Development of local skin dose evaluation system using 3D-printed plastic scintillator imitating skin layer

Han Cheol Yang [a], Kihong Pak [a], Seung Beom Goh [a], Young Ho Roh [a] and Yong Kyun Kim [a*]
[a]*Department of Nuclear Engineering, Hanyang University, Seoul, Korea*
[*]*Corresponding author: ykkim4@hanyang.ac.kr*

***Keywords :** Plastic scintillator, 3D printing, retrospective dosimetry,

1. Introduction

Workplaces that involve the use of high-level radioactive sources, such as in non-destructive testing or semiconductor defect inspection, always carry the risk of radiation exposure accidents. In local radiation exposure accident that exceeds the permissible dose limit, an evaluation of the exposed dose should be conducted. Currently, several methods such as computational simulation, chromosomal aberration tests, and EPR (Electron Paramagnetic Resonance) are used as retrospective dosimetry methods. [1] However, there has been no case of using customized phantom that reproduces the accident situation for retrospective dosimetry. This study is a basic study for skin imitation layer fabrication using a 3D printed plastic scintillator for the development of a local skin dose evaluation system. A thin scintillator layer which imitating the thickness of skin basal layer and tissue equivalent phantom layer were produced, and the results of absorption dose evaluation for gamma radiation sources were described

2. Methods and Results

2.1 Fabrication of skin imitation layer using 3D printing

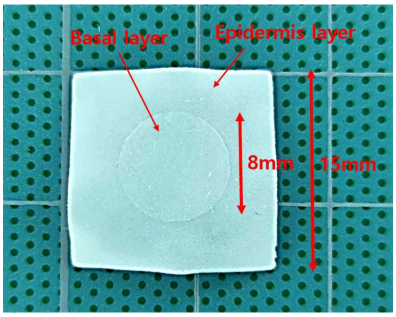

Fig. 1. Basal layer (plastic scintillator) & Epidermis layer (tissue-equivalent resin)

The deterministic effect on the skin is caused by the death of basal layer cells in the epidermis. [2] Hence, by imitating the basal layer of the skin using plastic scintillators, it is possible to evaluate the locally deposited radiation dose. The plastic scintillator was fabricated using a DLP-based 3D printer (IMD, Carima) with resin, which composed of D0241(monomer), PPO (primary-dye), TPO(photo-initiator) and ADS086BE (wavelength shifter).[3] The thickness was set to 50 µm, the average thickness of the basal layer.[4] The epidermal layer, including the stratum spinosum, which is 100 µm thick, was made using commercially available 3D printing resin (CUKM25W, Carima), with a composition similar to that of the skin. In order to attach the two layers, the epidermal layer was first manufactured, and then the basal layer was manufactured by adjusting the zero point of the 3D printer. Manufactured products are shown in Fig. 1.

2.2 Thickness measurement of skin imitation layer

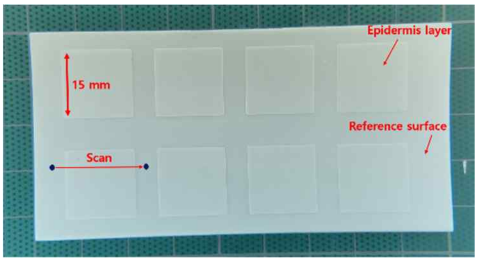

Fig. 2. Epidermal layer imitation samples for thickness measurement

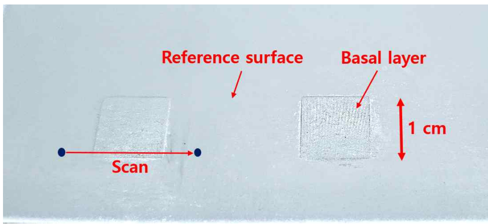

Fig. 3. Measurement method of thickness of basal layer imitation sample

The thickness accuracy of the fabrication was evaluated using a surface profilometer (Dektak-XT, Bruker). To prevent any sample displacement due to the tip of the instrument and enhance measurement accuracy, a reference surface made of CUKM25W was fabricated together under each sample (Fig. 2, Fig. 3). After scanning a total of 20 mm(epidermis) and 14 mm(basal) from the left reference plane to the right reference plane of the samples, both 1 mm of reference planes were set as leveling points to show a thickness of sample. (Fig. 4, Fig. 5)

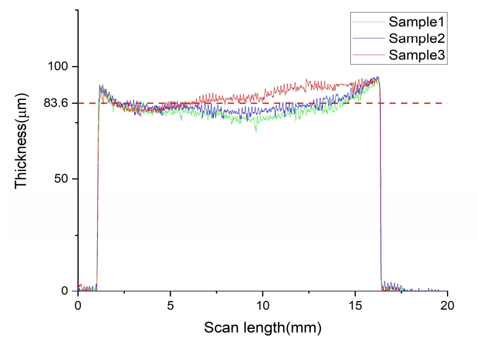

Fig. 4. Epidermis layer thickness measurement results

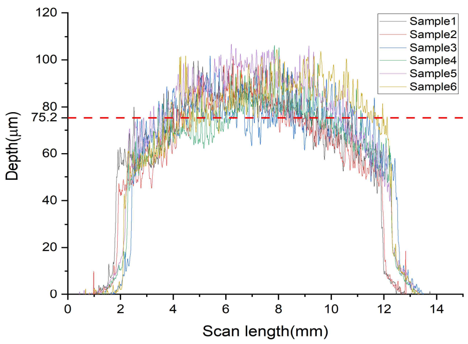

Fig. 5. Basal layer thickness measurement results

The measurement results indicated that the average thickness of the epidermal imitation layer was approximately 83.6±4.7 μm, while the average thickness of the basal layer made by plastic scintillators was approximately 75.2±12.9 μm. These outcomes were influenced by the over-curing of the plastic scintillator resin. Not only can this phenomenon be improved in the future, but in actual dose measurements, values can be corrected through computer simulations.

2.3 Absorbed dose evaluation using skin imitation layer

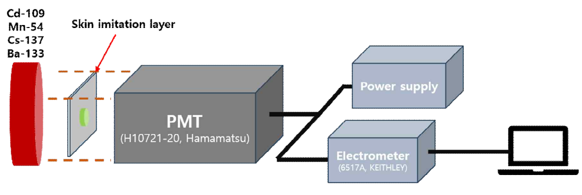

Fig. 6. Schematic diagram of a radiation dose measurement system using a skin imitation phantom

In order to validate the applicability of the manufactured basal layer scintillator, a system was set up to detect radiation. (Fig. 6) Cumulative charge values were obtained by measuring for one minute with each of four gamma sources and background. The result shows difference in values from between the background and sources, indicating the ability to measure the radiation dose by the basal layer scintillator (Table I). And the difference in this value can get bigger as more doses are exposed. If the relationship between the irradiation dose and signal yield is derived in the future work, it could serve as a skin dosimetry tool.

Table. I: Results of absorbed dose collection through a basal layer imitated scintillator

Source	Gamma energy (keV)	Activity* (kBq)	Coulomb (nC)	Ratio (%)
Background	-	-	12.34 ± 0.09	100
Cd-109	88.03	340.45	28.17 ± 0.92	228.2
Mn-54	834.85	315.30	12.41 ± 0.10	100.5
Cs-137	661.66 174.32(β)	357.75	39.14 ± 0.75	317.1
Ba-133	356.01 81.00	248.61	36.32 ± 0.46	294.2

*Theoretical value

3. Conclusions

The method of retrospective dosimetry has been discussed in relation to the fabrication and application of a localized radiation dose assessment system. Using 3D printing, a skin imitation layer which consists of plastic scintillator as basal layer and tissue-equivalent resin as epidermis layer with a total thickness of 150 μm was created, and the thickness as well as the radiation response of the fabricated layer was evaluated. By refining the 3D printing fabrication and post-processing procedures in the future, the thickness can be brought closer to the theoretical value. Finally, by integrating the signal transport system with proposed product, a local dose evaluation system can be established, which can provide auxiliary assistance in retrospective dosimetry.

REFERENCES

[1] Fattibene, Paola, et al. "Reflections on the future developments of research in retrospective physical dosimetry." Physics Open 14 (2023): 100132.
[2] ICRP, 2012 ICRP Statement on Tissue Reactions / Early and Late Effects of Radiation in Normal Tissues and Organs – Threshold Doses for Tissue Reactions in a Radiation Protection Context. ICRP Publication 118. Ann. ICRP 41(1/2).
[3] KIM. D. G *et al.,* "Scintillation light output of 3D printed plastic scintillators," Trans. of the Korean Nuclear Society Spring Meeting. 2018. p. 1-2
[4] ICRP, 1981. Limits for Inhalation of Radon Daughters by Workers. ICRP Publication 32. Ann. ICRP 6 (1).

ACKNOWLEDGEMENTS

This work was supported by the Nuclear Safety Research Program through the Korea Foundation Of Nuclear Safety(KoFONS) using the financial resource granted by the Nuclear Safety and Security Commission(NSSC) of the Republic of Korea. (No. RS-2023-00242425)