CONFORMAL AND CUSTOM RADIATION SHIELDING COMPOSITES FOR HUMAN EXTREMITY PROTECTION ENABLED BY NON-PLANAR ADDITIVE MANUFACTURING

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Key Words: Fused deposition modeling, radiation shielding, composite materials, hybrid additive manufacturing

Fused Deposition Modeling (FDM) is one of the most used methods for realizing additively manufacturable radiation shielding. Polymers, with their low average atomic number (Z) and high hydrogen content, are effective neutron moderators and form the matrix of FDM composite filaments. Filler materials for these composite filaments include high-Z materials like tungsten or tantalum for gamma radiation shielding or boron or cadmium compounds for thermal neutron absorption. Radiation workers handling radioactive material within shielded gloveboxes face both neutron, alpha, and gamma radiation environments. Due their vicinity and limited shielding, the hands and arms receive a significant majority of a dose compared to the rest of the body [1]. The radiation environment for handling and processing of plutonium-239 within a glovebox is gamma dominated, primarily from highly radioactive gamma emitting decay products (e.g., ^{241}Am), with a mode energy of 60 keV. Lead-lined rubber gloves are utilized to mitigate radiation exposure. However, a typical 30 mil (0.76 mm) thick glove only provide 100 µm of Pb equivalent shielding and that glove thickness or higher inhibits worker dexterity. FDM provides an opportunity to create custom shielding configurations with composition and distribution tailored to the specific radiation environment and geometry conformal to the specific radiation worker. These benefits reduce worker dose and improve ergonomics, both of which increase productivity and safety.The Los Alamos National Laboratory developed a multi-axis printer that has freedom in translational directions as well as the rotation of a mandrel. This printer also has the ability to combine fibers with polymeric materials to create non-planar in situ composites, as seen in Fig. 1**.** These features translate perfectly to the creation of personalized conformal spot shielding, such as vambraces or cuffs, for worker extremities in high-dose rate environments without affecting arm and hand mobility. 3D optical scans of a user’s arm can be imported into a CAD model to create a custom vambrace fit. Tungsten, boron carbide, and carbon fibers can be integrated into the print, increasing the toughness and radiation attenuation of parts with minor effect on composition (<10% by volume).

Figure 1 - 3D printed fiber-reinforced composites designed as a type of vambrace prototype for custom radiation shielding on gloved forearms.

Table 1 - Physical properties and shielding performance of current leaded glove and FDM composite alternatives. WPLA = Tungsten-embedded polylactic acid

	30 mil leaded glove only	15 mil glove unleaded + equal shielding by WPLA	15 mil glove unleaded + equal mass WPLA to leaded glove
Mass (shield) [g]	0	88	797
Mass (glove) [g]	1112	315	315
Mass (total) [g]	1112	403	1112
Thickness (shield) [mm]	N/A	0.215	2
Transmissivity of 0.06 MeV γ [%]	55.7	55.7	0.4

Analytical radiation transport calculations of 60 keV gamma photons using the NIST XCOM database [2] demonstrated significant mass and volume reduction between the traditional 30 mil Pb-loaded glove to 15 mil unleaded gloves with conformal forearm shielding made of COTS W-loaded PLA filament, as seen in Table 1. The present work demonstrates a feasibility study of non-planar 3D printing of composite materials for radiation shielding. Radiation transport modeling is performed on glove designs. Radiation shielding filament materials were 3D printed with fiber reinforce-ments demonstrating a novel method for creating a multifunctional composite radiation shield. To-date prototype assessment will be discussed.

[1] J. O. J. J. M. Wrzesień, "Hand exposure to ionising radiation of nuclear medicine workers," Radiation Protection Dosimetry, vol. 130, no. 3, pp. 325-330, 2008. [2] M. Berger, J. Hubbell, S. Seltzer, J. Chang, J. Coursey, R. Sukumar, D. Zucker and K. Olsen, "NIST Standard Reference Database 8 (XGAM)," 2010.