DOI: 10.1051/epjconf/201715401022

New applications and developments in the neutron shielding

Fatma Aysun Uğur

Osmaniye Korkut Ata University, Department of Physics, Osmaniye, Turkey

Abstract. Shielding neutrons involve three steps that are slowing neutrons, absorption of neutrons, and impregnation of gamma rays. Neutrons slow down with thermal energy by hydrogen, water, paraffin, plastic. Hydrogenated materials are also very effective for the absorption of neutrons. Gamma rays are produced by neutron (radiation) retention on the neutron shield, inelastic scattering, and degradation of activation products. If a source emits gamma rays at various energies, high-energy gamma rays sometimes specify shielding requirements. Multipurpose Materials for Neutron Shields; Concrete, especially with barium mixed in, can slow and absorb the neutrons, and shield the gamma rays. Plastic with boron is also a good multipurpose shielding material. In this study; new applications and developments in the area of neutron shielding will be discussed in terms of different materials.

1 Introduction

Penetrating radiation serves many useful purposes, but it can also damage or destroy living organism, and these effects must be considered when radiation is used. Experience has shown that radiation can be used safely if its dangers are understood and work with radiation is planned to minimize these dangers and eliminate unnecessary exposure. The human sense hearing, sights, taste, smell and touch- cannot detect ionization radiation. Therefore, we must use radiation detection and measuring devices to determine the radiation levels that present in any situation and also, we must apply radiation protection rules.

Ionized radiation has several forms: Alpha, beta, neutron particles and gamma, X-rays. Every kind of energy or mass is caused by excesses (or both) of unstable atoms. To reach a balanced state, they must release this extra energy or mass in the form of radiation [1].

When alpha, beta and neutron are particle type radiations, X and gamma are electromagnetic waves with high energies. Lead or depleted uranium used to be protected from X and gamma. The X-rays are similar to the gamma ray, the primary difference between them is that they originate from the electron cloud [1].

Concrete is the most common material used for shielding in nuclear facilities such as particle accelerators, medical hospitals containing radioactive sources and radiation generating equipment and especially nuclear power stations and storing radioactive waste [2].

The protective properties of concrete against radiation may vary depending on the concrete composites. The additives play an important role primarily in modifying the two properties of concrete; Structural strength and radiation protection capacity [2].
Neutron radiation consists of free neutrons and usually occurs as a result of spontaneous or induced nuclear fission neutrons [1].

They can travel hundreds or even thousands of meters in the air, effectively stopping when they are blocked by a hydrogen rich material such as concrete or water. Neutrons, which usually fail to ionize because an atom is not a direct charge, are often indirectly ionizing because they are absorbed into a stable atom, so they become unstable and increase the likelihood of emitting another ionizing radiation [1].

In fact, neutrons are the only type of radiation that can make other materials radioactive. The type and amount of protective material depends on the radiation dose, the activity of the source and the dose rate. However, there are other factors in choosing protective materials such as manufacturing, cost and weight. It is also very important that the materials used for this purpose are located in the country.

In this context, studies on the absorption of radiation in materials have become an important issue that exists locally and it is therefore desirable to have knowledge of effective materials for neutron and gamma ray shielding.
Many researchers have reported that concrete is an indispensable material for particle accelerators, medical hospitals, radioactive sources and radiation producing equipment, and in particular for nuclear power plants and radioactive waste repositories. Radiation shielding properties of concrete may vary depending on the concrete composites [2].

Composites play an important role in essentially changing the two properties of concrete structural strength and radiation protection capacity.

* Corresponding author: aysunugur@osmaniye.edu.tr

Thus, linear attenuation coefficients increase as the Z of the absorber increases because photoelectric interactions are increased in high Z materials especially for low energy photons [2].

Because of the high Z effect, lead and concrete are often used to draw the walls of the X ray chambers and sites, and minerals such as hematite and barite are incorporated into the concrete to enhance its effectiveness as a photon shield.

Another aspect of the concrete popularity is the hydrogen content for the neutron shield. Hydrogen in concrete is known to be a radiation protection (especially neutron) process. Concrete blocks absorb neutrons due to hydrogen content. There are several studies about radiation shield processes using concrete; [3-7]. Also, neutron dose transmission values determined for several new concrete types including colemanite and neutron shielding properties of some boron bearing compounds determined and calculated [8,9].

2 Results and Discussions

2.1 Neutron shielding takes place mainly in three stages

1) Neutron slowdown; Neutrons classified according to their energy; E > 100 MeV: High energy neutrons, 10-20 MeV > E > 100-200 keV: Fast neutrons, 100 keV > E > 0.1 eV: Epithermal neutrons, E ~ kT ~ 1/40 eV: Thermal / Slow Neutrons, E ~ meV: Cold and ultra-cold neutrons. Neutrons are slowed down by thermal energy with hydrogenous materials. These materials are usually water, paraffin and plastic. There are some difficulties in using these materials. Water can evaporate or flow, paraffin can burn, plastic is quite expensive. Very fast neutrons can be slowed down by putting lead or iron barriers in front of them.

2) Absorption of neutrons; As mentioned above, the absorbing of neutrons in hydrogenated materials is highly effective.

The neutron capture effect section of H-1 is 0.33 barn. The cross section of the neutron absorption effect of boron is a very high material. The only negative situation when using boron is to emit a gamma ray at low energies. Lead or iron material is used to slow down very fast neutrons. Lead is a very important material for shielding with large atomic number, dense and soft structure.

3) Absorption of gammas due to neutron interaction; Gamma rays are produced by neutron (radiation) retention on the neutron shield, inelastic scattering, and decay of activation products.

Neutron shielding calculations are generally done by computers. There is a classical calculation formula for mono-energetic photons. This equation was defined by Schaeffer in 1973. The protective material is placed in front of the neutrons for slow neutron neutrons, like steel. At the back of this material must be a material containing hydrogen at least 50 cm thick (Fig. 1).

$$\dot{D} = \dot{D}_0 e^{-\Sigma_R t} \qquad (2.1)$$

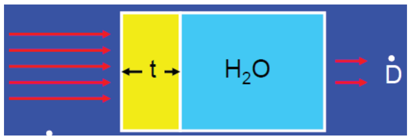

Fig. 1 Experimental Arrangement

$\dot{D}$ is the dose rate with shield, $\dot{D}_0$ is the dose rate without shield, t is the shield thickness(cm)

Σ_R is the neutron removal cross section(cm-1). If these calculations are made when an Am-Be neutron source is used, the building factor is approximately 5. When Equation 2.1 is regulated, the structure factor has the following effect in the equation.

$$\dot{D} = \dot{D}_0 e^{-\Sigma_R t} \qquad (2.2)$$

B is the building factor in Eq. (2.2). The material removal cross sections from NBS Handbook 63 are given in Table 1.

Table 1. Removal Cross Section of Material

Material	Removal Cross Section Σ_R (cm^{-1})
Water	0.1030
Iron	0.1576
Ordinary concrete	0.0942
Barytes concrete	0.0945
Graphite	0.0785

For what it is worth, the removal cross section is approximately 2/3 to 3/4 of the total cross section. In neutron shielding calculations, we might also use the mass attenuation coefficient symbolized ΣR/ρ. According to Schaeffer (1973), the mass attenuation coefficient (ΣR/ρ) for fast neutrons can be approximated with your choice of one of the following: [1].

$$\Sigma R / \rho = 0.19Z - 0.743cm^2 / g(Z \leq 8) \qquad (2.3)$$

$$= 0.125Z - 0.565cm^2 / g(Z > 8) \qquad (2.4)$$

$$\Sigma R / \rho = 0.206A - 1/3Z - 0.294 \approx 0.206(AZ) - 1/3 \qquad (2.5)$$

$$\Sigma R / \rho = 0.21A - 0.58 \qquad (2.6)$$

The previous equation can be written

$$\dot{D} = B\,\dot{D}_0\, e^{-\left(\Sigma R / \rho\right)\rho t} \qquad (2.5)$$

The lower energy of the gamma rays or neutrons is easier if it is to protect them. The more various high-energy gamma energies a radioactive source emits, the greater the need for shielding. For gamma rays, the higher the atomic number of the shielding material, the greater the weakening of the radiation.

For neutrons, the material allows the radiation to attenuate as the atomic number of the shielding drops. The greater intensity of both radiation and shielding material means the greater weakening of radiation. Although water and air have essentially the same effective atomic number, condensation of water causes a better shield.

Lead is a good shielding material with a large atomic number (Z = 82), high density (11.34 gr/cm^3), easily shaped, melted and relatively inexpensive. However, it is disadvantageous that it is weak, toxic, that the new lead material is obtained from natural lead and the recycling is contaminated. Lead can also be produced in a variety of forms. For example; standard bricks, interlocking bricks, sheets, tape, wire, pipe. It can be used in tungsten alloy as shielding material. Tungsten alloy contains iron, copper, cobalt and nickel. Tungsten has a high atomic number (74). It's very density (14-18 g/cm^3). It is strong, it is not toxic. It can be made finer than the lead. However, shaping and manufacturing are difficult and expensive at the same time. Another material used in shielding is uranium, which is enriched with high atomic number and density, as well as mechanically strong formation. The disadvantages of this material are expensiveness, radioactivity and its ability of quickly inflame. One of the best materials used in neutron shielding is water because it is even more homogeneous than the best shielding material. At the same time, it is transparent, inexpensive, radioactive sources and equipment can be installed in the water. Source leaks can be detected by sampling water. As the water shielding material, the disadvantages easily flow and evaporate. In addition, a leaking source can easily contaminate water.

Concrete is an important material to shielding both neutrons and gammas. Barium can be added to make it more effective. Very thick walls may be needed. It is difficult to change them.

3 Conclusions

For radiation sources emitting neutron and gamma, materials such as water, concrete, mixed concrete with barium, lead tunnels can be used as shielding material. These materials have certain advantages or disadvantages and they can be used according to the energy of radioactive materials and the type of radiation they emit.

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