Investigation of Excitation Functions Using New Evaluated Empirical and Semi-empirical Systematic for 14-15 MeV (n,t) Reaction Cross Sections

E. Tel[1], A. Aydin[2], E.G.Aydın[1], A Kaplan[3]

[1]Gazi University, Faculty of Art and Science, Department of Physics, Ankara- TURKIYE

[2]Kirikkale University, Faculty of Art and Science, Department of Physics , Kirikkale- TURKIYE

[3]Suleyman Demirel University, Faculty of Art and Science, Department of Physics, Isparta-TURKIYE

Abstract

The hybrid reactor is a combination of the fusion and fission processes. In the fusion-fission hybrid reactor, tritium self-sufficiency must be maintained for a commercial power plant. Working out the systematics of (n,t) reaction cross sections is of great importance for the definition of the excitation function character for the given reaction taking place on various nuclei at energies up to 20 MeV. In this study we have investigated asymmetry term effect for the (*n,t*) reaction cross sections at 14-15 neutron incident energy. It has been discussed the odd-even effect and the pairing effect considering binding energy systematic of the nuclear shell model for the new experimental data and new cross sections formulas (*n,t*) reactions developed by Tel *et al.*. The obtained empirical formulas by fitting two parameter for (*n,t*) reactions were given. The obtained results have been discussed and compared with the available experimental data.

INTRODUCTION

The hybrid reactor is a combination of the fusion and fission processes. The fusion plasma is surrounded with a blanket made of the fertile materials (U238 or Th232) to convert them into fissile materials (Pu239 or U233) by transmutation through the capture of the high yield fusion neutrons. The fertile materials may also undergo a substantial amount of nuclear fission, especially, under the irradiation of the high energetic 14.1 MeV- (D,T) neutrons. For self-sustaining (D-T) fusion driver tritium breeding ratio should be greater than 1.05. Working out the systematics of (n,t) reaction cross sections is of great importance for the definition of the excitation function character for the given reaction taking place on various nuclei at energies up to 20 MeV.

The systematic experimental studies for the cross sections of (*n, charged particle*) such as (*n, p*) and (*n, α*) at 14 – 15 MeV have been studied over the years for a large number of nuclei [6–9].

On the other hand, a number of empirical and semi-empirical formulas with different parameters for cross sections calculations of the reactions (*n, p*), (*n, t*), (*n, α*) and (*n, 2n*) at the different neutron energies has also been proposed by several authors [10–16] and Tel *et al.*[17] suggested using these new experimental data to reproduce a new empirical formula of the cross sections of the (*n,p*) reactions. This formula depends on the asymmetry parameter, $s = (N - Z)/A$, and has the pairing effect on the binding energy systematics of nuclear shell model. Tel *et al.* also obtained a new appropriate coefficient by using this formula for (*n,2n*) and (*n,α*) reactions[18].

In the present study, only empirical formulas of the (*n,t*) cross sections were obtained at the energy range of 14 – 15 MeV for different parameter groups by using Tel et al. formula[17]. Two different parameter groups by the classification of nuclei into odd-*A*, even-*A* for (*n, t*) reaction cross sections have been determined. In this way, it has been discussed odd-even effect and basic nucleon-nucleus interaction considering new experimental data and new cross section formulas developed by Tel *et al.* for (*n,t*) reactions.

II. EMPIRICAL SYSTEMATICS for 14-15 MeV NEUTRON REACTION CROSS SECTIONS

Recently nuclear data files have been prepared to study the neutron transport, nuclear heating and gas production, and radiation damage for materials irradiated by fast neutrons [4]. These data files include the information about total cross sections, elastic and inelastic cross sections for threshold reactions. However, nuclear models are frequently needed to provide the estimations of neutron-induced reaction cross sections, especially when experimental data are scarce or very difficult to perform.

According to previous reports[11 – 16], the cross sections for many nuclei significantly vary with the mass number *A*, neutron number *N* and proton number *Z* of the target nucleus. In addition, the attributable effects to the asymmetry parameter, *s= (N-Z)/A*, as well as to the isotopic, isotonic and odd-even properties of nuclei have been observed in the data.

The empirical cross sections of reactions induced by fast neutrons can be approximately expressed as follows,

$$\sigma(n,x) = C\sigma_{ne}\exp[as] \qquad (1)$$

where is the neutron non-elastic cross section, and the coefficients *C* and *a* are the fitting parameters determined from least-squares method for different reactions.

The non-elastic cross sections have been measured intensely for many nuclides in the MeV range, enabling us to find out their variation with atomic mass. The neutron non-elastic cross section is given by, where *R* is the nuclear radius and

$$\sigma_{ne} = \pi r_0^2 (A^{1/3} + 1)^2 \qquad (2)$$

where, $r_0 = 1.2 \times 10^{-13}$ cm.

Eq. (1) has a strong (*N-Z)/A* dependence. This case has already been shown by Betak *et al*. for neutron-induced reaction cross sections [1]. There are also several formulas describing the isotopic dependence of cross sections for different reactions at neutron energy of 14.5 MeV. The measured cross sections exhibit a large gradient for the lighter masses with increasing asymmetry parameter and then become almost constant for medium and heavy mass nuclei (starting from).

The best fitting can be obtained with the new free parameters in order to provide the minimum value of the following expression,

$$\chi^2 = \frac{1}{N}\sum_{i}^{N}\left(\frac{\sigma_{exp}^{i} - \sigma_{cal}^{i}}{\Delta\sigma_{exp}^{i}}\right)^2 \qquad (3)$$

where and are the experimental and the calculated cross sections, respectively, and is the error associated with . Details on the results of the best fitting parameters and the values of $\chi 2$ can be found for (*n,p*) reactions in Ref[14,16,17,23] and (*n, α*), (*n, 2n*) reactions in Ref[16,18–20].

III. RESULTS AND DISCUSSION

Odd-even and nucleon binding energy systematics have been compared with (*n,t*) measured cross sections with the empirical fits of Tel *et al.* as shown in Figs. 1-5. The (*n,t*) reaction cross sections include coulomb effect as seen in Figs. 1 – 4. In these reactions, it can be also seen that the reaction cross sections decrease by the increasing of the asymmetry parameter (Figs. 1–4). According to Levskovskii's formula [6], the proton and alpha emission probabilities increase with increasing relative proton number. The same relation can be also expected for *d, t* and *n* emissions. The pre-equilibrium reaction effects strongly depend on asymmetry parameter. Particularly, in the region I (*A* = 40 ~ 62), the (*n,p*) reaction is possible with compound process whereas this reaction is possible with pre-equilibrium process in region III (*A*=90 ~ 160). Moreover, in intermediate region II (*A*= 63 ~ 89) this reaction is also governed by both processes in the regions I and III [30]. In Figs. 1-5, reaction cross sections were classified according to odd-even properties by depending up on asymmetry parameter. As can be obviously seen from Figs. 1–5, reaction cross sections separate with each other (with relative to odd-even properties) with the raising of asymmetry parameter. This separation can be most observed for (*n,t*) reactions. This case shows a strong pairing effect by depending up on the target nuclei mass number-*A*.

In the present study, we have only investigated the (*n,t*) reaction cross sections at the energy of 14–15 MeV in two different groups by using Tel *et al.* formula as can be seen in Figs. 6–10. Since there is not enough experimental data for (*n,t*) reactions, it has been determined two different parameter groups by the classification of nuclei into odd-*A* and even-*A*. As can be clearly seen from Figs. 2 the (*n,t*) reaction cross sections separate with each other due to increasing of asymmetry parameter. Therefore, we could not perform a good fitting for this case. However, for the (*n,t*) cross sections values, a good fitting was achieved by considering the even-even correction (Figs. 6 and 9).

We have used nuclei which their mass number change from *A* = 46 to 209, atomic number change from *Z* = 22 to 83 and also neutron number change from *N* = 24 to 126. In Figs. 9-10, the experimental (*n,t*) cross sections of these nuclides have been fitted to depending on the asymmetry parameter. In Figs. 9-10, we have introduced two formulas by fitting two parameters for each formula presented by the considering of pairing effect of the nuclear shell model. We could not be able to use even-even, even-odd and odd-even systematic because of the lack of sufficient experimental data.

The coefficients *C* and *a* were determined by least-squares fitting method and the empirical formulas obtained by fitting two parameter for (*n,t*) reactions are given in the Table I and also in Figs. 6–8 and 9,10, respectively.

When the more experimental data for the neutron scattering and emission differential cross sections have been obtained by using new technology, it can be explained more reliable results and developed more nuclear reaction mechanisms and nuclear models. Also present kind of studies lead to improve and clarify the binding energy systematic of the nuclear shell model and the estimation of unknown data for the development of nuclear reaction theories.

Table I. The coefficients C and a, and the empirical and semi-empirical formulas for (*n*,*t*) reactions.

C	a	$\sigma(n,x) = C\sigma_{ne}\exp\left[as\right]$	χ^2
7.09	– 8.91	$\sigma(n,t)_{empirical} = 7.09(A^{1/3}+1)^2\exp\left[-8.91\ s\right]$	15.94
6.94	– 13.41	$\sigma(n,t)_{semi-empirical} = \begin{cases} 6.94(A^{1/3}+1)^2\exp\left[-13.41\ s\right] & \text{Even Z- Even N} \\ 121.21(A^{1/3}+1)^2\exp\left[-20.54\ s\right] & \text{Odd Z - Even N} \end{cases},$	5.05
121.21	– 20.54		

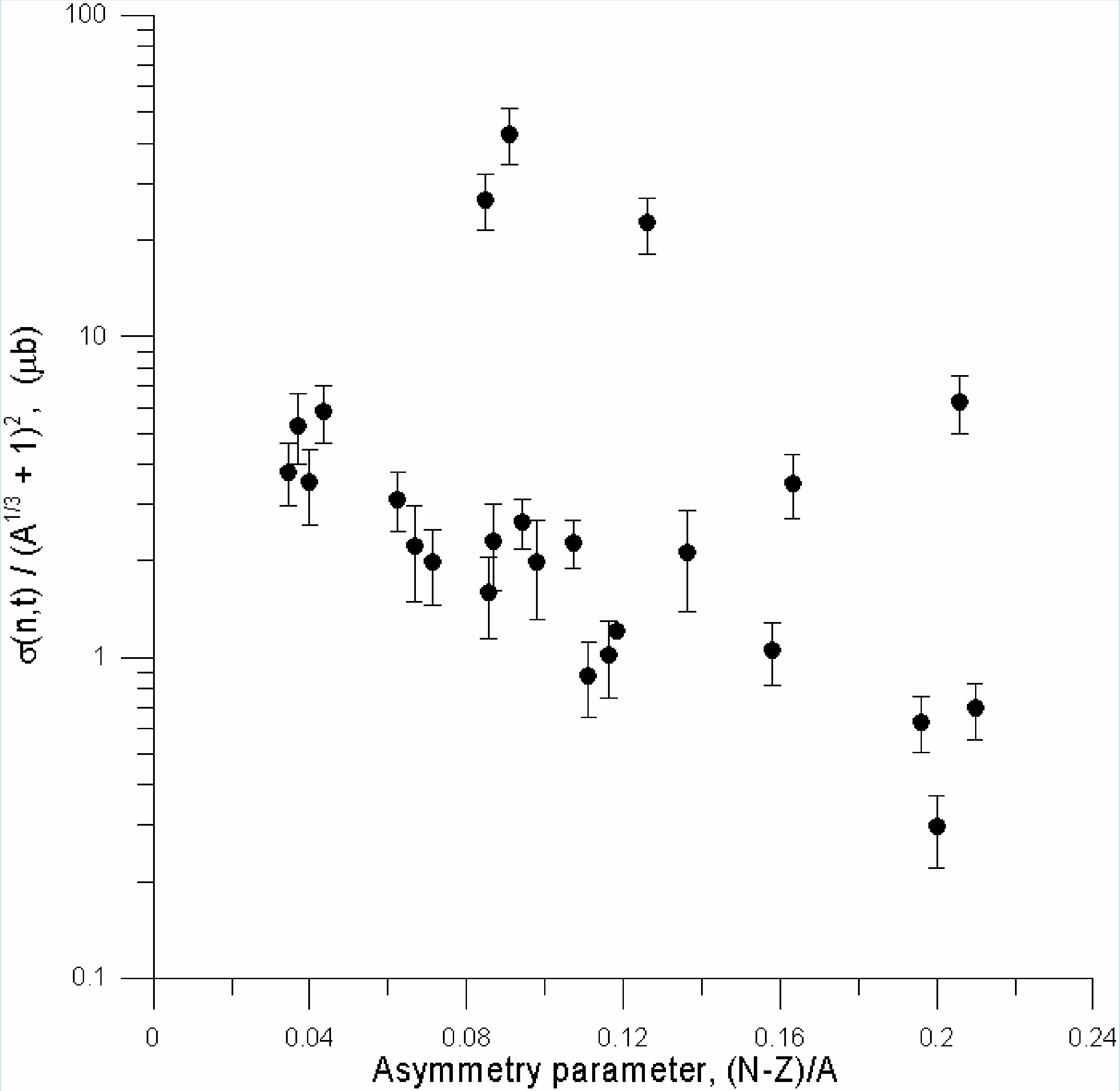


Fig. 1. Systematic of (*n,t*) reaction cross sections (in μb) induced by 14-15 MeV neutrons. Experimental data were taken from Ref [3, 4, 23].

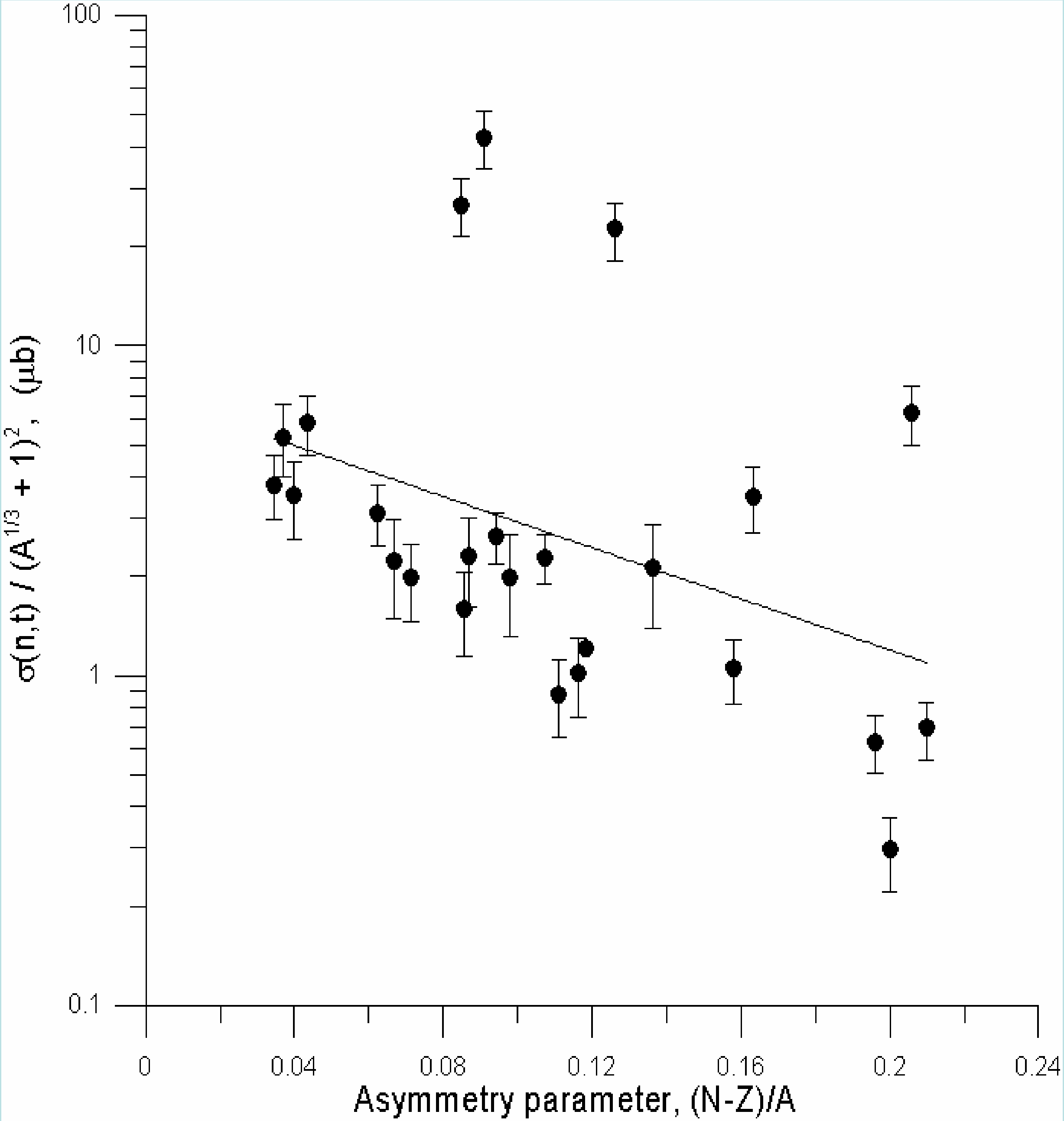


Fig. 2. Systematic of (*n,t*) reaction cross sections (in mb) for even-*Z*, even-*N* nuclides induced by 14-15 MeV neutrons.

The experimental points were fitted with and correlation coefficient was determined as *R2* = 0.80. Experimental data were taken from Ref [3,4,23].

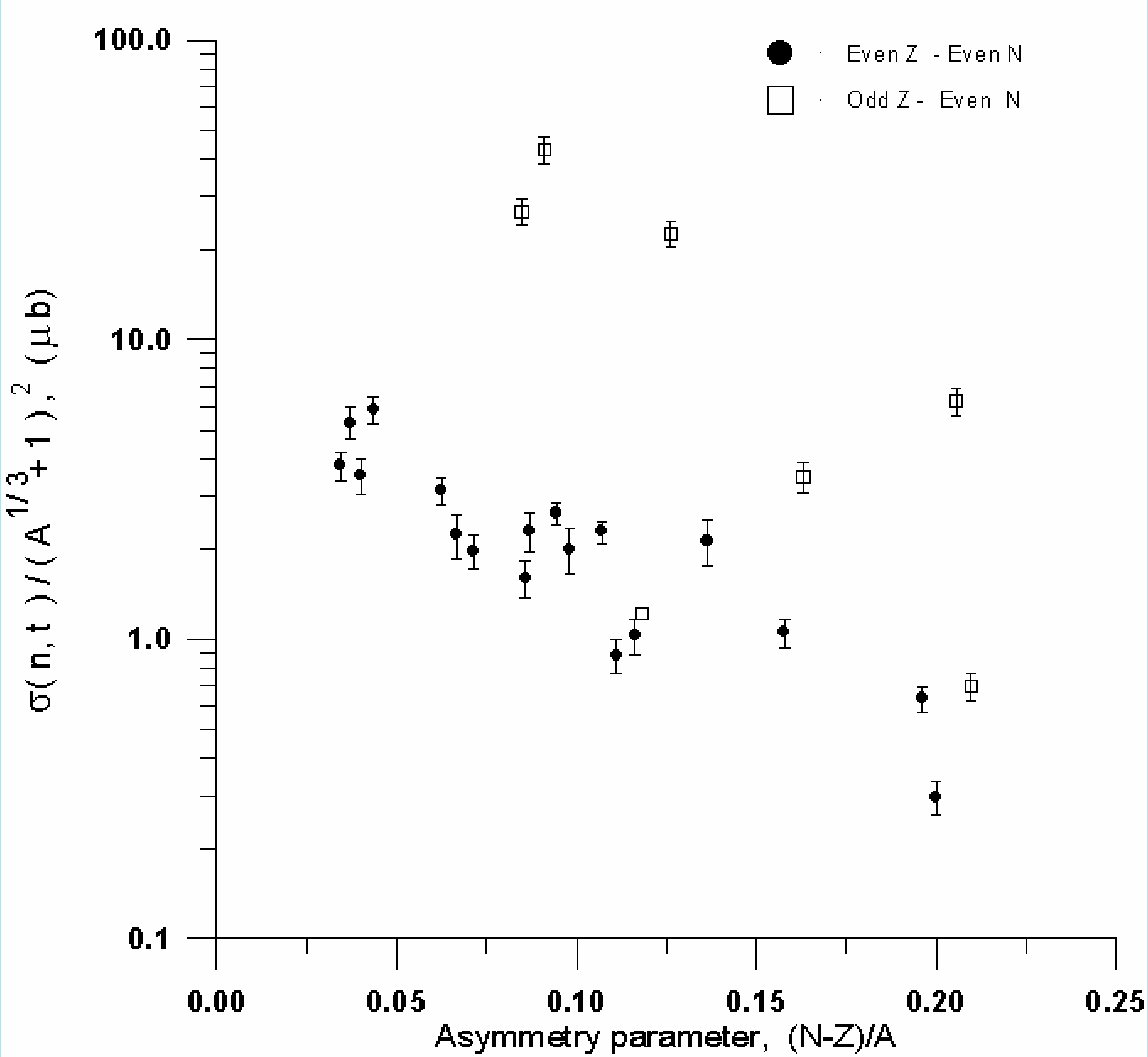
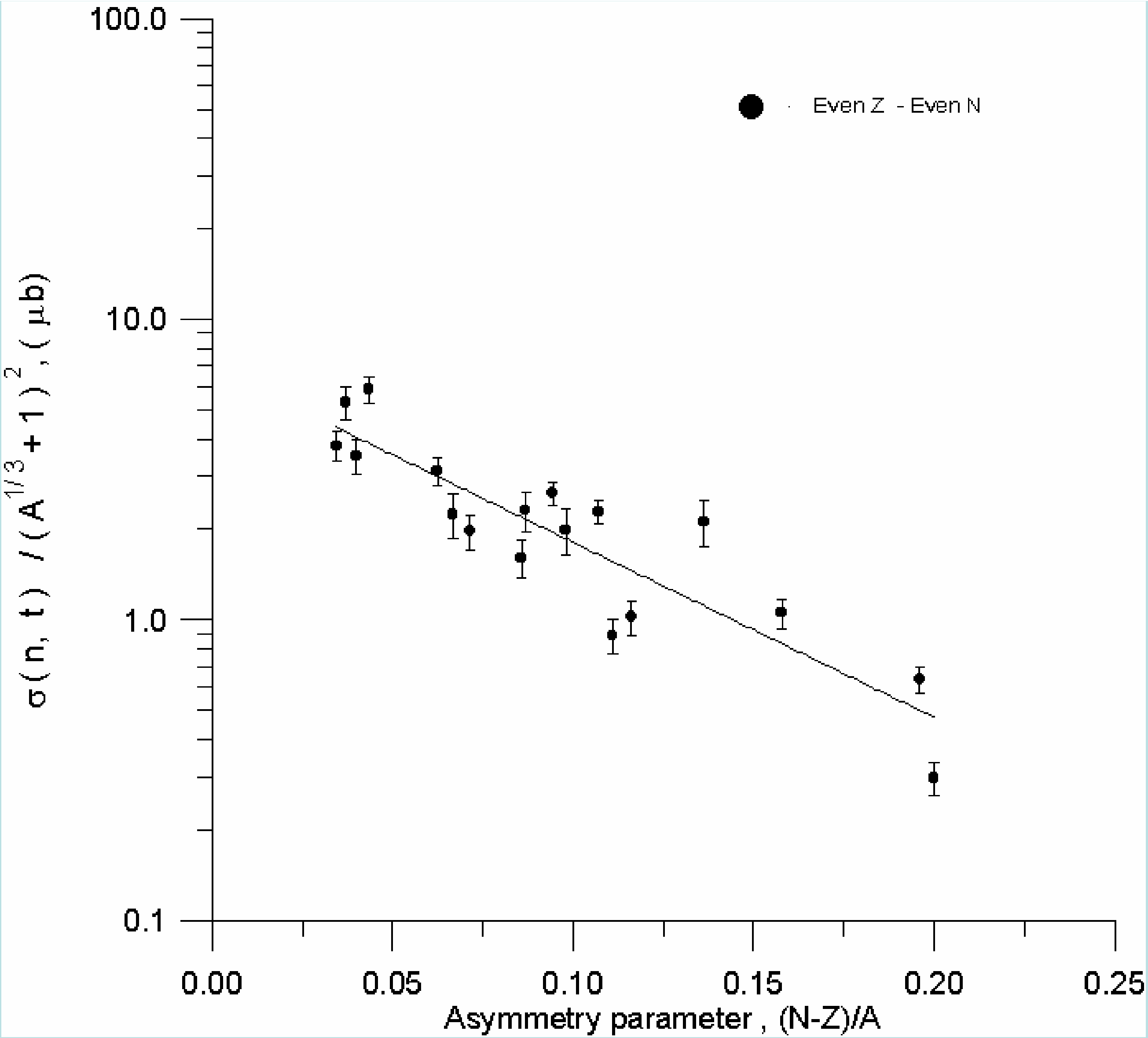


Fig. 3. Systematic of (*n,t*) reaction cross sections (in mb) for odd-*Z*, even-*N* nuclides induced by 14-15 MeV neutrons. The experimental points were fitted with and correlation coefficient was determined as *R2* = 0.73. Experimental data were taken from Ref [3,4,23].



100.0
10.0
1.0
0.1
Even Z - Even N
σ(n, t) / (A^1/3 + 1)^2, (μb)
0.00
0.05
0.10
0.15
0.20
0.25
Asymmetry parameter , (N-Z)/A

Fig. 4.

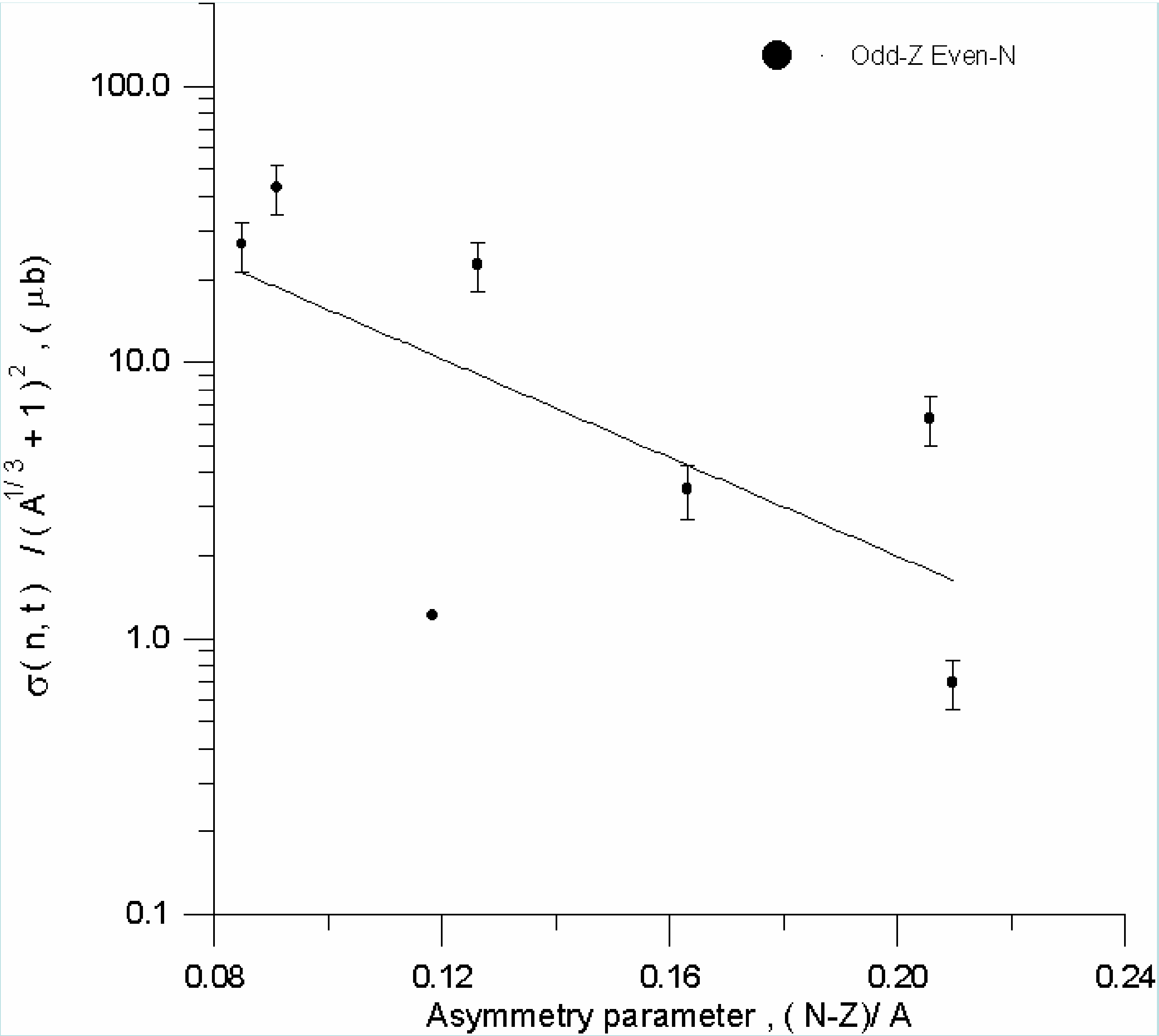
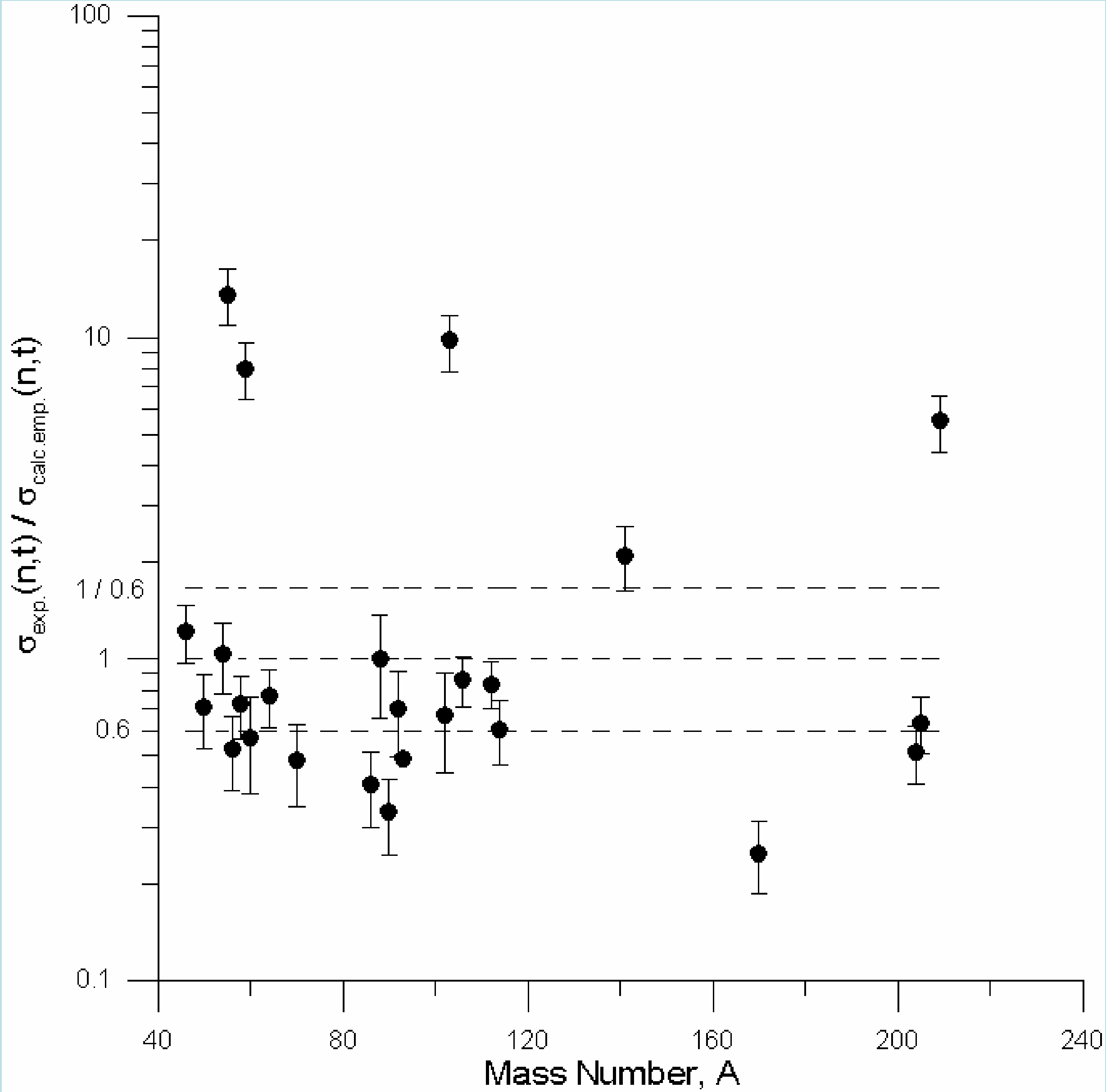

Odd-Z Even-N
100.0
10.0
1.0
0.1
0.08
0.12
0.16
0.20
0.24
Asymmetry parameter , (N-Z)/ A
σ(n, t) / (A^1/3 + 1)^2 , (μb)

Fig. 5.



100
10
1 / 0.6
1
0.6
0.1
40
80
120
160
200
240
Mass Number, A
$\sigma_{exp.}(n,t) / \sigma_{calc.emp.}(n,t)$

Fig. 6.

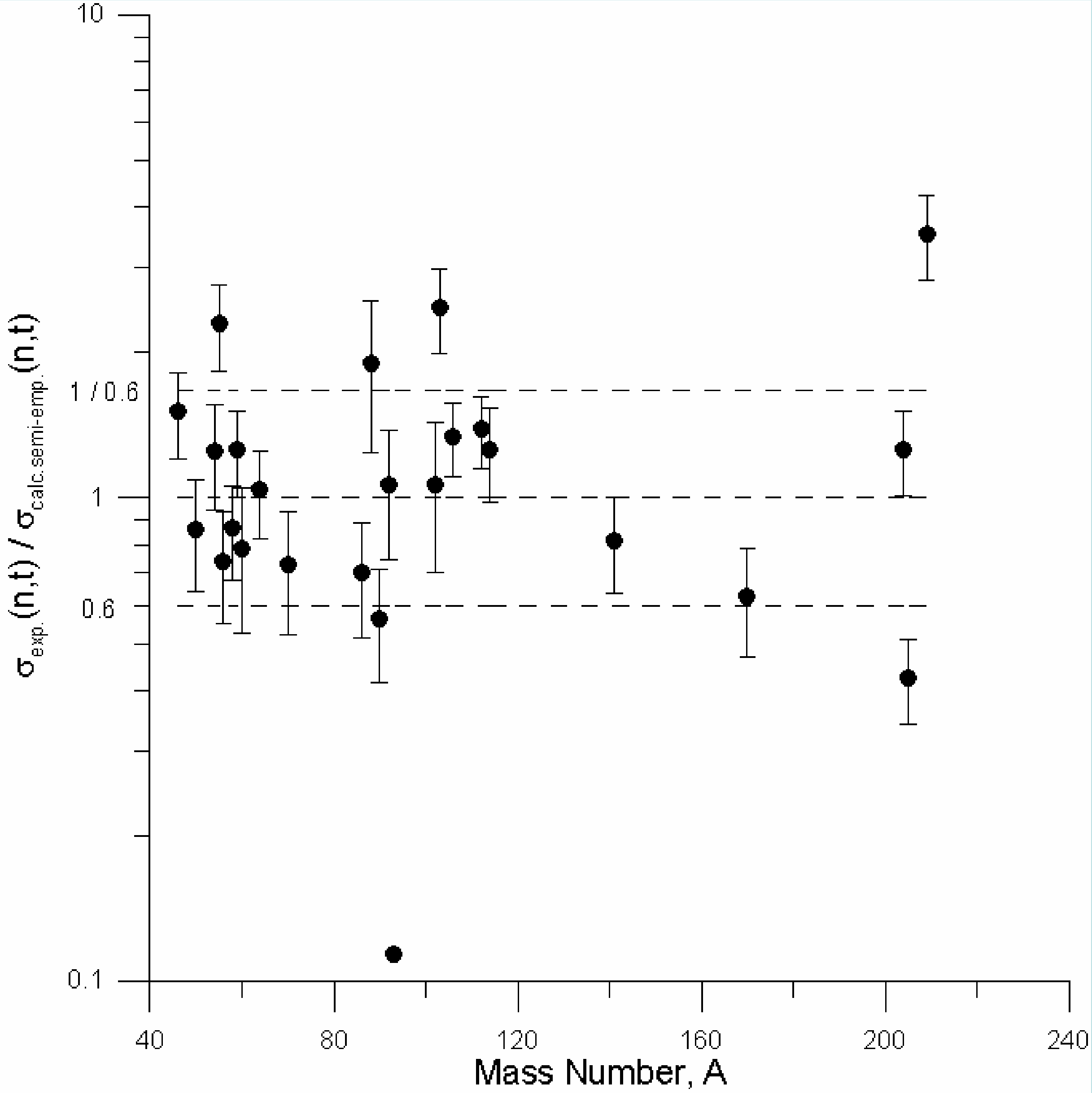

10
1 / 0.6
1
0.6
0.1
$\sigma_{exp.}(n,t) / \sigma_{calc.semi-emp.}(n,t)$
40
80
120
160
200
240
Mass Number, A

Fig. 7.

SUMMARY AND CONCLUSIONS

In this paper, we have discussed the odd-even effect and the pairing effect considering binding energy systematic of the nuclear shell model for the new experimental data. We have determined a different parameter groups by the classification of nuclei into even-even, even-odd and odd-even for (*n,t*) reactions cross sections. The obtained empirical formulas by fitting two parameter for (*n,t*) reactions were given and the following conclusions can be summarized as follows:

1. The (*n,t*) reaction cross sections for 14-15 MeV decrease by the increasing of the asymmetry parameter.

2. The tritium emission probabilities increase with increasing relative proton number.

3. The pre-equilibrium reaction effects strongly depend on asymmetry parameter.

4. The (*n,t*) cross sections values, a good fitting was achieved by considering the even-even correction.

Acknowledgement:

This work has been supported by State Planning Organization of Turkey project DPT-2006K # 120470

References

[1] E. Betak, E. Droste, S. Mikolajewski, W. Ratynski, E. Rurarz, T. Kempisty and S. Raman, Nucl. Sci. and Eng. **132**, 295 (1999).

[2] A. Yu. Korovin, A. Yu Konobeyev, P.E. Pereslavtsev, A. Yu. Stankovsky, C. Broeders, I. Broeders, U. Ficher, U. von Möllendorff, Nucl. Instrum. Methods Phys. Res., Sect. A **463,** 544 (2001).

[3] "Handbook for Calculations of Nuclear Reaction Data'', Reference Input Parameter Library, IAEA-TECDOC-1034, Nuclear Data Section, International Atomic Energy Agency (1998); "Evaluated Nuclear Structure Data File (ENSDF)'' National Nuclear Data Center, Brookhaven National Laboratory (1998).

[4] V. Mclane, CSISRS Experimental Nuclear Data File, National Nuclear Data Center Brookhaven National Laboratory, http://www.nndc.bnl.gov/ (1997).

[5] M.Walt "Angular distributions of elastically scarred neutrons", in Fast Neutron Physics, Part I : Techniques, p.509, J.B.Marion and J.L. Fowler, Eds., Interscience Publishers, New York (1960).

[6] V.N. Levkovskii, Sov. Phys. J. Exp.Theor. Phys. **18**,213 (1964).

[7] S. Pearlstein, Nucl. Sci. and Eng. **23**, 238(1965).

[8] D. W. Barr, C. I. Browne, and J. S. Gilmore, Phys. Rev. **123**, 859 (1961).

[9] A. Adam and L. Jeki, Acta Phys. Acad. Sci. Hung., **26**, 335 (1969).

[10] V. Weisskopf, Phys. Rev. **52,** 295 (1937).

[11] S. Ait-Tahar, Nucl. Phys.**13**, 121 (1987).

[12] A.Yu. Konobeyev, A. Yu. Korovin, and P.E. Pereslavtsev , Nucl. Instrum. Methods Phys. Res., Sect. B **93,** 409 (1994).

[13] A. Yu. Korovin, and A. Yu. Konobeyev, Nucl. Instrum. Methods Phys. Res., Sect. B **103,** 15 (1995).

[14] M. Belgaid, and M. Asghar, Appl. Radiat. Isot. **49,** 1497 (1998).

[15] M. Belgaid and M. Asghar, Nucl. Instrum. and Meth.,B., **149,** 383(1999).

[16] F. I. Habbani and K. T. Osman, Appl. Rad. and Isot., **54**, 283 (2001).

[17] E. Tel, B. Şarer, Ş. Okuducu, A. Aydin, and G. Tanir, J. Phys. G: Nucl. Part. Phys. **29**, 2169 (2003).

[18] E.Tel, Ş. Okuducu, M.H. Bölükdemir and G. Tanır, Inter. J. Modern Phys. E (IJMPE)(2006) (in press.).

[19] E. Tel, Ş. Okuducu, A. Aydin, B. Şarer and G. Tanir, Acta Physica Slovaca **54**, 191 (2004).

[20] E. Tel, A. Aydin, M. Übeyli and İ. Demirkol, Indian Journal of Physics **78(11),** 1229 **(**2004).

[21] E. Betak , R. Mikolajczak, J. Staniszewska , S. Mikolajewski, E. Rurarz., Radiochim. Acta 93, 311 (2005).

[22] S. M. Qaim, Nucl. Phys **A 382**,255 (1982).

[23] M. Belgaid, T. Sequeni, F. Kadem and M. Asghar, Nucl. Instrum. and Meth.,B., **201,** 545 (2003).

[24] M. Belgaid and A.Tassadit, F.Kadem, A.Amokrane , Nucl. Instrum. and Meth.,B., **239,** 303 (2005).

[25] J.J. Griffin, Phys. Rev. Lett., **17** 478 (1966).

[26] M. Blann and H.K. Vonach, Phys. Rev. C 28 1475 (1983).

[27] L.R. Veeser, E.D. Arthur and P. G. Young, Phys. Rev. **C 16** 1792 (1977).

[28] H. Gruppelaar, P. Nagel, P.E. Hodgson, LaRivasta Del, Nuovo Cimento **9**, (1986)

[29] D. Wilmore and P. E. Hodgson, Nucl. Phys. **55** 673 (1964).

[30] I. Kumabe and K. J. Fukuda Nucl. Sci. and Tech. **24,** 83 (1987).

[31] B. Haesner, W. Heeringa, H. O. Klages, H. Dobiasch, G. Schmalz, P. Schwartz, J. Wilczynski, B. Zeitnitz,
F. Kaeppeler, Phys. Rev. C**28**, 995 (1985).

[32] B.Antolkovic, G.Paic, P.Tomas, D.Rendic, Phys. Rev., 159, 777 (1967).

[33] E.B.Norman, B.Sur, Phys. Rev. C**57**, 2043 (1998)

[34] P.N.Tiwari, E.Kondaiah, Phys. Rev., **167**, 1091 (1968).