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Application of a Newly Developed Photoluminescence Glass Dosimeter for Measuring the Absorbed Dose in Individual Mice Exposed to Low-dose Rate ^{137}Cs γ-rays

YUKO HOSHI[1]*, TAKAHARU NOMURA[1], TAKESHI ODA[1], TOSHIYASU IWASAKI[1], KAZUKO FUJITA[1], TATSUYA ISHIKAWA[2], AKIRA KATO[2], TOHRU IKEGAMI[3], KAZUO SAKAI[1], HIROSHI TANOOKA[1] and TAKESHI YAMADA[1]

[1]Komae Branch, Bio-Science Department, Central Research Institute of Electric Power Industry, Iwado-kita 2–11–1, Komae-shi, Tokyo 201–8511, Japan
[2]Chiyoda Technol Corporation, Yushima 1–7–12, Bunkyo-ku, Tokyo 113–8681, Japan
[3]Asahi Technoglass Corporation, Nihonbashi-honcho 3–7–2, Chuo-ku, Tokyo 103–0023, Japan

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A photoluminescence glass dosimeter, GD-301, was applied to the measurement of low absorbed doses in mice exposed to low-dose rate ^{137}Cs γ-rays. The dosimeter system consists of small rod-shaped glass chip detectors capable of embedded in the body of a mouse and an automatic readout device equipped with a standard detector irradiated with ^{137}Cs γ-source. The measured absorbed doses were compared with the "exposure" estimated by an ionization chamber and with the doses measured by a BeO:Na thermoluminescence system. The results clearly demonstrate the superiority of the glass dosimetry regarding simplicity of operation, stability of long-term dose accumulation and good detector uniformity, which allow accurate tissue dosimetry.

INTRODUCTION

Direct measurements of absorbed doses in small experimental animals, such as mice, have been commonly performed using a thermoluminescent dosimeter (TLD)[1,2], since its small size enables it to be embedded in the mouse body, for instance, in the peritoneal cavity. However, TLD system, at least the version commonly available for general radiobiological

*Corresponding author: Phone; +81–3–3480–2111, Fax; +81–3–3480–3539, E-mail; hoshi@criepi.denken.or.jp

experiments, has a limitation especially in measuring low dose, due to a lack of detector uniformity, and a significant pre-dose inherent to surface contamination[3].

A new fully automatic photoluminescence dosimeter (PLD) was recently developed and is now commercially available. It consists of readout equipment with the standard dosimeter and small, one-element silver-activated metaphosphate glass detectors. PLD is based on the formation of fluorescence centers in silver-activated metaphosphate glass dosimeters. When exposed to UV light, radiation-induced photoluminescent fluorescence light is emitted, the intensity of which is proportional to the dose[4]. Compared with the TLD system, at least the one used here, it is superior in performance. It allows automatic correction of the pre-dose, and has excellent uniformity of the detectors in response to radiation of 10 to 100 μSv without any fade-out[5–7].

This paper deals with the application of PLD to measurements of the absorbed dose in individual mice kept for month-long periods in the low-dose rate ^{137}Cs γ-ray field.

MATERIALS AND METHODS

Experimental animals

Six-week-old female ICR mice (Nihon Clea Co. Ltd., Japan) were kept under clean conventional conditions within a facility (described below) equipped with a ^{137}Cs γ-ray source (370 GBq, 10 Ci). All animals were maintained on a light schedule from 07.00 to 19.00, given food and water *ad libitum* following the guideline for animal experiments of The Central Research Institute of Electric Power Industry (CRIEPI), Japan.

A facility for chronic low-dose rate γ-irradiation

Last year, CRIEPI constructed a new facility for the chronic low-dose irradiation of animals with a 370 GBq ^{137}Cs γ-ray-source. The plan of the irradiation floor is shown in Fig. 1. The facility has a capacity to keep about 700 mice simultaneously for irradiation at various dose rates, depending on the distance from the ^{137}Cs source, which is remotely controlled by computer in an adjacent control room. The mouse cages and shelves are made of plastic or wooden materials so as to reduce the random scattering of γ-rays.

Measurement of the radiation dose

The exposure rate was measured at several points in a γ-ray field using a dose-rate meter (AE-132a type, OHYO GIKEN Co. Ltd., Japan) coupled to an ionization chamber (C-110 type, OHYO GIKEN Co. Ltd., Japan). For the TLD system, BeO:Na chips (UD-170L type, Matsushita Electric Co. Ltd., Japan) were used with their readout system.

The absorbed dose in individual mice was measured by the PLD system (Asahi Technoglass Corporation, Japan). The elemental composition of the glass is as follows: P, 31.55; O, 51.16; Al, 6.13; Na, 11.00; Ag, 0.17 Wt%, and the effective atomic number, 12.039. The readout system (a full automatic type FGD-200, Asahi Technoglass Corporation, Japan) using a pulse UV-laser excitation is able to separate the intrinsic individual pre-dose from the

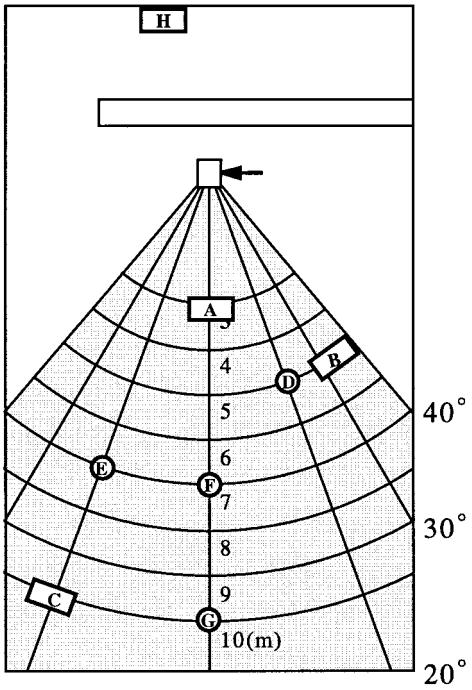

Fig. 1. Plan of the γ-irradiation floor. The dimensions of the room are fifteen meters by ten. The arrow indicates the location of the ^{137}Cs γ-ray-source. The shaded sector is the irradiation area, in which the mouse shelves are placed. The shelves can be freely settled at any place in the sector to change the dose-rate by changing the distance between the γ-source and the shelves. For example, locations A, B, C are 3, 5 and 10 m away from the source, respectively. Behind the shield concrete wall a shelf is placed for the non-irradiated control mice (H).

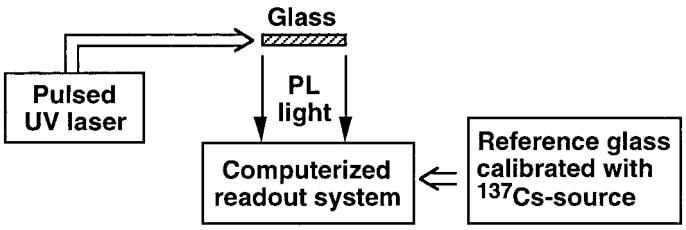

Fig. 2. Block diagram of the readout system. The glass dosemeter is excited by a pulsed N_2 laser (UV 4ns), and photoluminescence light is measured by the system. The readout is then corrected with reference glass calibrated in terms of the absorbed dose with ^{137}Cs γ-ray-source.

radiation induced reading[8]. An outline of readout system is shown in Fig. 2. SC-1-type glass detectors were used, and small-scale glass chips (GD-301; 8.5 mm in length, 1.5 mm in diameter) were specially designed for use in this experiment in which the chips were used embedded in the mouse peritoneal cavity by a simple surgical operation under anesthesia using Avertin. Before performing the readout procedures after exposure, the chips were removed

from the mice, washed with 70% ethanol and sonicated with distilled water. In a series of the experiments, TLD and PLD chips were embedded in the same mouse for a comparison.

RESULTS

Exposures measured by the ionization chamber and the doses in free air determined by the PLD system using GD-301 type glass-chips are summarized in Table 1. At locations A, B, D and E, where no obstacles causing γ-ray attenuation existed, no differences could be observed between the two values, giving the ratio of the PLD dose (A) to the calculated dose (E) based

Table 1. Comparison of the absorbed dose obtained with the PLD system with the exposure measured by the ionization chamber

Location of the measurement[1] (distance from γ-source in m)		Dose rate (E)[2] μGy/h	Dose rate μGy/h	(A)[3] A/E ratio
A	(3)	3428.6	3544.8 ± 44	1.03
B	(5)	1223.6	1257.1 ± 7	1.03
D	(5)	1148.6	1191.7 ± 8	1.04
E	(7)	645.1	657.1 ± 3	1.01
F	(7)	649.8	594.4 ± 7[4]	0.92
G	(10)	345.8	245.5 ± 35[5]	0.71
C	(10)	349.6	308.3 ± 3[4]	0.88

[1] The locations of the measurement are shown by A–G in Fig. 1.

[2] The dose rate was calculated on the basis of the present "exposure rate." The exposure was measured using the ionization chamber, as described in the Methods and Materials Section, about 9 month's ago immediately after completing the construction of the facility when no obstacles, such as desks and mouse shelves, existed within the irradiation area. The present exposure rate (E) was estimated on the basis of the reduced radioactivity (98%) due to the decay of the ^{137}Cs source.

[3] The absorbed dose represents the average of 3 independent measurements using glass chips placed at different heights at the same location, ± S.E.M.

[4] One or [5]two mouse shelves are presently placed between the radiation source and the location.

Table 2. Radiation dose (mouse dose) measured by the glass chips in the mouse peritoneal cavity compared with the free-air dose

Location of the measurement (distance from γ-source in m)	mouse dose μGy/h	free-air dose* μGy/h	mouse/air dose ratio
3	2579	3395	0.76
10	304.4 ± 2.5*	422.0 ± 0.2*	0.72

*Free-air doses were obtained by the same type small glass chips placed in free-air at the same location as the mouse cage was placed.

*Data represent the average of at least 3 independent measurements ± S.E.M.

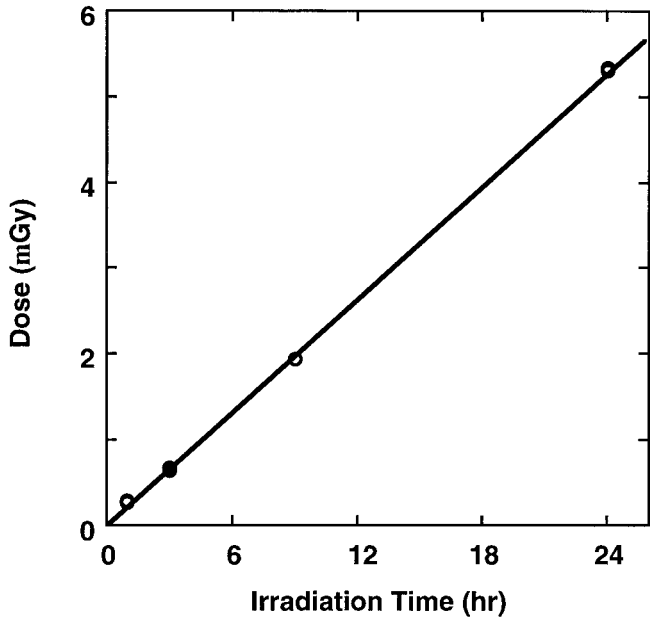

Fig. 3. Linearity in response of the PLD system to ^{137}Cs γ-radiation in a low-dose rate. The glass chips were embedded in the peritoneal cavity of mice placed 10 m away from the γ-ray-source, and then recovered at various times (given by the abscissa) to be measured by the readout system.

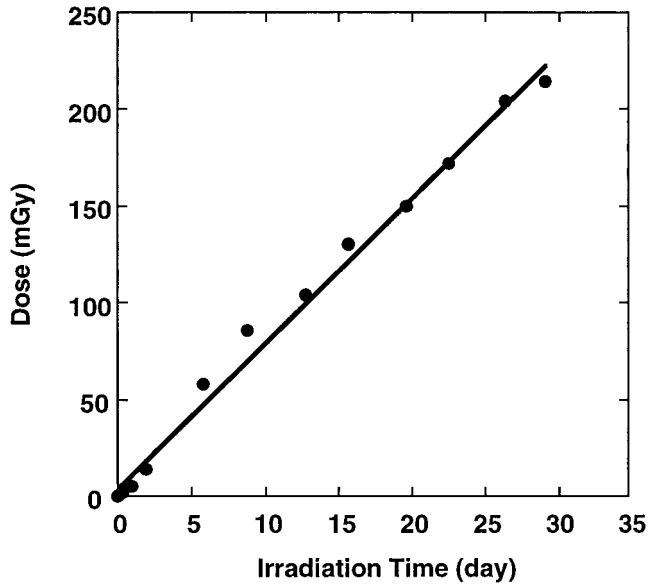

Fig. 4. Linearity in response of the PLD system to long-term ^{137}Cs γ-radiation. The experimental procedures were as described in Legend for Fig. 3, except that the time of the recovery of the glass chips from individual mice was longer than that in the experiments shown in Fig. 3, as shown by the abscissa.

on an exposure value, about 1.03. However, as the distance between the source and the measuring points increased, the difference became more noticeable; the PLD-to-ionization chamber ratio decreased to lower than 0.7 at a point (location G in Fig. 1) 10 m away from the source. This can be, at least partly, explained by the attenuation of γ-rays by the mouse shelves and desks placed between the source and the measuring points, which didn't exist at the time of a measurement by the ionization chamber immediately upon completing the construction of the facility. If we consider the uncertainties concerning the calculation of the absorbed dose by the PLD system, and the inaccuracy associated with estimating the exposure dose by ionization chamber, the measurements by the two methods are in reasonable agreement with each other.

Table 2 gives the radiation doses measured by embedded small-scale glass chips in peritoneal cavity of a mouse (mouse dose) compared with the dose obtained by the same-type chips placed in free-air (air dose) at the same location. The mouse doses were lower than the air doses, as expected based on the γ-ray attenuation by mouse tissues. The mouse-to-air-dose ratio was maintained at almost a constant level from 0.76 at 3 m to 0.72 at 10 m distance.

The linearity in response of the PLD system to the radiation in very low-dose rate range

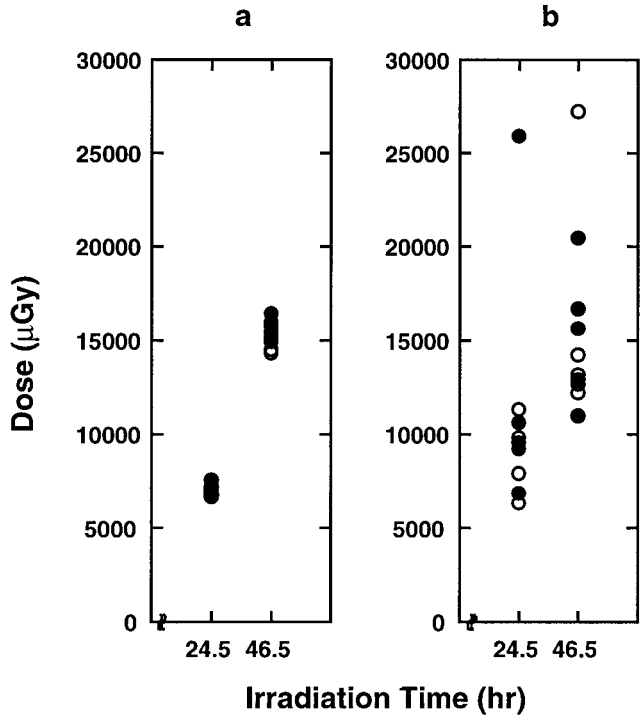

Fig. 5. Comparison of the detector uniformity between the PLD and TLD systems. A glass Chip was embedded together with a TLD chip in a mouse and recovered simultaneously at the times given by the abscissa. The open and closed circles represent data obtained at 0.4 m and 0.7 m heights respectively. One circle represents the result obtained with one chip. The results for the PLD system are shown at the left (a), and those for the TLD system, at the right (b).

is clearly shown in Fig. 3. The radiation doses obtained by a mouse dose experiments in which PLD chips were kept for various hours (irradiation time) in mice placed 10 m away from the source were plotted against the irradiation time in this figure. The increase in the dose is exactly proportional to the irradiation time, demonstrating a remarkably linear response of the system within the dose range.

Linearity was maintained at even a higher dose range, as shown in Fig. 4. In this experiment, mice bearing the PLD chips in their peritoneal cavity were maintained for up to one month in the γ-ray field (up to total dose of 200 mGy). The points well fitted to the straight line indicate the linear response of the system to the increase in radiation dose, along with very good detector uniformity of the glass chips.

The detector uniformity was further confirmed in comparison with the TLD system, as shown in Fig. 5. Making a sharp contrast to the points shown in the left figure for the PLD results, the dose data obtained with the TLD system in the right figure are scattered over wide ranges, indicating a striking difference in the response uniformity between the TLD and the PLD systems. The PLD system is definitely superior to the TLD system, at least as examined here, concerning their dosimetric properties, such as the response uniformity.

DISCUSSION

One of the primary goals of dosimetry is to determine the absorbed dose in tissue exposed to radiation. The Bragg-Gray principle provides a means of relating ionization measurements in a gas to the absorbed dose in some convenient material from which a dosimeter can be fabricated[3]. To obtain the tissue dose, either the material can be tissue equivalent or else the ratio of the absorbed dose in the material to that in tissue can be inferred from other information, such as calculations or calibration measurements.

However, under the experimental conditions commonly used for the whole-body irradiation of mice, it is practically difficult to estimate the accurate absorbed doses in individual mice by ionization measurements in free air because the estimation is profoundly influenced by complex factors, such as random scattering and the absorption of the radiation by a number of equipment around the mice, as well as time-to-time changes in a distance from the source, and in the orientation of the mice relative to the radiation source.

Direct and accurate measurements of the absorbed doses *in situ* are, therefore, are especially needed for the low-dose and low-dose-rate irradiation experiments, in which a quantitative analysis of the relationship between small doses and the biological effects should be performed based on the measured radiation doses. Apparently, the size of the ionization chamber relative to the mouse body does not permit us to perform an experiment in which the chamber is embedded in the mouse body so as to measure the absorbed dose. Thus, the TLD system has been used for this purpose in spite of its defects concerning batch uniformity.

There exist some TLDs which have good uniformity and high sensitivity comparable to the PLD[9–11]. They are, however, not commonly available for the general radiobiologists, non-dosimetry specialists like us. Pre-selection of TLD chips is usually needed to reduce the statis-

tical errors of the measurements by TLD. The statistical errors for reading the values of a TLD inserted into abdomen of mice were reported to be less than 3%[2]. For measurements by the PLD examined here, without the pre-selection of the glass chips, we obtained data with the statistical errors comparable to, or better than, the best values obtained with TLDs.

The present results clearly demonstrate that the PLD system used here is the most suitable system for measuring the absorbed doses in mice. Using the relevant ^{137}Cs calibration factors of the PLD system used here, the readout would also be interpreted in terms of the organ doses. Consequently, a PLD system consisting of a small-scale one-element glass detector and a commercially available readout system is a suitable dosemeter system for use in the measurements of the absorbed dose in the bodies of mice exposed to γ-radiation. In comparison with other dosemeter systems, the PLD system should offer a low uncertainty of measurement in the 10 μSv dose range. Combined with the remarkable long-term stability of the PLD system (Fig. 4), longer monitoring periods of one month could be used to detect low levels of exposures in individual mice monitoring.

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