INDC(JPN) - 189/U

NOT FOR PUBLICATION

PROGRESS REPORT

(January 2001 to December 2001 inclusive)

March 2002

Editor

J. Katakura

Japanese Nuclear Data Committee

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

Editor's Note

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

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

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

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C	12	(N,GAMMA)	NDG		JPN	THEO-PROG	INDC(JPN)-189U	MAR	02		KITAZAWA+.P.61.CALC WITH FOLDING MDL
C	16	P EMISSION	7.5+7		LEP	EXPT-PROG	INDC(JPN)-189U	MAR	02		SANAMI+.P17.DA/DE AT 25,65,125 DEG.
C	16	D EMISSION	7.5+7		LEP	EXPT-PROG	INDC(JPN)-189U	MAR	02		SANAMI+.P17.DA/DE AT 25,65,125 DEG.
C	16	T EMISSION	7.5+7		LEP	EXPT-PROG	INDC(JPN)-189U	MAR	02		SANAMI+.P17.DA/DE AT 25,65,125 DEG.
C	16	A EMISSION	7.5+7		LEP	EXPT-PROG	INDC(JPN)-189U	MAR	02		SANAMI+.P17.DA/DE AT 25,65,125 DEG.
O	16	(N,GAMMA)	NDG		JPN	THEO-PROG	INDC(JPN)-189U	MAR	02		KITAZAWA+.P.61.CALC WITH FOLDING MDL
O	16	A EMISSION	1.2+6	1.5+7	TOH	EXPT-PROG	INDC(JPN)-189U	MAR	02		BABA+.P80.DA/DE.GRIDDED-IONIZATION C
F	19	P EMISSION	1.4+8		OSA	EXPT-PROG	INDC(JPN)-189U	MAR	02		TERADA+.P71.DA/DE.E-TOF CHARG-P SPEC
F	19	A EMISSION	1.4+8		OSA	EXPT-PROG	INDC(JPN)-189U	MAR	02		TERADA+.P71.DA/DE.E-TOF CHARG-P SPEC
NA	23	RESON PARAMS	3.5+4	5.3+4	TIT	EXPT-PROG	INDC(JPN)-189U	MAR	02		IGASHIRA+.P85.TOF+HPGE.PART+TOTAL WG
MG	26	(N,D)	1.3+8	1.5+8	NAG	EXPT-PROG	INDC(JPN)-189U	MAR	02		SAKANE+.P55.ACT-SIG REL AL27(N,A)
AL	27	P EMISSION	1.4+8		OSA	EXPT-PROG	INDC(JPN)-189U	MAR	02		TERADA+.P71.DA/DE.E-TOF CHARG-P SPEC
AL	27	A EMISSION	1.4+8		OSA	EXPT-PROG	INDC(JPN)-189U	MAR	02		TERADA+.P71.DA/DE.E-TOF CHARG-P SPEC
SI	28	EVALUATION	2.0+7	2.0+8	KYU	EVAL-PROG	INDC(JPN)-189U	MAR	02		SUN+.P49.SOFT ROTAT+CC MDL.GNASH CAL
SI	28	EVALUATION		2.0+8	KYU	EVAL-PROG	INDC(JPN)-189U	MAR	02		SUN+.P47.SOFT ROTAT+CC MDL.GNASH CAL
SI	29	EVALUATION	2.0+7	2.0+8	KYU	EVAL-PROG	INDC(JPN)-189U	MAR	02		SUN+.P49.SOFT ROTAT+CC MDL.GNASH CAL
SI	29	(N,D)	1.3+8	1.5+8	NAG	EXPT-PROG	INDC(JPN)-189U	MAR	02		SAKANE+.P55.ACT-SIG REL AL27(N,A)
SI	30	EVALUATION	2.0+7	2.0+8	KYU	EVAL-PROG	INDC(JPN)-189U	MAR	02		SUN+.P49.SOFT ROTAT+CC MDL.GNASH CAL
SI	30	(N,D)	1.3+8	1.5+8	NAG	EXPT-PROG	INDC(JPN)-189U	MAR	02		SAKANE+.P55.ACT-SIG REL AL27(N,A)
SI		P EMISSION	1.4+8		OSA	EXPT-PROG	INDC(JPN)-189U	MAR	02		TERADA+.P71.DA/DE.E-TOF CHARG-P SPEC

ELEMENT S	A	QUANTITY	ENERGY MIN	MAX	LAB	TYPE	DOCUMENTATION REF	VOL	PAGE	DATE	COMMENTS
TI		P EMISSION	1.4+8		OSA	EXPT-PROG	INDC(JPN)-189U	MAR	02		TERADA+.P71.DA/DE.E-TOF CHARG-P SPEC
TI		A EMISSION	1.4+8		OSA	EXPT-PROG	INDC(JPN)-189U	MAR	02		TERADA+.P71.DA/DE.E-TOF CHARG-P SPEC
V	51	NONELA GAMMA	1.4+8		OSA	EXPT-PROG	INDC(JPN)-189U	MAR	02		MITSUDA+.P.70.HP-GE.NEW ANAL METHOD
CR	53	(N,D)	1.3+8	1.5+8	NAG	EXPT-PROG	INDC(JPN)-189U	MAR	02		SAKANE+.P55.ACT-SIG REL AL27(N,A)
CR	54	(N,D)	1.3+8	1.5+8	NAG	EXPT-PROG	INDC(JPN)-189U	MAR	02		SAKANE+.P55.ACT-SIG REL AL27(N,A)
FE		NONELA GAMMA	1.4+8		OSA	EXPT-PROG	INDC(JPN)-189U	MAR	02		MITSUDA+.P.70.HP-GE.NEW ANAL METHOD
FE		P EMISSION	5.5+7	7.5+7	TOH	EXPT-PROG	INDC(JPN)-189U	MAR	02		BABA+.P80.DA/DE.MULTI-COUNTER TELESC
FE		D EMISSION	5.5+7	7.5+7	TOH	EXPT-PROG	INDC(JPN)-189U	MAR	02		BABA+.P80.DA/DE.MULTI-COUNTER TELESC
FE		A EMISSION	5.5+7	7.5+7	TOH	EXPT-PROG	INDC(JPN)-189U	MAR	02		BABA+.P80.DA/DE.MULTI-COUNTER TELESC
NI		NONELA GAMMA	1.4+8		OSA	EXPT-PROG	INDC(JPN)-189U	MAR	02		MITSUDA+.P.70.HP-GE.NEW ANAL METHOD
NI		P EMISSION	5.5+7	7.5+7	TOH	EXPT-PROG	INDC(JPN)-189U	MAR	02		BABA+.P80.DA/DE.MULTI-COUNTER TELESC
NI		D EMISSION	5.5+7	7.5+7	TOH	EXPT-PROG	INDC(JPN)-189U	MAR	02		BABA+.P80.DA/DE.MULTI-COUNTER TELESC
NI		A EMISSION	5.5+7	7.5+7	TOH	EXPT-PROG	INDC(JPN)-189U	MAR	02		BABA+.P80.DA/DE.MULTI-COUNTER TELESC
ZN	67	(N,D)	1.3+8	1.5+8	NAG	EXPT-PROG	INDC(JPN)-189U	MAR	02		SAKANE+.P55.ACT-SIG REL AL27(N,A)
SR	87	(N,D)	1.3+8	1.5+8	NAG	EXPT-PROG	INDC(JPN)-189U	MAR	02		SAKANE+.P55.ACT-SIG REL AL27(N,A)
SR	90	RES INT ABS	5.0-1		JNC	EXPT-PROG	INDC(JPN)-189U	MAR	02		NAKAMURA+.P37.RI=104+-16 MB
SR	90	(N,GAMMA)	2.5-2		JNC	EXPT-PROG	INDC(JPN)-189U	MAR	02		NAKAMURA+.P37.SIG=10.1+-1.3 MB
ZR		NONELA GAMMA	1.4+8		OSA	EXPT-PROG	INDC(JPN)-189U	MAR	02		MITSUDA+.P.70.HP-GE.NEW ANAL METHOD
ZR		P EMISSION	1.4+8		OSA	EXPT-PROG	INDC(JPN)-189U	MAR	02		TERADA+.P71.DA/DE.E-TOF CHARG-P SPEC
MO	98	(N,D)	1.3+8	1.5+8	NAG	EXPT-PROG	INDC(JPN)-189U	MAR	02		SAKANE+.P55.ACT-SIG REL AL27(N,A)

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MO		NONELA GAMMA	1.4+8		OSA	EXPT-PROG	INDC(JPN)	-189U	MAR	02	MITSUDA+.P.70.HP-GE.NEW ANAL METHOD
MO	100	(N,D)	1.3+8	1.5+8	NAG	EXPT-PROG	INDC(JPN)	-189U	MAR	02	SAKANE+.P55.ACT-SIG REL AL27(N,A)
TC	99	(N,GAMMA)		4.0+4	KTO	EXPT-PROG	INDC(JPN)	-189U	MAR	02	KOBAYASHI+.P43.TOF.CFD OTHRS IN FIG.
RU	102	(N,D)	1.3+8	1.5+8	NAG	EXPT-PROG	INDC(JPN)	-189U	MAR	02	SAKANE+.P55.ACT-SIG REL AL27(N,A)
RH	103	(N,GAMMA)		4.0+4	KTO	EXPT-PROG	INDC(JPN)	-189U	MAR	02	KOBAYASHI+.P43.TOF.CFD OTHRS IN FIG.
PD	105	(N,D)	1.3+8	1.5+8	NAG	EXPT-PROG	INDC(JPN)	-189U	MAR	02	SAKANE+.P55.ACT-SIG REL AL27(N,A)
PD	106	(N,D)	1.3+8	1.5+8	NAG	EXPT-PROG	INDC(JPN)	-189U	MAR	02	SAKANE+.P55.ACT-SIG REL AL27(N,A)
PD	108	(N,D)	1.3+8	1.5+8	NAG	EXPT-PROG	INDC(JPN)	-189U	MAR	02	SAKANE+.P55.ACT-SIG REL AL27(N,A)
IN		(N,GAMMA)	3.0-3	3.0+4	KTO	EXPT-PROG	INDC(JPN)	-189U	MAR	02	YOON+.P42.TOF.SIG(THR)=199.6+-5.6 B
TE	123	(N,D)	1.3+8	1.5+8	NAG	EXPT-PROG	INDC(JPN)	-189U	MAR	02	SAKANE+.P55.ACT-SIG REL AL27(N,A)
DY	163	(N,D)	1.3+8	1.5+8	NAG	EXPT-PROG	INDC(JPN)	-189U	MAR	02	SAKANE+.P55.ACT-SIG REL AL27(N,A)
DY	164	(N,GAMMA)	1.0+4	9.0+4	TIT	EXPT-PROG	INDC(JPN)	-189U	MAR	02	IGASHIRA+.P85.TOF,NAI(TL).REL AU197
HF	179	(N,D)	1.3+8	1.5+8	NAG	EXPT-PROG	INDC(JPN)	-189U	MAR	02	SAKANE+.P55.ACT-SIG REL AL27(N,A)
TA	181	NONELA GAMMA	1.4+8		OSA	EXPT-PROG	INDC(JPN)	-189U	MAR	02	MITSUDA+.P.70.HP-GE.NEW ANAL METHOD
OS	189	(N,D)	1.3+8	1.5+8	NAG	EXPT-PROG	INDC(JPN)	-189U	MAR	02	SAKANE+.P55.ACT-SIG REL AL27(N,A)
TH	229	FISSION		1.0+4	KTO	EXPT-PROG	INDC(JPN)	-189U	MAR	02	KOBAYASHI+.P41.LEAD SDS.S(THR)=32.4B
TH	232	N EMISSION	2.6+6	1.2+7	TOH	EXPT-PROG	INDC(JPN)	-189U	MAR	02	MIURA+.P79.DA/DE.DEL, DIN ALSO DRVD
PA	231	FISSION		1.0+4	KTO	EXPT-PROG	INDC(JPN)	-189U	MAR	02	KOBAYASHI+.P41.LEAD SPECT.CFD OTHRS
U	235	FISSION	NDG		JAE	REVW-PROG	INDC(JPN)	-189U	MAR	02	KAWANO+.P22.JENDL-3.3 CFD ENDF/B-VI
U	238	N EMISSION	2.6+6	1.2+7	TOH	EXPT-PROG	INDC(JPN)	-189U	MAR	02	MIURA+.P79.DA/DE.DEL, DIN ALSO DRVD

ELEMENT S	A	QUANTITY	ENERGY MIN	MAX	LAB	TYPE	DOCUMENTATION REF	VOL	PAGE	DATE	COMMENTS
U	238	SPECT FISS N	1.4+8	1.8+8	KYU	EVAL-PROG	INDC(JPN)-189U	MAR	02		KAWANO+.P52.PREEQ+MOD.MADLAND-NIX
NP	237	EVALUATION	1.0-5	2.0+7	JAE	EVAL-PROG	INDC(JPN)-189U	MAR	02		NAKAGAWA+.P21.REVISION FOR JENDL-3.3
AM	241	EVALUATION	1.0-5	2.0+7	JAE	EVAL-PROG	INDC(JPN)-189U	MAR	02		NAKAGAWA+.P21.REVISION FOR JENDL-3.3
MANY		EVALUATION	2.0+7	3.0+9	JAE	EVAL-PROG	INDC(JPN)-189U	MAR	02		FUKAHORI+.P27.JENDL HIGH ENERGY FILE
MANY		EVALUATION	1.0-5	2.0+7	JAE	EVAL-PROG	INDC(JPN)-189U	MAR	02		KAWAI+.P21.63FP'S.AS-EU. JENDL-3.2
MANY		EVALUATION	NDG		JAE	EVAL-PROG	INDC(JPN)-189U	MAR	02		KAWANO+.P26.HEAVY NUCLIDES.JENDL-3.3
MANY		FISS PROD GS	NDG		JAE	EVAL-PROG	INDC(JPN)-189U	MAR	02		KATAKURA+.P29.JENDL FP DECAY DATA F.
MANY		FISS PROD GS	NDG		JAE	EVAL-PROG	INDC(JPN)-189U	MAR	02		KATAKURA+.P27.JENDL FP DECAY DATA F.
MANY		FISS PROD GS	NDG		JAE	EVAL-PROG	INDC(JPN)-189U	MAR	02		KATAKURA+.P28.JENDL FP DECAY DATA F.
MANY		FISS PROD BS	NDG		JAE	EVAL-PROG	INDC(JPN)-189U	MAR	02		KATAKURA+.P29.JENDL FP DECAY DATA F.
MANY		FISS PROD BS	NDG		JAE	EVAL-PROG	INDC(JPN)-189U	MAR	02		KATAKURA+.P28.JENDL FP DECAY DATA F.
MANY		FISS PROD BS	NDG		JAE	EVAL-PROG	INDC(JPN)-189U	MAR	02		KATAKURA+.P27.JENDL FP DECAY DATA F.

Prepared by JNDC CINDA Group

I. Aichi Shukutoku University

A. Department of Media Production and Theories

I-A-1

New Method for Calculating Aggregate Fission Product Decay Heat with Full Use of Macroscopic-Measurement Data

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A paper on this subject was published in J. Nucl. Sci. Technol. 38, 477-487, 2001 with the following abstract.

We propose a new "hybrid" method for calculating the aggregate decay heat from fission product nuclides after a fission burst. The decay heat from a given fissioning system is expressed as a linear combination of macroscopic-measurement data for other fissioning systems with a small residual term. This method is based on the linearity of the decay heat to the fission yield. The coefficients in the linear combination are obtained from fitting the fission yield of the given fissioning system with a linear combination of fission yields of other fissioning systems. To demonstrate usefulness of this method, it is applied to examining the consistency among measured decay heat powers of five fast and three thermal neutron induced fissions. The hybrid-method calculations agree well with the measurements and usual summation calculations at cooling times before 4000 s, except for a γ component measurement of the ^{235}U thermal fission at about 2000 s. These results indicate the consistency and reliability of the decay heat evaluation for these systems with the above exception. Furthermore, they also imply usefulness of the present method in predicting the decay heat of other fissioning systems, for which no measurements have been performed so far.

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I-A-2

Reactor Kinetics Calculated in the Summation Method and Key Delayed-neutron Data

Kazuhiro Oyamatsu

A paper on this subject was published in Proc. 2000 Nuclear Data Symposium (JAERI-Conf 2001-006, pp. 162-167, 2001) with the following abstract.

The point-reactor kinetics after a step reactivity insertion to a critical condition is solved directly form fission-product (FP) data (fission yields and decay data) for the first time. Numerical calculations are performed with the FP data in ENDF/B-VI. The inhour equation obtained directly from the FP data shows a different behavior at long periods from the one obtained from Tuttle's six-group parameter sets. The behavior is quite similar to the one obtained from the six-group parameter sets in ENDF/B-VI, that were obtained from FP data in a preliminary version of ENDF/B-VI. To identify the erroneous FP data, we examine the asymptotic form of the inhour equation at an infinitely long period. It is found that the most important precursors for long reactor periods are found ^{137}I, ^{88}Br and ^{87}Br. They cover more than 60 % of the reactivity. It is remarkable that ^{137}I alone covers 30-50 % depending on the fissioning system. In addition to the three precursors, ^{136}Te is found a candidate precursor for the peculiarity from the time dependence of the delayed neutron activity. It is recommended that the precision of their Pn values should be improved experimentally. For ^{137}I, ^{88}Br, and ^{87}Br, the relative uncertainty, dPn/Pn, should be decreased down to 2 % and for ^{136}Te to 5%.

II. Central Research Institute of Electric Power Industry

A. Nuclear Energy Systems Department

II-A-1

Chemical Isotopic Analyses and Calculations based on JENDL-3.2 Library for High Burn-up UO_2 and MOX Spent Fuels

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Chemical isotopic analyses were carried out on high burn-up UO_2 and MOX spent fuels, and ORIGEN2/82 code was verified with the original libraries and new libraries (ORLIBJ32) based on JENDL-3.2. The C/E values evaluated in the literatures were also reviewed. The burn-up and void dependency of the C/E for actinides and fission products were discussed. The difference of branch ratio from ^{241}Am to ^{242m}Am by (n, γ) reaction between libraries suggests the main reason of underestimation of the C/E of ^{244}Cm with ORLIBJ32.

I. Introduction

High burn-up UO_2 and MOX spent fuels have much higher neutron emission and heat generation than conventional UO_2 fuel. The variation in isotopic composition affects the rate of neutron emission and heat generation, and criticality of storage facility. It is therefore necessary to obtain basic data in order to verify computations prior to their use in the design and safety analyses for spent fuel storage.

In this study, chemical isotopic analyses were carried out on high burn-up PWR-UO_2, BWR-UO_2 and PWR-MOX spent fuels, and ORIGEN2/82 calculation using the original library and new library based on JENDL-3.2 were verified by the C/E (Calculation/Experiment). The C/E evaluated in the literatures were also reviewed. The dependency of burn-up and void fraction on the C/E were discussed and evaluated.

II. Isotopic Composition of UO_2 and MOX Spent Fuels

1. Chemical Isotopic Composition in Published Database and References

The isotopic composition of spent fuels for light water reactor is published in a database (SFCOMPO)[1]. The ranges of burn-up in this database are 8 to 47MWd/kgHM for PWR and 18 to 33MWd/kgHM for BWR. In the evaluation, the C/E of the sample ATM-103, -104 and -106 were referred as PWR fuels.

Recent JAERI's studies (ref.2) includes the chemical isotopic analysis of UO_2 fuels, in which the ranges of burn-up are 7 to 44MWd/kgHM for PWR and 28 to 38MWd/kgHM for BWR. In the evaluation, the C/E of the sample SF-95 and -97 was referred as PWR, and SF-98 and -99 were referred as BWR.

2. Chemical Isotopic Analyses of High Burn-up UO_2 and MOX Spent Fuels

Recently burn-up of UO_2 fuel has increased to 55MWd/kgHM and will be extended beyond 60MWd/kgHM. Therefore nuclide composition in higher burn-up fuel is necessary for evaluation of isotopic composition by computation codes. Central Research Institute of Electric Power Industry (CRIEPI) started chemical analysis studies by co-operative works with Institute for Transuranium Elements (ITU).

The high burn-up UO_2 and MOX spent fuels used in this study were irradiated in commercial PWR and BWR[4),5)]. For a high burn-up PWR-UO_2 fuel rod, four samples, of which burn-ups are 53, 60, 64 and 65 MWd/kgHM, were used to verify the computations. For MOX fuel, two samples, of which burn-ups are around 46 MWd/kgHM obtained from two segments, and for a high burn-up BWR-UO2 fuel rod, four samples, of which burn-ups are 57, 59, 62 and 66 MWd/kgHM, were used to verify the computation (**Table 1**).

Table 1 High burn-up UO_2 and MOX spent fuel used in the CRIEPI's study

Fuel	Fuel type	Burn-up (MWd/kgHM)	Enrichment (^{235}U/Puf)	Sample Number
UO_2 fuel rod	PWR	53-65	3.8wt%	4
	BWR	57-66	3.5wt%	4
MOX fuel segment	PWR	46	3.5wt%	2

III. ORIGEN2 and Libraries

The computational analyses were executed by ORIGEN2/82 code. In this study a new library (ORLIBJ32)[6] was used, and it was developed based on JENDL-3.2 by Japan Atomic Energy Research Institute (JAERI). The libraries used and referred are shown in **Table 2**.

Table 2 The libraries used and referred for the evaluation

Data	Library
Ref.1	PWRU, PUD50
Ref.2	PUD50, BWRU, ORLIBJ32, JENDL3.2(SWAT)
Ref.3	ORLIBJ32
Present study (the CRIEPI's study)	PUD50, BWRU, PWRPUPU, ORLIBJ32

IV. Evaluation of Isotopic Composition

1. PWR-UO_2 fuel

Figure 1 to **Figure 3** show the C/E of ^{235}U, ^{239}Pu and ^{241}Pu. The C/E in ref.2 is agreed with 0.92 to 1.06. The C/E of high burn-up fuel (CRIEPI's study) is rather overestimation and the trend of the C/E with both PUD50 and ORLIBJ32 at each burn-up is similar. The C/E for high burn-up fuel calculated with detailed cell code is also shown in **Fig.1** to **Fig.3**. In figures the C/E are improved and agrees with 0.99 to 1.11. Therefore it suggests the possibility that the C/E with ORIGEN calculation using library considering assembly geometry is improved. **Figure 4** shows the C/E of ^{244}Cm, which is the major neutron source in a spent fuel. The C/E calculated with the ORLIBJ32 shows an underestimation at each burn-up.

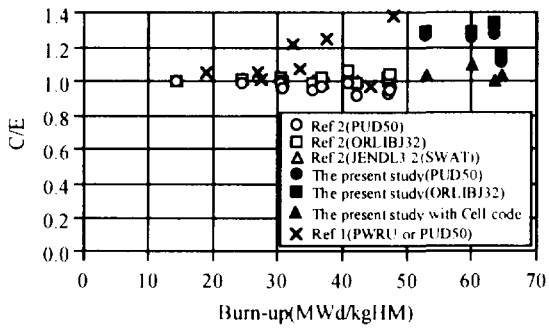


Fig. 1 The C/E of ^{235}U in literature and present study

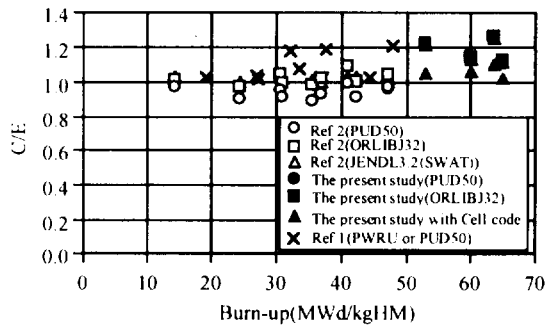


Fig. 2 The C/E of ^{239}Pu in literature and present study

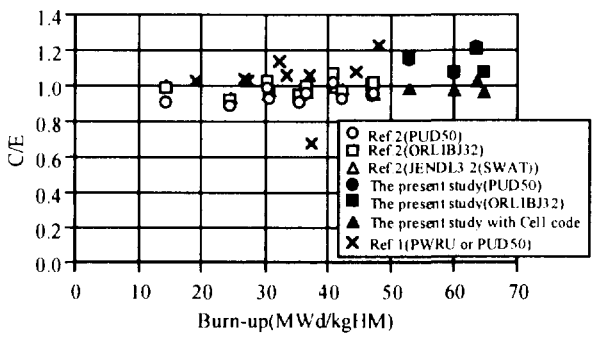


Fig. 3 The C/E of ^{241}Pu in literature and present study

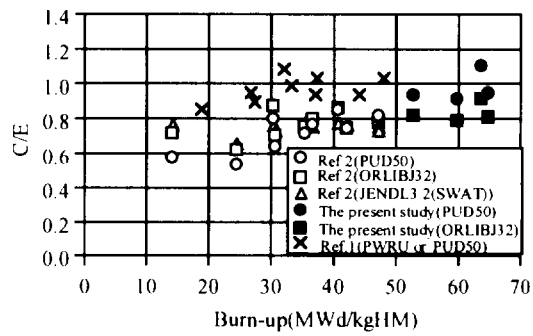


Fig. 4 The C/E of ^{244}Cm in literature and present study

The reaction chain to ^{244}Cm and the C/E of nuclides related to ^{244}Cm formation are shown in **Fig.5** and **Fig.6** respectively. ^{241}Am branches away from ^{242m}Am and ^{242}Am by neutron capture reaction. In the chain 2, ^{242}Am transforms to ^{242}Cm by _-decay in a short time and ^{243}Cm has large fission cross section. Therefore the chain 1 is the main flow to ^{244}Cm formation. Although the generation of ^{241}Am is overestimated in both libraries in **Fig.6**, that of ^{242m}Am is underestimated more in ORLIBJ32, and as it also influences the ^{243}Am formation and consequently the C/E of ^{244}Cm is underestimated. The branch ratio from ^{241}Am to ^{242m}Am by (n,γ) reaction is 20% in PUD50, but that is 9.6% in ORLIBJ32. Therefore it is suggested that the underestimation of the C/E of ^{244}Cm with ORLIBJ32 is due to the difference of the branch ratio between libraries.

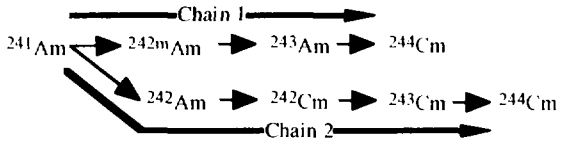
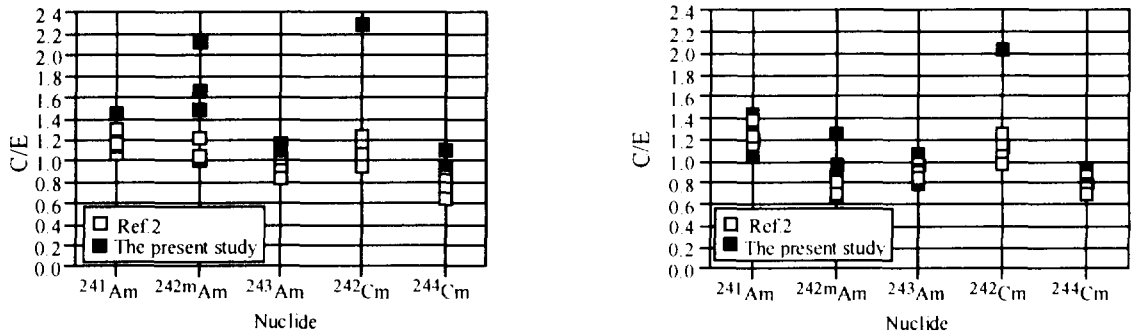


Fig. 5 The reaction chain for ^{244}Cm formation



(a) PUD50 library (b) ORLIBJ32 library

Fig. 6 The C/E of nuclides related to ^{244}Cm formation

In fission products (FPs), the C/E of ^{154}Eu with PUD50 increase remarkably with burn-up. The C/E of ^{154}Eu with ORLIBJ32 is improved and rather constant with burn-up. The difference is probably due to a smaller ^{154}Eu(n, γ) cross section in PUD50, and the amount of ^{154}Eu is overestimated compared to the real one. In both libraries, the C/E of the other FPs such as ^{143}Nd and ^{152}Sm agree with 0.93 to 1.09 and 1.02 to 1.28.

2. BWR-UO_2 fuel

There is axial void fraction history on BWR fuel. Thus in this study an interpolation of the C/E was executed by use of ORLIBJ32 at 0%, 40% and 70% void fraction. **Figure 7** shows the void dependency of the C/E of ^{239}Pu. The C/E with BWRU decreases with an increase of void fraction. With higher void fractions, neutron energy spectrum shifts harder and fission reaction on fissile nuclides results decrease. Thus residual fissile nuclides are increased at higher void fraction, and consequently the C/E is underestimated. On the other hand, the C/E with ORLIBJ32 is improved, because in ORLIBJ32 the void fraction is considered. The C/E of ^{235}U and ^{241}Pu also show a similar void dependency.

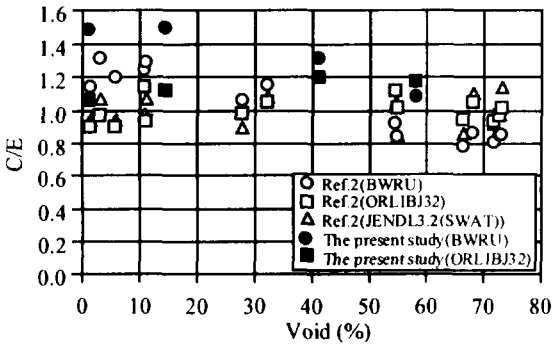


Fig. 7 The C/E of ^{239}Pu in literature and present study

The FPs has less void dependency or void dependency. **Table 3** shows the FPs, which have less void dependency in BWRU and can be classified into two groups. ^{137}Cs, ^{145}Nd, ^{146}Nd, ^{150}Nd and ^{147}Sm are generated directly by fission reaction. For this FPs, the fission yields from major actinides such as ^{235}U and ^{239}Pu are insensitive to changes in the neutron energy. Thus the C/E is relatively constant with void fraction and agrees with 0.9 to 1.09 without ^{147}Sm. The range of the C/E for ^{147}Sm is 0.56 to 1.14.

Table 3 Fission products with a weak void fraction dependency

Direct generation by fission	^{137}Cs, ^{145}Nd, ^{146}Nd, ^{150}Nd, ^{147}Sm
Indirect generation by the (n, γ) reaction	^{134}Cs, ^{150}Sm, ^{154}Sm

^{134}Cs, ^{150}Sm and ^{154}Sm are generated mainly by (n, γ) reaction from ^{133}Cs, ^{149}Sm and ^{153}Sm respectively. These (n, γ) cross sections are affected by neuron energy. The change in the (n, γ) cross section is compensated by the generation and transformation each other and consequently the C/E void dependency is small. The range of the C/E for these nuclides is 0.66 to 1.24. ^{149}Sm, ^{151}Sm and ^{154}Eu have void dependency. ^{149}Sm and ^{151}Sm are generated directly by fission reaction. The (n, γ) cross sections of this FPs are decreased by shifting to higher neutron energy and consequently the residual ^{149}Sm and ^{151}Sm is increased. Therefore the C/E at higher void fraction trends to lower value using BWRU library. Although ^{154}Eu is generated by the ^{153}Eu (n, γ) reaction, the behavior with void fraction is mainly dependent on the ^{154}Eu (n, γ) cross section which is decreased with shifts to higher neutron energy. Thus the C/E in higher void fraction trends to lower values using BWRU library.

3. PWR-MOX fuel

Table 4 shows the C/E of ^{239}Pu, ^{241}Pu and ^{244}Cm in the present study. In the present study and ref.3, ^{239}Pu and ^{241}Pu agreed with 0.89 to 1.13. The C/E of ^{244}Cm with ORLIBJ32 in the present study shows the underestimation as the similar to that of PWR-UO_2 fuel.

Table4 The C/E in the present study

	PWRPUPU			ORLIBJ32		
Burn-up (MWd/kgHM)	^{239}Pu	^{241}Pu	^{244}Cm	^{239}Pu	^{241}Pu	^{244}Cm
46.0 (MOX1)	0.95	0.98	0.95	1.13	1.07	0.80
46.5 (MOX2)	0.92	0.98	0.93	1.09	1.06	0.78

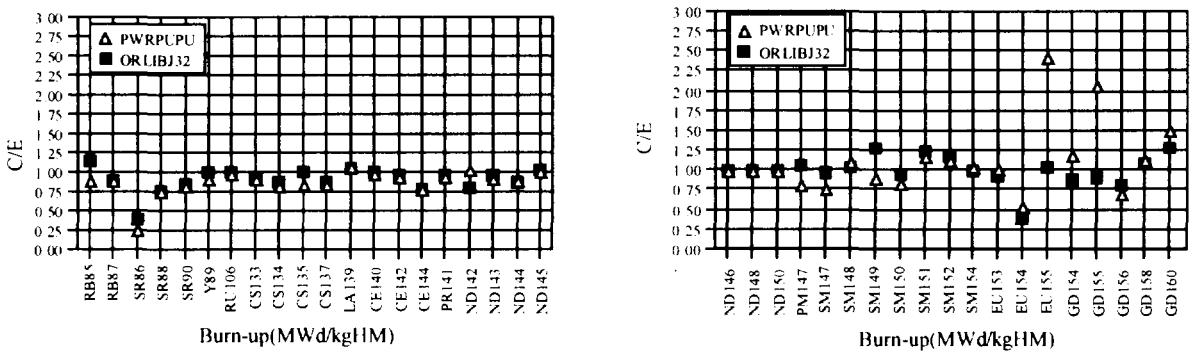


Fig. 8 The C/E of fission products in the present study (MOX1)

The summary of the C/E for FPs is shown in **Fig.8**. The C/E with ORLIBJ32 is smaller scatter than that with PWRPUPU. Especially the C/E of ^{155}Eu and ^{155}Gd are improved.

V. Summary

The chemical isotopic analysis was carried out on high burn-up UO_2 and MOX spent fuels irradiated in commercial plants, and ORIGEN2/82 calculation using the original library and new library based on JENDL-3.2 were verified. The C/E evaluated in the literatures were also reviewed.

The C/E of ^{235}U, ^{239}Pu and ^{241}Pu of high burn-up fuel in the present study is rather overestimation but it suggests the possibility that the C/E with ORIGEN calculation using library considering assembly geometry is improved. The C/E of ^{244}Cm was underestimated in ORLIBJ32. The branch ratio from ^{241}Am to ^{242m}Am by the (n,γ) reaction is 20% in PUD50, but that is 9.6% in ORLIBJ32. Therefore it is suggested that the underestimation of the C/E of ^{244}Cm with ORLIBJ32 is due to the difference of the branch ratio between libraries. The C/E of FPs such as ^{137}Cs, ^{145}Nd, ^{146}Nd, ^{150}Nd, ^{147}Sm, ^{134}Cs, ^{150}Sm and ^{154}Sm showed a weak void dependency, but ^{149}Sm, ^{151}Sm and ^{154}Eu showed a void fraction dependency. For MOX fuel, ^{239}Pu and ^{241}Pu agreed with 0.89 to 1.13 in the present study and ref.3. The C/E with ORLIBJ32 is smaller scatter than that in PWRPUPU for FPs.

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III. High Energy Accelerator Research Organization

A. Radiation Science Center

III-A-1 Radioactivity induced in a 2.5-GeV Electron Beam Dump

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The saturation activity of residual nuclei was estimated based on measurements when 2.5 GeV electron beams were totally absorbed in thick Al, Fe, Cu and Pb. The residual radioactivity was measured using activation gamma-ray spectroscopy. Tritium production yields in Al were measured using liquid scintillation counters.

The radioactivity in Al, Fe, Cu and Pb foils was measured at the KEKB Linac in the High Energy Accelerator Research Organization (KEK). [1,2] They were placed at several depths in a thick beam dump made of Cu or Pb plates and irradiated by 2.4-2.5 GeV electrons. The beam dump was 10 radiation length (r.l.) thick. The foils and the beam dumps were laterally large enough to absorb the electro-magnetic shower. The residual radioactivity was measured using activation gamma-ray spectroscopy by Pure-Ge detectors. The Al foil was dissolved in a solution of 2M NaOH. The amount of tritium from Al foils were measured using the liquid scintillation counter.[2]

The measured activities of ^{51}Cr, ^{48}V and ^{44}Sc in Fe foils are given in Figure 1 in units of mb/incident electron. That was normalized by the beam intensity (electrons/s), the foil thickness, and the density of target atoms and shown as a function of the depth in the beam stop in the units of r.l. The yields were integrated between 0 and 15 r.l., and the total activity in the beam stop was obtained. Both Al and Fe foils were irradiated in the Cu beam stop.

The photon track lengths in a thick target are approximately proportional to the radiation length of the material. The activities in Al and Fe foils were multiplied by the radiation length of Al and Fe. They were then converted to those in the Al and Fe beam stops.

The saturation activities in thick Al, Fe, Cu and Pb are listed in Table 1. The yields of activity for 2.5 GeV electrons were normalized in units of MBq W^{-1}. Above 1 GeV, the activity was constant in units of MBq W^{-1}., and yields in Table 1 were applicable for electrons between 1 GeV and 10 GeV.[1]

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Table 1. Estimated saturation activity in thick Al, Fe, Cu and Pb by 2.5 GeV electrons.
The results are given in units of MBq W^{-1}.

Material : Al		Material : Fe		Material : Cu		Material : Pb	
Nuclei	$MBqW^{-1}$	Nuclei	$MBqW^{-1}$	Nuclei	$MBqW^{-1}$	Nuclei	$MBqW^{-1}$
^{22}Na	15	^{52}Fe	0.26	^{60}Co	4.8	^{206}Bi	0.14
^{18}F	3.0	^{52}Mn	2.9	^{60}Co	7.9	^{205}Bi	0.27
^{7}Be	1.1	^{51}Cr	11	^{57}Co	4.1	^{204}Bi	0.12
^{3}H	6.5	^{49}Cr	1.1	^{56}Co	0.88	^{203}Pb	24
		^{48}Cr	0.093	^{59}Fe	0.29	^{201}Pb	3.3
		^{48}V	2.3	^{54}Mn	1.6	^{200}Pb	1.6
		^{48}Sc	0.045	^{52}Mn	0.44	^{200}Tl	3.8
		^{47}Sc	0.29	^{51}Cr	1.2		
		^{44}Sc	0.57	^{48}V	0.38		
				^{47}Sc	0.14		
				^{46}Sc	0.18		

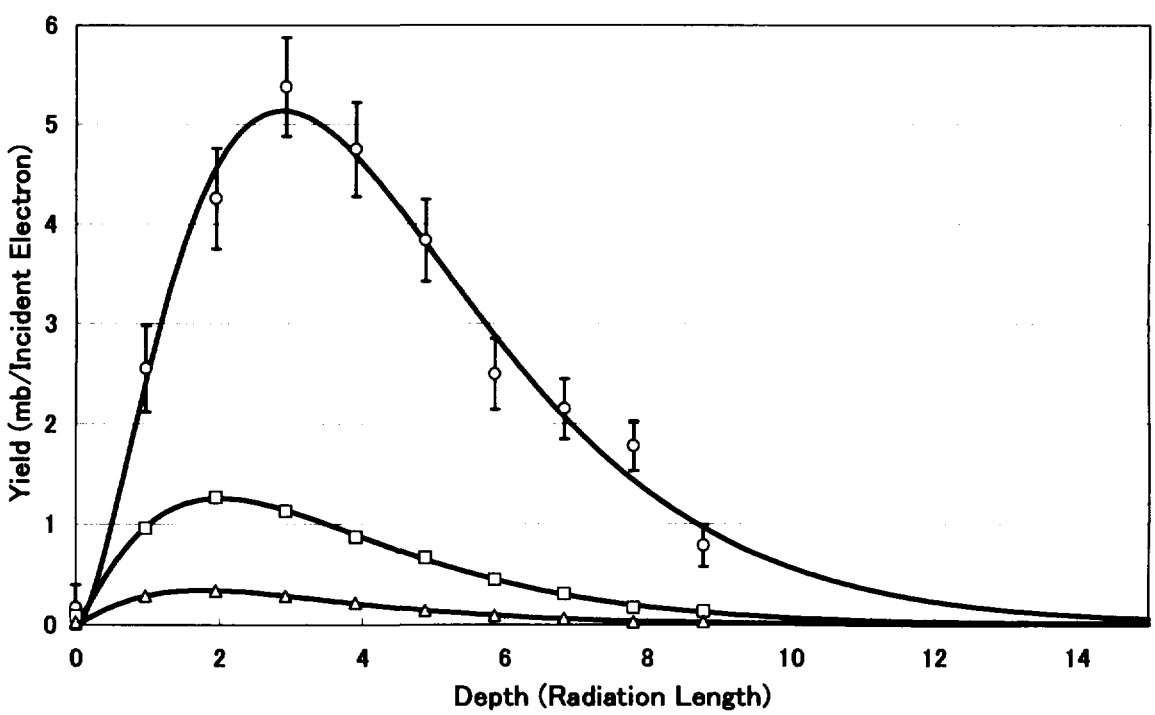

Fig.1 Depth distribution of the typical activity in the Fe beam dump for 2.5 GeV electrons.
Symbol: Measured; Line: fitted from the measured results;
Circle, ^{51}Cr; Square, ^{48}V; Triangle, ^{44}Sc.

III-A-2

Double Differential Hydrogen and Helium Production Cross Section of Oxygen and Nitrogen for 75 MeV Neutrons

Toshiya SANAMI[1,*], Tsutomu HIROISHI[2], Mamoru BABA[2], Masato HAGIWARA[2], Takako MIURA[2], Takao AOKI[2], Naoki KAWATA[2], Susumu TANAKA[3], Hiroshi NAKASHIMA[4], Shin-ichiro MEIGO[4] and Masashi TAKADA[5]

A paper on this subject was presented at Int. Conf. on Nuclear Data for Science and Technology, October 7–12, 2001, Tsukuba, Japan. The abstract of the presentation is following:

Double differential (n,xp), (n,xd), (n,xt) and (n,xα) cross section of oxygen and nitrogen were measured for 75 MeV incident neutrons at 25°, 65° and 125° angles using a specially designed spectrometer. The spectrometer has three counter telescope consisting of a low pressure gas proportional counter, a thin SSD and a BaF_2 scintillator. The energy dependence of the BaF_2 was calibrated with direct proton, deuteron and helium beams. The results were compared with the LA-150 data library. The library represent the experimental results of proton, triton and α-particle generally well, but shows the marked difference in the high energy part of deuteron one.

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IV. Japan Atomic Energy Research Institute

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

IV-A-1

Re-evaluation of Nuclear Data of Fission Product Nuclides for JENDL-3.2

Masayoshi Kawai, Tsuneo Nakagawa, Takashi Watanabe, Yutaka Nakajima,
Atsushi Zukeran, Hiroyuki Matsunobu, Teruo Sugi and SatoshiChiba

A paper on this subject was published in *J. Nucl. Sci. Technol.*, **38**, 261 – 269 (2001) with the following abstract.

Re-evaluation was performed for the neutron-induced reaction data of fission product nuclides compiled in the Japanese Evaluated Nuclear Data Library, JENDL-3.1. The nuclides whose data were re-evaluated are 63 nuclides from ^{75}As to ^{155}Eu. Main quantities revised are the resonance parameters, capture cross sections and inelastic scattering cross sections. As the results of re-evaluation, the thermal neutron capture cross sections, the resonance integrals and the capture cross sections in the keV region were largely improved. The evaluated data cover the neutron energy region from 10^{-5} eV to 20 MeV. The present results have been adopted to JENDL-3.2.

IV-A-2

Improvement of Evaluated Neutron Nuclear Data for ^{237}Np and ^{241}Am

Tsuneo Nakagawa, Osamu Iwamoto and Akira Hasegawa

A paper on this subject was published as *JAERI-Research* 2001-059 with the following abstract.

The nuclear data of ^{237}Np and ^{241}Am that are particularly important among the minor actinides were investigated by comparing JENDL-3.2 with the recent evaluated data and available experimental data. As a result of the study, several defects of JENDL-3.2 data were revealed. They were improved on the basis of experimental data or recent evaluated data. For the both nuclides, main quantities revised in the present work were the resonance parameters, cross sections, angular and energy distributions of secondary neutrons, number of neutrons per fission. The data were given in the neutron energy range from 10^{-5} eV to 20 MeV, and compiled in the ENDF-6 format.

IV-A-3

Comparison of ^{235}U Fission Cross Sections in JENDL-3.3 and ENDF/B-VI

Toshihiko KAWANO, Allan D. CARLSON, Hiroyuki MATSUNOBU,
Tsuneo NAKAGAWA, Keiichi SHIBATA,
Patrick TALOU, Philip G. YOUNG and Mark B. CHADWICK

A paper on this subject was published as *JAERI-Research* 2001-058 with the following abstract.

Comparisons of evaluated fission cross sections for ^{235}U in JENDL-3.3 and ENDF/B-VI are carried out. The comparisons are made for both the differential and integral data. The fission cross sections as well as the fission ratios are compared with the experimental data in detail. Spectrum averaged cross sections are calculated and compared with the measurements. The employed spectra are the ^{235}U prompt fission neutron spectrum, the ^{252}Cf spontaneous fission neutron spectrum, and the neutron spectrum produced by a ^{9}Be(d,xn) reaction. For ^{235}U prompt fission neutron spectrum, the ENDF/B-VI evaluation reproduces experimental averaged cross sections. For ^{252}Cf and ^{9}Be(d,xn) neutron spectra, the JENDL-3.3 evaluation gives better results than ENDF/B-VI.

IV-A-4

Evaluation of the Nuclear Data on (α,n) Reaction For F, Na, Al, Cr, Fe, Ni, and Cu

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This work was carried out as a part of activities of the Charged Particle Nuclear Data Working Group in Japanese Nuclear Data Committee. The results of evaluation were submitted to the International Conference on Nuclear Data for Science and Technology held at Tsukuba in 2001 with the following abstract.

Abstract

Evaluation of the nuclear data on (α,n) reaction, which are very important in analyzing radiation shielding and criticality safety relating to storage, transport, and handling of spent fuel was carried out for the following 18 nuclides.

F-19, Na-23, Al-27,Cr-50,-52,-53,-54, Fe-54,-56,-57,-58, Ni-58,-60,-61,-62,-64, Cu-63,-65.

The evaluated quantities are (α,n) reaction cross section, angular distribution and energy spectrum of emitted neutrons. The upper energy of the incident alpha particle was limited to 15 MeV, because the alpha ray from fuel material and radioactive nuclides built up in the spent fuel was assumed as the alpha source. The highest energy of 11.214 MeV is obtained by alpha decay from the meta-stable state of Po-212.

The evaluation work was performed on the basis of compiled experimental data and theoretical calculation programs. The experimental data on (α,n) reaction cross section are poor and the most part of data are old ones published before 1980.

The shape of (α,n) reaction cross section for light nuclides such as F-19 and Na-23 shows remarkable resonance structure in the whole energy range. Application of common evaluation method for this resonance region is difficult, because the light nuclides have strong individualities, and status of their experimental data is also different in each nuclide. Accordingly, individual method was adopted for each nuclide in this work.

As for F-19 and Na-23, the (α,n) reaction cross section data derived from experiments of the TTY(thick target neutron yield) were analyzed by using the GNASH program. In the case of Na-23, an experiment which measured the resonance structure in the energy range below 4.5 MeV was also considered. The evaluated values were obtained by theoretical calculation which reproduces well the experiments. The angular distributions for these nuclides were obtained by using the systematics of Kalbach-Mann, and assuming symmetric distribution at 90 degrees in the center of mass system.

As for Al-27 and isotopes of Cr, Fe, Ni, and Cu, theoretical calculation with the SINCROS program was widely adopted. There are no experimental data for 8 nuclides of Cr-52,-53,-54, Fe-56,-57,-58, Ni-61,-64. For such nuclides, the (α,n) cross sections were calculated by using the OMP set which was obtained from the fitting to the experiments of other reactions than (α,n) in the energy range up to 20 MeV. The data of TTY were also used to confirm the consistency with the cross sections, and/or to determine the absolute values of cross section for a couple of nuclides. For the nuclides with rich experimental data, the evaluated values were calculated by using the OMP set which reproduce well the most

reliable experimental data.

The energy spectra of secondary neutrons for all nuclides were also calculated by using the GNASH or SINCROS program. The thick target neutron yields were also derived from the evaluated cross sections.

In the present work, the nuclear data for (α,n) reaction were prepared for 18 nuclides as a part of the JENDL (α,n) reaction data file, in order to meet the demand from the fields of spent fuel reprocessing and high level waste which need control of radiation shielding and criticality safety.

IV-A-5

Interpretation of Integral Test Results of FP Cross Sections in JENDL-3.2 by Analyzing the STEK Experiments*

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The integral test of the fission product cross sections in JENDL-3.2 was made as an activity of the Subgroup 10 in the Working Party for Evaluation Cooperation in NEANSC by analyzing the sample reactivity worths measured at the STEK cores. Analyses were separately made by a JNDC team at JAERI and K.Dietze at JNC by using the 70-group cross sections. Neutron and adjoint fluxes used in the analysis by JNDC were converted from the 25-group ones which were adjusted to reproduce the reactivity worth for standard samples by Janssen et al. At ECN, while those used for analysis by K.Dietze were calculated with the reactor core design code system of JNC. The results of both analyses were very similar to each other for strongly absorbing nuclides and in good agreement with the experimental values except for nuclides heavier than A=130 for which the reactivity worth was underestimated by about 10%. However, there were some discrepancies for weakly absorbing nuclides: The analysis by K.Dietze gave a better agreement with the experimental values than those by JNDC. In order to interpret the discrepancies among both calculations and the experimental values, the neutron and adjoint fluxes used in the JNDC calculations were compared with those calculated by K.Dietze. For weakly absorbing nuclides, a detailed comparison of sample reactivity worths as well as adjoint spectra was made. Further sensitivity study clarified that the origin of worth difference can be identified to low accurate scattering components that was strongly influenced by the rough calculation of adjoint spectrum. Especially, for nuclides around mass number of 100, the effect of adjoint spectrum differences appeared in inelastic scattering reactivity worth.

N.B. *This article was presented at ND2001, on 7-12 October, 2001 at Tsukuba.

IV-A-6

New Evaluations of Heavy Nuclide Data for JENDL-3.3

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M. Kawai[*5], T. Yoshida[*6], T. Ohsawa[*7], K. Shibata[*8],
T. Nakagawa[*8], O. Iwamoto[*8], M. Baba[*9], and M. Ishikawa[*10]

A paper on this subject was presented at Int. Conf. on Nuclear Data for Science and Technology, October 7–12, 2001, Tsukuba, Japan, with the following abstract:

New evaluations of nuclear data for Uranium, Plutonium, and Thorium isotopes which are essential for applications to nuclear technology were carried out for the Japanese Evaluated Nuclear Data Library, JENDL-3.3. The objectives of the current release of JENDL were to fix several problems which have been reported for the previous version, to improve the accuracy of the data, and to evaluate covariances for the important nuclides. Quantities in JENDL-3.2 were extensively re-evaluated or replaced by more reliable values. The heavy nuclide data in JENDL-3.3 were validated with several benchmark tests, and it was reported that the current release gave a good prediction of criticalities.

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IV-A-7

JENDL High Energy File

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Fujio MAEKAWA, Shin-ichiro MEIGO, Chikara KONNO, Naoki YAMANO,
Alexander Yu. KONOBEYEV and Satoshi CHIBA

A paper on this subject will be published in Proc. of International Conference on Nuclear Data for Science and Technology (ND2001), Oct. 7 - 12, 2001, Tsukuba International Congress Center, Tsukuba, Japan with the following abstract.

Nuclear Data Center at Japan Atomic Energy Research Institute is developing the JENDL High Energy File in cooperating with Japanese Nuclear Data Committee. The JENDL High Energy File includes neutron and proton nuclear data 20 MeV to 3 GeV. In this report, reported are evaluation methods and results of the evaluation and benchmark tests for the JENDL High Energy File.

IV-A-8

Estimation of Beta- and Gamma-ray Spectra for JENDL FP Decay Data File

J. Katakura, T. Yoshida[†], K. Oyamatsu[‡] and T. Tachibana[*]

A paper on this subject was published in J. Nucl. Sci. Technol. 38, 470-476 (2001), with the following abstract:

Beta- and gamma-ray spectra of fission product nuclides were estimated by a theoretical model for the nuclides having no or incompletely measured spectral data. The estimation was performed with Gross Theory of Beta Decay. The estimated spectra were so stored in JENDL FP Decay Data File 2000 as to keep the consistency between the average decay energy value derived from the spectrum and that used for decay heat analysis. The JENDL spectra of FP nuclides and the aggregate beta- and gamma-ray spectra of fission product nuclides calculated using the JENDL spectra showed good agreement with measured data.

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IV-A-9

JENDL FP Decay Data File 2000

J. Katakura, T. Yoshida[†], K. Oyamatsu[‡] and T. Tachibana[*]

A paper on this subject was published in JAERI 1343 (2001), with the following abstract:

A decay data file of fission product (FP) nuclides has been developed for the use in nuclear technology field as one of special purpose files of JENDL (Japanese Evaluated Nuclear Data Library) in the format of ENDF/B and it is called JENDL FP Decay Data File 2000. The file includes the decay data for 1229 fission product nuclides: 142 stable and 1087 unstable nuclides. The data included for a nuclide are decay modes, their Q values and branching ratios, average decay energy values of beta-rays, gamma-rays and alpha-particles and their spectral data. The primary source of the decay data is ENSDF (Evaluated Nuclear Structure Data File), which is the internationally recognized data file of nuclear structure properties. The data in ENSDF, however, cover only measured ones. The data of the short-lived nuclides needed for the application fields such as decay heat prediction are often incomplete or not measured because of their short half-lives. For such nuclides a theoretical model calculation is applied to derive the needed data such as average decay energies and spectral data. The data in JENDL FP Decay Data File 2000 have been tested by summation calculation comparing its results with measured data of decay heat values and aggregate fission product spectra of various fissioning nuclei. The comparison showed good agreement between the calculated results and the measured values.

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IV-A-10

Development of JENDL FP Decay Data File 2000

J. Katakura, T. Yoshida[†], K. Oyamatsu[‡], T. Tachibana[*]
and Decay Heat Evaluation Working Group[§]

A paper on this subject was presented at Int. Conf. on Nuclear Data for Science and Technology, October 7–12, 2001, Tsukuba, Japan. The abstract of the presentation is following:

JENDL FP Decay Data File 2000 has been developed as a JENDL special purpose file. The file contains the decay data of 1229 fission product nuclides. Of these 1229 nuclides, 142 nuclides are stable and 1087 nuclides unstable. The decay data included in this file are half-life, decay modes, their Q values, average decay energy values of beta-, gamma- and alpha-rays, and spectral data of each radiation. The primary data source is ENSDF (Evaluated Nuclear Structure Data File). The data in the ENSDF file are not always complete because the data in the ENSDF file are based on experimentally measured ones and missing transitions to higher excited levels of a daughter nuclide cause incomplete decay scheme. Theoretical estimation was applied to obtain the decay data of nuclides with no or incompletely measured data.

In the theoretical estimation, beta strength function was calculated using Gross Theory of Beta Decay. The obtained beta strength function was applied to derive the average beta- and gamma-ray energy values and their spectra. When measured spectral data were available but they were incomplete, the estimated spectra were used to compensate the deficiency of the measured data. In JENDL FP Decay Data File 2000, the measured spectra are expressed as discrete data and the estimated spectra as continuous ones. The full spectra are constructed by merging the discrete and continuous ones. The average energy value calculated the full spectrum is consistent with the adopted average decay energy value which is used for decay heat calculation.

The average beta- and gamma-energy values and their spectral data in the file were employed to calculate decay heat values and aggregate spectra of fission product nuclides after fission event of various fissioning nuclides. The calculated results were compared with the measured data. The comparisons showed good agreement between the calculated results and the measured data.

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IV-A-11

FP Decay Heat Calculation Using JENDL FP Decay Data File

J. Katakura

A paper on this subject was presented at 2001 ANS Winter Meeting, Reno and the summary was published in Trans. Am. Nucl. Soc. 85, 318 (2001) .

The decay heat values of fission products after ^{235}U, ^{238}U and ^{239}Pu fission were calculated using JENDL FP Decay Data File 2000 and compared with those of ANS-5.1 standard. The differences between them were also presented and discussed.

IV-A-12

Nuclear Data Sheets for A=128

ENSDF group[1]

The new evaluation of A=128 mass chain was published in Nucl. Data Sheets 94, 227 (2000) with the following abstract:

The experimental results from various decays and reactions for A=128 mass chain have been compiled and evaluated. Experimantal methods, references, and comments are given in the text. Adopted values for the level and decay properties are tabulated. This evaluation for A=128 supersedes one by K. Kitao, M. Kanbe, Z. Matumoto (1983Ki14), published in Nuclear Data Sheets 38, 191 (1983).

Cutoff Date: All data available untill September 2000 have been considered for inclusion in this evaluation.

[1]Members are K. Kitao, M. Kanbe, S. Ohya, T. Horiguchi, Y. Tendow, T. Tamura, M. Oshima, H. Iimura and J. Katakura

B. Criticality Safety Laboratory

IV-B-1

Re-evaluation of the effective delayed neutron fraction measured by the substitution technique for a light water moderated low-enriched uranium core

Ken NAKAJIMA

A paper on this subject was published in *J. Nucl. Sci. Technol.*, **38**, *1120 – 1125* (2001) with the following abstract.

The effective delayed neutron fraction β_{eff} for a light water moderated low-enriched UO_2 core has been re-evaluated to obtain a benchmark data for the validation of calculation codes and nuclear data. Originally, the β_{eff} value was measured by the substitution method. In that method, the β_{eff} value was obtained from measured reactivity change by substituting an Sb-Cd-Pb absorber rod for a 2.6wt% UO_2 rod for all core regions. In the present evaluation, we have employed the latest value for the buckling coefficient of reactivity to re-evaluate the substitution reactivity with high accuracy. In addition, the correction factor, which was ignored in the previous measurement, has been calculated to compensate the difference in the absorption cross sections of fuel and absorber rods. Consequently, the obtained β_{eff} value in the present evaluation was 0.00771±0.00017, and it is more credible than the previous one. The present result is available as a benchmark data for the verification of delayed neutron data for light water reactors.

For comparison, we have calculated the β_{eff} value using a transport code TWODANT code with the JENDL-3.2 nuclear data library. The calculated β_{eff} value overestimated the experiments; the difference slightly exceeded the experimental error.

V. Japan Nuclear Cycle Development Institute

A. Waste Management and Fuel Cycle Research Center

V-A-1

Fine Structure of Giant Resonance in the ^{28}Si (γ, abs) reaction

Hideo Harada,*[1] Kazuyoshi Furutaka,*[1] Hideaki Ohgaki,*[2] and Hiroyuki Toyokawa*[2]

A paper on this subject was published in J. Nucl. Sci. Technol. **Vol. 38**, No. 7, p. 465, (2001). The content is as follows.

The photo-absorption cross section for ^{28}Si has been measured in the energy range 17.5-21.5 MeV, using a high-resolution high-energy photon spectrometer and laser compton photons. Four intermediate structure peaks in the giant dipole resonance of ^{28}Si have been resolved into about thirty fine-structure peaks. The comparison of the observed structure with those in (γ, p_0) and (γ, n_0) reactions shows that the energies of the fine structure peaks in (γ, *abs*) reaction have a correlation with those in both of the (γ, p_0) and (γ, n_0) reactions.

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*[2] *National Institute of Advanced Industrial Science and Technology*

V-A-2

Development of twin Ge detector and its performance

Y. Shigetome and H. Harada

A paper on this subject was published in Nuclear Instrument and Methods in Physics Research. **A469**, p. 185, (2001). The content is as follows.

Twin Gedetectorconsistsoftwolargegecrystals,closelypackedinacommon housing, has been designed and developed to realize high detection efficiency and peak-to-total ratio (*P/T*) for high-energy photons in the energy range 10-30 MeV. Performance of the twin Ge detector in an energy range up to 30 MeV is calculated by Monte Carlo simulation method. It is shown that this detector allows extending an energy range for high-resolution photon spectroscopy to over 10MeV.

V-A-3

Measurement of the Thermal Neutron Capture Cross Section and the Resonance Integral of the $^{90}Sr(n, \gamma)^{91}Sr$ Reaction

Shoji NAKAMURA[*1], Kazuyoshi FURUTAKA[*1], Hiroaki WADA[*1†], Toshiyuki FUJII[*2], Hajimu YAMANA[*2], Toshio KATOH[*1,*3] and Hideo HARADA[*1]

A paper on this subject is to be published in J. Nucl. Sci. Technol. Vol. 38, No. 12, (2001). The content is as follows.

The thermal neutron capture cross section (σ_0) and the resonance integral (I_0) of the $^{90}Sr(n, \gamma)^{91}Sr$ reaction were measured with an activation method to provide fundamental data for research on nuclear transmutation methods of radioactive wastes. Strontium chloride containing 3.7×10^2 kBq of ^{90}Sr was irradiated for 10 hours in the hydraulic transfer tube facility of Kyoto University Reactor. Flux monitor wires, Co/Al and Au/Al alloy wires, were irradiated together with the targets to determine the neutron flux and the fraction of epithermal component (Westcott's index) at the target position. A high purity Ge detector was used to measure the g rays from the irradiated targets and monitor wires. The σ_0 was obtained as 10.1 ± 1.3 mb, and I_0 as 104 ± 16 mb.

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V-A-4

Precise Measurement of Gamma-ray Emission Probabilities of ^{100}Ru

Kazuyoshi FURUTAKA[*1], Shoji NAKAMURA[*1], Hideo HARADA[*1], Toshio KATOH[*1,*3], Toshiyuki FUJII[*2], and Hajimu YAMANA[*2],

A paper on this subject was published in J. Nucl. Sci. Technol., Vol. 38, No.12, 1035, 2001. The content is as follows.

To precisely determine emission probabilities of γ rays of ^{100}Ru, β-γ coincidence measurements have been performed. A thin plastic scintillator was used to detect β rays emitted from the ground state of ^{100}Tc produced by thermal neutron capture reaction of ^{99}Tc, while γ rays de-exciting the excited states of ^{100}Ru populated via the β decays were detected using a high-purity germanium detector. In the data analysis, ratios of counting rates of β rays in coincidence with one of the ^{100}Ru γ rays to that of β ray singles were deduced at several finite β ray detection threshold energies. The ratios at the zero threshold energy were then deduced by extrapolating the ones at finite threshold energies to take the effect of cascading γ rays into account. From the ratios at the zero threshold energy, the emission probabilities of 539 and 591 keV γ rays of ^{100}Ru, which are emitted following the β decay of ^{100}Tc, were obtained to be 6.6 ± 0.5 % and 5.5 ± 0.3 %, respectively. By following the decay of the two γ rays, half-life of the ^{100}Tc nuclide was determined to be 15.27 ± 0.05 s.

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VI. Kyoto University

A. Research Reactor Institute

VI-A-1

Measurement of Neutron-Induced Fission Cross Sections of ^{229}Th and ^{231}Pa Using Linac-Driven Lead Slowing-Down Spectrometer

Katsuhei Kobayashi[1], Shuji Yamamoto[1], Samyol Lee[1], Hyun-Je Cho[1*],
Hajimu Yamana[1], Hirotake Moriyama[1], Yoshiaki Fujita[1], and Toshiaki Mitsugashira[2]

A paper on this subject was published in the Nuclear Science and Engineering, **139**, 273-281 (2001) with the following abstract.

Use is made of a back-to-back type double fission chamber and an electron linear accelerator-driven lead slowing-down spectrometer to measure the neutron-induced fission cross sections of ^{229}Th and ^{231}Pa below 10 keV relative to that of ^{235}U. A measurement relative to the ^{10}B(n, α) reaction is also made using a BF_3 counter at energies below 1 keV and normalized to the absolute value obtained by using the cross section of the ^{235}U(n,f) reaction between 200 eV and 1 keV.

The experimental data of the ^{229}Th(n,f) reaction, which was measured by Konakhovich et al., show higher cross section values, especially at energies of 0.1 eV to 0.4 eV. The data by Gokhberg et al. seem to be lower than the current measurement above 6 keV. Although the evaluated data in JENDL-3.2 are in general agreement with the measurement, the evaluation is higher from 0.25 eV to 5 eV and lower above 10 eV. The ENDF/B-VI data evaluated above 10 eV are also lower. The current thermal neutron-induced fission cross section at 0.0253 eV is 32.4$\pm$10.7 b, which is in good agreement with results by Gindler et al., Mughabghab, and JENDL-3.2.

The mean value of the ^{231}Pa(n,f) cross sections between 0.37 eV and 0.52 eV, which were measured by Leonard and Odegaarden, is close to the current measurement. The evaluated data in ENDF/B-VI are lower below 0.15 eV and higher above about 30 eV. The ENDF/B-VI and the JEF-2.2 are extremely higher above 1 keV. The JENDL-3.2 data are in general agreement with the measurement, although they are lower above about 100 eV.

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VI-A-2

Measurement of Neutron Capture Cross-Section of Indium in the Energy Region from 0.003 eV to 30 keV

Jungran Yoon[1], Taeik Ro[1], Samyol Lee[2], Shuji Yamamoto[2], and Katsuhei Kobayashi[2]

A paper on this subject was submitted to the Annals of Nuclear Energy with the following abstract.

The neutron capture cross-section of indium (In) has been measured in the energy region from 0.003 eV to 30 keV by the neutron time-of-flight (TOF) method with a 46-MeV electron linear accelerator (linac) of the Research Reactor Institute, Kyoto University. An assembly of $Bi_4Ge_3O_{12}$ (BGO) scintillators, which was composed of 12 pieces of BGO and placed at a distance of 12.7±0.02 m from the neutron source, was employed as a total energy absorption detectors for the prompt capture γ-ray measurement from the sample. In order to determine the neutron flux impinging on the capture sample, a plug of ^{10}B powder sample and the $^{10}B(n, \alpha)$ standard cross-section were used.

The data measured by Haddad et al. seem to be in good agreement with the present measurement. Popov et al. obtained the poor energy resolution data in the resonance region with a lead slowing-down spectrometer and the consistent data with the present above about 300 eV. The experimental data measured by Kononov et al. and Gibbons et al. showed good agreement with the present values in the higher energy region. However, the data measured by Block et al. seem to be a little higher than the present measurement above 800 eV. The evaluated data in ENDF/B-VI, JENDL-3.2, and JEF-2.2 have been in general agreement with the present result in the relevant energy region, although the JENDL-3.2 are higher than the measurement, the ENDF/B-VI and the JEF-2.2 from 2 keV to about 10 keV. Most of the previous experimental and the evaluated thermal neutron cross-sections are generally close to the present value of 199.6±5.6 b at 0.0253 eV.

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VI-A-3

Neutron Capture Cross Section Measurements of Tc-99 and Rh at Energies below 40 keV by Linac Time-of-Flight Method

Katsuhei Kobayashi[1,*], Samyol Lee[1], Shuji Yamamoto[1], Takaaki Yoshimoto[1], Yoshiaki Fujita[1], Guinyun Kim[2], Youngseok Lee[3], and Jonghwa Chang[4]

A paper of this subject was submitted to the International Conference on Nuclear Data for Science and Technology, held on Oct. 7-12, 2001, Tsukuba, Japan.

The neutron capture cross sections of ^{99}Tc and Rh have been measured relative to the ^{10}B(n, α) standard cross section at energies below about 40 keV by the neutron time-of-flight (TOF) method using a 46 MeV electron linear accelerator (linac) at the Research Reactor Institute, Kyoto University (KURRI). A pair of C_6D_6 scintillation detectors has been used for the relative measurement of the ^{99}Tc(n,γ) cross section, and the result has been normalized at 0.0253 eV to the reference cross section value (19.57b) in ENDF/B-VI. A total energy absorption detector, which was composed of 12 pieces of $Bi_4Ge_3O_{12}$ (BGO) scintillators, was employed for the absolute capture cross section measurement of Rh. Both of the cross sections with the existing experimental data and the evaluated data in ENDF/B-VI, JENDL-3.2 and JEF-2.2 have been investigated by comparing with the present results, as seen in the following figures.

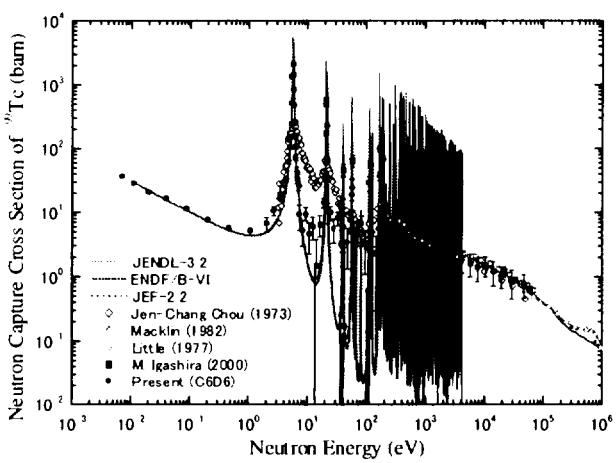

Fig. 1 ^{99}Tc(n, γ) reaction cross section.

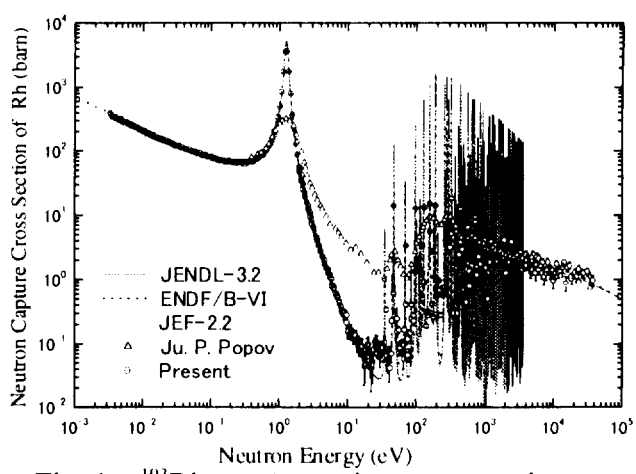

Fig. 1 ^{103}Rh(n, γ) reaction cross section.

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VII. Kyushu University

A. Department of Advanced Energy Engineering and Science

VII-A-1

Calculation of neutron-induced single-event upset cross sections for semiconductor memory devices

T. Ikeuchi, Y. Watanabe, Sun Weili[†], and H. Nakashima

A paper on this subject was published in Proc. of the 2000 Symposium on Nuclear Data, JAERI Conf-2001-006, 327 (2001), with the following abstract:

Neutron-induced single-event upset (SEU) cross sections for semiconductor memory devices are calculated by the Burst Generation Rate (BGR) method using LA150 data and QMD calculation in the neutron energy range between 20 MeV and 10 GeV. The calculated results are compared with the measured SEU cross sections for energies up to 160 MeV, and the validity of the calculation method and the nuclear data used is verified. The kind of reaction products and the neutron energy range that have the most effect on SEU are discussed.

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VII-A-2

Evaluation of Neutron and Proton Nuclear Data of ^{28}Si for Energies up to 200 MeV

Sun Weili[†], Y. Watanabe, E.Sh. Sukhovitskii[‡], O. Iwamoto[*], and S. Chiba[*]

A paper on this subject was published in Proc. of the 2000 Symposium on Nuclear Data, JAERI Conf-2001-006, 247 (2001), with the following abstract:

The neutron and proton nuclear data of ^{28}Si up to 200 MeV are evaluated for various nuclear engineering applications. The soft rotator model and the coupled-channel method are used to perform a consistent analysis of the collective band structure of ^{28}Si and nucleon scattering from ^{28}Si. The GNASH nuclear model code is used for compound and preequilibrium particle emission calculations, where the emission of ^{3}He is also included. Comparisons show overall good agreement with various experimental data.

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[‡] Radiation Physics and Chemistry Problems Institute, Belarus
[*] Japan Atomic Energy Research Institute

VII-A-3

Development of Quasi-Monoenergetic Neutron Source Using the $^{1}H(^{13}C,n)$ Reaction

Y. Watanabe, Y. Matsuoka, H. Nakamura, H. Nakashima, N. Ikeda[†], and K. Sagara[‡]

A paper on this subject was published in Engineering Sciences Reports, Kyushu University, **23**, 285 (2001), with the following abstract:

We have developed a new type of monoenergetic neutron source at the Kyushu University Tandem Laboratory using the inverse (p,n) reaction kinematics. The $^{1}H(^{13}C,n)$ reaction was chosen as a promising candidate. A major part of the neutron source consists of a hydrogen gas target having an entrance window made of 3 μm-thick tantalum foil and a 0.2 mm-thick tantalum disk as the beam stopper. An experiment for the feasibility test was performed using 56.0 and 59.3 MeV $^{13}C^{6+}$ beams. The preliminary result showed that the $^{1}H(^{13}C,n)$ reaction can produce the kinematically-collimated monoenergetic neutrons in the MeV region.

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[‡] Department of Physics, Kyushu University

VII-A-4

Semiclassical Distorted Wave Model Analysis of Inclusive $(N,N'x)$ Reactions for Incident Energies up to 400 MeV

Y. Watanabe, Weili Sun[†], K. Ogata[‡], M. Kohno* and M. Kawai[¶]

A paper on this subject was presented at Int. Conf. on Nuclear Data for Science and Technology, October 7–12, 2001, Tsukuba, Japan, with the following abstract:

The semiclassical distorted wave (SCDW) model with the Wigner transform of a one-body density matrix is applied to analyses of multistep direct processes in $(p,p'x)$ reactions on ^{12}C, ^{90}Zr, and ^{197}Au at incident energies near 150 MeV, and 392 MeV $(p,p'x)$ and 346 MeV (p,nx) reactions on ^{40}Ca. The calculations show good agreement with experimental double-differential cross sections over a wide mass range of target nuclei, except at backward angles.

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*Physics Division, Kyushu Dental College
[¶]Department of Physics, Kyushu University

VII-A-5

Light Charged-Particle Production in Proton-Induced Reactions on ^{12}C, ^{27}Al, ^{58}Ni, ^{90}Zr, ^{197}Au, and ^{209}Bi at 42 and 68 MeV

M. Harada†, Y. Watanabe, Y. Tanaka, Y. Matsuoka, K. Shin‡, S. Meigo†, H. Nakashima†, H. Takada†, T. Sasa†, O. Iwamoto†, T. Fukahori†, S. Chiba†, and S. Tanaka†

A paper on this subject was presented at Int. Conf. on Nuclear Data for Science and Technology, October 7–12, 2001, Tsukuba, Japan, with the following abstract:

Double-differential cross sections (DDXs) have been measured for light-charged particle production in proton-induced reactions on ^{12}C, ^{27}Al, ^{58}Ni, ^{90}Zr, ^{197}Au, and ^{208}Bi at incident energies of 42 and 68 MeV. The measured DDXs for ^{12}C, ^{27}Al, and ^{58}Ni are compared with the LA150 evaluation. Good overall agreement is found except for the (p, xd) reaction. The dependence of total yields of secondary charged-particles on target mass number is investigated.

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VII-A-6

Evaluation of Cross Sections for Neutrons and Protons up to 200 MeV on Silicon Isotopes

W. Sun†, Y. Watanabe, E.Sh. Sukhovitskiĭ‡, O. Iwamoto*, and S. Chiba*

A paper on this subject was presented at Int. Conf. on Nuclear Data for Science and Technology, October 7–12, 2001, Tsukuba, Japan, with the following abstract:

Neutron and proton nuclear data of $^{28,29,30}Si$ for energies from 20 MeV to 200 MeV are evaluated for various nuclear engineering applications. The soft rotator model and the coupled-channels method are used to perform a consistent analysis of the collective band structure and nucleon scattering data. The GNASH nuclear model code is used for compound and preequilibrium particle emission calculations including neutron, proton, deuteron, triton, ^{3}He, and α-particle. The evaluated results are compared with various experimental data and the LA150 evaluation.

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VII-A-7

Calculation of Light-Hadron Induced Single-Event Upset Cross Section for Semiconductor Memory Devices

T. Ikeuchi, Y. Watanabe, Weili Sun[†], and H. Nakashima

A paper on this subject was presented at Int. Conf. on Nuclear Data for Science and Technology, October 7–12, 2001, Tsukuba, Japan, with the following abstract:

Light-hadron induced single-event upset (SEU) cross sections for semiconductor memory devices are calculated by the Burst Generation Rate (BGR) method using LA150 data and JQMD calculation in the incident energy range between 20 MeV and 3 GeV. The calculated results are compared with experimental SEU cross sections, and the validity of the calculation method and the nuclear data used is examined. The range of the incident energy and the atomic and mass numbers of the reaction products that provides the important effects on SEU are investigated.

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VII-A-8

Continuum Cross Sections for Proton-induced Reactions on Biologically-important Target Nuclei

G.F. Steyn[†], A.A. Cowley[‡], Y. Watanabe, Weili Sun[*], S.V. Förtsch[†], and J.J. Lawrie[†]

A paper on this subject was presented at Int. Conf. on Nuclear Data for Science and Technology, October 7–12, 2001, Tsukuba, Japan, with the following abstract:

Continuum spectra from the (p,p') reaction on ^{12}C, ^{14}N and ^{16}O at incident energies of 150 and 200 MeV have been measured at scattering angles from 20° to 150°. The angular distributions at several emission energies are compared with theoretical predictions by means of the semi-classical distorted wave (SCDW) model. It is found that a statistical multistep direct (MSD) interpretation is appropriate also for these very light target nuclei.

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[*]Department of Applied Quantum Physics and Nuclear Engineering, Kyushu University

VII-A-9

NWY Model Calculations for Nucleon-Induced Multistep Direct Reactions

T. Kawano and S. Yoshida†

A paper on this subject was presented at Int. Conf. on Nuclear Data for Science and Technology, October 7–12, 2001, Tsukuba, Japan, with the following abstract:

Calculations of the preequilibrium process are performed with the theory of Nishioka, Weidenmüller, and Yoshida (NWY), which is a quantum mechanical approach to the preequilibrium nuclear reactions. For a one-step process, cross sections given by the NWY theory are sum of DWBA cross sections which excite various 1p-1h states, and those are averaged over the residual state weighted by the final states density. A true level density which is based on a random matrix model is used for this. A comparison of the calculated NWY one-step process with the experimental data is shown. For a two-step process, the NWY theory adopts a "sudden approximation." An example of the two-step cross section calculation is made for ^{208}Pb(p,p') reaction.

† Department of Physics, Tohoku University

VII-A-10

Interference Effect in the Scattering Amplitudes for Nucleon-Induced Two-Step Direct Process Using the Sudden Approximation

T. Kawano and S. Yoshida†

A paper on this subject was published in Phys. Rev. C, **64**, 024603 (2001), with the following abstract:

An implementation of calculation for two-step cross sections of the theory of Nishioka, Weidenmüller and Yoshida is described. Cross sections which excite a 2p-2h state are expressed in J-scheme, and a Yukawa interaction is assumed for the particle-hole pair creation. The Green's function which connects the one-step matrix element to the two-step one is represented in r-space. An interference effect among the amplitudes for the different intermediate states is examined by means of a spectroscopic amplitude. A strong interference appears for a certain configuration, and this is interpreted by a Boson approximation. Microscopically calculated two-step cross sections for ^{208}Pb(p,p') reactions are averaged together with the true level density which is based on the random matrix theory to give a two-step cross section to the continuum energy region.

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Effect of the Preequilibrium Process upon Fast Neutron Fission Spectra from ^{238}U

T. Kawano, T. Ohsawa[†], M. Baba[‡], T. Nakagawa[*]

A paper on this subject was published in Phys. Rev. C, **63**, 034601 (2001), with the following abstract:

A preequilibrium process for the prefission neutron which is emitted before scission is calculated with the model of Feshbach, Kerman, and Koonin. A forward-peaked angular distribution of the neutron emission from ^{238}U bombarded by 14 and 18 MeV neutrons is expressed with the statistical multistep compound process and the one-step direct process. The fission neutron energy spectra are calculated with the model of Madland and Nix, with some modifications by Ohsawa *et al.* The calculated total neutron emission spectra and their energy-angle distributions (double-differential cross sections) are compared with the experimental data, and a strength of the residual interaction V_0 is estimated. The comparisons of the calculations with the experimental data show that the 14 MeV data are well reproduced but the 18 MeV data are underestimated. Anisotropy is seen in the angle-differential fission spectra, and this is due to an existence of the prefission neutron.

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VIII. Nagoya University

A. Department of Energy Engineering and Science

VIII-A-1

Measurement of activation cross-sections of (n, np+d) reactions producing short-lived nuclei in the energy range between 13.4 and 14.9 MeV using an intense neutron source OKTAVIAN

H. Sakane, Y. Kasugai[1], M. Shibata, T. Iida[2],
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A paper on this subject was published in Annals of Nuclear Energy 29 (2002) 53-66, with the following abstract.

Activation cross sections for seventeen (n,np+d) reactions producing short-lived nuclei with half-lives between 42 s and 23 min, were measured in the energy range between 13.4 and 14.9 MeV by an activation method. The measured target isotopes were ^{26}Mg, ^{29,30}Si, ^{53,54}Cr, ^{67}Zn, ^{87}Sr, ^{98,100}Mo, ^{102}Ru, ^{105,106,108}Pd, ^{123}Te, ^{163}Dy, ^{179}Hf and ^{189}Os. Eleven cross sections for ^{26}Mg, ^{30}Si, ^{87}Sr, ^{100}Mo, ^{102}Ru, ^{105,106}Pd, ^{123}Te, ^{163}Dy, ^{179}Hf and ^{189}Os were obtained for the first time, and four cross sections for ^{53,54}Cr, ^{67}Zn and ^{108}Pd were obtained at six-point energies for the first time.

An intense 14 MeV neutron source, OKTAVIAN at Osaka University was used for irradiation. All cross section values were relatively obtained on the basis of the standard cross section of ^{27}Al(n,α)^{24}Na reaction (ENDF/B-VI). To obtain reliable neutron activation cross sections, careful attention was paid to neutron irradiation and induced activity measurement.

The present results were compared with the evaluated data in JENDL-3.2, JENDL-Activation File and ENDF/B-VI. The cross sections are underestimated for ^{102}Ru and ^{108}Pd in JENDL-3.2.

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VIII-A-2

Decay scheme of ^{126}La isomers

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A. Osa[1], M. Koizumi[1] and T. Sekine[1]

A paper on this subject will be published in Appl. Radiat. Isot., with the following abstract.

The decay of ^{126}La has been studied using the isotope separator on-line connected to an AVF cyclotron. For the ^{126}La radioactive sources produced by the ^{94}Mo (^{36}Ar, 3pn) reaction. γ-γ singles, γ-γ angular correlation and internal conversion electron measurements were carried out. From analysis of these data, 138 new γ-transitions were found for the decay of ^{126}La, and the decay scheme containing 137 γ-rays and 50 excited states was constructed. The probable spin and parity of the two b-decaying states in ^{126}La were found to be 4^+, 5^+ for the high-spin isomer with a half-life of 52(2) s and 0^+, 1^+, 2^+ for the low-spin isomer with a half-life far shorter than 50 s.

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VIII-A-3

A precise method of Q_β determination with small HPGe detector in an energy range of 1-9 MeV

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Y.Kawase[1], K. Shizuma[2]

A paper on this subject was published in Nuclear Instruments and Methods A 458 (2001) 656-669, with the following abstract.

The present paper describes a method to obtain accurate β^+-ray maximum energies with small HPGe detectors. In order to unfold $\beta^\pm$-ray spectrum observed, response functions for monoenergetic electrons and positrons were experimentally determined for four different sizes of HPGe detectors with diameters of 16-50 mm and with thicknesses of 10-13 mm. The reliability of the unfolding procedure was confirmed by a comparison between the experimental and its well-evaluated Q_β-value. The systematic errors is estimated to be 20 keV in an endpoint energy range of 1-4 MeV, and 30 keV in 4-9 MeV. The present method was applied for the Q_β measurement of the 2^-- isomer of ^{146}La; the Q_β-value was obtained to be 6580(60) keV.

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VIII-A-4

Normalization of gamma-gamma angular correlation coincidence counts using characteristic X-rays

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A. Osa[1], K. Koizumi[1], T. Sekine[1]

A paper on this subject was published in Nuclear Instruments and Methods A 463 (2001) 205-212, with the following abstract.

A new method to normalize coincidence counts for γ-γ correlations measured with a multi- Ge-detector system is described. This method uses characteristic KX-rays emitted following internal conversion or electron capture, which exhibit a coincidence with g-rays and an isotopic KX-γ angular correlation. Only the ratios between KX-ray counts and other quantities such as detector efficiencies, γ-ray singles counts and other kinds of efficiencies are required. Performance of this method was tested in on-line experiments using mass-separated ^{126}La and ^{128}La.

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IX. National Defense Academy

A. Department of Mathematics and Physics

IX-A-1

Folding Model Potential for the Neutron Direct Capture of ^{12}C and ^{16}O

Hideo Kitazawa, Masayuki Igashira*, Toshiro Ohsaki*, and Takayuki Matsushima

A paper of this title will be published in the Proc. Int. Conf. on Nuclear Data for Science and Technology, Oct. 7-12, 2001, Tsukuba, Japan, with the following abstract:

Folding model potentials of ^{12}C and ^{16}O are obtained for neutrons, using a nucleon-density distribution and the effective nucleon-nucleon interaction DDM3Y. These folded potentials, instead of a phenomenological optical potential, are applied to the calculation for the direct capture of low-energy neutrons on ^{12}C and ^{16}O. As a result, it is concluded that an observation of the neutron direct capture would be very useful to acquire the information on the nucleon-density distribution near the nuclear surface.

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A. National Metrology Institute of Japan

X-A-1

Characterization of a Thermal Neutron Field at the Heavy Water Neutron Irradiation Facility of the Kyoto University Reactor

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The heavy water neutron irradiation facility of the Kyoto University Reactor has been used for boron neutron capture therapy. It is necessary to make a clinical treatment plan prior to the treatment for effective therapy. It is desirable to measure the neutron flux and its spatial distribution just before the treatment, to make the reliable clinical treatment plan. The neutron flux distribution is normally obtained with a gold wire activation method. It takes, however, considerable time to obtain the neutron flux distribution with the activation method. We have tried to quickly obtain the neutron flux by using a small neutron probe[1)].

The probe consists of a thin optical fiber made of quartz glass and a very small scintillator assembly. The assembly consists of a thin film-like ZnS(Ag) that is bonding on a thin Mylar film[2)], and small amount of ^{6}LiF powder, as a neutron converter, put on the scintillator. The diameter of the assembly is 600μm. The assembly is coupled to an end surface of the optical fiber. A thin aluminum cap covers the assembly and the coupling section for light shielding. A photomultiplier is connected to the other end of the optical fiber. The scintillation signals are detected by the photomultiplier and processed with a NIM signal processing chain. The neutron flux distribution is obtained by moving the probe together with the optical fiber back and forth.

Figure 1 shows the pulse height distribution of the neutron probe. Gamma rays or electrons deposit lower energy in the scintillator compared to thermal neutrons that deposit energy through ^{6}Li(n, t)α reactions. Gamma-ray events, therefore, can easily be rejected by an ordinary pulse height discrimination method. Figure 2 shows the neutron flux distribution from the front surface of the Bi filter of the facility when the irradiation mode was 000011[3)] and the reactor power was 5MW. It took only several minutes to obtain the distribution. The absolute value of the thermal neutron flux was measured with a gold foil activation method. The activity of a gold foil with a thickness of 1 μm was measured with

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a $4\pi\beta$-γ coincidence technique. The neutron flux at 30cm from the surface of the Bi filter was $(3.07 \pm 0.03) \times 10^8 /cm^2 \cdot s$.

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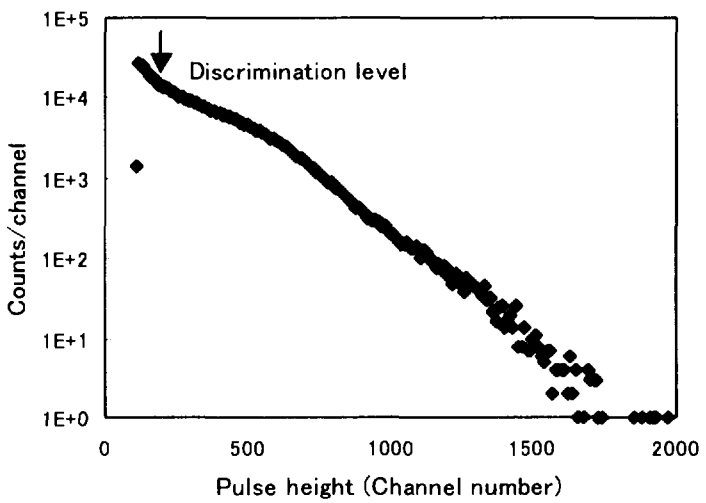

Fig.1 Pulse height distribution of the neutron probe.

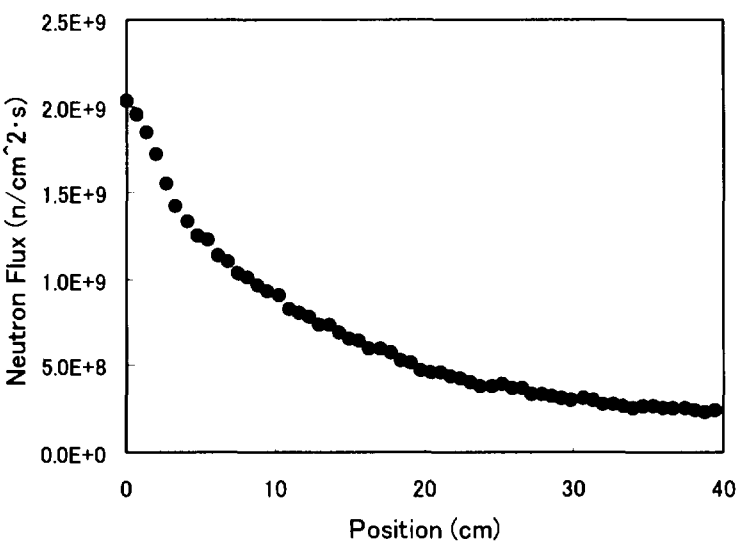

Fig. 2 Thermal neutron flux distribution at the heavy water neutron irradiation facility.

XI. Osaka University

A. Department of Nuclear Engineering

6 papers were presented at the ND2001 Nuclear Data Conference, October 2001, Tsukuba Japan, and submitted to its Proceedings which will be published as a supplement of J. Nuclear Science and Technology, 2002 Titles, authors and abstracts are copied in the following.

XI-A-1

Recent Measurements of Nuclear Data and Integral Tests for Fusion Reactor Application

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Differential and integral experiments including measurements of neutron, gamma-ray and charged particle emission DDXs, (n,2n) reaction cross section and leakage neutron and gamma-ray spectra from slab assemblies have been carried out at OKTAVIAN of Osaka University and FNS of JAERI. The measured data were utilized for benchmarking of five nuclear data files of JENDL-3.2, JENDL-fusion file, ENDF/B-VI, FENDL/E-1.0 and FENDL/E-2.0. In the present paper, their recent results are summarized.

XI-A-2

(n,2n) Reaction Cross Section Measurement with A Beam DT Neutron Source

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The method has been established to measure (n,2n) reaction cross section with the coincidence detection technique using a newly developed pencil beam DT neutron source at FNS of JAERI. A cylindrical manganese, the (n,2n) cross section of which was measured precisely with the foil activation method, was used to check the experimental method. It was confirmed from the experimental results that the present new method was basically functioning to measure only two neutrons emitted through (n,2n) reaction. Considering the not so strong angular dependence for Mn, by adoption of the TOF measurement the cross sections especially for medium heavy elements can be accurately determined. Consequently, by the present method, it is expected that complete (n,2n) reaction cross section measurements for stable-isotope producing elements by (n,2n) reaction would become possible with the coincidence detection and TOF methods.

XI-A-3

Fusion Neutronics Benchmark Experiment on Structural and Advanced Blanket Materials - Leakage Neutron Spectrum Measurement -

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Fusion neutronics benchmark experiments for copper and tungsten and advanced breeder materials of $LiAlO_2$, Li_2TiO_3 and Li_2ZrO_3 have been conducted at FNS of JAERI to validate five nuclear data files, i.e., JENDL-3.2, JENDL Fusion File, ENDF/B-VI, FENDL/E-1.0 and FENDL/E-2.0. From the result, all the nuclear data files were confirmed to be fairly reliable with respect to the prediction of neutron spectrum. However, some problems were pointed out. Especially for Zr, the discrepancy between the experimental and calculated spectra is remarkably large.

XI-A-4

Measurements of Secondary Gamma-Ray Production Cross Sections for ^{nat}Fe, ^{51}V, ^{nat}Mo, ^{nat}Zr, ^{nat}Ni and ^{181}Ta with Hp-Ge Detector Induced by DT Neutrons

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Secondary gamma-ray production cross sections for ^{nat}Fe, ^{51}V, ^{nat}Mo, ^{nat}Zr, ^{nat}Ni and ^{181}Ta induced by DT neutrons have been measured with an Hp-Ge detector at OKTAVIAN ,the Intense 14MeV Neutron Source Facility of Osaka University, Japan. A new method to analyze the measured spectrum was proposed to yield the continuum component of the gamma-ray production cross section. The measured data were compared with the theoretical calculation results with SINCROS-II and evaluated nuclear data.

XI-A-5

Fusion Neutronics Benchmark Experiment on Structural and Advanced Blanket Materials - Leakage Gamma-ray Spectrum Measurement -

Takashi Nishio[1], Yasuaki Terada[1,*], Isao Murata[1], Akito Takahashi[1], Fujio Maekawa[2], Takeo Nishitani[2] and Hiroshi Takeuchi[2]
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Benchmark experiments have been carried out to validate the nuclear data files of JENDL-3.2, JENDL fusion file, ENDF/B-VI, FENDL/E-1.0 and FENDL/E-2.0 for blanket materials of $LiAlO_2$, Li_2TiO_3 and Li_2ZrO_3 and structural materials, i.e., C, V, Fe, SS-316, Cu, Pb and W. Some discrepancies between measured and calculated spectra were observed. However, the C/E values for the energy multiplied integral spectrum show that all of the nuclear data files were fairly reliable.

XI-A-6

Measurements of Double Differential Cross Sections for Charged Particle Emission Reactions by 14.1MeV Incident Neutrons

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The double-differential cross sections for the ^{27}Al (n,x α), ^{27}Al, (n,xp), ^{nat}Ti(n,x α), ^{nat}Ti(n,xp), ^{nat}Zr(n,xp), ^{19}F(n,x α), ^{19}F(n,xp) and ^{nat}Si(n,xp) reactions at 14.1-MeV incident neutrons have been measured by using the two-dimensional energy and time-of-flight (E-TOF) charged-particle spectrometer. The measured data were compared with other experimental data, theoretical calculation results with SINCROS-II and evaluated nuclear data. As a result, fairly good agreements were obtained for aluminum and zirconium. However, for titanium, silicon and fluorine, underestimation of evaluated nuclear data was seen in the whole energy range of the spectra.

B. Faculty of Science

XI-B-1

Gamow-Teller Transitions from ^{58}Ni to Discrete States of ^{58}Cu

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Under the assumption that isospin is a good quantum number, symmetry is expected for the transitions from the ground states of $T = 1, T_z = \pm 1$ nuclei to the common excited states of the $T_z = 0$ nucleus. The symmetry can be studied by comparing the strengths of Gamow-Teller (GT) transitions obtained form a (p, n)-type charge-exchange reaction on a target nucleus with $T_z = 1$ and those from the β decay of $T_z = -1$ nucleus.

Among the $T = 1 \rightarrow 0$ candidates, we find that analogous transitions in $A = 58$ system, i.e., ^{58}Ni($T_z = 1$) to ^{58}Cu($T_z = 0$) and ^{58}Zn($T_z = -1$) to ^{58}Cu are suited for the accurate study of isospin symmetry. The former can be studied in a (p, n)-type CE reaction on the ^{58}Ni target, while the latter in the β decay of ^{58}Zn. The $A = 58$ system is attractive from both β-decay as well as CE reaction sides. They are (a) the β decay of ^{58}Zn has a large Q_{EC} value of 9.37 MeV, which allows the study of B(GT) values up to highly excited region: (b) the B(GT) values in the ^{58}Ni to ^{58}Cu transitions are determined independently of the ^{58}Zn β-decay study; since the ground states of ^{58}Cu and ^{58}Ni have $J^\pi = 1^+$ and 0^+, respectively, the B(GT) value of the ground-states transition obtained in the β decay of ^{58}Cu can be used as the calibration standard of B(GT) values obtainable in the CE reaction. If both type of analogous GT transitions can be measured, and compared, the isospin symmetry structure of nuclei with the same mass number can be studied. The β decay of ^{58}Zn to a few low-lying states of ^{58}Cu has been studied [1]. In addition, a plan to measure the β-delayed proton up to high excited states by using a "Silicon Ball" is in progress at ISOLDE, CERN [2].

As a part of the study, the GT transitions from $T_z = 1$ nucleus ^{58}Ni to $T_z = 0$ ^{58}Cu have been studied by using the zero-degree (^{3}He, t) reaction at 150 MeV/nucleon. In the study of GT transitions from ^{58}Ni to ^{58}Cu using a (p, n)-type CE reactions, important is the resolution allowing the study of strength of individual transition. It is found that (^{3}He, t) reaction is a good tool for such purpose. The good resolution of it has changed the image of the Gamow-Teller resonance in ^{58}Cu; fine structure has been observed [3] for the broad bump structure observed in the pioneering (p, n) reaction [4].

In April, 2000, a new beam line called "WS course" commissioned at RCNP, Osaka [5, 6]. It enables an accurate realization of dispersion matching and angular dispersion matching [7, 8]. Using a 150 MeV/u ^{3}He beam from the $K = 400$ RCNP Ring Cyclotron, further improvement of energy resolution, a resolution of 50 keV (FWHM), has been achieved (see the spectrum shown in Fig. 1) in combination with the spectrometer Grand Raiden [9]. States have been clearly resolved up to 8 MeV excitation, approximately the

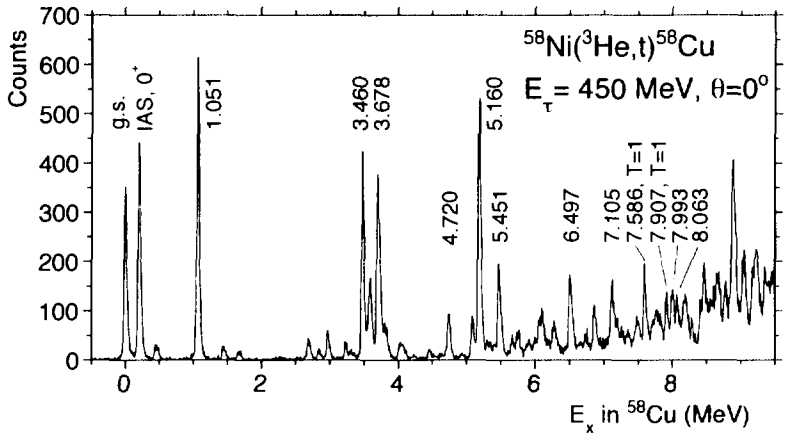

Figure 1: The ^{58}Ni(^{3}He, t)^{58}Cu spectrum measured at 0° with a resolution of 50 keV, the world-record resolution in a charge-exchange reaction at intermediate incident energies. Major states identified to have $L = 0$ character are indicated by their excitation energies.

maximum energy reached by the study of β decay. Owing to the energy resolution of 50 keV, there is almost no ambiguity in drawing the line of continuum in the energy region up to $E_x \leq 8$ MeV.

The yield of each peak was accurately obtained by employing a peak-decomposition program using the peak shape of the well-separated peak at 1.05 MeV as reference. The angular distribution of each peak was studied at three different angle cuts ($\theta \leq 0.25°$, $\theta = 0.25° - 0.5°$ and $\theta = 0.5° - 0.75°$). The ^{58}Cu states with a relative decrease in strength similar to that of the known 1^+ state at 1.052 MeV were assigned to be $L = 0$ GT states.

As the calibration standard, the B(GT) value from the β-decay ^{58}Cu g.s. $\rightarrow$ ^{58}Ni g.s. was used, because the g.s. of ^{58}Cu has $J^\pi = 1^+$. Using the accurate branching ratio of 81.2(5)% to the g.s. of ^{58}Ni measured by the total absorption spectrometer at GSI Darmstadt [10], B(GT) value for the transition ^{58}Ni g.s. $\rightarrow$ ^{58}Cu g.s. is obtained to be $B(\mathrm{GT}) = 0.155 \pm 0.001$. The B(GT) values of transitions to the other GT states was obtained using the proportional relationship between the reaction cross sections at 0° and B(GT) values given by [11, 12]

$$\frac{d\sigma^{\mathrm{CE}}}{d\Omega}(0°) \simeq K^{\mathrm{CE}} N^{\mathrm{CE}}_{\sigma\tau} |J_{\sigma\tau}(0)|^2 B(\mathrm{GT}), \tag{1}$$

where $J_{\sigma\tau}(0)$ is the volume integral of the effective interaction $V_{\sigma\tau}$ at $q = 0$, K^{CE} the kinematic factor for the CE reaction, and $N^{\mathrm{CE}}_{\sigma\tau}$ the distortion factor. The product $K^{\mathrm{CE}} N^{\mathrm{CE}}_{\sigma\tau}$ gradually decreases as the E_x value of the final nucleus increases. For estimating the change of the factor, a DWBA calculation was performed using the code DW81 [13]. It was found that the calculated 0° cross section decreases by about 10 % at $E_x = 8$ MeV. The resulting experimental B(GT) strengths are listed in Table 1 and shown in Fig. 2.

The uncertainties of these B(GT) values were estimated by taking into account the statistics of peak counts, ambiguities in the peak decomposition and the uncertainty of the B(GT) value in the β-decay measurement. The uncertainties due to the subtraction of the continuum were neglected. Since the proportionality is not well established for weak transitions with $B(\mathrm{GT}) < 0.04$, the uncertainties for them may be underestimated.

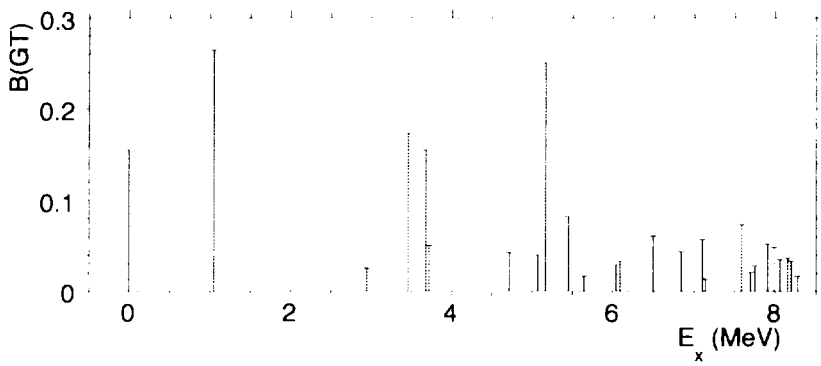

Figure 2: The B(GT) distribution studied in the high-resolution ^{58}Ni(^{3}He, t)^{58}Cu experiment.

The GT states which are analogous to the $M1$ states in ^{58}Ni are identified from the correspondence of both excitation energies and transition strengths. By using the nuclear resonance fluorescence (NRF) method and linearly polarized bremsstrahlung photons [15], a clear 1^+ identification was made for the 7.389 and 7.710 MeV states in ^{58}Ni in the region up to E_x = 8 MeV. The $M1$ assignment was also made for these states in the (e, e') reaction [16]. It was found that the 7.586 and 7.907 MeV GT states correspond to the well-assigned $M1$ states at 7.389 and 7.710 MeV, respectively. They are identified to have the isospin value $T = 1$, that of the mother nucleus ^{58}Ni.

Further discussions on the B(GT) strengths and the identification of isospin T are found in a paper accepted for publication in Eur. Phys. J. A.

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Table 1: Discrete states in ^{58}Cu and B(GT) values deduced from ^{58}Ni(^{3}He,t) measurements. The E_x values are in units of MeV. The literature E_x values are accurate within less than 1 keV. The B(GT) values are given to the states assigned to have $L = 0$ character. For details of the errors of B(GT) values, see text. Isospin value $T = 0$ is assigned to all the $L = 0$ states unless $T = 1$ is indicated.

Nucl. Data Sheets[a]		(^{3}He,t)		
E_x	J^π	E_x	B(GT)	isospin
0.0	1^+	0.0	0.155(1)[b]	
0.203	0^+	0.204	-	$T = 1$
0.444	(3^+)	0.444	-	
1.051	(1^+)	1.051	0.265(13)	
1.428	2^+	1.427	-	
1.652	2^+	1.651	-	
		2.949	0.025(3)	
		3.460	0.173(11)	
		3.678	0.155(10)	
		3.717	0.050(5)	
		4.720	0.042(4)	
		5.065	0.040(4)	
		5.160	0.250(14)	
		5.451	0.082(7)	
		5.645	0.016(3)	
		6.038	0.029(4)	
		6.086	0.033(4)	
		6.497	0.061(7)	
		6.844	0.044(5)	
		7.105	0.057(6)	
		7.143	0.014(4)	
		7.586	0.073(7)	$T = 1$
		7.700	0.021(4)	
		7.752	0.028(5)	
		7.907	0.052(5)	$T = 1$
		7.993	0.049(5)	
		8.063	0.035(5)	$(T = 1)$
		8.159[c]	0.037(5)	
		8.199[c]	0.033(4)	
		8.282[c]	0.016(4)	

[a] From ref. [14].
[b] Value from β-decay measurement, which is used as a $B(GT)$ standard.
[c] $L = 0$ assignment is less certain.

XII. Tohoku University

A. Cyclotron and Radioisotope Center

XII-A-1

Measurements of Double-Differential Neutron Emission Cross Sections of ^{238}U and ^{232}Th for 2.6, 3.6 and 11.8 MeV Neutrons

T. Miura, M. Baba, M. Ibaraki, T. Win, T. Sanami, Y. Hirasawa

A paper of the title was published in Annals of Nuclear Energy 28 (2001) p.937-951, with the following abstract.

Double-differential neutron emission cross sections (DDXs) of ^{238}U and ^{232}Th were measured for 2.6, 3.6 and 11.8 MeV incident neutrons using a time-of-flight (TOF) method at the Tohoku University 4.5 MV Dynamitron accelerator facility. In DDXs for En=2.6 MeV, discrete structures by vibrational level groups are visible clearly around excitation energy (Ex) around 0.75 and 1.15 MeV, while inelastic scattering to continuum-levels become dominant at En=3.6 MeV for both nuclei. For En=11.8 MeV, continuum structures with strong forward peaking are dominant with some discrete structures at around 0.7 – 4.0 MeV excitation energy for both of ^{238}U and ^{232}Th. Partial cross sections for the elastic and inelastic scattering processes were also derived from the DDX data.

XII-A-2

Measurement of Differential Neutron-Induced Charged-Particle Emission Cross Sections for 5 - 75 MeV Neutrons

Baba, M., Sanami, T., Nauchi, Y., Hirasawa, Y., Hirakawa, N., Nakashima, H.[1],. Meigo, S[1]., and Tanaka, S.[2]

A paper of the title was published in the proceedings of the Tenth International Symposium on Reactor Dosimetry (1999, Osaka) (*ASTM STP 1398*) p.447-454 with the following abstract.

Differential cross sections have been measured for the reaction for the $^{16}O(n,x\alpha)$ reaction between 11.5 and 15 MeV using a gridded-ionization chamber with gas samples, and the Fe, Ni(n,xp), (n,xd), $(n,x\alpha)$ reactions at 55 and 75 MeV using a $^{7}Li(p,n)$ source and multiple counter telescopes. The results were favorably compared with ENDF/B-VI, JENDL-3.2, and LA-150 library, but in marked disagreement in some cases.

[1] Tokai Establishment, Japan Atomic Energy Research Institute
[2] Takasaki Establishment, Japan Atomic Energy Research Institute

XII-A-3

Experimental Studies on the Neutron Emission Spectrum and Induced Radioactivity of the ^{7}Li(d,n) Reaction in 20-40 MeV region

M.Baba, T. Aoki, M. Hagiwara , M. Sugimoto[1], T. Miura, N. Kawata, A. Yamadera, H. Orihara

A paper of the title was presented in the Tenth International Symposium on Fusion Reactor Materials (2001, Barden-Barden) with the following abstract and will be published in Journal of Reactor Materials.

To improve the data accuracy of the neutron emission spectrum of ^{7}Li(d,n) reaction and the radioactivity (^{7}Be, ^{3}H etc) accumulated in the ^{7}Li target in IFMIF, we have measured the neutron emission spectrum and the radioactivity of induced in the lithium target for 25 MeV deuterons at the Tohoku University AVF cyclotron (K= 110) facility.
Neutron spectra were measured with the time-of-flight method at four laboratory angles by using a beam swinger system and a well collimated time-of-flight channel. Induced radioactivity was measured by detecting the gamma-rays from ^{7}Be with a pure Ge detector.

Experimental results are compared with other experimental data. The present result of neutron emission spectra are in qualitative agreement with other experimental data but that of ^{7}Be production was much larger than expected by the recent codes. Measurement will be extended to several incident energies up to 40 MeV.

[1] Tokai Establishment, Japan Atomic Energy Research Institute

XIII. Tokyo Institute of Technology

XIII-1

Measurement of Capture Gamma-Rays from the Broad 53-keV and the Narrow 35-keV Neutron Resonances of ^{23}Na

M. Igashira, T. Ohsaki, J. Hori, S. T. Park and S. Y. Lee

A paper of the title was published in J. Nucl. Sci. Technol., **38**, 91 (2001) with the following abstract.

The capture γ rays from the broad 53-keV and the narrow 35-keV p-wave neutron resonances of ^{23}Na were measured using a large anti-Compton HPGe γ-ray spectrometer. A neutron time-of-flight method was adopted with a 1.5-ns wide pulsed-neutron source by the ^{7}Li(p,n)^{7}Be reaction. The standard capture cross sections of ^{197}Au and a pulse-height weighting technique were employed to determine the number of neutrons incident on a capture sample. The numbers of observed primary γ-ray transitions were 15 and 13 for the 53- and 35-keV resonances, respectively. The partial capture kernels and the partial radiative widths corresponding to these transitions were derived for the first time. The total radiative widths of these resonances were also derived. The present results are compared with measurements by other authors and evaluations. Moreover, a new 4,909-keV state in ^{24}Na was found and its spin and branching ratio were determined from the analysis of the γ-ray transitions form the narrow 35-keV resonance.

XIII-2

Measurement of keV-Neutron Capture Cross Sections for ^{164}Dy

M. Igashira, T. Ohsaki, S. Mizuno, S. Y. Lee, G. Kim, Y. Lee, I. S. Ko, M. Cho, W. Namkung, D. Lee, H. Kim, Y. Kim, T. Ro, Y. Min and J. Moon

A paper of the title was published in Ann. Nucl. Energy, **28**, 1549 (2001) with the following abstract.

The neutron capture cross-sections of ^{164}Dy were measured in the neutron energy region of 10 to 90 keV using 3-MV Pelletron accelerator of the Research Laboratory for Nuclear Reactors at the Tokyo Insititute of Technology. Pulsed keV neutrons were produced from the ^{7}Li(p,n)^{7}Be reaction by bombarding a lithium target with the 1.5-ns bunched proton beam from the Pelletron accelerator. The incident neutron spectrum on a capture sample was measured by means of a TOF method with a ^{6}Li-glass detector. Capture γ-rays were detected with a large anti-Compton NaI(Tl) spectrometer, employing a TOF method. A pulse-height weighting technique was applied to observed capture γ-ray pulse-height spectra to derive capture yields. The capture cross-sections were obtained by using the standard capture cross-sections of ^{197}Au. The present results were compared with the previous measurements and the evaluated values of ENDF/B-VI.

XIV. University of Tsukuba

A. Tandem Accelerator Center

XIV-A-1

Radiation dose measurement at Tandem Accelerator Center of University of Tsukuba

T. Komatsubara[1], K. Shima[1], K. Sasa[1], T. Katabuchi[1], Y. Yamato[1], S. Ishii[1], T. Takahashi[1], H. Kimura[1], H. Oshima[1], Y. Tajima[1] and K. Furuno [1]

At Tandem Accelerator Center, University of Tsukuba, two electro-static accelerators of 12UD pelletron and 1MV tandetron are operating for researches of nuclear physics, material science, geological science and many applications. Many kinds of ion beam from proton to lead can be accelerated by the 12UD pelletron with terminal voltage up to 12 MV and the maximum beam current of 3 μA. The 1MV tandetron is useful for material analysis of PIXE and RBS by using of proton or ^{4}He ion beam. For the radiation safety administration, neutron and gamma dose rates were measured during irradiation experiments inside of experimental rooms and outside of the shielding wall to estimate neutron penetration rate.

Neutron dose rates were measured by a BF_3 neutron dose survey meter ALNOR 2202D. The tube of the BF_3 proportional counter is surrounded by a shield made of polyethylene and boron plastics in order to degrade fast neutron. The survey meter can also provide neutron pulse signals for counting integration measurements at very low dose rate. The dose survey meter is calibrated by using ^{241}Am+Be neutron source of 357MBq. The intensity of emitting neutron was 2.7×10^4 [n/sec]. Corresponding neutron dose is calculated to be 0.32 [μSv/h] at 1[m] from the source by using the effective dose coefficient $\Gamma = 1.19 \times 10^{-5}[\mu\mathrm{Sv/h{\cdot}m^2/(n/sec)}]$[1]. The results of the calibration are shown in Table 1 depending on the direction for the survey meter.

Gamma rays were measured by an ionization chamber survey meter Aloka IC-311. The results of the calibration are shown in Table 2 by using ^{137}Cs source of 371.4 kBq. The effective dose coefficient of $\Gamma = 0.0779$ [μSv/h/MBq·m^2] [1] is used.

Results of the measured radiations are shown in Table 3 for the 1MV tandetron experiment. Proton beam was accelerated up to 1.6 MeV by 0.8 MV terminal voltage. Beam current was 0.1 μA irradiated on a thick tantalum beam stopper. No radiation exceeding back ground has been measured at any position in the experimental room.

For the 12UD pelletron accelerator, the radiation measurement has been done by using proton beam accelerated up to 22 MeV by 11 MV terminal voltage. The ion beam was irradiated on a beam stopper of thick tantalum plate located in the counting room shown in figure 1. Intensity of the beam was limited to be 0.7 μA to stabilize the high terminal voltage. The beam current was decreased to avoid over scale of the dose survey meter for the measurement inside of the counting room. Small

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flux of neutrons through the concrete shielding wall have been measured as shown in Table 4. By normalizing beam intensity and distance from the irradiation point, the effective dose penetration rate can be determined to be 3.1×10^{-6} for the 1.2 m thick normal concrete of 2.3 g/cm^3 density.

Reference

1) Practical manual of shielding calculations for radioisotope facility, 2000, Nuclear Safety Technology Center, Hakusan 5-1-3-101, Bunkyo-ku, Tokyo, Japan

Table 1 Result of calibration for BF_3 neutron dose survey meter, ALNOR 2202D

ALNOR 2202D distance [mm]	^{241}Am+Be calculation [μSv/h]	θ=0 [μSv/h]	θ=90 [μSv/h]	θ=0 pulse [cpm]	θ=90 pulse [cpm]
200	8.0	10	6	203	130
250	5.1	5	3	125	88
300	3.6	3	2	83	68
coefficient		1.0	1.6	0.69×10^{-3} [μSv/pulse]	0.95×10^{-3} [μSv/pulse]

Table 2 Result of calibration for gamma survey meter of ionization chamber, Aloka IC-311

Aloka IC-311 distance [mm]	^{137}Cs calculation [μSv/h]	measure [μSv/h]
100	2.9	3.7
150	1.3	1.7
200	0.7	1.2
Back ground		0.2
coefficient		0.81

Table 3 Gamma and Neutron dose rates during the ion beam experiment of 1 MV tandetron

location	distance [m]	beam current [μA]	gamma IC-311 [μSv/h]	neutron ALNOR 2202D [μSv/h]	neutron pulse
scattering chamber	0.3	0.1	0	0	0/4min
switching magnet	3.3	0.1	0	0	0/4min
control desk	8.0	0.1	0	0	0/4min
entrance	5.2	0.1	0	0	0/4min

Table 4 Gamma and Neutron dose rates during the ion beam experiment of 12 UD tandem accelerator

location	distance [m]	beam current [μA]	gamma IC-311 [μSv/h]	neutron ALNOR 2202D [μSv/h]	neutron pulse [cpm]
Target room	8.0	0.45	200	9600	
Outside of wall	8.6	0.7	0	0.04	30/30min

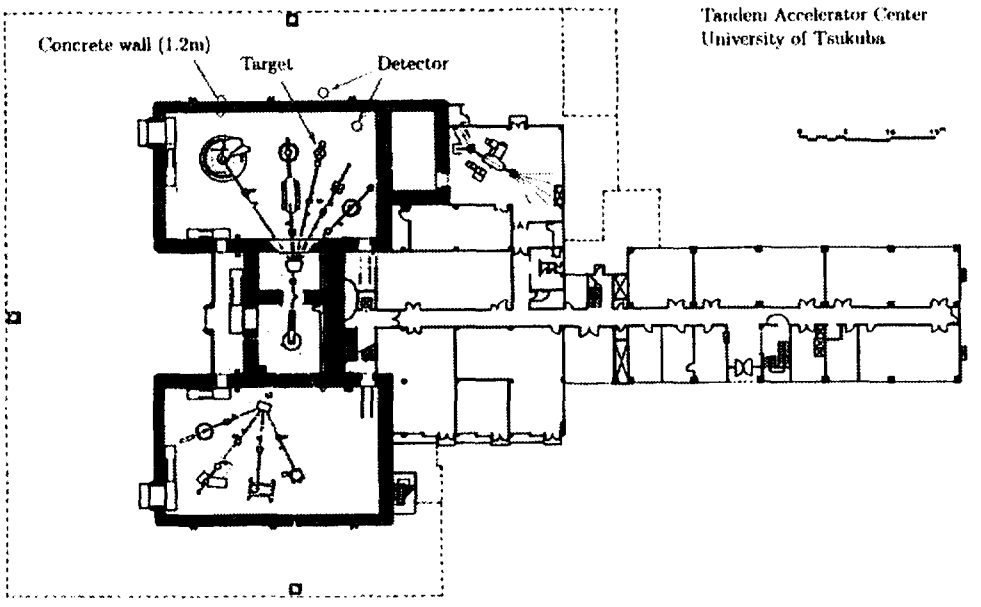

Figure 1. Location of a radiation target and detection positions for the 12UD pelletron experiment.