Comparative Analysis of Neutron, Proton, Alpha and Beta Radiation Shielding Parameters of PES and PVDC

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Abstract. In medical applications, where polymers and plastics are used as tissue equivalent and phantom materials, the determination of accurate values of radiation shielding parameters becomes very important. In this context, the present work is aimed at determining the values of radiation shielding parameters of two polymers, viz. polyethersulphone (PES) and polyvinylidenechloride (PVDC) and then doing a comparative analysis of their shielding abilities in order to find a better material for shielding. The neutron shielding parameter was determined and was also compared with some common neutron shielding materials such as Boric Acid, Boron Carbide and Graphite. Furthermore, the shielding against charged particles i.e. neutron, proton and alpha particle was also studied with the help of the parameters, ‘mass stopping power’ and ‘projected range’. It was speculated that PES is superior to PVDC for shielding against neutrons, protons, alpha and beta radiation due to higher content of low atomic number elements per monomer unit. So, PES can be used potentially for radiation shielding in medical field.

1. Introduction
Shielding from harmful radiations is always a major safety concern because of the ill-effects of unwanted radiation exposure on living beings. Nuclear technology has its applications in numerous fields such as, medicine, industry, energy production, space exploration, agriculture, military, scientific research and other scientific and technological fields. In nuclear fission reactors, costly graphite and boron carbide rods are used for neutron shielding. For the purpose of neutron shielding, lighter materials are required such as hydrogen and hydrogen based materials, water, polythene, paraffin wax, boric acid, concrete etc. Water, as a neutron shielding material is most easily available and very cost effective. But, water used for neutron shielding is in liquid form at room temperature.

In medical field, unwanted charged particles are emitted from PET (Positron Emission Tomography) scans, CT (Computerized Tomography) scans, Brain Imaging etc. which very harmful for patients, radiation workers and general public and can even cause cancer in later stage of life. Alpha particles and protons are positively charged particles and have lesser range than neutrons. Beta radiation comprises of fast moving electrons which have high penetration power than alpha particles due to their small size and requires both light (low Z element) and heavy (high Z element) materials for shielding [1]. The accurate values of the radiation attenuation parameters of materials containing elements with low atomic number are very important in some medical applications.
In medical applications, materials containing low atomic number elements such as polymers and plastics are often used as tissue equivalent and phantom materials [2]. It becomes worthwhile to investigate attenuation parameters of the polymeric materials. Such data may be very useful for the health physicists. So, in the present work, a comparative analysis of the polymers PES (polyethersulphone) and PVDC (polyvinylidenechloride) for neutron, proton, alpha and beta radiation shielding is done in order to find a better material for shielding in medical applications.

2. Materials and Methods

The specimens of polyethersulphone (PES) and polyvinylidenechloride (PVDC), in the form of flat polished thin films (thickness = 50 µm) were procured from Good Fellow Limited (England). These films were used as-received without any further treatment in the size of 1 cm x 1 cm. The monomer composition of PES is [C₁₂H₈O₃S₁] and its density is 1.37 g cm⁻³. The monomer composition of PVDC is [C₂H₂Cl₂] and its density is 1.63 g cm⁻³. A broad peak at 2θ = 17.78º in the diffraction pattern which is the characteristic peak of PES is observed. The XRD of PVDC contains two broad peaks at 2θ = 15.56º and 31.56º which indicate its semi-crystalline nature (As per our previous studies [3, 4]).

The fast neutron removal cross-section (Σ₉) for the polymers PES and PVDC was obtained. And it was also compared with some standard neutron shielding materials viz. Boric Acid, Boron Carbide and Graphite. Further, the SRIM (Stopping and Range of Ions in Matter) simulation software was employed to simulate the interaction processes of the positively charged protons and alpha particles, incident on the studied polymers. Mass stopping power and projected range for protons and alpha particles were obtained thereby. Finally, shielding from the negatively charged Beta particles was studied by the parameters: mass stopping power (MSP) and continuous slowing down approximation (CSDA) range from the ESTAR database for electron interaction provided by NIST [1]. The results obtained from present analysis can be utilized to compare the shielding abilities of PES and PVDC.

3. Results and Discussion

The fast neutron removal cross-section (Σ₉) for the polymers PES and PVDC along with some standard neutron shielding materials viz. Boric Acid, Boron Carbide and Graphite for comparison [5, 6] is shown in figure 1.

Figure 1. Fast Neutron Removal Cross-section (FNRC) of PES and PVDC along with comparison with Boric Acid, Boron Carbide and Graphite.
The fast neutron removal cross-section (FNRC) of PES is more than that of PVDC. This is because of the reason that materials containing low atomic number elements are good neutron absorbers. From the monomer compositions of PES and PVDC, it can be inferred that PES contains higher number of hydrogen atoms per monomer unit than PVDC. Also, it can be viewed that the FNRC of PVDC is comparable to that of Boron Carbide (B$_4$C), which is used in fission reactors. The FNRC of PES is higher than that of Boric Acid (H$_3$BO$_3$), Boron Carbide (B$_4$C) and Graphite (C), which indicates that it is an excellent neutron shielding material.

![Fig 2](image1.png)  ![Fig 3](image2.png)

**Figure 2.** MSP for protons as a function of kinetic energy for PES and PVDC.  
**Figure 3.** MSP for alpha particles as a function of kinetic energy for PES and PVDC.

The curves of mass stopping power (MSP) with kinetic energy obtained from SRIM simulations for protons and alpha particles in the energy range 0 to 10 MeV has similar shape as both of the particles carry positive charge (figures 2 and 3). The MSP for protons and alpha particles first increases with kinetic energy, then attains a maximum value and then it decreases. This occurs due to excitation and ionization of the target polymers.

![Fig 4](image3.png)

**Figure 4.** Projected Range for protons as a function of kinetic energy for PES and PVDC.
The variation of projected range for protons with kinetic energy for PES and PVDC obtained from SRIM simulations is as shown in figure 4. The projected range of PES is lower for protons in low energy region (see inset of figure 4) and for PVDC is lower in the high energy region (figure 4).

**Figure 5.** Projected Range for alpha particles as a function of kinetic energy for PES and PVDC.

The variation of projected range for alpha particles with kinetic energy for PES and PVDC obtained using SRIM simulations is as shown in figure 5. It can be speculated that the projected range of PVDC is lower than PES in the entire energy range 0 to 10 MeV (see inset of figure 5 also).

**Figure 6.** MSP for electrons as a function of kinetic energy for PES and PVDC. **Figure 7.** Projected Range for electrons as a function of kinetic energy for PES and PVDC.

The curve of mass stopping power (MSP) with kinetic energy for electrons in the energy range 0.01 to 1000 MeV is shown in figure 6. The MSP is observed to be lower in the low energy region while the values are observed to be highest in the high energy region. From figures 6 and 7, it is seen that the PES is better for beta particle shielding in the low energy region, while PVDC is better for beta particle shielding in the high energy region. This can be because of Bremsstrahlung radiation.

4. **Conclusions**
The neutron, proton, alpha and beta radiation shielding properties of the polymers PES and PVDC were compared. Polyethersulphone (PES) has better neutron shielding ability than
polyvinylidenechloride (PVDC). The costly Boron Carbide can be replaced by the cost effective PVDC for shielding neutrons. Also, PVDC is cost effective than Graphite, which is used as control rods. It can also be concluded that PES is superior to PVDC for shielding against positively charged protons and alpha particles except in the high energy region for proton shielding. Also, PES is better for beta particle shielding in the low energy region, while PVDC is better for beta particle shielding in the high energy region due to Bremsstrahlung radiation in high energy region. Hence, it can be speculated that Polyethersulphone (PES) is superior to PVDC for shielding against neutrons, protons, alpha and beta radiation due to higher content of low atomic number elements per monomer unit. PES can be used potentially for radiation shielding in medical field.

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