656

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PROGRESS REPORT

(July 1973 to June 1974 inclusive)

September 1974

Editors

S. Tanaka and A. Asami

Japanese Nuclear Data Committee

Japan Atomic Energy Research Institute

Tokai Research Establishment

Tokai-mura, Ibaraki-ken, Japan

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Editor's Note

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

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

This edition covers a period of July 1, 1973 to June 30, 1974. The information herein contained is of a nature of "Private Communication". No data contained in this report should be quoted without author's permission.

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ELEMENT S A	QUANTITY	LAB	ENERGY(EV) MIN MAX	TYPE	DOCUMENTATION REF VOL PAGE DATE	COMMENTS
BE	TOTAL XSECT	KTO	2.4+4	EXPT PROG	NEANDC(J)36L 32 9/74	BLOCK+.5.903+-0.011 BARNS.LINAC-TOF
C	TOTAL XSECT	KTO	2.4+4	EXPT PROG	NEANDC(J)36L 32 9/74	BLOCK+.4.684+-0.009 BARNS.LINAC-TOF
O	TOTAL XSECT	KTO	2.4+4	EXPT PROG	NEANDC(J)36L 32 9/74	BLOCK+.3.736+-0.007 BARNS.LINAC-TOF
MG 027	N,GAMMA	JAE	PILE	EXPT PROG	NEANDC(J)36L 18 9/74	SEKINE+.DOUBLE CAPT.PRELIM SIG=0.15B
S	DIFF ELASTIC	JAE	1.8+7	EXPT PROG	NEANDC(J)36L 7 9/74	YAMANOUTI+.20DEG TO 155DEG.NDG
S	DIFF INELAST	JAE	1.8+7	EXPT PROG	NEANDC(J)36L 7 9/74	YAMANOUTI+.20DEG TO 155DEG.NDG
CR	N,GAMMA	TIT	1.5+7	EXPT PROG	NEANDC(J)36L 66 9/74	KITAZAWA+.2.10+-0.36 MILLI-BARNS
FE	DIFF INELAST	KYU	1.4+7	EXPT PROG	NEANDC(J)36L 53 9/74	IRIE+.E+ANG DIST IN FIG C GRIFFIN TH
FE	N,GAMMA	TIT	1.5+7	EXPT PROG	NEANDC(J)36L 66 9/74	KITAZAWA+.1.19+-0.20 MILLI-BARNS
NI 058	N2N REACTION	JAE	PILE	EXPT PROG	NEANDC(J)36L 19 9/74	SEKINE+.3.8+-0.4MICROBARNS.
NI 065	N,GAMMA	JAE	PILE	EXPT PROG	NEANDC(J)36L 19 9/74	SEKINE+.18.6+-3.5 B
SE 085	FISS PROD GS	KTO	THR	EXPT PROG	NEANDC(J)36L 34 9/74	TAMAI+.PUBLISHED IN JIN-L 9(73) 1145
SE 086	FISS PROD GS	KTO	THR	EXPT PROG	NEANDC(J)36L 34 9/74	TAMAI+.PUBLISHED IN JIN-L 9(73) 1145
NB 093	N,GAMMA	TIT	2.4+4	EXPT PROG	NEANDC(J)36L 65 9/74	YAMAMURO+.LINAC.NDG
MO 094	INELST GAMMA	JAE	1.5+6 4.0+6	EXPT PROG	NEANDC(J)36L 8 9/74	SUGIYAMA+.EXCITATION + ANG-DISTR.NDG
RU 106	FISS PROD GS	KTO	NDG	EXPT PROG	NEANDC(J)36L 49 9/74	OKANO+.18 LVLS IN PD-106 DETERMINED
AG	N,GAMMA	TIT	2.4+4	EXPT PROG	NEANDC(J)36L 65 9/74	YAMAMURO+.LINAC.NDG
IN	N,GAMMA	JAE	3 3.0+4	EXPT PROG	NEANDC(J)36L 4 9/74	MIZUMOTO+.LINAC,TOF.LIQ-SCINT.NDG
IN	N,PROTON	KYU	1.4+7	EXPT PROG	NEANDC(J)36L 56 9/74	MATOBA+.INTEGRATED SIG=18.1+-5.4 MB
SN 120	INELST GAMMA	JAE	2.0+6 3.1+6	EXPT PROG	NEANDC(J)36L 9 9/74	KIKUCHI+.PUBLISHED IN NP A223(74)1
I 127	N,GAMMA	TIT	2.4+4	EXPT PROG	NEANDC(J)36L 65 9/74	YAMAMURO+.LINAC.NDG
HO 165	N,GAMMA	JAE	3 3.0+4	EXPT PROG	NEANDC(J)36L 4 9/74	MIZUMOTO+.LINAC,TOF.LIQ-SCINT.NDG
HO 165	N,GAMMA	TIT	2.4+4	EXPT PROG	NEANDC(J)36L 65 9/74	YAMAMURO+.LINAC.NDG
TA 181	N,GAMMA	JAE	3 3.0+4	EXPT PROG	NEANDC(J)36L 4 9/74	MIZUMOTO+.LINAC,TOF.LIQ-SCINT.NDG
W	N,GAMMA	JAE	0	EXPT PROG	NEANDC(J)36L 6 9/74	OHKUBO.LINAC.MULTIP-SCAT EFFECT IN W
W	ELASTIC SCAT	JAE	0	EXPT PROG	NEANDC(J)36L 6 9/74	OHKUBO.LINAC.MULTIP-SCAT EFFECT IN W
W	ELASTIC SCAT	JAE	4.0+0 2.0+3	EXPT PROG	NEANDC(J)36L 5 9/74	OHKUBO.PUBLISHED IN JAERI-M 5624
W	TOTAL XSECT	JAE	4.0+0 2.0+3	EXPT PROG	NEANDC(J)36L 5 9/74	OHKUBO.PUBLISHED IN JAERI-M 5624
AU 197	N,GAMMA	TIT	2.4+4	EXPT PROG	NEANDC(J)36L 65 9/74	YAMAMURO+.LINAC.NDG
PB 204	SPECT N,GAMM	JAE	THR	EXPT PROG	NEANDC(J)36L 15 9/74	KAWARASAKI.PBLISHED IN NIM114(74)153
PB 206	SPECT N,GAMM	JAE	THR	EXPT PROG	NEANDC(J)36L 15 9/74	KAWARASAKI.PBLISHED IN NIM114(74)153
TH 232	N,GAMMA	KTO	THR	EXPT PROG	NEANDC(J)36L 40 9/74	KOBAYASHI .ACTIV METHOD,7.35+-0.21 B
PA 231	FISSION	KTO	3.6+6 4.9+6	EXPT PROG	NEANDC(J)36L 36 9/74	KOBAYASHI+.VDG.SIGMA IN FIG.
PA 231	N,GAMMA	KTO	THR	EXPT PROG	NEANDC(J)36L 40 9/74	KOBAYASHI .ACTIV METHOD,201+-6 BARNS
U	N,GAMMA	JAE	3 3.0+4	EXPT PROG	NEANDC(J)36L 4 9/74	MIZUMOTO+.LINAC,TOF.LIQ-SCINT.NDG
U	TOTAL XSECT	JAE	1.2+1 3.0+4	EXPT PROG	NEANDC(J)36L 1 9/74	NAKAJIMA+.LINAC.TOF.AT LIQ-N TEMP
U 233	FISS YIELD	KTO	THR	EXPT PROG	NEANDC(J)36L 50 9/74	NISHI+.ISOMER YIELDS OF SB ISOTOPES
U 235	EVALUATION	JAE		EVAL PROG	NEANDC(J)36L 27 9/74	MATSUNOBU+.WORK IN PROGRESS.NDG
U 235	EVALUATION	JAE		EVAL PROG	NEANDC(J)36L 27 9/74	MATSUNOBU.TOT,FISS SIGS.ALPHA,NU
U 235	FISS YIELD	KTO	THR	EXPT PROG	NEANDC(J)36L 50 9/74	NISHI+.ISOMER YIELDS OF SB ISOTOPES
U 238	N,GAMMA	TIT	2.4+4	EXPT PROG	NEANDC(J)36L 65 9/74	YAMAMURO+.LINAC.NDG

ELEMENT S A	QUANTITY	LAB	ENERGY(EV) MIN MAX	TYPE	DOCUMENTATION REF VOL PAGE DATE	COMMENTS
PU 239	EVALUATION	JAE		EVAL PROG	NEANDC(J)36L 27 9/74	MATSUNOBU+.WORK IN PROGRESS.NDG
PU 240	EVALUATION	JAE		EVAL PROG	NEANDC(J)36L 27 9/74	MATSUNOBU+.WORK IN PROGRESS.NDG
PU 241	EVALUATION	JAE		EVAL PROG	NEANDC(J)36L 27 9/74	MATSUNOBU+.WORK IN PROGRESS.NDG
MANY	DIFF ELASTIC	JAE	1.5+6 1.4+7	EVAL PROG	NEANDC(J)36L 14 9/74	TANAKA.TBP IN JAERI-M REPORT
MANY	DIFF INELAST	JAE	1.5+6 1.4+7	EVAL PROG	NEANDC(J)36L 14 9/74	TANAKA.TBP IN JAERI-M REPORT
MANY	FRAG SPECTRA	JAE	NDG	EVAL PROG	NEANDC(J)36L 20 9/74	TASAKA+.PUBLISHED IN NSE 54(74)177
MANY	N,GAMMA	JAE	NDG	THEO PROG	NEANDC(J)36L 22 9/74	IGARASI.MODIFIED SIG FORMULA GIVN
MANY	TOT INELASTIC	JAE	NDG	THEO PROG	NEANDC(J)36L 22 9/74	IGARASI.MODIFIED SIG FORMULA GIVN
MANY	TOTAL XSECT	JAE	2.5+5 1.5+7	EVAL PROG	NEANDC(J)36L 14 9/74	TANAKA.TBP IN JAERI-M REPORT

I. Japan Atomic Energy Research Institute

A. Neutron Experiments-Linac

I-A-1. Transmission Measurements on Natural Uranium

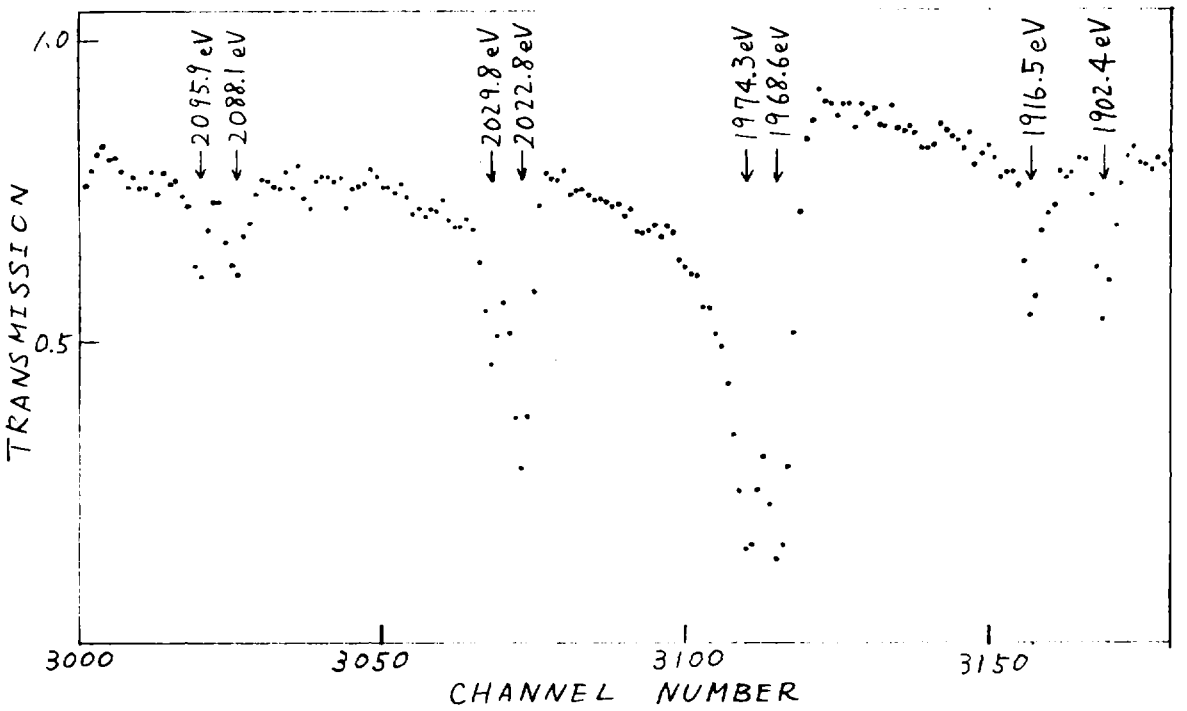
Y. Nakajima, A. Asami, M. Mizumoto, T. Fuketa and H. Takekoshi

The total cross section of ^{238}U has been measured by several investigators, however, the reported resonance parameters have fairly large discrepancies. The isotope ^{238}U is important in the field of nuclear reactor technology particulary as a fuel of the fast breeder reactor, where the breeding ratio depends on the resonance parameter.

Transmission measurements on natural U were performed in the energy range between 12 eV and 30 keV at a 190 m station of the JAERI linac neutron spectrometer. Samples are all metallic slabs and their thickness are 5 mm, 3 mm and 1.5 mm , respectively. The experimental condition for each sample is sumarized in Table 1. Especially the 3 mm sample has been measured at the liquid nitrogen temperature, where the Doppler broadening is reduced and the separation of close resonances becomes more clear than at the room temperature. The shape of the background was found to depend on the thickness of the sample, so that the transmission has been measured also with black resonance samples in the neutron beam. The background values without the black resonance samples were deduced by normalizing these data to the above transmission. A part of a preliminary transmission curve of 5 mm sample, which was obtained with this method, is shown in Fig. 1. The area analysis with the Atta-Harvey program is in progress.

Table 1.

Sample thickness	Burst width	Channel width	Temperature
5 mm	500 ns	400 ns	Room
	125 ns	100 ns	Room
3 mm	500 ns	400 ns	Liquid N_2
	62.5 ns	50 ns	Liquid N_2
1.5 mm	500 ns	400 ns	Room
	125 ns	100 ns	Room



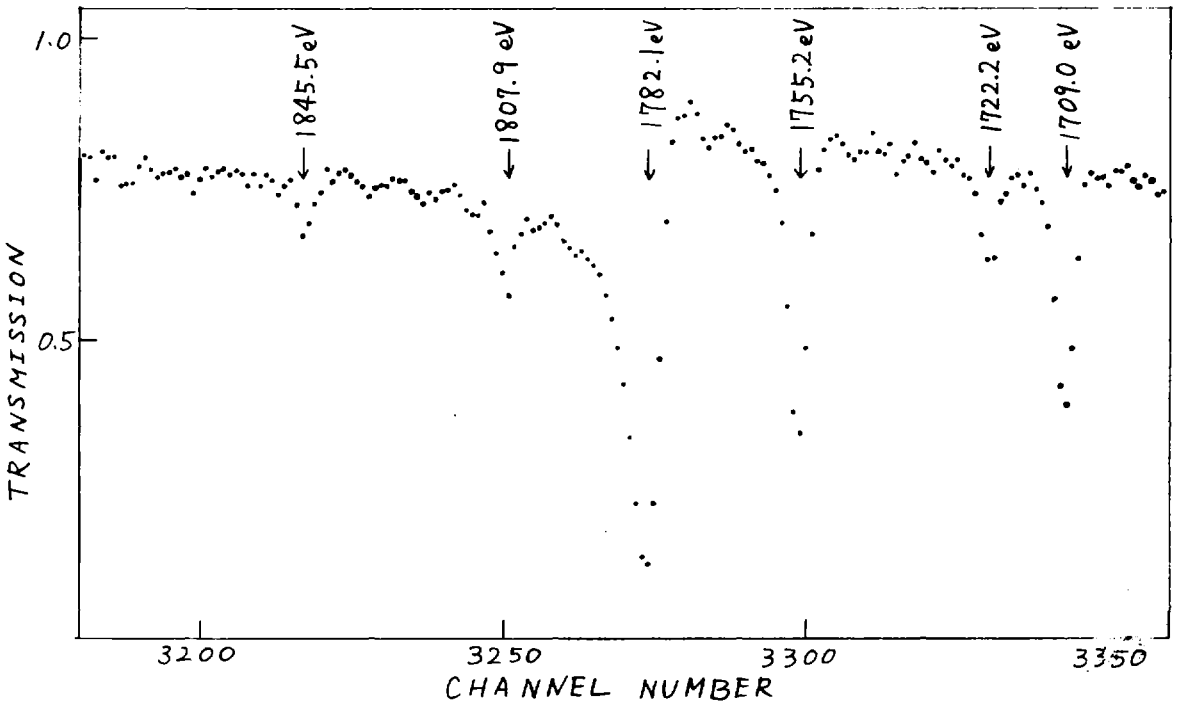


Fig. 1. Transmission of U. Sample thickness : 5 mm.
Channel Width : 50 nsec. Burst Width : 62.5 nsec.

I-A-2. Neutron Average Capture Cross section Measurements on Ta, In, Ho and U

M. Mizumoto, A. Asami, Y. Nakajima, Y. Kawarasaki,
T. Fuketa and R. C. Block*

Average capture cross section measurements were made on Ta, In, Ho and U samples using a 3500 l large liquid scintillation detector at a 52 m flight path length.

The energy region covered in the measurements was from a few keV to 30 keV, the energy resolution was about 4ns/m, and the statistical uncertainty of the raw data for each sample except U was less than 2 % without including systematic and normalization errors. For the purpose of obtaining the background at 35 keV, a 4 cm Al plate was left permanentely in the neutron beam during the experiment. Two kinds of measurements were made to determine the shape of the background, one was with a Na_2CO_3 sample in the upstream of the neutron beam, the other with a Pb sample at the capturing sample position. Neutron flux was measured by a ^6Li glass scintillation detector placed behind the capture tank, the path length of which was about 56 m.

The analysis of the data to obtain the cross section is in progress, and the cross section will be normalized to the standard cross section, which is to be measured with the Fe filterd neutron beam technique at KUR.

* Visiting Professor at Research Reactor Institute, Kyoto University from Rensselaer Polytechnic Institute

I-A-3. Transmission and Scattering Measurements in Natural Tungsten

M. Ohkubo

Transmission and scattering of natural tungsten up to 2 keV were measured with the JAERI Linac TOF facilities with the maximum resolution of 2.5ns/m, and the preliminary results were publsihed in JAERI-M 5624.

The scattering detector at 40m station was a pair of ^{6}Li-^{7}Li glass scintillators of 11.1cm dia. x 0.63cm thickness. Transmitted beam through scattering samples was simultaneously measured by another ^{6}Li glass scintillator. Resonance parameters were obtained by the area analyses of transmission and scattering data for about 50 levels below 1.2 kev, and spins for $^{183}W + n$ were confirmed for 13 levels. Strength function for natural tungsten was obtained to be $S_0 = (2.12 \pm 0.45)10^{-4}$ below 1.2 keV.

I-A-4. Scattered Neutron and Capture Gamma-ryas from Thick Tungsten Samples

M. Ohkubo

Scattered neutrons and capture gamma rays for tungsten plate samples of several thicknesses were measured by the detector system described previously. The scattering and capture yields for thick samples were very different from those for thin samples. The neutron trajectories in the samples were simulated by the Monte-Carlo method with assumed resonance parameters, sample thicknesses, and geometries. The calculated yield curves are in good agreement with the observed ones for samples of up to 1.9 mm thicknesses.

B. Neutron Experiments-Van de Graaff Accelerator

I-B-1. Elastic and Inelastic Scattering of 18.3 MeV Neutrons from Sulphur

Y. Yamanouti and S. Tanaka

Differential cross sections in an angular region from 20° to 155° for both elastic and inelastic neutron scattering (Q=0.0 MeV and -2.24 MeV) were measured on sulphur at a neutron energy 18.2 MeV by using a multi-angle time-of-flight spectrometer.

Data analysis is now in progress.

I-B-2. Energy Levels of ^{94}Mo through (n,n'γ) Reaction

Y. Sugiyama and S. Kikuchi

The energy levels of ^{94}Mo were studied by means of the (n,n'γ) reaction in the energy range 1.5 ∿ 4.0 MeV. A 30 cc Ge(Li) detector was used to detect γ-rays. From the threshold energies of γ-ray production cross sections, the energies of levels were determined. The γ-ray angular distributions were measured at En = 1.9, 2.6 and 3.1 MeV. Detailed analysis is now in progress.

I-B-3. Study of Energy Levels of ^{120}Sn through the (n,n'γ) Reaction

S. Kikuchi and Y. Sugiyama

The paper on this subject is published in "Nuclear Physics A223 (1974)1". The abstract of this study is as follows:

The energy levels of ^{120}Sn were studied by high resolution measurements of γ-rays from the (n,n'γ) reaction in the energy range 2.0 - 3.1 MeV. Fifteen levels at 1171, 1874, 2069, 2159, 2193, 2287, 2355, 2400, 2420, 2465, 2587, 2643, 2699, 2727 and 2835 keV were determined, and the spin-parity values were examined for twelve of them. The spin assignments were made by comparing the observed γ-ray angular distributions and level excitation functions with those calculated on the basis of statistical theory, as shown in Figs. 1 and 2. The level scheme obtained is shown in Fig. 3.

The authors are greatly indebted for the use of a ^{120}Sn sample in the ORNL pool by the courtesy of EANDC and US AEC.

Figure captions

Fig. 1. Angular distributions of the 925, 1184, 1229, 1249 and 412 keV γ-rays. Error bars indicate relative errors. All the curves are the angular distributions calculated with the spin values indicated. Notations J_i and J_f^π represent the spin of level from which γ-ray originates and the spin-parity of level to which γ-ray populates, respectively. For the 412 keV γ-ray, the shape of calculated angular distribution for $6 \rightarrow 5^-$ transition is not distinguishable from that for $4 \rightarrow 5^-$ transition.

Fig. 2. Excitation functions of levels. Level energies are shown in keV. The observed excitation functions are obtained from the γ-ray production cross sections.
Error bars indicate overall errors. Solid curves are excitation functions calculated with the spin-parity values indicated. A dashed curve for the 2193 + 2287 keV levels is the sum of the excitation functions of the 2193 and 2287 keV levels.

Fig. 3. Energy levels of ^{120}Sn. All energies are shown in keV. The 546 keV transition indicated by a dotted line is that assigned tentatively. The transitions with energies less than 200 keV were not observed on account of the detection threshold.

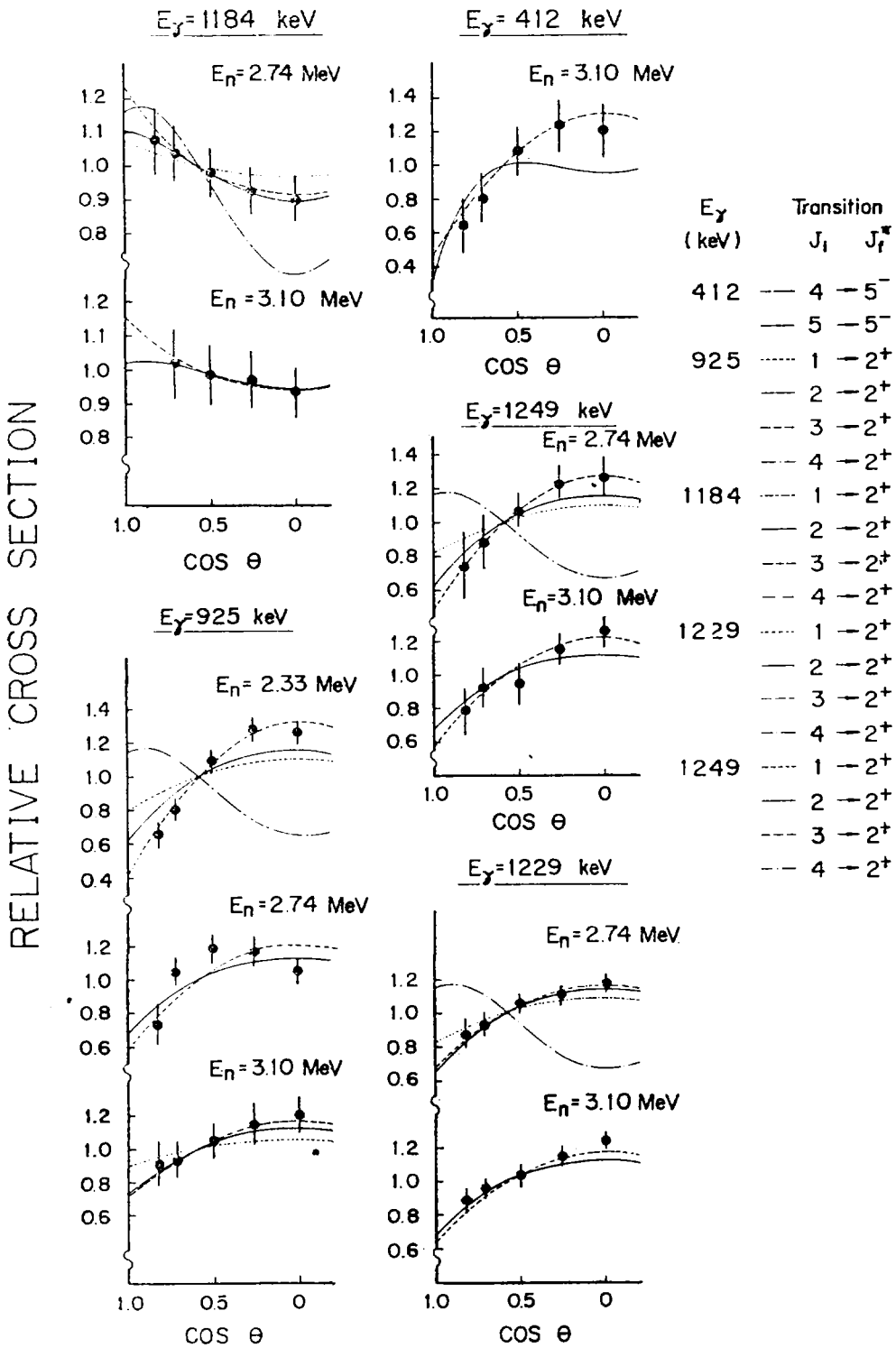

Eγ=1184 keV
En=2.74 MeV
En=3.10 MeV
Eγ=412 keV
En=3.10 MeV
Eγ=1249 keV
En=2.74 MeV
En=3.10 MeV
Eγ=925 keV
En=2.33 MeV
En=2.74 MeV
En=3.10 MeV
Eγ=1229 keV
En=2.74 MeV
En=3.10 MeV
RELATIVE CROSS SECTION
COS θ
Eγ (keV)
Transition
Ji Jf π
412 — 4 — 5⁻
— 5 — 5⁻
925 ····· 1 — 2⁺
— 2 — 2⁺
--- 3 — 2⁺
-·- 4 — 2⁺
1184 ····· 1 — 2⁺
— 2 — 2⁺
--- 3 — 2⁺
-·- 4 — 2⁺
1229 ····· 1 — 2⁺
— 2 — 2⁺
--- 3 — 2⁺
-·- 4 — 2⁺
1249 ····· 1 — 2⁺
— 2 — 2⁺
--- 3 — 2⁺
-·- 4 — 2⁺

Fig. 1.

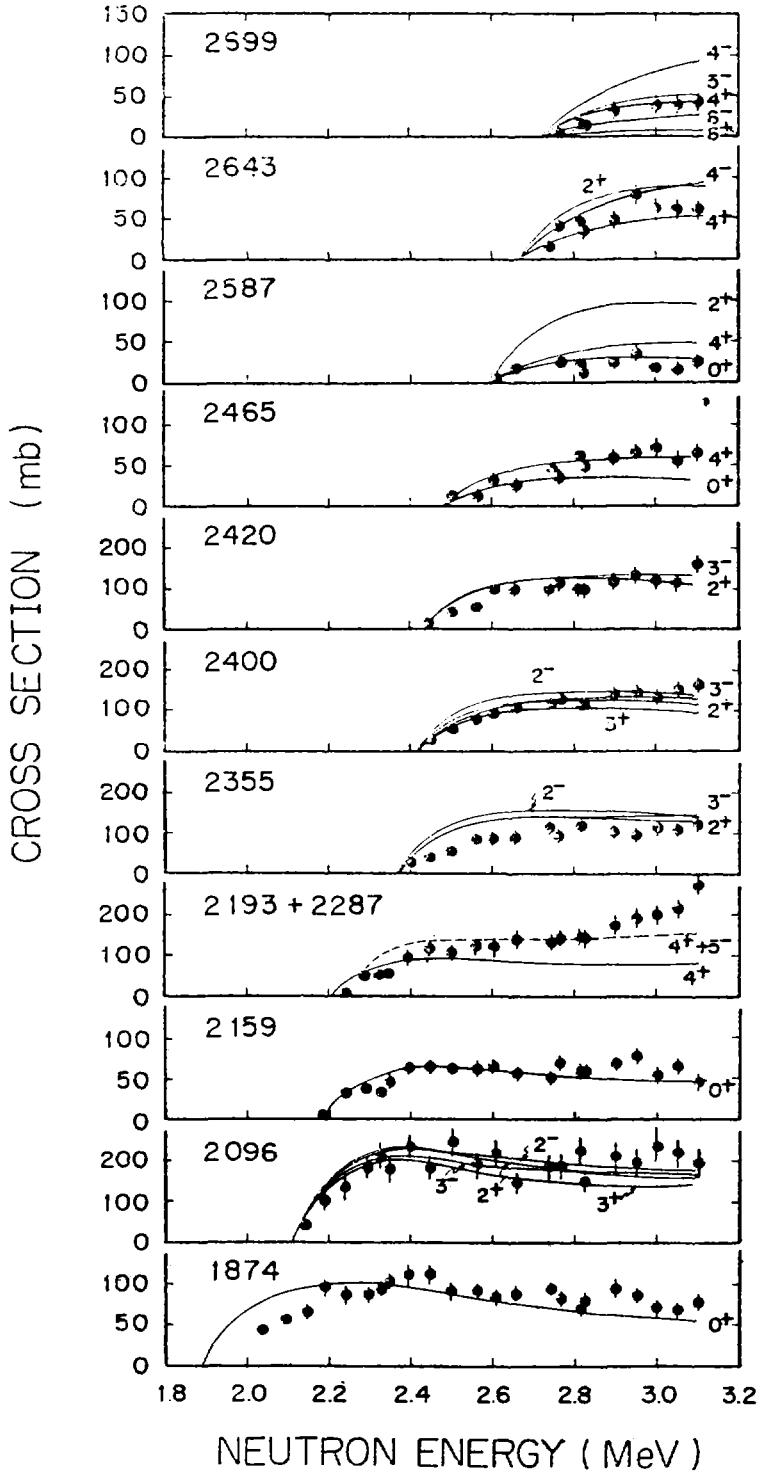

2599
2643
2587
2465
2420
2400
2355
2193 + 2287
2159
2096
1874
CROSS SECTION (mb)
NEUTRON ENERGY (MeV)
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2

Fig. 2.

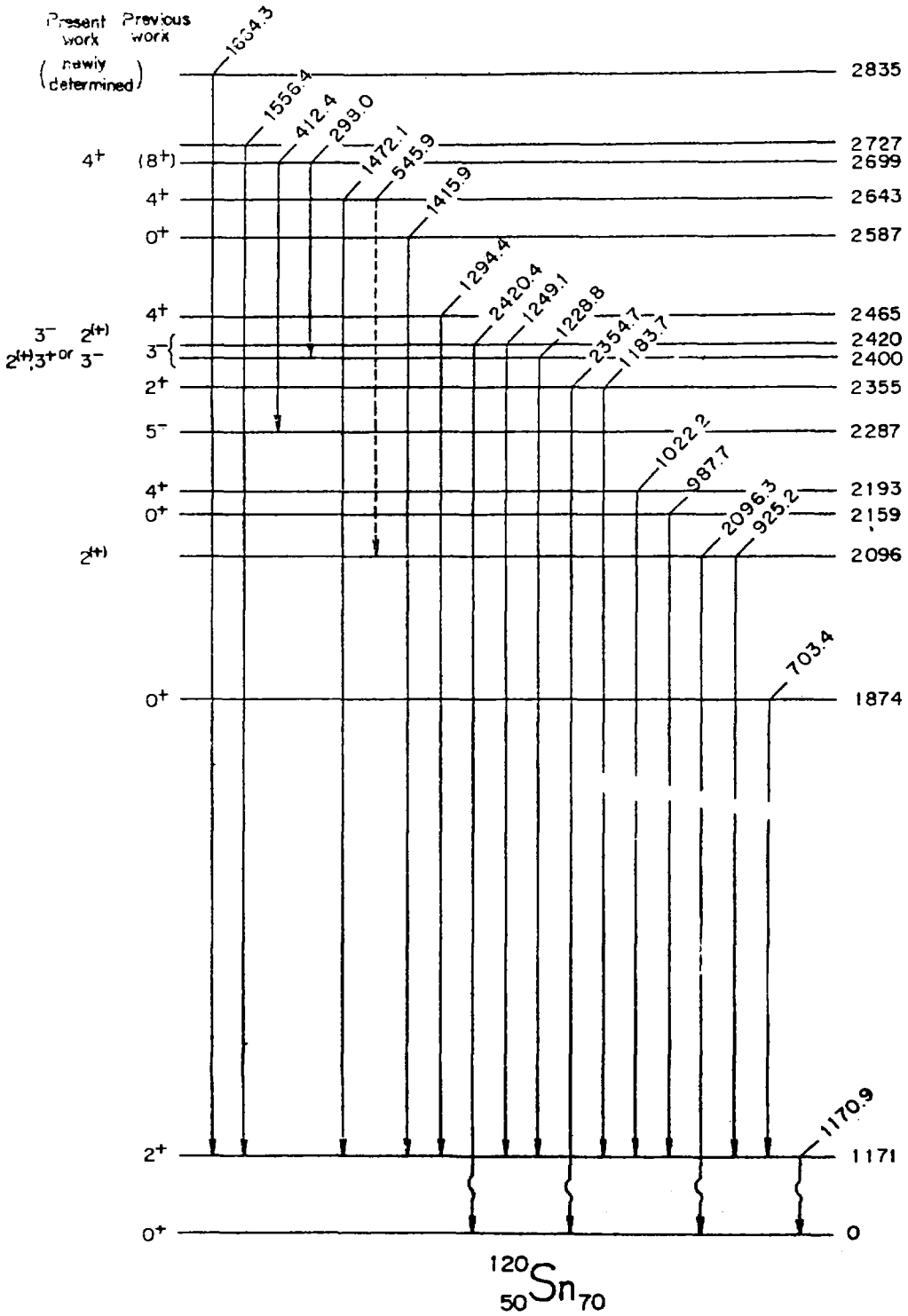

Present work
Previous work
(newly determined)
1634.3
1556.4
412.4
293.0
1472.1
545.9
1415.9
1294.4
2420.4
1249.1
1228.8
2354.7
1183.7
1022.2
987.7
2096.3
925.2
703.4
1170.9
2835
2727
2699
2643
2587
2465
2420
2400
2355
2287
2193
2159
2096
1874
1171
0
4+
(8+)
4+
0+
4+
3−
2(+)
2(+),3+ or 3−
2+
5−
4+
0+
2(+)
0+
2+
0+
120 50 Sn 70

Fig. 3.

I-B-4. Analysis of Neutron Cross Sections Using the Coupled-Channel Theory

Shigeya Tanaka

This work, presented at "Topical Discussions" in the 17th EANDC Meeting, Tokyo, will be published in the Proceedings with an abstract as follows:

Fast neutron total and scattering cross sections calculated with the coupled-channel theory and the spherical optical model are compared with experimental data. The optical-potential parameters used in both the calculations were obtained from comparison of calculations with scattering data for ^{209}Bi.

The calculations for total cross sections were made for thirty-five nuclides from ^{23}Na to ^{239}Pu in the energy range of 0.25 to 15 MeV, and good results were obtained with the coupled-channel calculations. The comparisons of the calculations with the elastic data for about twenty nuclides were made at incident energies of 8 and 14 MeV. In general, the coupled-channel calculations at 8 MeV have given better agreements with the experimental data than the spherical optical-model calculations. At 14 MeV, differences between both the calculations were small. The analysis was also made for the elastic and inelastic scattering by several nuclei such as Fe, Ni, ^{120}Sn, Pu in the low energy region, and good results have been given by the coupled-channel calculations.

Thus, it is demonstrated that the coupled-channel calculations with one set of the optical parameters well reproduce the total and scattering cross sections over a wide energy and mass region.

C. Others

I-C-1. Transmission of Lead-Capture γ Rays with a Tin Absorber

Y. Kawarasaki

The paper on this subject was published in Nucl.Instr. and Methods, 114 (1974) 153-155 with an abstract as follows.

Transmission measurement of the thermal-neutron-capture γ rays in lead was made with a tin absorber of varied thickness for direct determination of the nuclear resonance energy in tin and for obtaining an effective nuclear absorption cross section[1].

It was found that the resonance occurred at the energy of 6729.8 ± 0.9-keV γ rays from $^{204}Pb(n,\gamma)$. The γ-ray energy from $^{206}Pb(n,\gamma)$ was then measured to be 6738.1 ± 0.9 keV. The intensity ratio of the above two lines was determined to be 0.50 ± 0.03. The effective nuclear absorption cross section of the resonant level in ^{120}Sn[2] was measured to be 0.48 ± 0.05 b.

References:

1) N. Shikazono & Y. Kawarasaki, J.Phys. Soc. Japan 26(1969) 1319

2) Y. Kawarasaki, Proc. Int. Conf. on Photonuclear Reactions and Applications (Lawrence Livermore Lab.,1973) P. 305

I-C-2. A Survey for Elements to be Excitated by γ Rays Follwing Thermal Neutron Capture in Vanadium.

Y. Kawarasaki

The paper on this subject was published in J. Phys. Soc. Japan 36(1974) 907, whose abstract is as follows.

A surveying experiment was made in search of the photoexcitable levels in many elements using thermal neutron capture γ rays in vanadium. About 40 natural elements from Na to Bi in order of Z-number were surveyed and it was found that the following elements revealed the appreciable resonances in their scattering spectra; Ca, Ti, Nb, Mo, Cd, Sn, Sb, La, Nd, Sm, W, Hg and Tl.

I-C-3. Photoexcitation of the Tin-Isotope Levels

Y. Kawarasaki

After a surveying experiment[1] in search of the photoexcitable elements by neutron capture γ rays in vanadium, an experiment was undertaken succeedingly on nuclear resonance scattering from Sn. It is found to date that there are two levels excited by γ rays in V(n,γ), the energies of which are determined to be 6519 keV and 7306 keV, respectively, and that the inelastic components of the 7306-keV excitation is observed to be more than that of the 6519-keV one. In order to assign the isotopes responsible for the resonances and to derive the level parameters, the following experiment is now in progress, the measuremtnts of the angular distribution, the nuclear absorption cross section, the temperature dependence of the scattering yields, etc.

Reference:

1) Y. Kawarasaki, J. Phys.Soc. Japan 36(1974) 907

I-C-4. Reactor-Neutron Capture Cross Section of ^{27}Mg

T. Sekine and H. Baba

The reactor-neutron capture cross section of 9.45 minute ^{27}Mg has been determined by the activation method.

Magnesium oxide powder was irradiated in the JAERI Research Reactors and the magnesium fraction was purified by anion- and cation-exchange chromatography. The yield of ^{28}Mg formed by double neutron capture in ^{26}Mg was determined by measuring the γ rays emitted by the daughter, 2.3 minute ^{28}Al, with a Ge(Li) detector.

The preliminary experiments showed that the cross section for the neutron capture of ^{27}Mg was 0.15 barns which was much larger than the maximum value of 0.04 barns reported by Roy and Yaffe[1].

References:

1) L. P. Roy and L. Yaffe, Can. J. Chem. 35 (1957) 176.

I-C-5. Reactor-Neutron Capture Cross Section of ^{65}Ni and the $^{58}Ni(n,2n)^{57}Ni$ Reaction Cross Section for Fission Neutrons

T. Sekine and H. Baba

The reactor-neutron capture cross section of 2.56 hour ^{65}Ni and the $^{58}Ni(n,2n)^{57}Ni$ reaction cross section for fission neutrons have been obtained by the activation method.

The nickel metal plate or wire was irradiated in the JAERI Research Reactors. The sample was dissolved in aqua regia. The ^{58}Co produced by the $^{58}Ni(n,p)^{58}Co$ reaction was removed by anion exchange chromatography. Yields of ^{66}Ni formed by double neutron capture in ^{64}Ni and ^{57}Ni formed by the $^{58}Ni(n,2n)^{57}Ni$ reaction were determined by measuring the γ rays with a Ge(Li) detector.

Five experiments showed that the cross section for the reactor-neutron capture of ^{65}Ni was 18.6 ± 3.5 barns. The value agrees with the value of 24.3 barns given by Serement, Abu-Samra and Emmons[1], but is in disagreement with the value of 60 to 70 barns reported by Pinajian[2].

The $^{58}Ni(n,2n)^{57}Ni$ reaction cross section was 3.8 ± 0.4 microbarns based on the value of 111 millibarns for the $^{58}Ni(n,p)^{58}Co$ reaction. The value is not inconsistent with the 6 and 3 microbarns reported by the earlier workers[3].

References:

1) V. Serment, A. Abu-Samra and A. H. Emmons, Nucl. Tech. 9 (1970) 662.

2) J. J. Pinajian, J. Inorg. Nucl. Chem. 31 (1969) 1241.

3) J. C. Roy and J. J. Hawton, AECL-1181 (1960).

I-C-6. Calculation of Decay Power of Fission Products

Kanji TASAKA and Nobuo SASAMOTO

The paper on this subject was published in Nucl. Sci. and Eng. Vol. 54, P.177-189 (1974) with an abstract as follows.

The energy release rates of fission products have been calculated by summation of the contributions of respective fission product nuclides for several fissioning nuclides and excitation energies. An attempt is made to refine the existing values of beta or gamma energy release rates at short times after fission by including information of more fission products, mainly short-lives ones. In the calculation 443 radioactive and 125 stable nuclides are considered.

The unknown unclear data for short-lives nuclides are estimated theoretically or statistically. The Q values are obtained by using the semi-empirical mass formula of Myers and Swiatecki. Beta decay constant λ of the nucleus is derived from its Q value by using the empirical correlation between λ and Q.

Feasibility of the method is evaluated through comparison of the calculated results with experiment for the thermal neutron fission of ^{235}U. The results are in good agreement with the experimental ones for the gamma energy release rates at short times after the fission, usefulness of the estimated nuclear data is thus indicated. The calculated decay powers are in good agreement with the calorimetric measurements by Day and Cannon. The present results of decay power also agree well with the compilations by Shure and by Stehn and Clancy for the respective cooling times.

D. Japanese Nuclear Data Committee

The Japanese Nuclear Data Committee has three subcommittees: Subcommittees on Nuclear Data (SND), on Reactor Constants (SRC), and on Nuclear Data for Safeguards Techniques (SNDST). These Subcommittees consist of working groups which have been performing the actual productive activities. The Nuclear Data Laboratory, JAERI, takes charge of the secretariat of the JNDC.

Two new working groups were formed in June 1974: Working Group for Evaluation of Decay Heat (WGEDH) in SNDST and Working Group on Nuclear Data for Fusion Reacotors (WGNDFR) in SND, respectively. The objectives of the WGEDH are: (1) to provide basic nuclear data for calculation of decay energy, and (2) to evaluate the decay heat through comparison of calculated values with clean experimental values. Reactor safety people are requiring to receive the evaluated data whithin two years. The schedule of evaluation will try to meet with this requirement. The first meeting of WGNDFR will be held on 20th August 1974, and the activity will start with a survey work on the nuclear data required for the development of fusion reactors. A Japanese CTR nuclear data request list should be initiated by the Research Committee on Nuclear Fusion Reactor of the Atomic Energy Society of Japan and will be screened by the WGNDFR.

A Compilation Group for Japanese Evaluated Nuclear Data Library (JENDL) was also formed in June 1974. The first version of JENDL, JENDL-1, is planned to be completed in 1976. Preferential supports of the JNDC and JAERI are requisite to carrying out the above plan.

I-D-1. On the Modification of the Neutron Cross-Section Formulas

Sin-iti Igarasi

It is well known that the neutron total cross section σ_{tot}, shape elastic scattering cross section $\sigma_{el.s}$, and total reaction cross section σ_R are obtained directly from the optical model calculations. The total reaction cross section is composed of compound elastic scattering cross section $\sigma_{el.c}$, inelastic scattering cross section σ_{in}, neutron capture cross section $\sigma_{n,\gamma}$ and other cross sections such as fission cross section, (n,2n) reaction cross section etc. which we call here cross section of the competing process and denote as $\Delta\sigma$. The relation among these cross sections are described as follows;

$$\sigma_{tot} = \sigma_{el.s} + \sigma_R = \sigma_{el.s} + \sigma_{el.c} + \sigma_{in} + \sigma_{n,\gamma} + \Delta\sigma \quad . \tag{1}$$

In general, however, partial cross sections $\sigma_{el.c}$, σ_{in}, $\sigma_{n,\gamma}$ and $\Delta\sigma$ are not necessarily calculated by taking account of their mutuality, in the usual study of the nuclear cross sections.

In this work, we investigate the relation among those cross sections mentioned above, in the framework of the conventional statistical theory[1,2] of the nuclear cross sections, and derive modified formulas for the partial cross sections. In this short note, we present the results of our formulas for the cross sections. According to our results, the cross sections of the neutron capture and inelastic scattering for excitation of an individual level of the residual nucleus are given as follows;

$$\sigma_{n,\gamma}(E_n) = \frac{\pi}{k_n^2}(1-\alpha)\sum_{J\pi j\ell} g^J \frac{\langle \Theta^{J\pi}_{nj\ell}\rangle}{\langle \Theta^{J\pi}\rangle}\Big\{\langle \Theta^{J\pi}_{\gamma 1}\rangle - \langle \Theta^{J\pi}_{\gamma 2}\rangle \times \Big[\frac{\Delta\Theta^{J\pi}_{\gamma}}{\langle \Theta^{J\pi}\rangle} S^{J\pi}_{nj\ell;\gamma 2} - 1 + S^{J\pi}_{nj\ell;\gamma 2}\Big]\Big\} , \tag{2}$$

and

$$\sigma_{n,n'}(E_n) = \frac{\pi}{k_n^2}(1-\alpha)\sum_{J\pi j l j' l'} g^J \left\{ \frac{\langle \Theta^{J\pi}_{njl}\rangle \langle \Theta^{J\pi}_{n'j'l'}\rangle}{\langle \Theta^{J\pi}\rangle} S^{J\pi}_{njl;n'j'l'}\left(1+\frac{\Delta\Theta^{J\pi}_{\gamma}}{\langle \Theta^{J\pi}\rangle}\right) - \delta_{njl;n'j'l'}\frac{1}{4}Q^{J\pi}(\langle \Theta^{J\pi}\rangle)\cdot\langle \Theta^{J\pi}_{njl}\rangle^2 \right\}, \tag{3}$$

respectively. Here, the quantity $\langle \Theta^{J\pi}_{njl}\rangle$ is obtained by the use of neutron transmission coefficient $\langle T^{J\pi}_{njl}\rangle$ which is calculated by the optical model;

$$\langle \Theta^{J\pi}_{njl}\rangle - \frac{1}{4}Q^{J\pi}(\langle \Theta^{J\pi}\rangle)\cdot\langle \Theta^{J\pi}_{njl}\rangle^2 = \langle T^{J\pi}_{njl}\rangle, \tag{4}$$

and the quantity $\langle \Theta^{J\pi}_{\gamma i}\rangle$ is calculated by the following equation;

$$\langle \Theta^{J\pi}_{\gamma i}\rangle - \frac{1}{4}Q^{J\pi}(\langle \Theta^{J\pi}\rangle)\cdot\langle \Theta^{J\pi}_{\gamma i}\rangle^2 = \langle T^{J\pi}_{\gamma i}\rangle, \tag{5}$$

where we use two kinds of gamma-ray transmission coefficients $\langle T^{J\pi}_{\gamma 1}\rangle$ and $\langle T^{J\pi}_{\gamma 2}\rangle$ [3] which correspond to the gamma-ray absorption and the total gamma-ray widths respectively.

Two quantities $\Delta\Theta^{J\pi}_{\gamma}$ and α play the important role in our cross-section formulas. They are defined as follows;

$$\Delta\Theta^{J\pi}_{\gamma} = \langle \Theta^{J\pi}_{\gamma 2}\rangle - \langle \Theta^{J\pi}_{\gamma 1}\rangle, \tag{6}$$

and

$$\alpha = \Delta\sigma/\sigma_R, \tag{7}$$

respectively. The quantity $\Delta\Theta^{J\pi}_{\gamma}$ corresponds to the sum of the probabilities for the neutron and gamma-ray emissions through the cascade process from the compound nuclear states above the neutron separation energy. It is easily seen that the relation given in Eq.(1) is satisfied by using our cross-section formulas Eqs.(2) and (3). Quantities $Q^{J\pi}$ and $S^{J\pi}_{njl;c}$ in Eqs.(2) and (3) are correction factors for the resonance interference and width- fluctuation effects, respectively.

References:

1) W.Hauser and H.Feshbach : Phys. Rev. 88 327 (1952)

2) B.Margolis : Phys. Rev. 88 327 (1952)

3) A.M.Lane and J.E.Lynn : Nucl. Phys. 11 646 (1959)

I-D-2. Group Constants of Fission Products

Y. Kikuchi, I. Otake*, K. Tasaka, H. Nishimura, H. Hasegawa and S. Katsuragi

The preliminary version of evaluated data of the 28 important FP nuclides was published[1)] by JNDC FP Nuclear Data Working Group, and the group constants of 25 and 70 group structure were prepared with these data. Then they were lumped to the group constants of a pseudo FP nuclide at various burn-up stages, using the concentration as weights. Though these 28 important nuclides take more than 80% of total capture by fission products, the number of 28 is not enough to produce the lumped group constants. Therefore the data evaluated by Cook[2,3)] were used supplementalily for other nuclides.

JNDC adopted the statistical model down to 100 eV, in order to avoid the discontinuity at keV region, which is observed in Cook's evaluated data. This may sound rather rough, but the standard deviation due to the statistical fluctuation is small for the lumped group constants (less than 10% for the energy group between 100 and 215 eV).

The lumped capture cross section of JNDC group constants set is about 25% larger than that of Cook's set, when collapsed to one group with the spectrum of a typical large fast reactor. Such a large uncertainty of FP group constants fairly affects the reactor design. The detailed discussion is given in Ref. 4.

Then the group constants were tested by comparing the calculated results with the experimental ones measured at STEK facility in Petten, Netherlands. The reactivity worth due to capture was calculated for 3

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* Fuji Electric Co., Ltd.

samples, i.e., 2 irradiated samples (HFR-101: 60% FIMA and HFR-102: 30% FIMA) and one mock up sample (KFK-sample), with the flux and the adjoint flux of 4 STEK cores[5]. The results are given in Fig. 1 as the ratio to the experimental values. The calculated values with RCN set and Cook's set are also given for comparison.

The followings can be pointed out:

1) JNDC set overestimates the reactivities by 10% for HFR-101 sample, while RCN set and Cook's set underestimates them by 10%.

2) The results with JNDC set agree very well with the experimental values of HFR-102, while RCN and Cook's sets give 20% of underestimation.

3) The results with JNDC set and Cook's set depend on the core for KFK-sample, while the results with RCN set do not.

4) Cook's set always underestimates the reactivity.

It could be said from the above observations that the capture cross sections of Cook's set are a little too low. But it is not clear why one set gives good results for a sample and it does not for another sample, and why such a strong core dependence appears with JNDC and Cook's sets only for KFK sample. It is very difficult to say which set is the most reliable from the integral measurements of fission product mixtures, and the experiment on separated isotopes must be more helpful.

References

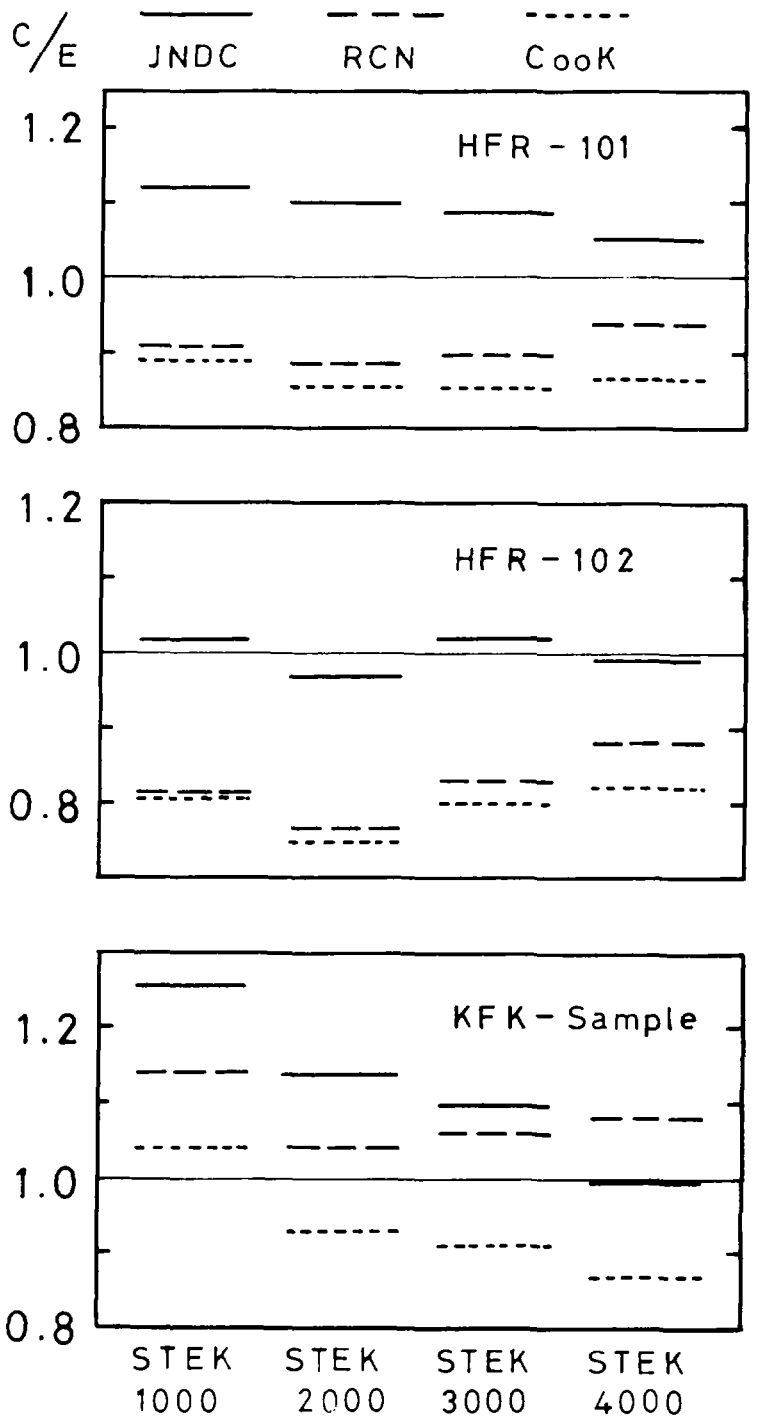
1) JNDC: Evaluation of Fission Product Nuclear Data for Fast Reactor, JAERI-M5752, 1974

2) J. L. Cook: Fission Product Cross Sections, AAEC/TM-549, 1969

3) Y. Kikuchi et al.: Production of FP Group Constants for Fast Reactors with Cook's Evaluated Data, JAERI-M5492, 1973

4) Y. Kikuchi et al.: Proceedings of International Symposium on Physics of Fast Reactors held at Tokyo, October 16-19, 1973, P649, 1973

5) H. Gruppelaar et al.: RCN-1 Pseudo Fission-Product Capture Group Cross Sections, RCN-205, 1974


C/E
JNDC
RCN
CooK
1.2
1.0
0.8
HFR - 101
HFR - 102
KFK - Sample
STEK 1000
STEK 2000
STEK 3000
STEK 4000

I-D-3. Activity of the Nuclear Data Evaluation Working Group

H Matsunobu* and other members

The object of this group is to prepare for the evaluated nuclear data which are required for fast reactor design. This group is composed of three sub-working groups which take charge of the following tasks respectively.

1) Evaluation of the nuclear data for heavy nuclides

In this sub-working group, evaluation works of the nuclear data on ^{235}U, ^{239}Pu, and ^{240}Pu in the energy range from 1 keV to 15 MeV have been performed on the basis of the experimental data compiled up to date. Evaluation on ^{238}U was already completed last year. On ^{241}Pu, compilation of the experimental data has been completed, but the compiled data are very poor in quantity. The situation of the experimental data on ^{240}Pu is also similar to ^{241}Pu except fission cross section. Accordingly, evaluation of most nuclear data on ^{240}Pu has been performed on the basis of the similarity of the nuclear data between ^{238}U and ^{240}Pu, and using theoretical calculation, whereas the fission cross section has been evaluated on the basis of the compiled experimental data.

At present, the final reports of evaluation for each nuclide are being prepared.

2) Compilation of the resonance parameters

Compilation of the resonance parameters of ^{235}U, ^{238}U, ^{239}Pu, and ^{240}Pu has been almost completed, whereas that of ^{240}Pu was started later and is now in progress. All the experimental data are included in the work except the case of ^{235}U, where only those reported since the

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* Sumitomo Atomic Energy Industries, Ltd.

publication of the KFK-120 are collected. The compiled parameters are mainly single level parameters even in ^{235}U, ^{239}Pu, and ^{240}Pu, although some of the multi-level parameters will be included in the final stage. These compiled data will be soon published together with short comments on the experimental method and analysis described in each reference.

3) Compilation and analysis of the nuclear data for light and medium-heavy nuclides

Compilation works of the nuclear data on O, Na, Cr, Fe, Ni, and Ta which are indispensable for fast reactor design have been continued since last year. The compiled data are composed of new experimental data published recently.

Besides data compilation, analysis of the differential elastic scattering cross section, strength function, and polarization for Fe was done using ELIESE-3 code based on the optical model and statistical theory. This result was reported by H. Yamakoshi at the 17th EANDC topical meeting held in Tokyo, in March 1974.

I-D-4. Evaluation of the Nuclear Data on ^{235}U

Hiroyuki Matsunobu*

Evaluation work of the nuclear data (σ_t, σ_f, α, and ν_p) on ^{235}U in the energy range from 1 keV to 15 MeV has been performed as a part of evaluation works in the sub-working group of JNDC.

The total and fission cross sections were evaluated on the basis of the compiled experimental data which were described briefly in the previous progress report. The evaluated numerical values were obtained by X^2-method using the polynomial fitting functions. The result of evaluation was reported at the Atomic Energy Society of Japan held in November 1973.

The compiled experimental data of α (ratio of capture to fission) are densely distributed in the energy range below 100 keV, and fluctuated remarkably in the range below 30 keV. This fluctuation may be caused by the effect of structure for ^{235}U. In evaluation, it is very difficult to reproduce the fluctuation of the experimental data. Therefore, we adopted a method to obtain the average value in this energy range using the polynomial fitting function.

One of the purposes of evaluation for α is to obtain capture cross section σ_c using the evaluated α and σ_f, because the experimental data for σ_c of ^{235}U are poor. However, there are also no experimental data for α in the energy range above 1 MeV. Accordingly, capture cross section in the energy range above 1 MeV is obtained by theoretical calculation based on the optical model and statistical theory in present evaluation.

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* Sumitomo Atomic Energy Industries, Ltd.

The energy dependence of the prompt neutron number per fission ν_p for ^{235}U has been studied by many researchers, and various formulae have been presented up to date. Looking over the distribution of the compiled experimental data, three different tendencies are observed for the energy dependence of ν_p. In the energy range from 40 keV to 2 MeV, the distribution of the data is dense, and the gradient of the energy dependence is most gentle. In the energy range from 2 to 7.5 MeV, considerable discrepancies between the experimental data are observed, and the gradient of the energy dependence is most steep. In the energy range from 7.5 $\sim$ 15 MeV, although the experimental data are poor, lineality for the energy dependence is very good. In present evaluation, the energy dependence of ν_p is represented by three straight lines using X^2-method in the above-mentioned energy ranges.

The results of evaluation for α and ν_p will be reported at the Atomic Energy Society of Japan which will be held in October 1974.

I-D-5.

Evaluation of Fission Product Cross Sections for Fast Reactor

Fission Product Nuclear Data Working Group

Evaluation of cross sections for 28 nuclides up to the end of 1973 was reported as JAERI-M Report 5752. F.P Reactor Constants Working Group have made test of these cross sections by comparing the calculated reactivity worths of lumped fission product with experimental data of Petten. Results showed that the present capture cross sections were probalbly overestimated by 10-20 %. Re-evaluation is under way and will finish this September. In this reevaluation the calculational method was improved by taking account of the effects of neutron width fluctuation and the interference between nuclear levels. Results will be included in JENDL/1.

Further evaluation work covering ultimately about 300 F.P nuclides is scheduled. The work will start from this fall and will continue for about 2 years.

II. Kyoto University

A. Research Reactor Institute

II-A-1.

Precision Neutron Total Cross Section Measurements of C, Be and O near 24 keV

R. C. Block*, Y. Fujita, K. Kobayashi and T. Osaki
Research Reactor Institute, Kyoto University

A full paper on this subject was submitted to the Journal of Nuclear Science and Technology.

The neutron total cross sections of Be, C and O were measured near 24 keV by making a linac-time-of-flight transmission measurements upon a neutron beam passing through a 30 cm thick iron filter. The cross sections of elemental Be, C and O were determined to be (5.903 ± 0.011) b, (4.684 ± 0.009) b and (3.736 ± 0.007) b respectively, which were tabulated in Table 1, at a mean neutron energy of 23.5 keV. These results differ by 0.5 % ~ 1.5 % from the ENDF/B-III evaluated cross sections. The Fe-filtered beam method is instrinsically capable of yielding an accuracy of ~0.1 %, which is comparable to that achieved in precision thermal cross section measurements. Detail discriptions about samples, background, dead time correction and detecting system are also given and discussed.

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* Visiting Professor at Kyoto University, on sabatical leave from Rensselaer Polytechnic Institute, Troy, New York, U. S. A.

Table 1 Final results for the 23.5 keV neutron total cross section of $_6C$, $_4Be$ and $_8O$

	Total Cross Section (barns)	Total Error		Partial Errors (%)						ENDF/B -III Cross Section (barn)
		(barn)	(%)	Counting Statistics	Sample Thickness uncertainty	Detection Efficiency Shift uncertainty	Dead Time correction uncertainty	Air Scattering correction uncertainty	BKG determination uncertainty	
$_4Be$	5.903	0.011	0.18	0.14	0.09	< 0.05	< 0.05	< 0.01	< 0.05	5.932
$_6C$	4.684	0.009	0.20	0.18	0.05	< 0.05	< 0.05	—	< 0.05	4.648
$_8O$*	3.736	0.007	0.19	0.16	0.08	< 0.05	< 0.04	< 0.03	< 0.04	3.678
$\frac{Al_2O_3-2Al}{3}$	3.735	0.009	0.23	0.18	0.12	< 0.05	< 0.05	< 0.05	< 0.05	
$\frac{SiO_2-Si}{2}$	3.738	0.012	0.32	0.30	0.08	< 0.05	< 0.05	< 0.02	< 0.05	

* Cross Section of $_8O$ is the weighted average of $(Al_2O_3-2Al)/3$ and $(SiO_2-Si)/2$

II-A-2. Gamma-ray Energies of Se-85 and Se-86

T. Tamai, R. Matsushita, J. Takada and Y. Kiso*

A paper on this subject was published in INORG. NUCL. CHEM. LETTERS, 9, 1145 (1973).

Although the half-lives of short-lived selenium nuclides in fission products were reported, the gamma-ray energies of these nuclides such as ^{85}Se and ^{86}Se have not been determined. The aim of the present study is to separate rapidly selenium from the other fission elements using paper electrophoresis and to measure the unknown gamma-ray energies of the short-lived selenium nuclides and their relative intensities.

A small amount of uranyl nitrate solution was irradiated under a thermal neutron flux of 2.35×10^{13} $n \cdot cm^{-2} \cdot s^{-1}$ for 10 s in the pneumatic tube of the Kyoto University Reactor. As a supporting electrolyte solution, a 10^{-2}M perchloric acid solution (pH=2.2) was used. A 0.1 M solution of potassium selenite was prepared as a carrier. A 0.1 M potassium permanganate solution was used as an oxidizing agent to oxidize selenite to selenate to make the migration zone of pertechnetate ion sharp. A visible migration-front of the permanganate ion was effective as a marker for the location of the migration position of permanganate and selenate ions. A 10^{-2}M silver nitrate solution was used as a stopping agent of bromide and iodide ions whose mobilities were larger than those of selenate ions.

As a results, the energies and their relative intensities of eight gamma-rays from both Se-85 and Se-86 are given in Table I.

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The half-lives of Se-85 and Se-86 obtained were (32.8±0.3) s and (14.3±0.5) s, respectively.

Table I

ENERGIES AND RELATIVE INTENSITIES OF GAMMA-RAYS FROM Se-85 AND Se-86

Se-86			Se-85		
E_γ (keV)	I_γ (%)	$T_{1/2}$(s)	E_γ (keV)	I_γ (%)	$T_{1/2}$(s)
49.0	15	14.4±2	344.4	100	32.8±0.3
154.3	30	14.3±0.5	382.1	17.1	32.7±2.3
207.7	100	15.9±1.2	432.3	11.1	26.0±2.7
941.3	237	20	611.4	6.4	27.4±2.3
1081.1	257	13.5	842.3	9.7	23.9±1.2
1208.3	293	19	869.0	7.1	21.9±0.2
1340.2	188		955.4	15.9	33.8±5.1
1399.9	108	15	1427.2	5.2	39.7±3.9

II-A-3.

Measurements of the Cross Section for the $^{231}Pa(n,f)$ Reaction

Katsuhei Kobayashi and Itsuro Kimura
Research Reactor Institute, Kyoto University

and

Hiroshi Gotoh and Hideyuki Yagi
Japan Atomic Energy Research Institute

Although several measurements[1)~3)] of the energy dependent cross section for the $^{231}Pa(n,f)$ reaction have been made, few measurements in the energy region more than about 3 MeV have been carried out previously.

In the present report, the cross section for the $^{231}Pa(n,f)$ reaction have been measured in the energy region from about 3.6 MeV to 4.9 MeV with a 2 MV Van de Graaff accelerator, by making use of a chamber composed of a silicon detector and an electro-deposited ^{231}Pa film of about 50 $\mu g/cm^2$. Fast neutron flux was monitored with the threshold reaction $^{115}In(n,n')^{115m}In$, whose values of the cross section had been obtained by the authors[4)]. The experimental method is the same as the previous paper in which the cross section for the $^{237}Np(n,f)$ reaction was measured[5)].

An indium foil was attached to just behind the ^{231}Pa film. Since sample distance from the mean neutron source position was about 10 mm, the neutron flux at the sample was corrected, as shown in Fig.1, by the following formula :

$$A(h, r_2, t_1) = \frac{1}{t_1}\int_0^{t_1} \frac{\phi n \sigma}{4\pi r_2^2} \ln\left\{1 + \frac{r_2^2}{(h+t)^2}\right\} dt$$

$$= \frac{\phi n \sigma}{4\pi r_2^2 t_1}\int_h^{h+t_1} \left\{\ln(x^2+r_2^2) - \ln x^2\right\} dx$$

$$= \frac{\phi n \sigma}{4\pi r_2^2 t_1}\left[(h+t_1)\ln\left\{1+\left(\frac{r_2}{h+t_1}\right)^2\right\} - h\ln\left\{1+\left(\frac{r_2}{h}\right)^2\right\}\right.$$

$$\left. + 2r_2\tan^{-1}\frac{h+t_1}{r_2} - 2r_2\tan^{-1}\frac{h}{r_2}\right]$$

Our preliminary results are shown in Fig.2. Although statistical errors come up to several to 10 %, the present results seem to agree with the Drake's[6].

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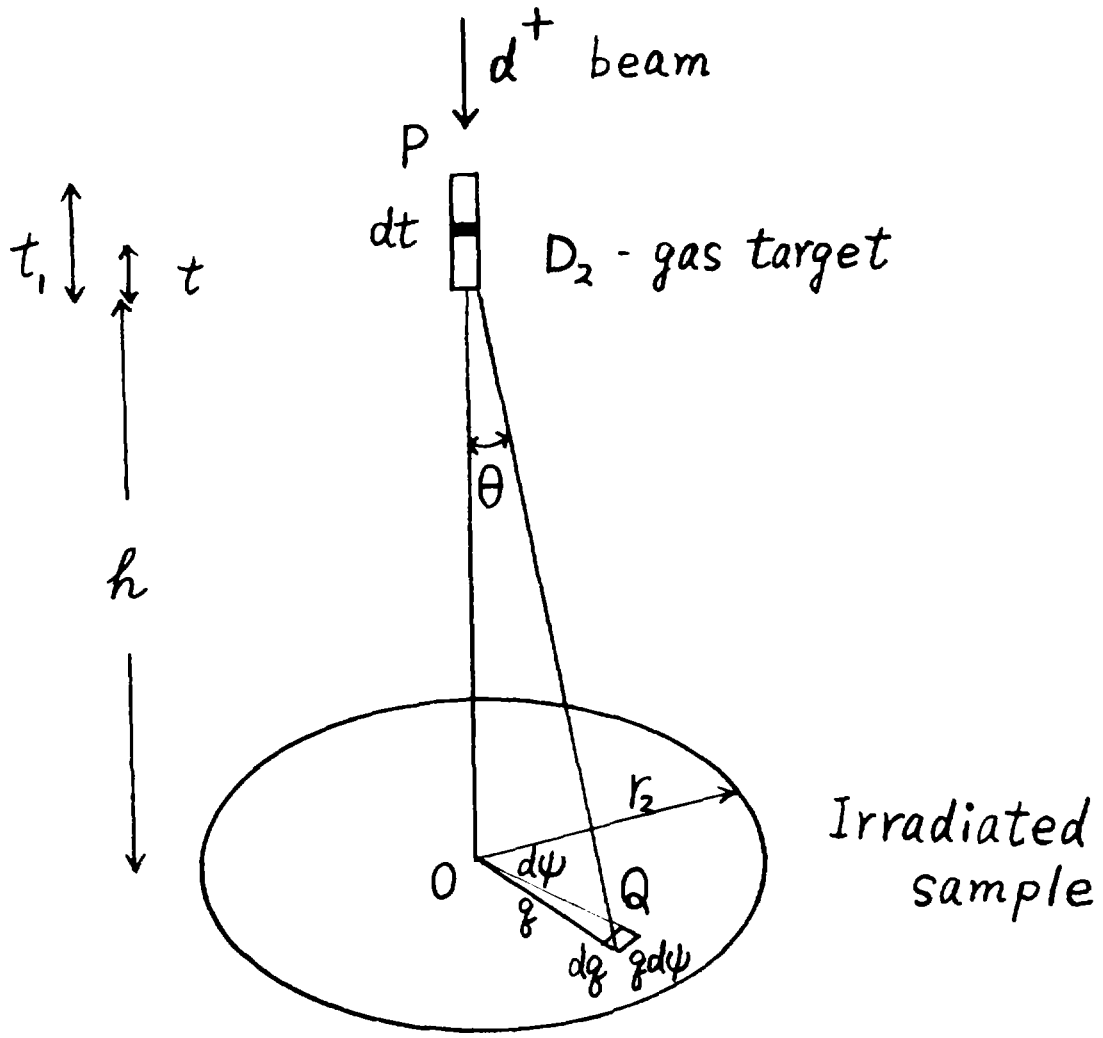

Fig. 1 Calculating geometry for neutron flux correction

Fig. 1 Calculating geometry for neutron flux correction

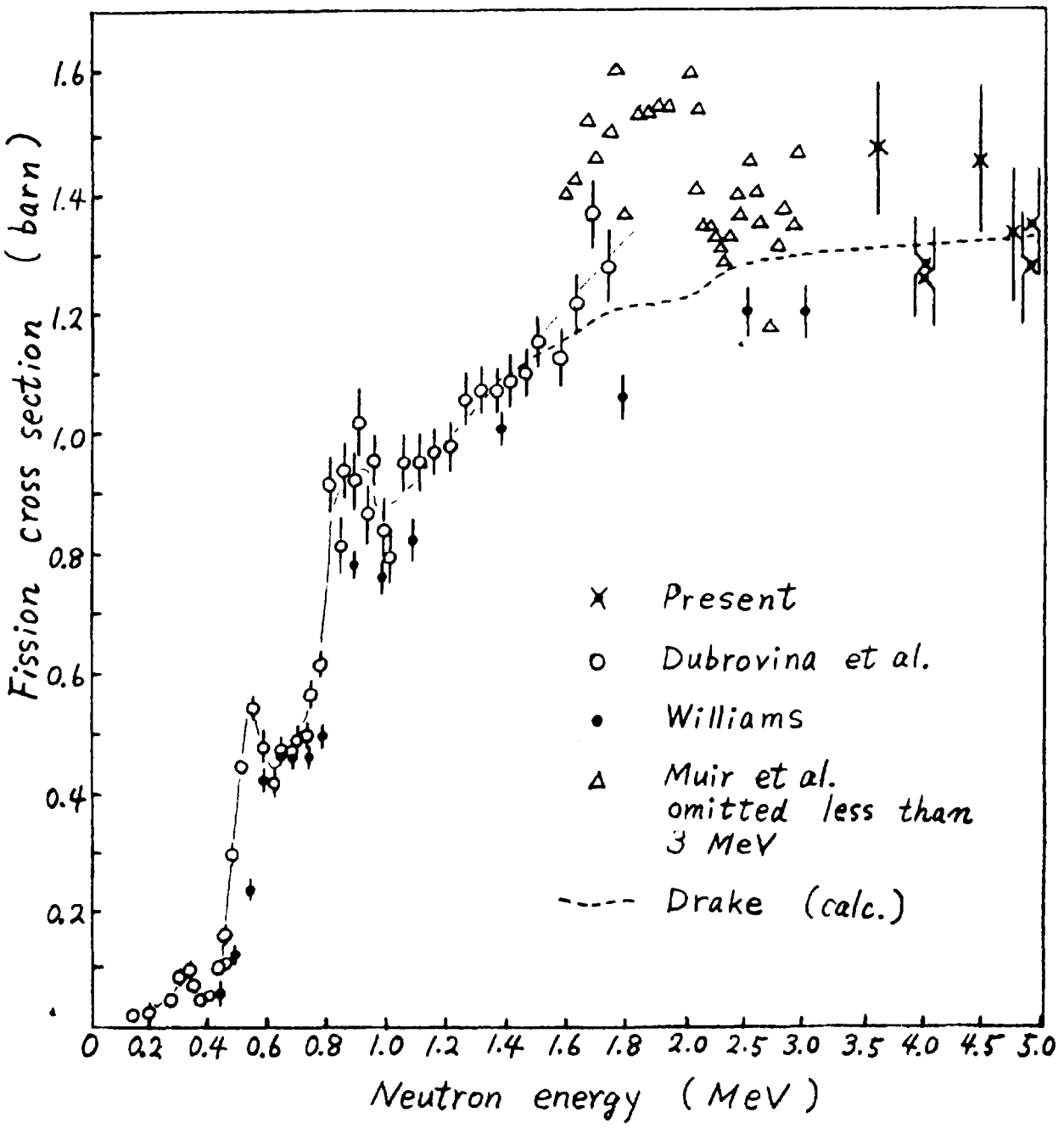

Fig. 2 Fission cross section for $^{231}Pa(n,f)$ reaction

II-A-4.

Measurements of the Cross Sections for the $^{232}Th(n,\gamma)^{233}Th$ and $^{231}Pa(n,\gamma)^{232}Pa$ Reactions using Maxwellian Thermal Neutrons

Katsuhei Kobayashi

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A short note on this subject was submitted to the Annu. Reports of the Research Reactor Institute, Kyoto University.

The thermal neutron cross sections for the $^{232}Th(n,\gamma)^{233}Th$ and $^{231}Pa(n,\gamma)^{232}Pa$ reactions have been measured by the activation method, by making use of the Kyoto University Reactor, KUR, where pure Maxwellian neutrons are available. Thermal neutron flux during sample irradiation was monitored with gold foils.

For the determination of the cross section for the $^{232}Th(n,\gamma)^{233}Th$ reaction, ^{233}Pa (half life $T_{1/2}$=27 d) into which ^{233}Th (half life $T_{1/2}$=22.3 m) completely decayed out, while ^{232}Pa (half life $T_{1/2}$=1.31 d) for the $^{231}Pa(n,\gamma)^{232}Pa$ reaction, were measured. Produced activities of ^{232}Pa, ^{233}Pa and ^{198}Au were measured with a Ge(Li) counter of 2 cc, whose efficiency had been previously obtained by the standard gamma-ray sources prepared at IAEA and ^{198}Au whose absolute disintegration rate had been calibrated with a $4\pi\beta\gamma$ counter.

The present values of the cross sections for the $^{232}Th(n,\gamma)^{233}Th$ and $^{231}Pa(n,\gamma)^{232}Pa$ reactions became to be 7.35 $\pm$ 0.21 barns and 201 $\pm$ 6 barns, respectively. They are shown in Table 1 and Table 2, comparing the earlier results. The

present results agreed with the recommended values found in the literature within the limits of error. Cross sections measured with pure Maxwellian thermal neutrons should be preferred as a recommended value.

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Table 1 Cross sections for $^{232}Th(n,\gamma)^{233}Th$ reaction to thermal neutrons

Cross section (barn)	Reference
7.35 ± 0.21	Present work
7.4 ± 0.1	Stehn[1]
7.5 ± 0.3	Tattersall[2]
7.45 ± 0.15	Stoughton[3]
7.6 ± 0.16	Hubert[4]
7.55 ± 0.25	Wade[5]
7.31 ± 0.10	Myasischeva[6]

Table 2 Cross sections for $^{231}Pa(n,\gamma)^{232}Pa$ reaction to thermal neutrons

Cross section (barn)	Reference
201 ± 6	Present work
200 ± 10	Stehn[1]
260 ± 13	Aleksandrov[7]
200 ± 5	Simpson[8]
293	Bjornholm[9]
200 ± 15	Smith[10]

II-A-5.

Measurements and Analyses of Energy and Space Distributions of Fast Neutrons in Test Assemblies

Hiroshi Nishihara*, Itsuro Kimura, Katsuhei Kobayashi, Shu A. Hayashi, Shuji Yamamoto, Satoshi Kanazawa* and Masato Ando*

A part of this work was presented at the International Symposium on Physics of Fast Reactors at Tokyo in October 1973 and was published in its proceeding[1].

In order to assess the nuclear data or group constants of some important reactor materials, fast neutron spectra in these materials have been measured by the time of flight method using an electron linear accelerator as a pulsed neutron source and the results have been compared with the predicted ones which were obtained by theoretical calculations with several different group constants. The characteristics of the test assemblies and the methods of calculation are given in Table 1 and Table 2 respectively. A similar work on a stainless steel (SUS 304) assembly is now in preparation and will be carried out soon. Throughout the all measurements, spatial distribution of fast neutron flux and high energy photon flux around a lead photo-neutron target have been measured by activation of nickel wires and gold foils and the results have been also compared with the

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predicted values.

We regard the boronated graphite assembly as a standard neutron spectrum field which can be used to calibrate detection efficiency of a neutron detector, because it has simple components, carbon and boron and very small amount of water (0.12 w/o) and the nuclear data of these components are much more accurately known than other elements. As a matter of fact, neutron spectra which have been calculated by different codes with different group constants satisfactorily agree each other.

A bank of three 12.6 cm dia. ^{6}Li glass scintillation counters (NE-912 + EMI 9618 R) and a boron-vaseline counter were used for neutron detection as shown in Fig.1. The detection efficiency of both detectors has been calibrated by making use of the boronated graphite assembly.

A result for the lead assembly is shown in Fig.2. It can be seen that the measured spectrum in the lead assembly (r=20 cm, μ=0) agrees with those predicted by theoretical calculations.

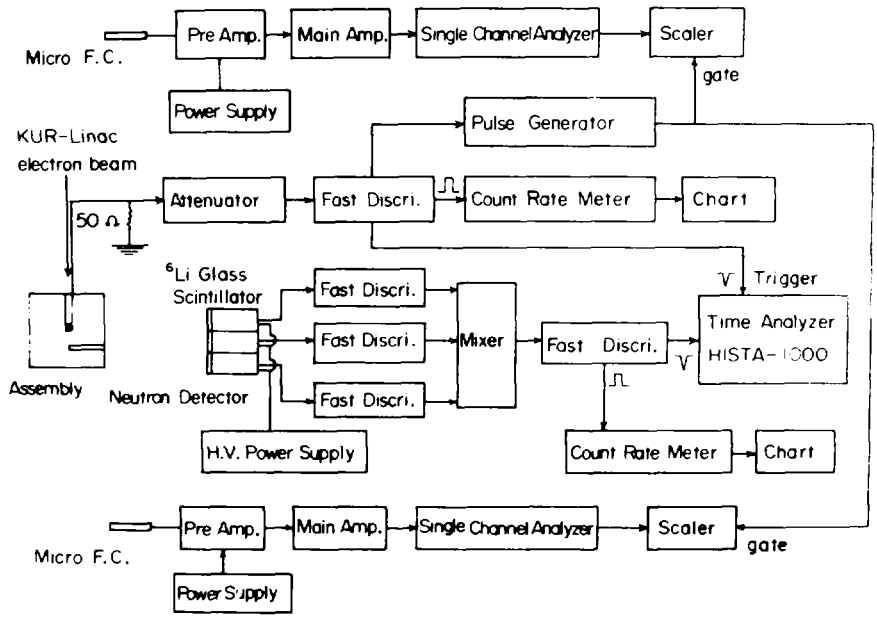
Table 1 Characteristics of Test Assemblies

Sample	Purity	Shape and size	Position and direction mainly measured
Boronated graphite	2.6 % boron in graphite	Rectangular prism 70cm x 70cm x 80cm	r=20 cm, μ=0.0
Iron	Soft steel	Rectangular prism 90cm x 1 m x 1 m	r=20 cm, μ=0.0 r=28 cm, μ=-0.7 r=28 cm, μ=+0.7 r=2, 10, 20, 40 cm, μ=1.0
Alumina	99.5 % al_2O_3	Powder packed in a spherical vessel of 60 cm diameter	r=15 cm, μ=0.0
Thoria	99.9 % ThO_2	Same above	r=15 cm, μ=0.0
Iron oxide	99.2 % Fe_2O_3	Same above	r=15 cm, μ=0.0
Lead	99.9 %	Cube 70cm x 70cm x 70cm	r=20 cm, μ=0.0 r=2, 10, 20, 30 cm, μ=1.0

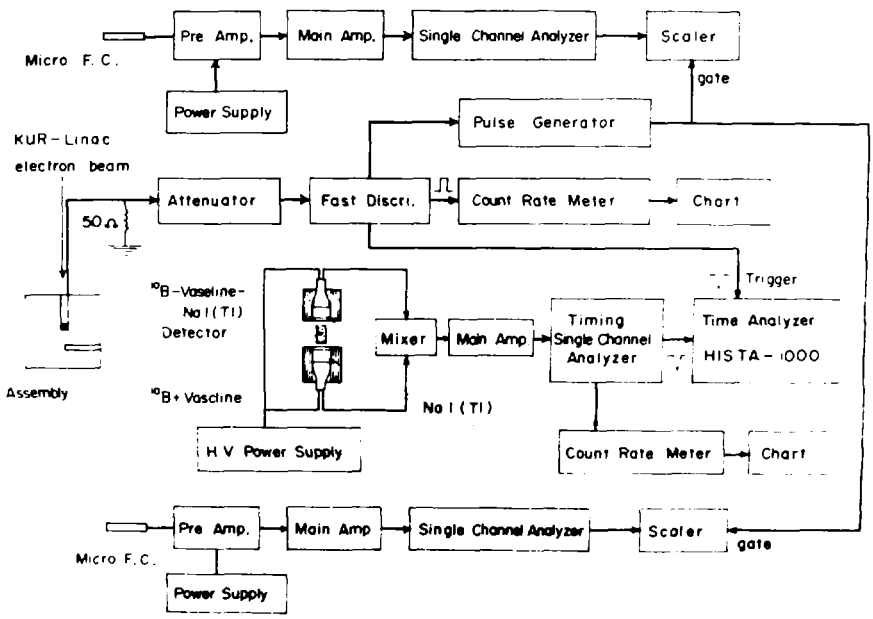
Table 2 Used computer codes and nuclear data

Sample	Computer code	Nuclear data
Boronated graphite	ANISN (Sn) DTF-IV (Sn)	RSIC-99* JAERI-FAST ABBN
Iron	ANISN (Sn) DTF-IV (Sn) CYGNUS (Monte Carlo)	RSIC-99* JAERI-FAST J-E** ABBN KFK-120
Alumina	DTF-IV (Sn)	JAERI-FAST ABBN
Thoria	DTF-IV (Sn)	J-M*** ABBN
Iron oxide	DTF-IV (Sn)	J-E** ABBN
Lead	ANISN (Sn)	RSIC-99* J-Pb**** ABBN

* 99 group constants, DLC-2, processed at Radiation Shielding Information Center (ORNL)
** Revised JAERI-FAST type 70 group constants made by Dr. Nakagawa
*** JAERI-FAST type constants for thorium
**** JAERI-FAST type constants for lead



(a)



(b)

Fig.1 Block diagrams of electronic circuits ;

(a) case of using a ^{6}Li glass scintillator bank

(b) case of using a ^{10}B-vaseline-NaI(Tl) detector

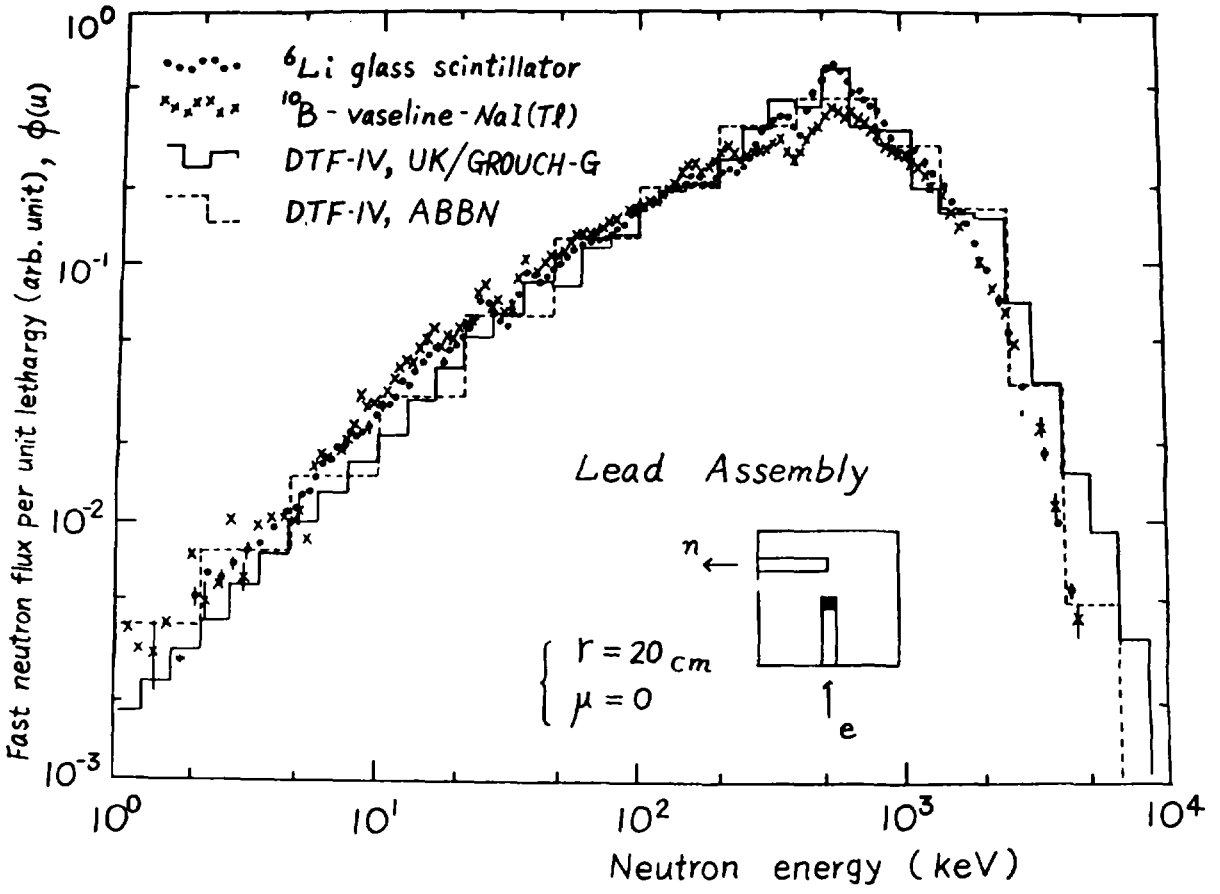


Fig.2 Fast neutron spectrum in the lead assembly

II-A-6. γ-ray studies in ^{106}Pd from the decay of ^{106}Ru

K. Okano, Y. Kawase and S. Yamada

In order to investigate the structure of higher-lying excited states in ^{106}Pd, γ-rays following the decay of 30sec ^{106}Rh which is in equilibrium with the 367day fission product ^{106}Ru have been investigated. Singles and coincidence spectra have been measured using 58 and 38 cc Ge(Li) detectors. γ-ray energies, relative intensities, decay scheme of γ-rays and energies of levels in ^{106}Pd have been determined. γ-γ angular correlations have been measured using two-NaI-one-Ge(Li) system with the NaI gates set at the 512 keV and 1.05 MeV peaks. Analyses have been performed on more than 25 cascades and the following spins were assigned to the levels in ^{106}Pd: 1562.3(2), 1706.5(0), 2001.6(0), 2242.5(2), 2278.1(0), 2308.8(2*), 2439.2(2), 2500.5(2*), 2624.6(0), 2828.5(0), 2878.0(0), 2902.6(2*), 2918.0(2*), 3054.7(1*), 3083.2(0*), 3163.5(0*), 3221.5(0), 3321.1(0*), all in keV. (The error in the level energies is about 0.15 keV). The spins marked with * are those newly determined by the present work. Others are in agreement with the results of previous works[1-4]. γ-ray multipolarities of several 2+ → 2+ transitions have also been determined.

A short note on this work appears in Annual Reports of the Research Reactor Institute, Kyoto University, vol.4(1974), and a full paper will also appear in near future.

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B. Institute of Atomic Energy

II-B-1. Independent Isomer Yields of Some Sb Isotopes in Thermal-neutron Fission of ^{233}U and ^{235}U

Tomota NISHI, Ichiro FUJIWARA, and Nobutsugu IMANISHI

Independent yields of ^{130}Sb and ^{132}Sb isomers in the thermal-neutron induced fission of ^{233}U and ^{235}U, and that of ^{128}Sb isomers for ^{233}U were measured by a radiochemical procedure.

A dilute solution of $UO_2(NO_3)_2$ containing 100 μg of ^{233}U or ^{235}U was irradiated in the Kyoto University Reactor for 30 sec. After the irradiation, the target solution was transfered in 10 ml of 6 M HCl containing each 10 mg of tin, antimony, tellurium, and strontium carriers.

Antimony was purified by distilling SbH_3 from a 6 M HCl solution in contact with metallic zinc-powder. SbH_3 was trapped into a 3 M HCl-Br_2 solution through a filter containing conced. NaOH solution to eliminate the tellurium contamination. Then Sb(V) was reduced to Sb(III) by addition of NH_2OHHCl, and Sb_2S_3 was precipitated by H_2S and mounted on a Millipore filter. The separation of antimony was carried out about 2 min after the end of irradiation. After the antimony separation, strontium was separated and used as a fission monitor.

After the chemical separation, γ rays emitted from the Sb samples were measured with a Ge(Li) detector.

The independent isomer yields were obtained by correcting the contribution to the measured activities due to the decay of precursors during the irradiation and the subsequent decay to the time of antimony separation. The results are shown in Table I.

Table I. Independent yields and isomer yield ratios of ^{128}Sb, ^{130}Sb, and ^{132}Sb. Cumulative yields of fission monitor and precursor are listed, too.

	Independent or cumulative* yield (%)					$\sigma_{high}/\sigma_{low}$
	^{92}Sr	Sn	Sb^m	Sb^g	Sb	
^{233}U-128 chain	6.6*[a]	0.62* ±0.04	0.050 ±0.005	0.070 ±0.004	0.12 ±0.006	1.40 ±0.017
^{233}U-130 chain		0.86* ±0.08	0.46 ±0.05	0.42 ±0.03	0.88 ±0.06	0.91 ±0.12
^{233}U-132 chain		0.11*[b]	1.09 ±0.10	0.43 ±0.04	1.60 ±0.11	0.40 ±0.06
^{235}U-130 chain	6.0*[a]	1.41* ±0.11	0.26 ±0.05	0.26 ±0.03	0.52 ±0.06	1.0 ±0.23
^{235}U-132 chain		0.55*[b]	1.62 ±0.20	0.97 ±0.10	2.59 ±0.22	0.60 ±0.09

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II-B-2. Excitation Functions for the Deuteron Induced Reactions on ^{64}Zn and ^{76}Ge

Tomota Nishi, Ichiro Fujiwara, Nobutsugu Imanishi, Hiromichi Nakahara*, and Hironobu Okamoto**

The paper on this subject was published in Bull. of the Insti. for Chem Res. Kyoto Univ. 52, 233 (1974) with an abstract as follows:

The excitation functions of $^{64}Zn(d,p)^{65}Zn$, $^{64}Zn(d,n)^{65}Ga$, $^{64}Zn(d,2n)^{64}Ga$, $^{64}Zn(d,\alpha)^{62}Cu$, $^{64}Zn(d,\alpha n)^{61}Cu$, $^{76}Ge(d,p)^{77}Ge$, $^{76}Ge(d,n)^{77}As$, $^{76}Ge(d,2n)^{76}As$, $^{76}Ge(d,\alpha)^{74}Ga$, and $^{76}Ge(d,\alpha n)^{73}Ga$ were studied with the radiochemical method. The experimental results were analyzed with the modified Peaslee theory. The ρ-values obtained by this analysis were compared with the previous works.

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III-1. Pre-Compound Decay from Fe (n,n') Reaction of 14.1 MeV Neutrons

Y. Irie, M. Hyakutake, N. Koori, M. Tsuji,
M. Matoba and M. Sonoda

Energy and angular distributions of neutrons from Fe (n,n') reaction were measured from 28° to 143° in about 10° steps at En=14.1 MeV by TOF method. The bias of the spectrometer was 1.0-1.5 MeV, the time resolution 2 ns and the flight path 1.5-1.8 m. The effect of multiple scattering to the shape of the obtained angular distributions was experimentally confirm -ed to be negligible.

Figure 1 shows the energy spectra of inelastically scattered neutrons for three laboratory angles. Figure 2 shows the comparison of the experimental energy spectrum N (En') with the compound and the pre-compound distri -butions given by Griffin's theory. It is seen that inelastic neutrons leading to low residual excitation energies below 8 MeV scatter predominantly in forward direction and show energy spectra attributed to the pre-compound distribution proposed by Griffin.

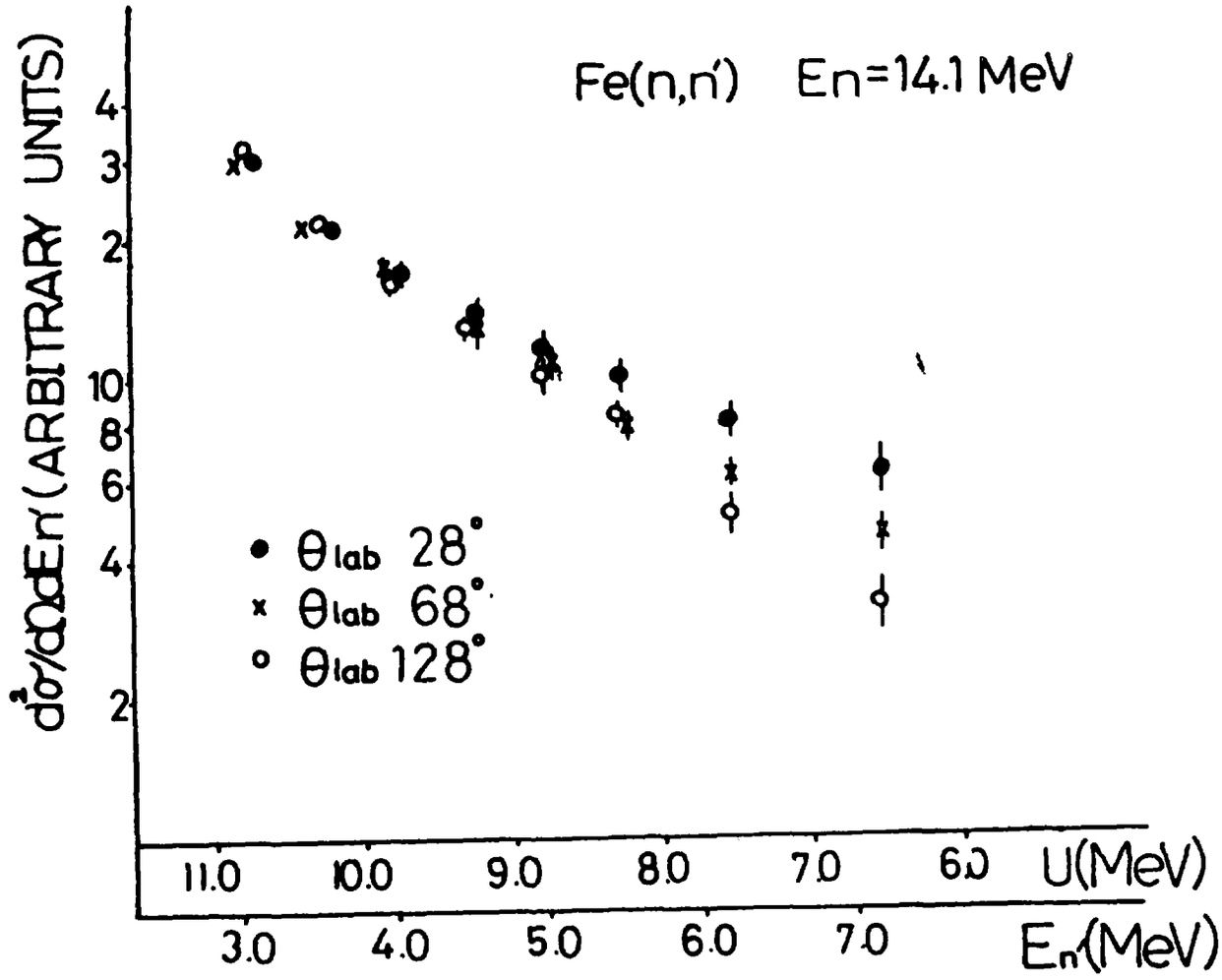

Fig. 1 Energy distributions of neutrons inelastically scattered from Fe. In abscissas, U is the residual excitation energy and En' the energy of scattered neutrons. The error bars indicate statistical errors only.

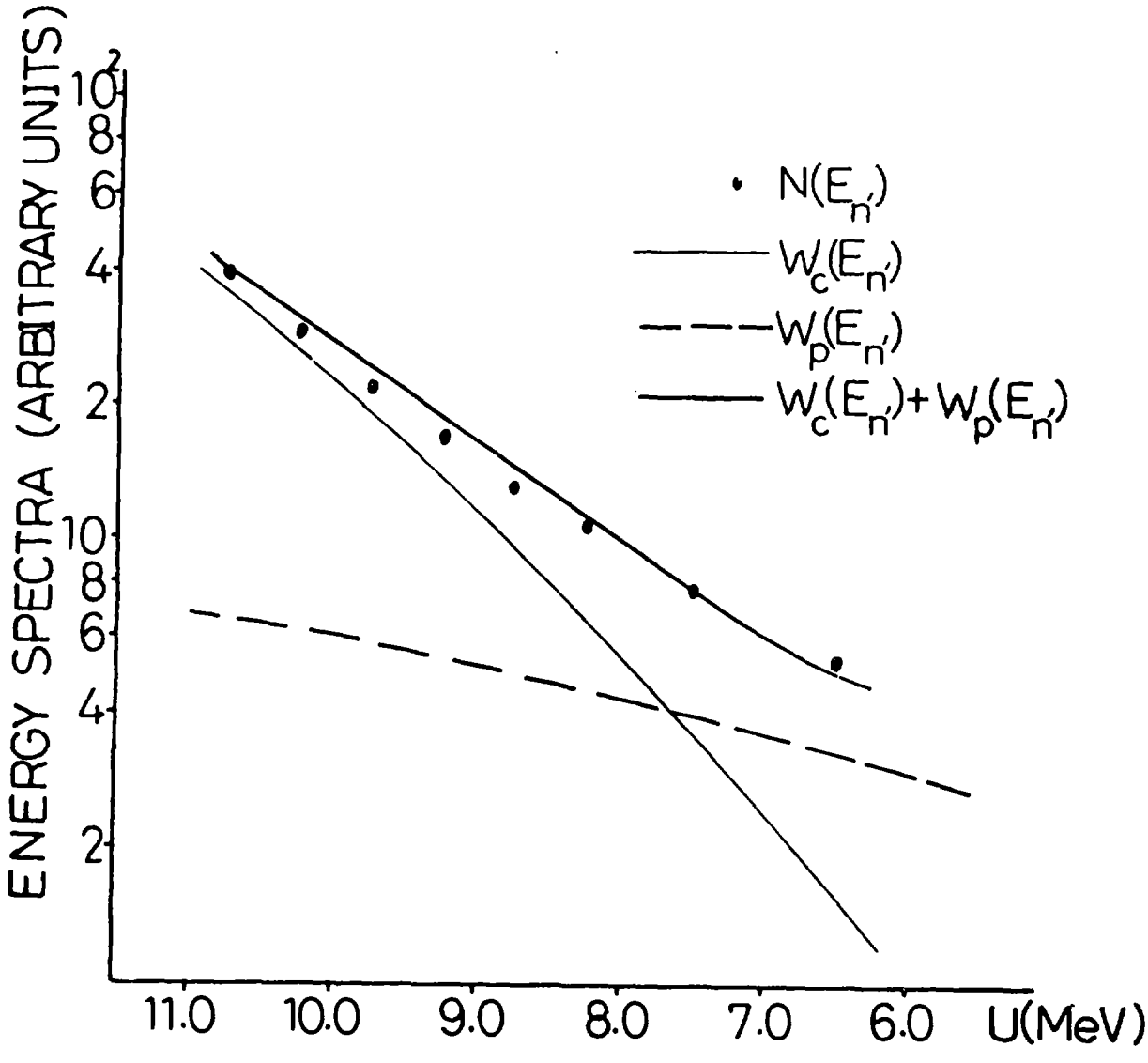

Fig.2. The comparison of the experimental energy spectrum N (En') with Griffin's theory. The compound distribution W_c (En') is normalized to N (En') in the high U region and the pre-compound distribution W_p (En') is normalized so that [N (En')-W_c (En')]/ W_p (En') is equal to unity in the low U region.

III-2. Pre-equilibrium proton emission in the In (n,p) reaction at 14 MeV

M. Matoba, J. Niidome*, N. Koori, M. Hyakutake,
Y. Irie and I. Kumabe

The In (n,p) reaction has been studied at 14.1 MeV using a semi-conductor detector telescope. The emitted proton spectra were obtained, which were analyzed with a statistical model and a pre-equilibrium model. The pre-equilibrium model reproduced well the emitted proton spectrum and the integrated cross section.

The integrated cross section of the In (n,p) reaction at 14.1 MeV is 18.1 ± 5.4 (mb).

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III-3. A new 14 MeV neutron time-of-flight spectrometer at the Kyushu University

M. Matoba, M. Hyakutake, T. Tonai*, J. Niidome**,
Y. Matsumoto and N. Kimura***

The full paper on the spectrometer reported in INDC (Jap) 17 L (1973) has been published in Nuclear Instr. and Meth. 116 (1974) 405.

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*** Present address: Kyushu Institute of Technology, Kitakyushu.

III-4. The Energy and Angular Distributions of Alpha Particles in the Fission of $^{252}Cf^{*}$

K. Tsuji, A. Katase, Y. Yoshida, T. Katayama,
F. Toyofuku and H. Yamamoto

The energy distributions of the alpha particle emitted in the fission of ^{252}Cf have been measured with the good angular resolution in order to investigate the dependence on the angle between the alpha particle and the light fragment. The energies of one of the fission fragments and the alpha particle and the time difference between the signals for the two particles were measured and recorded event by event. The time resolution was about 2 ns and the accidental events could be eliminated sufficiently. The light or heavy fragments were sorted by their kinetic energy.

The energy spectra were obtained at 9 angles from 65° to 105° and were well fitted by the gaussian distribution for the energy above about 13 MeV for each angle. The values of the most probable energy were found to take the minimum value of 14.0 MeV at 84° and increase rapidly with the angle on both sides of 84°. The width of the energy distributions was nearly independent of the angle and the FWHM value was about 8.6 MeV. The most probable angle of the alpha particle of the energy above 12.5 MeV with respect to the light fragment was found to be 84.3° and the FWHM value of the angular distribution was about 18°.

The energy distributions of the alpha particle were calculated by the Monte Carlo method in the three-point-charge approximation. In this calculation, the distributions of the mass ratio and the total kinetic energy were taken into consideration with the distributions of the initial emission position, initial kinetic energy and emission angle of the alpha particle. The energy spectra which were very similar to one measured at 90° were

obtained for some values from 21.5 fm to 26 fm of the distance Df between two fission fragments at the emission of the alpha particle. From the comparison of the calculated distribution with the experimental one for other angles, the value of about 22 fm for Df was seen to be preferable.

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* This report is the abstract of the paper (IAEA-SM-174/16) presented at the IAEA Third Symposium on the Physics and Chemistry of Fission held at Rochestser in August,1973.

III-5. Calculation of Radiative Capture Cross Section for ^{232}Th

Y.Kawamura, T.Ohsawa and M.Ohta

In an attempt to evaluate various types of cross sections of ^{232}Th for fast neutrons, radiative capture cross section has been calculated in the energy range from 10 keV to 2.5 MeV. This report presents some preliminary results of calculations based on the statistical model of nuclear reactions.

The cross section formula, as given by Margolis[1] on the basis of Hauser-Feshbach theory[2], is modified by including correction factor for width fluctuations, S[3]:

$$\sigma_{n\gamma}(E) = \frac{\pi \lambda\!\!\!^{-2}}{2(2I+1)} \sum_{\ell} T_{\ell}(E) \sum_{J} \left[\frac{\epsilon^{J}_{S\ell}(2J+1) f(E,E)}{1 + \xi^{J} f(E,0) \sum_{i,\ell'} \epsilon^{J}_{S'\ell'} T_{\ell'}(E-E_i)} S \right]$$

where

$$\xi^{J} = D^{J}(B_n) / 2\pi \Gamma^{J}_{\gamma}(B_n)$$

$$f(E,X) = \int_{X}^{B_n+X} E_{\gamma}^{3} \rho_{co}(B_n + X - E_{\gamma}) dE_{\gamma} \Big/ \int_{0}^{B_n+E} E_{\gamma}^{3} \rho_{co}(B_n + E - E_{\gamma}) dE_{\gamma}$$

$$S = \left\langle \frac{\Gamma_n \Gamma_{\gamma}}{\Gamma} \right\rangle \frac{\langle \Gamma \rangle}{\langle \Gamma_n \rangle \langle \Gamma_{\gamma} \rangle}$$

Other notations are those commonly used. Neutron transmission coefficients are calculated using an optical potential of the form

$$V(r) = V_c f_1(r) + i W_c f_2(r) + V_{SO} \left(\frac{\hbar}{m_\pi c} \right)^2 \frac{1}{r} \left| \frac{d f_1(r)}{dr} \right| (\vec{\sigma} \cdot \vec{\ell})$$

$$f_1(r) = \left\{ 1 + \exp[(r-R_1)/a] \right\}^{-1}, \quad f_2(r) = \exp\left\{ -[(r-R_2)/b]^2 \right\}$$

with the parameters obtained by the use of the code TOTAL[4]:

$$V_c = 41.37 \text{ MeV}, \quad W = 6.24 \text{ MeV}, \quad V_{so} = 7.00 \text{ MeV}$$

$$R_1 = 1.32A^{1/3}, \quad R_2 = 1.33A^{1/3}, \quad a = 0.47, \quad b = 1.0$$

Level density formula and its parameters are taken from ref.5, and level scheme for ^{232}Th reported in ref.6 is adopted here.

Calculations are performed using a code RACY-S[7] with some modifications and by treating ξ^J as an adjustable parameter. The correction for width fluctuations is taken into account only up to 150 keV, since S is known to approach unity with the increase of the number of exit channels. Results are shown in the figure together with experimental data of several authors. The solid line represents the values with width fluctuation correction, the broken line those without the correction.

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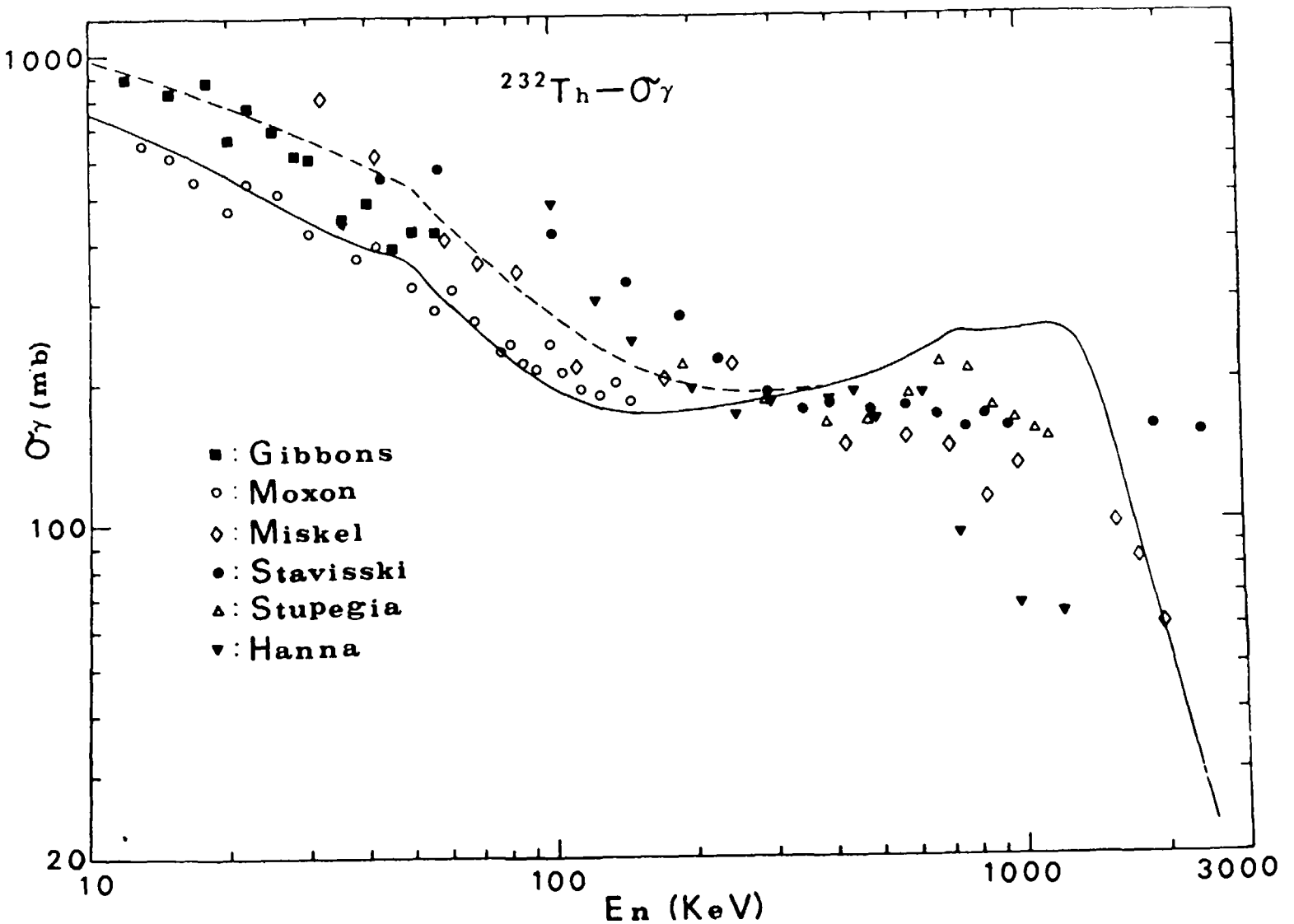

Calculated radiative capture cross section for ^{232}Th compared with experimental data taken from NEUDADA-file.

IV. Nagoya University
Department of Nuclear Engineering

IV-1. Decay of ^{170}Ho Isomers to Levels in ^{170}Er

Kiyoshi KAWADE, Akira HIEI, Hiroshi YAMAMOTO,
Susumu AMEMIYA, and Toshio KATOH

A paper on this subject was published in J. Phys. Soc. Japan 36 (1974) 1221.

Beta- and gamma-rays in the decay of ^{170}Ho isomers have been studied with Ge(Li), NaI(Tl) and plastic detectors. Sources were prepared by the ^{170}Er(n, p)^{170}Ho reaction with about 15 MeV neutrons. Fifty gamma-rays have been observed and thirty-six of them are assigned to the ^{170}Er level scheme including seven new levels at 1010.5, 1217.3, 1900.5, 1982.6 2039.3, 2684.8, and 3606.2 keV. The most probable spin assignments of $1^{\pm}$ and $4^{\pm}$ are proposed for the 43 sec and 2.8 min ^{170}Ho, respectively. Both Q_{β} values are 4.0 $\pm$ 0.2 MeV. The K = 0 assignment for the 2^{+} state at 959.8 keV is proposed from the E2 branching ratios to the ground-state band. It is found that the relative B(E2) values from gamma-vibrational band can not be explained by a single value of the band mixing parameter z_2.

IV-2. Decay of ^{154}Pm to Levels of ^{154}Sm

Hiroshi YAMAMOTO, Kiyoshi KAWADE, Hiroyasu FUKAYA, and Toshio KATOH

A paper on this subject was published in J. Phys. Soc. Japan 37 (1974) 10.

Decay of ^{154}Pm isomers has been studied with Ge(Li), NaI-(Tl) and plastic detectors. Sources were prepared by the ^{154}Sm (n, p)^{154}Pm reaction with about 15 MeV neutrons. Seventy-five gamma-rays have been observed and 57 of them are assigned to the ^{154}Sm level scheme including four new levels at 1815.8, 1879.3, 2592.3, and 2618.8 keV. Observed Q_β values were 3.9 $\pm$ 0.2 MeV. Most probable spin assignments of $0^\pm$ or $1^\pm$ and $3^\pm$ or $4^\pm$ are proposed for 1.7 $\pm$ 0.2 min and 2.9 $\pm$ 0.2 min ^{154}Pm, respectively.

V. Tokyo Institute of Technology
Research Laboratory of Nuclear Reactor

V-1. Precise Measurements of Neutron Capture Cross Section Near 24 KeV.

N. Yamamuro, T. Doi, T. Hayase, Y. Fujita*
K. Kobayashi* and R. C. Block**

Precise measurements of 24 KeV neutron capture cross section have been carried out with the Fe-filtered beam technique using the KUR 46 MeV electron linear accelerator. A pair of C_6F_6 scintillation countor is used as a γ-ray detector at 12 m flight path. The intensity of neutron flux can be measured by the same detector by replacing capture sample with ^{10}B sample. To determine the absolute flux and the detection efficiency, 5.2 eV saturating resonance in Ag and the spectrum weighting technique are applied.

It is expected that the 24 KeV neutron capture cross sections of Nb, Ag, I, Ho, Au and ^{238}U are obtained within the statistical accuracy of 3~5%.

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V-2. Measurements of the Radiative Capture Cross Section for 15.2-MeV Neutrons

H. Kitazawa, K. Sakurada and N. Yamamuro

We have constructed a plastic scintillation detector for 14-MeV neutron capture gamma rays. The detector measures the capture gamma spectrum through the detection of a pair of electrons produced in a thin lead foil. The observed cross sections were 1.19±0.20 mb for natural Fe and 2.10±0.36 mb for natural Cr. The observed gamma spectra were also compared with the ones predicted by the collective capture model.