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Signal Measurement Experiment of a 3D-Printed Skin Imitation Layer with an Anthropomorphic Phantom

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1. Introduction

The ICRP (International Commission on Radiological Protection) recommends evaluating the basal layer of the skin in cases of local radiation exposure accidents. As shown in Figure 1, the basal layer is located 70 µm below the epidermis surface and has a thickness of 50 µm [1,2,3].

However, current retrospective dosimetry methods do not accurately account for the posture of exposed individuals or the structure of human skin tissue. Consequently, a local skin dose evaluation system, fabricated using both a 3D printer and a 3D scanner to replicate the skin tissue structure and the victim's hand shape, has been proposed [4].

In this study, the overall components of the local skin dose evaluation system prototype are introduced, and determine whether the signal measurement results of the system exhibit linearity over measurement time.

2. Methods and Results

2.1 Configuration of the Local Skin Dose Evaluation System

The local skin dose evaluation system can be broadly divided into a measurement unit that generates a scintillation signal by radiation and a signal processing unit that converts the scintillation signal into an electrical signal.

The measurement unit is composed of a skin imitation layer fabricated by a DLP 3D printer (IMD-C, Carima™), and an anthropomorphic phantom and light guide fabricated by an SLA 3D printer (Form 3®, Formlabs©). A collimator (RCR25P-P01, Thorlabs) and optical fiber (FP1000URT, Thorlabs) are also part of the system.

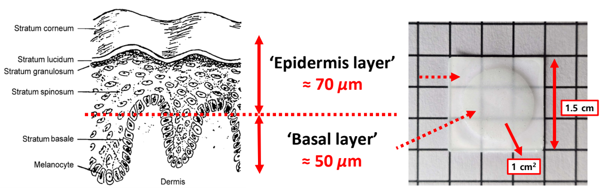

Fig. 1. The skin tissue structure presented by the ICRP and the 3D-printed skin imitation layer.

The skin imitation layer is composed of a skin epidermis imitation layer (CUKM25W, Carima™) that is 70 µm thick and a basal layer imitation layer (3D-printed plastic scintillator resin) that is 50 µm thick, as shown in Figure 1 [4]. Additionally, the shape of the anthropomorphic phantom was designed to imitate the shape of the exposed individual's hand at the time of the accident, as shown in Figure 2, using a hand-held 3D scanner (GO!SCAN 3D™, CREAFORM).

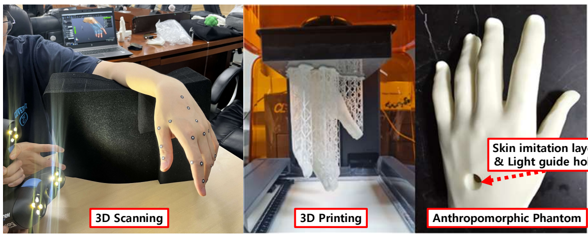

Fig. 2. The anthropomorphic phantom created using a 3D scanner and 3D printer.

The skin imitation layer and light guide were attached by curing transparent resin (V4 Clear, Formlabs©) used for light guide fabrication, instead of the commonly used silicone optical grease. The light guide, collimator, and optical fiber were positioned inside the anthropomorphic phantom to transport the scintillation signals emitted from the skin imitation layer to the signal processing unit.

The signal processing unit is composed of a PMT (H7422-40, Hamamatsu), an electrometer (6517A, Keithley), and a power supply (C8137-02, Hamamatsu).

Figure 3 shows the local skin dose evaluation system prototype, which is assembled by combining all the measurement unit and signal processing unit components.

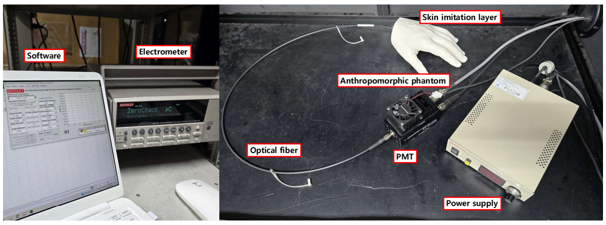

Fig. 3. The fully established local skin dose evaluation system prototype.

2.2 Signal Measurement Test of the Local Skin Dose Evaluation system prototype

To conduct the signal measurement evaluation of the local skin dose evaluation system prototype, an experimental setup was created as shown in Figure 4. The scintillation signals emitted from the skin imitation layer were converted into cumulative charge signals by the PMT and electrometer. This approach is intended to secure cumulative dose data in future research.

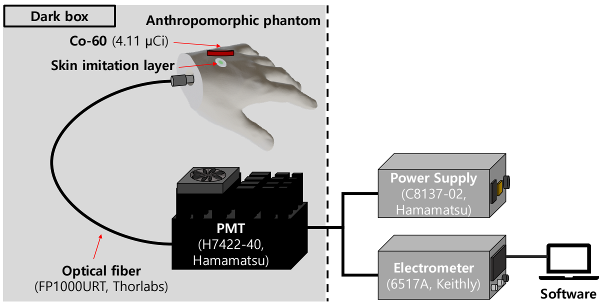

Fig. 4. Schematic diagram of the signal measurement experiment for the local skin dose evaluation system prototype.

The signal measurement was performed using a Co-60 (4.11 μCi) radiation source. In the laboratory experiment environment, the measurement time was varied for each test to confirm whether the cumulative charge measurements increase linearly according to the dose of the check source applied to the skin imitation layer.

Background noise and Cherenkov signals were measured separately to obtain the actual scintillation signals using the subtraction method. Each measurement was repeated three times to ensure reliable experimental results.

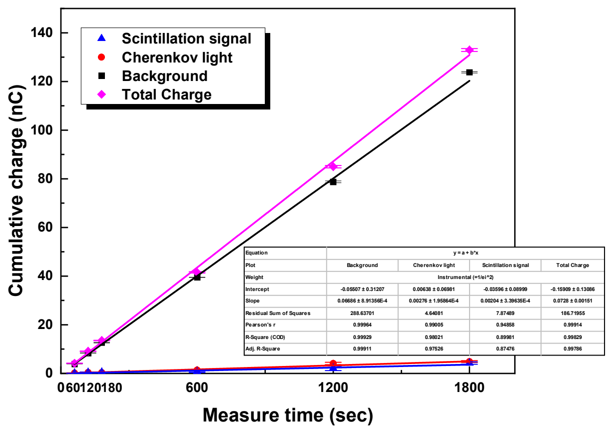

Fig. 5. Signal measurement experiment results of the local skin dose evaluation system prototype.

As shown in Figure 5, the R^2 value of the scintillation signal was 0.89981. For the Co-60 measurement, the average ratio of the background signal was 93.22%, the Cherenkov signal was 3.95%, and the plastic scintillator signal was 2.83% of the total cumulative charge signal.

3. Conclusions

This study aimed to determine whether the signal measurement results of the local skin dose evaluation system prototype exhibit linearity over measurement time. The system was composed of a skin imitation layer, an anthropomorphic phantom, and a light guide, all fabricated using a 3D printer. Additionally, various components for signal transport and processing, such as a collimator, optical fiber, a PMT, and an electrometer, were also included in the system.

The signal measurement tests of the local skin dose evaluation system prototype indicated reliable signal linearity over time. The actual signal from the skin imitation layer accounted for 2.83% of the total signal, and the R^2 value of the scintillation signal was 0.89981.

In future work, signal measurement evaluation experiments will be conducted using an X-ray source and radioisotopes to derive a dose conversion curve based on the cumulative charge obtained by the local skin dose evaluation system prototype. This curve will allow the local skin dose evaluation system prototype to be used for new retrospective dosimetry method based on cumulative dose evaluation, similar to TLD (ThermoLuminescent Dosimeter) or EPR (Electron Paramagnetic Resonance).

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