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Cross Section and Yield Calculations of Copper- 67 used in Medicine

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Abstract:
Radiopharmaceuticals used in positron emission tomography (PET) are among the most suitable isotopes for radioimmunotherapy. Copper-67 is a suitable radionuclide for labeling a wide range of tumors due to its long enough half-life to allow good biodistribution within the tumor. Among the possible methods for producing Copper-67 using a cyclotron, we investigate deuteron irradiation of natural zinc and copper targets. This paper examines alpha particle, proton beam, and deuteron irradiation of zinc isotopes, and proton irradiation of gallium-71. Key published and verified experimental findings for excitation functions served as the basis for calculating the cross-section and overall integral yield.

Keywords: 67Cu Production, cross section, Isotopes of Zinc, Excitation Function.

1. Introduction

Copper-67 radioisotope (T1/2 = 2.66 d) has a large application in medicine. One of its interests lies on its possible association with copper-64 which can be used for PET imaging, these two isotopes can then be linked to the same bio-marker ensuring a perfect superposition of the PET image with the distribution of the drug with copper- 67 in the patient body and in the tumor to be treated [1].

It releases low energy conversion and Auger electrons in addition to β-emission, for a total of roughly 1.2 electrons (with energies above 7 keV) per decay. copper- 67 decay, emitting gamma rays with energy maxima ranging from about 0.4 MeV to about 0.6 MeV The beta particles are effective in treating various tumor types when the radioisotope is delivered to the disease site [2]

The SPECT gamma photon is well-suited for imaging applications using the conventional Gamma Camera so that 67Cu localized in a tumor, can be scanned with tools often used in nuclear medicine facilities. It also releases an 185 keV gamma photon [3].

Accelerators create isotopes by bombarding suitable targets with charged nuclei beams that impinge on them to create the desired isotope. They mostly result from cyclotron-induced proton and deuteron irradiation of Zn and Ga targets [4].

68Zn target by high energy of proton(56,و) The obtained production yield of 67Cu good. 70Zn 70Zn(p,a) reaction obtained of 14.8mb in 15.5 MeV energy This reaction best production yield of 67Cu. 71Ga(p,2n+3p)67Cu this reaction obtained low yield of 67Cu [5], [6].

2. Materials and Methods

Samples were collected from equipment and vital organs from sheep carcasses.

There are various nuclear processes that can be used to produce ^{67}Cu. Excitation functions of ^{67}Cu production by the reactions of $^{nat,68.70}$ Zn+p , ^{70,67} Zn+d , ^{71}Ga+p , ^{68} Zn+α, ^{65} Cu+d Cross sections were computed utilizing the data from foreign libraries up to 70 MeV and in accordance with the SRIM code. The thick target integral yields were deduced using the determined. A Matlab sub programs was solved using the following yield equation:

$$Y = \frac{NLH}{M} I(1 - e^{\lambda t}) \int_{E1}^{E2} \left(\frac{dE}{d(\rho x)}\right)-1 \quad \sigma(E)\, dE \qquad ....(.1)$$

where Y is the activity of the product, M is the target element's mass number, I is the projectile current, dE/d(ρx) is the stopping power, NL is the Avogadro number, H is the enrichment (or isotopic abundance) of the target nuclide, σ(E) is the cross section at energy E, λ the decay constant of the product and t the time of irradiation.

3. Results and Discussion

67Cu can be obtained using different nuclear reactions. High intensity alpha particle beams, proton beams, and deuteron beams are needed for the majority of these processes [7], [8].

natZn(P,x)67Cu

67Cu from a natZn target in natZn(P,x)67Cu the proton energy-producing process is a useful energy range, is33-100M eV, the maxımum cross-section obtained according to M.L.Bonardi is 2.23m b at 83MeV as shown in figure. the energy range is 0.1158 GBq/C with optimum energy range of 33-100 MeV ,as shown in figure. This response doesn't seem appropriate for the purpose of [9]

68Zn(P,2P)67Cu

67Cu from a 68Zn target in 68Zn(P,2P)67Cu reaction has a beneficial range of proton energy for producing is 200 to 400 MeV using the two authors data D.L.Morrison et al. , A.A.Caretto et al , Hilgers et al. and Pupillo G. et al [10]. of a maximum cross-section of 22.8 mb in 355 MeV as figure. The obtained production yield of 67Cu is 3.7201 GBq/C in the selected energy range (figure 4). This reaction appears suitable for the purpose of copper-67production, but use very high energy with yield [11].

70Zn(p,a) 67Cu

This reaction obtained of 14.8mb in 15.5 MeV energy figure(6) The excitation function data acquired from S.Kastleiner et al, Hilgers et al [12]. and V.N.Levkovskij predicted that target irradiation lead to the creation of 67Cu with a maximum cross-section for and theoretical thick-target yields calculated is 0.1683GBq/C figure. This reaction best suitable for the purpose of copper-67production, because the range of energy is from10 to29.5 MeV [13].

71Ga(p,2n+3p)67Cu

data acquired from Porile et al. and G. Santistevan et al. predicted that target irradiation lead to the creation of 67Cu is 19 to 43 MeV with a maximum cross-section obtained of 2.5mb in 33 MeV energy for Figure(7) and low theoretical yields calculated is 0.048 GBq/C figure(8). This reaction appears not to be suitable for 67Cu- production [14].

70Zn (d,x) 67 Cu

Useful range for deuterons to produce the Copper-67. According to J.Kozempel et al. and Nigron et al [15]. The reaction 70Zn (d,x) 67 Cu has the range of energy used in the manufacturing of 67Cu this reaction was found to be from 15 to 20 MeV. In 19 MeV figure (9), the greatest cross-section measured is 24.8 mb. The calculated thick-target is 0.1361GBq/Figure(5). For the formation of copper-67, this reaction is extremely minor [16].

67Zn(d,2P) 67 Cu

the creation of 67Cu is 8 to 15 MeV for 67Zn(d,2P) from D.C.Williams et al. [17] and Seyedeh Fatemeh Hosseini et al. the excitation function data acquired predicted that target irradiation leads to with a maximum cross-section obtained of 4.51mb in 15 MeV energy figure(9) and theoretical yields calculated is 0.015 GBq/C figure(8). This reaction's extremely low yield makes it unsuitable for producing copper-67 [18].

68Zn(a,p+a)67Cu

According to V.N.Levkovskij The induced alpha on the 68Zn target can produce the reaction 68Zn(a,p+a)67Cu, maximum cross-section of 5.62 mb in this reaction makes a in the 45.7 MeV figure(11), in the energy range of 37.7-46MeV [19]. The theoretical yield of this reaction i is 0.0082 GBq/C.) figure.(10). The extremely low yield of this reaction suggests that it is not appropriate for the manufacture of copper-67 [20].

65Cu(a,2p) 67Cu

The creation of 67Cu is 21 to 40 MeV The excitation function data acquired for 65Cu(a,2p) from N.T.Porile etal. that target irradiation lead to with a maximum cross-section obtained of 2.77mb in 39 MeV energy figure(10) [21]and theoretical yields calculated is 0.0065 GBq/C figure(11). The extremely low yield suggests that this process is not appropriate for producing copper-67 (Table 1) [22].

Table 1. Nuclear Information on the Production of ^{67}Cu via Different Nuclear Reactions

	Reaction	En.Range MeV	Max. cs mb	Max. en MeV	Best yield GBq/C
1	$^{nat}Zn(p,x)^{67}Cu$	33-100	2.23	83	0.118
2	$^{68}Zn\ (p,2p)\ ^{67}Cu$	200-400	22.8	355	3.7201
3	$^{70}Zn\ (p,a)\ ^{67}Cu$	10-29.5	14.8	15.5	0.1683
4	$^{71}Ga(p,2n+3p)\ ^{67}Cu$	19-43	2.5	33	0. 048
5	$^{70}Zn\ (d,x)\ ^{67}Cu$	15-20	24.8	19	0.1361
6	$^{67}Zn\ (d,2p)\ ^{67}Cu$	8-15	4.51	15	0.015
7	$^{68}Zn\ (a,p+a)\ ^{67}Cu$	37.7-46	5.62	45.7	0.0082
8	$^{65}Cu(a,2p)\ ^{67}Cu$	21- 40	2.77	39	0.0065

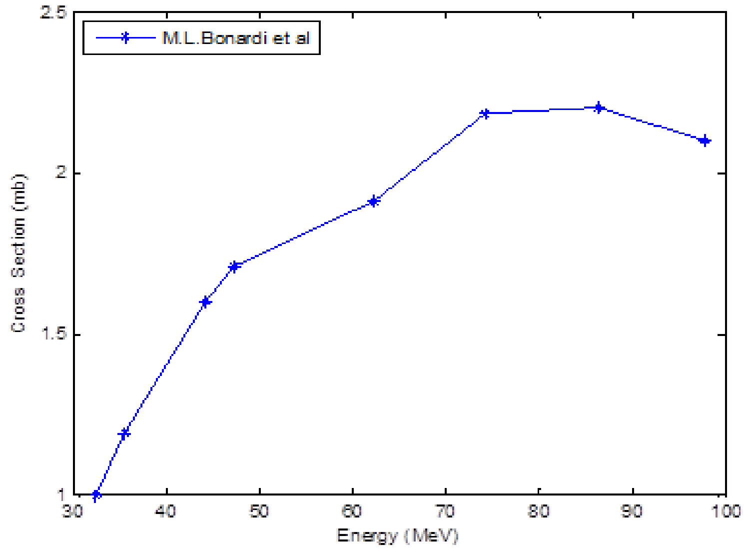

Figure.1. ^{67} Cu of the Reaction ^{nat}Zn(p,x) Excitation Function

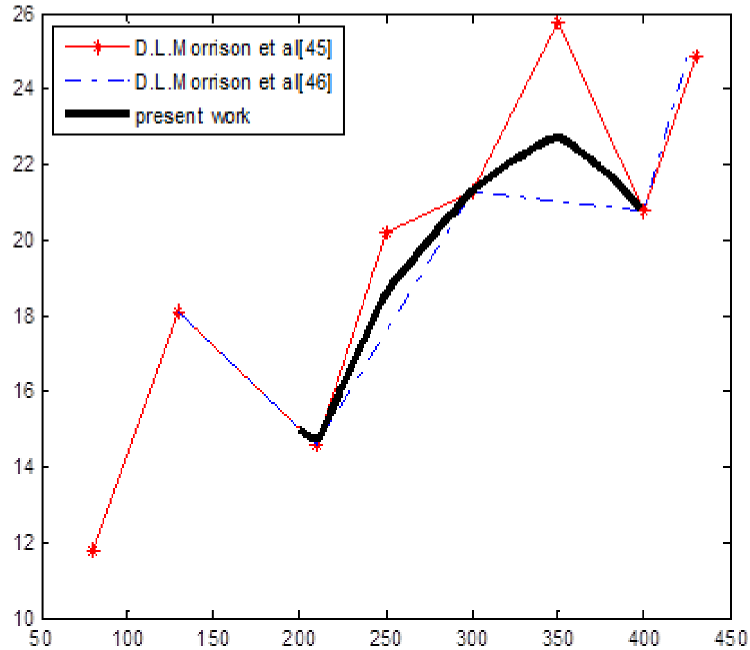

Figure 2. ^{67}Cu of the Reaction ^{68}Zn(p,2p) Excitation Function

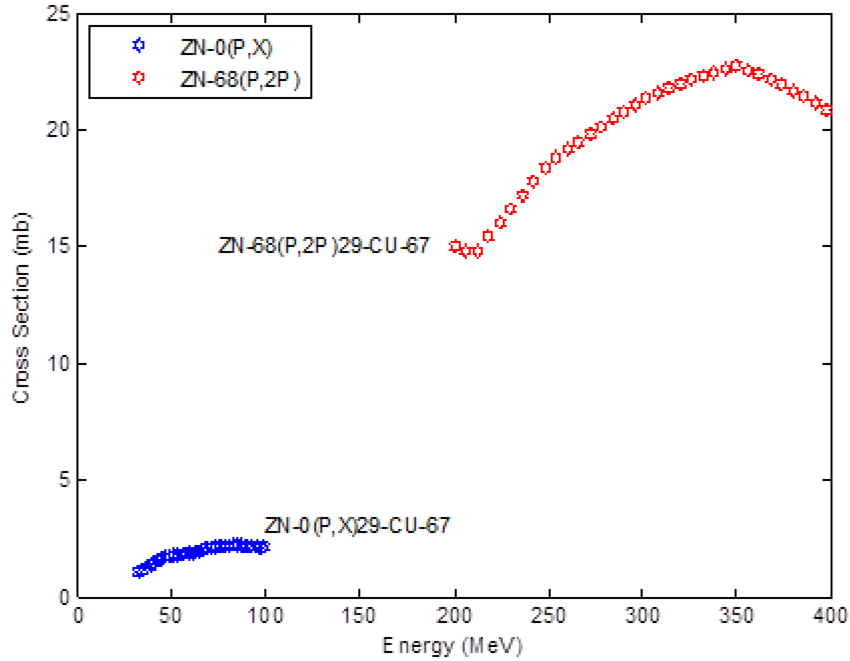

Figure 3. ^{67} Cu of Two Reactions ^{nat}Zn(P,x),and^{68}Zn(P,2P)) Excitation Function

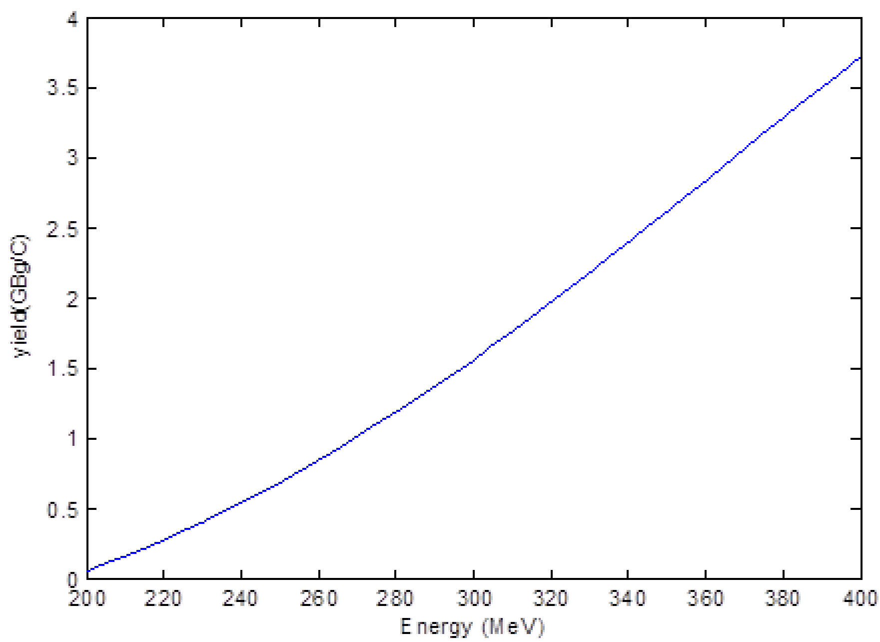

Figure 4. ^{68}Zn(p,2p)^{67}Cu Reaction (Yield)

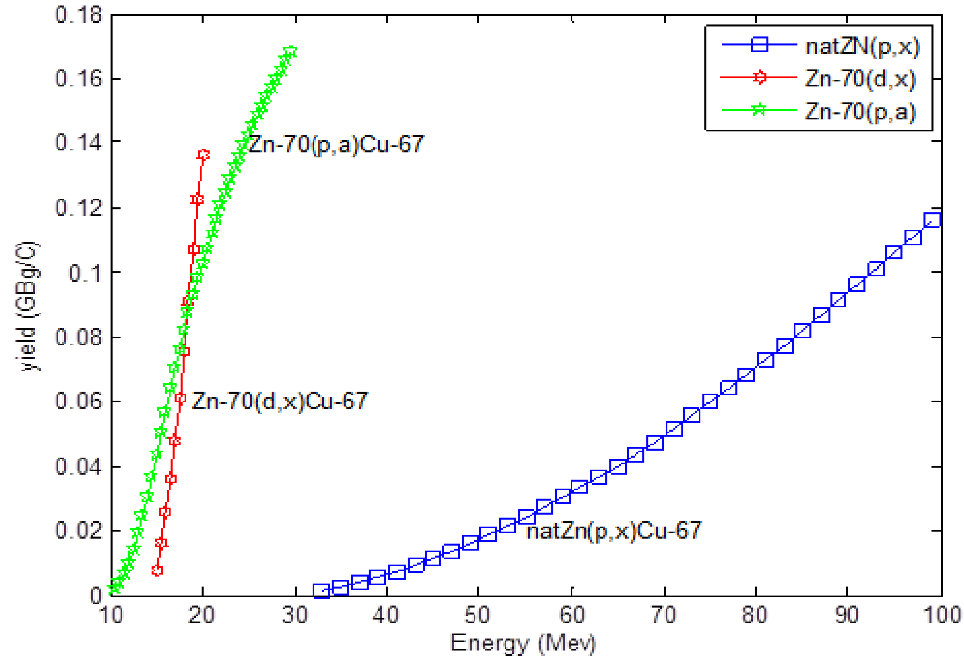

Figure 5. $^{nat}Zn(p,x)\ ^{67}Cu, ^{70}Zn(d,x)\ ^{67}Cu, ^{70}Zn(p,a)\ ^{67}Cu$ Reactions (Yield)

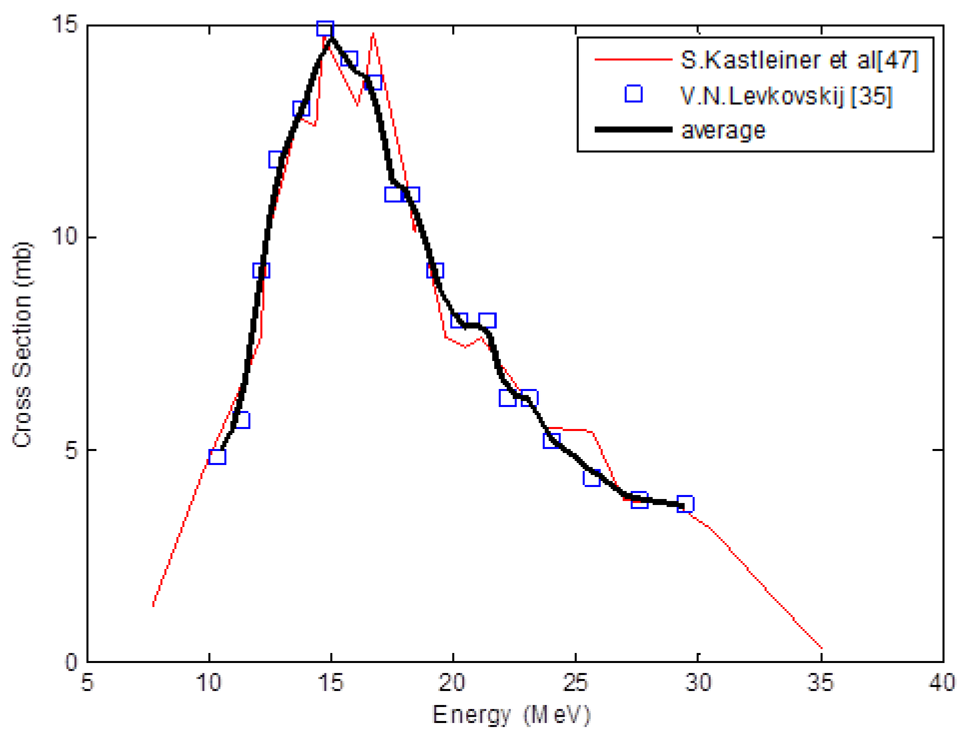

Figure 6. $^{70}Zn(p,a)\ ^{67}Cu$ -Excitation Function

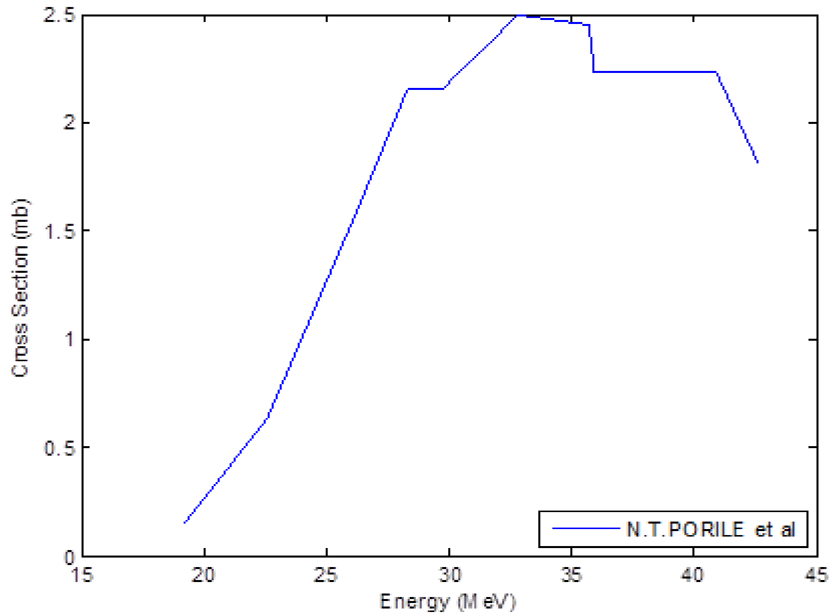

Figure 7. $^{71}Ga(P,2n+3P)$ Excitation Function

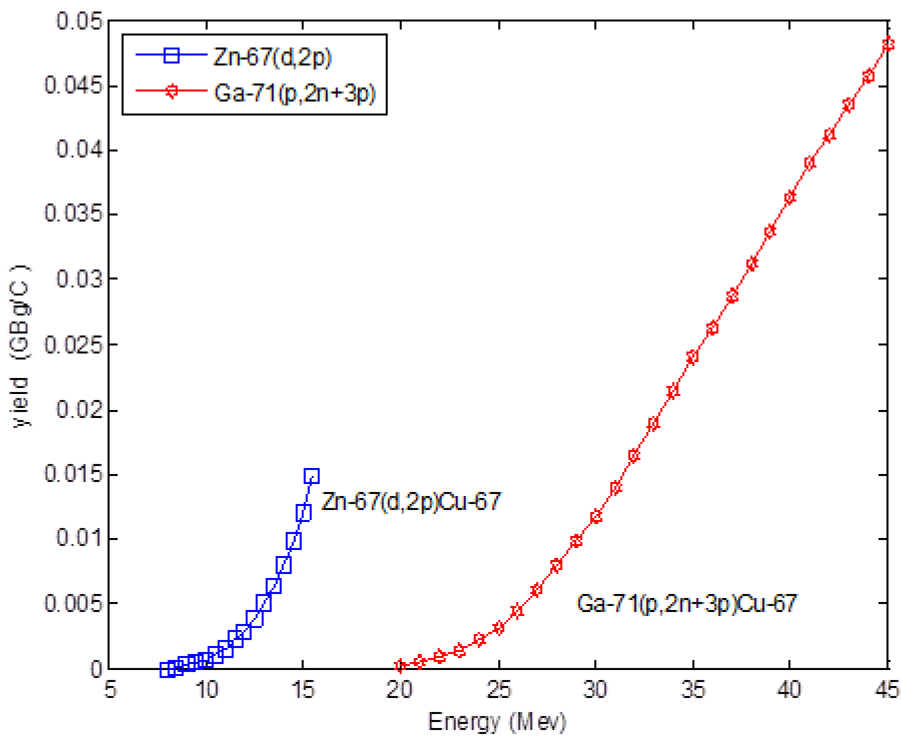

Figure 8. The Reactions $^{71}Ga(P,2n+3P)$ ^{67}Cu and $^{67}Zn(d,2p)^{67}Cu$ Yield

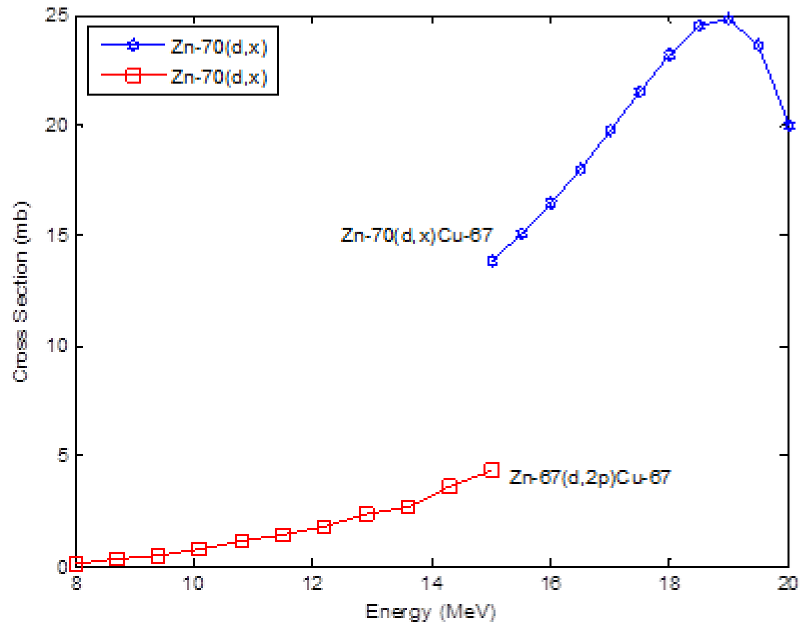

Figure 9. Two Reactions $^{70}Zn(d,x)$ and $^{67}Zn(d,2p)$ - Excitation Functions

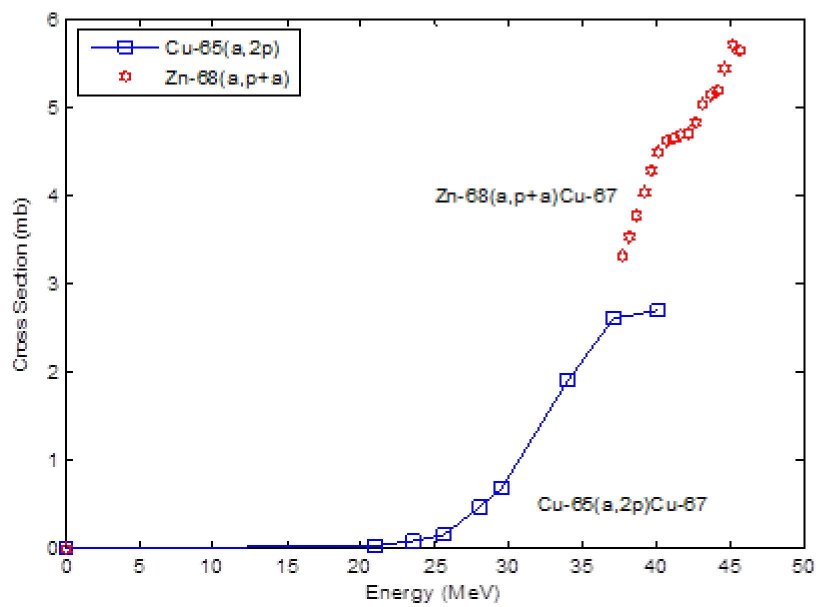

Figure 10. Two Reactions $^{68}Zn(a,p+a)$ and $^{65}Cu(a,2p)$ Excitation Function

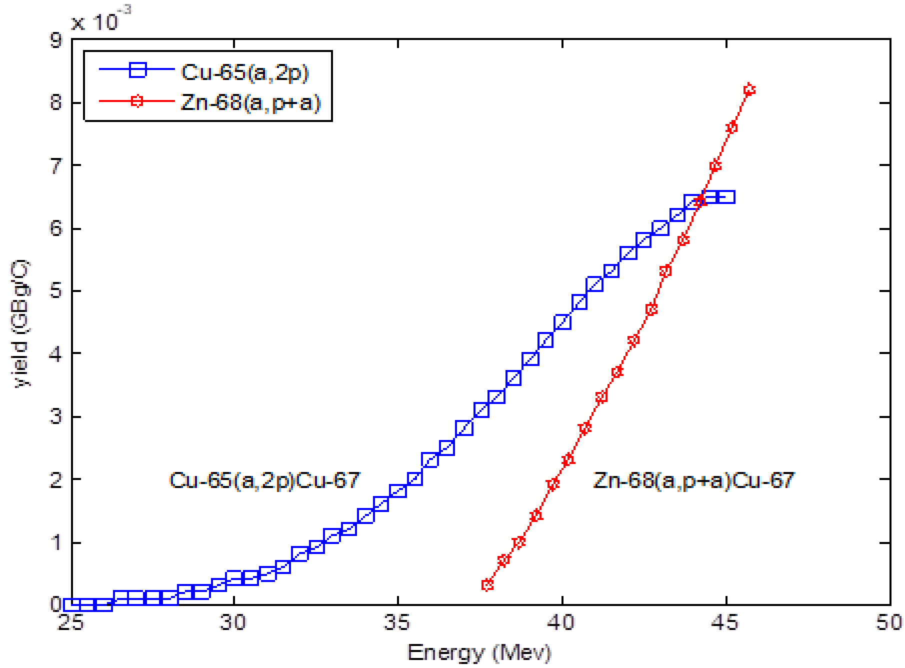

Figure 11. The Reactions ^{68}Zn(a,p+a) ^{67} Cu and ^{65}Cu(a,2p) ^{67}Cu- Yield

5. Conclusion

The production of Cu-67 be obtained using different nuclear reactions in table (1), the best projectile to obtained 67Cu are the protons, for low proton energies (10 – 29 MeV). The reaction70 Zn (p,a) gives the best yield 0.1683GBq/C figure (5), the reaction 68Zn(p,2p) has range of proton energy for producing 67Cu is 200 to 400 MeV the obtained production yield of 67Cu is 3.7201 GBq/C figure (4). This reaction appears suitable for the purpose of Copper-67production, but use very high energy with yield, for this reason prefer 70Zn (p, a) reaction to produce 67Cu.

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