Neutrons Yield by Bombarding Thorium (^{232}Th) Isotope with Charge Particle

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Abstract— **In the present work, the cross-sections of (p,n) reaction available in the literature as a function of proton energies for the high element target such as *^{232}Th(p,n)^{232}Ta* reaction[1] where Q-value is (-1.2771 MeV) and threshold energy is (1.2826MeV)in the ground state have been rearranged and interpolated for proton energies from (9 to 22MeV) in fine steps of (0.5 MeV) by using (MATLAB-7.6) . By using SRIM-2013 program , the stopping power has been recalculated by using computer program interpolated for proton energy . These cross sections together with the stopping powers calculated from the Zeigler semi – empirical formula have been used to calculate the neutron yield for reaction . The aim of the present work is to determine the neutron yield using the modified cross sections and stopping power of the above reactions . The results are compared with those published in the literature.**

Index Terms— **cross sections, stopping power, neutron yield, isotopes.**

I. INTRODUCTION

Interaction charged particles with matter : A charged particle passing through neutral atoms interacts mainly by means of the coulomb force with the electrons in the atoms. Even though in each encounter the particle loses on the average not more than a few electron volts of kinetic energy, ionization and excitation of atoms give the greatest energy loss per unit path length of the particle. The loss of kinetic energy in a nuclear encounter would be much larger, but such collisions are extremely rare compared to atomic encounters, roughly in proportion to the area of cross section of a nucleus compared to that of an atom, i.e. , $10^{-24}\ cm^2 / 10^{-16}\ cm^2 = 10^{-8}$. Hence, they do not contribute appreciably to the overall energy loss [2]. For kinetic energies larger than about $M_0 c^2$, where M_0 is the rest mass of the particle, energy loss by emission of electromagnetic radiation becomes increasingly important. The radiation is called *bremsstrahlung* (decelerating radiation). It is caused by the same mechanism as the emission of continuous X-rays. The basic process can be understood classically. According to Maxwell's equations, any accelerated charge radiates electromagnetic radiation. If a charged particle passes close to a nucleus, its velocity vector will be rapidly changed (at least in direction if not in magnitude), so that the particle undergoes an acceleration and hence it radiates [2].

Cross Sections Of Nuclear Reactions: To characterize the probability that a certain nuclear reaction will take place, it is customary to define an effective size of the nucleus for that reaction, called a cross section [2]. The reaction cross section data provides information of fundamental importance in the study of nuclear systems. The cross section is defined by [3]:

$$\sigma = R / I \qquad \text{------ (1)}$$

where R & I are the number of reactions per unit time per nucleus and the number of incident particles per unit time per unit area ,The cross section has the units of area and is of the order of the square of nuclear radius. A commonly used unit is the barn: ***1 barn = 10^{-24} cm^2***

In general, a given bombarding particle and target can react in a variety of ways producing a variety of light reaction products per unit time. The total cross section is then defined as [4]:

$$\sigma_{tot} = \sum_i \sigma_i \quad \text{------- (2)}$$

Where σ_i is the partial cross section for the process

Proton Stopping Power : For hydrogen projectiles, the nuclear stopping power is very small for all energies of interest [5]. The electronic stopping power is found to be proportional to projectile velocity, the specific dependence [6] being given by:

$$S_e = Z_1^{1/6} \times 8\pi e^2 a_o \frac{Z_1 Z_2}{(Z_1^{2/3} + Z_2^{2/3})^{3/2}} \times \frac{\upsilon}{\upsilon_o},$$

------- (3)

where $\upsilon \langle \upsilon_o Z_1^{2/3}$ and (Z_1) , (Z_2) are the atomic numbers of projectile and target respectively .(υ)is the projectile velocity, (a_o) , (υ_o) are the Bohr radius of the hydrogen atom and the Bohr velocity. In the present work ,by using the formulas proposed by Varelas and Biersack sited in Ziegler [5]

$$S_e = \frac{S_{Low} S_{High}}{(S_{Low} + S_{High})} \qquad \text{--------- (4)}$$

Where S_{Low} (Low energy stopping) is

$$S_{Low} = B_1 E^{1/2} \qquad \text{--------- (5)}$$

And S_{High} (High energy stopping) is

$$S_{High} = \frac{B_2}{E} \ln(1 + \frac{B_3}{E} + EB_4) \qquad \text{---------- (6)}$$

where B_1, B_2, and B_3 are fitting constants[5]

$B_4 = 4\ m / I\ M$

where (m) , (I) and (M) are the electron mass, the mean ionization potential, and projectile mass respectively . Eq.(4) asymptotically agree with eq.(3) at low energy , and with Bethe formula [5] at high energy .

Neutron Yields : For an accelerating beam traversing a target, the occurred nuclear reactions produce (N) light product particles per unit time, the yield is given by[7]

$$Y(x) = I_o N_d x \qquad \text{-------- (7)}$$

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Experimentally, the yield of neutrons detected per incident particle, Y_n , for an ideal, thin and uniform target and mono-energetic beam of energy (E) is given by

$Y_n = (N_d\, x)\quad (E_b)\quad (E_b)$ --------- (8)

where (N_d x) and (   ) the a real number density of target atoms, and the neutron-detection efficiency respectively . For a target which is not infinitesimally thin, the beam loses energy as it passes through the target, and the yield is then given by [7]

$$Y_n = \int_{E_t}^{E_b} \frac{\sigma(E`)\eta(E`) f dE`}{\frac{dE}{dx}(E`)} \qquad \text{-------- (9)}$$

in which $E_t = E_b$ -   E, where (E) is the energy loss of the beam in the target, f is the number of target atoms in each target molecule, and $\frac{dE}{dx}(E`)$ is the stopping power per target molecule, If the target is sufficiently thick, and there exist one atom per each molecule (i.e.,$f$= 1) and taking    (E`) = 1, then the resulting yield is called the thick-target yield which is given by

$$Y(E_b) = \int_{E_{thr}}^{E_b} \frac{\sigma(E)dE}{dE/dx} \qquad \text{--------- (10)}$$

where E_{thr} is the reaction threshold energy.

Thus, by measuring the yield at two closely spaced energies (E_1) and (E_2), one can determine the average value of the integrand over this energy interval as follows [8]:

$$[\frac{\sigma(E)}{dE/dx}]_{E_b} = \frac{Y(E_2)-Y(E_1)}{E_2-E_1} \qquad \text{--------- (11)}$$

Where (E_b) is the average of (E_1) and (E_2). If   (E) are available in the literature as a function of projectile energy (E_b) for natural elements, then the neutron yield can be calculated using eq.(11). If neutron yield is available as a function of projectile energy (E_b), then eq. (11) can be used to calculate   (E) as a function of (E_b). Thus, consequently one can calculated the neutron yield by using eq. (11).

For natural elements and if only one stable isotope is available in nature, then [9]

$Y_o = Y(E)$ -------- (12)

where (Y_o) is the neutron yield per 10^6 bombarding particle for the natural element.

If   (E) is calculated for a certain isotope whose concentration (enrichment) is C %, then [9]

$$Y_o = \frac{a}{c} Y(E) \qquad \text{--------- (13)}$$

where (a)is the abundance of the isotope in the natural element. If there exist more than one isotope that can be involved in the nuclear reaction and the cross sections are calculated as a function of incident energy for each isotope, then [9].

$$Y_o = \frac{a_1}{c_1} Y_1(E) + \frac{a_2}{c_2} Y_2(E) + \ldots.. \qquad \text{-------- (1 4)}$$

II. RESULT

The atomic mass isotopes of Thorium and Thallium mentioned in this study have been taken from the latest nuclear wallet cards released by the National Nuclear Data Center(NNDC) [10] ,to calculate the Q-value and threshold energy **(-1.2771 MeV and 1.2826MeV)** respectively in the ground state . In this study, neutron productions from the high nuclei depend on the cross sections because of the high probability to produced **^{232}Ta** when proton energy is equal (9.0MeV) when the cross sections **(4.4800mb)** as shown in fig.(1) and depend on stopping power as well as the energy of charge particle because the high nuclei bombarding by high energy of charge particle (proton). In fig.(2) we observed that the stopping power decreased with proton energy in Thorium isotopes **(^{232}Th)** such as maximum stopping power in **(0.0182MeV)** is **(0.0618MeV/(mg/cm^2))** and minimum in **(21 MeV** is **0.0104MeV/(mg/cm^2))**.

We calculated the neutron yield by application the function as fallow :

Yield = dE ---------------(7)

In fig. (3) the high neutron yield in proton energy **(21MeV)** is **(1.3659 (n/10^{6}proton))** as shown in table (1).

Table (1):The cross section , stopping power and neutron yield as a function of proton energy for ***^{232}Th(p,n)^{232}Ta*** reaction[1] where Q-value is **(-1.2771 MeV)** and threshold energy is **(1.2826MeV).**

p-energy (MeV)	X-sections (mb)	Stopping power (MeV/(mg/cm^2)	Yield (n/10^{6}proton)
9.0000	4.4800	0.0182	0.1230
9.5000	5.0800	0.0176	0.1442
10.0000	5.6800	0.0170	0.1670
10.5000	6.2800	0.0165	0.1903
11.0000	7.2267	0.0160	0.2260
11.5000	8.2600	0.0155	0.2657
12.0000	9.2933	0.0151	0.3078
12.5000	10.8091	0.0147	0.3675
13.0000	12.4455	0.0143	0.4347
13.5000	14.4800	0.0140	0.5182
14.0000	15.4000	0.0136	0.5651
14.5000	15.9333	0.0133	0.5981
15.0000	16.8222	0.0130	0.6462
15.5000	18.3538	0.0127	0.7206
16.0000	20.0462	0.0125	0.8047
16.5000	21.9500	0.0122	0.8992
17.0000	24.7000	0.0120	1.0330
17.5000	27.4500	0.0117	1.1706
18.0000	28.6154	0.0115	1.2447
18.5000	29.3846	0.0113	1.3008
19.0000	29.9231	0.0111	1.3485
19.5000	29.5385	0.0109	1.3556
20.0000	29.1538	0.0107	1.3630
20.5000	28.5800	0.0105	1.3575
21.0000	28.3000	0.0104	1.3659

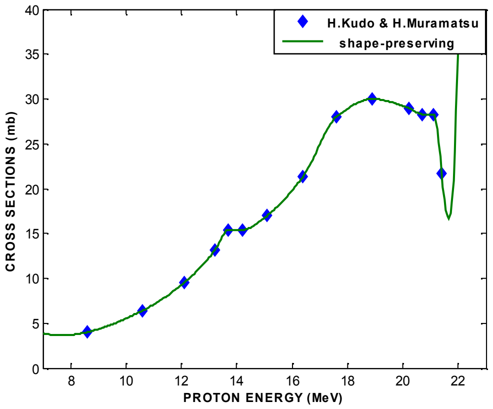

Fig. (1):The cross sections as a function of $^{232}Th(p,n)^{232}Ta$ reaction[1]

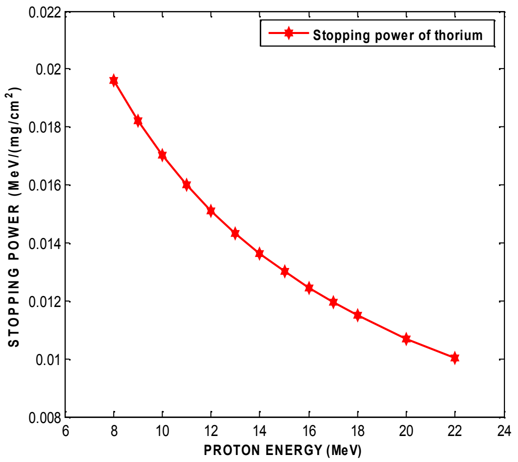

Fig.(2):The stopping power as a function of proton energy for $^{232}Th(p,n)^{232}Ta$ reaction

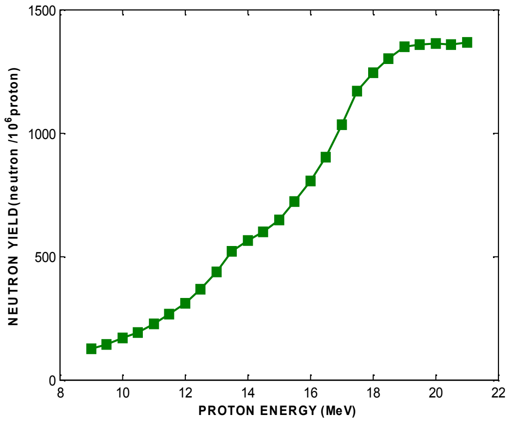

Fig.(3):The neutron yield as a function of proton energy for $^{232}Th(p,n)^{232}Ta$ reaction

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