Visualization of dose distribution inside soft X-ray machine based on OSL technology

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Abstract. In this study, as a part of the development of the radiation mapping technology, we are planning to develop the gamma-ray imager based on a passive detector such as a dosimeter. For this purpose, we demonstrated the use of nanoDot OSLD as a passive detector being irradiated inside a soft X-ray machine then combined the irradiation position (qualitatively) with radiation dose (quantitatively) for visualization purpose. The experimental results showed that the NanoDots exhibit good linearity and reproducibility when subjected to soft X-rays machine, Hence, the nanoDots showed a promising potential for visualization of dose distribution.

1. Introduction
The accident in Fukushima Daiichi Nuclear Power Plants on 11 March 2011, release a large number of radionuclides to the atmosphere[1], [2]. Very large amounts of radionuclides were detected from measurements inside the reactor buildings (mainly $^{137}$Cs and $^{134}$Cs)[3]. Therefore, to execute decommissioning tasks in the reactor buildings, radiation distribution measurements inside the buildings are necessary[4].

However, with the large amounts of radionuclides inside the reactor building, it is difficult to obtain information about radioactive distribution in this area because of the high-intensity radiation fields. The use of spectrometers or area monitors with active detectors is useless, they are not always working, easy to be broken and not resilient to high-intensity fields[5].

An integral type of gamma-ray imager based on Optically Stimulated Luminescence (OSL) technology is proposed[6]. OSL is a radiation measurement technique that uses the ability of OSL materials like Al$_2$O$_3$:C to store absorbed dose and then release it as light when stimulated with another light source having the appropriate wavelength[7].

The main purpose of the research is the development of gamma visualization technology based on OSL technology as a part of the development of the radiation mapping technology for the 1F decommissioning. Therefore, as the first phase of the proposed technique, this paper will present the visualization of dose distribution inside a soft X-ray machine by using OSL Dosimeter.

2. Materials and methods
OSL nanoDot dosimeters were purchased from Landauer, Inc. Following exposure through the irradiation process with a soft X-ray machine thus OSLD-absorbed doses were measured on a light photon counter (MicroStar InLight Reader, Landauer, Inc.).

2.1. Landauer NanoDot
The OSLDs used in this study were the Al2O3:C nanoDot manufactured by Landauer Inc. (Landauer Inc., Glenwood, IL). Each nanoDot is comprised of a retractable disk with an active Al2O3:C material inside a light-tight plastic casing and a unique barcode for easy identification. The plastic casing measures 1 x 1 x 0.2 cm³ seen in Figure 1. The casing has a density of 1.03 g/cm³. The casing is to ensure that no signal depletion occurs due to outside light exposure. The active Al2O3:C material is 5 mm in diameter and 0.2 mm thick.

Before use, the dosimeters are annealed to remove trapped charges. The reproducibility of this annealing regimen is especially important to ensure accurate dosimetry[8].

2.2. Microstar Reader

The microStar reader developed by Landauer, shown in Figure 2 is used to read nanoDot OSLDs. A single nanoDot was loaded onto the holder and placed inside the pull out drawer. A light-tight environment was produced once the drawer was closed to ensure no light leakage into the reader that may perturb the readout or damage the photomultiplier tube (PMT). Once inside the reader, the knob was turned causing the reader to push the nanoDot disc out of the cassette and in between the LED array and PMT. Instead of heating, the dose readout is performed by controlled illumination of the dosimeter with 540-nm light photons[9,10,11]. OSLDs can be read with either continuous wave optically stimulated luminescence (CW-OSL) or pulsed optically stimulated luminescence (POSL). POSL readers are more accurate because the emission photons are only read between stimulation pulses; however, they are costlier and less portable. In this experiment, MicroStar InLight reader with continuous-wave optically stimulated luminescence (CW-OSL) is used. Exposed OSLD were analyzed within 24 hours after radiation exposure.

For the readout procedure, the microStar required a warm-up period of at least 30 minutes prior to reading any OSLDs. Once all of the OSLDs were read, the data obtained from the reader was recorded on a personal computer and can easily be exported for further analysis.
2.3. Irradiation Equipment
The X-ray machine we were using for this experiment are from SOFTEX M-60W (60 kV, 20 mA) from SOFTEX Corp., Ebina-shi, Kanagawa, Japan (Figure 3). This X-ray machine is categorized as soft X-ray machine, with a purpose mainly for irradiation living cells such as microbiology.

![Figure 3. SOFTEX M-60W soft X-ray machine.](image)

All experiment in this research was carried out with the same setup. All OSLD nanoDots were exposed to 60 kVp and 2.5 mA x-ray beam for 1-minute duration with a source and dosimeter distance varied from 5 to 35 cm.

2.4. OSL Optical Annealer
Optical Annealer was used to remove the residual signals of the dosimeters after readout. This optical bleaching was done with light exposure to OSLDs after the readout to reset the OSLD for reuse. Figure 4 shows the OSLDs placed inside the Optical Annealer during optical bleach. The OSLDs were kept for optical bleaching to get the signal almost equal to the background signal, and the annealing time of 6 hours was found to be sufficient enough for this process.

![Figure 4. Optical Annealer for the bleaching process of OSLD.](image)

3. Result and discussions
In this experiment, we are using total of 434 pieces of nanoDot. Each of them are measured before and after irradiation.
3.1. Experimental result

We have prepared 45 x 45 cm size of paper for placing nanoDot dosimeter with a 2.5cm distance for each. Figure 5 shows the nanoDot array setup for the experiment.

![Figure 5. Two types of OSL dosimeter setup.](image)

To get an overview of the distribution, at first we use only 4 lines of nanoDot (73 pieces). From the experiment result, we estimate the dose distribution inside SOFTEX M-60W x-ray machine is rather to the left side (not centrally distributed) as depicted in Figure 6.

![Figure 6. Surface measurement result (4 lines).](image)

And to confirm the detail of the dose distribution based on the previous result, 19 lines of nanoDot (361 pieces) are prepared and arranged for irradiation setup. The proper result of the experiment is shown in Figure 7.
Figure 7. Surface measurement result (19 lines)

The graph shown in figure 7, is using 'Heat Map' mode from data analysis software. Later we changed the mode to 'Contour mode' to see the irradiation direction clearly. The result is shown in Figure 8.

Figure 8. Surface measurement result in ‘Contour mode’.

3.2. X-ray beam exposure distribution

SOFTEX M-60W has 3 irradiation position as shown in figure 3 chapter 2. Therefore, we carried out the experiment on every position to get an overview of the x-ray dose distribution. Here is the result for each position of the detection layer as depicted in Figure 9.
3.3. Discussion

The information of x-rays dose distribution inside the x-ray machine is necessary for irradiation purposes on the plate for future experiments. Therefore in 2012, The first experiment was conducted using an active device such as RAMTEC Smart type high precision dosimeter (reference dosimeter) with N30013 type waterproof Farmer chamber with the result shown as depicted in Figure 10.
Figure 10. Experimental result of x-ray dose distribution conducted in 2012.

Based on the result of the previous measurement, we try to do the same measurement using OSL nanoDot for visualization purposes. This experiment, as a part of the development of radiation mapping using a passive detector also shows a good result (Figure 8.). The comparison between current and previous measurements shows a good result as depicted in Figure 11.

Figure 11. Comparison of dose distribution measurement result : (a). in 2012, (b). in 2018

4. Conclusions
As a part of the development of the radiation mapping technology for the 1F decommissioning, we performed an experimental study on the visualization of dose distribution inside the x-ray machine based on OSL technology. Thus, to determine an x-rays dose distribution inside the x-ray machine, we were using a passive device such as OSL nanoDot at different irradiation positions. By combining the irradiation position (qualitatively) with radiation dose (quantitatively), we were able to visualize the radiation dose distribution inside soft X-ray machine.

To ensure the correctness of the method, we compared the experimental result with the previous measurement that used an active device such as RAMTEC high precision dosimeter. Based on the comparison between two experimental results it shows that there is no significant difference. Based on that fact, it can be concluded that the measurement using passive device OSL NanoDot dosimeter is feasible compared to the measurement using an active device such as RAMTEC high precision dosimeter. Also the OSL nanoDot, as a personal dosimeter normally worn by a person being monitored, are capable to measures beam exposure in-unit mGy/min per cm².

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