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INFLUENCE OF TEMPERATURE DURING THE GAMMA IRRADIATION
THERMOLUMINESCENCE OF SOILS AND LiF AND
CaF₂ DOSIMETERS

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THERMOLUMINESCENCE OF SOILS AND DOSIMETERS

INFLUENCE OF TEMPERATURE DURING THE
GAMMA IRRADIATION PERIOD ON THE SUBSEQUENT
THERMOLUMINESCENCE OF SOILS AND LiF AND
CaF₂ DOSIMETERS

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FOOTNOTES:

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FIGURE LEGENDS:

- Fig. 1 Glow curves for Hanford sandy loam showing the effect of temperature during irradiation and the effect of post-irradiation heating.
- Fig. 2 Glow curves for soil No. 4FF showing the effect of temperature during irradiation and the effect of post-irradiation heating.
- Fig. 3 Thermoluminescent decay curves for Hanford sandy loam and soil No. 4FF (truncated glow curve) irradiated at 0° and 70°C .
- Fig. 4 Glow curves for LiF (TLD-100) dosimeters showing the effect of temperature during their exposure to gamma radiation.
- Fig. 5 Glow curves for CaF_2 (TLD-100) dosimeters showing the effect of temperature during their exposure to gamma radiation.

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Influence of Temperature During the Gamma Irradiation Period
on the Subsequent Thermoluminescence of Soils and LiF and
CaF₂ Dosimeters

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It is well known that soil temperature varies diurnally from day to day and season to season. It also varies widely with geographic location. These effects can be seen from the extensive data on soil temperature reported by several investigators (1, 2). Perhaps, the most comprehensive paper on soil temperature is the one by Chang (2), who has attempted to obtain the soil temperature record from all stations collecting such data throughout the world. At our experimental site in the Cs137 radiation field established to study the effect of gamma radiation on an ecosystem, the ground surface temperature can range diurnally from around 20° C to about 60° C during the warmest period of the year. During the coldest period of the year, the ground surface temperature can range diurnally from around -14° C to about 16° C.

In view of these diurnal and seasonal temperature variations, a question was raised as to what effect the temperature of the soil during its exposure to gamma irradiation had on its subsequent thermoluminescence. This paper gives the results of the laboratory experiments showing the effect of soil temperature during irradiation and how it might be circumvented when comparing exposure levels of samples collected at different times of the day or seasons of the year. The effect of temperature during the irradiation of lithium fluoride (TLD-100) and calcium fluoride (TLD_200) dosimeters are presented also.

MATERIALS AND METHODS

The two soils that were used for this study were Hanford sandy loam and soil No. 4FF. The chemical characteristics of these soils were reported previously (3). Hanford sandy loam is a slightly acidic soil with illite as its predominant clay mineral. Soil No. 4FF is a non-saline calcareous (33 per cent lime) soil. Its predominant clay mineral is montmorillonite. The LiF (TLD-100) and CaF_2 (TLD-200) were in the extruded rod (1 mm dia. x 6 mm) and ribbon (3.18 mm x 3.18 mm x 0.89 mm) forms, respectively. These were obtained from The Harshaw Chemical Company. Both of these dosimeters were annealed at 400° C for one hour followed by two hour heating at 100° C before exposure to Co60 gamma radiation. The post-irradiation annealing before readout was done by heating at 100° C for 10 minutes. The pre-readout, post-irradiation heating regimens used for the soils are stated at the appropriate places in the text.

All samples were irradiated to 1,000 R with the UCLA 10,000 curie Co60 source, using about 16 minute exposure periods. The samples were kept at three temperature levels (approximately 0°, 25° and 70° C) during the irradiation periods. This was accomplished by equilibrating the samples at each temperature before irradiation as follows. The samples were placed in a plastic vial (1.45 cm dia. x 5.3 cm ht.) and it was placed in the center of a brass cylinder (5 cm dia x 8.3 cm ht.) which acted as a heat sink. The cylinder was solid except for the sample compartment and the slot (1 cm x 4.3 cm) cut through it to expose the plastic vial to radiation without shielding by brass. This brass cylinder

was in the center of an expanded polystyrene foam insulating block, which provided at least 7.7 cm of insulation around the cylinder. The overall dimension of the block was 20 cm x 20 cm x 26.3 cm. The cover of the insulating block consisted of two recessed parts that fitted together tightly. At the center of the inner half was a 1 mm hole through which passed fine lead wires (guage No. 33) to a 1 mm thermistor in the sample compartment. The lead wires were then sandwiched between the inner and the outer halves of the cover during the irradiation period. The temperature of the sample compartment was determined quickly at the end of each irradiation period by attaching the lead wires to a reader without removing the inner cover. By this technique, the temperature of the samples that were initially at 0 °C increased < 0.5 °C during the 16 minute irradiation period. The temperature of the 70-degree samples decreased < 1 °C. The 25-degree samples showed no measureable change of temperature.

After irradiation the samples were allowed to reach ambient temperature (25° C) and read out in the thermoluminescence apparatus described previously (5). The samples that did not receive pre-readout, post-irradiation annealing treatment were always read out 30 minutes after irradiation. A sample heating rate of 500° C/min. was used on all samples with Ar as the flush gas (1 l./min.). As in all previous experiments (3,4,5), 30 mg. of soil sample was used for all readouts.

RESULTS AND DISCUSSION

Figure 1 shows the glow curves for Hanford sandy loam that was kept at 0° , 25° and 70° C during exposure to Co60-gamma irradiation. The top set of glow curves were read out without post-irradiation heating 30 minutes after irradiation. By comparing the areas under the curves, which represent the integrated light outputs, it is evident that the effect of temperature during irradiation was 0° C $>$ 25° C $>$ 70° C. Also, the peak heights are lower and displaced to the right with increasing temperature during the irradiation period. Thus, the temperature during the irradiation period could be a factor that needs to be considered in relating soil thermoluminescence to exposure level.

It was pointed out above that soil temperature can vary over a considerable range during the course of a day and season to season. This fact obviously necessitates the elimination of the effect of temperature during the irradiation period when comparing the thermoluminescence of soils subjected to irradiation under different temperature regimes. In order to do this, various post-irradiation heating regimens before readout were tried. The middle set of curves in figure 1 show the effect of heating the irradiated samples for 10 minutes at 100° C before readout. After this treatment, the integrated light output of the samples exposed at 0° and 25° C were virtually the same. The integrated light output of the sample irradiated at 70° C, however, was appreciably different from the 0- and 25-degree samples. By heating the samples for 20 minutes at 100° C, the light output for the three treatments were virtually the same. Thus, by using an appropriate post-irradiation heating regimen, the effect of temperature during

irradiation could be eliminated in this soil.

Figure 2 shows the glow curve for the highly calcareous soil No. 4FF. Without pre-readout, post-irradiation heating this soil also showed a definite effect of temperature during the irradiation period. This effect occurred primarily in the shallow electron (hole) trap zone ($< 250^{\circ}\text{C}$ range). By using the heating regimen of 20 minutes at 100°C , the effect of temperature during irradiation appeared to be eliminated in this soil also. The variations of the peak heights and the total integrated light output shown in the figure were within experimental error. This was verified by the fact that the intervals of one standard deviation for repeated readouts overlapped. The post-irradiation heating temperature was limited to 100°C , because it was found previously (4) that the thermoluminescence capacity of soils begins to degenerate in the neighborhood of this temperature. This probably means that below 100°C the decrease of thermoluminescence was due only to the thermal release of electrons (holes) from the traps, while above this temperature, the number of traps, the trapping efficiency or of the efficiency of conversion of the energy of trapped electrons (holes) to photons changes.

Figure 3 shows the thermoluminescent decay curves for Hanford s.l. and soil No. 4FF that were irradiated at 0° and 70°C and stored at room temperature (25°C) between readings. The points on the graph were obtained by measuring the areas under the glow curves, which represent the integrated light outputs as stated above. The data for Hanford s.l. represents the areas under the total glow curve, while those for soil No. 4FF are for the truncated glow curve, i.e. only that portion of the glow

curve from ambient to 212° C heating temperature. The curves show that the thermoluminescent decay was very rapid the first 24 hr. after irradiation. Between 24 and about 84 hr., the decay was much slower, but still fairly rapid. After about 84 hr., the decay was much slower. The important point to note, however, is that initially, the thermoluminescent glow of the 0-degree samples were greater than that of the 70-degree samples, but as evidenced by the convergence and the final coincidence of the curves, the difference between the two treatments was nullified with lapse of time. The point of coincidence occurred at about 48 and 108 hr. after irradiation for Hanford s.l. and soil No. 4FF, respectively.

The results presented above show that the effect of temperature of the soil during its exposure to radiation could be nullified in two ways. The effect of the post-irradiation heating was to hasten the decay to a point not only where the effect of sample temperature was eliminated, but where the decay rate was relatively very low. With a heating regimen of 100° C for 20 minutes, the glow curve areas were about 37.2 cm^2 and 10.1 cm^2 for Hanford s. l. and soil No. 4FF (truncated glow curve), respectively. These values correspond to about 58 and 168 hr. of decay time at room temperature (25° C). The post-irradiation heating is obviously advantageous in that readings could be done relatively soon after irradiation. On the other hand, the allowance of sufficient decay time at room temperature may be advantageous if the breakdown of the thermoluminescence capacity of the soil is appreciable during the post-irradiation heating and must be avoided.

In order to monitor the radiation exposure of the soils, LiF (TLD-100) and CaF_2 (TLD-200) dosimeters were placed in the vials with

the soils. Interestingly, it was found that the thermoluminescent glows of TLD-100 (fig. 4) and TLD-200 (fig. 5) were also influenced by their temperature during irradiation. Figure 4 shows that the integrated light output for the 0-degree treatment was considerably lower than for 25- and 70-degree treatments. Note that the peak heights differed considerably among the treatments. TLD-200 differed from TLD-100 in that its integrated light output was the largest for the 0-degree treatment. Its peak heights decreased and shifted to the right with increasing temperature during irradiation. The behavior of TLD-200 conformed more or less to what one might expect, since at the higher temperatures fewer shallow electron (hole) traps are expected to be filled. The behavior of TLD-100, however, suggests that other factor(s) could be involved also. At the time of this writing, no further work was done with these dosimeters, since our primary interest was soil thermoluminescence. In any case, temperature during irradiation could be an important factor when using these dosimeters in gamma-radiation fields set up in natural environment where the ambient temperature varies widely during the exposure period. These results also indicate that pre-readout, post-irradiation heating at 100° C for 10 min. was not sufficient to eliminate the effect of temperature during irradiation.

SUMMARY

The influence of temperature (0° to 70° C) during the exposure period to Co60-gamma radiation on the thermoluminescence of two soils and LiF (TLD-100) and CaF_2 (TLD-200) dosimeters was examined.

The thermoluminescence of these materials were affected by their temperature during irradiation. The effect of temperature during irradiation was eliminated in the soils by using a pre-readout, post-irradiation heating regimen of 100° C for 20 min. or by allowing the thermoluminescent decay to progress for an appropriate length of time. For the two soils examined, this time was about 58 and 168 hr. The pre-readout, post-irradiation heating regimen (100° C for 10 min) sometimes used for TLD-100 and TLD-200 dosimeters did not eliminate the effect of temperature during irradiation.

Fig. 1 Glow curves for Hanford sandy loam showing the effect of temperature during irradiation and the effect of post-irradiation heating.

Fig. 2 Glow curves for soil No. 4FF showing the effect of temperature during irradiation and the effect of post-irradiation heating

Fig. 3 Thermoluminescent decay curves for Hanford sandy loam and soil No. 4FF (truncated glow curve) irradiated at 0° and 70° C.

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Fig. 5 Glow curves for CaF_2 (TLD-200) dosimeters showing the effect of temperature during their exposure to gamma radiation.