CHARGED PARTICLE INTERACTION WITH SHIELDING AND DOSIMETRIC MATERIALS

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Abstract

Electron interaction parameters for few shielding and dosimetric materials are calculated for charged particles (electron, proton and alpha). Large variations for effective atomic numbers (Z_{eff}) and electron densities (N_{eff}) are observed for the charge particles in the selected energy region. Inconsistent variations of Z_{eff} and N_{eff} are observed for the charged particles in the low energy region. The charged particle shows maximum values of Z_{eff} for total interaction. Variation in N_{eff} is found to be as expected and same as Z_{eff}.

Keywords: *SSNTD, Neutron absorber, Glass, Charged particle, Z_{eff}*

Introduction

Interaction of different types of radiations with materials is one of the most essential branches in nuclear technology and medical applications. Interactions of photon, neutron, electron, proton and alpha with human organs, shielding and dosimetric are important to assess cancer and medical imaging, protection against radiation and dose estimation methodologies. Interaction of radiations with materials is described by basic interaction parameters (effective atomic number) to provide materials properties.

Effective atomic number (Z_{eff}) and electron density (N_{eff}) for multi-elemental compound or composite material are used similar to atomic numbers and electron densities for elements [1]. Z_{eff} and N_{eff} for a compound or composite material are described using the constituent elements and radiation interaction. The interaction of un-charged particle (photon) with alloys, semiconductors, glasses, concrete, superconductors, human organs, biological sample, dosimetric materials, etc are reported in literature.

In nuclear technology, materials and radiation represent ″the heart″ and whole technology depends on their interaction. Shielding and dosimetric materials are very important materials for nuclear technology, whose characteristics are required for interaction radiation. Glasses and neutron absorbing material are highly demanding for shielding and dosimetric purpose. These materials interact with the photons, neutrons, electrons, protons, helium and other charge particles, information regarding the photons and neutrons interaction with these materials being available in literature [2, 3]. However, charge particle interaction couldn't be found in literature.

Interaction of charge particles with a few types of materials (biomolecules, glasses, biological materials, dosimeters) has been reported in literature [4-6].

In the interaction of charge particles, characteristic distance was found in order of 10^{-5} to 10^{-3} m as compared with uncharged radiations $\approx 10^{-1}$ m [7]. Energy loss for charge particle interaction is found to be very high as compared with photon interaction. In case of photon, interaction is dependent upon atomic number and photon energy. However, in case of charged particles the interaction is dependent upon electron density of interacting material, atomic number of the atoms, charge of particle and velocity ($1/v^2$) or kinetic energy. Therefore, particles with greatest charge have the largest specific energy loss; and therefore alpha particle loses energy at a rate greater than proton for the same velocity. As a result of which, ionization density per unit volume for alpha particle is found larger than the proton. The charge particles transfer their kinetic energy to the medium, which may create defects to result in modification in response against the radiation interaction. Therefore, it is very important to examine the interaction of charge particles and assess the possible effects on material properties.

In the present study, charged particles i.e. electron, proton and alpha interaction were studied by using stopping power of constituent elements to compute Z_{eff} and N_{eff}. The projected ranges of charge particles were also computed for selected materials. The stopping power and projected range data for elements was taken NIST. The results of the investigation would be very useful for charge particle shielding and dosimetry applications.

Materials and Methods

The shielding and dosimetric materials used in present work were: solid state neutron track detectors (SSNTD), glass and neutron absorbers, which composition is given in Table 1. These are very important materials used in nuclear reactors, accelerators and research laboratories.

Table 1. Elemental compositions of materials

Type	Description	Density [g.cm^{-3}]	Element weight [%]
SSND	Amber	1.1	H(11.18); C(79.95); O(8.87)
	Makrofol	1.20	H(5.55); C(75.58); O(18.88)
	PET	1.44	H(4.19); C(62.50); O(33.30)
Glass	Pyrex	2.23	B(0.041); O(0.54); Na(0.028); Al(0.012); Si(0.38);K(0.0033)
	Soda lime	2.52	O(0.468); Na(0.096); Mg(0.001); Al(0.007); Si(0.345); S(8×10^{-4}); K(0.003); Ca(0.075); Ti(6×10^{-4}); Fe(0.003)
Neutron absorber	B_4C	2.52	B(78.26); C(21.74)
	B_2O_3	2.46	B(31.05); O(68.95)
	$Gd(NO_3)_3$	2.30	Gd(45.81);N(12.24);O(41.95)

The stopping power of a compound or composite material is theoretically calculated by using the mixture rule (i.e. sum of multiplication of proportion by weight element and mass stopping power of element) using mass stopping power from NIST database [8].

Z_{eff} and N_{eff} for charged particles (electrons, protons and alpha) were reported in [9]. In the present investigation, these parameters are calculated in the same manner. These interaction parameters are computed using three steps, as follows:
- obtaining mass stopping powers of a material using the NIST database
- construction of a pool of elemental stopping power data
- interpolation of Z values between the adjacent stopping cross-section of elements.

Z_{eff} calculation for charged particles was carried out using the logarithmic interpolation formula as given below:

$$Z_{eff} = \frac{Z_1(\log p_2 - \log p) + Z_2(\log p - \log p_1)}{(\log p_2 - \log p_1)} \quad (1)$$

where p_1 and p_2 are the stopping cross-section in between which the stopping cross section p of a material lies, Z_1 and Z_2 are the elements atomic numbers corresponding to the cross-sections p_1 and p_2, respectively. Detailed information about the above formula is provided in [9].

Now, the N_{eff} of the given material for the charge particles are calculated through the formula given below:

$$N_{eff} = N_A \frac{Z_{eff}}{A}\left(\frac{electron}{g}\right) \quad (2)$$

where <A> is the average atomic mass of a material.

Results and discussion

Stopping powers, projected ranges, Z_{eff} and N_{eff} corresponding to the charged particles for the selected shielding and dosimetric materials are shown in Figs 1-4. These parameters evolution for charged particles is shown for kinetic energy from 10^{-2} to 10^{3} MeV.

Figs. 1 (a)-(c) shows variation of the stopping power with charged particles. The magnitude of stopping power for electrons is higher than the one obtained for the protons and alpha particles. It is found that the electrons interaction provides the largest stopping power in low- and high- energy, whereas it is the lowest in middle energy region. However, in case of protons and alpha particles interaction, the stopping power is the largest in middle energy region and the lowest in high energy region.

It is also to be noted that there is shift in the peak stopping power from protons to alpha interaction.

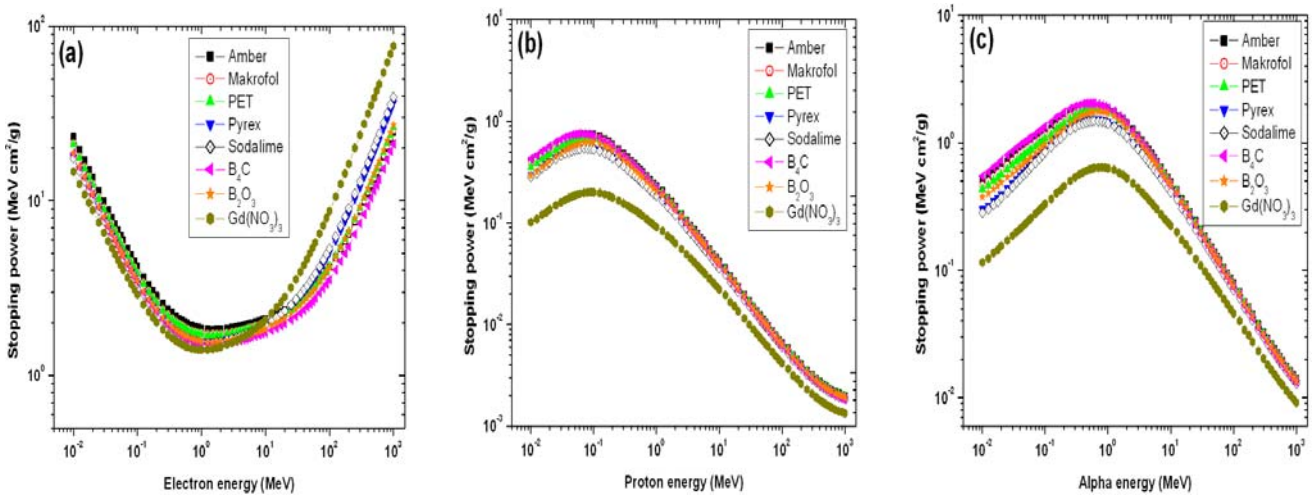


Fig. 1. Variation of the stopping power with charged particles energy; a) electron, b) proton, and c) alpha particle

The projected ranges for charged particles are shown in Figs. 2 (a)-(c) for selected shielding and dosimetric materials. It is to be observed that the projected ranges for charged particles increase with the kinetic energies. There is a noticeable variation in the projected range for electron, proton and alpha particle; the range reduces in middle energy region with charge and mass of the particle.

Z_{eff} variation for selected shielding and dosimetric materials is shown in Fig. 3 (a)-(c). Z_{eff} values of the selected materials are found to be the highest for electron interaction. The variation of Z_{eff} values with charged particle energy is found to be uniform along with smooth as compared with proton and alpha interaction. It is to be noted that the Z_{eff} is non-uniform in low energy region of proton and alpha particle interactions. The Z_{eff} value of $Gd(NO_3)_3$ was found as the largest for electrons followed by soda lime, whereas soda lime is having the largest value of Z_{eff} for protons and alpha particles.

N_{eff} variation for selected shielding and dosimetric materials is shown in Figs. 4 (a)-(c). The variation of N_{eff} can be explained similar to the Z_{eff} values. It is to be noted that the N_{eff} values of $Gd(NO_3)_3$ are found to be lowest among all the remaining selected materials for the charged particles.

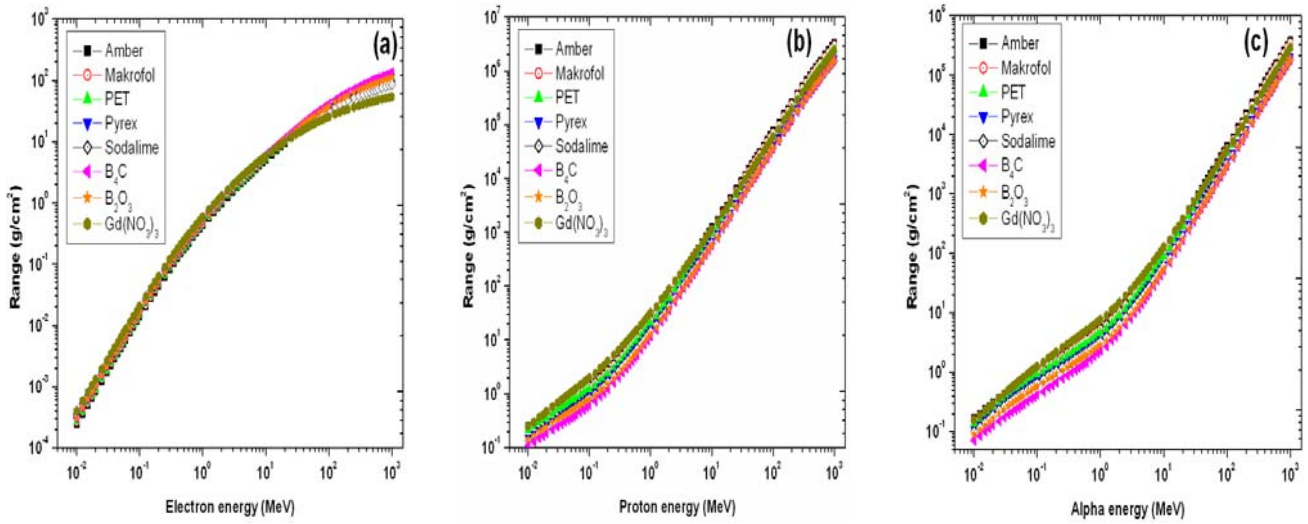


Fig. 2. Variation of the projected ranges with charged particles energy; a) electron, b) proton, and c) alpha particle

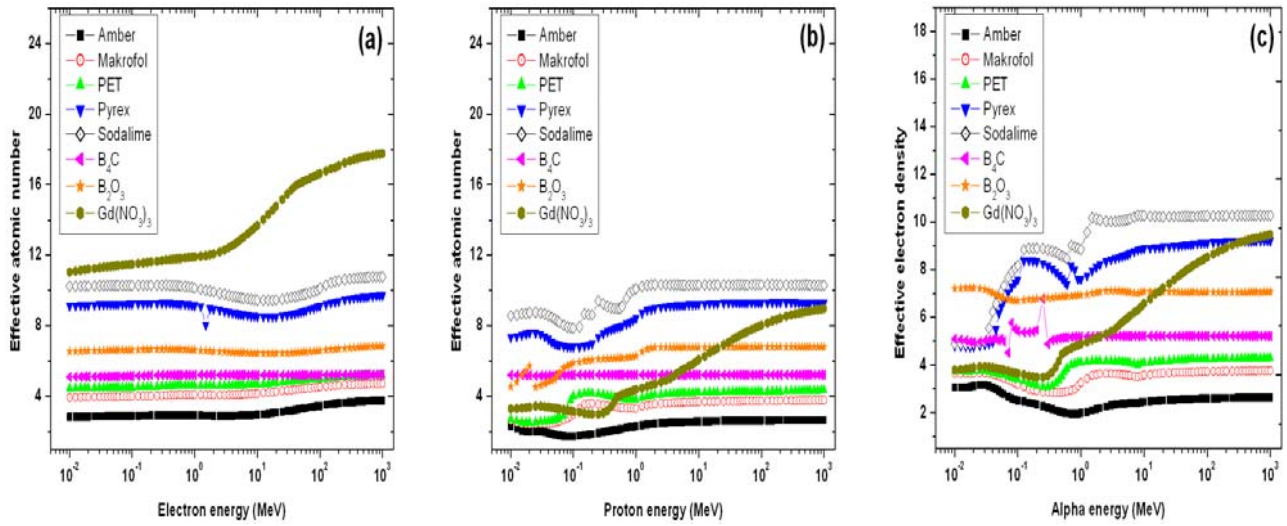


Fig. 3. Variation of Z_{eff} for selected materials with charged particles energy; a) electron, b) proton, and c) alpha particle

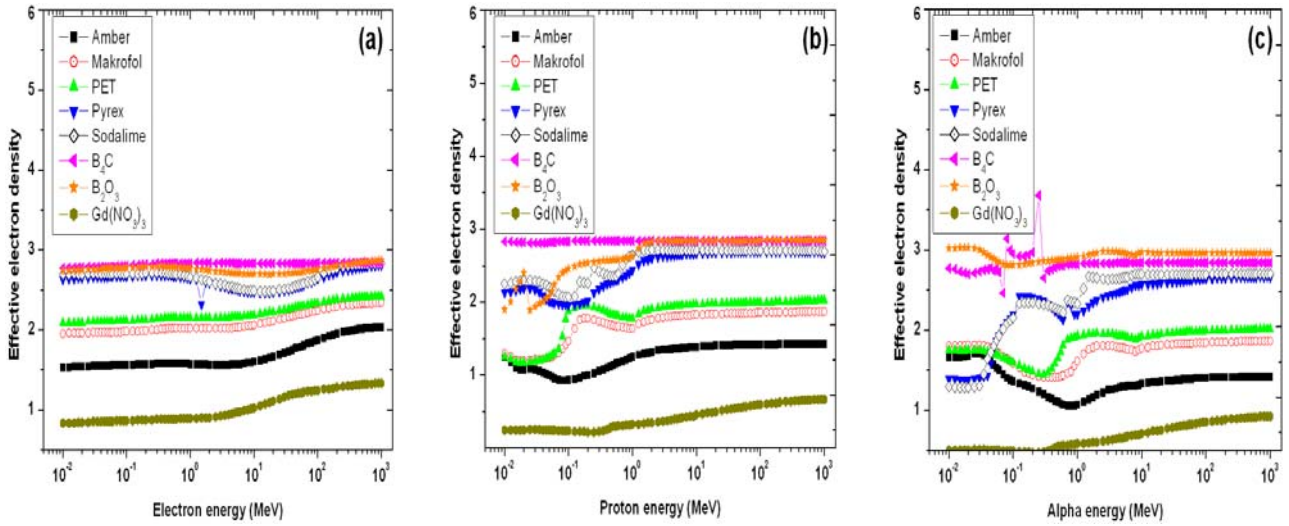


Fig. 4. Variation of N_{eff} for selected materials with charged particles energy; a) electron, b) proton, and c) alpha particle

Conclusions

The Z_{eff} and N_{eff} of shielding and dosimetric materials such as SSNTD, glasses and neutron absorbers were calculated for charged particles (electron, proton and alpha particle, respectively).

Variation of Z_{eff} and N_{eff} with kinetic energy of charged particles (electron, proton and alpha) has been calculated. The maximum values of Z_{eff} were found in higher energies region for electron interaction, whereas for the particles, the maximum values of Z_{eff} were found to be in relatively low energies region.

The lowest values of Z_{eff} were found for SSNTD; for the neutron absorbers having boron content were found the highest values of Z_{eff}.

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