Calculation of Cross Section for Reactions Induced Proton with Molybdenum to product Technetium Isotopes.

حساب المقاطع العرضية لتفاعلات البروتون المستحث مع المولبيديوم لإنتاج نظائر التكنيتيوم

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Abstract

In this research was the study of Technetium products protons interactions of Molybdenum element with the importance of used medical and therapeutic. It has been calculated stopping power and evaluation yields for induced protons to produce Technetium from Molybdenum isotopes ($^{92}_{42}Mo$, $^{94}_{42}Mo$, $^{95}_{42}Mo$, $^{96}_{42}Mo$, $^{97}_{42}Mo$, $^{98}_{42}Mo$ and $^{100}_{42}Mo$) in the energy range from threshold energy up to 65 MeV proton energy have been calculated, except for $^{96}_{42}Mo(p,n)^{96}_{43}Tc$ reaction where the proton energy have 80 MeV. Complete energy range starting from threshold energy for each reaction have been analyzed statistically and the Recommended cross sections were reproduced in fine steps of incident proton energy in 0.01 MeV intervals with their corresponding errors. The stopping power according to Zeigler formula was used in order to obtain the cross sections and calculated yield for each reaction based on the complete spectrum of cross sections.

Keywords: Cross sections; Stopping power; Technetium yields, induced proton, Molybdenum target element.

الملخص

في هذا البحث تم دراسة نواتج التكنيتيوم من تفاعلات البرترونات مع عنصر المولبيدينوم لأهمية استخداماتهما الطبية و العلاجية. ولقد تم حساب قدرة الايقاف وتقييم نواتج البرترونات المستحثة لإنتاج التكنيتيوم من نظائر المولبيدينوم المتوسطة ($^{92}_{42}Mo$ $^{94}_{42}Mo$, $^{95}_{42}Mo$, $^{97}_{42}Mo$, $^{98}_{42}Mo$, $^{100}_{42}Mo$) بمدى طاقي من طاقة العتبة الى 65MeV لطاقات البروتون, ماعدا تفاعل $^{96}_{42}Mo(p,n)^{96}_{43}Tc$ حيث تصل طاقة البروتون الى 80MeV حيث تم تحليل كامل لمدى الطاقة ابتداءا من طاقة العتبة لكل تفاعل للحصول على المقاطع العرضية المختارة وقد تم معالجتها احصائيا لحساب المقاطع العرضية لفترات صغيرة من طاقة البروتون الساقطة مقدارها 0.01MeV مع الاخطاء المصاحبة لكل قراءة. لقد تم استخدام صيغة زكلر لحساب قدرة الايقاف الناتجة وبذلك تمكنا من تقيم النواتج المحسوبة لكل تفاعل بعد الحصول على طيف متكامل للمقاطع العرضية.

1. Introduction

Nowadays, many different stable and radioactive isotopes, each with unique physical and chemical properties, play significant roles in technological applications of importance to our modern society and are substantial to scientific research. One of the most common applications is the use of the radioisotopes in medicine. Medical radioisotopes are used to label some special chemical compounds to form radiopharmaceuticals[1].

Medical radioisotopes have been used for decades for both diagnostic and therapeutic purposes. For diagnostic use, a radioactive isotope is attached to a bio-active molecule that allows the radiologist to map out disease or body function using radiation detectors located outside of the patient's body. This powerful invasive technique enables physicians to look for numerous types of disease in a non-invasive manner. [2].

The cross sections evaluation for calculated yields for induced proton on Molybdenum to produce Technetium, Molybdenum target elements are calculated according to the available

International Atomic Energy Agency (IAEA) libraries and other experimental published data. The stopping power depends on the type and energy of the incident particle and on the properties of the materials it passes. In passing through matter, fast charged particles ionize the atoms or molecules which they encounter. The yield for a target having any thickness can be defined as the ratio of the number of nuclei formed in the nuclear reaction to the number of particles incident on the target. Thick target yield is defined for a fixed macroscopic energy loss, E_{in}-E_{out}, in a thick target. Integral yield is defined for a finite energy loss down to the threshold of the reaction, E_{in}-E_{th}. The recommended cross sections discussed in the present work and the target stopping powers of Ziegler [3,4] and SRIM program (2003) were used to Evaluation the calculated yields for a target of significant thickness. The cross sections of calculated yields for induced proton on Molybdenum to produce Technetium published by different authors [17-36] in the energy range (1.48 – 80.00) MeV. Recommended values have been calculated, the cross sections were reproduced in fine steps of incident proton energy in 0.01 MeV intervals with the corresponding errors. In this study the stopping power have been calculated using SRIM program and Ziegler formulae [3,4] corpuscle to three regions based on the velocity of the incident proton (V). The calculated recommended cross sections for these reactions have been evaluated and a systematic behavior of calculated yields with proton energy and target numbers (Z) have been observed throughout the studied isotopes. This study concerns with the nuclear reactions used in the production of Technetium from induced protons on Molybdenum target element which are important in medical applications. Beside the general interest of basic nuclear physics, intermediate energy activation cross-section data are of increasing importance for a wide variety of applications. The remarkable applications are in the field of space and environmental sciences, medical sciences (radioisotope production, dosimetry application, radiation therapy etc.), We have used Molybdenum as target material for the production of medically important radioisotopes; such as production of ${}^{93}_{43}Tc$, ${}^{94}_{43}Tc$, ${}^{95}_{43}Tc$ and ${}^{99m}_{43}Tc$. These isotopes can be produced commercially by nuclear reactors. But the facility is not available around the world and also expensive[5].

2. Theoretical part

(2-1) Stopping Power

Incident protons with certain energy will lose all their energies in a definite distance in a medium before it stopped completely. This technique was first used by Ziegler to extract the summed correction terms in order to normalize stopping calculations for reactions, to extrapolate energies types[4]. 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, for that reason one can be compilation the energy loss of the charge corpuscle to three regions (high, intermediate and low energy). The behavior of ions in each region can be explained as the following [6]:

(2-1-1) The high energy region

This region can occurs when the velocity of the incident corpuscle (ϑ) is ($\vartheta \geq 2\vartheta_0 Z_1$) where ($Z_1$) is the atomic number of ion and (ϑ_0) represents the Bohr velocity (ϑ_0= 2.18×10^6 m/s) and this is about the velocity of the conduction electrons in solid. Ions with velocity below (ϑ_0) have adiabatic collisions with target electrons and hence small stopping power. The stopping power increases with decreasing ion-velocity [7].

The electronic stopping power (S_e) is to prevail with Bethe (1933) equation applies in this region [8]:

$$-\frac{dE}{dx} = NS_e = \frac{4\pi K^2 e^4 Z_1^2}{m\vartheta^2} NZ_2\left[\ln\left(\frac{2m\vartheta^2}{I}\right) - \ln\left(1-\beta^2\right) - \beta^2\right] \quad \dots (1)$$

Where N: is the atomic density of the medium [$N=N_a$ (ρ/A)].

N_a: is the Avogadro's number ($N_a=6.022\times10^{23}mole^{-1}$).

ρ: is the density of matter.

A: is the mass number.

e,m: are the charge and mass of the electron respectively.

Z_1, Z_2: are the atomic numbers of ion and target respectively.

β: is the ratio between incident corpuscle velocity and the velocity of light $\beta = \dfrac{\vartheta}{c}$.

I: is the mean ionization and excitation potential.

K: is the coulomb constant $K = \dfrac{1}{4\pi\varepsilon_0} = 8.99\times10^{9}\,Nm^{2}C^{-2}$.

(2-1-2) The Intermediate Energy Region

The intermediate energy region occurs when the velocity (ϑ) of the incident corpuscle is in the range ($2\vartheta_0 Z_1 > \vartheta \geq \vartheta_0 Z_1^{2/3}$); it includes the maximum stopping power. In this region the effect of effective charge is clear and that is because of loss its energy which is mean decrease of corpuscle velocity and charge Z_1 decreased too, and that because of loss or acquire electrons and there will be elastic collision with the nuclei of atoms occur. Thus equation (1) was modified, and its express electronic stopping power as Bethe-Bloch (1933) [8].

$$-\frac{dE}{dx} = NS_e = \frac{4\pi K^2 e^4 Z_1^2}{m\vartheta^2} NZ_2 L \qquad \ldots (2)$$

Where L is the stopping atomic number and depends on the velocity of incident corpuscle and the medium of the target.

$$L = L_0 + Z_1 L_1 + Z_1^2 L_2 \qquad \ldots(3)$$

Where $L_0 = \ln(2wv^{1/2} / I) - C/Z_2$ …(4)

C/Z_2 is the shell correction.

$Z_1 L_1$ is the Barkas effect correction from the polarization.

$Z_1^2 L_2$ is Bloch-correction to transform from quantum to classical form.

(2-1-3) The Low energy region

It occurs when the incident corpuscle velocity (ϑ) ($\vartheta < \vartheta_0 Z_1^{2/3}$) in this region, to calculate the cross section for electronic stopping on the Thomas-Fermi potential as a function of velocity. The equation for this region is given by [9,10]:

$$S_e = 8\pi e^2 a_0 \frac{Z_1^{7/6} Z_2}{Z^{2/3}} \left(\frac{\vartheta}{\vartheta_0}\right) \qquad \ldots(5)$$

Where $Z^{2/3} = Z_1^{2/3} + Z_2^{2/3}$ … (6)

and a_0 represents the Bohr radius, $a_0 = \dfrac{h^2}{me^2} = 5.29\times10^{-11}\,\mathring{A}$ …(7)

In the scope of this work, the electronic stopping powers were programmed and using the empirical formulae given by Ziegler as flows [4]:

1- Energy range $(1\text{-}10)\times10^{-3}$ KeV

$$-\frac{dE}{dx} = A_1 E^{1/2} \qquad \ldots (8)$$

2- Energy range $(10\text{-}999)\times10^{-3}$ KeV

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

$$\left(-\frac{dE}{dx}\right)_{Low} = A_2 E^{0.45} \qquad \ldots (10)$$

$$\left(-\frac{dE}{dx}\right)_{High} = \left(\frac{A_3}{E}\right)\ln\left[1+\left(\frac{A_4}{E}\right)+A_5E\right] \quad \ldots (11)$$

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

$$\left(-\frac{dE}{dx}\right) = \left(\frac{A_6}{\beta^2}\right)\left[\ln\left(\frac{A_7\beta^2}{1-\beta^2}\right)-\beta^2-\sum_{i=0}^{4}A_{i+8}(\ln E)^i\right] \quad \ldots (12)$$

Where E : is the proton energy in (MeV).

A_i: are the coefficients given by Ziegler [4,11].

β: is the ratio between incident corpuscle velocity and the

(2-2) Data Reduction and Analysis

Method Used to Obtain the Recommended Cross Sections is as the following:

a. The sets of experimental cross sections data were 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 0.01 MeV for available different energy range for each author.

b. The normalization for the statistical distribution of cross sections errors to the corresponding cross section values for each author has been done.

c. The interpolation for the nearest data for each energy interval as a function of cross sections and their corresponding errors have been done using Matlab-7.0.

d. The interpolated values were calculated to obtain the adopted cross section which is based on the weighted average calculation according to the following expressions [12]:

$$\sigma_{w.a.} = \frac{\sum_{i=1}^{n}\frac{\sigma_i}{(\Delta\sigma_i)^2}}{\sum_{i=1}^{n}\frac{1}{(\Delta\sigma_i)^2}} \quad \ldots (13)$$

Where the standard deviation error is:[12]

$$S.D. = \frac{1}{\sqrt{\sum_{i=1}^{N}\frac{1}{(\Delta\sigma_i)^2}}} \quad \ldots (14)$$

Where σ_i: is the cross section value.

$\Delta\sigma_i$: is the corresponding error for each cross section value.

(2-3) Yield Calculations

The Yield of calculated detected per incident particle, Y, for an ideal, thin, and uniform target and monoenergetic particles beam of incident energy E_b is given by [13].

$$Y = (nt)\sigma(E_b)\varepsilon(E_b) \quad \ldots (15)$$

Where n: is the number of target atoms per unit volume.

t: is the target thickness.

σ: is the reaction cross section.

ε: is the proton-detection efficiency.

For target which is not infinitesimally thin, the beam loses energy as it passes through the target, and the Yield is then given by [14,15].

$$Y = \int_{E_{thr}}^{E_b}\frac{n\sigma(E)\varepsilon(E)fdE}{-\frac{dE}{dx}(E)} \quad \ldots (16)$$

In which ($E_{thr} = E_b - \Delta E$)

Where E_{thr} : is the reaction threshold energy.

ΔE : is the energy loss of the beam in the target.

f : is the number of target atoms in each target molecule.

$-\frac{dE}{dx}(E)$: is the stopping power of the medium as a function of the beam energy.

If the target is sufficiently thick, and there exist one atom per each molecule (i.e., $f = 1$) and taking the efficiency $\varepsilon(E) = 1$, then the resulting calculated yield is called the thick-target yield which is given by [16]:

$$Y(E_b) = \int_{E_{thr}}^{E_b} \frac{n\sigma(E)dE}{-(dE/dx)} \qquad \ldots (17)$$

Since stopping power $= \frac{1}{n}\left(-\frac{dE}{dx}\right)$.

3. Results and Discussion

Table (1) present the international atomic energy Agency (IAEA) libraries (EXFOR) used in the present work for available measuring data collected to calculate yields of induced proton on Molybdenum to produce Technetium. The available data in the literature, taken from EXFOR library, concerning the measurement of the calculated yields of induced proton on Molybdenum to produce Technetium cross sections for the target Molybdenum mentioned in table-1were evaluated in the present work in order to calculate the Recommended cross sections using adopt.m program, which is written in the present work using Matlab-7.0. The Recommended evaluated cross sections are calculated (using adopt.m program) and plotted as a function of incident proton energy starting from threshold energy for each reaction. The results for each calculated yields for induced proton on Molybdenum to produce Technetium are discussed as follows:

1- $^{92}_{42}Mo(p,\gamma)^{93}_{43}Tc$ Reaction

The cross sections data published by Arifov L.Ja.et al.(1980) [17] for this reaction have been plotted, interpolated, and recalculated in steps of 0.01 MeV from threshold energy 1.48 up to 5.08 MeV of the incident proton energy in order to obtain the adopted cross sections of this reaction. The results of Recommended cross sections and the experimental results for the authors mentioned above are shown in figures (1).

Table(1):International libraries used for available measuring data collection for induced proton on Molybdenum isotopes.

Target Element	Reaction		Target Element	Reaction	
	Library	Product		Library	Product
$^{92}_{42}Mo$	EXFOR*	$(p,\gamma)^{93}_{43}Tc$	$^{97}_{42}Mo$	EXFOR*	$(p,2n)^{96}_{43}Tc$
$^{94}_{42}Mo$	EXFOR	$(p,2n)^{93}_{43}Tc$	$^{98}_{42}Mo$	EXFOR*	$(p,n)^{98}_{43}Tc$
	EXFOR	$(p,n)^{94}_{43}Tc$		EXFOR	$(p,\gamma)^{99m}_{43}Tc$
	EXFOR	$(p,\gamma)^{95}_{43}Tc$	$^{100}_{42}Mo$	EXFOR	$(p,2n)^{99m}_{43}Tc$
$^{95}_{42}Mo$	EXFOR	$(p,n)^{95}_{43}Tc$		EXFOR*	$(p,n)^{100}_{43}Tc$
$^{96}_{42}Mo$	EXFOR	$(p,2n)^{95}_{43}Tc$		EXFOR*	$(p,\gamma)^{101}_{43}Tc$
	EXFOR	$(p,n)^{96}_{43}Tc$	……	…….	…….

*** only one author gives data.**

2- $^{94}_{42}Mo(p,2n)^{93}_{43}Tc$ Reaction

The cross sections data published by Levkovskij V.N. (1991) [18], and Rosch F.,at al. (1993) [19],or this reaction have been plotted, interpolated, and recalculated in steps of 0.01 MeV from threshold energy 13.80 up to 29.50 MeV of the incident proton energy in order to obtain the Recommended cross sections of this reaction. The results of adopted cross sections and the experimental results for the authors mentioned above are shown in figures (2).

3- $^{94}_{42}Mo(p,n)^{94}_{43}Tc$ Reaction

The cross sections data published by Flynn D.S. et al. (1979) [20], Skakun E.A.et al.(1987)[21], Levkovskij V.N. (1991) [18],and Skakun E.A.et al.(1992)[22] for this reaction have been plotted, interpolated, and recalculated in steps of 0.01 MeV from threshold energy 5.10 up to 18.30 MeV of the incident proton energy in order to obtain the adopted cross sections of this reaction. The results of Recommended cross sections and the experimental results for the authors mentioned above are shown in figures (3).

4- $^{94}_{42}Mo(p,\gamma)^{95}_{43}Tc$ Reaction

The cross sections data published by Sautere T. et al.(1997) [23],and Sautere T. et al.(1997) [23] for this reaction have been plotted, interpolated, and recalculated in steps of 0.01 MeV from threshold energy 1.48 up to 2.52 MeV of the incident proton energy in order to obtain the Recommended cross sections of this reaction. The results of adopted cross sections and the experimental results for the authors mentioned above are shown in figures (4).

5- $^{95}_{42}Mo(p,n)^{95}_{43}Tc$ Reaction

The cross sections data published by Flynn D.S. et al. (1979) [20], Trufanov A.M. et al.(1982) [24], Skakun E.A.et al.(1987)[21],Izumo M. et al.(1991)[25], Skakum E.A.et al.(1992) [22],Zhuravlev Yu.Yu.et al.(1994)[26],and Bitao H.et al.(1998)[27] for this reaction have been plotted, interpolated, and recalculated in steps of 0.01 MeV from threshold energy 2.50 up to 28.19 MeV of the incident proton energy in order to

obtain the Recommended cross sections of this reaction. The results of adopted cross sections and the experimental results for the authors mentioned above are shown in figures (5).

6- $^{96}_{42}Mo(p,2n)^{95}_{43}Tc$ Reaction

The cross sections data published by Hogan J.J.(1972) [28],and Levkovskij V.N.(1991) [18], for this reaction have been plotted, interpolated, and recalculated in steps of 0.01 MeV from threshold energy 12.10 up to 65.00 MeV of the incident proton energy in order to obtain the Recommended cross sections of this reaction. The results of adopted cross sections and the experimental results for the authors mentioned above are shown in figures (6).

7- $^{96}_{42}Mo(p,n)^{96}_{43}Tc$ Reaction

The cross sections data published by Hogan J.J.(1972) [28],Flynn D.S.et al.(1979)[20],Skakun E.A.et al.(1987)[21],Levkovskij V.N.(1991) [18],and Zhuravlev Yu.Yu.et al.(1994)[26] for this reaction have been plotted, interpolated, and recalculated in steps of 0.01 MeV from threshold energy 3.82 up to 80.00 MeV of the incident proton energy in order to obtain the adopted cross sections of this reaction. The results of Recommended cross sections and the experimental results for the authors mentioned above are shown in figures (7).

8- $^{97}_{42}Mo(p,2n)^{96}_{43}Tc$ Reaction

The cross sections data published by Levkovskij V.N.(1991) [18],for this reaction have been plotted, interpolated, and recalculated in steps of 0.01 MeV from threshold energy 12.10 up to 29.50 MeV of the incident proton energy in order to obtain the Recommended cross sections of this reaction. The results of adopted cross sections and the experimental results for the authors mentioned above are shown in figures (8).

9- $^{98}_{42}Mo(p,n)^{98}_{43}Tc$ Reaction

The cross sections data published by Trufanov A.M.et al.(1982) [24],for this reaction have been plotted, interpolated, and recalculated in steps of 0.01 MeV from threshold energy 6.00 up to 9.00 MeV of the incident proton energy in order to obtain the Recommended cross sections of this reaction. The results of adopted cross sections and the experimental results for the authors mentioned above are shown in figures (9).

10- $^{98}_{42}Mo(p,\gamma)^{99m}_{43}Tc$ Reaction

The cross sections data published by Sauter T.et al.(1997) [23],and Gyurky Gy.et al.(2014)[29],for this reaction have been plotted, interpolated, and recalculated in steps of 0.01 MeV from threshold energy 1.48 up to 3.07 MeV of the incident proton energy in order to obtain the Recommended cross sections of this reaction. The results of adopted cross sections and the experimental results for the authors mentioned above are shown in figures (10).

11- $^{100}_{42}Mo(p,2n)^{99m}_{43}Tc$ Reaction

The cross sections data published by Levkovskij V.N.(1991) [18],Lagunas-Solar M.C.et al.(1996)[30],Scholten B.et al.(1999)[31],Takacs S.et al.(2003)[32],Gagnon K.(2011)[33],Manenti S.et al.(2014)[34],and Takacs S.et al.(2015)[35]for this reaction have been plotted, interpolated, and recalculated in steps of 0.01 MeV from threshold energy 5.70 up to 64.80 MeV of the incident proton energy in order to obtain the adopted cross sections of this reaction. The results of Recommended cross sections and the experimental results for the authors mentioned above are shown in figures (11).

12- $^{100}_{42}Mo(p,n)^{100}_{43}Tc$ Reaction

The cross sections data published by Skakun E.A.et al.(1987) [21], for this reaction have been plotted, interpolated, and recalculated in steps of 0.01 MeV from threshold energy 4.00 up to 9.00 MeV of the incident proton energy in order to obtain the Recommended cross sections of this reaction. The results of adopted cross sections and the experimental results for the authors mentioned above are shown in figures (12).

13- $^{100}_{42}Mo(p,\gamma)^{101}_{43}Tc$ Reaction

The cross sections data published by Daly P.J.et al.(1968) [36], for this reaction have been plotted, interpolated, and recalculated in steps of 0.01 MeV from threshold energy 8.09 up to 19.90 MeV of the incident proton energy in order to obtain the adopted cross sections of this reaction. The results of Recommended cross sections and the experimental results for the authors mentioned above are shown in figures (13).

When the widths of unstable states are small compared with their separation, the states are distinct and observable. And if the states are overlap and strongly mixed, these states do not have distinctly observable wave functions. Because of the instability of the compound nucleus, results in an uncertainty in the energy of these states. The energy uncertainty is given by the width of the resonance and lifetime of the state. Therefore, the resonance will have the character of the energy distribution of any decaying state of width, lifetime, and a maximum total cross section.

In analyzing for induced proton on Molybdenum to produce Technetium in sections we note that the discrete nuclear states that are populated in ordinary decays have discrete separations, widths, and lifetimes. Thus if we were to calculate the cross sections at a given incident proton energy of a nuclear state, it is very unlikely that the overlap of the energy distributions of two different states could cause confusion as to the stationary state resulting from the decay.

The stopping power of medium target elements for proton-particles has been calculated in the present work by using method Ziegler empirical formulae and Ziegler coefficients mentioned in table (2), as a theoretical calculation results.

Table (2): Coefficients for stopping of proton used in the Zeigler formula [4,14].

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
H	**1.262**	**1.44**	**242.6**	**1.20E+04**	**0.1159**	**0.0005099**	**54360**	**-5.052**	**2.049**	**-0.3044**	**0.01966**	**-0.0004659**
Mo	**6.425**	**7.248**	**9545**	**480.2**	**0.005367**	**0.02141**	**2517**	**-17.85**	**6.725**	**-0.9116**	**0.05339**	**-0.001148**
Tc	**7.056**	**8.187**	**9865**	**388.6**	**0.005283**	**0.02191**	**2474**	**-18.23**	**6.848**	**-0.9297**	**0.05446**	**-0.001370**

For energy 1-10 KeV/amu use coefficients A-1.
For energy 10-999KeV/amu use coefficients A-2 to A-5.
For energies above 1000 KeV/amu use coefficients A-6 to A-12.

For these calculations, the (stop. m) program has been written in Matlab-7.0 for this purpose.

The calculated yields for induced proton on Molybdenum to produce For these calculations, the (stop. m) program has been written in Matlab-7.0 for this purpose.

The calculated yields for induced proton on Molybdenum to produce Technetium are very important quantity as well as the cross sections in analyzing problems of diagnosis, physical therapy, and medicine treatments as the following :

Technetium-93,94,95,99m finds significant application in medical field. The production possibility in different energy region via different nuclear reactions are clarified in the following discussion :

- ❖ Isotope, ${}^{93}_{43}Tc$ (2.75h), it is used in Auger electron therapy, also used in Tumor imaging application[37].
- ❖ Isotope, ${}^{94}_{43}Tc$ (4.88h) is ideal for purposes of diagnosing diseases in humans[37].
- ❖ Isotope, ${}^{95}_{43}Tc$ (20.0h), due to its comparatively longer half-life is also promising for tracking long processes, like, metabolic pathways for brain and heart, studies with proteins, anti bodies, etc[38].
- ❖ Isotope, ${}^{99m}_{43}Tc$ (6.02),is one of the most important medical radioisotopes is widely used in nuclear medicine is follows [2,39]:

1- In a treatment for hyperthyroidism, certain types of cancer such as thyroid and lymphoma, blood imbalances and pain relief for certain types of bone cancer.
2- Used in eradicate and damage all tumor cells.
3- To obtain imaging in Anger cameras (scintillation cameras),
4- Technetium-99m is used to image the skeleton and heart muscle in particular, but also for brain, lungs, liver, spleen, kidney, gall bladder, bone marrow, salivary and lachrymal glands, heart blood pool, infection and numerous specialized medical studies.
5- It is can also be used to calibrate particle detectors.

Therefore, the calculated yield for Molybdenum target (${}^{92}_{42}Mo$, ${}^{94}_{42}Mo$, ${}^{95}_{42}Mo$, ${}^{96}_{42}Mo$, ${}^{97}_{42}Mo$, ${}^{98}_{42}Mo$ and ${}^{100}_{42}Mo$) were calculated in the present work using equation (15).

The main aim of this study is to increase a calculated yields for induced proton on Molybdenum to produce Technetium by increasing the energy of proton beams which can interact with different targets. The stopping power and calculated yields of the for induced proton on Molybdenum to produce Technetium for Molybdenum target isotopes maintained above have been obtained. The results have been shown in figure (14) respectively for each target element.

In all figures, the calculated yields of most of the for induced proton on Molybdenum to produce Technetium seem to depend strongly on the structure of the individual nucleus, the incident proton energy, and stopping power of the target element.

Generally, the behavior of the stopping power decreases with increasing the yields which agrees with Ref. [11,12]. It is clear from the calculated results shown in these figures that for the calculated yield values for 20-100% abundance target element ${}^{92}_{42}Mo$, ${}^{94}_{42}Mo$, ${}^{96}_{42}Mo$, ${}^{98}_{42}Mo$ and ${}^{100}_{42}Mo$ follow the trend in the asymmetry parameter of proton excess (N-Z)/A so that by increasing this parameter the maximum calculated yields will be decrease as shown in table (3). This increment may be attributed to the fact that by decrease the number of neutrons the outer shells are populated by an excess calculated which increases the occurrence probability for induced proton on Molybdenum to produce Technetium.

Table (3): The maximum calculated yield and the asymmetry parameter for the 20-100% abundance elements.

Reactions	Maximum neutron yield (atom*1.0E-9)	Energy of Proton(MeV)	(N-Z)/A
${}^{96}_{42}Mo(p,2n){}^{95}_{43}Tc$	11479.00	25	0.125
${}^{98}_{42}Mo(p,n){}^{98}_{43}Tc$	1397.80	9	0.142
${}^{100}_{42}Mo(p,n){}^{100}_{43}Tc$	1091.20	9	0.160

For even-even elements with Z=N the asymmetry parameters are zero; i.e. the elements are symmetric (Z=A/2, N=A/2). The binding energy, the Q-values, and the calculated yields differ by much larger amounts among the medium elements than within any group.

Hence, for even-Z and even-A target elements ${}^{96}_{42}Mo$, ${}^{98}_{42}Mo$ and ${}^{100}_{42}Mo$ for induced proton on Molybdenum to produce Technetium the maximum calculated yield were found to be a function of the target neutron number (N) and the asymmetry parameter (N-Z)/A, where the maximum calculated yield decrease with increasing (N) and increasing asymmetry parameter.

4. Conclusions

1- In the Search, we have measured the excitation functions for the production of ${}^{93}_{43}Tc$, ${}^{94}_{43}Tc$, ${}^{95}_{43}Tc$, ${}^{96}_{43}Tc$, ${}^{98}_{43}Tc$, ${}^{99m}_{43}Tc$, ${}^{100}_{43}Tc$ and ${}^{101}_{43}Tc$ radio-nuclides through the proton-induced activation on Molybdenum target element in the energy range 1.48-80.0MeV.
2- Molybdenum is used as a target material for the production of medically important radioisotopes, such as ${}^{99m}_{43}Tc$, ${}^{95}_{43}Tc$, ${}^{94}_{43}Tc$ and ${}^{93}_{43}Tc$.
3- Technetium-99m radioisotope is a most important medical radioisotope for diagnostic tests and in nuclear medicine.
4- Medical use of this radioactive element in the field of imaging technologies has increased and is expected to continue in the coming years.
5- The calculated excitation function is in reasonable agreement with sets of experimental cross section measurements reported by EXFOR Library.

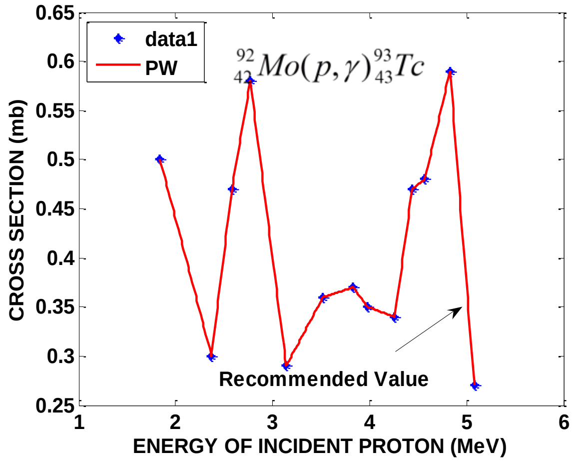

Figure1:The recommended cross section of the $^{92}_{42}Mo$ target element (present work) compared with EXFOR Library.
Data1:Ref.No.[17].

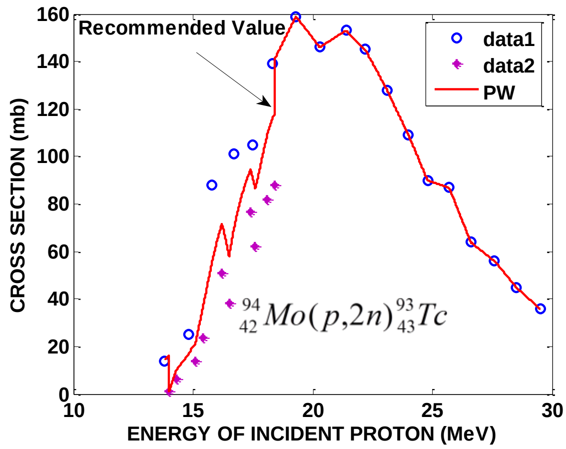

Figure2:The recommended cross section of the $^{94}_{42}Mo$ target element (present work) compared with EXFOR Library.
Data1:Ref.No.[18]; Data 2:Ref.No.[19].

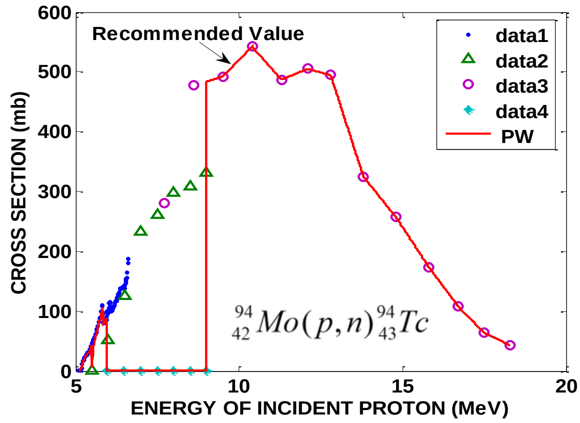

Figure3:The recommended cross section of the $^{94}_{42}Mo$ target element (present work) compared with EXFOR Library.
Data1:Ref.No.[20]; Data2:Ref.No.[21]; Data3:Ref.No.[18]; Data4:Ref.No.[22].

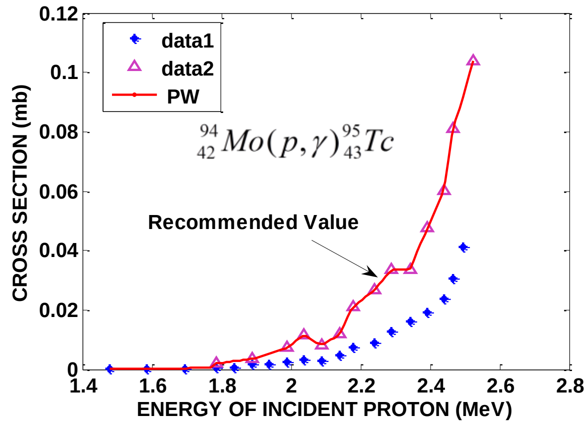

Figure4:The recommended cross section of the $^{94}_{42}Mo$ target element (present work) compared with EXFOR Library.
Data1:Ref.No.[23]; Data 2:Ref.No.[23].

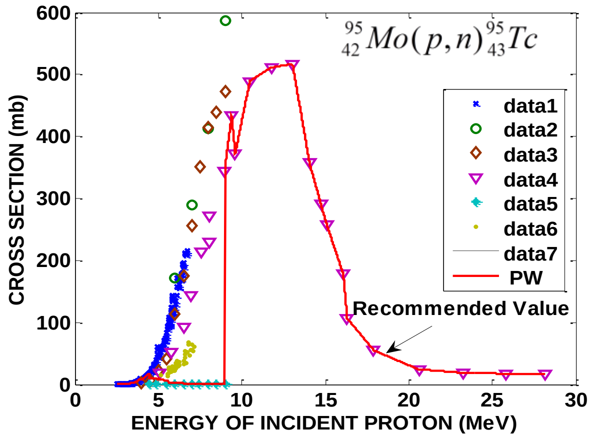

Figure5:The recommended cross section of the $^{95}_{42}Mo$ target element (present work) compared with EXFOR Library.
Data1:Ref.No.[20]; Data2:Ref.No.[24]; Data3:Ref.No.[21]; Data4:Ref.No.[25]; Data5:Ref.No.[22]; Data6:Ref.No.[26]; Data7:Ref.No.[27].

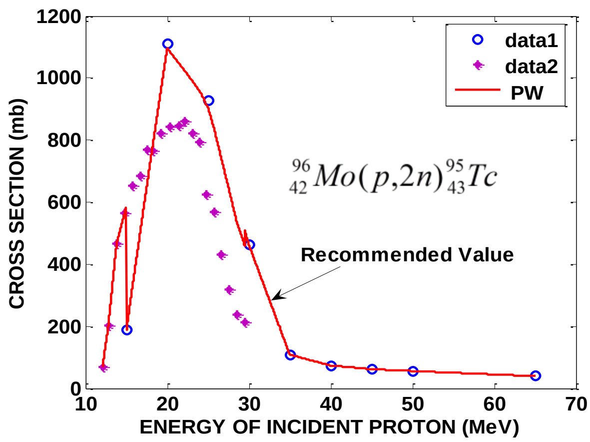

Figure6:The recommended cross section of the $^{96}_{42}Mo$ target element (present work) compared with EXFOR Library.
Data1:Ref.No.[28]; Data 2:Ref.No.[18].

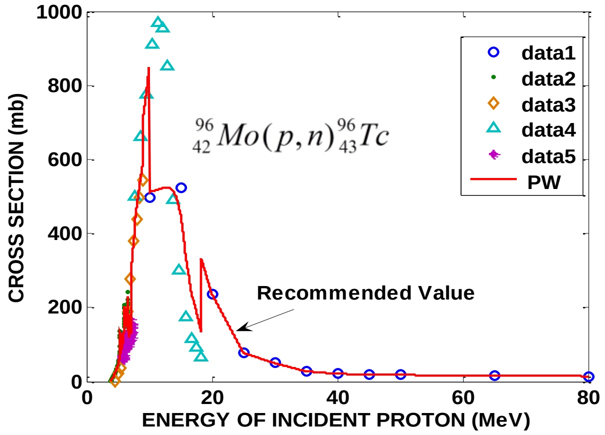

Figure7:The recommended cross section of the $^{96}_{42}Mo$ target element (present work) compared with EXFOR Library.
Data1:Ref.No.[28]; Data2:Ref.No.[20]; Data3:Ref.No.[21]; Data4:Ref.No.[18]; Data5:Ref.No.[26].

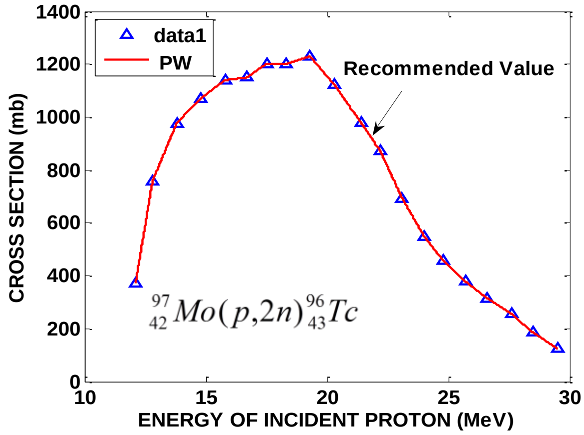

Figure8:The recommended cross section of the $^{97}_{42}Mo$ target element (present work) compared with EXFOR Library.
Data1:Ref.No.[18].

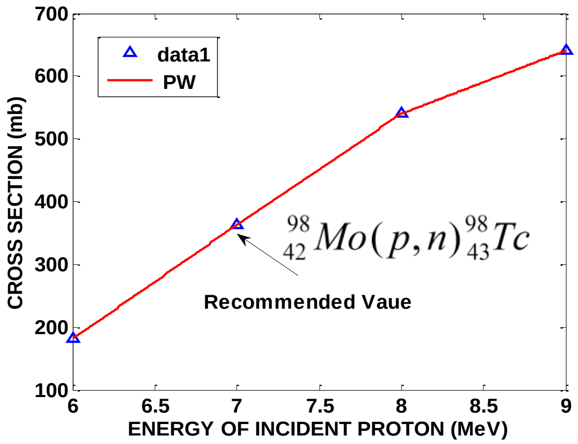

Figure9:The recommended cross section of the $^{98}_{42}Mo$ target element (present work) compared with EXFOR Library.
Data1:Ref.No.[24].

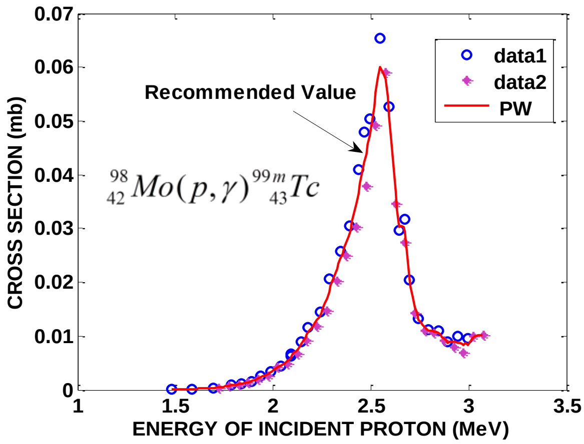

Figure10:The recommended cross section of the $^{98}_{42}Mo$ target element (present work) compared with EXFOR Library.
Data1:Ref.No.[23]; Data 2:Ref.No.[29].

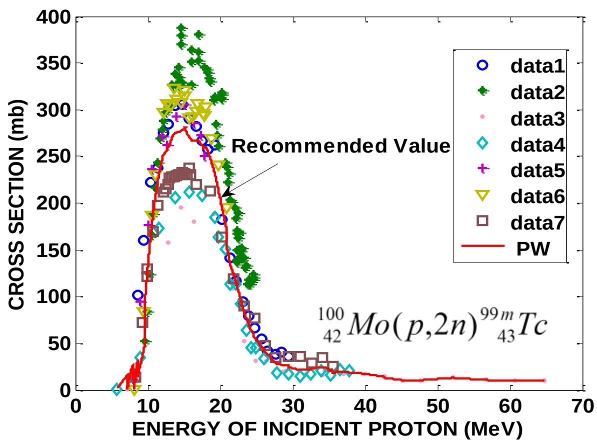

Figure11:The recommended cross section of the $^{100}_{42}Mo$ target element (present work) compared with EXFOR Library.
Data1:Ref.No.[18]; Data2:Ref.No.[30]; Data3:Ref.No.[31]; Data4:Ref.No.[32]; Data5:Ref.No.[33]; Data6:Ref.No.[34]; Data7:Ref.No.[35].

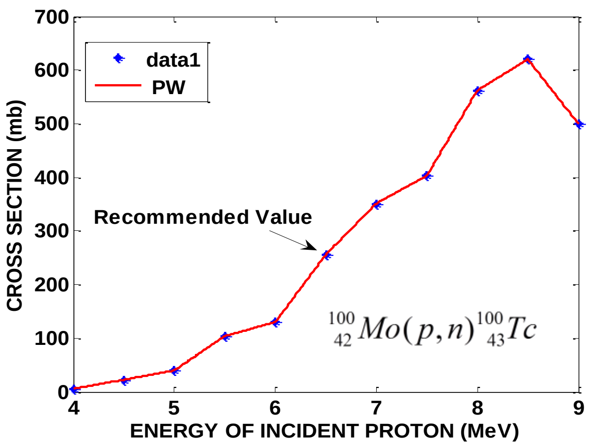

Figure12:The recommended cross section of the $^{100}_{42}Mo$ target element (present work) compared with EXFOR Library.
Data1:Ref.No.[21].

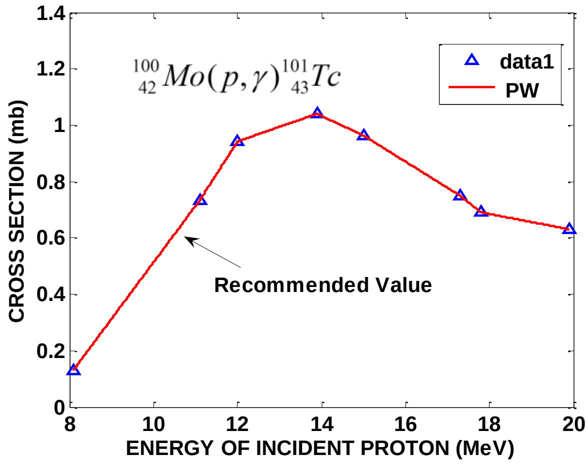

Figure13:The recommended cross section of the $^{100}_{42}Mo$ target element (present work) compared with EXFOR Library.
Data1:Ref.No.[36].

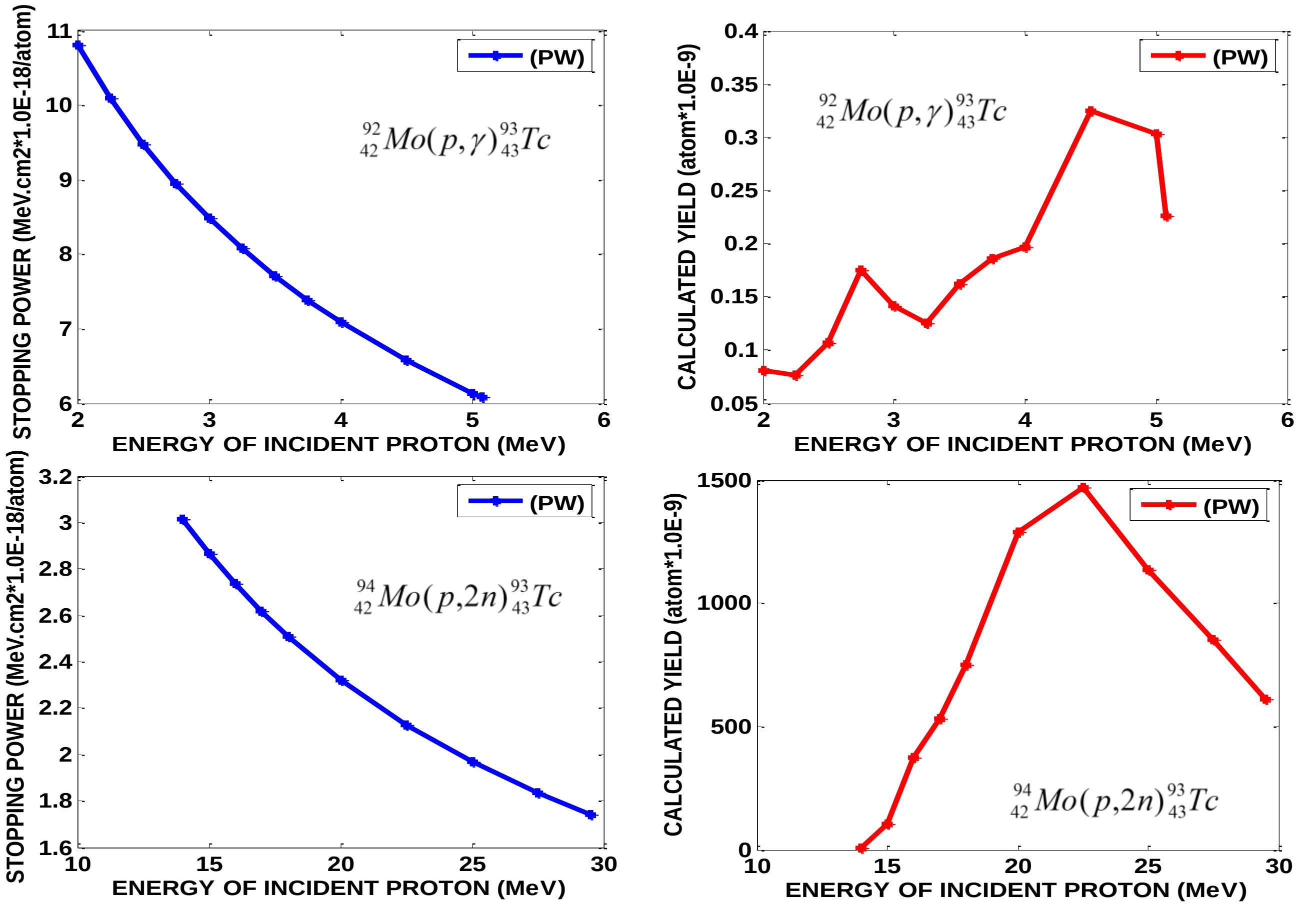

Figure (14): Left side; the comparison between the calculated stopping power in the present work (pw) of incident proton in Mo. Right side; the calculated yield as calculated in the present work compared with experimental results based on the adopted cross section of incident proton in Mo reaction.

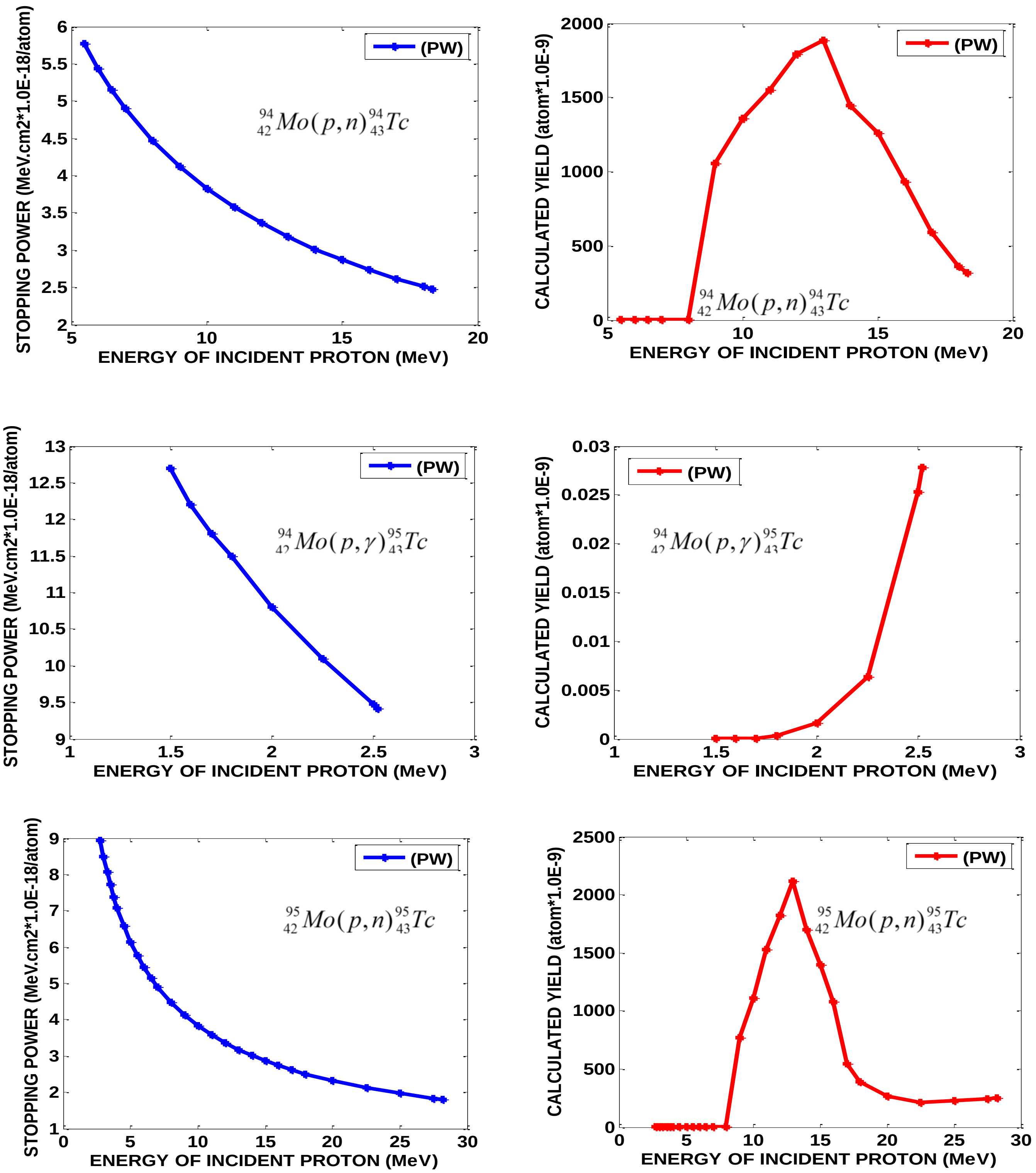

Figure (15): To be continued (2/2).

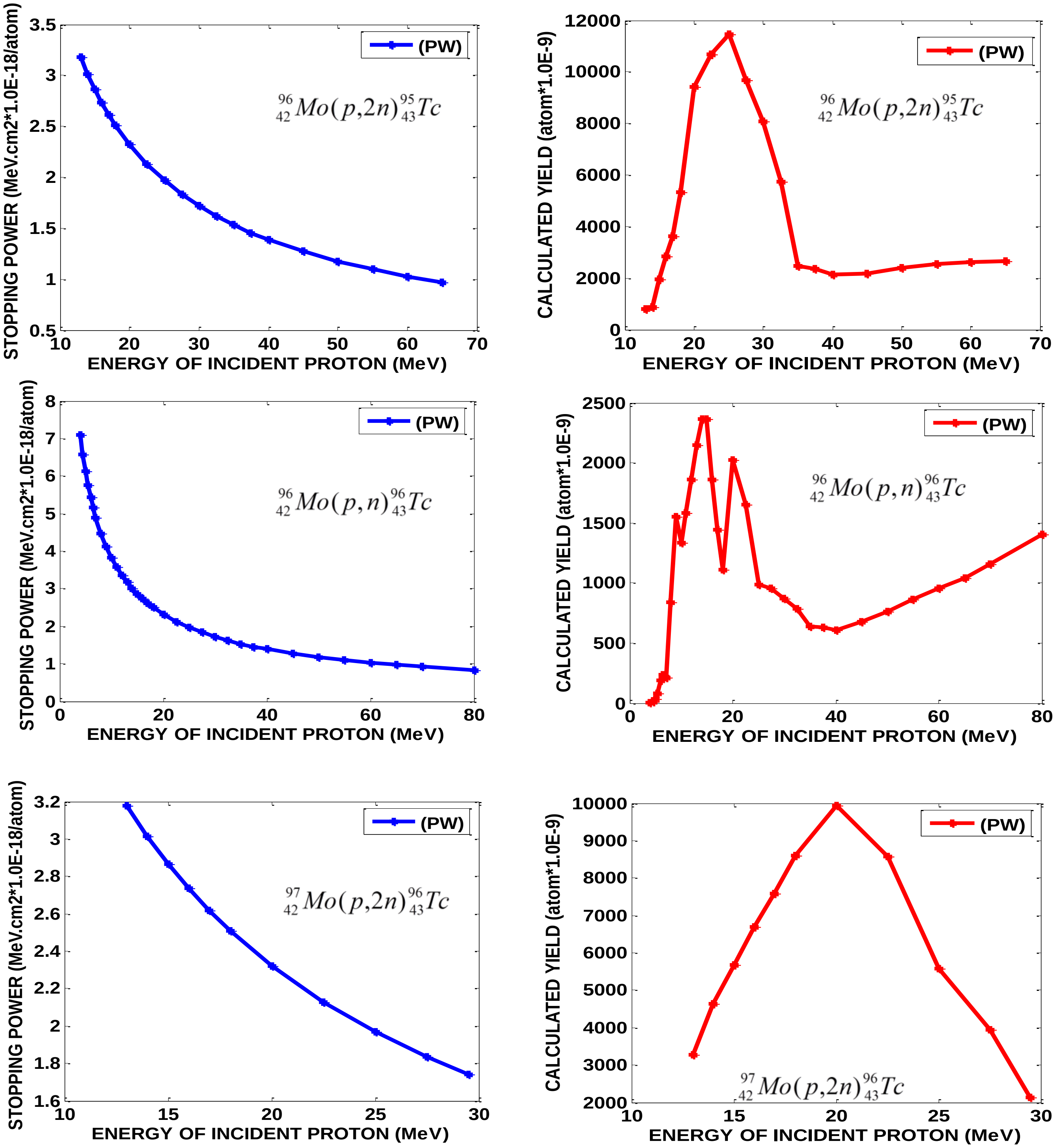

Figure (15): To be continued (2/2).

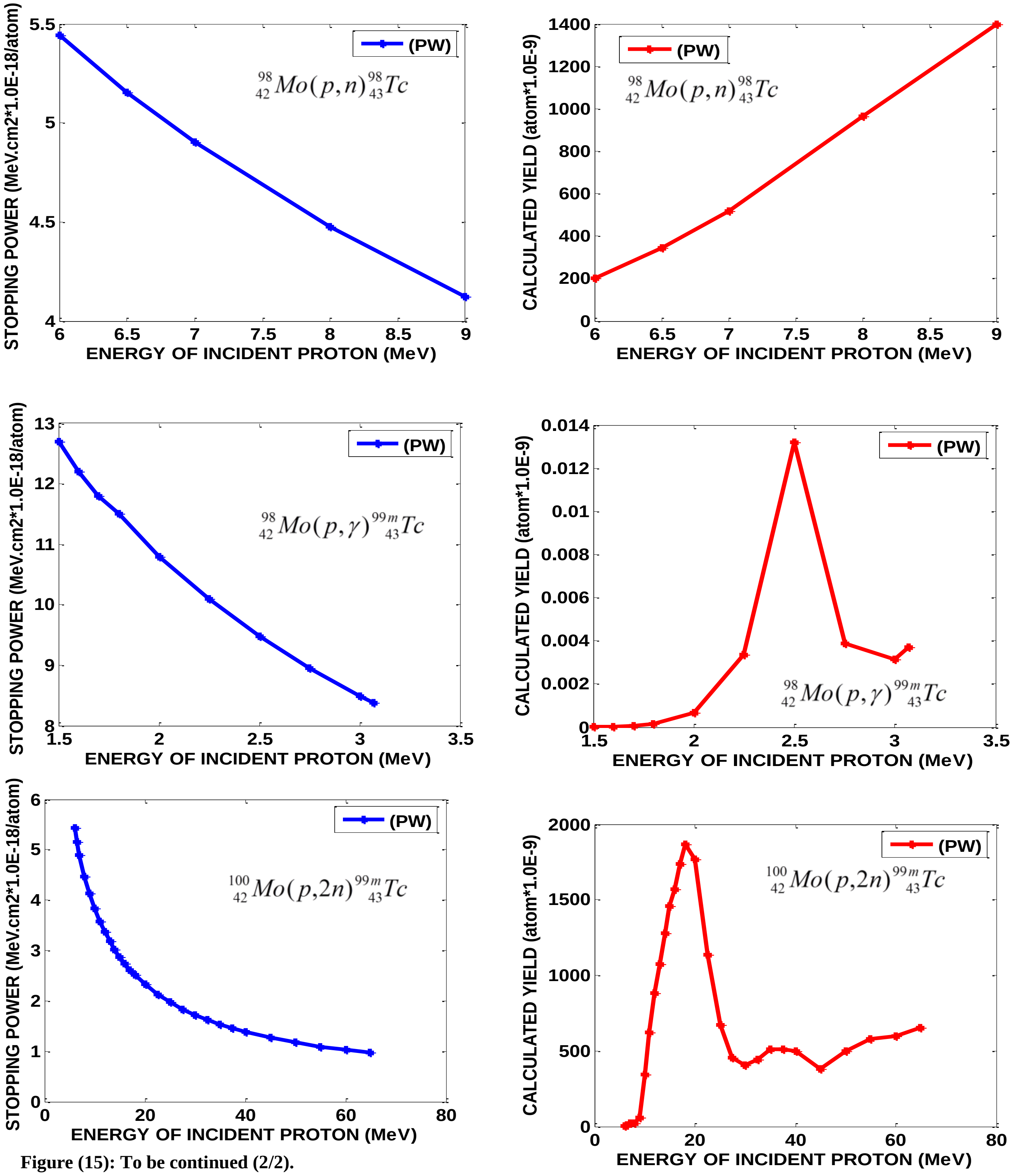

Figure (15): To be continued (2/2).

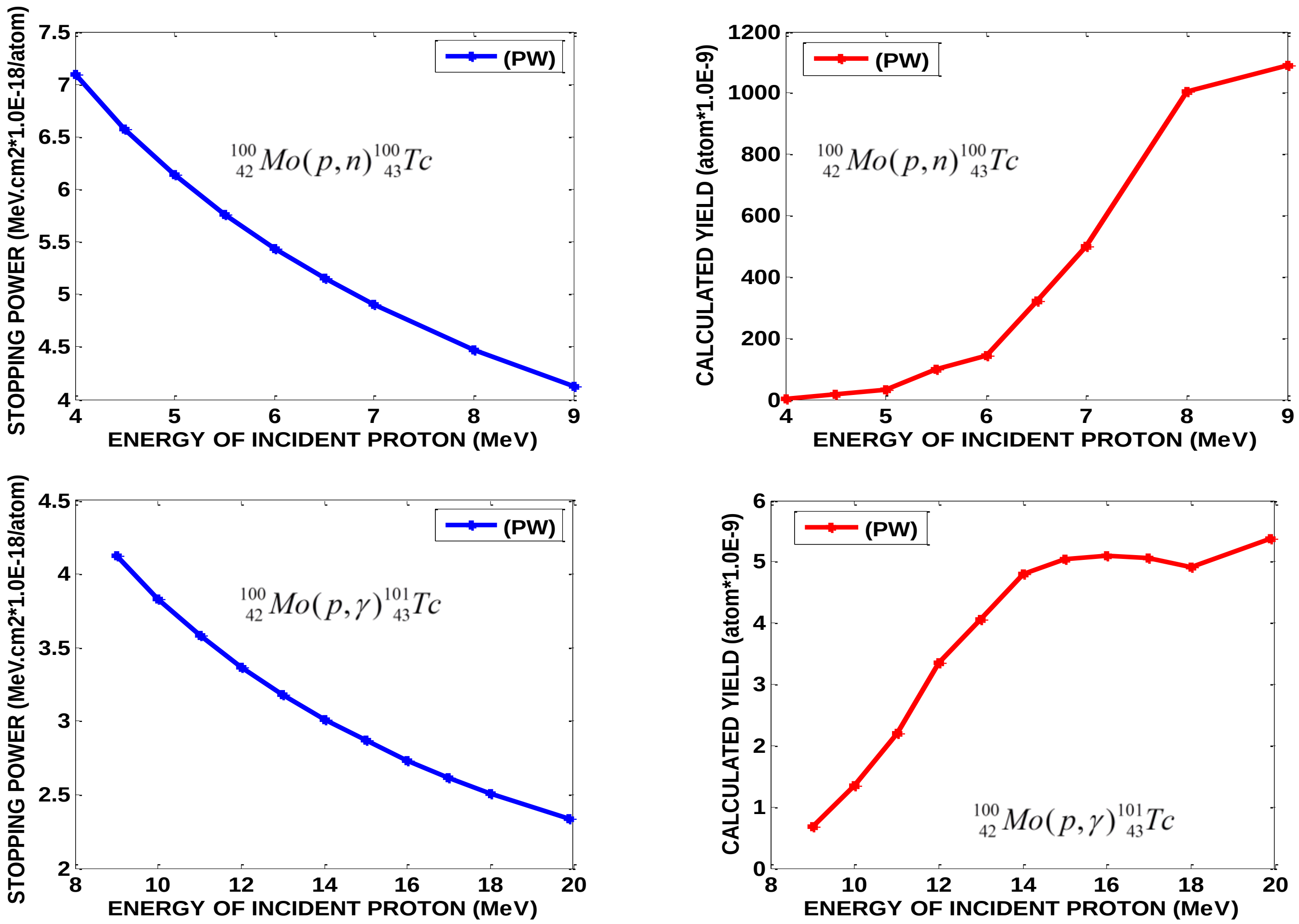

Figure (15): To be continued (2/2).

References

[1] Azzam A., Cleskey M. M, Roeder B., Spiridon A.,Simmons E., Goldberg V.Z., Banu A., Trache L., and Tribble R. E., "Medical radioisotopes production a comprehensive cross section study for the production of Mo and Tc radioisotopes via Proton induced nuclear reactions on natMo", Radioisotopes – Applications in Bio-Medical Science,Vol.36,No.7,PP.953-978(2011).

[2] Derek U., and Seth A. H.," Nuclear medicine without nuclear reactors or Uranium enrichment", Journal of Nuclear Medicine,Vol.13,No.4,P.3(2013).

[3] Ziegler J.F., "Handbook of stopping cross-sections for energetic ions in all elements", Pergamon Press, Oxford, Vol.5, (1980).

[4] Ziegler J.F.," Stopping and ranges elements", Helium Pergamum Press, Oxford, Vol.4, (1977).

[5] Mayeen U.K., Guinyun K., Kwangsoo K., and Dongchul S.,"Experimental studies of Proton induced reaction cross-sections on natMo", Pohang Accelerator Laboratory, Pohang University of Science and Technology, Pohang ,PP.790-784 (2005).

[6] Lindhard H.H. and Schardff M., “Hydrogen stopping powers and ranges in all elements”, Phys.Rev,Vol.124, PP.128-130 (1961).

[7] Powers D. and Olson H.J., Evaluated cross section and thick target yield data bases of Zn+P processes for practical applications", Phys. Rev, Vol.73, PP.2271- 2273 (1980).

[8] Beth H.A.," New cross sections and inter comparison of proton monitor reactions on Gallium", Bloch F., Ann. Phys VoI.16, PP.285-288(1933).

[9] Lindhard G., and Winther A., limiting factor for the progress of radionuclide based diagnostics and therapy", Mat. Fys. Medd. Dan. Vid., Selsk, Vol.34,PP.264-268 (1964).

[10] Ashely J.C., Ritchi R.H.,and Brant W.,"In vitro and in vivo evaluation of Copper64-octreotide conjugates", Phys. Rev, B5, PP. 2329-2332 (1972).

[11] Andersen H.H.,and Ziegler J.F.,"Hydrogen stooping powers and ranges in all Elements",Vol.3,Pergamon Press, Oxford, Vol.3 (1977).

[12] Knole G.F., “Radiation detection and measurement”, John Wiley and Sones, (2000).

[13] Nukulin V. Ya., and Polukhin S.N., “Saturation of the Neutron yield from mergajoule plasma focus facilities”, Journal of Plasma Physics, Vol.33, No.4,PP.304-308 (2007).

[14] Becturts K.H. and Wirtz K., “Neutron Physics”, Springer (1964).

[15] Norman E.B., Chupp T.E., Lesko K.T., and Schwalbac P., "Differential neutron production cross sections for 800-MeV Protons", Nucl. Phys. A, Vol.390, PP.561-564 (1982).

[16] Feige Y., Olthman B.G., and Kasiner J., Geophs. Res. Vol.73, PP.3135-3137 (1968).

[17] Arifov L.Ja., Artemova S.A., Mazitov B.S., and Ulanov V.G.," Measurement of the energy dependence of the isomeric ratio for the 92-Mo(p,g) reaction", 30.Conf.Nucl.Spectr.and Nucl.Struct.,Leningrad, P.328(1980).

[18] Levkovskij V.N.," Activation cross section nuclides of average masses(A=40-100)by Protons and Alpha-particles with average energies (E=10-50 MeV)",Levkovskij, Act. Cs. By Protons and Alphas, Moscow(1991).

[19] Rosch F.,and Qaim S.M.," Nuclear data relevant to the production of the positron emitting technetium isotope Tc-94m via Mo-94(p,n)-reaction",Radiochimica Acta Vol.62,P.115 (1993).

[20] Flynn D.S.,Hershberger R.L., and Gabbard F.," Sub-Coulomb proton absorption for isotopes of zirconium and molybdenum", Physical Review, Part C, Nuclear Physics Vol.20, Issue.5, P.1700(1979).

[21] Skakun E.A., Batij V.G., Rakivnenko Yu.N., and Rastrepin O.A.," Excitation functions and isomer ratios for up-to-9 MeV Proton interactions with Zr and Mo isotope nuclei", Yadernaya Fizika Vol.46,P.28(1987).

[22] Sauter T., and Kappeler F.," (P,Gamma) rates of 92-Mo, 94-Mo, 95-Mo,98-Mo: towards an experimentlly founded data base for process studies",Physical Review, Part C, Nuclear Physics Vol.55,P.3127(1997).

[23] Skakun E.A., and Batij V.G.," Level density parameters from excitation cross sections of isomeric states", Zeitschrift fuer Physik A, Hadrons and Nuclei Vol.344, P.13 (1992).

[24] Trufanov A.M., Lovchikova G.N., Salnikov O.A., and Simakov S.P.," Simultaneous study of the mechanism of Mo-95,98(p,n)Tc-95,98 reaction and nuclear level Density", Yadernaya Fizika Vol.36, P.299(1982).

[25] Izumo M., Matsuoka H., Sorita T., Nagame Y.,Sekine T., Hata K., and Baba S.," Production of 95mTc with proton bombardment of 95Mo",Applied Radiation and Isotopes Vol.42, P.297 (1991).

[26] Zhuravlev Yu.Yu., Zarubin P.P., and Kolozhvari A.A.," Excitation Functions of (P,N) Reaction on the Mo Isotope Nuclei in the Energy Interval from Thresholds To 7.2 MeV", Izv. Rossiiskoi Akademii Nauk, Ser. Fiz. Vol.58, Issue.5, P.106 (1994).

[27] Bitao H., Juravlev U.U.,and Zarubin P.P.," Isobaric analogue resonance observed in isomeric ratios resulting from the reaction (P,N) on targets Mo-95 and Ru-104 Jour. of Physics, Part G (Nucl. and Part. Phys.) Vol.24, P.2261 (1998).

[28] Hogan J.J.," Mo-96(P,XN)Reaction from 10 to 80 MeV", Physical Review, Part C, Nuclear Physics Vol.6, P.810 (1972).

[29] Gyurky Gy., Vakulenko M., Fulop Zs., Halasz Z., Kiss G.G., Somorjai E.,and Szucs T.," Cross section and reaction rate of 92Mo(p,g)93Tc determined from thick target yield measurements", Nuclear Physics, Section A Vol.922, P.112(2014).

[30] Lagunas-Solar M.C., Zeng N.X., Mirshad I., and Grey-Morgan T.," An Update on the Direct Production of 99mTc with Proton Beams and Enriched 100Mo Targets", Transactions of the American Nuclear Society Vol.74, P.137 (1996).

[31] Scholten B., Lambrecht R.M., Cogneau M., Ruiz H.V., and Qaim S.M.," Excitation Functions For the Cyclotron Production of 99-M-Tc and 99-Mo", Applied Radiation and Isotopes Vol.51, P.69(1999).

[32] Takacs S., Szucs Z., Tarkanyi F., Hermanne A., and Sonck M.," Evaluation of proton induced reactions on 100Mo: New cross sections for production of 99mTc and 99Mo", Journal of Radioanalytical and Nuclear Chemistry Vol.257, P.195(2003).

[33] Gagnon K., Benard F., Kovacs M., Ruth T.J., Schaffer P., Wilson J.S., and Mcquarrie S.A.," Cyclotron production of 99mTc: Experimental measurement of the 100Mo(p,x)99Mo, 99mTc and 99gTc excitation functions from 8 to 18 MeV", Int. Journal of Nuclear Medicine and Biology Vol.38, P.907(2011).

[34] Manenti S., Holzwarth U., Loriggiola M., Gini L., Esposito J., Groppi F., and Simonelli F.," The excitation functions of 100Mo(p,x)99Mo and 100Mo(p,2n)99mTc", Applied Radiation and Isotopes Vol.94, P.344(2014).

[35] Takacs S., Hermanne A., Ditroi F., Tarkanyi F., Aikawa M.," Reexamination of cross sections of the100Mo(p,2n)99mTc reaction", Nucl. Instrum. Methods in Physics Res., Sect.B Vol.347, P.26(2015).

[36] Daly P.J., Seppelt B.M., and Shaw P.F.D.," Radiative capture cross sections in medium-weight and heavy nuclei", Nuclear Physics, Section A Vol.119, P.673(1968).

[37] The Technetium-99m Generator, "Washington state department of health", Fact sheet PP.320-083(2002).

[38] European Commission," Preliminary report on supply of radioisotopes for medical use and current devel opments in nuclear medicine", Luxembourg, 30 October 2009 SANCO/C/3/HW, Rev. 8, (2009).

[39] Lambrecht R.M., Sekine T., Veraruiz H." The accelerator production of Molybdenum-99", Appl. Radiat. Isotopes ,Vol.42,No.9,PP.643-657(1991).