Production of Medical Radioisotope Iodine-125 by using Sb and Te target elements

Prof. Dr. Iman Tarik ALAlawy

Raghad Saadoon Mohammed

The University of AL-Mustansiriyah, Department of physics

drimantarik@yahoo.com

Abstract

Iodine-125 of half-life (59.4d) is a radioactive medical isotope. The cross sections for the reactions ${}^{125}_{52}Te_{73}(p,n)\,{}^{124}_{52}Te_{72}(d,n){}^{125}_{53}I_{72}$, ${}^{123}_{51}Sb_{72}(\alpha,2n){}^{125}_{53}I_{72}$ and ${}^{127}_{53}I_{74}(p,3n){}^{125}_{54}Xe_{71}$: ${}^{125}_{53}I_{72}$, taken from EXFOR library have been evaluated. The recommended excitation functions have been calculated by evaluation the cross section. The results are in good agreement with a polynomial fitting of degree 6,8,9,10 degree. This evaluation is used to calculate the integral yield of radioactive Iodine-125. The most useful reaction for the production of Iodine-125 is ${}^{124}_{52}Te_{72}(d,n){}^{125}_{53}I_{72}$ reaction with no impurity with yield $0.611MBq(0.02mCi)/\mu Ah$ and useful energy range 5.5→7.5MeV from cyclotron using high enrichment for Te-124.

Keywords: Recommended cross section; stopping power; enrichment; yield; I-125

انتاج نظير اليود-١٢٥ المشع باستخدام اهداف الأنتيمون و التيلوريوم

أ. د. ايمان طارق العلوي رغد سعدون محمد

الجامعة المستنصرية - قسم الفيزياء

الخلاصة

نظير اليود-١٢٥هو نظير طبي بعمر نصفي (٥٩،٤يوم). لقد تم تقييم المقاطع العرضية للتفاعلات ${}^{125}_{52}Te_{73}(p,n){}^{125}_{53}I_{72}$ و ${}^{124}_{52}Te_{72}(d,n){}^{125}_{53}I_{72}$ و ${}^{123}_{51}Sb_{72}(\alpha,2n){}^{125}_{53}I_{72}$ و ${}^{127}_{53}I_{74}(p,3n){}^{125}_{54}Xe_{71}$: ${}^{125}_{53}I_{72}$ التي تم اعتمادها من مكتبةEXFOR. دوال الاثارة

التي تم تقيمها وتوصيتها وحسابها بتقييم المقاطع العرضية. ان النتائج كانت متوافقة بشكل جيد بملائمة من نوع متعددة الحدود بدرجة ٦و٨و٩و١٠. ان النتائج المقيمة قد تم استخدامها لحساب نواتج النظير المشع يود-١٢٥من هذه التفاعلات، ان التفاعلات الاكثر فائدة لانتاج يود-١٢٥ (I-125) هو $^{124}_{52}Te_{72}(d,n)^{125}_{53}I_{72}$ بعدم وجود شوائب وناتج $0.611\,MBq(0.02\,mCi)/\mu Ah$ وبمدى طاقة يمكن الاستفادة منه هو $(E_d = 5.5 \rightarrow 7.5MeV)$، باستخدام تخصيب عالي لهدف التيلوريوم (Te-124).

الكلمات المفتاحية: تقييم المقاطع العرضية، قدرة الايقاف، التخصيب، النواتج.

Introduction

Iodine–125 radioisotope has a half–life of 59.4d used in medical research, diagnostics and treatments. One of the most common effective medical applications of Iodine–125 is its involvement in the treatment of prostate cancer. Iodine–125 used as nuclear imaging tracers to evaluate the anatomic and physiologic function [1, 2].

When $^{125}_{53}I_{72}$ is used therapeutically, it is encapsulated in Titanium seeds and implanted in the area of the tumor, where it remains. The low energy of the gamma spectrum in this case 0.0355MeV limits radiation damage to tissues far from the implanted capsule. Iodine–125, due to its suitable longer half–life and less penetrating gamma spectrum, is also often preferred for laboratory tests that rely on Iodine as a tracer that is counted by a gamma counter, such as in radio immunoassaying [3].

Many studies have been developed for using Iodine–125 by Goolden A. W. G. et al. (1968) [4]; Venikov N. I. et al. (1993) [5]; Bastian Th. et al. (2001) [6]; Hohn A. et al. (2001) [7]; Weinreich R. and Knust J. E. (2005) [8]; Gul K. (2009) [9]; and Uddin M. S. et al. (2011) [10a], for different applications in diagnostic and treatments by studying the excitation functions, enrichments, differential and integral yields, and impurities levels.

Theoretical Basics

The binding energy can be expressed as follows [11]:

$$B.E._{total}(A,Z) = \left[\left(ZM_p + NM_n\right) - M(A,Z)\right]c^2 \qquad (1)$$

Where M(A,Z) is the mass of a specific nucleus, M_p is the mass of a proton (1.007277amu), M_n is the mass of a neutron (1.008665amu), A is the mass number (number of nucleons), Z is the number of protons in a nucleus, N is the number of neutrons in a nucleus and c is the speed of light.

The Q- value of the reaction is [12]:

$$Q= \left[(M_a + M_x) - (M_b + M_Y)\right]c^2 \qquad (2)$$

From this equation, the Q-value can be obtained from only the masses of the particles involved in the reaction (or from the mass defect).

The threshold energy can be obtained by the following equation:

$$E_{th} = \frac{-Q(M_a + M_X)}{M_X} \qquad (3)$$

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. As the incident ion slows down in the stopping medium the problem becomes further complicated by the attachment (capture and loss) of electrons to the ion so that it is no longer fully ionized. At this lower ion velocity, the participation of the valence electrons in the stopping process becomes more important [13].

The beam particles hitting a target are get slowed down by interactions with the electrons (straggling) until they are in thermal equilibrium with their surroundings. As a consequence one gets a spectrum if the projectiles are completely stopping in the target, even if all nuclear reactions were two-body reactions [14].

In the scope of this work, the electronic stopping powers are programmed and calculated using the Ziegler formulae expressions valid for the energy range as follows [15→17]:

1- Energy range (1-10)×10^{-3} MeV

$$-\frac{dE}{dx} = A_1 E^{1/2} \qquad (4)$$

2- Energy range (10-999)×10^{-3} MeV

$$\left(-\frac{dE}{dx}\right)^{-1} = \left(-\frac{dE}{dx}\right)_{Low}^{-1} + \left(-\frac{dE}{dx}\right)_{High}^{-1} \qquad (5)$$

$$\left(-\frac{dE}{dx}\right)_{Low} = A_2 E^{0.45} \qquad (6)$$

$$\left(-\frac{dE}{dx}\right)_{High} = \left(\frac{A_3}{E}\right)\ln\left[1+\left(\frac{A_4}{E}\right)+A_5 E\right] \qquad (7)$$

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

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

Where: E is the proton or deuteron energy in (MeV), A_i are the coefficients given by Ziegler, β is the ratio between incident corpuscle velocity and the velocity of light $\beta = \frac{v}{c}$.

While the electronic stopping powers are also programmed and calculated using the Ziegler formulae expressions valid for the energy range of incident alpha as follows [15→17]:

1- Energy range 1kev – 10MeV

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

$$\left(-\frac{dE}{dx}\right)_{Low} = A_1 E^{A2} \quad (10)$$

$$\left(-\frac{dE}{dx}\right)_{High} = \left(\frac{A_3}{E/1000}\right) \ln\left[1 + \left(\frac{A_4}{E/1000}\right) + \left(\frac{A_5 E}{1000}\right)\right] \quad (11)$$

2- Energy range > 10 MeV

$$\left(-\frac{dE}{dx}\right) = \left(A_6 + A_7 EE + A_8 EE^2 + A_9 EE^3\right) \quad (12)$$

Where $EE = \ln(1/E)$ and A_i (i =1 – 9) are the coefficients given by Ziegler [15, 16] for incident alpha. The stopping power of elements for proton, deuteron and alpha have been calculated in the present work using Zeigler formulae for different energy ranges. Table (3) shows the necessary coefficients used in the present calculations of the stopping of proton, deuteron and alpha in the target elements [15, 16].

For any energy, E the Yield of product nuclei can be expressed as the function of the cross section as [18]:

$$Yield = I(\phi\ n)\ H\ \left(1 - e^{-\lambda t}\right) \int_{E_{out}}^{E_{in}} \sigma(E) \left(\frac{dE}{dx}\right)^{-1} \quad (13)$$

Where: Yield is the activity in (Bq), I is current of projectile in (μA), ϕ is beam flux in (1/s), n is number of atoms per unit volume $(\frac{N}{A})$, N is Avogadro's number, A is the mass number of the target in (amu), H is isotopic abundance (or enrichment) of the target, λ is decay constant of the product $(\frac{0.693}{t_{1/2}}) \text{in} (h^{-1})$, t is time of irradiation in (h), $\frac{-dE}{dx}$ is the stopping power and $\sigma(E)$ is cross section at energy E in (mb).

Data Reduction and Analysis

Table (1) shows the international EXFOR library used in the present work for available measuring data for proton, deuteron and alpha particle induced reactions for the Iodine–125 target element

Table (2) shows some properties of Iodine–125 element a product in the nuclear reactions used in the present work. Natural abundances [19] and enrichment are given for different target material. For radioactive isotopes the half-life and the decay constant are maintioned. This table also includes the calculated total binding energy and the binding energy per nucleon in MeV of all nuclear reactions under significance circumstances. Calculations such as these are required for several purposes to compare the stability of one nucleus with that of another, in order to find out the energy release in a nuclear reaction.

Table (2) also shows the results of the calculated Q-values and the threshold energies compared with the experimental values which are taken from National Nuclear Data Center (NNDC) [20], both are in a very good agreement. For ${}^{125}_{52}Te_{73}(p,n){}^{125}_{53}I_{72}$ endoergic reaction the -Q value is -0.968117MeV. For ${}^{124}_{52}Te_{72}(d,n){}^{125}_{53}I_{72}$ exoergic reaction the +Q value is +3.3762842MeV. For ${}^{123}_{51}Sb_{72}(\alpha,2n){}^{125}_{53}I_{72}$ endoergic reaction the Q-value is -14.11MeV.

Method Used to Obtain the Recommended Cross Section

The interpolations for the nearest data for each energy interval as a function of cross sections and their corresponding errors have been done using Matlab-8.

1- The sets of experimental cross sections data are 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 0.01MeV for available different energy range for each author.
2- The normalization for the statistical distribution of cross sections errors to the corresponding cross section values for each author has been done.
3- The interpolated values are calculated to obtain the recommended cross section which is based on the weighted average calculation according to the following expressions [21].

$$\sigma_{w.a.} = \frac{\sum_{i=1}^{n} \frac{\sigma_i}{(\Delta\sigma_i)^2}}{\sum_{i=1}^{n} \frac{1}{(\Delta\sigma_i)^2}} \qquad (14)$$

Where the standard deviation error is:

$$S.D. = \frac{1}{\sqrt{\sum_{i=1}^{N} \frac{1}{(\Delta\sigma_i)^2}}} \quad (15)$$

Where σ_i is the cross section value and $\Delta\ \sigma_i$ is the corresponding error for each cross section value.

Results and Discussion

The experimental results in the International Atomic Energy Agency (IAEA); (EXFOR) library leaves little doubts that the hypothesis of Cross Section gives an excellent account of many diverse types of nuclear reactions. The features of iodine production nuclear reactions induced by particles protons, deuteron and alpha mainly on the $_{52}Te$ target element and on the $_{51}Sb$ target in selected reactions have been collected, recommended and plotted as shown in figures (1→3) for direct reactions and figure (4) for indirect reaction. These plots are analyzed using the Matlab-8 for selected energy range given by different authors.

In order to calculate the cross sections of these reactions for the mentioned target elements, we recommenders the cross sections for EXFOR library using the recom.m program, which is written in the present work using Matlab-8. It is important to note that the energy range of the reaction, taken from different authors, is not identical. For this reason, the determination of the energy range has been done in the present work by interpolating and recalculating the energy in steps of interval of 0.01 MeV, starting from the threshold energy, ending with energy given for the incident particle. In addition to the statistical treatments for cross section errors, distribution have been made in order to obtain the recommended cross sections for a given reaction, which is based on the statistical variation treatment as a weighted average calculation according to equation (14). The results for each reaction are discussed for direct and indirect reactions as follows:

1- Direct Reactions

a. $^{125}_{52}Te_{73}(p,n)^{125}_{53}I_{72}$ ***Reaction***

The measured data for the cross sections of $^{125}_{52}Te_{73}(p,n)^{125}_{53}I_{72}$ reaction reported by Hohn A. et al. (2001) [22], have been plotted, interpolated, and recalculated in fine steps of 0.01MeV from 5.5MeV up to 100.5MeV for incident proton by using recom.m program, as shown in figure (1).

b. $^{124}_{52}Te_{72}(d,n)^{125}_{53}I_{72}$ ***Reaction***

The measured data for the cross sections of ${}^{124}_{52}Te_{72}(d,n){}^{125}_{53}I_{72}$ reaction reported by Bastian Th. et al. (2001) [23], have been plotted, interpolated, and recalculated in fine steps of 0.01MeV from 5.8MeV up to 14.1MeV for incident deuteron by using recom.m program, as shown in figure (2).

c. ${}^{123}_{51}Sb_{72}(\alpha,2n){}^{125}_{53}I_{72}$ ***Reaction***

The measured data for the cross section of ${}^{123}_{51}Sb_{72}(\alpha,2n){}^{125}_{53}I_{72}$ reaction reported by Uddin M. S. et al. (2011) [10b], have been plotted, interpolated, and recalculated in fine steps of 0.01MeV from 14.8MeV up to 39.6MeV for incident alpha by using recom.m program, as shown in figure (3).

2- Indirect Reactions

Many nuclei are radioactive. This means they are unstable, and will eventually decay by emitting a particle, transforming the nucleus into another nucleus, or into a lower energy state. It decays takes place until a stable nucleus is reached. Radioactive decay data play a key role in the therapeutic application of a radionuclide and knowledge of the energy of the ionizing radiation is important. The effect of low-energy, electrons emitted following electron capture (EC) and positron emission (β^+) decay is not negligible. Therefore, in this section we discussion the second way to produce the importance medical isotopes via indirect interactions.

A medical radioisotope can be classified into two major groups: diagnostic and therapeutic radionuclide, depending on half-life and its decay mode. The decaying properties of the radioisotopes can be also classified into two groups; β^+-emitters, EC and gamma-emitters.

The results for this reaction is tabulated in table (4) and discussed as follows:

$${}^{127}_{53}I_{74}(p,3n){}^{125}_{54}Xe_{71} \xrightarrow{(\beta^+,EC)} {}^{125}_{53}I_{72} \xrightarrow{(EC)} {}^{125}_{52}Te^{*}_{73} \xrightarrow{\gamma-emission} {}^{125}_{52}Te_{73}$$ ***Reaction***

The measured data for the cross sections of ${}^{127}_{53}I_{74}(p,3n){}^{125}_{54}Xe_{71}$reaction reported by Paans A. M. J. et al. (1976) [24], Diksic M. and Yaffe L. (1977) [25], Syme D. B. et al. (1978) [26a], Syme D. B. et al. (1978) [26b], Lundqvist H. et al. (1979) [27], Sakamoto K. et al. (1985) [28], Lagunas Solar M. C. et al. (1986) [29], and Deptula C. et al. (1990) [30], have been plotted, interpolated, and recalculated in fine steps of 0.01MeV by using recom.m program, as shown in figure (4a).

Iodine-125 used for cancer prostate and lung cancer treatment [1, 31], so that can be produced by ${}^{127}_{53}I_{74}(p,3n){}^{125}_{54}Xe_{71}$ reaction. ${}^{125}_{54}Xe_{71}$ (1.6530MeV, $(1/2)^+$, $t_{1/2} = 16.9h$) decay to ${}^{125}_{53}I_{72}$(0.1858MeV, $(5/2)^+$, $t_{1/2} = 59.4d$)

undergoes electron capture (EC 99.7%), and positron emission (β^+ 0.3%) with decay energy 1.4672MeV as shown in figure (4b). Then $^{125}_{53}I_{72}$ decay to $^{125}_{52}Te^*_{73}$(0.0355MeV, $(3/2)^+$, $t_{1/2} = 0.16ns$), undergoes electron capture (EC 100%) with decay energy 0.1503MeV. $^{125}_{52}Te^*_{73}$ so reach to the ground state undergoes gamma emission with decay energy 0.0355MeV.

Empirical Formulae for recommended Cross Sections

Using the recommended cross sections as an input data, a Matlab-8 has been executed to obtain the fitting equation and the fitting parameter of the fit formula with lower chi squared value ($\chi^2_{\min}$). To obtain a more suitable expression the energy region data have been excluded till an acceptable value of ($\chi^2_{\min}$) has been reached. This indicates that such an expression is valid for a limited wide range of the proton–particle energy or deuteron-particle energy or alpha-particle energy, where the fitting formula selected for each reaction has been tried to fit these data and a more satisfactory formula has been obtained. This procedure has been followed for all the reactions as showing in figure (5) respectively. Within the scope of this work one type of formulism has been considered in this study: Polynomial fit expression "with different degrees (six, eight, nine and ten degrees) were found" of the general form:

$$Y = A_O + A_1 X + A_2 X^2 + A_3 X^3 + ... = \sum_{i=0}^{N} A_i X^i \qquad (16)$$

Where Y is the cross section, X is the incident proton, deuteron or alpha energy, $A_0, A_1, A_3 .....A_i$ are parameters which were fitted to the recommended data in an increasing order to obtain the best adequate expression. Our trails were directed to fit the evaluated cross sections taken from EXFOR library.

Stopping Power and Calculated Yield

The stopping power of target elements for proton, deuteron and alpha particles have been calculated in the present work using:

a- Adopt SRIM (2003) [32], as an experimental results.

b- Ziegler equations (4→12) and Ziegler coefficients mentioned in table (3) have been used, as a theoretical calculation results. For (p,n), (d,n) and (α,2n) reactions calculations, the (stopp.m, stopd.m and stopa.m) programs have been written in Matlab-8 for this purpose respectively.

Therefore, the calculated yield for $^{125}_{53}I_{72}$ and has been calculated in the present work using equation (13). The (yield.m) program has been written for this purpose in Matlab-8 either on the basis of the calculated recommended (p,xn), (d,xn) and (α,xn) reactions values when it available

or on the basis of the evaluated (p,xn), (d,xn) and (α,xn) cross section reactions.

The main aim of this study is to increase calculated yield from these reactions by increasing the energy of proton, deuteron or alpha beams which can interact with different targets. The stopping power and calculated yield of these reactions, have been obtained and the results are shown in figures (6,7,8).

In all figures, the calculated yield of most for these reactions seem to depend strongly on the structure of the individual nucleus, the incident proton, deuteron or alpha energy, the cross section, and stopping power of the target element.

Useful Energy and the Production Yield for incident particle on enriched target

Natural Tellurium target composition is the following [33]:

^{120}Te 0.09% ; ^{122}Te 2.46% ; ^{123}Te 0.87% ; ^{124}Te 4.61% ;

^{125}Te 6.99% ; ^{126}Te 18.71% ; ^{128}Te 31.79% ; ^{130}Te 34.49% ;

The excitation function for the production of iodine radioisotopes in natural Tellurium target for 10 to 35MeV of incident proton is measured by Arcerbit E. et al. (1974) [34]. Table (5) shows the cyclotron production of Iodine isotope I-125 and the reaction contribution for the production of the Iodine isotopes as a function of the energy range of incident particles on. The Antimony ($^{123}_{51}Sb_{72}$), and Tellurium ($^{124}_{52}Te_{72}$, $^{125}_{52}Te_{73}$), targets elements. After a certain degree target enrichment, the following sequences is to be performed.

Incident deuteron on enrichment Te-124 target to produce I-125

The production of $^{123}_{53}I_{70}(t_{1/2} = 13.2h)$, has been carried out by Firouzbakht M. L. et al. (1993) [35a], while the production of $^{124}_{53}I_{71}(t_{1/2} = 4.18d)$, has been carried out by Firouzbakht M. L. et al. (1993) [35b,c], and the production $^{125}_{53}I_{72}(t_{1/2} = 59.4d)$, has been carried out by Bastian Th. et al. (2001) [23]. The detailed recommended cross section of $^{124}_{52}Te_{72}(d,n)^{125}_{53}I_{72}$ reaction over the energy range 5.8−14MeV, the $^{124}_{52}Te_{72}(d,2n)^{124}_{53}I_{71}$ reaction over the energy range 7.5−23.6MeV, and $^{124}_{52}Te_{72}(d,3n)^{123}_{53}I_{70}$ reaction over the energy range 7.5−23.6MeV, have been calculated. The results of the recommended cross sections of I–123, I–124 and I–125 over the entire energy range of interest are plotted in figure (9).

The Tellurium–124 target was an isotopic enrichment of the following:

For the $^{124}_{52}Te_{72}(d,n)^{125}_{53}I_{72}$ reaction Bastian Th. et al. (2001) [23] performed the following isotopic compositions: ^{123}Te 0.2% and ^{124}Te 99.8%.

For the $^{124}_{52}Te_{72}(d,2n)^{124}_{53}I_{71}$ and $^{124}_{52}Te_{72}(d,3n)^{123}_{53}I_{70}$, Firouzbakht M. L. et al. (1993) [35b,c], gave no data for the enrichment.

Figure (9) shows the excitation functions of deuteron induced nuclear reactions on Te-124 and the calculated yields of I–123, I–124 and I–125. This useful energy range for the production of I–123 is carried out over the interval of useful energy is $(E_d = 18 \rightarrow 22.5MeV)$. The calculated yield should be $45.9MBq(1.2mCi)/\mu Ah$. The production of I–124 in this energy range is regarded to be an impurity of 26% with I–123. It can be seen from figure (9), that below 18MeV the contamination of I–124 is 100%. While the energy range $(E_d = 5.5 \rightarrow 7.5MeV)$, can be regarded as a useful energy for the production of I–125 without any impurities.

Biological Effects of the Radioactive Iodine-125

In one of branch medicine that uses radiation to provide information about the functioning of a person's specific organs or to treat disease it called nuclear medicine, in some cases radiation can be used to treat diseased organs, or tumors.

Radioactive Iodine treatment is based on the fact that the thyroid actively accumulates Iodine, which it uses to produce thyroid hormones required for normal body function. This (RAI) is like the Iodine found in foods such as fish, seaweed, and iodized salt, except that it releases an electron, or beta particle, which creates its therapeutic action [36].

For use in treatment, the (RAI) is given dissolved in water or as a capsule. It is absorbed quickly by the stomach and intestines, and then carried in the bloodstream to the thyroid, where it is taken up by the gland. While in the thyroid gland, the (RAI) disrupts the function of some of the thyroid cells the more radioactive Iodine give, the more cells cease to function. As the cells stop functioning, excessive amounts of thyroid hormones are no longer produced, and symptoms of hyperthyroidism begin to disappear [36].

In the present work used the radioiodine isotope Iodine-125 and will discussion the biological side effect of treatment in radioiodine after decay inside body of humane.

Iodine-125 is an intense Auger electron emitter, and can be attached to (DNA) compounds which have a chance to reach the cell nucleus and produce a therapeutic effect. Iodine-125 is used extensively in radioimmunoassay. And also used to detection of osteoporosis and in diagnostic imaging and in tracing the impact of pharmaceutical drugs in the body and in the imaging of tumors in the planning of the receptors in the

brain and in the treatment of prostate cancer, lung cancer and would like an alternative to I-131 in the treatment of brain cancer [1,31].

The decay of ${}^{125}_{53}I_{72}$ by electron capture (EC) to the corresponding excited Tellurium nuclides, emits a much lower energy internal conversion electron (0.0355MeV) which does relatively little damage due to its low energy, even though its emission is more common. The relatively low energy gamma from ${}^{125}_{53}I_{72}/{}^{125}_{52}Te_{73}$ decay is poorly suited for imaging, but can still be seen, and this longer lived isotope is necessary in tests which require several days of imaging, for example fibrinogen scan imaging to detect blood clots. ${}^{125}_{53}I_{72}$ emit copious low energy Auger electrons after their decay, but these do not cause serious damage double stranded (DNA) breaks in cells, unless the nuclide is incorporated into a medication that accumulates in the nucleus, or into (DNA) [3].

Conclusions

1. Although higher enrichment of the targets (${}_{51}Sb$, ${}_{52}Te$) have been used ,for the production of Iodine isotopes, to reduce the appearance of impurities, this impurity not disappear. So that, the area of the energy range for the cyclotron must be specify to obtain a higher production of radioactive Iodine required with less percentage of impurity.
2. The characteristic of the diagnosis and treatment radioisotopes is to ensure the access of radiation to the organ for diagnostic or treated without moving to the tissue.
3. The recommended excitation function has been calculated by evaluation the cross sections data. The results are in good agreement with a polynomial fitting of degree two to ten. This evaluation is used to calculate the integral yield of radioactive Iodine isotopes
4. Since Iodine-125 radioisotope have important application in nuclear medicine, the major uses in medical application have been used successfully for treatment and diagnostic.
   - Among three reactions for the production of Iodine-125 (${}^{125}_{52}Te_{73}(p,n)$, ${}^{124}_{52}Te_{72}(d,n)$, ${}^{123}_{51}Sb_{72}(\alpha,2n){}^{125}_{53}I_{72}$); the most useful reaction is:
     For incident deuteron: The ${}^{124}_{52}Te_{72}(d,n)$ reaction with no impurity, with yield $0.611MBq(0.02mCi)/\mu Ah$ and the useful energy range 5.5→7.5MeV. There are no experimental data to be compared with.

Table (1): International EXFOR library used for available measuring cross sections data collection for Iodine production reactions

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Direct Reactions				
Target Element	***Reaction***	***Product***	***Energy Range (MeV)***	***Author's Ref.no.***
$^{125}_{52}Te_{73}$	(p,n)	$^{125}_{53}I_{72}$	5.5−100.5 5.5−100.5(PW)	Hohn A. et al. (2001) [22]
$^{124}_{52}Te_{72}$	(d,n)		5.8−14.1 5.8−14.1(PW)	Bastian Th. et al. (2001) [23]
$^{123}_{51}Sb_{72}$	$(\alpha,2n)$		14.8−39.6 14.8−39.6(PW)	Uddin M. S. et al. (2011) [10b]
Indirect Reactions				
Target Element	***Reaction***	***Product***	***Energy Range (MeV)***	***Author's Ref.no.***
$^{127}_{53}I_{74}$	$(p,3n)$	$^{125}_{53}I_{72}$	45.35−65.48 20−85 20.8−158.5 21.3−159 39.056−98.96 20.21−50.69 18.1−66.9 45−100 18.1−159.0(PW)	Paans A. M. J. et al. (1976) [24] Diksic M. and Yaffe L. (1977) [25] Syme D. B. et al. (1978) [26a] Syme D. B. et al. (1978) [26b] Lundqvist H. et al. (1979) [27] Sakamoto K. et al. (1985) [28] Lagunas Solar M. C. et al. (1986) [29] Deptula C. et al. (1990) [30]

Table (2): Nuclear Properties (half-life, decay constant, threshold energy, Q-value, binding energy, natural abundance and enrichment) for the reaction to production Iodine.

Radio-isotope	Half-Life [13, 14]	Decay constant	Reaction Process used	Threshold Energy (MeV) [20]	Q–Value (MeV) [20]	Binding Energy (MeV) (pw)		Target Material		
						Total	Per nucleon	Isotope	Natural Abundance % [19]	Enrichment %
$^{125}_{53}I_{72}$	59.4(10)d	0.012 d^{-1}	$^{125}_{52}Te_{73}(p,n)$	0.975926(0.0605) 1.487301(pw)	-0.96811(0.06) -1.475403 (pw)	1030.76	8.246	$^{125}_{52}Te_{73}$	7.07	98.3[22]
			$^{124}_{52}Te_{72}(d,n)$	0.0(0.0) 0.0(pw)	3.376284(0.07) 2.874795 (pw)	1024.13	8.260	$^{124}_{52}Te_{72}$	4.74	99.8[23]
			$^{123}_{51}Sb_{72}(\alpha,2n)$	14.34 15.608386 (pw)	-14.11 -15.116233 (pw)	2879.42	23.797	$^{123}_{51}Sb_{72}$	42.7	98.28[10 b]

Table (3): Coefficients for stopping of proton, deuteron and alpha particles used in the Zeigler formula [15, 16].

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
$_{52}Te$	6.979	7.871	1.162E4	392.4	0.004402	0.02651	2065	-20.07	7.426	-0.9899	0.05707	-0.001209
$_{51}Sb$	3.97	0.6459	131.8	0.2233	2.723	4.582	0.1046	-0.1317	-0.009193	———	———	———

For proton and deuteron:
For energies 1-10 keV/amu use coefficient 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.

For alpha particle:
For energy 1keV-10MeV/amu use coefficients A-1 to A-5.
For energy 10-300MeV/amu use coefficients A-6 to A-9.

Table (4): Properties of indirect reactions for the production of radioiodine-125.

Radio nuclide	Half–Life [13, 14]	Reaction	Energy Range (MeV)	Decay Mode [37]	Decay Energy (MeV)	Diagnostic Application	Therapy Tissue range
$^{125}_{53}I_{72}$	59.4(10)d	$^{127}_{53}I_{74}(p,3n)^{125}_{54}Xe_{71}$	45.35−65.48[24] 20−85[25] 20.8−158.5[26a] 21.3−159[26b] 39.056−98.96[27] 20.21−50.69[28] 18.1−66.9[29] 45−100[30] 18.1−159.0(PW)	$^{125}_{54}Xe_{71} \xrightarrow{\beta^+(0.3\%),EC(99.7\%)} {}^{125}_{53}I_{72}$	1.4672	the detection of osteoporosis and imaging of tumors [31]	10µm Prostate and Lung Cancer [1, 31]
				$^{125}_{53}I_{72} \xrightarrow{EC(100\%)} {}^{125}_{52}Te^{*}_{73}$	0.1503		
				$^{125}_{52}Te^{*}_{73} \xrightarrow{\gamma-emission} {}^{125}_{52}Te_{73}$	0.0355		

Table (5): Useful Energy and the Production Yield for the Production of Radioiodine-125

Target Element	Reaction	Product	Enrichment %	Useful Energy (MeV)	Yield MBq(mCi)/µAh	Radioiodine impurity %	Author's Ref.no
$^{123}_{51}Sb_{72}$	$(\alpha,2n)$	$^{125}_{53}I_{72}$	———	20→30 20→30	——— 1.64(0.044)	(0.059)$^{126}_{53}I_{73}$ (2.411)$^{124}_{53}I_{71}$, (0.23)$^{126}_{53}I_{73}$	[10c] (PW)
$^{124}_{52}Te_{72}$	(d,n)			5.8→7.5	0.613 (0.017)	No Impurity	(PW)
$^{125}_{52}Te_{73}$	(p,n)		———	7→18 5.5→10	——— 2.63 (0.071)	——— No Impurity	[38] (PW)

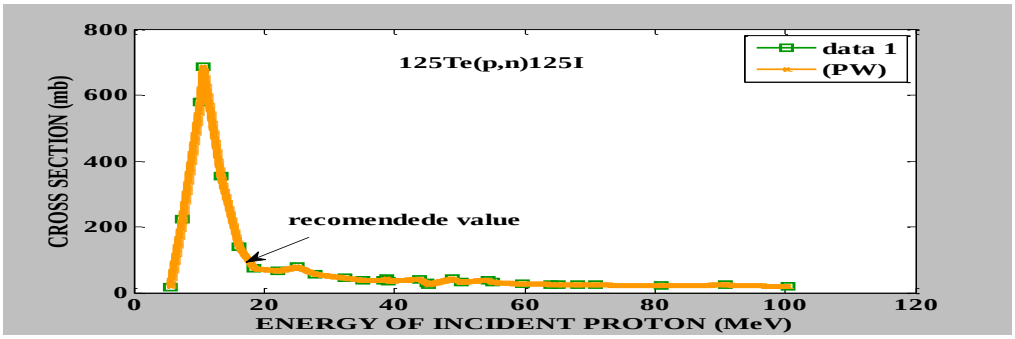

Figure (1): The recommended value cross sections of the ${}^{125}_{52}Te_{73}(p,n){}^{125}_{53}I_{72}$ reaction as calculated by the present work compared with EXFOR Library.
Data 1: [22] Hohn A. et al. (2001). Data 2: Present Work (PW).

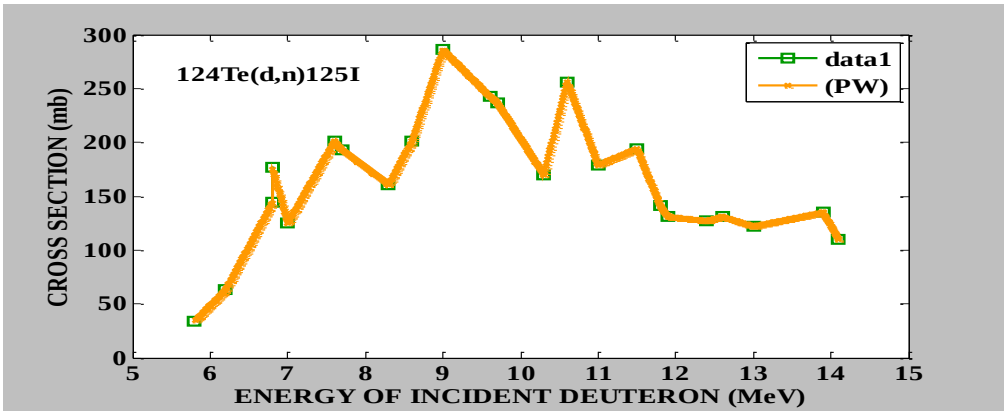

Figure (2): The recommended value cross sections of the ${}^{124}_{52}Te_{72}(d,n){}^{125}_{53}I_{72}$ reaction as calculated by the present work compared with EXFOR Library.
Data 1: [23] Bastian Th. et al. (2001). Data 2: Present Work (PW).

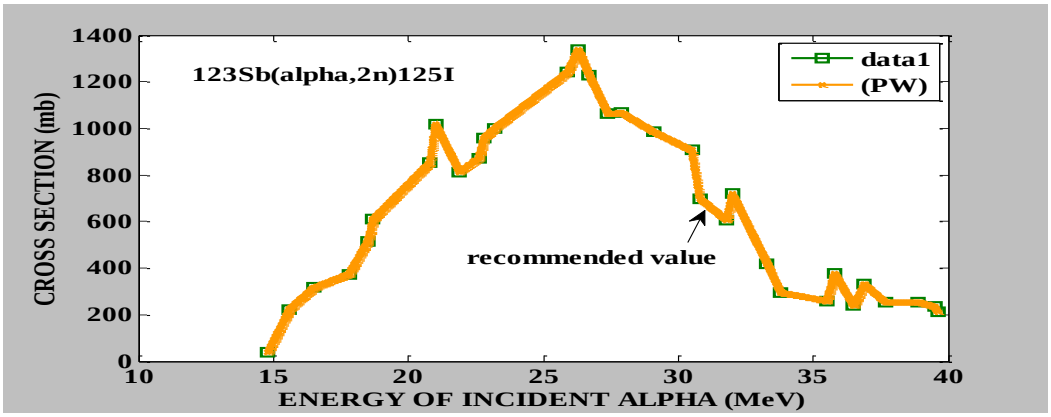

Figure (3): The recommended value cross sections of the ${}^{123}_{51}Sb_{72}(\alpha,2n){}^{125}_{53}I_{72}$ reaction as calculated by the present work compared with EXFOR Library.
Data 1: [10b] Uddin M. S. et al. (2011). Data 2: Present Work (PW).

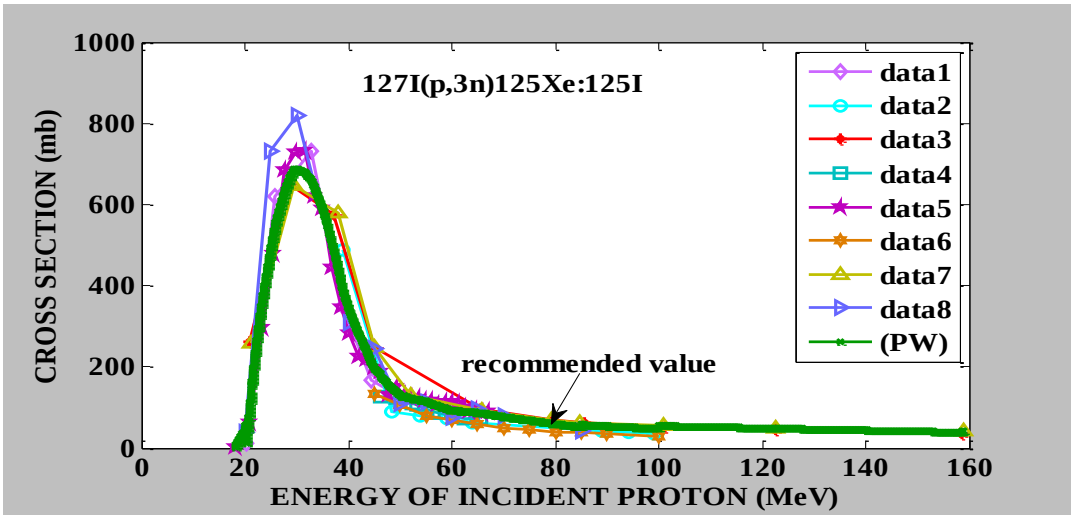

Figure (4a): The recommended cross sections of $^{127}_{53}I_{74}(p,3n)^{125}_{54}Xe_{71}$ reaction as calculated by the present work compared with EXFOR Library.

Data 1: [24] Paans A. M. J. et al. (1976).
Data 2: [25] DiksicM. and Yaffe L. (1977).
Data3: [26a] Syme D. B. et al. (1978).
Data 4: [26b] Syme D. B. et al. (1978).
Data 5: [27] Lundqvist H. et al. (1979).
Data 6: [28] Sakamoto K. et al. (1985).
Data 7: [29] Lagunas Solar M. C. et al. (1986).
Data 8: [30] Deptula C. et al. (1990).
Data 9: Present Work (PW).

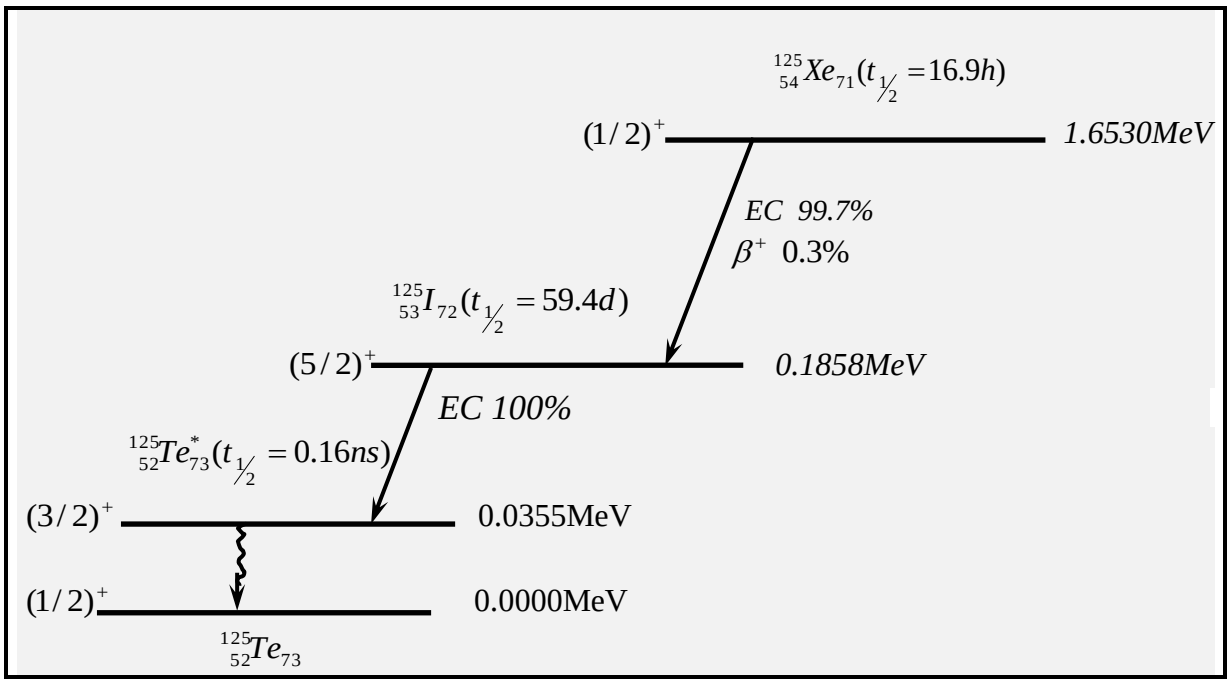

Figure (4b): Decay scheme of $^{125}_{54}Xe_{71}$ from $^{127}_{53}I_{74}(p,3n)^{125}_{54}Xe_{71}$ reaction for the production of $^{123}_{53}I_{70}$.

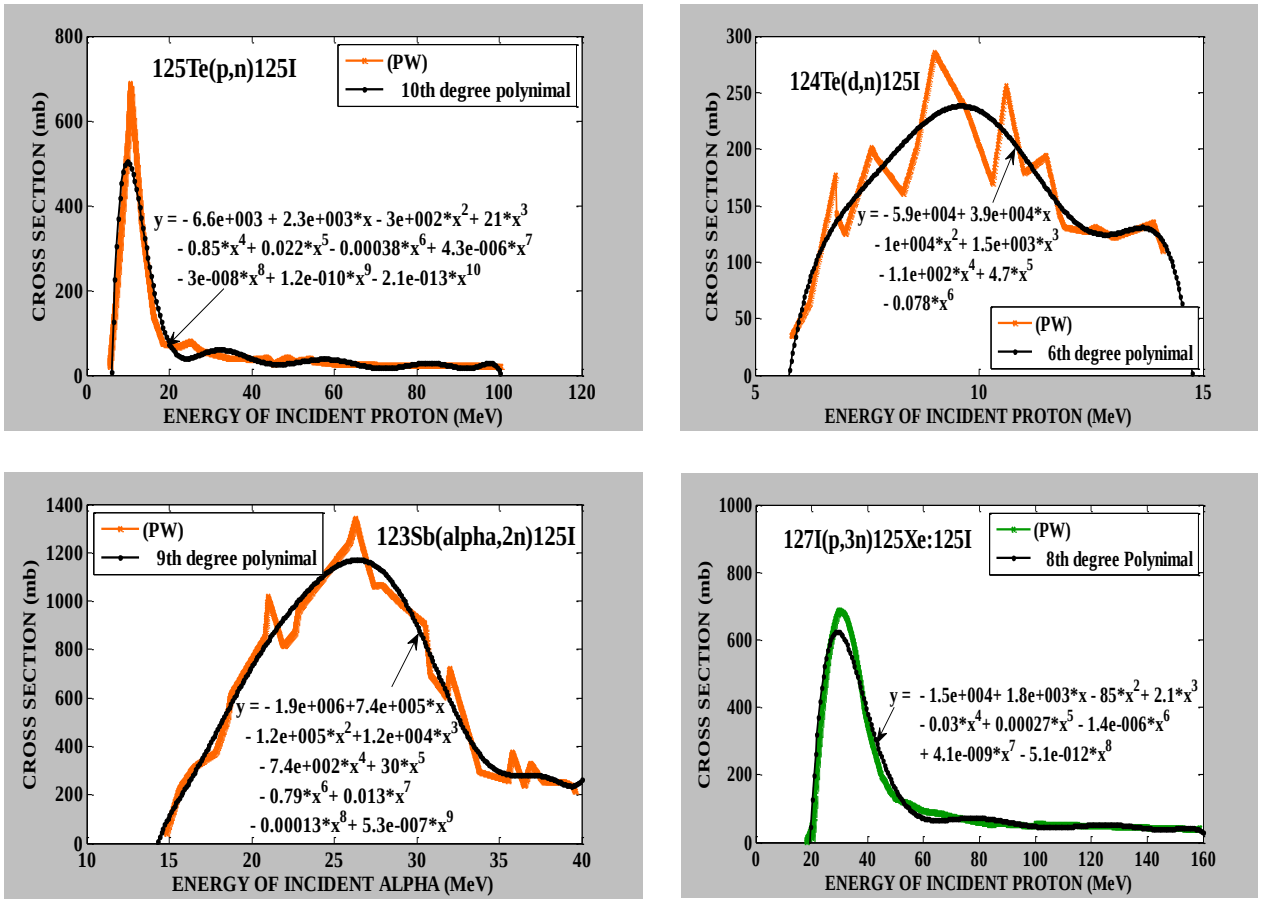

Figure (5): The fitting equations for recommended cross sections for Iodine production reactions under study in the present work.

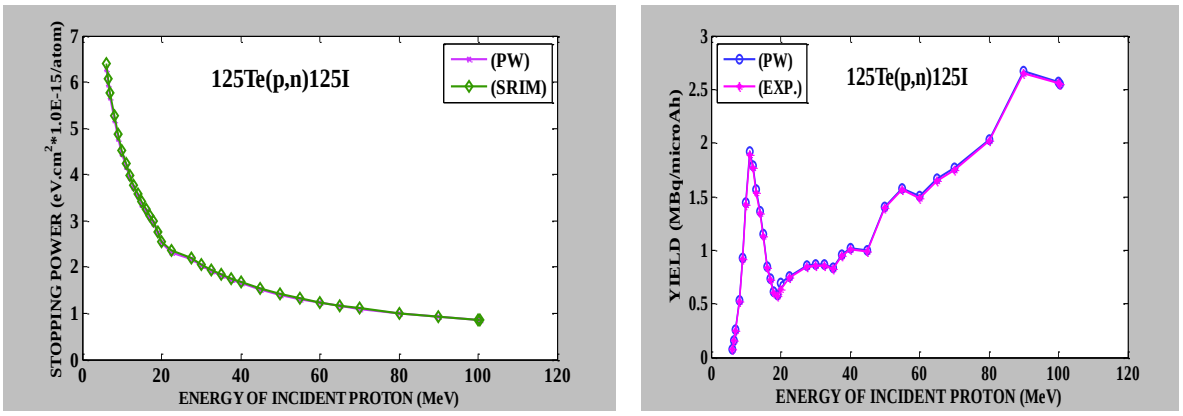

Figure (6): Left side: comparison between the calculated stopping power in the present work and SRIM (2003) of incident proton in ${}^{125}_{52}Te_{73}$.

Right side: calculated yield in the present work compared with the experimental results based on the recommended cross sections for proton induced reactions in ${}^{125}_{52}Te_{73}$.

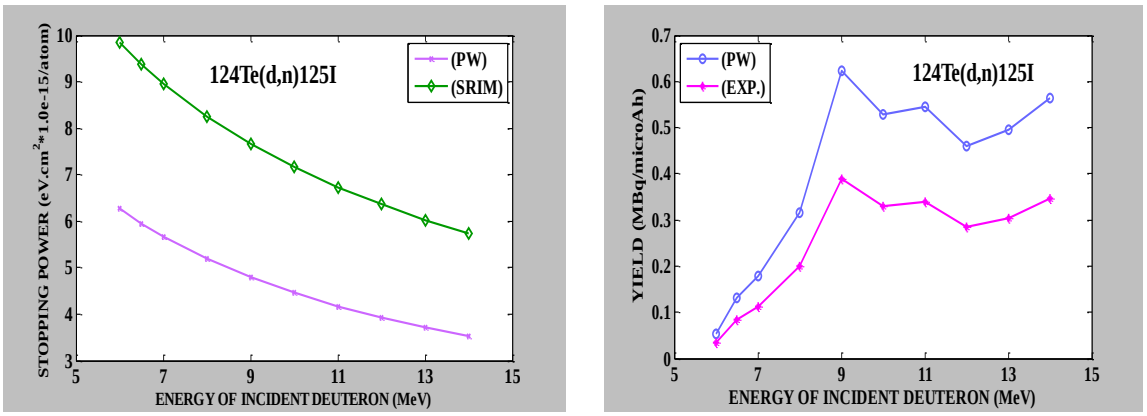

Figure (7): Left side: comparison between the calculated stopping power in the present work and SRIM (2003) of incident deuteron in $^{124}_{52}Te_{72}$.

Right side: calculated yield in the present work compared with the experimental results based on the recommended cross sections for deuteron induced reactions in $^{124}_{52}Te_{72}$.

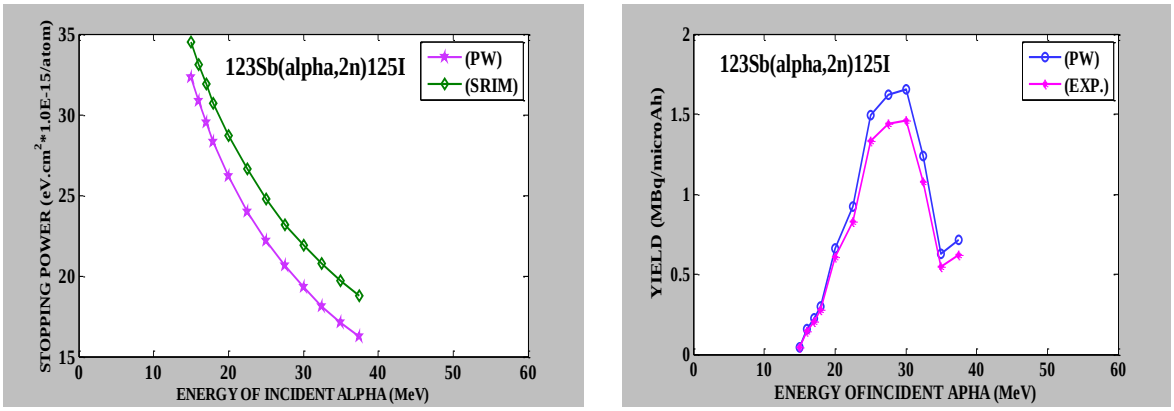

Figure (8): Left side: comparison between the calculated stopping power in the present work and SRIM (2003) of incident deuteron in $^{123}_{51}Sb_{72}$.

Right side: calculated yield in the present work compared with the experimental results based

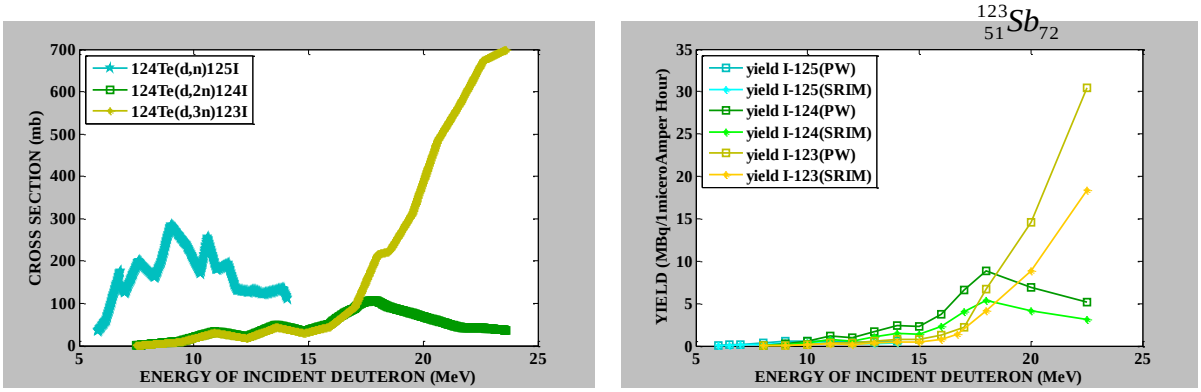

Figure (9): Left side: the recommended cross sections of the $^{124}_{52}Te_{72}(d,n)^{125}_{53}I_{72}$, $^{124}_{52}Te_{72}(d,2n)^{124}_{53}I_{71}$ and $^{124}_{52}Te_{72}(d,3n)^{123}_{53}I_{70}$ reactions versus the incident deuteron energy.

Right side: the calculated yield compared with the experimental results based on the recommended cross sections of incident deuteron in Te-124.

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