Journal of Nuclear and Radiation Physics, Vol. 2, No. 1, 2007, pp. 1-12

# THIN TARGET YIELDS AND EMPIRE-II PREDICTIONS ON THE ACCELERATOR PRODUCTION OF TECHNETIUM-99m

**M. B. Challan[a], M. N. H. Comsan[a], and M. A. Abou-Zeid[b].**

[a]*Inshas Cyclotron Facility, Nuclear Research Center, Cairo, P. Code 13759, Egypt.*
[b]*Department of Physics, Mansoura University, Mansoura, P. Code 35516, Egypt.*

*Rec. 24/5/2006* *Accept. 30/12/2006*

Thin target yields of $^{99m}$Tc radionuclide produced on accelerator by means of the reactions $^{nat}$Mo(p,x) from threshold up to 18 MeV are given. The experimental data have been measured employing the stacked foil activation technique. To the best of our knowledge the theoretical analysis of the excitation functions based on the EMPIRE-II code, used for the first time, gave good agree the theoretical and experimental data. This code could be used to predict the cross sections of the isomeric states for the $^{100}$Mo(p,x)$^{99m}$Tc. Effects of various free parameters used in the calculations are also discussed. A significant contribution of pre-equilibrium CN component has been observed at these energies. Methods of cyclotron production of $^{99m}$Tc are considered.

**Keywords:** *Proton Induced Nuclear Reactions, Cross Sections, Thin Target Yield, Stacked Foil Activation Technique, Isotope Production, Compound Nuclei, Molybdenum, Natural Targets*

## INTRODUCTION

In the nowadays the radionuclides production for medical use has been considered as an important application for public health. The application of $^{99m}$Tc in nuclear medicine has quite superior significance, which as a significant medical radioisotope has been highly nominated, it now involved in about 80% of all scans carried out per the year over all the worlds. The availability of this nuclide, which can be eluted with saline from a commercial generator consisting of $^{99}$Mo adsorbed on an alumina column and its nuclear properties ($T_{1/2}$ = 6.01 h, $E\gamma$ = 140.5 keV, $I\gamma$ = 89.06%) have led to the widespread use of $^{99m}$Tc for imaging purposes [1].

In the past and recent years a proper competence has been developed around the world in the field of the estimation of the nuclear data for the reactions induced by charged particles (mainly protons, deuterons, and α -particles) on technetium isotopes.

The continuing concern to assure the continuing supply of $^{99}$Mo for the $^{99}$Mo→$^{99m}$Tc generator motivated us to examine alternative production methods Rojas-Burke, (1995) [2]. Accelerators can be used instead of nuclear reactor to produce some medical isotopes. There are discrepancies between the reports of Beaver and Hupf (1971) [3], Almeida and Helus (1977) [4], Lagunas-Solar et al (1991) [5], and Levkowski (1991) [6] of the experimental thick target yields for the $^{nat}$Mo(p,pn)$^{99}$Mo nuclear reaction. Beaver and Hupf (1971) [3] suggested that a 22 MeV cyclotron is capable of producing a sufficient quantity of $^{99}$Mo by $^{100}$Mo(p,pn)$^{99}$Mo and the $^{nat}$Mo→$^{99}$Mo nuclear reaction to serve as a reserve $^{99}$Mo→$^{99m}$Tc generator. Almeida and Helus (1977) extended the experimental measurements up to 25 MeV and reported yields in good agreement with Beaver and Hupf (1971) [3]. Lambrecht (1988) [7] noted the requirement for nuclear data concerning the cyclotron production of $^{99m}$Tc and $^{99}$Mo at an IAEA Consultants' meeting on "Data Requirements for Medical Radioisotopes" that was held in Tokyo in (1988). This stimulated some interest Lagunas-Solar et al., (1991, 1993) [5, 8], but failed to resolve the practical aspects necessary to lead to a conclusion on feasibility of accelerators for production of these medically important radionuclides. However, Lagunas-Solar et al., (1991) [5] rationalized that their experimental measurements for reactions leading to $^{99}$Mo with 68→8 MeV protons on $^{nat}$Mo is possible. Lagunas-Solar et al., (1991) and Lagunas-Solar et al., (1993) [5,8] qualified their predictions as justifiable to meet regional needs of developing nations for $^{99}$Mo→$^{99m}$Tc generator. They extrapolated their data from natural isotopic composition Mo to highly enriched $^{100}$Mo targets. Unfortunately, no evaluation details are given in the nuclear data tables of $^{100}$Mo(p,pn)$^{99}$Mo cross sections measured by Levkowski (1991) [6].

Recently the cross section measurement and yield calculation carried out by Scholten et al., (1999) [9] for the $^{100}$Mo(p.pn)$^{99}$Mo process showed that the $^{99m}$Tc production at a cyclotron is not very suitable due to the low cross section (~120 mb) over the proton energy range of 30 – 50 MeV, which lies the region of the maximum of the excitation function. Even if a very thick target of highly enriched $^{100}$Mo is constructed to cover the full investigated energy range $E_p$= 65 → 10 MeV. The $^{98}$Mo(p.γ)$^{99m}$Tc nuclear reaction was found to have a cross section < 0.2 mb over the proton energy range studied. The earlier assignment of this reaction channel as a potential route for production of $^{99m}$Tc with a medical cyclotron is a more worse trend to be investigated in this study from natural target. Special efforts have been recently exerted at the Inshas Variable Energy Cyclotron Facility, Nuclear Research Center, Cairo, EGYPT to produce some medical radionuclides described by M. N. Comsan [10]. In this paper, the experimental values of the yields and the excitation functions obtained at the MGC-20 cyclotron, NRC, Cairo, Egypt with using of stacked foils technique have been presented.

## EXPERIMENTAL TECHNIQUE

In the present measurements the stacked foil activation technique has been used. The natural molybdenum foil (99.99% pure) of 25 μm±1.4% thick which is equivalent to 25.7 mg/cm$^2$ ±1.4% was used as targets. Two stacks containing 7 and 9 molybdenum foils respectively were separately irradiated by 15 and 18 MeV initial proton energy. Aluminum foils inserted in the target assembly served as energy absorbers. Copper foils of 10 and 20 μm thick inserted between the target stacks were used for monitoring of proton energy and current. The reaction cross sections of Cu with protons given by IAEA [11] were used at calculations of cross sections and yields for molybdenum. The energy losses in the stacks foils were calculated SRIM code. An energy-range calculation was carried out to estimate the proton energy at the half-thickness of each target [12].The beam current was monitored by a current integrator with the Faraday cup. The average beam current was about 150 nA during 1h.

The off-line counting of the irradiated samples was carried out using vertical coaxial closed end 70% HPGe $\gamma$-ray detector (resolution $\approx$ 2 keV for 1.33MeV $\gamma$-ray of $^{60}$Co) coupled to the ORTEC's PC based multi-channel analyzer. The detector was pre-calibrated using standard sources, which was also used for the determination of the geometric factors and efficiency of detection. The radionuclides were identified over their characteristic gamma lines as well as from their half-lives. The nuclear data required for the calculations were taken consistently from the Table of Isotopes [13, 14]. Counting rates were converted to disintegration rates by applying corrections for counter efficiencies, branching ratios and growth and decay characteristics of metastable and ground states. Finally the production cross-section for each nuclide was determined by comparison to the observed disintegration rate and known cross section for the monitor reactions.

## NUCLEAR MODELS CALCULATIONS

The role of the nuclear model calculations has been well recognized for nuclear data evaluation, and for computing codes with respect to the experimental data and for model parameterization and systematics. They are aiming to provide reliable data calculations, particularly in cases where there is a lake of data or there are discrepancies. In this work calculations for the nuclear reactions have been carried out using EMPIRE-II system Herman, (2005) [15]. EMPIRE-II accounting for the major nuclear reaction mechanisms, including the Optical Model (OM), the Multi-step Compound, Exciton Model, full featured Hauzer-Feshbach Model, with a comprehensive parameter library mainly covering nuclear mass, OM data, discrete levels and decay schemes. The Monte Carlo pre-equilibrium approach has been particularly successful in approximating the experimental values. As the determination of the nuclear level density is of main impact on the results, taking into account the dependence of the most crucial "level density parameter" on the nuclear excitation energy. The preliminary theoretical results predict cross section values higher than ~70 mb in the energy interval 14-19 MeV. The considered reactions appear to be confirmed as a promising production route for $^{99m}$Tc.

## RESULTS AND DISCUSSION

Nuclear data on gamma lines of radionuclides $^{99m}$Tc, $^{96}$Tc, $^{48}$V, $^{57}$Ni, $^{62}$Zn, $^{62}$Zn and $^{65}$Zn (half life, decay mode, Eγ and Iγ) in irradiated foils were taken from [13], reaction Q-values were taken from [14].

From the measured intensities of the identified gamma rays, the cross-sections at different incident energies were computed. If the sample having the initial number of nuclei $N_0$ is irradiated by a beam of flux $\phi$ for a time $t_i$ and the activity in the sample is recorded for a time $t_m$ after elapse of time $t_c$, by a detector of geometry dependent efficiency $G\varepsilon$; the reaction cross-section $\sigma$ is given by the expression:

$$\sigma_r = \frac{C_p \lambda \exp(\lambda t_c)}{N_0 \phi \theta K G \varepsilon \left[1-\exp(\lambda t_i)\right]\left[1-\exp(\lambda t_m)\right]}, \tag{1}$$

where, $C_p$ being the counts under photo-peak, $\lambda$ the decay constant of residual nuclei, $\theta$ is the branching ratio of the particular radiation. K is the γ-ray self-absorption correction for the material of the sample and is given by:

$$K = \left[ \{1-\exp(\mu d)\} \middle/ \mu d \right], \tag{2}$$

where, $\mu$ is the γ-ray absorption coefficient for the sample and d is the thickness of the sample.

The thin target yields for the production of $^{96}$Tc and $^{99m}$Tc by nuclear reactions on a natural molybdenum target in the energy range from threshold up to 18 MeV are presented in Figure 1. The cumulative excitation functions for the production of $^{96}$Tc and $^{99m}$Tc are presented in Figure 2. The experimental data for the thin targets yields are compared with the model calculations (solid lines). New measurements appear to be desirable in order to reduce the present experimental uncertainties.

In Figures 2. and 3. the thick target yield Y(E, ΔE) is defined as two parameters function of incident energy E (MeV) on the target and energy loss ΔE (MeV) in the target itself. For the production of $^{96}$Tc, and $^{99m}$Tc by nuclear reactions on a natural molybdenum target in the energy range up to 18 MeV, reactions such as (p,xn) could be considered.

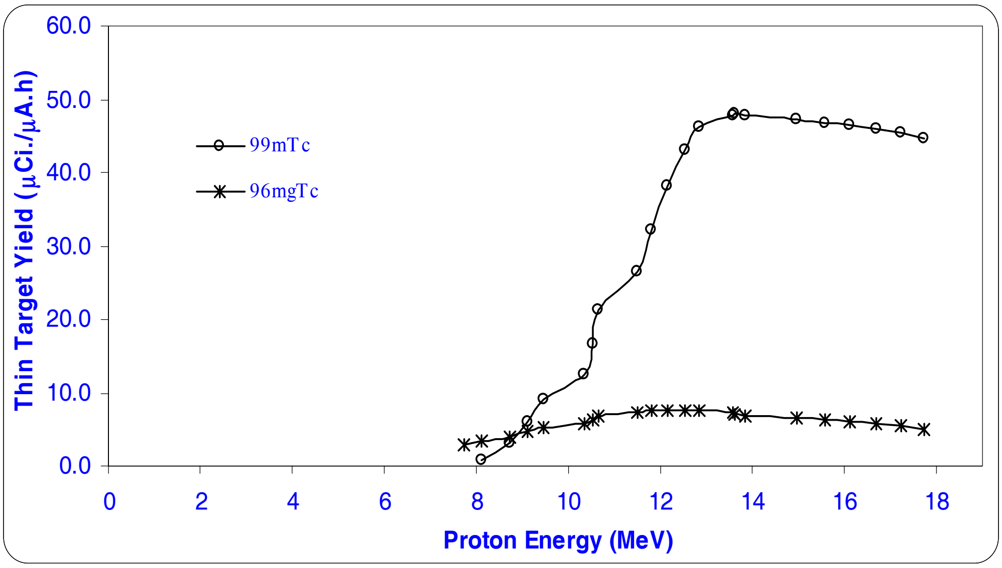

**Figure 1.** Thin target yields for ${}^{96(m+g)}$Tc, and ${}^{99m}$Tc.

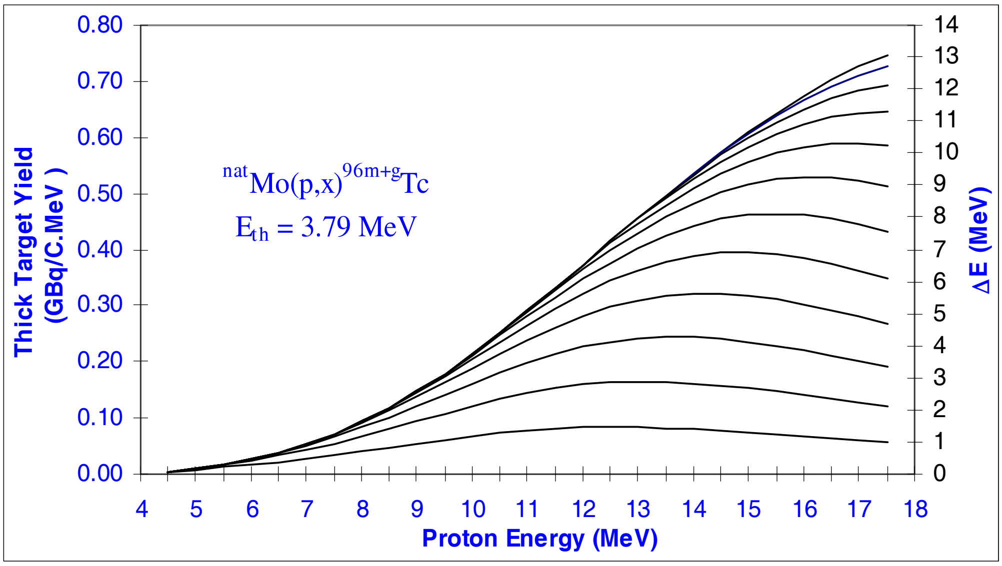

**Figure 2.** The thick target yield as a function of target thickness (in MeV) for the production of ${}^{96m+g}$Tc.

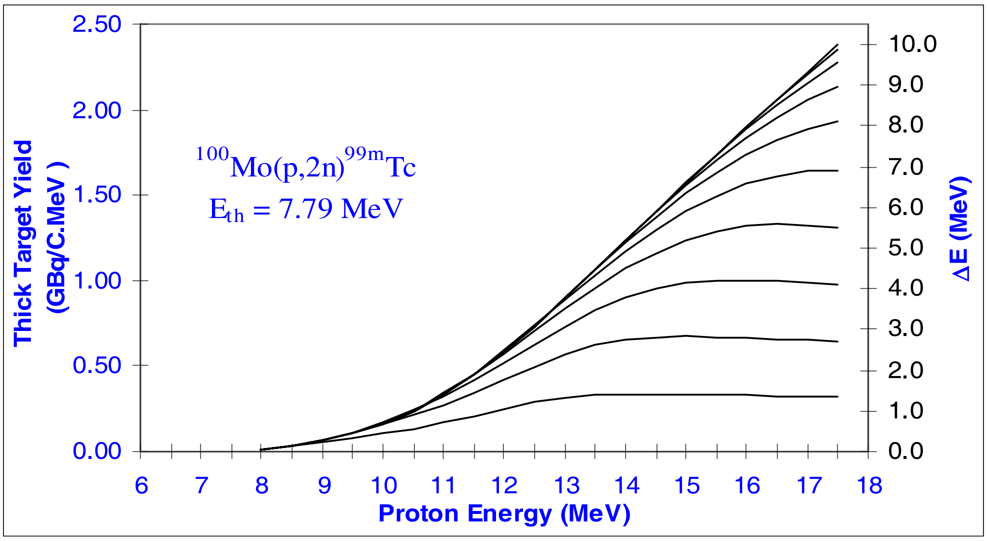

**Figure 3.** The thick target yield as a function of target thickness (in MeV) for the production of $^{99m}$Tc.

## THE $^{nat}$Mo(p,x)$^{96m+g}$Tc REACTION

A literature survey showed that several authors have measured cross-sections for the production of the $^{96}$Tc isotope using enriched and/or natural molybdenum targets. A summary of the works for the production of $^{96mg}$Tc from natural Mo targets, total cross section, and thin, thick yields as a function of proton energies, the data obtained and their estimated errors are tabulated in Table 1. The excitation function of the $^{nat}$Mo(p,x)$^{96m+g}$Tc reaction obtained in this work is shown in Figure 4., the experimental data for more recent works. The data reported by S. Takacs et al., (2002) [16] present cross-section data for the $^{nat}$Mo(p,x)$^{96mg}$Tc process in their paper measured the stacked samples were irradiated in vacuum at an external beam line of a cyclotron accelerator with high energy precision. Data are given up to 38 MeV and are in very good agreement with our data, in the match energy range. M. Bonardi et al., (2002) [17] presented numerical data measured on natural molybdenum targets up to 43.7 MeV. The type of cross-section they present concerns cumulative elemental cross-section for the $^{nat}$Mo(p,x)$^{96mg}$Tc process. The trend of the high-energy tail of the excitation function is reproduced by the inclusion of the pre-equilibrium calculation of EMPIRE-II code [15], while the cross section obtained by EMPIRE-II disagree with the experimental data, this disagreement reveal that the good selection of optical model parameters produces particles transmission coefficient which is responsible elevating the cross sections results. As well as the level densities calculation could uses different models or even a mix such as Fermi Gas model (FG) + Hartree-Fock approach (BCS) which is the default option for level density functions in EMPIRE-II, which consider the deformation-dependent collective effects. For the nuclei involved in the reaction induced by protons with a few MeV show more suitable with Gilbert-Cameron density function; its parameters are adjusted to the cumulative number of low-lying states and to the mean level distance at neutron binding energy. In discrete-level spectroscopy with light particle induced reactions in general and particularly not in this case $^{96g}$Tc ($7^+$), $^{96m}$Tc ($4^+$), the residual nuclei are not populated in states with very high excitation energies. Therefore, the level density functions describing the continuum spectra are not crucial for the calculated cross sections.

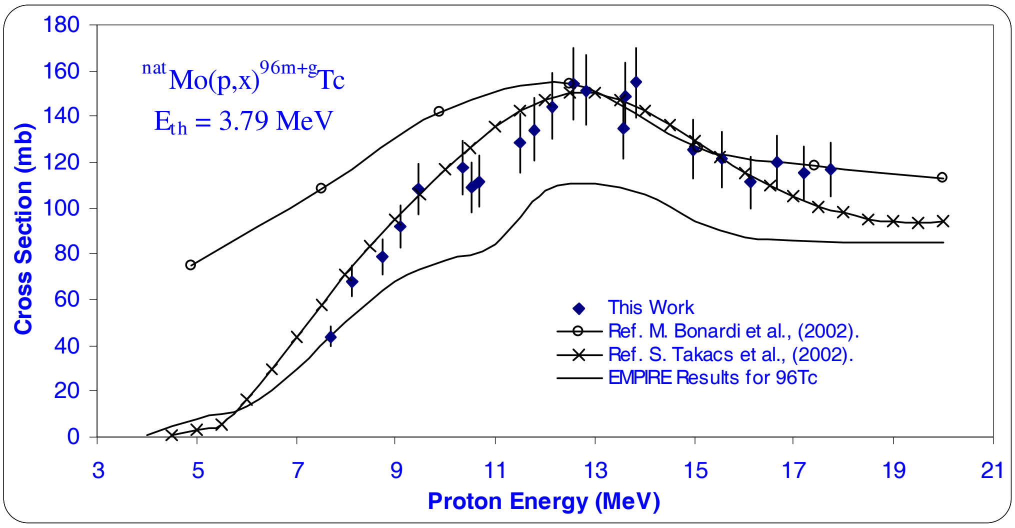

**Figure 4.** The excitation function of the $^{nat}$Mo(p,x)$^{96m+g}$Tc reaction.

## THE $^{nat}$Mo(p,x)$^{99m}$Tc REACTION

Three reactions contribute to the production of $^{nat}$**Mo**(p,x)$^{99m}$Tc by direct way are $^{98}$Mo(p,γ), $^{100}$**Mo**(p,2n), and indirect way by $^{100}$Mo(p,pn). The excitation function of the $^{nat}$Mo(p,x)$^{99m}$Tc reaction obtained in this work is shown in Figure 5. The production of $^{96mg}$Tc from natural Mo targets, total cross section, and thin, thick yields as a function of proton energies, the data obtained and their estimated errors are tabulated in Table 2. The excitation function of the $^{98}$Mo(p,γ)$^{99m}$Tc reaction cross section is very small and the errors are large as reported by B. Scholten et al., (1999) [9]. This reaction is of no practical relevance for the production of $^{99m}$Tc. This result obtained by Scholten is contrary to that previously claimed by Lagunas-Solar et al. (1991) [8] who supposed a high (p,γ) cross section, is responsible for $^{99m}$Tc production. Presumably, as Scholten proposed due to some impurity effect. He also noted that, capture reactions in the MeV region have a cross section typically of the order of 1 mb, both in (n,γ) and (p,γ) processes [9].

Possibly the whole trend may be a reaction of the $^{100}$Mo(p,2n)$^{99m}$Tc reaction (on the 9.63% $^{100}$Mo present in the naturally highly pure Mo sample). In contrast, our results on the $^{nat}$Mo(p,x)$^{99m}$Tc reaction are higher than the data reported by Scholten et al., (1999) [9] in the same time are in good agreement with others Lagunas-Solar et al., (1991); Levkowski et al., (1991) [5, 6] in the same energy region. It is shown from the Figure 5. that, EMPIRE-II is capable to predict, assign the level spin and parity for isomeric state responsible mainly for this process and evaluate the cross section pertained to it.

**Table 1.** Measured Cross Sections Values for Production of $^{96m+g}$Tc, on Natural Mo Targets at Different Energies.

| Incident Energy $E_p$ (MeV) | $^{nat}$Mo(p,x)$^{96m+g}$Tc | | Differential Yields µCi/µA·h | Integral Yields GBq/C·MeV |
|---|---|---|---|---|
| | σ(mb) | ±δσ(mb) | | |
| 17.74±0.75 | 117.00 | 11.70 | 50.47 | 0.75 |
| 17.21±0.73 | 115.14 | 11.51 | 53.64 | 0.73 |
| 16.67±0.71 | 120.00 | 12.00 | 56.44 | 0.70 |
| 16.12±0.68 | 111.25 | 11.13 | 59.35 | 0.67 |
| 15.56±0.66 | 121.34 | 12.13 | 62.32 | 0.64 |
| 14.98±0.64 | 125.74 | 12.57 | 65.29 | 0.61 |
| 13.83±0.59 | 154.72 | 15.47 | 68.17 | 0.57 |
| 13.62±0.58 | 148.95 | 14.90 | 70.74 | 0.53 |
| 13.56±0.57 | 134.97 | 13.50 | 72.90 | 0.50 |
| 12.84±0.54 | 151.37 | 15.14 | 74.54 | 0.46 |
| 12.56±0.53 | 154.47 | 15.45 | 75.43 | 0.41 |
| 12.15±0.52 | 144.21 | 14.42 | 75.33 | 0.37 |
| 11.79±0.50 | 134.29 | 13.43 | 74.17 | 0.33 |
| 11.49±0.49 | 128.42 | 12.84 | 71.80 | 0.29 |
| 10.67±0.45 | 111.67 | 11.17 | 68.24 | 0.25 |
| 10.54±0.45 | 109.15 | 10.92 | 63.63 | 0.21 |
| 10.34±0.44 | 117.59 | 11.76 | 58.10 | 0.18 |
| 9.46±0.40 | 108.23 | 10.82 | 52.02 | 0.15 |
| 9.10±0.39 | 92.18 | 9.22 | 45.73 | 0.12 |
| 8.73±0.37 | 78.52 | 7.85 | 39.40 | 0.09 |
| 8.11±0.34 | 67.99 | 6.80 | 33.19 | 0.07 |
| 7.71±0.33 | 43.80 | 4.38 | 27.38 | 0.05 |

Lagunas-Solar et al., (1991) [5] postulated that the production of $^{99m}$Tc could be due to two distinct reaction channels. The excitation function shows the first maximum at 19 MeV and was ascribed to the reaction channel $^{98}$Mo(p,γ)$^{99m}$Tc (Q=-6.36 MeV). It was strongly argued by Lagunas-Solar (1993) [8] that the $^{98}$Mo(p,γ)$^{99m}$Tc nuclear reaction with 20→10 MeV protons on enriched $^{98}$Mo was viable and would have the added advantage of potentially reducing costs of cyclotron installation and operation. The second maximum in the cross section appeared at 42 MeV and was suggested to be due to the $^{100}$Mo(p,2n)$^{99m}$Tc (Q=-7.85 MeV) reaction. Scholten measurements using highly enriched Mo as target material depict clearly that the peak at $E_p$≈17 MeV is due to the $^{100}$Mo(p,2n)$^{99m}$Tc reaction and not the $^{98}$Mo(p,γ)-process at higher energies no other peak was observed. The second maximum in the excitation function at higher energies reported by Lagunas-Solar et al. (1991) [5] is thus obscure. It should be emphasized that the $^{100}$Mo(p,2n)$^{99m}$Te reaction cannot be compared to a normal (p,2n) reaction in this mass region, since the produced activity is an isomeric state. The systematics is generally valid for total (p,xn) cross sections but not for the formation of higher spins isomers. Even detailed statistical model calculations, incorporating precompound model and nuclear structure effects are often incapable of reproducing the isomeric cross section Nagame et al., (1994) [18]. An accurate experimental database is thus crucial to consider the feasibility of this reaction for a possible production of $^{99m}$Tc at a cyclotron. A limiting factor in this regard would be the level of co-produced long-lived $^{99g}$Tc impurity. Experimentally this is very hard to determine and was outside the scope of the present work.

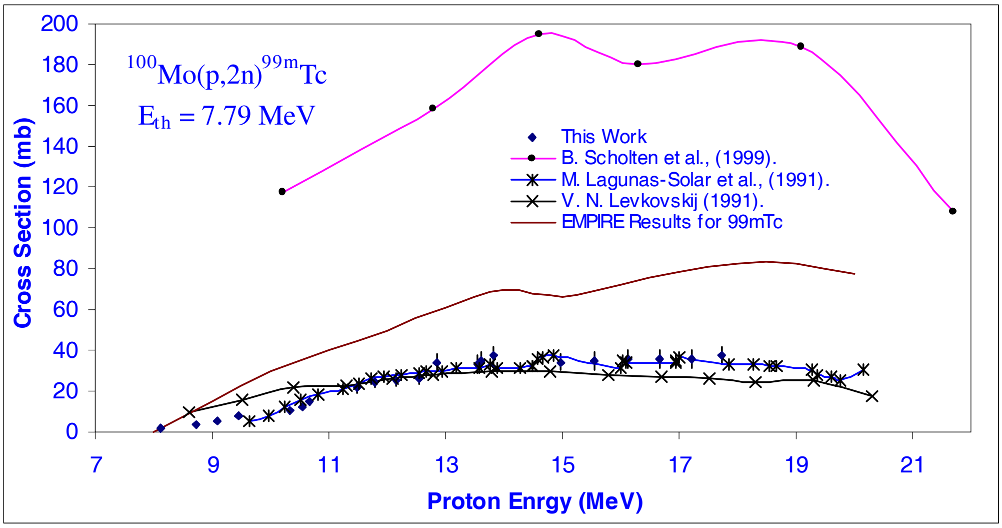

**Figure 5.** The excitation function of the $^{100}$Mo(p,2n)$^{99m}$Tc reaction.

**Table 2.** Measured cross sections values for production of $^{99m}$Tc on natural Mo targets at different energies.

| Incident Energy $E_p$ (MeV) | $^{nat}$Mo(p,x)$^{99m}$Tc |  | Differential Yields μCi/μA·h | Integral Yields GBq/C·MeV |
|---|---|---|---|---|
|  | σ(mb) | ±δσ(mb) |  |  |
| 17.74±0.75 | 37.25 | 3.82 | 44.7 | 2.38 |
| 17.21±0.73 | 35.73 | 3.66 | 45.6 | 2.22 |
| 16.67±0.71 | 35.46 | 3.64 | 46.0 | 2.06 |
| 16.12±0.68 | 35.90 | 3.68 | 46.4 | 1.90 |
| 15.56±0.66 | 34.72 | 3.75 | 46.9 | 1.73 |
| 14.98±0.64 | 34.12 | 3.69 | 47.3 | 1.57 |
| 13.83±0.59 | 37.28 | 4.03 | 47.7 | 1.40 |
| 13.62±0.58 | 34.82 | 3.76 | 47.9 | 1.23 |
| 13.56±0.57 | 33.07 | 3.72 | 47.7 | 1.06 |
| 12.84±0.54 | 33.83 | 3.81 | 46.3 | 0.90 |
| 12.56±0.53 | 26.44 | 2.98 | 43.1 | 0.73 |
| 12.15±0.52 | 25.49 | 2.87 | 38.1 | 0.58 |
| 11.79±0.50 | 24.41 | 2.96 | 32.3 | 0.45 |
| 11.49±0.49 | 21.53 | 2.61 | 26.5 | 0.33 |
| 10.67±0.45 | 15.01 | 1.82 | 21.3 | 0.24 |
| 10.54±0.45 | 11.83 | 1.44 | 16.7 | 0.16 |
| 10.34±0.44 | 10.72 | 1.43 | 12.6 | 0.11 |
| 9.46±0.40 | 8.21 | 1.09 | 9.0 | 0.06 |
| 9.10±0.39 | 4.81 | 0.64 | 5.9 | 0.03 |
| 8.73±0.37 | 3.51 | 0.47 | 3.2 | 0.01 |
| 8.11±0.34 | 1.41 | 0.29 | 0.7 | 2.46E-03 |

# REFERENCES

[1] *XI Congress of the Latinamerican Association of Biology and Nuclear Medicine (ALASBIN)*, Santiago, Chile, October 8-11, 1989.

[2] Rojas-Burke, J., "The Future Supply of Molybdenum-99.", *Newsline J. Nucl. Med.* **36**, 15N, (1995).

[3] Beaver, J.E., Hupf, H.B., "Production of $^{99m}$Tc on a Medical Cyclotron: a Feasibility Study.", *J. Nucl. Med.* **12**, p. 739 (1971).

[4] Almeida, G.L., Helus, F., "On the Production of $^{99}$Mo and $^{99m}$Tc by Cyclotron". *Radiochem. Radioanal. Lett.* **28**, p205(1977).

[5] Lagunas-Solar, M.C., Kiefer, P.M., Carvacho, O.F., Lagunas, C.A., and Po Cha Ya, "Cyclotron Production of NCA $^{99m}$Tc and $^{99}$Mo. An Alternative Non-Reactor Supply Source of Instant $^{99m}$Tc, and $^{99}$Mo→$^{99m}$Tc Generators.", *Appl. Radiat. Isot.* **42**, 643(1991).

[6] Levkowski, N., "Medium Mass Nuclides (A=40-100) Activation Cross Sections by Medium Energy (E=10-50 MeV) Protons and $\alpha$-Particles (Experiment and Systematics).", Inter-Vesti, Moscow, USSR, 215(1991).

[7] Lambrecht, R.M., Waters, S.L., Lu, H., Qaim, S.M., Umezawa, H., Beyer, G.J., Heinzl, H., Bonardi, M., Nozaki, T., Hashizume, A., Lagunas-Solar, M.C., Kitao, K., and Berenyi, D., "Summary of Conclusions and Recommendations of Working Group I: Experimental Data. In: Okamoto, K. (Ed.), Consultants" *Meeting on Data Requirements for Medical Radioisotope Production*, Tokyo, Japan, 1987. Report INDC (NDS)-195/GZ, *IAEA*, Vienna, pp. 13-16(1988).

[8] Lagunas-Solar, M.C., "Production of $^{99m}$Tc and $^{99}$Mo for Nuclear Medicine Applications via Accelerators as an Option to Reactor Methods.", *Presented at the 18th Annual Conference of the Australian Radiation Protection Society,* University of Sydney, Sydney, NSW, Australia, Oct. 6-8, 1993.

[9] Scholten, B., Lambrecht, R. M., Cogneau, M., Vera Ruiz, H., and Qaim, S. M., "Excitation Functions for the Cyclotron Production of $^{99m}$Tc and $^{99}$Mo", *Appl. Radiat. Isot.* **51**, pp. 69-80(1999).

[10] Comsan, M.N.H., "Status Report of Inshas Ion Accelerators", *Proceeding of the Fifth Conference and Workshop on Cyclotrons and Applications*, Cairo, Egypt, Feb. 22-26, 2003, p. 7.

[11] Tarkanyi, F, Takacs, S., Gul, K., Hermanne, A., Mustafa, M.G., Nortier, M., Oblozinsky, P., Qaim, S.M., Scholten, B., Shubin, Yu.N., Youxiang., Z., *IAEA-TECDOC-1211*, International Atomic Energy Agency, Vienna, Austria, 49(2001). http://iaeand.iaea.org.at/medical, 2001.

[12] Ziegler, F., "SRIM 2003 code", SRIM.com, 1201 Dixona Dr., Edgewater, 21037, USA, available from www.SRIM.org, (2003).

[13] Firestone, R.B., Baglin, C.M., Chu, F.S.Y., and Zipkin, J., "*Table of Isotopes*", 8th Edition 1996, Vols. I and II. Wiley, New York. Firestone, R.B., Baglin,C.M., and Chu, F.S.Y., "*Table of Isotopes*", 8th Edition 1998, Update on CD-ROM. Wiley, New York.

[14] "Reaction Q-values, and Thresholds", *Los Alamos National Laboratory, T-2 Nuclear Information Service. Available from <http://t2.lanl.gov/data/qtool.html>*, 2005.

[15] Herman, M., "EMPIRE-II Statistical Model Code for Nuclear Reaction Calculations", (Londi), *IAEA*, Vienna, Austria, March, Version 2.19, 2005. Available from: http://www-nds.iaea.org/empire/, 2005.

[16] Takacs, S., Tarkanyi, F., Sonck, M., and Hermanne, A., "Investigation of the $^{nat}Mo(p,x)^{96mg}Tc$ Nuclear Reaction to Monitor Proton Beams: New Measurements and Consequences on the Earlier Reported Data", *Nucl. Instr. and Meth.* **198**, pp. 183-196(2002).

[17] Bonardi, M., Birattari, C., Groppi, F., and Sabbioni, E., "Thin-Target Excitation Functions, Cross-Sections and Optimized Thick-Target Yields for $^{nat}Mo(p,xn)^{94g,95m,95g,96(m+g)}Tc$ Nuclear Reactions Induced by Protons from Threshold up to 44 MeV. No Carrier Added Radiochemical Separation and Quality Control", *Appl. Radiat. and Isot*. **57**, pp. 617–635(2002).

[18] Nagame, Y., Baba, S., and Saito, T., "Isomeric Yield Ratios for the $^{95}Mo(p,n)^{95m,g}Tc$ Reaction", *Appl. Radiat. Isot.* **45**, No. 3, pp. 281-285(1994).

# النواتج المتحصلة من الأهداف الرقيقة وتنبؤات الامباير-٢ لإنتاج التكنيشيوم-٩٩م بواسطة المعجلات

**محسن بخيت شعلان١)، محمد ناصف قمصان١)، محمود أحمد أبوزيد٢)**

*١) منشأة السيكلوترون بأنشاص، مركز البحوث النووية، القاهرة، كود بريدي ١٣٧٥٩، مصر.*

*٢) قسم الفيزياء، كلية العلوم، جامعة المنصورة، المنصورة، كود بريدي ٣٥٥١٦، مصر.*

قيست النواتج المتحصلة من الأهداف الرقيقة وتنبؤات شفرة الإمباير-٢ لإنتاج التكنيشيوم-٩٩م بواسطة التفاعل $^{nat}Mo(p,x)$ بطاقة بروتونات معجلة تبدأ من عتبة التفاعل وحتى ١٨ م.أ.ف. تم قياس النتائج باستخدام تقنية التنشيط للرقائق المتضامة. وفي حدود علمنا فإن التحليل النظري لدوال الإثارة قد تم تضمينها في هذا البحث للمرة الأولى. وبصفة عامة تتفق الحسابات النظرية مع بيانات النتائج التجريبية. شفرة الإمباير-٢ يمكن استخدامها للتنبؤ بالمقاطع المستعرضة للمستويات الايزومرية لإنتاج $^{nat}Mo(p,x)^{99m}Tc$. تمت مناقشة تأثيرات العوامل المتعددة المستخدمة في الحسابات. وقد تلاحظ وجود مساهمة فعالة لمركبة ما قبل الإتزان للنواة المركبة عند الطاقات المختلفة. يتضمن البحث مناقشة إمكانية استخدام المعجلات كوسيلة لإنتاج $^{99m}Tc$.