NOT FOR PUBLICATION

NEANDC(J)-56/U

INDC(JAP)-42/U

PROGRESS REPORT

(July 1977 to June 1978 inclusive)

September 1978

Editor

S. Kikuchi

Japanese Nuclear Data Committee

Japan Atomic Energy Research Institute

Tokai Research Establishment

Tokai-mura, Ibaraki-ken, Japan

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Editor's Note

This is a collection of reports which have been submitted to the Japanese Nuclear Data Committee at the Committee's request. The request was addressed to the following individuals who might represent or be in touch with groups doing researches related to the nuclear data of interest to the development of the nuclear energy program.

Although the editor tried not to miss any appropriate addressees, there may have been some oversight. Meanwhile, contribution of a report rested with discretion of its author. The coverage of this document, therefore, may not be uniform over the related field of research.

In this progress report, each individual report is generally reproduced as it was received by the JNDC Secretariat, and the editor also let pass some simple obvious errors in the manuscripts if any.

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TABLE OF CONTENTS

CONTENTS OF THE JAPANESE PROGRESS REPORT INDC(JAP)42U (=NEANDC(J)56U), September 1978

ELEMENT S A	QUANTITY	LAB	ENERGY(EV) MIN	MAX	TYPE	DOCUMENTATION REF VOL PAGE DATE	COMMENTS
Be 009	Diff Inelast	TOH	3.2+6	7.0+6	Expt Prog	NEANDC(J)56U 61 Sep 78	Baba+.NDG
Be 009	(n,α)	YOK	1.4+7		Expt Prog	NEANDC(J)56U 54 Sep 78	Shirato+.COUNTER-TELESCOPE.FIG.TABLE
Be 009	(n,α)	TOH	3.2+6	7.0+6	Theo Prog	NEANDC(J)56U 61 Sep 78	Baba+.PWBA CALCULATION.NDG
Be 009	(n,t)	YOK	1.4+7		Expt Prog	NEANDC(J)56U 54 Sep 78	Shirato+.COUNTER-TELESCOPE.TABLE
Be 009	(n,t)	TOH	1.4+7	1.5+7	Expt Prog	NEANDC(J)56U 62 Sep 78	Hino+.GE(LI).478MEV GAMMA.FIG
Be 009	(n,2n)	TOH	1.4+7		Expt Prog	NEANDC(J)56U 64 Sep 78	Sugimoto+.TOF,COINCIDENCE METHOD,NDG
Be 009	Tot Inelastic	TOH	3.2+6	7.0+6	Expt Prog	NEANDC(J)56U 61 Sep 78	Baba+.NDG
C 012	Inelastic γ	TOH	1.4+7	1.5+7	Expt Prog	NEANDC(J)56U 62 Sep 78	Hino+.GE(LI),4.43MEV GAMMA
Fe 054	(n,α)	KYU	1.5+7		Expt Prog	NEANDC(J)56U 44 Sep 78	Fukuda+.GE(LI), ACT SIG=84.0+-7.5 MB
Fe 054	(n,p)	KYU	1.5+7		Expt Prog	NEANDC(J)56U 44 Sep 78	Fukuda+.GE(LI), ACT SIG=355+-22 MB
Co 059	(n,p)	KYU	1.5+7		Expt Prog	NEANDC(J)56U 44 Sep 78	Fukuda+.GE(LI), ACT SIG=53.1+-4.5 MB
Co 059	(n,2n)	KYU	1.5+7		Expt Prog	NEANDC(J)56U 44 Sep 78	Fukuda+.GE(LI), ACT SIG=752+-60 MB
Co 059	(n,2n)	JAE	PILE		Expt Prog	NEANDC(J)56U 17 Sep 78	Sekine+.ACTIVATION, SIG=.233+-.017 MB
Ni 058	(n,p)	KYU	1.5+7		Expt Prog	NEANDC(J)56U 44 Sep 78	Fukuda+.GE(LI), ACT SIG=338+-26 MB
Ni 058	(n,2n)	KYU	1.5+7		Expt Prog	NEANDC(J)56U 44 Sep 78	Fukuda+.GE(LI), ACT SIG=373+-29 MB
Ni 060	(n,p)	KYU	1.5+7		Expt Prog	NEANDC(J)56U 44 Sep 78	Fukuda+.GE(LI), ACT SIG=134+-11 MB
Ni 062	(n,α)	KYU	1.5+7		Expt Prog	NEANDC(J)56U 44 Sep 78	Fukuda+.GE(LI), ACT SIG=25.8+-3.3 MB
Br 079	Reson Params	JAE	5.0+0	2.8+3	Expt Prog	NEANDC(J)56U 9 Sep 78	Ohkubo+.TRANSMISS,CAPTURE,NDG

ELEMENT S A	QUANTITY	LAB	ENERGY(EV) MIN	MAX	TYPE	DOCUMENTATION REF VOL PAGE DATE	COMMENTS
Zr 096	(n,2n)	KYU	1.5+7		Expt Prog	NEANDC(J)56U 44 Sep 78	Fukuda+.GE(LI), ACT SIG=1639+-128 MB
Mo 092	(n,p)	KYU	1.5+7		Expt Prog	NEANDC(J)56U 44 Sep 78	Fukuda+.GE(LI), ACT SIG=71.8+-5.7 MB
Mo 095	(n,p)	KYU	1.5+7		Expt Prog	NEANDC(J)56U 44 Sep 78	Fukuda+.GE(LI), ACT SIG=44.8+-3.5 MB
Mo 098	(n,α)	KYU	1.5+7		Expt Prog	NEANDC(J)56U 44 Sep 78	Fukuda+.GE(LI), ACT SIG=8.1+-0.8 MB
In 115	Tot Inelastic	JAE	5.6+6	7.7+6	Expt Prog	NEANDC(J)56U 25 Sep 78	Yamamoto+.VDG,P-RECOIL.TABLE,GRAPH
Nd 143	(n,γ)	JAE	3.0+3	5.0+5	Expt Prog	NEANDC(J)56U 7 Sep 78	Nakajima+. LINAC,TOT,LIQUID-SCIN,NDG
Nd 145	(n,γ)	JAE	3.0+3	5.0+5	Expt Prog	NEANDC(J)56U 7 Sep 78	Nakajima+.LINAC,TOT,LIQUID-SCIN,NDG
Nd 146	(n,γ)	JAE	3.0+3	5.0+5	Expt Prog	NEANDC(J)56U 7 Sep 78	Nakajima+.LINAC,TOT.LIQUID-SCIN,NDG
Nd 148	(n,γ)	JAE	3.0+3	5.0+5	Expt Prog	NEANDC(J)56U 7 Sep 78	Nakajima+.LINAC,TOT,LIQUID-SCIN,NDG
Eu	(n,γ)	JAE	5.0+3	5.0+5	Expt Prog	NEANDC(J)56U 5 Sep 78	Asami+,LINAC,TOT,LIQUID-SCINTI,NDG
Tb 159	Reson Params	JAE	5.0+0	1.2+3	Expt Prog	NEANDC(J)56U 8 Sep 78	Ohkubo+.PUBLISHED IN JAERI-M7545(78)
Ho 165	Reson Params	JAE	5.0+0	6.0+2	Expt Prog	NEANDC(J)56U 9 Sep 78	Ohkubo+.TRANSMISS,CAPTURE,NDG
W 183	Reson Params	JAE	5.0+0	2.0+3	Expt Prog	NEANDC(J)56U 9 Sep 78	Ohkubo+.TRANSMISS,CAPTURE,SCATT,NDG
Au 197	Inelastic γ	TIT			Theo Prog	NEANDC(J)56U 66 Sep 78	Kobayashi+.EVAPORATION MDL.FIG
Au 197	Nonelastic γ	TIT	1.0+6	1.5+6	Theo Prog	NEANDC(J)56U 66 Sep 78	Kobayashi+.EVAPORATION MDL.FIG
Au 197	(n,γ)	TIT			Theo Prog	NEANDC(J)56U 66 Sep 78	Kobayashi+.EVAPORATION MDL.FIG
Th 232	Fiss Prod γ	TOK	FAST		Expt Prog	NEANDC(J)56U 70 Sep 78	Akiyama+.DECAY ENERGY RELEASE,NDG
Th 232	(n,γ)	KUR	1.0+3	4.5+5	Expt Prog	NEANDC(J)56U 32 Sep 78	Kobayashi+.LINAC,TOF,C6D6-SCIN.FIG
Th 232	(n,γ)	KYU	1.0+4	1.6+7	Eval Prog	NEANDC(J)56U 53 Sep 78	Ohsawa+.OPTICAL MDL.H-F MDL. NDG

ELEMENT S A	QUANTITY	LAB	ENERGY(EV) MIN	MAX	TYPE	DOCUMENTATION REF VOL PAGE DATE	COMMENTS
Th 232	(n,2n)	KYU	1.0+4	1.6+7	Eval Prog	NEANDC(J)56U 53 Sep 78	Ohsawa+.PEARLSTEIN'S METHOD, NDG
Th 232	Tot Inelastic	KYU	1.0+4	1.6+7	Eval Prog	NEANDC(J)56U 53 Sep 78	Ohsawa+.OPTICAL MDL.H-F MDL. NDG
U	Fiss Prod γ	TOK	FAST		Expt Prog	NEANDC(J)56U 70 Sep 78	Akiyama+.DECAY ENERGY RELEASE,NDG
U 235	Evaluation	JAE	1.0+2	2.0+7	Eval Prog	NEANDC(J)56U 14 Sep 78	Matsunobu+.FOR JENDL-2,NDG
U 235	Fiss Prod γ	TOK	FAST		Expt Prog	NEANDC(J)56U 70 Sep 78	Akiyama+.DECAY ENERGY RELEASE,FIG
U 238	Evaluation	JAE	1.0+2	2.0+7	Eval Prog	NEANDC(J)56U 14 Sep 78	Matsunobu+.FOR JENDL-2,NDG
U 238	Fiss Prod γ	TOK	FAST		Expt Prog	NEANDC(J)56U 70 Sep 78	Akiyama+.DECAY ENERGY RELEASE,NDG
Pu 239	Evaluation	JAE	1.0+2	2.0+7	Eval Prog	NEANDC(J)56U 14 Sep 78	Matsunobu+.FOR JENDL-2,NDG
Pu 240	Evaluation	JAE	1.0+2	2.0+7	Eval Prog	NEANDC(J)56U 14 Sep 78	Matsunobu+.FOR JENDL-2,NDG
Pu 241	Evaluation	JAE	1.0+2	2.0+7	Eval Prog	NEANDC(J)56U 14 Sep 78	Matsunobu+.FOR JENDL-2,NDG
Cm 245	Evaluation	JAE	1.0-5	2.0+7	Eval Prog	NEANDC(J)56U 10 Sep 78	Igarasi+.PUBLISHED IN JAERI-M7733
Cf 252	Spect Fiss γ	KYU	SPON		Expt Prog	NEANDC(J)56U 52 Sep 78	Toyofuku+.IONIZATION CHAMB.103GAMMAS
MANY	(n,γ)	KYU	1.4+7		Eval Prog	NEANDC(J)56U 45 Sep 78	Kumabe+.EMPIRICAL FORMULA FOR A-Z
MANY	(n,γ)	JAE		5.0+2	Expt Prog	NEANDC(J)56U 8 Sep 78	Ohkubo.PUBLISHED IN NSE 66(78) 217
MANY	(n,γ)	JAE	1.0+3		Comp Prog	NEANDC(J)56U 16 Sep 78	Matsunobu+.PUBLISHED IN JAERI-M7568
MANY	(n,p)	KYU	1.4+7		Eval Prog	NEANDC(J)56U 45 Sep 78	Kumabe+.EMPIRICAL FORMULA FOR A-Z
MANY	(n,p)	KYU	1.4+7		Theo Prog	NEANDC(J)56U 48 Sep 78	Kumabe+.A=30-90.PRE-EQUIRIBRIUM MDL
MANY	(n,p)	KYU	1.4+7		Theo Prog	NEANDC(J)56U 50 Sep 78	Kumabe+.GEOMETRY DEP. HYBRID MODEL

I. HIROSHIMA UNIVERSITY

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I-1 Precision Measurements of Gamma-Ray Intensities

Y. Yoshizawa, Y. Iwata, T. Katoh*, J. Ruan**, T. Kojima**
and Y. Kawada***

Gamma-ray intensities were measured with Ge(Li) detectors in the energy region of 279-2754 keV. The energy region is extended to 2754 keV from 1836 keV in this year. Measurements were performed at Hiroshima and Nagoya. The detectors were calibrated with standard sources of ^{22}Na, ^{46}Sc, ^{54}Mn, ^{60}Co, ^{85}Sr, ^{88}Y, ^{134}Cs and ^{203}Hg and also with cascade gamma rays of ^{24}Na, ^{52}Mn, ^{90}Nb and ^{108m}Ag.

Relative intensities of ^{154}Eu were determined with the errors of 0.3 % for strong gamma rays as shown in Table I. Relative intensities of ^{56}Co have been also measured and the result will be obtained in near future.

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Table I. Relative gamma-ray intensities for ^{154}Eu

Gamma-ray energy (keV)	Relative intensities (%)
444.5	1.62 ± 0.03
519.7	14.36 ± 0.06
625.2	0.93 ± 0.04
676.5	0.47 ± 0.05
692.4	5.189 ± 0.027
723.2	58.27 ± 0.15
756.8	13.19 ± 0.10
815.5	1.52 ± 0.09
845.4	1.68 ± 0.03
850.7	0.69 ± 0.03
873.1	35.10 ± 0.11
892.8	1.49 ± 0.05
904.1	2.62 ± 0.05
924.7	0.20 ± 0.05
996.2	30.02 ± 0.09
1004.7	51.86 ± 0.12
1140.7	0.672 ± 0.019
1246.2	2.49 ± 0.04
1274.4	100.00 ± 0.17
1494.2	2.055 ± 0.015
1596.7	5.230 ± 0.022

I-2 Evaluation of Gamma-Ray Intensities

Y. Yoshizawa, H. Inoue, M. Hoshi, K. Shizuma and Y. Iwata

Relative gamma-ray intensities and intensities per decays were evaluated again for 17 nuclides. Decay rates of these nuclides except ^{180m}Hf can be determined by means of the β-γ or X-γ coincidence method. Therefore, these gamma rays are useful for calibrations of precision intensity measurements.

Table I. Evaluated values of gamma-ray intensities

Nuclide	Energy (keV)	Relative intensity (%)	Intensity per decay (%)
^{22}Na	1274.5		99.94 ±0.02
^{24}Na	1369	100.0000±0.0030	99.9942±0.0030
	2754	99.8866±0.0074	99.8808±0.0074
^{46}Sc	889.2	99.9965±0.0016	99.9836±0.0016
	1120.5	100.0000±0.0012	99.9871±0.0012
^{54}Mn	834.8		99.976 ±0.003
^{60}Co	1173.3	99.91 ±0.02	99.89 ±0.02
	1332.5	100.0000±0.0015	99.9816±0.0015
^{85}Sr	514.0		98.4 ±0.4
^{88}Y	898.0	95.0 ±0.5	94.3 ±0.5
	1836.0	100.00 ±0.07	99.24 ±0.07

Table I. (Continued)

Nuclide	Energy (keV)	Relative intensity (%)	Intensity per decay (%)
^{95}Nb	765.8		99.80 ±0.02
^{108m}Ag	434.0	99.360±0.090	90.5 ±0.7
	614.4	99.883±0.034	91.0 ±0.7
	723.0	100.000±0.022	91.1 ±0.7
^{133}Ba	276.4	11.57 ±0.04	7.170±0.025
	302.9	29.54 ±0.08	18.31 ±0.06
	356.0	100.00 ±0.29	61.97 ±0.12
	383.9	14.39 ±0.05	8.92 ±0.03
^{134}Cs	604.7	100.00 ±0.008	97.639±0.008
	795.8	87.35 ±0.04	85.29 ±0.04
^{137}Cs	661.6		85.3 ±0.3
^{139}Ce	165.9		79.99 ±0.16
^{180m}Hf	215.3	86.3 ±1.6	81.5 ±1.5
	332.3	100.0 ±0.6	94.4 ±0.5
	443.2	87.0 ±0.8	82.1 ±0.7
^{198}Au	411.8		95.52 ±0.06
^{203}Hg	279.2		81.48 ±0.08
^{207}Bi	569.7	100.00 ±0.03	97.74 ±0.03
	1063.6	75.5 ±0.3	73.8 ±0.3

II. JAPAN ATOMIC ENERGY RESEARCH INSTITUTE

A. Linac Laboratory, Division of Physics

II-A-1 Neutron capture cross section measurements of Eu

A. Asami, Y. Nakajima, T. Yamamoto*,
Y. Kawarasaki and Y. Furuta

The neutron capture cross section of natural europium has been measured in the energy region between 5 and 500 keV with a capture detector on a 52 m flight path of the JAERI Linac neutron spectrometer.

The detector is a 3500 l liquid scintillator tank, and two neutron flux detectors are provided, one of a ^{6}Li-glass scintillator, and the other ^{10}B-NaI(Tl) detector. The sample is powder of europium oxide with the thickness of 2.386×10^{-3}, and is contained in an aluminium can. To obtain accurate cross section data much attention was paid to background determination, and for this purpose six spectra were measured at the same time.

Analysis of the data includes the corrections for the effects of (1) multiple scattering in the sample and in the ^{6}Li glass scintillator, and (2) resonance self-shielding.

Preliminary results so far obtained up to 200 keV[1] are in good agreement with those of Moxon et al.[2] except at higher energies. Both these two sets of data are higher than the previous data of Macklin et al.[3] and of Konks et al.[4].

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II-A-2 Neutron Capture Cross Section Measurements of $^{143, 145, 146, 148}Nd$

Y. Nakajima, A. Asami, Y. Kawarasaki,

Y. Furuta, T. Yamamoto* and Y. Kanda**

Neutron capture cross sections of $^{143, 145, 146, 148}Nd$ isotopes have been measured in the energy region of a few to 500 keV with a large liquid scintillator, 3,500 l volume, on a 52 m flight path of the JAERI 120-MeV linac neutron time- of-flight spectrometer. The measurements were made in two stages; in the first stage the time resolution was 1.7 nsec/m and in the second stage that was 0.53 nsec/m. The neutron flux was measured with either a ^{6}Li-glass scintillator at lower energies or a ^{10}B-NaI detector at higher energies. Samples are powder of oxide, enriched to 92 to 95%, loaned by ORNL. Attention is particularly paid to determination of the backgrounds and for this purpose eight neutron or capture TOF spectra were measured in a cyclic manner for the combination of the detectors, the samples and the blacksamples-in and -out. Data analysis is in progress.

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* Department of Nuclear Engineering, Tohoku University

** Department of Engineering, Kyushu University

II-A-3 Neutron Capture Probabilities for Thick Samples at Resonance Energies

Makio Ohkubo

A paper on this subject has been published in Nucl. Sci. Eng., 66, 217-228 (1978).

Slow Neutron Resonances in TB-159

Makio Ohkubo and Yuuki Kawarasaki

A report with the above title has been published in JAERI-M 7545 (Feb. 1978) with the following abstract:

An experiment of neutron resonances in Tb-159 was carried out using the JAERI linac time-of-flight facility. Transmission and capture measurements were made on terbium samples of two thicknesses, using ^{6}Li-glass scintillators and Moxon-Rae detector at the 47m station of the TOF facility; the neutron flux was monitored with a ^{6}Li-glass transmission type flux monitor. Transmission data were analyzed with an area analysis program up to 1.2 keV, and capture data with Monte-Carlo program CAFIT, to obtain $2g\Gamma_n^o$, Γ and Γ_γ. Spin determinations were also made for large resonances. Between 754 to 1192 eV, 50 new levels were analyzed. The results are as follows; average level spacing $\langle D \rangle = 4.4 \pm 0.4$ eV below 600 eV, s-wave strength function $S_o = (1.55 \pm 0.15)10^{-4}$ for 206 levels below 1.2 keV, and average radiation width $\langle \Gamma_\gamma \rangle = 107 \pm 7$ meV for lower 25 levels. Average capture cross section $\langle \sigma_c \rangle$ were obtained from 50 eV to 30 keV.

II-A-4 Neutron Resonance Parameters of ^{183}W, ^{165}Ho and ^{79}Br

M. Ohkubo, Y. Kawarasaki and T. Yamamoto*

(1) ^{183}W

Neutron transmission, scattering and capture measurements on ^{183}W (WO_3 powder, 81.7% enriched) were made with a pair of ^{6}Li-glass and ^{7}Li-glass detector and a Moxon-Rae detector, at the 47 m station of the JAERI linac time-of-flight spectrometer[1] in the energy region below 2 keV. Analyses were almost finished on the transmission data. Analyses in capture and scattering data are in progress. (M. Ohkubo and Y. Kawarasaki)

(2) ^{165}Ho

Transmission and capture measurements on ^{165}Ho with two thicknesses of sample were made with a detection system in reference 1. Analyses were made with the Harvey-Atta code for transmission data, and with CAFIT Monte-Carlo code for capture data. Resonance parameters for ~100 levels below 600 eV were obtained. (T. Yamamoto and M. Ohkubo)

(3) ^{79}Br

Transmission and capture measurements were made on natural (CBr_4) and enriched ($Na^{79}Br$, 98.6% enriched) bromic compounds with detectors in reference 1. Transmission data were analyzed for ~30 levels of ^{79}Br up to 2.8 keV, and the isotopic identification of the resonances were newly made in that energy region. Further measurements and analyses, including those on ^{81}Br, are in progress. (M. Ohkubo)

1) M. Ohkubo and Y. Kawarasaki; JAERI-M 7545 (1978)
"Slow Neutron Resonances in Tb-159"

* Department of Nuclear Engineering, Tohoku University

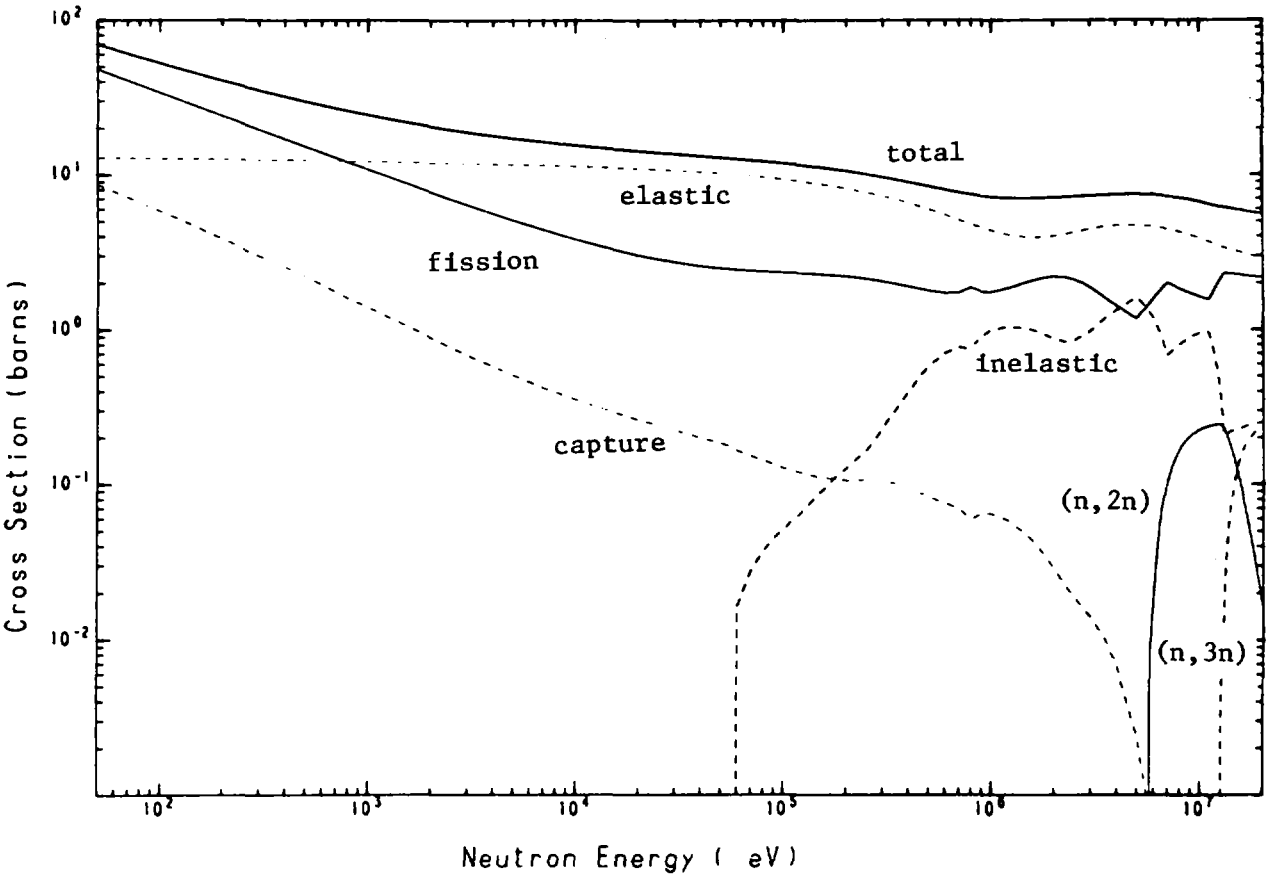
B. Nuclear Data Center, Division of Physics and Working Groups of Japanese Nuclear Data Committee

II-B-1 Evaluation of Neutron Nuclear Data for ^{245}Cm

Sin-iti IGARASI and Tsuneo NAKAGAWA

Evaluation of neutron nuclear data for ^{245}Cm was performed below 20 MeV. The evaluation was made to select suitable resonance parameters in the energy region up to 60 eV, and the thermal values of the capture and fission cross sections were obtained with the adopted resonance parameters. Calculations were carried out with the Reich-Moore formula and the differences between multilevel and single-level calculations were taken as the background cross sections.

In the energy region higher than 60 eV, the fission cross section was reproduced using semi-emprical formula. The total, elastic and inelastic scattering, capture, (n,2n) and (n,3n) cross sections were obtained by optical and statistical model calculations. The number of neutrons per fission was also estimated. Fig. shows the present results above 50 eV.


total
elastic
fission
inelastic
capture
(n,2n)
(n,3n)
Cross Section (barns)
Neutron Energy (eV)

II-B-2 Precise Benchmark Tests of JENDL-1

T. Kamei*, T. Hojuyama**, M. Sasaki**, Y. Seki**, A. Zukeran***
and Y. Kikuchi

Benchmark tests of JENDL-1 were continued in Working Group on Integral Tests for JENDL in JNDC on the reaction rate distributions and sodium void coefficients in MZB core, the control rod worths in MZC core, the multi control rods worths and reaction rate distribution in ZPPR-3 core with very precise methods.

The calculated results with JENDL-1 were compared with those with JAERI-Fast set version-2, MICS 5 (the standard group constants set in MAPI) and/or NNS-5 (the standard group constants set in NAIG). The followings were pointed out :

1) JENDL-1 underestimates the fission rates of ^{235}U and ^{239}Pu and overestimates those of ^{240}Pu in the blanket of MZB core.

2) JENDL-1 gives fairly satisfactory results on the sodium void coefficients of MZB core, though some anomalous C/E values appear in the outer core due to the errors of leakage component.

3) The C/E values are about 0.95 for the control rod worths in MSC core and do not depend on the ^{10}B enrichment.

4) The C/E value of the multi control rods worth in ZPPR-3/1B increases with increasing number of inserted rods. The mean C/E value is 1.02, which is as satisfactory as the results with the other sets.

5) JENDL-1 underestimates the fission rate of ^{235}U near the inserted control rods and in the outer core of ZPPR-3/2B.

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** Nuclear Development Center, Mistrubishi Atomic Power Industries inv.

*** Power Reactor and Nuclear Fuel Development Corporation

It is difficult, however, to feed back these results directly on the microscopic cross sections in JENDL-1, since contribution of each nuclide cannot be deduced in such sophisticated problems mentioned above. Moreover, some calculated results might depend on the adopted method such as group collapsing, cell calculation, self-shielding corrections etc. Taking account of the present results as a whole, we conclude that applicability of JENDL-1 is as satisfactory as that of the existing other sets.

II-B-3

Consistent Evaluation of the Nuclear Data for Heavy Nuclides

H. Matsunobu*, Y. Kanda**, M. Kawai†,
T. Murata†, and Y. Kikuchi††

Evaluation work of the nuclear data for ^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu, and ^{241}Pu has been continued as a part of the activities in Working Group on Heavy-Nuclide Nuclear Data of Japanese Nuclear Data Committee since spring, 1977 in which JENDL-1[1] was published.

The important part of this work is evaluation of the fission cross sections, and to keep the consistency among the evaluated data for each nuclide. The fission cross section of ^{235}U was evaluated on the basis of the most recent experimental data published in the "Specialists Meeting on Fast Neutron Cross Sections of ^{233}U, ^{235}U, ^{238}U, and ^{239}Pu" held at ANL in 1976, and after that. The fission cross sections of other nuclides were determined using the most reliable absolute data and ratio data to fission cross section of ^{235}U. The evaluated data of fission cross section for ^{235}U were somewhat modified within the errors of measured data in order to give good agreement between the fission cross section derived from the ratio data and the absolute data for each nuclide.

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†† Japan Atomic Energy Research Institute

The elastic and inelastic scattering cross sections and the capture cross section are obtained using some experimental data and calculation based on the optical model and statistical theory. Consistency of the optical potential parameters were also examined systematically for five nuclides.

The result of evaluation will be reported in the fall meeting of Atomic Energy Society of Japan to be held in October, 1978.

1) Kikuchi, Y., Nakagawa, T., Matsunobu, H., Kanda, Y., Kawai, M., and Murata, T. : "Neutron Nuclear Data of ^{235}U, ^{238}U, ^{239}Pu, ^{240}Pu, and ^{241}Pu Adopted in JENDL-1" JAERI-M 6996 (1977)

II-B-4

Compilation of Measured Capture Cross Sections for JENDL-Fission Product Nuclear Data File

H. Matsunobu* and T. Watanabe**

A paper on this subject was published in "JAERI-M 7568" in March, 1978 with an abstract as follows :

The status of experimental data of neutron capture cross section is reviewed on 38 fission product (FP) nuclides important for fast reactor calculations. The experimental data in the energy range above 1 keV are compiled for the following 24 FP nuclides from among the above 38 FP nuclides :

^{96}Zr, ^{95}Mo, ^{97}Mo, ^{98}Mo, ^{100}Mo, ^{99}Tc, ^{102}Ru, ^{104}Ru, ^{103}Rh, ^{105}Pd, ^{108}Pd, ^{109}Ag, ^{127}I, ^{133}Cs, ^{139}La, ^{142}Ce, ^{141}Pr, ^{146}Nd, ^{148}Nd, ^{150}Nd, ^{147}Sm, ^{149}Sm, ^{152}Sm, ^{153}Eu.

Appendix I gives outlines of the experiments (neutron energy, number of data points, cross section, neutron source, experimental method, standard cross section, β- and γ-ray data etc.) in tables. Appendix II illustrates the compiled data of neutron capture cross section in figures.

This work was made as a part of evaluation work in Fission Product Nuclear Data Working Group of Japanese Nuclear Data Committee. The authors were supported under the contract with JAERI.

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** Kawasaki Heavy Industries, Ltd.

II-C-1 Fission Neutron Cross Section for the $^{59}Co(n,2n)^{58}Co$ Reaction

T. Sekine and H. Baba

Fission neutron cross section of the $^{59}Co(n,2n)^{58}Co$ reaction was measured with the activation method. Cobalt metal was covered with cadmium foil for reduction of the formation of ^{60}Co and irradiated with reactor neutrons. γ radiation of ^{58}Co was detected using a Ge(Li) detector equiped with a Compton suppression system.

The preliminary experiments showed that the cross section was 0.233 ± 0.017 mbarn on the basis of 0.258 ± 0.013 mbarn for the $^{55}Mn(n,2n)^{54}Mn$ reaction. The result is much lower than the earlier value, 0.40 ± 0.04 mbarn[1], but is in good agreement with the predicted value, 0.17 mbarn[2].

References:

1) A. Calamand, STI/DOC/10/156 (1974).

2) T. Sekine and H. Baba, J. Inorg. Nucl. Chem., in press.

III. KYOTO UNIVERSITY

A. Institue of Atomic Energy

III-A-1 Independent Isomer Yields of Sb Isotopes in α-particle Induced Fission of ^{232}Th

T. Nishi, I. Fujiwara and N. Imanishi

The independent yields of Sb isotopes from ^{232}Th fission were measured radiochemically at incident α-particle energies of 30 and 110 MeV.

$^{232}ThF_4$ targets 10 mg/cm^2 thick which were deposited on aluminum foils 5.4 mg/cm^2 thick and covered by similar aluminum foils, were irradiated for 1 min with α-particles of energies of 30 and 110 MeV at external course of the RCNP Osaka University cyclotron facilities. After irradiation, the $^{232}ThF_4$ targets and aluminum catcher foils were dissolved in aqua-regia containing boric acid along with tin and antimony carriers. Tin and antimony were separated from the target solution in a few minutes and mounted on millipore filters. γ-rays emitted from the samples were observed with a Ge(Li) detector connected to a 4k pulse height analyzer. Observed γ-rays belong to ^{128}Sn, ^{122}Sb, ^{126}Sb, ^{128}Sb and ^{130}Sb, and the yields of these nuclides were obtained by correcting chemical yields, detection efficiencies, and γ-ray abundances. The intensity of incident α-particle was measured with a calibrated secondary electron monitor.

Table 1 shows the independent isomeric cross sections of antimony isotopes thus obtained in the ^{232}Th fission induced by 30 and 110 MeV α-particles. The ^{122}Sb and ^{126}Sb nuclides are shielded, while for ^{128}Sb and ^{130}Sb nuclei, the precursors ^{128}Sn

and ^{130}Sn decay to them, respectively. In the present work, the contribution of ^{128}Sn to ^{128}Sb during the irradiation and before the time of chemical separation, was corrected on the basis of the cumulative yields of ^{128}Sn. For the 130 chain, the correction was omitted, because the contributions were estimated to be little and, furthermore, the high and low spin states of ^{130}Sn exclusively decay to the high and low spin states of ^{130}Sb, respectively.

In Fig. 1, isomeric cross section ratios for ^{122}Sb(8,2$^-$), ^{126}Sb(7$^-$8$^-$,5$^+$), ^{128}Sb(8$^-$,5$^+$) and ^{130}Sb(8$^-$,5$^+$) are plotted as a function of number of neutrons. In the same figure, are shown the mean values of the results[1)] for ^{233}U, ^{235}U and ^{239}Pu induced by thermal-neutrons and the results[2)] of iodine isotopes in the proton induced fission of ^{238}U. The results show that high spin states are more easily populated with increasing the incident energy and with shifting from asymmetric fission mode to symmetric fission one.

References;

1) N. Imanishi, I. Fujiwara and T. Nishi, Nucl. Phys. A263 (1976) 141

2) M. Diksic and L. Yaffe, Can. J. Chem. 53 (1975) 3116

Table 1. Independent or cumulative formation cross section of some antimony isotopes and their ratios. (mb)

	$^{122}Sb(8,2^-)$		$^{126}Sb(7^-8^-,5^+)$		$^{128}Sb(8^-,5^+)$		$^{130}Sb(8^-,5^+)$	
	σ_{high}	σ_{low}	σ_{high}	σ_{low}	σ_{high}	σ_{low}	σ_{high}	σ_{low}
^{232}Th + 30 MeV α	——	——	5.10 ±0.85	1.16 ±0.20	4.95 ±0.70	1.60 ±0.27	6.42* ±1.2	4.81* ±1.0
σ_{high} / σ_{low}	——		4.4 ± 1.0		3.09 ± 0.68		1.34 ± 0.38	
^{232}Th + 110 MeV α	9.17 ±1.2	1.42 ±0.20	25.8 ±3.9	4.15 ±0.50	6.66 ±0.57	1.88 ±0.16	2.50* ±0.20	1.63* ±0.42
σ_{high} / σ_{low}	6.5 ± 1.1		6.2 ± 1.2		3.54 ± 0.43		1.53 ± 0.41	

* Cumulative formation cross section

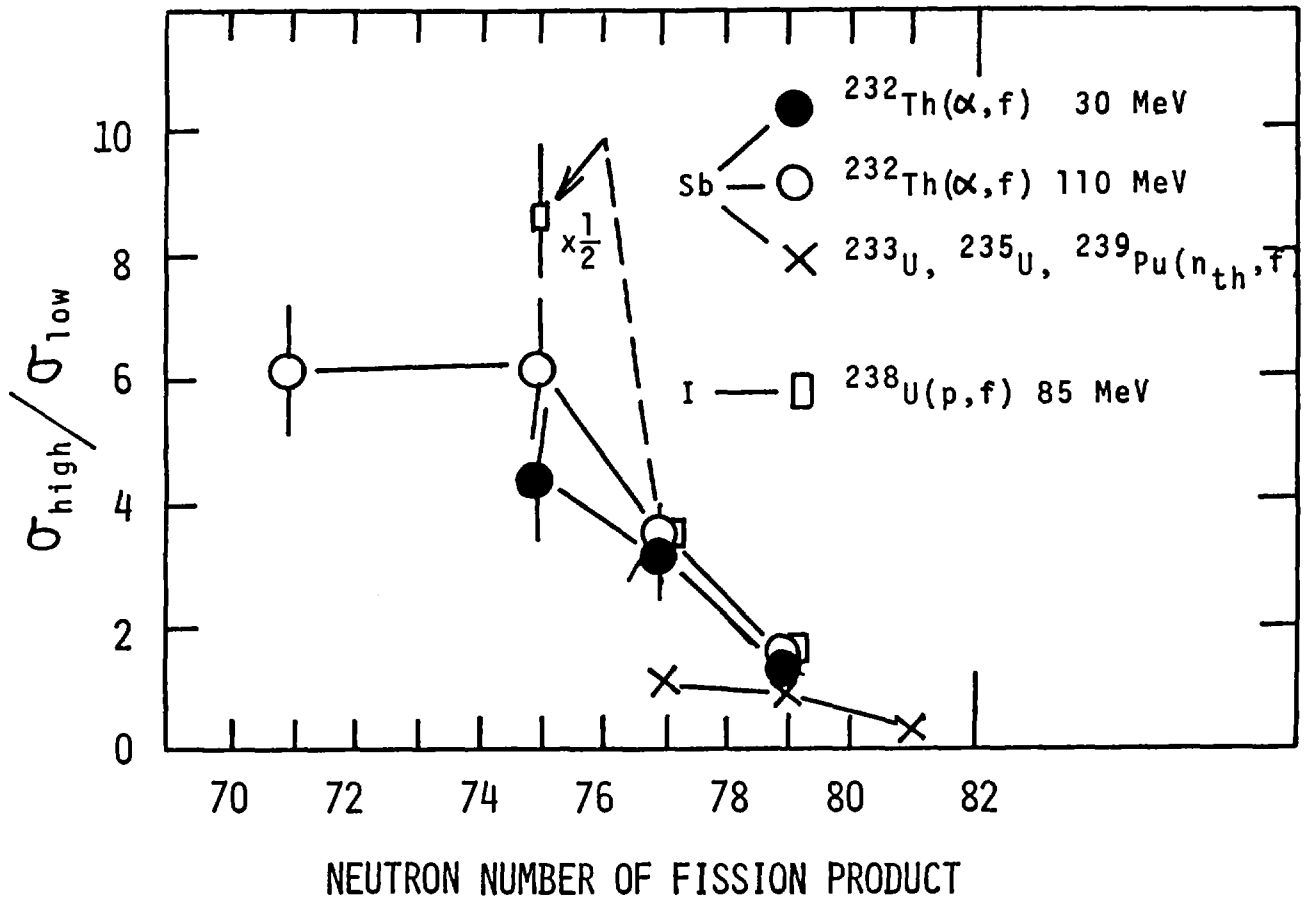

Fig. 1. Ratios of isomeric formation cross section vs. neutron number.

III-A-2 Mass Yield Curve of ^{232}Th Fission Induced by 110 MeV α-particle

T. Nishi, I. Fujiwara, N. Imanishi and Y. Horikawa*

Mass yield curve of ^{232}Th fission were measured at an incident α-particle energy of 110 MeV. The experimental method was similar to the one given in the preceding report.

Cumulative or independent yields were measured for 25 nuclides ranging from A = 81 to A = 153. As shown in Fig. 1, the charge dispersion curve for the mass chains 131, 133 and 134 was composed from the yields of Sb, Te, I and Cs isotopes. The width σ of the charge dispersion curve was deduced to be equal to 1.23. Assuming that the same chage dispersion curve at all mass chains and applying the UCD assumption referring to known data[1] of numbers of pre- and post-fission neutrons, we have deduced the values of chain yields from the measured cumulative yields. The results are shown in Fig. 2 along with the data for the ^{232}Th fission induced by 40 MeV α-paticles[2].

Yields of symmetric fission increase rapidly and the width of the mass yield curve becomes broader with increasing the incident energy. The total fission cross section is obtained to be 2.44 b from the present mass yield curve and is in good agreement with data of 2.25 b obtained by using a solid state track detector[3].

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* Present Address: Kansai Electric Power Co.

References:

1) T. C. Raginski, M. E. Davis and J. W. Cobble, Phys. Rev. C4 (1971) 1361

2) M. Dksic, D. K. McMillan and L. Yaffe, J. Inorg. Nucl. Chem. 36 (1976) 7;
E. Cheifetz and Z. Fraenkel, Phys. Rev. C2 (1970) 256

3) J. Ralarosy, M. Debeauvais, G. Ramy and J. Tripler, Phys. Rev. C8 (1973) 2372

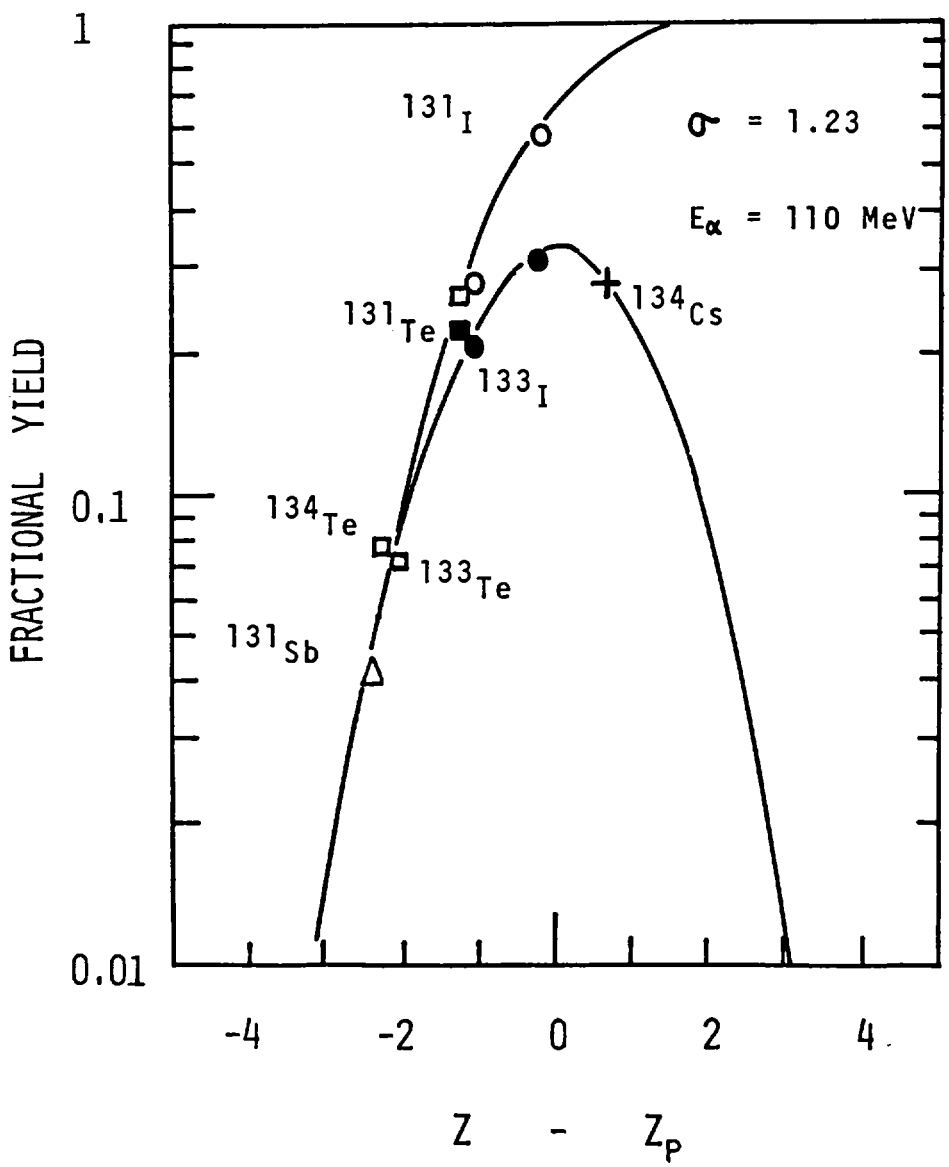

Fig. 1. Charge dispersion for fission products with A around 130.

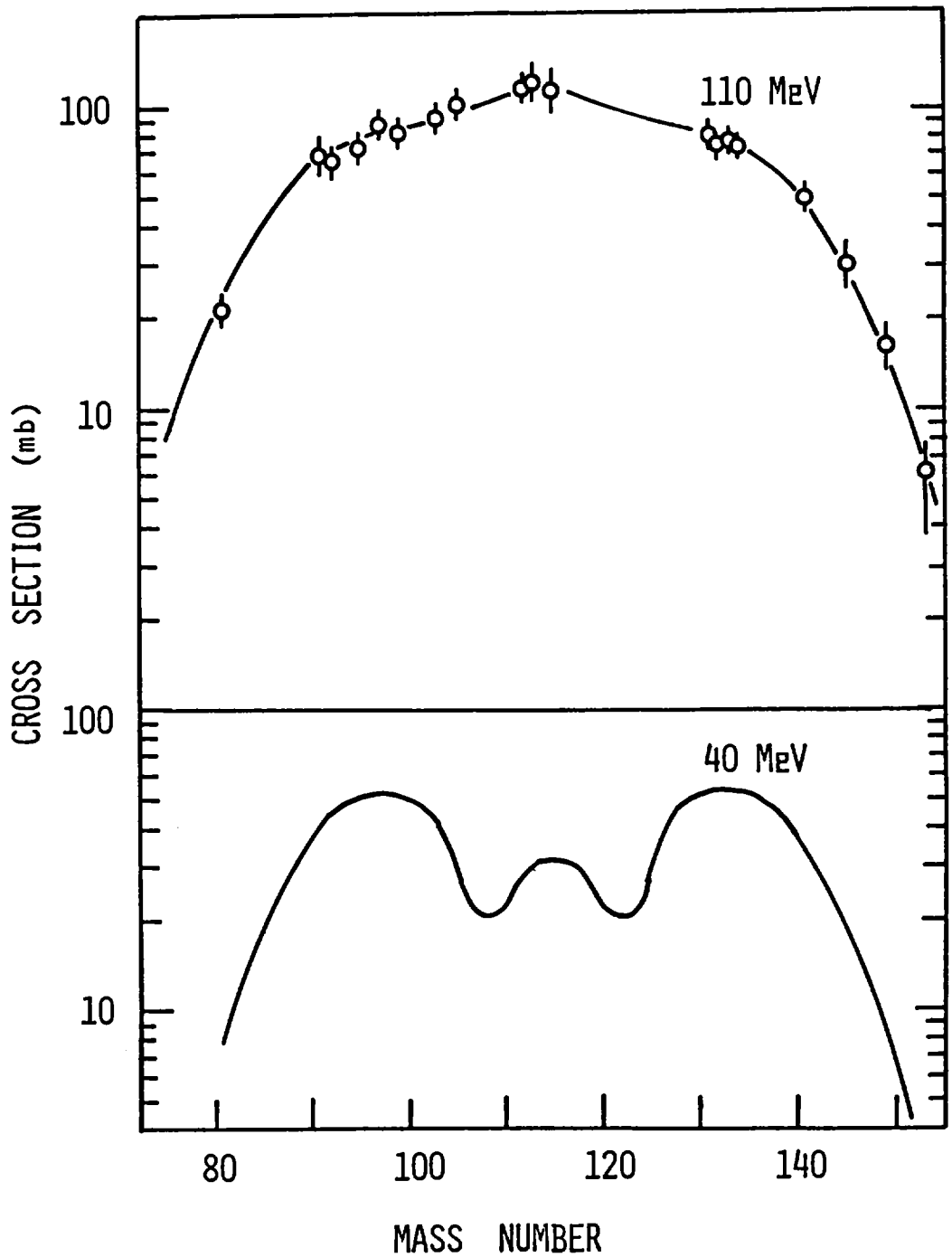

Fig. 2. Mass yield curve for α-induced ^{232}Th fission.

B. Research Reactor Institute

III-B-1

MEASUREMENT OF THE $^{115}In(n,n')^{115m}In$ REACTION CROSS SECTION USING A PROTON RECOIL DETECTOR WITH A CsI(Tl) SCINTILLATOR

Shuji Yamamoto, Katsuhei Kobayashi, Shu A. Hayashi
Itsuro Kimura, Hiroshi Gotoh* and Hideyuki Yagi*

A paper on this subject was submitted to Annu. Rep. Res. Reactor Inst., Kyoto Univ.

The cross section for the $^{115}In(n,n')^{115m}In$ reaction from 5.60 MeV to 7.65 MeV has been measured with a CsI(Tl) proton recoil counter as a fast neutron flux monitor.

Monochromatic neutrons were produced by the $D(d,n)^3He$ reaction with the 5.5 MV Van de Graaff accelerator at Japan Atomic Energy Research Institute. The experimental arrangement is shown in Fig. 1. The CsI(Tl) scintillator was 0.5 mm in thickness and 38 mm in diameter, and the polyethylene radiator about 30 μm thick. The sensitive area of the crystal was confined by the cylindrical gold collimator of 10 mm in diameter, 30 mm long, to detect protons recoiled forward. By rotating a gold backing plate in every 10 minutes, the radiator was alternately set in and out of the position in front of the CsI(Tl) scintillator, in order to measure total and background counts.

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An indium sample foil, 20 mm in diameter and 0.5 mm thick, was attached on the window of the counter case as shown in Fig. 1. The 335 keV gamma-rays from the ^{115m}In were measured with a coaxial-type Ge(Li) detector of 30 cc, whose detection efficiency was calibrated with the standard gamma-ray sources of ^{57}Co, ^{113}Sn, ^{137}Cs, and ^{203}Hg.

The obtained results of the cross section for the $^{115}In(n,n')^{115m}In$ reaction from 5.60 MeV to 7.65 MeV are shown in Table 1 and Fig.2. In this case we used 0.461[1] as the emission rate of the 335 keV gamma-ray per disintegration of ^{115m}In. The data by the previous workers are also plotted in the Fig. 2. The errors estimated in the present experiment are listed in Table 2. These errors were added quadratically to give a total error of about 5.1 %. The absolute neutron flux was accurately determined within 3 % by using the CsI(Tl) proton recoil counter, as shown in Table 2. However, the error of the induced activities of the indium sample was about 4 %, which mainly caused by a worse total experimental error.

The present results generally agree well with those of Santry and Butler[2], and with those of Smith et al.[3] in the energy region from 6.64 MeV to 7.65 MeV. However, the values of Smith et al. are rather higher by about 10 % than the present in the 5.60 MeV to 6.12 MeV region. Menlove's results[4] are generally higher than the authors'. The measured values agree with ENDF/B-IV data, while the evaluation of Smith et.al.[1] does not always show good agreement with the present results.

References :

1) D. L. Smith, et al., ANL/NDM-26 (1976).

2) D. C. Santry and J. P. Butler, Can. J. Phys., 54 (1975) 757.

3) D. L. Smith and J. W. Meadows, ANL/NDM-14 (1975).

4) H. O. Menlove et al., Phys. Rev., 163 (1967) 1308.

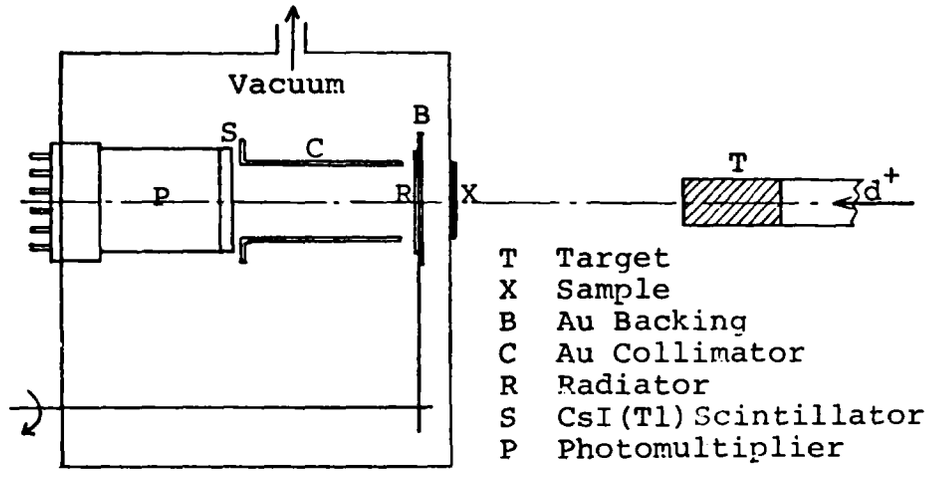

Fig. 1 Experimental arrangement and schematic figure of the proton recoil counter with a CsI(Tl) scintillator

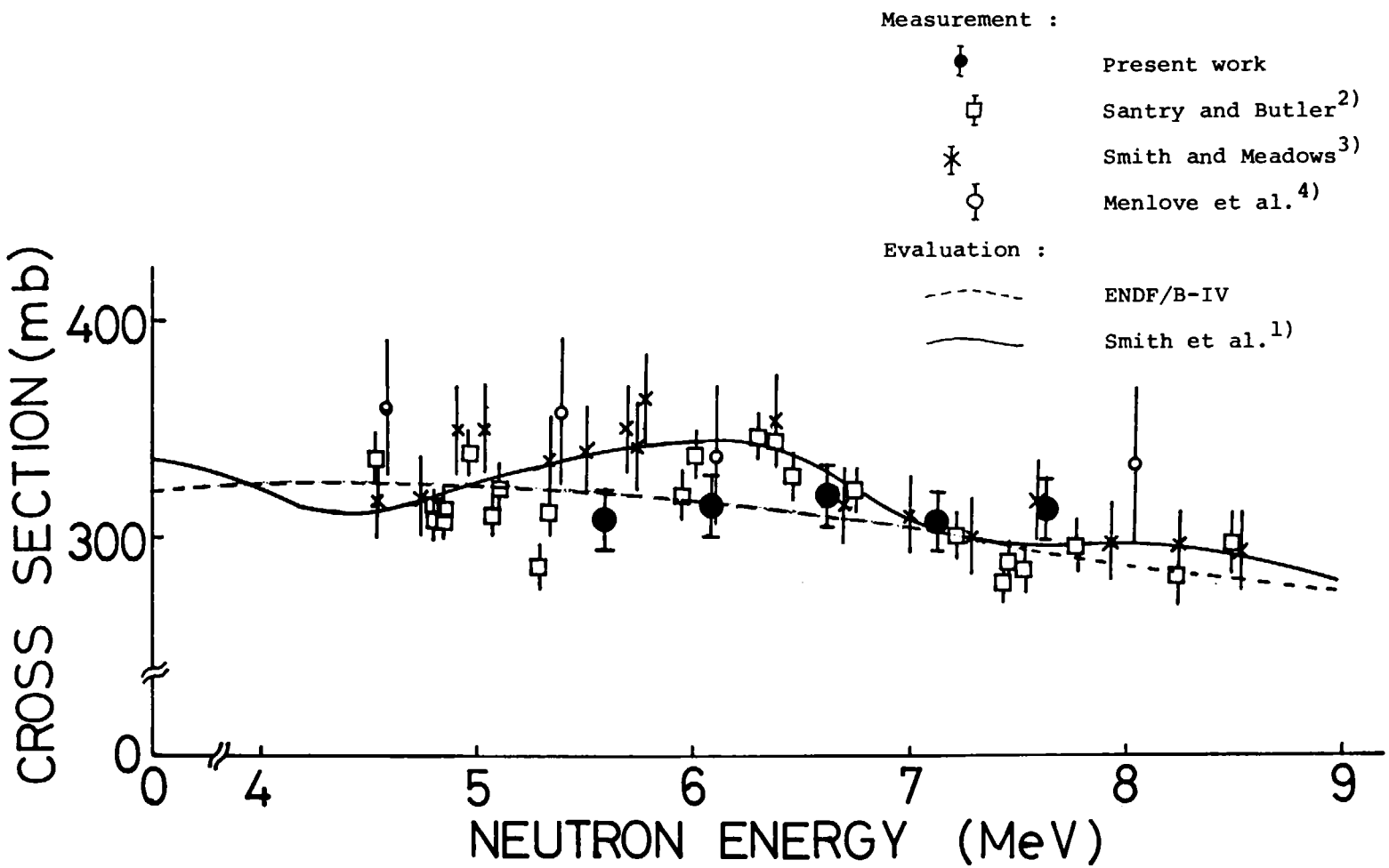

Fig. 2 Cross section for the $^{115}In(n,n')^{115m}In$ reaction,

Table 1 Present values of the cross section for the $^{115}In(n,n')^{115m}In$ reaction

Neutron energy (MeV)	Cross section (mb)
5.60	302.7 ± 14.5
6.12	310.6 ± 14.9
6.64	317.3 ± 15.2
7.15	304.8 ± 14.6
7.65	316.7 ± 15.2

Table 2 Summary of the estimated errors from the present cross section measurement

n-p scattering cross section		0.5 %
Weighing of polyethylene radiator	$<$	1 %
Geometry and efficiency of the proton recoil detector		1.5 %
Multiple neutron scattering in the detector system	$<$	0.5 %
Statistics of proton recoil counting	$<$	1 %
Gamma-ray efficiency of the Ge(Li) detector	$\sim$	4 %
Statistics of induced activity measurement of ^{115m}In	$<$	1 %
Others		2 %
Total error	$\lesssim$	5.1 %

III-B-2 MEASUREMENT OF THE CROSS SECTION FOR THE $^{232}Th(n,\gamma)$ REACTION FROM 1 keV TO 450 keV

Katsuhei Kobayashi, Yoshiaki Fujita and Nobuhiro Yamamuro*

A paper on this subject is a recent preliminary work of the cross section measurement for the $^{232}Th(n,\gamma)$ reaction. The result was presented to the Fall Meeting of the Atomic Energy Society of Japan, in October 7 - 10, 1978 with an abstract as follows :

In order to assess the $^{232}Th/^{233}U$ breeding cycle, which is of present interest, accuracies of 3 to 10 % have been requested[1] in the $^{232}Th(n,\gamma)$ cross section. However, most available data in rather old measurements and evaluations in the keV region differ from the recent data of ORNL[2] and ANL[3] by more than 50 %. In the present work, the cross section for the $^{232}Th(n,\gamma)$ reaction have been measured by the linac-TOF method from 1 keV to 450 keV, and have been compared with earlier values.

Natural thorium sample has high gamma radioactivities from ^{208}Tl and ^{212}Bi isotopes in the thorium-decay chain. These isotopes cause high background and troublesomes in the measurement of the $^{232}Th(n,\gamma)$ cross section. Then, before the TOF experiment, we chemically purified the thorium sample (ThO_2) by an ion-exchange method, and eliminated the background isotopes which gave the high

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radioactivities, so that the background was extremely reduced and much improved to that of 1/80 of the original thoria sample three days after the chemical purification.

The energy dependent cross section for the $^{232}Th(n,\gamma)$ reaction was measured with a pair of C_6D_6 scintillation detectors (NE-230, 11 cm diam., 5 cm thick). The energy dependent cross section curve was obtained relative to the $^{10}B(n,\alpha\gamma)$ cross section. Background in the TOF experiment was determined by using notch filters of ^{23}Na and ^{32}S, which gave the saturated background levels in the TOF spectrum at the resonances of 2.85 keV and 103 keV, respectively. Moreover, by assuming that the energy dependence of the background curve is the same as that of the Na and S run, the experiment with only Na or S filter was carried out to measure the cross section near the resonance region. These results in the three runs (Na and S run, Na run, and S run) showed good agreement with each other except the resonance region. We normalized these energy dependent cross sections to the previous value of 520 mb at 23.7 keV by the authors[4]. The present result is shown in Fig. 1. The statistical error is about 3 to 5 %.

Generally, the result measured by Macklin[2] is lower, especially below 50 keV, than the present. On the other hand, the data by Poenitz[3] is a little higher than the authers'. The cross sections by Forman et al.[5] are obviously higher. The evaluated curve of the ENDF/B-IV shows good agreement with our present data below 50 keV. In the higher energy region, there exist large discrepancies between the ENDF/B-IV evaluation and the present measure-

ment. If the ENDF/B-IV data above 50 keV region are made lower by the step-value at the 50 keV, and are re-normalized, the whole curve of the ENDF/B-IV evaluation falls into good agreement with the present data. The evaluated values of the JENDL-1 are generally higher than those of the present measurement.

The energy dependence of the $^{232}Th(n,\gamma)$ cross section was also measured with the Fe and Si filtered neutron beams[6]. The cross section at 146 keV with the Si filtered beam is obtained as follows, when the $^{10}B(n,\alpha\gamma)$ reaction is used as a standard reference[7] and the $^{232}Th(n,\gamma)$ cross section at 24 keV is known,

$$Y_x(146) = \frac{C_x(146)}{C_b(146)} \cdot \frac{C_b(24)}{C_x(24)} \cdot \frac{Y_b(146)}{Y_b(24)} \cdot Y_x(24)$$

where C is the counts with the C_6D_6 detectors, Y is the capture yield, and x and b subscripts denote the sample(Th) and the boron standard sample. The cross section at 55 keV is also measured with the Si filtered beam just same as the above method.

When we normalize the $^{232}Th(n,\gamma)$ cross section at the 24 keV to 520 mb, the cross sections for the $^{232}Th(n,\gamma)$ reaction at the 55 and 146 keV are 0.328 $\pm$ 0.20 barns and 0.165 $\pm$ 0.008 barns, respectively. These experimental errors include the statistical one, and the systematic one of about 3 %. These present results show good agreement in the energy dependence with our energy dependent cross section.

References :

1) WRENDA 76/77, INDC(SEC)-55/URSF., and BNL-50444, USNDC-13 ('75).

2) R. L. Macklin and J. Halperin, Nucl. Sci. Eng., 64 (1977) 849.

3) W. P. Poenitz and D. L. Smith, ANL/NDM-42 (1978).

4) N. Yamamuro et al., J. Nucl. Sci. Technol., to be published.

5) Forman et al., Knoxville Conf., Vol.2 (1971) 735.

6) K. Kobayashi et al., Annals of Nucl. Energy 4 (1977) 449.

7) Y. Fujita et al., Annual Meeting of the Japan Atomic Energy Society, D-6 (1977).

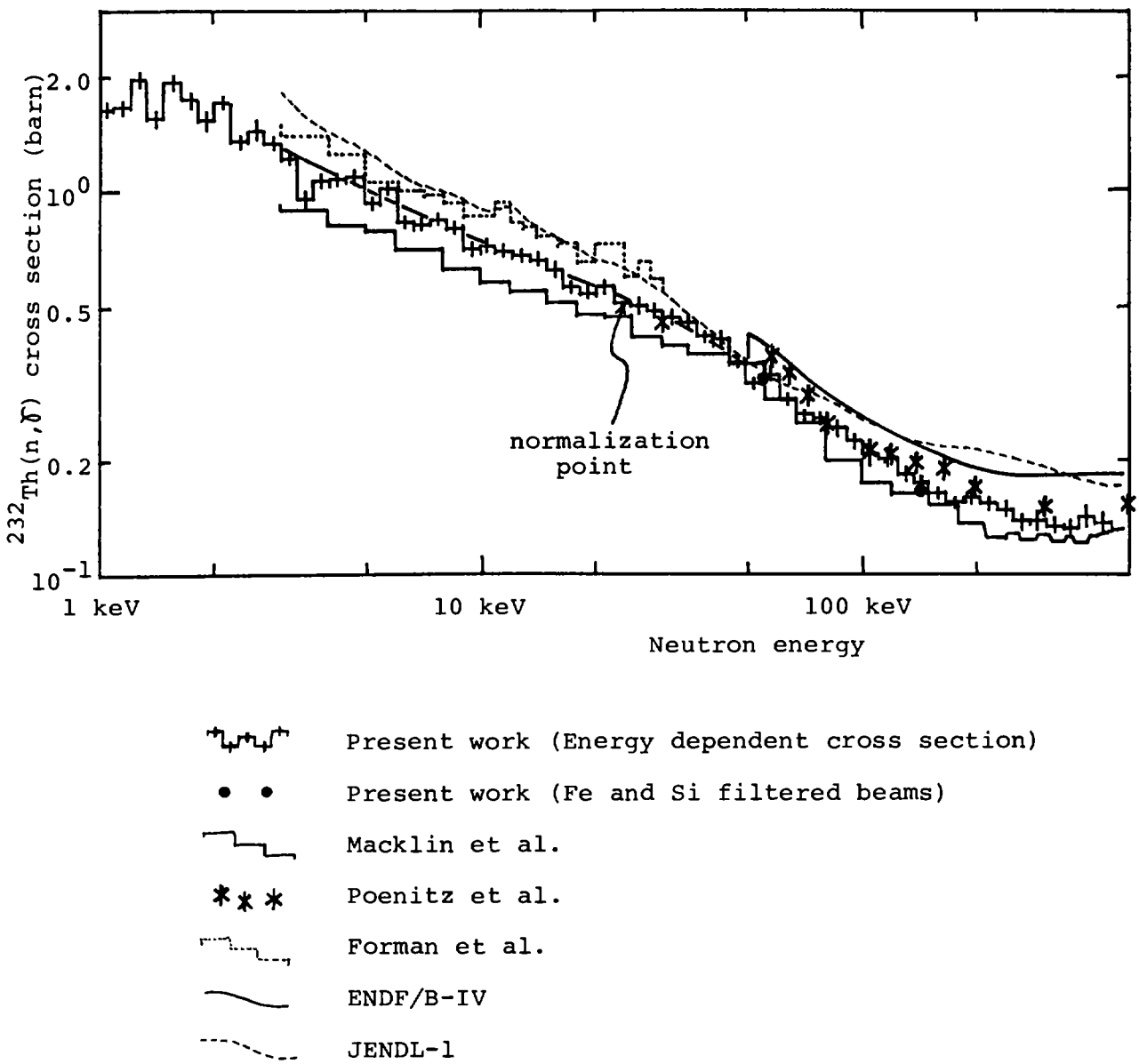

Fig. 1 Cross section for the ^{232}Th(n,γ) reaction

III-B-3

MEASUREMENT AND ANALYSIS OF NEUTRON SPECTRA IN ZIRCONIUM, TITANIUM, LITHIUM AND TEFLON PILES

I. Kimura, Shu A. Hayashi, K. Kobayashi, S. Yamamoto,
H. Nishihara*, T. Mori*, S. Kanazawa*, and M. Nakagawa**

Accurate nuclear data for reactor materials are required in order to investigate the nuclear characteristics, safety features and economical conditions of reactors. Zirconium, titanium, lithium and flourine are or would be important structual materials for nuclear reactors.

In the present work, in order to assess the nuclear data or group constants of the above materials, neutron spectra in the zirconium, titanium, lithium and teflon piles were measured from several keV to a few MeV region by the linac time-of-flight method with ^{6}Li glass scintillators and ^{10}B-vaseline-plug NaI(Tl) detectors[1].

The measured spectra have been compared with those of one-dimentional multi-group transport calculations with the Abagyan et al.'s constants (ABBN)[2] and those made from ENDF/B-IV data by the SUPERTOG code[3]. Table 1 shows the experimental and calculational conditions which are taken in the present work. In addition to the spectrum measurement, spatial distribution of neutrons in the pile has been measured by the activation method with nickel wires, by which the spherical symmetry of the system to apply the one-dimentional Sn calculations has been experimetally confirmed.

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** Japan Atomic Energy Research Institute

The neutron spectra in the zirconium pile are shown in Fig. 1. It can be seen that the measured spectrum at r=15 cm, μ=0 generally agrees with the predicted above several 100 keV region, however, that shows rather higher than the predicted below 100 keV.

Fig. 2 shows the neutron spectra in the titanium pile. The calculated results with the constants made from ENDF/B-IV are compared with those of the measured at r=25 cm, μ=0 and r=35 cm, $\mu=\pm 0.7$. Agreement between the measurement and the calculation is good above several hundreds' keV region. But there exist large discrepancies between the measured and calculated spectra in the 20 to 200 keV region.

The measured spectrum at r=15 cm, μ=0 in the lithium assembly is generally in good agreement with the calculated, as shown in Fig. 3. The predicted result with the constants made from the ENDF/B-IV is generally lower than the measurement below 100 keV region.

The neutron spectrum in the teflon pile has been measured at r=22.5 cm, μ=0, and the result shows general agreement. Below 100 keV, the predicted spectrum is higher than the measured. Near the dip around 400 keV, on the other hand, the calculated result is lower than the measured spectrum.

References :

1) I. Kimura et al., Nucl. Instr. Meth., 137 (1976) 85.

2) L. P. Abagyan et al., "Group Constants for Nuclear Reactor Calculations", Consultants Bureau, (1964).

3) R. Q. Wright, et al., ORNL-TM-2679 (1969).

Table 1 Experimental and calculational conditions which are taken in the present work

Material	Size	Measurement		Calculation	
		Detector	Position	Group const.	Code
Zirconium	Spherical pile radius = 30 cm	^{6}Li glass scintillator ^{10}B-vaseline-plug NaI(Tl) detectors	r = 15 cm μ = 0	made from ENDF/B-IV	ANISN P_8, S_8
				ABBN	DTF-IV P_1, S_8
Titanium	14-hedral pile mean radius = 53 cm	^{6}Li glass scintillator ^{10}B-vaseline-plug NaI(Tl) detectors	r = 25 cm μ = 0 r = 35 cm μ = $\pm$ 0.7	made from ENDF/B-IV	ANISN P_8, S_8
Lithium	Assembly : 50 cm x 40 cm x 60 cm , made from blocks(20 cm x 20 cm x 10 cm)	^{6}Li glass scintillator	r = 15 cm μ = 0	made from ENDF/B-IV	ANISN P_8, S_8
				ABBN	DTF-IV P_1, S_8
Teflon	14-hedral pile mean radius = 49 cm	^{6}Li glass scintillator ^{10}B-vaseline-plug NaI(Tl) detectors	r = 22.5 cm μ = 0 r = 32 cm μ = $\pm$ 0.7	made from ENDF/B-IV	ANISN P_8, S_8

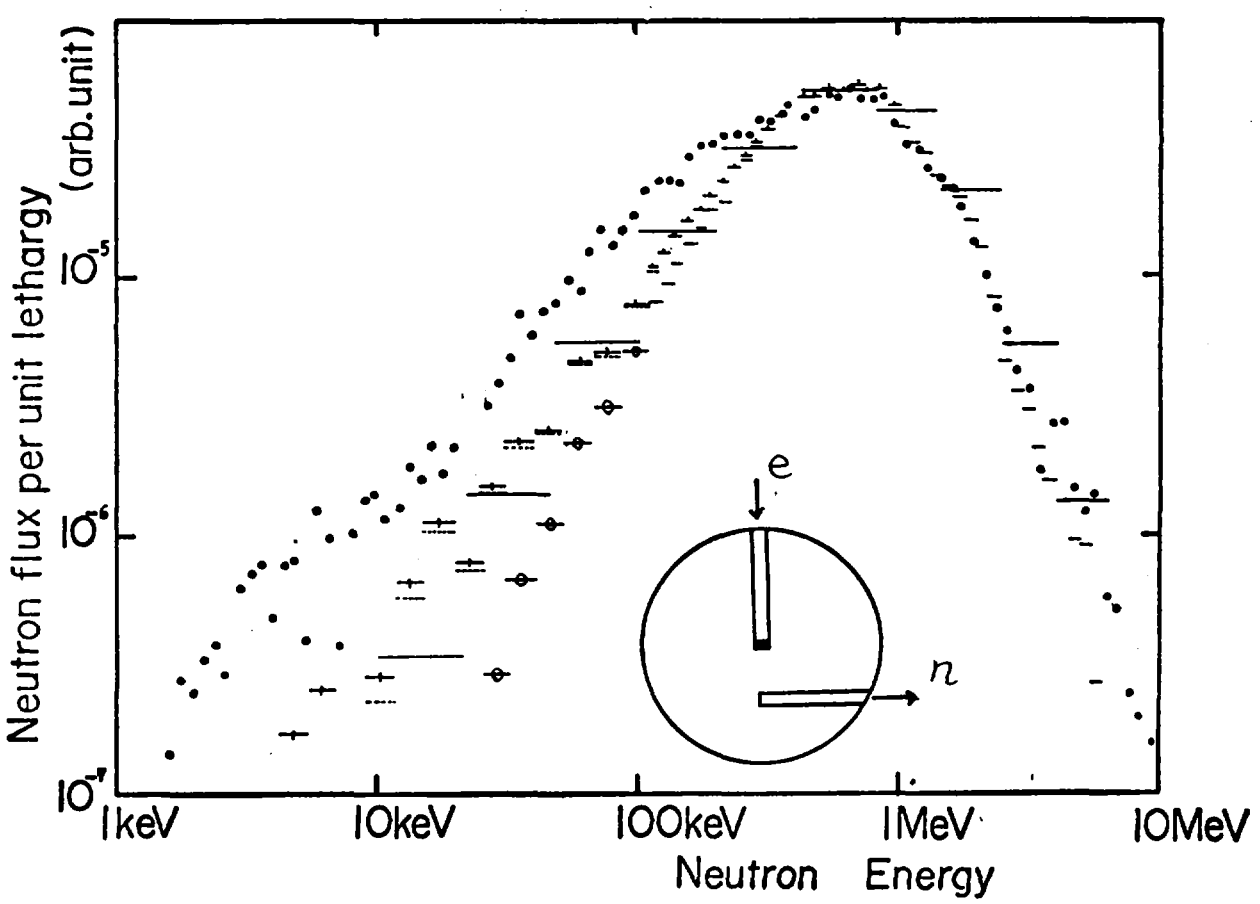

Figure 1 Neutron spectra in a zirconium pile

• • • • • ^{6}Li glass scintillator

ANISN, ENDF/B-IV with room return

ANISN, ENDF/B-IV without room return

DTF-IV, ABBN

ESELEM5, P_0

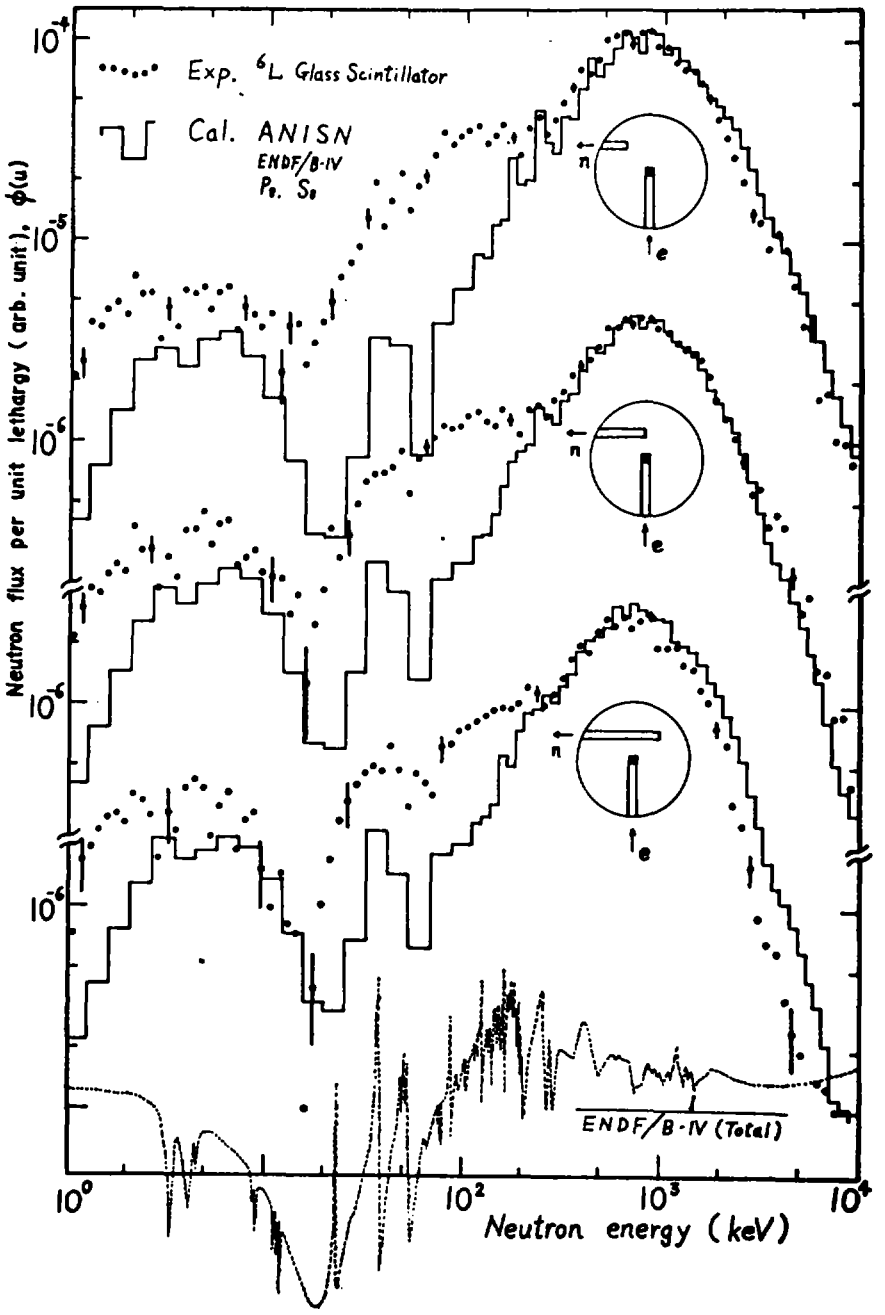

Figure 2 Neutron spectra in a titanium pile

• • • • • ^{6}Li glass scintillator

ANISN, ENDF/B-IV

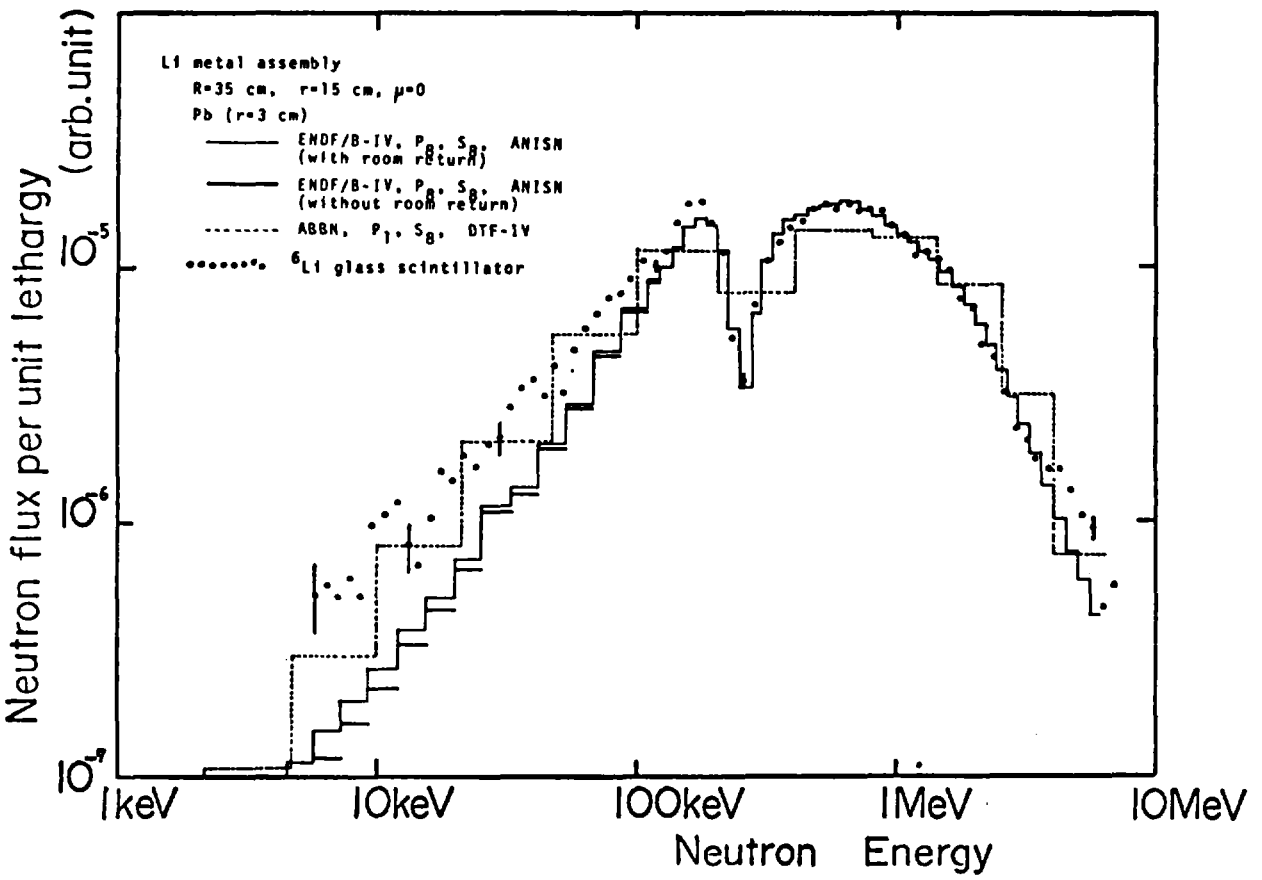

Figure 3 Neutron spectra in a lithium assembly

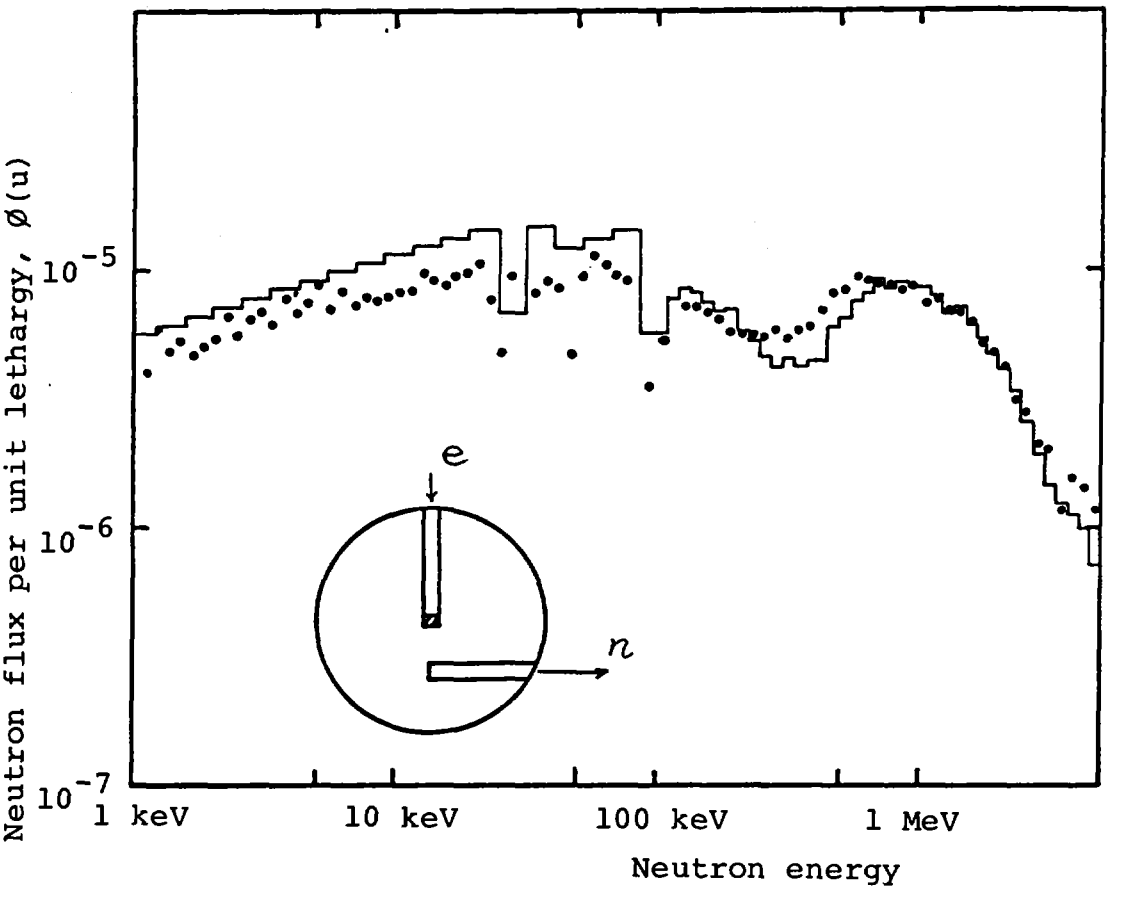

Figure 4 Neutron spectra in a teflon pile

•••• ^{10}B-vaseline-plug NaI(Tl) detectors

ANISN, ENDF/B-IV

IV. KYUSHU UNIVERSITY

Department of Nuclear Engineering, Faculty of Engineering

IV-1 Activation Cross sections on Fe, Co, Ni, Zr and Mo for 14.6 MeV Neutrons

K. Fukuda, K. Matsuo, S. Shirahama and I. Kumabe

Many workers have measured the activation cross sections for 14 MeV neutrons. However relatively a few data have been reported for the reactions leading to the long-lived nuclei. Therefore we have measured the reaction cross sections leading to the long-lived nuclei on Fe, Co, Ni, Zr and Mo for 14.6 MeV neutrons with a shielded Ge(Li) detector.

Table 1 shows the results obtained from the present work.

Table 1 Cross sections for (n,p), (n,α), (n,2n) and (n,np) reactions with 14.6 MeV neutrons

Reaction	$T_{1/2}$	E_γ (keV)	η (%)	σ (mb)
$^{54}Fe(n,p)^{54}Mn$	312.5 d	834.8	100	358±22
$^{59}Co(n,p)^{59}Fe$	44.6 d	1099.3	56	53.1±4.5
$^{58}Ni(n,p)^{58}Co$	70.78 d	810.6	99.4	338±26
$^{60}Ni(n,p)^{60g}Co$	5.272 y	1332.5	100	134±11
$^{92}Mo(n,p)^{92m}Nb$	10.13 d	934.5	95.5	71.8±5.7
$^{95}Mo(n,p)^{95g}Nb$	35.1 d	765.8	99	44.8±3.5
$^{54}Fe(n,\alpha)^{51}Cr$	27.71 d	320.1	9.8	84.0±7.5
$^{62}Ni(n,\alpha)^{59}Fe$	44.6 d	1099.3	56	25.8±3.3
$^{98}Mo(n,\alpha)^{95}Zr$	65.5 d	756.7	54.6	8.1±0.8
$^{59}Co(n,2n)^{58}Co$	70.78 d	810.6	99.4	752±60
$^{96}Zr(n,2n)^{95}Zr$	65.5 d	756.7	54.6	1639±128
$^{58}Ni(n,np)^{57}Co$	271 d	122.1	85.6	373±29

η : Intensity of γ-rays per disintegration

IV-2 Empirical Formulae for the (n,p) and (n,α) reactions for 14 MeV neutrons

I. Kumabe and K. Fukuda

The 14 MeV (n,p) and (n,α) cross sections are fairly well described by the empirical formulae given by Levkovskii[1]. However large discrepancies between the experimental and calculated cross sections for both the reactions are observed in the cases of nuclei with a relatively small or large value of (N-Z)/A for a given value of Z and also for lightest and heaviest nuclei.

For the (n,p) reaction the ratios of the experimental to calculated cross sections $\sigma_{exp}/\sigma_{cal}$ as a function of mass number A are plotted in the upper part of Fig. 1. In this figure the points for many isotopes of one element are connected each other by the straight lines. The decreasing trend with increasing mass number for one element is seen. Therefore we have undertaken to improve this formula.

We assume the form of improved formulae as follows.

$$\sigma = a\ A^b \exp\ [-c(N-Z)/A]$$

The parameters a, b and c were determined so as to minimize X^2.

The results of the best-fit parameters and X^2 values for the (n,p) reaction are listed in Tables 1 and 2, respectively, and $\sigma_{exp}/\sigma_{cal}$ are plotted in the lower part of Fig. 1. As is seen in Fig. 1, no appreciable decreasing trend with increasing mass number for one element is seen. Furthermore X^2 values are remarkably improved and are grouped around 1.0. Similar searches were carried out for the (n,α) reaction. The results of the best-fit parameters and X^2 values are listed in Tables 3 and 4, respectively, and $\sigma_{exp}/\sigma_{cal}$ are plotted in Fig. 2. Similar remarkable improvements of X^2 values were obtained for the (n,α) reaction.

The agreement between the experimental cross sections and the calculated ones based on the statistical and / or pre-equilibrium models is not so good comparing with the cross sections calculated from the present formulae. Therefore the present formulae for the 14 MeV (n,p) and (n,α) reactions are very useful for the quick and more accurate estimation of the cross sections.

References

1) V.N. Levkovskii : Sov. J. Nucl. Phys. 18 (1974) 361

Table 1 Empirical formula for (n,p) reaction

	A	Empirical formula
Levkovskii	40 ~ 202	$45.2(A^{1/3}+1)^2 \exp[-33(N-Z)/A]$
Present	40 ~ 62	$21.8A \exp[-34(N-Z)/A]$
	63 ~ 89	$0.75A^2 \exp[-43.2(N-Z)/A]$
	90 ~ 160	$0.75A^2 \exp[-45.0(N-Z)/A]$

Table 2 X^2 values

A	Levkovskii	Present
40 ~ 62*	1.42	0.88
63 ~ 89	2.92	1.44
90 ~ 160	2.31	1.09

* Except for ^{45}Sc

Table 3 Empirical formula for (n,α) reaction

	A	Empirical formula
Levkovskii	30 ~ 150	$18.1(A^{1/3}+1)^2 \exp[-33(N-Z)/A]$
Present	30 ~ 60	$51.0A^{1/2} \exp[-30(N-Z)/A]$
	61 ~ 105	$55.0A^{1/2} \exp[-33(N-Z)/A]$
	106 ~ 150	$7.6 \times 10^{-4}A^3 \exp[-40(N-Z)/A]$

Table 4 X^2 values

A	Levkovskii	Present
30 ~ 60	3.14	1.88
61 ~ 105	1.25	1.21
106 ~ 150	8.38	0.58

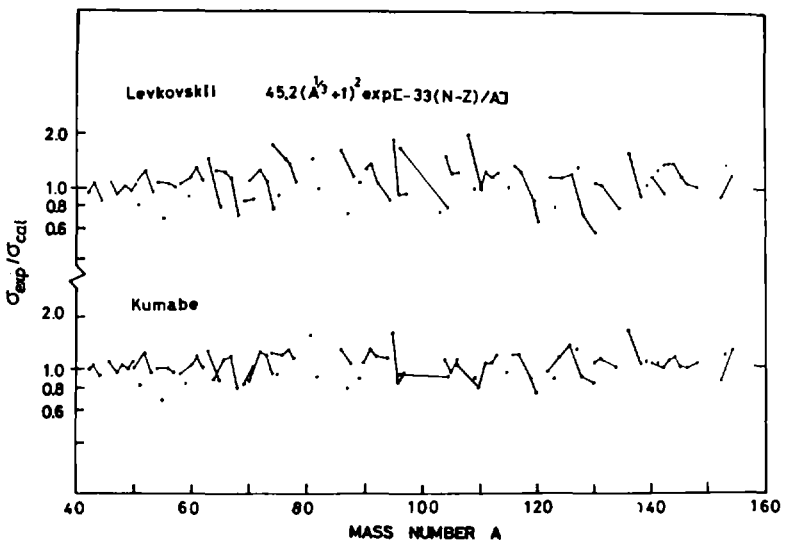

Fig. 1 Ratios of experimental to calculated cross sections $\sigma_{exp}/\sigma_{cal}$ plotted versus mass number for (n,p) reaction.

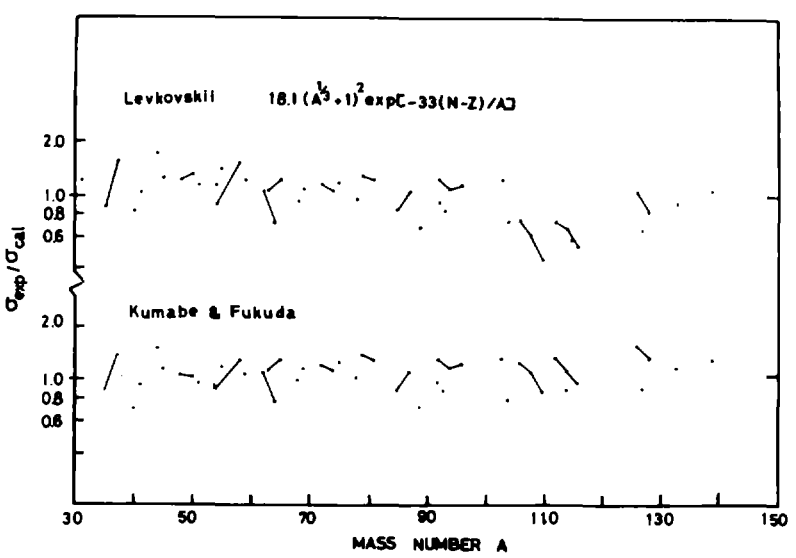

Fig. 2 Ratios of experimental to calculated cross sections $\sigma_{exp}/\sigma_{cal}$ plotted versus mass number for (n,α) reaction.

IV-3 Analysis of (n,p) Cross Sections on Medium-Mass Nuclei at 14 MeV

I. Kumabe and K. Fukuda

Recently we have compared[1] the experimental 14 MeV (n,p) cross sections on the heavy nuclei (A>90) with both the statistical and pre-equilibrium models, and have shown that there exists the appreciable contribution of the compound process for nuclei with A=90~120, while the contribution of the compound process for nuclei with A>120 is smaller than a few percents. Therefore it is interesting to compare the experimental cross sections on the medium-mass nuclei (A=30~90) with the calculations based on both the statistical and pre-equilibrium models and to know the contribution of the pre-equilibrium process.

In the present work the experimental values evaluated by Levkovskii[2] were compared with the following calculated ones. The theoretical calculations were carried out in same manner as the previous work[1] except for the level density parameter $a=(0.00917S+0.170)A$[3] for the statistical calculation.

The ratios of the experimental to calculated cross sections in terms of the statistical model are plotted in the upper part of Fig. 1. In this figure the points for many isotopes of one element are connected each other by the straight lines. The deviations of the points from 1.0 increase with mass number, and the increasing trend with mass number for one element is seen.

The ratios of the experimental to the calculated cross sections in terms of both models are plotted in the lower part of Fig. 1. The deviations of points from 1.0 are remarkably reduced, and no appreciable increasing trend with mass number for one element is seen.

It may be concluded from this figure that the contribution of the pre-equilibrium process increases with mass number A and moreover with mass number A for many isotopes of one element.

References

1) I. Kumabe, M. Hyakutake and Y. Fujino : J. Nucl. Sci. Technol. 14 (1977) 919

2) V.N. Levkovskii : Sov. J. Nucl. Phys. 18 (1974) 361

3) H. Yamakoshi et al. : Youshi-syu I, 1978 Annual Meeting of the Atomic Energy Society of Japan, p 171

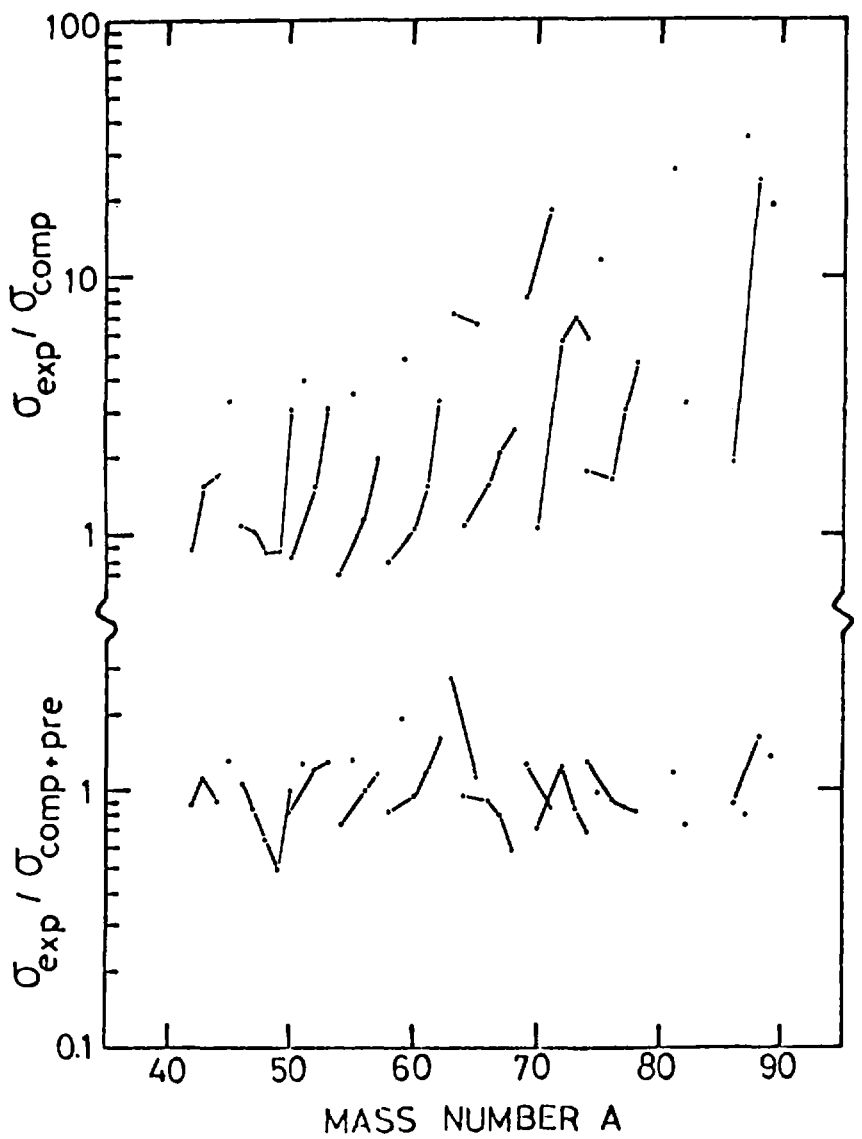

Fig. 1 Ratios of experimental to calculated cross sections in terms of the statistical model and both the statistical and pre-equilibrium models plotted in upper and lower parts, respectively, versus mass number

IV-4 Analysis of Total (n,p) Cross Sections at 14 MeV with Geometry-Dependent Hybrid Model

I. Kumabe and M. Hyakutake

Recently, we have analyzed[1] the 14 MeV (n,p) cross sections in terms of the pre-equilibrium exciton model, and found gross mass-number dependence of the ratios of the experimental to calculated cross sections $\sigma_{exp}/\sigma_{cal}$. We also found the correlation between the gross mass-number dependence of $\sigma_{exp}/\sigma_{cal}$ and $a/\bar{a}$, where a is the level density parameter and $\bar{a}$ the mean level density parameter which is equal to A/7.5.

On the other hand, Blann has demonstrated that the calculations based on the geometry-dependent hybrid (GDH) model[2] give reasonable agreement with experimental spectra for various reactions. Therefore it is very interesting to compare the experimental cross sections for the 14 MeV neutrons with the calculations based on GDH model of Blann.

The values after the subtraction of the calculated (n,p) cross section based on the statistical evaporation model from the experimental ones evaluated by Levkovskii[3] were compared with GDH model.

In the present calculation average nuclear density along trajectory and single exciton lifetimes have been selected. The initial number of excited neutrons and protons were chosen to be 1.25 and 0.75[5], respectively.

The GDH calculation was carried out with the use of the code HYBRID[4] taking into account the pairing energy. Here σ_{exp} are the calculated cross sections multiplied by 0.59.

Here $a/\bar{a}$ and $\sigma_{exp}/\sigma_{cal}$ are plotted in the upper and middle parts of Fig. 1, respectively. We found the correlation between the gross mass-number dependences of $\sigma_{exp}/\sigma_{cal}$ and $a/\bar{a}$ except for A>180 which is similar behavior as in the case of the exciton model. Thus the correction of

$(a/\bar{a})^2$ to σ_{cal} was carried out. The values of $(\sigma_{exp}/\sigma_{cal})/(a/\bar{a})^2$ are plotted in the lower part of Fig. 1. The deviations of the points from 1.0 are considerably reduced.

References

1) I. Kumabe, M. Hyakutake and Y. Fujino : J. Nucl. Sci. Technol. 14 (1977) 919

2) M. Blann : Nucl. Phys. A213 (1973) 570

3) M. Blann : COO-3494-14 (1974), Dept. Chem, and Nucl. Structure Res. Lab. Univ. Rochester.

4) V.N. Levkovskii : Sov. J. Nucl. Phys. 18 (1974) 361

5) M. Blann et al. : Nucl. Phys. A257 (1976) 15

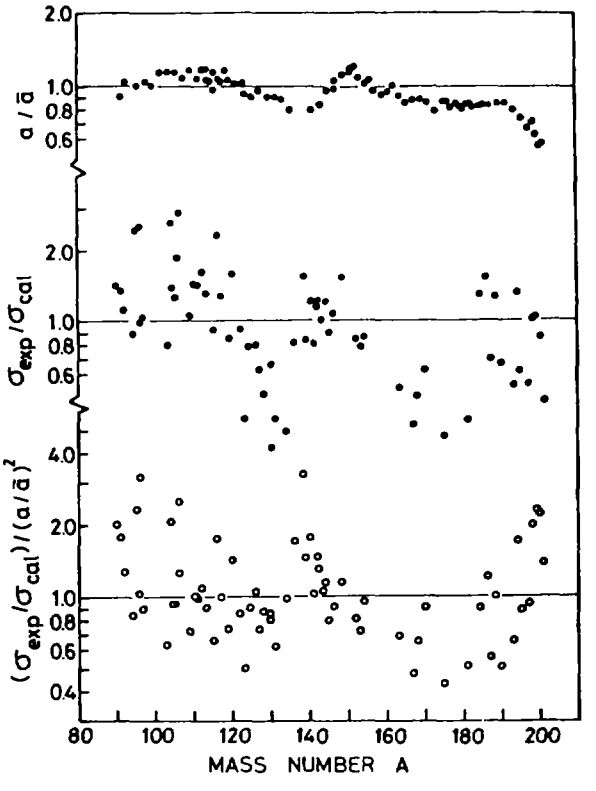

Fig. 1 Ratios of level density parameter to mean level density parameter $a/\bar{a}$, ratios of experimental to calculated cross sections $\sigma_{exp}/\sigma_{cal}$, and values of $(\sigma_{exp}/\sigma_{cal})/(a/\bar{a})^2$ plotted in upper, middle and lower parts, respectively, vs. mass number

IV-5 Assignment of prompt gamma rays in the fission of ^{252}Cf

F. Toyofuku, Y. Yoshida, K. Tsuji and A. Katase

Prompt gamma rays in the fission of ^{252}Cf were measured with a Ge(Li) detector in coincidence with fission fragments which were detected with an ionization chamber telescope[1]. The chamber had a sector-shaped anode split into two parts with a circular narrow break and a relatively wide gap between a cathode and a Frisch grid to have a large solid angle. Five quantities were obtained for an event in list mode. They were the energy of the gamma ray, the energy loss, the total energy, the incident position of the fission fragment and the time difference between two particles. The atomic number of light fragments could be assigned within the accuracy of about 2 from the values of the total energy and the energy loss corrected according to the incident position of the fission fragment.

Gamma rays of 103 could be assigned in the present work in regard to the atomic number of the fission fragment which emitted the respective gamma rays. Their yields per fission were also determined. These gamma rays include 49 gamma rays assigned by Cheifetz et al.[2] Further analyses are in progress.

References :

(1) Y. Yoshida, K. Tsuji, F. Toyofuku and A. Katase, to be published in Nucl. Instr. and Meth.

(2) E. Cheifetz, J.B. Wilhelmy, R.C. Jared and S.G. Thomson ; Phys. Rev. C4 (1971) 1913.

IV-6 Calculation of Neutron Cross Sections of Inelastic Scattering and Some Competing Processes for ^{232}Th

T. Ohsawa, M. Ohta and Y. Kawamura*

A paper on this subject was published in Memoirs of the Faculty of Engineering, Kyushu Univeristy, vol.38, No.2, pp.127-141, with an abstract as follows:

With the aim of providing evaluated cross section curves for ^{232}Th, calculation is made for neutron cross sections for inelastic scattering, radiative capture and (n, 2n) reactions in the energy range 10 keV to 16 MeV. For (n, n') and (n, γ) reactions, the calculation is carried out by using the optical model and the Hauser-Feshbach formalism with the inclusion of effects due to level-level interference and level fluctuation. Pearlstein's method is used to estimate (n, 2n) reaction cross section.

The results are compared with ENDF/B-IV evaluation, and possible sources of discrepancy between them are discussed.

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Department of Physics

V-1 Differential Cross Sections for the Breakup Reactions of ^{9}Be Bombarded by 14.1 MeV Neutrons*

S. Shirato, K. Shibata and M. Saito

Differential cross sections for the two-body breakup reactions in the bombardment of ^{9}Be with 14.1 MeV neutrons were measured by using the same counter-telescope that was used in our previous n-p[1], n-d[2] and n-t[3] works. A beryllium target of 1.44 ± 0.05 mg/cm^2 in thickness was prepared on a 1 mm thick carbon plate by vacuum evaporation. The reaction products, ^{6}He, α and t, and background protons were separated by the two-dimensional ΔE-E analysis. The uncertainty in the particle identification is 5 ∿ 10%, except the complete separation between α-particles and tritons.

The measured energy spectra of the reaction products were reproduced by calculations taking into account the finite geometrical effect, the energy losses in the target and the counter gas and the energy width of incident neutrons. As a typical example, the measured spectrum of ^{6}He recoils produced in the ^{9}Be(n,α)^{6}He reaction is shown in Fig. 1, where the calculated spectrum is also shown (the dashed curve) as well as the estimated one from the recoil triton spectrum[3] measured using a ^{3}H-Ti-Cu target (the dash-dotted curve). The existence of peaks corresponding to the first (1.80 MeV) and second (3.4 MeV?) excited states of ^{6}He is not clear at present due to a

* Supported in part by a Grant-in-Aid for Scientific Research from the Ministry of Education.

long tail produced by degraded neutrons. Even though the 3.4 MeV level of ^{6}He exists, the contribution in the direct observation was estimated to be less than 50 μb/sr at 0°.

In Table I, the present result is given and compared with the results of Perroud and Sellem[4] and of Smolec et al.[5] Our result is in good agreement with the result of Perroud and Sellem. The result of Smolec et al. seems to be systematically larger than ours.

The angular distribution for the ^{9}Be(n,α_0)^{6}He(G.S.) reaction is shown in Fig. 2. Our experimental result together with that of Perroud and Sellem is reproduced fairly well by the plane-wave Born approximation calculation (PWBA) assuming the α-^{5}He cluster in ^{9}Be. In this assumption, the differential cross section is given by

$$\frac{d\sigma}{d\Omega} \propto |(Q_\alpha{}^2 + k_{Be}{}^2)\ j_o(Q_\alpha R_{\alpha\text{-}h})\ j_1(Q_n R_{n\text{-}h})|^2 ,$$

where j_ℓ is the ℓ-th order spherical Bessel function, $R_{n\text{-}h}$ and $R_{\alpha\text{-}h}$ are the interaction radii for the n-^{5}He and the α-^{5}He sub-systems respectively, and $\vec{Q}_n = \vec{k}_n + \frac{1}{6}\vec{k}_\alpha$ and $\vec{Q}_\alpha = \vec{k}_\alpha + \frac{4}{9}\vec{k}_n$ are the momentum transfers expressed in terms of the wave vectors of incident neutrons ($\vec{k}_n$) and emitted α-particles ($\vec{k}_\alpha$). k_{Be} is the relative wave number of the α-^{5}He system which is reduced from the binding energy of ^{9}Be. The best fit (the dashed curve in Fig. 2) was obtained in the case that $R_{\alpha\text{-}h}$ = 5.8 fm and $R_{n\text{-}h}$ = 4.3 fm. We calculated the angular distribution in the DWBA, but at present, unfortunately, reasonable values of the potential parameters could not be found to fit the experiment over the whole angular region.

At present, a measurement of the four-body breakup reaction

of the n-^{9}Be system at 14.1 MeV is in progress. We used a scattering chamber[6] designed especially for this experiment, in which a ^{3}H-Ti-Cu target as the neutron source, a self-supported Be target of 1.66 mg/cm^2 thick and two counter-telescopes (each one consists of 2 proportional gas counters and a Si detector) were set. We could not observed any coincidence event in the measurements carried out at 0°-40° and 20°-20°. However, at the 40°-102° geometry, we observed the correlated α-α energy spectrum from the four-body breakup together with the α-^{6}He coincidences from the two-body breakup. Fig. 3 shows the preliminary result. We expect a structure which corresponds to the sequential decay $^{10}Be \rightarrow \alpha + {}^6He^* \rightarrow \alpha + \alpha + 2n$. The above results on the four-body breakup suggest that the sequential decay is a main process in the breakup mechanism. This is consistent with the conclusion derived from the proton-induced ^{9}Be breakup data.[7] It is noted that the correlation spectrum has been observed for the first time by the neutron-induced breakup reaction.

References:

1) S. Shirato and K. Saitoh, J. Phys. Soc. Japan 36 (1974) 331.
2) S. Shirato, K. Saitoh, N. Koori and R.T. Cahill, Nucl. Phys. A215 (1973) 277.
3) S. Shirato, Y. Suda, S. Tsuruta and S. Oryu, Nucl. Phys. A267 (1976) 157.
4) J.P. Perroud and Ch. Sellem, Nucl. Phys. A227 (1974) 330.
5) W. Smolec, S. Burzynski, K. Rusek, I.M. Turkiewicz, J. Turkiewicz and P. Zupranski, Nucl. Phys. A257 (1976) 397.
6) S. Shirato, K. Shibata and M. Saito, to be published.
7) S.T. Emerson, V. Valkovic, W.R. Jackson, C. Joseph, A. Niiler, W.D. Simpson and G.C. Phillips, Nucl. Phys. A169 (1971) 317.

Table I. Measured differential cross sections for the reactions $^{9}Be(n,\alpha)^{6}He$ and $^{9}Be(n,t)^{7}Li$ at 14.1 MeV.

Measured particle	This work		Perroud-Sellem[4]		Smolec et al.[5]	
	CM mean angle (deg)	CM cross-section (mb/sr)	CM mean angle (deg)	CM cross-section (mb/sr)	CM mean angle (deg)	CM cross-section (mb/sr)
α_0	7.9	0.06 ± 0.04	6.6	0.05 ± 0.07	10.6	0.29 ± 0.10
	61.5	0.90 ± 0.12	63.0	0.99 ± 0.06	60.9	1.29 ± 0.15
α_1	8.1	2.45 ± 0.15	5.6	2.06 ± 0.27	10.2	5.04 ± 0.17
	62.5	1.84 ± 0.28	63.9	1.55 ± 0.14	62.9	4.00 ± 0.17
^{6}He	171.2	2.09 ± 0.27	166.5	1.85 ± 0.08	171.4	3.25 ± 0.18
	112.2	0.38 ± 0.11	109.8	0.24 ± 0.03	128.8	0.61 ± 0.31
t_0	9.4	0.95 ± 0.10	6.9	1.00 ± 0.14	-	-
	72.4	0.59 ± 0.13	74.9	0.40 ± 0.06	-	-
t_1	9.8	0.95 ± 0.08	7.2	0.83 ± 0.13	-	-
	75.5	0.55 ± 0.13	78.6	0.25 ± 0.06	-	-

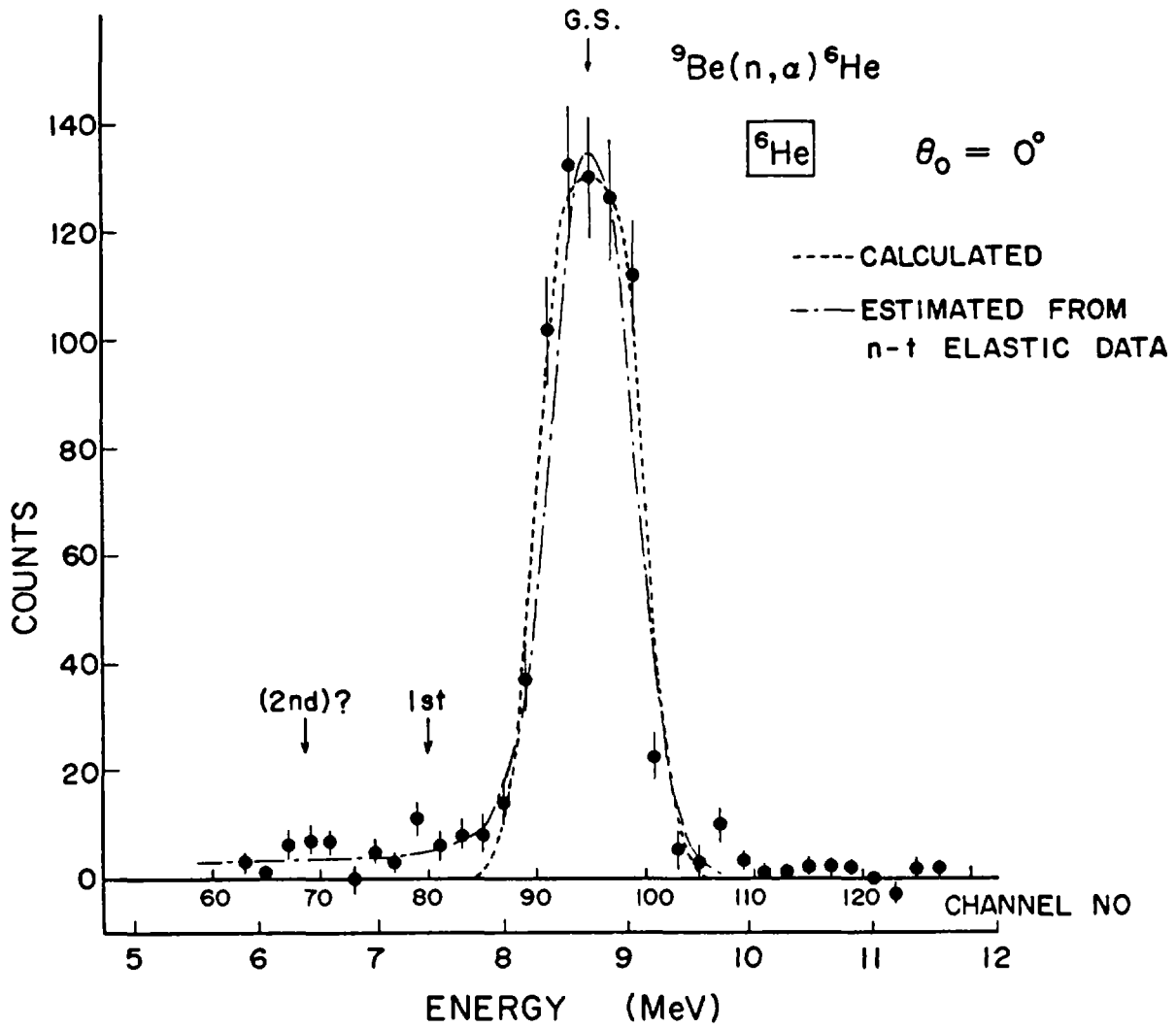

Fig. 1. Energy spectrum of ^{6}He recoils in the ^{9}Be(n,α)^{6}He reaction at the telescope-setting angle $\theta_0 = 0^0$. The calculated spectrum is the result of simulation based on the finite geometrical frequency function, the energy loss distribution and the energy width of incident neutrons. The estimated one based on the measured recoil tritons in the n-t elastic scattering is the result taking into account implicitly a practical information of the incident neutron energy distribution including degraded neutrons.

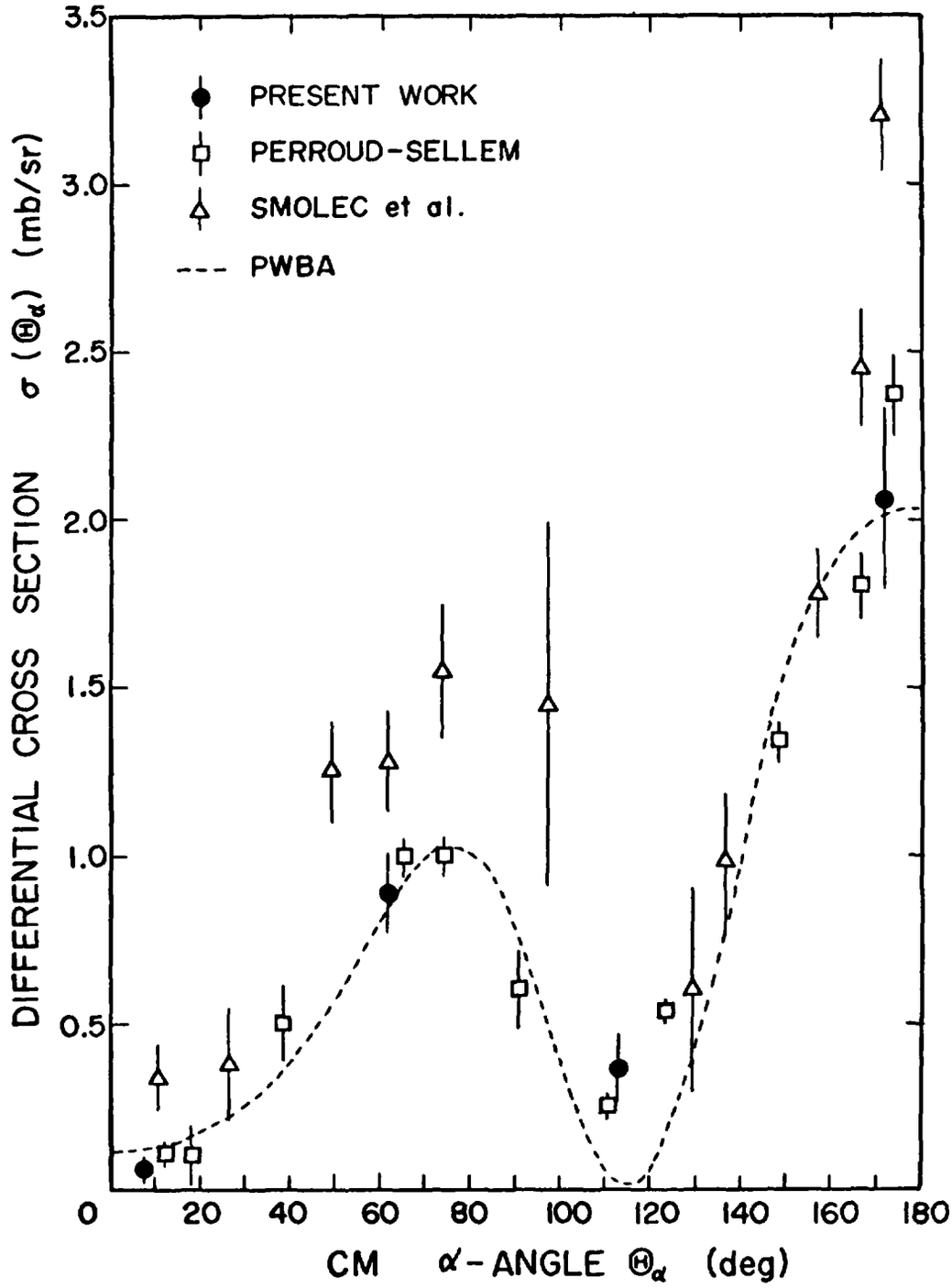

Fig. 2. Angular distribution for the $^{9}Be(n,\alpha_0)^{6}He(G.S.)$ reaction at 14.1 MeV. The data of other authors were taken from Refs. 4 and 5.

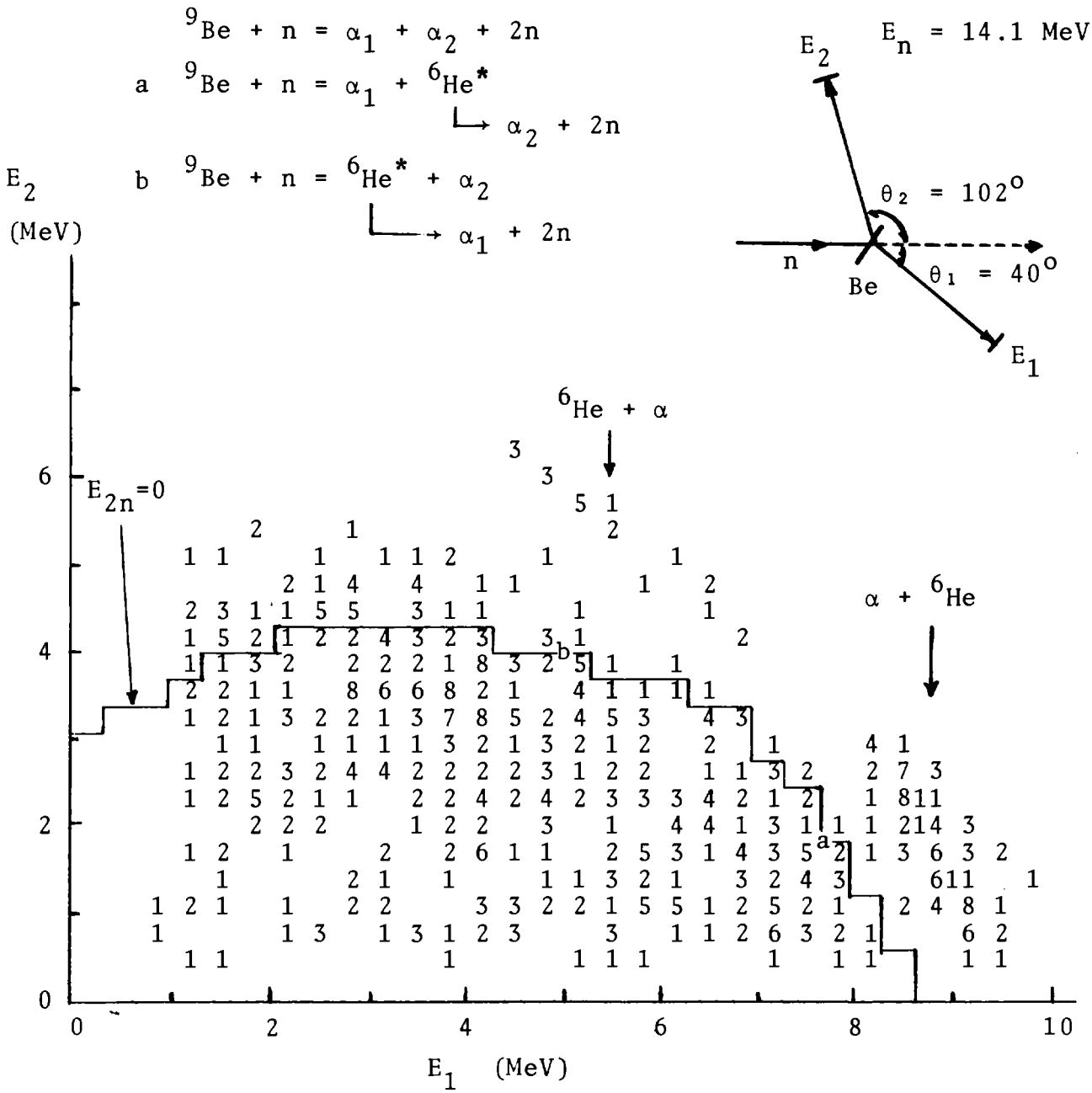

Fig. 3. Correlation spectrum (relative counts 10 = 75 mb/sr^2/MeV^2) observed in the 40°-102° setting of two telescopes. The data were taken with the RIKKYO CAMAC 6x8 dimensional data acquisition system. The solid line indicates the three-body kinematic locus of $\alpha_1 + \alpha_2 + 2n$ at the zero relative energy between two neutrons ($E_{2n} = 0$). The locus was corrected for the energy losses in the Be target and the counter gas.

VI. TOHOKU UNIVERSITY

Department of Nuclear Engineering, Faculty of Engineering

VI-1 A Study of Interactions of Fast Neutrons with ^{9}Be

M.Baba, T.Sakase, T.Nishitani, T.Yamada, and T.Momota

Double-differential neutron cross sections of ^{9}Be were studied at the incident energies between 3,2 and 7.0 Mev, and the results are summarized in Annu.Rep.Fast Neutron Lab.Tohoku Univ.(NETU-27)

For the inelastic cross sections and neutron spectra, considerable disagreements were found between the present results and ENDF/B-IV. The cross sections and neutron spectra of (n,2n) reaction seemed not to be reduced entirely to sequential process following inelastic scattering. An analysis of cross section and angular distribution of $(n,\alpha_{0,1})$ reaction was also tried in terms of Plane-Wave Born approximation.

Details of this study will be presented in the proceedings of International Conference on "Neutron Physics and Nuclear Data for Reactors and applied purposes"(Harwell,25-29Sept.1978).

VI-2 CROSS SECTIONS FOR THE REACTIONS $^{9}Be(n,t_1\gamma)$ AND $^{12}C(n,n'\gamma)$ BETWEEN 13.5 AND 15.0 MEV

Y. Hino, S. Itagaki, E. Moriya, T. Yamamoto and K. Sugiyama

The $^{9}Be(n,t)$ reaction is important in the fusion reactors. There were serious discrepancies between earlier results[1) - 4)] on the cross sections of the $^{9}Be(n,t_1\gamma)$ reaction in the region of 14 MeV neutron energy. The present measurement has been carried out in order to clear the disagreements. The 0.478 MeV gamma rays produced from the interactions of the neutron with ^{9}Be were detected with a Ge(Li) detector. Fig. 1 shows the comparison of the present results with the experimental data of the $^{9}Be(n,t_1\gamma)$ reaction in the energy region of 14 MeV.

Measurement of the production cross section for 4.43 MeV gamma rays from the $^{12}C(n,n'\gamma)$ reaction was also performed as a confirmation of the present study.

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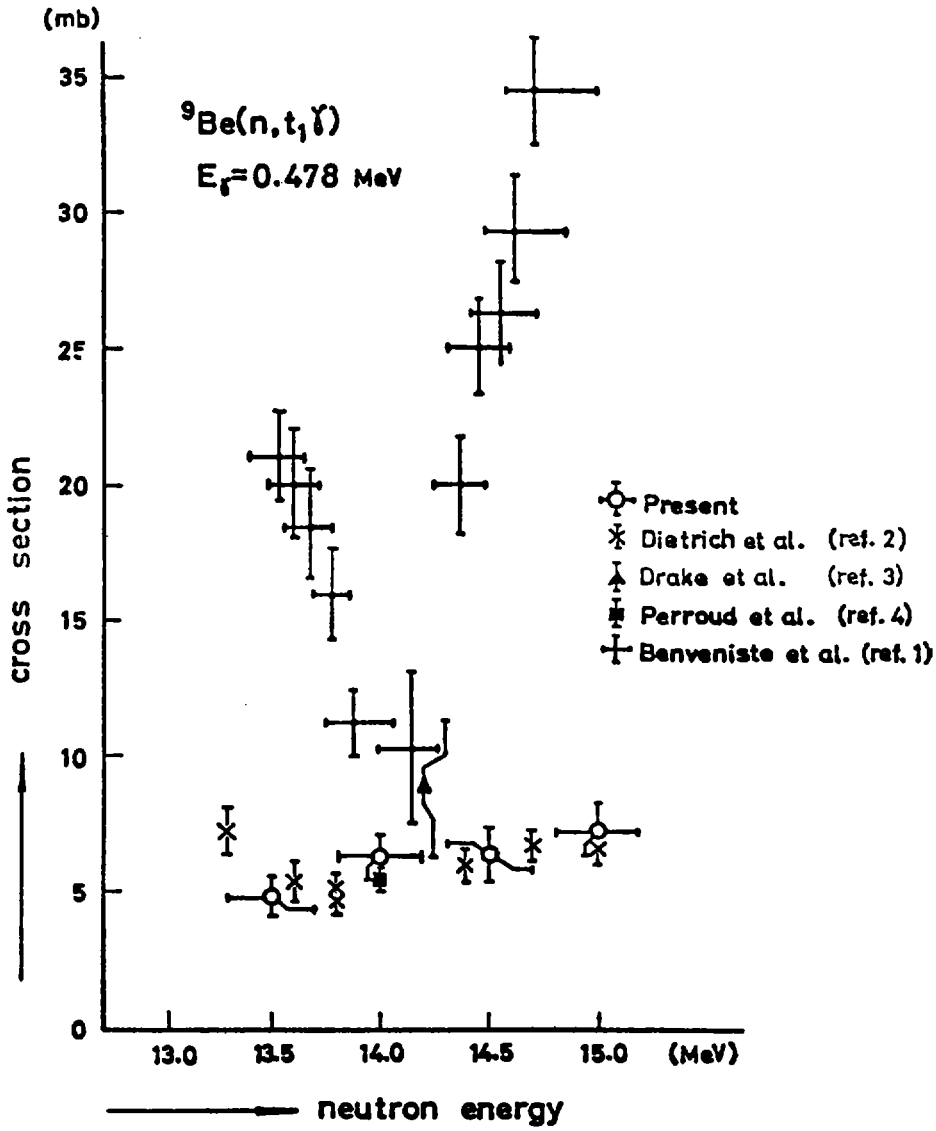
(mb)
35
30
25
20
15
10
5
0
cross section
^{9}Be(n,t$_1\gamma$)
E$_\gamma$=0.478 MeV
Present
Dietrich et al. (ref. 2)
Drake et al. (ref. 3)
Perroud et al. (ref. 4)
Benveniste et al. (ref. 1)
13.0
13.5
14.0
14.5
15.0
(MeV)
neutron energy

Fig. 1

VI-3 AN EXPERIMENTAL STUDY ON THE $^{9}Be(n,2n)$ REACTION

M. Sugimoto, S. Iwasaki, S. Sato, H. Takahashi,
K. Muramatsu, M. Montani and K. Sugiyama

The (n,2n) reaction on ^{9}Be at neutron energy of 14 MeV was studied by the two experimental methods, 1) conventional time-of-flight technique using the time reference gated by the associated particles and 2) coincidence method between two neutron detectors, for the measurements of the angular correlation of the emitted neutrons. NE-213 liquid scintillators (2 in. ϕ X 2 in. and 5 in. ϕ X 2 in.) were used for the neutron detectors which efficiencies were determined by the measurements of the fission neutron spectrum of ^{252}Cf.

From the method 1) we can obtain the results only for the differential cross section or energy distribution, and they are useful informations for the (n,2n) reaction mechanism. The estimation of the background from various sources was difficult and the results were only tentative ones in the method 2).

The detailed description of the methods and results were submitted to the internal report.[1] The obtained data were consistently agreed with the others.[2),3)]

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VI-4 LOW ENERGY CROSS SECTIONS FOR $^6Li(p,^3He)^4He$ REACTIONS

T. Shinozuka, K. Tanaka and K. Sugiyama

Cross section measurement of the $^6Li(p,^3He)^4He$ reaction which is of interest in the CTR program was performed in the proton energies from 100 to 700 keV. The total cross sections of the reaction were obtained by integrating the fitted curves of the angular distributions. Corrections for charge variations of the protons in the target have been done. The present result shows about 50 percent greater than those by Beaumevieille[1] and by Bertrand et al.[2] for $E_p > 350$ keV, and are in agreement with the tedency reported by Gemeinhardt et al.[3] and by Spinka et al.[4]

In order to obtain the reaction cross section in the region of thermal energy, so called "astrophysical S-function" has been calculated. The result gives $\tilde{S}_0(E) = 3.0$ MeV barn.

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VII. TOKYO INSTITUTE OF TECHNOLOGY

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VII-1 The Radiation Width in γ-Ray Producing Reactions

T. Kobayashi and H. Kitazawa

γ-ray production cross sections are requested for shielding and heating calculations in fission and fusion reactors.
When the experimental data not available, these cross sections are theoretically calculated, using a GROGI code[1] which has been programmed on the base of the nuclear evaporation model and rewritten to involve the Brink-Axel type's profile function for the radiation width. A previous study[2] clarified that this code produces the satisfactory results for many nuclei except for light nuclei; however, near the magic nuclei and for neutrons below few MeV for which the γ-ray production cross sections are technologically useful, it does not give a good agreement between theory and experiment. Probably, it may be not valid to use the Brink-Axel type's profile function irrespective of reaction mechanism. Generally speaking, the inelastic scattering preferably excites collective states, while the radiative capture excites particle-hole states.

Using the γ-ray strength function extracted from experimental data, we have calculated the γ-ray production cross section of ^{197}Au to have a good agreement between the calculated and the observed. In Fig.1, a dot-dashed curve shows the γ-ray strength function extracted from (n,γ) reaction data[3] by a spectrum fitting method (S.F.M.)[4], and a double dot-dashed curve from (n, n'γ) reaction data[3]. The circles[5] show the strength function extracted with constant temperature level density formula with T=0.753MeV by the spectrum fitting method, the open triangles[6] with T=0.6MeV, and the solid triangles[7] by a sequential extraction method (S.E.M.)[4].

A dotted curve is derived from the Brink-Axel type's profile function. As is easily seen, this profile function is not suitable for the (n,γ) reaction. A peak at about 5.5MeV is called "pigmy resonance" which is a remarkable feature for (n,γ) and (d, pγ) reactions near the magic nuclei, but its physical origin is not so clear. Fig. 2 shows a comparison between the calculated and observed γ-ray strength functions of ^{197}Au. A dotted curve is obtained with the Brink-Axel type's profile function and a solid curve with the γ-ray strength function obtained by the present study. Our curve faithfully follows the experimental data.

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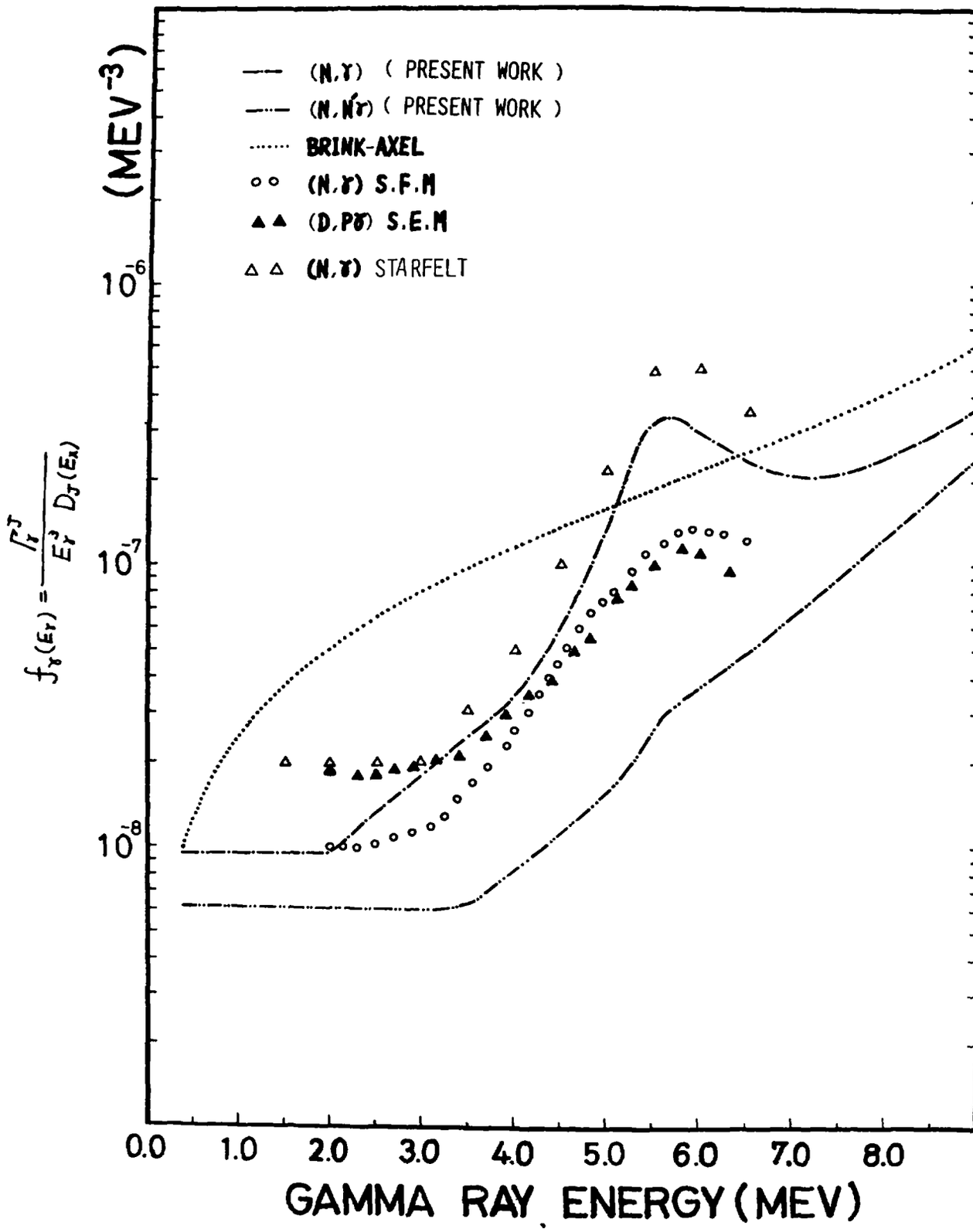

FIG - 1 GAMMARAY STRENGTH FUNCTIONS OF (N,γ) AND (N,N'γ) REACTION

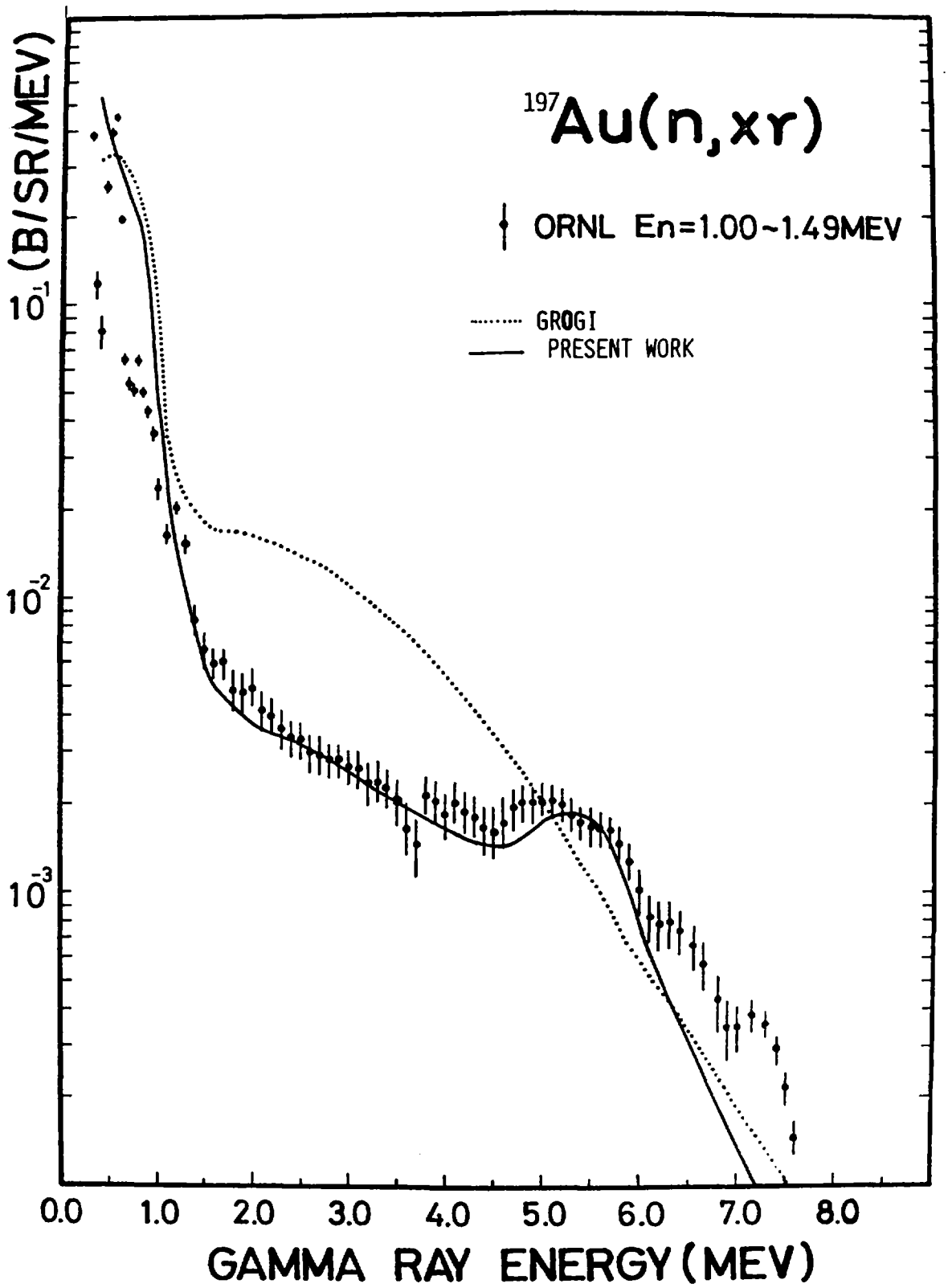

FIG - 2 GAMMARAY PRODUCTION CROSS SECTION OF AU-197

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VIII-1 Experimental Study of Fission-Product Decay Energy Release Rates from Fast-Neutron Fission of ^{235}U, ^{238}U, Nat.U and ^{232}Th

M. Akiyama and S. An

The fission-product decay energy release rates have been measured for fast-neutron fission of ^{235}U, ^{238}U, Nat.U and ^{232}Th. ^{235}U foil consisted of about 0.5mg of 90% enriched uranyl nitrate sandwiched by 0.075mm Ni foils. Other fission foils are metallic foils of 1/2 in. diameter, 1mil (^{238}U), 6.5mil (Nat.U) and 4mil (^{232}Th) thickness, respectively. The Samples have been irradiated with fast neutron at Fast Neutron Source Reactor "YAYOI" of University of Tokyo. The Gamma-ray energy spectra have been measured using 3"ϕ × 3"L NaI detection system for the cooling time 10^3 to 10^6 seconds. Counting times have been chosen to provide good statistics within the cooling time range of interest. Total energy release rates for gamma-ray have been obtained to integrate the gamma-ray energy spectra. The preliminary data for ^{235}U are shown in Figure 1. It can be seen that the measured gamma-ray energy release rates agree with that calculated by the summation method.

The same experiment to obtain the beta-ray energy release rates has been carried on using the beta-ray detection system consisted of the plastic scintillation detector combined with the transmission type ($\Delta E/\Delta x$ type) proportional detector to eliminate the gamma-ray effect. The same experimental program has been planed for the more short cooling times using the fast pneumatic-tube irradiation facility and for other fissile materials (^{239}Pu and ^{233}U).

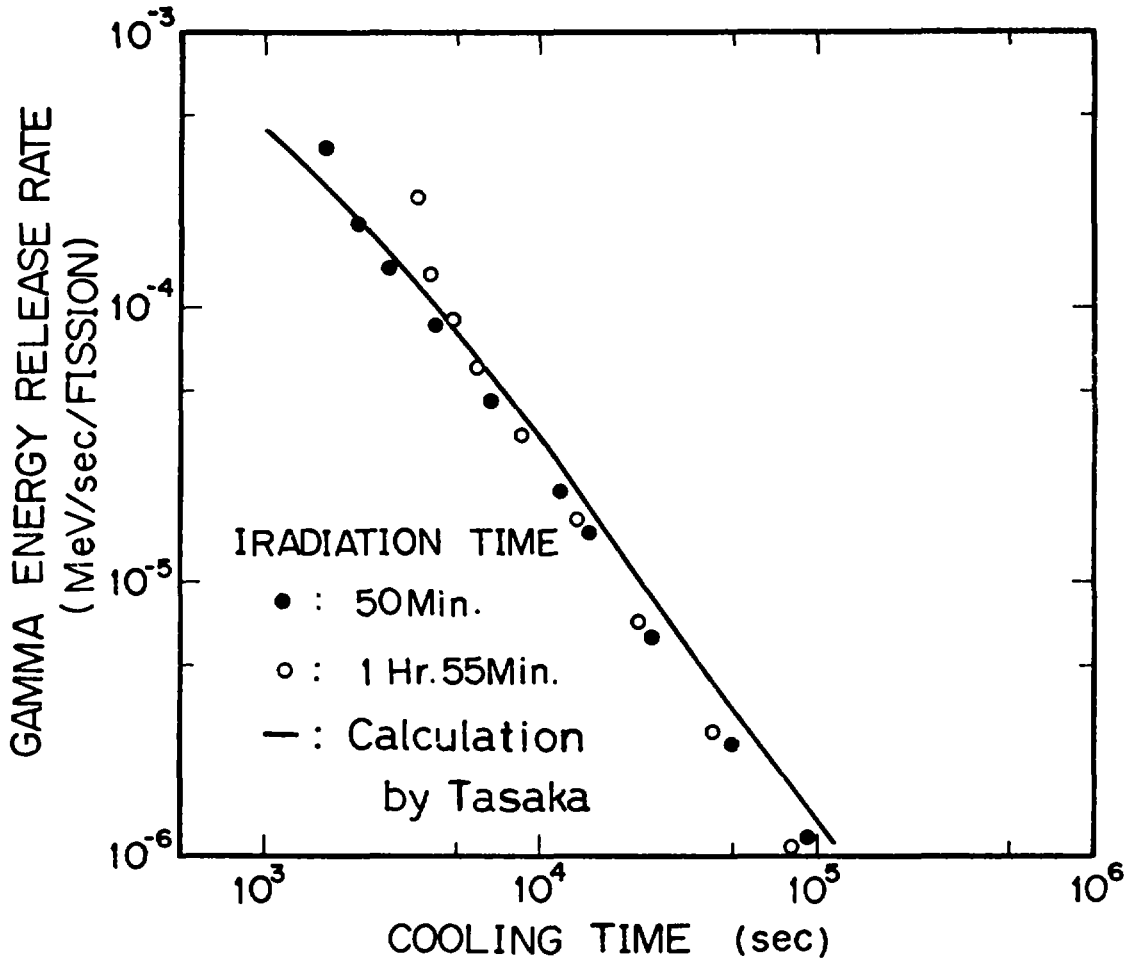

Fig.1. Experimental results of gamma-ray energy release rates from the fission products of U^{235} by fast neutrons