THE STUDY OF NUCLEAR REACTIONS FOR PRODUCTION OF ISOTOPES FOR MEDICAL RADIOACTIVE ARSENIC BY USING DIFFERENT CROSS SECTIONS

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THE STUDY OF NUCLEAR REACTIONS FOR PRODUCTION OF ISOTOPES FOR MEDICAL RADIOACTIVE ARSENIC BY USING DIFFERENT CROSS SECTIONS

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ABSTRACT

This presented study is to make comparison of cross sections to produce ^{71}As, ^{72}As, ^{73}As and ^{74}As via different reactions with particle incident energy up to 60 MeV of alpha 100 MeV of proton as a part of systematic studies on particle-induced activations on enriched Ge, Ga, Rb and Nb targets and neutron capture. Theoretical calculation of production yield, and suggestion of optimum reaction to produce ^{71}As, ^{72}As, ^{73}As and ^{74}As, based on the main published and approved experimental results of excitation functions were calculated.

KEYWORDS: ^{71}As, ^{72}As, ^{74}As, Excitation Functions, Longer Lived PET Isotope, Accelerator Isotope Production, Half-Life, Radiopharmaceuticals

INTRODUCTION

Isotopes provide tools to do certain jobs better, easier, quicker, more simply, or more cheaply than any other method. In some cases the job could not be done at all without the use of isotopes. Both radioisotopes and enriched stable isotopes are essential to a wide variety of applications in medicine, where they are used in the diagnosis and treatment of illnesses. In addition, extensive application of isotopes in biomedical research finds wide parallel uses in research in chemistry, physics, biology, and geosciences.

Elemental arsenic consists exclusively of ^{75}As. The element finds application in the form of many metal alloys and agents for pest control. Arsenic is, furthermore, essential for organisms, as it is involved in different metabolic processes, and nonradioactive arsenic compounds are of interest as anticancer agents. Due to the high toxicity of arsenic in its three-valent form, studies concerning behavior and distribution of arsenic compounds are also important for ecological systems [1]. For tracer studies in those two areas the radionuclides ^{74}As (T½ = 17.77 d) have been suggested [2], although the former is rather short-lived, the therapy uses arsenic-74, a radioactive isotope that is one of a small number of positron emitters with a half-life suitable for medical imaging. When arsenic-74 decays, a positron (the antimatter equivalent of an electron) is produced that instantly annihilates with a nearby electron, releasing tell-tale gamma rays that give away its location. In addition several other radioisotopes of arsenic are very promising with regard to applications in different fields of pharmacology, diagnostics, and cancer treatment [1, 3, 4]. Especially ^{72}As (T½ = 26.01 h) is a very promising radionuclide for Positron Emission Tomography (PET), as it is an intense β^+ emitter with a suitable half-life and positron energy and The diagnostic β^+emitters and ^{71}As (T½ = 65.28 h), are potential analytical tools in nuclear medicine. Furthermore the radionuclide ^{73}As(T½ = 80.30 d) appears to be more suitable for environmental research[5,6] studies than ^{74}As, firstly, its half-life is longer and secondly, the emitted radiation is rather soft, thus causing less radiation hazard.

METHODS

The feasibility of the production of $As^{71, 72, 74}$ via various nuclear reactions was investigated. Excitation functions of $As^{71, 72, 74}$ production by the reactions of $^{69,71}Ga$+A, ^{nat}Ge+p, ^{nat} Pb+p, ^{93} Np+p, and $As^{70, 71, 72, 73}$ +n

were calculated using the available data in the international libraries up to 100 MeV. According to SRIM (Stopping Range of Ions in Matter) code [7], the thick target integral yields were deduced using the calculated evaluated cross sections. A Matlab sub programs was used

to solve the following yield equation[8]:

$$Y = NP\sigma(E).10^{-30}(1 - e^{-\lambda t}) \quad (1)$$

Whereas, $\sigma(E)$ (mb) is the average cross section at a specific energy (E); N is the number of target atoms/cm2, λ is the decay constant of the produced isotopes, P is the number of incident protons/sec for (1 μA) and t is the irradiation time (t= 1 h). The integral target yield is calculated by summing up the differential yields.

RESULTS AND DISCUSSIONS

Production by Alpha Particles

A: The induced alpha on the ^{69}Ga target can produce the reaction ^{69}Ga (a,2n) ^{71}As. According to Levkovskij [9], M.Ismail [10] and.A.Rizvi et al [11], this reaction makes a maximum cross-section of 825 mb in the 27 MeV figure (1, 2), in the energy range of 15-60 MeV. Thus, the theoretical yield of this reaction in the mentioned range is 2500 GBq/C, figure 3.This reaction appears very good to produce.

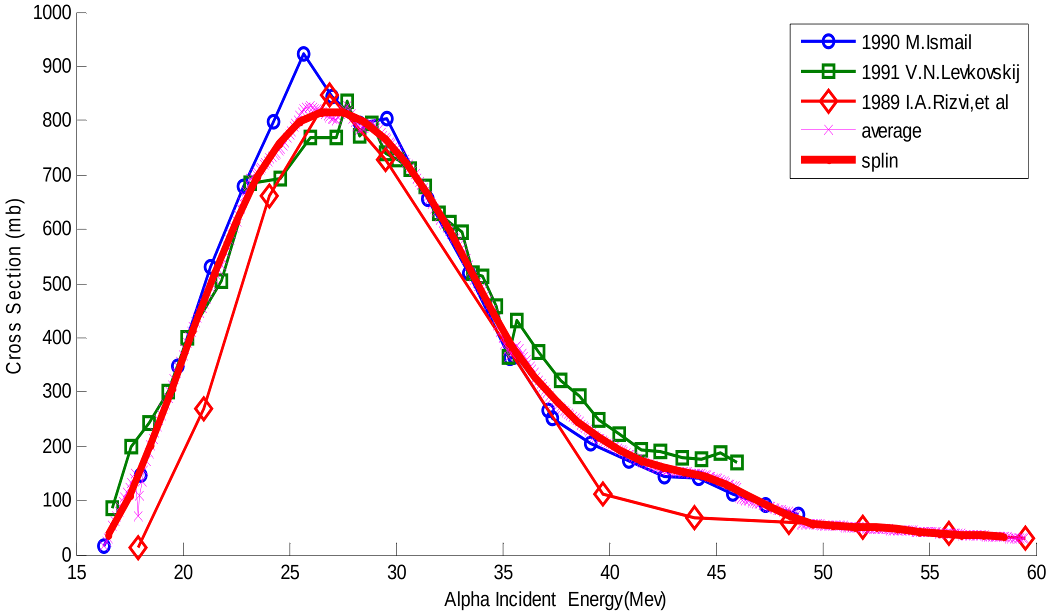

Figure 1: Cross Sections of ^{71}As of the Reaction ^{69}Ga (a, 2n) ^{71}As

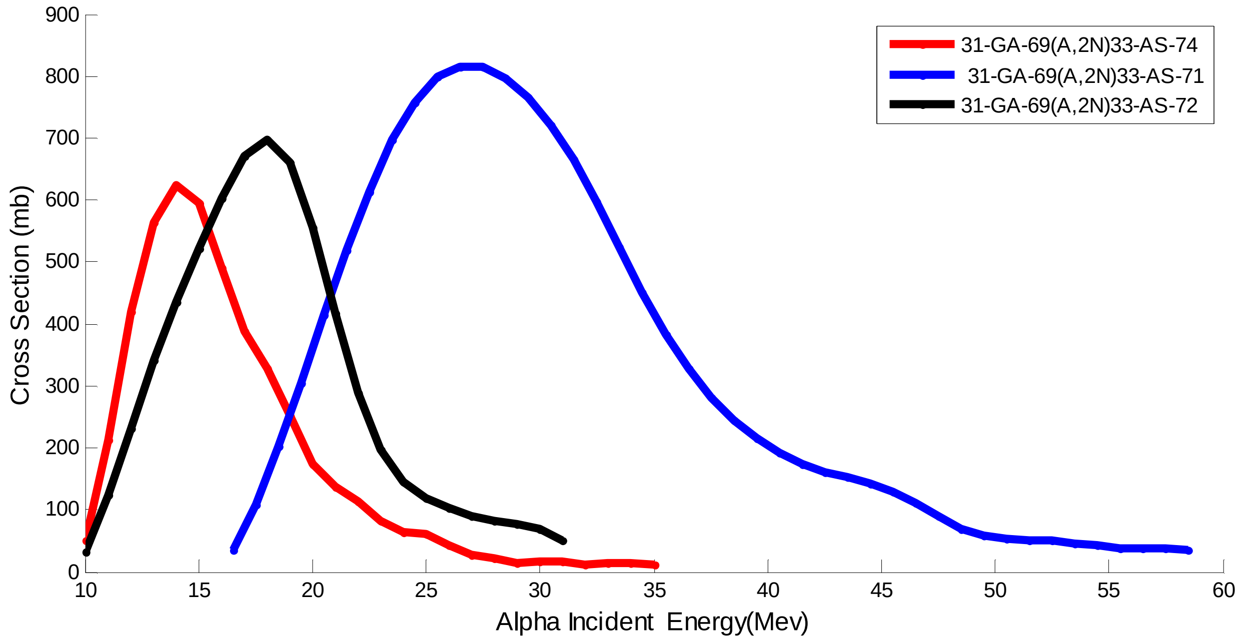

Figure 2: Cross Sections of [71,72,74] as of the Three Reactions ^{69}Ga (A,2n) [7,] ^{69}Ga (A, N) and ^{69}Ga (A, N)

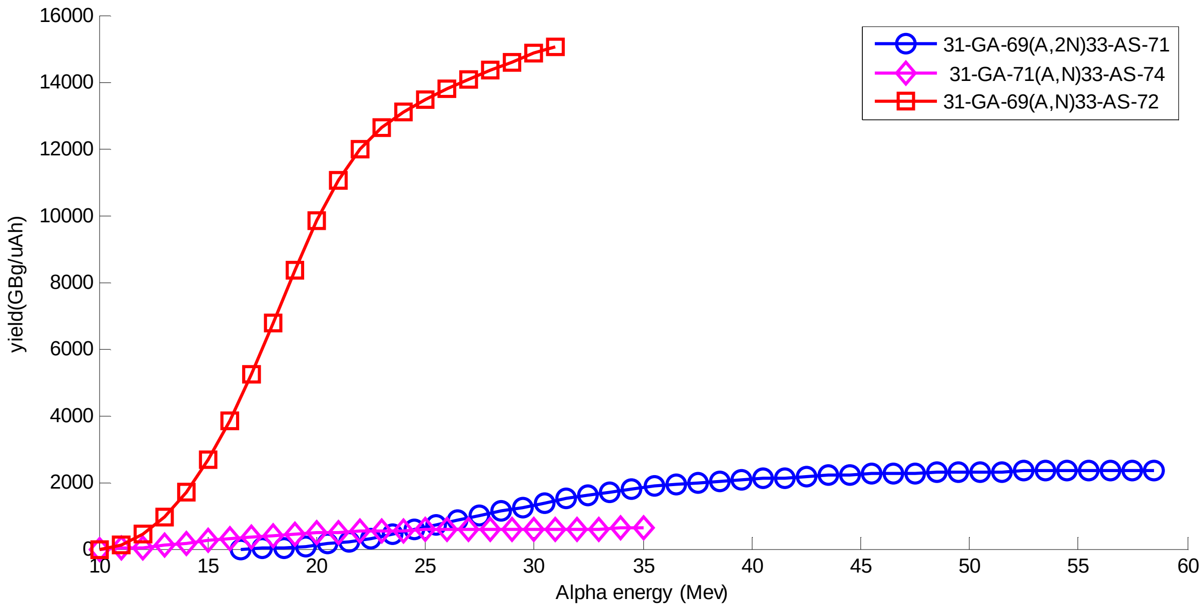

Figure 3: Yield of the Three Reactions ^{69}Ga (a, 2n) [7,] ^{69}Ga (a, n) and ^{69}Ga (a, n)

The induced alpha on the ^{69}Ga target can produce the reaction ^{69}Ga (a, n) ^{72}As. According to I.A.Rizvi etal [11], M.Ismail [10] and Levkovskij [9], this reaction makes a maximum cross-section of 690 mb in the 18 MeV figure (4,2), in the energy range of 10-35 MeV. Thus, the theoretical yield of this reaction in the mentioned range is 15000. GBq/C. Figure (3), this reaction appears to be excellent for the production.

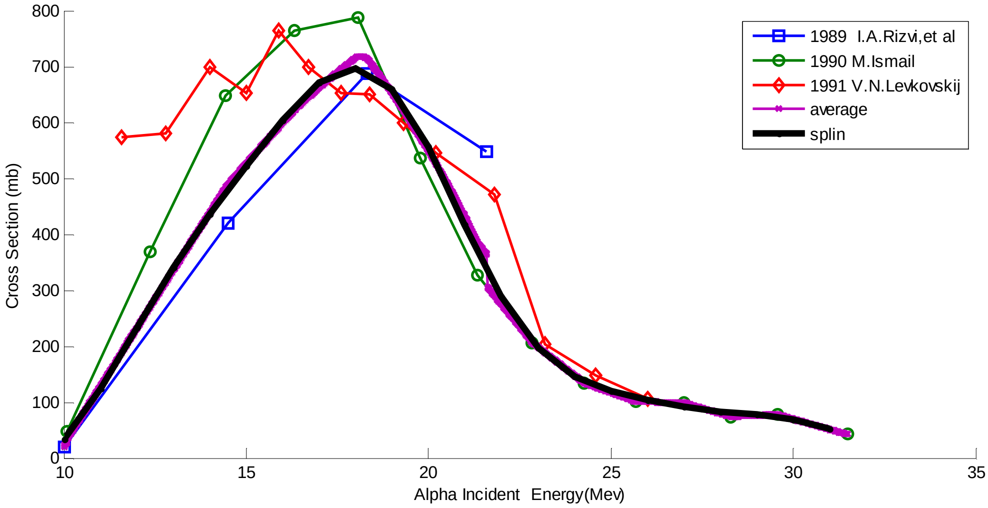

Figure 4: Cross Sections of ^{72}As of the Reaction ^{69}Ga (a, n) ^{72}As

The induced alpha on the ^{71}Ga target can produce the reaction ^{71}Ga (a, n) ^{74}As. According to M. Ismail [10] and Levkovskij [9], this reaction makes a maximum cross-section of 612 mb in the 14 MeV figure (5, 2), in the energy range of 10-35 MeV. Thus, the theoretical yield of this reaction in the mentioned range is 1500. GBq/C. Figure 3, this reaction appears to be very suitable for the purpose of produce ^{74}As.

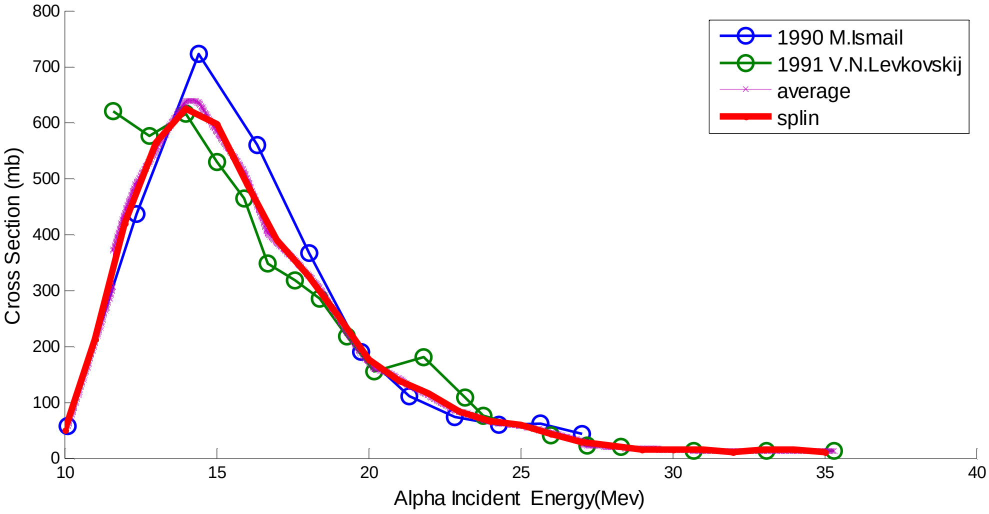

Figure 5: Cross Section of ^{74}As **of the Reaction** ^{71}Ga (a, n) ^{74}As

Production by Proton Particles

- ^{nat}Rb (p,x) ^{71},^{72,73,74}As reaction is high energy range of proton producing ^{71},^{72,73,74}As from a ^{nat}Rb target is 0 to3000 MeV,the maximum cross-section obtained according to E.Gialabert et al [12] as shown in figure(6,7,8,9,10). The obtained production yield of ^{71,72,73,74}As using SRIM code and eq.(1) in the chosen energy range is 12x10^{6} GBq/C as shown in figure 11. These reactions appears are not useful to As-71,72,73,74 production, because need to high-energies.

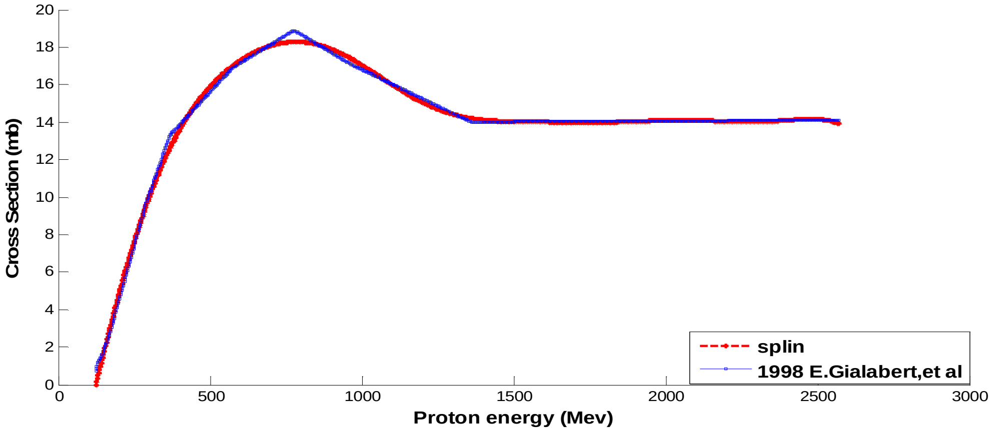

Figure 6: Cross Section of ^{71}As of the Reaction ^{nat}Rb (p,x) ^{71}

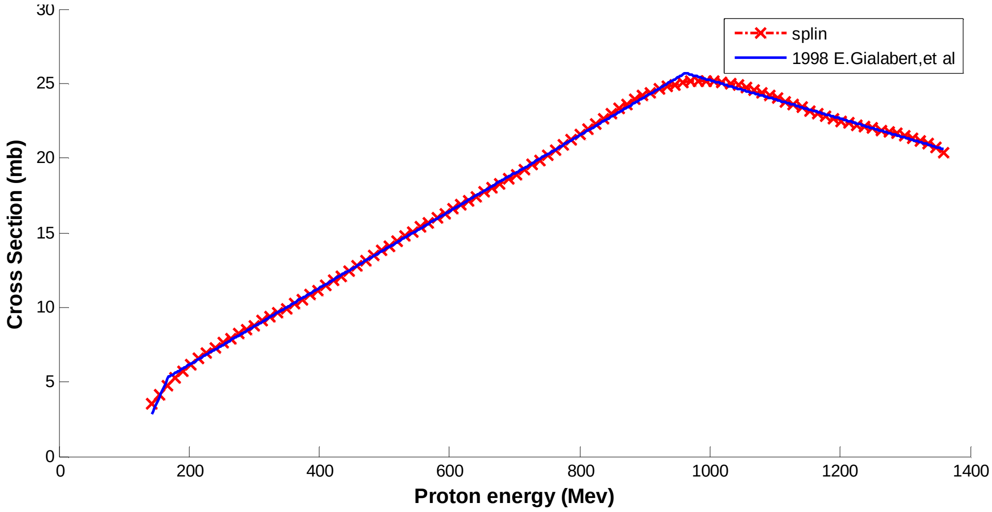

Figure 7: Cross Section of ^{72}As of the Reaction ^{nat}Rb (p,x) ^{72}

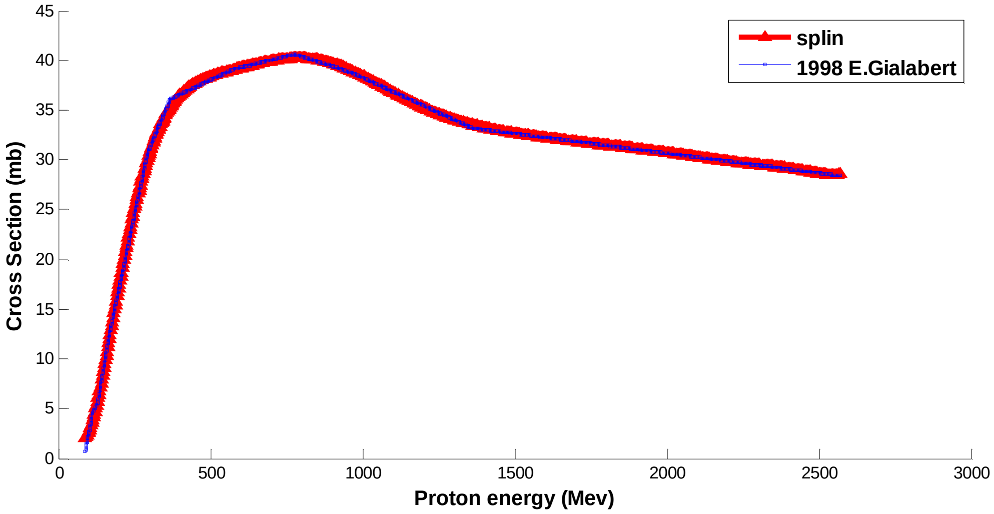

Figure 8: Cross Section of ^{73}As **of the Reaction** ^{nat}Rb (p,x) ^{73}

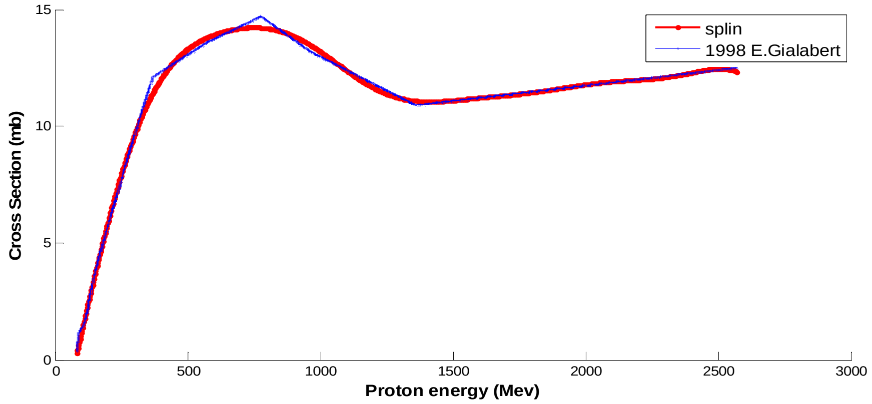

Figure 9: Cross Section of ^{74}As of the Reaction ^{nat}Rb (p,x) ^{74}

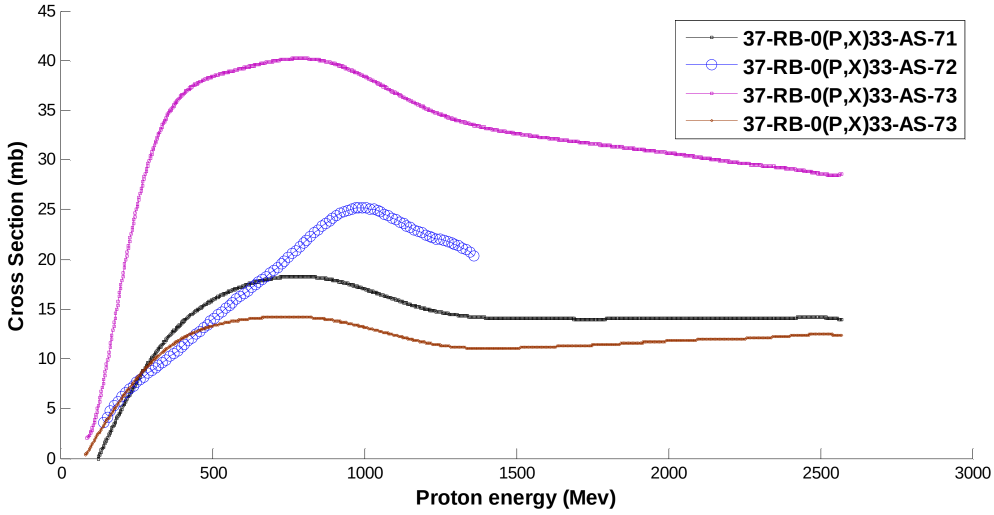

Figure 10: Cross Sections of ^{71,72,73,74}As of the four Reactions ^{nat}Rb (p,x) ^{71},^{72,73,74}As

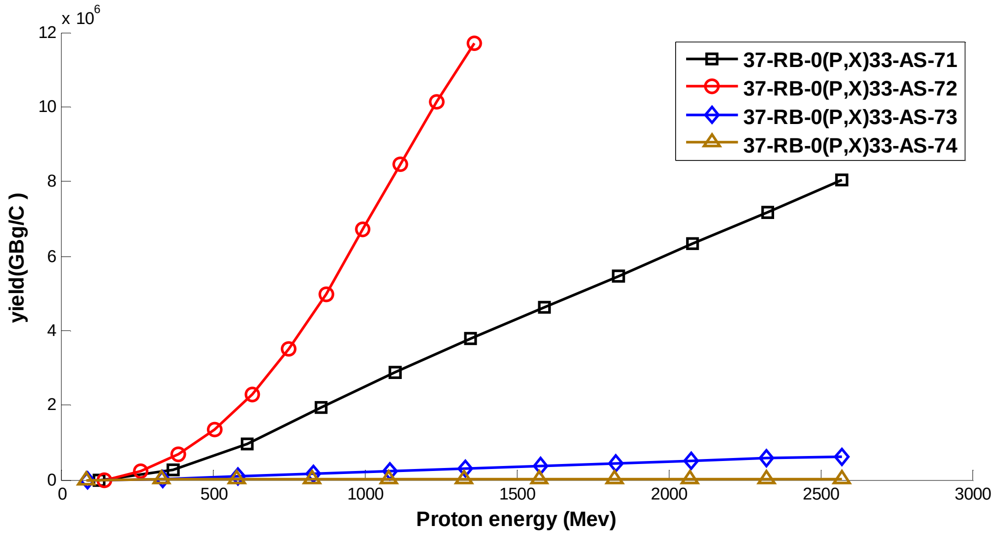

Figure 11: Yield of the Four Reactions ^{nat}Rb (p,x) ^{71},^{72,73,74}As

- ^{93}Nb (p,x)^{71},^{72,73,74}As reaction is high energy range of proton producing ^{71},^{72,73,74}As from a ^{93}Nb target is 0 to3000 MeV,the maximum cross-section obtained according to Yu.E.Titarenko et al [13]and R.Michel et al[14] as shown in figure 12. The obtained production yield of ^{71,72,73,74}As using SRIM code and eq.(1) in the chosen energy range is $12x10^6$ GBq/C as shown in figure 13. These reactions appears not to be suitable for the purpose of Arsenic -71,72,73,74 production.

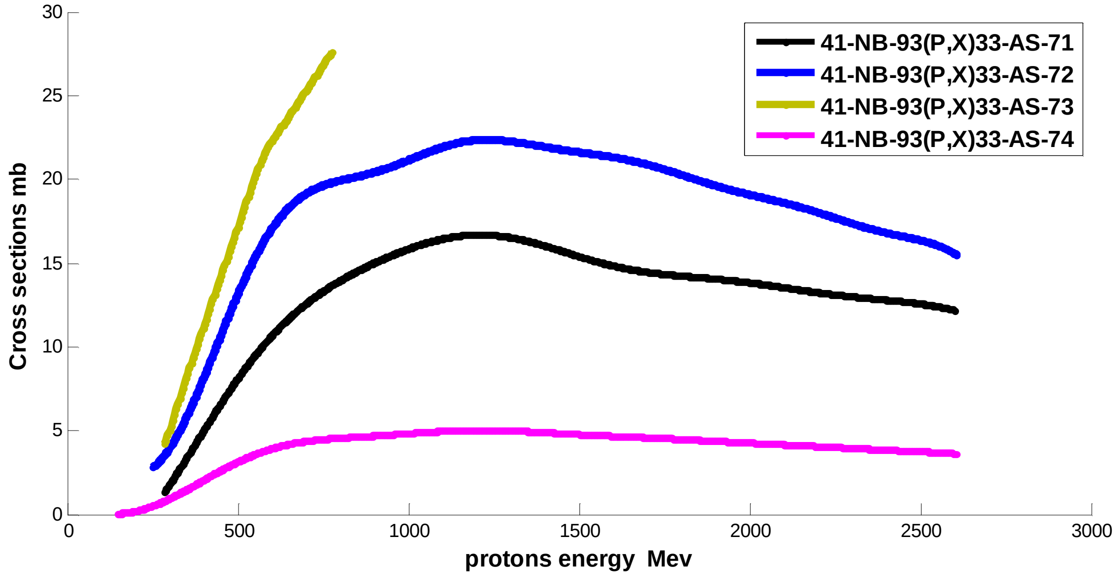

Figure 12: Cross Sections of ^{71,72,73,74}As of the four Reactions ^{93}Nb (p,x) ^{71},^{72,73,74}As

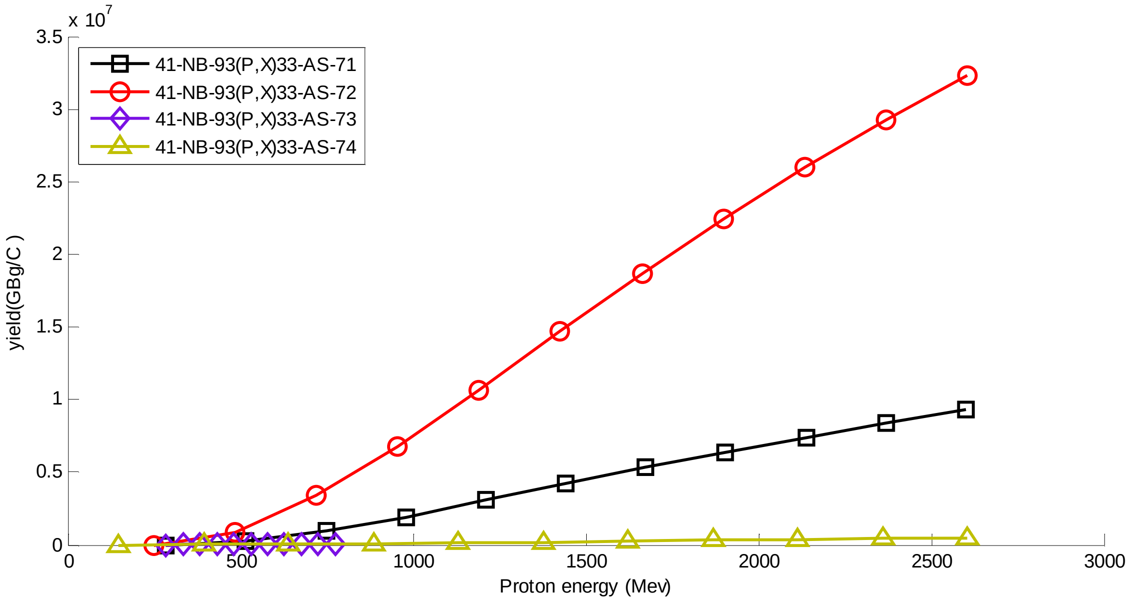

Figure 13: Yield of the four Reactions ^{93}Nb (p,x) ^{71},^{72,73,74}As

- **C:** The ^{nat}Ge (p,x) ^{71},^{72,73,74}As reaction is an important proton incident particle for producing ^{71,72,73,74}As from enriched ^{nat}Ge,Several authors I.Spahn etal [15], T.Horiguchi et al[16] and D.Basile et al[17] in the energy range from 0 to 100 MeV,the reaction for producing ^{71,72,73,74}As as shown in figures (14,15,16,17,18). The theoretical thick-target yield obtained using SRIM as shown in figure 19. These reactions appears to be good for the purpose of Arsenic -71,72,73,74 production.

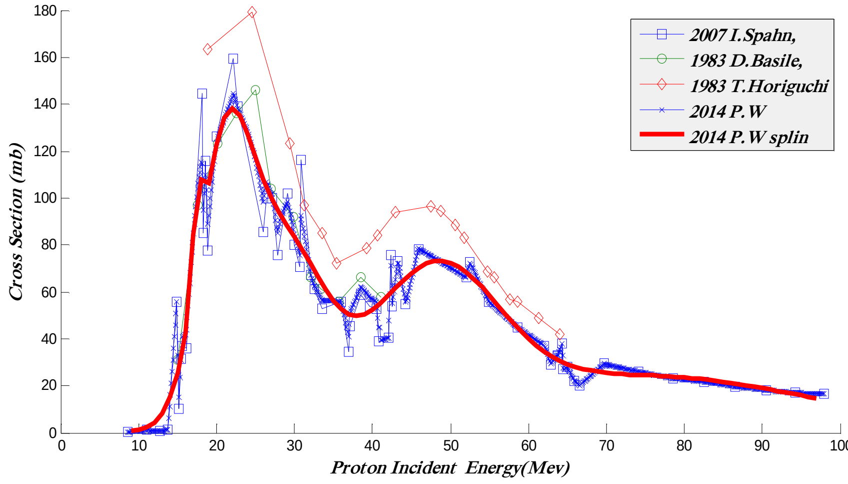

Figure 14: Cross Section of ^{71}As of the Reaction ^{nat}Ge (p,x) ^{71}

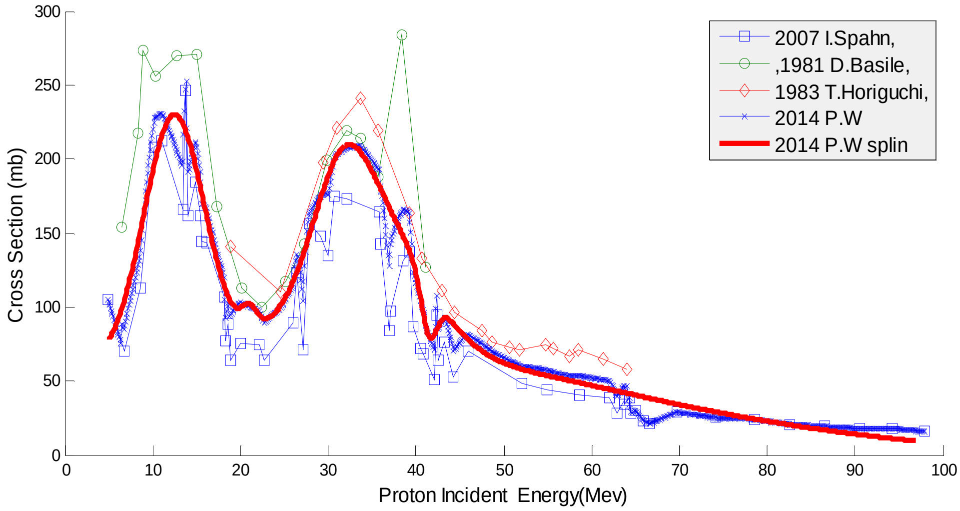

Figure 15: Cross Section of ^{72}As of the Reaction ^{nat}Ge (p,x) ^{72}

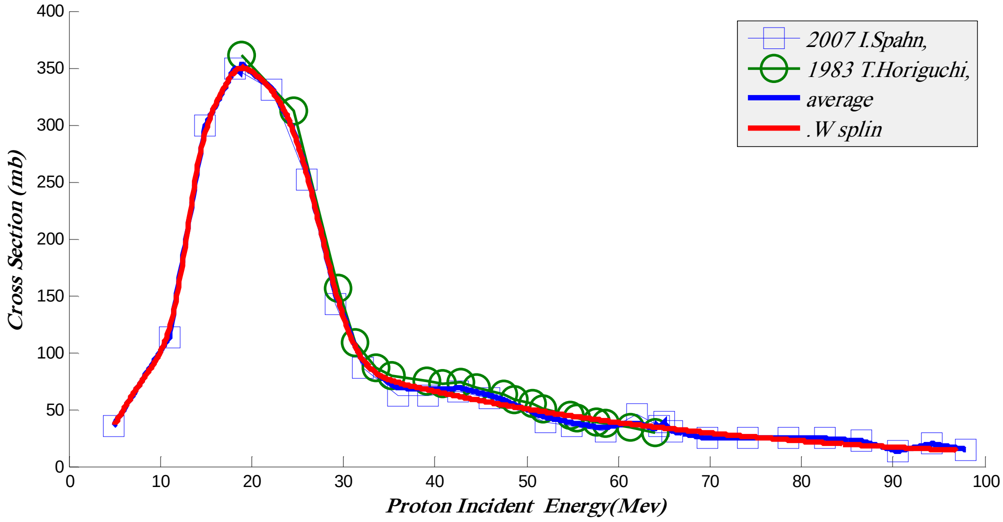

Figure 16: Cross Section of ^{73}As of the Reaction ^{nat}Ge (p,x) ^{73}

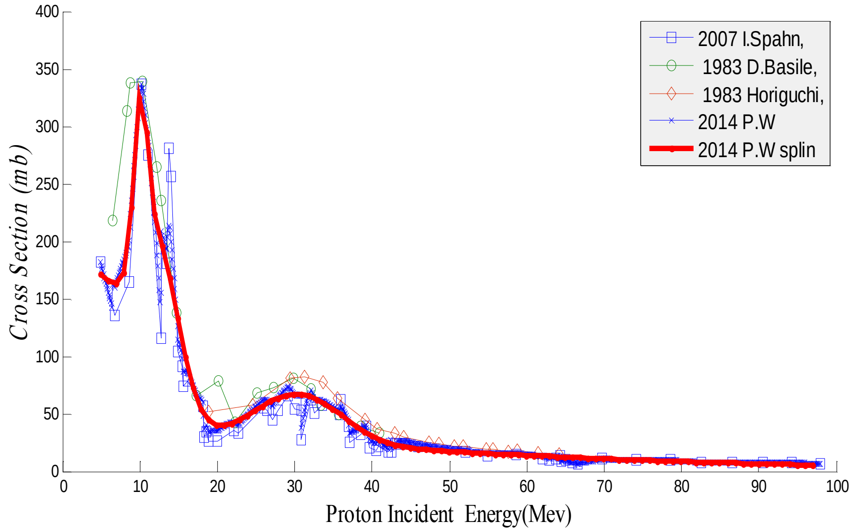

Figure 17: Cross Section of ^{74}As of the Reaction ^{nat}Ge (*p*,x) ^{74}

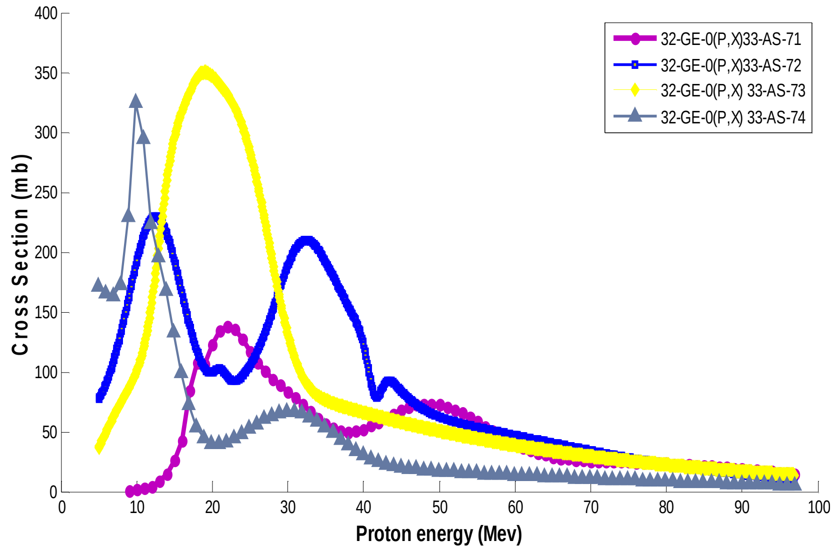

Figure 18: Cross Sections of ^{71,72,73,74} As of the four Reactions ^{nat}Ge (p,x) ^{71,72,73,74}As

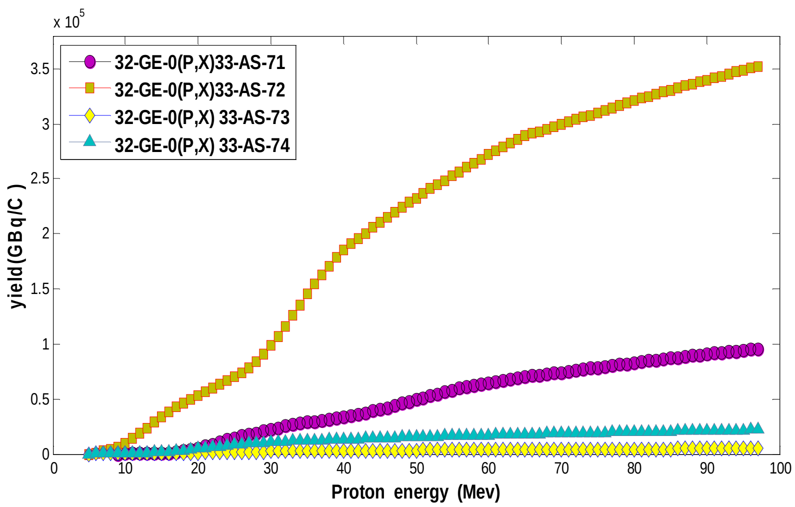

Figure 19: Yield of the Four Reactions ^{nat}Ge (p,x) ^{71}, ^{72,73,74}As

Production by Neutron Capture

The excitation functions of the neutron induced reaction on ^{70,71,72,73}As to produce ^{71,72,73,74}As with neutron flux : 1×10^{12} n/cm^2/s, and the cross section as shown in figure 20 according A.J. Koning and D. Rochman[18,19,20,21]. These reactions appears to be good for the purpose of Arsenic -71,72,73,74 production.

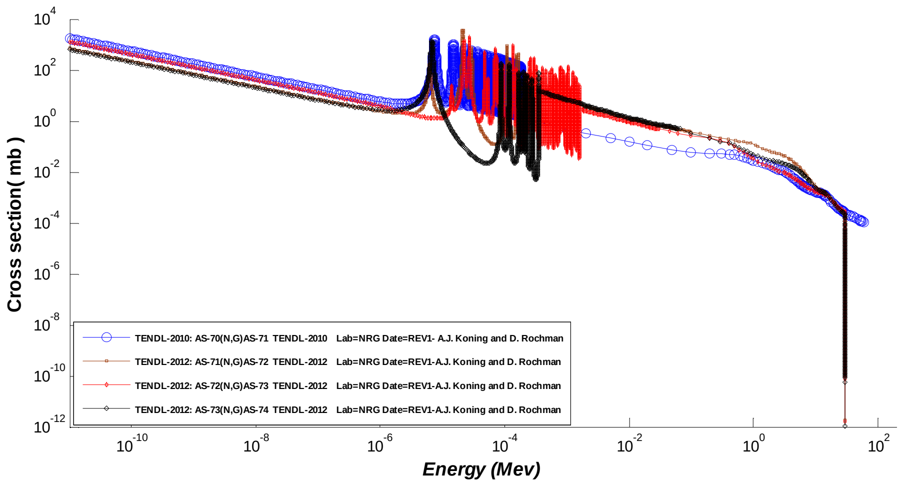

Figure 20: Cross Sections of ^{71,72,73,74}As of the ^{70,71,72,73}As (N,G) ^{71,72,73,74}As

CONCLUSIONS

The production of ^{71,72,73,74}As can be obtained using different nuclear reactions in table 1, for low alpha energies (10– 35 MeV) the reaction ^{69}Ga (a, n) ^{72}As gives the large yield (15000 GBq/C), while for the other possible reactions as the ^{69}Ga (a,2n) reaction to produce ^{71}As in energies (15-60MeV), and ^{71}Ga (a, n) reaction to produce ^{74}As, which occurs in an energy range greater than 60 Mev,we found the best reactions to produce ^{71,72,73,74}As in reaction ^{nat}Ge (p,x) because the proton easier in terms of availability of alpha and the natural target cheaper in terms of price, figure 19.

The **neutron capture** reactions in reactor play an important role too in ^{71,72,73,74}As production, for low energies, but to provide the nuclear reactor is a difficult and expensive, figure 20.

Table 1: Nuclear Data of ^{71,72,73,74} as Production via Various Nuclear Reactions

	Reaction	Range of energy (Mev)
1	^{69}Ga (a,2n) ^{71}As	10 - 35
2	^{69}Ga (a, n) ^{72}As	15 - 60
3	^{71}Ga (a, n) ^{74}As	10 - 35
4	^{nat}Ge (p,x) ^{71}As	10 - 100
5	^{nat}Ge (p,x) ^{72}As	10 - 100
6	^{nat}Ge (p,x) ^{73}As	10 - 100
7	^{nat}Ge (p,x) ^{74}As	10 - 100
8	^{nat}Rb (p,x) ^{71}As	100- 3000
9	^{nat}Rb (p,x) ^{72}As	100 - 1400
10	^{nat}Rb (p,x) ^{73}As	100- 3000
11	^{nat}Rb (p,x) ^{74}As	100- 3000
12	^{93}Nb (p,x) ^{71}As	250 - 3000
13	^{93}Nb (p,x) ^{72}As	250 - 3000
14	^{93}Nb (p,x) ^{73}As	280 - 800
15	^{93}Nb (p,x) ^{74}As	150- 3000
16	^{70,71,72,73}As (N,G) ^{71,72,73,74}As	10^{-10} - 10^{2}

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