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Investigation of Neutron Attenuation through FeB, Fe_2B and Concrete

D. Sariyer*

Manisa Celal Bayar University, Turgutlu Vocational High School, Turgutlu, Manisa, Turkey

Neutrons produced in high-energy nuclear facilities are very penetrative and travel deeply through many materials. Neutron shielding slows down the high-energy neutrons to thermal energies and absorbing them with suitable materials is an important problem. Neutron attenuation in the shielding is accomplished through elastic and inelastic scattering reactions. For shielding to be efficient, minimum thickness needs to be achieved. To shield from these neutrons, concrete and iron are important materials. In this study, the neutron attenuation effects through shielding materials (concrete, FeB, and Fe_2B) were investigated for various thicknesses of the materials. The high-energy neutrons were generated from the interaction protons with energies of 50–1000 MeV and copper target. Neutron dose rate attenuation curves were determined by using FLUKA Monte Carlo code. The results show that the extent of attenuation related to neutron energy depends on the density and thickness of the shielding material.

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PACS/topics: neutron attenuation, ferroboron, FLUKA

1. Introduction

Neutron radiation is generated when high-energy particles interact with matter in high-energy nuclear facilities and it is harmful to the environment and humans. Shielding is widely used to protect from the harmful effects of neutrons [1, 2]. Efficient shielding against neutrons is an important problem because neutrons are very penetrative and travel deeply through many materials. Shielding material attenuates the high-energy neutrons to thermal energies and then these neutrons are captured by nuclei of the shielding material. Neutron attenuation is accomplished through elastic and inelastic scattering reactions [2–4]. For shielding to be efficient, minimum thickness needs to be achieved. Many kinds of shielding materials have been used and tested over the years. Although, ideal shielding materials that absorb both fast and slow neutrons at the same time with the same rates have not been obtained. Attenuation of neutrons through materials varies with the atomic number Z, density, and the thickness of the material [5]. Concrete and iron is commonly used as high energy neutron shielding material in many nuclear facilities [4, 5].

Concrete is commonly employed in building construction as radiation shields. Concrete generally consists of cement, aggregates, and water. The shielding properties of concrete depend on its composition. Heavy atomic number elements are shield by elastic or inelastic scattering of fast neutrons and light elements effective by absorbing thermal neutrons [1, 5].

The studied alloys FeB and Fe_2B are formed by combining iron with boron compound between 10 and 20%, and between 8 and 10%, respectively. Boron is an element characterized with a high absorption of the slow neutrons [6, 7]. Iron is an excellent shielding material against the high-energy neutrons due to the high Z and low capture cross-section but it is relatively highly transparent for neutrons below 1 MeV [5, 8, 9].

Neutron interaction with the matter depends on neutron energy and the density of the shielding material. In this study, the neutron attenuation effects through shielding materials (concrete, FeB, and Fe_2B) were investigated for various thicknesses of the materials. Neutron dose rate attenuation curves were determined by using FLUKA Monte Carlo code.

2. Material and methods

Neutron attenuation curves in shielding materials (concrete, FeB, and Fe_2B) were determined by using Monte Carlo simulation code of FLUKA. The source neutron spectrum was from the interaction of proton beam (50, 100, 250, 600, and 1000 MeV) and copper target.

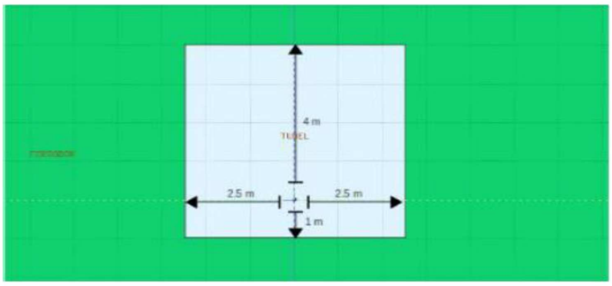

Fig. 1. Position of beam axis in simulation geometry.

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*e-mail: demet.sariyer@cbu.edu.tr

TABLE I

The compositions and density of the materials [10].

Material	Air inside the tunnel	Standard concrete	Ferroboron (FeB)	Ferroboron (Fe_2B)	Copper (Cu)
density [g/cm^3]	0.00120484	2.34	7.15	7.43	8.96
element (fraction) [%]	C (0.0001248), O (0.231781), N (0.755267), Ar (0.012827)	C (23.0), O (40.0), Si (12.0), Ca (12.0), H (10.0), Mg (2.0)	Fe (83.8), B (16.2)	Fe (91.17), B (8.83)	Cu (100)

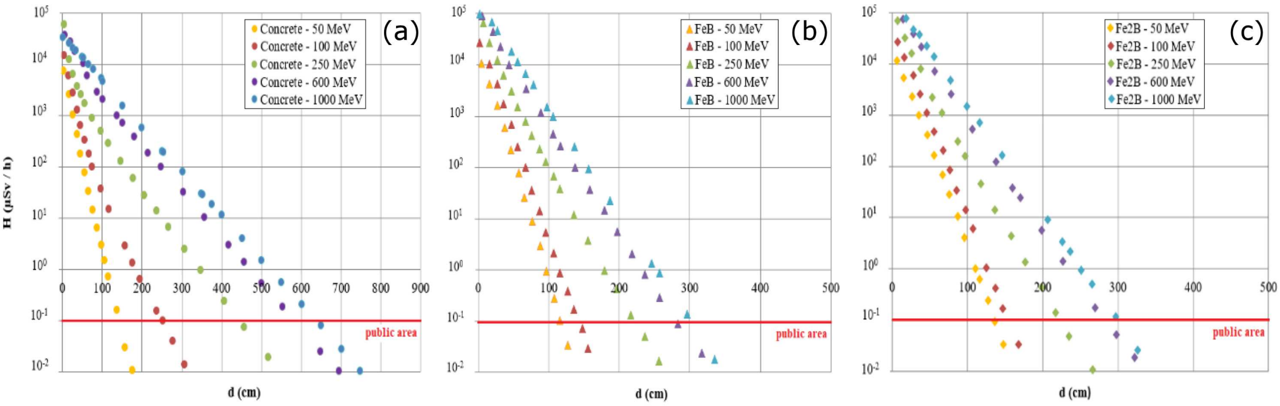

Fig. 2. Neutron dose rate attenuation curves as a function of depth in concrete (a), (b) FeB, and (c) Fe_2B.

Copper target whose dimensions were $5 \times 5 \times 5$ cm^3 was parallelepiped shaped, with the axis coincident with incoming beam direction. Shield was modeled in an abnormal operational situation at a single point. A simplified shielding geometry was designed as a tunnel with dimensions of $5 \times 5 \times 10$ m^3 for simulation. In the tunnel, the beam axis was placed asymmetrically (1 m from floor), side walls 2.5 m away from the beam axis. The position of the beam axis in the simulation geometry is shown in Fig. 1. The total shield thickness, neutrons collided with walls made of shielding materials was taken as 24 m. The elemental compositions and densities of the materials used in this study are shown in Table I.

3. Results and discussion

The properties of neutron dose attenuation through different shielding materials (concrete, FeB, and Fe_2B) were investigated by using FLUKA Monte Carlo code. Neutrons dependent on proton energies lead to different attenuation dose distributions because scattering and slowing down play important roles for neutron attenuation. Neutron attenuation length determines dose equivalent provided by the shielding. Neutron dose rate attenuation curves as a function of depth in shielding materials (concrete, FeB, and Fe_2B) for different proton energies are given in Fig. 2a–c.

Figure 2a–c shows sample materials and the neutron beam attenuated as a function of thickness of the shielding material. It shows that attenuation of the high-energy neutrons for the fixed beam line geometry through materials depend not only on neutron energy but also on the composition of material or its density. For example, when the minimum shielding thicknesses for concrete, FeB, and Fe_2B to attenuate the neutron dose to 0.1 μSv/h (public area) are compared, the result show that they are nearly same for 50 MeV, smaller than half for 100 MeV and 250 MeV, approximately half for 600 MeV, and substantially bigger than half for 1000 MeV, respectively.

The attenuation length of neutrons determines the attenuation of dose equivalent provided by the shielding material. This length could be used to determine the thickness of shielding required to reduce the dose to acceptable levels. Nowadays, there are many shielding applications related to neutron attenuation properties of concrete and FeB [1, 6, 7, 11], but similar studies related to Fe_2B are not present in literature.

4. Conclusion

This study reports the neutron attenuation in concrete, FeB, and Fe_2B as a result of the high-energy neutrons moderation (slowing down) that takes place in a medium when neutrons pass through it. Neutron energy spectra penetrated through concrete, FeB, and Fe_2B shields were calculated with FLUKA Monte Carlo code. The simulations showed that neutron attenuation through shielding materials was dependent on proton energy and density of the shielding material. In fact, the materials with high densities, FeB and Fe_2B, have better neutron attenuation effects than concrete.

It is known that boron is a good thermal neutron absorber material and iron is important shielding material for slowing down fast neutrons. FeB and Fe_2B are alloys which are formed by combining iron with boron compound between 10 and 20%, and 8 and 10%, respectively. They are least costly boron additives for steel and other ferrous metals. Therefore, we recommend that FeB and Fe_2B which are iron boron alloys are proposed as ideal neutron attenuators.

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