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DEVELOPMENT OF ADVANCED SHIELD SYSTEMS FOR FAST NEUTRONS

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Abstract

Neutron shielding capabilities of different materials were investigated using Monte Carlo method. MCNP5 was used to evaluate the capability of some hydrogen rich materials as possible neutron shields. Materials like magnesium borohydride (Mg (BH4)2), beryllium borohydride (Be (BH4)2) and zirconium hydride (ZrH2) were compared with conventional neutron shielding materials such as water and polythene. Their richness in hydrogen makes them effective neutron shields. A combination of hydrogen rich materials and high-Z atoms improves the fast neutron shielding capabilities of both conventional materials and hydrogen rich materials. Also, the thickness of hydrogen rich materials can be reduced by combining with steels without compromise to their shielding capabilities.

Keywords

nuclear safety, safety culture, management systems, safety culture assessment, nuclear regulation

1.1. Introduction

Materials like concrete, polythene, water and depleted uranium have been used as radiation shields. Even though they have served as effective shield materials but they also have their own short comings. Concrete has durability problems and space limitations **(1, 2)** due to its bulkiness. Concrete has a relatively high percentage of hydrogen atoms, but the problem is as temperature increases, there is rapid loss of water, hence hydrogen **(2).** This makes concrete not attractive as a neutron shielding material at high temperatures. Depleted uranium is mildly radioactive, polythene has a fairly low heatproof temperature **(3)** and water needs to be contained since it is a liquid. Hence there is need for development of advanced shield systems which can minimize or overcome some of the short comings. The new advanced materials should make the shield compact, lighter, more effective as radiation attenuator and probably less costly.

Compounds with a high concentration of hydrogen atoms, such as water, polythene and borohydrides can form good shields against neutrons. Most of these compounds also have an advantage that they are readily available and inexpensive. However, low density materials can emit gamma rays when blocking neutrons, meaning that neutron radiation shielding is most effective when it incorporates both high and low atomic number elements **(4, 5, 6)**.

1.2. Significance

Advanced radiation shields are expected to be used in fast reactors being built for electricity generation, thermal heating and space ships. Also, they can be used as a replacement to current shields in order to improve the nuclear safety and reduction in cost as well. The shields will be used for both land based reactors and ship based reactors.

2. Materials

2.1 Borohydrides and metal hydrides

Borohydrides are developed by material scientists in view of their ability to be vectors for hydrogen storage **(7, 8)**. The hydrogen density in these borohydrides is also attractive in neutron shielding, since hydrogen has a good cross section to interact with neutrons. Alkali (group 1) borohydrides are very common and are produced on a very large scale. Examples of borohydrides are magnesium borohydride, beryllium borohydride and zirconium borohydride.

Just like Borohydrides, metal hydrides were developed as potential hydrogen storage materials **(7, 8)**. It is the amount of hydrogen which makes them attractive as neutron shielding candidate materials. Examples are magnesium hydride, titanium hydride, lithium hydride and zirconium hydride. Metal hydrides like titanium hydride and lithium hydride are already in use as radiation shields for space ships.

2.2 Steels

HT-9 is a ferritic/martensitic stainless steel alloy. This alloy has a high chromium (Cr) content of approximately 12% providing superb resistance to atmospheric temperature corrosion and degradation **(9)**. It is being investigated as a possible replacement of to austenitic stainless steel for duct applications in liquid metal fast breeder reactors. It is also being developed for application as fuel pin and wrapper material in liquid cooled fast nuclear reactors **(9)**.

Further, the presence of the molybdenum (Mo) improves the corrosion resistance **(9)**. Research has shown that HT-9 steel is resistant to swelling and irradiation creep in neutron environments. Because of these properties, it is also considered as a possible alloy for fusion reactor structures. It is also these properties which can make it a good neutron shielding candidate.

Boron is added to steel because of its effect on hardenability enhancement. Boron is added to unalloyed and low alloyed steels to enhance the hardness level through enhancement hardenability **(10)**. Because boron has a good neutron capture cross section, boron stainless steel is a good candidate in neutron shielding.

3. Methodology

A radiation source code to measure neutron flux was developed using MCNP5 **(11)**. Endf cross section libraries were used for neutron measurements. Shielding material samples were chosen from water, polythene, magnesium borohydride, beryllium borohydride and zirconium hydride.

3.1 Effect of material thickness

Samples were irradiated with neutrons with a 1 MeV neutron source. The sample thicknesses were varied in increments of 5cm up to 60cm. At every thickness, neutron flux was measured. This was done for all materials chosen.

3.2 Effect of combining hydrogen rich materials and steels

Samples of 50 cm thickness were used. The volume ratio of steels in the samples was varied from 0 % to 100 %. A 14 MeV neutron source was used and the neutron flux was measured for every volume ratio of steel. Steels used were HT9, carbon stainless and boron stainless.

4. Results

4.1 Effect of sample thickness on shielding

A 1 MeV neutron source was used to investigate the effect of material thickness on radiation shielding. The material thicknesses were varied from 5 cm to 60 cm. The results are shown in Figure 1.

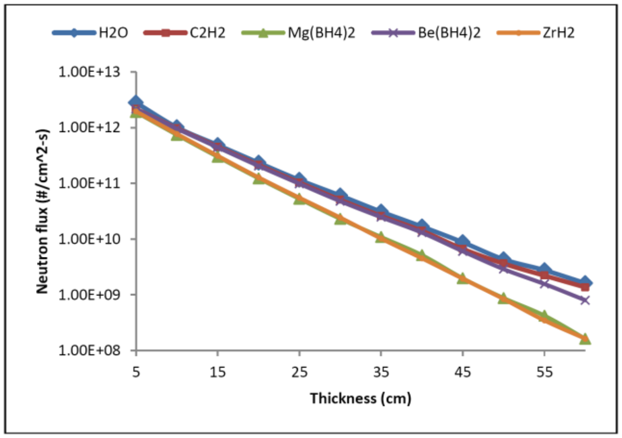
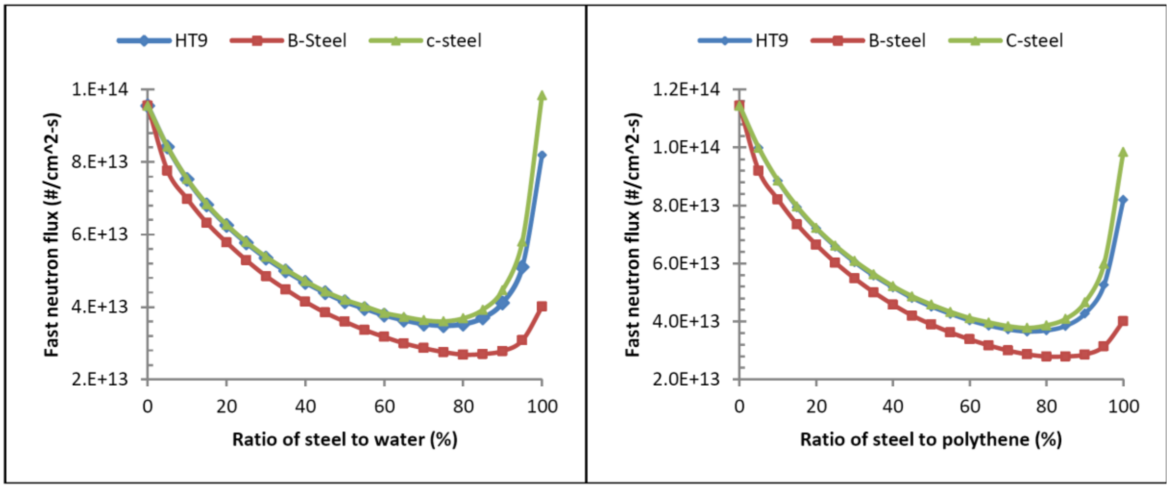


Figure 1. Graphs of neutron flux versus material thickness for different materials

At low thicknesses all materials tend to shield neutrons the same. But as thickness increases, magnesium borohydride and zirconium hydride provide with a better shield. Beryllium borohydride tend to behave just as water and polythene.

4.2 Effect of combing steels and hydrogen rich materials

The material thicknesses were kept at 50 cm. The volume percentages of steels were varied from 0 % to



(a) Water + steels (b) Polythene + steels

Figure 2 Graphs showing the effect of combining steel and conventional shields.

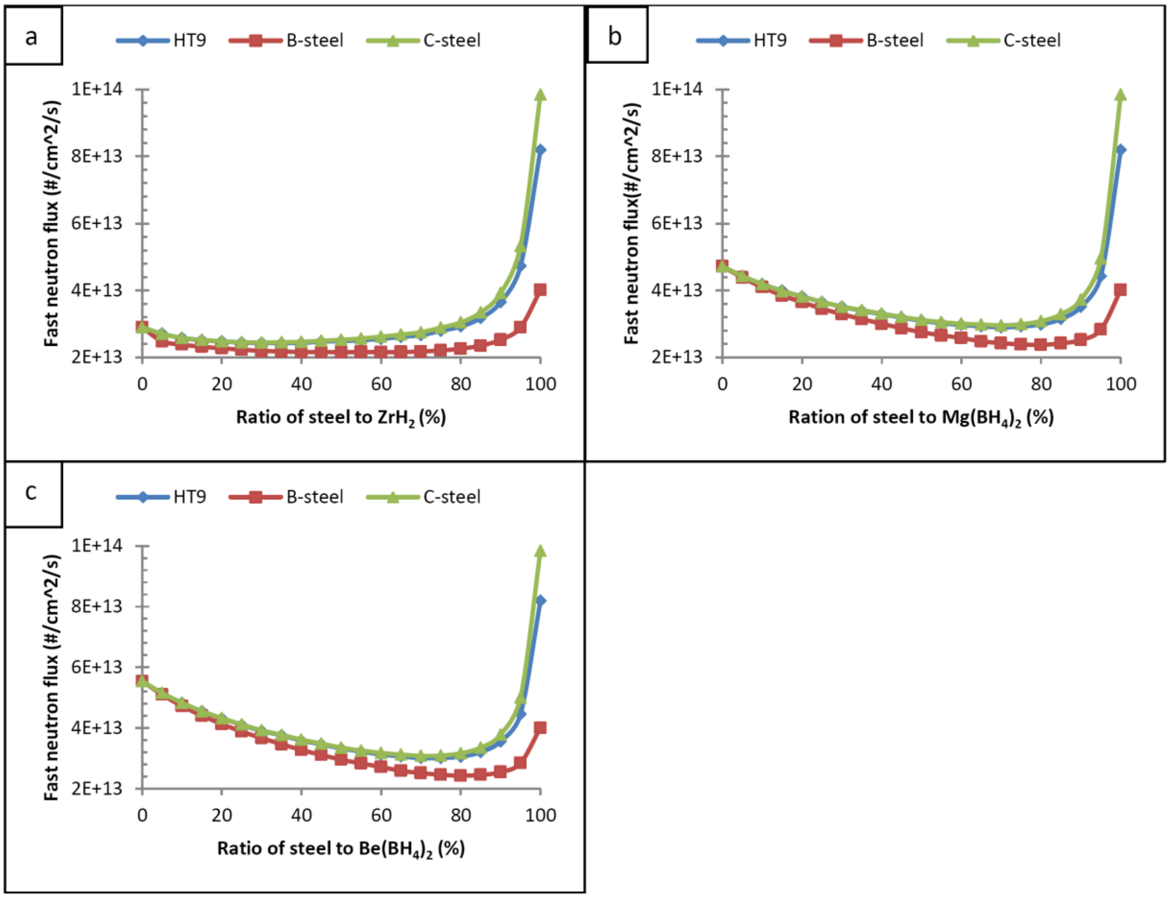


Figure 3 Graphs showing the effect of combining steel and hydrogen rich material.

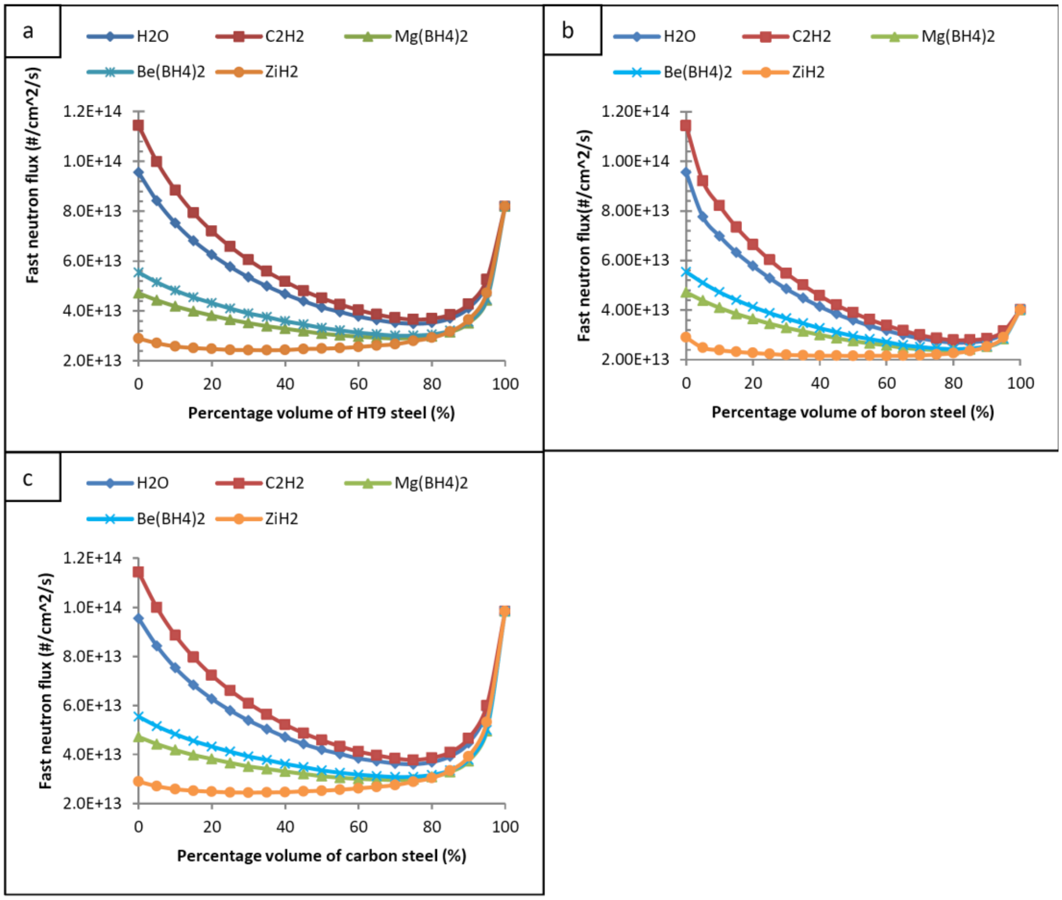


Figure 4 Graphs comparing the fast neutron shielding effectiveness of different materials

100 % and their effects to fast neutron shielding were investigated. Steels considered were HT-9, boron stainless steel and carbon steel.

4.2.1 Water and polythene

Water and polythene have a hydrogen density of and respectively and a density of 1.0 g/cm3 and 0.9 g/cm3 respectively. Water and polythene are not effective shields of fast neutrons as shown in Fig 2 a and b. Combining them with steel improves their fast neutron shielding capabilities. Combining them with HT-9 and carbon stainless steel has almost a similar effect. But combining then with boron stainless steel has more effects than the other two. They are most effective when about between70 % and 85 % of steel is added. 3 22 / 10 7.6cm □3 22 / 10 7.7cm □

(a) Water + steels (b) Polythene + steels

4.2.2 Metal hydrides and borohydrides

Most of the metal hydrides and borohydrides have a hydrogen concentration of above and densities close to 1.0 g/cm3 with the exception of ZrH2 which has a density of 5.6 g/cm3. Figures 3a, b and c show the effect of combining steels and hydrogen rich material. Combining steels and zirconium hydride has very little effect if any in improving the shielding capabilities of zirconium hydride as shown in figure 3a. There is a notable improvement in the shielding capabilities of magnesium borohydride and beryllium borohydride when combined with some steels. 3 22 / 10 0.7cm □

4.2.3 Comparisons of shielding capabilities

Figures 4 a, b and c show the effect of combining steels and hydrogen rich materials as fast neutron shields. Boron stainless steel has superior fast neutron shielding capabilities, that even adding hydrogen rich materials has little effect as shown in figure 4b.

The fast neutron shielding capabilities of conventional shielding materials are largely improved by combining with steels. At the ratio of about 75 % steel, the shielding capabilities of conventional materials almost match that of borohydrides.

Zirconium hydride has the best fast neutron capabilities. Adding steels does not improve its shielding capabilities like other materials. Water and polythene have their shielding capabilities greatly improved to match even those of zirconium hydride by combining them with steels.

5. Conclusions

Other hydrogen rich materials like borohydrides and metal hydrides can be used as neutron shields since they offer better shielding capabilities than conventional shielding materials. Combining hydrogen rich materials with steel would provide with more effective fast neutron shields. Zirconium hydride has good fast neutron shielding capabilities even without combining it with steels.

Since zirconium is a high-Z material, combining it with steel has very little effect in the shielding of fast neutrons. This shows that zirconium hydride could be an effective fast neutron shielding material without the help of steels.

There is need for further investigation to find out if these materials can also shield against photons and their performance at very high temperatures.

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