Feasibility Study of the Application of Local Skin Dose Assessment System by Using 3D-Printed Plastic Scintillator

Seung Beom Goh[a], Kihong Pak[a], Han Cheol Yang[a], Jae Chang Kim[a], Yong Hyun Kim[a], Jae Young Jeong[a],
Junehyung Bernaski[a], Chan Jung Kim[a], Yong Kyun Kim[a*]
[a]Nuclear Engineering, Hanyang Univ., 222, Wangsimni-ro, Seongdong-gu, Seoul, 04763, Korea
[*]Corresponding author: ykkim4@hanyang.ac.kr

***Keywords :** Local skin dose assessment, Monte Carlo simulation, ICRP report, 3D-printed plastic scintillator

1. Introduction

When radiological accidents occur, the skin is frequently exposed in the majority of instances, and it is an organ where deterministic effects often occur with highly affected on skin basal layer.

Based on the threshold doses for deterministic effects presented in reports such as ICRP Publication 118, physician can assess the severity of a radiation exposed patient's symptom and prepare appropriate medical responses in accordance with the determined thresholds.

Therefore, assessing the locally exposed dose on the skin is crucial for appropriate measures regarding the exposed area. However, current dose assessment techniques are focus on major organs rather than local area on the skin. Moreover, using a current dose assessment device such as TLD with high effective atomic number for assessing local radiation dose does not consider the geometry of the exposed area, potentially leading to inaccurate dose assessment results.

To address this issue, a methodology of local skin dose assessment with a 3D-printed plastic scintillator which can meet a thickness of the basal layer (50-150 μm) was proposed. Furthermore, this scintillator is integrated with a human phantom which fabricated by 3D scanning and 3D printing technologies.

Consequently, this innovative approach can improve accuracy of local skin dose assessment using by anatomical geometry. Prior to the actual system development, we assessed the feasibility of the 3D-printed plastic scintillator for imitating basal layer.

In this paper, dose conversion coefficients of the developed scintillator for local skin dose were derived using ICRP simple cube model. Furthermore, absorbed dose to the skin and the scintillator in a representative radiation exposure scenario were estimated using Monte Carlo simulations.

2. Methods and Results

2.1 Monte Carlo Simulation Methodology

In ICRP Publication 116 [1] dose conversion coefficients for alpha, beta, and gamma radiation were derived through Monte Carlo simulations. Notably, for radiation types such as alpha and beta particles, which can exert significant deterministic effects even when localized to the skin, special dose conversion coefficients [pGy cm^2] for the skin were determined. These coefficients were derived using a simple cube model geometry that simulates a 50 μm thick with 1 cm^2 area of the basal layer.

We aimed to establish the reliability of our simulation by reproducing the dose conversion coefficients presented by ICRP using MCNPX version 2.7.0. To achieve this, we compared the dose conversion coefficient data calculated for the basal layer and the 3D-printed plastic scintillator, respectively, with the dose conversion coefficient data provided by ICRP.

However, since there are only photon dose conversion coefficients that derived by ICRP/ICRU reference voxel phantom in ICRP 116, the photon dose conversion coefficients for skins and scintillators were derived using the same methodology as alpha and beta radiation (simple cube model). The simulation geometry and dose conversion coefficient comparison graphs (alpha, beta, gamma) are shown in Figure 1.

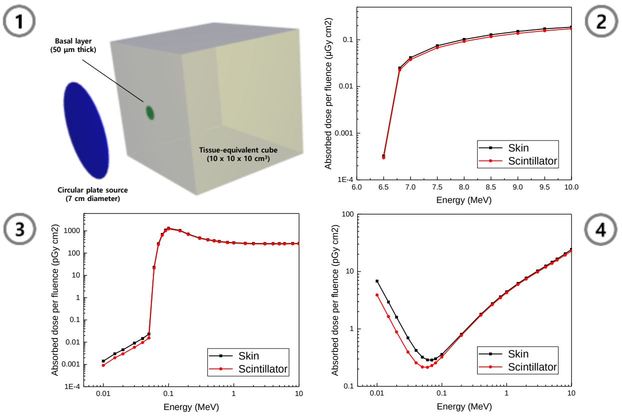

Fig. 1. (1) Simple cube model geometry and dose conversion coefficients for (2) alpha (3) beta and (4) gamma radiation as presented by ICRP, these reproduced dose conversion coefficients for basal layer and 3D-printed plastic scintillator.

It was found that the maximum difference between the skin model and the scintillator is 22%, and the discrepancies increase in the energy range below 0.1 MeV (β, γ). The discrepancies are due to the differences in the material compositions of the skin and the scintillator, as shown in Table 1. However, the trends of our calculated results align closely with those presented by ICRP and thus, we regard as our simulation to be reasonably reliable.

2.2 Establishing Local Exposure Scenarios

Prior to MCNPX simulation, accident scenarios were formulated based on past radiation exposure incidents.

This scenario involves prolonged radiation exposure to an operator's skin during the course of defect inspection of electronic devices using an X-ray generator (100 kVp, 0.1 mA). The operator intentionally bypassed interlocks and continued the inspection of samples, resulting in skin exposure over 100 hours. The corresponding scenario situation presented in Figure 2.

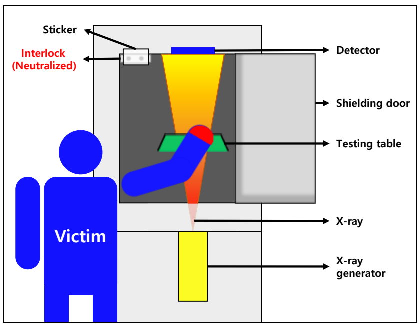

Fig. 2. Schematic representation of the X-ray generator radiation exposure accident scenario.

Based on this accident scenario, we conducted dose assessments for both the skin and the 3D-printed plastic scintillator, and subsequently compared the results of each assessment.

2.3 Accident Scenario Simulation Result

For dose assessment of the basal layer, we positioned the simple cube model, as suggested by ICRP. On top of the collimator of the X-ray generator. Subsequently, we utilized the F6 tally for the basal layer and the 3D-printed plastic scintillator. The energy spectrum of the emitted X-rays from the X-ray generator is presented in Figure 3 [2].

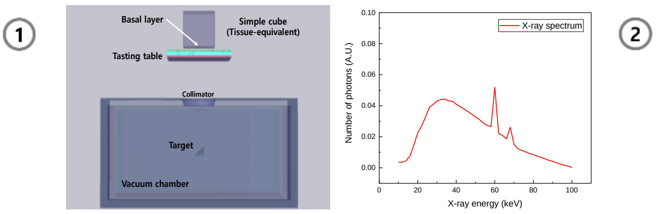

Fig. 3. Simulation geometry of X-ray generator (1), Energy spectrum of X-rays in MCNPX simulation (2).

The statistical uncertainties in all calculation results were less than 6%. the absorbed dose values calculated for the basal layer and the 3D-printed plastic scintillator were compared as shown in Table 1.

Table 1. Absorbed dose values for basal layer and 3D-printed plastic scintillator of the basal layer derived from Monte Carlo simulations.

	Absorbed dose (Gy)	Dose ratio	Material elements
Skin (ICRP) [3]	23.9	1.00	H, C, N, O, Na, Mg, P, S, Cl, K, Ca, Fe, Zn
Scintillator	19.4	0.81	H, C, N, O

As shown in Table 1, the difference in absorbed dose values between the basal layer and the simulated 3D-printed plastic scintillator is derived to be 19%. This difference in absorbed dose can be compensated by introducing a dose compensate factor and comparing with other dosimetry methods. Consequently, the 3D-printed plastic scintillator imitating the basal layer can be used to develop a local skin dose assessment system.

3. Conclusions

The feasibility of utilizing the simulated 3D-printed plastic scintillator for the basal layer in conducting localized skin dose assessment was investigated through MCNPX simulations. The simulation results indicated an absorbed dose difference of 19% when compared to actual skin. The difference in absorbed dose between the two materials is due to the composition of their constituent elements, as indicated in Table 1. Through further research, introducing factors that allow the conversion of absorbed dose values from the simulated 3D-printed plastic scintillator to actual local skin absorbed dose could lead to even more accurate dose assessment.

In future work, the local skin dosimetry system will be fabricated and utilized for the actual skin dose measurements in order to verify the applicability.

REFERENCES

[1] ICRP, 2010. Conversion Coefficients for Radiological Protection Quantities for External Radiation Exposures. ICRP Publication 116, Ann. ICRP 40(2-5).

[2] Madhava Bhat et al. “Diagnostic X-ray spectra: A comparison of spectra generated by different computational methods with a measured spectrum”, Medical Physics, Vol. 25, p. 114, 1998.

[3] Detwiler, Rebecca S., et al. Compendium of material composition data for radiation transport modeling. No. PNNL-15870 Revision 2. Pacific Northwest National Lab.(PNNL), Richland, WA (United States), 2021.

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)