appropriate post-irradiation annealing treatment has not been applied.
—In most experiments the materials were stored for only some days at a unique specific temperature.

In this work the influence of temperature and humidity on the stability of the response of LiF:Mg,Ti, CaF_2:Dy and $Li_2B_4O_7$:Mn,Si thermoluminescent detectors was investigated. The detectors were stored under different conditions of temperature and relative humidity for periods of up to one month, which is

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a period of time normally employed in individual monitoring. Two kinds of experiments were carried out; namely, the materials were irradiated after and before the storage period.

2. Experimental Procedures

The fading characteristics were investigated on four commercially available TL detectors, namely, LiF:Mg,Ti(TLD-100), LiF:Mg,Ti(TLD-700), CaF_2:Dy(TLD-200) and $Li_2B_4O_7$:Mn,Si. Excepting $Li_2B_4O_7$:Mn,Si, a material manufactured by the Studsvik Energiteknik AB Company, Sweden, the other three dosimeters are produced by the Harshaw Chemical Company, U.S.A. During the experiment, the dosimeters were submitted to temperature and relative humidity conditions of 20°C and 50%, 20°C and 90%, 35°C and 50%, 50°C and 50% and 50°C and 90%. The samples were stored under these conditions for periods varying from 1 day to 30 days. In order to obtain the relative humidities of interest, the detectors were stored inside glass jars containing different saturated salt solutions. The TL response was studied as a function of the storage period for dosimeters irradiated at different times before and after storage. The evaluation of the dosimeters was performed in a Toledo 654 TL reader, U.S.A., coupled to a microcomputer Hewlett Packard 9835 A, U.S.A., provided with a printing press. In order to avoid non-uniformity batch problems, the TL response of each dosimeter of one type was corrected by its sensitivity factor, which can be determined by formula (1):

$$f_{s_i} = \frac{R_i}{\bar{R}} \quad (1)$$

Table 1. Annealing procedures used for the TL dosimeters investigated and the exposure values used to their irradiation

TL dosimeter	Pre-annealing treatment	Post-annealing treatment	Exposure (C/kg)
TLD-100	400°C/1h + 100°C/3h	100°C/20 min	6.45×10^{-4}
TLD-700	400°C/1h + 100°C/3h	100°C/20 min	6.45×10^{-4}
TLD-200 (A)	400°C/1h + 100°C/3h	100°C/1h	1.29×10^{-4}
TLD-200 (B)	400°C/1h + 100°C/3h	100°C/20 min	1.29×10^{-4}
$Li_2B_4O_7$:Mn,Si	300°C/1h	100°C/20 min	6.45×10^{-4}

where f_{s_i} is the sensitivity factor of the ith dosimeter of the batch, R_i is its response and $\bar{R}$ is the batch mean response.

The annealing procedures used for each type of dosimeter are presented in Table 1, where the exposures given are also shown. In the case of TLD-200, two kinds of post-irradiation annealings were used, namely, 100°C for 1 h and 100°C for 20 min. The dosimeters post-annealed at 100°C for 1 h are identified as TLD-200 (A), and the others as TLD-200 (B). Taking into account the exposures received by all dosimeters, the reproducibility of their responses can be considered better than 3%.[14, 15] After the end of each experiment all TL dosimeters from one set, stored at different climate conditions, were measured together, after the corresponding post-irradiation annealing.

3. Results and Discussions

The fading curves of the thermoluminescent dosimeters investigated, for irradiations after and before the storage period, under different temperature and relative humidity conditions, are presented in Figs 1–10. Each TL response of one type of dosimeter, for each storage period, at a considered temperature and

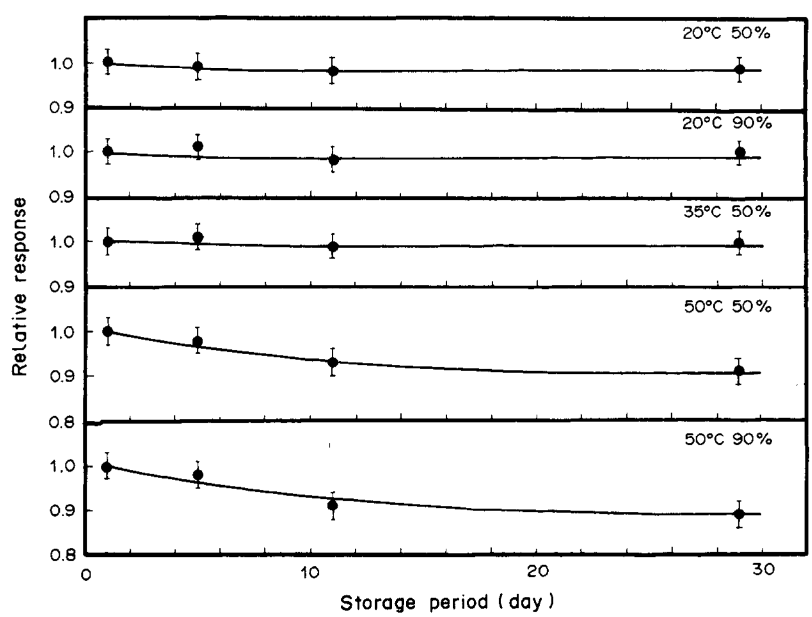

Fig. 1. TLD-100 fading curves for dosimeters irradiated after the storage period under different temperature and relative humidity conditions.

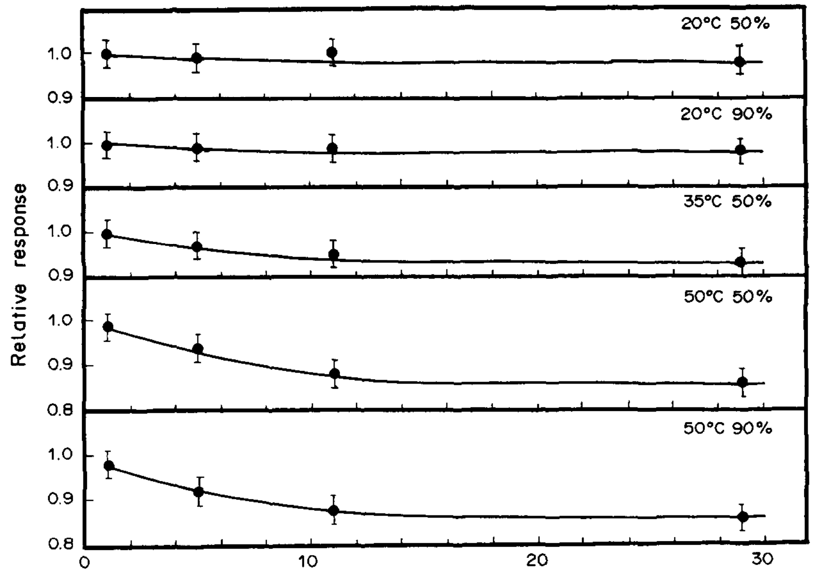

Fig. 2. TLD-100 fading curves for dosimeters irradiated before the storage period under different temperature and relative humidity conditions.

relative humidity condition, was normalised to its TL response for a period of 1 day at 20°C and a relative humidity of 50%.

LiF:Mg,Ti (TLD-100 and TLD-700)

TLD-100 fading curves for dosimeters irradiated after and before the storage period under different temperature and relative humidity conditions are, respectively, presented in Figs 1 and 2. The same kind of curves are presented in Figs 3 and 4 for TLD-700. Figure 3 is related to dosimeters irradiated after the storage period, and Fig. 4 to dosimeters irradiated before the storage period.

One can observe that these four sets of curves are very similar, considering each temperature and relative humidity condition. Additionally, the fading presented by the dosimeters irradiated after the storage period is practically the same as that exhibited by the dosimeters irradiated before the storage period. This fact was not observed for the other types of dos-

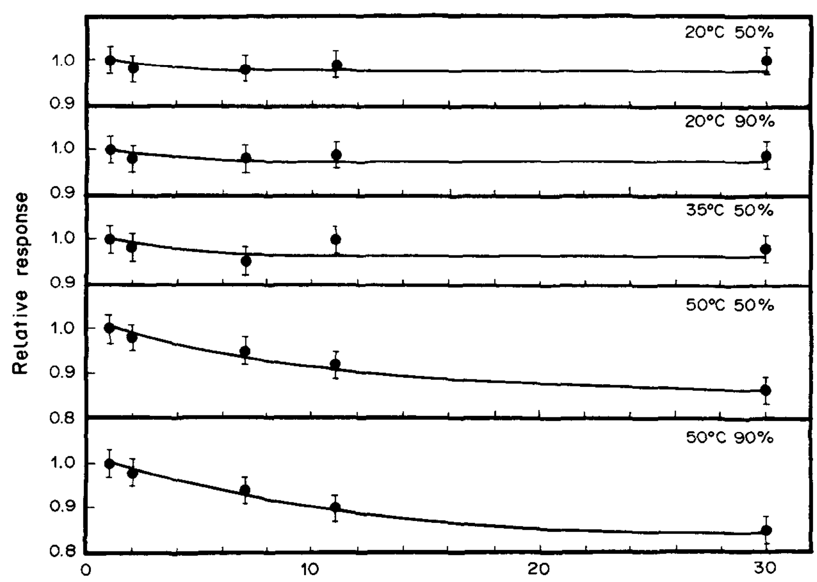

Fig. 3. TLD-700 fading curves for dosimeters irradiated after the storage period under different temperature and relative humidity conditions.

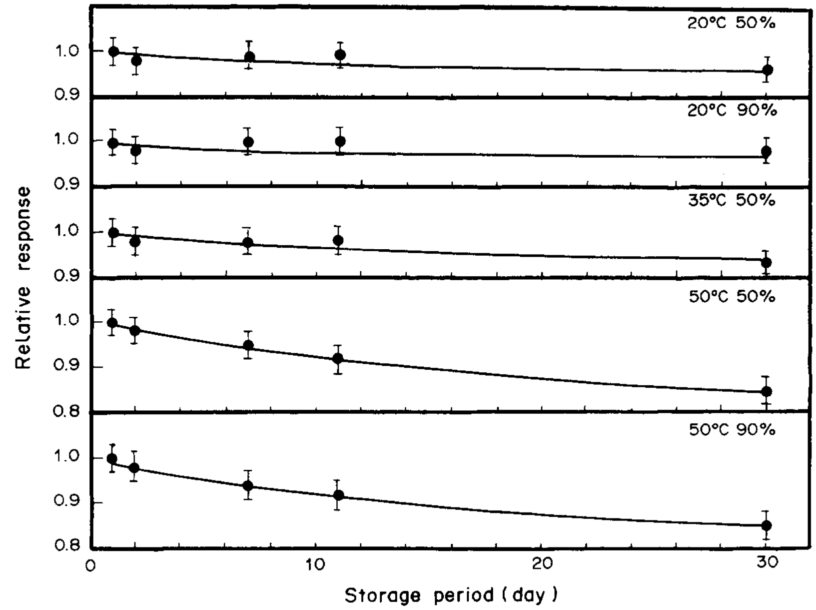

Fig. 4. TLD-700 fading curves for dosimeters irradiated before the storage period under different temperature and relative humidity conditions.

imeters investigated. This effect might be explained by the fading of the traps themselves rather than by the loss of electrons or holes from the traps. Relative humidity conditions seem to have no influence on the fading of the TL response of TLD-100 and TLD-700.

CaF_2:Dy (TLD-200)

Figures 5 and 6 present the fading curves for TLD-200 post-annealed at 100°C for 1 h, respectively, for dosimeters irradiated after and before the storage period under different temperature and relative humidity conditions. Figures 7 and 8 present the fading curves for the same dosimeter post-annealed at 100°C for 20 min, respectively, for samples irradiated after and before the storage period under different temperature and relative humidity conditions. It can be observed that the loss of sensitivity for dosimeters post-annealed at 100°C for 1 h is lower. The samples post-annealed at 100°C for 20 min present a fading higher than presented by TLD-100 and TLD-700. TLD-200 fading seems to be independent on the relative humidity conditions.

$Li_2B_4O_7$:Mn,Si

$Li_2B_4O_7$:Mn,Si fading curves for dosimeters irradiated after and before the storage period under differ-

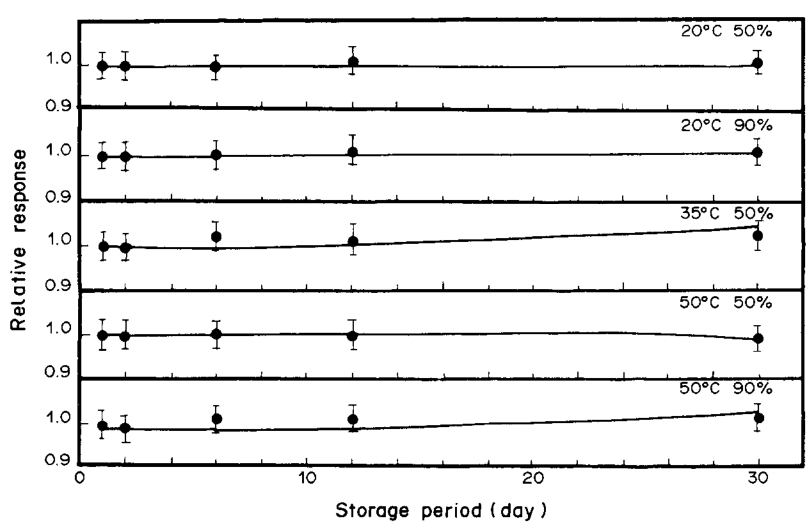

Fig. 5. TLD-200(A) fading curves for dosimeters irradiated after the storage period under different temperature and relative humidity conditions.

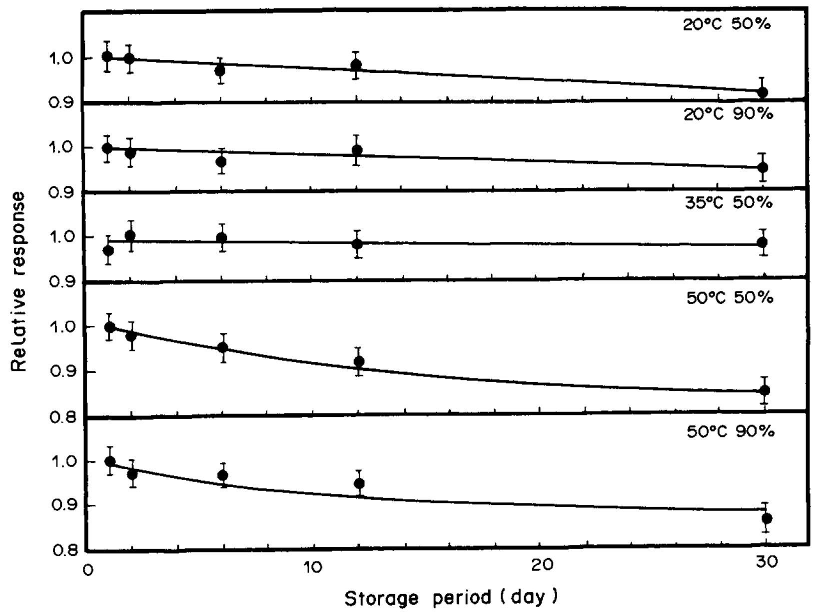

Fig. 6. TLD-200(A) fading curves for dosimeters irradiated before the storage period under different temperature and relative humidity conditions.

ent temperature and relative humidity conditions are, respectively, presented in Figs 9 and 10. If these curves are compared with LiF:Mg,Ti fading curves, it can be observed that relative humidity conditions seem to influence the TL response of $Li_2B_4O_7$:Mn,Si at temperatures above 35°C. However, $Li_2B_4O_7$:Mn,Si dosimeters irradiated after the storage period do not present a significant fading.

4. Conclusions

TLD-100 and TLD-700 fading curves are independent of the fact that the dosimeters are irradiated after or before the storage period. This behaviour can be useful for controlling the fading presented by these dosimeters when they are used in individual monitoring. If some TLD-100 or TLD-700 dosimeters are left in the laboratory under the same environmental conditions experienced by the individual monitoring dosimeters, it does not matter when irradiated, it is possible to determine the correction factors to be applied to the monitoring dosimeters in order to correct their TL responses due to the influence of fading. To a first approximation, fading correction factors may also be applied to the other detector types providing there is not a short term exposure just

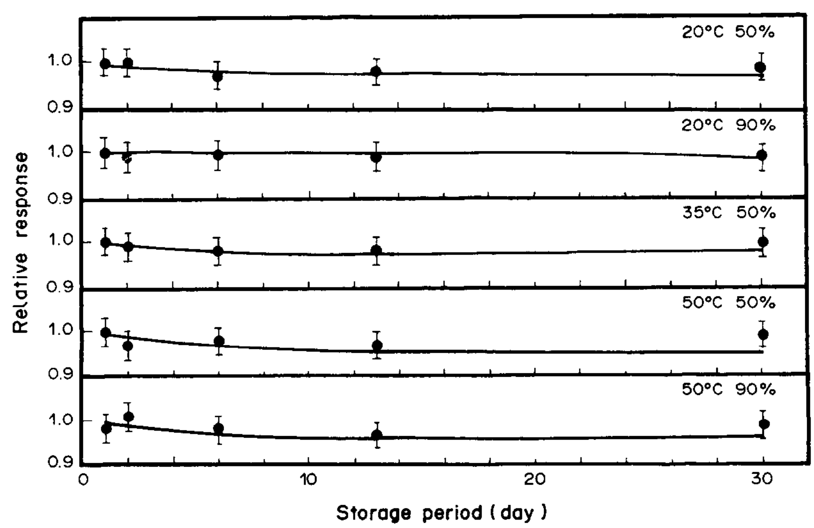

Fig. 7. TLD-200(B) fading curves for dosimeters irradiated after the storage period under different temperature and relative humidity conditions.

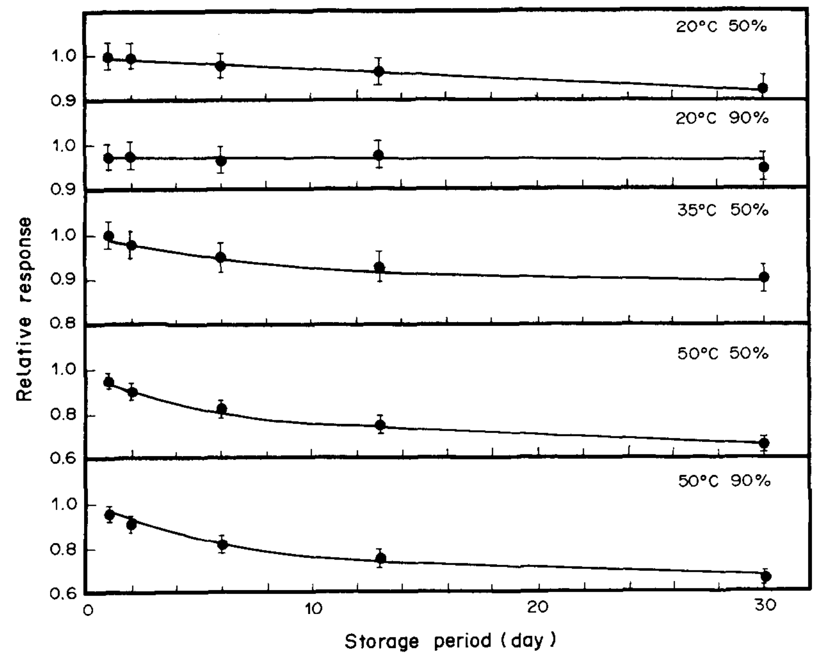

Fig. 8. TLD-200(B) fading curves for dosimeters irradiated before the storage period under different temperature and relative humidity conditions.

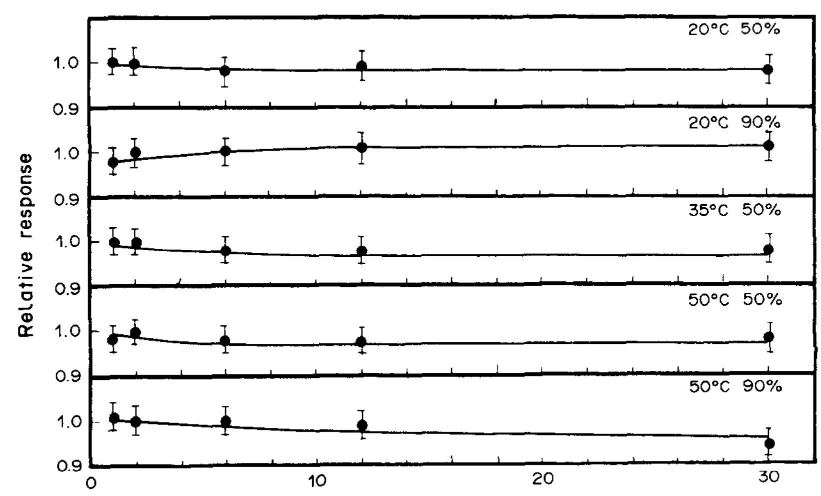

Fig. 9. $Li_2B_4O_7$:Mn,Si fading curves for dosimeters irradiated after the storage period under different temperature and relative humidity conditions.

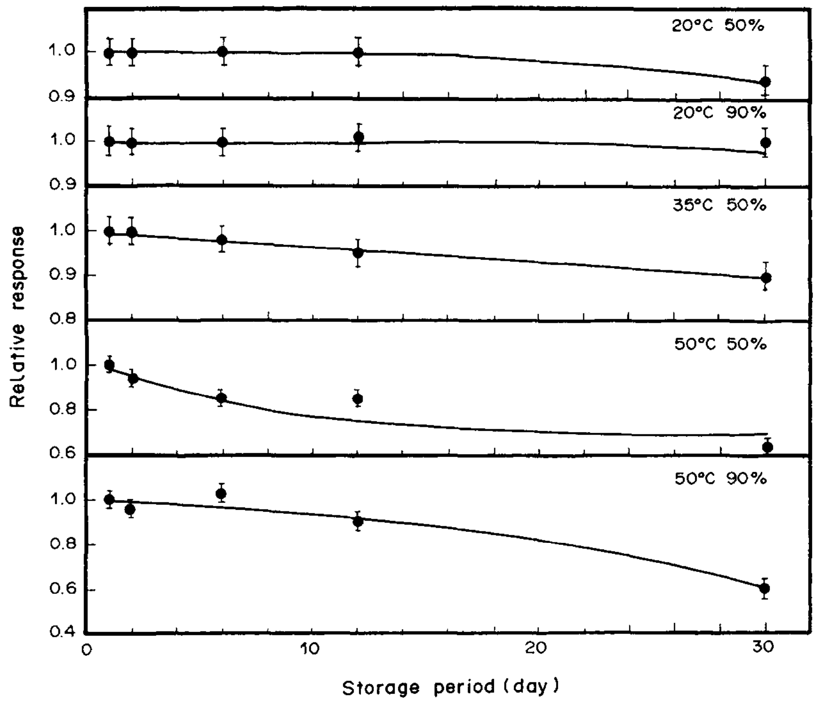

Fig. 10. $Li_2B_4O_7$:Mn,Si fading curves for dosimeters irradiated before the storage period under different temperature and relative humidity conditions.

before read out. The fading correction detectors have to be irradiated before storage.

TLD-200 fading curves show how important the post-irradiation annealing procedure can be. The dosimeters post-annealed at 100°C for 1 h presented a very low fading, interesting for routine applications, while the samples post-annealed at 100°C for 20 min showed a high fading.

Although the $Li_2B_4O_7$:Mn,Si dosimetric TL glow peak temperature is a little higher than the TLD-100 or TLD-700 TL peak 5 (dosimetric peak) temperature, $Li_2B_4O_7$:Mn,Si dosimeters present a fading higher than the one presented by TLD-100 or TLD-700 dosimeters at temperatures above 35°C. The relative humidity seems to be responsible for this behaviour. $Li_2B_4O_7$:Mn,Si is a hygroscopic phosphor.

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