Flexible sheet with radiophotoluminescence glass beads for remotely monitoring high beta-surface-contamination

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Abstract

A flexible sheet was made with radiophotoluminescence (RPL) glass beads on an experimental basis for visualization of high beta-surface-contamination. A simple RPL observation system for remote contamination monitoring was constructed with a homemade UV floodlight and a commercially available digital camera with supplementary optical lenses and filters. In preliminary experiments, RPL images were well observed with the digital camera of the present system. Their precise RPL intensity was determined after the correction of nonlinear response of the camera. It was expected from experiments that RPL images of beta-surface-contamination could be quantitatively evaluated through calibration, i.e., the conversion of camera images to dose data on the sheet-type glass dosimeter.

Keywords: Radiophotoluminescence, sheet-type glass dosimeter, digital camera, UV floodlight, beta-surface-contamination, visualization

1. Introduction

In Japan, a large amount of radioactive materials has been released from the Fukushima Daiichi nuclear power plant in March, 2011. Now three years after the Fukushima disaster, monitoring of the contamination due to radioactive cesium has been required for the reduction of radiation exposure of workers who are engaged in the decommission of the broken nuclear reactors.

Radiophotoluminescence (RPL) of silver-activated metaphosphate glass (glass dosimeter) is well known to be proportional to absorbed dose (Piesch et al., 1986). Moreover, glass dosimeters have advantages of less fading effect compared to thermoluminescent dosimeters (Hsu et al., 2006) and of reliable repeatability for dose measurement (Maki et al., 2011a). Glass dosimeters in the shape of a rectangular plate or a rod are generally used for personal dosimetry and environmental monitoring. Also, spherical RPL glass dosimeters have been developed for use in radiotherapy (Nakagawa et al., 2007). Recently, bead-type RPL glass dosimeters, of which diameter is around 0.1 mm, have been successfully developed by means of melting-cooling method (Sato et al., 2013). In this study, we have developed a new sheet-type glass dosimeter for visualization of beta-surface-contamination by bonding micro-size RPL glass beads to a flexible backing sheet. Such a flexible sheet is expected to be useful for the visualization of high beta-surface-contamination (radioactive cesium) through the covering with the sheet and its subsequent RPL excited by an ultraviolet (UV) floodlight. The sheet-type dosimeter responds more sensitively to beta-rays from surface contamination directly under the sheet than to gamma radiation, which is favorable for the observation of the distribution of surface contamination due to radioactive cesium. Also, excellent characteristics of glass dosimeters, i.e., their long term stability and reliable repeatability are suitable for this purpose.

A commercially available digital camera with supplementary optical lenses and filters and a set of UV LEDs as an excitation light source have been prepared for the observation and visualization of beta-surface-contamination. In addition to the remote contamination observation, this system enables to analyze detailed beta-radioactivity distribution by taking the sheets back. At first, this paper describes a new sheet-type glass dosimeter system for the observation of beta-surface-contamination and then shows preliminary experimental results on its characteristics.

2. Materials and methods

Silver-activated metaphosphate glass was prepared for the production of RPL glass beads. The details of the production process have been described in our previous paper

(Sato et al., 2013). The median diameter of produced RPL glass beads was 180 μm . Such beads were uniformly bonded to a thin aluminum sheet with acrylic adhesive. The surface density of glass beads on the sheet was about 0.02 g/cm².

Fig. 1 shows a schematic drawing of the whole system for the observation of an RPL image on a sheet-type glass dosimeter. The system consists of a digital camera (EX-F1, Casio) and a floodlight made of 100 UV LEDs (NS365L-5RLO, Nitride Semiconductor). Radiant power of the UV LED ranges from 2.4 mW to 6.0 mW. The distance between the floodlight and the sheet-type glass dosimeter was fixed to 35 cm. In the observation of RPL images, two optical long pass filters (Y-52, R-60, Hoya) were set to the camera for the efficient reduction of background light. This type of LED has high directivity of which half-power angle is 10°, which is used to an advantage in uniform excitation of the sheet-type glass dosimeter at a far position. Camera images of RPL of sheet-type glass dosimeters were taken under fixed photographing conditions (e.g. shutter speed, f-number). Also, a set of microscopic optical lenses was mounted on the camera in case of imaging with high resolution. The removal of the microscopic optical lenses from the camera enables wide view imaging, though spatial resolution deteriorates. A personal computer was used for shutter control of the camera and for image processing as mentioned later.

Brightness of camera images was measured by use of a light power meter and a red LED, of which wavelength is close to that of RPL of the glass dosimeter. **A non-linear response of the camera** was corrected from the comparison between light intensity measured with the optical power meter and brightness of images taken by the camera.

In order to examine the characteristics of the present system, a sheet-type glass dosimeter was irradiated with X-rays through a copper mesh and its RPL was observed with the present system. Observed RPL images were analyzed for the examination of the sensitivity, uniformity, resolution and others of the RPL observation system.

3. Results and Discussions

Fig. 2 shows camera images of a sheet-type glass dosimeter which were observed with the present system. The sheet-type glass dosimeter was irradiated with X-rays (~10 Gy) through a #50 mesh of copper wires of which diameter was 0.2 mm. Fig. 2 (a) shows an image taken with the system on which a set of the microscopic optical lenses was mounted. Fig. 2 (b) represents an image taken with the system to which the long pass optical filters were added under UV light excitation. The position of the copper wires was recognizable in the image. It was confirmed from these images that RPL photons from the sheet-type glass dosimeter were clearly detected and their distribution

could be visualized with the present system.

Fig. 3 shows a similar RPL image taken with the present system 35 cm from the dosimeter without the microscopic optical lenses. Fig. 4 shows a schematic drawing of the arrangement of X-ray irradiation for a sheet-type glass dosimeter. The sheet was irradiated with X-rays (~10 Gy) through an 8 mm $\varnothing$ collimator and a #50 mesh of copper wires of which diameter was 0.2 mm as shown in Fig. 4. Absorbed dose of the glass beads was calculated by comparison with similar glass samples irradiated with a standard X-ray source. (Maki et al., 2011b). It was confirmed that RPL photons were detected even without the microscopic optical lenses and the digital camera could be used as an RPL detector.

In order to evaluate RPL intensity on the basis of data on camera images, full-color camera images were converted to 8-bit gray scale image data, which was based on the R (Red) component. Consequently, RPL distribution was visualized with the image processing. Also background images of the same sheet without X-ray irradiations were observed under the same photographing conditions, and then data on RPL intensity were obtained from the difference in average brightness between images of irradiated and non-irradiated cases. Moreover, correction for non-linearity of the camera response was done according to the procedure described in the former section.

Fig. 5 shows an example of the relation between absorbed dose of the glass beads in the sheet and its relative RPL intensity measured with the present system. The dose of the sheet-type dosimeter was controlled with X-ray irradiation time. In Fig. 5, circles and triangles indicate corrected and uncorrected RPL intensity, respectively. It was confirmed from the figure that RPL intensity measured with the present system was approximately proportional to absorbed dose above 2.5 Gy in case the correction on the nonlinear response of the camera was performed.

Fig. 6 shows a profile of RPL brightness on line A in Fig. 3. A striped pattern of RPL brightness due to the copper mesh is distinguishable, so that the spatial resolution of the system is considered to be roughly less than 0.2 mm under the present condition. Fig. 5 also shows that the RPL intensity of the sheet varies with its position. This result seems to be because of the unevenness of the size and shape of glass beads and of their arrangement, and the variation in sensitivity was evaluated to be about 40% from difference between maximum brightness and average brightness on irradiated area.

The observable range of radioactive-contamination level or radiation dose depends on operation conditions of the system, e.g. shutter speed of the camera, intensity of UV light excitation and others. Optimization of these conditions are needed according to the

degree of beta surface contamination and experiment environments.

4. Conclusion

The flexible sheet-type glass dosimeters for the visualization of beta-surface-contamination were made through the bonding of RPL glass beads to thin aluminum sheets with acrylic adhesive. Moreover, a remote RPL observation system was constructed by use of a digital camera with supplementary optical lenses and filters and a homemade UV floodlight for visualization of beta-surface-contamination. In the preliminary experiments, RPL images were well observed with the present system, and moreover it was expected that distribution of beta-surface-contamination could be quantitatively evaluated through the conversion of camera images to RPL intensity distribution on the sheet-type glass dosimeter. In order to finally evaluate radioactive cesium surface-contamination density, further calibration experiments or calculations are needed on the relation between the dose of the sheet-type glass dosimeter and surface-contamination density.

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Figure captions

Fig. 1 Schematic drawing of observation system for RPL on sheet-type glass dosimeter.

Fig. 2 Images of sheet-type glass dosimeter.

Fig. 3 RPL image of sheet-type glass dosimeter irradiated with X-rays through #50 copper mesh.

Fig. 4 Schematic view of X-ray irradiation system together with collimator and mesh.

Fig. 5 Relation between absorbed dose of the glass and relative RPL intensity measured with the present system.

Fig. 6 Brightness profile on line A in Fig. 3.

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6