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Nuclear shielding properties and buildup factors of Cr-based ferroalloys

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ABSTRACT

This paper presents the radiation attenuation properties and buildup factors of ferroalloys described by the chemical structure of Cr-Fe-Si-C. By using Geant4 Monte Carlo simulations, Phy-X library, and several theoretical approaches, we successfully demonstrated the potential use of ferroalloys in nuclear shielding applications. The results indicate that the density and higher atomic numbers of Cr and Fe play a main role to enhance the radiation attenuation properties and then the nuclear shielding performance of the present alloys. The energy response of μ and μ/ρ depicts that PE, CS, and PP are the major attenuation processes within the energy range of 15–600 keV, 800 keV–10 MeV, and at 15 MeV, respectively. At each energy, Z_{eff} increases with Cr content of the alloy, hence $(Z_{eff})_{CrFeSiC4} > (Z_{eff})_{CrFeSiC3} > (Z_{eff})_{CrFeSiC2} > (Z_{eff})_{CrFeSiC1}$. This study suggests that the studied ferroalloys are superior radiation shields compared to ordinary concrete, barite concrete, and RS360. They thus have high potential to perform better in radiation protection functions.

1. Introduction

The use of photon beams (ionizing radiation) has increased in recent years, so also is the exposure of man and the biosphere in general. The immediate and the delayed catastrophic effects of radiation exposure of any biological and physical system has made radiation protection through the use of shields mandatory in many radiation facilities all over the world. Among the classes of radiation, photons and neutrons are mostly used in diverse technologies applied in medicine, power generation, agriculture et al. These radiations, unlike other particulate types of radiation, are highly penetrating and also possess the capacity to ionize atoms. Hence, many radiation protection systems emphasize neutron and photon shielding. Recently, the need to replace some common radiation shielding materials due to the demands emerging radiation technologies has placed on shielding materials has made research into novel materials as radiation shields common. From the early days of radiation discovery and applications, lead (Pb) and Pb-based materials are the basic gamma radiation shields due to the physical, mechanical and radiation absorption features. However, the environmental, and health hazards associated with Pb has become a cause of major concern (Movahedi et al., 2014; AbuAlRoos et al., 2019). Lead has in fact been reported to have adverse effects on the hematological, cardiovascular, nervous, reproductive, and nervous systems of man (Movahedi et al., 2014; AbuAlRoos et al., 2019). Other classical shields such as concrete and depleted uranium also have drawbacks that have increased the search for alternative radiation shields (Singh et al., 2018; Olarinoye et al., 2020).

Many synthetic composite materials such as glasses, ceramics, and alloys have been investigated for their radiation shielding abilities (Tekin and Kilicoglu, 2020; Alshahrani et al., 2021a; Rammah et al., 2021; Olarinoye and Oche, 2020; Akman et al., 2019). These studies have shown that the chemical composition of these materials determine their effectiveness in radiation absorption, physical, and other related features. Also, the presence of dense atoms such as Pb, Ba, Bi, and W always influence positively the photon shielding capacities of these classes of materials. However, the availability and cost of these elements has made the production of radiation shields from these chemical species economically unrealistic. For example, the cost (in US $) per lb of

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