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Environment friendly La^{3+} ions doped phosphate glasses/glass-ceramics for gamma radiation shielding: Their potential in nuclear safety applications

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ABSTRACT

Gamma-photon, neutron, and proton shielding parameters of La^{3+} ions doped multicomponent phosphate glasses/glass-ceramics of composition $50P_2O_5–30Sb_2O_3–10CaO–5Al_2O_3–5TeO_2+xLa_2O_3$ (La0–La5): x = 0–5 in steps of 1 mol% have been evaluated. These parameters were evaluated utilizing the WinXcom and EXABCal computer codes. Results revealed that the maximum values of MAC were 25.72, 26.85, 27.39, 27.91, and 28.41 cm^2/g for La0–La5, respectively. Furthermore, the maximum and minimum values of LAC were obtained at 15 keV and 10 MeV, respectively with values of 91.82 and 0.107 cm^{-1}, 94.67 and 0.108 cm^{-1}, 98.55 and 0.111 cm^{-1}, 101.62 and 0.113 cm^{-1}, 105.22 and 0.115 cm^{-1}, 107.96 and 0.116 cm^{-1}. Values of HVL and *MFP* were varied according to the order $(La5)_{HVL} < (La4)_{HVL} < (La3)_{HVL} < (La2)_{HVL} < (La1)_{HVL} < (La0)_{HVL}$ for all energies. The Z_{eff} values were found to be maximum at 0.06 MeV and varied from 29.08 to 30.28 for La0 to La5, while the least values of Z_{eff} were recorded at 1.5 MeV and varied from 14.88 to 15.53 for La0 to La5 samples. The buildup factors (B) at 15 MeV followed the trend $(La0)_B < (La1)_B < (La2)_B < (La3)_B < (La4)_B < (La5)_B$. The values of Σ_R for fast neutrons were 0.0911, 0.0989, 0.1078, 0.1157, 0.1242, and 0.1316 cm^{-1} for La0– La5, respectively. The maximum range of proton was obtained at the maximum kinetic energy (10 MeV) having the values: 0.574, 0.569, 0.559, 0.553, 0.544, and 0.540 mm for La0– La5, respectively. Therefore, the increase of La^{3+} doping in La0–La5 samples has a positive influence on their radiation shielding capability. It can be concluded that, La0–La5 samples can attenuate photons, neutrons, alpha particles, and protons and as such, they can be applied successfully in nuclear shielding applications.

1. Introduction

Recently, radioisotopes and ionizing radiation (i.e., X- and γ-rays) which are produced from artificial and natural radiation sources have been tremendously used in several medical applications. Furthermore, ionizing radiation can be applied in food processing and production industries, security, and for material characterization. Despite the benefits resulting from applying ionizing radiation, it also causes dangerous effects on human living tissues and the environment. Therefore, looking for environmentally friendly structural materials for use as radiation shields is a main issue for continuous adoption of ionizing radiation in several applications. The choice of materials as shields depends on some significant parameters such as efficiency, cost, physical, and thermal characteristics of the shield. Neutron, X- and γ-rays are of major concern owing to their high penetrating capacity. Therefore, radiation protection features are crucial when evaluating any material for ionizing radiation protection efficiency.

Formerly, concrete, lead (Pb), rocks, polymers, and depleted uranium have been utilized as shields, but they have disadvantages that limit their application [1,2]. Concrete suffers from unstable properties and cracking trends owing to its chemical structure changes with temperature [3]. All these disadvantages have encouraged scientists and investigators to suggest novel materials like glasses to be used as alternative shielding materials [4–14].

Phosphate oxide (P_2O_5)-based glasses play a major important role in the field of materials science and widely applied in diverse applications due to their high thermal stability, and low melting temperature [15,16]. Glasses of TeO_2 and $TeO_2–P_2O_5$ can be utilized in solar cells as well as being effective for radiation shields [17]. Additive of rare earth elements such as Gd_2O_3, Sm_2O_3, Er_2O_3, Yb_2O_3, and La_2O_3 improves the chemical, physical, mechanical, thermal, and radiation shielding features of glasses [18–23].

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