

## PROGRESS REPORT

(August 1969 to June 1970 inclusive)

August 1970

edited by

T. Momota

aided by

T. Fuketa and K. Okamoto

Japanese Nuclear Data Committee

Japan Atomic Energy Research Institute Tokai Research Establishment Tokai-mura, Ibaraki-ken, Japan

NOT FOR PUBLICATION

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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 might have been some oversight. Meanwhile, contribution of a report rested with discretion of its author. The coverage of this document, therefore, might not be uniform over the related field of research.

This edition covers a period of August 1, 1969 to June 30, 1970. The informations herein contained are of a nature of "Private Communication." They should not be quoted without author's permission.

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     (S. Kobayashi)

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ELEMENT SA	QUANTITY	түре	ENERGY MIN MA	٩X	DOCUMENTATION REF VOL PAGE DA	L TE	.AB	COMMENTS
Н 001	DIFF ELASTIC	EXPT-PROG	1.4 7		EANDC(J)19L,58 8/	70 Y	OK	TANAKA+.DIFFSIG AT 8 ANGA.PUB IN JPJ
H 002	N, PROTON	EXPT-PROG	1.4 7		EANDC(J)19L,58 8/	70 Y	(OK	KOORI+.DIFFSIG AT 9 ANGS.FIG GIVN
H 002	N, PROTON	EXPT-PROG	1.5 7		EANDC(J)19L,66 8/	70 T	TIT	ARAI.E-P ANG-DIST IN BREAK-UP,FIGS
LI 006	SCATTERING	EXPT-PROG	1.0 3 1.1	14	EANDC(J)19L, 6 8/	70 H	IAR	ASAMI + . NDG
С	TOTAL XSECT	REVW-PROG	0 2.0	06	EANDC(J)19L,20 8/	70 J	AE	NISHIMURA+.NDG
NA 023	RESON PARAMS	EXPT-PROG	2.9 2		EANDC(J)19L,71 8/	70 R	RP 1	YAMAMURO+.WG=0.47PM0.045EV TBP
NA 023	N , GAMMA	EXPT-PROG	THR 2.0	0-1	EANDC(J)19L,71 8/	70 R	RPI	YAMAMURO+.0.50PM0.03B AT THR FIG GIV
AL	THRMLSCATLAW	EXPT-PROG			EANDC(J)19L,60 8/	70 T	ЮН	/KIMURA+.TOF,POWDER D1FFR180DEGC
AL 027	DIFF ELASTIC	EXPT-PROG	4:56 8.0	) 6	EANDC(J)19L,13 8/	70 J	AE	TANAKA+.VDG 30T0150DEG.OPTMDL.NDG
AL 027	DIFF ELASTIC	EXTH-PROG	4.8 6 8.0	) 6	EANDC(J)19L,12 8/	70 J	AE	TSUKADA+.OPTMDL+MOLDAUER CALC NDG
AL 027	DIFF ELASTIC	EXPT-PROG	1.4 6		EANDC(J)19L,75 8/	70 I	SS	KATORI+.DEPOLARIZATION,FIGS GIVN
AL 027	DIFF INELAST	EXPT-PROG	4.5 6 8.0	6	EANDC(J)19L,13 8/	70 J	AE	TANAKA+.H-F,COUPLED-CHANNEL TH.NDG
AL 027	DIFF INELAST	EXTH-PROG	4.8 6 8.0	) 6	EANDC(J)19L,12 8/	70 J.	AE	TSUKADA+.OPTMDL+MOLDAUER CALC NDG
SI	DIFF ELASTIC	EXPT-PROG	4.5 6 8.0	) 6	EANDC(J)19L,13 8/	70 J.	AE	TANAKA+.VDG 30T0150DEG.OPTMDL.NDG
SI	DIFF INELAST	EXPT-PROG	4.5 6 8.0	) 6	EANDC(J)19L,13 8/	70 J.	AE	TANAKA+.H-F, COUPLED-CHANNEL TH.NDG
SI 028	N, PROTON	EXPT-PROG	PILE		EANDC(J)19L,26 8/	70 K	T0	KIMURA+.MEAN S=4.90PM0.32 MILLI-B
SI 029	N, PROTON	EXPT-PROG	PILE		EANDC(J)19L,26 8/	70 K	TO	KIMURA+.MEAN S=2.98PM0.17 MILLI-B
SI 030	N, ALPHA	EXPT-PROG	PILE		EANDC(J)19L,26 8/	70 K	TO	KIMURA.MEAN S=0.130PM0.020 MILLI-B
S	DIFF ELASTIC	EXPT-PROG	4.5 6 8.0	) 6	EANDC(J)19L,13 8/3	70 J.	AE	TANAKA+.VDG 30T0150DEG.OPTMDL.NDG
S	DIFF INELAST	EXPT-PROG	4.5 6 8.0	) 6	EANDC(J)I9L,13 8/3	70 J.	AE	TANAKA+.H-F,COUPLED-CHANNEL TH.NDG
V 051	N, ALPHA	EXPT-PROG	PILE		EANDC(J)19L,26 8/	70 K	TO	KIMURA+.MEAN S=0.0217PM0.0015MELLI-B
CR	N, GAMMA	THEO-PROG	1.0 4 2.0	) 7	EANDC(J)19L,21 8/	70 J.	AE	N1SHIMURA+.COMPUTER CALC,NDG
FE	DIFF ELASTIC	EXPT-PROG	1.4 6 2.2	2 6	EANDC(J)19L, 9 8/	70 J.	AE	TOMITA+.LEGENDRE COEF(L=0T06)IN FIG
FE	INELST GAMMA	EXPT-PROG	1.4 6 2.2	26	EANDC(J)19L, 9 8/	70 J.	AE	TOMITA+.LEGENDRE COEF(L=0T04)IN FIG
FE	N, GAMMA	THEO - PROG	1.0 4 2.0	) 7	EANDC(J)19L,21 8/	70 J	AE	NISHIMURA+.COMPUTER CALC,NDG
FE 056	DIFF INELAST	EXPT-PROG	1.4 6 2.2	26	EANDC(J)19L, 9 8/	70 J	AE	TOMITA+.LEGENDRE COEF(L=0T04)IN FIG
CO 059	RESON PARAMS	EXPT-PROG	8.0-1 3.0	) 3	EANDC(J)19L, 3 8/	70 J	IAE	NAKAJIMA+.RES PAPS.PUB 1N NST 7 (70)
CO 059	DIFF ELASTIC	EXPT-PROG	1.4 6		EANDC(J)19L,75 8/	70 J	SS	KATORI+.DEPOLARIZATION,FIGS GIVN
NI	DIFF ELASTIC	EXPT-PROG	1.4 6		EANDC(J)19L,75 8/	70 I	SS	KATORI+.DEPOLARIZATION,FIGS GIVN
NI	N, GAMMA	THEO-PROG	1.0 4 2.0	7	EANDC(J)19L,2I 8/	70 J	IAE	NISHIMURA+.COMPUTER CALC,NDG
NI 058	N, PROTON	THEO-PROG	1.5 7		EANDC(J)19L,73 8/	70 T	гок	OBU+.ANALOGUE STATE RES.PUB IN PTP43
CU	DIFF ELASTIC	EXTH-PROG	1.7 6 2.2	26	EANDC(J)19L,12 8/	70 J	JAE	TSUKADA+.OPTMDL+MOLDAUER CALC NDG

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ELEMENT S A	QUANTITY	TYPE	ENE MIN	RGY MAX	DOCUMENTATION REF VOL PAGE DATE	LAB	COMMENTS
ฒ	DIFF ELASTIC	EXPT-PROG	1.4 6		EANDC(J)19L,75 8/70	ISS	KATORI+.DEPOLARIZATION,FIGS GIVN
au	DIFF INELAST	EXTH-PROG	1.7 6	2.2 6	EANDC(J)19L,75 8/70	JAE	TSUKADA+.OPTMDL+MOLDAUER CALC NDG
ល	PHOTO-FISSN	EXPT-PROG	2.5 8	1.0 9	EANDC(J)19L,54 8/70	KYU	KATASE+.SIG IN FIG
CU 065	RESON PARAMS	EXPT-PROG	2.3 2		EANDC(J)19L,70 8/70	RP1	YAMAMURO+.TRANS,WN=15PM1.SMILLI-EV
ZN	DIFF ELASTIC	EXPT-PROG	4.5 6	8.0 6	EANDC(J)19L,13 8/70	JAE	TANAKA+.VDG 30T0150DEG.OPTMDL.NDG
ZN	DIFF ELASTIC	EXTH-PROG	1.76	8.0 6	EANDC(J)19L,12 8/70	JAE	TSUKADA+.OPTMDL+MOLDAUER CALC NDG
ZN	DIFF INELAST	EXTH-PROG	1.76	8.0 6	EANDC(J)19L,13 8/70	JAE	TANAKA+.H-F, COUPLED-CHANNEL TH.NDG
ZN 064	N, PROTON	EXPT-PROG	P I LE		EANDC(J)19L,26 8/70	кто	KIMURA+.MEAN S=35.5PM2.8 MILLI~B
GE	PHOTO-FISSN	EXPT-PROG	2.5 8	1.0 9	EANDC(J)19L,54 8/70	KYU	KATASE+.SIG IN FIG
NB 093	N2N XSECTION	EXPT-PROGQ	P I LE		EANDC(J)19L,26 8/70	кто	KIMURA+.MEAN S=0.432PMO.033 MB.ISOM
MO	N,GAMMA	THEO-PROG	1.0 4	2.0 7	EANDC(J)19L,21 8/70	JAE	NISHIMURA+.COMPUTER CALC,NDG
MO 092	N, PROTON	EXPT-PROG	P I LE		EANDC(J)19L,26 8/70	кто	KIMURA+.MEAN S=6.00PM0.45 MB,ISOM
AG	PHOTO-F1SSN	EXPT-PROG	2.5 8	1.0 9	EANDC(J)19L,54 8/70	KYU	KATASE+.SIG IN FIG
IN	PHOTO-FISSN	EXPT-PROG	2.5 8	1.0 9	EANDC(J)19L,54 8/70	KYU	KATASE+.SIG IN FIG
SN	PHOTO-FISSN	EXPT-PROG	2.5 8	1.0 9	EANDC(J)19L,54 8/70	KYU	KATASE+.SIG IN FIG
SB	PHOTO-FISSN	EXPT-PROG	2.5 8	1.0 9	EANDC(J)19L,54 8/70	KYU	KATASE+.SIG IN FIG
TE	PHOTO-FISSN	EXPT-PROG	2.5 8	1.0 9	EANDC(J)19L,54 8/70	KYU	KATASE+.SIG IN FIG
CS 133	INELST GAMMA	EXPT-PROG	5.0 5	9.6 5	EANDC(J)19L. 8 8/70	JAE	KIKUCHI.ANGDIST OF CFD C THEORY
LA	DIFF ELASTIC	EXPT-PROG	1.5 6	3.66	EANDC(J)19L, 7 8/70	JAE	TANAKA+.MEASURED IN 500KEV STEP.NDG
LA	DIFF INELAST	EXPT-PROG	1.5 6	3.6 6	EANDC(J)19L, 7 8/70	JAE	TANAKA+.MEASURED IN 500KEV STEP.NDG
PR 141	DIFF ELASTIC	EXPT-PROG	1.5 6	3.6 6	EANDC(J)19L, 7 8/70	JAE	TANAKA+.MEASURED IN 500KEV STEP.NDG
PR 141	DIFF INELAST	EXPT-PROG	1.5 6	3.6 6	EANDC(J)19L, 7 8/70	JAE	TANAKA+.MEASURED IN 500KEV STEP.NDG
SM	PHOTO-FISSN	EXPT-PROG	2.5 8	1.0 9	EANDC(J)19L,54 8/70	KYU	KATASE+.SIG IN FIG
EU 151	N,ALPHA	EXPT-PROG	P I LE		EANDC(J)19L, 2 8/70	JAE	OKAMOTO+.S FROM 5.4D+48D PM-148.NDG
EU 152	N, GAMMA	EXPT-PROG	2.5-2	3.4 0	EANDC(J)19L, 1 8/70	JAE	ASAMI+.GE(LI),ISOM RATIO
HO 165	PHOTO-FISSN	EXPT-PROG	2.5 8	1.0 9	EANDC(J)19L,54 8/70	KYU	KATASE+.SIG IN FIG
AU 197	PHOTO-FISSN	EXPT-PROG	2.5 8	1.0 9	EANDC(J)19L,54 8/70	KYU	KATASE+.SIG IN FIG
TI 046	N, PROTON	EXPT-PROG	PILE		EANDC(J)19L,26 8/70	кто	KIMURA+.MEAN S=11.2PM0.63 MILLI-B
TI 047	N, PROTON	EXPT-PROG	PILE		EANDC(J)19L,26 8/70	кто	KIMURA+.MEAN S=19.0PM].2 MILLI-B
TI 048	N, PROTON	EXPT-PROG	PILE		EANDC(J)19L,26 8/70	кто	KIMURA+.MEAN S=0.294PM0.025 MILLI-B

ELEMENT S A	QUANTITY	түре	ENE MIN	RGY MAX	DOCUMENTATION REF VOL PAGE DATE	LAB	COMMENTS
PB 204	TOT INELASTC	EXPT-PROG	PILE		EANDC(J)19L,26 8/70	<b>КТ</b> О	KIMURA+.MEAN S=18.9PM2.0 MB,ISOM
PB 204	N2N XSECTION	EXPT-PROG	P I LE		EANDC(J)19L,26 8/70	KT0	KIMURA+.MEAN S=1.90PM0.18 MILLI-B
PB 207	DIFF ELASTIC	EXPT-PROG	1.5 6	3.5 6	EANDC(J)19L, 7 8/70	JAE	TOMITA+.EXCIT FUNC AT 125 DEG.NDG
PB 207	DIFF INELAST	EXPT-PROG	1.5 6	3.5 6	EANDC(J)19L, 7 8/70	JAE	TOMITA+.EXCIT FUNC AT 125 DEG.NDG
PB 208	GAMMA N	EXPT-PROG		1.0 7	EANDC(J)19L, 4 8/70	JAE	NAKAJIMA+.N-SPECTR GIVN
BI 209	DIFF ELASTIC	EXPT-PROG	1.4 7		EANDC(J)19L,50 8/70	KYU	MATOBA+.TOF,20 TO 160 DEGS.NDG
BI 209	DIFF INELAST	EXPT-PROG	1.4 7		EANDC(J)19L,50 8/70	KYU	MATOBA+.TOF,2.6,4.2,5.7MEV LVLS.NDG
TH 232	FISSION	EXPT-PROG	PILE		EANDC(J)19L,37 8/70	кто	KOBAYASHI+.AVG SIG=67PM7 MILLI-B
TH 232	FISS YIELD	EXPT-PROG	P I LE		EANDC(J)19L,37 8/70	кто	KOBAYASHI+.5 NUCLIDES REL TO BA-140
TH 232	PHOTO-FISSN	EXPT-PROG	2.0 8	1.2 9	EANDC(J)19L,50 8/70	KYU	SONODA+.SIG IN FIGS
U	PHOTO-FISSN	EXPT-PROG	2.0 8	1.2 9	EANDC(J)19L,50 8/70	KYU	SONODA+.SIG IN FIGS
U 238	DIFF INELAST	THEO-PROG	5.0 4	1.5 7	EANDC(J)19L,22 8/70	JAE	IGARASI+.H-F AND OPTMDL,NDG
MANY	RESON PARAMS	EXPT-PROG			EANDC(J)19L,15 8/70	JAE	IDENO+.CORRELATION ANAL OF RES-SPACE
MANY	THRMLSCATLAN	THEO-PROG	COLD		EANDC(J)19L,16 8/70	JAE	/NAKAHARA.CAL FOR MONOATOM-L10 METAL
MANY	THRMLSCATLAW	THEO-PROG	COLD		EANDC(J)19L,56 8/70	OSA	NISHIGORI.FORMAL TH.PUB IN PTP 45N006
MANY	LVL DEN LAW	REVW-PROG	PILE		EANDC(J)19L,17 8/70	JAE	BABA+.PUBLISHED IN JAERI-1183+ERRATA
H20	THRMLSCATLAN	EXPT-PROG	THR		EANDC(J)19L,45 8/70	кт0	/FUJITA+.N-PSPECTR C GD,CD,B POISONS
NBD	THRMLSCATLAW	EXPT-PROG	THR		EANDC(J)19L,62 8/70	TOH	/KIMURA+.TOF,POWDER D1FFR.NDG
TAD	THRMLSCATLAW	EXPT-PROG	THR		EANDC(J)19L,62 8/70	TOH	/KIMURA+.TOF,POWDER DIFFR.NDG
TIO	THRMLSCATLAW	EXPT-PROG	THR		EANDC(J)19L,62 8/70	TOH	/KIMURA+.TOF,POWDER DIFFR.NDG
SRFED	THRMLSCATLAW	EXPT-PROG	THR		EANDC(J)19L,62 8/70	TOH	/KIMURA+.TOF,POWDER DIFFR.SR2FE205

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#### I. Japan Atomic Energy Research Institute

### A. Neutron Experiments - Reactor

# I-A-1. Dependence of the <sup>152</sup>Eu Activation Ratio on Neutron Energy T. Asami and Y. Ohno

The activation ratio of  $^{152m}Eu(9.3 hr)$  to  $^{152}Eu(12 y)$  produced by the  $^{151}Eu(n, r)^{152}Eu$ ,  $^{152m}Eu$  reaction was investigated mainly at the neutron resonances.

Europium enriched to 92.12% was used and the normalization of neutron flux was made with gold sample. The irradiations were made with monochromatic neutrons from a crystal spectrometer at energies of 0.0253, 0.080, 0.321, 0.461, 1.055 and 3.361 eV. The gamma-ray spectra from the irradiated samples were measured with a Ge(Li) detector and the decays of four gamma rays were followed.

Detailed analyses of the data are now in progress.

# I-A-2. The Cross Section of ${}^{151}Eu(n_{th}, \alpha)$ ${}^{148}Pm$ Reaction K. Okamoto, and H. Umezawa

The cross section of  $(n, \alpha)$  reaction of <sup>151</sup>Eu induced by pile neutrons was determined by a radiochemical method. Samples of <sup>151</sup>Eu-oxide were irradiated by the JRR-2 for about 300 hours with  $10^{13} \text{ n/cm}^2$ , sec of neutron flux and promethium was extracted from the irradiated sample by cation exchange technique with 2-methyllactate solution. A cobalt wire was always irradiated with the europium sample to measure the neutron flux. Radioactivities of 5.4-day <sup>148</sup>Pm(1-) and 42-day <sup>148m</sup>Pm(6-) were measured with a proportional counter and a Ge(Li) detector connected to a multichannel pulse height analyzer. The final analysis of the experimental data is in progress. - 3 -

Fuketa

### B. Neutron Experiments - Linac

A full paper on this subject was published in the Journal of Nuclear Science and Technology  $\underline{7}$  (1970) 7 - 12 with an abstract as follows:

Neutron transmission measurements on <sup>59</sup>Co have been made for neutron energies from 0.8 eV to 3 keV using the time-of-flight spectrometer of a linear accelerator at the Japan Atomic Energy Research Institute. The maximum time resolution was 10 nsec/m. Resonance parameters of the 132-eV resonance of <sup>59</sup>Co were determined from the neutron transmissions of several samples of different thicknesses by the thick-thin method, using an area analysis method based on the Breit-Wigner single-level formula.

The following results were obtained,  $E_0 = 132.0 \pm 0.5 \text{ eV}$ ,  $\Gamma = 6.0 \pm 0.2 \text{ eV}$ ,  $\Gamma_n = 5.15 \pm 0.06 \text{ eV}$  and J = 4. The value of the potential scattering radius, obtained from the transmission of the thickest sample, was  $R' = 5.3 \pm 0.5 \text{ fm}$ .

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### I-B-2. $^{208}$ Pb( $\gamma$ ,n) Reaction near Threshold

Y. Nakajima, R. Bergere\*, M. Mizumoto, and T. Fuketa

The following is an epitome of the paper presented at 1970 Spring Sectional Meeting of the Physical Society of Japan.

Photoneutron spectra of the  $^{208}$ Pb( $\gamma$ ,n) reaction have been measured with the time-of-flight spectrometer<sup>1)</sup> at the JAERI accelerator. The experimental conditions are the following:

Electron energy: 10.5 MeV, Electron pulse width: 150 ns,

Channel width: 62.5 ns, Flight path length: 50 m,

Detector: <sup>6</sup>Li glass scintillator.

The spectra were measured at  $85^{\circ}$  and  $130^{\circ}$  to the direction of photon.

First, the photoneutron spectra of  ${}^{208}$ Pb(7,n) reaction had been measured by Bertozzi et al.<sup>2)</sup> up to 2 MeV neutron energy. Then, they have been recently greatly improved up to 350 keV neutron energy by Bowman et al.<sup>3)</sup>. As is seen in the Table, our data are in good agreement with these data.



Multipole assignments of the absorbed photon will be made in the favourable resonances.

Recent measurements in Saclay of  ${}^{208}$ Pb (r,n) cross section seem to show some intermediate structure near the threshold<sup>4)</sup>. Our high resolution data are compared with the data of Saclay and preliminary results and discussion are presented.

Present Data	Bertozzi et al.	Bowman et al.
91.5 keV		89.7 keV
		98.3
		114.7
130		128.7
		139.5
		156.0
168		166.8
18 <b>2</b>		181.3
257	264 keV	256.7
301		299
317	324	318.7
333		335
430	437	
460		
546	557	
615	624	 

Table	1.	Resonance	Energy
Tante	<b>+</b> •	resonance	THETRY

### References:

- 1) A. Asami et al.: JAERI 1138 (1967).
- 2) W. Bertozzi et al.: Phys. Letters, <u>6</u>, (1963) 108.
- 3) C.D. Bowman et al.: Phys. Rev. Letters, <u>23</u> (1969) 796.
- 4) R. Bergère: Private communication.

I-B-3. Low Energy Neutron Scattering Cross Section of <sup>6</sup>Li<sup>+</sup> A. Asami and M. C. Moxon<sup>\*</sup>

A full paper on this work, which was outlined in the previous report (EANDC (J) 13L. P. 6), was presented at the IAEA Conference on Nuclear Data for Reactors held at Helsinki in June 1970, and to be published in the proceedings of the conference. (paper number CN-26/25)

<sup>+</sup> The measurements were made at A.E.R.E., Harwell.

<sup>\*</sup> A.E.R.E., Harwell, Didcot, Berks., U.K.

### C. Neutron Experiments - Van de Graaff Accelerator

# I-C-1. Elastic and Inelastic Neutron Scattering Cross Sections of <sup>207</sup>Pb Y. Tomita, S. Tanaka and M. Maruyama

Neutron scattering experiment on <sup>207</sup>Pb is in progress. So far, excitation functions has been measured at 125<sup>°</sup> and at neutron energies between 1.5 and 3.5 MeV.

### I-C-2. Scattering of 1.5 to 3.6 MeV Neutrons by La and Pr

S. Tanaka, Y. Tomita and S. Kikuchi

Measurement of the differential cross sections for elastic and inelastic scattering of neutrons from lanthanum and praseodymium has been completed at neutron energies of 1.50 to 3.57 MeV in 500-keV steps, and the analysis of the results is now in progress.

## I-C-3. Elastic and Inelastic Scattering of Neutrons in 20 MeV Region Y. Yamanouti, S. Tanaka, S. Kikuchi and K. Tsukada

Preliminary time-of-flight experiments to get information on neutron background and shielding in 20 MeV region by using the  $T(d,n)^{4}$ He reaction have been completed. A design of a multi-angle detector system is now in progress. The system consists of four detectors placed at different scattering angles in steps of  $10^{\circ}$ . The detectors are rotatable around a scatterer with the maximum flight paths of 8 m.

# I-C-4. Energy Levels of 133Cs Excited by Means of (n,n'r) Reaction Shiroh Kikuchi

The low-lying levels of  $^{133}$ Cs have been investigated by using the  $^{133}$ Cs(n,n'r) reaction in the neutron energy range of  $0.50 \sim 0.96$  MeV. Four levels above 600 keV were ascertained from threshold information of the excitation functions of the gamma rays, and a preliminary report has been published<sup>1)</sup>.

In order to study the spins and parities of these levels, the angular distributions of the gamma rays were measured and compared with the theoretical prediction based on the Satchler theory<sup>2)</sup>. Further examination of the spin and parity assignments was carried out by comparing the observed excitation functions with those calculated on the basis of the Moldauer formalism<sup>3)</sup>.

Detailed analyses are now under progress.

### References:

- S. Kikuchi, Y. Yamanouti and K. Nishimura, J. Phys. Soc. Japan <u>28</u> (1970) 1089.
- 2) G. R. Satchler, Phys. Rev. <u>94</u> (1954) 1304, ibid. <u>104</u> (1956) 1198, ibid. 111 (1958) 1747.
- 3) P. A. Moldauer, Phys. Rev. <u>123</u> (1961) 968, ibid. <u>129</u> (1963) 754, Rev.
   Mod. Phys. <u>36</u> (1964) 1079.

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### I-C-5. Neutron Scattering Cross Sections of Iron

Y. Tomita, K. Tsukada and M. Maruyama

A full paper on this subject was reported in IAEA 2nd International Conference on Nuclear Data for Reactors, Helsinki, 17 June, 1970, CN-26/29, and will be published in Proceedings of the conference. The following is its abstract:

The differential cross sections of elastic and inelastic scattering and the angular distributions of gamma-rays associated with decay of the first excited state were measured for iron by the time-of-flight method. The measurement was made in the energy range 1.43--2.15 MeV in steps of about 40 keV and at thirteen lab angles between  $30^{\circ}$  and  $146^{\circ}$ . Energy spread of the incident neutrons was about 50 keV FWHM. Gamma-rays were observed by the neutron detector. Absolute values of the (n,n'r) cross sections were normalized to the (n,n') cross sections. The measured cross sections were corrected for the effect of flux attenuation and multiple scattering and for source-to-sample geometrical effect by the Monte Carlo Method.

The angular distributions in the centre-of-mass system were fitted with Legendre polynomials of the form

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \frac{1}{4\pi} \sum_{\ell=0}^{L} B_{\ell} P_{\ell} (\cos \theta)$$

where L was taken as 6 for elastic scattering and 4 for inelastic scattering and gamma-rays. These coefficients are shown in Fig. 1 for elastic scattering, in Fig. 2 for inelastic scattering and in Fig. 3 for gamma-rays as functions of incident neutron energies. Uncertainties shown in the figures include only those due to statistics in the measurement and in the Monte Carlo calculations. The largest uncertainties not included would be those in the detector efficiency, which was determined by the use of the known cross sections of the  ${}^{3}\text{H}(p,n){}^{3}\text{H}e$  and  ${}^{7}\text{Li}(p,n){}^{7}\text{B}e$  reactions. These uncertainties may amount to 5% or more. Strong structures are seen in the coefficients of l = 1 to 3 for elastic scattering at about 1.6 MeV and 2.05 MeV. They also appear to lesser degrees in the coefficients of l = 0for elastic scattering, l = 0 and 2 for inelastic scattering and l = 0, 2and 4 for gamma-rays. The widths of the humps are about 200 MeV, which are of the same magnitude as were observed 1(2)(2)(2) for the structures at lower energies. It is of much interest whether or not each of the observed structures can be attributed to a single partial wave and be regarded as an intermediate resonance. The analysis on this point is in progress.







Fig. 2 Legendre expansion coefficients for the differential inelastic scattering cross sections of <sup>56</sup>Fe.



Fig. 3 Legendre expansion coefficients for the angular distributions of gamma-rays from the first excited state of Fe.

### References:

- J. E. Monahan and A. J. Elwyn, Phys. Rev. Lett. <u>20</u> (1968) 1119; A. J.
   Elwyn and J. E. Monahan, Nucl. Phys. <u>A123</u> (1969) 33.
- 2) J. Cabé, K. Laurat, P. Yvon and G. Bardolle, Nucl. Phys. Alo2 (1967) 92.
- 3) E. Barnard, J. A. M. De Villiers, C. A. Engelbrecht, D. Reitmann and
   A. B. Smith, Nucl. Phys. <u>All8</u> (1968) 321.

# I-C-6. <u>Width Fluctuation and Resonance Interference Effects in Neutron</u> Scattering Cross Sections of Aluminum, Copper and Zinc

K. Tsukada, Y. Tomita, S. Tanaka and M. Maruyama

A full paper on this subject was reported in IAEA 2nd International Conference on Nuclear Data for Reactors, Helsinki, 17 June, 1970, CN-26/30 and will be published in Proceedings of the conference with an abstract as follows:

Neutron scattering cross sections of aluminum, copper and zinc have been analyzed in the energy region of 1 to 8 MeV by means of the optical and statistical models, the width fluctuation effect and the resonance interference effect being taken into account. Data of the cross sections used in the analysis include those at 4.81, 5.96, 7.03 and 8.03 MeV for aluminum, at 1.71 and 2.24 MeV for copper and at 1.71, 2.24, 4.48, 5.92, 6.97 and 7.99 MeV for zinc which were measured in our laboratory, and data available in BNL-400 and CCDN. Best fit sets of optical-model parameters are searched for the angular distributions of elastic scattering, the inelastic scattering cross sections and the total cross sections at each energy. By using a computer code "STAX2", calculations on the basis of Hauser-Feshbach's formulation and Moldauer's formulation are performed. In the latter formulation, the calculations are carried out with the maximum and zero values of Moldauer's parameter Q. Difference in fitting among the three calculations appears in backward angles in a limited energy region. Systematic energy variations of the optical-model parameters are seen more or less in the region lower than 4 MeV for all cases. In the region higher than 4 MeV, where the Moldauer effect is to be ineffective, the energy variations are not so pronounced. Judging from these two, the calculation with the maximum value of Q is considered to be best among the three calculations to reproduce the measured data, though fluctuations in the cross sections and simple forms of the angular distributions in the lower energy region make the choice ambiguous.

### I-C-7. Fast Neutron Scattering from Al, Si, S and Zn

S. Tanaka, K. Tsukada, M. Maruyama and Y. Tomita

A full paper on this subject was reported in IAEA 2nd International Conference on Nuclear Data for Reactors, Helsinki, 17 June, 1970, CN-26/31 and will be published in Proceedings of the conference with an abstract as follows:

Differential cross sections for elastic and inelastic neutron scattering have been measured for natural samples of Al, Si, S and Zn at incident energies from 4.5 to 8 MeV in about 1-MeV steps. Scattered neutrons were observed at angles from  $30^{\circ}$  to  $150^{\circ}$  in  $10^{\circ}$  steps with a Mobley bunching system of the JAERI 5.5 MV Van de Graaff accelerator and a time-of-flight spectrometer. The absolute differential cross-section scale was fixed with reference to the n-p scattering cross section. The data were corrected for flux attenuation, multiple scattering in the samples and source-to-sample angular spread of neutron energy using a Monte Carlo computer code.

The differential cross sections were analysed using the optical model for the elastic scattering, the statistical theory for the compound processes, and the coupled-channels and DWBA theories for the direct inelastic scattering. The optical potential parameters were obtained by fitting the sum of the shape-elastic and compound-elastic scattering cross sections to the measured elastic data. The inelastic data for low-lying levels are compared with the combined predictions by the Hauser-Feshbach and coupled-channels (or DWBA) calculations. The comparison shows a good agreement for  $^{27}$ Al and  $^{32}$ S. For the first states in Zn even isotopes, the direct processes are predominant in the energy region higher than 5.9 MeV.

### D. Others

I-D-1. Deviations from the Statistical Distributions of Neutron Resonance Levels of Intermediate and Heavy Nuclei

K. Ideno and M. Ohkubo

A paper on this subject was reported in JAERI-Memo 4072 (unpublished) (1970).

Correlation analysis between spacings of arbitrary pairs of neutron resonance levels in individual nuclei is described. It is found that the observed neutron resonance levels of intermediate and heavy nuclei show simple correlations in the level positions. There appear very frequently pairs of levels separated at particular spacings and the observed levels are also preferentially distributed from each other at periodical positions with particular periods. For example, in the observed resonances of  $^{240}Pu^{1)}$  the level positions are found to be strongly correlated with a period of 213  $\pm$  1 eV in the energy region from zero to 2000 eV and also from 3600 to 5000 eV. It is shown that these regular behaviours in the occurrences of neutron resonances are very rarely expected for a statistical ensemble of levels. For the observed resonances of  $^{123}Sb^{2)}$ , the distribution of the relative level positions with respect to neutron zero energy is discussed.

### References:

1) W. Kolar and K. H. Böckhoff, J. Nucl. Energy <u>22</u> (1968) 299.

2) G. V. Muradyan, Yu. V. Adamchuk, Soviet J. Nucl. Phys. <u>8</u> (1969) 495.

### I-D-2. Thermal Neutron Scattering from Simple Liquids

Y. Nakahara

A paper on this subject was submitted to Journal of Nuclear Science and Technology (Tokyo) with an abstract as follows:

A new phenomenological method is proposed to calculate double differential scattering cross sections for thermal neutron scattering from simple monoatomic liquid metals such as liquid sodium.

A general expression for coherent part of the cross section has been obtained from a system of classical Vlasov equations for fully ionized ions and electrons interacting with each other through Coulomb or effective potentials. It is shown that the fine structure seen in the reduced scattering law for liquid sodium measured by Randolph can be explained successfully with our method.

Quantum effects of electrons have been estimated by applying the Balescu equation to electrons and are found not to be as important as in solid metals.

Comparison between our ion-electron model and Nelkin - Ranganathan's neutral atom model shows that the explicit consideration of charges of ions and the existence of conduction electrons gives an excellent improvement.

The gross structure of the reduced scattering law is determined by incoherent scattering. The incoherent part of the scattering law has been calculated combining the effective width model and the harmonic lattice model.

The reduced scattering law is given by the combination of the coherent and incoherent parts. The calculated reduced scattering law for liquid sodium shows an excellent qualitative and quantitative agreements with experimental values, except for energy transfers comparable to the energy of thermal motions of ions in liquid sodium. I-D-3. Average Level Spacings and the Nuclear Level Density Parameter H. Baba and S. Baba

A paper on this subject was published as JAERI-1183.

The average level spacing  $\underline{D}_{O}$  was computed with neutron resonance capture data summarized in BNL-325, and compared with those given by several authors. The values thus fixed with reliability were plotted versus the neutron number to see the systematic behavior of  $\underline{D}_{O}$ . The less reliable or ambiguous group of the  $\underline{D}_{O}$ 's was then fixed by taking the systematics into consideration. It was also decided from the systematics that the error involved in the  $\underline{D}_{O}$ 's would be at most of the order of a factor two.

The level density parameter <u>a</u> was calculated with the fixed value of the level spacing  $\underline{D}_{O}$ . The effect of an alternative choice of the level density formula or the moment of inertia on <u>a</u> was discussed and its dependence on the nuclear radius parameter was studied as well.

\* Errata: Table 2, the last line,  ${}^{244}_{96}$  cm<sub>148</sub> should be replaced by  ${}^{245}_{96}$  cm<sub>149</sub>, 5/2<sup>+</sup> by 0<sup>+</sup>, 6.720 by 5.696, 1.27 by 0.77, 20<sup>+6</sup><sub>-18</sub> by 20 <sup>+</sup> 6, 23.06<sup>+4.78</sup><sub>-0.51</sub> by 28.90<sup>+0.84</sup><sub>-0.60</sub>, and 23.40<sup>+4.78</sup><sub>-0.51</sub> by 29.29<sup>+0.84</sup><sub>-0.61</sub>.

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### I-D-4. Half-lives of Some Fission Product Nuclides

S. Baba, H. Baba and H. Natsume

A paper on this subject was submitted to the J. Inorg. and Nuclear Chem.

In the course of a radiochemical study of the proton-induced fission of  $^{238}$ U, a large number of fission product nuclides with medium half-lives were repeatedly separated and their yields were determined by measuring the radioactivities. Their half-lives were then determined with good precision as well as their intensities in the process of least squares fitting analysis of the  $\beta$ -decay curves. Resulting half-lives are summarized in Table 1.

Nuclide	Half-life	
72 <sub>Zn</sub>	46.6 ± 0.2 h	
86 <sub>Rb</sub>	18.61 ± 0.04 d	
<sup>89</sup> Sr	50.55 ± 0.09 d	
91 <sub>Y</sub>	58.51 ± 0.06 d	
99 <sub>Mo</sub>	66.5 ± 0.2 h	
112 <sub>Pd</sub>	20.12 ± 0.06 h*	
115 <sub>Cd</sub>	53.38 ± 0.04 h	
115mCd	44.8 ± 0.3 d	
129m <sub>Te</sub>	33.52 ± 0.12 d	
136 <sub>Cs</sub>	13.00 ± 0.02 d	Ք ՄՈ
140 <sub>Ba</sub>	12.789 ± 0.006d	
141 <sub>Ce</sub>	32.6 ± 0.2 d	some
143 <sub>Pr</sub>	13.57 ± 0.02 d	tho
147 <sub>Nd</sub>	10.98 ± 0.01 d	livo
149 $_{\rm Pm}$	53.08 ± 0.11 h	which
153 <sub>Sm</sub>	46.44 ± 0.08 h	tho
156 <sub>Eu</sub>	15.17 ± 0.03 d	ure - analı
161 <sub>Tb</sub>	6.90 ± 0.02 d	anar

Table 1

\* The observed value is somewhat smaller than reported values. This is likely due to the coexistence of the shorterlived isotope, <sup>109</sup>Pd (13.5h), which could not be resolved in the least squares fitting analysis. I-D-5. Direct Measurement of Nuclear Reaction Times by the Use of the Blocking Effect in Single Crystals M. Maruyama, K. Tsukada, K. Ozawa, F. Fujimoto<sup>\*</sup>, K. Komaki<sup>\*</sup>,

M. Mannami and T. Sakurai \*\*

A full paper reporting the results on the  ${}^{28}Si(p,p')$ ,  ${}^{70}Ge(p,p')$  and  ${}^{72}Ge(p,p')$  reactions, which were outlined in the previous report (INDC (JAP) 4E p.10), was published in Nuclear Physics A145 (1970) 581.

The measurement of reaction times of the  ${}^{63,65}Cu(p,p'){}^{63,65}Cu^*(lst and 2nd excited states)$  reactions has been performed using the same method and the analysis of the observed data is now in progress.

\*\* Department of Physics, Kyoto University, Kyoto.

<sup>\*</sup> Institute of Physics, College of General Education, University of Tokyo, Tokyo.

### E. Japanese Nuclear Data Committee

## I-E-1. Evaluation of the Total Neutron Cross Section of Carbon up to 2 MeV K. Nishimura, S. Igaraski, T. Fuketa and S. Tanaka

A treatment of least-squares method has been applied to the evaluation of carbon total neutron cross section in the energy region 1 eV to 2 MeV. The number of total cross-section data, which were available from CCDN and collected from other published reports, amount to almost 2,200 points. A fourth order polynomial is adopted as an empirical formula for these crosssection data. Two different methods for the assignment of weight have been tried in the least-squares fit, i.e., equal weight and weight of inverse square of error. The results indicate that the difference in the crosssection values obtained with the two different weight assignments does not exceed 1% in the entire energy region. The numerical data are classified into two groups of experimental data sets, one obtained by the time-offlight (TOF) and the other by the direct-current-beam (DCB) method. In order to find out systematic trend depending on the different methods of measurements, the least-squares fits with the equal weight and the weight of inverse square of error are applied to TOF and DCB data, separately. Systematic deviations of about 3.5% for the equal weight and about 2.5% for the weight of inverse square of error, are found in the cross section at 350 keV between TOF and DCB data. The cross-section curve obtained by the weight of inverse square of error is compared with those of ENDF/B, KFK 750 and UK data file.

### I-E-2. Fast Neutron Capture Cross Sections of Cr, Fe, Ni and Mo

K. Nishimura, T. Asami, S. Igarasi, M. Hatchya\* and H. Nakamura\*\*

In the keV-energy region, neutron radiative capture cross sections for such reactor materials as Cr, Fe, Ni and Mo have been measured by a number of authors. A variety of standard cross sections used in different groups of measurements makes a systematic comparison among their results difficult. In the present work, the Au(n, r) cross section measured by Poenitz et al. is adopted as a common standard cross section. By multiplying the normalization factors to the each  $(n, \gamma)$  cross section in different groups of measurements, the renormalized (n, r) cross sections for Cr, Fe, Ni and Mo have been obtained. By the use of the results of the systematic study of level density parameter a and strength function  $1/\xi^{0}$ , statistical model calculations have been performed up to about 10 MeV. The competition with neutron inelastic scattering is taken into account in the statistical model calculations. Collective and direct model calculations have been performed above several MeV region. Calculations are made by the use of a computer code RACY. The results of calculations from 10 keV to 20 MeV are adjusted to the renormalized (n, r) cross sections for Cr, Fe, Ni and Mo, and are compared with the curves of ENDF/B, KFK 750 and UK data.

A full paper will be published in the proceedings of the IAEA International Conference on Nuclear Data for Reactors (Helsinki, 1970). The number assigned to this paper is CN-26/28.

<sup>\*</sup> Mitsui Shipbuilding & Engineering Co., Ltd.

<sup>\*\*</sup> Fuji Electric Co., Ltd.

### I-E-3. Analysis of Neutron Inelastic Scattering by <sup>238</sup>U

S. Igarasi, H. Nakamura, T. Murata", and K. Nishimura

Total and partial inelastic scattering cross sections of <sup>238</sup>U are investigated in the range of neutron energy from 50 keV to 15 MeV. Optical model and Hauser-Feshbach's formula are mainly used in the energy range from 50 keV to 1.5 MeV and evaporation model is used above 1.5 MeV. Values and trends of optical potential parameters and level density parameters are searched for by fitting the calculated values of the inelastic scattering cross sections and the emitted neutron spectra to the experimental data. Spin and parity for each discrete level of <sup>238</sup>U are tentatively determined, after surveying experimental and theoretical information, and comparing results of calculations with experimental data for excitation functions. Effects of competitive processes, such as  $(n, \gamma)$ , (n, f), etc. are taken into account in the calculations. Above 1.5 MeV, the inelastic scattering cross sections are obtained by using Hauser-Feshbach's model which includes contribution from continuous state of the target nucleus, and by using calculated cross section for compound formation and experimental data for (n,f), (n,2n), (n,3n) and (n, r) cross sections. The inelastic scattering cross section obtained in this work is comparable to that presented in KFK-120.

A full paper will be published in the proceedings of the IAEA International Conference on Nuclear Data for Reactors (Helsinki, 1970). The number assigned to this paper is CN-26/27.

\*\* Nippon Atomic Industry Group Co., Ltd.

<sup>\*</sup> Fuji Electric Co., Ltd.
### I-E-4. GRAPH - A Computer Program for Plotting of Experimental Data in NEUDADA's Output Tape -

S. Igarasi and T. Nakagawa

This is a program, which is written in FORTRAN IV language, in order to plot the experimental data. Input-data for this program are arranged in transmission format. The transmission format is one of the output format from NEUDADA system. A computer to be used for this program is IBM 360/75 or FACOM 230-60 and a plotter is CALCOMP plotter. Using the computer program GRAPH, one can obtain several types of graphs for experimental data or any other numerical data, if they are arranged in the transmission format. An example of output graphs is shown below. Manual of GRAPH will be published in JAERI-memo.



### I-E-5. Other Works on Review and Evaluation in JNDC

S. Igarasi, S. Iijima, K. Nishimura and other members of JNDC

1) Works on review and evaluation of cross section of  $^{235}$ U,  $^{238}$ U,  $^{239}$ Pu,  $^{240}$ Pu,  $^{241}$ Pu, Cr, Fe, Ni, Na and  $^{16}$ O had started last year. Experimental data for  $\sigma_t$ ,  $\sigma_c$ ,  $\sigma_f$ ,  $\sigma_{el}$ ,  $\sigma_{inel}$  and  $\nu$  of  $^{235}$ U,  $^{238}$ U,  $^{239}$ Pu,  $^{240}$ Pu and  $^{241}$ Pu, and those for  $\sigma_{el}$  and  $\sigma_{in}$  of Cr, Ni, Fe, Na and  $^{16}$ O have been collected from published reports, and NEUDADA or SCISRS files, in the energy range from 1 keV to 20 MeV. These collected data are recompiled in the form of tables and graphs. The review and evaluation works are now in progress.

2) Review and evaluation works of fission product data (level scheme, decay constants, fission yields, cross sections, etc.) have started recently. Fission yield data will cover for fissions from  $^{235}$ U,  $^{238}$ U,  $^{239}$ Pu. Cross sections will be estimated in the energy region from 100 eV to 10 MeV for about 18 nuclides (Z=32~67) with long life-time.

# I-E-6. An Area-Analysis Program for Neutron Resonances based on the Atta-Harvey Code

A. Tachibana<sup>\*</sup>, T. Iwaki<sup>\*\*</sup>, E. Kimura, A. Asami, Y. Nakajima, and T. Fuketa

A report on this subject was published in JAERI-memo 3728 (1969) with an abstract as follows:

Modification of the Atta-Harvey Area-Analysis Code was made with regard to the calculation of the neutron width consistent with the total width and to the evaluation of the error of computed value of neutron width in addition to the minor change of the program. Instruction for the use of the program and the program list are given.

\*\* Mitsubishi Atomic Power Industries, Inc.

<sup>\*</sup> The Japan Atomic Power Company.

### II. Kyoto University Research Reactor Institute

### II-1. Measurements of Average Cross Sections for Some Threshold Reactions to the Neutrons with the Fission-type Reactor Spectrum

I. Kimura, K. Kobayashi and T. Shibata

A paper on this subject was submitted to the Journal of Nuclear Science and Technology. (A part of this work was reported in the previous report: EANDC (J) 13 L, p.23 (1969)).

Threshold reactions play an important role in the points of (1) measurement of fast neutron flux and spectrum, (2) evaluation of radiation damage in reactor materials and (3) scheduling fuel cycles.

In order to evaluate the reaction rate of some threshold reactions for any purpose, not only the energy dependent cross sections for the reactions, but also the energy spectrum of fast neutrons, should be known as precisely as possible. However, there have existed quite poor data or remarkable discrepancies among data of the fission-spectrum-averaged cross sections for most of threshold reactions, much less of the energy dependent cross sections.

Several experimental workers have measured average cross sections by making use of fission plates<sup>1)~6)</sup>, and several experimenters have also measured them averaged over some reactor spectra<sup>7)~18)</sup>. However, these cross section data are lacking in generality, unless the neutron spectrum is close to that of fission neutrons, because the expression of the energy spectrum of fission neutrons has become a subject of discussion recently<sup>4)19)~21)</sup>.

In the present work, the fast neutron spectrum in the core of the Kyoto University Reactor, KUR, which is a light-water-moderated reactor, has been experimentally and theoretically shown to be almost same as that of fission neutrons, as depicted in Figs.  $1 \sim 3^{22} \sim 24^{\circ}$ . Furthermore, this fact was reexamined by comparing the reaction rates of some threshold reactions for the neutrons in the core and for ones from the surface of a fission plate which was made of 90% enriched uranium. Thereafter, the average cross sections for the  $^{46}\text{Ti}(n,p)^{46}\text{Sc}$ ,  $^{47}\text{Ti}(n,p)^{47}\text{Sc}$ ,  $^{48}\text{Ti}(n,p)^{48}\text{Sc}$ ,  $^{28}\text{Si}$  $(n,p)^{28}\text{Al}$ ,  $^{29}\text{Si}(n,p)^{29}\text{Al}$ ,  $^{30}\text{Si}(n,\alpha)^{27}\text{Mg}$ ,  $^{51}\text{V}(n,\alpha)^{48}\text{Sc}$ ,  $^{64}\text{Zn}(n,p)^{64}\text{cu}$ ,  $^{92}\text{Mo}(n,p)^{92m}\text{Nb}$ ,  $^{93}\text{Nb}(n,2n)$ ,  $^{92m}\text{Nb}$ ,  $^{204}\text{Pb}(n,n')^{204m}\text{Pb}$  and  $^{204}\text{Pb}(n,2n)^{203}\text{Pb}$ reactions have been measured.



Fig. 1 Integral flux of fast neutrons in the core of KUR above effective threshold energy, measured with threshold reactions shown in Table 1:  ${}^{103}$ Rh(n,n') ${}^{103}$ Rh,  ${}^{58}$ Ni(n,p) ${}^{58}$ Co,  ${}^{27}$ Al(n,p) ${}^{27}$ Mg,  ${}^{24}$ Mg(n,p) ${}^{24}$ Na,  ${}^{56}$ Fe(n,p) ${}^{56}$ Mn and  ${}^{27}$ Al(n,  $\alpha$ ) ${}^{24}$ Na.



Fig. 2 Fast neutron spectrum in the core of KUR obtained by the associated Laguerre expansion method,

000 spectral analysis by  ${}^{103}$ Rh(n,n') ${}^{103m}$ Rh,  ${}^{115}$ In(n,n') ${}^{115m}$ In,  ${}^{58}$ Ni(n,p) ${}^{58}$ Co,  ${}^{27}$ Al(n,p) ${}^{27}$ Mg,  ${}^{24}$ Mg(n,p) ${}^{24}$ Na,  ${}^{56}$ Fe(n,p) ${}^{56}$ Mn and  ${}^{27}$ Al(n,  $\alpha$ ) ${}^{24}$ Na.



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The sample foils were irradiated in the core of KUR, where the fast neutron spectrum had been found out to be close to that of fission neutrons. The fast neutron flux of  $\phi_{\rm fast} \approx 10^{12} \text{ n/cm}^2/\text{sec}$  during irradiation of samples was monitored with the  $^{58}\text{Ni}(n,p)^{58}\text{Co}$ ,  $^{24}\text{Mg}(n,p)^{24}\text{Na}$  and  $^{27}\text{Al}(n,\alpha)$  $^{24}\text{Na}$  reactions whose average cross sections were 104, 1.4 and 0.63 mb, respectively<sup>24)</sup>. The flux values obtained with these monitors agreed with each other within 2% in each of the present measurement.

Detail specifications of samples are summarized in Table 1. Induced activities of sample foils were measured with the Ge(Li) counter, of which detection efficiency had been previously calibrated by comparing with IAEA standard gamma sources. The values of average cross sections in this work have been obtained from the photopeak-counts of each gamma-ray spectrum. The results of the present measurements are shown in Tables  $2 \sim 13$ . In these data, the error was estimated to be one standard deviation of the errors which came from monitor-counting, statistical error and the total systematic error taken to be 5%.

Making use of the fission plate, the average cross sections for the  ${}^{46}\text{Ti}(n,p){}^{46}\text{Sc}$ ,  ${}^{47}\text{Ti}(n,p){}^{47}\text{Sc}$ ,  ${}^{48}\text{Ti}(n,p){}^{48}\text{Sc}$ ,  ${}^{64}\text{Zn}(n,p){}^{64}\text{Cu}$ ,  ${}^{92}\text{Mo}(n,p){}^{92\text{m}}\text{Nb}$  and  ${}^{93}\text{Nb}(n,2n){}^{92\text{m}}\text{Nb}$  reactions have been also measured. These results are tabulated in Table 14. The values of the cross sections for these reactions obtained with the fission plate agree with those obtained in the core of KUR in an experimental error.

Other cross sections will be obtained by making use of this fast neutron field with the fission-type-reactor spectrum in the core of KUR in future.

isotope abundance	reaction	half life	measured energy	foil specification
7.93 %	<sup>46</sup> Ti(n,p) <sup>46</sup> Sc	84 d	0.89, 1.12 MeV 7 -ray	1/2" dia. 0.01" thick 99.73% pure
7.28 %	47 <sub>Ti(n,p</sub> )47 <sub>Sc</sub>	3.43 à	0.16 MeV 7-ray	1/2" dia. 0.01" thick 99.73% pure
73.94 %	<sup>48</sup> Ti(n,p) <sup>48</sup> Sc	44 h	0.98, 1.04, 1.314 MeV 7 -ray	1/2" dia. 0.01" thick 99.73% pure
92.18 %	<sup>28</sup> Si(n,p) <sup>28</sup> Al	2.3 m	1.78 MeV 7-ray	8 mm X 8 mm X 0.2 mm sliced from p-type crystal
4.71 %	<sup>29</sup> Si(n,p) <sup>29</sup> Al	6.6 m	1.28 MeV 7-ray	8 mm X 8 mm X 0.2 mm sliced from p-type crystal
3.14 %	$^{30}$ Si(n, $\alpha$ ) <sup>27</sup> Mg	9.5 m	0.84 MeV 7-ray	8 mm X 8 mm X 0.2 mm sliced from p-type crystal
99.75 %	$51_{V(n,\alpha)}^{48}$ Sc	44 h	0.98, 1.04, 1.314 MeV 7 -ray	1/2" dia. 0.003" thick 99.72% pure
48.89 %	<sup>64</sup> Zn(n,p) <sup>64</sup> Cu	12.8 h	1.34 MeV 7-ray	8 mm dia. 0.01 mm thick 99.9% pure
15.86 %	92 <sub>Mo(n,p</sub> )92m <sub>Nb</sub>	10.2 d	0.934 MeV 7-ray	1/2" dia. 0.003" thick 99.92% pure
100 %	93 <sub>Nb(n,2n)</sub> 92m <sub>Nb</sub>	10.2 d	0.934 MeV 7-ray	1/2" dia. 0.005" thick 99.84% pure
1.4 %	<sup>204</sup> Pb(n,n') <sup>204m</sup> Pb	66.9 m	0.375, 0.899, 0.912 MeV, 7-ray	10 mm X 10 mm X 1 mm 99.9% pure
1.4 %	204 <sub>Pb(n,2n)</sub> 203 <sub>Pb</sub>	52.1 h	0.279 MeV 7-ray	10 mm X 10 mm X 1 mm 99.9% pure

Table 1 Characteristics of sample foils used for average cross section measurement

Cross section (mb)	Reference	e
11.2 ± 0.6 <sub>3</sub>	Present	(reactor)
8.2	Mellish <sup>8)</sup>	(reactor)
8.0	Roy <sup>9)</sup>	(preferred)
10	Durham <sup>11)</sup>	(reactor)
11.1	Comera <sup>12)</sup>	(reactor)
17 ± 3	Niese <sup>13)</sup>	(reactor)
9.0 ± 0.1	Hogg <sup>14)</sup>	(reactor)
12.8 ± 0.6	Boldeman <sup>3)</sup>	(converter)
12.6 ± 0.4	Köhler <sup>15)</sup>	(reactor)
10.2 ± 0.4	Bresesti <sup>5)</sup>	(converter)

Table 2 Comparison of fission-average cross sections for the  ${}^{46}\text{Ti}(n,p){}^{46}\text{Sc}$  reaction.

Table 3 Comparison of fission-average cross sections for the  ${}^{47}\text{Ti}(n,p){}^{47}\text{Sc}$  reaction.

Cross section (mb)	Reference	e
19.0 ± 1.2	Present	(reactor)
0.42	Mellish <sup>8)</sup>	(reactor)
18	Durham <sup>11)</sup>	(reactor)
18 ± 3	Niese <sup>13)</sup>	(reactor)
15 ± 0.6	Hogg <sup>14)</sup>	(reactor)
22 <sup>±</sup> 1.5	Boldeman <sup>3)</sup>	(converter)
13.2 ± 1.0	Köhler <sup>15)</sup>	(reactor)

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Cross section (mb)	Reference	
0.29 <sub>4</sub> ± 0.02 <sub>5</sub>	Present	(reactor)
0.15	Mellish <sup>8)</sup>	(reactor)
0.53	Durham <sup>11)</sup>	(reactor)
0.44 ± 0.08	Niese <sup>13)</sup>	(reactor)
0.25 ± 0.01	Hogg <sup>14)</sup>	(reactor)
0.21 ± 0.016	Boldeman <sup>3</sup> )	(converter)
3.3 ± 0.2	Köhler <sup>15)</sup>	(reactor)

Table 4 Comparison of fission-average cross sections for the  ${\rm ^{48}Ti(n,p)^{48}Sc}$  reaction

Table 5 Comparison of fission-average cross sections for the  ${}^{28}Si(n,p){}^{28}Al$  reaction

Cross section (mb)	Reference	
4.9 <sub>0</sub> ± 0.3 <sub>2</sub>	Present (reactor)	
4.0	Roy <sup>9)</sup> (preferred)	

Table 6 Comparison of fission-average cross sections for the  ${}^{29}Si(n,p){}^{29}Al$  reaction

Cross section (mb)	Reference
2.9 <sub>8</sub> ± 0.1 <sub>7</sub>	Present (reactor)
2.7	Roy <sup>9)</sup> (preferred)

-			
	Cross section (mb)	Refer	ence
-	0.13 <sub>0</sub> ± 0.02 <sub>0</sub>	Present	(reactor)
-	0.15 ± 0.02	Niese <sup>13)</sup>	(reactor)

Table 7 Comparison of fission-average cross sections for the  ${}^{30}\text{Si}(n, \alpha){}^{27}\text{Mg}$  reaction

Table 8 Comparison of fission-average cross sections for the  ${}^{51}V(n, \alpha){}^{48}Sc$  reaction

Cross section (mb)	Reference	
0.021 <sub>7</sub> ± 0.001 <sub>5</sub>	Present	(reactor)
0.08	Hughes1)	(converter)
0.016	Saeland <sup>7)</sup>	(reactor)
0.035	Roy <sup>9)</sup>	(preferred)

Table 9 Comparison of fission-average cross sections for the  ${}^{64}Zn(n,p){}^{64}Cu$  reaction

Cross section (mb)	Reference	
35.5 ± 2.8	Present	(reactor)
44	Mellish <sup>8)-</sup>	(reactor)
39	Roy <sup>9)</sup>	(preferred)
28	Passell <sup>10)</sup>	(reactor)
31	Durham <sup>11)</sup>	(reactor)
27 <b>±</b> 1.6	Boldeman <sup>3)</sup>	(converter)
26.9 ± 1.2	Rau <sup>17)</sup>	(reactor)

Cross section (mb)	Reference	
6.0 <sub>0</sub> ± 0.4 <sub>3</sub>	Present	(reactor)
1.3	Mellish <sup>8)</sup>	(reactor)
2.6	Roy <sup>9</sup> )	(preferred)
6.0	Hogg <sup>14)</sup>	(reactor)
6.2 ± 0.4	Boldeman <sup>3)</sup>	(converter)
6.74 ± 0.27	Rau <sup>17</sup> )	(reactor)
5.75 ± 0.25	Bresesti <sup>5)</sup>	(converter)

Table 10 Comparison of fission-average cross sections for the  $92_{Mo}(n,p)^{92m}Nb$  reaction

Table 11 Comparison of fission-average cross sections for the 93Nb(n,2n)92mNb reaction

Cross section (mb)	Reference	
0.43 <sub>2</sub> ± 0.03 <sub>3</sub>	Present	(reactor)
0.33	Fabry <sup>16</sup> )	(reactor)

Table 12 Comparison of fission-average cross sections for the  ${}^{204}Pb(n,n'){}^{204m}Pb$  reaction

Cross section (mb)	Reference	
18. <sub>9</sub> ± 2. <sub>0</sub>	Present	(reactor)
22	Durham 11)	(reactor)
15.3 ± 0.7	Köhler <sup>18)</sup>	(reactor)

Table 13	Comparison of fission-average cross sections
	for the $204_{Pb}(n,2n)^{203}Pb$ reaction

1.9 <sub>0</sub> ± 0.1 <sub>8</sub>	Present	(reactor)
3.3	Roy <sup>9)</sup>	(preferred)
5.0	Durham <sup>11)</sup>	(reactor)

Table 14 Comparison of average cross section values obtained in the core of KUR and on the fission plate

	average cross section (mb)			
reaction	KUR core	fission plate		
<sup>46</sup> Ti(n,p) <sup>46</sup> Sc	11. <sub>2</sub> ± 0.6 <sub>3</sub>	10. <sub>8</sub> ± 0.6 <sub>1</sub>		
47 <sub>Ti(n,p</sub> )47 <sub>Sc</sub>	19.0 <sup>±</sup> 1.2	17. <sub>3</sub> ± 0.9 <sub>0</sub>		
<sup>48</sup> Ti(n,p) <sup>48</sup> Sc	0.29 <sub>4</sub> ± 0.02 <sub>5</sub>	0.27 <sub>2</sub> ± 0.05 <sub>2</sub>		
<sup>64</sup> Zn(n,p) <sup>64</sup> Cu	35. <sub>5</sub> ± 2. <sub>8</sub>	37.4 ± 3.0		
92 <sub>Mo</sub> (n,p) <sup>92m</sup> Nb	6.0 <sub>0</sub> ± 0.4 <sub>3</sub>	6.0 <sub>4</sub> ± 0.4 <sub>5</sub>		
93 <sub>Nb(n,2n</sub> )92m <sub>Nb</sub>	0.43 <sub>2</sub> ± 0.03 <sub>3</sub>	0.40 <sub>2</sub> ± 0.03 <sub>4</sub>		

### References:

- Hughes, D.J., "Pile Neutron Research", p.96, Addison-Wesley Publishing Co., 1953.
- 2) Depuydt, H. and de Hevergnies, M.N., J. Nucl. Energy A/B 16 (1962) 447.
- 3) Boldeman, S.W., J. Nucl. Energy A/B 18 (1964) 417.
- 4) Fabry, A., Nukleonik <u>10</u> (1967) 280.

- 5) Bresesti, A.M., Bresesti, M. and Rydin, R.A., Nucl. Sci. Eng. 29 (1967) 7.
- 6) Grundl, J.A., Nucl. Sci. Eng. <u>30</u> (1967) 39.
- 7) Saeland, E., Lykaas, M. and Samsahl, K., Jener Report (1954) 23.
- 8) Mellish, C.E., AERE-R/2630 (1958).
- 9) Roy, J.C. and Hawton, J.J., AECL-1181 (1960).
- 10) Passell, T.O. and Heath, R.L., Nucl. Sci. Eng. <u>10</u> (1961) 308.
- 11) Durham, R.W., Navalker, M.P. and Ricci, E., AECL-1434 (1962).
- 12) Comera, J., Interner CEA-Report, DPE-SPE, Note E-87 (1963).
- 13) Niese, S., Morzek, P. and Herold, C., Kernenergie <u>6</u> (1963) 37.
- 14) Hogg, C.H. and Weber, L.D., ASTM Special Tech. Publ. No.341 (1963).
- 15) Kohler, W., Nukleonik <u>8</u> (1966) 9.
- 16) Fabry, A., Proc. Conference on Radiation Measurements in Nuclear Power, at Berkeley, 1966.
- 17) Rau, G., Nukleonik <u>9</u> (1967) 228.
- 18) Kohler, W. and Knopf, K., Nukleonik <u>10</u> (1967) 181.
- 19) Grundl, J.A., Nucl. Sci. Eng. <u>31</u> (1968) 191.
- 20) McElroy, W.N., Berg, S. Crockett, T.B. and Tuttle, R.J., Nucl. Sci. Eng. <u>36</u> (1969) 15.
- 21) McElroy, W.N., Nucl. Sci. Eng. <u>36</u> (1969) 109.
- 22) Kimura, I., Kobayashi, K. and Shibata, T., Ann. Reports, Research Reactor Institute, Kyoto University, <u>1</u> (1967/68) 95.
- 23) Kanda, K., Nanjo, T., Kobayashi, K., Nakagome, Y. and Kumura, I., Ann. Reports, Research Reactor Institute, Kyoto University, <u>2</u> (1969) 18.
- 24) Kimura, I., Kobayashi, K. and Shibata, T., KURRI-TR-61 (1969).

II-2.

# Measurement of Average Cross Section for the <sup>232</sup>Th(n,f)

Reaction for the Fission-type Reactor Spectrum

K. Kobayashi and I. Kimura

A paper on this subject was published in Annual Reports of the Research Reactor Institute, Kyoto University<sup>1)</sup>.

The fast neutron spectrum in the core of the Kyoto University Reactor was measured with several methods, and the results proved to be close to the fission neutron spectrum<sup>2)~5)</sup>. The average cross section for the  $^{232}$ Th(n,f) reaction has been measured in the field of this quasi-fission spectrum.

The thorium sample was a foil of 99.95% pure, 1/2 inch in diameter and 0.004 inch thick. This was irradiated in the field of the fast neutron flux about  $10^{12} \text{ n/cm}^2/\text{sec}$  for 30 minutes, and its induced activities were directly measured with a planer-type Ge(Li) counter. In order to monitor the fast neutron flux during the foil irradiation, the  ${}^{58}\text{Ni}(n,p){}^{58}\text{Co}$ ,  ${}^{24}\text{Mg}(n,p){}^{24}\text{Na}$  and  ${}^{27}\text{Al}(n,\alpha){}^{24}\text{Na}$  reactions were used. In the present work, the relative fission yields for five nuclides,  ${}^{140}\text{Ba}$ ,  ${}^{135}\text{Xe}$ ,  ${}^{132}\text{Cs}$ ,  ${}^{95}\text{Zr}$  and  ${}^{91}\text{Sr}$ , were obtained and the normalized values of them to the value of  ${}^{140}\text{Ba}$  preferred by Bresesti et al. ${}^{5)}$  agreed with the earlier data considerably, as shown in Table 1 and Fig. 1. From these results, the average cross section for the  ${}^{232}\text{Th}(n,f)$  reaction has become to be 67  $\pm$  7 mb, and has been shown in Table 2, comparing with measured and calculated values.

### References:

 Kobayashi, K. and Kumura, I., Ann. Repts. Research Reactor Institute, Kyoto University, <u>3</u> (1970) 84.

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- Kimura, I., Kobayashi, K. and Shibata, T., Ann. Repts. Research Reactor Institute, Kyoto University, <u>1</u> (1967/1968) 95.
- 3) Kanda, K., Nanjyo, T., Kobayashi, K., Nakagome, Y. and Kimura, I., Ann. Repts. Research Reactor Institute, Kyoto University, <u>2</u> (1969) 18.
- 4) Kimura, I., Kobayashi, K., Shibata, T., KURRI-TR-61 (1969).
- 5) Kimura, I., Hayashi, Shu A., Kobayashi, K., Ishihara, S. and Shibata, T., KURRI-TR-67 (1969).
- Bresesti, M., Burei, G., Ferrari, P. and Moretto, L., J. Imorg. Nucl. Chem. Vol. 29 (1967) 1189.
- 7) Iyer, R.H., Mathews, C.K., Ravindran, N., Rengan, K., Singh, D.V.,
   Ramaniah, M.V. and Sharma, H.D., J. Inorg. Nucl. Chem. Vol. 25 (1963) 465.
- 8) Katcoff, S., Nucleonics Vol. 18, No. 11-November (1960) 201.
- 9) Zysin, Yu. A., Lbov, A.A. and Sel'chenkov, L.I., "Fission Product Yields and their Mass Distribution" Authorized Translation from the Russian, Consultants Bureau, New York, 1964.
- 10) Watt, B.E., Phys. Rev. <u>87</u> (1952) 1037.
- Cranberg, L., Frye, G., Nereson, N. and Rosen, L., Phys. Rev. <u>103</u> (1956) 662.
- 12) Leachman, R.B., Proc. Int. Conf. on Peaceful Uses of Atomic Energy, Geneva, Vol. II (1956) 193.
- 13) McElroy, W.N., Nucl. Sci. Eng. <u>36</u> (1969) 109.
- Bresesti, M., Del Turco, A.M., Ostidich, A., Rota, A. and Segre, G.,
   Proc. of a Symposium, Harwell, 1962 "Neutron Døsimetry" Vol. I, p. 27 (1963).
- 15) Beckurts, K.H. and Wirtz, K., "Neutron Physics" Springer-Verlag, 1964.
- 16) Fabry, A., Proc. Conference on Radiation Measurements in Nuclear Power at Berkeley, 1966.

 Stehn, J.R., Goldberg, M.D., Wiener-Chasman, R., Mughabghab, S.F.,
 Magurno, B.A. and May, V.M., BNL-325 Second Edition, Supplement No. 2 (1965).



Table 1 Comparison of the fission yields for the  $^{232}$ Th(n,f) reaction measured in the present work and reported in the literatures  $^{29}$ .

Nuclide	Present work	Preferred Value by Bresesti et al.6)	Iyer et al. <sup>7)</sup>	Katcoff <sup>8)</sup>	Zysin et al. <sup>9)</sup>
140 <sub>Ba</sub>	7.64 %	7.64 %	8.50 ± 0.23 %	6.2 %	6.2 ± 2.0 %
135 <b>X</b> e	3.9 ± 0.9*				
132 <sub>Cs</sub>	2.5 ± 0.3*			2.4( <sup>132</sup> Te)	2.4 ± 0.7( <sup>132</sup> Te)
$95_{\rm Zr}$	5.0 ± 0.5*		5.15 ± 0.31		
91 <sub>Sr</sub>	6.6 <b>±</b> 1.0 <sup>*</sup>		6.80 ± 0.55	7.2	6.4 ± 0.7

\* Normalized to preferred value of <sup>140</sup>Ba by Bresesti et al.<sup>6)</sup>

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average cross section (mb)		reference
67 ± 6	Present data	measured in the core of KUR
71.6*	Present calculation	from the fission spectrum shown by Watt <sup>10</sup> )
70.9*	Present calculation	from the fission spectrum shown by Cranberg <sup>11)</sup>
68.6 <sup>*</sup>	Present calculation	from the fission spectrum shown by Leachman <sup>12)</sup>
85.0 <sup>*</sup>	Present calculation	from the SAND-II spectrum developed by McElroy <sup>13)</sup>
71.9	<b>E</b> arlier data	Bresesti et al. <sup>14)</sup>
28	<b>E</b> arlier data	Beckurts and Wirtz <sup>15)</sup>
69	<b>E</b> arlier data	Fabry <sup>16)</sup>

Table 2 Fission-average cross section for the  $^{232}$ Th(n,f) reaction

\* In the present calculation, the energy dependent cross section for the <sup>232</sup>Tn(n,f) reaction is cited from the reference (17).

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## II-3. The Measurement and the Calculation of Neutron Spectra in Iron

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### Assemblies

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This paper was published in Annual Reports of Research Reactor Institute, Kyoto University<sup>1)</sup>.

The energy spectra of fast neutrons in two iron assemblies (90 cm X 90 cm X 100 cm and 50 cm X 50 cm X 50 cm) have been measured by the timeof-flight method with an electron linear accelerator at the Research Reactor Institute, Kyoto University. The block diagram of the measurement is shown in Fig. 1. The experimental results have been compared with the theoretical spectra calculated by a one dimensional Sn code, with three different cross section data, the YOM set<sup>2</sup>, the ABBN set<sup>3</sup> and the KFK library<sup>4</sup>. The results are depicted in Fig. 2. It has been found that: (1) the YOM set gives the gross shape of neutron spectra most properly, (2) the KFK library gives the better information about the fine structure of spectra, (3) for this case, however, the agreement is not satisfactory enough, especially around 1 MeV. From the last fact, a doubt about the total cross section in the KFK library in this energy range may arise.

#### References:

 I. Kimura, H. Sekimoto, H. Nishihara, K. Kobayashi, Shu A. Hayashi, K. Kobayashi, M. Hayashi, S. Yamamoto and T. Shibata, Ann. Repts. Research Reactor Institute, Kyoto University, <u>3</u> (1970) 58.

<sup>\*</sup> Department of Nuclear Engineering, Kyoto University.

- 2) S. Yiftah, D. Okrent and P.A. Moldauer, Fast Reactor Cross Sections, Pergamon Press, 1960.
- 3) I.I. Bondarenko (ed.), Group Constant for Nuclear Reactor Calculations, Consultant Bureau, 1964.
- 4) J.J. Schmidt, KFK-120, 1962.



Fig. 1 Block diagram to measure neutron spectra in iron assemblies by neutron time-of-flight method at KURRI.

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Comparison of the experimental spectrum of the neutrons from the surface of the bigger iron assembly, with the theoretical prediction (calculation with the KFK set for n = 16)



Comparison of the experimental spectrum of the neutrons from the surface of the smaller iron assembly, with the theoretical prediction (calculation with the KFK set for n = 16)



Comparison of the experimental spectrum of the neutrons from the reentrant hole of 30 cm in depth of the bigger iron assembly, with the theoretical prediction (calculation with the KFK set for n = 16, R = 57.8 cm)



Comparison of the experimental spectrum of the neutrons from the reentrant hole of 15 cm in depth of the smaller iron assembly, with the theoretical prediction (calculation with the KFK set for n = 16, R = 31 cm)

Fig. 2 Comparison of the experimental and theoretical neutron spectra in the iron assemblies.

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### II-4. Measurements of Neutron Spectra in Light Water Y. Fujita, O. Aizawa<sup>\*</sup> and M. Fujino<sup>\*\*</sup>

Measurements of steady state energy spectra of thermal neutrons in light water poisoned with 1/v or non-1/v absorber have been made with an electron linear accelerator facility at Kyoto University Research Reactor Institute and time-of-flight techniques. Boron, cadmium and gadolinium were used as absorbers.

Measured spectra are compared with calculated spectra obtained by using free-gas, Nelkin and Haywood models for neutron scattering. They are shown in Figs. 1, 2 and 3. Absorption cross sections of gadolinium and cadmium are taken from Westcott-representations and the evaluated values in ENDF/B. The difference between them in the case of gadolinium has little influence on the spectrum predictions. Ratio of experimental to calculated spectrum is shown in Fig. 4.

Details have been published on Reference 1).

#### References:

 Y. Fujita, O. Aizawa and M. Fujino, Annual Report of Research Reactor Institute, Kyoto University, Vol. 3 (1970) 121-129.

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Fig. 1 Thermal neutron spectra in gadolinium-poisoned light water.



Fig. 2 Thermal neutron spectra in cadmium-poisoned light water.



Fig. 3 Thermal neutron spectra in boron-poisoned light water.



Fig. 4 Ratio of experimental to calculated spectrum using Westcott-value and the evaluated in ENDF/B for the absorption cross sections of gadolinium. Scattering kernel used is Haywood model.

### II-5. The Age of Fission Neutrons to Indium Resonance in Water and Polyethylene

K. Kanda, M. Hayashi, H. Nakagawa and T. Shibata

A paper on this subject was published in Ann. Repts of Res. Reactor Inst. Kyoto Univ. Vol. 3 (1970) 93. The abstract and some results are as follows.

The age of fission neutrons to indium resonance energy was measured in two materials, water and polyethylene, using a fission plate of 27 cm in diameter combined with the KUR heavy water thermal column.

In the experiment the infinite plane detector method was employed, where the age is half of the second moment of the slowing-down flux distribution at the 1.46 eV resonance of indium.

The calculation of the age was done with Greuling-Goertzel and Selengut-Goertzel approximations. In both materials the former approximation was in good agreement with the experimental values, while the latter gave considerably larger values.

	Atomic density of	Calculated		Measured
Medium	hydrogen mol/cm <sup>3</sup>	G-G	S-G	monparou
Water	6.670 x 10 <sup>22</sup>	26.87 cm <sup>2</sup>	33.31cm <sup>2</sup>	26.53 <sup>±</sup> 0.69 cm <sup>2</sup>
Polyethylene	8.286 x 10 <sup>22</sup>	20.10 cm <sup>2</sup>	23.85cm <sup>2</sup>	20.15 <sup>±</sup> 0.66 cm <sup>2</sup>

Results of the calculated and measured ages



100 cm

Schematic drawing of the experimental facilities

### III. Kyushu University Depertment of Nuclear Engineering

### III-1. (n,n) and (n,n') Reactions Bi<sup>209</sup> Induced by 14.1 MeV Neutrons

M. Matoba, H. Tawara, M. Hyakutake, Y. Wakuta, A. Katase and M. Sonoda

Elastic and inelastic scattering cross sections of 14.1 MeV neutrons have been measured for  $Bi^{209}$  at laboratory angles between  $20^{\circ}$  and  $160^{\circ}$  in  $5^{\circ}$  or  $10^{\circ}$  step using associated-particle time-of-flight technique reported previously<sup>1)</sup>. Overall time resolution is 1.2 nsec for direct neutrons with a neutron detector biased at 3 MeV.

Angular distributions for elastic scattering and inelastic scattering from 2.6, 4.2, and 5.7 MeV state of Bi<sup>209</sup> were obtained. Corrections for multiple scattering and angular resolution were made. Analyses by Optical model and DWBA method are now in progress.

### Reference:

1) M. Matoba et al. EANDC (J) 13 L (1969) P. 33.

### III-2. Fission of U and Th by Gamma Rays From 200 MeV to 1150 MeV

M. Sonoda, A. Katase, Y. Wakuta, H. Tawara and M. Hyakutake

We have been making studies<sup>1)</sup> of the photofission for U and Th above the photomeson production threshold with surface barrier semiconductor detectors.

The total cross sections per equivalent quanta are shown in Fig. 1 and Fig. 2 for U and Th respectively. We have carried out the analyses of the results based on an assumption that the pion creation and reabsorption within the target nucleus are the dominant cause of the photofission. The results are shown in Fig. 3 and Fig. 4 together with those obtained by other workers<sup>2)</sup>. The shaded area in Fig. 3 shows a range of uncertainty of the deduced photofission cross sections due to the error of smoothing procedure of the experimental yield curve. From Fig. 4 it is clearly seen that the assumption made above certainly explains the characteristic behaviour of the photofission above the meson photoproduction threshold. The obtained fissility values are given in the following table.

	f	Energy Range (MeV)
U	0.85 ~ 1.0	200~ 500
Th	0.34 ~ 0.47	200~ 500



Fig. 1 Photofission cross section per equivalent quanta for U as a function of maximum bremsstrahlung energy.

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Fig. 2 Photofission cross section per equivalent quanta for Th as a function of maximum bremsstrahlung energy.



Fig. 3 Photofission cross section vs. photon energy.



Fig. 4 Photofission cross section vs. photon energy and photoproduction cross section of pions corrected with fermi motion.

### References:

- M. Sonoda, A. Katase, Y. Wakuta, M. Seki, A. Yoshimura, T. Akiyoshi,
   I. Fujita and S. Yamawaki: Genshikaku Kenkyu.
   Circular in Japanese <u>9</u> (1964) 491. and <u>10</u> (1966) 542.
   Y. Wakuta, M. Sonoda, A. Katase, H. Tawara and M. Hyakutake: J. Phys.
   Soc. Japan <u>26</u> (1969) 851.
- 2) J.A. Jungerman and H.M. Steiner: Phys. Rev. <u>106</u> (1957) 585.
  T.M. Methasiri and S.A.E. Johanson: Lund 7005 (1970).
  H.G.De. Carvalho, G. Cortini, E. Del. Giudice, G. Pontenza, R. Rinzivillo and G. Ghigo: Nuovo Cimento <u>32</u> (1964) 1717.
  C.E. Roos and U.Z. Peterson: Phys. Rev. <u>124</u> (1961) 1610.
  E.V. Minarik and U.A. Novikov: Soviet Physics-JETP <u>5</u> (1957) 253.

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#### III-3. Photo- Fission Cross Sections of the Medium-Mass Nuclei

A. Katase, M. Matoba, Y. Kanda, M. Chijiya, M. Sonoda,

Y. Wakuta, H. Tawara and M. Hyakutake

The photo-fission cross sections of Ho, Sm, Te, Sb, Sn, In, Ag, Ge, Cu and Au were measured for the energies of 1000, 600, 450 and 250 MeV.<sup>1)</sup> The polycarbonate foil was used as fission detector which was pressed on a target film evaporated on a polycarbonate backing.

After etching, detector foils were scanned by microscope. Fission tracks were easily discriminated from the background, which were increased with the maximum photon energy. Sandwitch foils were scanned to ascertain the correctness of the discrimination of the fission events. The tracks, which had the corresponding collinear tracks in the paired foils respectively, were found to be counted as fission tracks.

The number of target nuclei was obtained from the weight of the target. The obtained cross sections for the equivalent quanta are plotted in Fig. 1. The scannings for Ge and Cu and the analysis are in progress.

#### Reference:

1) A. Katase et al. EANDC (J) AL (1969) p. 34.



Fig. 1 Photofission cross section per equivalent quanta vs. maximum bremsstrahlung energy.

### IV. Osaka University Depertment of Nuclear Engineering

### IV-1. Quasiclassical Approximation for Slow Neutron Scattering

T. Nishigori

The detail of the present note was published in Prog. Theor. Phys. <u>43</u> (1970), No. 6.

With the aid of a new method of the short-collision-time expansion and the well-defined quasiclassical prescription proposed in a previous paper,<sup>1)</sup> the following quasiclassical formula for the differential incoherent scattering cross section is derived.

$$\frac{d^{2} \sigma_{inc}}{d Q d \varepsilon_{f}} = a_{inc}^{2} - \frac{P_{f}}{P_{i}} e^{\varepsilon z_{2} k T} \frac{e x p (-P^{2} \lambda_{0}^{c})}{\sqrt{2P^{2} \lambda_{2}^{c}}} \left[ \varphi(x) - \frac{1}{P^{2} \lambda_{2}^{c}} - \frac{\lambda_{4}^{c}}{4 \lambda_{2}^{c}} \varphi^{(4)}(x) + \frac{1}{(P^{2} \lambda_{2}^{c})^{2}} \left\{ \frac{1}{8} - \frac{\lambda_{6}^{c}}{\lambda_{2}^{c}} \varphi^{(6)}(x) + \frac{1}{32} \left( -\frac{\lambda_{4}^{c}}{\lambda_{2}^{c}} \varphi^{(6)}(x) \right) \right\} \right]$$
(1)

with

$$x = \frac{\varepsilon}{\sqrt{2P^2 \lambda_2^c}}$$
 and  $\varphi^{(2n)}(x) = \frac{d^{2n}}{dx^{2n}} \frac{1}{\sqrt{2\pi}} e^{-x^2/2}$ , (2)

where  $\varepsilon = \varepsilon_i - \varepsilon_f$  and  $\vec{P} = \vec{P}_i - \vec{P}_f$  are the energy and momentum lost by the neutron, respectively, and  $\lambda_{2n}^c(p^2)$  are the cumulants associated with the classical symmetric scattering function.

The expansion (1) is complementary to the expansion in powers of  $p^{a}$  presented in the previous paper, or to the usual phonon-type expansions.

The quasiclassical formula (1) satisfies the condition of detailed balance and a sum rule, and has the correct limit of weak binding of the target system.

For a system of molecules, the short time limit of (1) just coincides

with the result of the Krieger-Nelkin approximation.<sup>2)</sup> In order to see the effectiveness of the correction terms in (1) to the Krieger-Nelkin approximation, a numerical calculation was made for HCl gas at  $348^{\circ}$ K, and compared with the Krieger-Nelkin calculation and the exact quantum mechanical calculation by Lurie.<sup>3)</sup> The correction terms are seen to be quite effective for smaller scattering angle and in the vicinity of the quasielastic peak for any scattering angle, where the Krieger-Nelkin approximation is particularly inaccurate. The result is shown in Fig. 1 for the scattering angle of  $20^{\circ}$ .

### References:

- 1) T. Nishigori and S. Sunakawa, Prog. Theor. Phys. <u>41</u> (1969), 619.
- 2) T. J. Krieger and M. S. Nelkin, Phys. Rev. <u>106</u> (1957), 290.

3) N. A. Lurie, J. Chem. Phys. <u>46</u> (1967), 352.



Fig. 1

### V. Rikkyo (St. Paul's) University. Department of Physics

V-1. Differential Cross Section for Neutron-Proton Scattering at 14.1 MeV

M. Tanaka, N. Koori and S. Shirato

The n-p differential cross sections at 14.1 MeV were measured with a counter-telescope at 8 setting angles;  $\theta_0 = 0^\circ$ ,  $10^\circ$ ,  $20^\circ$ ,  $30^\circ$ ,  $40^\circ$ ,  $50^\circ$ ,  $59^\circ$ ,  $64^\circ$ . The results of the differential cross section in the C.M. system are  $58.6 \pm 1.0$ ,  $56.9 \pm 0.9$ ,  $56.0 \pm 1.0$ ,  $54.7 \pm 1.0$ ,  $53.4 \pm 1.0$ ,  $53.2 \pm 1.1$ ,  $51.1 \pm 1.3$  and  $51.5 \pm 1.4$  mb/sr at, respectively,  $172.0^\circ$ ,  $159.2^\circ$ ,  $139.8^\circ$ ,  $120.1^\circ$ ,  $100.3^\circ$ ,  $80.4^\circ$ ,  $62.5^\circ$  and  $52.5^\circ$  of the mean neutron-scattering angle ( $\theta_n$ ) in the C.M. system. A least squares fit of the data gives the C.M. differential cross section:  $\sigma(\theta_n) = 52.9 (1 - 0.0639 \cos \theta_n + 0.0288 \cos^2 \theta_n)$  mb/sr, which is clearly asymmetric about  $90^\circ$ . The ratio of the cross sections at  $180^\circ$  and  $90^\circ$  is  $1.093 \pm 0.022$ , and the total cross section is  $671 \pm 10$  mb. The present results are in good agreement with the theoretical results based on the one-pion-exchange potentials.

The details of this work and the results have been published in J. Phys. Soc. Japan, <u>28</u> (1970) 11.

### V-2. Differential Cross Section for the D(n,p)2n Reaction at 14.1 MeV N. Koori and S. Shirato

The breakup proton energy spectra from the D(n,p)2n reaction at 14.1 MeV have been measured with a counter-telescope at  $0^{\circ}$ ,  $7^{\circ}$ ,  $10^{\circ}$ ,  $20^{\circ}$ ,  $30^{\circ}$ ,  $35^{\circ}$ ,  $40^{\circ}$ ,  $50^{\circ}$ ,  $60^{\circ}$ . The remarkable n-n final-state enhancement peaks were found in the spectra observed at the forward lab angles. Corrections for
degraded neutrons and comparisons with various theoretical works are in progress. Typical examples of the uncorrected results are shown in Fig. 1. Values of the cross section seem to be in good agreement with he results of our previous work<sup>1)</sup> using a somewhat different electronic ircuit system.



Fig. 1

1) S. Shirato and N. Koori: Nuclear Phys. Al20 (1968) 387.

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## VI. Tohoku University Laboratory of Nuclear Science

## VI-1. Neutron Debye-Scherrer Diffraction Works Using a Linear

Electron Accelerator

M. Kimura, M. Sugawara, M. Oyamada, Y. Yamada, S. Tomiyoshi<sup>\*</sup>, T. Suzuki<sup>\*</sup>, N. Watanabe<sup>\*\*</sup>, and S. Takeda<sup>\*\*</sup>

A paper on this subject was published in Nuclear Instruments and Methods <u>71</u> (1969) 102. The abstract and a typical figure are as follows.

Neutron diffraction patterns were obtained by the time-of-flight method using Tohoku Linac for the case of powdered samples as well as for single crystals. Thermal neutron beams of 35-50  $\mu$ sec pulse width were obtained by poisoned water moderator. Powder patterns of Al at different temperatures have shown many lines of high indices, which enabled to calculate the Debye temperature with considerable accuracy. Several other powdered samples including Si, ZnO were also examined. Magnetic peaks of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>, CaFe<sub>2</sub>O<sub>4</sub> were identified.

Count collecting time of 2 or 3 h was enough to reach the reliability R to the level of a several percent. High index lines appeared very conspicuously, in contrast to the reactor-chopper results.

The fwhm of the diffraction lines was 2.0-1.5% in case the scattering angle  $2\theta$  was  $90^{\circ}$ . It depended on the energy of diffracting neutrons, becoming smaller for neutrons of wavelength shorter than 1Å, that is for higher index lines.

<sup>\*</sup> Research Institute for Iron, Steel and other Metals, Tohoku University.

<sup>\*\*</sup> Faculty of Engineering, Tohoku University.



Fig. Debye patterns for Al powder

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## VI-2. Neutron Debye-Scherrer Diffraction Works using a Linear Electron Accelerator. (II)

- M. Kimura, N. Watanabe, M. Oyamada, Y. Yamada, S. Tomiyoshi\*,
- T. Suzuki<sup>\*</sup>, M. Hirabayashi<sup>\*</sup>, H. Asano<sup>\*</sup>, S. Takeda<sup>\*\*</sup>, F. Takahashi<sup>\*\*</sup>.

D. Watanabe<sup>\*\*\*</sup>, O. Terasaki<sup>\*\*\*</sup>, and Y. Ishikawa<sup>\*\*\*</sup>

The following is an abstract of the papers published in Research Report of Laboratory of Nuclear Sciences, Tohoku University, Vol.2, No.1, June 1969, P.81-96; Vol.2, No.2, Dec., 1969 P.89-118; and Vol.3 No.1 (to be published).

Further measurements of neutron Debye Scherrer patterns for various powdered samples were performed using the same facility with some improvements. Various magnetic materials were investigated. Patterns for  $Sr_2Fe_2O_5$ were reproduced in Fig. 1. Doublet (O21 and 120), Triplet (101, 040, 130) peaks were resolved which were impossible by conventional spectrometer. From the patterns, the spin direction of the magnetic atoms were concluded.  $TaD_{0.72}$  and  $NbD_{0.89}$  were measured as the examples of metallic hydride structure analysis. Many doublets which were not resolved by the usual spectrometer (Somenkov; Soviet Physics-Solid State <u>10</u>, No.5, 1968) were resolved and it was shown that the structural analysis is possible with the sample of 20-30 cc and with the counting time of several hours (Fig. 2). Debye temperatures of TiOx (0.8 < x < 1.2) were calculated from the intensity ratios of various diffraction lines of the powdered TiOx samples.

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Fig. 1



Fig. 2

#### VI-3. Scattering Kernel for BeO

N. Watanabe, M. Kimura, F. Takahashi, M. Oyamada, Y. Yamada, and S. Tomiyoshi<sup>\*</sup>

The following is an abstract of the paper published in Research Report of Laboratory of Nuclear Sciences, Tohoku University, Vol.2, No.2, Dec., 1969, p.100-105.

To examine the scattering kernel in the BeO, measurements of timedependent spectra of thermal neutrons in small beryllium oxide assemblies  $(B^2 = 0.065 \text{ cm}^{-2} \text{ and } B^2 = 0.079 \text{ cm}^{-2})$  were made using the time-of-flight crystal spectrometer with electron linear accelerator pulsed neutron source.

Numerical calculations of time-dependent spectra were also made using various scattering kernels. The peaks of the spectra, especially the second Bragg peak within the experimental time, were fairly sensitive to the Debye temperature or to the phonon frequency distribution used. In fig. 1, calculated spectra using Placzek kernel are compared to the experimental results for  $B^2 = 0.079 \text{ cm}^{-2}$ . It will be observed that if the inelastic scattering cross section is calculated using the first term of Placzek expansion with Debye temperature of 1050°K, the agreement between the calculated and experimental are fairly good. Pryor and Sabine measured the total cross section of  $5\text{\AA}$  neutrons for the temperature between  $100^{\circ}\text{K}$ 2000°K<sup>1)</sup>. The cross section calculated using Placzek kernel with Debye temperature of 1050°K was found to be very close to their measurement. Further test were made using various phonon frequency distributions. The frequency distribution measured by Sinclair<sup>2</sup> turned out to be inconsistent with our measurements and the distribution calculated by Borgonovi<sup>3)</sup> gave very good agreement with our data.

\* Institute for Iron, Steel and Other Metals, Tohoku University.



Fig. 1 Time-dependent spectra in the center of BeO ( $B^2 = 0.079$  cm<sup>-2</sup>). The dot-dushed line, the solid line and the dushed line show the calculated spectra using Placzek kernel with Debye temperature of 1200°K, 1050°K, 950°K respectively.

## References:

- 1) Pryor A.W. and Sabine T.M., J. Nucl. Materials 14 (1964) 275-281.
- Sinclair R.N., Proceedings of the Symposium on Inelastic Scattering of Neutrons in Solids and Liquids, Vienna, (1963) p.199.
- 3) Boegonovi G., GA-8758 (1968).

## VII. Tokyo Institute of Technology Research Laboratory of Nuclear Reactor

## VII-1. Measurement and Pole Diagram Analysis of the D(n,p)2n Reaction Cross Section at 14.5 MeV

E. Arai

For the theoretical interpretation of the continuous neutron spectra of the D(n,p)2n reaction, Chernukhin et al.<sup>1)</sup> introduced the pole approximation method into the calculation of the reaction cross sections. Although there exist some discrepancies, especially at high neutron energies, between the theoretical predictions and the very careful measurements by Brüllmann et al.<sup>2)</sup>, we may conclude that the experimental results support the theoretical treatment of the reaction mechanism. However, the effect of the final-state interaction was not clearly observed in the neutron spectrum, because the measurement of the neutron spectrum without coincident proton or neutron detection made it impossible to distinguish between the n-n and n-p final-state interactions.<sup>1)</sup>

It was the aim of the present work to improve this point, for which the cross section of the D(n,p)2n reaction was measured as a function of not only neutron energy and neutron emission angle, but also of proton energy.

A cascade type accelerator at 350 kV generated 14.5 MeV neutrons by means of the  $T(d,n)\alpha$  reaction. From the associated  $\alpha$ -particles the energy distribution of inelastically scattered neutrons was determined by means of the time-of-flight method. A liquid scintillator (NE230) set at the center of a goniometer served as the proton detector and as the scattering sample as well. Its main constituent is  $C_6D_6(D:H72:1)$  and it has a large enough active volume of 50 mm  $\phi$  x 30 mm to cover the neutron cone at a distance of 23 cm from the tritium target. A photomultiplier (56 AVP) coupled with the scintillator gave the pulseheight signal for the proton energy and a timing signal. The former signal was fed to y-axis input of the 4096-channel pulseheight analyser. The timing signals from the scatterer and from the  $\alpha$ -detector were sent to a fast coincidence unit, of which the output signal stopped the time-to-pulseheight converter. A plastic scintillator with a diameter of 175 mm and a thickness of 25 mm detected the scattered neutrons and generated start signals for the TAC. The neutron flight path was 174 cm long and the time resolution of the whole system was 2.0 ns. The output of the TAC was fed to the x-input of the 4096-channel analyser used as a two-dimensional analyser with 32 channels for the x-axis and 128 channels for the y-axis. The detection efficiency of the neutron detector, which was essential to calculate cross sections, was determined by replacing the scattering sample with a normal benzene scintillator (NE231), and the well known proton cross section was used as a standard.

The reaction cross sections were measured at four neutron emission angles in the  $10^{\circ} - 40^{\circ}$  region. Fig. 1 - 4 show the experimental results. The pole approximation method was applied to interprete the measured cross sections. Chernukhin's derivation of the reaction cross section<sup>1)</sup> was developed for the calculation of the reaction cross sections as a function of energies of emitted neutrons and protons and of neutron emission angle. A FORTRAN programme was written for a HITAC 5020 E and the theoretical values were calculated. The solid curves in Figs. show those theoretical result. If we take into account the finite resolution of the proton and neutron energy measurements, we obtain the dotted curves. A reasonable agreement between the observed and calculated cross sections was obtained<sup>3)</sup>



Fig. 1 Inelastic neutron cross sections of deuterons as a function of proton energy,  $E_p$ , inelastic neutron energy,  $E_n$ , and emission angle,  $\theta_n = 10^{\circ}$  (lab.).





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References:

- Yu. I. Chernukhin and R. S. Shuvalov, Soviet Journal of Nuclear Physics <u>4</u> (1967) 197.
- M. Brüllmann, H. Jung, D. Meier and P. Marmier, Physics Letters
   <u>25B</u> (1967) 269, and Nuclear Physics <u>All7</u> (1968) 419.
- 3) E. Arai, to be published in Zeitschrift für Physik.

VII-2. Thick-Sample Neutron Transmission Measurements of the 229 eV Resonance in <sup>65</sup>Cu<sup>+</sup>

N. Yamamuro and R. C. Block

Thick-Sample neutron transmission measurements were carried out upon copper to determine the orbital angular momentum of the 229 eV resonance in  $^{65}$ Cu. Characteristic s-wave resonance-potential interference was observed in the transmission data, and together with reported capture spectra results<sup>1)</sup>, leads to a J<sup> $\pi$ </sup> of 2<sup>-</sup> for this resonance. A neutron width of (15 <sup>±</sup> 1.5) meV is obtained from this measurement.

## References:

 W. E. Stein, B. W. Thomas and E. R. Rae, Bull. Am. Phys. Soc., Series II 14 (1969) 513.

<sup>&</sup>lt;sup>†</sup> The measurements were made at Department of Nuclear Science, Rensselaer Polytechnic Institute, Troy, N.Y.

<sup>\*</sup> Rensselaer Polytechnic Institute.

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VII-3. <u>Measurement of Thermal and Resonance Capture in Sodium</u> N. Yamamuro, R. W. Hockenbury<sup>\*</sup>, R. H. Wolfe<sup>\*\*</sup> and R. C. Block<sup>\*</sup>

A paper on this subject was submitted to the Nuclear Science and Engineering.

Neutron capture measurements upon sodium have been carried out over thermal energies and at energies near the 2.85 KeV resonance. The resonance energy measurements were carried out using the 1.25 meter diameter capture detector. The thermal capture measurements were carried out by cycling the thick sodium sample, a 'black' cadmium sample, and compensating aluminum foils into the capture detector with an automatic sample changer controlled by an on-line computer.

The data were reduced to capture yields and multiple scattering corrections were applied using the Monte Carlo code. The radiation widths deduced from the resonance measurements are listed in Table I. The low energy capture cross section is plotted in Fig. 1, along with a least squares fit to the data. A thermal value of  $(0.50 \pm 0.03)$  barn is obtained for this measurement.

\*\* Siena College

<sup>+</sup> The measurements were made at Department of Nuclear Science, Rensselaer Polytechnic Institute, Troy, N.Y.

<sup>\*</sup> Rensselaer Polytechnic Institute

Table I

Radiation Width of the 2.85 KeV Resonance in Sodium

$\Gamma_r$ (eV)
0.55 ± 0.04*
0.47 ± 0.03*
0.44 ± 0.025*
0.47 ± 0.025*

 $\Gamma_{\gamma} = 0.47 \pm 0.045^{**} (eV)$ 

\* Statistical error only.

\*\* Includes a ± 9% estimated systematic error.



Fig. 1 Capture cross section of sodium from 0.025 to 0.200 eV.

## VIII. University of Tokyo

## VIII-1. Institute of Physics, College of General Education

## VIII-1-1. Analysis of the <sup>58</sup>Ni(n,p)<sup>58</sup>Co Reactions Leading to Parent Analogues of Collective States

M. Obu and T. Terasawa

The proton energy spectra for the reaction  ${}^{58}\text{Ni}(n,p){}^{58}\text{Co}$  at  $\text{E}_n = 14.8$ MeV show two strong peaks at  $\text{E}_p = 11.5$  and 14.5 MeV at forward angles.<sup>1)</sup> The experimental data on these peaks were analyzed by assuming that they corresponded to the (n,p) reactions leading to the parent analogue states P of the El and Ml giant resonance states C of  ${}^{58}\text{Ni}$ . The parent analogue states P were obtained by using the relation  $|P\rangle \propto T_+$   $|C\rangle$  from the El and Ml giant resonance states C, which were treated in the particle-hole framework. Calculations were performed for the Q values and the differential cross sections of the (n,p) reactions leading to these parent analogue states.

The estimated Q values were -5.0 and 0.1 MeV, which were in reasonable agreement with the experimental values -3.3 and -0.3 MeV, respectively. Figs. 1 and 2 show the calculated angular distributions with the experimental ones. The strengths of the isospin and spin-isospin dependent parts of the effective two body interaction between the incident and the target nucleons were adjusted to yield the observed values of the differential cross sections around the first peak. The strengths  $|V_{\tau}|$  and  $|V_{\sigma\tau}|$  were estimated to be 20 ~ 30 MeV for Yukawa interaction with range of 1 fm. These values are consistent with those<sup>2</sup> deduced from other experimental data. One of the interesting results of the present analysis is the following: The peak with Q = -5.0 MeV corresponds to the parent analogue of an El state which is rather weakly excited in the photo-nuclear reaction. For the (n,p) reaction leading to the parent analogue of the main peak of the El giant resonance, the Q value is estimated to be  $\sim -9$  MeV. In the experiment<sup>1)</sup> mentioned above, the strong peak with Q  $\sim -9$  MeV was not observed because of the large background of the compound nuclear reaction cross section. It would be possible, however, to observe such strong peak in the experiment at higher neutron energy.

A full paper on this subject was published in Prog. Theor. Phys. <u>43</u> (1970) 1231.

#### References:

1) R. N. Glover and K. H. Purser, Nucl. Phys. <u>24</u> (1961) 431.

2) G. R. Satchler, Nucl. Phys. A<u>95</u> (1967) 1.

Anderson, Bloom, Wong, Hornyak and Madsen, Phys. Rev. <u>177</u> (1969) 1416.



VIII-2. Institute for Solid State Physics

# VIII-2-1. Depolarization in Elastic Scattering of 1.36-MeV Polarized Neutrons

K. Katori<sup>\*</sup>, T. Nagata<sup>\*</sup>, A. Uchida and S. Kobayashi<sup>\*\*</sup>

There has been considerable experimental and theoretical interests in the effect of a target-spin dependent interaction on nuclear reactions. One of the direct measurements is the transmission of polarized neutrons through a polarized target ( $^{165}$ Ho,  $^{59}$ Co)<sup>1</sup>). The results show the upper limit of the spin-spin interaction in the optical potential is one MeV. Another method is the measurement of the depolarization of polarized nucleons scattered from a non-zero spin target. In elastic scattering of nucleons from a non-zero spin target, Bohr theorem<sup>2</sup> allows the spin flip. Then, the depolarization parameter D( $\theta$ ) deviates from unity only when there exists a spin-spin interaction between a projectile and a target nucleus in direct reactions. A few experiments have been performed<sup>3</sup>. They showed no detectable deviation of D( $\theta$ ) from unity.

The work reported here consists of a triple scattering experiment. An angular dependence of  $D(\theta)$  for  ${}^{27}\text{Al}(I = 5/2^+)$ ,  ${}^{59}\text{Co}(7/2^-)$ ,Ni(O<sup>+</sup>),  ${}^{63}$ , ${}^{65}\text{Cu}(3/2^-)$  and  ${}^{209}\text{Bi}(9/2^-)$  has been studied at  $\text{E}_n = 1.4$  MeV at the laboratory angles  $\theta_2 = 30^\circ$ ,  $38^\circ$ ,  $80^\circ$ ,  $120^\circ$  and  $150^\circ$ . Neutron polarization was measured by a liquid helium, time-of-flight, scintillation polarimeter with a spin precession solenoid. Experimental method and procedure are given elsewhere<sup>4)</sup>.

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The results are shown in Fig. 1 ~ 4. The departure of  $D(\theta)$  from unity for Al, Co, Cu and Bi was observed particularly at the backward angles, but not observed for Ni. This fact shows that the spin flip of incident neutrons takes place along the normal to the scattering plane in the elastic scattering process for non-zero spin targets.

From the experimental point of view, it is convenient to choose zaxis along the normal to the reaction plane. In elastic and inelastic scattering of the spin one half projectile, the observables such as the







Fig. 2





Fig. 3

Fig. 4

cross section, polarization and depolarization respectively are described in this co-ordinate frame by

$$\sigma(\theta) = \frac{1}{2} (\sigma_{++} + \sigma_{+-} + \sigma_{-+} + \sigma_{--})$$

$$P(\theta) = \frac{\sigma_{++} - \sigma_{--} - \sigma_{+-} + \sigma_{-+}}{\sigma_{++} + \sigma_{+-} + \sigma_{-+} + \sigma_{--}}$$
and 
$$D(\theta) = \frac{\sigma_{++} + \sigma_{--} - \sigma_{+-} - \sigma_{-+}}{\sigma_{++} + \sigma_{+-} + \sigma_{-+} + \sigma_{--}} *$$

 $\sigma_{+-}$  denotes the partial cross section for initially spin-up and finally spin-down states with respect to the z-axis. It is easily shown that the depolarization parameter is related to the spin flip probability as D( $\theta$ ) = 1 - 2S( $\theta$ )<sup>4</sup>.

To interpret these experimental results, compound nucleus reaction process as well as the direct reaction process was considered to contribute to the cross section at this energy. The differential cross section  $\sigma(\theta)$  are assumed to be described by incoherent sum:  $\sigma(\theta) = \sigma(\theta)^{\text{Se}}$ +  $\sigma(\theta)^{\text{Ce}}$ . The shape elastic scattering cross section  $\sigma(\theta)^{\text{Se}}$  was calculated with the optical model, which includes the spin-spin interaction in the form  $-V_{I\sigma} f(r) \vec{1} \cdot \vec{\sigma} \cdot \vec{5}$ . The optical potential parameters were taken from the work of Perey and Buck<sup>6</sup>. The compound nucleus cross section  $\sigma(\theta)^{\text{Ce}}$  was calculated with the Hauser-Feshbach theory<sup>7</sup> which includes relevant inelastic scattering channels<sup>8</sup>. In Fig. 5, 6 are shown calculated curves of depolarization D<sup>Se</sup> and partial cross sections  $\sigma^{\text{Se}}$ .

In order to investigate how the spin flip proceeds through the compound nucleus reaction process, the depolarization parameter is represented by

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<sup>\*</sup> In elastic scattering,  $\sigma_{+-} = \sigma_{-+}$  because of the time reversal invariant.



Fig. 6

the cross section as follows:

$$D(\theta) = \frac{\sigma_{++}^{se} + \sigma_{++}^{se} + \sigma_{--}^{se} + \sigma_{--}^{ce} - 2(\sigma_{+-}^{se} + \sigma_{+-}^{ce})}{\sigma_{++}^{se} + \sigma_{++}^{se} + \sigma_{--}^{se} + 2(\sigma_{+-}^{se} + \sigma_{+-}^{ce})} = \frac{\sigma_{++}^{se}(\theta)}{\sigma_{++}^{se}(\theta) + \sigma_{-}^{ce}(\theta)} D^{se} + \frac{\sigma_{++}^{ce} - \sigma_{+-}^{ce}}{\sigma_{++}^{se}(\theta) + \sigma_{--}^{ce}(\theta)}$$

In Fig. 1 ~ 4 full lines show the first term where  $D^{Se}$  is unity. Calculations of the second term is now in progress. At  $E_n = 1.36$  MeV, it appears that almost spin flip proceeds through the compound nucleus reaction process.

References:

- 1) R. Wagner et al., Phys. Rev. <u>139</u> ('65) B29.
  - T. R. Fisher et al., Phys Rev. <u>157</u> ('67) 1149.
  - T. R. Fisher et al., Nucl. Phys. <u>A130</u> ('69) 609.
  - S. Kobayashi et al., J. Phys. Soc. Japan 22 ('67) 368.
  - S. Kobayashi et al., Progr. Theor. Phys. 40 ('68) 1451.
  - K. Nagamine et al., Nucl. Phys. A<u>145</u> ('70) 203.
- 2) A. Bohr, Nucl. Phys. <u>10</u> ('59) 486

- J. S. Schaller et al., Proc. 2nd Inter Sympo. on Polarization
   Phenomena of Nucleons ed. P. Huber and H. Schopper (Karlsruhe, 1966)
   p. 314.
  - L. Rosen et al., Phys. Rev. <u>121</u> ('61) 1423.
  - C. J. Batty et al., Nucl. Phys. A<u>143</u> ('73) 151.
  - R. Beurtey et al., Private communication.
- 4) K. Katori et al., J. Phys. Soc. Japan <u>28</u> ('70) 1116.
- 5) A. P. Stamp, Phys. Rev. <u>153</u> ('67) 1052.
- 6) F. Perey and B. Buck, Nucl. Phys. <u>32</u> ('62) 353.
- 7) W. Hauser and H. Feshbach, Phys. Rev. <u>87</u> ('52) 366.
- 8) Computer Calculations were performed by the ELIESE-II Code.We are greatly indebted for it to Dr. S. Igarashi.