Nuclear Data for Science and Technology (1988 MITO), 229- 232, Copyright © 1988 JAERI.

DIFFERENTIAL AND INTEGRAL STUDY FOR PB(N,2N) CROSS SECTION

S. Iwasaki, N. Odano, S. Tanaka, J.R. Dumais
and
K. Sugiyama

Department of Nuclear Engineering , Tohoku University
Aramaki-Aoba, Sendai 980, Japan

Abstract: In this papar we studied Pb(n,2n)reaction including neutron emission spectra from differential and integral aspects. New measurement have been done at 14.1 MeV, and compared with those by Takahashi et al. Theoretical calculation using the multistep Hauser-Feshbach theory with the preequilibrium process effect (GNASH code) which reproduced the experimental cross section rather satisfactorily. Deduced (n,2n) cross section was discussed in conjunction with our new lead shell transmission experiment for 14MeV neutrons.

(lead, 14MeV, (n,2n), cross section, differential, integral, lead shell, neutron multiplication factor)

Introduction

As well known, lead is a potential candidate of the thermal blanket neutron multiplier of a fusion reactor. Request of accuracy for the cross section of the Pb(n,2n) reaction used in the blanket design was stated to be 3% /1/. Status of the cross sections at 14MeV is far from the request, because the available experimental cross section are scarce and scattered from 1.8 to 2.6b. They also discussed the recent status of the experimental cross section is about 7% /1/ and recomended further experimental study to meet the cross section uncertainty to the request.

At the IAEA advisory group meeting /2/in 1987, they proposed and recomended that a benchmark calculation for the lead shell transmission experiment performed by Elfruth et al/3/, and also recomended similar experiment.

In this study, we have done a new differential cross section measurement at 14.1MeV. The cross section was analysed by a theoretical calculation and the Pb(n,2n) cross section was deduced. Also we have started a series of integral experiment with lead shells, and discuss the results in related to the (n,2n) cross section.

Differential Cross section Measurement

New measurement of double differential cross section for Pb(n,2n) reaction was done at 14.1MeV by using a time-of-flight method/4/. Though basic measurement technique was almost the same as the previous one /5/, some points were improved. Main features of the present experiment were as follows; use of the 14.1-MeV neutrons emitted from the T(d,n) reaction in the 90deg. direction by which the energy resolution was improved; setting gamma window for the prompmt gamma-peak position (not applying the n-gamma shape discrimination on the prompt gamma peak) in the time-of-flight spectra to determine the time reference channel in high accuracy; using double monitoring systems to reduce the systematical error due to the instability in the case of the single one; using a special sample position changer with remote controle system for the use of the 90deg. neutron beam; in this geometry, position and size of beam spot on the tritium target and its stability are very important and were measured using activation technique during the experiment; using new thin copper target chamber /6/ to decrease the scattering component on the source neutrons; new large main detector /7/ was used at 6m from the target position in the 90 deg. direction. Cylindrical shape scattering sample was hang by two thin threads from two wheels at 13cm from its center as shown in Fig. 1.

The lead sample was a 3cm-dia. and 4-cm height high purity lead metal cylinder. Carbon and polyethylene samples which were used for the cross section calibration had the same size of 14mm dia. and 40mm length.

The secondary neutron spectra were measured at eight scattering angles from 30 to 150deg. Background level of each run was estimated by sample-out run.

Corrections for the finite sample size effects such as multiple scattering, attenuation and finite angular spread were done by a Monte-Carlo code MULTIPLE/8/ with the nuclear data based on the ENDF/B-IV for the lead and B-V for the polyethylene sample, respectively.

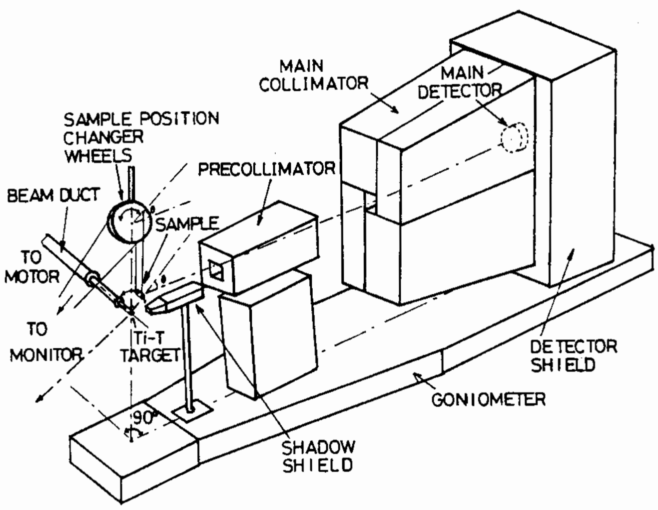

Fig. 1 Experimental set up for measurement of Pb(n,xn) cross section using the 90 deg. neutron beam from the T+d reaction.

Results and Comparison of the DDX

Typical example of the cross sections were shown in Fig. 2 together with the OKTAVIAN's experimental data/9/ with almost the same experimental arrangement to ours. Over all agreement is good. Descrepancy of the elastic cross section may be due to the small setting error of the scattering angles. Two resolved inelastic scattering cross sections are consistent with each other considering the difference of the energy resolutions between them. Below 5MeV, the (n,2n) component region, good agreement is obtained with the exception of the region less than 0.1MeV. In this energy region, the OKTAVIAN data are systematically larger than the present ones.

In this figure, two evaluated cross section curves by ENDF/B-IV and JENDL-3T*)/10/ were also drawn for comparison. The elastic and the two inelastic scattering cross sections of the experimental data are reproduced rather well by the two evaluations. However, in the low energy part of the cross sections, two evaluated ones show a contrast with each other, i.e., the ENDF/B-IV curve are relatively softer than the experiment, while the JENDL-3T curve is harder than the experiment. Both evaluation could not reproduce the experiment.

In Fig. 3, angle integrated cross section obtained from present differential data was shown.

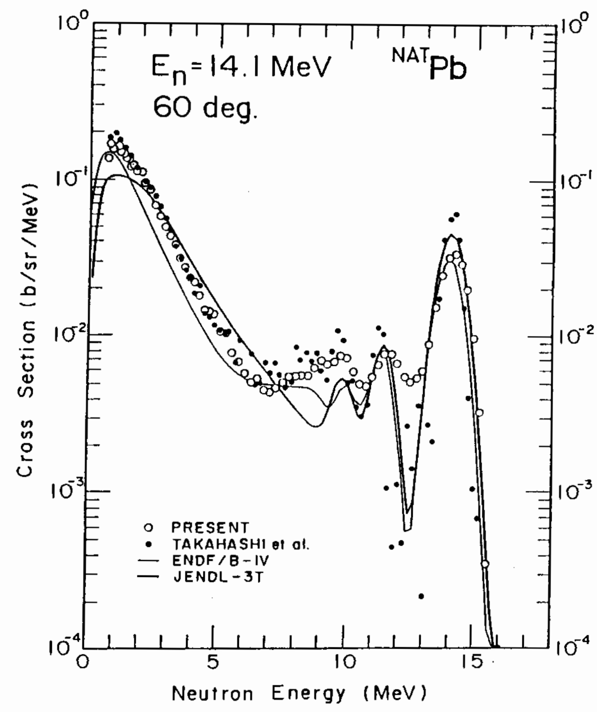

Fig. 2 Example of the cross section obtained in the present experiment compared with the OKTAVIAN's data and those by two evaluated nuclear data files.

----

*) JENDL-3T is a temporary file for testing the evaluated data which are for JENDL-3. The data in JENDL-3T will be partly revised in JENDL-3.

Calculation

In order to reproduce the obtained secondary neutron spectrum, a simplified input version of the GNASH86 /11/ plus ELIESE3 /12/code system by N. Yamamuro /13/ was employed. The best fit parameters of the GNASH and ELIESE system was searched to reproduce the experimental data.

Newest data base of the level data given in Nuclear Data Sheets/14/ were adopted for the calculation. As for the optical model potential, we joined two parameter sets of Ohio University group together at 10MeV; above 10MeV, the Finlay's potential /15/, while below 10MeV, the Annand's potential /16/ were used. This unified parameter set gave the total cross section from 0.1 MeV to 20 MeV in good agreement with the Shwartz's high resolution data /17/.

In the present study, the level density parameters of the Gilbert-Cameron type level density formula in GNASH was considered as a free parameters within a reasonable range. At neutron binding energy, Oak Ridge group /19/ gave the best parameter of the density of s- and d-wave levels of the neutron elastic resonance in Pb-206+n by the constant temperature model with T=0.9MeV and, if they used the Fermi-gas formula, a-parameter value should be about 14 which were quite larger than the Gilbert-Cameron parameter values. Therefore, the best parameter set was searched in the range a = 11 - 16 MeV^{-1} for Pb isotopes.

As seen Fig. 3, the neutron spectra above 6MeV are rather flat up to about 10MeV, where some discrete inelastic scattering components dominates. We have tried to reproduce part of this inelastic component with the preequilibrium process by adjusting neutron g-parameters (equi-distant level spacing) of each target nucleus, too.

Further we checked the validity of the parameters by comparing the emission spectra at 18MeV by Inoue et al /19/. The results of the calculation at 14.1MeV was shown in Fig. 3. Rather good agreement was obtained for the case of 14.1MeV with the exception in the energy region less than 2MeV, but at 18MeV complete fitting could not be attained (not shown). The used parameter set is shown in Table 1. From the present calculation, the (n,2n) cross section was deduced as 2.21b at 14.1MeV which is a little larger than the previous cross section /5/.

Table 1 List of main input parameters for GNASH calculations for Pb-206,207 and 208 targets.

nucleus	a-parameters (MeV^{-1})	K-values (Kalbach)	neutron state dansity(g) for PE model
Pb-209	11.41		-
Pb-208	12.0		12.53
Pb-207	13.0	120	14.47
Pb-206	14.0	(common)	15.84
Pb-205	14.48		-
Pb-204	16.22		-

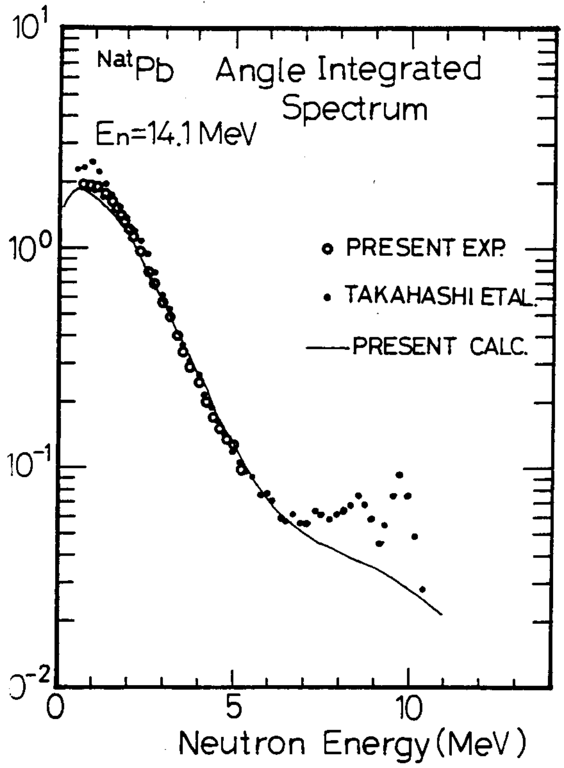

Fig. 3 Angle integrated cross sections compared with other experiments and the present model calculation.

Integral Experiment of Lead Shell

We have started a new program of the lead shell transmission experiment and reaction rate distribution measurement in the lead shell of two different thicknesses (t=5 and 10cm). The tentative results in the case of thinner shell (t=5cm, I.D. 6cm, O.D. 16cm:A shell) were obtained.

In Fig. 4, the experimental arrangement is shown. The shell was supported by a low mass aluminum stand. The tritium target was placed at the end of a 15cm-long and low mass aluminum vacuum chamber (wall thickness = 1mm). The outside of end plate was cooled by air blow. The

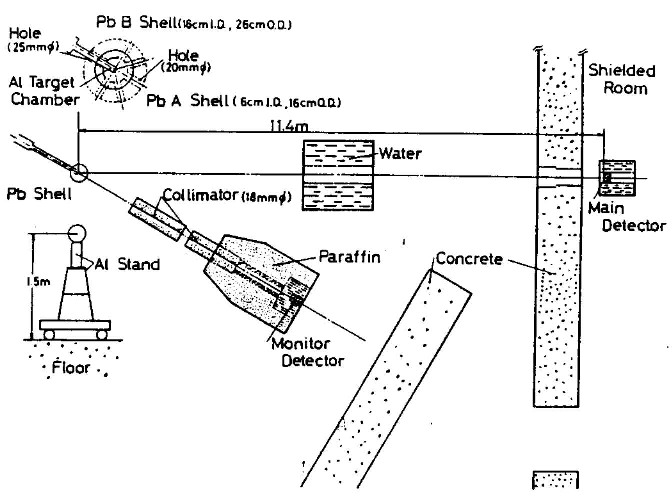

Fig. 4 Experimental arrangement for the measurement of leakage neutrons from lead shell.

lead shell has two holes of which front side is for monitor (20mmdia.) and rear side for target chamber insert (25mmdia.). Through the front hole the source neutrons passed in the direction of 0deg. where a monitor of 1"thickx1"dia. NE213 in a shield detected the neutrons through the narrow channel (18mm dia.) collimator without perturbation due to lead shell.

The 14 MeV neutrons were produced by bombarding a 2-nsec width pulsed deuteron beam of 2MeV on a titanium-tritium target through a Harver foil which degraded the deuteron energy down to about 150keV prior to the target. The repetition rate of the beam was 0.5MHz.

Leakage neutrons from the shell was observed by the same detector as the differential scattering case which was located in a shielded room at about 11m from the target position. The threshold energy of the detector system was about 200keV.

Measurement for the lead shell in and out in order to obtain a leakage current from the surface of the shell per source neutron. Neutron flux was monitored by an aluminum activation technique in addition to the monitor detector. The two monitor results agreed with each other within a discrepancy of 1% in both lead. The scattering effect on the present flux monitoring due to the lead shell was negligible small.

The experimental result is compared with the calculational one by using a 3D Monte-Carlo code, MCNP /20/ with the cross section library based on the ENDF/B-IV as shown in Fig. 5. Above 10 MeV, agreement is fairly good, but, in the region of the (n,2n) component below 5MeV, shape of the both spectra are quite different.

Partial and total multiplication factors together with the previous experiments of the shell of nearly equal wall thickness to the present one by Hansen et al.(t=5.6cm)/21/, and Takahashi's old (t=6cm)/22/ and new measurement (t=5cm) /23/ are summarized in Table 2. From the

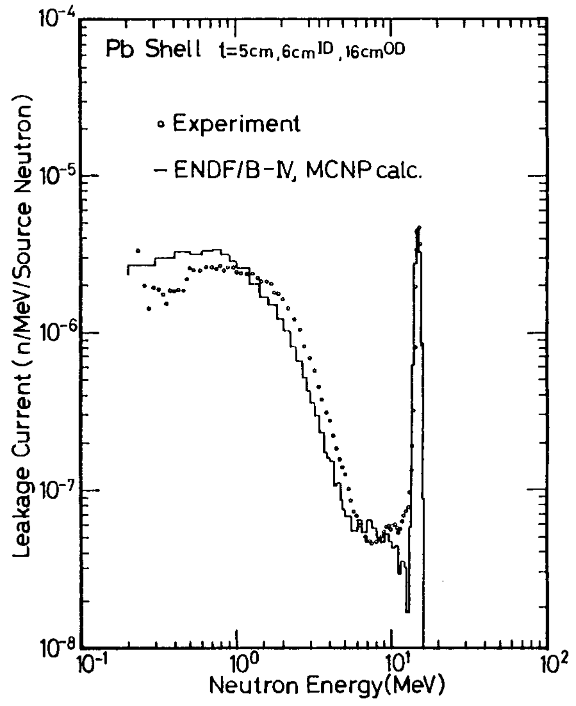

Fig.5 Leakage neutron spectra from the t=5cm lead shell.

Table 2 Comparison of experimental and calculational neutron multiplication factors in lead shells(t=5cm)

Energy Region (MeV)	LLNL /21/ (A)*1)	OSAKA /23/ (B)	TOHOKU (C)	ENDF/ B-IV (D)*2)	Ratio	
(partial multiplication)						
					(A/D)	(C/D)
0.3- 1	-	-	0.208	0.285	-	0.730
1 - 5	0.529	-	0.411	0.315	1.679	1.305
5 -10	0.034	-	0.032	0.029	1.103	1.172
10 -15	0.660	-	0.659	0.652	1.011	1.012
0.3- 5	-	-	0.619	0.600	-	1.031
(total multiplication)						
					(A/D)	(C/D)
1 -15	1.233	-	1.102	0.996	1.276	1.140
0.3-15	-	-	1.311	1.281	-	1.023
					(B/D)	
0.1-15	-	(1)1.32	-	1.29	1.023	-
		(2)1.35	-	1.29	1.046	-
0.3-15	-	1.41*3)	-	1.28*4)		

*1) t=5.6cm, *2) MCNP calc.(Tohoku cases)
*3) t=6cm /22/, *4) MCNP calc. (by E.T.Cheng, see ref./22/.)

table, the partial multiplication ratio values (C/D) show good agreement in the energy region 5-15MeV, while less than 5MeV, the ratios are apart from 1.0. Partial multiplication factor of the (n,2n) component region between 0.3 to 5MeV of the present and ENDF/B-IV are 0.619 and 0.600, respectively. This means that the (n,2n) cross section of the experiment would result to be 1.031 times the 2.167b of ENDF/B-IV, 2.23b, neglecting the differences of both spectra below 0.3MeV.

Although, Takahashi/23/ did not give partial multiplication factors for t=5cm case, our results are considered to be consistent with those of Takahashi comparing the both emission spectra (not shown). The present result is consistent with that of Hansen et al's in the high energy regions above 5MeV, while in the 1 to 5MeV region, both differ by 29%, and Hansen et al's is inconsistent with us even taking into account the different thicknesses of the lead shell. Hansen et al. estimated a larger cross section of 2.310b using ALICE/CCh code by fitting their neutron emission spectrum. This value is slightly larger than the present one.

Discussion and Summary

Pb(n,2n) cross section was studied experimentally and theoretically. Multistep Hauser-Feshbach calculation was performed and showed rather good agreement with new experimental neutron emission data.

Deduced cross section from the differential data was about 2.21b at 14.1MeV which is consistent with the previous our data within error band . This is also consistent with recent integral experimental data including our preliminary results (2.23b). This value is also consistent with recent GDR group's conclusion/14/,/15/ that the cross section of 2.26b was recomended. It can be concluded from the present study that the true cross section would close to 2.23b. However the further experimental and theoretical studies over wide incident energy range should be carried out to establish the cross section within the 3% uncertainty.

Part of this work was financially supported by JAERI.

Messrs. Sakamoto and Fujisawa are aknowledged for great help to operation of the Dynamitron accelerator at Fast Neutron Laboratory.

Dr. Yamamuro is acknowledged for his helpful advices and offering many unpublished documents to use the new GNASH-ELIESE3 joint system.

The authors address their thanks to Drs. Nakagawa and Narita of JAERI for his great help.

References

1. D.L. Smith et al,: Report of office of basic energy sciences program to meet high priority nuclear data needs of the office of fusion energy, 1986 REVIEW, September 1986, ANL, DOE/ER/02490-4 (1986).
2. IAEA Advisory Group Meeting on Nuclear Data for Fusion Reactor Design. At Gaussig, December, 1-5,1986.
3. T. Elfruth et al.,: Atomkernenergie Kerntechnik Vol.49 (1987)No.3.
4. S. Iwasaki et al.,: Progress Report of Fast Neutron Laboratory Apr. 1987 - Mar. 1988, NETU-50, Department of Nuclear Engineering, Tohoku Univ. May (1988).
5. S. Iwasaki et al.: Proc. Conf. Nuclear Data for Basic and Applied Sci. Vol.1 p191 (1986).
6. M. Baba et al.:Progress Rep. FNL 1 Apr. 1986 -31 Mar. 1987, NETU-49, p6 (1987).
7. by M. Baba, Tohoku University.
8. T.Tamura, et al.:Unpublished.(1984).
9. A.Takahashi et al.:OKTAVIAN Report, A-87-03 (1987).
10. JENDL compilation group, Nuclear Data Center, JAERI: private communication (1987).
11. P.G. Young et al: LA-6947 (1977) (GNASH86 is new JAERI version of GNASH).
12. S. Igarashi: JAERI-1224 (1972).
13. N. Yamamuro: private communication, and this conference.
14. Nuclear Data Sheets, 22(1979), 23(1977), 24(1978), 25(1978), 26(1979), 27(1979), 43(1984), 45(1985), 46(1985).
15. R.W.Finlay, et al.: Phys. Rev. C, 30 796 (1984).
16. J.R.M. Annand et al.:Nuclear Physics A443 249 (1985).
17. Schwartz et al.:Report NBS-Mono-138 (1974).
18. D.J. Horen, et al.:Phys. Rev. C20 478 (1979).
19. T. Inoue et al: Progress Report of FNL Apr. 1984-Mar. 1985, NETU-46, p18 Dept Nucl. Eng., Tohoku Univ. May (1985).
20. Los Alamos Monte Carlo Group: LA-7396-M Revised (1981).
21. L.F. Hansen et al.: Nuclear Science and Engineering 92 382 (1986).
22. A. Takahashi: Proc. Nucl. Data for Basic and Applied Science, p59, Santa Fe, NM 13-17 May (1985).
23. A. Takahashi: Presented at the US-Japanese University Work-shop on Fusion Neutronics, UCLA USA, Jan. 27-29, 1988.
24. D. Hermsdorf et al.: INDC(GDR)-039/L, Aug. 1986, Nucl. Data Section, IAEA (1986).
25. D.Albert: International Symposium for Fusion Nuclear Technology, Tokyo March, (1988).