Empirical Formula for Neutron Yield for (α,n) Reactions from ^{63}cu and ^{65}cu

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Abstract

The calculated neutron yields from (α, n) reactions are very important in analyzing radiation shielding of spent fuel storage, transport and safe handling. The cross sections of ^{63}Cu (α, n) ^{66}Ga and ^{65}Cu (α, n) ^{68}Ga reactions are calculated for different α-energies using different sets of programs using Matlab language. The values deduced energy is from threshold to E_{α}= 30 MeV and to E_{α}= 40 MeV for ^{63}Cu (α, n) ^{66}Ga and ^{65}Cu (α, n) ^{68}Ga respectively. The weight average cross section was then used to calculate the neutron yields y_0 $(n/10^6\alpha)$ for each reaction .The empirical formula was then suggested to calculate total neutron yield to each isotope.

Keywords: Neutron yield, Cross section ,Empirical formula.

Introduction

The nuclear data on (α,n) reactions play an important role in the fields of radiation shielding and critically safety relating to storage,transport and handling of spent fuel [1],as well as for the design and operation of a nuclear fuel cycle facility and particle accelerator facility [2]. The cross section for ^{63}Cu (α, n) ^{66}Ga has been measured for E_{α}= (7.8- 46) MeV by Levkovskij. (1991) [3] and the cross section for ^{63}Cu (α, n) ^{66}Ga reaction has been measured for (8-37) MeV by Zhukova at. et al [4] and for (7.8-42.5) MeV by Bryant at .et al [5] and for (8-40) MeV by Porile and Morrison [6] and for (8-38) MeV by Zweit at .et al [7] and for (8-38) MeV by Singh at .et al [8] . The cross section for^{65}Cu (α, n) ^{68}Ga reaction has been measured for E_{α}= (9- 45) MeV by Bhardwai [9] , and measured for (7.8- 46) MeV by Levkovskij. (1991) [3], and for (7.8- 46) MeV by Bryant at. et al [5], and for (7.8- 40) MeV by Porile at. et al [6], and for (7.8- 41.7) MeV by Bonesso. et al [10], and for (8.9- 40) MeV by Singh at. et al [8], and for (8.5-36.3) MeV by Szelecsenyi. et al [11]. In JENDL the total cross section and neutron yield for these reactions have been presented [12].The cross sections evaluations for (α,n) reactions for^{63}Cu and^{65}Cu target elements are calculated according to the available international atomic energy agency (IAEA) libraries and other experimental published data[12]. The stopping power depends on the type and energy of the incident particle and on the properties of the materials it passes. In passing through matter ,fast charged particles ionize the atoms or molecules which they inter. The yield for a target having any thickness can be defined as the ratio of the number of nuclei formed in the nuclear reaction to the number of particles incident on the target.

Thick target yield is defined for a fixed macroscopic energy loss ,E_{in} -E_{th}, in a thick target. Integral yield is defined for a finite energy loss down to the threshold of the reaction ,E_{in}-E_{th} .The recommended cross sections discussed in the present work and the target stopping powers of SRIM program 2003 [SRIM 2003] were used to calculate the alpha yield for a target of significant thickness .

Data Reduction and Analysis

The Q-values and threshold energies of these reactions were calculated by using the atomic mass obtained from the following equations [13] :

$Q=931.5\,[M_{\alpha} + M_x - M_n - M_y]$…………..(1)

$E_{th}=-Q\,[1+M_{\alpha}/M_x]$…………………… (2)

Where M_n represents the mass of neutron and M_{α},M_x and M_y are the atomic mass (in amu) of ^{4}He ,target and product nucleus respectively. The cross section data of ^{63}Cu(α,n) ^{66}Ga were published by [3-8] and of ^{65}Cu(α,n) ^{68}Ga were published by [3,5-6,8-10]. These data are plotted, interpolated and recalculated in steps of 1 MeV from threshold to 30 MeV for ^{63}Cu and from 9 to 40 MeV for ^{65}Cu by using different sets of programs using matlab language to obtain weighted average values for each reaction.

*The normalization for the statistical distribution of cross sections errors to the corresponding cross section values for each another has been done .

*The interpolation for the nearest data for each energy interval as a function of cross sections and their corresponding errors have been done using matlab program.

*The interpolation values were calculated to obtain the adopted cross section which is based on the weighted average calculation according to the following expressions [13] :

$$\sigma_{w.a.} = \frac{\sum_{i=1}^{n} \frac{\sigma_i}{(\Delta\sigma_i)^2}}{\sum_{i=1}^{n} \frac{1}{(\Delta\sigma_i)^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where the standard deviation error is

$S.D = \frac{1}{\sqrt{\sum_{i=1}^{n} \frac{1}{(\Delta\sigma_i)^2}}}$ ....(4)

Where σ_i is the cross section value, $\Delta\sigma_i$ is the corresponding error for each cross section value.

Neutron Yields

For an accelerating beam trans versing a target ,the occurred nuclear reactions produce N light particles per unit time and is given by [13] :

$Y = I_O\, N\, d\, \sigma x$ … … … … . . … … (5)

Experimentally the yield of neutrons detected per incident particle Y_n for an ideal ,thin and uniform target and mon energetic beam of energy E is given by [13] :

$Y_n = (Ndx)\sigma(E_b)\eta(E_b)$ … … …. (6)

Where Ndx is the areal number density of target atom and η is the neutron –detection efficiency 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 [14]:

$Y_n = \int_{E_t}^{E_b} \frac{\sigma(\acute{E})\eta(\acute{E}) f d\acute{E}}{-\frac{dE}{dX}(\acute{E})}$ … ....(7)

Where E_t is $(E_b - \Delta E)$ where ΔE is the energy loss of the beam in the target, f is the number of target atoms in each molecule, and $\frac{dE}{dX}$ $(\acute{E})$is the stopping power per target molecule, if the target is sufficiently thick, and there exists one atom per each molecule (i.e.f=1) and taking $\eta(E) = 1$,then the resulting yield is called the thick –target yield which is given by [15]:

$Y(E_b) = \int_{E_{thr}}^{E_b} \frac{\sigma(E)dE}{\frac{dE}{dX}}$.......................(8)

Where E_{thr} is the reaction threshold energy. Thus by measuring the yield at two closely spaced energies E1 &E2,one can determine the average value of the integrand over this energy interval as follows [15]:

$$\left[\frac{\sigma(E)}{\frac{dE}{dX}}\right]_{E_b} = \frac{Y(E_2) - Y(E_1)}{E_2 - E_1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(9)$$

Where E_b is the average of E1 &E2,if $\sigma(E)$ is the cross section which is available in the literature as a function of projectile energy E_b for natural elements, then the neutron yield can be calculated using equation (9)

Results and Discussion

A-Cross Section Calculation

The Q-value and threshold energies for ^{63}Cu(α,n) ^{66}Ga and ^{65}Cu(α,n) ^{68}Ga are presented in the table (1). The adopted value of cross section which is calculated in the present work are presented in the figures (1,2) from threshold to E_α=30 MeV and to E_α=40

MeV for $^{63}Cu(\alpha,n)^{66}Ga$ and $^{65}Cu(\alpha,n)^{68}Ga$ respectively. In each figure, the cross sections are compared with those deduced from the previous measurements.

B-Yield calculation

Neutron yields for $^{63}Cu(\alpha,n)^{66}Ga$ and $^{65}Cu(\alpha,n)^{68}Ga$ reactions calculated from reproduced cross section refs. [3-8], and [3,5-6,8-10] are presented in figures (3,4) together with the calculated weighted averages. The results obtained are consistent with each other. The neutron yields calculated in the present work have been considered as adopted neutron yield values by using the adopted neutron yields as an input data ,a matlab computer program have been executed to obtain the fitting parameters A& B for the power which fits formula equations

For $^{63}Cu(\alpha,n)^{66}Ga$ reaction is:

f(x) = a1*exp(-((x-b1)/c1)^2) + a2*exp(-((x-b2)/c2)^2) + a3*exp(-((x-b3)/c3)^2) + a4*exp(-((x-b4)/c4)^2) + a5*exp(-((x-b5)/c5)^2) + a6*exp(-((x-b6)/c6)^2)………………(10)

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a1 =        70.51
b1 =        31.18
c1 =        1.435
a2 =       -403.3
b2 =        28.16
c2 =        3.197
a3 =       -918.5
b3 =        24.83
c3 =        3.953
a4 =       -55.09
b4 =        21.07
c4 =        2.537
a5 =         1879
b5 =        26.03
c5 =        6.429
a6 =        120.3
b6 =        15.81
c6 =        4.015
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And for $^{65}Cu(\alpha,n)^{68}Ga$ reaction is:

F(x) = a1*exp(-((x-b1)/c1).^2) + a2*exp(-((x-b2)/c2).^2) + a3*exp(-((x-b3)/c3).^2) + a4*exp(-((x-b4)/c4).^2)…………(11)

a1 = 4547
b1 = 21.55
c1 = 5.059
a2 = -4067
b2 = 21.57
c2 = 4.947
a3 = 843.9
b3 = 31.69
c3 = 8.037
a4 = 48.48
b4 = 14.23
c4 = 3.291

Conclusions

In the present work, the more recent cross section of (α,n) reactions for intermediate nuclei are reproduced and used to calculate the neutron yields at different α-particle energies .The obtained n-yields have been formalized using fitting procedure, as well as empirical formula has been established which combines the variation of n-yields with projectile kinetic energy and target atomic .

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Table No.(1):Q-values and threshold energies for (α,n) reactions with ^{63}Cu , ^{65}Cu

Reaction	Threshold energy (MeV)	Q-value(MeV)
^{63}Cu(α,n) ^{66}Ga	8.16±0.03	-7.513±0.032
^{65}Cu(α,n) ^{68}Ga	6.16±0.04	-5.843±0.12

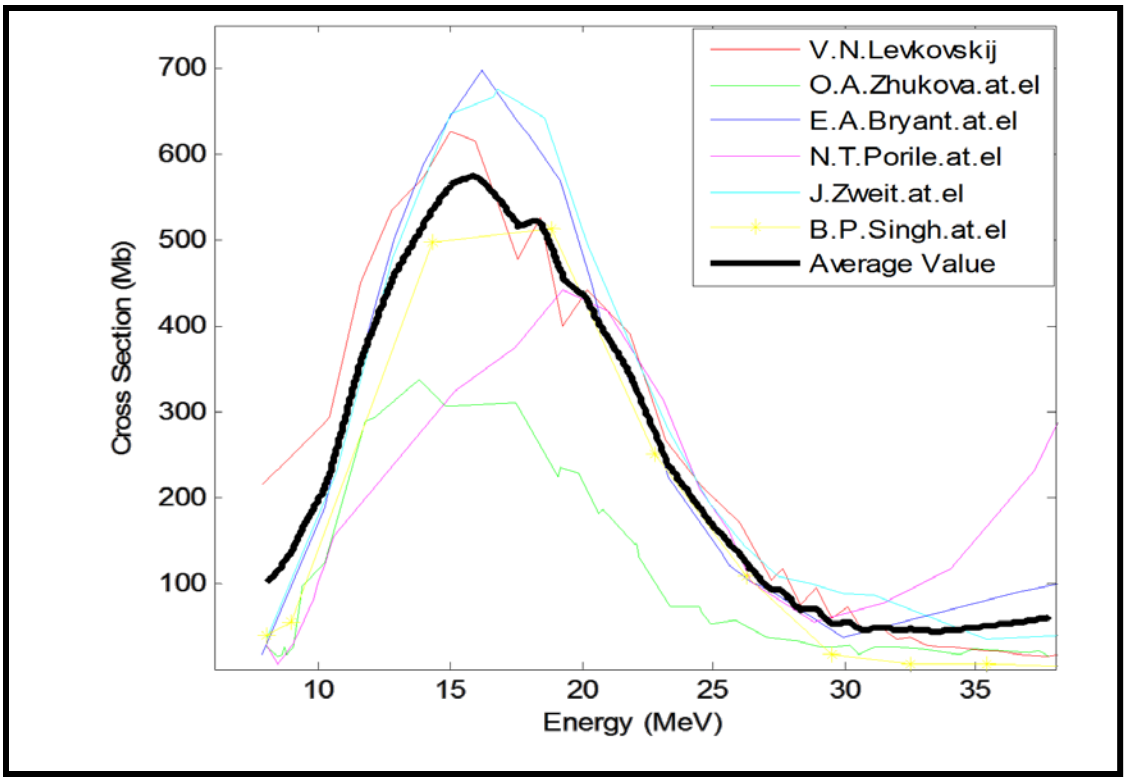

Figure No .(1) : Cross sections of ^{63}Cu (α, n) ^{66}Ga reaction

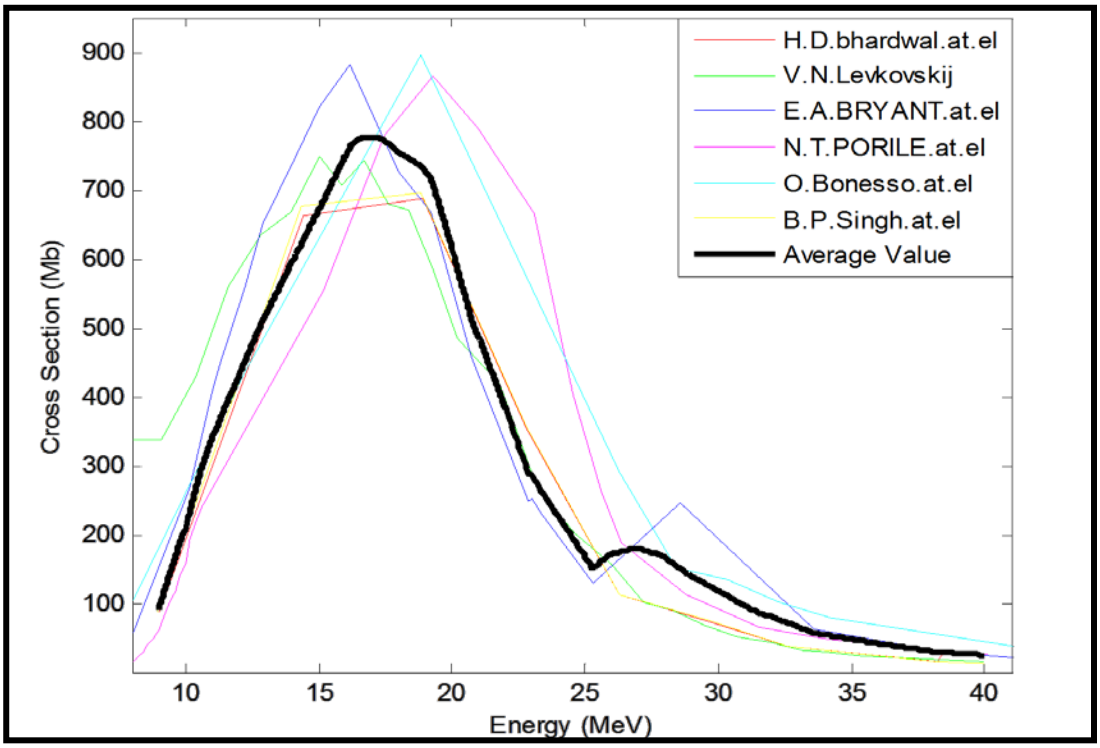

Figure No.(2) : Cross sections of ^{65}Cu (α, n) ^{68}Ga reaction

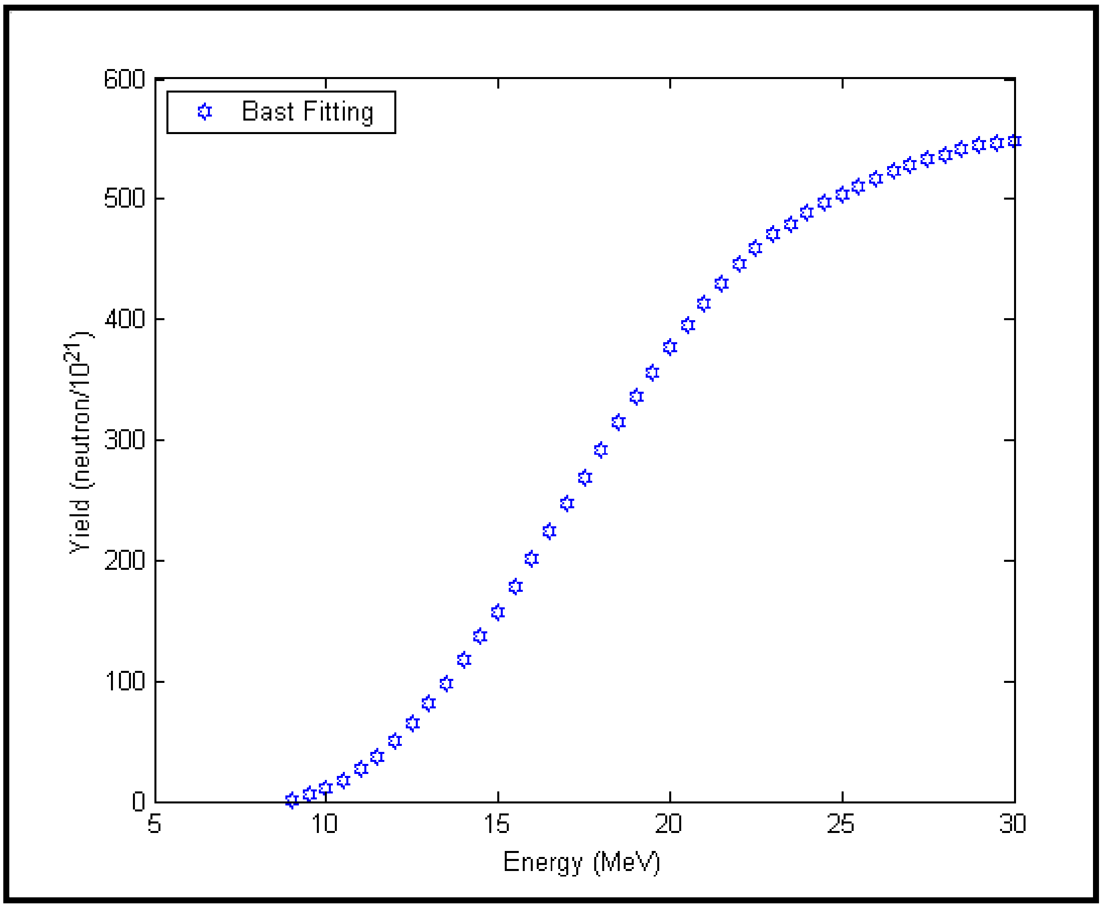

Figure No.(3) : Total Neutron yield of ^{63}Cu (α, n) ^{66}Ga reaction

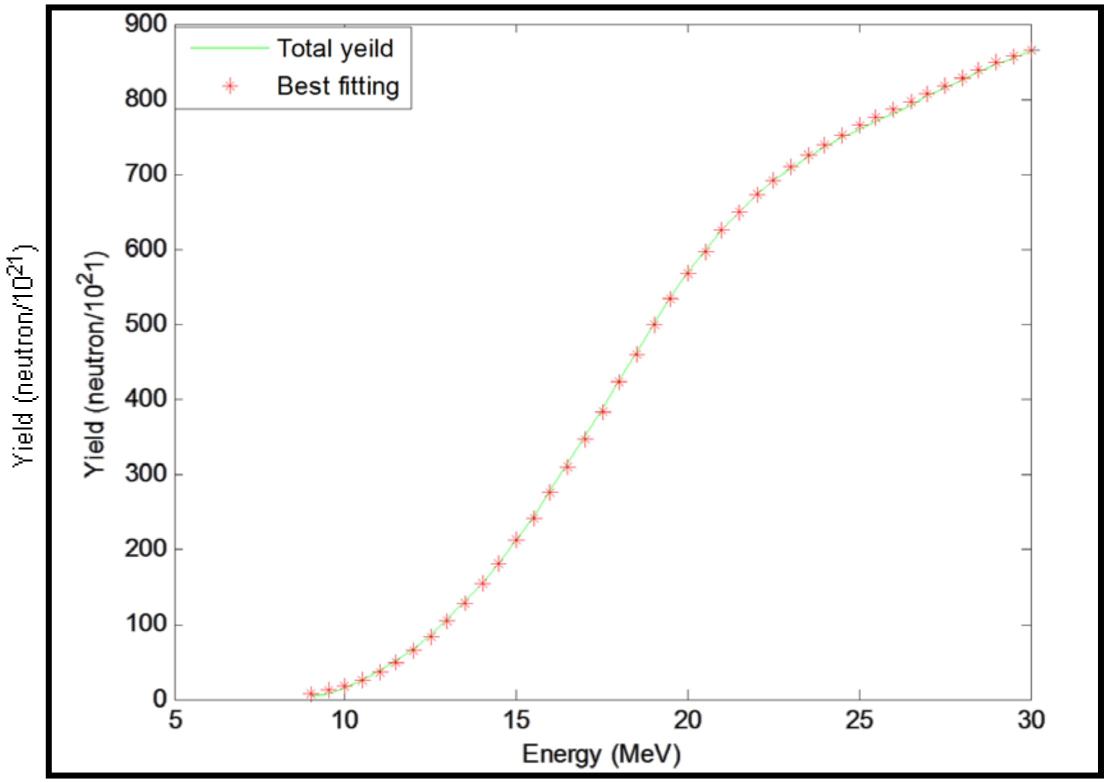

Figure No.(4) : Total Neutron yield of ^{65}Cu (α, n) ^{68}Ga reaction

الصيغة التجريبية للحصيلة النيوترونية لتفاعلات (ألفا،نيوترون) من ^{63}cu و ^{65}cu

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الخلاصة

ان حسابات الحصيلة النيوترونية لتفاعلات(α, n) مهمة جدا في تحليل الاشعاع الناتج من تدريع للوقود المستنفذ وتخزينه ونقله والمعاملة الآمنة له . حسبت المقاطع العرضية لتفاعلات ^{66}Ga (α, n) ^{63}Cu و ^{68}Ga (α, n) ^{65}Cu عند طاقات الفـــــــــا المختلفة باستعمال مجموعة برامج بلغة ماتلاب ، وقد تم الاخذ بعين الاعتبار طاقات الفا من طاقة العتبة الى 30 MeV والى 40MeV لتفاعل ^{66}Ga(α, n)^{63}Cu و ^{68}Ga (α, n) ^{65}Cu على التوالي ، واستخدمت هذه القيم للمقاطع العرضية الموزونة في حساب الحصيلة النيوترونية y_0 (نيوترون/مليون الفا) لكل تفاعل ، بعد ذلك اقترحت الصيغة التجريبية لحساب حصيلة النيوترون الكلية في كلا النظيرين .

الكلمات المفتاحية:الحصيلة النيوترونية ، المقطع العرضي ،الصيغة التجريبية .