Special issue of the International Conference on Computational and Experimental Science and Engineering (ICCESEN 2014)

Neutron Shielding Properties of Concrete and Ferro-Boron

D. Sariyer[a,*], R. Küçer[b] and N. Küçer[b]

[a]Celal Bayar University, Turgutlu Vocational High School, 45400, Turgutlu, Manisa, Turkey

[b]Celal Bayar University, Faculty of Arts and Sciences, Department of Physics, 45140, Muradiye, Manisa, Turkey

The problem of shielding against high-energy neutrons has always attracted a great deal of attention. Neutron shielding requires slowing down energetic neutrons and absorbing with a shield material. Concrete is one of the best known materials for neutron shielding and ferro-boron is described as an alternative shielding material in this study. FLUKA Monte Carlo simulation code was used for the application of shielding calculation. When the simulation results are compared, it is clear that ferro-boron is more effective in neutron shielding than the concrete.

DOI: 10.12693/APhysPolA.128.B-201

PACS: 02.70.Uu, 28.41.Qb, 87.52.–g, 87.52.Ga

1. Introduction

Neutrons have no electrical charge and are not easily stopped by matter because they interact with atoms of matter only via the nuclei. Energetic neutrons are more difficult to shield because absorption cross-section is much lower. Firstly, it is necessary to moderate these neutrons through elastic or inelastic scattering interactions and then slowed neutrons are absorbed with the shielding material. Shielding must be made with appropriate thickness and types of shield materials such as concrete, heavy concrete, and iron [1].

Concrete is a material which is commonly used as a radiation shielding and in building construction such as nuclear power stations, particle accelerators and medical hospitals. Concrete is very significant for neutron shielding, because concrete contains some elements (hydrogen, carbon etc.) to moderate the fast neutrons which are very penetrative [2].

ferro-boron is a binary alloy of iron with boron content between 10% and 20% and is the lowest cost boron additive for steel and other ferrous metals. In addition to iron it is good for shielding of fast neutrons due to the high Z and low capture cross-section. For the absorbing of the slow neutrons, a material with high absorption cross-section is needed. At the same time, boron is often incorporated into neutron shielding because of its large absorption cross-section (760 b) and ^{10}B, a constituent of 19.9% of nature boron, has large thermal neutron absorption cross-sections (3840 b) [3].

For shield calculation in the shield design purposes, several analytical methods and advanced multi-particle Monte Carlo transport codes can be available. Monte Carlo transport codes, such as FLUKA provide the most accurate result for shielding design, in particular for complicated three-dimensional geometries [4, 5].

In this paper, minimum thicknesses of side wall shielding for standard concrete and ferro-boron have been determined by means of the computer code FLUKA.

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

2. Materials and methods

In this study, the simulations were performed with the version 2011.2b of the FLUKA Monte Carlo code shield design required to attenuation in shield materials of secondary neutrons generated by abnormal operation situation.

For simulations, input files have been prepared. In these input files, beam properties, irradiation geometry, materials definition, physical setting and detector properties have been represented in a sequential order. For simulation geometry, a 10 m long tunnel section with dimensions of 5×5 m^2 was modeled for shielding of 50–1000 MeV protons in the simulation. In the tunnel, the beam axis was placed asymmetrically (1 m from floor) and side walls 2.5 m from away the beam axis. Spherical standard concrete and ferro-boron shields were used to simulate the tunnel walls as shield materials. The total length of the shield thickness was taken as 24 m. The elemental compositions and densities of the materials used for shielding design are shown in Table I.

TABLE I

The compositions and density of the materials [5].

material	element	fraction [%]	density [g/cm^3]
air inside the tunnel	C	0.0001248	0.00120484
	O	0.231781	
	N	0.755267	
	Ar	0.012827	
standard concrete	C	23.0	2.34
	O	40.0	
	Si	12.0	
	Ca	12.0	
	H	10.0	
	Mg	2.0	
ferro-boron	Fe	83.8	7.15
	B	16.2	

Copper whose dimensions were $5\times5\times5$ cm^3 was chosen as a target material. The target was parallelogram, with the axis coincident with the incoming beam direction.

Simulations have been started for 6×10^8 primary proton particles and the code was run for 5 cycles. Simulation results have been read from FLUKA output file. USRBIN detector has been used to obtain dose distributions for each of material thicknesses. Dose distributions were determined by using USRBIN detector whose sizes were 3400, 3000, and 1900 cm for x, y, and z axis. Dose distributions were performed in order to estimate the shield thicknesses of concrete and ferro-boron against the secondary neutrons produced in the interaction of 50, 100, 250, and 1000 MeV protons on a copper target.

3. Results and discussion

We used the Monte Carlo transport code FLUKA to study shielding materials for high-energy neutrons. The neutrons which were from the interaction of proton beam and copper target, collided with walls made of shielding materials: concrete or ferro-boron. The shielding thicknesses were calculated as the neutron dose determined as 0.1 μSv/h (a non-designated area) and as 10 μSv/h (controlled radiation area) on the other of the shielding wall [6]. The calculated shielding thicknesses are given in Table II.

TABLE II

Calculated minimum concrete and ferro-boron shielding thicknesses (in [cm]).

Proton beam energy [MeV]	Design dose equivalent rate			
	public area 0.1 µSv/h		controlled area 10µSv/h	
	concrete	ferro-boron	concrete	ferro-boron
50	150.379	120.455	85.227	80.303
100	257.197	150.379	135.606	95.455
250	451.515	230.682	260.985	145.53
1000	646.332	311.404	413.477	209.33

According to Table II, the thickness of the ferro-boron is less than 50% of the thickness of the concrete for shielding thicknesses, especially at high energies.

For concrete shielding case, all our calculated results are in good agreement with Magistris et al. and Agesteo et al. [6, 7]. But applications of ferro-boron were made only for nuclear power reactors by Keshavamurthy et al. and Raju et al. [8, 9]. Comparison for ferro-boron could not be made for high-energy protons, because there were no similar studies.

4. Conclusion

In this study, the shielding thicknesses of concrete and ferro-boron were determined for different proton energies with FLUKA Monte Carlo code. According to the thickness values of shielding, it can be considered that the ferro-boron is a good shielding material for high-energy neutrons. Finally, ferro-boron is more advantageous than 50% concrete for non-designed area, close to 50% for controlled area for shielding thicknesses especially at high energies.

Also, ferro-boron could be used in combination with concrete (concrete/ferro-boron) or added to concrete in a form of particle alloy. In future studies, we will be investigating these types of ferro-boron and other materials.

Acknowledgments

The numerical calculations reported in this paper were performed at TUBITAK ULAKBIM, High Performance and Grid Computing Center (TRUBA Resources).

References

[1] M. Nyarku, R.S. Keshavamurthy, V.D. Subramanian, A. Haridas, E.T. Glover, *Ann. Nucl. En.* **53**, 135 (2013).

[2] NCRP Report No. 144, *Radiation Protection for Particle Accelerator Facilities*, 2003.

[3] J.E. Martin, *Physics for Radiation Protection — A Handbook*, 2nd ed., Wiley-VCH Verlag, Weinheim 2006.

[4] R. Küçer, N. Küçer, G. Türemen, *J. Korean Phys.* **62**, 591 (2013).

[5] A. Ferrari, P.R. Sala, A. Fasso, J. Ranft, *FLUKA: A Multi-Particle Transport Code*, CERN-2005-010, Geneva 2011.

[6] M. Magistris, M. Silari, *Shielding Requirements and Induced Radioactivity in the 3.5 GeV SPL*, CERN, Geneva 2005.

[7] S. Agosteo, M. Magistris, M. Silari, *Radiat. Protect. Dosim.* **146**, 414 (2011).

[8] R.S. Keshavamurthy, D.V. Subramanian, R.R. Prasad, A. Haridas, P. Mohanakrishnan, S.C. Chetal, *En. Proced.* **7**, 273 (2011).

[9] S. Raju, A.K. Rai, B. Jeyaganesh, M. Vijayalakshmi, T. Jayakumar, B. Raj, *En. Proced.* **7**, 264 (2011).