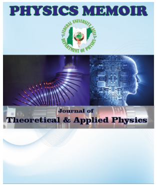

PHYSICS MEMOIR
Available online @ http://jtap.physicsmemoir.com.ng

Phys. Memoir 1 (2019) 61–66

Journal of Theoretical & Applied Physics

Brief Report

Calculation of the Excitation Functions of Alpha-Induced Reaction for the Production of ^{123,124}I from Threshold to 40 Mev

Ahmad Danladi Adamu[a], Nicodemus Kure[b,*], Emmanuel Joseph Adoyi[c], Isaac Daniel Hyuk[b], Bello Ayodeji Ibrahim[d]

[a]*Scientific Equipment Development Institute, Minna, Nigeria*
[b]*Department of physics, Kaduna State University, Kaduna, Nigeria*
[c]*Department of physics, Nigeria Defense Academy, Kaduna, Nigeria*
[d]*Division of Agricultural Colleges, Ahmadu Bello University, Zaria, Nigeria*

Abstract

EXIFON 2.0 code has been used to calculate the (α, n) and $(\alpha, 2n)$ reactions of ^{122}Sb for the cyclotron production of ^{123,124}I which have application in positron emission tomography imaging. For both reactions, the threshold for the reaction obtained from the evaluation compared well with measured values. Results obtained shows good agreement with measurements from EXFOR. It was observed that there is a need for optical model contribution to the pre-equilibrium mechanism of EXIFON at 16MeV for $(\alpha, 2n)$ and 27MeV for (α, n) reactions. However, the results show good agreement with available measured data at lower energy level.

Keywords: Excitation function, Nuclear reaction, iodine-123,124, Nuclear model calculation

Article History :
Received 16 November 2018
Received in revised form 05 February 2019
Accepted for publication 24 February 2019
Published 27 March 2019

1. Introduction

Alpha emitters have great advantages over beta emitters use in cancer therapy due to a higher Linear Energy Transfer (LET) and the limited alpha range in tissue. The increased availability and improved radiochemistry of alpha-particle-emitting nuclides for targeted therapy have presented new possibilities for their use in radio immunotherapy. At the present day, radioisotope production for nuclear medicine is important because of its common use in tomography device. Both single photon emissions computed tomography (SPECT) and positron emission tomography (PET)

*Corresponding author tel. no: +2349036041268
Email address: nicodemus.kure@kasu.edu.ng (Nicodemus Kure)

are used for diagnosis in nuclear medicine. In particular, the radionuclides ^{123,124}I are used for these purposes. Therefore, these radionuclides play important role in medical applications and researches. Gamma-emitted short-lived $^{123}I(T_{1/2} = 13.2h)$ and long-lived ^{124}I ($T_{1/2} = 4.18d$) [1] isotopes can be used as diagnostic image in SPECT and PET [2, 3]. Beside, the ^{124}I allows for studying of important organs such as brain and heart [4]. The longer-lived ^{125}I ($T_{1/2} = 59.4d$) isotope is used as a source for internal radiotherapy, bone dosimetry and a biological tracer [5]. Another iodine radionuclide $^{122}I(T_{1/2} = 3.6min)$, is very short-lived isotope and used in PET for brain blood-flow studies [6]. For each reaction a critical evaluation of excitation function was carried out using the EXIFON 2.0.

2. Theoretical Framework

EXIFON code is an analytical model within a pure statistical multi-step reaction model capable of giving a unique description of emission spectra, angular distributions and activation cross section including equilibrium, pre-equilibrium as well as direct theory (collective and non-collective) processes [7]. The code is restricted to neutron-, proton-,and alpha-induced reactions with neutrons, protons and alphas, photons in the outgoing channels.Three basic ideas mainly influenced this step from simple compound nucleus models and single step direct models towards statistical multi-step theory. They include the classification of nuclear states by their complexity or exciton numbers as proposed by [8], the distinction between bound and unbound state configuration as proposed by Feshbach [9] and the possibility of treating the chaotic nuclear Hamiltonian as a random matrix as proposed by Agassi [10].

These ideas were realized in many body theories by the born series expansion of the related part of the mass operator in powers of the residual interaction with the latter replaced by random matrices. Thus, expression for the differential cross section of the reaction (a,xb) after energy ensemble were obtained as

$$(a, xb) = (SMD) + (SMC) + (MPE), \tag{1}$$

where

- SMD = Statistical Multi-Step Direct Process;
- SMC = Statistical Multi-Step Compound Process
- SMD + SMC = 1st chance emission process
- MPE = Multi particle emission process calculated in a pure SMC concept.

In all these cases, we can account for neutron, proton and alpha induced reactions with neutron, protons, alphas and protons in the outgoing channels.In the statistical multi-step model, the total emission spectrum of the process (a, xb) given as $d\sigma_{a,xb}/dE$ is given in three main parts as [7].

$$\frac{d\sigma_{a,xb}(E_a)}{dE_b} = \frac{d\sigma^{SMC}_{a,b}(E_a)}{dE_b} + \frac{d\sigma^{MPE}_{a,xb}(E_a)}{dE_b} \tag{2}$$

where $d\sigma^{SMC}_{a,xb}(E_a)/dE$ is SMC emission which is based on a masters equation and $d\sigma^{MPE}_{a,xb}(E_a)/dE_b$ is Multiple Particle Emission Process (MPE), reaction which include the second chance, third chance emission etc. summarized in this term i.e.

$$\sum_c \frac{d\sigma_{a,cb}(E_a)}{dE_b} + \sum_c \frac{d\sigma_{a,cdb}(E_a)}{dE_b} + ... \tag{3}$$

The first and second term together i.e. (SMC + SMD) represent the first chance emission process. The SMD cross section is the sum over S-step direct processes given as

$$\frac{d\sigma^{SMD}(E_a)}{dE_b} = \sum_{s=1} \frac{d\sigma^{(s)}_{a,b}(E_a)}{dE_b} \tag{4}$$

While the SMC cross section has the form

$$\frac{d\sigma^{SMD}_{a,b}}{dE_b}(E_a) = \sigma^{SMC}_a(E_a) = \sum_{N=N_0}^{N^1} \frac{\tau N(E)}{\hbar} \sum_{\Delta N} \Gamma^{\Delta,N}_{N,b}(E, E_b) \uparrow \tag{5}$$

where $b = n, p, \alpha, \gamma$. $\tau_\mu(E)$ is the factor satisfying the time integrated master equation given as

$$-\hbar\delta_{NNO} = \Gamma^{(+)}_{N-2}(E) \downarrow \tau_{N-2}(E) + \Gamma^{(-)}_{N+2}(E) \downarrow E_{N+2} - \Gamma_N(E)\tau_N(E) \tag{6}$$

The SMC formation cross section $\sigma^{SMC}_a(E_a)$ for incident energies below 3 Mev and above 18 Mev over predicts the cross section. Therefore, we replace it by

$$\sigma^{SMC}_a(E_a) = \sigma^{Dm}_a(E_a) - \sum_C \sigma^{SMD}_{a,c}(E_a) \tag{7}$$

Which hold in the whole energy range. Equation (7) is taken from probability conservation of nuclear structure effects are pairing effect; Pauli blocking effects, shell-structure effects, and low energy behaviour are included in SMC description. The Multiple Particle Emission (MPE) are calculated in a pure SMC concept. For second-chance processes (a, cb) and $c \neq \gamma$ we write

$$\frac{d\sigma_{a,cb}(E_a)}{dE_b} = \int dE_c \frac{d\sigma_{a,c}(E_a)}{dE_c} \sum_{\Delta N} \Gamma^{\Delta,N}_{N-1,b}(E_1, E_b) \uparrow \tag{8}$$

In this case the master equation has to be solved from each intermediate excitation energy $E_1 = E - B_c - E_c$ where

2.1. Result and Discussion

The results of the excitation function calculated of ^{122}Sb$(\alpha, 2n)^{123}$I and ^{122}Sb$(\alpha, 2n)^{124}$I are plotted in Figures 1 and 2, with EXFOR.

The excitation functions calculated with EXIFON code for the radionuclide ^{123}I is as shown in the Figure 1. The excitation function calculation was compared with experimental measurements for ^{121}Sb$(\alpha, 2n)^{123}$I reaction. The calculation is in good agreement with the measured values in the energy range above 13MeV and below 16MeV. The calculation deviated significantly above this energy point. At an energy beyond 40MeV, the theoretical results for this reaction are discrepant for ^{121}Sb$(\alpha, 2n)^{123}$I reaction. The excitation functions calculated with EXIFON code for the

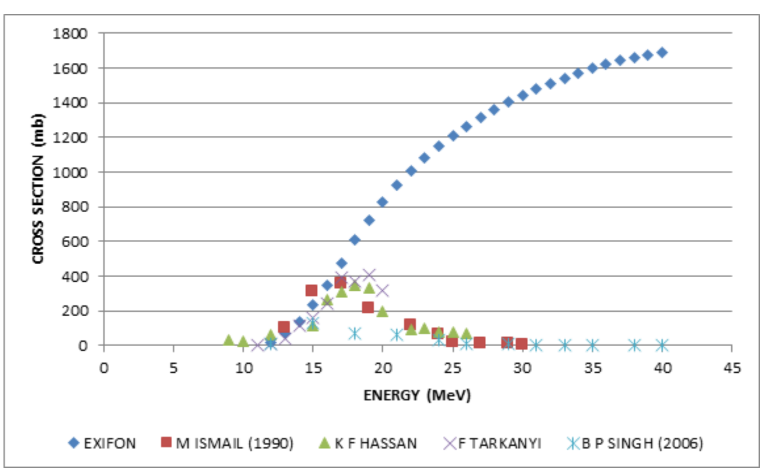

Figure 1. Experimental data along with the results of calculations using the nuclear model code EXIFON for the $^{122}Sb(\alpha, 2n)^{123}$I reaction.

radionuclide ^{124}I is as shown in the Figure 2. The radionuclide can be formed through several different reactions with

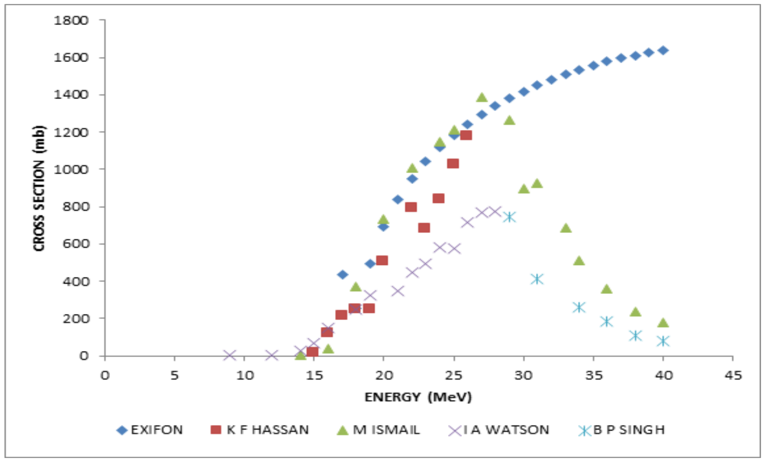

Figure 2. Experimental data along with calculated results from EXIFON for the ^{122}Sb (α, n) ^{124}I reaction.

alpha, proton and deuteron induced. The excitation function calculation was compared with experimental measurements by Ismail, Hassan et al, Tarkanyi et al and Singh et al. [11-14] for ^{121}Sb$(\alpha, n)^{124}$I reaction. The calculation is in reasonably good agreement with the measurement by Ismail and Hassan et al. [11, 12] from threshold to about 27MeV and deviated beyond this energy level for the excitation function of EXIFON. 2.0 code.

3. Conclusion

The excitation functions for production of radionuclides ^{123}I and ^{124}I, which are important for SPECT and PET, were investigated via alpha induced reactions. The calculations by EXIFON modula code results were compared with the experimental data from EXFOR and the data have predicted that the radioisotope ^{123}I and ^{124}I can be produces from ^{121}Sb via alpha induced.

4. Acknowledgments

We thank the referees for the positive enlightening comments and suggestions, which have greatly helped us in making improvements to this paper.

References

[1] S. M. Qaim, T. Bisinger, K. Hilgers, D. Nayak & H. H Coenen, "Emission Intensities in the Decay of ^{64}Cu, ^{78}Br and ^{124}I", Radiochin. Acta. **95** (2007) 67.
[2] A. Hohn, B. Scholten, H. H Coenen & S. M Qaim, "Excitation Functions of (p,xn) reactions on highly enriched ^{122}Te: relevance to the production of 120gI", Appl. Radait. Isot. **49** (1998). 93.
[3] B. Schoten, Z. Kovacs, F, Tarkanyi & S.M Qaim, "Excitation functions of ^{124}Te (p,xn)^{124,123}I reactions from 6 to 31 MeV with Special Reference to the Production of ^{124}I at a Small Cyclotron", Appl. Radiat. Isot. **46** (1995) 255.
[4] A. M. S Braghirolli, W. Waissmann, J. B. Silva & G. R. Santos, "Production of Iodine 124 and its Applications in Nuclear Medicine", Appl. Radiat. Isot. **90** (2014) 138.
[5] E. B, Silberstein, "Radioiodine: The Classic Theranostic Agent", Semin. Nucl. Med. **42** (2012) 164.
[6] C. A. Mathis, T. Sargent III & A. T. Shulgin, "Iodine-122-labeled Amphetamine Derivative with Potential for PET Brain Blood-Flow Studies", J. Nucl. Med. **26** (1985) 1295.
[7] H. Kalka, "EXIFON - A Statistical Multi-step Reaction Code", Report of Technicshe University Dreschen. (1991).
[8] J. J. Griffin, "A Unique Classification of Nuclear States", Phy. Lett. **248** (1967) 5
[9] H. Feshbach, A. Kerman, & S. E. Koonin, (1980), "Multistep Processes in Neutron Induced Reactions", Ann. of Phy. **12** (1980) 429.
[10] D. Agassi, H. A. Weidenmulter & G. Mantzouranis, (1975) "Generalized Exciton Model for the Description of Preequilibrium Processes", Phy. Rep. **22** (1975) 145.
[11] M. Ismail, "measurement and analysis of the excitation function for alpha-induced reactions on Ga and Sb Isotopes", Phys. Rev. **41** (1990) 87.

[12] K. F Hassan, S. M, Qaim, Z. A Saleh & H. H coenen, "Alpha-Particle Induced Reactions on natSb and 121Sb with Particular Reference to the Production of Medically Interesting Radionuclide ^{124}I", Appl. Radiat. Isot. **64** (2006) 101.

[13] F. Tarkanyi, S. Takecs, B. Kiraly. F. Szclecsenyi, I. Ando, J. Bergman, S. J. Heselius, O. Solin, A. Hermanne, Yu N. Shubin & A.V. Ignatyuk, "Excitation function of ^{3}He- and α Particle Induced Nuclear Reactions on ^{nat}Sb for Production of Medically relevant ^{123}I and ^{124}I Radioisotopes", Appl. Radiat. Isot. **67** (2009) 1001.

[14] B. P. Singh, M. K. Shama, M. M. Musthafa, H. D. Bhardwaj & R Prasad, "A study of preequilibrium emission in some proton- and alpha-induced reactions", Nucl. Instum. Methods phys. Res. Sect.**562** (2006) 717.