Iranian Journal of Medical Physics

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Gamma-Ray and Fast Neutron Shielding Parameters of Two New Titanium-Based Bulk Metallic Glasses

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ARTICLE INFO

Article type:
Original Paper

Article history:
Received: Aug 21, 2019
Accepted: Jan 18, 2020

Keywords:
Glass
Photons
Fast Neutrons
Radiation
Lead

ABSTRACT

Introduction: Low-density bulk metallic glass (BMG) with good structural characteristics has the potential of being used for structural radiation shielding purposes. This study was conducted on two new low-density titanium (Ti)-based BMGs (i.e., $Ti_{32.8}Zr_{30.2}Ni_{5.3}Cu_9Be_{22.7}$ and $Ti_{31.9}Zr_{33.4}Fe_4Cu_{8.7}Be_{22}$) to investigate their photon and fast neutron shielding capacities.

Material and Methods: The mass attenuation coefficients, half-value layers, effective atomic numbers, and exposure buildup factors of the two BMGs were calculated at the photon energy values of 15 keV and 15 MeV. Computation of mass attenuation coefficients and effective atomic numbers was accomplished using the XCOM and auto-Z_{eff} software, respectively. In addition, the geometric progression procedure-based computer code EXABCal was used for calculating the exposure buildup factors of BMG. The fast neutron removal cross-sections were also calculated for the two BMGs. The calculated photon and fast neutron shielding parameters for BMGs were compared with those of lead (Pb), heavy concrete, and some recently developed glass shielding materials and then analyzed according to their elemental compositions.

Results: The results showed that though Pb had a better photon shielding capacity, Ti-BMG attenuated photons better than heavy concrete. Furthermore, BMG had a higher neutron removal cross-section, compared to heavy concrete and some recently developed glass shielding materials. The neutron removal cross-sections of $Ti_{32.8}Zr_{30.2}Ni_{5.3}Cu_9Be_{22.7}$ and $Ti_{31.9}Zr_{33.4}Fe_4Cu_{8.7}Be_{22}$ were obtained as 0.1663 and 0.1645 cm^{-1}, respectively.

Conclusion: his study revealed that Ti-based BMG with high strength and low density have potential applications in high-radiation environments, particularly in nuclear engineering for source and structural shielding.

► *Please cite this article as:*
Olarinoye IO, Oche CO. Gamma-Ray and Fast Neutron Shielding Parameters of Two New Titanium-Based Bulk Metallic Glasses. Iran J Med Phys 2021; 18: 139-147. 10.22038/ijmp.2020.42684.1635.

Introduction

The quest for reducing energy consumption and operational cost has encouraged material scientists and engineers to investigate low-density structural materials. Consequently, low-density materials with superior mechanical and physical properties [1-5] have always been a subject of active research in the material science community. Bulk metallic glasses (BMGs) are among such novel materials, which have attracted much interest. These are metallic alloys having an amorphous atomic arrangement obtained by rapid cooling from a high temperature [5]. The amorphous nature of BMGs gives them a high yield strength (above 2 GPa) [6-9]. Furthermore, BMGs exhibit other interesting properties, such as low stiffness, high hardness, low surface roughness, low shrinkage during casting, and high corrosion resistance [1-4, 10]. These properties have encouraged the use of different BMGs in biomedical, automobile, defense, and aerospace industries [11-14]. However, the deployment of many BMGs for these applications has been hindered by their low glass-forming ability (GFA). Consequently, the improvement of the GFA of metallic alloys has led to the design of BMG alloy compositions based on empirical rules [5, 15-19].

In structural engineering, Ti-based BMGs are currently the most suitable low-density BMGs [5, 10]. This is due to their low densities (4-7 gcm^{-3}), high strength and toughness, fabrication ease (due to low-temperature requirement), high mechanical properties (similar to crystalline Ti), and low production cost. Accordingly, recent research has improved the GFA of Ti-based BMG [5]. Recently, two Ti-based BMGs, namely $Ti_{32.8}Zr_{30.2}Ni_{5.3}Cu_9Be_{22.7}$ (T1) and $Ti_{31.9}Zr_{33.4}Fe_4Cu_{8.7}Be_{22}$ (T2), [16, 19] with a high compressive fracture strength (about 1800 MPa) and a GFA greater than 50 have been reported. These materials were adjudged to be good materials in structural engineering applications. The potential use of these materials for structural engineering applications also suggests that they may be good options for structural radiation shield. The beryllium content of the BMG also suggests that they may be good material for fast neutron absorber.

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