Testing Ammonia Borane as a Promising Non-Toxic, Lightweight, Hydrogen Rich Material for Aprons in Nuclear Medicine

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Abstract: ***The current study aims to find a non-toxic, low density, hydrogen-rich material that can be used in aprons without causing health problems for nuclear medical workers that could hinder their work and negatively affect patients. Five samples were tested in terms of fast neutron removal cross-section (C21H25ClO5, C2H4, LiH,H3NBH3,MgH2) mathematically using computer program called Phy-x/PSD it is a computer program designed to calculate the fast neutron removal cross section, and it was obtained that ammonia borane ($H3NBH3$) with a density of 0.78 (g/ cm3) has the highest fast neutron removal cross-section with the value of (0.122959317985393cm-1) and the least for polyethylene ($C2H4$) with the value of (0.0838038707225853 cm-1) which made the ammonia borane a better candidate than polyethylene and other compounds that have been tasted in previous research for multi-layer aprons in nuclear medicine, and may approve a proper protection against the hazard radiations that its produced in nuclear medicine filed by several ways, due to it is low density and non-toxicity, And it contains the three most important elements that play a major role in protection shields, which are (hydrogen, boron, nitrogen).***

Keywords: Non-Toxic, Neutrons, Aprons, Nuclear medicine, Radiation

1. Introduction

Recently, dealing with radioactive materials has increased in various fields, and we have seen its importance and a lot of benefits from it. One of the most important sectors that use radioactive materials and radiations such as neutrons in particular is nuclear medicine, where Neutron rays are produced by research reactors are being used in nuclear medicine and other medical applications in several ways [2]. such as “treatment of patients with neutrons that are used for tumors of medium radiosensitivity, the combination of neutron radiation and normal radiation leads to a considerable increase in the tumor destroying effect” [1]. “Neutron rays are particles without charge that can pass through a high-density material such as lead faster than other particles” [18]. When exposed to neutron rays without proper protection, there is a high probability that they will damage the DNA and cause cancer in the exposed person they are a radiation hazard for the entire body, and medical staff handling these radiations daily throughout the year may further exacerbate the risk. The study aims to find a suitable material to attenuate neutron radiation, which is non-toxic and provides appropriate protection for medical staff and patients.

1.1 Previous Research

Neutron shields require certain materials, “materials are typically constructed from low atomic number elements (hydrogen, carbon, and oxygen) with high scattering cross sections that can effectively moderate or thermalize incident neutrons” [3]. Hydrogen is a good candidate for a neutron moderator because “its mass is almost identical to that of the incident neutron, and so a single collision will reduce the speed of the neutron substantially” [7]. From previous research it was also found that some elements play a major role in the radiation shields, as studies have shown that “boron has one of the largest neutron absorption cross sections of all the elements of the periodic table, and nitrogen has a large neutron absorption cross section than carbon” [4]. Since hydrogen reduces the speed of neutrons, boron and nitrogen absorb the neutrons that have been slowed down by hydrogen this will offer the greatest shielding against neutron radiation. One of the compounds consisting of these three elements is ammonia borane (H_3NBH_3) , “ammonia borane is a colorless solid it has high hydrogen content of 19.6% Wt” [6,9]. with a density of 0.78 (g/ cm3). “Ammonia borane has attracted attention as a carbon free energy source owing to its non-toxicity” [5]. this would make it environmentally friendly and suitable for radiation shields.

2. Research Methodology

In this paper, ammonia borane was theoretically tested in terms of fast neutron removal cross section which is “the probability that a fast or fission energy neutron undergoes a first collision, which removes it from the group of penetrating, uncollided neutrons”[20] .

Using Phy x/PSD it's a “computer program that developed for calculation of parameters relevant to shielding and has been dosimetry ” [8].

Result was compared with the following compounds that have high hydrogen storage :
(C21H25ClO5, C2H4, LiH, H3NBH3, MgH2)

Using the following equation for fast neutron removal cross-section :

$$\Sigma_R = \sum_i \rho_i \, (\Sigma_R/\rho)_i \qquad (1)$$

“Where, ρ_i and $(\Sigma_R/\rho)_i$ are the partial density and mass removal cross-section of the ith constituent”[8].

3. Results and Discussion

With the help of Phy-x/PSD mathematically the Fast neutron removal cross-section of the following compounds was calculated:

Table 1: The Fast neutron removal cross-section of various compounds that contain high hydrogen storage

Compounds	Density (g/ cm^3)	FNRCS (1/cm)
($C_{21}H_{25}ClO_5$)	1.2	0.0973251231530604
(C_2H_4)	0.65	0.0838038707225853
(LiH)	0.78	0.116357382695051
(H_3NBH_3)	0.78	0.122959317985393
(MgH_2)	1.45	0.110996914730814

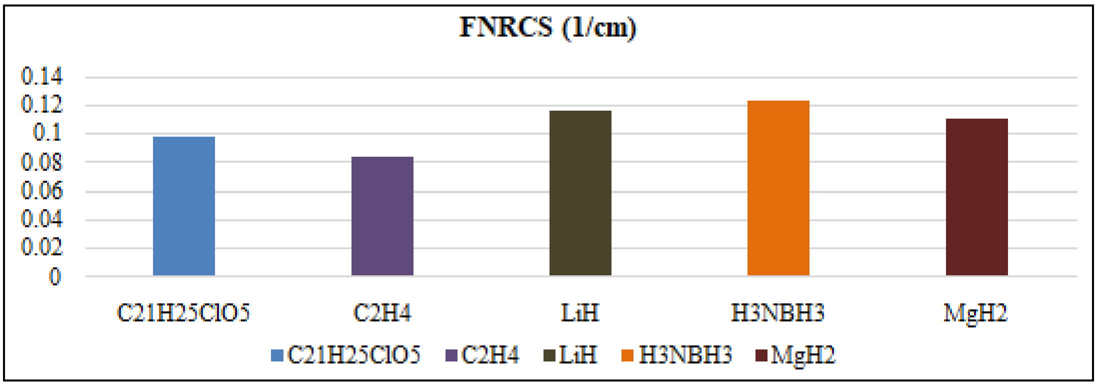

Figure 1: The comparison of the Fast neutron removal cross-section of various compounds

As shown in Fig and Table 1, there is a variation in results, the first sample is polyethylene (C_2H_4) and represents the lowest value of the Fast neutron removal cross-section among the compounds with the value of (0.0838038707225853 cm^{-1}). “Polyethylene is the second-most-commonly-used commercial polymer” [19]. but studies have shown a potential toxicity problem with polyethylene, “it is not biodegradable, it can persist for a long time in water and soil, strangling otherwise fruitful land” [19].

Then it's followed by Epoxy Resin ($C_{21}H_{25}ClO_5$) It is considered as the most used material in shields to protect against neutrons and photons. Epoxy resin has been tested in previous research to prove it efficiency for neutron radiation shield. “For example, B4C was added to epoxy resins to improve their thermal neutron-shielding properties” [11]. As shown in Figure 1, epoxy resin represents the second lowest value of all compounds with a value of (0.0973251231530604 cm^{-1}).

Magnesium hydride (MgH_2) “it remains an attractive hydrogen storage material due to the high hydrogen capacity and low cost of production” [10]. As it shown in Fig1 magnesium hydride has the third lowest value of all compounds with a value of (0.110996914730814 cm^{-1}).

As represented in fig and table 1 the convergent values between lithium hydride (LiH) and ammonia borane (H_3NBH_3) , where the value of lithium hydride (0.116357382695051 cm^{-1}) and the value of ammonia borane (0.122959317985393 cm^{-1}).

Ammonia borane has the highest value in terms of fast neutron removal cross-section, this is due to its high content of hydrogen, low density, and its containment of boron and nitrogen as previously mentioned they have a high cross-section, this could make ammonia borne a great candidate for multilayer shield. “A multilayer shield consists of two or more layers of different materials. In this arrangement, the incoming radiation will have more chances to be scattered and absorbed by the shield”[12]. “Neutron shielding may also incorporate high atomic weight elements or layers of higher atomic weight shielding material to reduce dose from gamma radiation produced from neutron capture interactions (n,γ)” [3].

Using ammonia borane in a multi-shield with a material such as tungsten carbide where the “tungsten carbide has low half value layer and mean free path compared to lead for all thickness at different energies, studies have showed that tungsten carbide has a potential to replace lead in nuclear medicine”[13]. Lead represent a virulent hazard, Previous studies have shown that “Lead dust on the skin and the clothes of workers can be carried home and is known as “take-home exposure”; it settles on surfaces from where it is then inhaled or ingested by young children with normal mouthing behaviors” [14]. Also due to lead heavy weight it might causes an orthopedic trauma, and this was proven by a study done on lead aprons [17].

We must take the replacement of lead by tungsten into consideration since "the tungsten apron prove an effective shielding material against gamma radiation exposure" [15].

Using a material that slows down fast neutrons and absorb it such as ammonia borane and a material that absorbs secondary gamma rays such as tungsten carbide in a multilayer apron this could make a suitable protection for workers and patients in nuclear medicine.

4. Conclusion

The above results of fast neutron removal cross-section of ($C_{21}H_{25}ClO_5, C_2H_4, LiH, H_3NBH_3, MgH_2$) lead to draw the conclusions that ammonia borane (H_3NBH_3) can be used in multilayer aprons in nuclear medicine to provide appropriate protection for workers and patients since ammonia borane has the highest fast neutron removal cross-section value and low density compared to other compounds was tested in this paper.

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