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Temperature dependency of radiophotoluminescence glass dosimeter sensitivity

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Temperature dependency of radiophotoluminescence glass dosimeter sensitivity was examined by irradiation of the dosimeter elements in an artificial climate experiment chamber. Two laboratories (A and B) independently measured the radiation dose of the elements irradiated simultaneously. The dosimeter elements were irradiated by γ-rays from a combined source of ^{137}Cs (3.3 MBq) and ^{60}Co (1.9 MBq) at four different temperature levels; −10°C, 0°C, 20°C and 30°C. Statistically significant decrease of the sensitivity at low temperature was observed by both laboratories, however, declining rates of the sensitivity with temperature were different for each. Average decrease rates were 0.047±0.025% deg^{-1} and 0.091±0.033% deg^{-1} for laboratories A and B, respectively. The maximum declining rate of 0.052% deg^{-1} and 0.17% deg^{-1} were observed by A and B, respectively. The reason for this discrepancy between the two laboratories was unknown, and further study is required to elucidate this problem.

KEYWORDS: radiophotoluminescence glass dosimeter, sensitivity, temperature dependency

I. Introduction

Radiophotoluminescence glass dosimeters have several merits for measurement of cumulative radiation dose in comparison to TLD detectors: lower fading effect, lower variation of sensitivity between individual elements in the same lot, and higher stability of sensitivity at different temperature. The repeatable readout capability of the glass dosimeter is also preferable for monitoring use. Therefore, glass dosimeters are widely used for measurement of environmental γ-ray doses, for example environmental monitoring around nuclear industrial facilities. However, loss of sensitivity at low temperature has recently been reported: approximately 3% drop at 2°C from the value at 14.5°C [1), 2)]. To confirm this loss, temperature dependency of glass dosimeter sensitivity was examined in an artificial climate experiment chamber at the Institute of Environmental Sciences. Experimental results obtained by two laboratories are presented in this paper.

II. Material and methods

The irradiation experiment was carried out in a large chamber of Artificial Climate Experiment Facility at Institute for Environmental Sciences. The measurements of the chamber are 11 m by 12 m and 13 m in height. Experiment tables with wood tops were constructed on steel frames. An irradiaion table was made by placing a plastic board on the two experimental tables (**Fig. 1**). The irradiation table was placed in the middle of the chamber and used, with one exception, as described later.

Two laboratories examined the sensitivity variation of glass dosimeters in this study; laboratories A and B. Both laboratories used the same type glass dosimeter system, SC-1, Asahi Techno Glass, Tokyo, Japan. Dosimeter elements for both laboratories were simultaneously irradiated on the irradiation table, and then their doses were independently measured in each laboratory.

Dosimeter elements were irradiated by γ-rays from a combined source of ^{137}Cs (3.3 MBq) and ^{60}Co (1.9 MBq) at four different temperatures: −10°C, 0°C, 20°C and 30°C. The two sources were selected to get sufficient irradiation dose rate for our experiment. The temperature was controlled with variation of less than 1.6°C throughout the experiments. Irradiation experiments were carried out as a series of three. Irradiations at 0°C and 20°C were examined in the first and second experiment series, while sensitivity at four different temperatures, -10°C, 0°C, 20°C and 30°C, were measured in the third series.

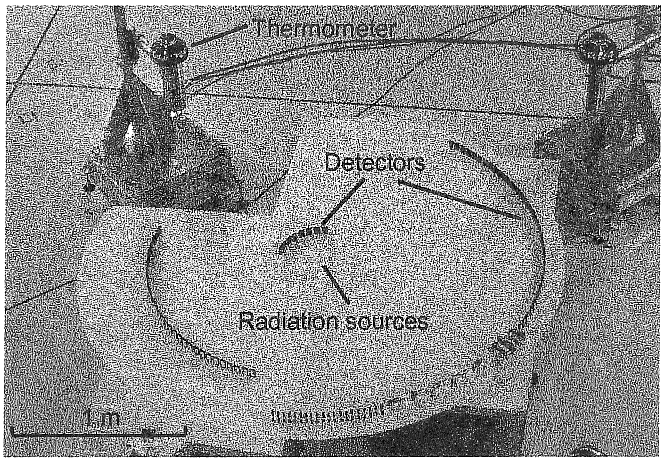

Fig. 1 Irradiation experiment in a large chamber of Artificial Climate Experiment Facility in Institute for Environmental Sciences.

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Table 1 Temperature dependency of measurement results for glass dosimeters in first and second experiment series.

Laboratory	Experiment series	Dose rate (μGy h^{-1})	Lot	Dose (μGy) Temperature 0°C	Dose (μGy) Temperature 20°C	Dose ratio [a] 0°C/20°C
A	1	0.7	1	125.4 ± 2.1	126.0 ± 2.2	0.995 ± 0.013
			2	124.9 ± 1.0	125.1 ± 1.3	0.998 ± 0.011
			3	127.3 ± 1.5	127.0 ± 1.3	1.002 ± 0.013
		1.1	1	128.9 ± 1.7	128.5 ± 1.6	1.003 ± 0.011
			2	128.8 ± 1.9	128.3 ± 2.3	1.004 ± 0.011
			3	126.8 ± 1.5 *	127.5 ± 1.2	0.995 ± 0.006
		3.3	1	137.0 ± 2.0	138.3 ± 1.7	0.991 ± 0.019
			2	134.5 ± 1.4	135.9 ± 1.8	0.990 ± 0.016
			3	135.9 ± 2.2 *	134.0 ± 1.2	1.014 ± 0.019
	2	0.7	1	120.6 ± 2.4 **[b]	122.7 ± 2.0 [b]	0.983 ± 0.017
			2	122.6 ± 2.3	122.8 ± 2.0	0.998 ± 0.015
			3	120.6 ± 2.4	122.2 ± 1.4	0.987 ± 0.015
B	1	0.7	4	125.4 ± 2.1 *	127.9 ± 2.4	0.980 ± 0.013
	2		4	121.5 ± 1.7 †	126.4 ± 2.0	0.961 ± 0.013

Mean ± one standard deviation for 10 samples or [b] 20 samples.
Shaded results were from the same elements at different temperature.
[a] Mean and standard deviation of dose ratios of individual elements for shaded results, otherwise ratio of mean doses at different temperatures and standard deviation from propagation of error.
Statistically significant difference from 20°C, * p<0.05, ** p<0.001; † p<0.0001.

Table 2 Temperature dependency of measured results for glass dosimeter in third experiment series.

Laboratory	Dose rate (μGy h^{-1})	Lot	Dose (μGy) Temperature -10°C	0°C	20°C	30°C
A	0.7	1	118.1 ± 1.9 **	118.5 ± 2.0 *	120.8 ± 2.1	–
		2	119.5 ± 1.6	119.1 ± 1.4 [b]	120.0 ± 1.6	–
		3	118.6 ± 2.2	121.9 ± 1.9 *	119.7 ± 1.8	–
		4	117.4 ± 1.6 **	–	119.8 ± 1.8	–
		5	117.7 ± 1.3 **	119.2 ± 2.4	120.3 ± 1.6	–
B	0.7	2	124.5 ± 2.2 **	125.7 ± 1.6 *	127.9 ± 2.2	131.2 ± 1.0 *
		4	122.1 ± 2.2	119.5 ± 1.7 †	122.7 ± 0.7	123.7 ± 2.0 **

See footnotes of Table 1.
Statistically significant difference from 20°C, * p<0.05; ** p<0.01; † p<0.0001.

Table 3 Ratio [a] of measured results to those at 20°C in third experiment series.

Laboratory	Dose rate (μGy h^{-1})	Lot	Ratio to 20°C [a] Temperature -10°C	0°C	20°C	30°C
A	0.7	1	0.978 ± 0.016 **	0.981 ± 0.024 *	1.000 ± 0.018	–
		2	0.996 ± 0.015	0.992 ± 0.017 [b]	1.000 ± 0.013	–
		3	0.991 ± 0.010	1.018 ± 0.022 *	1.000 ± 0.015	–
		4	0.980 ± 0.018 **	–	1.000 ± 0.015	–
		5	0.978 ± 0.018 **	0.991 ± 0.024	1.000 ± 0.014	–
B	0.7	2	0.974 ± 0.024 **	0.983 ± 0.021 *	1.000 ± 0.017	1.026 ± 0.019 *
		4	0.995 ± 0.013	0.974 ± 0.015 †	1.000 ± 0.006	1.008 ± 0.017 **

See footnotes of Table 1.
Statistically significant difference from 20°C, * p<0.05; ** p<0.01; † p<0.0001.

Cumulative dose for the elements was approximately 130 μGy with dose rate of approximately 0.7 μGy h^{-1}. The cumulative dose corresponded to a typical dose during 3 months in the Aomori area. The elements were irradiated for 187 h with 110 cm as the distance from the source in the first and second series. Since the irradiation period for these experiment series was the same, and the interval between the series was nearly half a year, the cumulative dose in the second series slightly decreased mainly with decay of ^{60}Co. The irradiations in the third series were carried out for 162 h with 100 cm distance from the source. To check dose rate dependency on sensitivity, two dose rates were examined in the first series by laboratory A other than the level described above. The elements were irradiated with 50 cm and 85 cm

Table 4 Ratio of measured results at low temperature to high one for the same elements.

Laboratory	Measured ratio		
	-10°C/20°C	0°C/20°C	0°C/30°C
A	0.985 ± 0.017 (0.944 - 1.017, 50)	0.995 ± 0.015 † (0.951 - 1.024, 100)	-
B	0.974 ± 0.013 (0.956 - 0.996, 9)	0.971 ± 0.015 (0.949 - 1.002, 20)	0.959 ± 0.008 (0.952 - 0.976, 10)

Mean ± one standard deviation.
Range and number of samples are in parentheses.
† Statistically significant difference from laboratory B ($p<10^{-7}$).

as distances from the source for 41 h and 111 h, respectively. The dose rates in each condition were 3.3 μGy h^{-1} and 1.1 μGy h^{-1}, respectively. The irradiation with 3.3 μGy h^{-1} was carried out on the plastic board directly placed on the floor at a different time from the other irradiation.

The same elements were compared in different temperature conditions in most experiments, however, different elements from the same lot were used for one part. Two to five lots of elements were simultaneously irradiated under the same conditions by both laboratories. Laboratory B calibrated elements in their standard irradiation room for every experiment. Laboratory A did not calibrate elements for every experiment but did so every three months by having some of them irradiated in the Institute of Radiation Measurements (Tokai, Ibaraki).

The dose of irradiated element was measured after annealing for 1 h at 70°C by both laboratories. The period between the end of irradiation and measurement were different by laboratories and the experiment series. At first and second experiment series, the dose was measured just after and 1.5h after the irradiation by laboratory A and B, respectively. At third experiment series, both laboratories annealed the elements 5 h after irradiation, and measured the dose 7 h after that.

III. Results and discussion

The results of the first and second experiment series are shown in **Table 1**, and those of the third series are given in **Table 2**. All dose data in this paper included background radiation. Mean and one standard deviation (SD) for 10 or 20 elements from the same lot are shown in the tables, lot-by-lot. Shaded results were obtained from the same elements at different temperature. When the same elements were used under different temperature conditions, dose ratios of the given temperature to 20°C were calculated for individual elements, and then mean and standard deviation of the ratios are shown in the tables. If different elements in the same lot were irradiated at a different temperature, dose ratio in tables are the ratio of the mean values in each temperature, and standard deviation was obtained by propagation of error. The dose ratios to 20°C for the third experiment series are shown in **Table 3**.

Observed doses from the irradiation with dose rate of 3.3 μGy h^{-1} were higher than those with lower dose rate. The reason for this difference was considered to be scattering of γ-rays by the concrete floor. Measured doses from elements under the same condition varied slightly in one lot and by lot-to-lot. When SDs shown in **Tables 1** and **2** were expressed as ratios to their mean values (coefficient of variance; CV), CV was under 2.0%, and mean and SD of

Table 5 Decrease rate of sensitivity for the same elements.

Laboratory	Dose decrease (% deg^{-1})		
	-10°C/20°C	0°C/20°C	0°C/30°C
A	0.051 ± 0.056	0.027 ± 0.075	-
B	0.088 ± 0.042	0.146 ± 0.075	0.136 ± 0.027

Mean ± one standard deviation

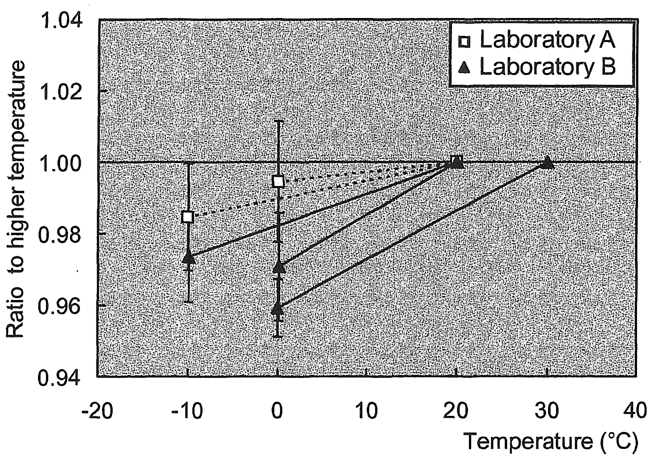

Fig. 2 Decrease of sensitivity in comparison to that at 20°C or 30°C for the same elements.
Vertical bars indicate one standard deviation.

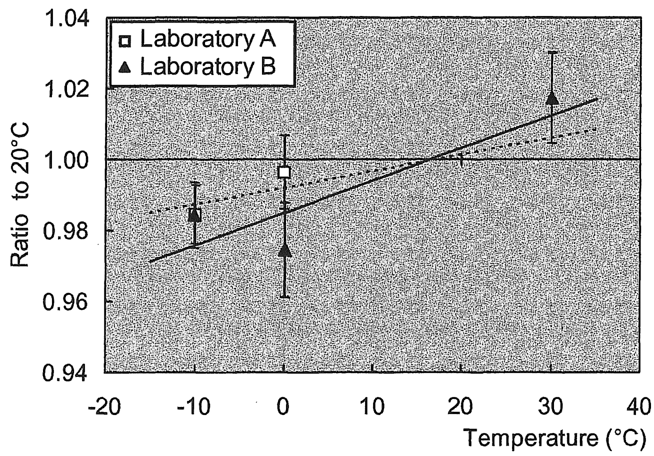

Fig. 3 Change of sensitivity in comparison to that at 20°C for all elements.
Vertical bars indicate one standard deviation.
Oblique lines are regression lines including 1.0 at 20°C as data for each laboratory.

Table 6 Ratio of measured results to those at 20°C for all elements.

Laboratory	Dose ratio to 20°C			
	Temperature			
	-10°C	0°C	20°C	30°C
A	0.985 ± 0.008	0.996 ±0.010	1	-
B	0.984 ± 0.015	0.975 ±0.010	1	1.017 ±0.013
A+B	0.984 ± 0.009	0.992 ±0.013	1	1.017 ±0.013

Table 7 Change rate of sensitivity from 20°C for all elements.

Laboratory	Dose variation rate from 20°C (% deg^{-1})			
	-10°C	0°C	20°C	30°C
A	0.052 ± 0.028	0.018 ± 0.051	1	-
B	0.052 ± 0.051	0.13 ± 0.05	1	0.17 ± 0.13
A+B	0.052 ± 0.031	0.040 ± 0.067	1	0.17 ± 0.13

Mean ± one standard deviation.

CVs for all irradiation conditions was 1.4±0.3%. CVs of mean doses for different lots at the given temperature and dose rate were under 1.6% and 4.2% for laboratories A and B, respectively. Mean and SD of CVs between lots under the same conditions were 0.8±0.4% (15) and 3.0±1.2% (4) for laboratories A and B, respectively, with number of samples in parentheses. Since laboratory B examined only two lots, the relatively large variance observed may be due to chance. In total, the representativeness of measured dose was very good.

The differences of measured dose were tested by t-test for paired samples or independent samples, and results are shown in **Tables 1** and **2**. In comparison to the results for 20°C, 14 pairs out of 29 pairs had statistically significant differences including one case which showed higher sensitivity at lower temperature. The decrease of sensitivity from 20°C to -10°C was clearer than that to 0°C. As shown in **Table 1**, dose ratio of 0°C to 20°C did not depend on dose rate from 0.7 μGy h^{-1} to 3.3 μGy h^{-1}.

Ratios of measured doses at low temperature to those at 20°C or 30°C for the same elements are summarized in **Table 4** and **Fig. 2**. All data from the same elements (shaded results in **Table 1** and **3**) were merged by laboratory. Range of the ratios and number of samples are also given in the table. All ratios in **Table 4** differed from 1.0 with a highly statistically significant level. The decreases of sensitivity by laboratory A were clearly lower than those by laboratory B. The difference between both laboratories was not statistically significant for the ratio of -10°C/20°C. Decrease rate per degree Celsius are shown in **Table 5** for the results from the same elements. Sensitivity dependency on temperature was reported to be under 0.1% deg^{-1} by Peisch and Burgkhardt[3]. The mean values of the decrease rates by laboratory A were under the reported upper value, while some of those by laboratory B exceeded it.

The mean ratios and their SDs of mean dose ratio in **Tables 1** and **3** are given for all elements in **Table 6** and **Fig. 3**. These values were obtained by treating each mean value as a single datum neglecting its SD. The ratios of measured results at -10°C to those at 20°C were almost same for laboratories A and B, while the ratios of 0°C/20°C were different for each. The variation rates of measured dose per degree Celsius are shown in **Table 7**. The variation rate at 0°C by laboratory B was much higher than that by laboratory A. Regression lines of the rate were obtained including 1.0 at 20°C as datum for each laboratory, and are shown in **Fig. 3**. The slopes of the regression line were 0.047±0.025% deg^{-1} and 0.091±0.033% deg^{-1}for laboratories A and B, respectively. These gradients were considered to be average sensitivity dependency on temperature for each laboratory.

IV. Summary

The sensitivity dependency of radiophotoluminescence glass dosimeters on temperature was examined in an artificial climate experiment chamber. Statistically significant declines at low temperature were observed by two laboratories. Average decrease rates were 0.047% deg^{-1} and 0.091% deg^{-1}for laboratories A and B, respectively. The maximum decline rates of 0.052% deg^{-1} and 0.17% deg^{-1} were observed by laboratories A and B, respectively. The reason for this discrepancy between two laboratories was unknown, and further study is required to explain this.

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