Additional Evaluation of Alpha Induced Neutron Production Nuclear Data
— ^{9}Be, ^{27}Al, ^{28,29,30}Si—

Toru Murata and Keiichi Shibata*
AITEL corp.; 8 Shinsugita-cho, Isogo-ku, Yokohama, Japan
*JAERI; Tokai-mura, Naka-gun, Ibaraki-ken, Japan
murat@green.ocn.ne.jp, * shibata@ndc.tokai.jaeri.go.jp

Alpha particle induced neutron production cross sections, emitted neutron energy spectrum and angular distributions were evaluated for the target nucleus ^{9}Be,^{27}Al and Si isotopes; ^{28}Si,^{29}Si and ^{30}Si in the incident energy region below 15 MeV.

1. Introduction

Though, JENDL (α,n) Reaction Data File 2003 has been released for 13 nuclides, additional nuclear data for the reaction are required. For ^{9}Be, requirement of detailed angular distributions of neutrons to several excited states of ^{12}C was made to estimate intensity of standard radio-active neutron source. Neutron production data of ^{27}Al are necessary to investigate new type nuclear fuel of non-proliferate. The data for Si are necessary to estimate the neutron emission rate of high level radio-active vitrified solid which includes alpha emitting TRU.

2. Method of nuclear data calculation and evaluation

The neutron production nuclear data were calculated by analyzing the experimental cross sections with a resonance formula code[1] and statistical model code EGNASH2 which is developed by researchers of JAERI-NDC by combining ELIESE-3 [2] and GNASH code[3]. Evaluation of cross section was made by modifying the obtained cross section slightly to reproduce the experimental thick target neutron yields.

3. Results of evaluation

3.1 ^{9}Be+α Reaction

The following nuclear data were already included in JENDL (α,n) reaction file.

- Total neutron production cross section
- Partial (α,n_i) reaction cross section; i=0,1,2,3
- The (α,α'n) reaction cross section
- Emitted neutron gross energy spectrum in Kalbach systematics[4].

In the present work,

- Experimental angular distributions [5] of neutrons emitted by the reaction (α,n_0), (α,n_1), (α,n_2) and (α,n_3) were fitted with Legendre polynomials at first. Then Legendre coefficients and partial cross section were analyzed with Blatt-

Biedenharn resonance formula. The coefficients of Legendre polynomials of angular distributions were evaluated by merging experimental and calculated coefficients.

- Continuum energy spectrum of neutrons were determined to reproduce the experimental data of Obst et al.[5] approximately.

Figure 1 shows calculated cross section of the $^{9}Be(\alpha,n_0)$ reaction and their Legendre coefficients of L=1,2,3 comparing with experimental data. Evaluation of Legendre coefficients will be made tracing experimental data with the shape of calculated values.

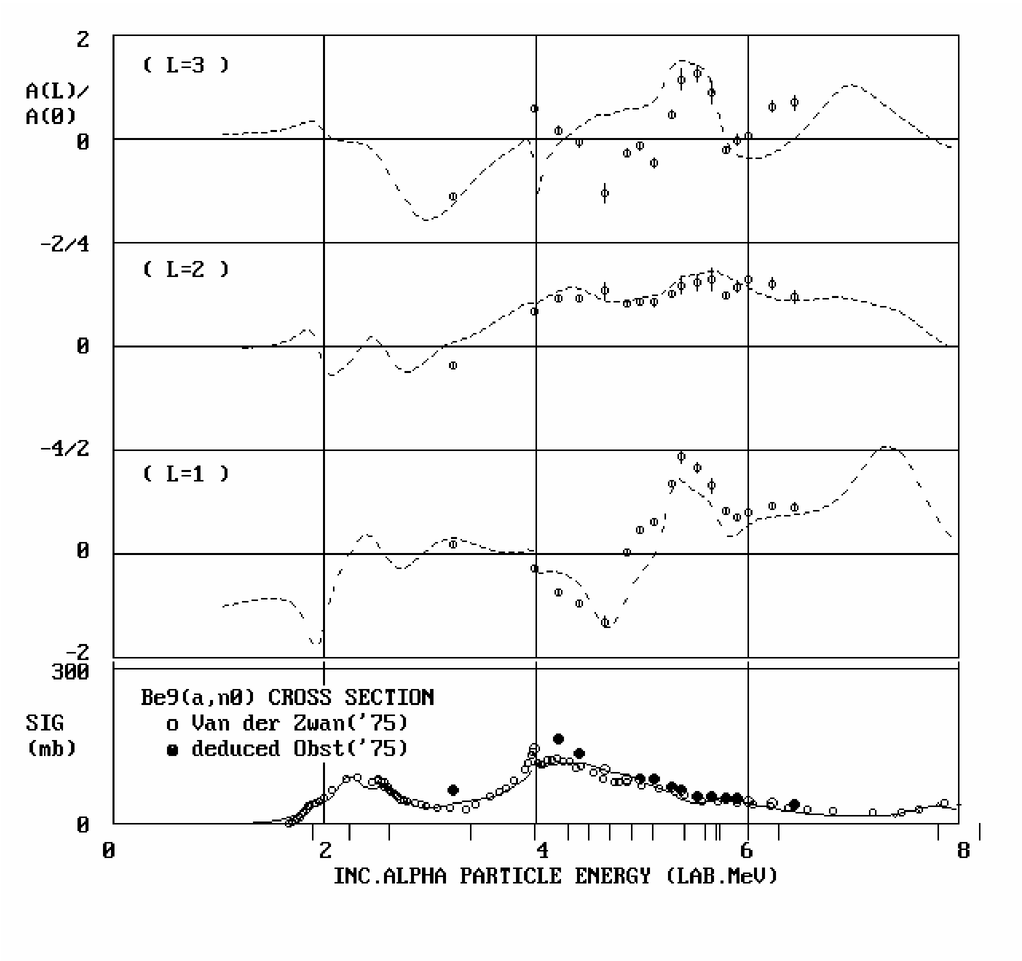

Fig.1 Present (tentative) evaluated $^{9}Be(\alpha,n_0)$ cross section is shown in the bottom figure by solid line comparing with the experimental data by Van der Zwan[6] and by Obst et al.[5] which were deduced from angular distributions. Top three figures show Legendre coefficients ratios (L=1,2 and 3) of $^{9}Be(\alpha,n_0)$ angular distributions; dashed lines show calculated results using resonance parameters to reproduce the bottom figure cross section and dots show experimental ones obtained by analyzing angular distributions by Obst et al.[5]

3.2 $^{27}Al+\alpha$ Reaction

Neutron production cross section was evaluated on the experimental data measured by Holmqvist and Ramstrom [7], Flynn et al.[8] and Howard et al.[9] in the resonance structure region in the incident energy below 5.5 MeV. In the higher energy region, the cross sections were measured by Stelson and Mcgowan[10] with neutron counting method and by Sahakundu et al.[11] with activation method measuring ^{30}P activity. The cross sections measured by the activation method do not correspond to neutron production cross section in the high energy region where other neutron production channels are open besides the (α,n) reaction.

Evaluation was made, in the resonance structure region, to reproduce the structure with sum of Lorenz functions. In the higher energy region, calculated cross section with EGNASH-2 code was normalized to the lower energy region cross section.

Figure 2 shows the evaluated neutron production cross section comparing with the experimental cross sections. Figure 3 shows the thick target neutron yields calculated using the evaluated cross section and alpha particle stopping power, comparing with the experimental thick target neutron yields measured by Bair and Gomez del Campo[12] and by West and Sherwood[13].

Emitted neutron energy spectrum were calculated with EGNASH-2 code in the whole incident energy region, and given in the form of Kalbach systematics[4].

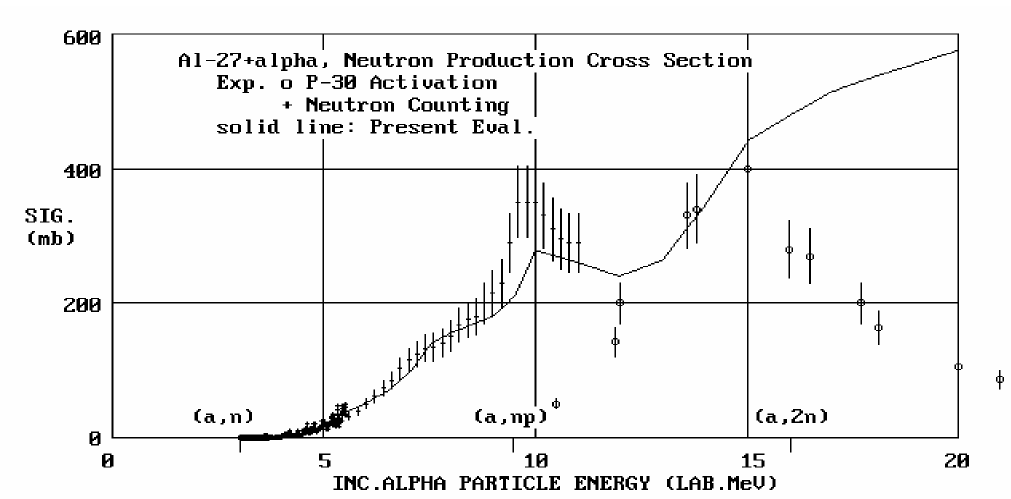

Fig.2 Neutron production cross section of ^{27}Al+α reaction. Note that the experimental data of ^{30}P activity do not correspond to the neutron production cross section.

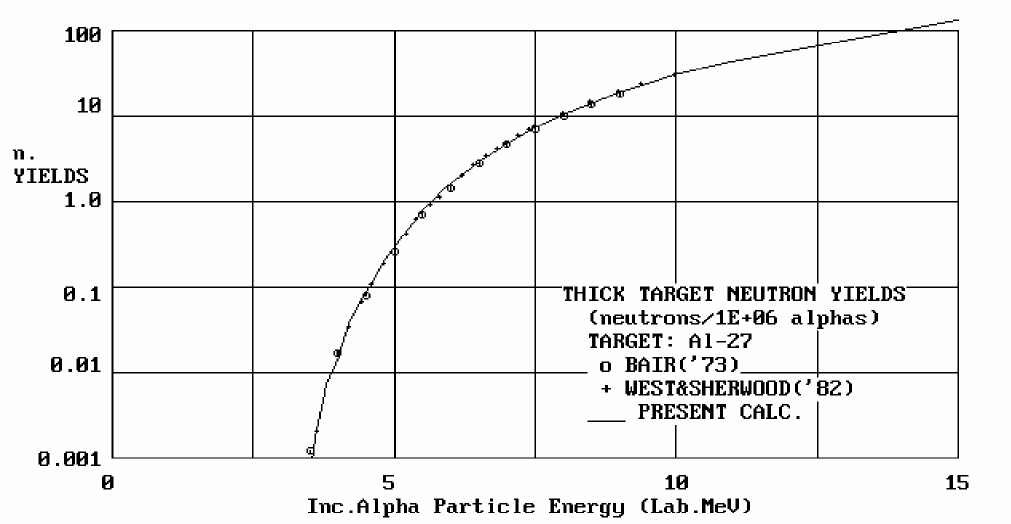

Fig.3 Thick target neutron yields (n/10^{6}α) of ^{27}Al+α reaction.

3.3 Si+α Reaction

Experimental cross sections were measured by Cheng and King[14)] for ^{28}Si, by Flynn et al.[8)] and by Gibbons and Macklin[15)] for ^{29}Si, by Flynn et al.[8)] for ^{30}Si. Evaluation methods are almost same as those for ^{27}Al.

The evaluated neutron production cross sections are shown in Fig.4 for ^{28}Si, Fig.5 for ^{29}Si and Fig.6 for ^{30}Si comparing with the experimental cross sections. Figure 7 shows the calculated thick target neutron yields of Si isotopes and natural Si comparing with the experimental thick target neutron yields [12), 13)].

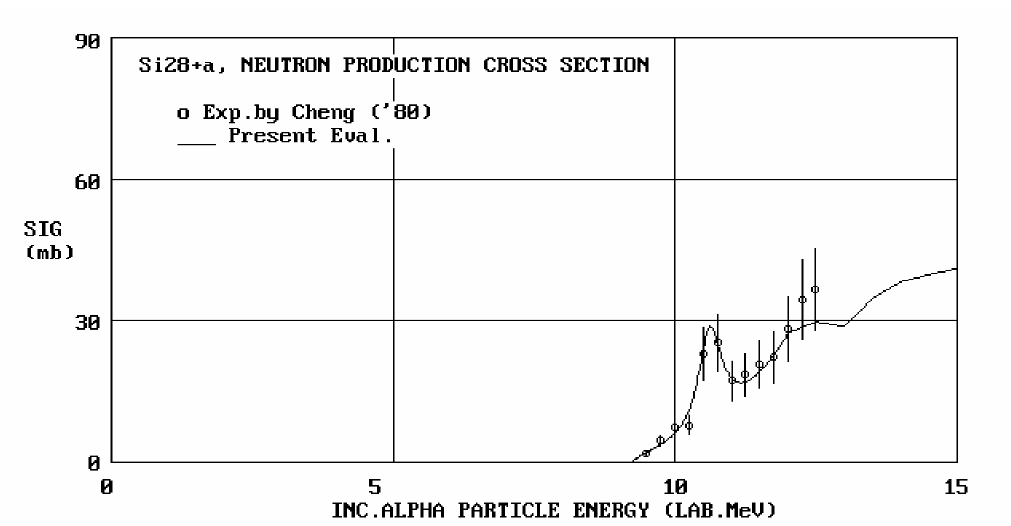

Fig.4 Neutron production cross section of ^{28}Si+α reaction.

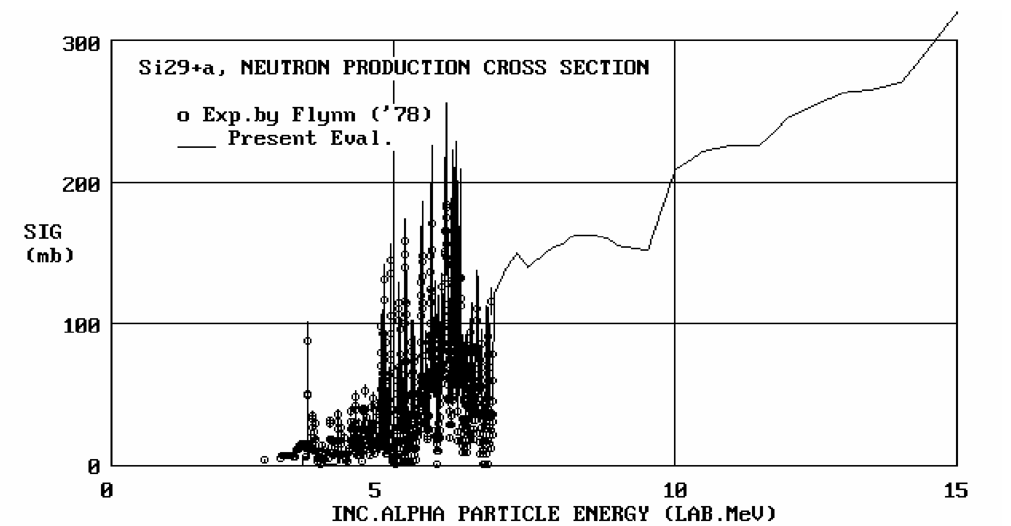

Fig.5 Neutron production cross section of ^{29}Si+α reaction.

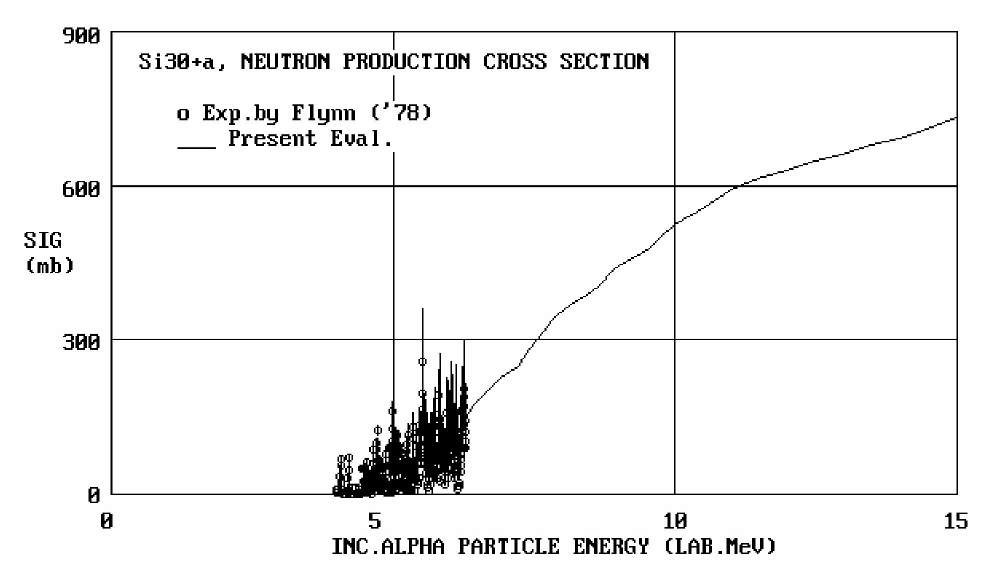

Fig.6 Neutron production cross section of ^{30}Si+α reaction.

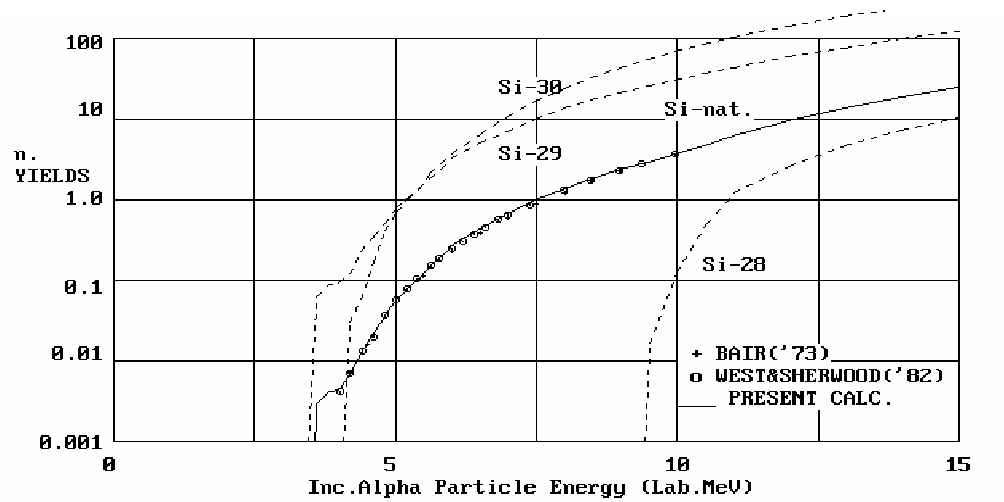

Fig.7 Thick target neutron yields (n/10^6α) of ^{nat}Si+α reaction. The same quantity of each Si isotope calculated using the evaluated cross section is also shown in dashed line.

4. Conclusion

For alpha particle bombardment of ^{27}Al,^{28}Si,^{29}Si and ^{30}Si, neutron production cross sections and emitted neutron energy spectrum were evaluated on the experimental data and theoretical calculation. For these nuclides, though they show resonance structure in low energy region, excitation energy of the compound nuclei is so high that no spin-parity assignment was made in ENSDF (Evaluated Nuclear Structure Data Files) and definite resonance analysis cannot be applied . So, simple Lorenzian fitting was made.

Angular distributions of neutrons emitted by the ^{9}Be(α,ni),i=0,1,2 and 3 were analyzed with a resonance formula. But complex resonance structures make it not easy to obtain good agreement between calculated results and experimental data for the cross sections and angular distributions simultaneously with consistent resonance parameters for each final state; ground, 1^{st},2^{nd} and 3^{rd} . If it will be done successfully, alpha particle incident excited states of ^{13}C; Ex=10-15 MeV will be determined definitely.

Acknowledgements

Thanks are due to Drs. T.Nakagawa and A.Ichihara (JAERI NDC) for helpful support in trouble shooting while utilization of EGNASH-2 code.

References

1) Murata,T. JAERI-Conf 98-003, 1998, p.215
2) Igarasi,S. JAERI 1224, 1972
3) Young,P.G.,Arthur,E.D.; LA-6947
4) Kalbach,C.: Phys.Rev.C37,2350(1988)
5) Obst,A.W.,Grandy,T.B.,Weil,J.L.: Phys.Rev.C5,738(1972)
6) Van Der Zwan,Geiger,K.W.:Nucl.Phys.A246(1975)93
7) Holmqvist,B.,Ramstrom,E.: Physica Scripta 33,107(1986)
8) Flynn,D.S.Sekharab,K.K.,Hiller,B.A.,Laumer,H.,Weil,J.L.,Gabbaed,F.: Phys.Rev.C18,1566(1978)
9) A.J.Howard et al.:Astrophysical Journal,188,131(1974)
10) Stelson,R.H.,Mcgowan,F.K.: Phys.Rev. B133,911(1964)
11) Sahakundu,S.M.,Qaim,S.M.,Stocklin,G.: Appl. Radiation and Isotopes 30,3 (1979)
12) Bair,J.K.,Gomez del Campo,J.: Nucl.Sci.Eng.71,18(1979)
13) West,D,Sherwood,A.C.: Ann.Nucl.Energy 9,551(1982)
14) Cheng,C.W.,King,J.D.: Cand.J.Phys.58,697,(1980)
15) Gibbons,J.H.,Macklin,R.L.: Phys.Rev.114,571(1959)