International Journal of Applied
and Natural Science (IJANS)
ISSN(P): 2319-4014; ISSN(E): 2319-4022
Vol. 4, Issue 6, Oct -Nov 2015, 13-20

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

PRODUCTION YIELDS OF YTTERBIUM -169 MEDICALLY RELEVANT RADIONUCLIDE WITHIN MEDIUM ENERGY RANGE FOR THE PROTONS, DEUTERONS AND ALPHA PARTICLES

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ABSTRACT

Ytterbium 169 radioactive source emits 52 keV a characteristic γ-rays and x- rays with energies of various 65 to 310 keV which has found more applications in medical of brachytherapy applications. Among the possible methods for cyclotron production of Ytterbium 169 we investigate the proton, deuteron irradiation on Thulium-169, and alpha particles irradiation on natural Erbium (^{nat}Er). The total isotopes production yield based on the main published and approved experimental results of excitation functions were calculated.

KEYWORDS: Excitation Function, Isotopes Production Yield of Ytterbium-169, Nuclear Medically Relevant

INTRODUCTION

Radionuclide classified as related to radioactive isotopes medically as diagnosis or therapeutic radionuclide, depending on the decay properties [1]. Ytterbium 169 (half-life of 32 days) and emits gamma radiations (49 – 308) KeV. The mean gamma energy is 93 keV (neglecting those energies below 10 KeV, which have no dosimetric significance [2]. Ytterbium 169 is considered among radionuclide radiation therapy brachytherapy, only a limited number of radionuclides can be used for brachytherapy has a large applications as a clinical radionuclide [3,4], so decays rapidly by electron capture as shown in this nuclear equation: [5].

$$^{169}_{70}\mathrm{Yb} + \ ^{0}_{-1}e \rightarrow \ ^{169}_{69}\mathrm{Tm} + \ ^{0}_{0}\gamma \tag{1}$$

Accelerators are used to produce isotopes by bombarded targets with beams of charged particles impinge on targets to produce the required isotope [6]. In this study, We will take all of Protons, Deuterons induced nuclear reactions on thulium and alpha particles induced nuclear reactions on natural Erbium, theoretical excitation functions of Ytterbium 169 productions were calculated using different charged energetic particles. Theoretical calculations of the production yields were done using SRIM (Stopping Range of Ions in Matter) code [7] to determine the suggested possible optimum reaction in Ytterbium 169 production.

METHODS

Nuclear data play a very important role in the choice of a radioisotope for a medical purpose, In terms of the main criteria for the selection suitable decay of radioactive nuclides for use diagnosis and treatment [8]. Nuclear decay and structure data determine the suitability of a radioisotope for diagnostic application while the data of nuclear reaction study the possibility of its production in a optimization form [9]**.** The feasibility of the production of Ytterbium 169 via various nuclear reactions was investigated. Excitation functions of ^{169}Yb production by the reactions of ^{169}Tm (p,x), ^{169}Tm(d,x), and ^{nat}Er(α,x) were calculated using the available data in the international libraries. According to SRIM code [7], the thick target integral yields were deduced using the calculated evaluated cross sections. A Matlab(7.8 2009a) sub programs was calculated from the following equation **[10]** :

$$Y = \frac{N_L H}{M} I(1 - e^{-\lambda t}) \int_{E1}^{E2} \left(\frac{dE}{d(\rho x)}\right)^{-1} \sigma(E) dE \quad (2)$$

Where Y is the activity (in Bq) of the product, N_L is the Avogadro number, H is the enrichment (or isotopic abundance) of the target nuclide, M is the mass number of the target element, I is the projectile current, dE/d(ρx) is the stopping power, σ (E) is the cross section at energy E, λ the decay constant of the product and t the time of irradiation.

The limits of the integration give the energy range of the projectile effective in the target, and the yield is then valid for that energy range. The calculated yield value represents the maximum yield which can be expected from a given nuclear process. Such calculations are often done in radionuclide development programs. The assumptions made include: specific energy range, beam current of 1 µA, and, irradiation time of 1 h, the calculated yield is given in the units MBq/µA·h **[10]**.

We first calculate the average value of nuclear cross section for the different libraries data by applied the following weighted mean formula [11].

$$\boldsymbol{W} = \frac{\sum w_i\, y_i}{\sum w_i} \quad (3)$$

Where: $w_i = 1/\sigma_i^2$

σ_i= standard deviation of sample i, y_i=cross section value of sample i.

Data Reduction and Analysis

- **Production by protons Particles**

^{169}Tm (p, x) ^{169}Yb reaction

The weighted average cross section for proton induced reaction on ^{169}Tm were calculated using equation (3). The obtained production yield of this isotope using equation (2), and the calculated stopping power values were shown in Table 1 by SRIM code [7]. Figure 1, Figure 2, represent the results calculation showed that the range of energy from (3 to 45)MEV. According to Spahn, I, et al [12], Sonnabend, et al [13] and Tárkányi, F., et al [5].

Table 1: Stopping Power for Proton Incident on ^{169}Tm

Energy MeV	Stopping Power for Hydrogen in Thulium MEV / (Mg/ Cm^2)	Energy MeV	Stopping Power for Hydrogen in Thulium MEV / (Mg/ Cm^2)
3	0.040387	25	0.010234
4	0.034271	26	0.009967
5	0.029997	27	0.009699
6	0.026805	28	0.009449
7	0.024323	29	0.009218
8	0.022322	30	0.008987
9	0.02067	31	0.008786
10	0.01929	32	0.008585
11	0.018099	33	0.008396

Table 1: contd.,			
12	0.017068	34	0.00822
13	0.016168	35	0.008044
14	0.015367	36	0.007888
15	0.014657	37	0.007732
16	0.014016	38	0.007584
17	0.013436	39	0.007445
18	0.012916	40	0.007306
19	0.012455	41	0.007187
20	0.011995	42	0.007068
21	0.011611	43	0.006949
22	0.011227	44	0.00683
23	0.010875	45	0.006711
24	0.010554		

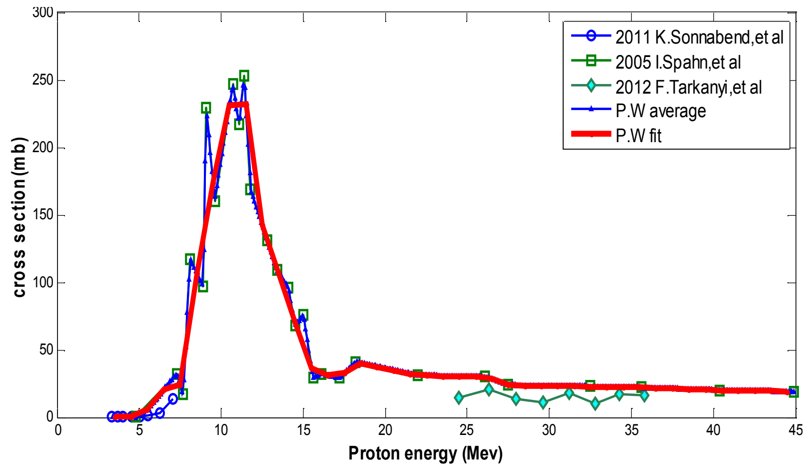

Figure 1: Fitting for Weighted Average Cross Sections of the Reaction ^{169}tm(p, x)^{169}Yb

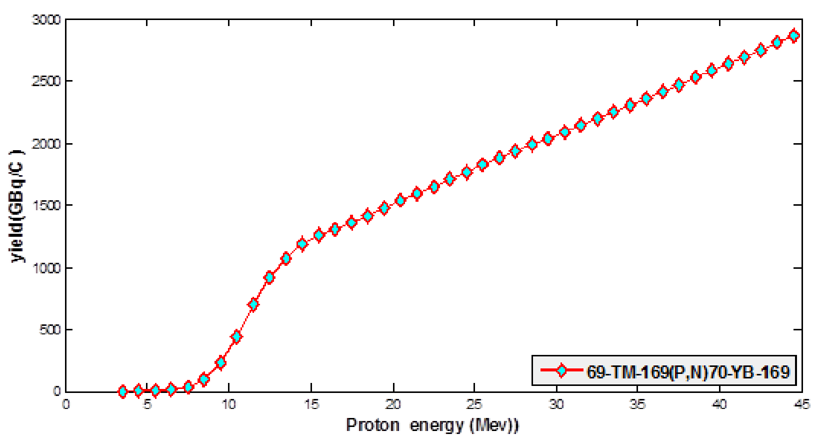

Figure 2: Isotopes Production Yield for the Reaction ^{169}Tm(p, x)^{169}Yb

- **Production by Deuteron Particles**

^{169}Tm(d, x) ^{169}Yb reactions

The weighted average cross sections for proton induced reaction on ^{169}Tm were calculated using equation (3). The obtained production yield of this isotope using equation (2), and the calculated stopping power values were shown in Table

2 by SRIM code [7]. Figure 3, Figure 4, represent the results calculation showed that the range of energy from (4 to 93)MeV. According to F.Tarkanyi, et al [14], and A.Hermanne, et al [15].

Table 2: Stopping Power for Deuteron Incident on ^{169}Tm

Energy MEV	Stopping Power for Hydrogen in Thorium MEV / (mg/ cm^2)	Energ y MEV	Stopping Power for Hydrogen in Thorium MEV / (mg/ cm^2)
4	0.050092	22	0.01811
5	0.044584	23	0.017573
6	0.04037	24	0.017081
7	0.037006	25	0.016589
8	0.034253	26	0.016172
9	0.031941	27	0.015756
10	0.029979	28	0.015368
11	0.028278	29	0.015008
12	0.026796	30	0.014647
13	0.025485	31	0.014331
14	0.024314	32	0.014015
15	0.023263	33	0.013717
16	0.022313	34	0.013437
17	0.021452	35	0.013156
18	0.020661	36	0.012908
19	0.019966	37	0.01266
20	0.01927	38	0.012426
21	0.01869	39	0.012206

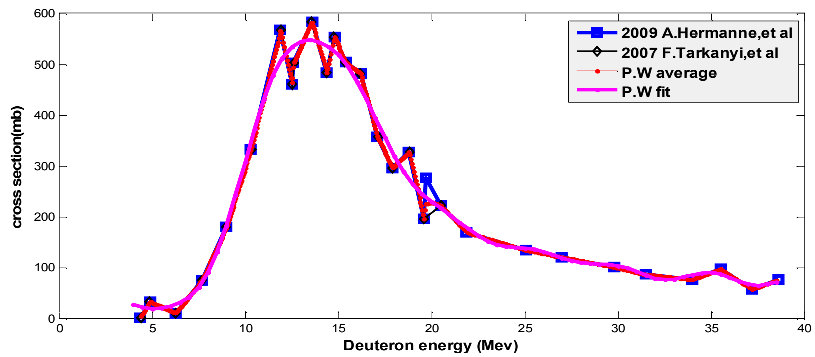

Figure 3: Fitting for Weighted Average Cross Sections of the Reaction ^{169}Tm(d, x)^{169}Yb.

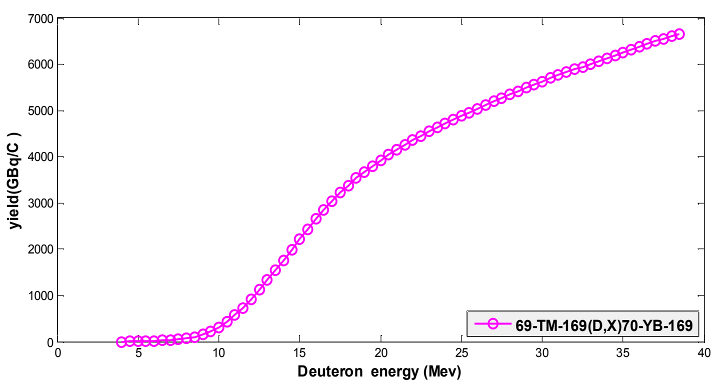

Figure 4: Isotopes Production Yield for the Reaction ^{169}Tm(D, X)^{169}Yb

- **Production by alpha Particles**

^{nat}Er ***(α, x)*** ^{169}***Yb reactions***

The weighted average cross sections for proton induced reaction on ^{nat}Er were calculated using equation (3). The obtained production yield of this isotope using equation (2), and the calculated stopping power values were shown in Table 3 by SRIM code [7]. Figure 5., Figure 6, represent the results calculation in the range of energy from (10 to 55)MeV. According to Homma, et al [16], A.Archenti,et al [17], and Király, B., et al [18].

The excitation functions for the results of the proton, Deuteron and alpha induced interactions Figure 7. Leading to the production yield of Ytterbium -169 has been displayed in Figure 8.

Table 3: Stopping Power for Alpha Incident on ^{nat}Er

Energy MEV	Stopping Power for Hydrogen in Thorium MEV / (Mg/ Cm^2)	Ener gy MEV	Stopping Power for Helium in Erbium MEV / (Mg/ Cm^2)
10	0.183235	33	0.088693
11	0.173825	34	0.086979
12	0.165516	35	0.085266
13	0.158108	36	0.083733
14	0.151402	37	0.0822
15	0.145396	38	0.080743
16	0.139891	39	0.079362
17	0.134886	40	0.077981
18	0.130282	41	0.076786
19	0.126228	42	0.075591
20	0.122175	43	0.074397
21	0.118692	44	0.073202
22	0.115209	45	0.072007
23	0.112006	46	0.071006
24	0.109084	47	0.070006
25	0.106162	48	0.069005
26	0.10364	49	0.068004
27	0.101118	50	0.067004
28	0.09876	51	0.066153
29	0.096566	52	0.065303
30	0.094373	53	0.064452
31	0.092443	54	0.063602
32	0.090514	55	0.062751

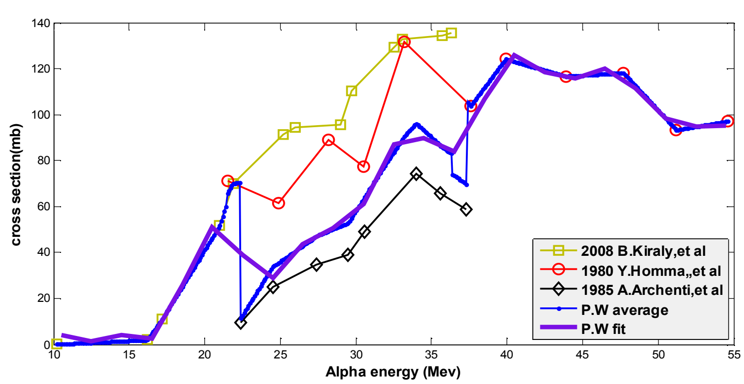

Figure 5: Fitting for Weighted Average Cross Sections of the Reaction^{nat}Er (α, x)^{169}Yb.

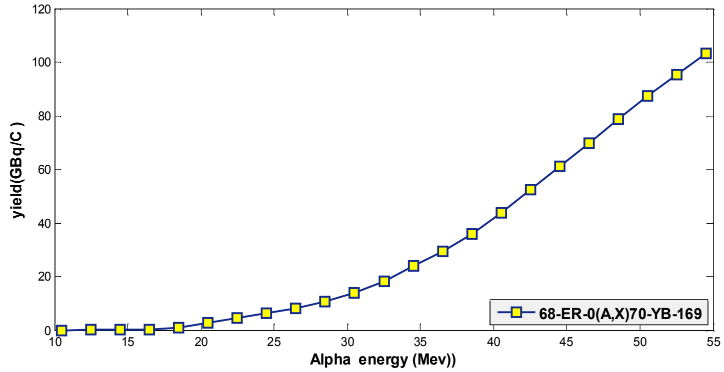

Figure 6: Isotopes Production Yield for the Reaction ^{nat}Er (α, x)^{169}Yb

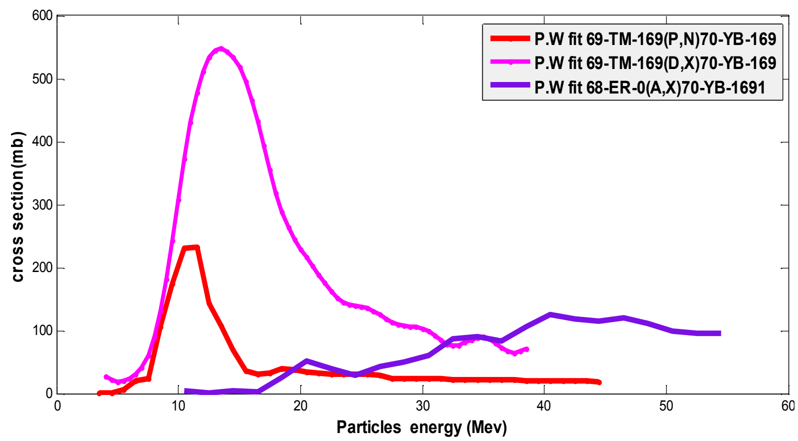

Figure 7: Fitting for Weighted Average Cross Sections of the Reaction ^{169}Tm(p, x) ^{169}Yb, ^{169}Tm (d, x) ^{169}Yb and ^{nat}Er (α, x) ^{169}Yb

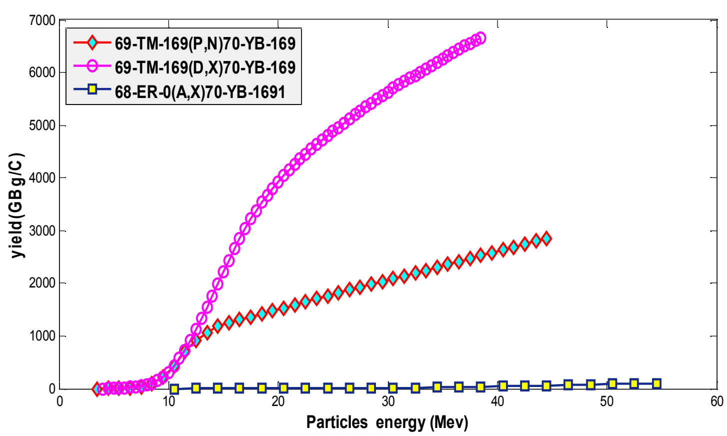

Figure 8: Isotopes Production Yield for the Reactions ^{169}Tm(p, x)^{169}Yb, ^{169}Tm(d, x)^{169}Yb and ^{nat}Er (α, x)^{169}Yb.

CONCLUSIONS

In the radioisotope production, nuclear data are needed mainly for optimization of production routes. This involves a selection of a projectile energy range that will maximize Isotopes production yield. In this study use determine the appropriate reaction in order to obtain the isotopes under study (^{169}Yb), the three charged particles, Protons, Deuterons and Alpha, were used as projectiles in order to determine the kind of reaction giving the best result for the special use, maximum Isotopes production yield.

For the radioactive isotopes production by using of charged particles interaction, we obtained the isotopes production yield Through the equation (2) and SRIM 2011 [7]. The results were as follows:

- **Production by Protons Particles**

The reaction $^{169}Tm(p,x)\,^{169}Yb$ with range of energy (3 to 45MeV) and maximum cross sections 232 mb at 11.5 MeV gives (2800 GBq/C) as shown Fig.1.,Fig.2 and shown in Table 4.

- **Production by Deuterons Particles**

For the reaction $^{169}Tm(d,x)\,^{169}Yb$ within range of energy (4 to 40 MeV) and maximum cross sections 548 mb at 14 MeV gives (6660 GBq/C) as shown Fig.3.,Fig.4 and shown in Table 4.

- **Production by Alpha Particles**

And for the reaction $^{nat}Er(\alpha,x)\,^{169}Yb$ within range of energy (10 to 55 MeV) and maximum cross sections 126 mb at 40 MeV gives only (103 GBq/C) as shown Fig.5.,Fig.6 and as shown in Table 4.

Through of the above we conclude that $^{169}Tm(d,x)\,^{169}Yb$ reaction appears to be the best for the purpose of production. And this is very clear by observing in Fig.8

Table 4: Nuclear Data of the Reactions to Isotopes Production Yield of ^{169}Yb

Reaction	Energy Range (MeV)	Max. CS (Mb)	Yield (GBQ/C)	Yield (GBQ/MAH)
$^{169}Tm(p,x)\,^{169}Yb$	3 - 45	232	2800	10.08
$^{169}Tm(d,x)\,^{169}Yb$	4 - 40	548	6660	23.976
$^{nat}Er(\alpha,x)\,^{169}Yb$	10 - 55	126	103	0.3708

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