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PROGRESS REPORT

(January 1996 to December 1996 inclusive)

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Editor

J. Katakura

Japanese Nuclear Data Committee

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

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 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 addressed, 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 or research.

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

This edition covers a period of January 1, 1996 to December 31, 1996. The information herein contained is of a nature of "Private Communication." Data Contained in this report should not be quoted without the author's permission.

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H	1	ELASTIC	2.0+7	1.0+9	JEA	EVAL-PROG	INDC(JPN)-177U			MAR 97	CHIBA+.LSQ METH+PHASE SHIFT ANAL
H	1	TOT INELAST	2.0+7	1.0+9	JEA	EVAL-PROG	INDC(JPN)-177U			MAR 97	CHIBA+.LSQ METH+PHASE SHIFT ANAL
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V	51	A EMISSION	1.4+7		OSA	EXPT-PROG	INDC(JPN)-177U			MAR 97	TAKAHASHI+.2D E-TOF SPEC,DA/DE,FIG

ELEMENT S	A	QUANTITY	ENERGY MIN	MAX	LAB	TYPE	DOCUMENTATION REF	VOL	PAGE	DATE	COMMENTS
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CO		NUCL PROD	2.0+7	1.5+8	TOH	EXPT-PROG	INDC(JPN)-177U			MAR 97	KIM+.ACT METH,P-LI N SOURCE,FIG GVN
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NI	58	A EMISSION	1.4+7		TOH	EXPT-PROG	INDC(JPN)-177U			MAR 97	SANAMI+.GRIDDED IC,DA/DE
CU		NUCL PROD	2.0+7	1.5+8	TOH	EXPT-PROG	INDC(JPN)-177U			MAR 97	KIM+.ACT METH,P-LI N SOURCE,FIG GVN
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I	129	(N,2N)	1.4+7		OSA	EXPT-PROG	INDC(JPN)-177U			MAR 97	MURATA+.ACT SIG=0.92+-0.11BARN
BA		NUCL PROD	1.3+7	1.5+7	NAG	EXPT-PROG	INDC(JPN)-177U			MAR 97	MURAHIRA+.SHORT-LIFE ACT SIGS
CE		NUCL PROD	1.3+7	1.5+7	NAG	EXPT-PROG	INDC(JPN)-177U			MAR 97	MURAHIRA+.SHORT-LIFE ACT SIGS
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SM	149	SPECT (N,G)	5.5+5		TIT	EXPT-PROG	INDC(JPN)-177U			MAR 97	IGASHIRA+.ANTI-COMPTON NAI SPEC
DY	161	SPECT (N,G)	5.5+5		TIT	EXPT-PROG	INDC(JPN)-177U			MAR 97	IGASHIRA+.ANTI-COMPTON NAI SPEC
DY	163	SPECT (N,G)	5.5+5		TIT	EXPT-PROG	INDC(JPN)-177U			MAR 97	IGASHIRA+.ANTI-COMPTON NAI SPEC
HF		NUCL PROD	1.3+7	1.5+7	NAG	EXPT-PROG	INDC(JPN)-177U			MAR 97	MURAHIRA+.SHORT-LIFE ACT SIGS

ELEMENT S	A	QUANTITY	ENERGY MIN	MAX	LAB	TYPE	DOCUMENTATION REF	VOL	PAGE	DATE	COMMENTS
W		NUCL PROD	1.3+7	1.5+7	NAG	EXPT-PROG	INDC(JPN)-177U			MAR 97	MURAHIRA+.SHORT-LIFE ACT SIGS
BI		N EMISSION	1.2+7		TOH	EXPT-PROG	INDC(JPN)-177U			MAR 97	SODA+.DOUBLE TOF METH,DA/DE
U	235	ETA	2.5-2		KYO	EXPT-PROG	INDC(JPN)-177U			MAR 97	NISHIO+.CORR MEAS WITH FIS FRAG,FIG
U	235	NU	2.5-2		KYO	EXPT-PROG	INDC(JPN)-177U			MAR 97	NISHIO+.CORR MEAS WITH FIS FRAG,FIG
AM	243	FISSION	1.0-1	1.0+4	KYO	EXPT-PROG	INDC(JPN)-177U			MAR 97	KOBAYASHI+.PB SLOWING-DOWN SPEC,FIG
MANY		POTNTAL SCAT	2.0+7	1.0+8	JEA	THEO-PROG	INDC(JPN)-177U			MAR 97	CHIBA+.N OMP OF 1P-SHELL NUCLEI
MANY		(N,P)	1.3+7	1.5+7	NAG	EXTH-PROG	INDC(JPN)-177U			MAR 97	KASUGAI+.SYSTEMATICS TO (N-Z)/A
MANY		LVL DENSITY	2.5-2		KYO	EXPT-PROG	INDC(JPN)-177U			MAR 97	NISHIO+.LDL OF U235 THR FIS FRAG,FIG

I. Electrotechnical Laboratory

A. Quantum Radiation Division

I-A-1 $^{208}Pb(\gamma_{pol},\gamma)$ Reaction with Laser-Compton Backscattering

H.Ohgaki, T.Noguchi, S.Sugiyama, T.Mikado, M.Chiwaki, K.Yamada, R.Suzuki, N.Sei, T.Ohdaira, and T.Yamazaki

Polarized gamma-rays are of interest in the field of nuclear physics, because the real photon has a high spin selectivity and a polarized beam assigns an unambiguous parity. We have developed a linearly polarized Laser Compton Photons (LCPs) to investigate the multipolarities in a nucleus. Our LCP facility uses a conventional Nd:YAG laser and Nd:YLF laser with electrons circulating in the electron storage ring TERAS at ETL. We can generate LCP energy ranging from 1 to 20 MeV.[1] We began to use the LCPs for a nuclear fluorescence experiment to assign the parities of J=1 levels in ^{208}Pb. At first, the well-known levels were measured for checking the system.[2] Then we moved to high energy to assign several unknown levels. The completely linear-polarized LCP of 7.8 MeV with 13% energy spread bombards a natural lead rod. We measure the elastically scattered photon in the direction of 90° by a pure Ge detector that has 120% relative detection efficiency. The incoming photon beam was highly, >90%, linear polarized beam whose polarization axis was changed in 100 sec. interval. The upper part of fig.1 shows the energy spectrum of the elastic scattering photons against the parallel polarized photons. The lower one shows that of the elastic scattering photons against the perpendicularly polarized photons. Thus the upper peak means that this resonance level has the positive parity originated in M1 transition. On the other hand, the lower peak shows the negative parity originated in E1 transition. As is shown in figure 1, we can assign the parity very easy. We should note that the small amount of scattered-photon was leaked from lower spectrum to upper one. This leakage originated from a wide collimator that defined the detector solid angle. Table 1 shows the experimental result. We found a new positive parity state in ^{208}Pb at the excitation energy of 7240.3 keV, which was assigned to be negative parity before. This mean that there are two M1 transitions, 7240.3 and 7278.82 keV, in upper excitation energy. Of course, the total amount of such M1 transition in upper energy region does not increase largely. The other unknown states, 6972 and 7685.3 keV, are tentatively assigned to be negative parity. As is shown in figure 1, these two transitions are not clear in the lower spectrum, but there is no sign in upper one. The unknown 7278.5 keV state is not observed, because the transition strength of this state is too small to find out or hidden behind 7278.82 keV peak. In this experiment, we used a natural lead target. So there are several excitation states that originated from ^{206}Pb and ^{207}Pb are found in figure 1. They are also assigned and listed in table. In ^{206}Pb we found a new M1 transition in this energy region. The 7202.4 keV transition was assigned to be negative before.[3] However, our experiment clearly shows this transition should be positive parity, besides the other ^{206}Pb transitions, 7487.4 and 7543.2 keV, were observed to be negative parities. This 7202.4 keV transition may be one of the "missing" M1 transtion in ~7 MeV energy region.

References

1)H.Ohgaki, T.Noguchi, S.Sugiyama, T.Mikado, M.Chiwaki, K.Yamada, R.Suzuki, N.Sei, T.Ohdaira, and T.Yamazaki, Nucl. Instr. and Meth. A375(1995)602.
2)H.Ohgaki et al., Nucl. Instr. and Meth. A353(1994)384.
3)R.Ratzek, U.E.P.Berg, C.Blasing, A.Jung, S.Schennach, R.Stock, F,-J.Urban, and H.Wickert, Phys. Rev. Lett., vol.56, No.6(1986)568.
4)T.Chapuran, R.Vodhanel, and M.K.Brussel, Phys. Rev.C, vol.22(1980)1420.

Table 1 Summary of the spin, parities of $Pb(\gamma_{pol},\gamma)$ levels.

Ex (keV)	E_γ(MeV)	J^π	Γ_0^2/Γ(eV)[4]	acknowledgement
6483.6	6480.2	1^-		
6720.5	6719.7	1^-	7.6	
6972	6999.3	1^-		unassigned
7063.5	7063.3	1^-	15.7	
7083.4	7081.9	1^-	8.8	
7240.3	7241.9	1^+	1.7	unassigned
7278.5		?		unassigned
7278.96	7279.2	1^+	1.7	
7332.5	7332.6	1^-	26.9	
7685.3	7690.2	1^-		unassigned
	7180.6	1^+		?
7202.4	7202.4	1^+	1.8	^{206}Pb, known as 1^-
7306	7306	(1/2, 3/2)?	3.0	^{207}Pb
7487.4	7487.4	1^-	1.7	^{206}Pb
7543.2	7543.2	1^-	2.3	^{206}Pb

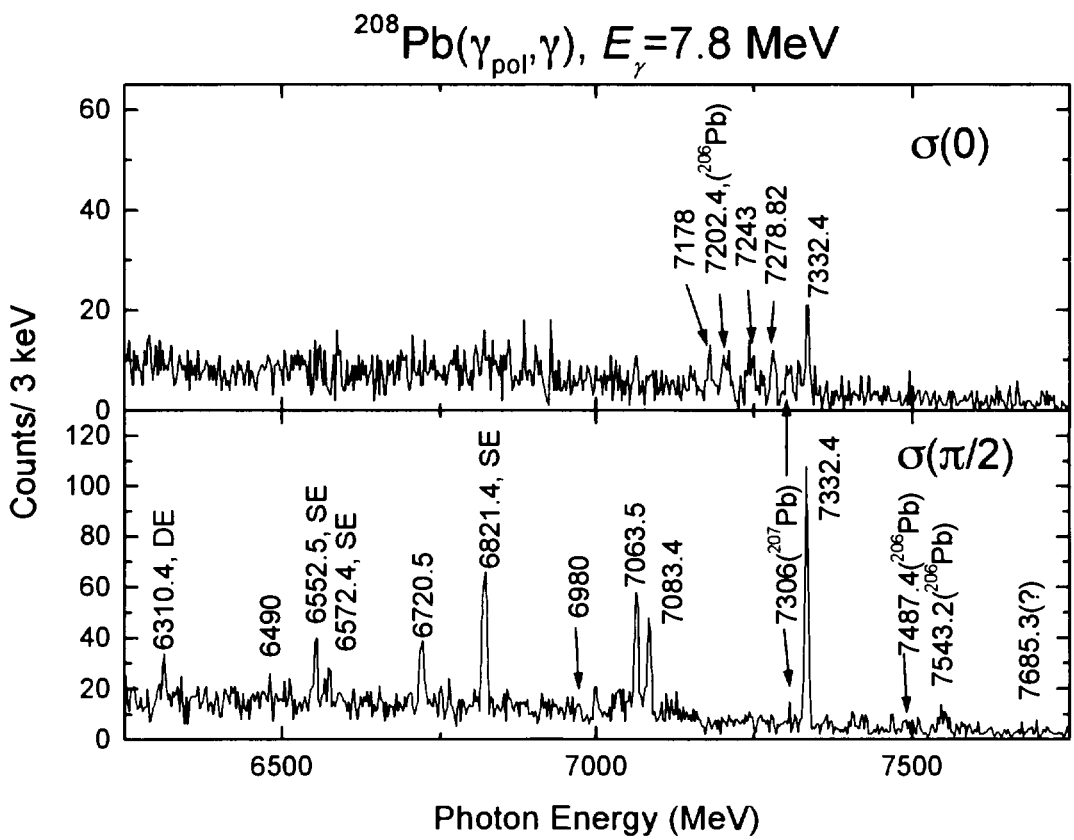

Fig.1 Energy spectra of the $^{208}Pb(\gamma_{pol},\gamma)$ reaction. The incident gamma-ray energy was 7.8 MeV and its energy spread is 13.3%. Upper part of this figure shows the elastically scattered photon in the plane parallel to the electric vector of the incident polarized gamma-ray and the lower one show that in the perpendicular plane.

II. Japan Atomic Energy Research Institute

A. Nuclear Data Center and Working Groups of Japanese Nuclear Data Committee

II-A-1 Applicability of Optical Model Potentials for Intermediate-Energy Nuclear Data Evaluations in the 1*p*-shell Mass Region

S. Chiba and M. Harada*

A paper on this subject was published in J. Nucl. Sci. Technol. 33, 346 (1996) with the following abstract:

Applicability of two kinds of optical model potentials to evaluation of neutron nuclear data for the 1*p*-shell mass region (^{6}Li to ^{16}O) has been studied in the intermediate energy region (20 to 100 MeV). A global optical potential proposed by Walter and Guss, and a microscopic one by Jeukenne-Lejeune-Mahaux (JLM) have been chosen as representatives of the phenomenologiacal and microscopic approaches, respectively. The total and reaction cross sections, and elastic and inelastic scattering angular distributions calculated by using these potentials have been compared with experimental data. It was found that both the potentials give good explanation of the experimental values in spite of the fact that these potentials were not adjusted in this mass region. The present results have indicated that the JLM potential is suitable to the intermediate-energy nuclear data evaluation for the 1*p*-shell mass region. A qualitative interpretation of the sensitivity of the total cross section to the parameters in the JLM approach has been carried out: it was found that the oscillatory and phase-correlated pattern of the sensitivity coefficients to the real and imaginary potential strengths obeys a simple sine- and cosine-rule with the amplitude decreasing as $E^{-1/2}$ as derived by a semi-classical model.

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* Faculty of Energy Conversion Engineering, Kyushu University

II-A-2

Evaluation of Neutron Cross Sections of Hydrogen from 20 MeV to 1 GeV

S. Chiba, S. Morioka* and T. Fukahori

A paper on this subject was published in J. Nucl. Sci. Technol. 33, 654 (1996) with the following abstract:

The neutron cross sections of hydrogen (^{1}H) have been evaluated in the energy region from 20 MeV to 1 GeV. Evaluated quantities are the total, elastic and inelastic scattering and capture cross sections, covariance matrix of total cross section and photon production cross section associated with the capture process. The total cross section was evaluated by combining the results obtained from the generalized least-squares method and the phase-shift data. The phase-shift data have been also used to calculate the elastic and inelastic scattering cross sections and their angular distributions. The capture cross section was calculated from the deuteron photo-disintegration cross section in conjunction with the principle of detailed balance. The presently evaluated data give a good description of the available experimental data in general and are also in good accord with those values given in ENDF-B/VI that are available below 100 MeV.

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* CRC Research Institute

II-A-3

Estimation of Uncertainties in ^{1}H, Zr and ^{238}U Nuclear Data Contained in JENDL-3.2

Keiichi SHIBATA, Yutaka NAKAJIMA, Tokio FUKAHORI,
Satoshi CHIBA, Tsuneo NAKAGAWA and Toshihiko KAWANO

A paper on this subject was published in JAERI-Research 96-041 (1996) with the following abstract:

Uncertainties have been estimated for the total, elastic scattering and capture cross sections of ^{1}H, the capture, (n,2n) reaction and inelastic scattering cross sections of natural Zr, and the inelastic scattering cross sections and resolved resonance parameters of ^{238}U. Considering the evaluation method taken for each data, standard deviations and correlation matrices were determined in 18 energy group structure.

II-A-4

Estimation of Covariance Data for JENDL-3.2

K. SHIBATA, S. CHIBA, A. HASEGAWA, M. ISHIKAWA,
Y. KANDA, T. KAWANO, Y. KIKUCHI, H. MATSUNOBU,
T. MURATA, Y. NAKAJIMA, N. ODANO and M. SUGIMOTO

A paper on this subject was published in Proc. Int. Conf. on the Physics of Reactors, Mito, Sep. 16-20 1996, Vol. 3, p. F31 (1996) with the following abstract:

Covariance data for JENDL-3.2 are being estimated by a working group in the Japanese Nuclear Data Committee. Various useful tools have been developed through the activities of the working group. Error estimation depends on how evaluated data were obtained; measurements or nuclear model calculations. Methods of covariance estimation are discussed together with several results for JENDL-3.2 covariance files.

II-A-5

Decay and Fission Yield Data Library for ORIGEN2 Code to Reproduce the Decay Heat Values Recommended by the Atomic Energy Society of Japan

J. Katakura

A paper on this subject was published in J. Atom. Ener. Soc. of Japan, **38**, 609 (1996) (in Japanese) with the following abstract:

The decay heat values calculated with ORIGEN2 code, which is widely used for the evaluation of radioactivity and the decay heat analysis of spent fuel, are not consistent with the "recommended decay heat values" by the Atomic Energy Society of Japan, the adoption of which to the safety assessment of light water reactor has been authorized by Japanese Atomic Energy Safety Commission. The discrepancy between them has caused perplexity in the use of ORIGEN2 code. In order to diminish the discrepancy, fission product decay data and fission yield data of ORIGEN2 code are replaced with the data contained in the JNDC Nuclear Data Library of Fission Products that was used for making the "recommended decay heat values." The decay heat calculation with ORIGEN2 code using the replaced data is able to obtain the decay heat values agreeing with the "recommended values" within nearly 1% for most of the cooling time region except for a limited region where the maximum discrepancy of 3case of 1 s irradiation. In the case of longer cooling time(1 yr), the discrepancy is diminished to nearly 0.5% for whole range of the cooling time.

II-A-6 Mass Chain Evaluation of A=118-129

ENSDF Group*

ENSDF group of Japan has the responsibility of A=118 to 129 mass chain evaluation. In 1996 the new evaluation of A=129 was published in Nuclear Data Sheet[1].The evaluation includes all data available before December 31, 1995. The data types newly evaluated are shown in Table 1.

Table 1: New data contained in A=129 evaluation

Nuclide	Data Type
^{129}Cd	Adopted Levels
^{129}In	Adopted Levels, Gammas ^{129}Cd β^- Decay (0.27 s)
^{129}Sn	Adopted Levels, Gammas ^{129}In β^- Decay (0.61 s) ^{129}In β^- Decay (1.23 s)
^{129}Sb	Adopted Levels, Gammas ^{129}Sn β^- Decay (2.23 min) ^{129}Sn β^- Decay (6.9 min) ^{129}Sb IT Decay (17.7 min) ^{130}Te(d,^{3}He) ^{130}Te(t,α)
^{129}Te	Adopted Levels, Gammas ^{129}Sb β^- Decay (4.40 h) ^{129}Sb β^- Decay (17.7 min) ^{129}Te IT Decay (33.6 d) ^{128}Te(n,γ) E=thermal ^{128}Te(d,p) ^{128}Te(t,d) ^{130}Te(p,d) ^{130}Te(d,t) ^{130}Te(^{3}He,α)
^{129}I	Adopted Levels, Gammas ^{129}Te β^- Decay (69.6 min) ^{129}Te β^- Decay (33.6 d) ^{128}Te(p,p),(p,p') IAR
^{129}I	^{128}Te(^{3}He,d) Coulomb Excitation ^{130}Te(α,t)
^{129}Xe	Adopted Levels, Gammas ^{129}I β^- Decay ^{129}Xe IT Decay ^{129}Cs ϵ Decay Coulomb Excitation (HI,xnγ)
^{129}Cs	Adopted Levels, Gammas ^{129}Ba ϵ Decay (2.23 h) ^{129}Ba ϵ Decay (2.16 h) (HI,xnγ)
^{129}Ba	Adopted Levels, Gammas ^{130}Ba(d,t) (HI,xnγ)
^{129}La	Adopted Levels, Gammas ^{129}La IT Decay (HI,xnγ)
^{129}Ce	Adopted Levels, Gammas ^{129}Pr ϵ Decay (HI,xnγ)
^{129}Pr	Adopted Levels (HI,xnγ)
^{129}Nd	Adopted Levels (HI,xnγ)

References

[1] Y. Tendow, Nucl. Data Sheets, 77, 631 (1996)

*Members are A. Hashizume, T. Ichimiya, H. Iimura, M. Kambe, K. Kitao, J. Katakura, K. Miyano, K. Ogawa, M. Oshima, S. Ohya, T. Tamura and Y. Tendow

II-A-7 Systematics of Fission Cross Sections at the Intermediate Energy Region

Tokio FUKAHORI and Satoshi CHIBA

A paper on this subject will be published in Proc. of the First Internet Symposium on Nuclear Data, Apr. 8 - Jun. 15, 1996, JAERI Tokai, Japan, JAERI-Conf (1997) with the following abstract.

The systematics was obtained with fitting experimental data for proton induced fission cross sections of Ag, ^{181}Ta、^{197}Au, ^{206,207,208}Pb, ^{209}Bi, ^{232}Th, ^{233,235,238}U, ^{237}Np and ^{239}Pu above 20 MeV. The low energy cross section of actinoid nuclei is omitted from systematics study, since the cross section has a complicated shape and strongly depends on characteristic of nucleus. The fission cross sections calculated by the systematics are in good agreement with experimental data.

II-A-8 Status of PKA, KERMA and DPA Files of JENDL

T. Fukahori, S. Chiba, K. Shibata, Y. Ikeda, T. Aruga, Y. Watanabe, T. Murata, N. Yamano, and M. Kawai

A paper on this subject will be published in Proc. of the Ninth International Symposium on Reactor Dosimetry, Sep. 2-6, 1996, Prague, Czech Republic with the following abstract.

In the Japanese Nuclear Data Committee, the PKA/KERMA file containing PKA spectra, KERMA factors and DPA cross sections in the energy range between 10^{-5} eV and 50 MeV is being prepared from the evaluated nuclear data. The processing code ESPERANT was developed to calculate quantities of PKA, KERMA and DPA from evaluated nuclear data for medium and heavy elements by using the effective single particle emission approximation (ESPEA). For light elements, the PKA spectra are evaluated by the SCINFUL/DDX and EXIFON codes, simultaneously with other neutron cross sections. In this paper, status of the PKA/KERMA file is reported.

B. Advanced Science Research Center

II-B-1

Nucleon-induced preequilibrium reactions in terms of the quantum molecular dynamics

S. Chiba, M.B. Chadwick*, K. Niita** , T. Maruyama, T. Maruyama and A. Iwamoto

A paper on this subject was published in Phys. Rev. C53, 1824 (1996) with the following abstract:

The preequilibrium (nucleon-in, nucleon-out) angular distributions of ^{27}Al, ^{58}Ni, and ^{90}Zr have been analyzed in the energy region from 90 to 200 MeV in terms of the quantum molecular dynamics theory . First, we show that the present approach can reproduce the measured (*p,xp'*) and (*p,xn*) angular distributions leading to continuous final states without adjusting any parameters. Second, we show results of a detailed study of the preequilibrium reaction processes, the stepwise contributions to the angular distribution, comparisons with the quantum-mechanical Feshbach-Kerman-Koonin theory, and the effects of momentum distribution and surface refraction/reflection to the quasifree scattering. Finally, the present method was used to assess the importance of multiple preequilibrium particle emission as a function of projectile energy up to 1 GeV.

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* University of California, Theoretical Division, LANL

** Research Organization for Information Science and Technology

II-B-2

Analysis of proton-induced fragment production cross sections by the quantum molecular dynamics plus statistical decay model

S. Chiba, O. Iwamoto, T. Fukahori, K. Niita*, T. Maruyama, T. Maruyama and A. Iwamoto

A paper on this subject was published in Phys. Rev. C54, 285 (1996) with the following abstract:

The production cross sections of various fragments from proton-induced reactions of ^{56}Fe and ^{27}Al have been analyzed by the quantum molecular dynamics (QMD) plus statistical decay model (SDM). It was found that the mass and charge distributions calculated with and without the statistical decay have very different shapes. These results also depend strongly on the impact parameter, showing an importance of the dynamical treatment as realized by the QMD approach. The calculated results were compared with experimental data in the energy region from 50 MeV to 5 GeV. The QMD + SDM calculation could reproduce the production cross sections of the light clusters and intermediate-mass to heavy fragments in a good accuracy. The production cross section of ^{7}Be was, however, underpredicted by approximately 2 orders of magnitude, showing the necessity of another reaction mechanism not taken into account in the present model.

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* Research Organization for Information Science and Technology

II-B-3

Time scale of the preequilibrium process in intermediate-energy nucleon-induced reactions

S. Chiba, K. Niita* and O. Iwamoto

A paper on this subject was published in Phys. Rev. C54, 3302 (1996) with the following abstract:

The time scale required to reach thermal equilibrium in intermediate-energy nucleon-induced preequilibrium reactions was investigated by quantum molecular dynamics (QMD). The average kinetic energy of two colliding particles in their center-of-mass system was taken to be the measure of such thermal equilibration. The corresponding time was found to be of the order of 20 fm/c ($\sim 7\times 10^{-23}$ sec), a time scale that is much shorter than the time believed for the compound reaction, i.e., $\sim 10^{-18}$ sec. An interpretation of the reason why the kinetic energy brought by the projectile is dumped so fastly to thermal equilibrium is discussed. The equilibration time of 20 fm/c gives a justification of our "hybrid" approach of using the QMD plus the statistical decay model (SDM) which are connected at a time scale of $\sim$ 100 fm/c.

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* Research Organization for Information Science and Technology

C. Department of Fuel Cycle Safety Research

II-C-1 ORIGEN2 Library Based on JENDL-3.2

Yoshitaka NAITO and Masayoshi KAWAI*
Japan Atomic Energy Research Institute, Tokai, JAPAN
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For LWR Application

ORIGEN2 libraries for typical PWR(17 × 17 assembly) and BWR(8 × 8 assembly) were made. Especially for the case of BWR, we made three libraries for different void ratio, 0, 40 and 70 %.

Single pin cell models were used for this activity, which were based on typical data of PWR and BWR fuels. In this model, initial ^{235}U enrichment is 4.1 and 3.8 wt %. For the irradiation history, typical one was assumed.

To make the new ORIGEN2 libraries, SWAT code system was used with the updated SWAT library based on JENDL-3.2. This new library was prepared by CRECTJ5 code from pointwise cross sections processed with the RESENDD or RECENT code. This library contains 147 group cross section data for capture, fission, (n,2n), (n,3n), (n,p) and (n,α) reaction of 247 isotopes in JENDL-3.2. The energy range of it is 1.0×10^{-5} eV to 20 MeV.

In SWAT, these 147 group data were collapsed to one group data by using spectra at UO_2 pellet supplemented with fission spectrum above 10 MeV as a weighting function. Then, one group data were formated to ORIGEN2 library.

Also, utility programs were developed to make subroutines of variable actinide cross section from the output file of SWAT.

At last, the new decay data for ORIGEN2 will be prepared based on JNDC FP Library second version in near future. The verification test of the new libraries will be made near future.

For FBR Application[1]

A preliminary work to make an ORIGEN2 library for FBR applications from JENDL-3.2 has been done. The first, 73 group cross sections for all 340 nuclides in JENDL-3.2 were prepared from the pointwise cross sections processed with the RESENDD code by using the CRECTJ5 code and a typical FBR core spectrum.

The first three groups are given in the energy region from 10 MeV to 20 MeV.The remainders blow 10 MeV have the same energy group structure of the 70 group cross section set JFS-3-J3.2 which was made from JENDL-3.2 and is in common use for FBR core designs in Japan. Secondary, typical FBR 70 group spectra were calculated with JFS-3-J3.2. The 73 group cross sections for capture, fission, (n,2n), (n,3n), (n,p) and (n,α) reactions were collapsed into one group ones by using region dependent spectra supplemented with fission spectrum above 10 MeV as a weighting function. Thirdly, the resonance self-shield corrections were employed region wise to capture and fission cross sections of main isotopes of FBR, taking into account of region-dependent neutron spectra. Finally, the results are compiled into the ORIGEN2 library.

The data verification and applicability test of the new library will be made near future.

[1]This work has been performed by Toshiba Corporation under contract with Power Reactor and Nuclear Fuel Development Corporation

III. Kyoto University

A. Research Reactor Institute

III-A-1

Measurement of Fission Cross Section with Pure Am-243 Sample using Lead Slowing-Down Spectrometer

Katsuhei Kobayashi, Shuji Yamamoto, T. Kai, Yoshiaki Fujita,
Hideki Yamamoto*, Itsuro Kimura* and Nobuo Shinohara+

By making use of back-to-back type double fission chambers and a lead slowing-down spectrometer coupled to an electron linear accelerator, the fission cross section for the ^{243}Am(n,f) reaction has been measured relative to that for the ^{235}U(n,f) reaction in the energy range from 0.1 eV to 10 keV. The measured result was compared with the evaluated nuclear data appeared in ENDF/B-VI and JENDL-3.2, whose evaluated data were broadened by the energy resolution function of the spectrometer. General agreement was seen between the evaluated data and the measurement except that the ENDF/B-VI data were lower in the range from 15 to 60 eV and that the JENDL-3.2 data seemed to be lower above 100 eV.

1. Introduction

Americium isotopes are minor actinides which are produced subsequently to ^{237}Np nuclide in light water reactors. The nuclear data for the minor actinides are of great interest in the design of reactors with MOX or Pu fuels and for the design of systems for spent fuel reprocessing or waste disposal. The fission cross sections are important for transmutation of the burdensome actinides[1,2].

Numerous measurements of the nuclear data for ^{237}Np and ^{241}Am have been made previously[3]. The fission cross section for ^{243}Am is not always enough both in quality and in quantity, especially, the measured data have not been reported below 5 keV except for thermal neutron energy[3,4]. In the lower energy region, ^{243}Am has a small subthreshold fission cross section. The cross section is still important not only for systematic studies of fission mechanism but also for transmutation in light water reactors because they have higher neutron fluxes at the relevant energies. The authors have recently measured the fission cross sections of ^{237}Np and ^{241}Am in the neutron energy range from 0.1 eV to 10 keV[5,6].

In the present study, at first, we have prepared the pure ^{243}Am sample by anion-exchange method to remove the ^{239}Pu impurity produced through the alpha-decay of ^{243}Am. After the chemical purification, the fission cross section for the ^{243}Am(n,f) reaction has been measured relative to that for the ^{235}U(n,f) reaction by making use of back-to-back type double fission chambers and a lead slowing-down spectrometer coupled to 46 MeV electron linear accelerator (linac) of Research Reactor Institute, Kyoto University (KURRI). The experimental technique

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is same as before[5,6]. The measured result is compared with the evaluated data in JENDL-3.2[7] and ENDF/B-VI[8].

2. Experiments and Measurements

The cross section for the ^{243}Am(n,f) reaction has been measured in the energy region from 0.1 eV to about 10 keV using a lead slowing-down spectrometer, which was installed beside a 46 MeV linac at the Research Reactor Institute, Kyoto University (KURRI). The characteristics of the KULS (relation between neutron slowing-down time and its energy, and the energy resolution) were obtained by calculations with the MCNP Monte Carlo code[9] and by experiments using resonance filters. Neutron intensity of the spectrometer can be much stronger than that obtained by conventional neutron time-of-flight method, although the neutron energy resolution was about 35 to 40 % full width at half maximum[10,11]. More detailed descriptions are given elsewhere[5,6,11].

Impurities of ^{239}Pu are accumulated in the ^{243}Am sample through its alpha-decay. Am solution was purified by an anion-exchange method using nitric acid-methyl alcohol mixed media[12,13], in order to remove U, Np, Pu and Cm from the Am sample. The purified Am solution was electrodeposited on a stainless steel plate (28 mm in diam. and 0.2 mm thick: radioactive are of 20 mm in diam.). According to the alpha spectrometry, the ratios of impurity-counts to ^{243}Am-counts and of ^{241}Am-counts to ^{243}Am-counts were 0.00004 and 0.007, respectively. A highly enriched ^{235}U sample (99.91 %) was also prepared by the electrodeposition method. The number of ^{243}Am and ^{235}U atoms was determined by alpha spectrometry. The electrodeposited samples were set as back-to-back type double fission chamber with a mixed gas of 97 % Ar and 3 % N_2 at the pressure of 1 atm.[14].

The linac was operated for about 200 hours with the conditions of pulse width: 33 ns, repetition rate: 200 Hz, peak current: 1.9 A, and electron energy: 31$\pm$1 MeV.

The fission cross section of ^{243}Am is obtained by

$$\sigma_{Am}(E) = \frac{C_{Am}}{C_U} \frac{N_U}{N_{Am}} \sigma_U(E)$$

where C_{Am} and C_U are fission counts for ^{243}Am and ^{235}U, respectively. N_{Am} and N_U are numbers of atoms for the respective samples. $\sigma_U(E)$ is the reference cross section for the ^{235}U(n,f) reaction, which was cited from the ENDF/B-VI file[8].

3. Results and Discussion

Figure 1 shows the cross sections measured at the time when 4 weeks, 5 months and 13 months have passed after the chemical purification. In the neutron energy region around 0.3 eV, one can see that the cross sections are getting higher as the time passes, due to the accumulated impurity of ^{239}Pu by the alpha-decay of ^{243}Am. The present result, which has been corrected with the growth influence of the ^{239}Pu impurity[15], is shown in Fig. 2 and is compared with the evaluated cross sections in JENDL-3.2 and ENDF/B-VI, which are broadened by the energy resolution function of the KULS. The experimental uncertainties are considered to be mainly due to (1) the statistical error in fission counts, (2) assignment of fission counts, (3) number of

atoms for the ^{243}Am and the ^{235}U deposits, and (4) the reference fission cross section for the ^{235}U(n,f) reaction. Total amount of the experimental uncertainties is 4 to 6 %.

It is seen in Fig. 2 that both of the evaluation data are discrepant each other in the energy regions below 0.3 eV and above 15 eV. Although the ENDF/B-VI data are in general agreement with the present measurement, they are lower at energies between 15 and 60 eV. The JENDL-3.2 data seem to be lower than the measurement in general above 100 eV. At the narrow dip of around 3 eV, one can see discrepancy between the evaluated and the measured data. The reason would be due to the inappropriate resolution function of the lead slowing-down spectrometer.

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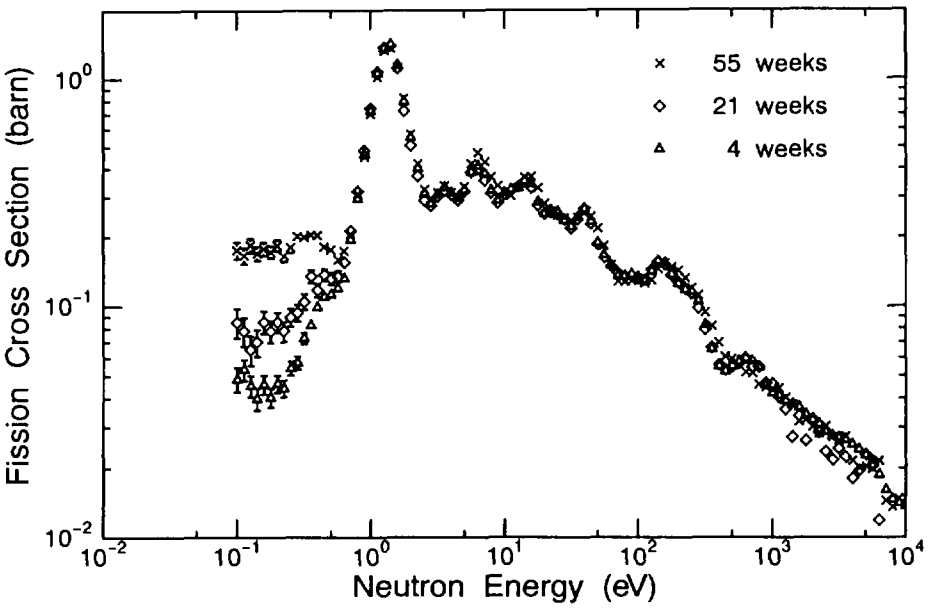

Fig. 1 Comparison of the measured data depending on the time after the chemical purification.

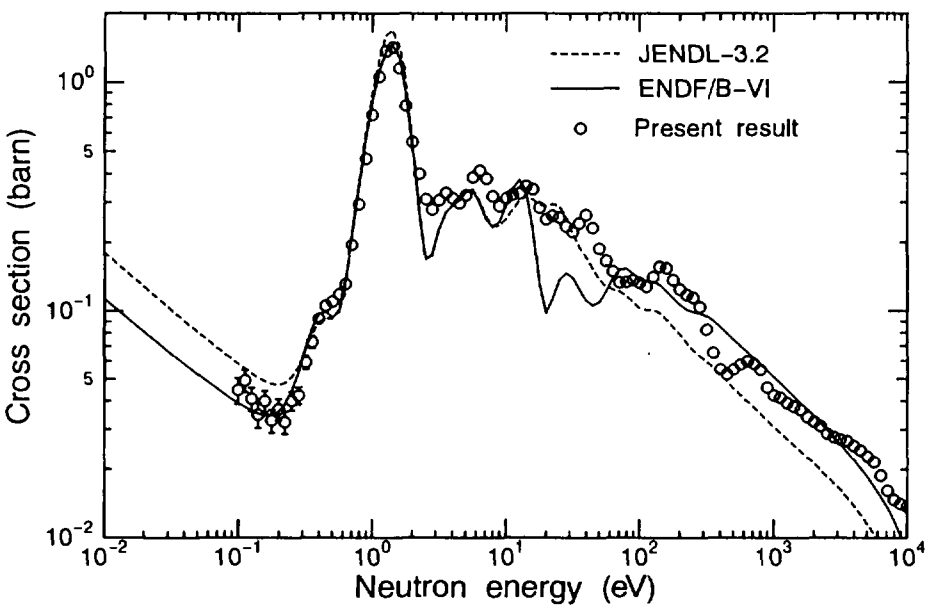

Fig. 2 Comparison of the evaluated fission cross sections of ^{243}Am with the present measurement.

III-A-2

The Influence of Impurities for Cross Section Measurement of ^{241,243}Am(n,f) Reactions

Tetsuya Kai[1], Katsuhei Kobayashi[1], Shuji Yamamoto[1], Yoshiaki Fujita[1], Itsuro Kimura[2], Mitsuharu Miyoshi[2], Hideki Yamamoto[2]and Nobuo Shinohara[3]

A paper on this subject was presented at 1996 Seminar on Nuclear Data at Tokaimura, JAERI held on Nov. 21-22, 1996.

For the nuclear data measurements, in general, cross section value of the sample containing impurities may be bigger than that with the pure sample depending on the amount of impurities and on the nuclear characteristics[1) 2)]. Particularly, it have to be careful to measure the fission cross sections of minor actinides because many kinds of them are produced and accumulated in the sample through the complicated decay processes. Therefore, the extensive experimental studies have recently been concentrated on the importance of the chemical and isotopic composition of the sample materials and of its physical properties[1) 2) 3)].

In this study, following cases have been considered as the influence of impurities for fission cross section measurements with:

(a) the sample which contains impurities originally.

(b) the sample whose decay products are accumulated as impurities after chemical purification.

In practice, the impurity problems have been investigated as typical examples for the measurements of the ^{241}Am(n,f) and ^{243}Am(n,f) cross sections, respectively[4) 5) 6)]. The experiments have been performed by making use of back-to-back type double fission chambers using the Am and the ^{235}U deposits and of a lead slowing-down spectrometer coupled to an electron linear accelerator as presented in Ref. 6) and 7).

Both of the ^{241,243}Am(n,f) cross sections measured with the pure samples were in general agreement with the evaluated data in JENDL-3.2[8)] and ENDF/B-VI[9)], where the evaluated data were broadened by the energy resolution of the KULS. The result with the ^{241}Am sample on the market is shown in Fig. 1. The measured values are much larger than that with the pure sample. We have experimentally investigated the problem and found that the purchased sample contained ^{239}Pu impurity of about 0.3 % at least by the careful α-ray spectrometry. The sample contains some other impurities in addition to ^{239}Pu because the larger cross section has not been corrected properly with the amount of ^{239}Pu impurity except for the energy region around the 0.3 eV resonance.

On the other hand, the measurement of ^{243}Am fission cross section have to be also performed with careful consideration of ^{239}Pu ingrowth, because it is produced through the following decay chain;

$$^{243}\mathrm{Am} \xrightarrow[7370y]{\alpha} {}^{239}\mathrm{Np} \xrightarrow[2.355d]{\beta^-} {}^{239}\mathrm{Pu} \xrightarrow[24110y]{\alpha} {}^{235}\mathrm{U}$$

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[2]Department of Nuclear Engineering, Kyoto University
[3]Japan Atomic Energy Research Institute

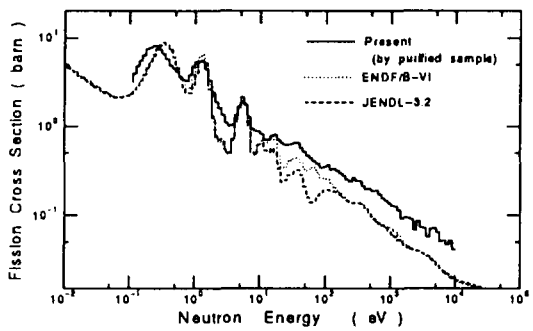

Fig. 1 Comparison of the measured cross section for the purchased sample and the evaluated data.

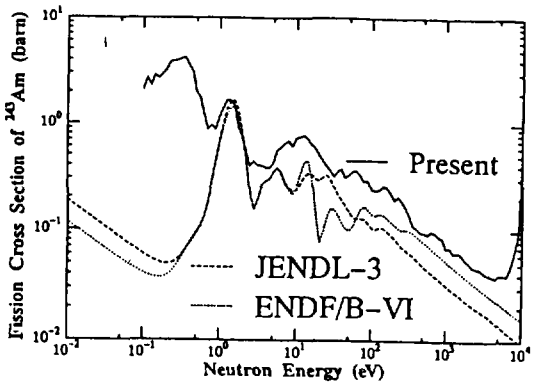

Fig. 2 Comparison of the measured cross section for the purchased sample and the evaluated data.

This ^{239}Pu ingrowth makes an important contribution to the measured fission cross section even if we have purified the ^{243}Am sample by the chemical processing. Figure 2 also shows the ^{243}Am(n,f) cross section measured with the sample on the market. There is a remarkable difference between this result and the evaluated data around 0.3 eV, which is clearly cause by ^{239}Pu impurity produced by the α-decay of ^{243}Am. We have followed the growth of ^{239}Pu impurity in the ^{243}Am sample after the chemical purification by the calculation and periodical measurements. In Fig. 3, the results of the measurements performed at 4 weeks, 21 weeks and 55 weeks after the purification is shown. It is obviously observed that the measured values below 0.5 eV increased depending on the time after the purification.

The estimation for the influence of ^{239}Pu ingrowth was performed as shown in Fig. 4. It was found by experiments and calculations that the cross section value increased as time went on. As a result, the present cross section for the ^{243}Am(n,f) reaction has been derived and displayed in Fig. 5 with the correction of ^{239}Pu accumulation (about 18 % around 0.3 eV in 4 weeks after the chemical process).

Through the present experimental investigation, it is found that the measurement has to be done as soon as possible after the chemical purification not to make the correction larger and that the pure sample is indispensable for these kinds of measurements.

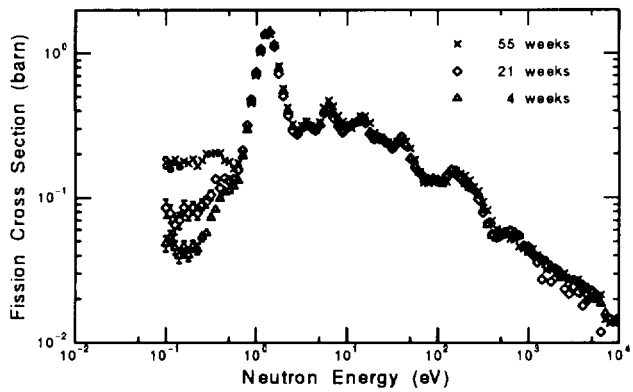

Fig. 3 Ingrowth of ^{239}Pu in ^{243}Am(n,f) cross section after chemical separation.

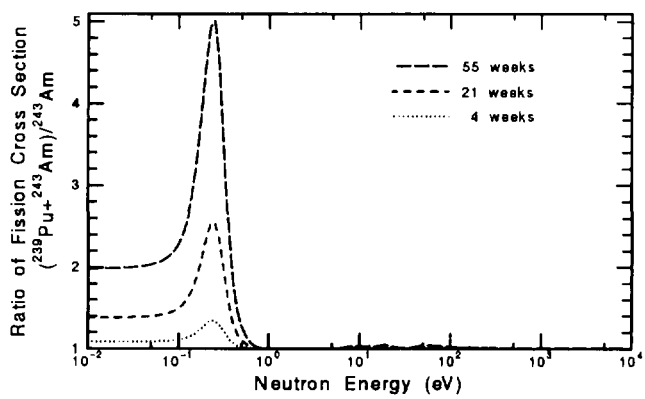

Fig. 4 Energy dependent influence of ^{239}Pu ingrowth.

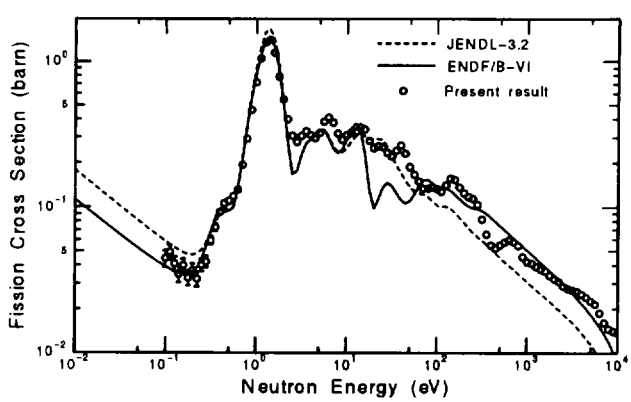

Fig. 5 Present ^{243}Am(n,f) cross section with the correction of ^{239}Pu ingrowth.

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III-A-3 Application of BGO Scintillators to Absolute Measurement of Neutron Capture cross Sections between 0.01 eV and 10 eV

Shuji Yamamoto, Katsuhei Kobayashi and Yoshiaki Fujita

A paper on this subject was published in Journal of Nuclear Science and Technology, Vol.33, No.11, 815–820 with the following abstract:

Applying a total energy absorption gamma-ray detector composed of 12 bricks (5x5 cm^2, 7.5 cm thick) of BGO scintillators, the absolute measurement of capture cross sections for Au and Sb has been made in an energy region between 0.01 and 10 eV using the linac time-of-flight method. Incident thermal neutron flux was absolutely determined by using the BGO detection system with a Sm sample. To extent the neutron flux measurement from the thermal neutron region to higher neutron energies, the $^{10}B(n,\alpha\gamma)$ reaction was applied. Absolute capture yield for the relevant capture sample was obtained by the saturated capture yield at a large resonance of the sample.

Gold was selected to investigate the application of the BGO detection system to the absolute measurement of the capture cross sections, since the $^{197}Au(n,\gamma)^{198}Au$ reaction cross section is a well known standard one. The result of the $^{197}Au(n,\gamma)^{198}Au$ reaction cross section showed good agreement with the evaluated data in JENDL Dosimetry File and ENDF/B-VI. Then, the detection system was applied to the $Sb(n,\gamma)$ cross section measurement. Antimony has a large scattering-to-capture cross section ratio comparing to that of gold. The result showed good agreement with the evaluated data in JENDL-3.2 and ENDF/B-VI.

III-A-4

Characteristics of the Kyoto University Lead Slowing-down Spectrometer (KULS) Coupled to an Electron Linac

Katsuhei Kobayashi, Shuji Yamamoto, Akihiro Yamanaka*+, Yoshihiro Nakagome
Yoshiaki Fujita, Satoshi Kanazawa* and Itsuro Kimura*

A paper on this subject has been accepted for publication in *Nuclear Instruments and Methods in Physics Research A* with the following abstract.

A lead slowing-down spectrometer coupled to a 46 MeV electron linear accelerator (linac) was installed at Research Reactor Institute, Kyoto University (KURRI). The size of this Kyoto University Lead Slowing-down Spectrometer (KULS) is 1.5 m cubic, and it is covered with Cd sheets 0.5 mm thick. One of the eleven experimental holes in the KULS is covered with bismuth layers 10 to 15 cm thick to suppress high energy capture gamma-rays from lead.

The characteristics of this KULS have been experimentally obtained and the results are compared with the predicted values by Monte Carlo calculations using the MCNP code. (1) The slowing-down constant K in the relation $E=K/t^2$ between neutron slowing-down time t and energy E is 190 ± 2 (keV μs^2) for the bismuth hole and 156 ± 2 (keV μs^2) for an ordinary lead hole, respectively. The K values agree with the calculated ones. (2) The measured energy resolution $\Delta E/E$ at full width at half maximum (FWHM) was about 40 % for both holes, while the calculated values were lower by about 10 % than the measured ones in the relevant energy region. (3) The neutron energy spectrum from 0.01 eV to 20 MeV and the spatial distribution of neutrons in the KULS were measured by foil activation method. The angular neutron spectrum perpendicular to the linac electron beam was also experimentally obtained in the energy range from a few eV to about 10 MeV by neutron time-of-flight (TOF) method. The measured results are compared with the calculated ones in which we have used three evaluated nuclear data JENDL-3, ENDL-85 and ENDF/B-IV for lead. Through the comparison, integral check of the nuclear data has been performed.

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B. Department of Nuclear Engineering

III-B-1

A system for correlation measurement of fission fragments and prompt neutrons for thermal neutron induced fission

K. Nishio, H. Yamamoto, I. Kanno, I. Kimura, Y. Nakagome [1]

A paper on this subject has been accepted for the publication in Nucler Instruments and Method in Physics Research A [1]. In order to obtain the multiplicity and energy of neutrons from the specified fission fragment, a system consisting of two fragment detectors and a neutron detector was developed. The system with electronic circuits is shown in Fig.1. The kinetic energy of the fragment 1 (FF1) was obtained with a silicon surface barrier detector (SSBD). Another fragment (FF2) was detected by a newly developed parallel plate avalanche counter (PPAC), and the energy was determined by the time difference between the signals of the SSBD and the PPAC. The PPAC was designed so as to determine the incident position of the FF2, by which the fragment direction, θ, was obtained. The prompt neutron emitted from the specified fragment was detected with an organic liquid scintillator (NE213), and the energy was determined by the time-of-flight method. In this setup, the angle of neutron emission from the FF1 became θ, which was used to transform the neutron energy to the value of the fragment center-of-mass system.

With this system, we tried to carry out the fragment-neutron simultaneous measurement for $^{235}U(n_{th},f)$, and succeeded in obtaining the neutron energy spectrum in the center-of-mass system and the neutron multiplicity depending on the fragment mass [2].

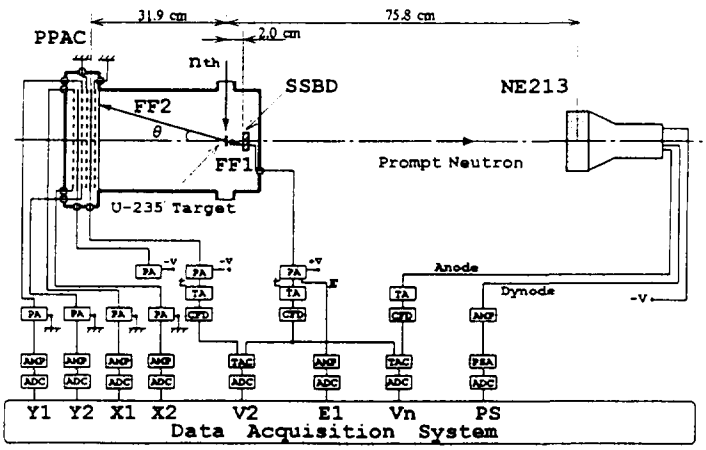

Fig. 1 Experimental setup for the correlation measurement of fission fragments and neutrons.

References

[1] K. Nishio, H. Yamamoto, I. Kanno, I. Kimura and Y. Nakagome, Nucl. Instrum. Meth. A, in press.

[2] K. Nishio, Y. Nakagome, H. Yamamoto, I. Kimura, submitted to Nucl. Phys.A.

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III-B-2

Multiplicity and Energy of Neutrons from Fission Fragments for $^{235}U(n_{th},f)$

K. Nishio, Y. Nakagome [1], H. Yamamoto, I. Kimura

A paper on this subject was submitted to Nuclear Physics A for publication [1]. By using a newly developed system [2] for the correlation measurement of fission fragments and neutrons, we have obtained the multiplicity and energy of neutrons from the specified fragment mass (m^*) for $^{235}U(n_{th},f)$ with better statistical accuracy than previous works.

The experiment was carried out using the thermal neutrons from the Kyoto University Reactor. The average energy of neutrons in the fragment center-of-mass system, $\langle\eta\rangle$, is shown in Fig. 1. It is seen that the $\langle\eta\rangle(m^*)$ distributes of bell-type and is nearly symmetric around the half mass division of the compound nucleus. On the other hand, the average neutron multiplicity versus mass, $\langle\nu\rangle(m^*)$, has a saw-tooth trend as shown in Fig. 2. The present $\langle\nu\rangle(m^*)$ is compared with the results so far [3][4][5], and is close to the data by Maslin *et al.* The shape difference between the $\langle\eta\rangle(m^*)$ and $\langle\nu\rangle(m^*)$ has its origin in the distribution of the level density parameter, $a(m^*)$, since the $\langle\eta\rangle$ and $\langle\nu\rangle$ are the good indicators of the nuclear temperature (T) and the excitation energy (E_{ex}), and both of them are related by $E_{ex} = a\,T^2$.

We obtained the neutron multiplicity against the total kinetic energy (TKE) for the specified fragment, from which the slope, $-\,d\nu/dTKE$, is obtained and is plotted against the mass in Fig. 3. It is clear from this figure that the $-\,d\nu/dTKE(m^*)$ shows saw-tooth trend. This value represents a deformability of the fragment at the scission point, which follows that for the symmetric mass division heavy fragment around 130 u is stiff, whereas the complementary fragment (105 u) are soft or deformable.

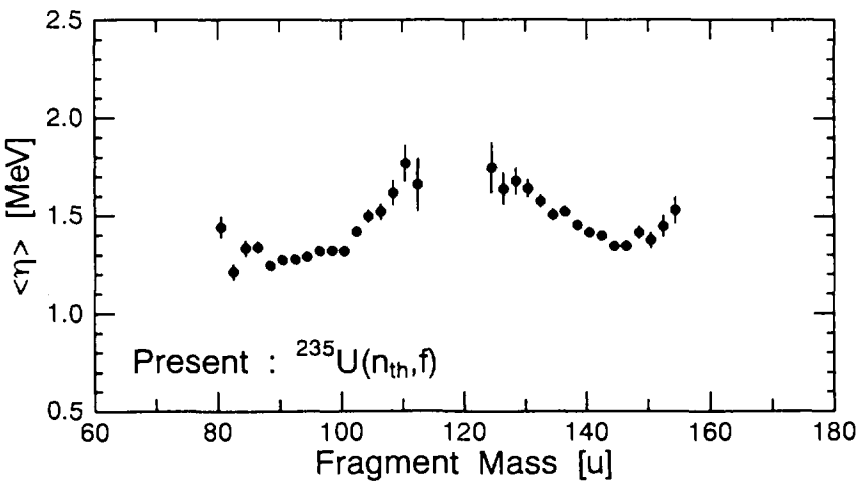

Fig. 1 Average energy of neutrons from fission fragments, $\langle\eta\rangle$.

[1] Research Reactor Institute, Kyoto University, Kumatori-cho, Sennan-gun, Osaka 590-04, Japan

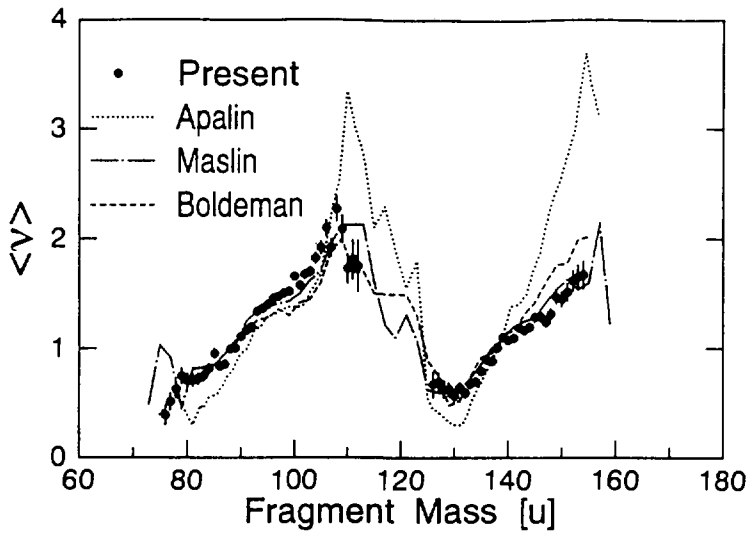

Fig. 2 Average neutron multiplicity from fission fragments. The data by Apalin *et al.* [3], Boldeman *et al.* [4] and Maslin *et al.* [5] are plotted for comparison.

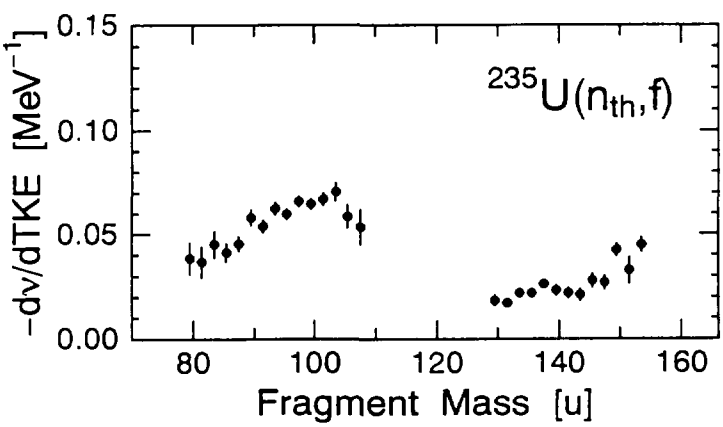

Fig. 3 - d ν / d *TKE* against the mass.

References

[1] K. Nishio, Y. Nakagome, H. Yamamoto, I. Kimura, submitted to Nucl. Phys.A.

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[4] J.W. Boldeman, A.R. DE L. Musgrove and R.L. Walsh, Aust. J. Phys. **24** (1971) 821.

[5] E.E. Maslin and A.L. Rodgers, Phys. Rev. **164** (1967) 1520

III-B-3 Level Density Parameters of Fission Fragments Following Thermal Neutron Induced Fission of ^{235}U

K. Nishio, I. Kimura, Y. Nakagome [1],

Level density parameters (LDPs) of fission fragments following the thermal neutron induced fission of ^{235}U were determined as a function of the fragment mass by measuring the energy and multiplicity of prompt neutrons from a specified mass, and the result was submitted to the Journal of Nuclear Science and Technology for publication [1].

The LDP, a, was derived from the relation, $E_{ex} = a\ T^2$, where E_{ex} and T mean the excitation energy and the nuclear temperature of the fission fragment, respectively. The E_{ex} is determined from the neutron multiplicity and the average neutron emission energy, and the T from the neutron energy spectrum in the fragment center-of-mass system. The details of this measurement are described elsewhere [2]. The a as a function of the fragment mass, m^*, is shown in Fig. 1. It is seen that the $a(m^*)$ for $^{235}U(n_{th},f)$ shows a saw-tooth distribution with the minimum value around 132 u and is similar to that for $^{252}Cf(sf)$ [3].

To interpret the shape of $a(m^*)$, the calculation using the phenomenological expression including the shell-correction energy, δW, by Iljinov *et al.* [5] was made. The $\delta W(m^*)$ of fission fragment for $^{235}U(n_{th},f)$ were taken from Ref. [4] as shown in Fig. 2 (a). The calculated results are compared with the experimental data in Fig. 2 (b). In this figure, the calculations assuming the collective motion of the fragments ($K_{rot} \neq 1$, $K_{vib} \neq 1$) or not ($K_{rot} = 1$, $K_{vib} = 1$) are depicted. The line represents the asymptote when the excitation energy of the fragment increases to infinity. It is seen from this figure that ; (1) the global saw-tooth trend of $a(m^*)$ observed in this measurement is explained by the $\delta W(m^*)$, and (2) the fragments have collective motions.

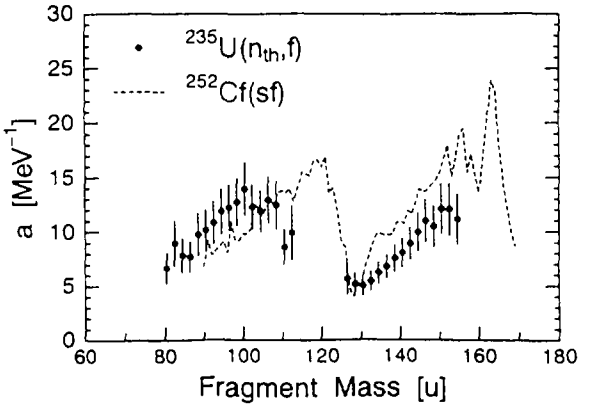

Fig. 1 Level density parameters of fission fragments for $^{235}U(n_{th},f)$. Data for $^{252}Cf(sf)$ from Ref. [3] is also shown.

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[1] Research Reactor Institute, Kyoto University, Kumatori-cho, Sennan-gun, Osaka 590-04, Japan

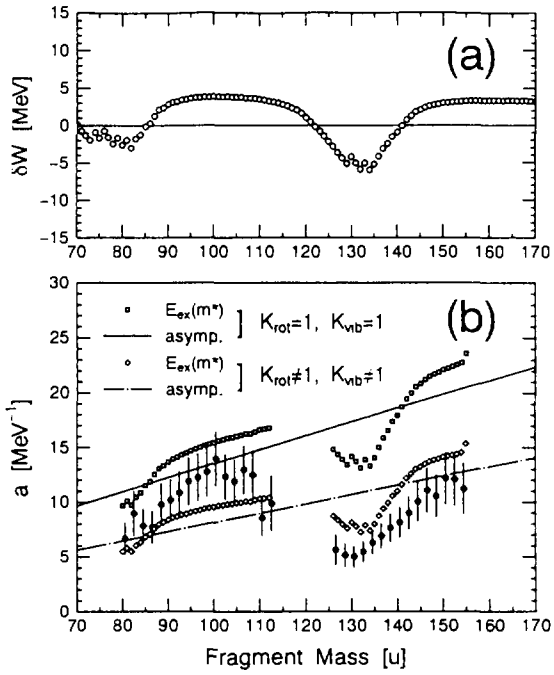

Fig. 2 (a) Shell-correction energy of fission fragments for $^{235}U(n_{th},f)$ taken from Ref. [4]. (b) Calculated level density parameters by using the expressions by Iljinov *et al* [5].

References

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[2] K. Nishio, H. Yamamoto, I. Kanno, I. Kimura and Y. Nakagome, Nucl. Instrum. Meth. A, in press.

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[5] A.S. Iljinov, M.V. Mebel, N. Bianchi, E. De Sanctis, C. Guaraldo, V. Lucherini, V. Polli, A.R. Reolon and P. Rossi, Nucl. Phys. **A543** (1992) 517.

IV. Kyushu University

A. Department of Energy Conversion Engineering

IV-A-1 Evaluation of Neutron Cross Sections of Carbon-12 for energies up to 80 MeV

M. Harada, Y. Watanabe, S. Chiba*, and T. Fukahori*,

A paper on this subject was submitted to *J. Nucl. Sci. and Technol.* with the following abstract and is now in press (1997):

We have evaluated the cross sections of ^{12}C for neutrons up to 80 MeV, paying more attention to the intermediate energy range above 20 MeV. For energies below 20 MeV, the evaluated data of JENDL-3.2 were adopted with some modifications. In the energy range above 20 MeV, total cross section and its covariance matrix were evaluated using a generalized least-squares method with available experimental data. The spherical optical model was used to evaluate reaction and elastic scattering cross sections. Inelastic scattering to the first 2^+ state was calculated based on the DWBA. The optical potentials used in these calculations were obtained by means of the microscopic folding model based on the Jeukenne-Lejeune-Mahaux theory. Double-differential emission cross sections for neutron, proton, deuteron, triton, ^3He and alpha-particle and other heavier products were calculated using the Monte-Carlo method by which three-body simultaneous breakup process and two-body sequential decay process were taken into account in n+^{12}C multibody breakup reactions. Kerma factors calculated from the evaluated cross sections were also compared with measurements and other evaluations.

*Japan Atomic Energy Research Institute

IV-A-2 A Consistent Analysis of (p,p') and (n,n') Reactions Using the Feshbach-Kerman-Koonin Model

S. Yoshioka, Y. Watanabe, M. Harada, K. Sato, Y. Nakao, H. Ijiri, S. Chiba*, T. Fukahori*, S. Meigo*, M. Iwamoto*, and N. Koori**

A paper on this subject was presented at the 1996 Symposium on Nuclear Data, Nov. 21-22, 1996, JAERI, Tokai, Japan with the following abstract:

Double-differential proton emission cross sections were measured for proton-induced reactions on several medium-heavy nuclei ($^{54,56}Fe$, ^{60}Ni, ^{90}Zr, and ^{93}Nb) at two incident energies of 14.1 and 26 MeV. The (p,p') data for ^{56}Fe and ^{93}Nb were compared with available data of (n,n') scattering for the same target nuclei and incident energies, and both data were analyzed using the Feshbach-Kerman-Koonin model to extract the strength V_0 of the effective N-N interaction which is the only free parameter used in multistep direct calculations.
detector system.

* Japan Atomic Energy Research Institute
** Faculty of Integrated Arts and Sciences, The University of Tokushima

IV-A-3 Semi-classical distorted wave model analysis of multistep direct (p,p'x) reactions to continuum at intermediate energies

Y. Watanabe, H. Shinohara, M. Higashi, M. Kawai*, and M. Kohno**

The semi-classical distorted wave (SCDW) model[1-3] to describe multistep direct (MSD) reactions was extended so that one can take into account the leading three MSD steps. Using the extended SCDW model, we have analyzed preequilibrium angular distributions of ^{58}Ni(p,p'x) reactions at incident energies of 65, 120 and 200 MeV and ^{90}Zr(p,p'x) reactions at 160 MeV.

The result of the ^{58}Ni(p,p'x) reaction at 120 MeV was shown in Fig.1. The SCDW calculation with no adjustable parameter gives overall good agreement with the experimental angular distributions, except at very small and large angles. Similar results were obtained for the other reactions. From these analyses, it has been found that the nonlocality correction to distorting potentials by the Perey factor is essential to reproduce the absolute magnitude of the (p,p'x) cross sections. The in-medium effect was also investigated using the in-medium N-N scattering cross sections[4] derived in terms of the G-matrix theory on the SCDW calculation. As a result, the effect was found to be small, because the 1-step process which takes place in the peripheral region of the nucleus is dominant in the MSD reactions . In addition, we have compared the SCDW calculations with other model calculations (AMD, QMD, and FKK) and discussed with attention to the step-wise MSD contributions to the angular distributions. It was found that the shape of the 1-step angular distributions depends strongly upon the models, but the multistep components are not different in shape and the relative contribution to each step is generally similar.

A part of this work was presented by M. Kawai at the Fifteenth International Workshop on Nuclear Theory, 10 to 16 June, 1996, Rila mountains, Sofia, Bulgaria.

[1] Y.L. Luo and M. Kawai, Phys. Rev. C**43**, 2367 (1991).
[2] M. Kawai and H.A. Weidenmüller, Phys. Rev. C**45**, 1856 (1992).
[3] Y. Watanabe and M. Kawai, Nucl. Phys. **A560**, 43 (1993).
[4] M. Kohno, M. Higashi, Y. Watanabe, and M. Kawai, to be submitted to Phys. Rev. C.

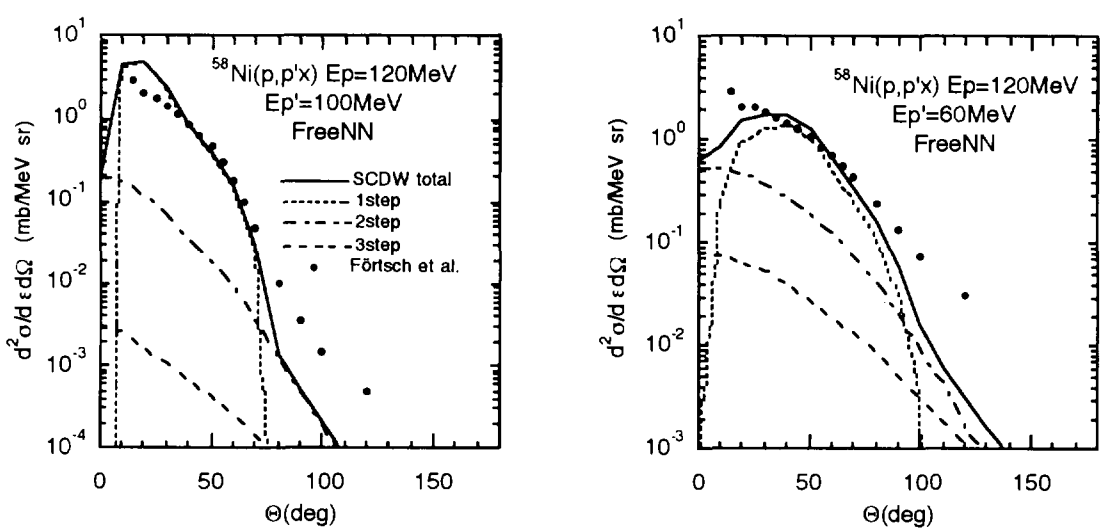

Fig.1 Comparison between theoretical and measured angular distributions for the ^{58}Ni(p,p'x) reaction at an incident energy of 120 MeV for two emission energies.

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**Physics Division, Kyushu Dental College

IV-A-4 Helium Production Cross Section Measurement by Helium Atoms Measurement System

Y.TAKAO, Y.KANDA, M.MIWA, H.ETOH, K.YAMAGUCHI,
T.YONEMOTO, and K.NAGAE

A paper on this subject was presented at the 1995 Symposium on Nuclear Data, and published in JAERI-Conf 96-008, p.165, with the following abstract:

Proton-induced helium production cross sections for nickel at proton energies up to 16MeV have been measured with a helium accumulation method. The cross sections are useful quantity to estimate parameters on a proton and an α-particle used in nuclear data evaluation because they are independent of neutron-relating interactions and provide different kinds of information for the nuclear data evaluation.

A sample is a nickel sheet (chemical purity 99.98%, sizes $12 \times 9 \times 0.119$ mm^3) sandwiched between two gold foils (chemical purity 99.99%, size $12 \times 9 \times 0.051$ mm^3) which are collectors for the emitted α-particles from the nickel surfaces. Nine nickel samples were irradiated by protons ranging from 8.8 to 17.5 MeV at Kyushu University Tandem Accelerator Laboratory. The number of helium atoms produced and accumulated in the nickel foil and two gold collectors was measured using the helium atoms measurement system.

B. Department of Nuclear Engineering

IV-B-1

Analysis of continuum spectra in (p, d) reactions

K. Yamaguchi, S. Aoki, H. Murohka, A. Nohtomi, Y. Uozumi, T. Sakae, M. Matoba

Physics interests in (p, d) reaction were focused in only the spectroscopy of low lying states, and highly excited continuum states were out of the interests. We propose a new method to analyze continuum spectra which are highly excited via a (p, d) reaction.

This method is based on an assumption that the continuum spectrum in an excitation region from 5 to 10 MeV is a group of single hole states populated by a one-step pickup process. Since each strength can be estimated using DWBA, the double differential cross section spectrum is expressed by

$$\frac{d\sigma}{d\Omega}(E) = \sum_{l,j} \left| F(E)\sigma_{l,j}^{DW}(E) \right|,$$

where

$$F(E) = \sum_{l,j} C^2 S_{l,j} \cdot \left\{ \frac{n_0}{2\pi} \frac{\Gamma(E)}{(|E - E_F| - E_R)^2 + \Gamma^2(E)/4} \right\},$$

n_0 is a normalization factor filling the sum rule condition on the l, j orbit.

And, $\Gamma(E)$ is a non-asymmetric Lorentz function that gives a strength distribution of single-hole states;

$$\Gamma(E) = \frac{\varepsilon_0 (E - E_F)^2}{(E - E_F)^2 + E_0^2} + \frac{\varepsilon_1 (E - E_F)^2}{(E - E_F)^2 + E_1^2},$$

with constants,

$$\varepsilon_0 = 19.4(MeV), \qquad E_0 = 18.4(MeV),$$
$$\varepsilon_1 = 1.40(MeV), \qquad E_1 = 1.60(MeV).$$

Figure 1 is the results of this method applied to the ^{64}Ni(p, d)^{63}Ni reaction at 65 MeV. The experiment was carried out at the Research Center for Nuclear Physics, Osaka University.

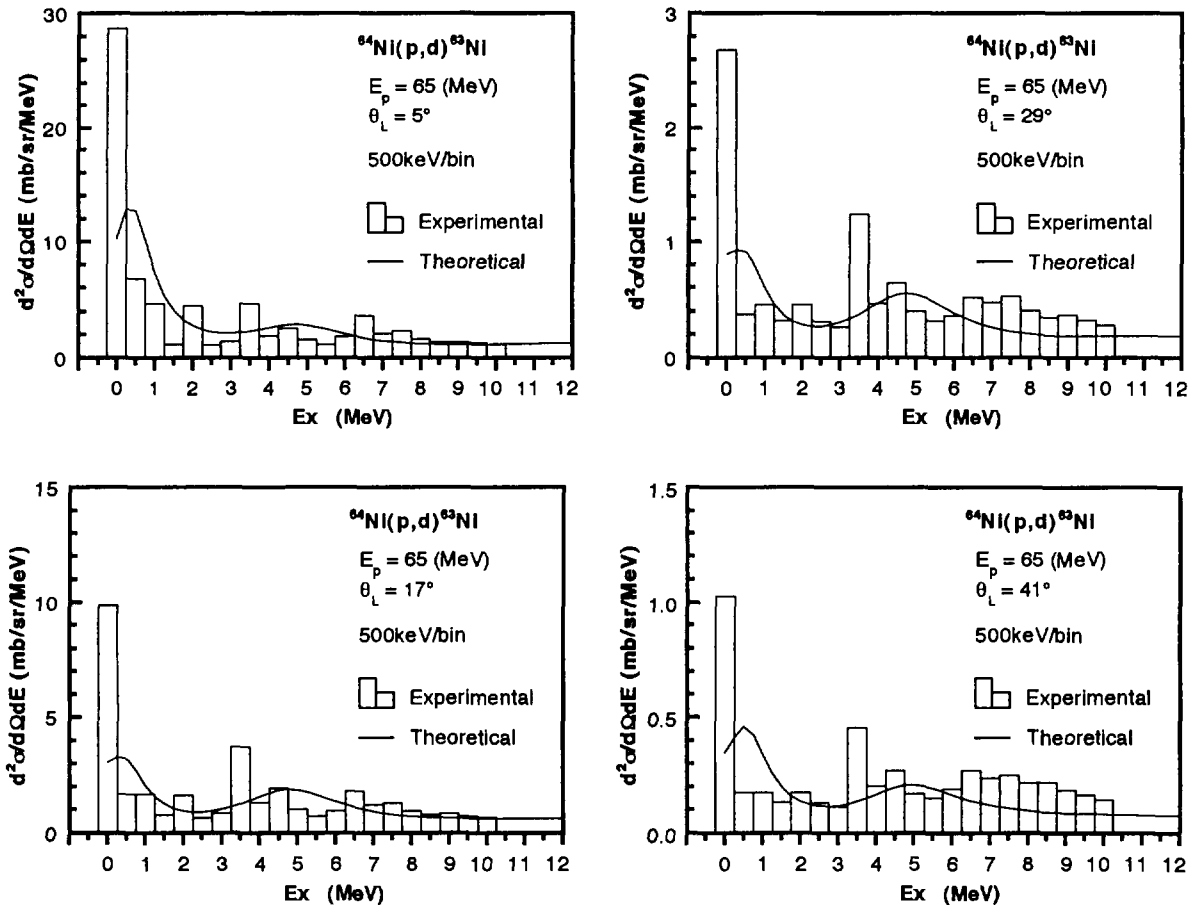

Fig. 1 Double differential cross section spectrum of ^{64}Ni(p, d)^{63}Ni reaction at 65 MeV. Curves were obtained by the method proposed presently.

IV-B-2 Measurement of intermediate energy protons by a stacked GSO(Ce) spectrometer

H. Yoshida, K. Anami, H. Murohka, Y. Uozumi, S. Aoki, D. Konishi, T. Yamamoto, A. Nohtomi, T. Sakae, M. Matoba, T. Maki[1] and N. Koori[2]

We have been interested in studying intermediate energy $(p, p'x)$ preequilibrium reactions at the ring-cyclotron facility of the Research Center for Nuclear Physics (RCNP). A full energy detector, shown in fig. 1, which consists of three plastic scintillators and four GSO(Ce) crystals has been developed to measure wide energy range of proton spectra. It is necessary in using any stopping detector to know the counter response being principally due to the certain probability that an incident particle will undergo a nuclear reaction in the detector material with losing part of its energy, or that a particle will scatter out of the detector before being stopped by the ionization process. The response is usually understood in terms of the peak-to-total ratio. The ratio is one of the important parameter to correct the experimental data. In the present report, we compare the ratio between experimental and calculated values.

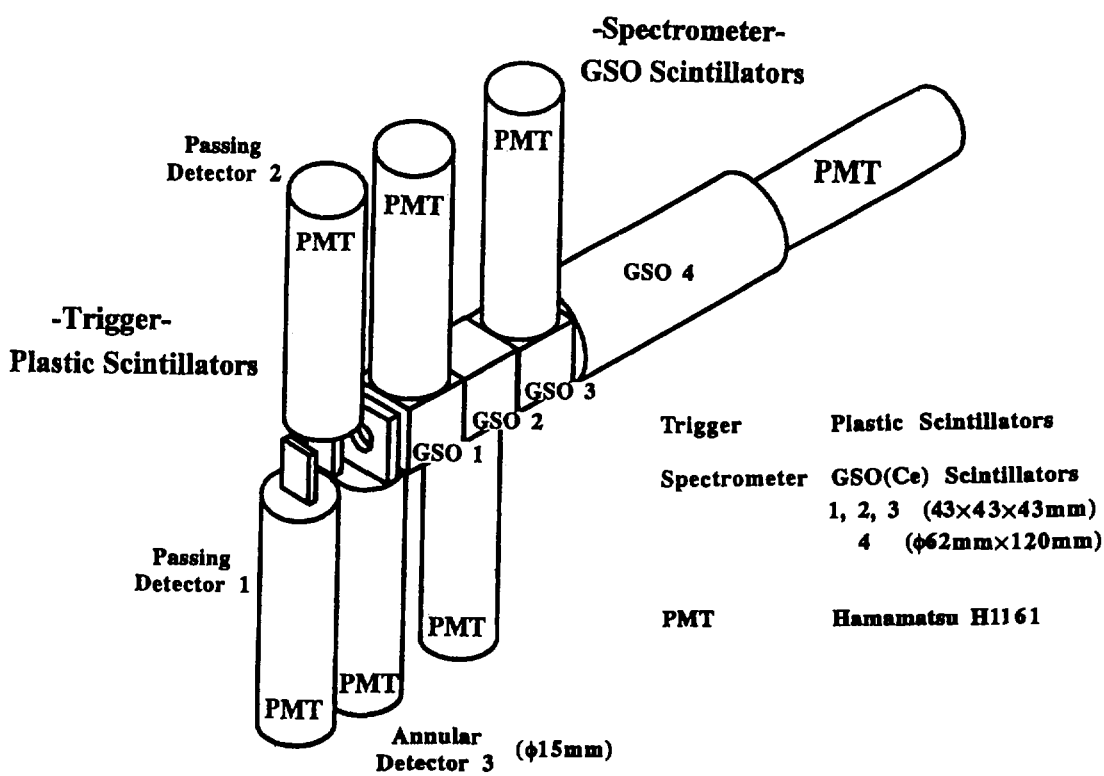

Fig. 1 A schematic diagram of the stacked GSO(Ce) spectrometer.

[1]School of Health Science, University of Occupational and Environmental Health

[2]Faculty of Integrated Arts and Sciences, The University of Tokushima

A Monte Carlo simulation code[1] has been developed to estimate the peak-to-total ratio of the spectrometer. In the simulation, a nuclear reaction, an elastic scattering and a multiple coulomb scattering are considered.

The response of our spectrometer was measured at RCNP using 392-MeV protons from the ring-cyclotron. Figure 2 shows the peak-to-total ratio of our spectrometer. Open circles are experimental values and a solid line is a calculated value with the Monte Carlo code. The experimental values are found to be in good agreement with the calculated one.

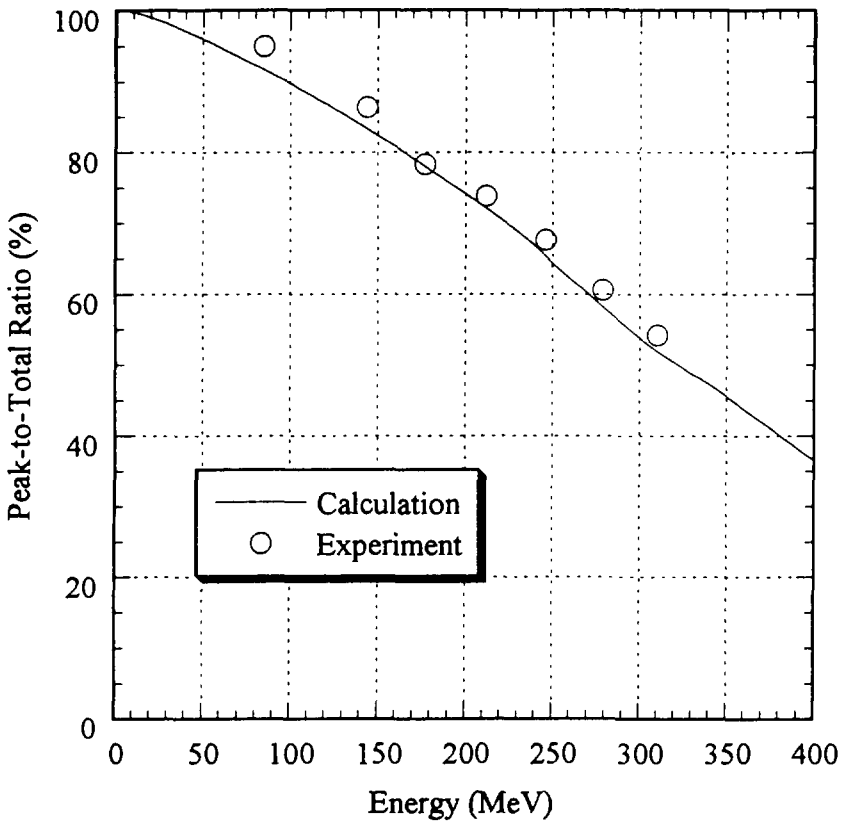

Fig. 2 The peak-to-total ratio of the stacked GSO(Ce) spectrometer.

Reference:
1) H. Yoshida: Master thesis, Kyushu Univ. (1996)

V. Nagoya University

A. Department of Energy Engineering and Science

V-A-1

Systematics for (n,p) excitations in the neutron energy between 13.3 and 15.0 MeV

Y. Kasugai[1], Y. Ikeda*, H. Yamamoto and K. Kawade

A paper on this subject was published in Ann. Nucl. Energy, vol. 23, pp. 1429-1444, 1996.

Systematics of (n,p) excitation functions in the neutron energy between 13.3 and 15.0 MeV were studied on the basis of experimental data measured by the Nagoya and Fusion Neutronics Source groups. The empirical formulae of a cross section (σ_{14}) at 14.0 MeV and a relative slpope (S) of excitation functions were deduced. These formulae covered the mass range between 19 and 188. The empirical formula of S was expressed as a function of (N-Z)/A and threshold energy, where N, Z, A are the mass proton and neutron numbers for the target nuclei, respectively. The empirical formula of σ_{14} was expressed by a simple formula with two fitting parameters. By using the proposed empirical formulae, the partial excitation functions between 13 and 15 MeV were reproduced. Comparing the experimental data with the calculated excitations , we concluded that the accuracy of the proposed empirical formulae was $\pm 20\%$.

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*Japan Atomic Energy Research Institute

V-A-2

Identification of a New Isotope ^{166}Tb

M. Asai, K. Tsukada*, S. Ichikawa*, A. Osa*, Y.Kojima, M. Shibata, H. Yamamoto, K. Kawade, N. Shinohara*, Y. Nagame,* H. Iimura *, Y. Hatsukawa* and I. Nishikawa*

A paper on this subject was published in J. Phys. Soc. Japan ,vol. 65, pp. 1135-1138, 1996.

A new neutron-rich isotope ^{166}Tb produced in 16 MeV proton-induced fission of ^{238}U has been identified using the JAERI on-line isotope separator (JAERI-ISOL) coupled to a gas-jet transport system. Dy KX-rays and γ -rays originating from the decay of ^{166}Tb were found in both mass-166 and 182 fractions, where the ^{166}Tb nuclides were mass-separated as elemental ions $^{166}Tb^+$ and monoxide ions $^{166}TbO^+$, respectively. The half-life of ^{166}Tb has been determined as 21 ± 6 s, which is much shorter than theoretical predictions. A decay scheme of ^{166}Tb has been proposed and a probable spin assignment for the ^{166}Tb ground state has been discussed.

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*Japan Atomic Energy Research Institute

V-A-3 Beta Decay of ^{153}Nd and Reflection Asymmetric Deformation in ^{153}Pm

A. Taniguchi[1], T. Ikuta, A. Osa[2], H. Yamamoto, K. Kawade,
J. Ruan[#], S. Yamada*, Y. Kawase* and K. Oakano*

A paper on this subject was published in J. Phys. Soc. Japan ,vol. 65, pp. 3824-3834, 1996.

The level structure of ^{153}Pm has been studied from the decay of. The radioactivities of ^{153}Nd were separated from the fission products of ^{235}U using the upgraded KUR-ISOL. A precise decay scheme of ^{153}Nd has been constructed up to 2 MeV and 115 γ -rays and 36 levels were involved in the decay scheme, in which 107 γ -rays and 28 levels were newly observed. The multipolarities and E2/M1 mixing ratios of 11 γ -transitions were deduced from the measurement of internal conversion electrons. From the results of the angular correlation measurements, the spin values of 450.5, 105.4 and 32.3keV levels were deduced to be $2/3^+$, $7/2^+$ and $5/2^+$, respectively and the previous assignments were confirmed. The half-lives of 32.3 and 105.4keV levels were determined to be 1.2(1)ns and 0.44(2)ns, respectively and the enhanced E1 transitions with B(E1)=$10^{-3}\sim10^{-4}$ W.u. were observed. The level structure was compared with the result of a calculation with a rotation-vibration coupling model (RVCM) and it was found that has a typical nuclear structure of the deformed nucleus. Moreover, the observation of enhanced E1 transitions between parity doublet bands indicates the possibility of the existence of the reflection asymmetric deformation in ^{153}Pm.

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[1]Present adress;Research Reactor Institute, Kyoto University,
[2]Present adress; Japan Atomic Energy Research Institute
* Research Reactor Institute, Kyoto University, # Department of Physics, Rikkyo University

V-A-4 Beta-Decay Energies of ^{121,123,125}Ba and $^{121-124,126}$ Cs

A. Osa[1], T. Ikuta[1], K. Kawade, H. Yamamoto and S. Ichikawa*

A paper on this subject was published in J. Phys. Soc. Japan ,vol. 65, pp.928-934, 1996.

The β^+-ray maximum energies of neutron-deficient ^{121,123,125}Ba and $^{121-124,126}$Cs isotopes were measured using single HPGe-detector method, which does not need an annihilation-photon detection system. The radioactive sources were produced by bombarding Mo targets with $^{32}S^{10+}$ and $^{35}Cl^{11+}$ ions, followed by on-line mass-separation. The analysis of the experimental -ray spectra using response functions to monoenergetic positrons yielded β^+-ray maximum energies and Q-values of orbital-electron capture (Q_{EC}-values) in the decay of these nuclides. The present experiment has extended the Q_{EC} determination to ^{121,123}Ba isotopes in addition to improving the accuracy for the othernuclides.

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*Japan Atomic Energy Research Institute

V-A-5

Measurement of formation cross sections producing short-lived nuclei by 14 MeV neutrons -Pr, Ba, Ce, Sm, W, Sn, Hf-

S. Murahira, Y. Satoh, N. Honda, A. Takahashi*,T. Iida*,
M. Shibata, H. Yamamoto and K. Kawade

A paper on this subject was presented at the 1995 symposium on nuclear data and published in JAERI-Conf 96-008, pp. 171-1762, 1996, with the following abstract:

Thirteen neutron activation cross sections for (n, 2n), (n, p), (n, np) and (n, α) reactions producing short-lived nuclei with half-lives between 56 s and 24 min were measured in the energy range of 13.4 and 14.9 MeV for Pr, Ba, Ce, Sm, W, Sn and Hf. The cross sections of ^{179}Hf(n, np)^{178m}Lu and ^{180}Hf(n, p)^{180}Lu were measured for the first time.

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*School of engineering, Osaka University

V-A-6

Measurement of beta-decay half-lives of short-lived nuclei with spectrum multi- scaler (SMS)

T. Hirose, T. Shibuya, S Murahira, H. Yamamoto,
T. Iida*, A. Takahashi*and K. Kawade

A paper on this subject was presented at the 1995 symposium on nuclear data and published in JAERI-Conf 96-008, pp. 177-180, 1996, with the following abstract:

The half-lives of short-lived nuclei produced by 14 MeV or thermal neutron bombardments were measured with a Ge detector, a spectrum multi-scaler (Laboratory Equipment Corpration SMA-48) and a high-rate spectroscopy amplifier (EG & ORTEC model 973) in the multi-scaling mode. The corrections for pile-up and dead-time losses were performed by applying source and pulser methods. The half-lives of ^{91m}Mo, ^{97m}Nb, ^{138}Cs, ^{139}Ba, ^{174}Tm and ^{203m}Pb were determined with accuracy of 0.22～0.9% and the accuracy has been much improved.

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* School of engineering, Osaka University

V-A-7 A Simple Method to Evaluate Differences of Fission Yields from Various Fissioning Systems

K. Oyamatsu and M. Sagisaka

A paper on this subject was published in Proc. 1995 Nuclear Data Symposium (JAERI-Conf 96-008, pp. 344-349 (1996)) with the following abstract.

A simple general method is proposed to give a measure of the difference of two data sets. In this method, we utilize an analogue of the overlap integral of two wave functions in quantumn mechanics. The method is applied to evaluate the difference in the fission yield between a fissioning system and the thermal fission of ^{235}U because the yield determines the necessary the decay data in the summation calculation. It is found that the decay data required for Th, Am, Cm, Cf, Es and Fm isotopes are substantially different from those for major actinides. This method is also applied to evaluate the difference between nuclear data libraries ENDF/B-VI and JNDC version 2. It is found that there are a substantial difference in values of the decay constants and a slight difference in the yield data while the decay energies are almost equal.

V-A-8 A Simple Method for Evaluation of Uncertainties in Fission Product Decay Heat Summation Calculations

H. Ohta, K. Oyamatsu and K. Tasaka

A paper on this subject was published in Proc. 1995 Nuclear Data Symposium (JAERI-Conf 96-008, pp. 290-295 (1996)) with the following abstract.

The present precision of nuclear data for the aggregate decay heat evaluation is analyzed quantitatively for 50 fissioning systems. In the practical calculation, a simple approximate method is proposed in order to avoid complication of the calculation and to point out easily the main causal nuclei of the uncertainties in decay heat calculations. As for the independent yield, the correlation among the values is taken into account. For this evaluation, nuclear data and their uncertainty data are taken from ENDF/B-VI nuclear data library.

VI. Osaka University

A. Department of Nuclear Engineering

VI-A-1

The Double Differential Cross Sections of Charged Particle Emission Reaction for Vanadium by 14.1 MeV Incident Neutrons

Akito TAKAHASHI, Kokooo, and Isao MURATA

The double differential cross sections of charged particle emission reactions induced by 14.1 MeV incident neutrons are important for evaluating nuclear heating and material damages in D-T fusion devices. Until now only a few data have been measured worldwide because of experimental difficulties in high backgrounds and low counting rates. The double differential cross sections of charged particle emission reaction for several fusion structural materials were measured by using the two dimensional E-TOF spectrometer at OKTAVIAN, the Intense 14 MeV neutron source facility of Osaka University.[1] Vanadium has high potential as an element of structural materials for fusion power reactors because of its very low activation property by fast neutrons and favorable balance between neutron absorption and multiplication reactions. In the present experiment, the DDX data for vanadium were measured at emission angles of 30°, 70° and 120° for the ^{51}V(n,xp) reaction and at 70° for the ^{51}V(n,x α) reaction.

The experimental results of DDX of the V(n,xp) reaction at the emission angle of 70° compared with JENDL Fusion-File and the experimental data of Grimes et al.[2] at the emission angle of 75° are shown in Fig.1. The comparison among the EDXs of present experiment, Grimes et al. and JENDL fusion-file for V(n,xp) reaction can be seen in Fig.2. The nuclear data of JENDL fusion-file is in good agreement with the present experiment rather than Grimes et al. between 3 MeV and 8 MeV. In case of V(n,x α) reaction, since it takes a long time to measure because of its small reaction cross section, the measurement only for the emission angle of 70 degree was conducted in the present experiment. The measured data for V(n,x α) reaction can be seen in Fig.3.

References:

(1)S.Ogino, et al., "Development of Neutron Induced Secondary Charged Particle Spectrometer Based on Two-dimensional E-TOF Analysis", OKTAVIAN Rep.,A-91-01(1991).

(2)S.M Grimes, et al., Phys. Rev.,C17.508(1978).

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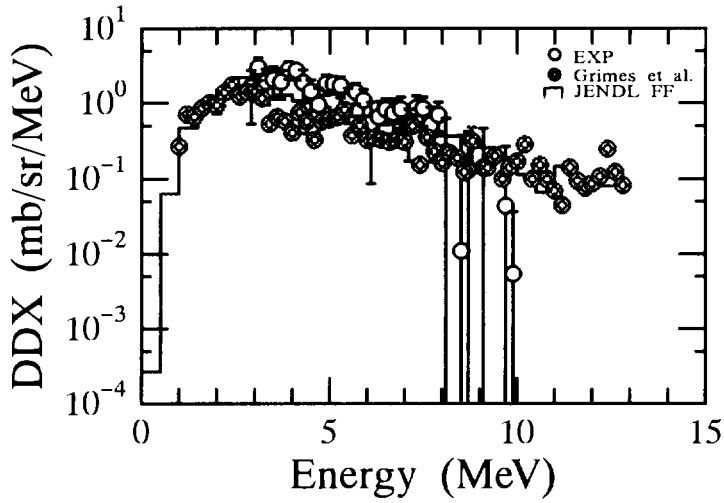

Fig.1. The DDX for V(n,xp) reaction at 70 degree

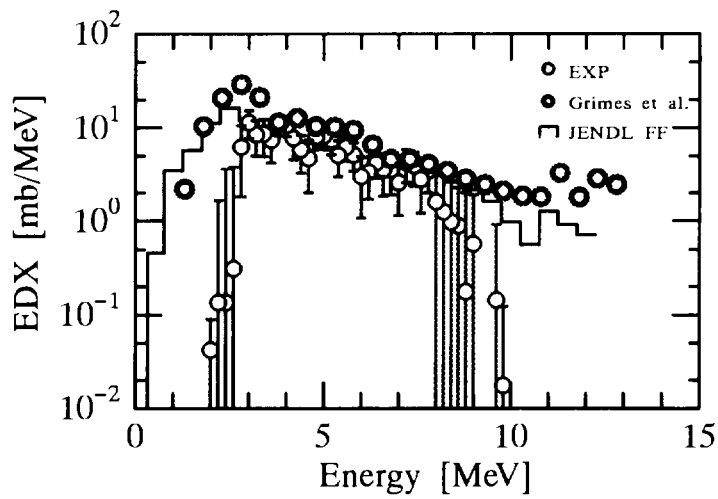

Fig.2. The EDX of V(n,xp) reaction

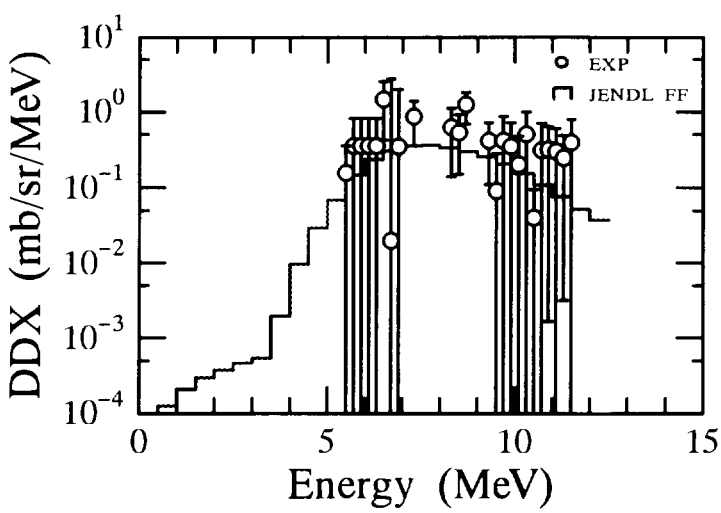

Fig.3. The DDX of alpha emission reaction at 70 degree

VI-A-2 Measurement of Reaction Cross Sections of ^{129}I Induced by DT Neutron

Isao MURATA, Daisuke NAKANO and Akito TAKAHASHI

The transmutation method of nuclear wastes, namely, minor actinides (MAs) and fission products (FPs), have been widely investigated. It is generally considered that the transmutation is performed by using fission reactor, fusion reactor, proton accelerator and so on. Recently, for the transmutation of FPs using fission reactor, the neutron capture cross section of some FPs induced by thermal neutrons have been measured.[1][2] However, there exist few measured nuclear data to estimate the feasibility of transmuting FPs with fusion reactor. In this study, ^{129}I, which is one of the most typical FPs from the standpoint of waste transmutation, was selected as a target sample. The cross sections were measured for the $^{129}I(n,2n)^{128}I$ and $^{129}I(n,\gamma)^{130}I$ reactions by DT neutrons, at OKTAVIAN facility of Osaka University, Japan.

The activation method was used in the measurement. The sample was a sealed source of ^{129}I, which was covered with a Cd foil. The irradiations were performed for 75 minutes to obtain the cross section of reaction producing ^{128}I ($T_{1/2}$=24.99m) and 22 hours for the ^{130}I ($T_{1/2}$=12.36h), respectively. The gamma-rays emitted from the irradiated sample were measured with a high purity Ge detector.

Figures 1 and 2 show the gamma-ray pulse height spectra associated with the $^{129}I(n,2n)$ and $^{129}I(n,\gamma)$ reaction cross sections, respectively. The measured cross sections of $^{129}I(n,2n)$ and $^{129}I(n,\gamma)$ reactions were 0.92±0.11 barn and 0.013±0.002 barn, respectively. For the $^{129}I(n,2n)^{128}I$ reaction, the evaluation of JENDL-3.2 overestimates cross section about 60 % to the experimental result. However, especially for the $^{129}I(n,\gamma)$ reaction, the measured cross section may include the contribution from the neutrons in MeV region as well as epithermal ones. Also, the obtained cross section of the $^{129}I(n,\gamma)^{130}I$ reaction was evaluated as an effective production cross section of ^{130}I including $^{129}I(n,\gamma)^{130m}I$ reaction.

In order to find out the contribution from the epithermal and MeV region neutrons, MCNP calculation was performed with a precise model including neutron source and irradiation room as wall as sample. The result showed that contributions for themal, epithermal, MeV region and DT neutrons were about 30 %, negligible, 50 % and 20 %, respectively. And it was also confirmed that the thermal neutron contribution could be removed with a Cd filter. Consequently, only MeV region neutron contribution is required to be removed by another measurement method. At the sample position, the MeV region neutrons are produced in mainly structural materials of the rotating target by one or more scatterings, while DT neutrons enter the sample directly without scattering. We, therefore, propose a new method as follows: A small absorber between neutron source and a sample is put as shown in Fig. 3. The absorber can reduce only DT neutrons without reducing MeV region neutrons. By comparing the measured cross sections with and without the absorber, the contribution from 14 MeV and MeV region can be clarified. To confirm the feasibility of the above method, MCNP calculation was conducted using the precise calculation model based on Fig. 3. The calculated neutron spectra are shown in Fig. 4. By using in an absorber, DT neutron contribution can be reduced effectively. From

this analysis, it is presumed that wa can measure (n,γ) reaction cross section for various sample induced by DT neutrons excluding MeV region neutrons.

References:

(1)T.Sekine, et al., J.Nucl.Sci.Technol., 30[11], 1099 (1993).

(2)H.Harada, et al., ibid., 31[3], 173 (1994).

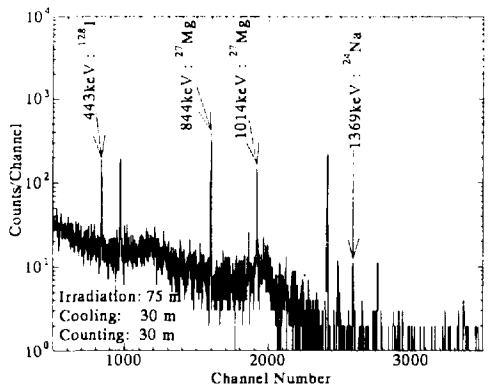

Fig. 1 Gamma-ray pulse height spectrum associated with the measurement of the (n,2n) reaction cross section

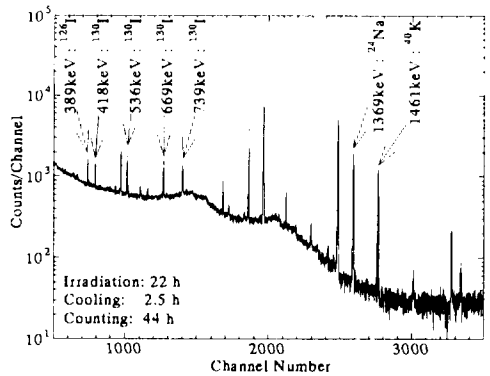

Fig. 2 Gamma-ray pulse height spectrum associated with the measurement of the (n,γ) reaction cross section

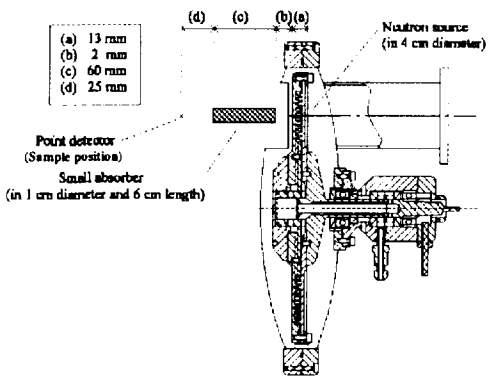

Fig. 3 Schematic arrangement of a new method

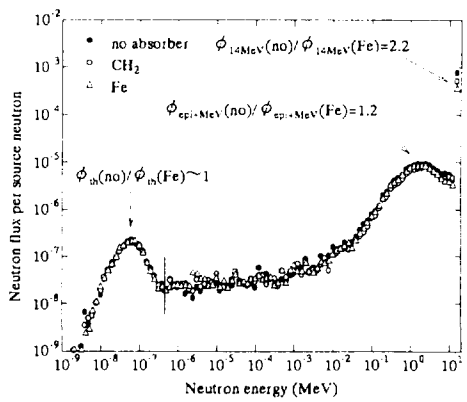

Fig. 4 Result of MCNP calculation

B. Faculty of Science

VI-B-1

Abrupt changes of the Characteristics of the Proton-Induced Fission of ^{238}U around 14-MeV Excitation

H. Baba*, A. Yokoyama*, N. Takahashi*, N. Nitani*, R. Kasuga*,
T. Yamaguchi*, D. Yano*, K. Takamiya*, N. Shinohara†, K. Tsukada†,
Y. Hatsukawa†, and Y. Nagame†

A paper on this subject was published in Zeitschrift für Physik A **356** (1996) pp. 61 - 70 with the following abstract.

Abstract:

An experiment combining the conventional radiochemical stacked target technique and rapid measurements using a gas-jet transport system were carried out with a purpose of precise determination of charge dispersion and distribution for the proton-induced fission of ^{238}U at two incident energies of 9.4 and 12.4 MeV. We determined the charge dispersion width as 1.01±0.05 charge unit at 17.9 MeV-excitation and 0.70 ± 0.04 charge unit except for the symmetric mass region at 14.8-MeV excitation. Fundamental differences were found also in the mass distribution characteristics between 17.9-MeV and 14.8-MeV excitations. This abrupt change of the fission characteristics strongly supports the existence of different fission mechanisms below and above around 14-MeV excitation.

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VI-B-2

Precision Determination of Charge Dispersion and Distribution in the Proton-Induced Fission of ^{238}U at 13.9MeV Excitation

A. Yokoyama*, N. Takahashi*, N. Nitani*, H. Baba*, R. Kasuga*,
T. Yamaguchi*, D. Yano*, K. Takamiya*, N. Shinohara†, K. Tsukada†,
Y. Hatsukawa†, and Y. Nagame†

A paper on this subject was published in Zeitschrift für Physik A **356** (1996) pp. 55 - 60 with the following abstract.

Abstract:

By means of a gas-jet transport system and the ordinary radiochemical stacked-target technique incorporated with the Ge γ-ray spectrometry, 126 product nuclides with half-lives ranging from seconds through a year were identified and their yields were determined in the proton-induced fission of ^{238}U at 13.9 MeV excitation. The charge dispersion width was determined for mass chains and concluded to be constant with respect to the mass. The average of the deduced widths was 0.69±0.04 charge unit which was just equal to that of thermal-neutron fission of ^{235}U and also consistent with values reported for proton-induced fission of ^{238}U. From the width thus obtained, we determined the most probable charges Z_p for observed isobaric multiplets. Considering the pre-scission neutron systematics and an appropriate charge polarization between the complementary fragments we deduced from the obtained Z_p the post-scission neutron number ν_{post} that turned out fairly consistent with Terrell's neutron systematics for thermal-neutron-induced and spontaneous fission. Thus obtained ν_{post} enabled us in turn to derive equations describing Z_p as functions of A. The obtained charge dispersion and charge distribution resulted in the mass-yield distribution resembling that of thermal-neutron fission.

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VII. Tohoku University

A. Department of Quantum Science and Energy Engineering

VII-A-1 Development of Monoenergetic Neutron Calibration Fields between 8 keV and 15 MeV

M.Baba, M.Takada [a], T.Iwasaki, S.Matsuyama , T.Nakamura [a],
H.Ohguchi [a,1)], T.Nakao [a,2)], T.Sanami and N.Hirakawa

A paper of this subjects gas been published in Nuclear Instruments and Methods on Physics Research A, 376 (1996) 115, with the following abstract.

For characterization and calibration of neutron dosimeters and spectrometers, monoenergetic neutron calibration fields have been developed at eight energy points between 8 keV and 15 MeV (8 and 27 keV, 0.25, 0.55, 1.0, 2.0, 5.0 and 15 MeV). Monoenergetic neutrons are obtained by the Sc(p,n) reactions for 8 and 27 keV, and by the ^{7}Li(p,n), T(p,n), D(d,n) and T(d,n) reactions between 0.25 and 15 MeV. Care was taken to reduce background neutrons by parasitic reactions and the scattering of primary neutrons at the target.

The neutron spectrum was characterized by the time-of-flight technique, and the neutron fluence was measured with two independent methods within ±5%. The field has been applied successfully for calibration and characterization of various neutron dosimeters and spectrometers.

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VII-A-2

Large Solid-angle Spectrometers for Studies of Double differential Charged-particle and Neutron Emission Cross Sections

M.Baba, S.Matsuyama, T.Sanami, D.Soda, N.Ito [1], I.Matsuyama,
T.Ohkubo, S.Iwasaki, N.Hirakawa and T.Kawano*

A paper of this subject has been published in the proceedings of ISINN-3 (International Seminar on Interaction of Neutrons with Nuclei 3, JINR, Dubna, April 1995) p.191 with the following abstrcat:

Large solid-angle spectrometers have been developed for studies of double-differential cross sections of (n,charged-particle) and (n,xn') reactions using a gas filled gridded-ionization chamber and an 80-cm long liquid scintillator, respectively. They proved to be very effective in fast neutron nuclear data measurement.

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1) Present address: Japan Atomic Energy Research Institute

VII-A-3

Measurements of Double-differential Neutron Emission Cross Sections for 18 and 11.5 MeV Neutrons

D.Soda, S.Matsuyama, M.Ibaraki, M.Baba, S.Iwasaki and N.Hirakawa

A paper of this subjects has been published in the proceedings of the 1995 Nuclear Data Symposium (JAERI-Conf. 96-008) p.146 with the following abstract:

Double-differential neutron emission cross sections (DDXs) of Fe and Si for 18 MeV neutrons and of Nb and Bi for 11.5 MeV neutrons have been measured at the Tohoku University 4.5 MV Dynamitron facility. In this study, the energy resolution was much improved than in previous studies by applying a long liquid scintillation detector (LLSD). Concerning the 11.5 MeV measurements, secondary neutron energy range was extended by adopting the double-TOF (D-TOF) method.

VII-A-4

Measurements of Double-differential Neutron-induced α Emission Cross Sections of ^{58}Ni and ^{nat}Ni

T. Sanami, M. Baba, S. Matsuyama, T. Kawano *, T. Kiyosumi,
Y. Nauchi, K. Saito, and N.Hirakawa

A paper of this subjects has been published in the proceedings of the 1995 Nuclear Data Symposium (JAERI-Conf. 96-008) p.231 with the following abstracts.

Double-differential (n, α) cross sections (DDXs) of ^{58}Ni and ^{nat}Ni were measured by using a high efficiency gridded ionization chamber. An energy resolution around 200 keV was accomplished using a thin sample (≃ 280 μg/cm^2) and a neutron source with low energy spread (≲150 keV). The cross sections and angular distributions corresponding to the ground and low-lying excited states of the residual nucleus, ^{55}Fe , were obtained. Furthermore, the ^{60}Ni (n, α) cross sections were also deduced by combining the (n, α) cross sections of ^{58}Ni and ^{nat}Ni . These results are compared with other recent experiments and an optical-statistical model calculation.

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B. Laboratory of Nuclear Science

VII-B-1

Study of the (e,e′x) reaction mechanism on ^{6,7}Li

T. Hotta, T. Tamae, T. Miura, H. Miyase*, I. Nakagawa, M. Sugawara, T. Tadokoro, A. Takahashi, E. Tanaka and H. Tsubota*

In the lightest p-shell nuclei, the giant dipole resonance (GDR) is not completely collectivized and may be represented as a set of components, each of them having its own orbital symmetry and its own decay properties. This has been theoretically understood[1] but not established experimentally. In order to study this structure of the GDR and the electrodisintegration reaction mechanism, ^{6,7}Li(e,e′x) cross sections have been measured at the momentum transfer not far from the photon point and the transferred energies around the GDR region. In the experiment, 134 MeV continuous electron beam was used and scattered electrons were measured at θ_e=26° and 42° using a magnetic spectrometer. Transferred energies were from 27 to 46 MeV for the ^{6}Li and from 13 to 37 MeV for the ^{7}Li. Charged particles emitted from the target were detected with SSD telescope arranged out of the scattering plane (ϕ_x =-45°, -135° for ^{6}Li, ϕ_x =-90° for ^{7}Li). In the ^{6}Li(e,e′p) reaction, events corresponding to three different final states, ground and 16.75MeV($3/2^+$) states of ^{5}He and a-n-p three-body final state, were identified in missing energy spectra.

To study the contributions from the direct knockout (DKO) process, the distorted wave impulse approximation (DWIA) calculation was carried out using the computer code DWEEPY[2]. In the calculation, the ground state wave functions that can reproduce the result of the quasi-elastic (e,e′p) experiment[3] were used. The DWIA calculation can reproduce the gross feature of the experimental results; the angular distribution, energy and momentum transfer dependence in the absolute cross section (Fig. 1). The same analysis was applied for the ^{7}Li(e,e′p) reaction and the angular distribution was also well reproduced. As a whole, the ^{6,7}Li(e,e′p) cross section can be explained by the DKO calculation and no significant excitation of the GDR states were observed in this measurement.

In the (e,e′t) reactions, two-cluster breakup channels, ^{6}Li(e,e′t)^{3}He and ^{7}Li(e,e′t)^{4}He, were clearly distinguished in the missing energy spectra. In contrast with the ^{6}Li(γ,t) reaction, the angular distributions for the (e,e′t) reactions are backward-peaked. The experimental results were compared with the calculation in which it was assumed that a virtual photon couples to one of the clusters in the

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ground states of the target nucleus. The forward-backward asymmetry in the measured angular distribution was well reproduced by the calculation (Fig. 2). More careful theoretical treatment is required to derive the detail information of the cluster structure and the breakup mechanism for the Li nuclei.

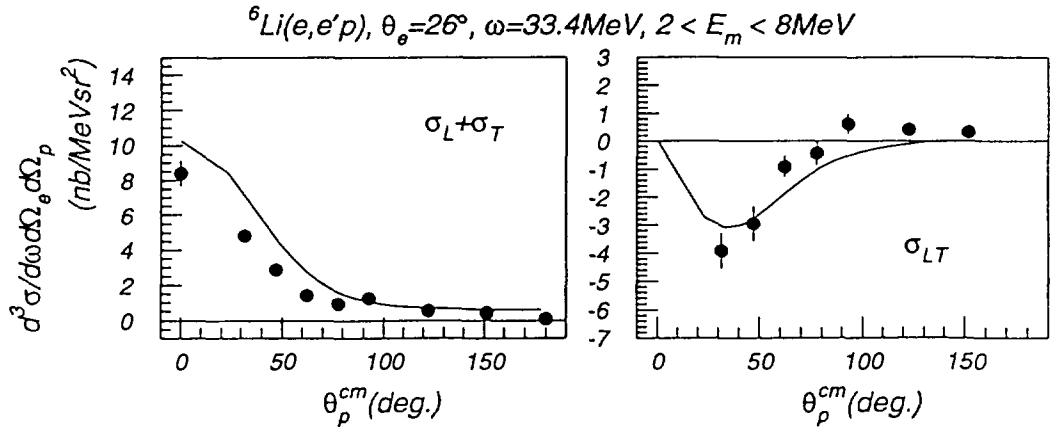

Fig. 1. Angular distribution for the ^{6}Li(e,e'p) reaction. The solid lines are the DWIA calculation results multiplied by 0.8.

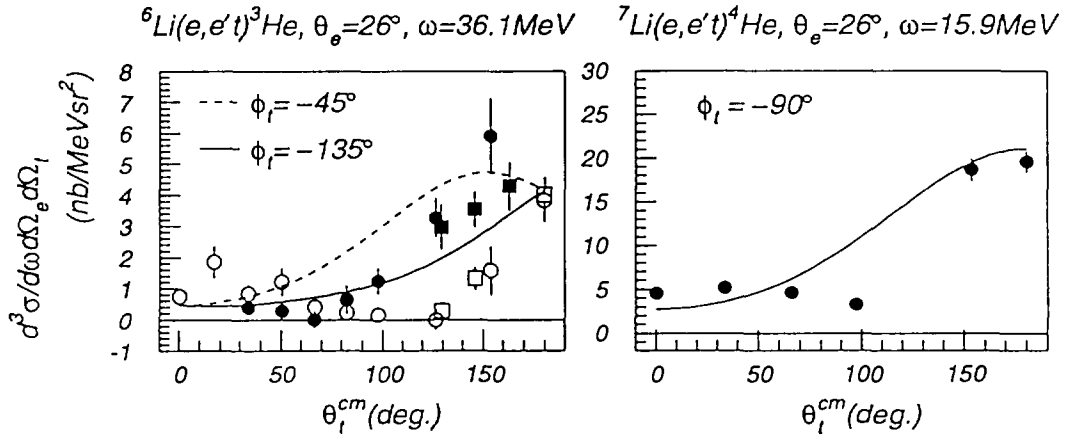

Fig. 2. (Left) Angular distribution for the ^{6}Li(e,e't) reaction at ϕ_t =-45° (solid circles and solid squares) and ϕ_t=-135° (open circles and open squares). (Right) Angular distribution for the ^{7}Li(e,e't) reaction. Curves represent the DWIA calculation normalized to the experimental data.

References:

1) R. A. Eramzhyan, B. S. Ishkhanov *et al.*, Phys. Rep. **136**, 229 (1986).

2) S. Boffi, C. Giusti and F. D. Pacati, Nucl. Phys. **A336**, 416 (1980).

3) J. B. J. M. Lanen, A. M. Van den Verg *et al.*, Phys. Rev. Lett. **64**, 2250 (1990).

VII-B-2

Study of $^{12}C(e,e'p_0)$ reaction above the giant resonance region

I. Nakagawa, T. Tamae, T. Hotta, T. Miura, H. Miyase*, M. Sugawara,, T. Tadokoro, E. Tanaka, and H. Tsubota*

On the (γ,p) reaction in the region E_γ=60~100 MeV, meson exchange currents (MEC's) play an important roll, but the contribution from direct-knockout (DKO) cannot be ignored. Ireland and Steenhoven compared the (γ,p) cross sections with DWIA calculations in the framework of the DKO model[1]. They described the 6 times excess of experimental data over the calculation by including MEC's, and concluded that the (γ,p) reaction is dominated by the MEC effects. However, there arises some uncertainties in evaluation of the final state interaction (FSI) when protons are emitted with low energies (T_p~ 40 MeV).

In order to investigate reliability of the DWIA calculation for low energy protons, we made an (e,e'p) experiment on ^{12}C at a low enegy and low momentum transfer region. We measured the $^{12}C(e,e'p_0)$ cross section using a 129 MeV continuous electron beam at a transfered energy of 40 MeV. Scattered electrons were measured with a double-focused magnetic spectrometer at θ_e=30° and 70° for transfered momenta of **q**=69 and 129 MeV/c, respectively. At these kinematical conditions, the longitudinal cross section dominates the transverse one[2], and the final state interaction can be studied under little influence from MEC's. Emitted protons were detected with telescopes of Si-solid state detectors which were arranged out of the scattering plane (ϕ_p=-45°,-135°). There is still possibility of contribution from giant resonances. However, an obtained large ratio of the form factors of 18.9 for 70° to 30° can be explained by neither GDR nor GQR.

We obtained the reduced cross sections $\rho(p_m)$ from the measured cross sections σ_{eep0} according to the following equation:

$$\rho(p_m) = \sigma_{eep0} / K\, \sigma_{ep}$$

where K is a kinematical factor and σ_{ep} is the off-shell electron-proton scattering cross section[3]. The results are compared to the existing quasi-elastic $(e,e'p_0)$ and (γ,p_0) data[1] in Fig. 1. There is a big difference in the reduced cross sections of the present and quesi-elastic data at same missing momenta $\mathbf{p}_m$. We also observe a large discrepancy in our experimental results themselves between θ_e =30° and 70°, though their proton energies are almost same. As shown in Fig. 1, DWIA calculations[4] give a good agreement with the data both at θ_e =30° and 70°. The discrepancy of the reduced cross section between θ_e =30° and 70° comes from the **q** dependence of FSI. It shows the DWIA calculation is still reliable in such a low energy region (T_p=16~26 MeV).

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From these results, we conclude that the direct process predominantly contributes to the $^{12}C(e,e'p_0)$ reaction in the present region and the DWIA calculation evaluates the FSI properly in the low energy and low momentum transfer region like the present experiment. Our results support the argument that the DKO component in the (γ,p) reaction is properly estimated in the DWIA calculation and the MEC's predominantly contributes to (γ,p) reaction at E_γ=60 ~ 100 MeV.

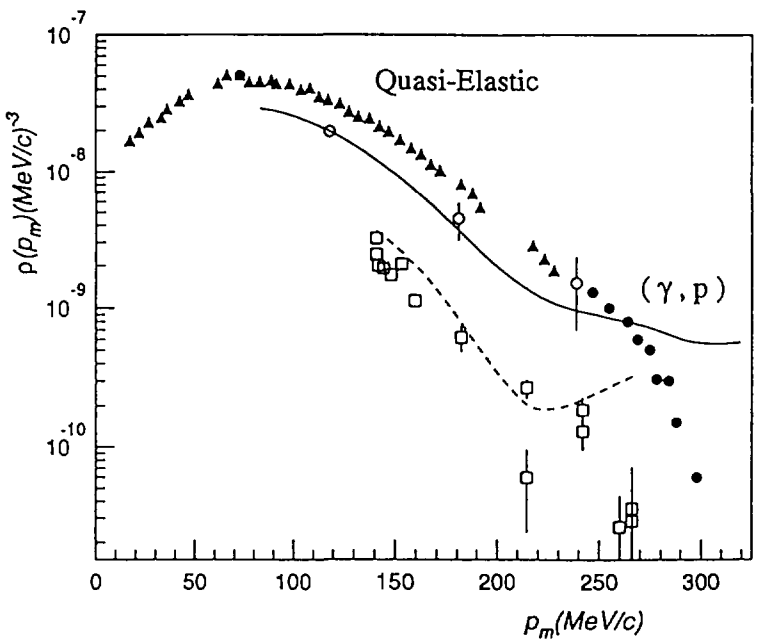

Fig. 1. Open circles and squares represent the present reduced cross sections at θ_e =30° and 70°, respectively. Solid triangles and circles represent the existing quasielasitc $(e,e'p_0)$ and (γ,p_0) data, respectively. DWIA calculations give a good agreement to present experimental data both for θ_e =70° (solid line) and 30° (dashed line).

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C. Cyclotron and Radioisotope Center

VII-C-1

Measurements of Secondary Neutrons Producted from Thick Targets Bombarded by Heavy Ions

T.Kurosawa[1], T.Nakamura[1], N.Nakao[2], T.Shibata[2]
Y.Uwamino[3], N.Nakanishi[3], A.Fukumura[4], Y.Kumamoto[4]

Abstract
We measured neutron angular and energy distributions of secondary neutron produced from high energy heavy ions stopping in targets of carbon, aluminum, copper and lead at HIMAC. Neutron spectra are much harder for the lighter target nucleus like carbon. This means that the momentum transfer in the forward direction from heavy ion beam to lighter nuclei is much higher than that to heavier nuclei.

1. Introduction

At the National Institute of Radiological Sciences, the HIMAC accelerator (Heavy Ion Medical Accelerator in Chiba) is routinely used for the heavy ion cancer therapy. During operation of this machine, we started to measure the angular and energy distributions of secondary particles produced from thick targets bombarded by carbon and helium ions, especially secondary neutrons, whose experimental data are very scarce. These data are needed to design shielding of the heavy-ion accelerator facility, and also are of interest for estimating neutron doses produced by nuclear interactions during irradiation of tumors with heavy ions.

2. Experimental Procedure

The target materials with the thicknesses and the incident energies of carbon and helium ions are shown in Table 1. The target shapes are 10cm by 10cm square. The target thickness was determined to stop the incident particles completely. We used three sets of NE213 organic liquid scintillator (12.7cm diam. by 12.7cm-long) for E counter and NE102A plastic scintillator (12.7cm by 12.7cm and 0.5cm thickness) for ΔE counter. A thin NE102A plastic scintillator(3cm diam. by 0.05cm thickness) was set just behind the end window of the beam line, and the output pulses of this scintillator were used as start signals of the TOF measurement and to count the absolute number of projectile incident on the target. For discriminating between neutrons and charged particles, we used the output pulses of the ΔE counter that was placed just in front of each E counter, and charged particles were identified from two-dimensional ΔE-E graphical plots, since neutrons do not produce output pulses from the ΔE counter.

The contribution of the background neutrons caused by the room-scattering was measured at 90 degree placing a rectangular iron block with the size of 15cm by 15cm by 60cm long between target and detector.

3. Data Analysis

After the neutron and gamma ray events were distinguished from the charged particles from two-dimensional ΔE-E graphical plots, the neutron and the gamma ray events were separated using two dimensional total-slow pulse height graphical plots. The neutron TOF spectrum was converted into the neutron energy spectrum by the following expression,

$$\Phi(E) = \frac{C(E, L_{th})}{\varepsilon(E, L_{th}) \cdot \Delta E \cdot Q \cdot \Delta\Omega} \cdot f_d$$

where $C(E, L_{th})$ is the light output distribution of neutron counts, ΔE the energy bin, ΔΩ the solid angle subtended by the detector to the center of the target. Q the incident heavy ion counts,

f_d the correction of dead time, $\varepsilon(E,L_{th})$ the detection efficiency for the neutron, L_{th} the discrimination level for the neutron pulse height, $\Phi(E)$ the neutron energy spectrum. The detection efficiencies were calculated with the Cecil code.

4.Results

4.1. Neutron spectra

Neutron spectra are plotted in Fig. 1 to 8. As examples, Figs. 1 to 4 give secondary neutron spectra from carbon, alminum, copper and lead target for 180MeV/nucleon carbon incidence, and Figs. 5 to 8 give those for 100MeV/u carbon. The neutron spectra spread up about twice of incident particle energy per nucleon in the forward direction and rapidly become soften with the increase of emitting angle. A broad peak in the forward direction can be seen around the neutron energy corresponding to 60 to 70% of projectile energy per nucleon, which may be due to knock on collision of projectile and target nuclei. Neutron spectra are much harder for a target of lighter nucleus like carbon. This means that the momentum transfer in the forward direction from projectile lighter nucleus is much higher than that of heavier nucleus. At larger emission angles, the neutron fluence becomes larger for heavier target than for lighter target, which reflects that the evaporation neutron emission becomes dominant in the neutron spectra.

4.2. Total Yields

The integrated neutron yields above 20MeV are shown in Fig. 9 to 12. The neutron yield in the forward direction is also larger for lighter target nucleus due to the stronger forwardness of secondary neutron production.

5.Conclusins

We measured neutron angular and energy distributions of neutron produced by helium and carbon ions stopping in targets of carbon, aluminum, copper, and lead. We are planning to do the repeated experiment for lower threshold. We are also proceeding the experiments for other heavy ions with several energies.

References

1) Z.W.Bell, Nucl. Instrum. Meth., 188, 105(1981).
2) R.A.Cecil, et al., Nucl. Instrum. Meth., 161, 439(1979).

Table 1 Projectile and target combinations and detector position for measuring the secondary particles.

Incident particle and energy [MeV/u]	Target thickness [cm]	Detector position[degree]
Helium 100	C[5] Al[4] Cu[1.5] Pb[1.5]	0, 7.5, 15
Helium 180	C[16] Al[12] Cu[4.5] Pb[5]	0, 7.5, 15, 30, 60, 90
Carbon 100	C[2] Al[2] Cu[1] Pb[1]	0, 7.5, 15, 30, 60, 90
Carbon 180	C[6] Al[4] Cu[1.5] Pb[1.5]	0, 7.5, 15, 30, 60, 90

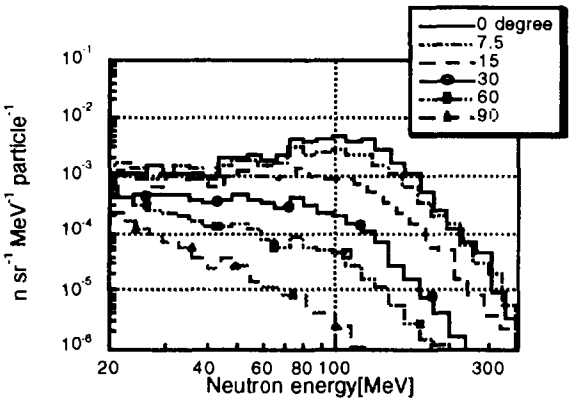

Fig. 1 : Neutron spectra from 180MeV/u carbon ions in a carbon target.

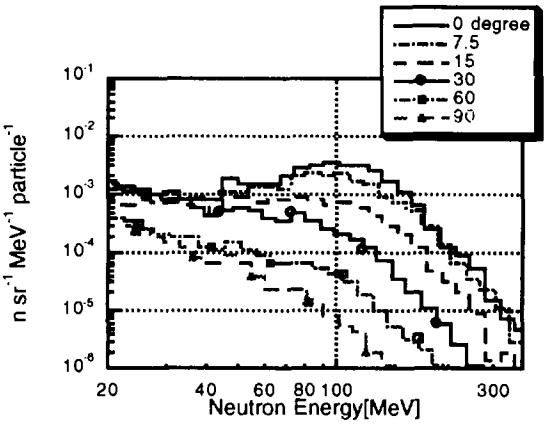

Fig. 2 : Neutron spectra from 180MeV/u carbon ions in a aluminum target.

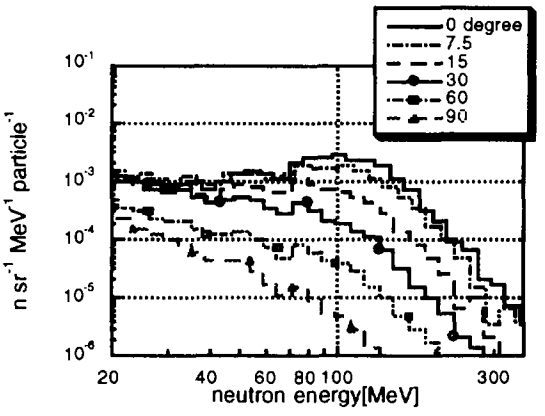

Fig. 3 : Neutron spectra from 180MeV/u carbon ions in a copper target.

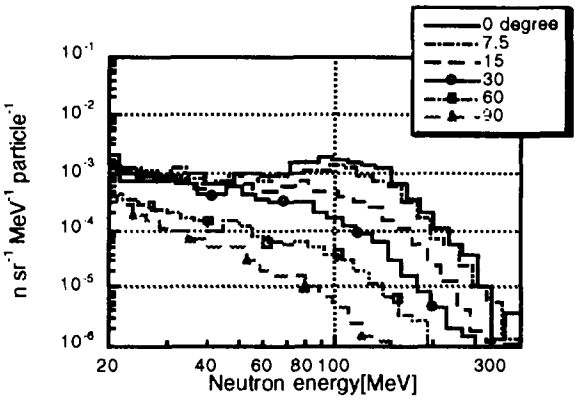

Fig. 4 : Neutron spectra from 180MeV/u carbon ions in a lead target.

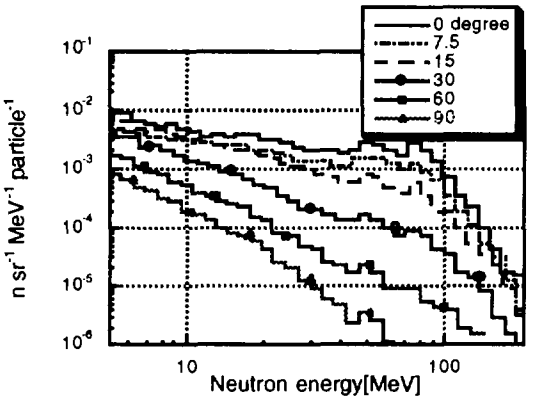

Fig. 5 : Neutron spectra from 100MeV/u carbon in a carbon target.

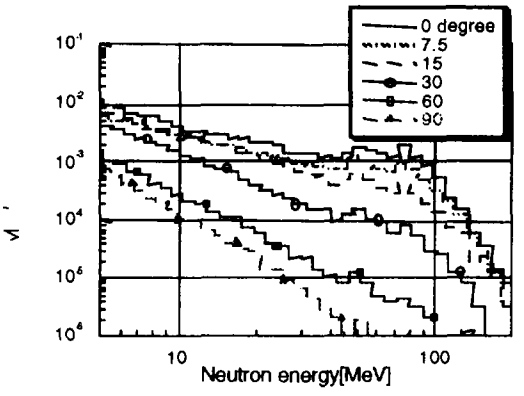

Fig. 6 : Neutron spectra from 100MeV/u carbon ions in a aluminum target.

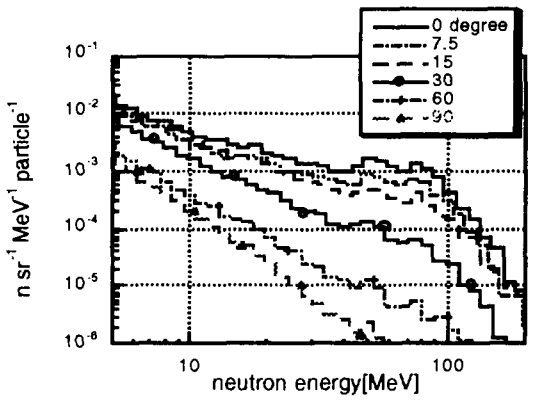

Fig.7 : Neutron spectra from 100MeV/u carbon ions in a copper target.

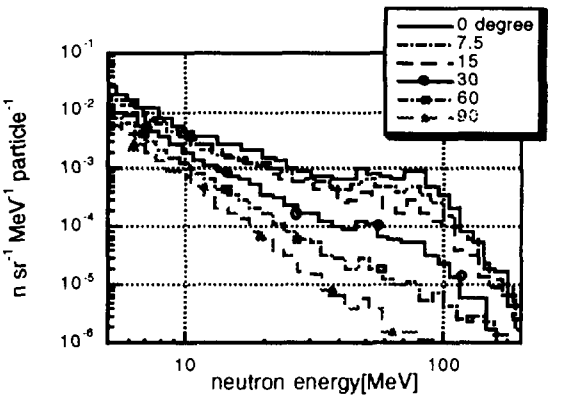

Fig. 8: Neutron spectra from 100MeV/u carbon ions in a lead target.

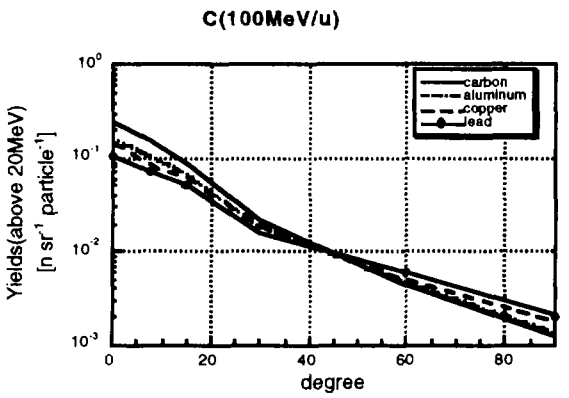

Fig. 9: The integrated neutron yields above 20MeV from 100MeV/u carbon ions.

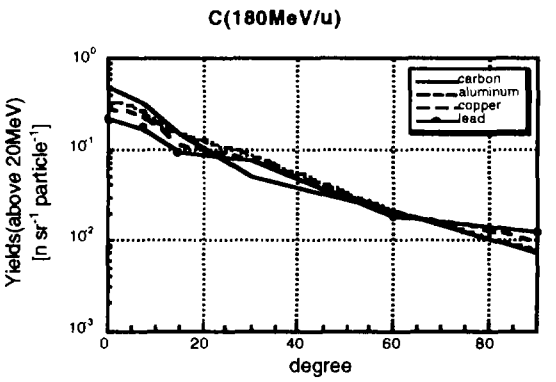

Fig. 10: The integrated neutron yields above 20MeV from 180MeV/u carbon ions.

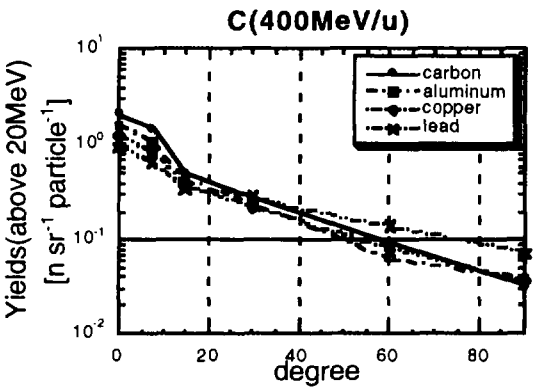

Fig. 11: The integrated neutron yields above 20MeV from 400MeV/u carbon ions.

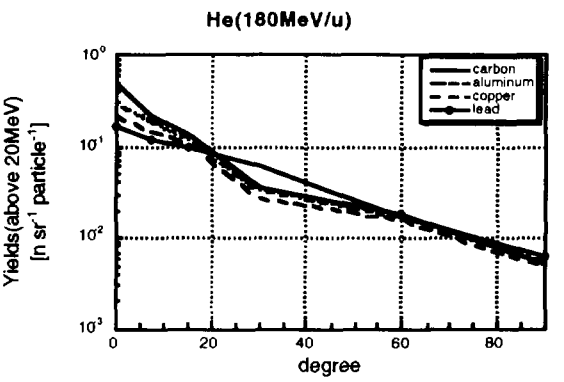

Fig. 12: The integrated neutron yields above 20MeV from 180MeV/u helium ions.

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VII-C-2

Measurements of Neutron Spallation Cross Sections(2)

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Y.Uwamino[3], N.Nakanishi[3], Su.Tanaka[4]

Neutron spallation cross sections of ^{59}Co (n,xn) $^{60-x}$Co , ^{nat}Cu (n,sp) ^{56}Mn, ^{nat}Cu (n,sp) ^{58}Co, ^{nat}Cu (n,xn) ^{60}Cu , ^{nat}Cu (n,xn) ^{61}Cu and ^{nat}Cu (n,sp) ^{65}Ni were measured in the quasi-monoenergetic p-Li neutron fields in the energy range above 20MeV which have been established at three AVF cyclotron facilities of 1)INS of Univ.of Tokyo, 2)TIARA of JAERI and 3)RIKEN. Our experimental data were compared with the ENDF/B-VI high energy file data by Fukahori and the calculated cross section data by Odano.

1. INTRODUCTION

With the increasing use of high energy and high intensity accelerator the induced radioactivity of the accelerator material, shielding material and the air of accelerator facility due to the primary accelerating charged particles as well as the secondary neutrons has become a serious problem. Nevertheless, neutron reaction cross section data in the energy range above 20 MeV are still very poor and no evaluated data file exists. In this study,we measured the neutron spallation cross sections using quasi-monoenergetic p-Li neutrons in the energy range above 20MeV.

2.EXPERIMENTS

The experiments were performed at three cyclotron facilities of 1) Institute for Nuclear Study (INS), University of Tokyo, 2) Takasaki Research Establishment, Japan Atomic Energy Research Institute (TIARA) and 3) Institute of Physical and Chemical Research (RIKEN).
Irradiation experiments utilized quasi-monoenergetic neutrons which were produced by the ^{7}Li(p,n)^{7}Be reaction of proton beams from the AVF cyclotron. The Li targets of 2 to 10 mm thicknesses were bombarded by proton beams of 20 to 150 MeV energies. The neutrons produced in the forward direction from the target were transported through the collimator for sample irradiation and the proton beams passed through the target were swept out by the magnet toward the beam dump. In the TIARA and RIKEN experiments, the whole neutron spectra were measured with the TOF method using an organic liquid scintillator. The absolute monoenegetic peak neutron fluence was determined with the PRT(Proton Recoil counter Telescope) at TIARA, and with the Li activation method to detect the ^{7}Be activity from the ^{7}Li(p,n)^{7}Be reaction at RIKEN.
The irradiation samples are natural copper (^{nat}Cu) and cobalt (^{59}Co). Table 1 shows the physical data of irradiation samples. The samples were irradiated 400cm and 837cm behind the the Li-target at TIARA and RIKEN, respectively. Irradiation experiments consisted of short irradiation time (1 to 2 hours under 120 MeV) and long irradiation time (about 20 hours) by considering the half life of produced nuclei. During sample irradiation, proton beam currents were monitored with the digital current integrator and scaler. The gamma rays emitted from irradiated samples were measured with a high purity Ge detector. The peak efficiency of Ge detector was obtained from the mixed standard source and the EGS4 calculation [1] in TIARA and RIKEN. The self absorption of samples was calculated with the PEAK code[2].

3.ANALYSIS

The reaction rates of identified radioisotopes were obtained by analyzing gamma-ray spectra after corrected for the peak efficiency, self-absorption and sum-coincidence effects, and for the beam current fluctuation during sample irradiation.
The cross section can be obtained from the measured reaction rate R as follows,

$$\sigma(E_{peak}) = \frac{R \times \dfrac{\int_{E_{min}}^{E_{max}} \sigma(E)\ \phi(E)\, dE}{\int_{E_{th}}^{E_{max}} \sigma(E)\ \phi(E)\, dE}}{\Phi(E_{peak})}$$

where E_{min} and E_{max} are the minimun and maximun energies of the monoenergetic neutron peak, E_{th} is the threshold energy of the relevant reaction, $\Phi(E_{peak})$ is the neutron fluence at monoenergetic peak energy , E_{peak}. Since the p-Li neutron spectra have continuum components lower than a monoenergetic peak, it is necessary to evaluate their contribution by estimating the cross section values in that energy region, which were cited from the evaluated data file, ENDF/B-VI[3] calculated by Fukahori and the calculated cross section data by Odano[4].
The errors of cross section data were estimated from the error propagation law by combining the errors of reaction rate (about 1 - 30%) , peak neutron fluence (about 4 - 15%), FWHM of peak neutron spectrum (2.8～5.0MeV), and of the reference cross section data used to estimate the contribution from the low energy neutron component (about 5 - 40%).

4.RESULT AND DISCUSSION

We obtained the cross section data of ^{59}Co(n,xn) $^{60-x}$Co , ^{nat}Cu(n,sp) ^{56}Mn, ^{nat}Cu(n,sp) ^{58}Co, ^{nat}Cu(n,xn) ^{60}Cu, ^{nat}Cu(n,xn) ^{61}Cu and ^{nat}Cu(n,sp) ^{65}Ni reactions. Figs.1 to 8 give the obtained cross section data. The experimental cross section data of ^{59}Co(n,xn) $^{60-x}$Co , ^{nat}Cu(n,sp) ^{56}Mn and ^{nat}Cu(n,sp) ^{65}Ni are compared with the calculation data by Odano and the ENDF/B-VI high energy file data calculated with the ALICE code[5]. Our experimental results are the first experimental data and are generally good agreement with the calculated data .

Reference

[1]W.R.Nelson, H.Hirayama, and D.W.O.Rogers, The EGS4 Code System, SLAC-265, Stanford Linear Accelerator Center, Stanford University (1985)

[2]T.Nakamura, T.Suzuki, Monte Calro Calculation of Peak Efficiencies of Ge(Li) and Pure Ge Detectors to Voluminal Sources and Comparison with Environmental Radioactivity Measurement, Nucl.Instrum.Methods, 205, 211 (1983)

[3]National Nuclear Data Center,Brookhaven National Laboratory, "Evaluated Nuclear Data File" ENDF/B-VI (1990)

[4]N.Odano and S.Iwasaki, JAERI-M 94-019, p310-319, Proceedings of 1993 Symposium on Nuclear Data (1994)

[5]M.Blann, CODE ALICE/89 (1989)

Table.1:Physical data of irradiation samples

Facility	Samples	Diameter	Thickness	Weight	Purity
TIARA	^{59}Co	33mm	2.0mm	20g	99.99%
	^{nat}Cu	33mm	2.0mm	20g	99.99%
RIKEN	^{nat}Cu	80mm	10mm	490g	99.99%

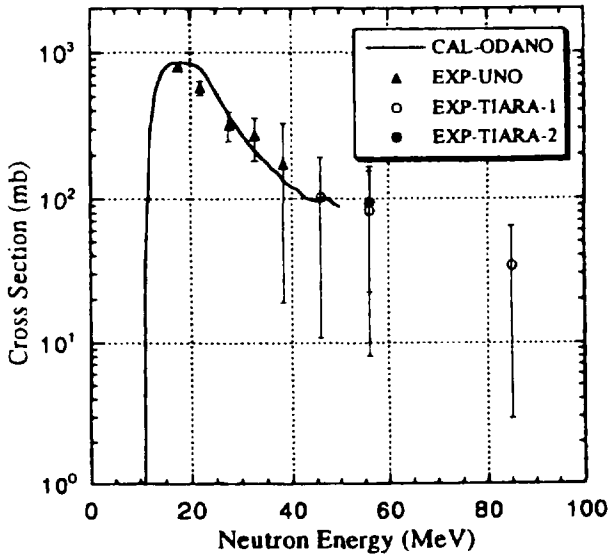

Fig.1 ^{59}Co(n,2n) ^{58}Co cross section

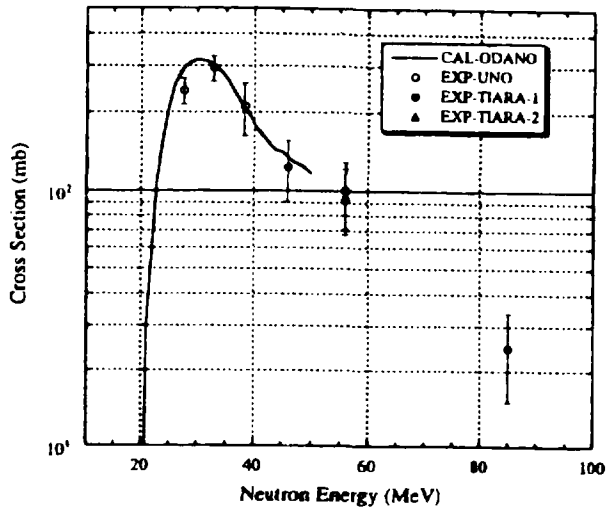

Fig.2 ^{59}Co(n,3n) ^{57}Co cross section

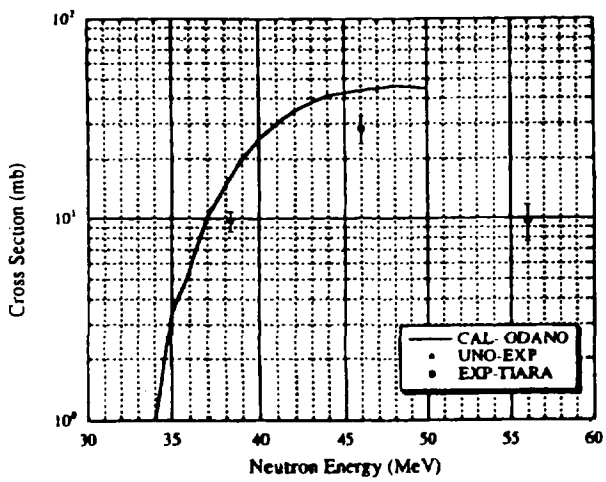

Fig.3 ^{59}Co(n,4n) ^{56}Co cross section

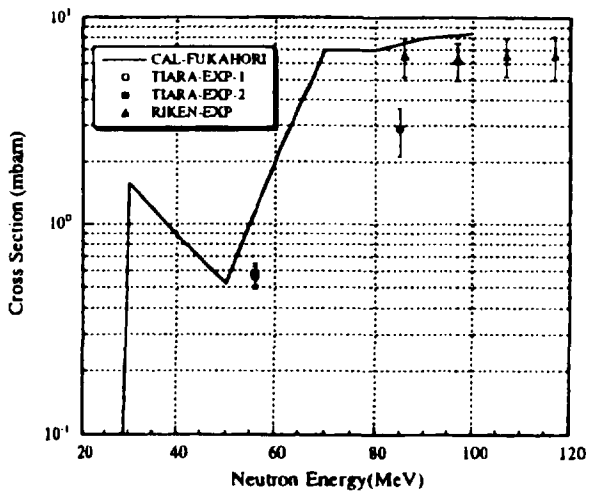

Fig.4 ^{nat}Cu(n,sp) ^{56}Mn cross section

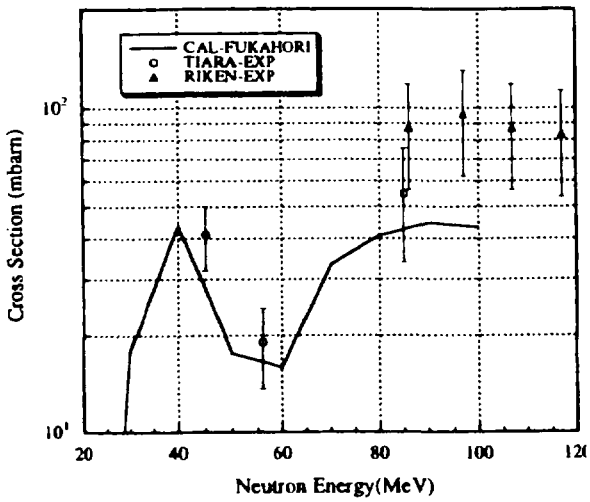

Fig.5 ^{nat}Cu(n,sp) ^{58}Co cross section

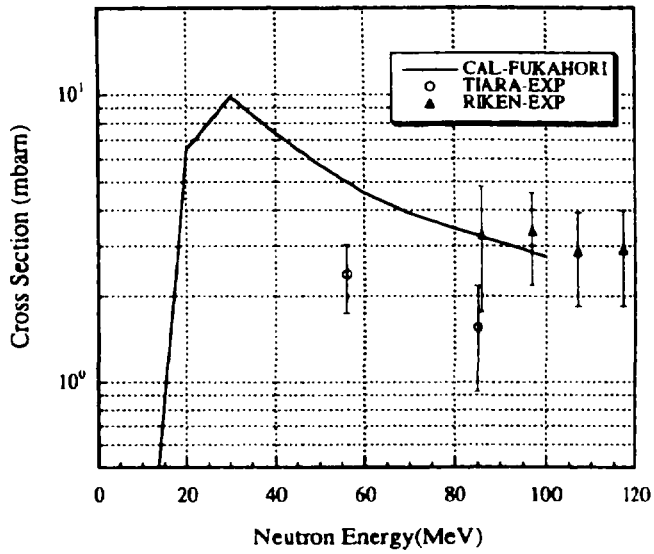

Fig.6 ^{nat}Cu(n,xn) ^{60}Cu cross section

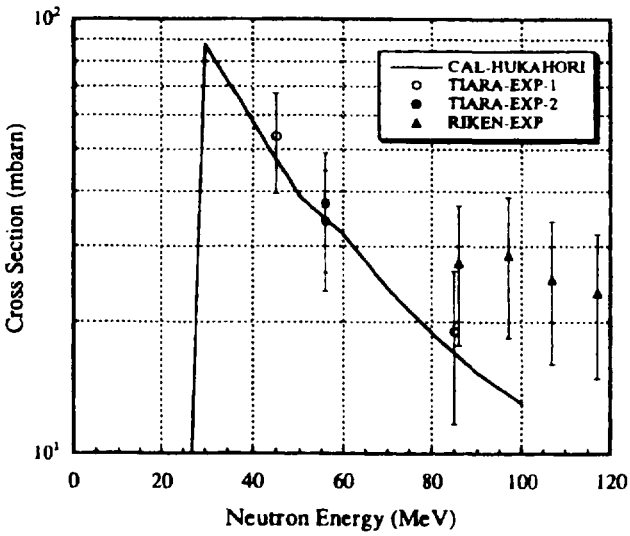

Fig.7 ^{nat}Cu(n,xn) ^{61}Cu cross section

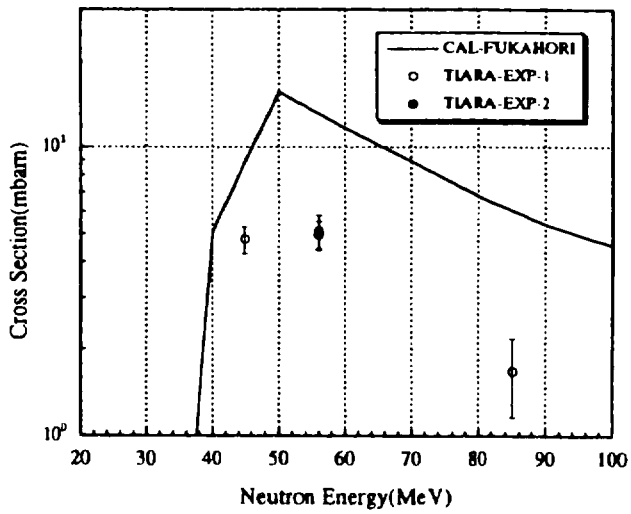

Fig.8 ^{nat}Cu(n,sp) ^{65}Ni cross section

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VIII. Tokyo Institute of Technology

VIII-1

Direct Neutron Capture in a Dispersion Potential of Light Nuclei

H. Kitazawa and M. Igashira

A paper on this subject was presented at the ninth International Symposium on Capture Gamma-Ray Spectroscopy and Related Topics, Budapest, Hungary, October 8-12, 1996, with the following abstract:

Low-energy neutron capture reactions on light nuclei are supposed to play an important role in the nucleosynthesis of intermediate-mass nuclei in an inhomogeneous big-bang model and in that of heavy elements during steller evolution. Also, drip-line light nuclei are found to have a radius much larger than other neighboring nuclei. It suggests the existence of a neutron-halo structure in those nuclei.

Stimulated by the above findings, a lot of experimental work has recently been performed to obtain neutron-capture cross sections of light nuclei in the steller energy region. Simultaneously, those cross sections have been calculated in the framework of a direct-capture model, because the reactions may be decoupled from resonance states. Consequently a reasonable agreement was found between theory and experiment. However, the results do not guarantee that the optical-potential parameters used in the calculations reproduce the observed total cross sections in this energy region.

The direct-capture cross section is generally sensitive to the incident wave function in the channel region, i.e. to optical-potential parameters. In the present study, we describe low-energy neutron direct-capture reactions on ^{12}C-nuclei, using the optical potential derived form the dispersion theory. This potential is quite successfully applied to direct-capture model calculations in explaining off-resonance neutron-capture cross sections of ^{12}C observed at 20-600keV. We also emphasize that the spatial nonlocality of a neutron-nucleus interaction potential for negative energies should be taken into account to describe the direct capture of low-energy neutrons by light nuclei.

VIII-2

Measurements of keV-Neutron Capture γ Rays of Fission Products

M. Igashira, S. Mizuno, T. Ohsaki, and H. Kitazawa

γ rays from the keV-neutron capture reactions by ^{143,145}Nd, ^{148,149}Sm, and ^{161,163}Dy have been measured at a neutron energy of 550 keV, using a large anti-Compton NaI(Tl) γ-ray spectrometer and the ^{7}Li(p,n)^{7}Be pulsed neutron source with a 3-MV Pelletron accelerator. The preliminary results for the capture cross sections and γ-ray spectra of those nuclei are obtained.[1)]

Reference:
1) M. Igashira: Proc. the 1995 Symposium on Nuclear Data, Tokai, Japan, November 16-17, 1995, JAERI-Conf 96-008, p. 123 (1996).

Measurements of Gamma Rays from keV-Neutron Resonance Capture by Odd-Z Nuclei in the 2s-1d Shell Region

M. Igashira, S. Y. Lee, S. Mizuno, T. Ohsaki, and H. Kitazawa

A paper on this subject was presented at the ninth International Symposium on Capture Gamma-Ray Spectroscopy and Related Topics, Budapest, Hungary, October 8-12, 1996, with the following abstract:

We have measured neutron capture gamma rays from the 27-keV, 44-keV, and 49-keV resonances of ^{19}F and from the 35-keV resonance of ^{27}Al with an anti-Compton HPGe spectrometer, employing the ^{7}Li(p,n)^{7}Be neutron source and a time-of-flight technique. Relative intensities of primary and secondary gamma-ray transitions were obtained. About half of primary transitions were first observed ones.