601

NOT FOR PUBLICATION

INDC(JAP) 17 L
EANDC(J) 30 L

PROGRESS REPORT

(July 1972 to June 1973 inclusive)

September 1973

edited by

T. Momota

aided by

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 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 the 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, 1972 to June 30, 1973. The information herein contained is of a nature of "Private Comminucation." No data contained in this report should be quoted without author's permission.

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I. Japan Atomic Energy Research Institute

A. Neutron Experiments-LINAC

I-A-1. Neutron Cross Section Measurements

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

The transmission measurements on natural uranium samples with a 190-m flight path are in progress. The neutron source target is composed of a water cooled tantalum and lead lamination with a borated paraffin reflector. The flight path tubes are filled with helium with Lumirror (mylar equivalent) windows. The neutron detector has been recently improved from a composition of four 5-inch-diameter ^{6}Li-glass scintillators to that of seven ones.

The capture cross section measurements on Ta and Au(as a reference) are under way with a 3,500ℓ liquid scintillator at about 50 m flight length. The window material for the evacuated flight path tube for this system is recently changed to Lumirror film from aluminum plate, after a practical test for rupture of the Lumirror films. The measurements on ^{151}Eu, ^{153}Eu, and ^{53}Cr are under contemplation with an agreement for lease of the enriched samples by the USAEC, but a technical contact on the actual sample preparation has not been started yet because of the business procedure.

The scattering cross section measurements are started with W samples at 45 m flight length using ^{6}Li-glass and ^{7}Li-glass scintillators. A detector system for simultaneous measurements at four scattering angles is under construction.

I-A-2. Slow Neutron Resonances of Antimony

M. Ohkubo, Y. Nakajima, A. Asami and T. Fuketa

The result of neutron transmission measurements on antimony with the former 20-MeV linac was published in J. Phys. Soc. Japan, 33 (1972) 1185-1196 with an abstract as follows :

The total neutron cross section of natural antimony has been measured by the transmission method using the time-of-flight spectrometer of the JAERI linear accelerator with the maximum time resolution of 10 nsec/m. The resonance energies of about 100 levels below 1400 eV have been determined. The neutron widths of 47 levels below about 400 eV and the total widths of 11 levels out of those 47 levels have been obtained by the area analysis and the thick-thin method. The isotope assignments of resonances by others are utilized in the analyses. The average level spacings and the strength functions for the energy region below 350 eV are obtained to be $\langle D\rangle=7.5\pm0.5$eV and $S=(0.26\pm0.06)\times10^{-4}$ for natural Sb, $\langle D\rangle=11\pm1$eV and $S_0=(0.23\pm0.07)\times10^{-4}$ for ^{121}Sb, and $\langle D\rangle=25\pm3$eV and $S_0=(0.28\pm0.1)\times10^{-4}$ for ^{123}Sb, respectively.

B. Neutron Experiments-Van de Graff Accelerator

I-B-1. Elastic and Inelastic Scattering of 17.96 MeV Neutrons from Carbon

Y. Yamanouti and S. Tanaka

Differential cross sections in an angular region from 20° - 155° in the lab system for both elastic and inelastic neutron scattering by carbon have been measured at an incident energy of 17.96 MeV. The 2^+ (Q=-4.43 MeV) level and 3^- (Q=-9.64 MeV) level were resolved by using a multi-angle time-of-flight spectrometer. The results were corrected for multiple scattering in the sample. The elastic scattering data were analyzed by the local optical model in its conventional form, and a coupled-channel analysis for the elastic and inelastic scattering is now in progress.

I-B-2. Fast Neutron Scattering from ^{94}Mo and Natural Molybdenum

S. Tanaka and Y. Yamanouti

The angular distributions of neutrons elastically and inelastically scattered from ^{94}Mo and natural molybdenum were measured in the energy range of 5.16 to 8.03 MeV with about 1-MeV steps. The measurement was done by using a multi-angle time-of-flight spectrometer with four 5" detectors and flight paths of 8 m. The ^{94}Mo sample was a metalic cylinder of 2 cmø x 2.2 cm and the molybdenum sample a hollow cylinder of (3.5-1.2) cmø x 3 cm. The inelastic cross sections were obtained for the first excited level of ^{94}Mo and for the combined first excited levels of molybdenum even-even isotopes from ^{94}Mo to ^{100}Mo.

Multiple scattering corrections in the samples are not yet made, and the data are in a preliminary stage. For ^{94}Mo, however, those corrections will not be large because of a small size of the sample. As an example, the differential cross section data for elastic scattering by ^{94}Mo is shown in Fig. 1.

The authors are greatly indebted for the use of the ^{94}Mo sample in the ORNL pool by the courtesy of EANDC and US AEC.

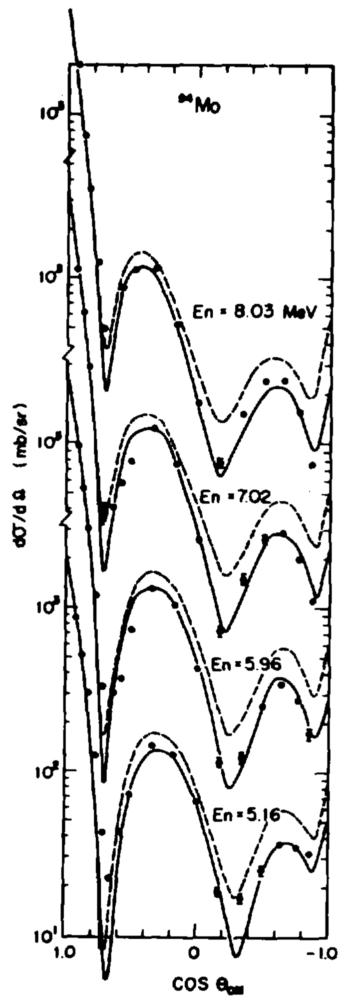


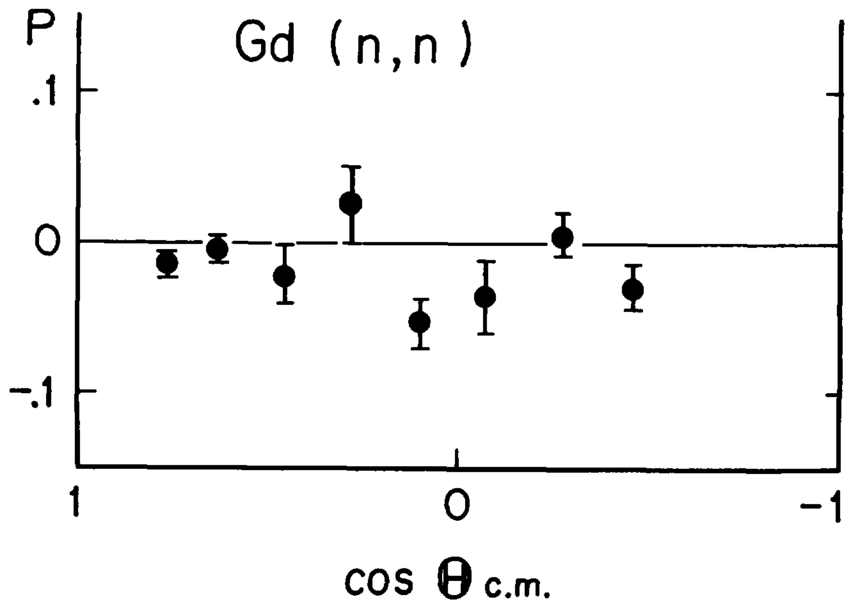
Fig. 1. Differential cross sections for elastic scattering by ^{94}Mo. The solid and dashed curves are cross sections calculated with the coupled-channels theory and with the spherical optical model, respectively. The optical potential used is the same as in "Optical Model Analysis for Neutrons Using the Coupled-Channels Theory" of this report.

I-B-3. Polarization of Neutrons Scattered by Gd

Y. Tomita, S.Tanaka, M.Maruyama, S.Kikuchi, K.Ideno, Y.Yamanouchi

and Y.Sugiyama

The polarization of neutrons elastically scattered by Gd was measured at E_n=1.5MeV and at angles between 40.3° and 116.5° by the time-of-flight method with a flight path of 3.6 m. The measurement was made using the partially polarized neutrons from the ^{3}T(p,n) reaction at 33.5° (P_0=35%) and a spin-flipping superconducting solenoid. Since the ground state and the first excited state at about 80 keV could not be resolved, the measured polarization includes the contribution of the first excited state. The measured values are shown in the figure.



.-B-4. Neutron Scattering from ^{207}Pb

Y. Tomita, S. Tanaka and M. Maruyama

Elastic and inelastic scattering of neutrons by ^{207}Pb was investigated. Excitation functions were measured in the energy range 1.37 - 3.56 MeV. No distinct intermediate structure was observed. Angular distributions were measured at five energies between 1.47 and 3.56 MeV. The results were analyzed by the optical model and Moldauer's theory, and values of the optical-potential parameters were determined.

The authors are greatly indebted to EANDC and US AEC for the use of a ^{207}Pb sample in the ORNL pool.

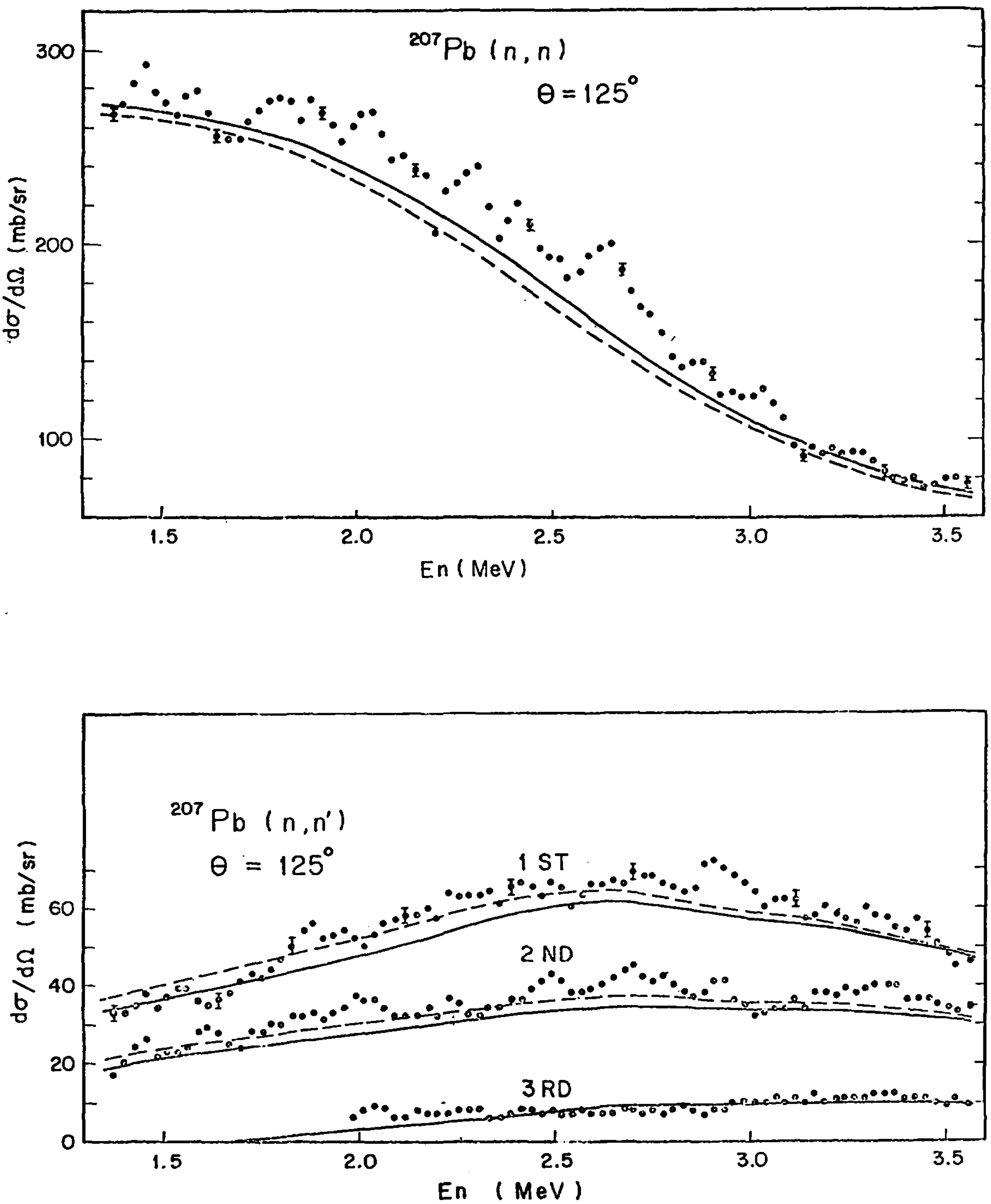
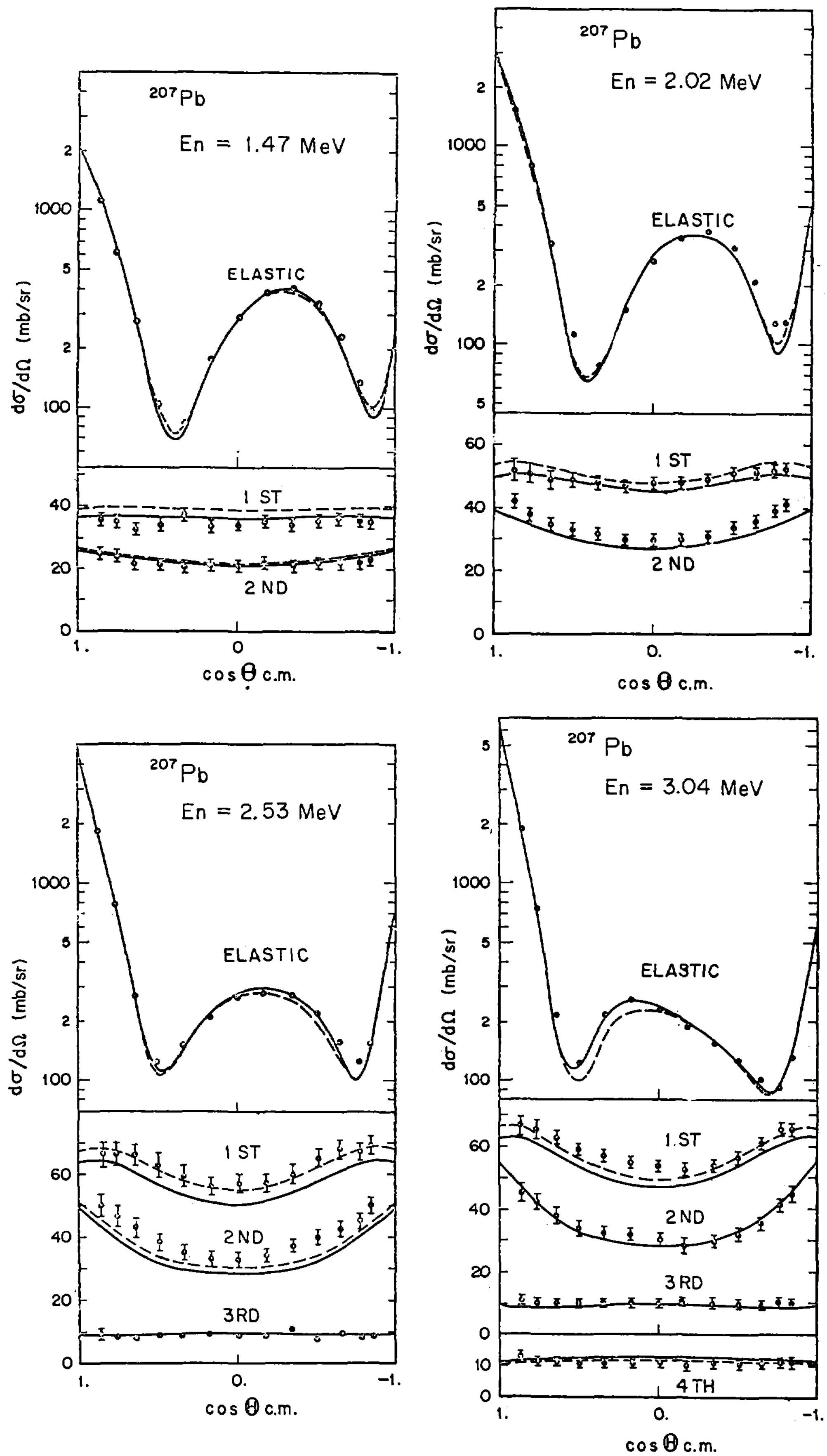


Fig. 1. Excitation functions observed at a scattering angle of 125°. Solid and broken lines represent the calculations with the parameters given in (2) and (3), respectively.

(a) elastic scattering

(b) the first, second and third excited states



^{207}Pb
En = 1.47 MeV
ELASTIC
1 ST
2 ND
^{207}Pb
En = 2.02 MeV
ELASTIC
1 ST
2 ND
^{207}Pb
En = 2.53 MeV
ELASTIC
1 ST
2 ND
3RD
^{207}Pb
En = 3.04 MeV
ELASTIC
1.ST
2ND
3RD
4TH
dσ/dΩ (mb/sr)
cos θ c.m.

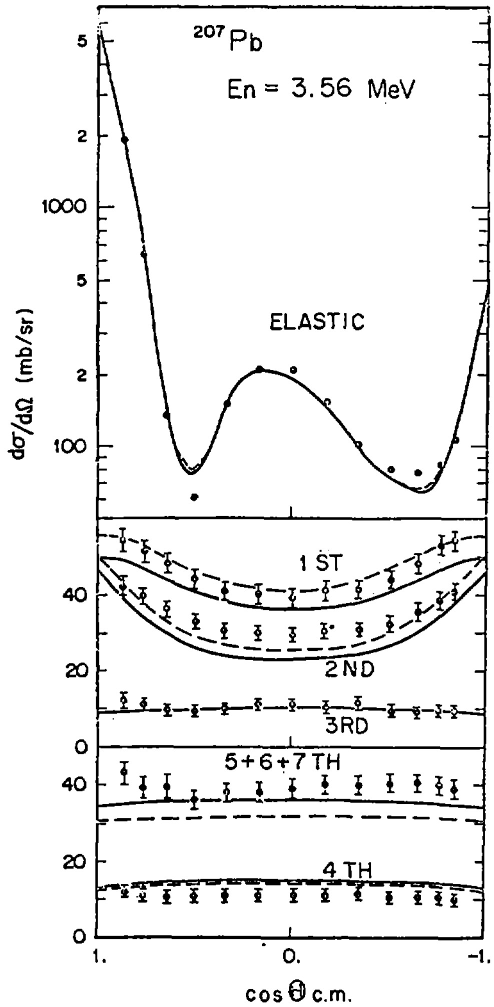


Fig. 2. Angular distributions for elastically and inelastically scattered neutrons. Solid lines are the best-fits of the optical model and Moldauer's theory. Broken lines represent the calculations with the parameters given in (3).

I-B-5. Optical Model Analysis for Neutrons Using the Coupled-Channels Theory

S. Tanaka

It has been demonstrated[1)] that the angular distributions of elastically scattered neutrons for rare-earth nuclei such as ^{139}La, ^{141}Pr, Er calculated with the coupled-channels theory[2)] fit the experimental data better than those calculated with the spherical optical model. The analysis using the coupled-channels theory has been extended to other nuclei and also to higher energy region, and the comparison with experimental data was made for the total cross sections as well as for the scattering cross sections.

All the calculations in the present analysis are based on an optical potential with one set of parameter values, which had been obtained from a comparison of spherical-optical-model calculations and experimental data for the scattering cross sections of ^{209}Bi in the energy range of 0.25 to 14 MeV. The optical potential and its parameter values used in the present analysis are as follows:

$$-V\frac{1}{1+\exp[(r-R)/a]}-4iW\frac{\exp[(r-R)/b]}{\{1+\exp[(r-R)/b]\}^2}$$
$$-V_{so}(\vec{\sigma}\vec{l})\lambda_\pi^2\frac{1}{ar}\frac{\exp[(r-R)/a]}{\{1+\exp[(r-R)/a]\}^2},$$

$V = 51.85 - 0.33E - 24(N-Z)/A$ (MeV), $a = 0.65$ (fm),

$W = \sqrt{2.55\,E}$ (MeV), $b = 0.48$ (fm),

$V_{so} = 7.0$ (MeV),

$R = 1.25\,A^{\frac{1}{3}}$ (fm).

In the coupled-channels calculations, the couplings between ground levels and low-lying levels are considered in the form of complex coupling. The values of the deformation parameters were taken from ref. 3).

The comparisons of the calculations with the scattering data were made for Fe, Ni, Zn, ^{120}Sn and Gd in the energy range of 1.5 to 8 MeV, in case there were experimental data available. This part of the analysis has been reported elsewhere[4,5], although some values of the optical parameters are a little different from the present ones, and good results are shown for the coupled-channels calculations.

The comparisons with elastic data at 8 MeV[6] were also made for ^{27}Al, S, Ca, V, Cr, ^{55}Mn, Fe, ^{59}Co, Ni, Cu, Zn, ^{75}As, ^{93}Nb, Mo, Cd, ^{113}In, Sb, Hf, ^{181}Ta and ^{197}Au. In general, better agreements with the experimental data were obtained for the coupled-channels calculations in the cases of the heavier nuclei than Cr with the present values of the optical parameters.

As for the total cross sections, the calculations were made for 35 elements from ^{23}Na to ^{239}Pu in the energy range of 0.25 to 15 MeV, and good results were obtained in almost all cases with the coupled-channels calculations. Fig. 1 shows examples of the results for some typical nuclei.

At present, further analysis is progressing.

References:

1) S. Tanaka, Y. Tomita, K. Ideno and S. Kikuchi, Nucl. Phys. A179 (1972) 513.

2) T. Tamura, Rev. Mod. Phys. 37 (1965) 679.

3) P. H. Stelson and L. Grodzins, Nuclear Data A 1 (1963) 21.

4) S. Tanaka, Topical Discussion in the 5th Meeting of INDC, Vienna, 1972, p. 51.

5) S. Tanaka, JAERI 1228 (1973) p. 106.

6) B. Holmqvist and T. Wiedling, AE - 430 (1971); Nucl. Phys. A188 (1972) 24.

7) D.G. Foster, Jr. and D. W. Glasgow, Phys. Rev. C3 (1971) 576; D. W. Glagow and D. G. Foster, Jr., Phys. Rev. C3 (1971) 604.

8) D. J. Hughes and R. B. Schwartz, BNL 325 (1958); M. D. Goldberg, S. F. Mughabghab, B. A. Magurno and V. M. May, BNL 325, 2nd Ed., Supplement No. 2 (1966).

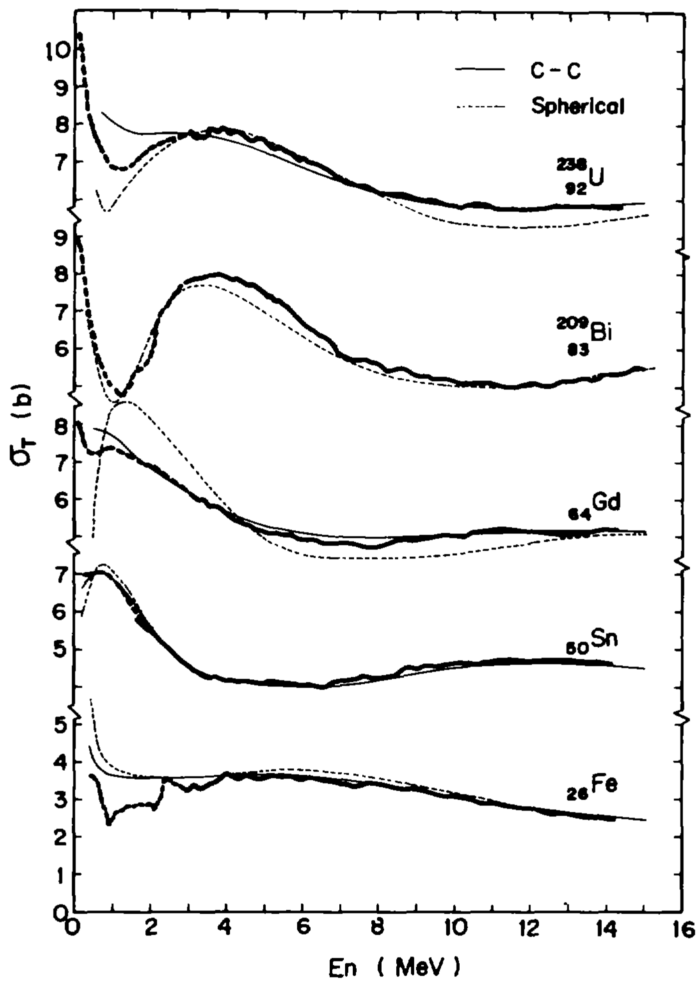
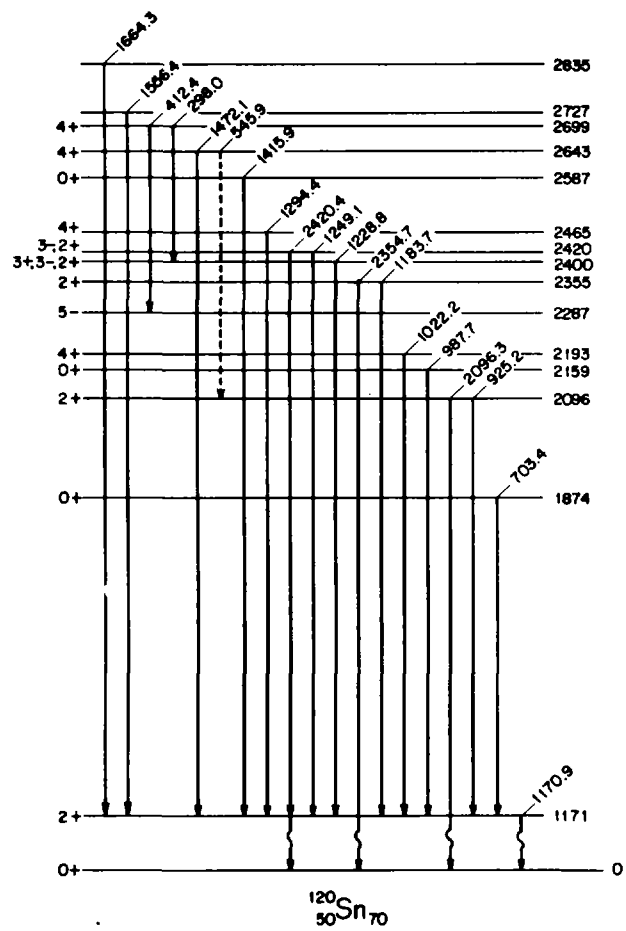


Fig. 1. Comparison between the experimental and calculated total cross sections. Thick solid curves are the data of Foster and Glasgow[7] and thick dotted curves are cited from BNL 325, 2nd Edition and its Supplement[8]. Thin solid curves represent the coupled-channels calculations and thin dotted ones the spherical-optical-model calculations.

I-B-6. Study of Energy Levels of ^{120}Sn through the $(n,n'\gamma)$ Reaction

S. Kikuchi and Y. Sugiyama

The energy levels of ^{120}Sn have been studied by high resolution measurements of γ-rays from the $(n,n'\gamma)$ reaction in the energy region 2.0 - 3.1 MeV. Fifteen levels of 1171, 1874, 2096, 2159, 2193, 2287, 2355, 2400, 2420, 2465, 2587, 2643, 2699, 2727 and 2835 keV have been determined, and the spin-parity values have been assigned to eleven of these fifteen levels. The spin assignments have been made by comparing the observed angular distributions of γ-rays and level excitation functions with those calculated on the basis of the statistical theory. The level scheme obtained is shown in fig. 1.



C. Others

I-C-1. Review on the Fission Cross Section of ^{235}U

Kazuaki Nishimura

The paper on this subject was published in JAERI 1228 (in Japanese) with an abstract as follows.

The experimental data of fission cross section of ^{235}U, which is important as one of the standard neutron cross sections, have been reviewed in the energy region from 100 eV up to 20 MeV. The reference compiled are classified into three data groups; i.e., 1) VDG data, 2) LINAC data, and 3) BOMB data. The names of authors, published year, and experimental errors reported are tabulated separately in the three data groups. In order to display the status of discrepancies among various experimental data, the values of the fission cross sections are plotted in the following five energy regions: 1) 100 eV - 100 keV, 2) 5 - 50 keV, 3) 50 - 300 keV, 4) 500 keV - 1.2 MeV and 5) 0.1 - 20 MeV, respectively. There are some LINAC or BOMB data including more than 60 data points in one experiment, and they are not plotted in the present review. The experimental data plotted are compared with the evaluation curve of Konshin and Nikolaev, as well as with Davey's one. The main origin of experimental errors in VDG data, normalization problem in LINAC data, and flux standards in BOMB data are investigated, respectively, to clarify the problem of evaluation for the fission cross section of ^{235}U.

I-C-2. SALLY (program for farmat conversion from ENDF/A to ENDF/B)

Tsuneo Nakagawa

Using this program, data in ENDF/A format are converted to ones in file 1, file 3, file 4 and file 5 of ENDF/B format.

This program is written in FORTRAN IV for FACOM 230-60 in JAERI. Requested core size is about 40K words. Typical running time in CPU, for example obtaining 1000 cards, is about 100 sec. The running time will be faster if arrangement of input data is in good order.

Debugging of this program is in progress.

I-C-3. Nuclear Resonance Scattering from Tin using Thermal-Neutron-Capture Gamma-Ray in Lead

Y. Kawarasaki

Re-measurement of the nuclear resonance scattering from natural tin using thermal-neutron-capture gamma-ray in natural lead[1)] was carried out by means of an improved measurement system[2)].

A whole measurement contains; 1) temperature variation of the tin scatterer from 18°C to 418°C by a step of 50°C, 2) angular distribution of the elastic peak at the angles of 90° to 135°, 3) transmission of the incident gamma-ray with the tin absorber of thickness upto 210 mm and 4) search of inelastic and/or cascade lines in much closer geometry.

From the result of the angular distribution measurement which shows the spin sequence of 0-1-0 and the presence of the cascade gamma-ray of 1171 keV, it is found that the isotope responsible for the resonance scattering should be Sn-120.

From the result of the transmission measurement, it is found that the resonance level is excited by the capture gamma-ray of 6731 keV following neutron capture in Pb-204[3)].

Further analysis for level width and energy of separation, and effective scattering cross-section is now in progress.

References:

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

2) Y. Kawarasaki: to be published

3) E. T. Jurney, H. T. Motz & S. H. Vergors; Nucl. Phys. A94 (1967) 351

I-C-4. Studies on Semiconductor Proton Recoil Counters

H. Gotoh, H. Yagi, Y. Harayama, K. Kobayashi*and I. Kimura*

Some progress was made on the study of neutron detectors for the absolute measurement of neutron flux. The authors(Gotoh,Yagi,Harayama) worked on the calculation method for the response function of the semiconductor proton recoil counter shown in Fig. 1. Deriving a new indefinite integral formula, the authors succeeded in representing the response function $n(E_p)$ of the counter with a radiator of finite thickness in a form of single numerical integration:

$$n(E_p) = 2n\cdot N\cdot\sigma(E_n)\cdot\frac{dR(E)}{dE}\bigg|_{E=E_p}\int_{\theta_{min}}^{\theta_{max}} \sin\theta\cdot\cos^2\theta\cdot f(\theta)\cdot d\theta, \qquad (1)$$

where $f(\theta)$ is an elementary function of the angle θ. Details on the calculation method will be seen in Nucl. Instr. Meth[1].

Further study including experimental works is now in progress.

Reference:

1) H. Gotoh, H. Yagi, Y. Harayama, Nucl. Instr. Meth. 109(1973)349-354

* Research Reactor Institute, Kyoto University

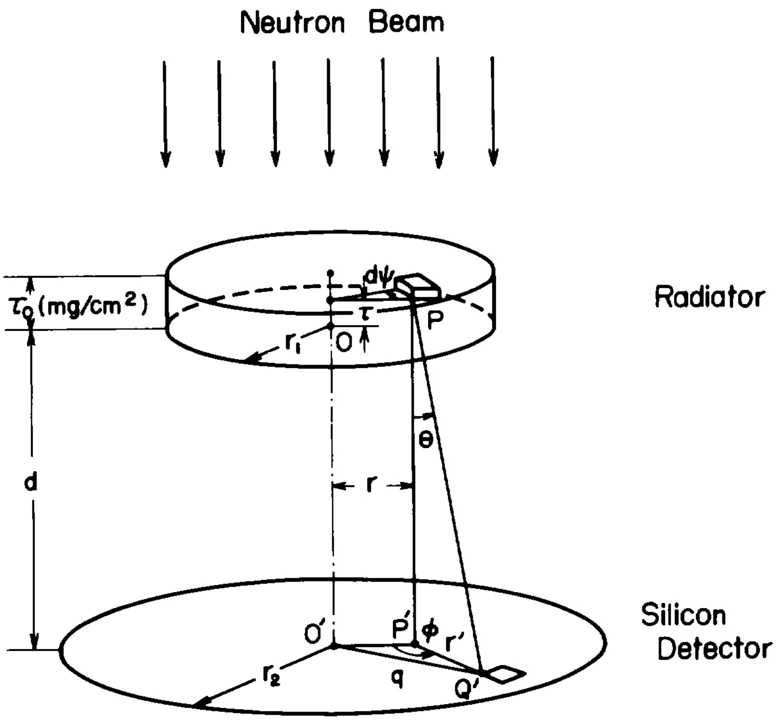


Fig. 1

A proton recoil counter with a radiator of finite thickness

I-C-5. Calculation of the Reaction Rate in a Cylindrical Sample Induced by a Cylindrical Fast Neutron Source

H. Gotoh, H. Yagi, K. Kobayashi*and I. Kimura*

Experimental arrangements, where a disc-shaped or cylindrical sample is irradiated by a disc-shaped or cylindrical fast neutron source, are widely used in the works of cross section measurement. The authors succeeeded in deriving simple and exact analytical expressions for the calculation of the reaction rate in the sample under the condition, that the emission of neutrons can be regarded as isotropic within the solid angle anticipated,

* Research Reactor Institute, Kyoto University

that the source and the sample possess a common axis, and that the attenuation effect and the multiple scattering effect of neutrons in the source and in the sample can be neglected.

For the disc-disc geometry shown in Fig. 1, the reaction rate is represented as

$$A(h,r_1,r_2,0,0) = \frac{Nn\sigma}{4\pi}\cdot\{\frac{1}{r_2^2}\cdot\ln[g(r_1/h,r_2/h) - \frac{r_1^2}{h^2}] + \frac{1}{r_1^2}\cdot\ln[g(r_1/h,r_2/h) - \frac{r_2^2}{h^2}]$$

$$- [h^2\cdot g(r_1/h,r_2/h)]^{-1}\}, \qquad (1)$$

where

$$g(r_1/h,r_2/h) = \frac{1}{2}\cdot\{[(1 + \frac{r_1^2}{h^2} + \frac{r_2^2}{h^2})^2 - 4\cdot\frac{r_1^2}{h^2}\cdot\frac{r_2^2}{h^2}]^{1/2} + 1 + \frac{r_1^2}{h^2} + \frac{r_2^2}{h^2}\}, \qquad (2)$$

N is the total emission rate of neutrons from the source, n is the total number of target nuclei in the sample, and σ is the reaction cross section.

For the cylinder- cylinder geometry shown in Fig. 2, the reaction rate is written as

$$A(h,r_1,r_2,t_1,t_2) = \frac{1}{t_1\cdot t_2}\cdot\{\int_0^{\min(t_1,t_2)} A(h+z,r_1,r_2,0,0)\cdot z\cdot dz$$

$$+ \int_{\min(t_1,t_2)}^{\max(t_1,t_2)} A(h+z,r_1,r_2,0,0)\cdot\min(t_1,t_2)\cdot dz$$

$$+ \int_{\max(t_1,t_2)}^{t_1+t_2} A(h+z,r_1,r_2,0,0)\cdot(t_1+t_2-z)\cdot dz\}. \qquad (3)$$

When $r_1 = r_2$ (= r), the formula (3) is simplified:

$$A(h,r,r,t_1,t_2) = \frac{Nn\sigma}{4\pi t_1 t_2 r}\cdot\{r[I_1(h)-I_1(h+t_1)-I_1(h+t_2)+I_1(h+t_1+t_2)]$$

$$-hI_2(h)+(h+t_1)I_2(h+t_1)+(h+t_2)I_2(h+t_2)-(h+t_1+t_2)I_2(h+t_1+t_2)\}, \quad (4)$$

where

$$I_1(z) = -\frac{z^2}{r^2}\cdot\ln(\frac{\eta+1}{2}) + \ln[\frac{2r}{z(\eta+1)}] + \frac{\eta+2}{(\eta+1)^2}, \quad (5)$$

$$I_2(z) = -\frac{2z}{r}\cdot\ln(\frac{\eta+1}{2}) + \frac{4r}{3z(\eta+1)}\cdot(4 + \frac{1}{\eta+1}), \quad (6)$$

$$\eta = (1 + \frac{4r^2}{z^2})^{1/2}. \quad (7)$$

A paper on the subject will be submitted to Nucl. Instr. Meth.

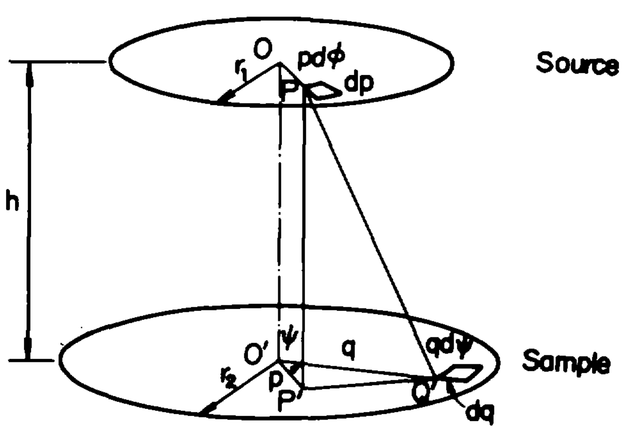


Fig. 1

Experimental arrangement for a disc source and a disc sample

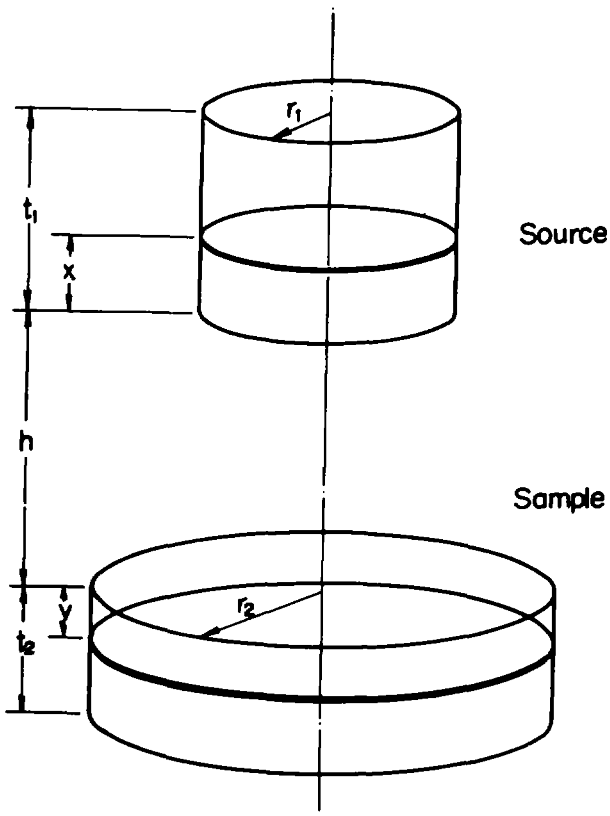


Fig. 2

Experimental arrangement for a cylindrical source and a cylindrical sample

D. Japanese Nuclear Data Committee

I-D-1. Activity of the Nuclear Data Evaluation Working Group

H. Matsunobu* and others (Evaluation of Nuclear Data Working Group)

The object of this group is to prepare the evaluated nuclear data which are required for fast reactor design. At present, the following three works are in progress in each sub-sorking group.

1) Evaluation of the nuclear data for 235U, 238U, 239Pu, 240Pu, and 241Pu

In this sub-working group, evaluation works on the nuclear data (σ_t, σ_f, σ_c, σ_{el}, σ_{in}, $\sigma_{n,2n}$, $\sigma_{n,3n}$, α, ν, and η) in the energy range from 1 keV to 15 MeV are being performed on the basis of the experimental data compiled by other working group for the above-mentioned nuclides.

The interim results of evaluation works for 4 nuclides except ^{241}Pu were reported in the 3rd Seminar on Neutron Cross Sections[1] held at JAERI in November 1972. After that, the final report for ^{238}U was presented to the Topical Meeting on Fast Reactor Physics[2] held at JAERI in June 1973.

At present, evaluation works for ^{235}U, ^{239}Pu, and ^{240}Pu are also in the final stage. Work for ^{241}Pu has been commenced since this spring, and the data compilation is in progress.

2) Compilation of the resonance parameters

In this sub-working group, compilation works on the resonance parameters for the above-mentioned 5 nuclides are being performed on the experimental data published after 1965. The data compilation for ^{235}U and ^{238}U has been almost completed at present, and evaluation works will be commenced after next spring.

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* Sumitomo Atomic Energy Industries, Ltd.

Relating to the data compilation, data process-code is being also prepared in order to produce the cross sections taking into account the effect of Doppler broadening from the compiled resonance parameters.

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

The evaluated nuclear data for nuclides constituting coolant, structure, and control materials for fast reactor are also indispensable for reactor design. Accordingly, we selected 6 elements of O, Na, Cr, Fe, Ni, and Ta on the basis of the importance from among the constituents of fast reactor.

As the first step to prepare the evaluated nuclear data for these elements, compilation works of the experimental data in the energy range below 15 MeV have been commenced for each isotope of 6 elements by the sub-working group since this spring.

References:

1) JAERI-1228

2) Proceedings on the First Topical Meeting on Fast Breeder Reactors (1973) (Japanese)

I-D-2. Evaluation of the nuclear data on ^{235}U

H. Matsunobu*

Evaluation work of the nuclear data (σ_t, σ_f, σ_c, σ_{el}, σ_{in}, α, ν and η) on ^{235}U in the energy range from 1 keV to 15 MeV is in progress as a part of evaluation works in the sub-working group of JNDC. This evaluation work is mostly based on the experimental data published after 1965, which were compiled by the members of other sub-working group. The interim report[1)]

* Sumitomo Atomic Energy Industries, Ltd.

on the present status of the nuclear data and a method of evaluation was presented to the 3rd Seminar on Neutron Cross Sections held at JAERI in November 1972.

At present, evaluation work of the total and fission cross sections is in the final stage. On the total cross section, numerical calculation using the polynomial fitting functions is in progress on the basis of the experimental data of Uttley et al.[2] and Foster-Glasgow[3] in the low and high energy range respectively. In the intermediate region from 2 to 6 MeV, there is an apparent systematic discrepancy between the data of Foster-Glasgow and of Cabe et al.[4], which are consistent with the data of Uttley et al. in the range from 0.1 to 1.0 MeV. So far, this discrepancy was a knotty problem in evaluation. But, we adopted the data of Foster-Glasgow in this energy range, because recently, we obtained a confidence to their data by the data of Heaton[5]. His data show a good agreement with the data of Uttley et al. and Foster-Glasgow.

On the fission cross section, there is a considerable differenc between the results of our evaluation and of Davey[6] in the range from 1 to 100 keV.

This difference is based on the fact that the most of experimental data published after 1965 show lower values compared with the evaluated values of Davey in this energy region. In the region above 1 MeV, the discrepancies between the measured data are small except the data of Pönitz[7]. Therefore, the difference between the evaluated data of Davey and ours is not so remarkable.

The final results of evaluation on the total and fission cross sections will be reported at Atomic Energy Society of Japan in this November. After that, evaluation of the remaining nuclear data will be performed by keeping the consistency with the above mentioned evaluated data.

References

1) H. Matsunobu, JAERI-1228 p. 1 (1973)

2) C. A. Uttley et al., 66PARIS 1 p. 165 (1966)

3) D. G. Foster and D. W. Glasgow, PR 3C, 576 (1971)

4) J. Cabe et al., 70 HELS 2, 31 (1970)

5) Heaton, NEUDADA (private communication) (1972)

6) W. G. Davey, NSE 26, 149 (1966)

7) W. P. Pönitz, 68WASH 503 (1968)

I-D-3. Neutron Cross Sections for ^{238}U between 1 keV and 20 MeV

Y. Kanda*

The paper on this subject was published in Proceedings of Atomic Energy Society of Japan, Topical Meeting on Fast Reactor Physics, 1973. (in Japanese) with an abstract as follows:

Neutron cross sections for ^{238}U are evaluated between 1 keV and 20 MeV on the basis of the experimental data which are selected from available experiments assessing the technical methods used, data handling, corrections applied and errors given in their reports. They are (n,γ), (n,n), (n,n'), (n,2n), (n,3n), (n,f), and total cross sections. The total cross section consistents with the sum of the other cross sections at each point.

* Kyushu University

I-D-4. Status of experimental data and evaluations of the cross sections for the $^{238}U(n,\gamma)$ and $^{238}U(n,n')$ reactions *

Y. Kanda *

Very accurate cross-sections for $^{238}U(n,\gamma)$ and $^{238}U(n,n')$ reactions in the energy range from 1 keV to 10 MeV are required for the development of fast reactors. Available experimental data for these reactions are not accurate enough to satisfy the requests, and are in disagreement with each other. Several evaluation works have been performed to deduce the most reliable cross sections for the reactions. In this report, their evaluation methods and techniques are reviewed and discussed mainly to clear up the role of experimental data and theoretical calculation contributed to their works.

It is valuable in the case of the capture cross-section to emphasize the experimental assesment carried out by Davey and the simultaneous evaluation method employed by Sowerby et al. and Poenitz. On the other hand, since the experimental inelastic scattering cross section data are too scarce to deduce cross sections for the neutron energy range required, it is necessary in this case to estimate from cross sections of other reactions for ^{238}U being guided by calculations from, for example, the optical model formulae.

* JAERI - 1228 (in Japanese)

* Kyushu University

I-D-5. Evaluation of Neutron Cross Sections for 28 Important Fission Product Nuclei

S. Iijima* and others (Fission Product Nuclear Data Working Group)

Fission Product Nuclear Data Working Group of Japanese Nuclear Data Committee (JNDC) has continued the evaluation work on cross sections for fission product nuclei in the energy range of 1 keV to 15 MeV. In earlier stage of work, we surveyed experimental data of the cross sections, existing evaluated cross section data and yield ratio of the fission product nuclei, in order to look for the way of evaluation method. After this survey, we decided to evaluate the cross section values of following 28 important fission product nuclei as the first step of the evaluation work.

Sr-90,	Zr-93,	Mo-95,	Mo-97,	Tc-99,
Ru-101,	Ru-102,	Rh-103,	Ru-104,	Pd-105,
Ru-106,	Pd-107,	Ag-109,	I-129,	Xe-131,
Cs-133,	Cs-135,	Cs-137,	Nd-143,	Ce-144,
Nd-144,	Nd-145,	Pm-147,	Sm-147,	Sm-149,
Sm-151,	Eu-153,	Eu-155.		

These nuclei are estimated to provide about 80% of capture cross section times mass yield ratio of all fission product nuclei. Therefore, they are treated here as the most important nuclei of the fission product and their cross section values are evaluated by using experimental data and calculated values. In this work, optical model of the nucleus and Hauser-Feshbach's formula are used in order to obtain total cross section, elastic scattering cross section, inelastic scattering cross section and capture cross section in the range of neutron energy E_n = 1 keV to 15 MeV.

Evaluated cross sections obtained here are compared with experimental data and the evaluated data supplied by Benzi et al. and Cook. Inter-comparison of the neutron capture cross sections show large discrepancies,

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particularly for unmeasured nuclei. In some cases the discrepancy amounts to a factor 2 to 5 for neutron energy below 1 MeV and a factor 10 above 1 MeV. Several comments should be made on the present results.

(1) Calculated values of the neutron capture cross sections were normalized to the measured data, when they exist, by adjusting the parameter $\xi = D/2\pi\Gamma\gamma$. The way of this normalization is somewhat arbitrary.

(2) Present calculation does not take into account of effect concerning the fluctuation of resonance level widths. This effect will reduce the neutron capture cross section at low energy by 5 to 20%. Therefore, the neutron capture cross section at low energy may be overestimated for unmeasured nuclei.

(3) Since few resonance cross section data exist for majority of fission product nuclei, any trustworthy evaluation below a few keV is intrinsically a difficult problem. Cook has generated resonance cross section by root sampling technique to conform with resonance integral data and thermal cross section. This may be the only feasible method at present, but all the same there is no measure to judge the truthness of the results.

(4) Systematics of physics parameters, particularly of radiation widths and resonance level spacings, have not been fully investigated. Further, the variation of neutron strength functions from a nucleus to another was taken into account only in the sense of optical model. These may have caused significant errors in the evaluated cross sections at low and intermediate energies.

For the future evaluation work, further measurements of cross sections and physics parameters are very essential and are strongly required. In particular, measurements of neutron capture cross section at a few tens of keV and below a few keV are of the greatest importance. Measurements and evaluation of level scheme are also still lacking, and the investigation of these will bring out fruitful results for the future evaluation of the cross sections of the fission product nuclei.

Numerical values of the cross sections obtained here are arranged in the format of ENDF/B type and stored in the magnetic tape. Tables and graphs of them will be given in the final report. The parameters used in order to estimate cross section values will be also given in tabular form or graph.

I-D-6. Program SPLINT

T. Narita*, Y. Kanemori**, Y. Yamakoshi*** and T. Nakagawa*

A program SPLINT is made to offer some pieces of graphical plot of experimental data and evaluated data on the same graphs. Those data mentioned below can be put in as the input data for this program;

i) Total cross section

ii) Elastic scattering cross section and its angular distribution

iii) Inelastic scattering cross section

iv) (n,γ) cross section

v) Fission cross section

These data are presented in the data library of NESTOR[1], UKNDL[2], ENDF/B-II and III[3], and KEDAK[4]. For the data of resonance energy region in ENDF/B library, they are rearranged by using a code RESEND[5] in the form of the cross section from the resonance parameters prior being treated by the program SPLINT.

This program is written in FORTRAN IV and is not machine dependent. A sample is shown below in Figure.

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* Japan Atomic Energy Research Institute
** Mitsui Shipbuilding Co., Ltd.
*** Ship Research Institute

References:

1. T. Nakagawa (to be published)

2. K. Parker, AWRE O-70/63

3. M. K. Drake, BNL-50274 (T-601)

4. D. Woll, KFK 880

5. RESEND, written by Odelli Ozer (BNL)

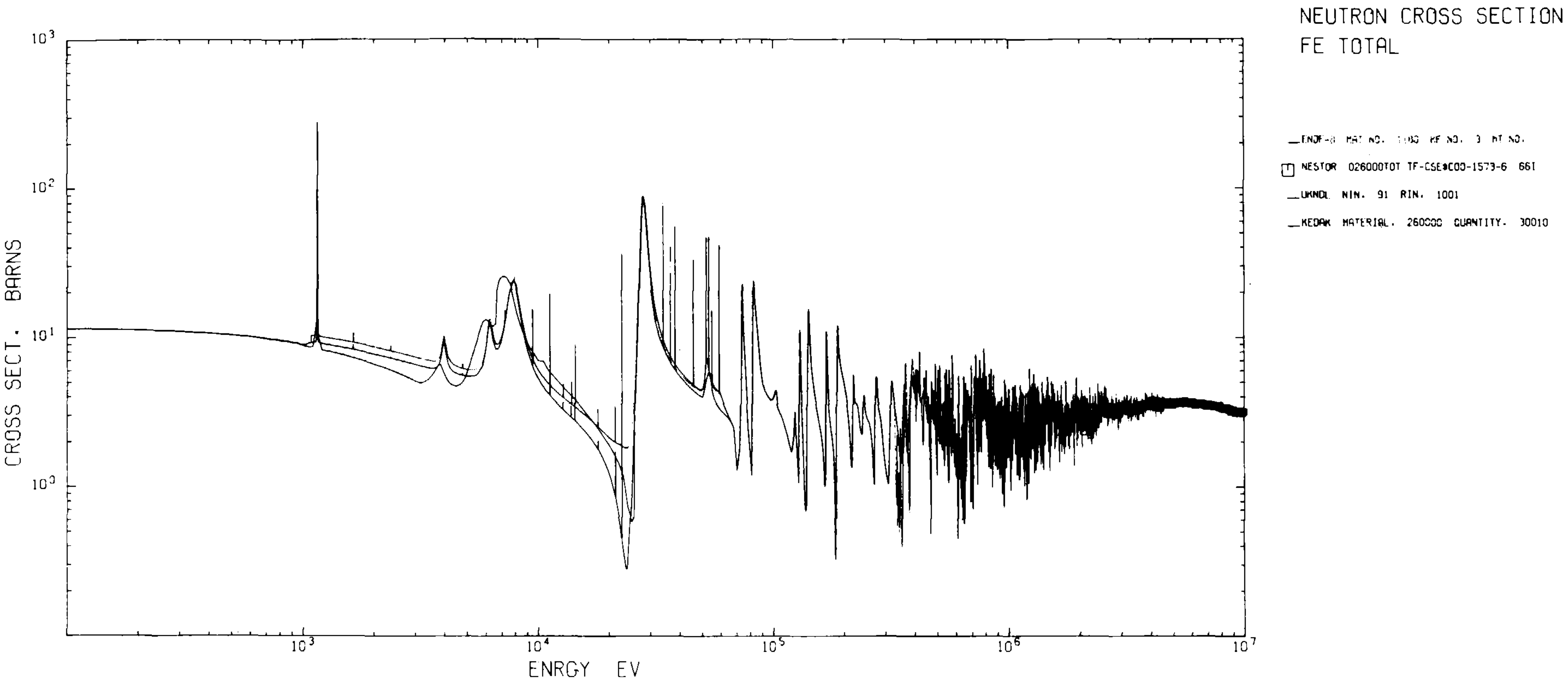
NEUTRON CROSS SECTION
FE TOTAL
ENDF-B MAT NO. RF NO. 3 MT NO.
NESTOR 026000TOT TF-CSE*COO-1573-6 661
UKNDL NIN. 91 RIN. 1001
KEDAK MATERIAL. 260000 QUANTITY. 30010
CROSS SECT. BARNS
ENRGY EV
10^3
10^2
10^1
10^0
10^3
10^4
10^5
10^6
10^7

Figure 1

I-D-7. Production of Group Constants Set of Fission Products*

Yasuyuki Kikuchi, Iwao Otake**, Kanji Tasaka,
Hideo Nishimura, Akira Hasegawa and Satoru Katsuragi

While the fast FP evaluation working group of JNDC proceeded the evaluation of 28 important FP nuclides, we examined the FP data files already evaluated in other countries as another working group of JNDC. We produced a set of group constants with one of these files in order to understand problems in processing FP cross section data and also to respond the urgent request for the FP group constants from the users.

The data set evaluated by Cook was chosen for this work, and was processed to the multi-group constants with 70 or 25 groups. The group structure is the same as the JAERI-Fast Set [1]. These group constants of 184 nuclides were lumped to the group constants of one pseudo FP nuclide at various stages of burn up, using the concentrations calculated with the independent yield data evaluated by Meek and Rider. The inelastic scattering matrix was calculated with the evaporation model by assuming an effective nuclear temperature for a pseudo nuclide. This work will be published as JAERI-M report.

The statistical behavior of the lumped FP cross section was examined. It was found that the standard deviation due to the statistical fluctuation of the resonance parameters was much reduced through lumping process. Hence for the evaluation of FP nuclide, the statistical model can be extended to the low energy region where this model cannot be applied for the evluation of an individual nuclide. With this method we can avoid anomalous energy dependence observed in the lumped group constants produced from the Cook's

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* To be presented at the IAEA symposium on Fast Reactor Physics held at Tokyo, in 1973

** Fuji Electric Co., Ltd.

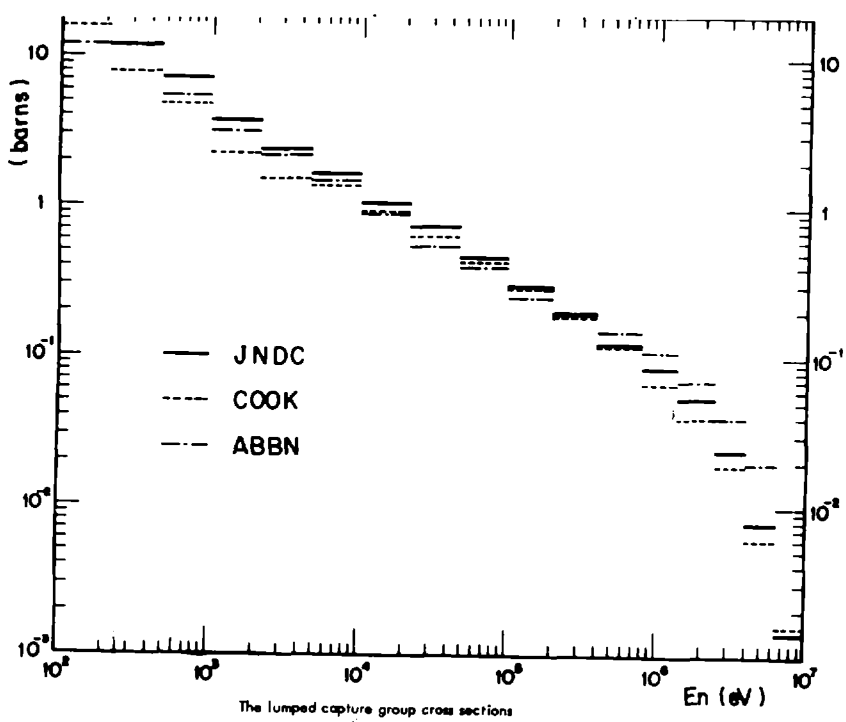
evaluated data. In his evaluation, Cook calculated the cross section in the low energy region with the resonance parameters produced by the Monte Carlo method, with fitting the calculated resonance integrals to the experimental data if they exist. This method often gives large discontinuity in the cross section curve at the connecting point with the statistical model and is not appropriate for the fast reactor calculations.

This conclusion was reflected on the evaluation by JNDC, and the statistical model was extrapolated down to 100 eV. The data of the 28 important nuclides evaluated by JNDC were also processed to the group constants. Thus we have now three sets of the FP group constants, i.e., those from the Cook's data, those from the JNDC data and those in the ABBN set[2]. They are compared in Figure and considerable differences are observed. The effects of these differences on the reactor characteristics are now under investigation.

References

1) S. Katsuragi et al. : JAERI-1195 and JAERI-1199

2) L.P. Abagyan et al.: "Group Constants for Nuclear Reactor Calculations", Consultant Burean, New York (1964)



The lumped capture group cross sections

II. Kyoto University

A. Research Reactor Institute

II-A-1. Measurement of Average Cross Sections for Some Threshold Reactions by means of a Small Fission Foil in Large Thermal Neutrons Field

Itsuro Kimura, Katsuhei Kobayashi and Toshikazu Shibata

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

In the present measurement, the average cross sections for the ^{58}Ni(n,p)^{58}Co, ^{27}Al(n,α)^{24}Na and ^{115}In(n,n')^{115m}In reactions were obtained with an enriched uranium-aluminium foil, which was fixed on the periphery of a thin aluminium rotor plate with the threshold foils. Diagonally across the plate, similar threshold foils were placed, but without the uranium-aluminium foil. The assembly was set in a large irradiating room of the heavy water thermal neutron facility of KUR, as shown in Fig.1, which eliminated the return neutron flux.

The number of fission neutrons, N, was obtained from the induced activities of the uranium-aluminium foil; it was derived from the counting rate of 1.596 MeV gamma-rays from ^{140}La which was in the condition of radioactive equilibrium with ^{140}Ba, the average number of prompt neutrons, irradiation and cooling time, detector efficiency and fission yield of ^{140}La-^{140}Ba.

The reaction rate A of the threshold reaction can be expressed in two ways; The first is the method using the shape factor F:

$$A = Nn\bar{\sigma}F ,$$

where n is the number of nuclei in question in a threshold foil and $\bar{\sigma}$ the average cross section of the reaction. For two circular foils of thickness t_1 and t_2, with the same radius R, and placed on facing the other as shown in Fig.2, the shape factor F has been given by Gotoh et al.[1)]

$$F = f(H,t_1,t_2,R) \ / \ 4\pi H^2 ,$$

where H is the distance between the two foils. Details of the above derivation will be published elsewhere.[1)]

Secondary, the reaction rate A can be calculated by the Monte Carlo method:

$$A = \frac{Nn \ \bar{\sigma} \ \langle P_1P_2 \rangle}{R^2 \ t_2} ,$$

where $\langle P_1P_2 \rangle$ is the mean path length through the threshold foil of all neutrons generated at random points P(x,y,z) and the random directions, as shown in Fig.2.

The results obtained by the present method are tabulated in Table 1, where we have also given earlier data by the present authors[2)3)] and some other workers[4)∿6)].

The values of the average cross sections for the $^{58}Ni(n,p)^{58}Co$, $^{27}Al(n,\alpha)^{24}Na$ and $^{115}In(n,n')^{115m}In$ reactions are found smaller than those proposed by McElroy et al.[6)], but represent results that validate the fission neutron spectrum with an average energy of about 2 MeV, and confirm the conclusion previously obtained by the present authors[2)7)].

References:

1) H. Gotoh, H. Yagi, K. Kobayashi and I. Kimura, Nucl. Instr. Meth., to be published.

2) I. Kimura, K. Kobayashi and T. Shibata, J. Nucl. Sci. Technol., 8 (1971) 59.

3) K. Kobayashi, I. Kimura, H. Gotoh and H. Yagi, J. Nucl. Energy, in print.

4) R. L. Simons and W. N. McElroy, BNWL-1312 (1970).

5) A. M. Bresesti, M. Bresesti, A. Rota et al., Nucl. Sci. Eng., 40 (1970) 331.

6) W. N. McElroy, R. J. Armani and E. Tochilin, ibid., 48 (1972) 51.

7) I. Kimura, K. Kobayashi and T. Shibata, "Proc. Consultants' Meeting on Prompt Fission Neutron Spectra", p.113 (1972) IAEA.

Table 1 Present results and earlier values of the average cross sections for the $^{58}Ni(n,p)^{58}Co$, $^{27}Al(n,\alpha)^{24}Na$ and $^{115}In(n,n')^{115m}In$ reactions

Reaction	Present results (mb)		Earlier values (mb)			
	Shape factor	Monte Carlo *	Authors 2) 3)	Simons & McElroy 4)	Bresesti et al. 5)	McElroy et al. 6)
$^{58}Ni(n,p)^{58}Co$	102.6 ± 5.2	101.6 ± 5.6	104	102	104.5 ± 4.0	124
$^{27}Al(n,\alpha)^{24}Na$	0.635±0.036	0.653±0.036	0.63	0.663	0.695±0.02	0.770
$^{115}In(n,n')^{115m}In$	176.5 ± 8.8	177.4 ± 9.8	177 175 ± 6	174	177 ± 6.0	199.5

* 50000 histories

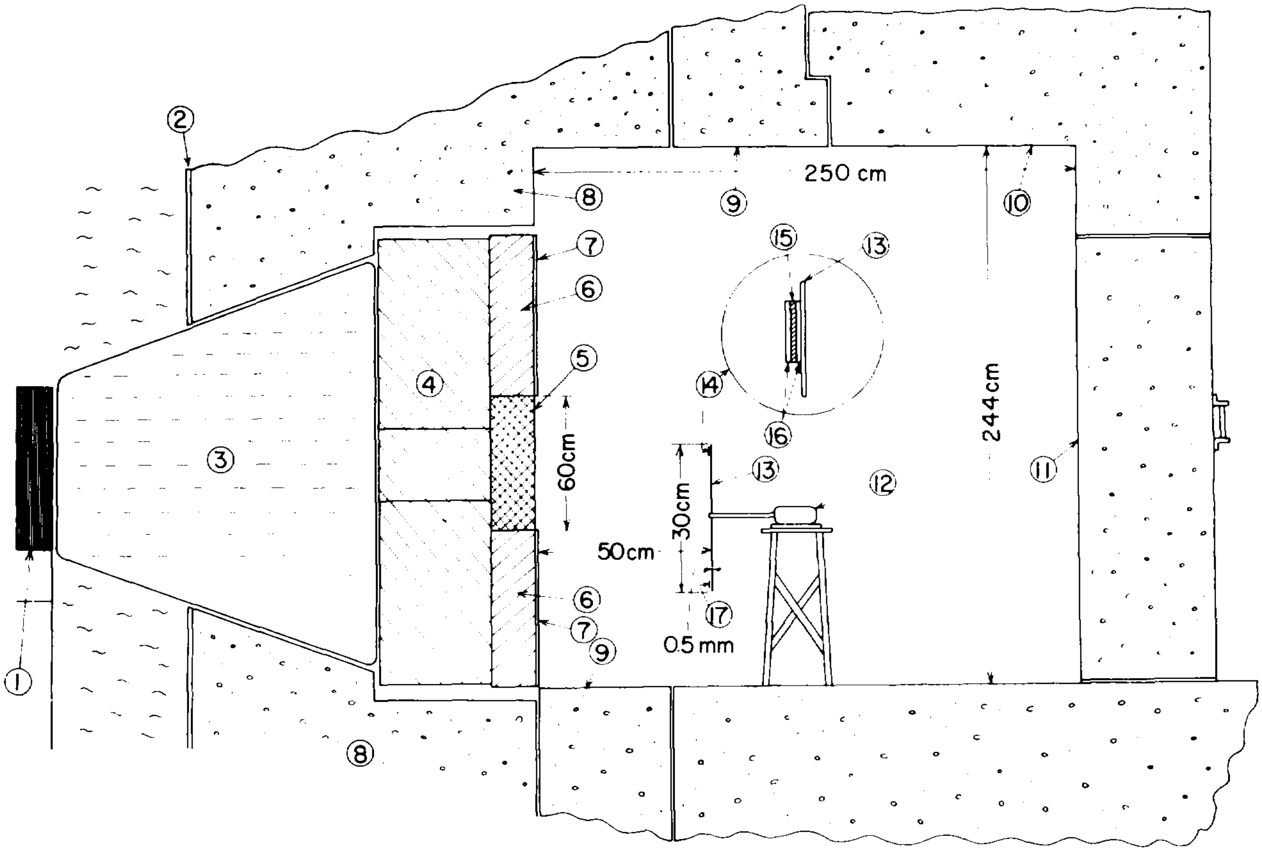


Figure 1 Experimental arrangement for irradiation of threshold foils with a small fission foil in a large thermal neutron field that is the irradiation room of the heavy water facility of the Kyoto University Reactor : (1) core, (2) tank, (3) heavy water, (4) graphite, (5) bismuth window, (6) lead, (7) boral, (8) reactor shield, (9) shutter, (10) concrete blocks, (11) door, (12) geared motor, (13) aluminium rotating plate, (14) threshold foils with a fission foil, (15) fission foil, (16) threshold foils, (17) threshold foils without fission foil.

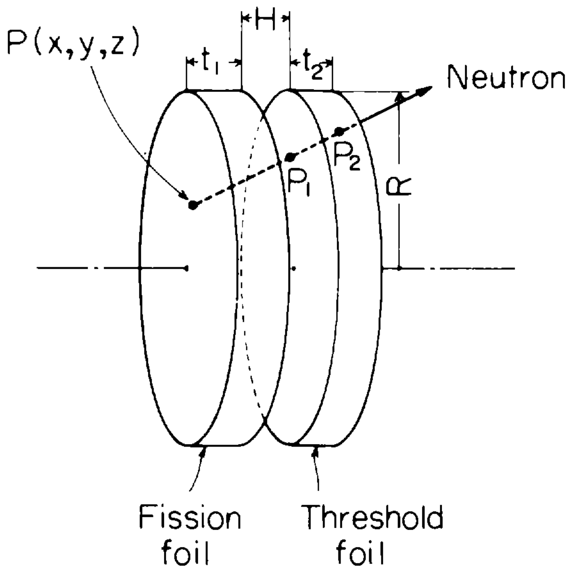


Figure 2 Geometry for Monte Carlo calculation of mean length of neutrons in a threshold foil.

II-A-. Measurement of the Average Cross Section for the $^{233}U(n,2n)^{232}U$ Reaction

Katsuhei Kobayashi, Tetsuo Hashimoto and Itsuro Kimura

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

The average cross section for the $^{233}U(n,2n)^{232}U$ reaction has been measured with a fission neutron spectrum in the core of the Kyoto University Reactor (KUR).

Prior to the present measurement, the authors made isotopically pure ^{233}U samples, with lower ^{232}U content, by the chemical processing after the thermal neutron irradiation of thoria. The ^{233}U sample obtained was reirradiated in the core of KUR. The average fast neutron fluxes obtained with the $^{58}Ni(n,p)^{58}Co$, $^{54}Fe(n,p)^{54}Mn$ and $^{46}Ti(n,p)^{46}Sc$ reactions agreed with each other within experimental error of 2 to 3 %. The measured result of the average cross section for the $^{233}U(n,2n)^{232}U$ reaction has become to be 4.08 $\pm$ 0.30 mb, as presented in Table 1, where it is compared with the value measured by Halperin et al.[1)] and with the calculated by Pearlstein[2)].

In order to assess the energy dependent cross section from the value of integral measurement, the calculated average cross sections, as shown in Table 2, obtained with the Maxwellian-type fission neutron spectrum and the energy dependent cross sections of ENDF/B-III[4)] and other authors[5)∿10)] have been compared with the present measured average cross section. The calculated results are about 32 to 91 % larger than the present measurement, assuming the Maxwellian distribution for the fission neutron spectrum. The result of Pearlstein's calculation by the statistical model assuming the Maxwellian is smaller than the present by about 19 %.

References:

1) J. Halperin, L. E. Idom, C. R. Baldock, et al., ORNL-4306 (1968).

2) S. Pearlstein, Nucl. Sci. Eng., 23 (1965) 238.

3) R. L. Simons and W. N. McElroy, BNWL-1312 (1970).

4) Evaluated Nuclear Data File, ENDF/B-III Mat. No. 1110.

5) M. K. Drake, GA-7076 (1966).

6) N. L. Snidow, BAW-393-5 (1966).

7) A. C. Douglas, AWRE O-100/64 (1965).

8) H. Alter and H. J. Lorenzi, NAA-SR-MEMO-8904 (1963).

9) M. H. Kalos and E. S. Troubetskoy, NDA 2134-2 (1960).

10) R. J. Howerton, UCRL-5351 (1958).

Table 1 Comparison of the average cross sections for the $^{233}U(n,2n)^{232}U$ reaction

Cross section (mb)	Reference
4.08 ± 0.30	Present work, measured in the core of KUR
3.5	Halperin et al.'s work, measured at the ETR
4.0	Renormalized value of Halperin et al., in case that 76.3 mb instead of 65 mb was used for the average cross section for the $^{54}Fe(n,p)^{54}Mn$ reaction [3)]
4.3	Renormalized value of Halperin et al., in case that 11.3 mb instead of 9.0 mb was used for the average cross section for the $^{46}Ti(n,p)^{46}Sc$ reaction [3)]
3.3	Pearlstein's work, calculated by the statistical model

Table 2 The average cross sections for the $^{233}U(n,2n)^{232}U$ reaction calculated with the energy dependent cross sections and the Maxwellian distribution with $\bar{T}$=1.3 MeV as the fission neutron spectrum

Cross section (mb)	Reference
7.8	ENDF/B-III
7.8	Drake (GA-7076)
7.8	Snidow (BAW-393-5)
7.8	Douglas (AWRE O-100/64)
5.9	Alter and Lorenzi (NAA-SR-MEMO-8904)
5.9	Kalos and Troubetskoy (NDA-2134-2)
5.4	Howerton (UCRL-5351)

I II-A-3. Gamma-ray energies of ^{95}Sr and ^{94}Sr

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

A paper on this subject was published in INORG. NUCL. CHEM. LETTERS, 9, 245 (1973).

The Sr from fission products was separated at migration time of 20 s by paper electrophoresis. The gamma-rays from Sr nuclides were measured by a Ge(Li) detector of 30 cm^3 active volume. The gamma-ray energies and their relative intensities of ^{95}Sr and ^{94}Sr were determined using an OKITAC-5090H computer. The energy and relative intensity of gamma-rays emitted from ^{95}Sr and ^{94}Sr are given in TABLE 1. The new gamma-rays from ^{94}Sr found indicate two intermediate levels to which the 1429.2 KeV level can decay. Three excited levels of ^{94}Y are indicated in decay scheme in Fig. 1.

TABLE 1

Energy and Relative Intensity of the Gamma-Rays Emitted from ^{94}Sr and ^{95}Sr

^{94}Sr ($T_{1/2}$: 78.9 s)		^{95}Sr ($T_{1/2}$: 25.9 s)	
Energy (KeV)	Intensity (%)	Energy (KeV)	Intensity (%)
622.4	2.5±0.2	686.2	100
704.6	0.9±0.5	827.5	13.3±1.5
724.6	1.6±0.3	945.1	13.1±3.5
806.8	2.1±0.2		
1429.2	100		

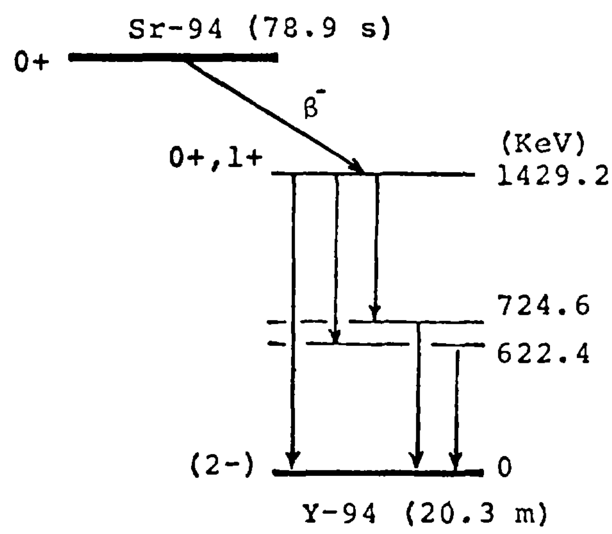


Fig. 1 Partial decay scheme for Sr-94.

II-A-4. Half-life and gamma-ray energies of Ba-143 and Ba-144

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

A paper on this subject will be published in INORG. NUCL. CHEM. LETTERS (in press).

The rapid isolation of barium from fission products was carried out by paper electrophoresis. The gamma-ray energies, their relative intensities and half-lives of ^{143}Ba and ^{144}Ba obtained by the direct gamma-ray measurement of the separated barium. The results are given in TABLE 1. Growth of photo-peak at 397 KeV from ^{144}La, i.e. daughter of ^{144}Ba was clearly observed in gamma-ray spectra obtained. From a comparison of the observed values with calculated curve on the growth and decay of the ^{144}La, apploximately 10 s was estimated to be half-life of ^{144}Ba. On the other hand, it is assumed that the gamma-rays of half-life of 20 s were emitted from ^{143}Ba.

TABLE 1

Half-lives and Relative Intensities of Gamma-ray Energies from Ba-143 and Ba-144

Nuclide	Energy(KeV)	Intensity(%)	Half-life(s)
Ba-143	211.3	100	19.9±0.5
	387.1	28.6±3.3	18.7±2.8
	431.6	52.4±6.2	20.8±1.3
	515.6*	24.3±7.0	16.3±1.4
	799.2	74.5±8.0	19.1±1.4
	925.7	20.8±7.8	21.1±3.0
	981.7	48.3±7.3	20.6±4.7
	1011.3*	55.8±7.8	16.5±1.6
Ba-144	103.7	23.2±3.1	13.2±1.5
	155.9	40.8±4.8	12.0±0.7
	172.1	27.2±3.7	9.3±0.4
	291.2	100	14.0±0.8

* This gamma-ray may be emitted from Ba-144.

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
Hiroshi Nakajima*

Fast neutron spectra in some reactor materials such as iron, aluminium and thorium have been measured by the time-of-flight method using an electron linear accelerator as a pulsed neutron source. At the same time, space distributions of fast neutron flux and gamma rays were measured by activation of nickel wires and gold foils.

The iron test assembly is a rectangular pile of soft steel, which is 100 cm long, 90 cm wide and 100 cm high. For both aluminium and thorium, oxide powder sample is packed in spherical vessels of stainless steel with 60 cm diameter. A lead photo-neutron target is placed at the center of each assembly.

For extraction of neutron beam, each pile is equipped with a reentrant hole of variable depth. Neutrons fly through a collimator system and along an evacuated flight tube. The total length of the flight path is 21.6 m. A bank of three 12.6 cm Ø ^{6}Li glass scintillation counters (NE 912 + EMI 9618 R) were used for neutron detection. A liquid scintillation counter (NE-213) and a boron-vaseline counter were also used to completement the poor response of NE 912 to neutrons of

* Department of Nuclear Engineering, Kyoto University

higher energies. Several independent methods for measuring the background were tried and results were comparatively examined. A new type high speed multichannel time analyzer with wire memories has been developed for the neutron time-of-flight analyses.

The space- and angular- distributions of neutron flux were calculated by means of the multi-group S_n code DTF-IV, assuming a spherically symmetric geometry. Validity of this assumption has been examined by measuring the space distribution of fast neutron flux by the activation method using nickel wires inserted radially into the test assemblies.

After performing some test calculation, it has been concluded that (1) the ordinary symmetrical 8 point angular quadrature "S_8" is satisfactory, (2) P_1 approximation of the scattering law shows only little differences from P_8 approximation, and (3) neutron beam emerging from the assembly and entering the flight path is properly described by the angular component of neutron flux, in the direction of the flight path, at the bottom of the reentrant hole.

In the DTF-IV calculation, the multi-group constant sets ABBN, JAERI-FAST and RSIC DLC-2/99G (for iron) were used. A JAERI-FAST type 70-group and 25-group constants for ^{232}Th have been produced from ENDF/B-2 data in cooperation with JAERI.

Spatial distributions of fast neutron flux determined by wire activation agree with those predicted by DTF-IV calculations and are spherically symmetric especially in the foreward semi-sphere of the test assembly.

For thoria : (1) The JAERI-FAST constants can describe the neutron spectrum satisfactorily in the energy range from about 3 keV to about 3 MeV as seen in Fig.1. (2) Agreement is also seen for the ABBN spectrum above 10 keV.

For alumina and iron comparison of the measured with the calculated are being done.

This paper will be presented at the International Symposium on Fast Reactor Physics in Tokyo in October 1973. Also it will be submitted to a journal soon.

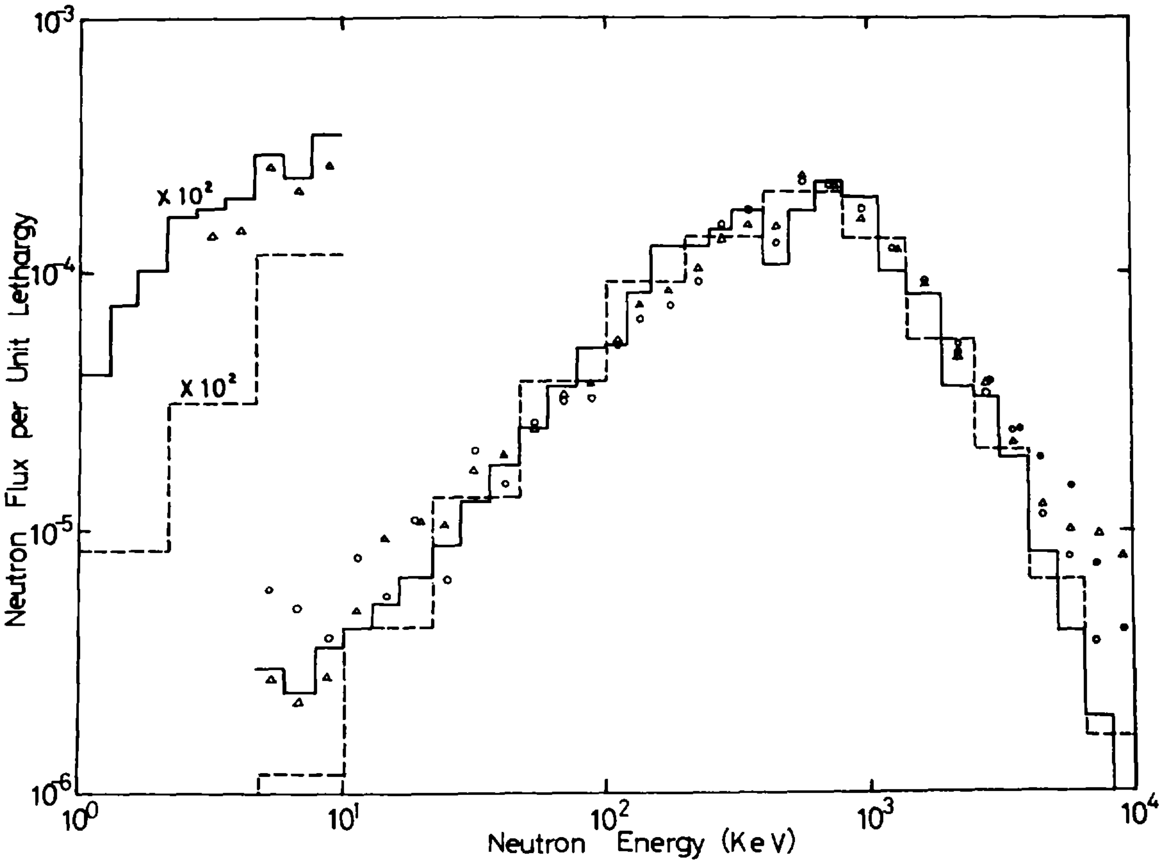


Figure 1
Lethargy spectrum of neutrons for r=15 cm and O=90°(u=0) in tl spherical thoria pile, comparing with theoretical prediction t DTF-IV with the JAERI-FAST and ABBN sets

B. Institute of Atomic Energy

II-B-1. Independent Yields of I, Sb and Te Nuclides in Neutron-Induced Fission of ^{233}U and ^{235}U.

Tomota Nishi, Ichiro Fujiwara and Nobutsugu Imanishi.

The independent yields of ^{131}I, ^{133}I, ^{131m}Te, ^{131g}Te, ^{133m}Te, ^{133g}Te, ^{128m}Sb, ^{128g}Sb, ^{130m}Sb, ^{130g}Sb, ^{131}Sb in the reactor-neutron-induced fission of ^{233}U and ^{235}U were investigated with radiochemical determinations. The cummulative yields of ^{128}Sn, ^{130}Sn, ^{131}Sn and ^{133}Sb were also determined in the fission of both uranium nuclides. The ^{233}U or ^{235}U (0.1mg) traget was irradiated in the KUR (Kyoto University Reactor) for 30 sec. I, Te or Sb nuclieds were separated from their precursors in a few minites after irradiation. The yield of each nuclide was determined by counting the photopeak area of the most predominant γ-rays emitted from the respective nuclide with a Ge(Li) detector and was normalized to the fission yield of ^{92}Sr. The contributions from the precursors during irradiation and chemical separations and the chemical yield of the carriers were both corrected. The independent yields of I, Te, and Sb nuclides and cummulative yields Sn and Sb nuclides in the neutron-induced fission of ^{233}U and ^{235}U are given in the Table I. and Table II. respectvely.

references

1) Chart of the nuclides. U.S.Atomic Energy Commission Division of Isotope Developement.(1968)

2) F.Pleasonton, Phys.rev., 174 1500 (1968)

Table I. Independent yields of I, Te, Sb nuclides and cummulative Sn, Sb nuclides in the neutron-induced-fission of ^{233}U. Fission-yield of 92-mass chain is 6.6%.

* Cummulative yield.

** Cummulative yield to Te nuclide.

Element \ Mass		128	129	130	131	132	133	134	135
Sn		0.62*±0.04	1.11*±0.08	0.86*±0.08	0.51*±0.15				
Sb	m	0.035±0.005		0.46±0.03					
	g	0.069±0.004		0.42±0.03					
	total	0.104±0.008	0.26±0.02	0.88±0.06	1.42±0.10		0.843±0.05		
Te	m				0.94±0.06		1.89±0.15		
	g				0.41±0.04		1.90±0.15		
	total				1.35		3.79	3.77*	
I					0.027±0.01		0.67±0.05	1.67±0.10	5.3 52±0.004
chain yield		0.72	1.37	1.74	>3.31		5.30**	5.44**	

Table II. Independent yieldsof I, Te, Sb nuclides and cummulative yields of Sn,Sb nuclides in the neutron-induced -fission of ^{235}U. Fission yield of 92 -mass chain is 6.0 %.[2]

* Cummulative yield.

** Cummulative yield to Te nuclide.

Element \ Mass		128	129	130	131	132	133	134	135
Sn		0.25±0.01*	0.92±0.07*	1.41±0.11*	0.80±0.07*				
Sb	m			0.26±0.04					
	g			0.26±0.04					
	total			0.52±0.08	1.54±0.1		2.29±0.12*		
Te	m				0.211±0.015		1.54±0.1		
	g				0.073±0.01		1.60±0.1		
	total				0.28		3.14	6.98*	
I					0.03±0.02		0.15±0.09	0.64±0.06	6.30±0.4*
chain yield		0.25	0.92	1.93	2.65		5.58**	7.62**	

III. Kyushu University

Department of Nuclear Engineering

III-1. A new 14 MeV time-of-flight spectrometer at the Kyushu University

M. Matoba, M. Hyakutake, T. Tonai* and J. Niidome

A new time-of-flight spectrometer used for the measurement of the scattering of 14 MeV neutrons was completed in October, 1972 at the Kyushu University. An experimental area was constructed which enabled us to use a shielded 7.6-m flight path. An energy resolution of 260 keV has been obtained at the relatively higher intensity of incident neutrons ($2x10^5$ neutrons/sec.cone.). This resolution is the best in the 14 MeV neutron spectrometers reported up to now. The reduction of the backgrounds was achieved with a set-up of the neutron detector out the measuring room, a study of the collimater and the use of an excellent neutron-γ rays discrimination circuit.

This spectrometer was used for study of neutron scattering from Fe and found to be quite satisfactory.

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* Present address, Mitsubishi Electric Co. Ltd., Itami.

III-2. Scattering of 14.1 MeV neutrons from Fe

M. Hyakutake , M. Matoba , T. Tonai , J. Niidome ,
S. Nakamura , and I. Kumabe

Differential cross sections for elastic and inelastic scattering of 14.1 MeV neutrons on natural sample of Fe have been measured in the angular range $10^\circ \leq \theta_{lab} \leq 160^\circ$ using a time - of - flight spectrometer. The flight path was taken to be 7.6 m and the threshold energy of the neutron detector was 4.5 MeV. Overall time resolution was 1.4 nsec. This corresponds to an energy resolution of about 2 % to 14 MeV neutrons. A typical time - of - flight spectrum at $\theta_{lab} = 40^\circ$ is shown in Fig. 1.

The data for elastic and inelastic scattering were corrected for flux attenuation. Further, the angular distribution for elastic scattering were corrected for multiple scattering and angular spread. Measured differential cross sections are given numerically in table 1.

These data were compared with the optical model predictions, the DWBA theory and the coupled channel calculations. A detailed paper will be soon published.

Table 1. Measured differential cross sevtions for the elastic scattering from natural Fe and the inelastic scattering from first 2^+level of Fe^{56}.

Q = o			Q = - 0.85 MeV		
θ cm (deg)	σ cm (mb/sr)	$\Delta\sigma$cm (mb/sr)	θ cm (deg)	σ cm (mb/sr)	$\Delta\sigma$cm (mb/sr)
10.2	2144.0	127.5			
15.3	1505.0	89.0			
20.4	997.4	42.0	20.4	11.61	2.03
25.4	534.1	23.2	25.5	15.01	2.22
30.5	203.0	9.2	30.5	13.86	1.27
35.6	74.3	3.2	35.6	12.90	1.02
40.7	39.3	1.6	40.7	12.85	0.90
45.7	37.6	1.8	45.8	10.64	0.96
50.8	36.8	1.5	50.8	8.36	1.00
55.8	27.5	1.4	55.9	7.09	0.85
60.9	16.3	1.2	60.9	6.35	0.82
65.9	6.63	0.57	66.0	6.19	0.68
71.0	6.95	0.56	71.0	5.86	0.58
76.0	12.8	1.5	76.0	5.93	1.48
81.0	21.2	1.2	81.1	5.28	0.69
86.0	24.1	1.6	86.1	5.98	0.96
91.0	22.1	1.0	91.1	4.32	0.56
101.0	14.5	0.8	101.1	3.58	0.58
111.0	8.21	0.91	111.0	2.44	0.71
120.9	5.88	0.47	120.9	2.71	0.46
140.7	8.53	0.61	140.7	1.99	0.50
160.4	9.19	0.66	160.4	2.55	0.56

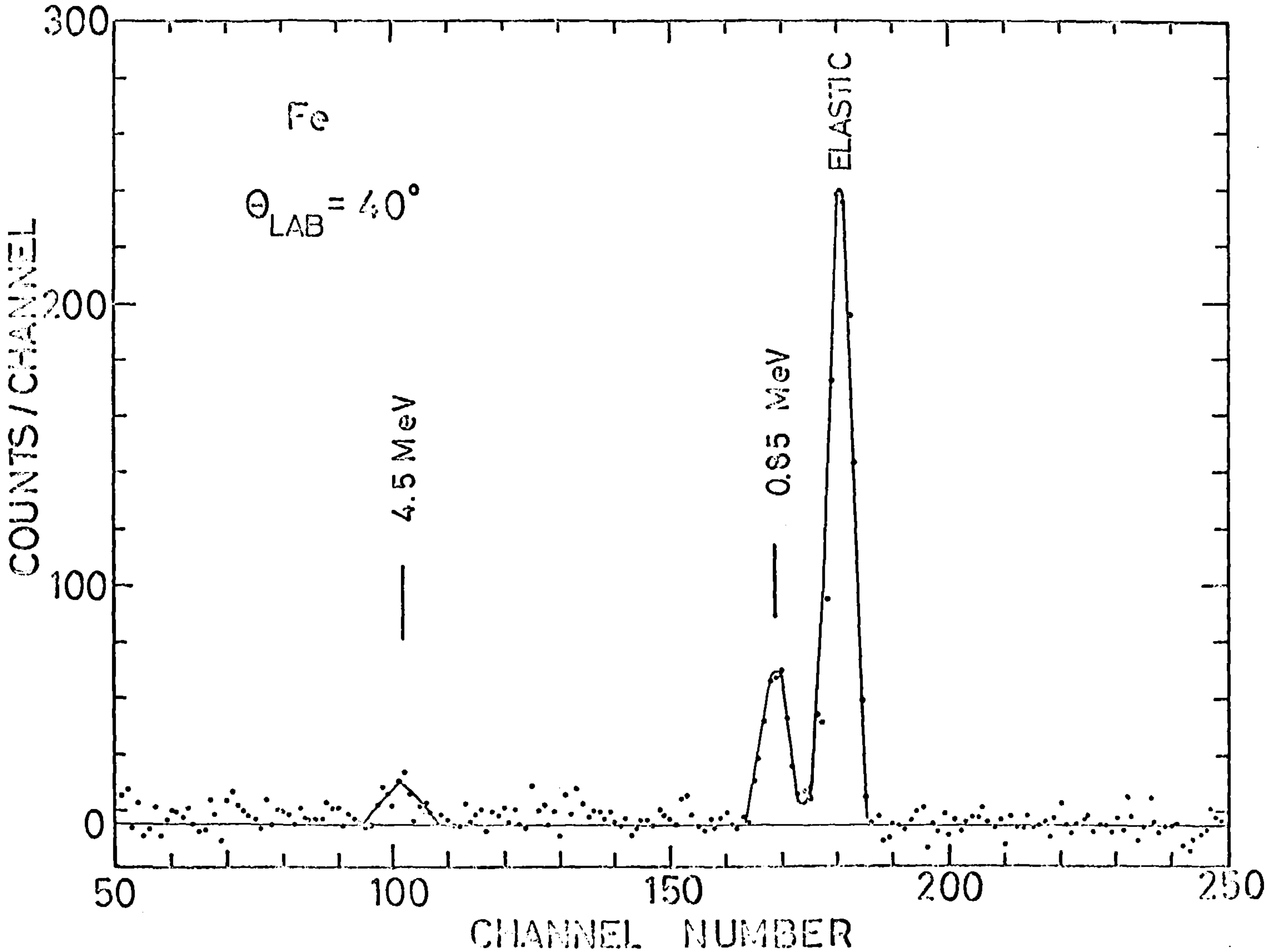

Fig. 1 . A typical time - of - flight spectrum at $\theta_{lab} = 40°$

III-3. Scattering of 14.1 MeV neutrons from ^{209}Bi .

M. Matoba, M. Hyakutake, H. Tawara, K. Tsuji, H. Hasuyama,
S. Matsuki,* A. Katase and M. Sonoda

This work was completed and a full paper has been published in Nuclear Physics A204 (1973) 129 with an abstract as follows:

Differential cross sections for the elastic and inelastic scattering of 14.1 MeV neutrons from ^{209}Bi have been measured with a time-of-flight system which had an energy resolution of 650 keV. For elastic scattering from ^{209}Bi, an optical-model analysis gave the best-fit potential parameters. The absolute cross sections for excitation of collective (2.66 and 4.36 MeV) states are reproduced by the results of distorted-wave calculations under the assumption of a core (^{208}Pb) excitation model using deformation parameters obtainned from (p, p') reactions.

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* Present address, Nara Women's University, Nara.

III-4. Cross Section Calculation Relevant to Fusion Reactor (I) — (n,2n)-Reaction —

M. Ohta, H. Nakashima and H. Nishihara*

A paper on this subject was published in Technology Reports of the Kyushu University, 46, (1973) 295.

By means of Pearlstein's method[1], the (n,2n)-reaction cross sections for the vacuum-wall-materials of the fusion reactor are estimated in the range of neutron energy from threshold to 25 MeV.

The (n,2n)-reaction cross sections for respective isotope of niobium, molybdenum, vanadium and nickel are calculated. Moreover, to the attainment of the relevant cross sections for the natural elements, these cross sections are averaged over the isotopes with the weight of natural abundance.

The resulting (n,2n)-reaction cross sections for the natural elements at the incident neutron energy of 14.1 MeV are as follows.

$$\sigma_{nat.Nb}(n,2n) = 1.14 \text{ b}$$

$$\sigma_{nat.Mo}(n,2n) = 1.23 \text{ b}$$

* Department of Nuclear Engineering, Kyoto University

$$\sigma_{nat.V}(n,2n) = 0.45 \text{ b}$$

$$\sigma_{nat.Ni}(n,2n) = 0.10 \text{ b}$$

The calculated cross sections are given in Figs. 1, 2, 3 and 4[2].

References:

1) S. Pearlstein, Nucl. Sci. & Eng. (1965) 238.

2) M. Bormann, Nucl. Phys. 65, (1965) 257

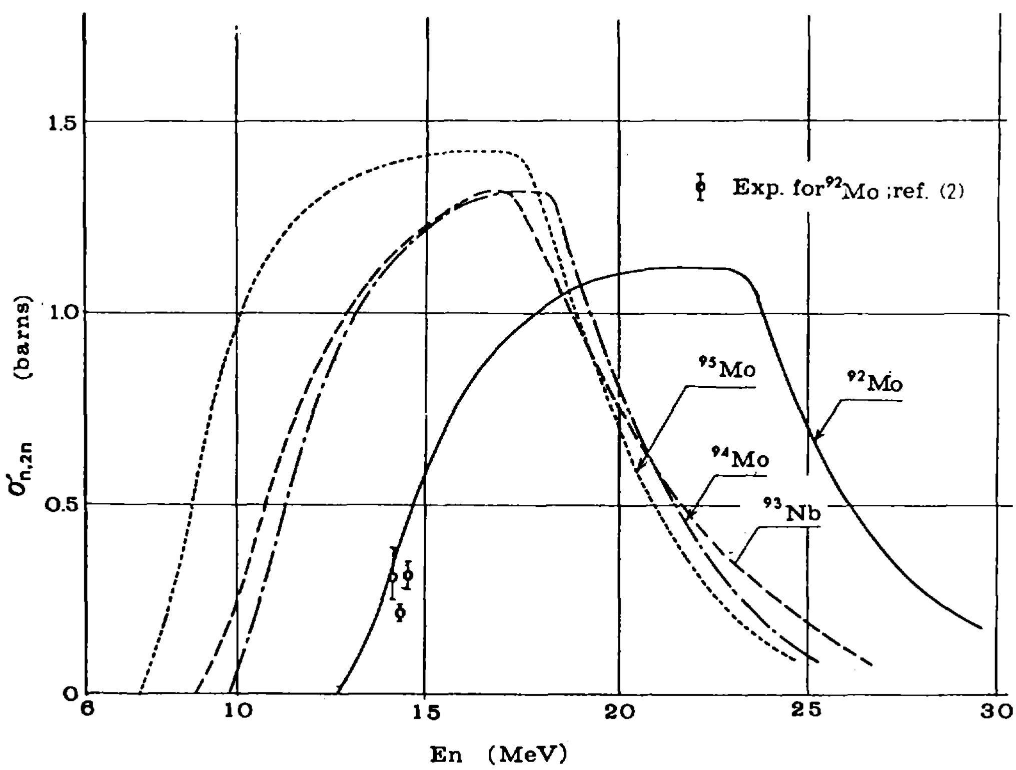


Fig.1 (n,2n)-Reaction Cross Sections for ^{93}Nb, ^{92}Mo, ^{94}Mo and ^{95}Mo

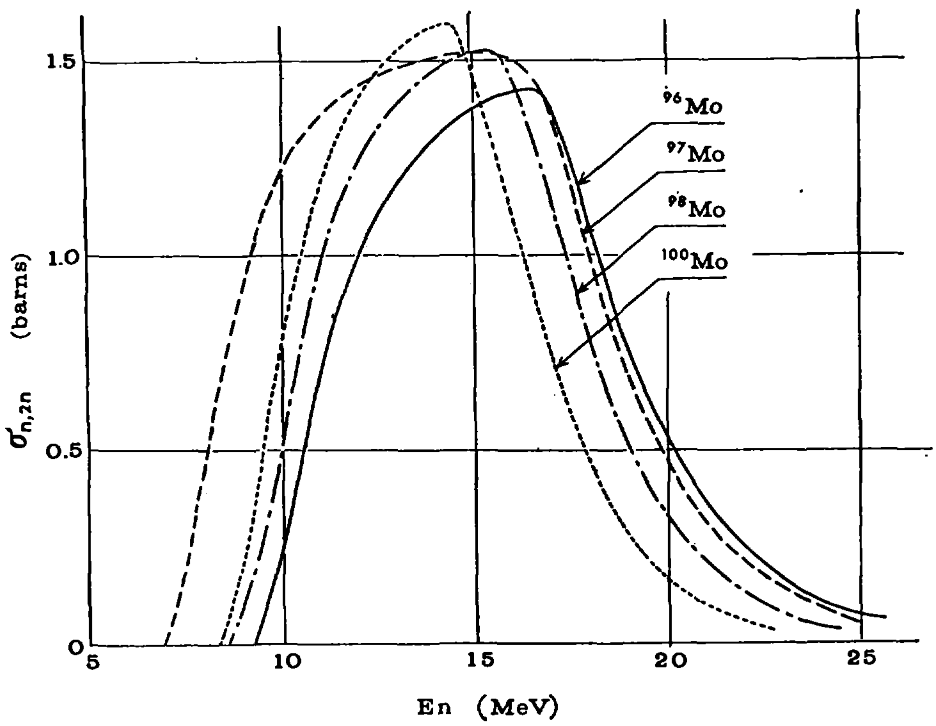


Fig.2 (n,2n)-Reaction Cross Sections for ^{96}Mo, ^{97}Mo, ^{98}Mo and ^{100}Mo

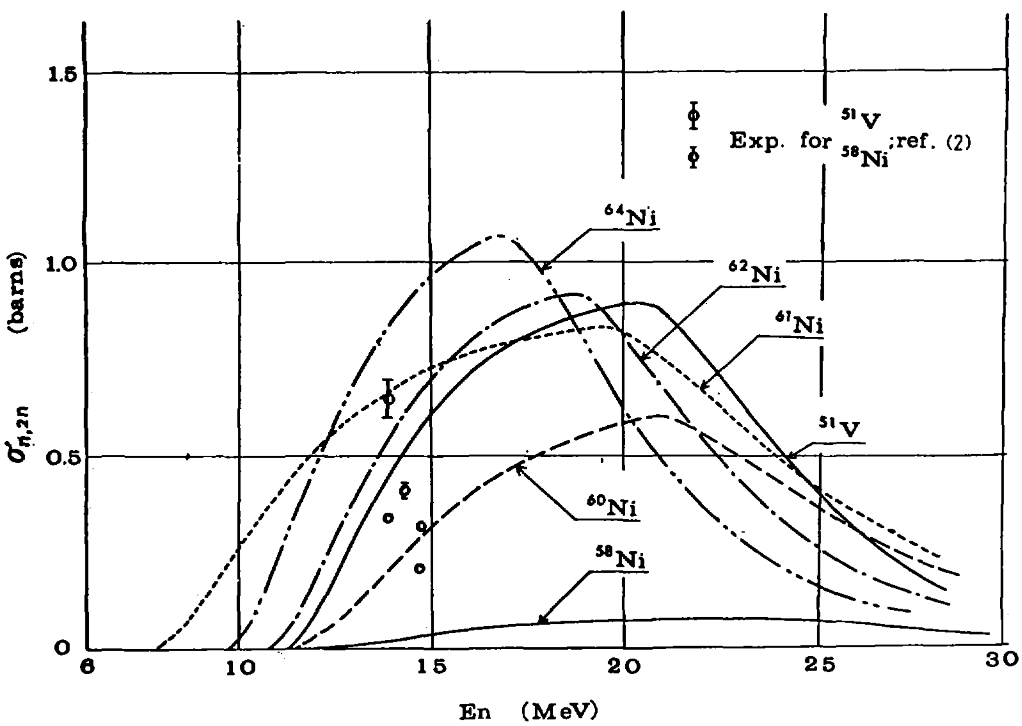


Fig.3 (n,2n)-Reaction Cross Sections for ^{51}V, ^{58}Ni, ^{60}Ni, ^{61}Ni, ^{62}Ni and ^{65}Ni

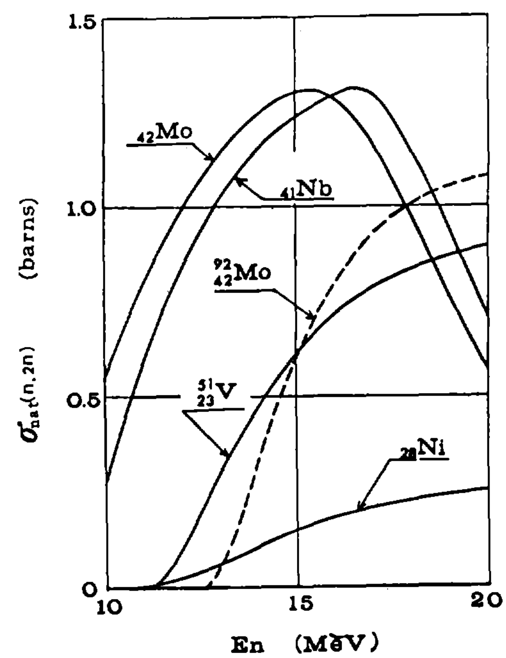


Fig.4 (n,2n)-Reaction Cross Sections for Natural Element of V, Ni, Nb and Mo.

III-5 Calculation of Neutron Inelastic Scattering Cross Sections for ^{233}Pa and ^{239}Np

K. Miyamoto*, M. Ohta and T. Ohsawa

A full paper of this work was submitted to Memoirs of the Faculty of Engineering, Kyushu University.

Neutron inelastic scattering cross sections of ^{233}Pa and ^{239}Np are calculated in the range of neutron energy from 30 KeV to 11 MeV. The optical model and Hauser-Feshbach's formula are used in lower energy region and the evaporation model is used in higher energy region. Calculations are performed by using a computer code ELIESE-2[1]. Tentative calculations are also made for cross sections of competitive processes, such as neutron capture, fission, (n,2n) reaction etc., and their effects on inelastic scattering cross sections are taken into account in the calculations.

The calculated cross sections are shown in Figs.1 and 2.

Reference:

1) S. Igarasi, JAERI-1169, Japan Atomic Energy Research Institute, (1968)

* Present address: Nippon Steel Tube Company Ltd.

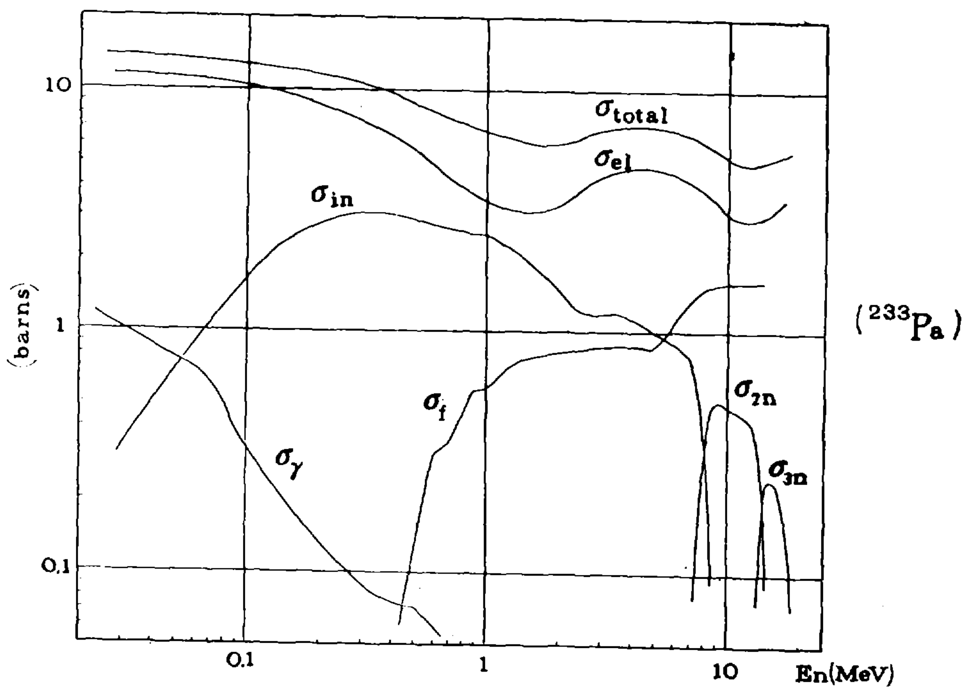


Fig.1 Calculated cross sections for ^{233}Pa

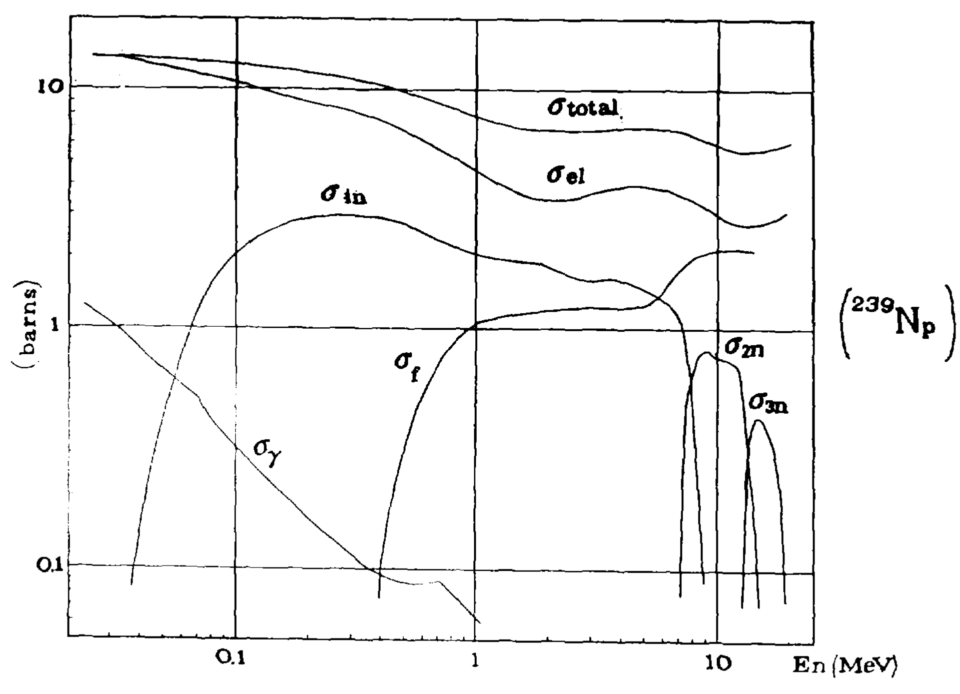


Fig.2 Calculated cross sections for ^{239}Np

IV. Osaka University
Department of Nuclear Engineering

IV-1. A Study on the Hierarchy of Nuclear Reactions

Y.Kitazoe, H.Suzuki and T.Sekiya

The hierarchy of nuclear reactions has been investigated through both a theoretical description and practical evaluations of the cross sections. In these evaluations we assume that some of the observed resonance peaks include include the states of different degrees of complexity. This assumption contrasts with the viewpoint of the R-matrix theory in which the resonance peaks include only the complicated mechanism states. To demonstrate a usefulness of the present formalism, we considered typical examples in which a complicated mechanism eigenvalue E_m will be just adjacent to a simple mechanism one E_s . Then the total neutron cross section formula takes the form

$$\sigma_T = \sigma_{Back} + \frac{1.3014}{\mu\sqrt{E}} g_J \, Re \, i \, e^{2i\delta_\ell} \Gamma^{0}_{mc} B_{mm}(E+\tfrac{i}{2}I)\left\{1 + \frac{\tau_{ms} A_{mm}(E+\frac{i}{2}I)}{E - E_s + \frac{i}{2}I}\right\}, \quad (1)$$

where

$$A_{mm}(\varepsilon) = \left(\varepsilon - E_m + \frac{i}{2}\Gamma_m - \frac{t_{ms}}{\varepsilon - E_s}\right)^{-1}, \quad (2)$$

$$B_{mm}(\varepsilon) = \left[\varepsilon - E_m + \frac{i}{2}\Gamma_m - \frac{t_{ms}}{\varepsilon - E_s} - \frac{J_{ms} A_{mm}(\varepsilon)}{(\varepsilon - E_s)^2}\right]^{-1}, \quad (3)$$

$$I/2 \simeq \frac{\Delta E}{2\sqrt{\pi}} \quad . \quad (4)$$

Equation (1) describes explicitly a hierarchy of nuclear reactions whose states proceed from the simple mechanism state χ_m into the complicated mechanism one χ_s . In Eq.(1), the E, E_m and E_s are in

Mev, μ is the reduced mass of the incident neutron, δ_ℓ the scattering phase shift, g_J the statistical spin factor and Γ°_{mc} ($= \Gamma_{mc}/\sqrt{E}$) is the escape width for the direct decay into the incident channel. On the other hand, the quantities t_{ms}, τ_{ms} and $\mathcal{T}_{ms}$ represent the coupling constants between the states χ_m and χ_s . In particular, the τ_{ms} and $\mathcal{T}_{ms}$ represent the strength of the exchange scatterings due to the identity of nucleons. includes both the potential scattering and the contribution of the other resonance levels. ΔE in Eq.(4) denotes the experimental energy resolution.

We evaluated the total neutron cross sections of Na^{23} and C^{12} by using the resonance formula (1). The result of the evaluation is shown by the curves A in Figs. 1 and 2, while the R-matrix formula yields the curves B in these figures. Tables 1 and 2 give the resonance parameters used in the present evaluation. As is evident from these figures, the curves A are in better agreement with the observed cross sections (the points in Figs. 1 and 2) than the curves B. The curves C give only the contribution of the exchange scatterings. This contribution is particularily remarkable in the neighborhood of the energies $E = E_s$. Thus, Figs. 1 and 2 illustrate typical examples where the antisymmetrization of the wave functions contributes explicitly to the observed resonance cross sections.

References

1) ENDF/B - III

2) D.B.Fossan, R.L.Walter, W.E.Wilson and H.H.Barshal: Phys.Rev. 123 (1961) 209.

3) G.Freier, M.Fulk, E.E.Lampi and J.H.Williams: Phys.Rev. 78(1950).

4) BNL 325 Second Edition Supplement No 2 (1966).

Table 1. The resonance parameters used in Fig.1.

<table>
<tr><th>The present formula</th><th>The R-matrix formula</th></tr>
<tr><td>E_m =731.5 Kev E_s =758.0 Kev
Γ_m° =3.217 $(\text{Kev})^{1/2}$ t_{ms}=700.0 Kev
τ_{ms}=66.5 $(\text{Kev})^2$ I =8.0 Kev
$\mathcal{T}_{ms}$=1.584 x 10^5 $(\text{Kev})^4$
J =6 ℓ =4</td><td>E_λ=715.0 Kev Γ_λ=65.0 Kev
E_μ=780.0 Kev Γ_μ=55.0 Kev
J =4 ℓ =2</td></tr>
<tr><td colspan="2">The resonance parameters for the background cross section
E_1=536.0 Kev Γ_1 =35.3 Kev   J=1 ℓ =0
E_2=597.0 Kev Γ_2 =25.8 Kev   J=1 ℓ =1
E_3=985.0 Kev Γ_3 =27.0 Kev   J=1 ℓ =2
a_c=5.046 fermi</td></tr>
</table>

a_c is the scattering length and the background cross section is assumed to take the form, $\sigma_{Back} = \frac{2.603}{\mu E} \sum_{\ell} (2\ell+1) \sin^2 \delta_\ell + \frac{1.3014}{\mu E} \sum_{J,\ell} \sum_{\lambda} R_e \, i \, e^{2i\delta_\ell} \Gamma_{\lambda c} A^J_{\lambda\lambda}$.

Table 2. The resonance parameters used in Fig.2

<table>
<tr><th>The present formula</th><th>The R-matrix formula</th></tr>
<tr><td>E_m =3.45 Mev E_s =3.03 Mev
Γ_m° =0.488 $(\text{Mev})^{1/2}$ t_{ms}=0.034 Mev
τ_{ms} =6.8 x 10^{-3} $(\text{Mev})^2$
$\mathcal{T}_{ms}$ =5.55 x 10^{-4} $(\text{Mev})^4$
J =1.5 ℓ=2</td><td>E_λ=2.95 Mev Γ_λ =0.1 Mev
E_μ=3.60 Mev Γ_μ =1.1 Mev
J =1.5 ℓ =2</td></tr>
<tr><td colspan="2">The resonance parameters for the background cross section</td></tr>
<tr><td colspan="2">E_1= -1.856 Mev Γ_1 =1.0 Mev   J=0.5 a_c =3.3 fermi</td></tr>
</table>

The background cross section takes the same form as that in table 1 and the resonance parameters for this cross section was taken from reference 4.

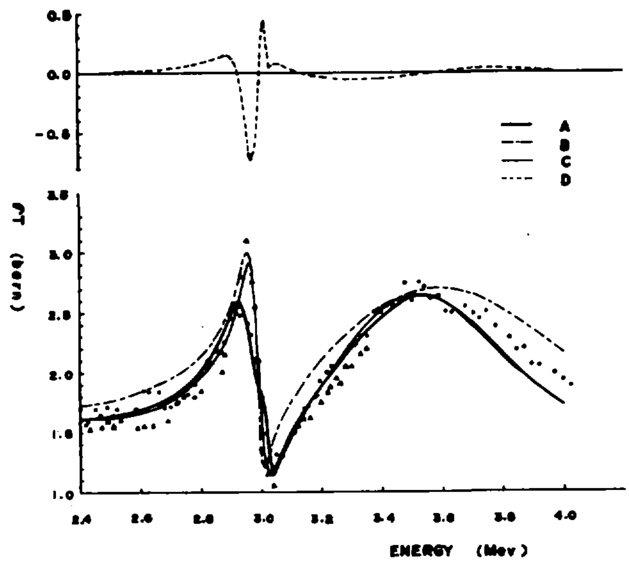


Fig.1. The neutron total cross section of Na ^{23}. The solid points are the most probable values of reference 1. The present and R-matrix formulae yield the curves A and B, respectively. The curve D gives only the contribution of the exchange scatterings.

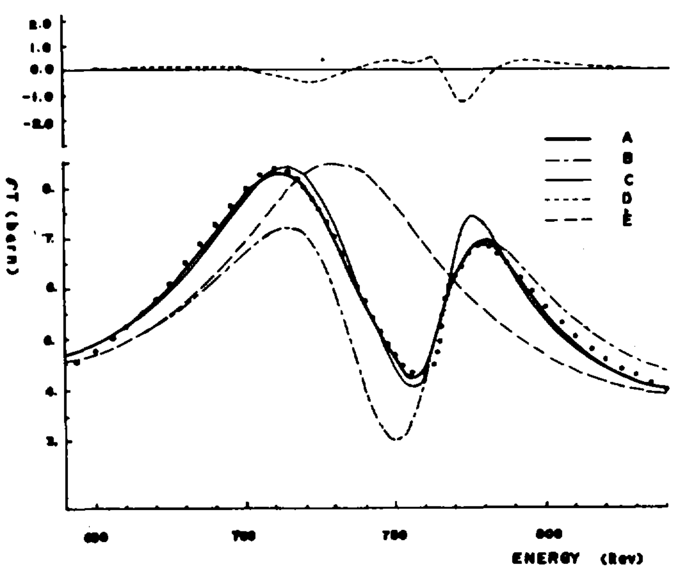


Fig.2. The neutron total cross section of C^{12}. The solid points and triangles are the data of references 2 and 3 , respectively. The present and R-matrix formulae yield the curves A and B, respectively. The curve D gives only the contribution of the exchange scatterings.

V. Tokyo Institute of Technology
Research Laboratory of Nuclear Reactor

V-1. Measurements of Neutron Capture Yield of Pd and Ho in the Resonance Region

N. Yamamuro, K. Yamada and Y. Fujita*

Preliminary measurement of neutron capture yield have been carried out by the use of the 40MeV LINAC and 20m flight path. A pair of NE-226 hydrogen free liquid scintillators has been used as a γ-ray detector and a ^{6}Li glass scintillator as a neutron detector. The determination of the efficiency of γ-ray detector was attempted with Ag black resonance and the pulse height weighting technique.[1] Relative capture yields of Pd and Ho were obtained between 50eV and 1keV.

Reference:

1) R. L. Macklin and J. H. Gibbons; Phys. Rev. 159 (1967) 1007

* Research Reactor Institute, Kyoto University

V-2. A Calculation of the Radiative Capture Cross Section of ^{208}Pb for Fast Neutrons

H. Kitazawa, K. Sakurada and N. Yamamuro

The raidative capture cross section for 14-MeV neutrons of ^{208}Pb has been calculated from the semi-direct capture model.[1] However, the calculated cross section was small by a factor of 3 to 4 than the observed one. It then was considered that this discrepancy for the collective capture model is due to the inadequacy of the particle-vibration coupling of a surface type. In the present work the particle-vibration coupling Hamiltonian H_c in the collective raidative capture of fast neutrons by nuclei is described in terms of the collective variable for density vibration as follows:

$$H_c = (v_1/4)2(NZ/A^2)Kj_1(k_D r)S(r)\left(\frac{\vec{r}\vec{\eta}}{|r|}\right)\tau_3$$

with

$$K = 9.931/R$$

$$S(r) = \begin{cases} 1 & r \leq R \\ 0 & r > R \end{cases}$$

where r is the position vector of an incident nucleon and η the separation vector of the centroids of the neutron and proton systems.

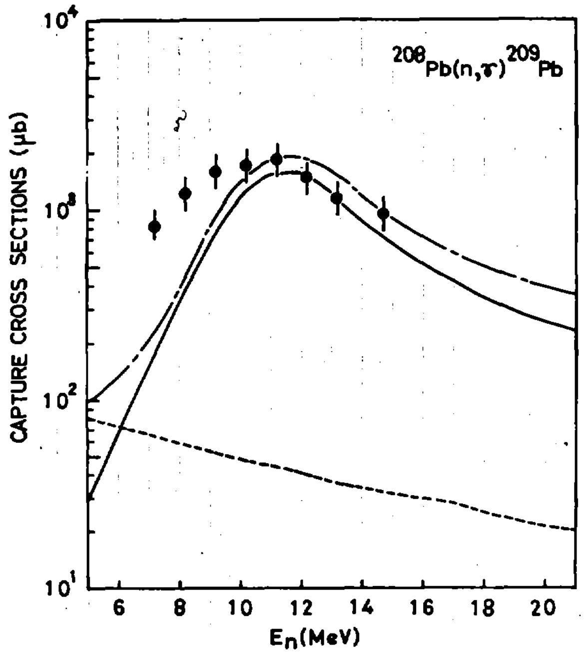
The radiative capture cross sections of ^{208}Pb for 5-21 MeV neutrons are calculated with the above Hamiltonian. The dashed, contenuous and dot-dashed curves in the figure show the direct, collective and total capture cross sections. The calculated cross sections are compared with the observed ones[2] for 7.2-14.7 MeV neutrons. Consequently, for 10-14.7 MeV neutrons the absolute magnitude of the radiative capture cross section as well as the shape of the capture gamma ray spectrum is successfully estimated by the direct and collective capture models. It seems that the disagreement between the calculated and observed cross sections for 7.2-10 MeV neutrons should be removed by taking a contribution of the statistical process to this reaction into consideration.

References:

1) H. Kitazawa; JAERI-1228 (in Japanese);

H. Kitazawa, S. Karashima, K. Koyama, K. Sakurada and N. Yamamuro; Bull. Tokyo Inst. Tech. 116 (1973) 11.

2) I. Bergqvist, D. M. Drake and D. K. McDaniels; Nucl. Phys. A191 (1972) 641.



Calculated and observed cross sections for the radiative neutron capture reaction of ^{208}Pb. The experimental points are taken from the work of I. I. Bergqvist et al.[2)]

The dashed, contenuous and dot-dashed curves show the direct, collective and total capture cross sections.

VI. Tohoku University

Department of Nuclear Engineering

VI-1. Total Cross Section of U-238 from 2 to 8 MeV

M. Baba, K. Nomoto, K. Kanda, N. Hirakawa,
J. Mitsui, and T. Momota

The total cross section of U-238 for the neutron energies from 2 to 8 MeV has been measured with the electron-linac time-of-flight facility at the Laboratory of Nuclear Science, Tohoku University. The facility has a flight path of 120 m long, and the electron burst available is 1 Ampere high and 10 nano second wide with the energy of 60 MeV and repetition frequency of 300 Hertz. The measurement was thus made with a resolution of 0.08 n sec/m.

The total cross section curve obtained has no significant structure and shows a broad maximum around 3.7 MeV. The values are in agreement with those of Kopsch et al[1] within 1 ∿ 2%, but higher than those of ENDF/B-II by 1 ∿ 2% for the neutron energies below 6 MeV. A recent publication from the Rensselaer Polytechnic Institute[2] reports a similar difference between their data and ENDF/B-III for the neutron energies between 2 and 6 MeV.

Numerical data of the present work are available from the Neutron Data Compilation Centre, NEA/OECD.

References:

1) D. Kopsch et al., Nuclear Data for Reactors, Vol 2, 39 (1970), IAEA.

2) S.H. Hayes, P. Stoler, J.M. Clement, and C.A. Goulding, NSE 50 243 (1973).