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Research Article

A comparison of cross sections for Selenium -73 radioisotopes produced by accelerators and reactors

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ABSTRACT

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***Background*:** Selenium-73 with half- life of 7.15 hour emits β^+ in nature and has six stable isotopes which are (^{74}Se,^{76}Se,^{77}Se,^{78}Se,^{80}Se and ^{82}Se). Selenium-73 has many applications in technology and radioselenium compounds of metallic have found various applications in medicine.

Objective: To make a comparison between different reactions that produced cross sections of Se-73 radioisotopes.

Subjects and methods: The feasibility of the production of Selenium -73 via various nuclear reactions was investigated. Excitation functions of ^{73}Se production by the reactions of ^{75}As (p,3n), ^{169}Tm(d,x), ^{74}Se, ^{nat}Se, ^{nat}Br (p,x) , ^{75}As (d,4n), ^{nat}Ge (^{3}He,x), ^{70}Ge (α, n), and ^{72}Ge (α, 3n) and neutron capture were calculated using the available data in the international libraries in accordance with SRIM code . Theoretical calculations of the thick target integral yields were deduced using the calculated cross sections by using Matlab program

Results: When proton induced reaction on ^{75}As, ^{74}Se, ^{nat}Se and ^{nat}Br to obtain ^{73}Se, the reaction ^{75}As(p,3n) with range of energy (22.5 to 45.5 MeV) and the maximum cross section is 315 mb at 36.5 MeV gives maximum yield (2*10^6 GBq/C).while for the reaction ^{75}As (d,4n) ^{73}Se with range of energy (25 to 56 MeV) , and maximum cross sections is 30 mb at 43MeV gives (0.085*10^6 GBq/C).

The three reactions ^{nat}Ge (^{3}He,x) , ^{70}Ge (α,n) and ^{72}Ge (α,3n) show that the best reaction to obtain ^{73}Se is ^{72}Ge (α,3n) within the range of energy (27 to 46 MeV) and maximum cross sections 494 mb at 42MeV give the maximum yield (0.03*10^6 GBq/C).

Conclusion: the use of proton as projectile is best compared with other particles in order to get maximum isotopes production yield of 73Se.

Introduction

Radioisotopes that related to radionuclide are medically uses in diagnoses or therapy, depending on their decay properties. Selenium 73 (half-life of 7.15 hour) and emits β^+ In nature, selenium has six stable isotopes, which are ^{74}Se (0.89 %), ^{76}Se (9.36 %), ^{77}Se(7.63 %), ^{78}Se(23.78 %), ^{80}Se(49.61 %) and ^{82}Se (8.73 %). Selenium has many applications in technology, because it has unique properties. The selenium is known to be major in physiology, selenium and the compounds of selenium are highly toxic in doses more than concentrations of tracer. The radio selenium compounds of metallic have found various applications in medicine, i.e. studies PET by using radio selected (1). The radioactive nuclide ^{73}Se is very advantageous substitute for Sulphur in PET diagnostics and may replace the most established isotope^{75}Se ($T_{1/2}$ = 120 day), due to it without gravity shorter half-life of 7.1 hour (2).

$$^{73}_{34}\text{Se} + {}^{0}_{-1}\text{e} \rightarrow {}^{73}_{33}\text{As} \quad \ldots\ldots\ldots (1)$$

Accelerators are produced radioisotopes by bombarded targets with beams of charged particles to obtain the required isotope (3). In this study, protons and deuterons are taken to induce nuclear reactions on thulium while alpha particles induced nuclear reactions on natural Erbium; theoretical excitation functions of Ytterbium 169 productions were calculated using different energies of charged particles. Production Yields were calculated theoretically by using SRIM code (Stopping Range of Ions in Matter) (4) for determining the suggested possible optimum reaction in Selenium 73 production.

Method

Nuclear data plays an important role in choosing of the radioisotopes for the medical purposes. In terms of the main criteria for selecting the appropriate decay of radionuclides for use in diagnosis and treatment (5), nuclear decay and structure data determine the appropriateness of radioactive isotopes in medical diagnosis, while nuclear reaction data study the extent to which the radioisotope can be optimally produced. (6).

The possibility of producing selenium-73 was verified through various nuclear reactions. Excitation functions of ^{73}Se production by the reactions of ^{75}As (p,3n), ^{169}Tm(d,x), ^{74}Se, ^{nat}Se, ^{nat}Br (p,x) , ^{75}As (d,4n), ^{nat}Ge (^{3}He,x), ^{70}Ge (α, n), and ^{72}Ge (α, 3n) were calculated using international data available in various libraries. By using the SRIM code (4), the thick target integrated yields were inferred using the calculated evaluated cross sections. The MATLAB programs (7.8 2009a) were calculated from the following equation (2) (7):

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

where Y is the activity (in Bq) of the product, H is the enrichment (or isotopic abundance) of the target nuclide, N_L is the Avogadro number, M is the mass number of the target element, I is the projectile current, σ(E) is the cross section at energy E, dE/d(ρx) is the stopping power, t the time of irradiation, λ is the decay constant. The integration limits give the energy range of the projectile effective in the target, and the yield is valid for that range of energy. 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, with irradiation time of 1 h, and beam current of 1 μA. Thus, the calculated yield is given in the units MBq/μA·h (7).

The production yield of isotopes using reactors can be calculated taking into account the radiation period and reactor flux using the equation (3)(8).

$$S = \frac{0.6\sigma\varphi}{A} I\left(1 - e^{-\lambda t}\right) \quad \ldots\ldots\ (3)$$

σ: is the neutron activation cross-section leading to the production of radioisotope of interest in barn, φ: the flux in n/cm^{2}/s.

t: time of irradiation, λ: decay constant.

A: atomic weight of target element.

We first calculate the average value of nuclear cross section for the different libraries data by applied the following weighted mean formula (9).

$$W = \frac{\sum \omega_i y_i}{\sum \omega_i} \quad \ldots\ldots (4)$$

Where: $\omega_i = 1/\sigma_i^{2}$

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

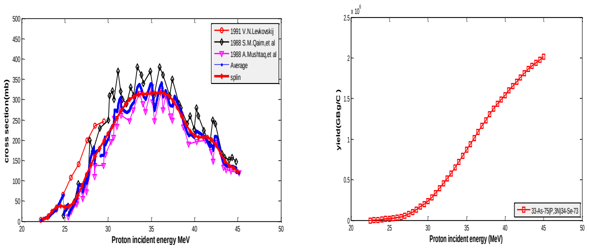
Results

A- Cyclotron production of ^{73}Se

1 -Production by protons incident

a. ^{75}As (p,3n) ^{73}Se reaction:

The excitation functions of the proton induced reaction on ^{75}As and the weighted average cross sections of all values were calculated using the relations (4) for several authors V. Levkovskij (10), S. M. Qaim, et al (11), and A. Mushtaq et al (12), in the energy range from 22.5 to 45 MeV. As shown in Fig. 1.a., the production yield of *^{73}Se* is determined by equation (2), and the stopping power values that calculated by using SRIM code (4), were shown in Fig. 1.b



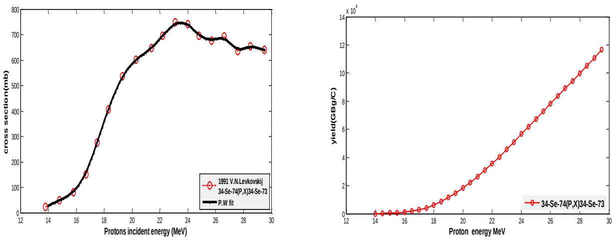
a. b.

Figure 1: a. Average cross sections of the reaction^{75}As (p,3n) ^{73}Se. b. Isotopes production yield for the reaction ^{75}As (p,3n) ^{73}Se

b. 74Se, natSe, natBr (p,x) 73Se reactions

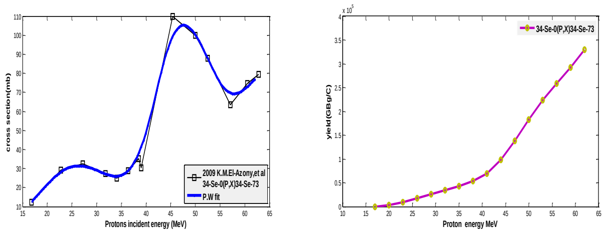
The production yield for proton induced reaction on ^{75}Se, ^{nat}Se, ^{nat}Br were determined by equation (2) and the calculated stopping power values by using SRIM code (4). Fig.2. ,fig.3. and fig.4. The evaluation of the results of the calculations showed that the ^{74}Se(p,x) ^{73}Se reaction with range of energy (14 to 29) MeV according to Levkovskij (10), the ^{nat}Se(p,x) ^{73}Se reaction with range of energy from (17 to 62) MeV according to K.M.El-Azony,et al (13), and the ^{nat}Br(p,x) ^{73}Se reaction with range of energy from (45 to 100) MeV according to M.Fassbender,et al (14).

The excitation functions for all results of the proton induced interactions Fig.5.a. Leading to the production yield of Selenium -73 have been displayed in Fig.5.b.



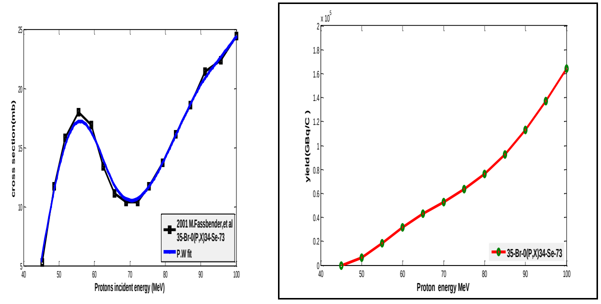
a. b.

Figure 2: a.Excitation function for the reaction^{74}Se (p,x) ^{73}Se. b.Isotopes production yield for the reaction^{74}Se (p,x) ^{73}Se.



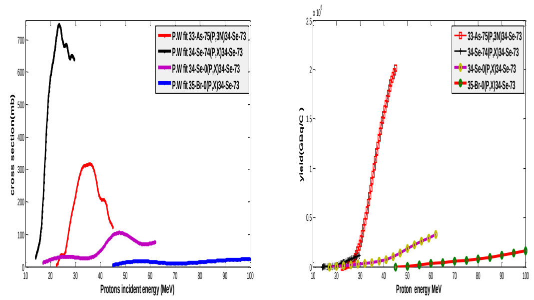
a. b.

Figure 3: a. Excitation function for the reaction ^{nat}Se(p,x)^{73}Se. b. Isotopes production yield for the reaction ^{nat}Se(p,x)^{73}Se



a. b.

Figure 4: a. Excitation function for the reaction ^{nat}Br(p,x)^{73}Se. b. Isotopes production yield for the reaction ^{nat}Br(p,x)^{73}Se.



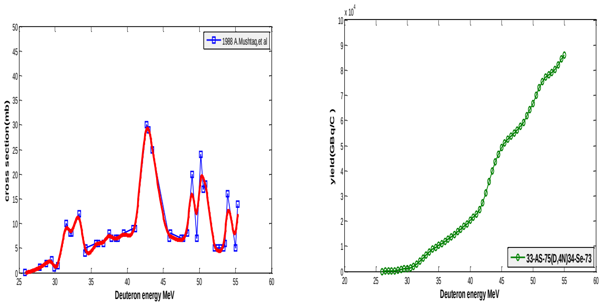
a. b.

Figure 5: a.Excitation function for production^{73}Se for reactions^{74}Se, ^{nat}Se , ^{nat}Br(p,x) ^{73}Se and ^{75}As(p,x) ^{73}Se. b. Isotopes production yield for the reactions^{74}Se, ^{nat}Se , ^{nat}Br (p,x) ^{73}Se and ^{75}As(p,3n) ^{73}Se.

2 -Production by deuterons incident

The excitation functions of the reaction ^{75}As (d,4n) ^{73}Se, were determined by A. Mushtaq, S.M.Qaim, et al (11).for energy range (25 to 56) MeV as shown in Fig.6.a.

The isotopes production yield results were shown in Fig.6. b. was determined by equation (2) and the calculated stopping power values by using SRIM code (4).



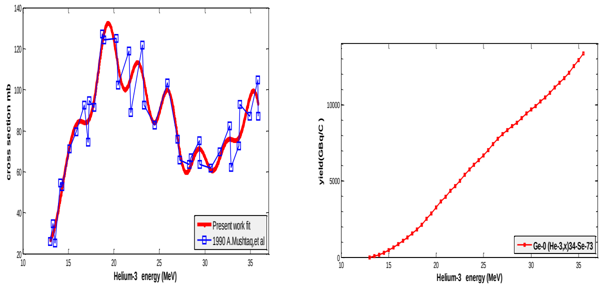
a. b.

Figure 6: a. Excitation function cross sections for the reaction ^{75}As (d,4n) ^{73}Se. b. Isotopes production yield for the reaction ^{75}As(d,4n)^{73}Se.

3 -Production by Helium-3 particles

The excitation functions of the reaction ^{nat}Ge (^{3}He,x)^{73}Se, were determined by A.Mushtaq, et al (15), for range of energy (12 to 36) MeV Fig.7.a.

The isotopes production yield results were shown in Fig.7.b, were determined by equation (2) and the calculated stopping power values by using SRIM code (4).



a. b.

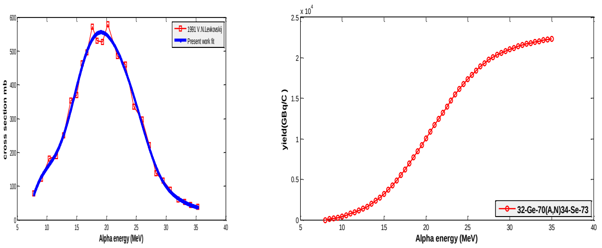
Figure 7: a. Excitation function for the reaction ^{nat}Ge (^{3}He,x)^{73}Se. b. Isotopes production yield for the reaction ^{nat}Ge (^{3}He,x)^{73}Se

4 -Production by alpha particles

a-70Ge (α, n)73Se

The Alpha particles induced reaction70Ge (α,n)73Se with range of energy (7 to 37) MeV Fig.8.a. According to V.N.Levkovskij (10).

The isotopes production yield results were shown in Fig.8. b. which was determined by equation (2) and the calculated stopping power values by using SRIM code (4)



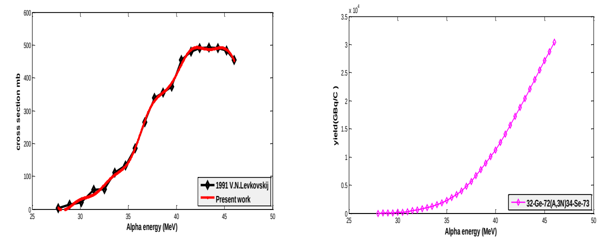
a. b.

Figure 8: a. Excitation function for the reaction ^{70}Ge (α,n)^{73}Se. b. Isotopes production yield for the reaction ^{70}Ge (α,n)^{73}Se

b-72Ge (α, 3n)73Se

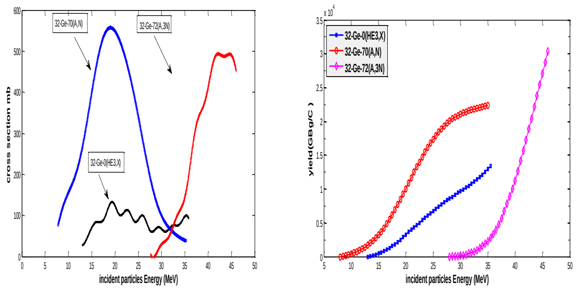
The alpha particles induced reaction ^{72}Ge (α,3n)^{73}Se with range of energies (27 to 46) MeV Fig.9. a. according to V.N.Levkovskij (10). The isotopes production yield results were shown in Fig.9. b. That determined by using equation (2) and the stopping power values were calculated by using SRIM code (57).

The excitation functions for each of Helium-3 and Alpha particles induced interactions Fig.10.a. leading to the production yield of Selenium -73, has been displayed in Fig.10.b.



a. b.

Figure 9: a. Excitation function for the reaction72Ge (α,3n)73Se. b. Isotopes production yield for the reaction 72Ge (α,3n)73Se



a. b.

Figure 10: a. Excitation function for production ^{73}Se for the reactions ^{nat}Ge (^{3}He,x) , ^{70}Ge (α,n) and ^{72}Ge (α,3n).b. Isotopes production yield for the reactions natGe (3He,x) , 70Ge (α,n) and 72Ge (α,3n)

All the nuclear data of ^{73} se that mentioned above for various nuclear reactions, can be summaries in table 1 below:

Table 1: Nuclear data of 73Se production by various nuclear reactions

Reaction	Energy Range (Mev)	Max. cs(mb)	Yield(GBq/C)	Yield(GBq/µAh)
^{75}As (p,3n)^{73}Se	22.5 - 45.5	315	2*10^{6}	7200
^{nat}Se (p,x) ^{73}Se	17 - 62	105	0.32*10^{6}	1152
^{nat}Br (p,x) ^{73}Se	45 - 100	24.5	0.16*10^{6}	576
^{74}Se (p,x) ^{73}Se	14 - 29	746.5	0.11*10^{6}	396
^{75}As (d,4n) ^{73}Se	25 to 56	30	0.085*10^{6}	306
^{nat}Ge (^{3}He,x) ^{73}Se	12 to 36	133	0.03*10^{6}	108
^{70}Ge (α,n) ^{73}Se	7 to 37	560	0.02*10^{6}	72
^{72}Ge (α,3n) ^{73}Se	27 to 46	494	0.013*10^{6}	46.8

B-Reactor production of ^{73}Se

^{74}Se (n, 2n) ^{73}Se reaction

The weighted average cross section for neutron induced reaction on ^{74}Se was calculated using equation (4) and shown in Fig.11 and table 2, According to M.Bormann,et al (16) , A.Abboud,et al (17) and M.Bormann,et al (18).

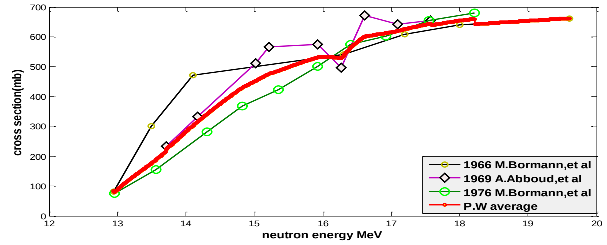


Figure.11. Excitation Function for Production ^{73}Se for the Reactions ^{74}Se (n, 2n)^{73}Se.

Table 2: Excitation Function for Production ^{73}Se for the Reactions ^{74}Se (n, 2n)^{73}Se

Neutron energy (Mev)	Cross-section (mb)	Neutron energy (Mev)	Cross-section (mb)
13	87.9274	16.5	581.4549
13.5	176.5097	17	615.2147
14	280.959	17.5	640.3161
14.5	375.0831	18	654.2727
15	449.6545	18.5	646.1875
15.5	498.3664	19	653.375
16	532.23	19.5	660.5625

.

Conclusion

1- Using cyclotrons and accelerators

a-Production by proton particles:

When proton induced reaction on ^{75}As, ^{74}Se, ^{nat}Se and ^{nat}Br to obtain ^{73}Se, the reaction ^{75}As(p,3n) with range of energy (22.5 to 45.5 MeV) and the maximum cross section is 315 mb at 36.5 MeV gives maximum yield (2*10^{6} GBq/C).

^{nat}Se (p,x) with range of energies (17to 62MeV), the maximum cross sections is 105 mb at 48.5 MeV gives yield (0.32*10^{6} GBq/C).

^{nat}Br(p,x) with range of energies (45 to 100MeV), the maximum cross sections is 24.5 mb at 100 MeV gives yield (0.16*10^{6} GBq/C).

^{74}Se (p,x) with range of energies (14 to 29), the maximum cross sections is 746.5 mb at 24.5 MeV gives yield (0.11*10^{6} GBq/C) as shown in Fig.5.a&b. and table (1).

b- Production by deuteron particles:

For the reaction ^{75}As (d,4n) ^{73}Se with range of energies (25 to 56 MeV), and the maximum cross sections is 30 mb at 43MeV, yield given is (0.085*10^{6} GBq/C) as shown in Fig.6. a.&b., and table (1) .

This result of isotopes production yield is considered low when compared with that produced by protons particles.

c- Production by Helium-3 and alpha particles:

Of the three reactions ^{nat}Ge (^{3}He,x) , ^{70}Ge (α,n) and ^{72}Ge (α,3n) show that the best reaction to obtain ^{73}Se is ^{72}Ge (α,3n) within the range of energies (27 to 46 MeV) and the maximum cross sections 494 mb at 42MeV gives the maximum yield (0.03*10^{6} GBq/C).

^{70}Ge (α,n) with range of energies (7 to 37 MeV), and maximum cross section is 560 mb at 19 MeV gives yield (0.02*10^{6} GBq/C).

^{nat}Ge (^{3}He,x) with range of energies (12 to 36 MeV), and maximum cross sections is 133 mb at 19 MeV gives yield (0.013*10^{6} GBq/C), that is very clear by observing Fig. 10.a.&b., and shown in table (1).

Through the above, we conclude that the use of proton as projectile are best compared with other particles in order to get maximum isotopes production yield of ^{73}Se .

2- Reactor production of ^{73}Se :

^{74}Se (n, 2n)^{73}Se reaction:

The *^{74}Se (n, 2n)^{73}Se* reactions with neutrons energies (13 to 19.5 MeV) have the maximum cross section 660.5 (mb) at 19.5 MeV as showen Fig.11, table (2).

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