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S. KIKUCHI

Japanese Nuclear Data Committee

Japan Atomic Energy Research Institute
Tokai Research Establishment
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## Editor's Note

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

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ZN 66 （N，P） $1.3+71.5+7$ NAG EXPT－PROG NEANDC（J）－155U AUG 90 KATOH＋．P84．ACT SIG IN FIG
$1.3+71.5+7$ JAE EXPT－PROG NEANDC（J）－15SU AUG 90 KONNO＋．P15．ACTSIG REL NB93（N2N），NDG $1.3+71.5+7$ JAE EXPT－PROG NEANDC（J）－155U AUG 90 KONNO＋．P15．ACT SIG REL NB93（N2N），NDG $1.3+71.5+7$ JAE EXPT－PROG NEANDC（J）－155U AUG 90 KONNO＋．P15．ACT SIG REL NB93（N2N），NDG NAG EXPT－PROG NEANDC（J）－155U AUG 90 KATOH＋．P84．TO MS，ACT SIG IN FIG KTO EXPT－PROG NEANDC（J）－155U AUG 90 KOBAYASHI＋．P52．SIG＝0．086＋－0．007 MB KTO EXPT－PROG NEANDC（J）－155U AUG 90 KOBAYASHI＋．P52．MS，SIG＝0．48＋－0．03MB KTO EXPT－PROG NEANDC（J）－155U AUG 90 KOBAYASHI＋．P52．TO MS，SIG＝670＋－50 MB 1．0－5 2．0＋7 JAE EVAL－PROG NEANDC（J）－155U AUG 90 LIU＋．P27．FOR JENDL－3，TBP IN NST 1．0－5 2．0＋7 JAE EVAL－PROG NEANDC（J）－155U AUG 90 LIU＋．P27．FOR JENDL－3，TBP IN NST 1．0－5 2．0＋7 JAE EVAL－PROG NEANDC（J）－155U AUG 90 LIU＋．P27．FOR JENDL－3，TBP IN NST CD 111 DIFF INELAST $2.1+63.0+6$ JAE EXPT－PROG NEANDC（J）－155U AUG 90 IKEDA＋．P11．ACT SIG TO MS，FIG GIVEN IN 113 DIFF INELAST $2.1+63.0+6$ JAE EXPT－PROG NEANDC（J）－155U AUG 90 IKEDA＋．P11．ACT SIG TO MS，FIG GIVEN


$\begin{array}{llll}\text { IN } 113(N, 2 N) & 1.3+7 & 1.5+7 & \text { JAE EXPT－PROG NEANDC（J）－155U AUG } 90 \text { KONNO＋．P15．AC SIG REL NB93（N2N），NDG } \\ \text { IN } 115 \text { DIFF INELAST FISS } & \text { KTO EXPT－PROG NEANDC（J）－155U AUG } 90 \text { KOBAYASHI＋．P52．TO MS，SIG＝190＋－1OMB }\end{array}$









$$
5.9+3 \text { JAE EXPT-PROG NEANDC (J)-155U AUG } 90 \text { NAKAJIMA+.P22.SO=0.77E-4 }
$$

$$
\text { JAE EXPT-PROG NEANDC(J)-155U AUG } 90 \text { HARADA+.P19.SIG=0.250+-0.013B }
$$

$$
K T O \text { EXPT-PROG NEANDC(J)-155U AUG } 90 \text { TAGO+.P48.HL=3.6S,EG SPEC IN TBL }
$$

$$
\text { NAG EXPT-PROG NEANDC(J)-155U AUG } 90 \text { SHIBATA+.P83.PUBL IN JPJ } 59,1204
$$

1.3+7 1.5+7 JAE EXPT-PROG NEANDC(J)-155U AUG 90 KONNO+.P15.ACT SIG REL NB93(N2N).NDG
 $H F 179$ (N,P) $1.3+71.5+7$ JAE EXPT-PROG NEANDC(J)-155U AUG 90 KONNO+.P15.ACT SIG REL NB93(N2N),NDG HF 180 DIFF INELAST $1.3+7$ 1.5+7 JAE EXPT-PROG NEANDC(J)-155U AUG 90 KONNO+.P15.MS,ACT SIG REL NB93(N2N) $H F 180(N, 2 N) \quad 1.3+71.5+7$ JAE EXPT-PROG NEANDC(J)-155U AUG 90 KONNO+.P15.ACT SIG REL NB93(N2N),FIG HF 180 (N,ALPHA) $1.3+71.5+7$ JAE EXPT-PROG NEANDC(J)-155U AUG 90 KONNO+.P15.ACT SIG REL NB93(N2N),NDG $\begin{array}{llll}\mathrm{AU} 197 \text { (N,GAMMA) } 1.2-21.0+0 \text { KTO EXPT-PROG NEANDC(J)-155U AUG } 90 \text { YAMAMOTO+.P59.BGO DET.SIG IN FIG } \\ \mathrm{PB} & \text { NONELA GAMMA } 7.8+61.3+7 \text { JAE EXPT-PROG NEANDC(J)-155U AUG } 90 \text { HASEGAWA+.P23.NAI DET,NDG }\end{array}$
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I, Electrotechnical Laboratory

## I-A-1 Precise Determination of Neutron Energy in $d+D$ Neutron Field

K. Kudo, N. Takeda, Matiullah* and A. Fukuda

The $d+D$ and $d+T$ neutrons which are produced by a low voltage Cockcroft-Walton accelerator are essentially quasimonoenergetic. The energy spread of neutrons, induced by the $D(d, n)^{3} H e$ or $T(d, n)^{4} H e$ reaction, depends mainly upon the slowing down process of deuterons and the depth distribution of the target atoms (viz. Ti-D or Ti-T target). However, the d+T neutrons which are emitted within a certain band of angles between $96^{\circ}-98^{\circ}$ to the deuteron beam direction, have very sharp distributions with energy spread less than 10 keV at neutron energies from 13.98 MeV to $14.00 \mathrm{MeV}(1)$, (2). We standardized and reported the $d+T$ neutron fields here at the ETL by developing and employing an improved associated $\alpha$-particle method ${ }^{(2)}$. We extended the above technique to the $d+D$ neutron standardization and is described in this report. The main objective of this work was to produce mono-energetic neutrons regardless of the target thickness/age and the energy of incident deuterons.

We designed the experimental layout for the d+D neutron standard field which cover the neutron energy range of 2.1 -

* Guest researcher from Center for Nuclear Studies, PINSTECH, P.O. Nilore, Islamabad, Pakistan
3.2 MeV is shown. in fig.l. The accelerated deuteron beam is transported to a Ti-D target which is positioned at the center of a low scatter experimental room. The target is mounted with an inclination of $45^{\circ}$ to the deuteron beam direction in order to cover the neutron emission angles between $0^{\circ}$ and $135^{\circ}$. In order to carry out the standardization process, the absolute neutron fluence was determined with the helpof a proton recoil technique with uncertainty less than $2 \%$. The proton recoil method consisted of a polyethylene radiator of varying thickness ranging from 0.5 mm to 1.0 mm (mounted on an aluminum disc of 0.2 mm thickness) and a Si surface barrier detector. Protons produced by the D(d, p) T reaction competing with the $D(d, n)^{3} H e$ reaction were monitored by the $S i$ barrier detectors positioned at different angles namely $89^{\circ}$ and $131^{\circ}$ as depicted in fig.l.

Figure 2 shows the predicted neutron energy distributions at different emission angles for 300 keV deuteron beam incident on a thick Ti-D target. Here we carried out calculations on the basis of the relativistic kinematics of a two-body reaction taking in to account both the angular differential cross section (3) for the $D(d, n)^{3}$ He reaction and the stopping power (4)


Fig.l
Layout of the d+D noutron standard field


Fig. 2
Calculated neutron energy distributions in case of a 300keV deuteron beam incident on a thick Ti-D target at different emission angles
for deutérons in a homogeneously distributed Ti-D target. For the sake of simplicity, the angular straggling of the deuterons in the target and neutron scattering from the target assembly were ignored. The full width at half maximum (FWHM) of the quasi-monoenergetic spectra is found to be 2.5\% and $10 \%$ at $85^{\circ}$ and $0^{\circ}$ respectively. The d+D neutrons emitted at $100^{\circ}$ show a very sharp distribution around 2.413 MeV with the smallest FWHM of $0.5 \%$. These $d+D$ neutrons provide excellent standards for the neutron energy and resolution for calibration purposes of neutron spectrometers, especially for those applied to fusion diagnostics.

We have been investigating the characteristics of the $d+D$ neutron field by applying the ${ }^{3} \mathrm{He}$ proportional counter which has already been used by us in the establishment of adt $d$ neutron standard field (2). The ${ }^{3} \mathrm{He}(\mathrm{n}, \mathrm{p}) \mathrm{T}$ reaction which produces a monoenergetic peak on a pulse height spectrum obtained from a ${ }^{3}$ He detector, is more favorable than that of the ${ }^{3}$ He scattering reaction for neutron spectroscopy. We have now concentrated our efforts on the modification of the Monte Carlo code (previousty developed by us by modifying the NRESP code (5) for the calculation of response functions of a ${ }^{3} \mathrm{He}$ proportional counter for the ${ }^{3} H e(n, p) T$ reaction. In this context, the cross section data have been taken from the ENDF/B-IV and $-V$ libraries and reported semi-empirical formulae of the stopping power (4) have been used in determination of the ranges of recoil nuclei of 3 He and $K r$ in the ${ }^{3} \mathrm{He}+K r$ target and ionizing gas. The calculated pulse height spectra arefolded with the Gaussian distribution whose resolution is proportional to the inverse square root of the pulse height, E, of a detector signal (i.e. dE/E=A/El/2, where A is a proportional constant).

Figure 3 shows the calculated spectra around the peak from the ${ }^{3} \mathrm{He}(\mathrm{n}, \mathrm{p}) \mathrm{T}$ reaction which were folded with the different resolutions expressed by the proportional constant from $0 \%$ to $15 \%$. As the $0 \%$ peak position just corresponds to the monoenergetic neutron energy plus the $Q$ value of the reaction, the
channel calibration can be well-done.for the other folded spectra. These folded spectra are fitted to an experimental spectrum by means of a $\chi 2$ fitting procedure. The preliminary results are shown in Fig. 4. Here, a properly folded spectrum was fitted to the experimental pulse height spectrum which was measured for an incident deuteron energy of 260 keV at $100^{\circ}$. This method yields precise calibrations of neutron energy at $2413 k e V$ and the energy resolution of the ${ }^{3}$ He detector system, as the energy spread of the d+D neutron at $100^{\circ}$ is negligible compared to that of the detector system. Another preliminary study showed that the mean energies of neutrons for different deuteron energies of 130,220 and 260 keV determined using the above method were in good agreement within the uncertainty less than $0.1 \%$ and that the neutron energy distribution at $100^{\circ}$ does not depend upon the incident energy of deuterons for a Ti-D target. Consequently, this special emission angle of $100^{\circ}$ to the deuteron beams is expected to provide the energy calibration point of 2413 keV with the FWHM of less than $0.5 \%$.


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II. Japan Atomic Energy Research Institute

## A. Fusion Reactor Physics Laboratory

Department of Reactor Engineeing

## II-A-1 Activation Cross Section Measurement at a Neutron Energy Range from 2.1 to 3.0 MeV by D-D Neutron Source at FNS

Y. Ikeda, C. Konno, K. Kosako and K. Oishi

As an extended scope of measurements of the 14 MeV neutron activation cross section, we started a series of measurements at the energy range from 2.1 to 3.0 MeV using the FNS accelerator. This program was primarily to apply the foil activation technique into the $D-D$ plasma diagnostics. It is also of importance to supplement the 14 MeV cross section data.

A Ti-D target was mounted on the $80^{\circ}$ beam line of $F N S$ and bombarded with $2 \mathrm{~mA} \mathrm{~d}^{*}$ beam of 350 keV to generate $D-D$ neutrons. The neutron flux at the sample was determined by using the reaction of ${ }^{115} \operatorname{In}\left(n, n^{\prime}\right)^{115 m}$ In because its cross section has a rather flat response around $2 \sim 3 \mathrm{MeV}$ energy. region. The reaction measured were ${ }^{47} \mathrm{Ti}(\mathrm{n}, \mathrm{p})^{47} \mathrm{Sc},{ }^{54} \mathrm{Fe}(\mathrm{n}, \mathrm{p})^{54} \mathrm{Mn}$, $\left.{ }^{58} \mathrm{Ni}(\mathrm{n}, \mathrm{p})^{58} \mathrm{Co},{ }^{64} \mathrm{Zn}(\mathrm{n}, \mathrm{p})^{64} \mathrm{Cu},{ }^{111} \mathrm{Cd}\left(\mathrm{n}, \mathrm{n}^{\prime}\right)\right)^{11 \mathrm{~m}^{\prime} \mathrm{Cd},{ }^{113} \mathrm{In}\left(\mathrm{n}, \mathrm{n}^{\prime}\right)^{113 \mathrm{~m}} \mathrm{In}, ~}$ ${ }^{11^{7}} \mathrm{Sn}\left(\mathrm{n}, \mathrm{n}^{\prime}\right)^{11^{17 m} \mathrm{Sn}}$ and ${ }^{135} \mathrm{Ba}\left(\mathrm{n}, \mathrm{n}^{\prime}\right)^{135^{3} \mathrm{ma}}$. Each foil sandwiched by In foils was placed at 10 cm radius at angles from $0^{\circ}$ to $165^{\circ}$ to the incident $\mathrm{d}^{*}$ beam direction centered the target. From the kinematics of $D(d, n)^{3} \mathrm{He}$ reaction, the energies of incident neutrons onto the samples varied from
2.1 to 3.0 MeV corresponding to the angles. After irradiation, reaction rates were derived by using the gamma-ray counts measured with Ge detectors. The energy spectra of incident $D-D$ neutrons was calculated by the Monte Carlo Code, MORSE-DD with a precise model of the target structure. The spectra were used to correct contributions of low energy neutrons to the total reaction rate. All cross section values were obtained in propotion to the cross section of ${ }^{115} \operatorname{In}\left(n, n^{\prime}\right)^{115 m} \operatorname{In}$ taken from ENDF/B-V dosimetry file.

Figures 1 to 8 show the results for ${ }^{47} \mathrm{Ti}(\mathrm{n}, \mathrm{p})^{47} \mathrm{Sc},{ }^{58} \mathrm{Ni}(\mathrm{n}, \mathrm{p})^{58} \mathrm{Co}$, ${ }^{64} \mathrm{Zn}(\mathrm{n}, \mathrm{p})^{69} \mathrm{Cu}$ and ${ }^{113} \mathrm{In}\left(\mathrm{n}, \mathrm{n}^{\prime}\right)^{113 \mathrm{~m}} \mathrm{In}$. For ${ }^{58} \mathrm{Ni}(\mathrm{n} . \mathrm{p})^{58} \mathrm{Co}$ and ${ }^{64} \mathrm{Zn}(\mathrm{n}, \mathrm{p})^{69} \mathrm{Cu}$, there is general agreement between the present data and those in the literatures. Since the reaction of ${ }^{58} \mathrm{Ni}(\mathrm{n}, \mathrm{p})^{58} \mathrm{Co}$ has been widely used in reactor dosimetry studies and has high reliability, the good agreement of our data of ${ }^{58} \mathrm{Ni}(\mathrm{n}, \mathrm{p})^{58} \mathrm{Co}$ with ENDF/B-V suggests validity of the cross section of ${ }^{115} \operatorname{In}\left(n, n^{\prime}\right)^{115 m}$ In used as the monitor. This was also supported by a good agreement of the data of ${ }^{54} \mathrm{Fe}(\mathrm{n}, \mathrm{p})^{54} \mathrm{Mn}$ with ENDF/B-V by the same reason. A steep rise by a magnitude of more than one order is observed in the cross section of ${ }^{64} \mathrm{Zn}(\mathrm{n}, \mathrm{p})^{64} \mathrm{Cu}$ from 2 to 3 MeV . This particular trend seems the reaction of Zn is one of good spectrum indices for the $D-D$ neutrons. For ${ }^{47} \mathrm{Ti}(\mathrm{n}, \mathrm{p})^{47} \mathrm{Sc}$, the present data give slightly lower values than those in the literature. Especially, there is no prominent peak at 2.4 MeV in the present data, which was found in the ENDF/B-V. The same proof for the systematic trend of the lower cross section values than $E N D F / B-V$ has been reported recently by Mannhart ${ }^{11}$. The reaction of ${ }^{113} \operatorname{In}\left(n, n^{\prime}\right)^{113 m}$ In occurs simultaneously in the $\operatorname{In}$ monitor foils. The threshold energy of this reaction is 391 keV and the cross section profile is quite similar to that of ${ }^{115} \operatorname{In}\left(n, n^{\prime}\right)^{115 m} \operatorname{In}$.

Considering the proper half-life of 99.5 m , this reaction is useful for the dosimetry detector. The reaction of ${ }^{11^{1}} \mathrm{Cd}\left(\mathrm{n}, \mathrm{n}^{\prime}\right)^{11^{1 m}} \mathrm{Cd}$ with a low threshold energy at 396 keV is also a candidate for the dosimetry detector for the low energy region. The present data gives reasonable agreement with the recent data. For the reaction of ${ }^{117} \mathrm{Sn}\left(\mathrm{n}, \mathrm{n}^{\prime}\right)^{117 \mathrm{~m}} \mathrm{Sn}$, the cross section was measured for the first time in the present experiment. The reaction of ${ }^{135} \mathrm{Ba}\left(\mathrm{n}, \mathrm{n}^{\prime}\right)^{135 \mathrm{~m}} \mathrm{Ba}$ seems attractive as a dosimetry detector because of a very low threshold energy at 268 keV and its half-life of 28.7 h long enough for the activity measurement. Only one data at 2.8 MeV was reported previously. The present measurement provided data at energies of 2.1 and 3.0 MeV .

## Reference

1. W. Mannhart, et al.; "Measurement of the ${ }^{47} \mathrm{Ti}(\mathrm{n}, \mathrm{p})^{47} \mathrm{Sc}$ Reaction Cross Section," Proc. of a Specialists' Meeting on Neutron Activation Cross Sections for Fission and Fusion Energy Applications, ANL, USA, 13th 15th September 1989.


Fig. 1 Cross section of ${ }^{47} \mathrm{Ti}(\mathrm{n}, \mathrm{p})^{47} \mathrm{Sc}$ Fig. 2 Cross section of ${ }^{54} \mathrm{Fe}(\mathrm{n}, \mathrm{p})^{54} \mathrm{Mn}$


# II-A-2 Activation Cross Section Measurements at Neutron Energy from 13.3 MeV to 15.0 MeV for ${ }^{84} \mathrm{Sr}, 113 \mathrm{In},{ }^{115} \mathrm{In},{ }^{178} \mathrm{Hf},{ }^{179 \mathrm{Hf} \text { and }}$ 

 180 HfC. Konno, Y. Ikeda and T. Nakamura

Systematic measurements of neutron activation cross sections around 14 MeV have been under way at FNS for the elements of fusion reactor structural materials.1).2) Activation cross sections for reactions on
 period. The measured reactions are summarized in Table 1.2.1. The experimental procedure was same as the one adopted previously ${ }^{11}$. Separated isotopes were used for Hf, while natural samples were used for Sr and In. All data were determined relatively to the cross section of ${ }^{93} \mathrm{Nb}(\mathrm{n}, 2 \mathrm{n})^{32 \mathrm{~m}} \mathrm{Nb}$ as the reference reaction.

Since the natural abundance of ${ }^{84} \mathrm{Sr}$ is only $0.55 \%$, data for this nuclide have been scarce. Particularly data for ${ }^{84} \operatorname{Sr}(\mathrm{n}, \mathrm{p})^{84 m+8 R b}$ and ${ }^{8.4} \operatorname{Sr}(n, n p)^{83} \mathrm{Rb}$ were measured previously only by Qaim ${ }^{31.4)}$. Our data agreed with his data within experimental errors. Qaims' also pointed out that the systematic of ( $\mathrm{n}, \mathrm{np}$ ) cross section for ${ }^{50} \mathrm{Cr},{ }^{58} \mathrm{Ni},{ }^{84} \mathrm{Sr},{ }^{92 \mathrm{Mo} \text {, }}$ ${ }^{36} \mathrm{Ru}$ and ${ }^{106} \mathrm{Cd}$ differed by a factor of 14.25 from that for other nuclei as shown in Fig. 1. Our data for ${ }^{84} \operatorname{Sr}(n, n p)^{83} R b$ supported this trend.

The cross section data in ! ${ }^{13}$ In and ${ }^{115}$ In have been measured by several experimetalists and our data agreed with the recent measured data within experimental errors. In the case of $115 \operatorname{In}(n, p)^{1150} \mathrm{Cd}$ the measured cross section data are very few since the half-life of 115 m ( Cd 44.8 days and the gamma-ray branching ratio is only $1.7 \%$. Our data covering wide energy range are larger by about $30 \%$ than that by Levkovskijor as shown in Fig. 2.

The cross section data for ${ }^{178} \mathrm{Hf},{ }^{179} \mathrm{Hf}$ and ${ }^{189} \mathrm{Hf}$ have been also scarce. In particular this is the first time to measure the cross section of $188 \mathrm{Hf}(\mathrm{n}, 2 \mathrm{n})^{179 \mathrm{~m} 2 \mathrm{Hf}}$. The measured cross section is shown in Fig. 3.

## References

1) Y. Ikeda, et al.: "Activation Cross Section Measurements for Fusion Reactor Structural Materials at Neutron Energy from 13.3 to 15.0 MeV Using FNS Facility", JAERI 1312 (1988).
2) C. Konno, et al.: "Reactor Engineering Department Annual Report", JAERI-M 89-128, 17•(1989).
3) S.M. Qaim, et al.: Nucl. Phys., A283; 269 (1977).
4) S.M. Qaim, et al.; Proc. of the 8 th symposium on fusion technology, June 17-21, 1974, Noordwijkerhout, the Netherlands, 939 (1974).
5) S.M. Qaim, et al.: Nucl. Phys., A382, 255 (1982).
6) V.N. Levkovskij et al.; Yad. Fiz., 10; 44 (1969).


* Separated isotope was used.
** Data were taken from Table of Isotopes, 7th Edition.


Fig. 1. Systematics of $(n, d)+(n, n p)$ reaction cross-sections at incident energy of $14.7 \mathrm{MeV}^{3}$ )


Department of Radioisotopes

II-B-1 Thermal Neutron Cross Section of the ${ }^{137} \mathrm{Cs}(n, \gamma){ }^{138} \mathrm{Cs}$ Reaction

H. Harada," H. Watanabe,* T. Sekine, Y. Hatsukawa, K. Kobayashi and T. Katoh**

A paper on this subject was published in J. Nucl. Sci. Tech. 27 (1990) 577.
About 0.1 MBq of ${ }^{137} \mathrm{Cs}$ was irradiated during a period of 10 min under a thermal neutron flux of $3.8 \times 10^{13} \mathrm{n} / \mathrm{cm}^{2} \cdot \mathrm{~s}$. The irradiated sample was purified chemically and its radioactivity was measured by means of $\gamma$-ray spectrometry. From the intensity ratio of $\gamma$-rays of ${ }^{137} \mathrm{Cs}$ and ${ }^{138} \mathrm{Cs}$, the thermal neutron cross section of the ${ }^{137} \mathrm{Cs}(n, \gamma){ }^{138} \mathrm{Cs}$ reaction was found to be $0.250 \pm 0.013 \mathrm{~b}$.

The cross section obtained is 2.3 times larger than the one reported by Stupegia. ${ }^{1)}$

## References:

1) D. C. Stupegia, J. Nucl. Energy, A12 (1960) 16.
[^0]
## C. Linac Laboratory, Department of Physics

II-C-1 Scattering of 18.5 MeV Neutrons from ${ }^{52} \mathrm{Cr}$

Y. Yámanouti, M. Sugimoto, M. Mizumoto, Y. Watanabe* and K. Hasegawa**

Neutron differential cross sections for elastic scattering and inelastic scattering to the excited states of $1.434 \mathrm{MeV}\left(2^{+}\right)$and 4.563 MeV (3-) on ${ }^{52} \mathrm{Cr}$ were measured at 18.5 MeV to study the reaction mechanism for the nucleon-nucleus scattering in the energy range around 20 MeV .

A pulsed beam of deuterons was provided by the JAERI tandem accelerator. Neutrons were generated by the ${ }^{2} H(d, n){ }^{3} H e ~ r e a c t i o n . ~ A n ~$ array of four 20 cm in diam by 35 cm thick NE213 liquid scintillator detectors was used for neutron measurements. The relative efficiency of the neutron detector was determined by measuring the angular distribution of neutrons from the ${ }^{1} H(n, n){ }^{1} H$ reaction.

The experimental data were analyzed by the phenomenological optical model and the microscopic JLM optical potential. The coupled-channel caluculations based on the collective model were performed to analyze the elastic and inelastic cross sections. The present data were also compared with proton scattering in the framework of the Lane model.

[^1]Y. Nakajima, M. Ohkubo; Y. Furuta, M. Mizumoto,. M. Sugimoto and Y. Kawarasaki

A paper on this subject was published in Annals of Nuclear Energy 17, 95-99 (1990) with the following abstract:

Neutron transmission measurements were carried out on a ${ }^{122} \mathrm{Sn}$ oxide sample enriched to $92.20 \%$ at a 190 m station of the Japan Atomic Energy Research Institute linac with the neutron time-of-flight method. Resonance energies and neutron widths were determined for 21 resonances between 1.5 and 30 keV by a shape analysis code based on the Breit-Wigner multi-level formula. The following average resonance parameters for $s$-wave neutrons were obtained: $D_{0}=1.17_{-0.08}^{+0.09} \mathrm{keV}, S_{0} \times$ $10^{4}=0.30_{-0.08}^{+0.12}$ and $R^{\prime}=5.60 \pm 0.05 \mathrm{fm}$. The present $s$-wave neutron strength function of ${ }^{122} \mathrm{Sn}$ is substantially larger than the theoretical prediction of the doorway state model.

Yutaka NAKAJIMA; Makio OHKUBO, Masayoshi SUGIMOTO, Motoharu MIZUMOTO and Yuuki KAWARASAKI


#### Abstract

A paper on this subject will be published in Annals of Nuclear Energy with the following abstract:


Neutron capture and neutron transmission measurements on ${ }^{133}$ Cs were made to obtain neutron resonance parameters. . Neutron capture areas up to 2 keV and neutron widths up to 5.9 keV for. each resonance: were derived. Below 100 eV five neutron radiative capture widths were obtained from the shape analysis of the transmission data. The following average $s$-wave resonance parameters were obtained: $\mathrm{S}_{0}=$ $(0.77 \pm 0.09) \times 10^{-4}, \overline{\mathrm{D}}=22.4 \pm 1.5 \mathrm{eV}, \bar{\Gamma}_{\gamma}=119 \pm 3 \mathrm{meV}$. The distribution of the level spacings is consistent with the two population Wigner distribution predicted theoretically. The statistic $\Delta_{3}$ is in good agreement with the value which Dyson and Mehta derived by using the orthogonal ensemble.

Neutron Induced Gamma-ray Production Cross Sections of Structural Materials in the $8-13 \mathrm{MeV}$ region
K. Hasegawa, M. Mizumoto, S. Chiba, M. Sugimoto, Y. Yamanouti, M. Igashira* and H. Kitazawa*

We have been continuing to measure neutron induced $\gamma$-ray production cross sections for last several years at the JAERI Tandem Accelerator. In 1989, we have measured the Cu and Ni data as the structural and shielding materials in addition to $\mathrm{Al}, \mathrm{Si}, \mathrm{Fe}, \mathrm{Pb}$ and Bi . The sample characteristics and measured energy points are given in Table 1 for our ( $n, x \gamma$ ) reaction cross section measurements. The monoenergetic neutron sources used are the $2 \mathrm{H}(\mathrm{d}, \mathrm{n})^{3} \mathrm{He}$ at 7.8 MeV and 10.0 MeV and the ${ }^{1 \mathrm{H}}\left({ }^{11} \mathrm{~B}, \mathrm{n}\right)^{11} \mathrm{C}$ reaction at 11.5 MeV and 13.0 MeV . Emitted $\gamma$-rays were measured with a $7.6 \mathrm{~cm} \phi \times 15 \mathrm{~cm} \mathrm{Na}(\mathrm{TI})$ detector surrounded by a $25.4 \mathrm{~cm} \phi \times 25.4 \mathrm{~cm}$ annular $\mathrm{Na}(\mathrm{TI})$ detector. The $r$ -ray pulse height spectra were unfolded with the computer program FERDOR before the various sample thickness corrections were made.

The measured results were compared with the existing data by the continuous neutron source at ORELA and with the new evaluated data JENDL-3 based on the multi-step Hauser Feshbach calculation. An example of total $\gamma$ -ray production cross section of iron is shown in Fig. 1. The energy dependence of our data is in good agreements with the Oak Ridge data, but the absolute values are $30 \%$ lower than Chapman et al.1) and $20 \%$ higher than Dickens et al.2).

Table 1 ( $n, x y$ ) Beaction Cross Section Measurements

| element | $\begin{aligned} & \text { size } \\ & \text { (mm) } \end{aligned}$ | weight <br> (g) | $D(\mathrm{~d}, \mathrm{n})^{3} \mathrm{He}$ |  | ${ }^{1} \mathrm{H}\left({ }^{11} \mathrm{~B}, \mathrm{n}\right)^{12} \mathrm{C}$ |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | 7. 8 MeV | 10.0 MeV |  |  | 13.0MeV |
|  |  |  | $90^{\circ}$ | $90^{\circ}$ | $90^{\circ}$ | $125^{\circ}$ | $90^{\circ}$ |
| C | $\phi 30 \times 30$ | 38.14 | $\bigcirc$ | $\bigcirc$ | $\bigcirc$ | $\bigcirc$ | $\bigcirc$ |
| $\mathrm{O}\left(\mathrm{H}_{2} \mathrm{O}\right)$ | ¢ $32 \times 40$ | 30.47 | $\bigcirc$ | $\bigcirc$ | $\bigcirc$ |  |  |
| A1 | $\phi 30 \times 30$ | 57.68 | $\bigcirc$ | $\bigcirc$ | $\bigcirc$ | $\bigcirc$ | $\bigcirc$ |
| Si | ¢ $30 \times 30$ | 49.51 | $\bigcirc$ | $\bigcirc$ | $\bigcirc$ | $\bigcirc$ | $\bigcirc$ |
| Si | $\phi 20 \times 30$ | 21.97 |  | $\bigcirc$ |  |  |  |
| Fe | $\phi 30 \times 30$ | 165.3 | $\bigcirc$ | $\bigcirc$ | $\bigcirc$ | $\bigcirc$ | $\bigcirc$ |
| Mi | $\phi 20 \times 30$ | 83.79 |  |  | $\bigcirc$ |  | $\bigcirc$ |
| Cu | $\phi 20 \times 30$ | 83. 98 |  |  | $\bigcirc$ | $\bigcirc$ | $\bigcirc$ |
| Pb | $\phi 30 \times 30$ | 243.2 | $\bigcirc$ | $\bigcirc$ | $\bigcirc$ | $\bigcirc$ |  |
| Pb | $\phi 20 \times 30$ | 108.6 |  | $\bigcirc$ |  |  | $\bigcirc$ |
| Bi | ¢ $30 \times 30$ | 210.6 | $\bigcirc$ | $\bigcirc$ | $\bigcirc$ |  | $\bigcirc$ |



Fig. 1 Total gamma-ray production cross section for iron

## References

1) G.T. Chapman et al., ORNL-TM-5416 (1976)
2) J.K. Dickens et al., ORNL-4798 (1972)

* Tokyo Institute of Technology

II-D-1 Evaluation of Neutron Nuclear Data for ${ }^{3} \mathrm{He}$ and ${ }^{4} \mathrm{He}$

## Keiichi SHIBATA

A paper on this subject was published in J. Nucl. Sci. Technol., 27,81 (1990) with the following abstract:

Neutron-induced reaction cross sections of ${ }^{3} \mathrm{He}$ and ${ }^{4} \mathrm{He}$ have been evaluated in the energy range of $10^{-5} \mathrm{eV} \sim 20 \mathrm{MeV}$. Evaluated quantities are the total and elastic scattering cross sections of ${ }^{4} \mathrm{He}$ and the total, elastic scattering, ( $n, p$ ) and ( $n, d$ ) reaction cross sections of ${ }^{3}$ He as well as the angular distributions of elastically scattered neutrons for both isotopes. The total and elastic scattering cross sections of ${ }^{4} \mathrm{He}$ were analyzed with the R-matrix theory in the overall energy region. As for ${ }^{3} H e$, the R-matrix calculation was performed to evaluated the total, elastic scattering and ( $n, p$ ) reaction cross sections below 1 MeV , and the evaluation of the cross sections in the energy region above 1 MeV was based on available experimental data. The evalrated data have been compiled into JENDL-3 in the ENDF-5 format.

Keiichi Shibata, Tetsuo Asami** ${ }^{\text {, }}$ Toru Murata* ${ }^{\mathbf{2}}$, Yukinori Kanda* ${ }^{3}$ Satoshi Chiba, Yutaka Nakajima and Shigeya Tanaka*4

A paper on this subject was published as JAERI-M 90-012 with the following abstract:

Neutron nuclear data of ${ }^{16} 0$ have been evaluated for JENDL-3 in the energy range from $10^{-5} \mathrm{eV}$ to 20 MeV . Evaluated quantities are the total, elastic and inelastic scattering, $(n, 2 n),(n, \gamma),(n, p),(n, d)$, $(n, \alpha),(n, n p)$ and $(n, n \alpha)$ reaction cross sections and the angular and energy distributions of emitted neutrons and gamma-rays. The total cross section below 3 MeV was calculated on the basis of the R-matrix theory. The inelastic scattering, ( $n, n p$ ) and ( $n, n \alpha$ ) reaction cross sections were obtained from the statistical model calculation. The gamma-ray production cross section was also calculated with the statistical model.

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* }\mp@subsup{}{}{1}\mathrm{ Nuclear Energy Data Center
*2 Toshiba, Ltd.
*3}\mathrm{ Kyushu University
*4 0-u College
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# Natural Silver and Its Isotopes 

## Liu Ting-jin*, Keiichi Shibata and Tsuneo Nakagawa

A paper on this subject was submitted to J. Nuc1. Sci. Technol. with the following abstract:

Neutron nuclear data of natural silver and its isotopes $\left({ }^{107} \mathrm{Ag}\right.$ and ${ }^{109} \mathrm{Ag}$ ) have been evaluated in the energy range of $10^{-5} \mathrm{eV} \sim 20$ MeV. Evaluated quantities are the total, elastic and inelastic scattering, capture, $(n, 2 n),(n, 3 n),(n, p),(n, \alpha),(n, n p),(n, n \alpha)$ reaction and $\gamma$-ray production cross sections, the resonance parameters and the angular and energy distributions of emitted neutrons and $\gamma$-rays. The evaluation is based on available experimental data and theoretical calculations. Multi-step Hauser-Feshbach calculation played an important role in the determination of the reaction cross sections. In the calculation, the precompound process was taken into account above 5 MeV , in addition to the compound one. The evaluated data have been compiled into JENDL-3 in the ENDF-5 format.

[^2]II-D-4

## Evaluation of Neutron Nuclear Data for Curium Isotopes

## Tsuneo NAKAGAWA

A paper on this subject was published as JAERI-M 90-101 with the following abstract:

The evaluation of neutron nuclear data of curium isotopes was made in the energy region from $10^{-5} \mathrm{eV}$ to 20 MeV . The data of ${ }^{241} \mathrm{Cm}$ were newly evaluated in the present work. The data of ${ }^{242} \mathrm{Cm},{ }^{243} \mathrm{Cm}$, ${ }^{244} \mathrm{Cm},{ }^{245} \mathrm{Cm},{ }^{246} \mathrm{Cm},{ }^{247} \mathrm{Cm},{ }^{248} \mathrm{Cm}$ and ${ }^{249} \mathrm{Cm}$ had been evaluated previously, and those of ${ }^{242} \mathrm{Cm}$ through ${ }^{245} \mathrm{Cm}$ were stored in JENDL-2. In the present work, the recent experimental data were reviewed, and their data were reevaluated except for ${ }^{248} \mathrm{Cm}$ and ${ }^{249} \mathrm{Cm}$. The results of the present work were compiled in ENDF-5 format and included in the latest version of Japanese Evaluated Nuclear Data Library, JENDL-3.

# II-D-5 Calculation of Neutron-Induced Reaction Cross Sections of Manganese-55 

## Keiichi SHIBATA

A paper on this subject was published in J. Nucl. Sci. Technol., 26, 955 (1989) with the following abstract:

Neutron-induced reaction cross sections of ${ }^{55} \mathrm{Mn}$ are calculated for the evaluated nuclear data libraries, ENDF/B-VI and JENDL-3. Simultaneously calculated are the inelastic scattering, ( $n, 2 n$ ), ( $n, p$ ), $(n, \alpha),(n, n p),(n, n \alpha)$ and $(n, \gamma)$ reaction cross sections, the angular distributions of emitted neutrons and protons, and the energy distributions of emitted particles and $\gamma$-rays. A unified Hauser-Feshbach code is applied to calculate these quantities. Precompound and direct-reaction processes are taken into consideration, in addition to the compound process. The calculated results reproduce the experimental data very well. Forward-peaked angular distributions of continuous neutrons are obtained from the calculation, and found to be consistent with the measurements at 14 MeV .

Japanese Evaluated Nuclear Data Library, Version-3<br>- JENDL-3 -<br>JENDL-3 Compilation Group<br>Keiichi SHIBATA, Tsuneo NAKAGAWA, Tetsuo ASAMI, Tokio FUKAHORI, Tsutomu NARITA, Satoshi CHIBA, Motoharu MIZUMOTO, Akira HASEGAWA, Yasuyuki KIKUCHI, Yutaka NAKAJIMA and Sin-iti IGARASI

The general purpose file of JENDL-3 has been completed. The report on JENDL-3 was published as JAERI 1319 with the following abstract:

The general purpose file of the third version of Japanese Evaluated Nuclear Data Library, JENDL-3, has been compiled by the JAERI Nuclear Data Center in cooperation with the Japanese Nuclear Data Committee. It contains neutron nuclear data for 171 nuclides which are needed for design of fission and fusion reactors and for shielding calculation. In the JENDL-3 evaluation, much effort was devoted to improve reliability of high-energy data for fusion application and to include gamma-ray production data. Theoretical calculations played an important role in achieving these purposes. A special method called simultaneous evaluation was adopted to determine important cross sections of fissile and fertile nuclides. This report presents a general description for the evaluation of light, medium-heavy and heavy nuclide data. Also given are the descriptive data for each nuclide contained in the File 1 part of JENDL-3.

JNDC FP Nuclear Data Working Group
M. Kawai ${ }^{1}$, S. Iijima ${ }^{1}$, H. Matsunobu ${ }^{2}$, T. Nakagawa, Y. Nakajima, M. Sasaki ${ }^{3}$, T. Sugi, T. Watanabe ${ }^{4}$; A. Zukeran ${ }^{5}$

The evaluation work of neutron nuclear data for 172 nuclides in a fission product (FP) mass region from $A s$ to $T b$ were completed, and the results were compiled in the ENDF-5 format: The JENDL-2 data for 100 FP nuclides have been reviesd with the present results.

The evaluation was made in the neutron energy region from $10^{-5} \mathrm{eV}$ to 20 MeV , and for the quantities of the total, elastic and inelastic scattering, capture and threshold reaction cross sections, angular distributions and energy distributions of emitted neutrons. In the low energy region, the resolved resonance parameters were given on the basis of recent experimental data. The parameters of a negative resonance were adjusted to the thermal cross sections. Above the resolved resonance region, the unresolved resonance parameters were evaluated so as to reproduce the capture cross section below 100 keV . In the high energy region, optical and statistical model calculation with CASTHY ${ }^{1)}$ and precompound theory and multi-step evaporation model

[^3]calculation with PEGASUS ${ }^{2)}$ were performed. The parameters for these theoretical calculations were determined to reproduce well the available experimental data. For the inelastic scattering of evenmass nuclides of $\mathrm{Ru}, \mathrm{Pd}, \mathrm{Cd}, \mathrm{Ba}, \mathrm{Ce}, \mathrm{Nd}$ and Sm, contributions from the direct reaction process were taken into consideration by using DWUCK4 ${ }^{3}$ ). For the capture cross section, the direct and semi-direct components were calculated according to from a simple formula given by Benzi and Reffo ${ }^{4)}$.

Table 1 shows all the nuclides stored in the JENDL-3 FP Nuclear data library together with their capture cross section at 0.0253 eV and the capture resonance integral.

## References

1) Igarasi, S.: J. Nuc1. Sci. Technol., 12, 67 (1975).
2) Iijima, S. et al.: JAERI-M 87-025, p. 3.37 (1987).
3) Kunz, P.D.: private communication.
4) Benzi, V. and Reffo, G.: CCDN-NW/10 (1969).

Table 1 Calculated $2200-\mathrm{m} / \mathrm{s}$ values and resonance integrals of
the capture cross section for 172 FP nuclides.

| Nuclide | 2200-m/s sig. (barns) | $\begin{gathered} \text { Res.integ. } \\ \text { (barns) } \end{gathered}$ |
| :---: | :---: | :---: |
| 33-As-75 | $4.500 E+00$ | $6.394 E+01$ |
| 34-Se-74 | $5.180 E+01$ | $5.801 \mathrm{E}+02$ |
| 34-Se-76 | $8.500 E+01$ | $4.113 \mathrm{E}+01$ |
| 34-Se-77 | $4.200 E+01$ | $3.211 E+01$ |
| 34-Se-78 | $4.300 \mathrm{E}-01$ | $4.743 \mathrm{E}+00$ |
| 34-Se-79 | $5.000 \mathrm{E}+01$ | $6.087 \mathrm{E}+01$ |
| 34-Se-80 | 6.100E-01 | $9.254 \mathrm{E}-01$ |
| 34-Se-82 | 4.420E-02 | 7.991E-01 |
| 35-8r-79 | $1.100 \mathrm{E}+01$ | $1.287 E+02$ |
| 35-Br-81 | $2.690 \mathrm{E}+00$ | $4.692 \mathrm{E}+01$ |
| $36-\mathrm{Kr}-78$ | $6.200 E+00$ | $2.576 E+01$ |
| $36-K r-80$ | $1.150 \mathrm{E}+01$ | $6.025 E+01$ |
| $36-\mathrm{Kr}-82$ | $2.800 E+01$ | $2.280 \mathrm{E}+02$ |
| $36-K r-83$ | $1.799 E+02$ | $1.477 E+02$ |
| $36-K r-84$ | $1.100 \mathrm{E}-01$ | $2.420 \mathrm{E}+00$ |
| $36-\mathrm{Kr}-85$ | $1.660 E+00$ | $1.824 \mathrm{E}+00$ |
| 36-Kr-86 | $3.000 \mathrm{E}-03$ | 2.325E-02 |
| 37-Rb-85 | $4.800 \mathrm{E}-01$ | $8.733 \mathrm{E}+00$ |
| 37-Rb-87 | $1.200 \mathrm{E}-01$ | $2.716 \mathrm{E}+00$ |
| 38-Sr-86 | $1.040 \mathrm{E}+00$ | $4.818 \mathrm{E}+00$ |
| 38-Sr-87 | $1.600 \mathrm{E}+01$ | $1.211 \mathrm{E}+02$ |
| 38-Sr-88 | $5.789 \mathrm{E}-03$ | 7.006E-02 |
| 38-Sr-89 | $4.200 \mathrm{E}-01$ | $4.140 \mathrm{E}-01$ |
| 38-Sr-90 | 9.000E-01 | 4.847E-01 |
| 39-Y-89 | $1.277 \mathrm{E}+00$ | 8.600E-01 |
| 39-Y-91 | $1.400 \mathrm{E}+00$ | $2.848 \mathrm{E}+00$ |
| 40-2r-90 | 4.584E-02 | $1.961 \mathrm{E}-01$ |
| 40-2r-91 | $1.247 \mathrm{E}+00$ | $6.951 \mathrm{E}+00$ |
| 40-2r-92 | 2.175E-01 | 7.023E-01 |
| 40-2r-93 | $2.239 E+00$ | $1.822 E+01$ |
| 40-2r-94 | 4.981E-02 | 3.210E-01 |
| 40-2r-95 | $1.200 \mathrm{E}+00$ | $7.794 \mathrm{E}+00$ |
| 40-2r-96 | 2.280E-02 | $5.872 \mathrm{E}+00$ |
| 41-Nb-93 | $1.152 \mathrm{E}+00$ | $9.488 \mathrm{E}+00$ |
| $41-\mathrm{Nb}-94$ | 1.577E+01 | $1.255 \mathrm{E}+02$ |
| 41-Nb-95 | $7.000 \mathrm{E}+00$ | $4.179 \mathrm{E}+01$ |
| 42-Mo-92 | 2.075E-02 | $9.681 \mathrm{E}-01$ |
| 42-Mo-94 | $1.311 \mathrm{E}-02$ | $1.401 \mathrm{E}+00$ |
| 42-Mo-95 | $1.399 E+01$ | $1.187 \mathrm{E}+02$ |
| 42-Mo-96 | 5.954E-01 | $1.755 \mathrm{E}+01$ |
| 42-Mo-97 | $2.102 \mathrm{E}+00$ | $1.716 \mathrm{E}+01$ |
| 42-Mo-98 | $1.300 \mathrm{E}-01$ | $6.555 \mathrm{E}+00$ |
| 42-Mo-99 | $8.000 E+00$ | $4.157 \mathrm{E}+01$ |
| 42-Mo-100 | $1.990 \mathrm{E}-01$ | $3.909 \mathrm{E}+00$ |
| 43-Tc-99 | $1.979 E+01$ | $3.195 \mathrm{E}+02$ |
| 44-Ru-96 | 2.900E-01 | $7.297 E+00$ |
| 44-Ru-98 | $8.000 \mathrm{E}+00$ | $1.151 \mathrm{E}+01$ |
| 44-Ru-99 | $7.303 \mathrm{E}+00$ | $1.689 \mathrm{E}+02$ |
| 44-Ru-100 | $5.022 \mathrm{E}+00$ | $1.120 \mathrm{E}+01$ |
| 44-Ru-101 | $3.359 E+00$ | $1.010 \mathrm{E}+02$ |


| Nuclide | $2200-\mathrm{m} / \mathrm{s} \text { sig. }$ <br> (barns) | Res.integ. (bàns) |
| :---: | :---: | :---: |
| 44-Ru-102 | $1.229 E+00$ | $4.315 \mathrm{E}+00$ |
| 44-Ru-103 | $8.000 \mathrm{E}+00$ | $9.133 E+01$ |
| 44-Ru-104 | $3.226 \mathrm{E}-01$ | $6.566 \mathrm{E}+00$ |
| 44-Ru-106 | 1.460E-01 | $2.005 E+00$ |
| 45-Rh-103 | $1.466 \mathrm{E}+02$ | $1.045 \mathrm{E}+03$ |
| 45-Rh-105 | $1.583 \mathrm{E}+04$ | $1.702 \mathrm{E}+04$ |
| 46-Pd-102 | $3.363 \mathrm{E}+00$ | 1.954E+01 |
| 46-Pd-104 | 5.231E-01 | $2.192 \mathrm{E}+01$ |
| 46-Pd-105 | $2.025 \mathrm{E}+01$ | $9.683 \mathrm{E}+01$ |
| 46-Pd-106 | 3.030E-01 | $9.311 \mathrm{E}+00$ |
| 46-Pd-107 | $2.008 \mathrm{E}+00$ | $1.089 \mathrm{E}+02$ |
| 46-Pd-108 | $8.504 \mathrm{E}+00$ | $2.524 E+02$ |
| 46-Pd-110 | 2.270E-01 | $2.816 \mathrm{E}+00$ |
| 47-Ag-107 | $3.862 \mathrm{E}+01$ | $1.032 \mathrm{E}+02$ |
| 47-Ag-109 | $9.053 \mathrm{E}+01$ | $1.472 \mathrm{E}+03$ |
| 47-Ag-110m | $8.200 E+01$ | $9.41 .2 \mathrm{E}+01$ |
| $48-C d-106$ | $9.695 \mathrm{E}-01$ | $1.074 \mathrm{E}+01$ |
| 48-Cd-108 | $1.087 \mathrm{E}+00$ | $2.719 \mathrm{E}+01$ |
| 48-Cd-110 | $1.102 \mathrm{E}+01$ | $4.006 \mathrm{E}+01$ |
| 48-Cd-111 | $2.392 \mathrm{E}+01$ | $4.842 \mathrm{E}+01$ |
| 48-cd-112 | $2.192 \mathrm{E}+00$ | $1.337 \mathrm{E}+01$ |
| 48-Cd-113 | $2.065 \mathrm{E}+04$ | $3.937 \mathrm{E}+02$ |
| 48-cd-114 | 3.404E-01 | $1.696 \mathrm{E}+01$ |
| 48-Cd-116 | 7.484E-02 | $1.745 \mathrm{E}+00$ |
| 49-In-113 | $1.207 \mathrm{E}+01$ | $3.255 \mathrm{E}+02$ |
| 49-In-115 | $2.010 \mathrm{E}+02$ | $3.210 \mathrm{E}+03$ |
| 50-Sn-112 | $1.009 \mathrm{E}+00$ | $3.051 E+01$ |
| 50-Sn-114 | $1.253 \mathrm{E}-01$ | $6.673 \mathrm{E}+00$ |
| 50-Sn-115 | $2.985 \mathrm{E}+01$ | $1.385 \mathrm{E}+01$ |
| 50-Sn-116 | 1.277E-01 | $1.240 \mathrm{E}+01$ |
| 50-Sn-117 | $2.173 \mathrm{E}+00$ | $1.870 \mathrm{E}+01$ |
| 50-Sn-118 | 2.178E-01 | $5.347 \mathrm{E}+00$ |
| 50-Sn-119 | $2.176 E+00$ | $5.334 \mathrm{E}+00$ |
| 50-Sn-120 | 1.392E-01 | $1.222 \mathrm{E}+00$ |
| 50-Sn-122 | 1.837E-01 | 9.327E-01 |
| 50-5n-123 | $3.000 E+00$ | $6.264 E+01$ |
| 50-Sn-124 | 1.355E-01 | $7.905 \mathrm{E}+00$ |
| 50-Sn-126 | 9.000E-02 | 1.500E-01 |
| 51-Sb-121 | $5.991 E+00$ | $2.153 \mathrm{E}+02$ |
| 51-5b-123 | $4.187 E+00$ | $1.232 \mathrm{E}+02$ |
| 51-Sb-124 | $1.740 E+01$ | $1.561 \mathrm{E}+02$ |
| 51-Sb-125 | $5.000 \mathrm{E}+00$ | $5.572 \mathrm{E}+01$ |
| 52-Te-120 | $2.340 \mathrm{E}+00$ | $2.252 \mathrm{E}+01$ |
| 52-Te-122 | $3.401 \mathrm{E}+00$ | $8.132 \mathrm{E}+01$ |
| 52-Te-123 | $4.181 E+02$ | $5.648 \mathrm{E}+03$ |
| 52-Te-124 | $6.802 \mathrm{E}+00$ | $5.986 \mathrm{E}+00$ |
| 52-Te-125 | $1.548 \mathrm{E}+00$ | $2.258 \mathrm{E}+01$ |
| 52-Te-126 | $1.034 \mathrm{E}+00$ | $8.085 \mathrm{E}+00$ |
| 52-Te-127m | $3.380 E+03$ | $1.336 E+03$ |
| 52-Te-128 | 2.140E-01 | $1.307 \mathrm{E}+00$ |

Table 1 (continued)

| Nuclide | 2200-m/s sig. <br> (barns) | Res.integ. (barns) |
| :---: | :---: | :---: |
| 52-Te-129m | $1.600 E+03$ | $7.524 \mathrm{E}+02$ |
| 52-Te-130 | 2.700E-01 | 2.850E-01 |
| 53-1 -127 | $6.200 \mathrm{E}+00$ | $1.477 E+02$ |
| 53-I -129 | $2.700 E+01$ | $2.940 E+01$ |
| 53-I -131 | $8.000 E+01$ | $7.781 \mathrm{E}+01$ |
| 54-Xe-124 | $1.650 E+02$ | $2.970 E+03$ |
| 54-Xe-126 | $4.269 E+00$ | $2.338 \mathrm{E}+01$ |
| 54-Xe-128 | $8.000 E+00$ | $1.248 \mathrm{E}+01$ |
| 54-Xe-129 | $2.100 E+01$ | $2.555 \mathrm{E}+02$ |
| 54-Xe-130 | $2.600 E+01$ | $1.780 \mathrm{E}+01$ |
| 54-Xe-131 | $8.503 \mathrm{E}+01$ | $9.001 \mathrm{E}+02$ |
| 54-Xe-132 | 4.500E-01 | $4.509 \mathrm{E}+00$ |
| 54-Xe-133 | $1.900 E+02$ | $9.006 E+01$ |
| 54-Xe-134 | $2.650 \mathrm{E}-01$ | 6.171E-01 |
| 54-Xe-135 | $2.648 \mathrm{E}+06$ | $7.614 E+03$ |
| 54-Xe-136 | 2.600E-01 | $1.415 \mathrm{E}-01$ |
| 55-Cs-133 | $2.900 E+01$ | $3.964 E+02$ |
| 55-Cs-134 | $1.397 E+02$ | $1.056 \mathrm{E}+02$ |
| 55-Cs-135 | $8.702 \mathrm{E}+00$ | $6.254 \mathrm{E}+01$ |
| 55-Cs-136 | $1.300 E+01$ | $5.738 \mathrm{E}+01$ |
| 55-Cs-137 | $1.099 \mathrm{E}-01$ | 6.801E-01 |
| 56-Ba-130 | $1.129 E+01$ | $1.774 \mathrm{E}+02$ |
| 56-Ba-132 | $7.000 \mathrm{E}+00$ | $3.129 E+01$ |
| 56-Ba-134 | $2.002 \mathrm{E}+00$ | $2.479 E+01$ |
| 56-Ba-135 | $5.839 E+00$ | $1.311 E+02$ |
| 56-Ba-136 | 4.001E-01 | $2.058 \mathrm{E}+00$ |
| 56-8a-137 | $5.123 \mathrm{E}+00$ | $4.831 \mathrm{E}+00$ |
| 56-8a-138 | 3.591E-01 | 1.880E-01 |
| 56-Ba-140 | $1.600 \mathrm{E}+00$ | 7.276E-01 |
| 57-La-138 | $5.708 \mathrm{E}+01$ | $3.647 \mathrm{E}+02$ |
| 57-La-139 | $8.927 E+00$ | $1.161 E+01$ |
| 58-Ce-140 | 5.673E-01 | 2.772E-01 |
| 58-Ce-141 | $2.912 \mathrm{E}+01$ | $5.031 E+02$ |
| 58-Ce-142 | $1.004 E+00$ | 9.409E-01 |
| 58-Ce-144 | $1.000 E+00$ | $2.546 \mathrm{E}+00$ |
| 59-Pr-141 | $1.335 \mathrm{E}+01$ | $1.897 \mathrm{E}+01$ |
| 59-Pr-143 | $9.000 E+01$ | $1.854 \mathrm{E}+02$ |
| 60-Nd-142 | $1.892 \mathrm{E}+01$ | $8.783 \mathrm{E}+00$ |
| 60-Nd-143 | $3.299 E+02$ | $1.302 \mathrm{E}+02$ |
| $60-\mathrm{Nd}-14.4$ | $3.804 E+00$ | $4.311 E+00$ |
| 60-Nd-145 | $4.384 \mathrm{E}+01$ | $2.040 E+02$ |
| 60-Nd-146 | $1.399 E+00$ | $2.911 E+00$ |
| 60-Nd-147 | $4.310 E+02$ | $6.311 E+02$ |
| 60-Nd-148 | $2.493 E+00$ | $1.474 \mathrm{E}+01$ |
| $60-\mathrm{Nd}-150$ | $1.202 \mathrm{E}+00$ | $1.591 E+01$ |
| 61-Pm-147 | $1.677 E+02$ | 2.207E+03 |
| 61-Pm-148 | $2.000 E+03$ | $2.506 E+03$ |
| 61-Pm-148m | $1.060 E+04$ | 3.589E+03 |
| 61-Pm-149 | $1.400 E+03$ | $1.566 E+03$ |
| 62-Sm-14.4 | $1.640 E+00$ | $1.505 \mathrm{E}+01$ |


| Nuclide | $\begin{gathered} 2200-\mathrm{m} / \mathrm{s} \text { sig. } \\ \text { (barns) } \end{gathered}$ | Res.integ. (barns) |
| :---: | :---: | :---: |
| 62-Sm-147 | $5.801 E+01$ | $7.779 E+02$ |
| 62-Sm-148 | $2.413 \mathrm{E}+00$ | $4.524 E+01$ |
| 62-Sm-149 | $4.015 \mathrm{E}+04$ | $3.495 E+03$ |
| 62-Sm-150 | $1.086 \mathrm{E}+02$ | $3.258 \mathrm{E}+02$ |
| 62-Sm-151 | $1.516 E+04$ | $3.410 \mathrm{E}+03$ |
| 62-5m-152 | $2.062 \mathrm{E}+02$ | $2.766 E+03$ |
| 62-Sm-153 | $4.200 E+02$ | $7.166 E+02$ |
| 62-5m-154 | $8.393 \mathrm{E}+00$ | $3.616 \mathrm{E}+01$ |
| 63-Eu-151 | $9.198 \mathrm{E}+03$ | $3.072 \mathrm{E}+03$ |
| 63-Eu-152 | $1.277 E+04$ | $2.159 E+03$ |
| 63-Eu-153 | $3.127 E+02$ | $1.412 \mathrm{E}+03$ |
| 63-Eu-154 | $1.348 \mathrm{E}+03$ | $1.292 \mathrm{E}+03$ |
| 63-Eu-155 | $4.046 E+03$ | $1.863 E+04$ |
| 63-Eu-156 | $1.000 \mathrm{E}+02$ | $1.425 E+03$ |
| 64-Gd-152 | $1.056 \mathrm{E}+03$ | $9.906 E+02$ |
| 64-Gd-154 | $8.499 E+01$ | $2.151 \mathrm{E}+02$ |
| 64-Gd-155 | $6.089 E+04$ | $1.536 E+03$ |
| 64-Gd-156 | $2.188 \mathrm{E}+00$ | $1.206 E+02$ |
| 64-Gd-157 | $2.541 E+05$ | $7.628 \mathrm{E}+02$ |
| 64-Gd-158 | $2.496 E+00$ | $6.398 \mathrm{E}+01$ |
| 64-Gd-160 | 7.961E-01 | $1.203 E+01$ |
| 65-Tb-159 | $2.652 \mathrm{E}+01$ | $4.711 E+02$ |

III. Kanazawa University

III-A-I

## Chromium and titanium isotopes produced in photonuclear <br> reactions of vanadium, revisited

K. Sakamoto, M. Yoshida, Y. Kubota, T. Fukasawa, A. Kumugise,
Y. Hamajima, S. Shibata*, and I. Fujiwara**

A paper on this subject was published in Nuclear Physics, A501, 693-709 (1989).

As a result, photonuclear production yields of ${ }^{51} \mathrm{Ti}$ and ${ }^{51} 49{ }^{48} \mathrm{Cr}$ from ${ }^{51} \mathrm{~V}$ were redetermined for bremsstrahlung end-point energies ( $\mathrm{E}_{0}$ ) of 30 to 1000 or 1050 MeV with the aid of radiochemical separation of Cr . The yield curves for ${ }^{51} \mathrm{Ti},{ }^{51} \mathrm{Cr},{ }^{49} \mathrm{Cr}$ and ${ }^{48} \mathrm{Cr}$ show a clear evidence for two components in the production process; one for secondary-proton reactions at $E_{0}<Q_{\pi \pm}$ and the other for protopion reactions, at $E_{0}>Q_{\pi^{ \pm}}, Q_{\pi \pm}$ being $Q$-values for ( $\gamma, \pi^{+}$) and ( $\gamma, \pi^{-} x n$ ) reactions. The contributions of the secondary reactions for production of the Ti and Cr isotopes at $\mathrm{E}_{0}>\mathrm{Q}_{\pi} \pm$ were then estimated by fitting calculated secondary yields to the observed ones at $E_{0}<Q_{\pi^{ \pm}}$, and found to be about $40 \%, 20 \%, 4 \%$ and $4 \%$ for ${ }^{51} \mathrm{Ti},{ }^{51} \mathrm{Cr},{ }^{49} \mathrm{Cr}$ and ${ }^{48} \mathrm{Cr}$, respectively, at $E_{0}=$ 400 to 1000 MeV . The calculation of the secondary yields was based on the

[^4]excitation functions for ${ }^{51} V(n, p)$ and $\left(p, x^{\prime} n\right)$ calculated with the ALICE code and the reported photoneutron and photoproton spectra from ${ }^{12} \mathrm{C}$ and some other complex nuclei.

The present results for ${ }^{49} \mathrm{Cr}$ are close to the reported ones, while the present ${ }^{48} \mathrm{Cr}$ yields differ by a factor of about 50 . For the ${ }^{51} \mathrm{Ti}$ and ${ }^{51} \mathrm{Cr}$ yields, there are some discrepancies between the persent and reported ones. The yield corrected for the secondaries, in units of $\mu \mathrm{b} /$ equivalent quantum, were unfolded into cross sections per photon, in units of $\mu \mathrm{b}$, as a function of monochromatic photon energy with the LOUHI-82 code. The results for the ${ }^{51} \mathrm{Ti}$ and ${ }^{49} \mathrm{Cr}$ are in disagreement in both the magnitude and shape with the theoretical predictions based on DWIA and PWIA. A Monte Carlo calculation based on the PICA code by Gabriel and Alsmiller does reproduce the gross feature of the present results.

## Barium and xenon isotope yields in photopion reactions

 of cesium-133K. Sakamoto, Y. Hamajima, M. Soto, Y. Kubota, M. Yoshida, A. Kunugise, M. Masatani, S. Shibata*, M. Imamura*, M. Furukawa**, and I. Fujiwara***

A paper on this subject is in press in Physical Review C, 42(3), Sept. 1990.

As a result, radiochemical yield measurements are reported for barium isotopes from ${ }^{133} \mathrm{Cs}\left(\gamma, \pi^{-x n}\right) 133-x B a$ for $x=0,2,4,5,6,7$ and 9 for bremsstrahlung maximum end-point energies ( $\mathrm{E}_{0}$ ) $=30-1050 \mathrm{MeV}$ and for ${ }^{133 \mathrm{Xe}}$ from ${ }^{133} \mathrm{Cs}\left(\gamma, \pi^{+}\right){ }^{133 \mathrm{~m}, \mathrm{~g}} \mathrm{Xe}$ for $\mathrm{E}_{\mathrm{O}}=300-1000 \mathrm{MeV}$. Emphasis was placed on Ba measurements near the pion threshold and for different target thicknesses in order to assess interfering secondary particle-induced reactions. Clear evidence of secondary reactions was found in the form of a shoulder in the yield curves for a range of values near $E_{0}<Q_{\pi^{-}}$, the $Q_{\pi}$ - value of ${ }^{133} \mathrm{Cs}(\gamma$, $\pi^{-} \mathrm{xn}$ ) reaction. This result was used for the correction of yields at $E_{0} \gtrsim Q_{\pi}$ - with the aid of reported measurements of photoproton spectra from ${ }^{12} \mathrm{C}$ and other complex nuclei and cross sections of ( ${ }^{133} \mathrm{Cs}+\mathrm{p}$ ) reactions.

The yields corrected for the secondaries, $\sigma_{q}\left(E_{0}\right)$, were unfolded into cross sections per photon of energy $k, \sigma(k)$. The characteristic features of $\sigma_{q}\left(E_{0}\right)$ and $\sigma(k)$ are then discussed in terms of $E_{0^{-}}$. and $k$-dependences and

[^5]product mass $\left(A_{p}=133-x\right)$, by comparing the present results with those for other systems currently obtained by our group. It was found that the present results of $\sigma(k)$ are generally reproduced by a cascade-evaporation calculation based on the PICA code of Gabriel and Alsmiller, only if the calculated values are shifted up in photon energy by 30 MeV and the neutron cutoff energy is chosen to be 1 MeV .
IV. Kinki University

IV-A-1

## The Optical Potential for Neutrons and Charged Particles

Takaaki Ohsawa

A paper on this subject was published in the Procedings of the 1989 Seminar on Nuclear Data, JAERI-M 90-025, pp. 115-136 (March, 1990) with the following abstract:

Problems and recent topics in the study on the nuclear optical model are described with particular reference to the application to nuclear data evaluation. This includes the following items: (a) Global optical potentials and their validity; (b) Regional optical potentials; (c) Nonlocal and equivalent local potentials; (d) Ambiguities in the optical potential parameters; (e) Application of dispersion relations; (f) Optical potentials for the calculation of the inelastic scattering cross section.

# Evaluation of Particle-Emission Cross Sections and Energy Spectra for V-51 

Takaaki Ohsawa and Toshikazu Shibata

A paper on this subject was published in the Annual Reports of Kinki University Atomic Energy Research Institute, Vol.26, pp.1-14 (Dec. 1989) with the following abstract:

With the aim of providing data necessary for estimation of induced radioactivity and gas-production rate in the first wall of a fusion reactor, an attempt was made to evaluate the particle-emission cross sections and energy spectra of the emitted particles for vanadium-51, one of the candidate materials. The evaluation was based mainly on the calculations in the framework of the pre-equilibrium model of nuclear reactions. The major part of the calculations were done using simplified version of the model. For comparison purpose, calculations were done also with a more sophisticated code of the model. Possible reasons of the observed differences between the two results were discussed.
V. Kyoto University

## A. Research Reactor Institute

$$
\mathrm{V}-\mathrm{A}-1
$$

Identification of ${ }^{152} \mathrm{Ce}$
I. Tago, Y. Kawase and K. Okano

A paper on this subject was published in Zeitschrift für Physik A - Atomic Nuclei, $335(1990) 477$.

The search for ${ }^{152}$ Ce has been carried out by means of $\gamma$-ray decay measurements on mass separated fission products. The $\mathrm{A}=152$ activities were obtained by a helium-jet type on-line isotope separator(KUR-ISOL). The oxidation technique was applied to enhance the ionization efficiency for ${ }^{152}$ Ce. From the precise measurements of $\boldsymbol{\gamma}$-rays and X -rays, the $\operatorname{Pr}-\mathrm{K} \mathrm{X}$-rays and two $\boldsymbol{\gamma}$ rays of 97.8 and 114.8 keV were found to be generated by the $\beta$ decay of ${ }^{152} \mathrm{Ce}$ with a half-life of $1.4(2) \mathrm{s}$. The $\beta-\gamma$ coincidence experiment showed that the $114.8 \mathrm{keV} \gamma$-transitions is delayed about 1. $\mu \mathrm{s}$.

## V-A-2 Gamma-rays and Half-1ife of ${ }^{152} \mathrm{Pr}$

I. Tago, Y. Kawase, K. Okano and T. Karlewski ${ }^{\dagger}$

The existence of ${ }^{152} \mathrm{Pr}$ and its associated two 7 -ray lines have been reported by Hill et al. in 1983. ${ }^{1)}$ Recently, rather precise $\gamma$-ray energies and relative intensities following the decay of ${ }^{152} \mathrm{Pr}$ have been reported together with the decay scheme of ${ }^{152} \operatorname{Pr} .{ }^{2)}$ As the beam intensity of KUR-ISOL has been considerably increased by the use of oxidation technique, ${ }^{3}$ ) precise $\gamma$-ray measurements have been performed on ${ }^{152} \mathrm{Pr}$ together with the search for ${ }^{152} \mathrm{Ce}$. As a result, 14 new $\gamma$-ray lines associated with the decay of ${ }^{152} \mathrm{Pr}$ were observed. The half-life of ${ }^{152} \mathrm{Pr}$ was newly determined as $3.6(1) \mathrm{s}$.

The He-jet type on-line isotope separator(KUR-ISOL) was used to select $A=152$ activities by setting the analyzer magnet at $A=168$. The decay rate of each $\boldsymbol{\gamma}$-ray peak was determined by taking. 16 spectra successively, each being measured for 0.4 s , after the ion beam being collected for 3 s . The energy calibration of the n-type $30 \%$ HPGe detector used was performed with a standard source of ${ }^{152} \mathrm{Eu}$. The efficiency curve was constructed using a set of calibrated sources including ${ }^{109} \mathrm{Cd},{ }^{57} \mathrm{Co},{ }^{139} \mathrm{Ce},{ }^{203} \mathrm{Hg},{ }^{1 / 3} \mathrm{Sn},{ }^{137} \mathrm{Cs},{ }^{88} \mathrm{Y}$ and ${ }^{60} \mathrm{Co}$.

The half-life of ${ }^{152} \mathrm{Pr}$ was determined to be $3.6(1) \mathrm{s}$ from the halflives of $\gamma$-rays at $72.5,164.0,226.6,285.0,1363.3$ and 1469.0 keV . It is somewhat shorter than the previous value, $3.8(2)$ s. ${ }^{2)}$ Gama-rays with similar half-lives to ${ }^{152} \operatorname{Pr}(w i t h i n ~ 10 \%)$ were assigned to originate from the

[^6]
#### Abstract

decay of ${ }^{152} \mathrm{Pr}$ and their energies and relative intensities (normalized at 164.2 keV line) are 1 isted in Table 1 together with the previously reported values. ${ }^{2)}$ Gamma-rays at 1009 and 1630 keV previously reported were not observed in the present study and estimated to be less than 0.3 in relative intensity. In the present experiment, 14 new $\gamma$-rays were observed, but they could not be placed in the level scheme reported. ${ }^{2)}$ For the construction of the complete decay scheme, more accurate experiments including $\boldsymbol{\gamma}-\boldsymbol{\gamma}$ coincidences are required.


## References

1) J. C. Hill, H. Yamamoto and A. Wolf, Phys. Rev. C27 (1983) 2857.
2) T. Karlewski, N. Hildebrand, M. Brígger, N. Kaffrell, N. Trautmann and G. Herrmann, Z. Phys. A330 (1988) 55.
3) Y. Kawase and K. Okano, Nucl. Instr. and Meth. B37-38 (1989) 116.

Table 1. Energies and relative intensities of $X$ - and $\gamma$-rays following the decay of ${ }^{152} \mathrm{Pr}$.

| Ref. 2) |  | Present results |  |
| :---: | :---: | :---: | :---: |
| - $\mathrm{E}_{\gamma}(\mathrm{keV})$ | $\mathrm{I}_{\gamma}$ | $\mathrm{E}_{\boldsymbol{\gamma}}(\mathrm{keV})$ | ${ }^{\text {I }}$ \% |
| 72.40(5) | 38.9(7) | $N d . K_{\alpha}$ <br> Nd K ${ }_{\beta}$ | $\begin{gathered} 1.18 .5(.120) \\ 22.7(25) \end{gathered}$ |
|  |  | 72.5(1) | 32.2(10) |
| 83.1 (4) | 1.6(8) | 82.2(1) | 1.1(1) |
| 141.2 (4) | 1.5(4) | 141.2(2) | $0.8(1)$ |
| 144.1 (1) | 1.9 (5) | 143.8(1) | 1.6 (1) |
|  |  | 152.7(1) | 2.0(2) |
| 164.2 (1) | 100.0 | 164.0(1) | 100.0 |
|  |  | 201.1(1) | 3.4(4) |
| 215.0 (2) | 7.9 (5) | 214.9(1) | 6.3(3) |
| 226.8 (1) | 17.8(5) | 226.6(1) | 19:0 (6) |
| 247.6 (1) | 10.7(5) | 247.3(1) | 9.5(3) |
|  |  | 269.2(2) | 1.0.(2) |
| 284.9 (1) | 81.0(8) | 285.0(1) | 78.6(16) |
| 290.9 (1) | 8.8(13) | 290.9(1) | 2.6(1) |
| 297.6.(1) | 13.2(6) | 297.7(1) | 15.1(5) |
| 303.2 (3) | 2.6(8) | 302.9(2) | 2.8(1) |
| 322.1 (5) ${ }^{\text {a }}$ | 3.5 (5) | 322.2(2) | 2.7(4) |
|  |  | 327.3(3) | 0.8 (1) |
|  |  | 334.9(2) | 0.7 (1) |
| 350.2 (2) | 3.5 (5) | 350.3(2) | 4.9(2) |
| 361.0 (10) | 1.5(17) | 361.2(3) | 1.2(1) |
| 391.7 (4) ${ }^{\text {a }}$ | 3.1(15) | 390.7(3) | 2.1(3) |
| 393.2 (2) | 4.9(12) | 393.2(3) | 5.6 (2) |
|  |  | 494.9(5) | 0.9 (2) |
|  |  | 588.0(4) | 0.8 (2) |
|  |  | 642.6(3) | 4.3(6) |
|  |  | 815.5(5) | 1.0(2) |
|  |  | 990.5(5) | 1.9 (4) |
| 1002.6 (5) | 6.3(13) | 1002.2(4) | 4.5(3) |
| 1009 ${ }^{\text {b }}$ |  | 1009 | $<0.3$ |
| 1014.6 (8) | 6.3(23) | 1014.1(4) | 7.1(4) |
| 1076.2 (4) | 7.4(24) | 1076.0(4) | 5.0 (4) |
| 1149.4 (8) | 5.2 (23) | 1148.5(4) | 3.7(4) |

1002.2(4) 4.5(3)
$1009<0.3$
1014.1(4) 7.1(4)
1148.5(4) 3.7(4)

Table 1. continued

| Ref. 2) |  | Present results |  |
| :---: | :---: | :---: | :---: |
| $\mathrm{E}_{\gamma}(\mathrm{keV})$ | $\mathrm{I}_{\gamma}$ | $\mathrm{E}_{\gamma}(\mathrm{keV})$ | $\mathrm{I}_{\gamma}$ |
| 1167.3 (7) | 8.9(16) | 1166.2(4) | 7.8 (5) |
| $1169^{\text {b }}$ ) |  | 1169.6(4) | 3.4(5) |
| 1178.1 (8) | 4.0(12) | 1178.1(4) | 4.3(4) |
| 1363.8 (1) | 36.6(27) | 1363.3(2) | 38.1(11) |
| 1446.9 (5) | 7.7 (23) | 1446.1(3) | 9.1(5) |
| 1469.75 (5) | 78.1(35) | 1469.0(3) | 80.3(24) |
| 1505.5 (5) ${ }^{\text {a) }}$ | 8.1(22) | 1506.3(4) | 8.6(12) |
| 1528.1 (5) | 4.6(19) | 1527.3(5) | 4.6(4) |
|  |  | 1547.0(6) | 2.5(5) |
|  |  | 1578.9(5) | 3.5(5) |
| 1591.0 (5) | 2.4(10) | 1589.8(5) | 2.5(3) |
|  |  | 1598.8(5) | 5.7(9) |
| $1630{ }^{\text {b }}$ ) |  | 1630 | $<0.3$ |
| $1649^{\text {b }}$ ) |  | 1649.5(6) | 3.0(5) |
| 1661.5 (10) | 2.6(14) | 1660.9(6) | 3.2(4) |
| $1715^{\text {b }}$ |  | 1714.2(6) | 2.8(5) |
| 1754.5 (4) | 6.7 (20) | 1753.5(5) | 7.2(6) |
|  |  | 1820.2(5) | 9.6(12) |
| 1940.9 (10) | 1.3(11) | 1939.7(10) | 1.4(6) |

a) Only seen in the $\beta$-gated $\gamma$-ray spectrum but not placed in the decay scheme.
b) Only seen in the $\gamma-\gamma$ coincidence spectra but not placed in the decay scheme.

# V-A-3 Measurement of $235_{\mathrm{U}}$ Fission Spectrum-Averaged Cross Sections for Some Threshold Reactions 

## Katsuhei Kobayashi and Tooru Kobayashi

At the heavy water thermal neutron facility of Kyoto University Reactor, KUR, a big fission plate of 31.3 cm in diameter and 1.1 cm thick, is installed to produce neutrons by thermal neutron induced-fission of ${ }^{235} 5_{U}$. The fission plate is made of $90 \%$ $235_{\mathrm{U}}$-enriched uranium oxide aluminum ( $\mathrm{UO}_{2}-\mathrm{Al}$ ) cermet plate ( 27 cm in diameter) clad by aluminum, and the total amount of uranium is about $1.1 \mathrm{~kg}^{1)}$. This fission plate is usually set at about 20 cm distance from the window of the heavy water facility to get higher neutron flux, as shown in Fig. 1. The fast neutron flux density attains to $1.8 \times 10^{9} \mathrm{n} / \mathrm{cm}^{2} / \mathrm{sec}$ at the KUR power level of 5 MW.

By means of a continuous energy Monte Carlo neutron transport code $\mathrm{MCNP}^{2)}$, it has been found that the neutron spectrum with the fission plate is close to that of fission neutrons of 235 U and that the effect of neutrons scattered by the wall, floor and window of the heavy water thermal neutron facility are negligibly small above about $1 \mathrm{MeV}^{3)}$, where most of the threshold reactions have a response.

Making use of the fission plate, twelve kinds of threshold reaction cross sections have been measured. The specification of sample foils and other experimental techniques such as the method of radioactivity measurement are the same as those de-
scribed in the previous papers ${ }^{4,5) \text {. The measured values are }}$ normalized to the average cross section of $0.706 \pm 0.028 \mathrm{mb}^{6}$ ) for the ${ }^{27} \mathrm{Al}(\mathrm{n}, \alpha){ }^{24} \mathrm{Na}$ reaction and tabulated in Table 1 , where the correlation matrix of the present measurement is shown. The experimental uncertainties are deduced by taking account of the error correlations between the data, as the authors did before ${ }^{5)}$. Experimental and/or evaluated data by Mannhart ${ }^{6)}$, Cullen ${ }^{7}$ ) and Calamand ${ }^{8)}$ are shown and compared in Table 2. Present results are in general agreement with other values, except for that the Calamand value for the ${ }^{103} \mathrm{Rh}\left(\mathrm{n}, \mathrm{n}^{\prime}\right)^{103 \mathrm{~m}_{\mathrm{Rh}}}$ reaction is lower and the ${ }^{47} \mathrm{Ti}(\mathrm{n}, \mathrm{p}){ }^{47} \mathrm{Sc}$ cross section is higher, respectively. Mannhart datum for the ${ }^{90} \mathrm{Zr}(\mathrm{n}, 2 \mathrm{n})^{89} \mathrm{Zr}$ reaction seems to be higher.

In Table 3, also given are the values calculated with the JENDL-3 data which has released very recently ${ }^{9}$, using Watt-type spectrum, Maxwellian spectrum and the ${ }^{235}{ }_{U}$ fission spectrum appeared in JENDL-3. Comparing with the present measurements, all of the calculated data for the ${ }^{27} \mathrm{Al}(\mathrm{n}, \mathrm{p}){ }^{27} \mathrm{Mg},{ }^{47} \mathrm{Ti}(\mathrm{n}, \mathrm{p}){ }^{47} \mathrm{Sc}$ and ${ }^{64} \mathrm{Zn}(\mathrm{n}, \mathrm{p})^{64} \mathrm{Cu}$ reactions are higher, and the ${ }^{115} \operatorname{In}\left(\mathrm{n}, \mathrm{n}^{\prime}\right)^{115 \mathrm{~m}_{\mathrm{In}}}$ reaction cross section is lower. Concerning the JENDL-3 spectrum, which is based on the Madland-Nix model ${ }^{10)}$ with average energy of 2.039 MeV , the calculated values for the ${ }^{27} \mathrm{Al}(\mathrm{n}, \alpha)^{24} \mathrm{Na}$ and ${ }^{48} \mathrm{Ti}(\mathrm{n}, \mathrm{p}){ }^{48} \mathrm{Sc}$ reactions seem to be lower than the others.

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Fig. 1 Experimental arrangement of the fission plate at the heavy water thermal neutron facility of Kyoto University Reactor, KUR.

Table 1 Present measurement of $235_{\mathrm{U}}$ fission spectrum-averaged cross sections and the correlation matrix.

| Reaction Cro | $\begin{aligned} & \text { section } \\ & \left(\begin{array}{l} \text { mb } \end{array}\right) \end{aligned}$ | (\%) |  |  | Correlation matrix ( $\mathrm{x}^{\text {l }} 000$ ) |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| ${ }^{27} \mathrm{Al}(\mathrm{n}, \alpha){ }^{24} \mathrm{Na}$ | 7060 | 3.97 | 100 |  |  |  |  |  |  |  |  |  |  |  |  |
| ${ }^{27} \mathrm{Al}(\mathrm{n}, \mathrm{p})^{27} \mathrm{Mg}$ | 3.810 | 5.49 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ${ }^{46} \mathrm{Ti}(\mathrm{n}, \mathrm{p}){ }^{46} \mathrm{Sc}$ | 11.70 | 5.94 | 67 | 72 | 100 |  |  |  |  |  |  |  |  |  |  |
| ${ }^{47} \mathrm{Ti}(\mathrm{n}, \mathrm{p})^{47} \mathrm{Sc}$ | 18.15 | 5.87 | 69 | 71 | 80 | 100 |  |  |  |  |  |  |  |  |  |
| ${ }^{48} \mathrm{Ti}(\mathrm{n}, \mathrm{p}){ }^{48} \mathrm{Sc}$ | . 3020 | 6.39 | 62 | 67 | 71 | 74 | 100 |  |  |  |  |  |  |  |  |
| ${ }^{54} \mathrm{Fe}(\mathrm{n}, \mathrm{p})^{54} \mathrm{Mn}$ | 76.60 | 6.54 | 63 | 69 | 68 | 72 | 62 | 100 |  |  |  |  |  |  |  |
| ${ }^{56} \mathrm{Fe}(\mathrm{n} . \mathrm{p}){ }^{56} \mathrm{mn}$ | 1.034 | 6.33 | 64 | 70 | 69 | 73 | 64 | 71 | 100 |  |  |  |  |  |  |
| ${ }^{58} \mathrm{Ni}(\mathrm{n}, \mathrm{p}){ }^{58} \mathrm{Co}$ | 105.0 | 5.73 | 71 | 78 | 77 | 82 | 71 | 73 | 75 | 100 |  |  |  |  |  |
| ${ }^{90} 2 \mathrm{r}(\mathrm{n}, 2 \mathrm{n})^{89} \mathrm{Z} 5$ | . 08599 | 7.56 | 55 | 59 | 58 | 61 | 54 | 55 | 56 | 63 | 100 |  |  |  |  |
| ${ }^{115} \mathrm{ln}\left(\mathrm{n}, \mathrm{n}^{0}\right)^{115 m} \mathrm{ln}$ | 189.5 | 6.07 | 65 | 73 | 72 | 82 | 66 | 68 | 69 | 78 | 59 | 100 |  |  |  |
| ${ }^{64} \mathrm{Zn}(\mathrm{n}, \mathrm{p})^{64} \mathrm{Cu}$ | 31.68 | 5.76 | 67 | 70 | 71 | 73 | 66 | 67 | 67 | 75 | 57 | 70 | 100 |  |  |
| ${ }^{93} \mathrm{Nb}(\mathrm{n} .2 \mathrm{n}){ }^{92 \mathrm{~m}} \mathrm{Nb}$ | . 4796 | 6.11 | 65 | 71 | 70 | 74 | 65 | 66 | 67 | 76 | 57 | 71 | 69 | 00 |  |
| ${ }^{103} \mathrm{Rh}\left(\mathrm{n}, \mathrm{n}^{\circ}\right)^{103 m \mathrm{Rh}}$ | 673.5 | 7.75 | 65 | 65 | 64 | 70 | 59 | 60 | 61 | 68 | 52 | 65 | 64 | 62 |  |

Table 2 Comparison of 235 fission spectrum-averaged cross sections.

| Reaction | Cross section ( mb ) |  | Cullen et al. | Calamand |
| :---: | :---: | :---: | :---: | :---: |
|  | Present | Mannhart |  |  |
| 27AI( $\mathrm{n}, \alpha$ ) 24 Na | . $7060 \pm .0280$ | . $7060 \pm .028$ | . 705 (6\%) | . $725 \pm .04$ |
| $27 \mathrm{Al}(\mathrm{n}, \mathrm{p}) 27 \mathrm{Mg}$ | $3.810 \pm 0.209$ | $3.95 \pm 0.20$ | 3.65 (5.5) | $4.0 \pm 0.45$ |
| $46 \mathrm{Ti}(\mathrm{n}, \mathrm{p}) 46 \mathrm{Sc}$ | $11.70 \pm .695$ | $11.6 \pm 0.4$ | 11.8 (11) | $12.5 \pm 0.9$ |
| $47 \mathrm{Ti}(\mathrm{n}, \mathrm{p}) 47 \mathrm{Sc}$ | $18.15 \pm 1.07$ | $17.7 \pm 0.6$ | 19.0 ( 7) | $20 \pm 2.3$ |
| $48 \mathrm{Ti}(\mathrm{n}, \mathrm{p}) 48 \mathrm{Sc}$ | . $3020 \pm .0193$ | . $302 \pm .01$ | 0.30 (6) | $.315 \pm .027$ |
| $54 \mathrm{Fe}(\mathrm{n}, \mathrm{p}) 54 \mathrm{Mn}$ | $76.60 \pm 5.01$ | $80.5 \pm 2.3$ | 78.1 ( 5) | $82.5 \pm 5$ |
| $56 \mathrm{Fe}(\mathrm{n}, \mathrm{p}) 56 \mathrm{Mn}$ | $1.034 \pm .0655$ | $1.09 \pm .04$ | 1.025 ( 1) | $1.07 \pm .08$ |
| 58Ni ( $\mathrm{n}, \mathrm{p}$ ) 58Co | $105.0 \pm 6.02$ | $108.9 \pm 5.3$ | 108.5 ( 5) | $113 \pm 7$ |
| $902 \mathrm{r}(\mathrm{n}, 2 \mathrm{n}) 89 \mathrm{Zr}$ | . $08599 \pm .00650$ | . $103 \pm .004$ |  | . $076 \pm .01$ |
| $115 \ln \left(\mathrm{n}, \mathrm{n}^{\prime}\right) 115 \mathrm{~m} / \mathrm{n}$ | $189.5 \pm 11.50$ | $190.3 \pm 7.3$ | 189 (4) | $188 \pm 11$ |
| $64 \mathrm{Zn}(\mathrm{n}, \mathrm{p}) 64 \mathrm{Cu}$ | $31.68 \pm 1.825$ |  |  | $31 \pm 2.3$ |
| $93 \mathrm{Nb}(\mathrm{n}, 2 \mathrm{n}) 92 \mathrm{mNb}$ | . $4796 \pm .0293$ |  |  | . $48 \pm .04$ |
| $103 \mathrm{Rh}(\mathrm{n}, \mathrm{n}$ ') 103 mRh | $673.5 \pm 52.20$ |  |  | $533 \pm 33$ |

Table 3 Comparison of the present ${ }^{235}$ U fission spectrumaveraged cross section with the calculated ones using JENDL-3 data.

| Reaction | Cross section ( mb ) <br> Present exp. |  | Watt-type |
| :---: | :--- | :--- | :--- | :--- |$\quad$| Comparison with calculations |
| :---: |
| Maxwellian |
| JENDL-3 spectrum |

V-A-4 Measurement of the U-238 Capture Cross Section with Neutron Filtered Beams

K. Kobayashi, S. Yamamoto and Y. Fujita

A paper on this subject was presented at the 1989 Seminar on Nuclear Data, which is appeared in JAERI-M 90-025, with the following abstract:

By using the linac time-of-flight method and Fe and/or Si filtered neutrons of 24,55 and 146 keV , the ${ }^{238} \mathrm{U}$ neutron capture cross sections were measured relative to the standard cross section for the ${ }^{10} \mathrm{~B}(\mathrm{n}, \alpha \gamma)$ reaction with a pair of $\mathrm{C}_{6} \mathrm{D}_{6}$ scintillators placed at the 12.4 m station. The measured value at 24 keV was normalized to 0.47 b appeared in the ENDF/B-VI file. The present data agree with the recent evaluations in ENDF/B-VI and JENDL-3 released very recently, and moreover with the recent measurement by Kazakov et al. The experimental uncertainties are 6 to $8 \%$, which are mainly derived from the counting statistics in the filtered neutrons. More careful works may be required in the data correction and uncertainty analysis for the present preliminary measurement.

At present, absolute measurement of the capture cross section with the filtered beams is in progress using BGO scintillators.

V-A-5
Application of a Resonance Capture Detector to the Precise Measurement of Neutron Total Cross Sections

K. Kobayashi, S. Yamamoto and Y. Fujita

A paper on this subject was published in the Nuclear Instruments and Methods in Physics Research A 287(1990) 570-575, with the following abstract:

A resonance capture detector, which is composed of eight pieces of BGO crystals and a capture sample of Ta, has been newly developed. This detector gave a good signal-to-noise ratio at the Ta resonances of $4.28,10.4,14.0,23.9,35.9$ and 39.1 eV in the linac TOF spectrum.

At first, the detector has been applied to the measurement of the well-known neutron total cross section of polyethylene. The results obtained at the resonance energies showed quite a good agreement with those from the ENDF/B-IV data. This fact verified that the detector was usable for the precise measurement of neutron total cross sections by the TOF method.

Next, the detection system has been used for measurement of the neutron total cross section of lead at the above six resonance energies. All of the results were about 11.2 b and constant with neutron energy. The accuracy of the measurement could be achieved with a standard deviation of 0.6 to $1.8 \%$. The present values are in good agreement with the ENDF/B-V and with the measurements made by Waschkowski et al. and Adamchuk et al.

# Absolute Measurement of Neutron Capture Cross Sections with BGO Scintillators 

Shuji Yamamoto, Katsuhei Kobayashi and Yoshiaki Fujita

By making use of the 46 MeV electron linear accelerator at the Research Reactor Institute, Kyoto University (KURRI), absolute capture cross sections for Au and Sb have been measured between 0.012 and 1.0 eV with BGO scintillators located at 12.7 m flight path. The experimental arrangement is shown in Fig. 1. Figure 2 illustrates the BGO detector system consisting of a dozen of BGO crystals shielded with ${ }^{6}$ LiF tiles for neutrons scattered by the sample in the measuring through hole.

In order to make an absolute measurement of neutron capture events, at first, we selected $S m$ as a capture sample, 1.8 x 1.8 cm squares and 0.5 mm thick plate. Compound nucleus of Sm has a capture cascade with high gamma-ray multiplicity. Therefore, in the measurement of capture gamma-rays from the Sm sample, missing the detection of capture events is very rare, as we described before ${ }^{1)}$. Then, we can assume that the detection efficiency $\varepsilon$ th $(\mathrm{Sm})$ appeared in Eq. (1) is equal to unity;

$$
\begin{equation*}
\mathrm{C}_{\mathrm{th}}(\mathrm{Sm})=\varepsilon_{\mathrm{th}}(\mathrm{Sm}) \mathrm{Y}_{\mathrm{th}}(\mathrm{Sm}) \Phi_{\mathrm{th}}=\mathrm{Y}_{\mathrm{th}}(\mathrm{Sm}) \Phi_{\mathrm{th}}, \tag{1}
\end{equation*}
$$

where the subscript "th" is for thermal neutrons, $C$ is counting rate, $Y$ is capture yield, and $\Phi$ is neutron flux. Samarium has a very large capture cross section to thermal neutrons, and a Sm sample is, therefore, "black" for impinging thermal neutrons. Then, Eq.(1) is rewritten as

$$
\begin{equation*}
\mathrm{C}_{\mathrm{th}}(\mathrm{Sm})=\Phi_{\mathrm{th}} \tag{2}
\end{equation*}
$$

The cross section of the ${ }^{10} \mathrm{~B}(\mathrm{n}, \alpha, \gamma)$ reaction for thermal neutrons is so large that the ${ }^{10} \mathrm{~B}$ sample of about $10 \mathrm{~g} / \mathrm{cm}^{2}$ thickness becomes black to the incident neutrons. Then, the following relation is derived:

$$
\begin{equation*}
\mathrm{C}_{\mathrm{th}}\left({ }^{10} \mathrm{~B}\right)=\varepsilon \mathrm{th}^{\left(10_{\mathrm{B}}\right) \mathrm{Y}_{\mathrm{th}}\left({ }^{10_{\mathrm{B}}}\right) \Phi \mathrm{th}=\varepsilon_{\mathrm{th}}\left({ }^{10} \mathrm{~B}\right) \Phi_{\mathrm{th}} . . . . ~} \tag{3}
\end{equation*}
$$

From Eqs. (2) and (3), the detection efficiency $\left.\varepsilon \operatorname{th}^{(10} \mathrm{B}\right)$ is given as

$$
\begin{equation*}
\left.\varepsilon \mathrm{th}^{(10} \mathrm{B}\right)=\mathrm{C}_{\mathrm{th}}\left({ }^{\left.10_{\mathrm{B}}\right) / \mathrm{C}_{\mathrm{th}}(\mathrm{Sm})=\varepsilon_{\mathrm{x}}\left({ }^{10 \mathrm{~B}}\right) . . . . .}\right. \tag{4}
\end{equation*}
$$

It has to be noted that this relation is applicable to any other neutron energies, because the ${ }^{10} \mathrm{~B}(\mathrm{n}, \alpha \gamma$ ) reaction emits 480 keV gamma-ray only for any incident neutron energies. On the other hand, at the first s-wave big resonance of 4.9 eV for Au , the capture yield is also close to unity. In addition, as the BGO scintillators are considered as a total energy absorbing detector, the following relations can be derived;

$$
\begin{align*}
\mathrm{C}_{4.9}(\mathrm{Au}) & =\varepsilon_{4.9}(\mathrm{Au}) \mathrm{Y}_{4.9}(\mathrm{Au}) \Phi_{4.9}=\varepsilon_{4.9}(\mathrm{Au}) \Phi_{4.9} \\
& =\varepsilon_{\mathrm{x}}(\mathrm{Au}) \Phi_{4.9}, \tag{5}
\end{align*}
$$

where $\Phi_{4.9}$ can be measured with the ${ }^{10} \mathrm{~B}$ measurement. The capture yields at neutron energy of $x$ for $A u$ and ${ }^{10} B$ as a standard cross section ${ }^{2)}$ are obtained from the following measurements;

$$
\begin{align*}
& \mathrm{C}_{\mathrm{X}}(\mathrm{Au})=\varepsilon_{\mathrm{X}}(\mathrm{Au}) \mathrm{Y}_{\mathrm{X}}(\mathrm{Au}) \Phi_{\mathrm{x}},  \tag{6}\\
& \mathrm{C}_{\mathrm{X}}\left({ }^{10} \mathrm{~B}\right)=\varepsilon_{\mathrm{X}}\left({ }^{10} \mathrm{~B}\right) \mathrm{Y}_{\mathrm{X}}\left({ }^{10} \mathrm{~B}\right) \Phi_{\mathrm{x}} . \tag{7}
\end{align*}
$$

The present result for ${ }^{197} \mathrm{Au}(\mathrm{n}, \gamma)$ reaction cross section is shown in Fig. 3, where the solid line is derived by the calculation, using the resonance parameters ${ }^{3)}$. Both results are in very good agreement with each other.

For the measurement of Sb capture cross section, the data
processing has been performed with the same procedures using the 6.2 eV resonance, as described above. The result obtained is illustrated in Fig. 4, comparing with the calculation using the resonance parameters ${ }^{3)}$. In the energy region above 0.1 eV , the present measurements show some structure and deviate a little from the calculation. This discrepancy would be investigated in future, although such a tendency was found in the neutron total cross section measured recently ${ }^{4}$ ).

References:

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Fig. 1 Experimental arrangement for the capture cross section measurement.


Fig. 2 BGO detector assembly.


Fig. 3 Capture cross section for the ${ }^{197} \mathrm{Au}(\mathrm{n}, 7)$ reaction.


Fig. 4 Capture cross section for the $\mathrm{Sb}(\mathrm{n}, \gamma)$ reaction.

VI, Kyushu University

# Incident Energy Dependence of Preequilibrium ( $p, p^{\prime}$ ) Spectra 

Y. Watanabe, K. Kodaka, Y. Kubo, N. Koori* , M. Eriguchi,<br>M. Hanada, and I. Kumabe

A paper on this subject was published in Z. Phys. A-Atomic Nuclei 336, 63-69 (1990) with the following abstract:

Proton energy spectra from ( $p, x p$ ) reactions on ${ }^{98} \mathrm{Mo}$ and ${ }^{106} \mathrm{Pd}$ have been measured at incident energies of 12,14 , and 16 MeV to investigate the incident energy dependence of preequilibrium ( $\mathrm{p}, \mathrm{p}$ ) process. The ( $\mathrm{p}, \mathrm{xp}$ ) energy spectrum for ${ }^{60} \mathrm{Ni}$ has also been measured at an incident energy of 18 MeV to confirm the mass number dependence. These spectra were compared with a calculation based on the exciton model in which the square of the average effective matrix element $|\mathrm{M}|^{2}$ was assumed to be $\mathrm{KA}^{-3} \mathrm{E}^{-1}$ and isospin conservation was taken into account. The calculated spectra using a constant K -value ( $430 \mathrm{MeV}^{3}$ ) were in good agreement with all the measured ones. The role of isospin conservation in preequilibrium process was discussed through the present analyses.

[^7]
# VI-A-2 Measurement of continuum proton spectra from 

 the ${ }^{12} \mathrm{C}\left(\mathrm{p}, \mathrm{p}^{\prime}\right) 3 \alpha$ reaction at 16 MeVY. Watanabe, M. Eriguchi, A. Nohtomi, and N. Koori*

Double differential proton emission cross sections were measured for ${ }^{12} \mathrm{C}\left(\mathrm{p}, \mathrm{p}^{\prime}\right) 3 \alpha$ reaction at 16 MeV , in order to investigate the mechanism of the $3 \alpha$ breakup process and apply the derived knowledge to more accurate evaluation of the ${ }^{12} \mathrm{C}\left(\mathrm{n}, \mathrm{n}^{\prime}\right) 3 \alpha$ cross sections and kerma factors. The experiment was performed using the tandem Van de Graaff accelerator at Kyushu University. A dE-E counter telescope[1] in which three silicon detectors are stacked was used to measure emitted protons up to as low threshold energies as possible ( $\mathrm{E}_{\mathrm{p}}>1.0 \mathrm{MeV}$ ). A target used was a self-supporting foil consisting of natural carbon, whose thickness was 0.524 $\mathrm{mg} / \mathrm{cm}^{2}$. The thickness was derived by means of measurement of energy loss for $5.3-\mathrm{MeV}$ alpha paericles emitted from ${ }^{210} \mathrm{Po}$.

Double differential proton emission cross sections measured at $80^{\circ}$ are shown by histgram in Fig.1. Continuum region is observed in proton energies less than those corresponding to a $3^{-}$peak. In this region there is a contribution of proton emissions followed by $3 \alpha$-breakup process. Multiparticle breakup processes of ${ }^{12} \mathrm{C}$ are classified according to the possible intermediate states [2]. As a preliminary analysis, the following two processes were considered using kinematically calculated phase space distributions [3].
(1) ${ }^{12} \mathrm{C}+\mathrm{p} \rightarrow \mathrm{p}^{\prime}+\alpha_{1}+{ }^{8} \mathrm{Be}$

(2) ${ }^{12} \mathrm{C}+\mathrm{p} \rightarrow \mathrm{p}^{\prime}+\alpha_{1}+\alpha_{2}+\alpha_{3}$.

The process (1) and (2) are referred to as three-body simultaneous breakup(3BSB) process and four-body simultaneous breakup(4BSB) process, respectively. The calculated results are shown in Fig.1. The absolute value was obtained by normalization of the calculated spectra to the

[^8]experimental ones. The solid curve represents proton spectra for the 4BSB process. The dashed curve shows the 3 BSB component including both sequential decays of ${ }^{8} \mathrm{Be}$ (g.s.) [dotted curve] and ${ }^{8} \mathrm{Be}(2.94 \mathrm{MeV})$ [dotted-dashed curve]. Note that the $\alpha-\alpha$ final state interaction was taken into account for the sequential decay process of ${ }^{8} \mathrm{Be}$.

As shown in Fig.1, the difference between the 3BSB and the 4BSB processes appears in the outgoing energies from 4 to 6 MeV near the threshold of $3 \alpha$ breakup. Both the spectra have almost same shape in the low energy region. From the present analysis of only proton spectra,we found it difficult to identify the dominant reaction mechanism of $3 \alpha$ breakup and it necessary to analyze both proton and $\alpha$ spectra. Therefore, the next plan to measure the double differential $\alpha$ emission cross sections at 16 MeV is now in progress.
references
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Fig. 1 Comparison of experimental and calculated spectra of proton emitted at $80^{\circ}$ from the reaction on ${ }^{12} \mathrm{C}$ with the bombarding proton of 16 MeV

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VI-A-3
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# Preequilibrium model analvsis of ( $p, n$ ) reactions on nuclei <br> in the $\mathrm{Cr}-\mathrm{Ni}$ region 

## I. Kumabe and Yukinobu Watanabe

A paper on this subject was published in Physical Review C 40, 535-539 (1989) with the following abstract:

The energy spectra of neutrons emitted from $25 \mathrm{MeV}(\mathrm{p}, \mathrm{n})$ reactions on nuclei in the Cr Ni region have been analyzed in terms of the preequilibrium exciton model introducing effective Q values, the pairing correlation, and the modified uniform spacing model in which the uniform spacing mode is modified so as to have a wide spacing at the magic number. The calculated energy spectra using the above model are in fairly good agreement with the observed spectra with pronounced structures.

VI-A-4 Systematics and Parameterization of Continuum
Angular Distributions for Application to
Reactions Induced by 14 MeV Neutrons

Isao Kumabe, Yukinobu Watanabe, Yoshimitsu Nohtomi, and Mitsuru Hanada

A paper on this subject was published in Nuclear Science and Engineering, 104 280287 (1990) with the following abstract:

Kalbach-Mann systematics are improved for application to reactions induced by 14 MeV neutrons. On the basis of this approach, new parameters for nucleon emission reactions are derived from Legendre polynomials fit 18 - and $25-\mathrm{MeV}$ ( $\mathrm{p}, \mathrm{n}$ ) and $18-\mathrm{MeV}$ ( $\mathrm{p}, \mathrm{p}$ ) data. For alpha-particle emissions, separate parameterizations are performed for equilibrium and preequilibrium components: Legendre coefficients obtained from Hauser-Feshbach calculations are parameterized for the former and the procedure used for nucleon emissions is applied to the latter. The angular distributions calculated using the present parameters show good agreement with those for $14-\mathrm{MeV}\left(\mathrm{n}, \mathrm{n}^{\prime}\right),(\mathrm{n}, \mathrm{p})$, and ( $\mathrm{n}, \alpha$ ) reactions.

IV-A-5

# Proton Induced Spallation Reaction Calculation Considering the Intranuclear Nucleons and the Preequilibrium effect 

K. Ishibashi, Y. Miura, T. Sakae, Y. Matsumoto, Y. Watanabe, A. Katase*, H. Takada**, T. Nishida**, Y. Nakahara**, and Y. Kaneko**

This work has been reported in JAERI-M 90-025, Proceedings of the 1989 Seminar on Nuclear Data, Eds. Y. Nakajima and M. Igashira, pp. 362-373, and is to be revised for submission to J. Nucl. Sci. Technol.

The double differential cross section of neutron production is calculated for the spallation reaction that is induced by incident protons of several hundred MeV . The intranuclear nucleons with highmomentum component are introduced into the High Energy Transport Code (HETC). The consideration of such nucleons is useful in the reproduction of the yield of the high-energy neutrons in the backward direction. The intranuclear cascade process calculation is terminated taking the preequilibrium effect into account in a local manner. The use of this method successfully represents the shape of the neutron spectra of an intermediate energy.

[^9]VI-A-6

# The Moving Source Model Analysis of Neutron Emission Cross Section from Proton Induced Spallation Reactions 

K. Ishibashi, K. Higo, and Y. Matsumoto

The spallation reaction is caused by bombarding targets with particles having an energy above a few hundred MeV. The reaction produces a number of neutrons. For the proton induced spallation reaction, the accumulation of the neutron emission data is not enough to apply it to engineering purposes. Therefore, it is desirable to parameterize the neutron data and to extend the results to the other energy regions or other target nuclei. A. Pearlstein ${ }^{1)}$ parameterized the double differential cross section on the neutron emission for the proton induced reaction. He employed a four-component evaporation model, and made a parameter fitting for the neutron spectra at each emission angle where data were available.

The moving source (MS) model ${ }^{21}$ is considered to be better suited for the parameterization because of its simple feature of representing the angular distribution of the emitted neutrons. In the present study, we adopt the MS model to study the systematic structure of the neutron data for the incident proton energy region of 600 to 800 MeV . The experimental neutron spectra are shown together with the results of fitting by the MS model in Fig. 1, where the target is lead and the incident proton energy is 585 MeV . The fitting was made by the use of those three components that correspond to the cascade, preequilibrium and evaporation processes. The agreement between the fitting and the experiment was excellent for the 585 MeV data for a wide variety of targets, while it was slightly worse for the 800 MeV data. The mass
number dependence of parameters was obtained from the fitting results for the 585 MeV data. In the energy region of 600 to 800 MeV , thus, the emitted neutron spectra are well analyzed by the MS model.

For the iron target bombarded by protons of 113 MeV , the results of fitting by the MS model are shown by the dashed curves in Fig. 2. In the forward direction of 7.5 and 30 deg., the dashed lines are in a poor agreement with the data at the neutron energy above several ten MeV . Taking this situation into account, we introduce the double moving source (DMS) model. The energy spectra of the emitted neutrons are assumed to be reproduced by the Watt distribution ${ }^{3)}$ in the moving frame. The DMS model is applicable only to the first process, i.e. the cascade process, that directly induced by the incident protons. The remaining two processes are treated by the moving source model. The solid lines in Fig. 2 show the results of fitting by the combination of DMS and MS models. The experimental data are expressed better by the the solid than by the dashed lines.

In conclusion, the use of the moving source (MS) model with three components reproduced the experimental neutron spectra in the incident proton energy region of 600 to 800 MeV . At the energy of 80 to 300 MeV , the introduction of the double moving source (DMS) model for the cascade process were found to lead to the good agreement with the experimental spectra. As for the incident energy of 25 MeV , the use of two components of the MS and the DMS models gave the satisfactory results. The MS and DMS models were found to be applicable to the nuclear data evaluation for a wide range of target masses and incident energies. It was confirmed that the angular behavior of neutrons was well described with simple velocity parameters.

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Fig. 1 Experimental neutron spectra and the results of fitting by the moving source (MS) model for lead for incidence protons of 585 MeV .


Fig. 2 Experimental neutron spectra and the results of fitting for iron for incident protons of 113 MeV . The dashed curves indicate the results of the MS model, and the solid ones does that of combinations of the double moving source (DMS) and the MS models.

EFFECT OF COVARIANCES OF EXPERIMENTAL DATA

ON REACTION MODEL PARAMETERS ESTIMATION
T. Kawano, M. Kihara, Y. Uenohara*, and Y. Kanda

A paper on this subject was published in Engineering Sciences Reports, Kyushu Univ., $12, \quad \operatorname{pp} 39-45,(1990)$, (in Japanese) with the following abstract:

Evaluation of nuclear reaction cross sections needs model parameters when it is performed by means of model calculations. As concerns the calculation of optical model and Hauser-Feshbach model, they call for optical model parameters and level density parameters. Bayesian method is applied to determine model parameters that yield the consistent cross sections with experimental data.

The experimental data that are usable in this estimation, are neutron induced reactions \{total, $(n, p),(n, \alpha)$, and ( $\mathrm{n}, 2 \mathrm{n}$ )\}. Here, some of data are presented with incomplete error information, and no correlation are found in them. Estimation of model parameters must be done with both

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* Present address : Reactor Engineering Group,
    Nuclear Engineering Laboratory, Toshiba Corporation
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reasonable error and covariance of experimental data.
Therefore it is necessary to re-evaluate the
experimental errors and make covariance matrices.
The model parameters are estimated by both the
original experimental errors and the re-evaluated errors.

VI-B-2
EFFICIENCY EXAMINATIONS FOR REACTION PARAMETER
ESTIMATION BY A STATISTICAL METHOD AND EXPERIMENTS
Y. Kanda, Y. Uenohara*, and T. Kawano

A paper on this subject was published in the Proceedings of A Specialists' Meeting on "Neutron Activation Cross Sections for Fission and Fusion Energy Applications", pp.263273, (1989), ANL, with the following abstract:

Nuclear reaction parameters in reaction model formulae have been estimated with Bayes method by using experimental data. A feature of the method is that prior parameters can be assumed taking account of early information. In the present work, prior optical potential parameters are changed and then posterior cross sections calculated from the estimated parameters of the early and the present are compared. They approximately agree in spite of the difference between the two prior cross sections. It shows that the estimation of the parameters does not depend on the initial values. In addition, proton-induced data are used to estimate the parameters together with the early neutron-induced reaction data. It is useful to obtain the parameters required for calculating activation cross sections.

[^10]VI-B-3
EXPERT SYSTEM FOR EVALUATION OF COVARIANCES
OF MEASURED ACTIVATION CROSS SECTIONS
Y. Uenohara*, M. Kihara, T. Kawano, and Y. Kanda

A paper on this subject will be published in the Proceedings of the International Conference on Supercomputing in Nuclear Applications, (1989), Mito, with the following abstract:

We tried to develop an expert system for re-evaluations of experimental errors in activation cross section measurements. The present system searches for the key words specifying the sources of systematic errors. If these basic items are not found, the present system deduces them by using the "Common Sense" of neutron cross section measurements. More detailed information on uncertainty usually is expressed in the natural language. In order to obtain the information, we tried to develop a natural language processing sub-system. This sub-system analyzes documentations and changes them into several patterns coded by LISP. As examples, the experimental errors and covariances of neutron activation cross sections for $\mathrm{Cr}, \mathrm{Mn}, \mathrm{Fe}, \mathrm{Co}$, and Ni isotopes have been re-evaluated by the present system.

[^11]$V I-B-4$
PARAMETER ESTIMATION IN NUCLEAR DATA EVALUATION
BASED ON EXPERIMENTS AND A STATISTICAL METHOD
Y. Kanda and Y. Uenohara*

A paper on this subject will be published in the Proceedings of the DOE Fusion Data Meeting, (1989), Ohio Univ., with the following abstract:

Parameterizing method of measured nuclear data and nuclear-reaction-model-calculated values has been developed in our laboratory by adopting $B$-spline functions. It has been successfully applied to simultaneous evaluation of fission cross sections for major heavy nuclides, nuclear parameter estimation in Hauser-Feshbach model formulae to reproduce neutron-induced cross sections of medium nuclides, simultaneous evaluation of some activation cross sections using both differential and integral experiments and adjustment of evaluated fission cross sections by relative integral measurements. They are briefly reviewed and the issues raised in the studies are discussed. Role of parameterizing is emphasized. It is pointed that these evaluations represent a possibility of comprehensive simultaneous evaluation with all available experiments. These evaluations mentioned above are an elemental part of it.

[^12]VII, Nagoya University

VII-A-1 Decay of 152 Nd

Michihiro Shibata, Hiroshi Yamamoto, Masahide Miyachi, Kiyoshi Kawade, Toshio Katoh, Tadaharu Tamai*, Sataro Nishikawa*, and Jian-Zhi Ruan**

A paper on this subject was published in Journal of the Physical Society of Japan vol. 59, no. 4, April, 1990, pp. 1204-1210, with the following abstract.

The decay of 11.6 min 252 Nd to levels of odd-odd ${ }^{252} \mathrm{Pm}$ has been studied with HpGe, Ge(Li) detectors, LEPS and a plastic scintillation detector by gamma-ray singles, time dependent gamma-ray singles, gamma-gamma coincidence and beta-gamma delayed coincidence measurements. Sources were prepared by a rapid chemical separation method from the fission products of ${ }^{235} \mathrm{U}$. Ten gamma-rays were observed and five of them are newly observed(19.5, 25.0, 44.4, 545.6 and 570.7 keV . Half-lives of the 16.1 and 28.5 keV trnsitions were measured to be $2.1 \pm 1.0 \mathrm{~ns}$ and $\leq 1.0 \mathrm{~ns}$, respectively.

A decay scheme of ${ }^{152} \mathrm{Nd}$ involving 2 new levels at 25.0 and 570.7 keV in 152 Pm and spin-parities are proposed. The Nilsson configurations of excited states in ${ }^{152} \mathrm{Pm}$ are discussed.

[^13]Toshio Katoh, Kiyoshi Kawade, Hiroshi Yamamoto, Akito Takahashi* and Toshiyuki Iida*

Measurement of activation cross sections of short lived nuclei produced by 14 MeV neutron were made by using the Intense Neutron Source(OKTAVIAN) at Osaka University. Cross sectios for Mg, Si, S, $\mathrm{Cl}, \mathrm{Cr}, \mathrm{Zn} \mathrm{Ga}$,Y and In were obtained by the activation method.

Pneumatic tubes were used for the transportation of samples between the irradiation points and the detector. Gamma-rays of irradiated samples were measured by a Ge detector, and cross sections were obtained from the amount of induced activities.

Measured cross sections are shown in following Figures.

[^14]

Fig. 4 Cross section of ${ }^{30} \mathrm{Si}(\mathrm{n}, \alpha)^{27} \mathrm{Mg}$.

Fig. 3 Cross section of ${ }^{28} \mathrm{Si}(\mathrm{n}, \mathrm{p})^{\mathbf{2 8}} \mathrm{Al}$

Fig. 6 Cross section of ${ }^{37} \mathrm{Cl}(\mathrm{n}, \mathrm{p})^{37} \mathrm{~S}$.


Cross section of ${ }^{30} \mathrm{Si}(\mathrm{n}, \mathrm{np})^{20} \mathrm{Al}$.
$n$
(qس) 40!7?.2S ssolo
寝


Fig. 7 Cross section of ${ }^{52} \mathrm{Cr}(\mathrm{n}, \mathrm{p})^{52} \mathrm{~V}$.


Fig. 10 Cross section of ${ }^{60} \mathrm{Zn}(\mathrm{n}, \mathrm{p})^{60} \mathrm{Cu}$.


Fig. 9 Cross section of ${ }^{3} \mathrm{Cr}(\mathrm{n}, \mathrm{np}){ }^{52} \mathrm{~V}$.



- Neutron Energy (MeV)
(qس) 40!700s ssodo

Fig. 14 Cross section of ${ }^{32} S(n, t)^{30} \mathrm{P}$.


Fig. 13 Cross section of $113 \mathrm{In}(\mathrm{n}, 2 \mathrm{n})^{112 \%} \mathrm{In}$.

Neutron Energy (MeV)
Fig. 16 Cross section of ${ }^{89} Y(n, \alpha)^{80 m} R b$.

Fig. 15 Cross section of ${ }^{71} \mathrm{Ga}(\mathrm{n}, \alpha)^{68} \mathrm{Cu}$.

VIII, Rikkyo (St, Paul's) University

## A. Department of Physics, Faculty of Science

## VIII-A-I

Measurements of the Neutron Emission Cross Sections of ${ }^{\text {nat }}{ }_{C}$ and ${ }^{\text {nat }}{ }_{F e}$ for 14.1 MeV Incident Neutrons

K. Hata*, S. Shirato and Y. Ando

Double differential cross sections (DDX) for elastic and inelastic neutron scattering from ${ }^{\text {nat }}{ }_{C}$ and ${ }^{\text {nat }}$ Fe at 14.1 MeV were measured using the neutron time-of-flight (TOF) facility of the 300 kV Cockcroft-Walton accelerator of Rikkyo University. Angular distributions were measured at angles from $10^{\circ}$ to $50^{\circ}$ in $10^{\circ}$ increments.

Neutron TOF spectra were obtained from the signals of scattered neutrons and the associated $\alpha$-particles produced in the ${ }^{3} H(d, n){ }^{4} \mathrm{He}$ reaction at 165 keV . Two well-shielded NE2.13 liquid scintillators of 2 in x 2 in and $10 \mathrm{~cm} \times 30 \mathrm{~cm}$ were used as neutron detectors, while a thin ( $50 \mu \mathrm{~m}$ ) NE102A plastic scintillator was done as an $\alpha$-particle detector ${ }^{1)}$. The time resolution ( 0.7 ns in FWHM) of the present TOF system using R2083 (Hamamatsu) photomultipliers was remarkably improved by the replacement of R1246X photomultipliers in our old system $(1.35 \mathrm{~ns})^{2}$ ). The cylindrical scattering samples of $3 \mathrm{~cm} \times 3 \mathrm{~cm}$ were made of natural graphite and iron of 99.9 \% purity.

[^15]The measured energy spectra of scattered neutrons are shown in figs. 1-a for ${ }^{n a t}{ }_{C}$ and $1-b$ for ${ }^{n a t} F e$, where the curves are the predictions of JENDL-3T3). Measured angular distributions for elastic scattering are in good agreement with optical model calculations, as seen in figs. 2-a for ${ }^{12} \mathrm{C}$ and 2-b for ${ }^{56} \mathrm{Fe}$. The preliminary analyses of measured differential crosis sections for inelastic neutron scattering from the first excited states of ${ }^{12} \mathrm{C}$ and ${ }^{56} \mathrm{Fe}$ were performed in exact finite-range DWBA calculations, as shown in figs. 3-a for ${ }^{12} \mathrm{C}$ and 3 -b for ${ }^{56}$ Fe. The optical potential parameters obtained by Gul et al. 4) for ${ }^{12} \mathrm{C}$ and by Hyakutake et al. ${ }^{5)}$ for ${ }^{56} \mathrm{Fe}$ were adopted in these calculations. The details of the present work are described in ref. 6.

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Fig. 1. Measured DDXs for (a) ${ }^{n a t} C$ and (b) nat $F e$. The curves at $40^{\circ}$ for ${ }^{n a t} C$ and at $30^{\circ}$ for ${ }^{n a t}$ Fe are the results of JENDL-3T ${ }^{3}$.


Fig. 2. Measured and calculated angular distributions for elastic neutron scattering from (a) ${ }^{12} \mathrm{C}$ and (b) ${ }^{56} \mathrm{Fe}$.


Fig. 3. Measured and calculated angular distributions for inelastic neutron scattering from (a) ${ }^{12} \mathrm{C}^{*}(1 \mathrm{st})$ and (b) ${ }^{56} \mathrm{Fe}^{*}(1 \mathrm{st})$.
IX. Tohoku University

## A. Cyclotron and Radioisotope Center

IX-A-1
Measurement of Neutron Activation Cross Sections

Between 15 and 40 MeV
T. Nakamura, H. Sugita, Y. Kondo, Y. Uwamino* and M. Imamura*

One paper on this subject was submitted to the Physical Review and another paper is now preparing for publication.

As for neutron activation cross sections, many experimental data have ever been published in the energy range of thermal to 20 MeV and the evaluated data files exist such as ENDF/B-V and JENDL-3. While, on the other hand, there have been very few experimental data above 20 MeV and no evaluated data files.

We have measured the neutron activation cross sections of 12 nucleids of $\mathrm{C}, \mathrm{Na}, \mathrm{Mg}, \mathrm{Al}, \mathrm{Si}, \mathrm{Ca}, \mathrm{V}, \mathrm{Cr}, \mathrm{Mn}, \mathrm{Cu}, \mathrm{Zn}$ and Au in the energy range of 15 to 40 MeV , by using semi-monoenergetic neutrons from the $\mathrm{Be}(\mathrm{p}, \mathrm{n})$ reaction.

A proton beam of energies of $20,22.5,25,27.5,30,32.5,35,37.5,40$ MeV is extracted from the SF cyclotron at the Institute for Nuclear Study, Univ. of Tokyo and hits the 1 -mm thick ( $E_{p}=20$ to 37.5 MeV ) and $2-\mathrm{mm}$ thick $\left(E_{p}=40 \mathrm{MeV}\right)$ Be targets which are backed by the water coolant. The water is

[^16]simultaneously used to absorb the residual proton energy because of the small neutron production cross section of ${ }^{16} 0(p, n)$.

The neutron spectra at 0 deg were measured with a 51 mm diameter by 51 mm long $\mathrm{NE}-213$ placed at 1.3 m from the Be target (1). An $\mathrm{n}-\mathrm{r}$ discrimination technique was utilized and the pulse height distribution by neutrons was unfolded to an energy spectrum with the revised FERDO code (2). The measured neutron spectra which subtracted the room-scattered components are shown with the unfolded errors in Fig. 1. In the figure, the monoenergetic peak neutron energy is indicated for each proton energy and the former is 4 to 5 MeV lower than the latter.

The samples were irradiated by this semi-monoenergetic neutrons in the forward direction at 5 to 20 cm distant from the Be target. The proton beam current was kept to be several $\mu A$ during the irradiation. The induced gama-ray activities of the irradiated samples were measured with a pure Ge detector and the activation rates were obtained after the correction of self-absorption, parent-daughter decay and sum-coincidence effects. The measurement of long-lived ${ }^{26} \mathrm{Al}$ (half-life of $7.2 \times 10^{5} \mathrm{y}$ ) produced by ${ }^{27} \mathrm{Al}(\mathrm{n}, 2 \mathrm{n})$ reaction was done by accelerator mass spectrometry(AMS) which has been equipped at the tandell Van-de-Graaf accelerator of the Research Center for Nuclear Science and Technology, Univ. of Tokyo (3). The ${ }^{26}{ }_{\mathrm{Al}} /{ }^{27} \mathrm{Al}$ isotopic ratios were obtained by AMS and were converted to the ${ }^{26} \mathrm{Al}$ activities.

The measured activation rate, $A_{i}$ is related to

$$
A_{i}=N \int_{0}^{E p} \sigma(E) \phi_{i}(E) d E,
$$

where $\mathbf{i}$ : ith experiment corresponding to each proton energy, $E_{p}$
N : number of target nucleus in a sample
$\sigma(E):$ activation cross section
$\phi_{i}(E)$ : neutron spectrum shown in Fig. 1.
Since the neutron spectrum $\phi_{i}(E)$ is not purely monoenergetic but has low energy component, the $\sigma(E)$ value can be obtained by unfolding this integral equation. We finally obtained it with the SAND-II code of iterative perturbation method (4), the NEUPAC code using J-1 type unfolding method (5) and the least-square fitting (LSF) method. These codes required the initial guess value of $\sigma(E)$ for unfolding, and they were calculated with the ALICE code (6), in case of the lack of any experimental and calculated data. The SAND-II code does not give unfolded errors, while on the other hand, the NEUPAC code gives the errors propagated from errors of initial guess values, neutron spectrum and activation rates.

Our results of activation cross sections are the first experimental data that have been obtained above 20 MeV . Some results are exemplified in Figs. 2 to 6 . Figure 2 shows the ${ }^{27} \mathrm{Al}(\mathrm{n}, \alpha)^{24} \mathrm{Na}$ cross section data. Our results unfolded by three codes, SAND-II, NEUPAC and LSF, agree quite well each other, except that a small bump around 25 MeV can only be seen by the SAND-II unfolding. Our data also show good agreement with the data by ENDF/B-V and Greenwood (7) as a whole, but are $5 \%$ smaller at a peak value around 13 MeV than them. The ${ }^{23} \mathrm{Na}(\mathrm{n}, 2 \mathrm{n})^{22} \mathrm{Na}$ cross sections are shown in Fig. 3. The experimental data and the theoretically evaluated data are largely dispersed and our results are close to the experimental data by Maslov et al. and Menlove et al. (8), and to the IRDF-85 data file.

Figure 4 shows the ${ }^{27} \mathrm{Al}(\mathrm{n}, 2 \mathrm{n})^{26} \mathrm{Al}$ cross section data. Our results given by SAND-II and NEUPAC show very good agreement each other. Our experimental results give a little lower values than Iwasakis' newest experimental data around 15 MeV (9). For comparison, the experimental data of ${ }^{27} \mathrm{Al}(\mathrm{n}, 2 \mathrm{n})^{26} \mathrm{Al}^{\mathrm{m}}$ (half-life of 6.3 sec ) cross section by Mani et al. (10)
are also shown in Fig. 4. The peak value of 150 mb at 20 MeV for ${ }^{27} \mathrm{Al}(\mathrm{n}, 2 \mathrm{n})^{26} \mathrm{Al}^{\mathrm{m}}$ is 1.6 times larger than that of 95 mb at $20-24 \mathrm{MeV}$ for ${ }^{27} \mathrm{Al}(\mathrm{n}, 2 \mathrm{n})^{26} \mathrm{Al}^{\mathrm{g}}$, but the former value in the lower energy region is much smaller than the latter value.

For ${ }^{\text {nat }} \mathrm{Si}(\mathrm{n}, \mathrm{XnYp}){ }^{28} \mathrm{Al}$ cross section data shown in Fig. 5, the SAND-II results have slightly larger peak value around 12 MeV than the NEUPAC results. Our results are compared with the theoretical ${ }^{28}$ Si(n,p) ${ }^{28}$ Al cross section data given by the IAEA compilation (11), and are about 10 to $25 \%$ smaller than the latter between 10 and 15 MeV . The ${ }^{\text {nat }} \mathrm{Cu}(\mathrm{n}, \mathrm{Xn}){ }^{62} \mathrm{Cu}$ cross section data are shown in Fig. 6. Our results unfolded by three codes also show good agreement within their unfolded errors. The IAEA data for ${ }^{63} \mathrm{Cu}(\mathrm{n}, 2 \mathrm{n})^{62} \mathrm{Cu}(11)$ give about 30 to $40 \%$ higher values than our results and the GNASH calculation for ${ }^{\text {nat }} \mathrm{Cu}(\mathrm{n}, \mathrm{Xn}){ }^{62} \mathrm{Cn}$ by Yamamuro (12) gives closer values to our experimental data.

The authors wish to thank to Drs. H. Nagai and K. Kobayashi and Mr. H. Yamashita for their kindful cooperation on the ${ }^{26}$ Al measurement by the AMS system. This work was financially supported by a Grant-in-Aid for Cooperative Research of the Japanese Ministry of Culture and Education.

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Fig. 1 Semi-monoenergetic neutron energy spectra for proton energies of 20 , $22.5,25,27.5,30,32.5,35,37.5,40 \mathrm{MeV}$


Fig. 2 Measured ${ }^{27} \mathrm{Al}(\mathrm{n}, \alpha)^{24} \mathrm{Na}$ cross section data, together with the cited data


Fig. 3 Measured ${ }^{23} \mathrm{Na}(\mathrm{n}, 2 \mathrm{n}){ }^{22} \mathrm{Na}$ cross section data, together with the cited data


Fig. 4 Measured ${ }^{27} \mathrm{Al}(\mathrm{n}, 2 \mathrm{n})^{26} \mathrm{Al}$ cross section data, together with the cited data


Fig. 5 Measured ${ }^{\text {nat }}{ }_{\text {Si }}(\mathrm{n}, \mathrm{XnYp}){ }^{28} \mathrm{Al}$ cross section data, together with the cited data


Fig. 6 Measured ${ }^{\text {nat }} \mathrm{Cu}(\mathrm{n}, \mathrm{Xn})^{62} \mathrm{Cu}$ cross section data, together with the cited data

IX-B-1
Measurement of Double-differential Neutron Emission Spectra from ${ }^{238} \mathrm{U}$
M.Baba, H.Wakabayashi, N.Ito, K.Maeda and N.Hirakawa

A paper of this title has been published in "Journal of Nuclear Science and Technology 27 (No.7) 601 (1990), with the following abstract:

We have performed the measurement of neutron emission spectra from ${ }^{238} U_{U}$ using a time-of-flight technique, and deduced the following data; 1) the prompt fission neutron spectra for 2 MeV incident neutrons at two emission angles of 90 - and 135-deg., 2) the double-differential neutron emission cross sections at the incident energies of $1.2,2.0,4.2,6.1$ and 14.1 MeV . The emission spectra and the cross sections for scattering process were also deduced by subtracting the fission neutrons from the experimental spectra. The experimental results were compared with other experiments and the evaluations of JENDL-3 and ENDF/B-IV.

From the fission spectrum data ranging from 2 to 12 MeV , we have derived the best fit parameters for the Maxwellian and Watt type distribution functions. The experimental spectra are described with the Maxwellian spectrum with temperature of $1.24-1.26 \mathrm{MeV}$ and are softer than both evaluations.

The spectra and cross sections for inelastic-scattering showed substantial disagreement with the evaluations concerning the discrete levels between 0.5 and 1.2 MeV , and continuum neutrons due to pre-equilibrium processes. The secondary neutron angular distributions at 14 MeV incident energy were reproduced fairly well with the systematics.

M.Baba, S.Matsuyama, T.Ito, N.Ito, T.Teraoku and N.Hirakawa

Double-differential neutron emission cross sections were measured for Li-6 at 14.1 MeV and for C at 14.1 and 18.0 MeV incident energies using Tohoku University Dynamitron TOF spectrometer.

In the present experiment, we employed a post-acceleration beam chopping system (PACS) /l,2/ installed recently at Dynamitron accelerator to improve the time resolution of the $T O F$ spectrometer by reducing the pulsed beam duration. By using PACS, we could obtain much improved separation between the peaks of scattered neutrons. The partial scattering cross sections were also derived from emission spectra.

The experimental results showed general agreement with our previous data /3,4/, while the cross sections for the second.level of $C$ at 7.66 MeV were smaller significantly than previous measurements.

More details of the data are reported in Refs. 1 and 2.

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IX-C-1 Photopion Production from Nuclei
K. Shoda, H. Tsubota*, T. Yamaya**, B-N. Sung***, K. Kagaya, T. Takeshita, H. Yamazaki, T. Shimada and T. Taniuchi

1) ${ }^{28} \mathrm{Si}\left(\mathrm{e}, \pi^{+}\right)^{28} \mathrm{Al}$ by 200 MeV electron beam: Energy distributions of $\pi^{+}$for spin-isospin flip transitions have been studied. The typical raw spectra are shown in Figs. 1 and 2. Strong transitions leaving states around 7 and 12 MeV in ${ }^{28} \mathrm{Al}$ are found. $\pi^{+}$angular distributions are also studied.
2) ${ }^{9} \mathrm{Be}\left(\mathrm{e}, \pi^{+}\right)^{9}{ }^{\mathrm{Li}}$ by 200 MeV electron beam: Energy distributions and angular distributions of $\boldsymbol{\pi}^{+}$have been studied. The photon-difference method was used to analyze spectra. The results show that quasi-free process is very small in this energy region. Strong transitions leaving residual states around $4.7,7.3,10.9,14.6$ and 17.4 MeV are found. By comparison of experimental results and DWIA calculations it is found that there is configurational splitting due to excitation of valence nucleons and core. The angular distributions are shown in Figs. 3 and 4.

[^17]3) Published papers:

Spin-Isospin Flip Transitions in ${ }^{40} \mathrm{Ca}\left(\gamma, \pi^{+}\right){ }^{40} \mathrm{~K}$ Reaction.
Nucl. Phys. A503 (1989) 766.
Energy and angular distributions of the ( $\boldsymbol{\gamma}, \pi^{+}$) reaction have been studied with 185 MeV electrons. Some strong transitions were found.


Fig. $1 \pi^{+}$energy spectrum of ${ }^{28} \mathrm{Si}\left(\mathrm{e}, \pi^{+}\right){ }^{28} \mathrm{Al}$ at $60^{\circ}$. $\mathrm{E}_{\mathrm{e}}=200 \mathrm{MeV}$.

Fig. 3 Angular distribution of $9_{\mathrm{Be}}\left(\boldsymbol{r}, \pi^{+}\right){ }^{9} \mathrm{Li} \quad\left(\mathrm{E}_{\mathrm{X}}=7.3 \mathrm{MeV}\right)$.



Fig. $2 \pi^{+}$energy spectrum of ${ }^{28} \mathrm{Si}\left(\mathrm{e}, \pi^{+}\right)^{28} \mathrm{Al}$ at $90^{\circ} \cdot \mathrm{E}_{\mathrm{e}}=200 \mathrm{MeV}$.


Fig. 4 Angular distribution of $9_{\mathrm{Be}\left(r, \pi^{+}\right)} 9_{\mathrm{Li}} \quad\left(\mathrm{E}_{\mathrm{X}}=10.9 \mathrm{MeV}\right)$.
H. Hatta, Y. Kawazoe*, H. Miyase**, M. Nomura, M. Sugawara, T. Tadokoro, T. Tamae, E. Tanaka***, H. Tsubota**
${ }^{6} \mathrm{Li}(\mathrm{e}, \mathrm{e} \cdot \mathrm{p})$ and ${ }^{6} \mathrm{Li}\left(\mathrm{e}, \mathrm{e}{ }^{\prime} \mathrm{t}\right)$
The ${ }^{6} \mathrm{Li}(\mathrm{e}, \mathrm{e} \cdot \mathrm{p})$ and ${ }^{6} \mathrm{Li}(\mathrm{e}, \mathrm{e}$ 't) coincidence cross sections were measured at $\theta_{p}=0,30,60,90,150,180$ degrees $\left(\phi_{p}=90\right.$, 135 degrees), at excitation energies between 36 and 40 MeV using a 135 MeV continuous electron beam from the pulse beam stretcher. Scattered electrons were detected at $\theta e^{=} 26$ degrees. The mean value of the momentum transfer was $q=63$ MeV/c.


Fig. 1 Proton missing energy spectrum.


Fig. 2 Triton missing energy spectrum.

[^18]$12_{C}\left(\mathrm{e}, \mathrm{e}^{\prime} \mathrm{p}_{0}\right)$
The ${ }^{12} C\left(e, e^{\prime} p_{0}\right)$ coincidence cross sections were measured at angles on and off the scattering plane $\left(\theta_{p}=180\right.$ and 90 degrees), and at excitation energies between 43 and 47 MeV . The mean value of the momentum transfer was $q=70 \mathrm{MeV} / \mathrm{c}$.


Fig. $3{ }^{12} \mathrm{C}(\mathrm{e}, \mathrm{e} \mathrm{p})$ angular distribution.

IX-C-3 Photonuclear Reactions using Tagged Photons
S. Ito, O. Konno, K. Maeda*, H. Matsuyama, I. Nomura, T. Sasaki, T. Suda*, Y. Sugawara, T. Terasawa
${ }^{6} \mathrm{Li}, \quad{ }^{7} \mathrm{Li}(\gamma, \mathrm{pp})$
The ( $r, p p$ ) reaction at photon energies below the pion threshold must be a quite special reaction, since the E1 photo-absorption process can not contribute directly. One of the possible reaction mechanisms is the inter-nuclear nucleon -nucleon collision following initial ( $\gamma, \mathrm{p}$ ) or ( $\boldsymbol{r}, \mathrm{pn}$ ) reaction. Therefore we can expect to study nuclear medium effects on a nucleon in a nucleus using the ( $\gamma, \mathrm{pp}$ ) reaction.

We have measured the ( $\gamma, \mathrm{pp}$ ) reactions on ${ }^{6} \mathrm{Li}$ and ${ }^{7} \mathrm{Li}$ nuclei at $\mathrm{E}_{r}=72$ to 103 MeV . Angular correlations between two protons are shown in Fig. 1. One can see a bump centered at


Fig. 1 Angular correlations between two protons.

[^19]$\theta_{p p} 160^{\circ}$. this bump is thought as come from an n-p collision following the photo-absorption by a quasi-deuteron. One can also see a group of small pp yields at $\theta_{\mathrm{pp}} \leq 60^{\circ}$. (We did not measure at $\theta_{\mathrm{pp}}=0 \pm 15^{\circ}$ ). This group can be considered as come from $a \operatorname{p-p}$ collision following a single proton photoabsorption. The quasi-deuteron process, in which the initial photon energy is shared among a proton and a neutron, can not contribute to this group because of high ( 20MeV) proton detector threshold.

The ${ }^{7} \mathrm{Li} /{ }^{6} \mathrm{Li}$ ratios of the summed yields for $\theta_{\mathrm{pp}}=160^{\circ}$ and $\theta_{\mathrm{pp}} \leq 60^{\circ}$ are shown in Table 1. They can be connected with the $(r, p n)$ and the $\left.(r, p)_{0}\right)$ cross sections in both nuclei. The ${ }^{7} \mathrm{Li} /{ }^{6} \mathrm{Li}$ ratios of the $(\gamma, \mathrm{p})$ cross sections, in which the same proton transmission coefficient is assumed in ${ }^{7} \mathrm{Li}$ and ${ }^{6}$ Li, are also shown in Table 1. Contrary to our expectation, the ${ }^{7} \mathrm{Li} /{ }^{6} \mathrm{Li}$ ratio for $\theta_{\mathrm{pp}} 160^{\circ}$ in the $(\gamma, \mathrm{pp})$ reaction has opposite tendency to the ${ }^{7} \mathrm{Li} /{ }^{6} \mathrm{Li}$ ratio for the ( $\gamma, \mathrm{pn}$ ) part of the ( $\gamma, p$ ) cross sections.

Table 1. ${ }^{7} \mathrm{Li}(\gamma, \mathrm{pp}) /{ }^{6} \mathrm{Li}(\gamma, \mathrm{pp})$ ratios for the bumps and ${ }^{7} \mathrm{Li}(\gamma, \mathrm{p}) /{ }^{6} \mathrm{Li}(\gamma, \mathrm{p})$ ratios for the $(\gamma, \mathrm{pn})$ and $\left(\gamma, \mathrm{p}_{0}\right)$ regions.

|  | ${ }^{7} \mathrm{Li}(r, \mathrm{pp}) /{ }^{6} \mathrm{Li}(r, \mathrm{pp})$ |
| :---: | :---: |
| $\theta_{\mathrm{pp}}{ }^{-160^{\circ}}$ | $0.75 \pm 0.14$ |
| $\theta_{\mathrm{pp}} \leq 60^{\circ}$ | $3.3 \pm 2.1$ |
|  | ${ }^{7} \mathrm{Li}(\gamma, \mathrm{p}) /{ }^{6} \mathrm{Li}(\gamma, \mathrm{p})$ |
| $(\gamma, \mathrm{pn})$ region | $\sim 1.3$ |
| $\left(\gamma, \mathrm{p}_{0}\right)$ region | $\sim 2$ |

X. Tokyo Institute of Technology

X-A-1 Anomaly of the Alpha-Particle Optical Potential in the ${ }^{27} \mathrm{Al}(\mathrm{n}, \mathrm{a}){ }^{24} \mathrm{Na}$ Reaction

H. Kitazawa, Y. Harima and N. Mukai

We determined an alpha-particle optical potential whose real Woods-Saxon potential exhibits a fast increase of its strength in the vicinity of the Coulomb barrier, using the dispersion theory and taking account of available data on the nuclear rainbow scattering at intermediate alpha-particle energies. This potential was applied with considerable success to the Hauser-Feshbach model calculation of the ${ }^{27} \mathrm{Al}(\mathrm{n}, \alpha)^{24} \mathrm{Na}$ reaction cross sections below 20 MeV neutron energy.

A paper on this subject has been published in Nuclear Physics A510 (1990) 429.

# X-A-2 Mechanism for Electric Dipole Transitions from Broad pWave Neutron Resonance in ${ }^{24} \mathrm{Mg}$ 

T. Uchiyama, M. Igashira and H. Kitazawa

Neutron Capture gamma rays from the $84-\mathrm{keV} \mathrm{p}_{3 / 2}$-wave resonance, 266$\mathrm{keV} \mathrm{p}_{1 / 2}$-wave resonance and $431-\mathrm{keV} \mathrm{p}_{3 / 2}$-wave resonance in ${ }^{24} \mathrm{Mg}$ which have large reduced neutron width have been measured with an anti-Compton $\mathrm{NaI}(\mathrm{Tl})$ detector, using a time-of-flight technique. Successful extraction of gamma-ray intensities for transitions to low-lying states in ${ }^{25} \mathrm{Mg}$ was performed by an iterative unfolding method in order to deduce partial radiative widths. Also, we made an experimental contrivance separating the kernel of the $266-\mathrm{keV}$ broad resonance from that of the $257-\mathrm{keV}$ overlapping narrow resonance. Radiative widths were obtained for the E1 transitions to the ground ( $5 / 2^{+}$), $585-\mathrm{keV}\left(1 / 2^{+}\right)$, $975-\mathrm{keV}\left(3 / 2^{+}\right), 1965-\mathrm{keV}\left(5 / 2^{+}\right), 2564-\mathrm{keV}\left(1 / 2^{+}\right)$and $2801-\mathrm{keV}\left(3 / 2^{+}\right)$states, and compared with theoretical calculations based on the valence capture model which has been developed by Lane and Mughabghab. Consequently, we found that in the $\mathrm{p}_{3 / 2}$-wave resonance capture the observed and calculated widths for the transitions to the $1 / 2^{+}$states are in excellent agreement, however the experimental widths for the transitions to the $5 / 2^{+}$states are $20-50 \%$ of the theoretical ones. These noteworthy features in the retardation of E1 transition are explained in terms of the renormalized effective charge which depends on the orbital angular momentum for the single-particle component of final bound states, as a result of the coupling of the single-particle transition with the isovector field generated by the giant dipole resonance. Moreover, the nonadiabatic coupled channel calculation using a particle-rotator coupling model was
carried out for partial radiative widths of the $266-\mathrm{keV} \mathrm{p}_{1 / 2}$-wave resonance. The calculations reproduced the observed values satisfactorily.

A paper on this subject has been published in Phys. Rev. C41 (1990) 862.

# X-A-3 Valence Capture Mechanism in Resonance Neutron Capture by ${ }^{13} \mathrm{C}$ 

S. Raman*, M. Igashira, Y. Dozono, H. Kitazawa, M. Mizumoto** and J.E. Lynn***

The partial radiation widths of three (two electric dipole and one electric quadrupole) primary $\gamma$ transitions in ${ }^{14} \mathrm{C}$, subsequent to neutron capture by the $153-\mathrm{keV}, 2+$ resonance in ${ }^{13} \mathrm{C}$, have been remeasured. Both electric dipole transitions, accounting for more than $80 \%$ of the total radiation width, can be explained as valence neutron transitions. The deduced total radiation width of $0.215_{-0.035}^{+0.084} \mathrm{eV}$ for this resonance disagrees with the previous value of $2.4 \pm 0.9$ eV and significantly affects the production of $\mathrm{A} \geqq 14$ nuclei in primordial nucleosynthesis.

A paper on this subject has been published in Phys. Rev. C41 (1990) 458.

* Oak Ridge National Laboratory, Oak Ridge, Tennessee 37831
** Japan Atomic Energy Research Institute, Tokai-mura, Naka-gun, Ibarakiken, Japan
*** Argonne National Laboratory, Argonne, Mlinois 60439


# X-A-4 Electromagnetic Transitions from Broad s-Wave Neutron Resonance in the sd-Shell Nuclei ${ }^{24} \mathrm{Mg},{ }^{28} \mathrm{Si}$ and ${ }^{32} \mathrm{~S}$ 

H. Kitazawa, M. Igashira, Y. Achiha, Y. Lee, N. Mukai, K. Muto and T. Oda

We have examined electromagnetic transitions from p-wave resonances with large reduced neutron widths in 1 p and $2 \mathrm{~s}-1 \mathrm{~d}$ shell nuclei. Consequently it was shown that E1 transitions from these resonances in nuclei with even-proton number are successfully explained by the Lane-Mughabghab valence capture model or by a core-particle strong coupling model ${ }^{1-3)}$. The validity of the valence capture model was due to the fact that the transition matrix element cancels out inside the nucleus, while that of the core-particle model was due to the fact that the configuration consisting of the coupling between the $1 \mathrm{~s}-2 \mathrm{~d}$ and $1 \mathrm{f}-2 \mathrm{p}$ shell neutrons and the vibrational or rotational states in even-even target nuclei mixes considerably in the resonance state.

In the present study, observation was performed for electromagnetic transitions from the s-wave neutron resonances at 654 keV in ${ }^{24} \mathrm{Mg}, 180 \mathrm{keV}$ in ${ }^{28} \mathrm{Si}$ and 103 keV in ${ }^{32} \mathrm{~S}$. Experiment was made by using the Pelletron accelerator of the Tokyo Institute of Technology. Capture gamma rays were measured with an anti-compton $\mathrm{NaI}(\mathrm{Tl})$ detector, using a time-of-flight technique. As a result, we found strong E1 and M1 transitions from these resonances to low-lying states with considerable spectroscopic factor. Partial radiative widths were derived for these transitions. The observed widths for E1 transition are in excellent agreement with the valence-model calculations. The agreement comes from a strong cancellation of the transition matrix element inside the nucleus, in accordance with the conclusion for p-wave resonance capture mentioned above. Moreover, we found that E1 and M1 transitions can be understood by assuming a
configuration-mixing wave function $\Psi_{R}\left(1 / 2^{+}\right)=a\left(0^{+} \otimes 1 / 2^{+}\right)+b\left(1^{+} \otimes 1 / 2^{+}\right)$ $+c\left(1^{+} \otimes 3 / 2^{+}\right)$for each resonance. The M1-transition strengths are also compared with more detailed calculations using the Wildenthal interaction in the (sd) ${ }^{\mathrm{n}}$ full space.

A paper on this subject will be submitted to the 7 th International Symposium on Capture Gamma-Ray Spectroscopy and Related Topics, held in California, on 14-19 October 1990.

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M. Igashira, H. Kitazawa, S. Kitamura, H. Anze and M. Horiguchi

We have studied capture gamma rays from broad neutron resonances in 1 p and $2 \mathrm{~s}-1 \mathrm{~d}$ shell nuclei. For nuclei with even protons, electric dipole transitions were successfully explained by the Lane-Mughabghab valence capture model and a particle-vibrator or particle-rotator coupling model. However, the information about nuclei with odd protons is not enough. Therefore, measurement was performed for capture gamma rays from broad neutron resonances in ${ }^{14} \mathrm{~N},{ }^{19} \mathrm{~F}$, and ${ }^{27} \mathrm{Al}$.

Employing an anti-Compton $\mathrm{NaI}(\mathrm{Tl})$ detector and a time-of-flight technique, we have observed neutron capture gamma rays from the $644-\mathrm{keV}$ s-wave resonance $\left(1 / 2^{+}\right)$in ${ }^{14} \mathrm{~N}$, from the $27-\mathrm{keV}$ p-wave resonance $\left(2^{-}\right), 49-\mathrm{keV}$ p-wave resonance ( $1^{-}$), and $97-\mathrm{keV}$ p-wave resonance $\left(1^{-}\right)$in ${ }^{19} \mathrm{~F}$, and from the $35-\mathrm{keV}$ swave resonance $\left(2^{+}\right)$and $142-\mathrm{keV}$ s-wave resonance $\left(3^{+}\right)$in ${ }^{27} \mathrm{Al}$. Pulsed neutrons were produced from the ${ }^{7} \mathrm{Li}(\mathrm{p}, \mathrm{n})^{7} \mathrm{Be}$ reaction by bombarding a natural lithium target with a $1.5-\mathrm{ns}$ bunched proton beam from the 3-MV Pelletron accelerator at the Tokyo Institute of Technology. The average proton-beam current was 7-10 $\mu \mathrm{A}$ for a pulse repetition rate of 2 MHz . Neutrons incident on a capture sample were monitored by two ${ }^{6} \mathrm{Li}$-glass scintillation detectors.

Consequently, strong primary M1 transitions to low-lying states were observed in all residual nuclei, in addition to the primary E1 transition to the ground state in ${ }^{15} \mathrm{~N}$ and some primary E1 transitions to low-lying states in ${ }^{20} \mathrm{~F}$. Partial radiative widths were extracted for all these primary transitions. The radiative width for M1 transition ranges from 0.1 eV to 4.0 eV , particularly the
transition to the second excited state in ${ }^{15} \mathrm{~N}$ has a strength nearly equal to the Weisskopf unit. Also, the radiative width for the E1 transition to the ground state in ${ }^{15} \mathrm{~N}$ was extracted to be 9.5 eV . The value is twice larger than the old one obtained from the ${ }^{14} \mathrm{C}(\mathrm{p}, \gamma){ }^{15} \mathrm{~N}$ reaction.

The valence-capture-model calculation was made for both E1 and M1 transitions, but the results do not explain these observed E1 and M1 transitions at all. For E1 transitions, it is probable that unpaired protons play an important role in radiative neutron capture.

A paper on this subject will be submitted to the 7th International Symposium on Capture Gamma-Ray Spectroscopy and Related Topics, held in California, on 14-19 October 1990.
$X-A-6 \quad$ The ${ }^{13,12} \mathrm{C}\left({ }^{18} \mathrm{O}, \mathrm{X}\right),{ }^{13,12} \mathrm{C}\left({ }^{15} \mathrm{~N}, \mathrm{X}\right)$ reactions at $\mathrm{E}_{1 \mathrm{ab}}=2.4 \mathrm{MeV} / \mathrm{u}$.
H. Funaki, M. Shimizu and E. Arai

The evaporation residues (ER) from the fusion reactions of ${ }^{12,13} \mathrm{C}\left({ }^{16} \mathrm{O}, \mathrm{X}\right),{ }^{12,13} \mathrm{C}\left({ }^{15} \mathrm{~N}, \mathrm{X}\right)$ were measured at an incident energy of $2.4 \mathrm{MeV} / \mathrm{u}$. The mass numbers of evaporation residues were determined using a time-of-flight telescope.

The experiments were performed at the Tokyo Institute of Technology Heavy Ion Linac Laboratory. Beams of ${ }^{16} O^{6+}$ and ${ }^{15} N^{5+}$ was produced by a PIG ion source and accelerated to $2.4 \mathrm{MeV} / \mathrm{u}$. The electric beam current was typically 1 nA on the target. At forward angles it was necessary to reduce the beam intensity to 0.1 nA . The size of beam spot was about $10 \times 10 \mathrm{~mm}^{2}$. Self-supporting ${ }^{13} \mathrm{C}$ targets were prepared from 99\% enriched ${ }^{13} \mathrm{C}$ powder. By measuring Rutherford back scattering of 3.2 MeV protons at $165^{\circ}$ the target thickness and ${ }^{13} \mathrm{C}$ fraction were determined to be $176 \mu \mathrm{~g} / \mathrm{cm}^{2}$ and $53 \%$, respectively. ${ }^{12} \mathrm{C}$ targets were $80 \mu \mathrm{~g} / \mathrm{cm}^{2}$ thick natural carbon foils.

A time-of-flight telescope consists of a multi-channel plate detector described in ref. 1 for time-zero signal and a surface barrier detector (thickness $300 \mu \mathrm{~m}$ : area $300 \mathrm{~mm}^{2}$ ) for the stop and energy signal generation. The flight path was 50 cm . The overall time resolution was about 300 psec (FWHM) for $38 \mathrm{MeV}{ }^{16} \mathrm{O}$ ions. The data were accumulated event-by-event on a hard disk and analyzed after the measurements. The mass $m$ of the reaction products was calculated from the relation $m \propto E t^{2}$. A correction was done for the pulse height defect of the surface barrier detector. The angular distributions of elastic scattering and evaporation residues were measured between $\theta=4^{\circ}$ and $18^{\circ}$ in steps of $1^{\circ}$.

Figure 1 illustrates the angular distributions of ER. Heavy products such as $A=25$ and $A=26$ have detectable cross sections only at $\theta \leq 12^{\circ}$. These results can be explained by a kinematical consideration: These ER are produced only through the evaporation of nucleons and therefore their transverse momentum is small. Lighter products than $A=24$, which were produced through the evaporation of at least one $\alpha-$ particle, have greater transverse momentum and therefore can be observed at $\theta \geq 12^{\circ}$. The experimental angular distributions and energy spectra of ${ }^{12,13} \mathrm{C}\left({ }^{15} \mathrm{~N}, \mathrm{X}\right)$ reaction are compared with statistical model calculations using the CASCADE code ${ }^{2)}$ in ref. 3.

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Fig. 1. Angular distributions of evaporation residues. The curves are to guide the eye.
XI. Toshiba Corporation

XI-A-1

## Simplified Method of Calculation of PKA Spectra, DPA Cross Sections and Kerma Factors for Medium and Heavy Weight Nuclides

Shungo IIJIMA and Masayoshi KAWAI

A Paper on this subject was published in J. Nucl. Sci. Technol., 27, pp. 375-378 (1990). The abstract is as follows:

The data of PKA (primary knock-on atom) spectra, DPA (displacement per atom) cross sections and kerma (kinetic energy release in matter) are rather customarily calculated with the energy balance method and/or rather crude approximations for particle emission spectra. Results were often affected significantly by a slight violation of energy balance or by the crudeness of the reaction model. In the present work, an improved and simplified method to calculate PKA/kerma data by directly summing up the kinetic energies of PKA and charged particles is proposed. In the method, the evaluated neutron data file of ENDF/B-5 format is fully utilized, supplementing the average energy values of emitted charged particles from cross section calculation code. An approximate and compact expression is given of the kerma factor and DPA cross section for reaction sum including multiparticle emissions, which is valid for medium and heavy weight nuclides.

As an example, the data of natural iron were calculated. The result was in good agreement with that calculated by Howerton 1) and Caswell et al. 2) for kerma factor and with that by RADHEAT-V43) for DPA cross section. Several percent violations of energy balance turned out to give rise to considerable discrepancies of kerma factor between the direct method and the energy balance method.

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XI-A-2

## Calculation of Fe-56 Reactions Induced by High Energy Neutrons and Protons

K. Hida and S. Iijima

A paper on this subject was published in the proceedings of the Second International Symposium on Advanced Nuclear Energy Research - Evolution by Accelerators -, p. 710 (1990) with the following abstract:

Nuclear data for $\mathrm{Fe}-56$, induced by 20 to 300 MeV neutrons and protons, are evaluated mainly based on theoretical calculations. First, we investigated the applicability of using the optical potentials proposed so far to calculating the total and reaction cross sections for the energy range of interest. Then, the pre-equilibrium and evaporation model code ALICE ${ }^{(1)}$ was used to calculate the isotope production cross sections and emitted particle energy spectra. Although ALICE can be used for calculating angular distributions for emitted particles, the distributions were evaluated using the Kalbach's systematics. (2) The evaluated data agree reasonably well with available experimental data. A method to generate evaluated nuclear data library in ENDF-6 formats is also discussed.

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(2) C. Kalbach; Phys. Rev. , C37. 2350 (1988).
XII. The University of Tokushima

## A. College of General Education

## XII-A-1 ANALYSIS OF $6,7 \mathrm{Ti}\left(\mathrm{N}, \mathrm{N}^{\prime}\right)$ INELASTIC SCATTERING

N. Koori, M. Eriguchi ${ }^{++}$, Y. Watanabe ${ }^{++}$, M. Hyakutake ${ }^{+}$, and I. Kumabe ${ }^{++}$

We have reported measurements of the polarized proton scattering on ${ }^{6,7} \mathrm{Li}$ around 14 $\mathrm{MeV}[1]$. In the analysis on the basis of the spherical optical model (SOM) and coupled channel (CC) method, it has been clarified that the analysis cannot reproduce the inelastic scattering data, especially their analyzing powers. We have tried a possible way for reproducing the inelastic scattering data in the framework of the optical model.

First the optical potentials derived from the SOM analysis for the elastic scattering data of $6,7 \mathrm{Li}$ were used for the entrance and exit channels in the DWBA and CC calculations for the inelastic scattering. For the exit channel, the energy dependence in the V and W parameters was taken into account for the potentials. By these calculations, the inelastic scatterings were not reproduced so well, in spite of the fact that both differential cross sections and analyzing powers of the elastic scattering were fitted very well. Since the excited states of ${ }^{6} \mathrm{Li}$ ( 2.185 $\mathrm{MeV}, 3^{+}$) and ${ }^{7} \mathrm{Li}\left(4.63 \mathrm{MeV}, 7 / 2^{-}\right)$can decay into the channels $\mathrm{d}+\alpha$ and $\mathrm{t}+\alpha$, respectively, the optical potential for these exit channels may be different from those of the entrance channels. We tried to search the potential for the exit channel. Then, appreciable improvement in the fit was obtained for the analyzing powers as shown in Figs. 1 and 2.

[^20]The angular distributions for the inelastic scattering are ameliorated at forward angles and the analyzing powers also improved in its fit. If the obtained parameters are compared with those of the entrance channel, it can be say the excited states spread very much and this is reasonable in an image of the decaying states.

It is meaningful to calculate the neutron scattering on the basis of the analysis of the proton scattering for modelling the nucleon scattering on light nuclei. We calculated the differential cross sections and analyzing powers of the neutron scattering at 14 MeV , using the optical potentials derived from the proton scattering. The calculated results for ${ }^{6} \mathrm{Li}+\mathrm{n}$ and ${ }^{7} \mathrm{Li}+\mathrm{n}$ scatterings agree reasonably well with the experimental data. The differential cross sections of the elastic scattering on ${ }^{6} \mathrm{Li}$ are reproduced well, but those of the inelastic scattering are different in the angular distribution at forward and backward angles. The differential cross sections of the elastic scattering on ${ }^{7} \mathrm{Li}$, which include those of the inelastic scattering leading to the 1st excited state, are also reproduced well by the calculation, if the Coulomb barrier of about 2 MeV is taken into account. The neutron inelastic scattering indicate similar difference in the angular distribution at forward and backward angles as the proton inelastic scattering. The data of analyzing powers for the ${ }^{6} \mathrm{Li}+\mathrm{n}$ elastic scattering measured at TUNL are reproduced very well as indicated in Fig.3.

As a result, studies on proton scattering are valuable for understanding and modelling of nuclear reactions inclusive of neutron scattering on light nuclei, because much precise analyses are possible for proton scattering.

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Fig.1. Differential cross sections and analyzing powers for the ${ }^{6} \mathrm{Li}\left(\mathrm{p}, \mathrm{p}^{\prime}\right)$ scattering at 14 MeV . Solid curves indicate the SOM (for the elastic scattering) and DWBA (for the inelastic scattering) calculations. Dashed curves for the inelastic scattering indicate DWBA calculations with a different optical potential for the exit channel.


Fig.2. Differential cross sections and analyzing powers for the ${ }^{7} \mathrm{Li}(\mathrm{p}, \mathrm{p}$ ) scattering at 14 MeV . Solid curves indicate the SOM (for the elastic scattering) and DWBA (for the inelastic scattering) calculations. Dashed curves for the inelastic scattering indicate DWBA calculations with a different optical potential for the exit channel.


Fig. 3 Differential cross sections and analyzing powers for the ${ }^{6} \mathrm{Li}(\mathrm{n}, \mathrm{n})$ elastic scattering measured at TUNL. Dashed curves are of the calculation with the optical potential derived from the present proton scattering data.

N. Koori, Y. Watanabe ${ }^{+}$, M. Eriguchi ${ }^{+}$, and I. Kumabe ${ }^{+}$

We have newly measured the ${ }^{6} \mathrm{Li}(\mathrm{p}, 2 \mathrm{p})$ reaction at 14 MeV in order to analyze the continuum spectra of ${ }^{6} \mathrm{Li}(\mathrm{p}, \mathrm{xp})$ reaction reported previously[1]. In the previous analyses of the ${ }^{6} \mathrm{Li}(\mathrm{p}, \mathrm{xp})$ reaction, we performed the DWBA calculation for the discretized-continuum states, which were proposed in the CDCC (coupled discretized-continuum channel) calculation by Kamimura and Sakuragi. The continuum spectra, however, could not be reproduced well in the low energy region, where the ( $\mathrm{p}, 2 \mathrm{p}$ ) process may become dominant.

Examples of the measured $2 p$ correlation spectra are shown in Fig. 1. The spectra were obtained with two counter-telescopes consisting of Si detectors set at $\theta_{1}=50^{\circ}$ and $\theta_{2}=45^{\circ}$ $120^{\circ}$; the spectra are of the telescope set at $\theta_{2}$. The summed spectra of the correlation spectra were consistent with the previous continuum spectrum of the reaction, as shown in Fig.2.

In the present time, instead of the previous DWBA calculation, the continuum spectra were analyzed with assumptions of the sequential decay processes and final state interactions in the reaction. Following sequential decay processes leading to the 4 -body breakup reaction may be contributed:

$$
\begin{align*}
\mathrm{p}+{ }^{6} \mathrm{Li} & ->\mathrm{L}_{\mathrm{Li}}{ }^{*}+\mathrm{p}_{1}:{ }^{6} \mathrm{Li}^{*}-->\mathrm{d}^{*}+\alpha: \mathrm{d}^{*}-->\mathrm{n}+\mathrm{p}_{2} & \text { (Process 1) } \\
& ->5_{\mathrm{Li}}+\mathrm{d}^{*}: 5_{\mathrm{Li}}->\mathrm{p}_{1}+\alpha: \mathrm{d}^{*}-->\mathrm{n}+\mathrm{p}_{2} & \text { (Process 2) } \\
& ->{ }^{3} \mathrm{He}^{*}+\alpha:{ }^{3} \mathrm{He}^{*}-->\mathrm{p}_{1}+\mathrm{d}^{*}: \mathrm{d}^{*}-->\mathrm{n}+\mathrm{p}_{2} & \text { (Process 3) } \\
& ->\mathrm{p}_{1}+\mathrm{d}^{*}+\alpha: \mathrm{d}^{*}-->\mathrm{n}+\mathrm{p}_{2} & \text { (Process 4) } \\
& ->\mathrm{p}_{1}+\mathrm{p}_{2}+{ }^{5} \mathrm{He}:{ }^{5} \mathrm{He}->\mathrm{n}+\alpha & \text { (Process 5) } \\
& ->\mathrm{p}_{1}+\mathrm{p}_{2}+\mathrm{n}+\alpha & \text { (Process 6) } \tag{Process6}
\end{align*}
$$

[^21]As compared in Fig. 3 the calculated spectrum fits very well to the measured one, especially in the low energy region. Process 1 through the 3rd (dash-dotted line) and 5th (dash-doubledotted line) excited states of ${ }^{6} \mathrm{Li}$ and Process 2 (short-dashed line) are dominant in the low energy region. In the intermediate energy region of $6-10 \mathrm{MeV}$ the DWBA calculations provide a good estimation as described previously. Similar calculations for the ${ }^{6} \mathrm{Li}(\mathrm{n}, \mathrm{xn})$ reaction also show good fit for the continuum spectrum, which was measured by Chiba et al.[2], as compared in Fig. 4.

Studies on proton induced reactions on light nuclei are valuable for deep understanding and good modelling of neutron induced ones. The continuum spectra in the low energy region may contributed by decays from highly excited states formed by inelastic scattering.

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Fig.1. Measured 2p correlation spectra.


Fig.2. Summed spectrum of the correlation spectra (solid circles) compared with a measured continuum spectrum (solid line).


Fig.3. Comparison of spectra calculated by assumption of sequential decay processes the measured one.


Fig.4. Calculated ${ }^{6} \mathrm{Li}(\mathrm{n}, \mathrm{xn})$ spectra compared with measured one.


[^0]:    * Nuclear Fuel Technology Development Division, Power Reactor and Nuclear Fuel Development Corp., Tokai-mura, Naka-gun, Ibaraki-ken 319-11
    ** Department of Nuclear Engineering, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-01

[^1]:    * Department of Nuclear Engineering, Kyushu University
    ** Department: of Nuclear Engineering, Tohoku University

[^2]:    * Exchange scientist under the program promoted by the Science and Technology Agency.

    Permanent address: Institute of Atomic Energy, Beijing, The People's Republic of China.

[^3]:    1 Toshiba Corporation
    2 Sumitomo Atomic Energy Industries, I.td.
    ${ }^{3}$ Mitsubishi Atomic Power Industries, Inc.
    ${ }^{4}$ Kawasaki Heavy Industries, Ltd.
    5 Hitachi Ltd.

[^4]:    * Institute for Nuclear Study, University of Tokyo, Tanashi, Tokyo 188, Japan ** Otemon Gakuin University, Ibaragi, Osaka 567, Japan

[^5]:    * Institute for Nuclear Study, University of Tokyo, Tanashi, Tokyo 188, Japan ** Department of Chemistry, Faculty of Science, Nagoya University, Nagoya 464, Japan
    *** School of Economics, Otemon Gakuin University, Ibaragi, Osaka 567, Japan

[^6]:    †Institut fuir Kernchemie, Universität Mainz, FRG

[^7]:    * Present adress: Tokushima University, Tokushima 770

[^8]:    * Present address: Tokushima University, Tokushima 770.

[^9]:    * Tohwa University
    ** Japan Atomic Energy Research Institute

[^10]:    * Present address : Reactor Engineering Group, Nuclear Engineering Laboratory, Toshiba Corporation

[^11]:    * Present address : Reactor Engineering Group,

    Nuclear Engineering Laboratory, Toshiba Corporation

[^12]:    * Present address : Reactor Engineering Group, Nuclear Engineering Laboratory, Toshiba Corporation

[^13]:    * Research Reactor Institute, Kyoto University ** Rikkyo University

[^14]:    * Osaka University

[^15]:    * Present address: Hitachi Seisakusho Co.

[^16]:    *Institute for Nuclear Study, University of Tokyo

[^17]:    *College of General Education, Tohoku University
    **Department of Physics, Tohoku University
    ***Department of Physics, Seoul University, Korea

[^18]:    *Institute for Material Science, Tohoku University
    **College of General Education, Tohoku University ***Department of Physics, Tohoku University

[^19]:    *College of General Education, Tohoku University

[^20]:    ++ Department of Nuclear Engineering, Kyushu University.

    + Present address: Sasebo Technical College.

[^21]:    + Department of Nuclear Engineering, Kyushu University.

