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An Analytical Approach is Developed to Estimate the Values of Range of Alpha Particles Emitted from Radon Gas

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Abstract: Numerical assessments of radon exhalation from soil samples together with the detection probability of alpha particles by CR39 and LR115 detectors were the first objective of this work with demonstration of how radon propagates in various media using SRIM2013 software. The analytical approach was developed to estimate the values of range and detection probabilities by SSNTDs of alpha particles emitted from radon gas and progenies. It was found that the new version of SRIM2013 produced a deviation in stopping power, alpha range and detection probability of both alpha detectors.

Keywords: alpha energy, alpha range, detection probability, SRIM, CR39, LR115

I. INTRODUCTION

Historically, the first expression for the stopping power was given by Bohr . That was a classical consideration of the particle interaction with a free electron, where the energy lost in the collision with one electron was integrated in some assumed limits of interaction and the expression for the stopping power was derived [1]. Niels Bohr's early work is analysis of the stopping of charged particles by matter. One of Bohr's original conclusions was that the energy loss of ions passing through matter could be divided into two components; nuclear stopping (energy loss to the medium's atomic positive cores) and electronic stopping (energy loss to the medium's light electrons). Bohr, in his first papers, correctly deduced that the electronic stopping would be far greater than the nuclear stopping for energetic light ions such as are emitted by radioactive sources. His conclusion was based on recoil kinematics considering only the relative masses and abundance of the target electrons and nuclei [2]. In 1900 Marie Curie found that energetic particles having left radioactive materials could penetrate thin foils. Then further experiments on the interaction of α-particles with different gases gave rise to the discovery of the energy deposition maximum, the so called Bragg peak. The first theoretical treatment about scattering of electrically charged particles was published by J.J.Thomson in his book on electricity [3]. When a fast ion passes through matter, it loses energy principally by scattering electrons within the matter it passes through and, more importantly at low energies, by scattering from the nuclei of the atoms [4-6]. Stopping power and range have applied a crucial role in many aspects of physics such as heavy-ion physics, nuclear physics, atomic physics, and solid-state physics and in any applied areas involving particle-interaction see for example [7-13]; this have fostered ongoing revisions and new calculations of these quantities. Due to the complexity of the atomic structures of both projectile and target, the various studies have all had to adopt some approximation in order to simplify the calculation and/or to rely on a semi-phenomenological treatment and compassion with experimental data must be carried out [14]. The aim of the present work is to calculate the range of alpha particle using SRIM2013 and compare the results with data from SRIM2008 and SRIM2003. Next is the calculation of detection probability in SSNTDs using SRIM2013.

II. THEORY

The interaction of α-particle with matter depends on the following [15].

- The type of energy of radiation.
- Nature of absorbing medium.

Alpha-particle interact with electrons and nuclei via coulomb interaction. Due to coulomb interaction, α-particle may excite an electron to higher energy state. Ionization and excitation break chemical bond and generate reactive species that cause for further chemical reactions. This particles move at high speed. For example α-particle has 1Mev kinetic energy will move with a speed of $6:9\text{x}10^6$ m/s. The number of ion pairs per unit volume or per unit length on the path produced by α-particle is very high. The majority of the interactions occur with electrons and only a small number of interactions are with nuclei. Since the initial heavy charged particle (only such particles can produce tracks) is much heavier than electrons. The direction of the particle effectively does not change and the path is almost completely a straight line. This may not be true if the particle interacts with a nucleus, where a significant deviation from the initial direction may occur. The energy transferred to the orbiting electron in collision by α- particle is only a small fraction of α-particle energy due to very small mass of an electron compared to that of an α- particle. This can be shown for the maximum energy transfer which occurs when α-particle has a head on collision with an electron. One can assume the velocity of the orbiting electron is negligible to the velocity V_0 of the incident α- particle. After the collision the electron moves with a velocity u and α-particle moves with the velocity v [16]. Using conservation of energy and momentum for the elastic collision for the electron and α-particle we get:

$$\frac{1}{2}MV_0^2 = \frac{1}{2}Mv^2 + \frac{1}{2}mu^2 \qquad \text{Conservation of kinetic energy} \qquad (1)$$

$$MV_0 = Mv + mu \qquad \text{Conservation of momentum} \qquad (2)$$

Where m, and M are the mass of the electron and α-particle. By solving equations (1) and (2) we get:

$$v = \frac{(M-m)V_0}{(M+m)} \qquad (3)$$

Therefore, the energy lost (E) by an α-particle in a single collision with an electron is

$$E = E_\alpha \frac{4Mm}{(M+m)^2} \qquad (4)$$

Where E_α is the energy of the incident α-particles. Energy lost by α-particle in a single collision is very small. However the energy gained by the orbiting electron is often more than the binding energy of the atom and is therefore removed from the atom. The interacting atom is said to be ionized due to this α-particle electron collision. The physical quantity that describes the slowing down of charged particles in mater is the stopping power *dE/dx* where *dE* is the energy lost in the distance *dx*. Stopping power is given in J/m or in keV/m. The energy lost by a particle in the distance *dx* is the energy transferred to the material so this quantity is also called the linear energy transfer (LET). The Bohr relation for stopping power of heavy particle is given by [17] ;

$$-\frac{dE}{dx} = \frac{4\pi N z^2 K_o e^4}{m_o\, v^2}\, ln(\frac{2m_o v^2}{I}) \qquad (5)$$

where z is charge of incoming particle, $N = \frac{N_{Avog}\ \rho}{A}$ is number of electron per unit volume in the stopping material, m_o is rest mass of electron, υ is the velocity of the particle, e is the electron charge, $K_o=1/4\pi€_o$, and I is the mean excitation energy of the medium and is normally taken from experimental data. This was modified by taking into account the quantum effects by Bethe, and the relativistic effects by Bloch, and finally the well-known Bethe–Bloch expression for the stopping power was given as:

$$-\frac{dE}{dx} = \frac{Z^2 e^4}{4\pi\epsilon_o^2 m_o v^2}\, N \left[ln\, \frac{2m_o v^2 W_{max}}{I^2(1-\beta^2)}\ 2\beta^2 - \delta - U\,\right] \qquad (6)$$

where β =υ/c, m_o the rest mass of the electron, I the average excitation potential of electrons in the stopping material, W_{max} the maximal value of transferred energy of electron, Ȣ the correction for polarization of the material and U takes into account non-participation of inner electrons in the collision. The stopping power given in the above equation takes into account only collisions with electrons. Events with nuclei are not considered in this formula. There is one important drawback of this formula. It was derived using the perturbation theory and the first Born approximation [18-19].

The stopping of high velocity light ions in matter usually assumes two major simplification in stopping theory; (1) the ion is moving much faster than the target electrons and is fully stripped of its electrons, and (2) the ion is much heavier than the target electrons [2].

III. RESULT AND DISCUSSION

First of all we study the stopping power of alpha particles in air as presented in figure (1). In this figure we assume that the maximum energy of incident alpha particle is 10 MeV. On can conclude from these figures that the stopping power of alpha particle increases rapidly as the energy of alph particle increase this picture is dominates these figures as long as the energy of alpha particle less than 1,8 MeV this picture can be seen in more details for air in figure (2). When the energy of the alpha particles increases from 1.8 MeV to 10 Mev the behavior of the stopping power is exactly difference. One can conclude that there is almost an exponential decay of the stopping power of alpha particle, this pictures can be seen in more details in figure (3) for air. In passing through matter, charged particles ionize and thus loss energy gradually but continuously along its path until their energy is (almost) zero, after traveling a certain distance. This distance is called the range of the particle, which usually approximated to a straight line as seen in figure (4). The range of alpha particle in a given medium can be calculated from the flowing integral [10]

$$R(E) = -\int_{E_o}^{0} \frac{dE}{S(E)} \quad \text{where } S(E) = -\frac{dE}{dx} \qquad (7)$$

E_o (MeV) is the initial energy of ion. Since particle energy in SRIM software started from 0.01 MeV – 10 MeV ,the range can be written as;

$$R(E) = -\int_{10}^{0.01} \frac{dE}{-\frac{dE}{dx}} = \int_{0.01}^{10} \frac{dE}{-\frac{dE}{dx}} = \int_{0.01}^{10} \frac{dE}{S(E)} \qquad (8)$$

S(E) represent the analytical equation obtained by fitting the stopping power data with corresponding alpha energies E_o. To fit the data of stopping power [in SRIM program using the OriginPro8 software the following formula is used, where a_n , b_n are the best fit parameters in air and they are listed in table (1)

$$S(E) = \sum_1^9 a_n\, E^n,\ \ 0.01\, Mev \le E \le 1.8\ \ Mev, \text{and } \ S(E) = \sum_1^6 b_n\, E^n,\ \ 1.8\, Mev \le E \le 10\ \ Mev \qquad (9)$$

By using numerical integration in Fortran language to solve the range integration with change in energy step (0.01 MeV), the range of charged particle is computed. We can use the same procedure for CR and LR detectors. Figure (5), shows the calculated values of the range as a function of alpha particle energy plotted for air using SRIM2003,SRIM2008 and SRIM2013. Using the polynomial fitting procedure to these plots, 5th degree polynomials were used to find the relation between R(E) and E.

$$R(E) = a_o + a_1E + a_2E^2 + a_3E^3 + a_4E^4 + a_5E^5 \qquad for\ ai \qquad (10)$$

$$R(E) = b_o + b_1E + b_2E^2 + b_3E^3 + b_4E^4 + b_5E^5 \qquad for\ CR-39 \qquad (11)$$

$$R(E) = c_o + c_1E + c_2E^2 + c_3E^3 + c_4E^4 + c_5E^5 \qquad for\ LR-1 \qquad (12)$$

where R in mm , E in MeV, The fitting parameters are presented in table (2). Because of continuously update to SRIM library, the calculated results of the range and stopping power should be changed with. One of these updates for example is; the air (medium) density which is an important input data for the program. Table 3 shows the differences in the density used in SRIM program. From this table, one can see that air density increased with time, due to increases of pollutant specially CO_2 in local air, and this phenomenon will increases the stopping power and reduce the range of alpha particle in air as seen in figures (6-9).

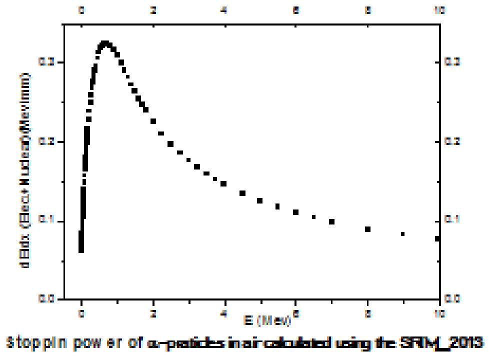


Figure (1)

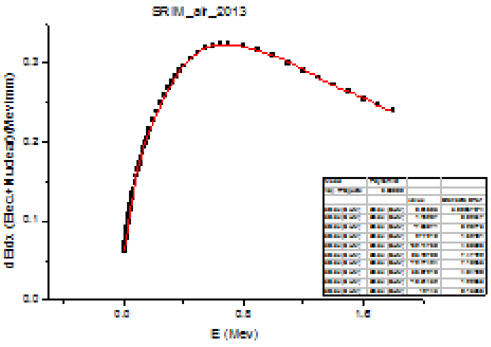


Figure (2)

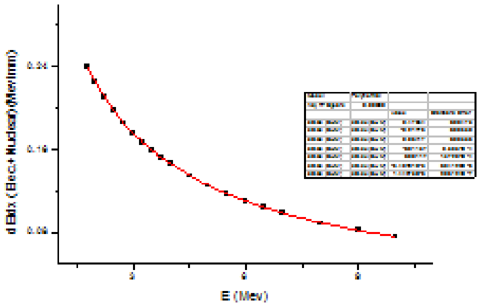


Figure (3)

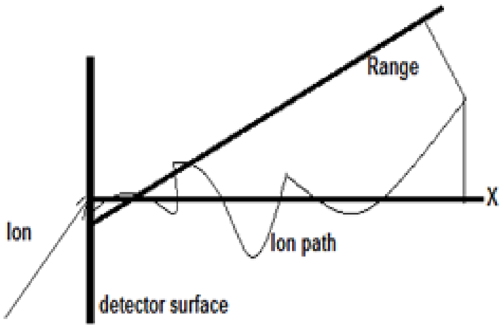
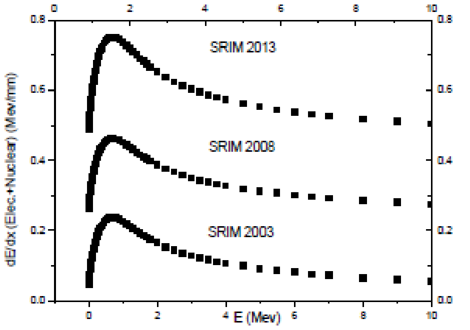


Figure (4)

a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9
0.04695	1.76297	-7.95971	27.7219	-62.14768	85.78708	-72.7742	36.97219	-10.31432	1.2143
b_0	b_1	b_2	b_3	b_4	b_5	b_6			
0.47834	-0.21776	0.06417	-0.01137	0.00117	$-6.40791*10^{-5}$	$1.44273*10^{-6}$			

Table (1). a_n , b_n the best fit parameters



Comparative stopping power of α–praticles in air for SRIM 2003 , SRIM 2008 & SRIM 2013

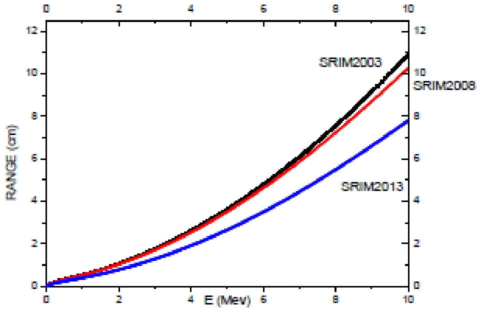
Figure 5.

a_o	0.7163	b_o	$9.51342*10^{-4}$	c_o	$6.70578*10^{-4}$
a_1	2.92139	b_1	0.00396	c_1	0.00336
a_2	0.15825	b_2	$2.69929*10^{-4}$	c_2	$9.91989*10^{-5}$
a_3	0.10016	b_3	$1.37928*10^{-4}$	c_3	$1.07668*10^{-4}$
a_4	-0.01017	b_4	$-1.42234*10^{-5}$	c_4	$-1.03704*10^{-5}$
a_5	$3.37885*10^{-5}$	b_5	$5.04952*10^{-7}$	c_5	$3.49362*10^{-7}$

table (2) These constants were used to calculate the stopping power - dE/dx by SRIM2003 and 2013.

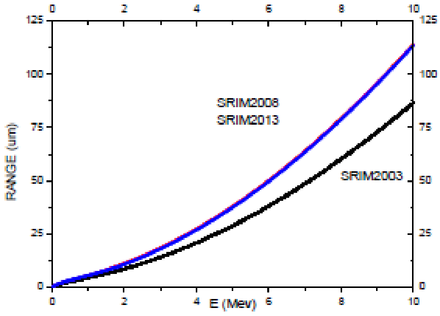
Density (gm/cm^3)	air	CR-39	LR-115
SRIM 2003	0.001208	1.32	1.40
SRIM 2008	0.001248	1.00	1.48
SRIM 2013	0.001630	1.00	1.48

Table(3) The differences in the density used in SRIM program.



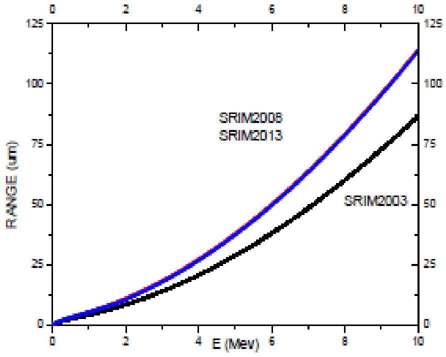
Comparative Range of α–praticles in air for SRIM 2003 , SRIM 2008 & SRIM 2013

Figure 6.



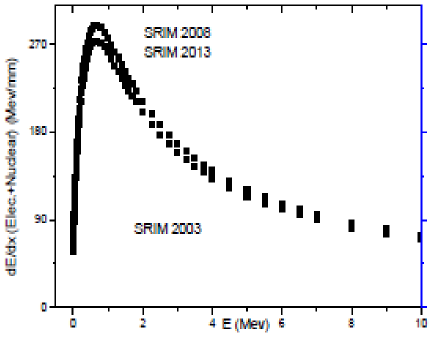
Comparative Range of α–praticles in CR-39 for SRIM 2003 , SRIM 2008 & SRIM 2013

Figure 7.



Comparative Range of α–praticles in CR-39 for SRIM 2003 , SRIM 2008 & SRIM 2013

Figure 8.



Comparative stopping power of α–praticles in LR-115 for SRIM 2003 , SRIM 2008 & SRIM 2013

Figure 9.

Table (4) contains, the alpha range in air for

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