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Study of the calculated yields for induced deuterons on Zinc to produce Copper and Gallium

دراسة نواتج الديوترونات المستحثة في الزنك لإنتاج النحاس والكاليوم

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البحث مستل

Abstract

In this research was the study of copper products and Gallium deuterons interactions of zinc element with the importance of used therapeutic and pharmaceutical and diagnostic. It has been calculated stopping power and evaluation yields for induced deuterons to produce Copper and Gallium from Zinc isotopes ($^{64}_{30}Zn$, $^{66}_{30}Zn$, and $^{68}_{30}Zn$) in the energy range from threshold energy up to 25.8 MeV deuteron energies have been calculated. Complete energy range starting from threshold energy for each reaction have been analyzed statistically and the adopted cross sections were reproduced in fine steps of incident deuteron energy in 0.01 MeV intervals with their corresponding errors. The stopping power according to Zeigler formula was used in order to obtain the cross sections and calculated yield for each reaction based on the complete spectrum of cross sections.

Keywords: Cross sections; Stopping power; induced deuterons Zinc to target element. Copper yield, Gallium yield .

الخلاصة

في هذا البحث تم دراسة نواتج النحاس والكاليوم من تفاعلات الديوترونات مع عنصر الزنك لأهمية استخداماتهما العلاجية والدوائية والتشخيصية. ولقد تم حساب قدرة الايقاف وتقييم نواتج الديوترونات المستحثة لإنتاج النحاس والكاليوم من نظائر الزنك المتوسطة ($^{64}_{30}Zn$, $^{66}_{30}Zn$ and $^{68}_{30}Zn$) بمدى طاقي من طاقة العتبة الى 25.8 MeV لطاقات الديوترونات ، حيث تم تحليل كامل لمدى الطاقة ابتداءا من طاقة العتبة لكل تفاعل للحصول على المقاطع العرضية المختارة وقد تم معالجتها احصائيا لحساب المقاطع العرضية لفترات صغيرة من طاقة البروتون الساقطة مقدارها 0.01 MeV مع الاخطاء المصاحبة لكل قراءة. لقد تم استخدام صيغة زكلر لحساب قدرة الايقاف الناتجة وبذلك تمكنا من تقيم النواتج المحسوبة لكل تفاعل بعد الحصول على طيف متكامل للمقاطع العرضية.

1. Introduction

The calculated yields for induced deuteron on Zinc to produce Copper and Gallium have been intensively studied with high energy resolution up to energies accessible with conventional electrostatic accelerators. In addition to the intrinsic value of calculated yields for induced deuteron on Zinc to produce Copper cross section in the investigation of nuclear spectroscopy and reaction mechanisms, such data are essential for the polarization of calculated yields for induced deuteron on Zinc to produce Copper and Gallium [1-4]. The cross sections evaluation for the reactions that produce therapeutic radionuclides Copper and Gallium are calculated according to the available data in International Atomic Energy Agency (IAEA)[5] libraries and other experimental published data. 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 encounter. 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_{out}, 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 calculated stopping powers [6,7] were used to evaluate the calculated yields for a target of significant thickness. The cross sections for induced deuteron on Zinc to produce Copper and Gallium published by different authors [6-13] in the energy range (5.3– 25.8) MeV have been used. Adopted values have been calculated, the cross sections were reproduced in fine steps of incident deuteron energy in 0.01 MeV intervals with their corresponding errors. In this study the stopping power have been calculated using Ziegler formulae [6,7] and SRIM program (2003) [8] corpuscle to three regions based on the velocity of the incident deuteron (V). The calculated adopted cross sections for these reactions have been evaluated and a systematic behavior of calculated yields with deuteron energy and target numbers (Z) have been observed throughout the studied isotopes. This study concerns with the nuclear reactions used in the production of Copper and Gallium from induced deuterons on Zinc target element which are important in medical applications and therapy.

2. Theoretical part

a. Stopping Power

Incident protons with certain energy will lose all their energies in a definite distance in a medium before it stopped completely. The mechanism for the stopping power of ions penetrating condensed matter depends on the charge and velocity of the incident corpuscle and the nature of the matter, for that reason one can be compilation the energy loss of the charge corpuscle to three regions (high, intermediate and low energy). The behavior of ions in each region can be explained as the following [9]:

i. The high energy region (1000-100000)KeV

This region can occurs when the velocity of the incident corpuscle (V) is ($V \geq 2V_0Z_1$) where (Z_1) is the atomic number of ion and (V_0) represents the Bohr velocity (V_0= 2.18×10^6 m/s) and this is about the velocity of the conduction electrons in solid. Ions with velocity below (V_0) have adiabatic collisions with target electrons and hence small stopping power. The stopping power increases with decreasing ion-velocity [13].

The electronic stopping power (S_e) is to prevail with Bethe (1933) equation applies in this region [14]:

$$-\frac{dE}{dx} = NS_e = \frac{4\pi K^2 e^4 Z_1^2}{mV^2} NZ_2\left[\ln\left(\frac{2mV^2}{I}\right) - \ln\left(1-\beta^2\right) - \beta^2\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where $-\frac{dE}{dx}$: The energy loss of the particle per unit path called stopping power .

N: is the atomic density of the medium [$N=N_a$ (ρ/A)].

N_a: is the Avogadro’s number (N_a=6.022×10^{23}mole^{-1}).

ρ: is the density of matter.

A: is the mass number.

e,m: are the charge and mass of the electron respectively.

Z_1, Z_2: are the atomic numbers of ion and target respectively.

β: is the ratio between incident corpuscle velocity and the velocity of light $\beta = \frac{V}{c}$.

I: is the mean ionization and excitation potential.

K: is the coulomb constant $K = \frac{1}{4\pi\varepsilon_0}$ = 8.99×10^9Nm^{2}C^{-2}.

ii. The intermediate energy region (10-999)keV

The intermediate energy region occurs when the velocity (V) of the incident corpuscle is in the range ($2V_0Z_1 > V \geq V_0Z_1^{2/3}$); it includes the maximum stopping power. In this region the effect of effective charge is clear and that is because of loss its energy which is mean decrease of corpuscle velocity and charge Z_1 decreased too, and that because of loss or acquire electrons and there will be elastic collision with the nuclei of atoms occur. Thus equation (1) was modified, and its express electronic stopping power as Bethe-Bloch (1933) [14].

$$-\frac{dE}{dx} = NS_e = \frac{4\pi K^2 e^4 Z_1^2}{mV^2} NZ_2 L \qquad \text{……………………(2)}$$

Where L is the stopping atomic number and depends on the velocity of incident corpuscle and the medium of the target.

$L = L_0 + Z_1 L_1 + Z_1^2 L_2$ ……………………...(3)

Where $L_0 = \ln(2wV^{1/2} / I) - C/Z_2$ ……………………...(4)

C/Z_2 is the shell correction.

$Z_1 L_1$ is the Barkas effect correction from the polarization.

$Z_1^2 L_2$ is Bloch-correction to transform from quantum to classical form.

w is the resonance frequency.

iii. The low energy region(1-10)KeV

It occurs when the incident corpuscle velocity (V) ($V<V_0Z_1^{2/3}$) in this region, to calculate the cross section for electronic stopping on the Thomas-Fermi potential as a function of velocity. The equation for this region is given by [15,16]:

$$S_e = 8\pi e^2 a_0 \frac{Z_1^{7/6} Z_2}{Z^{2/3}} \left(\frac{V}{V_0}\right) \qquad \text{………………………(5)}$$

Where $Z^{2/3} = Z_1^{2/3} + Z_2^{2/3}$ ………………………(6)

a_0 represents the Bohr radius, $a_0 = \frac{h^2}{me^2} = 5.29 \times 10^{-11} \overset{\circ}{A}$ ………………….(7)

and h represents Plank constant.($h=6.62\times10^{-34}$J.s)

In the scope of this work, the electronic stopping powers were programmed and using the empirical formulae given by Ziegler as flows [6]:

1- Energy range (1-10)×10^{-3} MeV

$$-\frac{dE}{dx} = A_1 E^{1/2} \qquad \text{………………………(8)}$$

2- Energy range (10-999)×10^{-3} MeV

$$\left(-\frac{dE}{dx}\right)^{-1} = \left(-\frac{dE}{dx}\right)_{Low}^{-1} + \left(-\frac{dE}{dx}\right)_{High}^{-1} \qquad \text{………………..(9)}$$

$$\left(-\frac{dE}{dx}\right)_{Low} = A_2 E^{0.45} \qquad \text{……………………(10)}$$

$$\left(-\frac{dE}{dx}\right)_{High} = \left(\frac{A_3}{E}\right) \ln\left[1 + \left(\frac{A_4}{E}\right) + A_5 E\right] \qquad \text{……………..(11)}$$

3- Energy range (1000-100.000)×10^{-3} MeV

$$\left(-\frac{dE}{dx}\right) = \left(\frac{A_6}{\beta^2}\right)\left[\ln\left(\frac{A_7\beta^2}{1-\beta^2}\right) - \beta^2 - \sum_{i=0}^{4} A_{i+8} (\ln E)^i\right] \qquad \text{……..(12)}$$

Where E : is the deuteron energy in (MeV).

A_i: are the coefficients given by Ziegler [6,17].

β: is the ratio between incident corpuscle velocity and the velocity of light.

b. Calculated Yield

The Yield of calculated detected per incident particle, Y, for an ideal, thin, and uniform target and monoenergetic particles beam of incident energy E_b is given by [18].

$$Y = (nt)\sigma(E_b)\varepsilon(E_b) \quad \text{……………………(13)}$$

Where n: is the number of target atoms per unit volume.
t: is the target thickness.
σ: is the reaction cross section.
ε: is the deuteron -detection efficiency.

For target which is not infinitesimally thin, the beam loses energy as it passes through the target, and the Yield is then given by [19,20].

$$Y = \int_{E_{thr}}^{E_b} \frac{n\sigma(E)\varepsilon(E) f dE}{-\frac{dE}{dx}(E)} \quad \text{……………………(14)}$$

In which ($E_{thr} = E_b - \Delta E$)
Where E_{thr} : is the reaction threshold energy.
ΔE : is the energy loss of the beam in the target.
f : is the number of target atoms in each target molecule.
$-\frac{dE}{dx}(E)$: is the stopping power of the medium as a function of the beam energy.

If the target is sufficiently thick, and there exist one atom per each molecule (i.e., $f = 1$) and taking the efficiency $\varepsilon(E) = 1$, then the resulting calculated yield is called the thick-target yield which is given by [21]:

$$Y(E_b) = \int_{E_{thr}}^{E_b} \frac{n\sigma(E) dE}{-(dE/dx)} \quad \text{………………………(15)}$$

Since stopping power $= \frac{1}{n}\left(-\frac{dE}{dx}\right)$.

3. Data Reduction and Analysis

Method used to obtain the adopted cross sections is as the following:

a. The sets of experimental cross sections data were collected for different authors and with different energy intervals. The cross sections with their corresponding errors for each value are re-arranged according to the energy interval 0.01 MeV for available different energy range for each author.

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

c. 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-7.0 .

d. The interpolated values were calculated to obtain the adopted cross section which is based on the weighted average calculation according to the following expressions [22]:

$$\sigma_{w.a.} = \frac{\sum_{i=1}^{n} \frac{\sigma_i}{(\Delta\sigma_i)^2}}{\sum_{i=1}^{n} \frac{1}{(\Delta\sigma_i)^2}} \quad \text{……………………...(16)}$$

Where the standard deviation error is:

$$S.D. = \frac{1}{\sqrt{\sum_{i=1}^{N} \frac{1}{(\Delta\sigma_i)^2}}} \quad \text{.........................(17)}$$

Where σ_i: is the cross section value.

$\Delta\sigma_i$: is the corresponding error for each cross section value.

4. Results and Discussion

Table (1) present the International Atomic Energy Agency (IAEA)[5] libraries (EXFOR) used in the present work for available measuring data collected for calculated yields for induced deuteron on Zinc to produce Copper. The available data in the literature, taken from EXFOR library, concerning the measurement of the calculated yields for induced deuteron on Zinc to produce Copper and Gallium cross sections for the target Zinc mentioned in table(1) were evaluated in the present work in order to calculate the adopted cross sections using adopt.m program, which is written in the present work using Matlab-7.0 . The adopted evaluated cross sections are calculated (using adopt.m program) and plotted as a function of incident deuteron energy starting from threshold energy for each reaction. The results for each calculated yields for induced deuteron on Zinc to produce Copper and Gallium are discussed as follows:

1- ${}^{64}_{30}Zn\ (d,2p)^{64}_{29}Cu$ Reaction

The cross sections data published by Daraban L. et al.(2008) [1], for this reaction have been plotted, interpolated and recalculated in steps of 0.01 MeV from threshold energy 12.9 up to 18.2 MeV of the incident proton energy in order to obtain the adopted cross sections of this reaction. The results of adopted cross sections and the experimental results for the authors mentioned above are shown in figures (1).

Table (1): International libraries used for available measuring data collection for induced deuteron on Zinc reactions .

Target Element	Library	Reaction and Product	Target Element	Library	Reaction and Product
${}^{64}_{30}Zn$	EXFOR*	$(d,2p)^{64}_{29}Cu$	${}^{68}_{30}Zn$	EXFOR*	$(d,n)^{67}_{31}Ga$
	EXFOR	$(d,n+\alpha)^{61}_{29}Cu$		EXFOR*	$(d,3n)^{65}_{31}Ga$
	EXFOR*	$(d,2n)^{64}_{31}Ga$		EXFOR*	$(d,2n)^{68}_{31}Ga$
${}^{66}_{30}Zn$	EXFOR	$(d,\alpha)^{64}_{29}Cu$	...	...	...

*** only one author gives data.**

2- $^{64}_{30}Zn(d,n+\alpha)^{61}_{29}Cu$ **Reaction**

The cross sections data published by Bissem H.H.et al. (1980) [2]. and Daraban L.et al.(2008) [1],for this reaction have been plotted, interpolated, and recalculated in steps of 0.01 MeV from threshold energy 12.9 up to 25.8 MeV of the incident deuteron energy in order to obtain the adopted cross sections of this reaction. The results of adopted cross sections and the experimental results for the authors mentioned above are shown in figures (2).

3- $^{64}_{30}Zn(d,2n)^{64}_{31}Ga$ **Reaction**

The cross sections data published by Bissem H.H. et al. (1980) [2] for this reaction have been plotted, interpolated, and recalculated in steps of 0.01 MeV from threshold energy 11.7 up to 23.8 MeV of the incident deuteron energy in order to obtain the adopted cross sections of this reaction. The results of adopted cross sections and the experimental results for the authors mentioned above are shown in figures (3).

4- $^{66}_{30}Zn(d,\alpha)^{64}_{29}Cu$ **Reaction**

The cross sections data published by Hilgers K.et al. (2003) [3], and Gilly J. L.et al. (2004) [4] for this reaction have been plotted, interpolated, and recalculated in steps of 0.01 MeV from threshold energy 5.4 up to 13.86 MeV of the incident deuteron energy in order to obtain the adopted cross sections of this reaction. The results of adopted cross sections and the experimental results for the authors mentioned above are shown in figures (4).

5- $^{66}_{30}Zn(d,n)^{67}_{31}Ga$ **Reaction**

The cross sections data published by Bissem H.H.et al. (1980) [2], for this reaction have been plotted, interpolated, and recalculated in steps of 0.01 MeV from threshold energy 20 up to 25.8 MeV of the incident deuteron energy in order to obtain the adopted cross sections of this reaction. The results of adopted cross sections and the experimental results for the authors mentioned above are shown in figures (5).

6- $^{66}_{30}Zn(d,3n)^{65}_{31}Ga$ **Reaction**

The cross sections data published by Bissem H.H.et al. (1980) [2],for this reaction have been plotted, interpolated, and recalculated in steps of 0.01 MeV from threshold energy 31.7 up to 99.5 MeV of the incident deuteron energy in order to obtain the adopted cross sections of this reaction. The results of adopted cross sections and the experimental results for the authors mentioned above are shown in figures (6).

7- $^{68}_{30}Zn\ (d,2n)^{68}_{31}Ga$ **Reaction**

The cross sections data published by Gilly J.L.et al. (1963) [4], for this reaction have been plotted, interpolated, and recalculated in steps of 0.01 MeV from threshold energy 5.3 up to 11.6 MeV of the incident deuteron energy in order to obtain the adopted cross sections of this reaction. The results of adopted cross sections and the experimental results for the authors mentioned above are shown in figures (7).

When the widths of unstable states are small compared with their separation, the states are distinct and observable. And if the states are overlap and strongly mixed, these states do not have distinctly observable wave functions. Because of the instability of the compound nucleus, results in an uncertainty in the energy of these states. The energy uncertainty is given by the width of the resonance and lifetime of the state. Therefore, the resonance will have the character of the energy distribution of any decaying state of width, lifetime, and a maximum total cross section.

In analyzing for induced deuteron on Zinc to produce Copper and Gallium cross sections we note that the discrete nuclear states that are populated in ordinary decays have discrete separations, widths, and lifetimes. Thus if we were to calculate the cross sections at a given incident deuteron energy of a nuclear state, it is very unlikely that the overlap of the energy distributions of two different states could cause confusion as to the stationary state resulting from the decay.

The stopping power of medium target elements for deuteron -particles has been calculated in the present work using two methods:

1-We adopt SRIM (2003) [8], as an experimental results where SRIM is a program build for Ziegler empirical formulae.
2-We used Ziegler empirical formulae and Ziegler coefficients mentioned in table (2), as a theoretical calculation results.

Table (2): Coefficients for stopping of deuteron used in the Zeigler formula [6,17].
For these calculations, the (stop.m) program has been written in Matlab-7.0 for this purpose.

Target Element	A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9	A-10	A-11	A-12
${}^{2}_{1}H_1$	1.262	1.44	242.6	1.20E+04	0.1159	0.0005099	54360	-5.052	2.049	-0.3044	0.01966	-0.0004659
${}_{29}Cu$	3.696	4.175	4673	387.8	0.02188	0.01479	3174	-11.18	4.252	-0.5791	0.03399	-0.0007314
${}_{30}Zn$	4.21	4.75	6953	295.2	0.006809	0.0153	3194	-11.57	4.394	-0.598	0.03506	-0.0007537
${}_{31}Ga$	5.041	5.697	7173	202.6	0.006725	0.01581	3154	-11.95	4.537	-0.6169	0.03613	-0.0007759

For energies 1-10 KeV/amu use coefficients A-1.
For energies 10-999 KeV/amu use coefficients A-2 to A-5.
For energies above 1000 KeV/amu use coefficients A-6 to A-12.

The calculated yields for induced deuteron on Zinc to produce Copper are very important quantity as well as the cross sections in analyzing problems of diagnosis, physical therapy, and medicine treatments as the following : Gallium-67,68 finds significant application in medical field .The production possibility in different energy region via different nuclear reactions are clarified in the following discussion [23]:

a- The gallium radionuclide ${}^{67}_{31}Ga$ is widely used in nuclear medicine for radio diagnostic as follows:

1-Gallium-67 is a tumor seeking isotope for soft tissue tumors as well as bone seeking and dynamic studies .
2- It is used in Auger electron therapy, also used in Tumor imaging application

b- The Gallium radionuclide ${}^{68}_{31}Ga$ is widely used in nuclear medicine is follows:

1- for diagnosing tumors, Gallium-68 tracers is being in many neuroendocrine tumor studies in human.
2-Gallium-68 decays principally by positron emission and it used in conjunction with positron emission tomography (PET) scanners for imaging various organs and their physiological functions.
This is an economical source of ${}^{68}_{31}Ga$ in hospitals.
3- Gallium-68 finds significant application in assessment to detect blood-brain barrier defect to image tumor.

Therefore, the calculated yield for Zinc target (${}^{64}_{30}Zn$, ${}^{66}_{30}Zn$, ${}^{68}_{30}Zn$) were calculated in the present work using equation (15). The main aim of this study is to increase a calculated yields for induced deuteron on Zinc to produce Copper and Gallium by increasing the energy of deuteron beams.

The stopping power and calculated yields maintained above have been obtained. The results have been shown in figure (8). In all figures, the calculated yields of most of most reactions seem to depend strongly on the structure of the target nucleus, the incident deuteron energy, and stopping power of the target element.

Generally, the behavior of the stopping power decreases with increasing the calculated yields which agrees with Ref. [1-4]. It is clear from the calculated results shown in these figures that for the calculated yield values of 20-100% abundance target element ${}^{64}_{30}Zn$ and ${}^{66}_{30}Zn$ follow the trend in the asymmetry parameter of deuteron excess (N-Z)/A so that by increasing this parameter the maximum calculated yields will be increase as shown in table (3). This increment may be attributed to the fact that by increasing the number of neutrons the outer shells are populated by an excess calculated which increases the occurrence probability for induced deuteron on Zinc to produce Copper and Gallium.

Table (3): The maximum calculated yield and the asymmetry parameter for the 20-100% abundance elements.

Reactions	Maximum calculated yield (atom*1.0E-9)	(N-Z)/A
${}^{64}_{30}Zn(d,n+\alpha)\,{}^{61}_{29}Cu$	760.990	0.0625
${}^{66}_{30}Zn(d,3n)\,{}^{65}_{31}Ga$	515.710	0.0910

For even-even elements with Z=N the asymmetry parameters are zero; i.e. the elements are symmetric (Z=A/2, N=A/2). The binding energy, the Q-values, and the calculated yields differ by much larger amounts among the medium elements than within any group.

Hence, for even-Z and even-A target elements ${}^{64}_{30}Zn$ and ${}^{66}_{30}Zn$ for induced deuteron on Zinc to produce Copper and Gallium the maximum calculated yield were found to be a function of the target neutron number (N) and the asymmetry parameter (N-Z)/A, where the maximum calculated yield increase with increasing (N) and increasing asymmetry parameter.

5- Conclusions

1- The characteristic feature of cross sections is the appearance of many sharp resonances. Each resonance in the induced deuteron on Zinc to produce Copper and Gallium is higher by the same amount (close to threshold energy).

2- The yield production by deuteron incident to produce Copper and Gallium from Zinc isotopes as target element which have large cross sections for yield production, and they could have influence on safety design and operation of these facilities. Hence, accelerators using deuterons are used in such fields as physics, biology, deuteron therapy and medicines .

3- Because the widths of nuclear states are either small compared with their separation or overlapped. Therefore, we conclude that it is reasonable to speak of discrete quasibound stationary states because their separation is far greater than their width, and we also concluded that such nuclear states do not contribute to the density of final states because there is only one nuclear state that can be reached in a given decay process.

4- In case of incident deuteron induced data for the production of Copper and Gallium , a comparison of all experimental and theoretical results showed that cross section theory was successful in reproducing most experimental data . The recommended excitation functions and calculated integral yields help to optimize the energy range for each nuclear reaction for the production of therapeutic radionuclides seem to be the most useful .

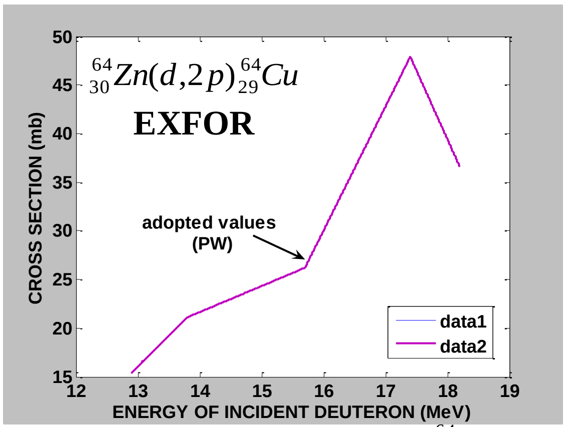


Figure (1): The adopted cross section of the $^{64}_{30}Zn$ target element (present work) compared with EXFOR Library.
Data 1:Ref. No.[1]; Data 2: (PW).

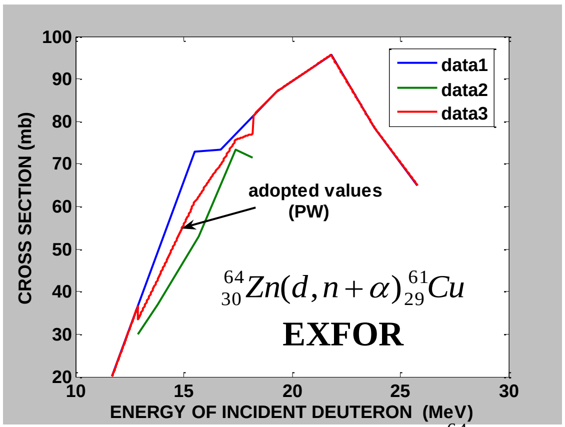


Figure (2): The adopted cross section of the $^{64}_{30}Zn$ target element (present work) compared with EXFOR Library.
Data 1:Ref. No.[2]; Data 2:Ref. No.[1]; Data 3: (PW).

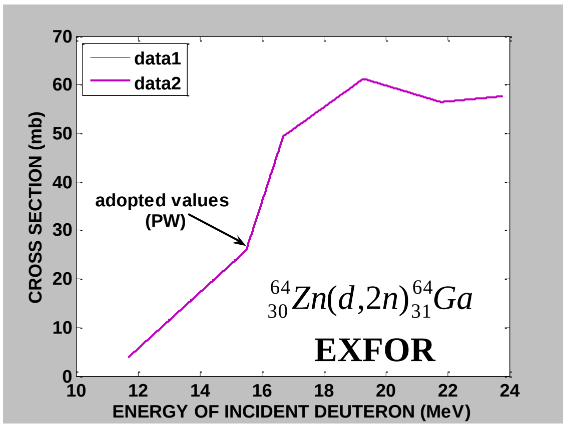


Figure (3): The adopted cross section of the $^{64}_{30}Zn$ target element (present work) compared with EXFOR Library.
Data 1:Ref. No.[2]; Data 2: (PW).

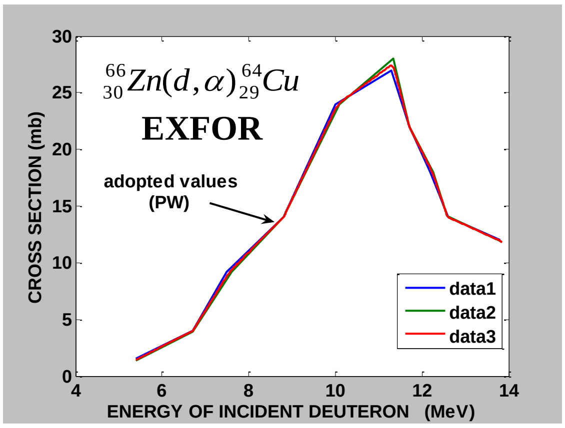


Figure (4): The adopted cross section of the $^{66}_{30}Zn$ target element (present work) compared with EXFOR Library.
Data 1:Ref. No.[3]; Data 2:Ref. No.[4]; Data 3: (PW).

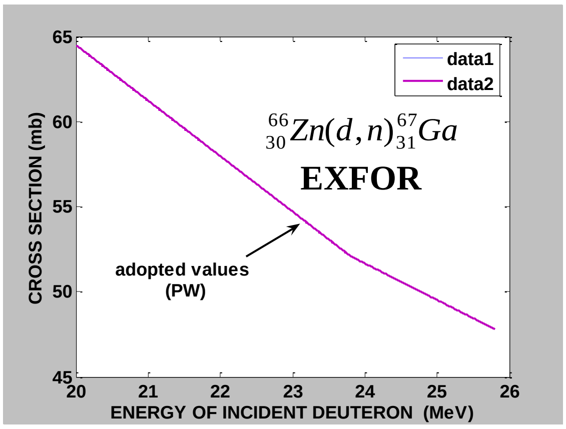


Figure (5): The adopted cross section of the $^{66}_{30}Zn$ target element (present work) compared with EXFOR Library.
Data 1:Ref. No.[2]; Data 2: (PW).

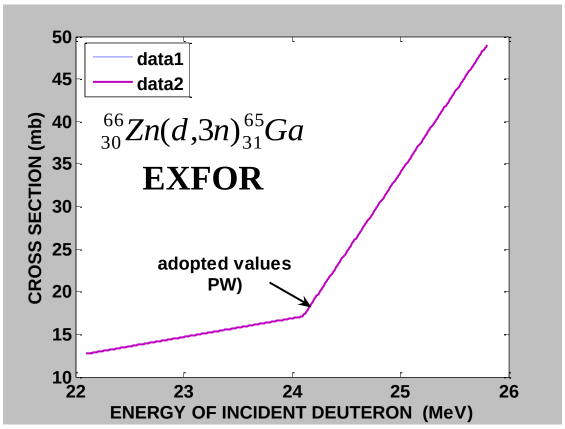
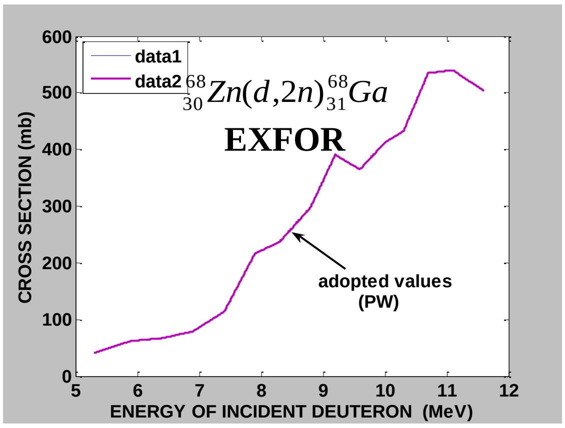


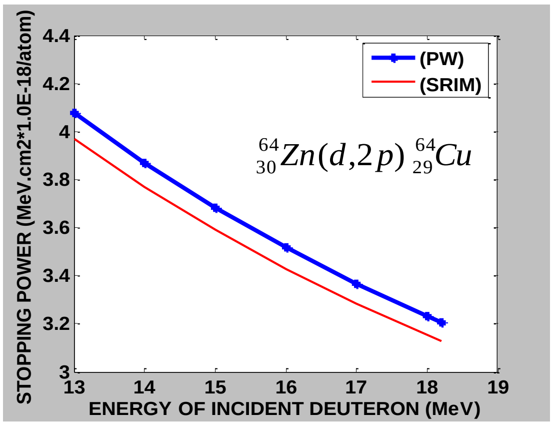
Figure (6): The adopted cross section of the $^{66}_{30}Zn$ target element (present work) compared with EXFOR Library.
Data 1:Ref. No.[2]; Data 2: (PW).

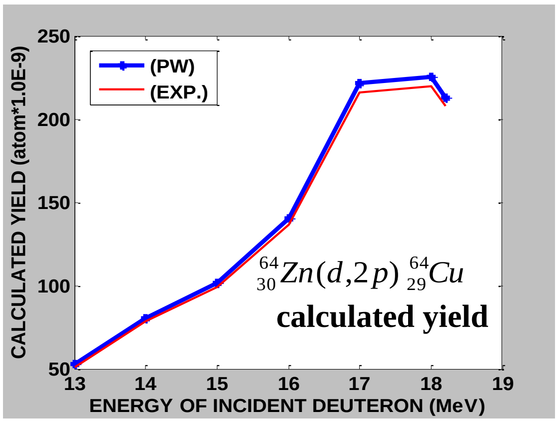


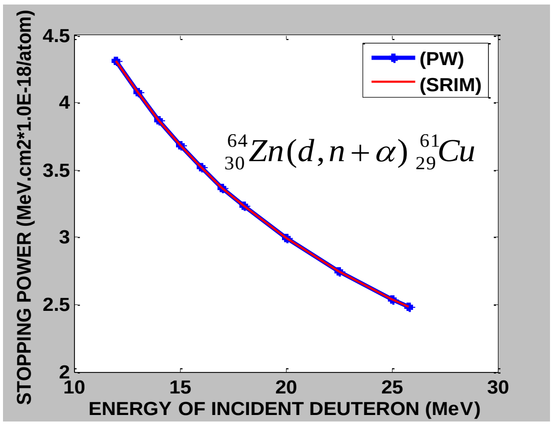
(7): The adopted cross section of the $^{68}_{30}Zn$ target

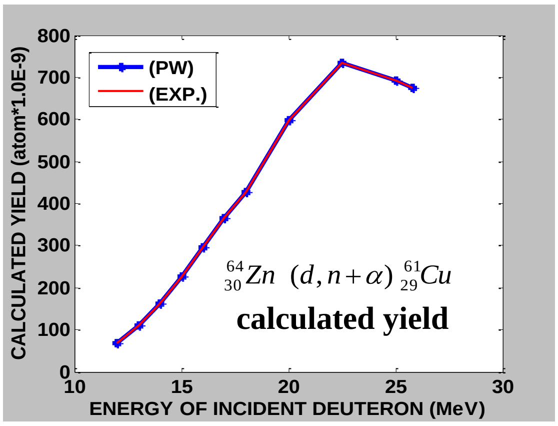
t (present work) compared with EXFOR Library.

Data 1:Ref. No.[4]; Data 2: (PW).









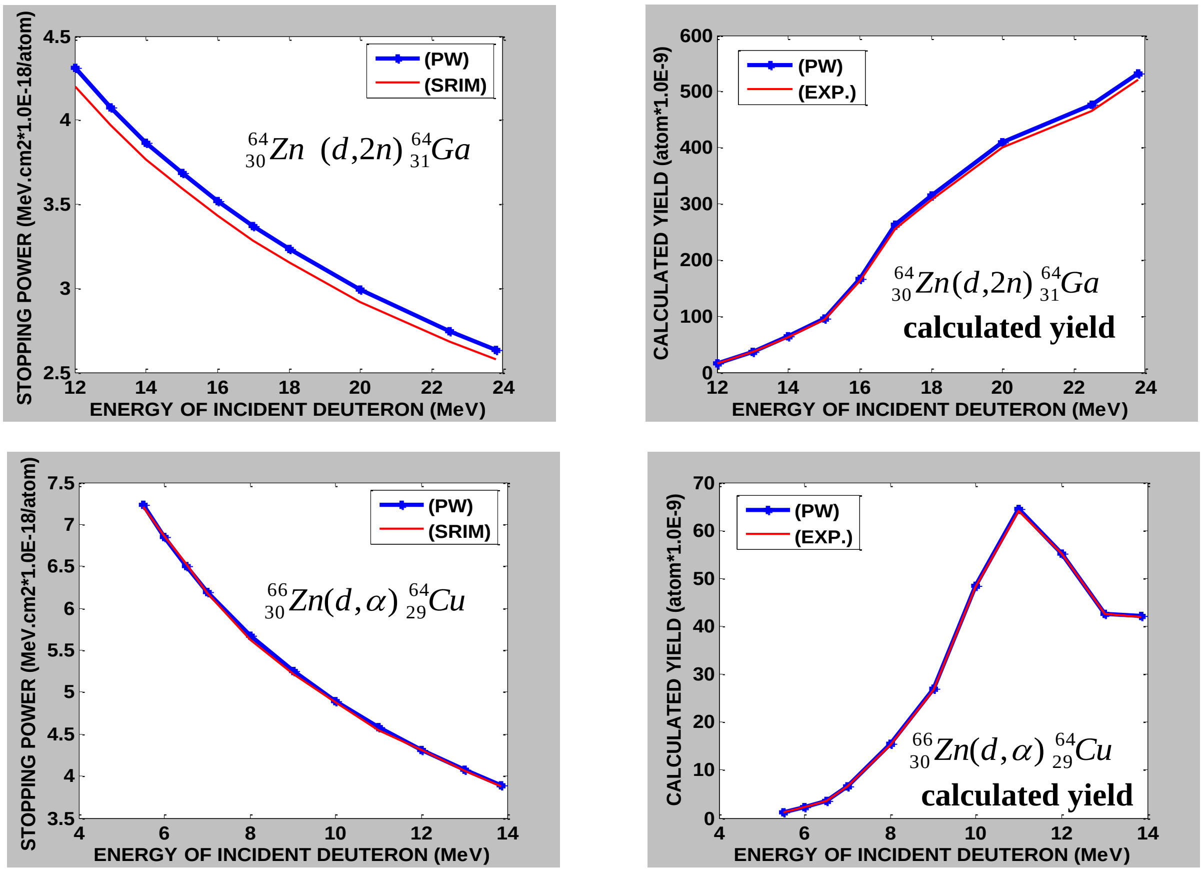
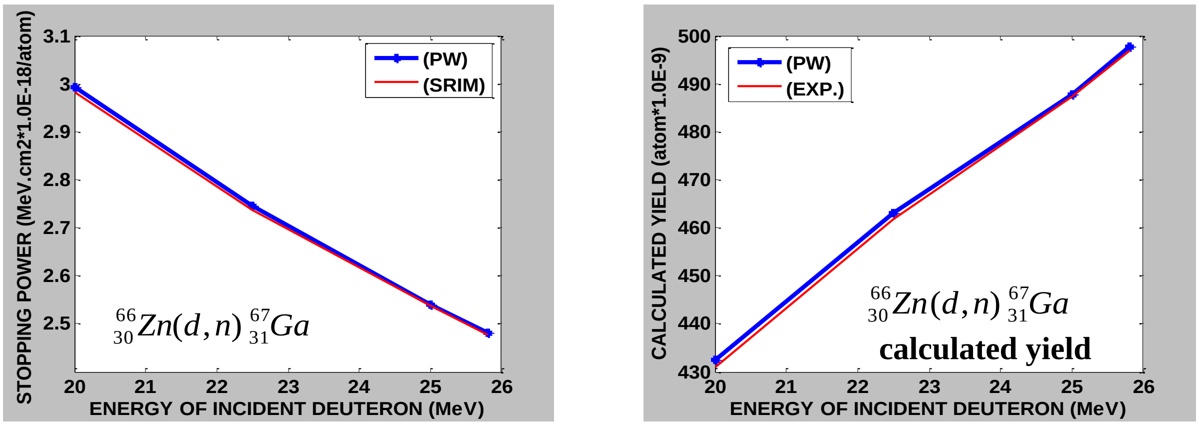


Figure (8): Left side; the comparison between the calculated stopping power in the present work (pw) and SRIM (2003) of incident deuteron in Zn. Right side; the calculated yield as calculated in the present work compared with experimental results based on the adopted cross section of incident deuteron in Zn reaction.



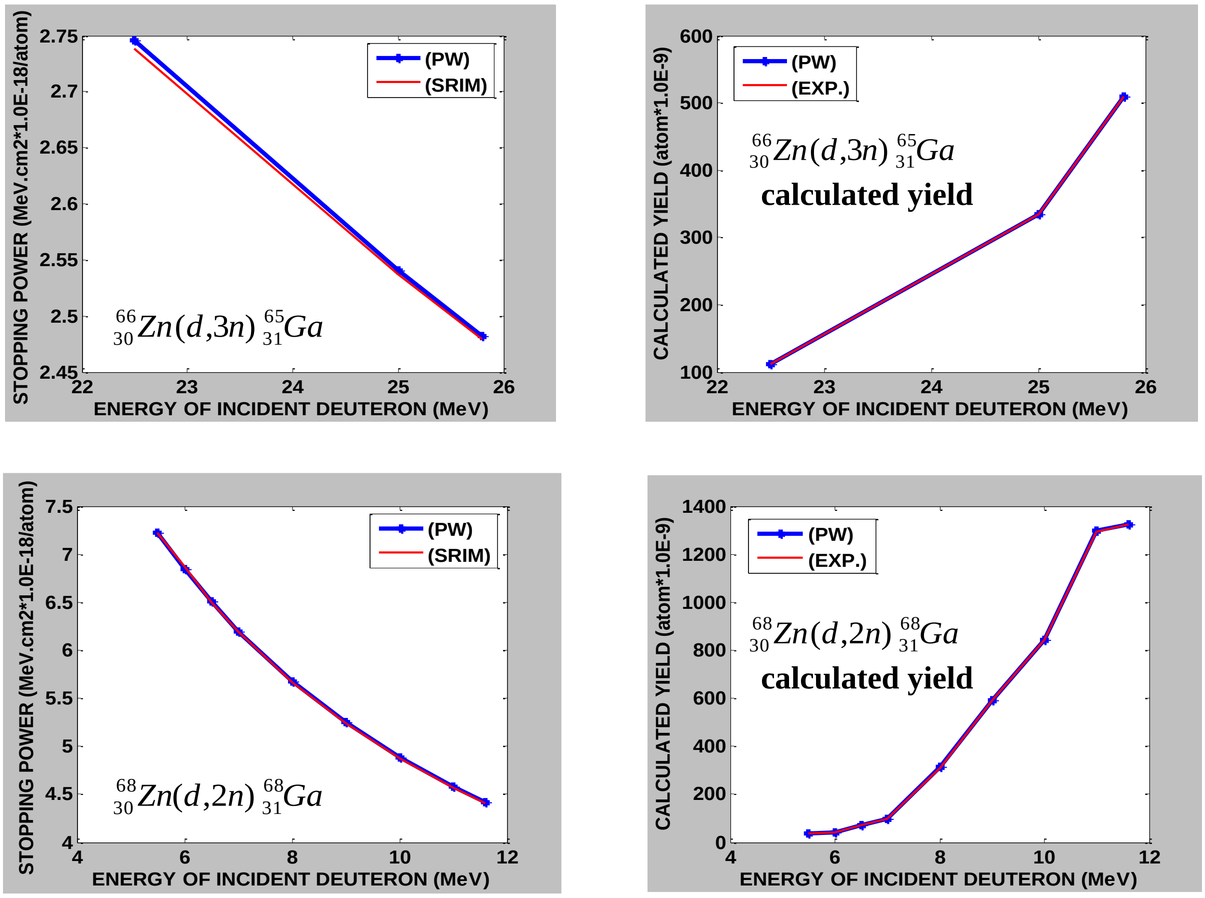


Figure (8) : To be continued(2/2).

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