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CROSS SECTION AND NEUTRON YIELD FOR PROTON INTERACTION WITH INTERMEDIATE AND HEAVY NUCLEUS

SHAFIK Y.QASTIN & HUDA M.TAWFEEQ

Physics Department, College of Ibn Al-Haytham - Baghdad University, Iraq

ABSTRACT

In this study reacting proton with intermediate and heavy nucleus as a target (^{64}Ni, ^{67}Zn, ^{75}As, ^{103}Rh, ^{111}Cd, ^{114}Cd, ^{165}Ho, ^{169}Tm, ^{186}W) the experimental data of cross sections have been published in Exfor library as a function of proton energy. We have calculated the cross section of the above mentioned data and results have been obtained by using (Matlab-8.3 2014a) program. The stopping powers have been calculated from Zeigler formula by using SRIM-2013 with the results of cross sections to calculate the neutron-yield for reactions, and also comparing between cross section for each one of those reactions with published experimental data of cross sections at Exfor library as a function of proton energy to show compatibility, as well as those reactions to be used in the production of radioisotopes such as (^{64}Cu, ^{67}Ga, ^{75}Se, ^{103}Pd, ^{111}In, ^{114m}In, ^{165}Er, ^{169}Yb, ^{186}Re), We also did found comparisons between neutron yields of the mentioned reactions to choose the best reactions of highest neutron yield.

KEYWORDS: Cross Section (Excitation Function), Stopping Power, Neutron Yield, Data Evaluation, Radioactive Isotopes

INTRODUCTION

The first major advance of particle accelerators occurred in 1934 with the invention of the cyclotron, it is machine used to accelerate charged particles to very high speeds, and it became possible to create the nuclear instability that is a prerequisite for radioactivity. By directing a beam of fast moving charged particles at a nucleus target, it induced a reaction that results in the formation of a radioisotope with a short half-life [1]. Particle accelerators and, in particular, cyclotrons, were very important in the preparation of radioisotopes during the years from 1935 to the end of World War II. After that reactors were used to produce radioactive elements, but the use of accelerators for this purpose became less common. As the techniques for using radiotracers became more sophisticated, it was clear later that reactor produced radioisotopes could not completely satisfy the growing demand and, therefore accelerators were needed to produce new radioisotopes that could be used in new ways in both industry and medicine [1]. The study of nuclear reactions of proton with intermediate and heavy nucleus as a target which has a high neutron yield due to the advantages of the (*p*,*n*) reactions to produce radioisotopes as (^{64}Cu, ^{67}Ga, ^{75}Se, ^{103}Pd, ^{111}In, ^{114m}In, ^{165}Er, ^{169}Yb, ^{186}Re). They are very important because it provides a base for a wide range of technical applications, particularly using the reactions induced by intermediate energy protons; it is possible to produce directly radioisotopes which are used in medicine and industry, recent decades, where widespread uses of diagnostic and therapeutic radioisotopes had occurred. Depending on the type of radiation, the diagnostic isotopes are classified into two groups: β^+, β^- emitters (^{64}Cu, ^{186}Re, etc.) used in Positron Emission Tomography (PET), *E.C* and γ-emitters (^{67}Ga, ^{75}Se,^{103}Pd, ^{111}In, ^{114m}In,^{165}Er, ^{169}Y,) used in Single Photon Emission Computed Tomography (SPECT). The total cross section of such a production is also important in accelerator technology from the point of view of radiation protection safety [2].

NUCLEAR REACTION

The *Q*-value of the X(a,b)Y reaction is defined as the difference between the final and initial kinetic energies and is given by [3,4,5]:

$$Q = [M_a + M_X - (M_b + M_Y)] \times 931.5 \quad (1)$$

The threshold energy for a nuclear reaction is defined as the smallest value of a projectile's kinetic energy at which a nuclear reaction can take place [5, 6].

$$E_{th} = -Q\left(1 + \frac{M_a}{M_X}\right) \quad (2)$$

NUCLEAR CROSS SECTION

To study nuclear reactions, it is necessary to have a quantitative measure of the probability of a given nuclear reaction. In which the cross section of nuclides is the effective area presented [7]. When an accelerated charged particle interacts with a target nucleus a nuclear reaction takes place, ultimately leading to a stable or radioactive product nucleus. A nuclear reaction is characterized by a cross-section, describing the probability that a particle can interacts [6, 8]. The cross section has the units of area as it's the square of nuclear radius. The standard unit for measuring a nuclear cross section (σ) is the barn (b), which is equal to (1barn=10^{-24} cm²) or (1barn=10^{-28} m²). The reaction cross section data provides information of fundamental importance in the study of nuclear systems. The cross section is defined by [9]:

$$\sigma = \frac{R}{I} \quad (3)$$

Where *R* is the number of reactions per unit time per nucleus. *I* is the number of incident particles per unit time per unit area, In general, a given bombarding particle and target can react in a variety of ways producing a variety of light reaction products per unit time. The total cross section is than defined as [5]:

$$\sigma_{total} = \sum \sigma_i \quad (4)$$

Where σ_i is the partial cross section for the process.

STOPPING POWER

The energy of charged particle loses per unit path length of the material it traverses. Generally speaking, any charged particle can have either electronic, nuclear, or gravitational interaction with the particles of the material through which it passes. However the gravitational interaction is too low to be of any significance and is generally ignored. The total stopping power is then just the sum of the stopping powers due to electronic and nuclear interactions [10, 11, 12].

$$-\frac{dE}{dx} = S_{total} = S_{electronic} + S_{nuclear} \quad (5)$$

Where $S_{electronic}$ is the electronic stopping power, $S_{nuclear}$ is the nuclear stopping power. The electronic stopping power is always much larger than the nuclear stopping power. For most practical purposes the nuclear component of the stopping power can also be ignored as it is generally only a fraction of the total stopping power. For particles such as

electrons, this statement is always valid since they are not affected at all by the strong nuclear force.

***Electronic* Stopping**

Electronic Stopping Power (S_e) the beam particles hitting a target get slowed down by interactions with the electrons until it they are in thermal equilibrium with their surroundings. As a consequence one gets a wide neutron spectrum if the projectiles are completely stopped in the target, even if all nuclear reactions were two-body reactions. The loss of kinetic energy in a nuclear encounter would be much larger [4]. In the scope of this work, the electronic stopping powers were calculated using the Ziegler formulae [11]. Reliable data are available for many elements over a wide range of energies. However, in order to obtain values for all elements over a continuous range of proton energies, the stopping power as a function of proton energy E (keV) and the target atomic number Z_2. S_e is assumed to be proportional to $E^{0.45}$ for E < 25 keV, except for $Z_2 \leq 6$ where it is proportional to $E^{0.25}$, for 25 keV ≤ E ≤ 10 MeV [12,13].

$$(\frac{1}{S_e}) = (\frac{1}{S_{Low}}) + (\frac{1}{S_{High}}) \tag{6}$$

S_{Low} (Low energy stopping) is

$$S_{Low} = A_1 E^{A_2} + A_3 E^{A_4} \tag{7}$$

S_{High} (High energy stopping) is

$$S_{High} = \frac{A_5 \ln(\frac{A_6}{E} + A_7 E)}{E^{A_6}} \tag{8}$$

Where E(KeV) energy of proton and the coefficients A_i for each Z_2, available from SRIM [12,13]. For 10 MeV ≤ E ≤ 2 GeV.

$$S_{High} = A_9 + A_{10}(\frac{\ln E}{E}) + A_{11}(\frac{\ln E}{E})^2 + A_{12}(\frac{E}{\ln E}) \tag{9}$$

For use in the parameterization Proton stopping, $S_t(^1H)$, in various target materials for 10 kev ≤ E ≤ 100 MeV, High-energy proton stopping Se ~St , Proton stopping power for 1 kev ≤ E ≤ 10 GeV and $Z_2 \leq 92$, based on a combination of theoretical calculations and experimental data (for 20 keV ≤ E ≤ 1 MeV) [14,15].

***Nuclear* Stopping Power (S_n)**

A beam of charged particles bombarding the neutral atoms of a target interacts with the atomic nuclei and atomic electrons of the target. The ratio of the energy lost in interaction with the atomic electrons, to the energy lost in the interaction with the atomic nuclei ($2m_p / m_e \cong 4x10^3$) [10].

Thus the energy lost by interaction with the nuclei is negligible compared with that lost by interaction with the electrons. For solid targets with a given thickness there will be the more nuclear interactions and hence the electronic stopping is comparable with the nuclear cross section [11]. The theory of ion-solid interactions is well established and it has been discussed in detail. Where the authors also described the computer program SRIM. Which can be used for calculating stopping power and range for ion target combinations with Z≤92 [12, 14, 16]. For sufficiently high projectile

energies, $S_t \sim S_e$. S_n , in units of eV/10^{15} atoms/cm^2 , for any projectile with energy E (KeV), is given by [12,14].

$$S_n(E) = \frac{8.462 Z_1 Z_2 M_1 S_n(\varepsilon)}{(M_1 + M_2)(Z_1^{0.23} + Z_2^{0.23})} \tag{10}$$

Where the reduced ion energy, ε , is defined as

$$\text{Reduced Ion Energy} = \varepsilon = \frac{32.53 M_1 M_2 (E / M_1)}{Z_1 Z_2 (M_1 + M_2)(Z_1^{0.23} + Z_2^{0.23})} \tag{11}$$

Where M_1 and M_2 are the projectile and target masses (amu), and Z_1 and Z_2 are the projectile and target atomic numbers. For $\varepsilon \leq 30$ keV.

$$S_n(\varepsilon) = \frac{\ln(1 + 1.1383\varepsilon)}{2(\varepsilon + 0.01321\varepsilon^{0.21226} + 0.19593\varepsilon^{0.5})} \tag{12}$$

For ε > 30 keV , unscreened nuclear stopping is used, and $S_n(\varepsilon)$ simplifies to

$$S_n(\varepsilon) = \frac{\ln \varepsilon}{2\varepsilon} \tag{13}$$

NEUTRON YIELDS

The neutron yield (Y_n) detected per incident particle (proton, deuteron alpha), for an ideal thin, and uniform target and mono-energetic particles beam of incident energy E_b is given by [17].

$$Y_n = (N_d x)\sigma(E_b)\eta(E_b) \tag{14}$$

Where N_d is the real number density of target atoms, x is the target thickness, σ is the reaction cross section and η is neutron detection efficiency. If the target is sufficiently thick, for a target which is not infinitesimally thin, the beam loses energy as it passes through the target, if the target is sufficiently thick, and there exist one atom per each molecule (i.e., f =1) and taking (E`)=1, then the resulting yield is called the thick-target yield which is given by [17,18,19].

$$Y_n(E_b) = N \int_{E_{th}}^{E_b} \frac{\sigma(E)}{dE/dx} dE \tag{15}$$

Where E_{thr} is the reaction threshold energy, σ(E) is the cross section, dE/dX is the incident particle initial energy, N is the atomic number of target per unit volume, which is defined as follows [20]:

$$N = \frac{w \rho N_a}{A} \tag{16}$$

Where, w is the abundant in the combination, is the combination density, A is the mass number, N_A is the Avogadro's number. Thus by measuring the yield at two closely spaced energies (E1) and (E2), one can determine the average value of the integrand over this energy interval as follows [20]:

$$Y(E_2) - Y(E_1) = \left[\frac{\sigma(E)}{dE/dx}\right]_{E_b} (E2 - E1) \tag{17}$$

Where (E_b) is the average of (E_1) and ($E2$). If σ (E) are available in the literature as a function of projectile energy (E_b) for natural elements, then the neutron yield can be calculated using eq. (13). If neutron yield is available as a function of projectile energy (E_b), then eq. (13) can be used to calculate σ (E) as a function of (E_b). Thus consequently one can calculate the neutron yield by using eq. (17), for natural elements and if only one stable isotope is available in nature [21].

RESULTS AND DISCUSSION

These reactions are the important interactions that lead to the radioactive isotopes production such as (Copper-64, Gallium-67, Selenium-75, Palladium-103, Indium-111, Indium-114^m, Erbium-165, Ytterbium-169 and Rhenium-186).

The $^{64}_{28}Ni\,(p,n)\,^{64}_{29}Cu$ Reaction

The cross sections of the $^{64}_{28}Ni\,(p,n)\,^{64}_{29}Cu$ reaction have been published as a function of proton energy by Adam [22], Avila [23], Szelecsenyi [24], Levkovskij [25] in Exfor library. We've used the energy range (1.0-24.5MeV) lower than the threshold energy (2.4956MeV) within the step of (0.5 MeV), the cross section is directly proportional with proton energy until it reaches to (11.0 MeV), it's the maximum value of the cross section (σ_{Max}=742.95 mb), then it decreases with the increase of proton energy as shown in figure 1.

The $^{67}_{30}Zn\,(p,n)\,^{67}_{31}Ga$ Reaction

The cross sections of the $^{67}_{31}Zn\,(p,n)\,^{67}_{32}Ga$ reaction have been published as a function of proton energy by Szelecsenyi [26], Hermanne [27], Levkovskij [28] and little [29] in Exfor library. We've used the energy range (4-29.5MeV) higher than the threshold energy (1.8105MeV) within the step of (0.5 MeV), the cross section is directly proportional with proton energy until it reaches to (11.0 MeV), it's the maximum value of the cross section (σ_{Max}=739.09 mb), then it decreases with the increase of proton energy as shown in figure 2.

The $^{75}_{33}As\,(p,n)\,^{75}_{34}Se$ Reaction

The cross sections of the $^{75}_{33}As\,(p,n)\,^{75}_{34}Se$ reaction have been published as a function of proton energy by Levkovskij [30], Brodovitch [31], Johnson [32], and Albert [33] in Exfor library. We've used the energy range (2.0-59.95MeV) higher than the threshold energy (1.6693MeV) within the step of (0.8MeV), the cross section is directly proportional with proton energy until it reaches to (9.2MeV), its maximum value of the cross section (σ_{Max}=692 mb), then it decreases with the increase of proton energy as shown in figure 3.

The $^{103}_{45}Rh\,(p,n)\,^{103}_{46}Pd$ Reaction

The cross sections of the $^{103}_{45}Rh\,(p,n)\,^{103}_{46}Pd$ reaction have been published as a function of proton energy by Sudar [34], Hermanne [35], Harper [36] and Johnson [37] in Exfor library. We've used the energy range (2.305-39.055 MeV) higher than the threshold energy (1.3385MeV) within the step of (0.75 MeV), the cross section is directly proportional with proton energy until it reaches to (9.805MeV), it's the maximum value of the cross section (σ_{Max}=509.93 mb), then it decreases with the increase of proton energy as shown in figure 4.

The $^{111}_{48}Cd\,(p,n)\,^{111}_{49}In$ Reaction

The cross sections of the $^{111}_{48}Cd(p,n)^{111}_{49}In$ reaction have been published as a function of proton energy by Tarkanyi [38], Marten [39], Skakun [40] in Exfor library. We've used the energy range (3.8-43.8MeV) higher than the threshold energy (1.6596MeV) within the step of (0.8MeV), the cross section is directly proportional with proton energy until it reaches to (11.8MeV), it's the maximum value of the cross section (σ_{Max}=755mb), then it decreases with the increase of proton energy as shown in figure 5.

The $^{114}_{48}Cd(p,n)^{114m}_{49}In$ Reaction

The cross sections of the $^{114}_{48}Cd(p,n)^{114m}_{49}In$ reaction have been published as a function of proton energy by Said [41], Tarkanyi [42], Zaitseva [43] and Wing [44] in Exfor library. We've used the energy range (4.4-62.4MeV) higher than the threshold energy (2.2486MeV) within the step of (1.0MeV), the cross section is directly proportional with proton energy until it reaches to (11.4MeV), it's the maximum value of the cross section (σ_{Max}=284.81 mb), then it decreases with the increase of proton energy as shown in figure 6.

The $^{165}_{67}Ho(p,n)^{165}_{68}Er$ Reaction

The cross sections of the $^{165}_{67}Ho(p,n)^{165}_{68}Er$ reaction have been published as a function of proton energy by Tarkanyi [45], Beyer [46] in Exfor library. We've used the energy range (5.5-37.5MeV) higher than the threshold energy (1.1674MeV) within the step of (0.6MeV), the cross section is directly proportional with proton energy until it reaches to (10.9MeV), it's the maximum value of the cross section (σ_{Max}=150.1mb), then it decreases with the increase of proton energy as shown in figure 7.

The $^{169}_{69}Tm(p,n)^{169}_{70}Yb$ Reaction

The cross sections of the $^{169}_{69}Tm(p,n)^{169}_{70}Yb$ reaction have been published as a function of proton energy by Tarkanyi [47], Sonnabend [48], Spahn [49] in Exfor library. We've used the energie range (3.3-44.7MeV) higher than the threshold energy (1.6910MeV) within the step of (0.9MeV), the cross section is directly proportional with proton energy until it reaches to (11.4MeV), it's the maximum value of the cross section (σ_{Max}= 291 mb), then it decreases with the increase of proton energy as shown in figure 8.

The $^{186}_{74}W(p,n)^{186}_{75}\mathrm{Re}$ Reaction

The cross sections of the $^{186}_{74}W(p,n)^{186}_{75}\mathrm{Re}$ reaction have been published as a function of proton energy by Hussain [50], Xiaodong [51] in Exfor library. We've used the energy range (5.0-17.8MeV) higher than the threshold energy (1.3700MeV) within the step of (0.4MeV), the cross section is directly proportional with proton energy until it reaches to (9.0MeV) and it's the maximum value of the cross section (σ_{Max}= 39.231 mb), then it decreases with the increase of proton energy as shown in figure 9.

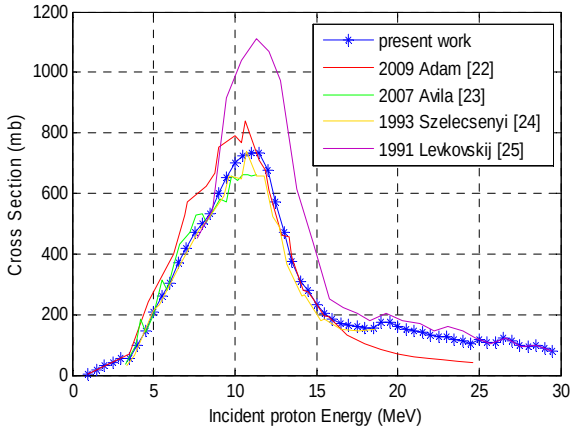
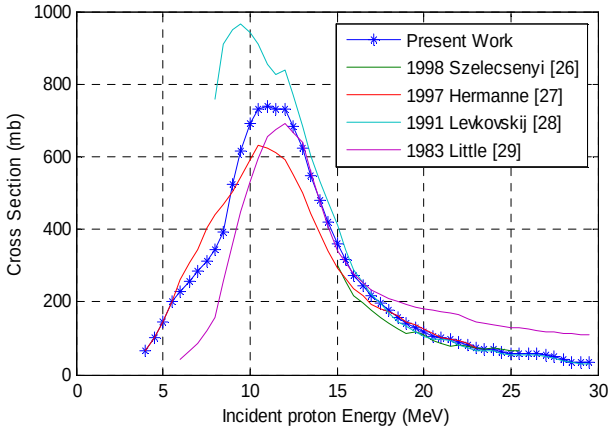


Figure 1



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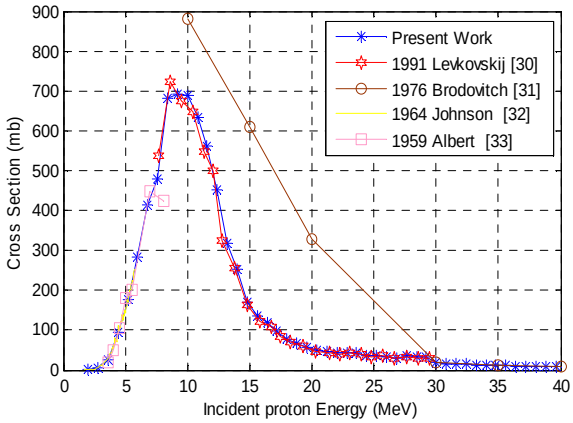

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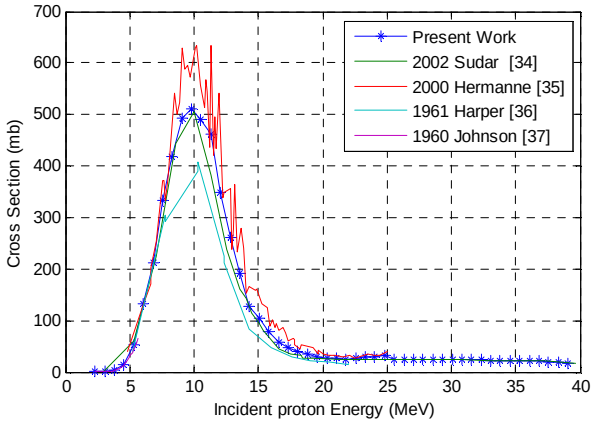
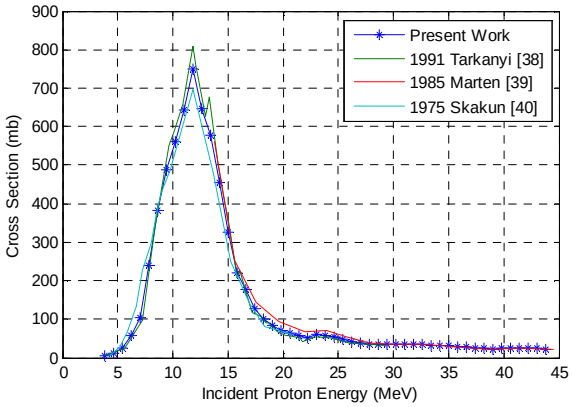


Figure 4



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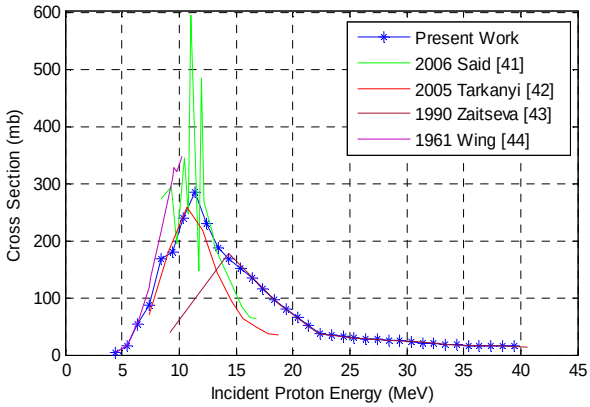

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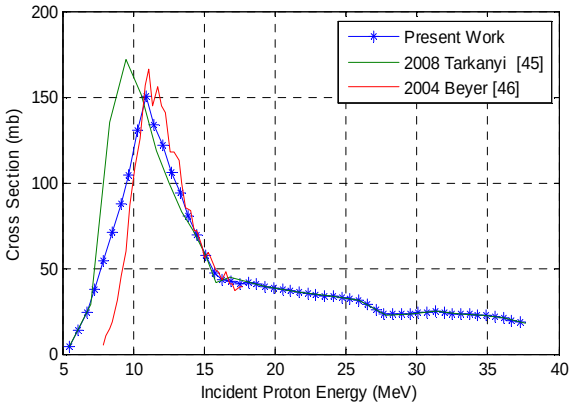

Figure 7

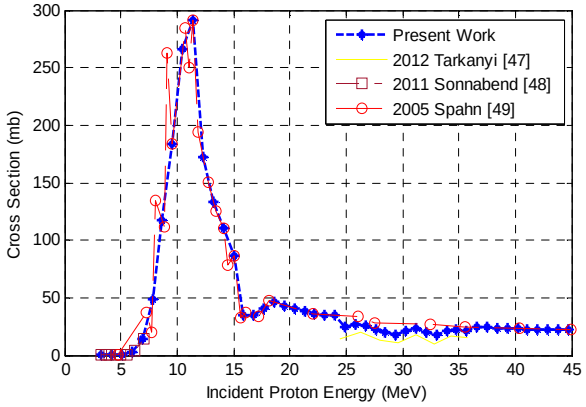

Figure 8

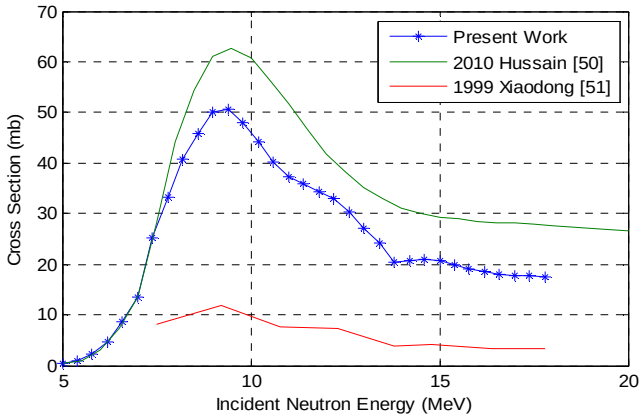

Figure 9

CONCLUSIONS

From the results of cross sections and neutron yield for *(p,n)* reactions with many of intermediate and heavy nucleus, we have observed in this study many conclusions for this study as per below points:

From the results of cross sections for *(p,n)* reaction with many intermediate and heavy nucleus targets to produce radioisotopes with short half life, those radioisotopes are producing by cyclotron more demanded [52].

Copper-64: has a half-life ($T_{1/2}$=12.7 h) and decay properties (β^+, 0.653 MeV [17.8%] β^-, 0.579 MeV [38.4%]) [54].These characteristics make it useful for both high resolution PET imaging and targeted end radiotherapy. In addition, its electron capture decay associated with Auger emission gives more efficient cell killing when this radioisotope is deposited in the cell [53]. The well-established applications in the molecular imaging of cancer [54].

Gallium-67: has a half-life of ($T_{1/2}$=3.217 d) decays to stable ^{67}Zn by electron capture. Its decay emissions include gamma rays of 93.3 keV (37.0%), 184.6 keV (20.4%) and 300.2 keV (16.6%). Gallium behaves in the body in a similar way to ferric iron. It is commonly used as a trivalent citrate compound for nuclear medicine imaging, and is a valuable agent in the detection and localization of certain neoplasms and inflammatory lesions.[52] This radioisotope ^{67}Ga is well known and widely used in the field of nuclear medicine. ^{67}Ga has become one of the most frequently employed

cyclotron produced radioisotope over the last two decades and is a widely used single photon marker for detecting the presence of malignancy and for diagnosis of inflammatory diseases. [55] γ-emitters from ^{67}Ga used in Single Photon Emission Computed Tomography (SPECT) [55].

Selenium-75: has a half-life of ($T_{1/2}$=119.78 d) decays to stable ^{75}As by electron capture 100 %. Its decay emissions include gamma rays of 120.8(17.2%), 136(58.5%), 265(58.6%), 279.5(24.9%) [57]. used in the form of seleno-methionine to study the production of digestive enzymes [59]. ^{75}Se radioisotopes are widely used in medicine, industry and agriculture. ^{75}Se is used in high activity brachytherapy, assessment of pancreatic exocrine function, study of bile acids and evaluation of illeal function, industrial radiography and as a tracer in the assessment of chemical, biochemical, biophysical processes, metabolic researches and agricultural studies [57].

Palladium-103: has a half-life of ($T_{1/2}$=16.9991 d) decays to stable ^{103}Rh by electron capture 100 %. Which de-excites by means of a heavily converted internal transition. As a result of both processes (EC and IT), X-rays and Auger electrons are emitted which are ideally suited for brachytherapy (its electron capture decay resulting in abundant emission of Auger electrons and low energy X-rays (20–22 keV)) [98, 58]. ^{103}Pd used to make sealed seeds (brachytherapy) permanent implant seeds for early stage prostate cancer [59]. ^{103}Pd is extensively used in the treatment of prostate cancer and ocular melanoma, and is mostly applied in the form of sealed seeds (brachytherapy) [58].

Indium-111: has a half-life of ($T_{1/2}$=2.83d) decays to stable ^{111}Cd by electron capture 100 %. There are two prominent gamma rays, one at 171.3 keV and one at 245.4 keV [52]. Indium-111 octreotide, a radiolabeled somatostatin analogue, binds to somatostatin receptors, which are very common in several cancers. Indium-111 may, therefore, be useful for the visualization of metastases in cancer patients. [52]. ^{111}In Used for specialist diagnostic studies, brain studies, infection and colon transit studies [59].

Indium-114^{m}: is nucleus of the nucleus of ^{114}In in the first energy level excited. ^{114m}In has a half-life of ($T_{1/2}$=49.51 d) decays to stable by electron capture (E.C) with positron ($^{+}\beta$) 3.25 % and decay to ^{114}In by Internal Transition (IT) 96.75%, ^{114m}In used in radio-immunotherapy, therapeutic radioisotope. The use of positron emitters radionuclides such as (^{64}Cu, ^{114m}In, ^{123}I, ^{149}Tb, ^{195m}Hg, etc), for radionuclide therapy is questionable because the interaction of positrons in tissues results in the 511 keV annihilation photons. These constitute a major contribution to the absorbed dose in the surrounding healthy tissues. Nevertheless, positron emitters may be valuable for the selection of radio-immunotherapy candidates by confirming tumor targeting and/or estimating radiation doses [60].

Erbium-165: has a suitable half-life of ($T_{1/2}$=10.36 h) decays to stable ^{165}Ho by electron capture 100 %. Erbium-165 is one from very few radionuclides exists that decay exclusively by EC-mode without any accompanying radiation, ^{165}Er is one of them. Auger electrons are emitted by isotopes that decay by electron capture (EC) or have internal conversion (IC) in their decay of these isotopes a cascade of very low energy electrons is emitted [61].

Ytterbium-169: has a half-life of ($T_{1/2}$=32.018 d) decays to stable ^{169}Tm by electron capture 100 %. ^{169}Yb can be used for cerebrospinal fluid studies in the brain [59]. Many methods to produced of ^{169}Yb in nuclear reactor or by accelerators cyclotron, The average cross section of the $^{168}Yb(n,gamma)^{169}Yb$ process is very high as compared to that of the $^{169}Tm(p,n)^{169}Yb$ reaction. However, the abundance of ^{168}Yb in natural ytterbium is only 0.13 %. In practice, In cyclotron production via the $^{169}Tm(p,n)^{169}Yb$ reaction, the cross section is lowest then reaction in reactor , but the abundance of ^{169}Tm in natural 100% [62].

Rhenium-186: has a half-life of ($T_{1/2}$=3.7183 d) decays to stable ^{186}W by electron capture (E.C) 7.47 % and decay to ^{186}Os by electron emitted (β^-) 92.53 % with $E_{Max\beta}$ = 1.1 MeV, Eγ =137 keV [63]. ^{186}Re Used for pain relief in bone cancer, beta emitter with weak gamma for imaging [59]. ^{186}Re is a beta and gamma emitter which is used in metabolic radiotherapy and radio immunotherapy (RIT). After labelling with hydroxethylidene diphosphonate (HEDP) is a new compound used for the palliation of painful skeletal metastases. Make it a useful radioisotope for the treatment of small tumors in the body. One of the most common applications of ^{186}Re is palliation of painful bone metastasis caused by prostate or breast cancer, and it is also useful for treating painful arthritis.[64] In addition, the γ-ray emitted with E_γ =137 keV (branching ratio of 9.5%), which can be imaged by Single Photon Emission Computed Tomography (SPECT) to determine the distribution of the radioactivity in the body [63].

In figure 10, we've noted abundant reactions with high neutron yield value when the proton is interacting with intermediate nuclei target such as (^{64}Ni, ^{67}Zn, ^{75}As, ^{103}Rh, ^{111}Cd, ^{114}Cd) compared with heavy nuclei target (^{165}Ho, ^{169}Tm, ^{186}W).

In figure 11, the $^{75}_{33}As(p,n)^{75}_{34}Se$ reaction has high neutron yield compared with $^{169}_{69}Tm(p,n)^{169}_{70}Yb$ reaction, as the stopping power of incident proton on nucleus target ^{75}As *is* lower than ^{169}Tm and also the $^{75}_{33}As(p,n)^{75}_{34}Se$ reaction has a high cross section as shown in figure (3) with dependence on equation (17), when incident proton on intermediate mass nuclei target ^{75}As has a high neutron yield compared with heavy mass nuclei ^{169}Tm target.

When incident charged particle such a proton on intermediate and heavy mass nuclei ^{103}Rh and ^{165}Ho targets, We've noted the $^{103}_{45}Rh(p,n)^{103}_{46}Pd$ reaction is high neutron yield compared with $^{165}_{67}Ho(p,n)^{165}_{68}Er$ reaction, as shown in figure 12 because ^{103}Rh target has low stopping power of Incident proton compared with ^{165}Ho target, as well as the abundance of ^{103}Rh and ^{165}Ho is 100%, the $^{103}_{45}Rh(p,n)^{103}_{46}Pd$ reaction has a high cross section as shown in figure (4) with dependence on equation (17).

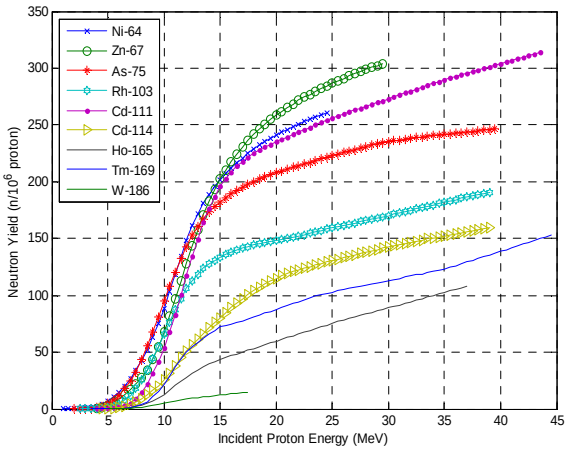

Figure 10: Neutron Yield of Intermediate and Heavy Nuclei as a Target

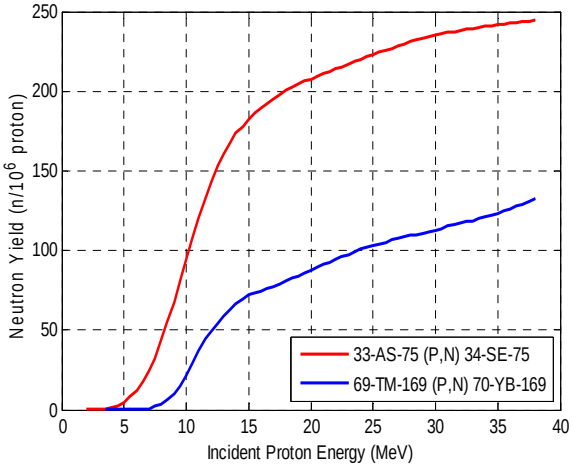

Figure 11: Neutron Yield of Intermediate and Heavy Nuclei as a Target

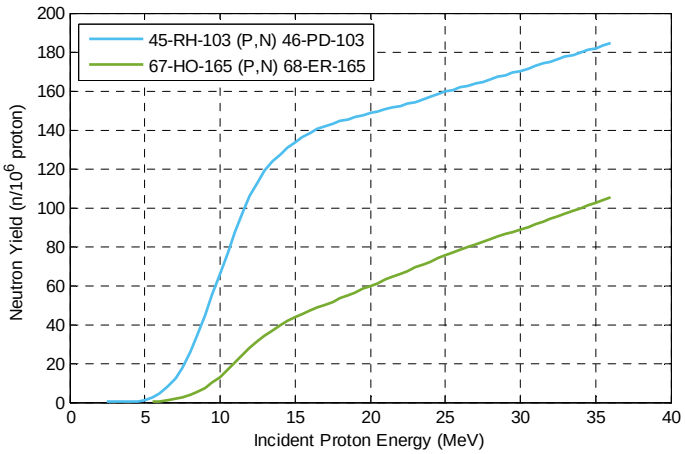

Figure 12: Neutron Yield of Intermediate and Heavy Nuclei as a Target

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