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(January 2003 to December 2003 inclusive)

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(Ed.) A. Ichihara
Japanese Nuclear Data Committee
Japan Atomic Energy Research Institute
Tokai Research Establishment
Tokai-mura, Naka-gun, Ibaraki-ken, Japan

Note

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BE	9	A EMISSION	1.4+7		OSA	EXPT-PROG	INDC(JPN)-193			MAR 04	MURATA+.P73.DADE.SILICON SSD.NDG
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AL	27	(N,P)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
AL	27	(N,P)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P54.ACTSIG.NDG
AL	27	(N,ALPHA)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
SI	28	EVALUATION		3.0+9	KYU	EVAL-PROG	INDC(JPN)-193			MAR 04	WATANABE+.P46.FOR JENDL-HE.NDG
SI	28	TOTAL		2.0+8	KYU	EVAL-PROG	INDC(JPN)-193			MAR 04	SUN+.P45.CC MDL ANAL.NDG
SI	28	SCATTERING		2.0+8	KYU	EVAL-PROG	INDC(JPN)-193			MAR 04	SUN+.P45.CC MDL ANAL.NDG
SI	29	EVALUATION		3.0+9	KYU	EVAL-PROG	INDC(JPN)-193			MAR 04	WATANABE+.P46.FOR JENDL-HE.NDG
SI	30	EVALUATION		3.0+9	KYU	EVAL-PROG	INDC(JPN)-193			MAR 04	WATANABE+.P46.FOR JENDL-HE.NDG
SI	30	TOTAL		2.0+8	KYU	EVAL-PROG	INDC(JPN)-193			MAR 04	SUN+.P45.CC MDL ANAL.NDG
SI	30	SCATTERING		2.0+8	KYU	EVAL-PROG	INDC(JPN)-193			MAR 04	SUN+.P45.CC MDL ANAL.NDG
K	41	(N,P)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
K	41	(N,ALPHA)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG

ELEMENT S	A	QUANTITY	ENERGY MIN	MAX	LAB	TYPE	DOCUMENTATION REF	VOL	PAGE	DATE	COMMENTS
TI	47	(N,P)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
TI	47	(N,ALPHA)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
V	51	(N,P)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
V	51	(N,ALPHA)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
CR	52	SCATTERING		2.0+8	JAE	EVAL-PROG	INDC(JPN)-193			MAR 04	SUKHOVITSKIJ+.P22.CC MDL ANAL
FE	54	(N,P)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
FE	54	(N,ALPHA)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
CO	59	(N,P)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
CO	59	(N,ALPHA)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
NI	58	(N,P)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
NI	58	(N,ALPHA)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
NI	61	(N,P)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
NI	61	(N,P)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P54.ACTSIG.NDG
NI	61	(N,ALPHA)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
CU	65	(N,P)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
CU	65	(N,ALPHA)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
ZN	67	(N,P)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
ZN	67	(N,ALPHA)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
GA	69	(N,P)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
GA	69	(N,ALPHA)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG

ELEMENT S	A	QUANTITY	ENERGY MIN	MAX	LAB	TYPE	DOCUMENTATION REF	VOL	PAGE	DATE	COMMENTS
BR	79	(N,P)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
BR	79	(N,ALPHA)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
SR	87	(N,D)	1.3+7	1.5+7	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SAKANE+.P52.(N,NP+D).ACTSIG.NDG
NB	93	(N,P)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
NB	93	(N,ALPHA)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
MO	92	(N,P)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
MO	92	(N,ALPHA)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
MO	95	(N,D)	1.3+7	1.5+7	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SAKANE+.P52.(N,NP+D).ACTSIG.NDG
MO	100	(N,D)	1.3+7	1.5+7	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SAKANE+.P52.(N,NP+D).ACTSIG.NDG
TC	99	RES INT ABS	5.0-1		KTO	EXPT-PROG	INDC(JPN)-193			MAR 04	KOBAYASHI+.P42.RI=330+-19B
TC	99	(N,GAMMA)	5.0-3	4.7+4	KTO	EXPT-PROG	INDC(JPN)-193			MAR 04	KOBAYASHI+.P42.TOF.REL 10B(N,A).NDG
TC	99	(N,GAMMA)	8.0+3	5.4+5	TIT	EXPT-PROG	INDC(JPN)-193			MAR 04	IGASHIRA+.P67.TOF.CFD OTHS.NDG
TC	99	SPECT (N,G)	8.0+3	5.4+5	TIT	EXPT-PROG	INDC(JPN)-193			MAR 04	IGASHIRA+.P67.TOF.NDG
TC	99	RESON PARAMS	5.6+0	2.0+1	KTO	EXPT-PROG	INDC(JPN)-193			MAR 04	KOBAYASHI+.P42.DERIVED FROM CAP.NDG
RU	96	(N,P)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
RU	96	(N,ALPHA)	2.1+6	3.1+6	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SHIMIZU+.P53.ACTSIG.NDG
RU	104	(N,D)	1.3+7	1.5+7	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SAKANE+.P52.(N,NP+D).ACTSIG.NDG
PD	106	(N,D)	1.3+7	1.5+7	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SAKANE+.P52.(N,NP+D).ACTSIG.NDG
AG	109	RES INT ABS	5.0-1		JNC	EXPT-PROG	INDC(JPN)-193			MAR 04	NAKAMURA+.P34.TO META.RI=67.9+-3.1B
AG	109	(N,GAMMA)	2.5-2		JNC	EXPT-PROG	INDC(JPN)-193			MAR 04	NAKAMURA+.P34.TO META.SIG=4.12+-.10B

ELEMENT S A	QUANTITY	ENERGY MIN	MAX	LAB	TYPE	DOCUMENTATION REF	VOL	PAGE	DATE	COMMENTS
CD 113	(N,D)	1.3+7	1.5+7	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SAKANE+.P52.(N,NP+D).ACTSIG.NDG
CD 116	(N,D)	1.3+7	1.5+7	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SAKANE+.P52.(N,NP+D).ACTSIG.NDG
SN 118	(N,D)	1.3+7	1.5+7	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SAKANE+.P52.(N,NP+D).ACTSIG.NDG
SN 119	(N,D)	1.3+7	1.5+7	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SAKANE+.P52.(N,NP+D).ACTSIG.NDG
SN 120	(N,D)	1.3+7	1.5+7	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SAKANE+.P52.(N,NP+D).ACTSIG.NDG
TE 123	(N,D)	1.3+7	1.5+7	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SAKANE+.P52.(N,NP+D).ACTSIG.NDG
TE 128	(N,D)	1.3+7	1.5+7	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SAKANE+.P52.(N,NP+D).ACTSIG.NDG
TE 130	(N,D)	1.3+7	1.5+7	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SAKANE+.P52.(N,NP+D).ACTSIG.NDG
I 129	EVALUATION	NDG		JAE	EVAL-PROG	INDC(JPN)-193			MAR 04	NAKAGAWA+.P19.FULL EVALUATION
I 129	(N,GAMMA)	1.5+4	9.0+4	TIT	EXPT-PROG	INDC(JPN)-193			MAR 04	IGASHIRA+.P69.TOF.REL 197AU.NDG
PR 141	(N,GAMMA)	2.5-2		KTO	EXPT-PROG	INDC(JPN)-193			MAR 04	YOON+.P41.SIG=11.6+-1.3B
PR 141	(N,GAMMA)	3.0-3	1.4+5	KTO	EXPT-PROG	INDC(JPN)-193			MAR 04	YOON+.P41.TOF.REL 10B(N,A).NDG
ND 143	EVALUATION	NDG		JAE	EVAL-PROG	INDC(JPN)-193			MAR 04	NAKAGAWA+.P19.FULL EVALUATION
ND 145	SPECT (N,G)	+3		TIT	EVAL-PROG	INDC(JPN)-193			MAR 04	IGASHIRA+.P67.STAT MDL.M1 SCISSORS
DY 161	(N,GAMMA)	1.0+4	9.0+4	TIT	EXPT-PROG	INDC(JPN)-193			MAR 04	IGASHIRA+.P68.TOF.REL 197AU.NDG
DY 161	SPECT (N,G)	+3		TIT	EVAL-PROG	INDC(JPN)-193			MAR 04	IGASHIRA+.P67.STAT MDL.M1 SCISSORS
DY 162	(N,GAMMA)	1.0+4	9.0+4	TIT	EXPT-PROG	INDC(JPN)-193			MAR 04	IGASHIRA+.P68.TOF.REL 197AU.NDG
DY 163	(N,GAMMA)	1.0+4	9.0+4	TIT	EXPT-PROG	INDC(JPN)-193			MAR 04	IGASHIRA+.P68.TOF.REL 197AU.NDG
DY 164	(N,GAMMA)	1.0+4	9.0+4	TIT	EXPT-PROG	INDC(JPN)-193			MAR 04	IGASHIRA+.P68.TOF.REL 197AU.NDG
ER 167	SPECT (N,G)	+3		TIT	EVAL-PROG	INDC(JPN)-193			MAR 04	IGASHIRA+.P67.STAT MDL.M1 SCISSORS

ELEMENT S	A	QUANTITY	ENERGY MIN	MAX	LAB	TYPE	DOCUMENTATION REF	VOL	PAGE	DATE	COMMENTS
W	184	(N,D)	1.3+7	1.5+7	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SAKANE+.P52.(N,NP+D).ACTSIG.NDG
W	186	(N,D)	1.3+7	1.5+7	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SAKANE+.P52.(N,NP+D).ACTSIG.NDG
OS	189	(N,D)	1.3+7	1.5+7	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SAKANE+.P52.(N,NP+D).ACTSIG.NDG
OS	190	(N,D)	1.3+7	1.5+7	NAG	EXPT-PROG	INDC(JPN)-193			MAR 04	SAKANE+.P52.(N,NP+D).ACTSIG.NDG
AU	197	(N,GAMMA)	1.0+0	1.0+3	JNC	EXPT-PROG	INDC(JPN)-193			MAR 04	SHCHERBAKOV+.P36.BGO DET.NDG
BI	209	(N,GAMMA)	2.0+5	3.0+6	JAE	EVAL-PROG	INDC(JPN)-193			MAR 04	ICHIHARA+.P21.TO META,GS.STATMDL CAL
BI	209	(N,GAMMA)	1.0+4	5.2+5	TIT	EXPT-PROG	INDC(JPN)-193			MAR 04	IGASHIRA+.P69.TOF.REL 197AU.NDG
NP	237	(N,GAMMA)	1.0+0	1.0+3	JNC	EXPT-PROG	INDC(JPN)-193			MAR 04	SHCHERBAKOV+.P36.BGO DET.NDG
NP	237	(N,GAMMA)	2.5-2		JNC	EXPT-PROG	INDC(JPN)-193			MAR 04	KATOH+.P35.SIG=141.7+-5.4B
NP	237	RES INT CAP	3.6-1		JNC	EXPT-PROG	INDC(JPN)-193			MAR 04	KATOH+.P35.RI=862+-51B
NP	238	(N,GAMMA)	MAXW		JNC	EXPT-PROG	INDC(JPN)-193			MAR 04	HARADA+.P37.GE+BGO.ACTSIG=479+-24B
MANY		EVALUATION	NDG		JAE	EVAL-PROG	INDC(JPN)-193			MAR 04	KAWANO+.P19.TH,U,PU. FOR JENDL-3.3
MANY		FISSION	+7	3.0+9	JAE	EVAL-PROG	INDC(JPN)-193			MAR 04	FUKAHORI+.P20.AG-243AM.SYSTEMATICS

(Prepared by JNDC CINDA Group)

I. Aichi Shukutoku University

A. Department of Media Theories and Production

I-A-1

Saturation of Nuclear Matter and Radii of Unstable Nuclei

K. Oyamatsu*[1,2] and K. Iida*[2]

*[1] *Department of Media Theories and Production, Aichi Shukutoku University*

*[2] *The Institute of Physical and Chemical Research (RIKEN)*

A paper on this subject was published in Progress of Theoretical Physics **109**, 631-650, 2003 with the following abstract.

We systematically examine relations among the parameters characterizing the phenomenological equation of state (EOS) of nearly symmetric, uniform nuclear matter near the saturation density by comparing macroscopic calculations of radii and masses of stable nuclei with experimental data. The EOS parameters of interest here are the symmetry energy coefficient S_0, the symmetry energy density derivative coefficient L and the incompressibility K_0 at normal nuclear density. We estimate a range of (K_0, L) from empirically reasonable values of the slope of the saturation line (the line joining the saturation points of nuclear matter at finite neutron excess) and find a strong correlation between S_0 and L. In light of the uncertainties on the values of K_0 and L, we perform macroscopic calculations of the radii of unstable nuclei expected to be produced in future facilities. We find that the matter radii depend appreciably on L, while being almost independent of K_0. This dependence implies that if the matter radii are measured with an accuracy of ±0.01 fm for a sufficiently large number of neutron-rich nuclides to allow one to smooth out the expected staggering of the radii due to shell and pairing effects, it might be possible to derive the value of L within ±20 MeV.

I-A-2

Proton-nucleus elastic scattering and the equation of state of nuclear matter

Kei Iida*[1], Kazuhiro Oyamatsu*[1,2], and Badawy Abu-Ibrahim*[1,3]

*[1] *The Institute of Physical and Chemical Research (RIKEN)*

*[2] *Department of Media Theories and Production, Aichi Shukutoku University*

*[3] *Department of Physics, Cairo University, Egypt*

A paper on this subject was published in Physics Letters B **576**, 273-280, 2003 with the following abstract.

We calculate differential cross sections for proton-nucleus elastic scattering by using a Glauber theory in the optical limit approximation and nucleon distributions that can be obtained in the framework of macroscopic nuclear models in a way dependent on the equation of state of uniform nuclear matter near the saturation density. We find that the peak angle calculated for unstable neutron-rich nuclei in the small momentum transfer regime increases as the parameter L characterizing the density dependence of the symmetry energy decreases. This is a feature associated with the L dependence of the predicted matter radii.

I-A-3

Empirical properties of asymmetric nuclear matter to be obtained from unstable nuclei

K. Oyamatsu*[1,2] and K. Iida*[2]

*[1] *Department of Media Theories and Production, Aichi Shukutoku University*

*[2] *The Institute of Physical and Chemical Research (RIKEN)*

A paper on this subject was published in Nuclear Physics A718, pp. 363c-366c, 2003 with the following abstract.

We examine relations among the parameters characterizing the phenomenological equation of state (EOS) of nearly symmetric, uniform nuclear matter near the saturation density. The EOS parameters of interest here are the symmetry energy S_0, the symmetry energy density-derivative coefficient L and the incompressibility K_0 at the normal nuclear density. By comparing macroscopic calculations of radii and masses of stable nuclei with the experimental data, we systematically obtain about 200 different EOS's, and find an empirically allowed region of (K_0, L), together with a strong correlation between S_0 and L. In the light of the uncertainties in the values of K_0 and L, we macroscopically calculate radii of unstable nuclei. We find that the matter radii depend strongly on L while being almost independent of K_0, a feature that will help to determine the L value via systematic measurements of nuclear size.

I-A-4

Neutron Optical Potentials in Unstable Nuclei and the Equation of State of Asymmetric Nuclear Matter

K. Oyamatsu*[1,2] and K. Iida*[2]

*[1] *Department of Media Theories and Production, Aichi Shukutoku University*

*[2] *The Institute of Physical and Chemical Research (RIKEN)*

A paper on this subject was published in Proc. 2002 Symposium on Nuclear Data, Nov. 2002, JAERI, Tokai, Japan, JAERI-Conf 2003-006, pp. 225-231, 2003 with the following abstract.

Neutron single particle potential is one of the basic macroscopic properties to describe structure and reactions of nuclei in nuclear reactors and in the universe. However, the potential is quite uncertain for unstable nuclei primarily because the equation of state (EOS) of asymmetric nuclear matter is not known well. The present authors studied systematically the empirical EOS of asymmetric nuclear matter using a macroscopic nuclear model; about two hundred EOS' s having empirically allowed values of L (symmetry energy density derivative coefficient) and K_0 (incompressibility) were obtained from the fittings to masses and radii of stable nuclei. It was suggested that the L value could be determined from global (Z, A) dependence of nuclear radii. In the present study, the single particle potential is examined assuming kinetic energies of non-interacting Fermi gases. The potential in a nucleus can be calculated easily, once the density distribution is solved using the effective nuclear interaction (EOS). Neutron and proton single particle potentials are calculated systematically for ^{80}Ni using the two hundred EOS' s. It is found that the neutron-proton potential difference has clear and appreciable L dependence, while the potential for each species does not show such simple dependence on L.

I-A-5

The Equation of State of Nuclear Matter and the Neutron Star Structure

K. Oyamatsu*[1,2], and K. Iida*[2]

*[1] *Department of Media Theories and Production, Aichi Shukutoku University*

*[2] *The Institute of Physical and Chemical Research (RIKEN)*

A paper on this subject was published in Proceedings of the 5th Symposium on Science of Hadrons under Extreme Conditions, JAERI-Conf 2003-009, pp. 106-114, 2003 (in Japanese) with the following abstract.

We examine a relationship between the phenomenological equation of state of nuclear matter near normal nuclear density and the structure of neutron stars. We find that the neutron star mass at fixed central density is an increasing function of the symmetry energy density derivative coefficient L, and that L must be large enough to support a neutron star having the observed canonical mass (1.4 solar mass). This feature could provide a constraint on the L value, which would complement a possible constraint to be obtained from systematic measurements of radii of neutron-rich nuclei. We expect, on the other hand, that the L value, once determined experimentally, would enable us to describe more precisely the structure of neutron stars having low central densities (2-3 times the nuclear density).

I-A-6

Relativistic equation of state for supernova and neutron star

H. Shen[*1], H. Toki[*2], K. Oyamatsu[*3] and K. Sumiyoshi[*4]

[*1] *Department of Physics, Nankai University, China*

[*2] *Research Center for Nuclear Physics (RCNP), Osaka University*

[*1] *Department of Media Theories and Production, Aichi Shukutoku University*

[*2] *Numazu College of Technology*

A paper on this subject was published in Nuclear Physics **A721**, 1048c-1051c, 2003 with the following abstract.

We construct the equation of state (EOS) of nuclear matter at finite temperature and density with various proton fractions within the relativistic mean field (RMF) theory for use in supernova simulations. The properties of nuclear matter with both uniform and non-uniform distributions are studied consistently. We tabulate the outcome in terms of the pressure, free energy, entropy, etc. at a sufficiently large number of mesh points in the density range $\rho_B=10^{5.1}\sim10^{15.4}$ g/cm^3, the temperature range T=0~100 MeV and the proton fraction range Y_p=0~0.56 to be used for supernova simulations. We also discuss the EOS of neutron star matter at zero temperature in a wide density range including hyperons.

II. High Energy Accelerator Research Organization

A. Radiation Science Center

II-A-1

Measurements of Photo-Neutrons from Thick Targets Irradiated by 2 GeV Electrons

S.Ban*, T.Sanami, K.Takahashi, H.S.Lee, T.Sato, S.Maetaki and K.Shin

Photo-neutron energy spectra were measured when 2.04 GeV electrons incident on thick targets using the time-of-flight method. Neutron yields for 90 degrees targets were obtained. The irradiation was performed at the injection Linac in Pohang Light Source, POSTECH. The organic liquid scintillator, NE-213 was located at 10.4 m distant from the target. Their efficiencies were calculated using the SCINFUL code. The measured neutron energy range was approximately between 2 MeV and 400 MeV. Thick Pb blocks, 15-30 cm, were placed in the middle of the flight path to suppress X-rays. These Pb blocks also reduced neutrons toward the detector, and this effect was estimated using the LAHET 2.7 code.

to be published in the Proceedings of the Sixth International Topical Meeting on Nuclear Applications of Accelerator Technology, AccApp'03, June 1 to 5, 2003, San Diego, California, U.S.A.

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*Present Address : High Energy Accelerator Research Organization, Tsukuba, Ibaraki, 305-0801, Japan

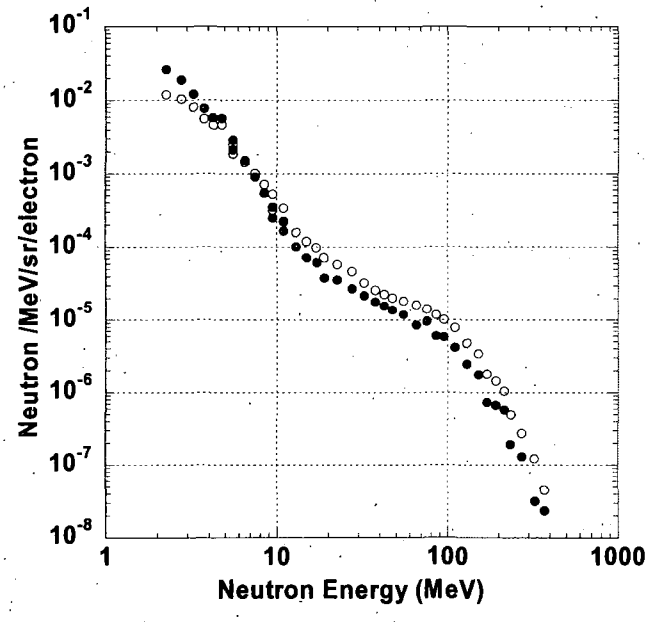

Figure. Measured neutron spectra toward 90 degrees from 10-radiation-length thick Cu and Pb targets irradiated by 2.04 GeV electrons. Data are shown in unit of neutron /MeV/sr per incident electron.
Open circle: Cu target, Full circle: Pb target

II-A-2

Characteristics of high-energy neutrons estimated by radioactive spallation products on Au at 500 MeV neutron irradiation facility of KENS

Hiroshi Matsumura[1], Kazuyoshi Masumoto[1], Noriaki Nakao[1], Qingbin Wang[1], Akihiko Toyoda[1], Masayoshi Kawai[1], Takahiro Aze[2], Masatsugu Fujimura[2]

1. Introduction

In high-energy proton-accelerator facilities, high-energy neutrons are secondarily generated by the bombardment of proton beam. Such neutrons have high penetrability and induce activation of surrounding materials. Therefore, it is very important to investigate (1) the spectra and intensity of neutrons at the beam loss points, (2) their attenuation characteristics in shielding materials and (3) activation products induced by high-energy neutron irradiation from the view points of radiation safety. The neutron spectra can be estimated with Monte Carlo simulation codes. However, the accuracy is not clear because of the lack of the experimental data. Therefore, the high-energy-neutron irradiation course of KENS, used 500 MeV primary proton beam, was constructed for the shielding experiments [1]. We have investigated the spectra and the attenuation for secondary neutrons at the zero degree direction in the concrete shield and compared with the results calculated by the simulation code. The experiments on thermal neutrons and fast neutrons less than about 100 MeV in this irradiation course were already reported in [1-4].

In this study, we will discuss a spectrum of high-energy neutrons ranging from 10 to 500 MeV. For this purpose, the reaction rates for 13 radionuclides produced by the spallation reaction of Au target were measured by radiochemical separation techniques. These spallation products are produced from ^{197}Au at the different threshold energies ranging from several MeV to several hundred MeV. By measuring the reaction rates of these spallation products, neutron spectra can be experimentally obtained and compared with the result calculated with MARS14 code. Furthermore, the reaction rates can be used as the basic data of neutron-induced nuclear reactions at intermediate energies also. As this experiment is in progress, preliminary results will be reported in this paper.

Present address

[1] High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki 305-0801, JAPAN

[2] Graduate School of Integrated Basic Sciences, Nihon University, Setagaya-ku, Tokyo 156-8550, JAPAN

2. Experimental

For the neutron irradiation, the high-energy-neutron irradiation course of KENS designed for the shielding experiment was used. The details of this course are described in [1]. The secondary neutrons were generated by the bombardment of 500 MeV protons on W targets, and zero degree direction was used for irradiation of Au foils by collimating with beam guide. The primary protons are stopped entirely in W targets. The course has eight irradiation positions, called as slots 1 – 8, along with the neutron beam direction in the concrete shield.

The Au foils (chemical purity: 99.99%) of 0.05 or 0.10 mm in thickness were used as the targets. In each slot, the Au foils of three kinds of weight were irradiated. Their typical weights were 0.01 g for the measurements of short half-life nuclides; 0.2 g for the measurements of long half-life nuclides; 0.2 or 0.4 g for the measurements of nuclides after radiochemical separation. The foils were sealed in a polyethylene bag individually. The plastic capsules containing the Au targets were fixed at the bottom of the shield plugs, inserted into 5 slots, and set on the beam axis. The depths of slots 1, 2, 3, 4, and 5 used in this experiment are 0cm, 40cm, 80cm, 130cm, and 185cm from the surface of the concrete shield, respectively. The irradiation time was 8160 minutes. The average current of primary protons was 5.38 μA. As the fluctuation of the proton current was within 3%, it was neglected.

After the irradiation, γ-ray spectrometry was performed with high-purity Ge detectors coupled each with a 4K-channel pulse-height analyzer. The pertinent nuclear data were taken from [5]. The radioactivities of ^{196}Au, ^{194}Au, ^{192}Au, ^{188}Pt, ^{189}Ir, ^{185}Os, ^{183}Re, ^{181}Re, ^{175}Hf, and ^{171}Lu were determined non-destructively. Those of ^{173}Lu, ^{171}Lu, ^{169}Yb and ^{167}Tm were measured after radiochemical separation. The detector efficiency was obtained by a calibrated point source mixed ^{109}Cd, ^{57}Co, ^{139}Ce, ^{203}Hg, ^{113}Sn, ^{85}Sr, ^{137}Cs, ^{88}Y and ^{60}Co.

3. Results and discussion

The reaction rates of ^{197}Au(n, X)^{196}Au, ^{194}Au, ^{192}Au, ^{188}Pt, ^{189}Ir, ^{185}Os, ^{183}Re, ^{181}Re, ^{175}Hf, ^{173}Lu, ^{171}Lu, ^{169}Yb and ^{167}Tm in slots 1 - 5 were obtained. All the reaction rates are cumulative ones for the respective decay chains. The unit of the reaction rate is atom^{-1}μC^{-1}, which means the probability per a target atom and per 1 μC of primary protons.

The reaction rates were also calculated by the MARS14 as follows. Firstly, the neutron spectrum at each slot was calculated by the MARS14. Although the cross section data is still lacking in case of neutron-induced reactions, it can be considered that neutron reactions resemble proton reactions in the case of the complicated spallation reaction which emits nucleons more than ten. Therefore, it was assumed that the excitation functions of neutron reactions are the same as those of proton reactions which produced the same nuclide. By this assumption the reaction rate is calculated in the following formula,

$$\text{Reaction rate} = \int_0^{500\text{MeV}} N(E_n) \cdot \sigma(E_p)\, dE$$

where E_n and E_p are the energies of neutron and proton, N is the number of neutron per 1 μC of primary proton by MARS14, and σ is the cross section of proton induced reaction. The excitation functions of ^{197}Au(p, X)^{188}Pt, ^{189}Ir, ^{185}Os, ^{183}Re, ^{173}Lu and ^{167}Tm are experimentally understood well, and those taken from literatures were substituted for $\sigma(E_p)$.

In figure 1, the reaction rates were plotted as a function of the mass number of products (A_p). The experimental values were shown by the open symbols attached to the solid line which was drawn through the points to guide the eye. The closed symbols indicate the results by MARS14, and the dashed lines were also drawn through the points to guide the eye. Both the profiles of the reaction rates decrease with a decrease in A_p. However, the decreases in the reaction rate from the experiment are steeper than those from the calculation. In the case of $A_p > 180$, the experimental values of slots 1 and 2 are about 1.5 times as large as those by MARS14. On the other hand, the MARS14 tend to overestimate the reaction rates at $A_p < 175$. In consideration of the excitation function, it can be said that the effective neutron energies are 100 – 200 MeV for the ^{188}Pt and ^{189}Ir productions and 350 – 500 MeV for the ^{173}Lu and ^{167}Tm productions. Therefore, it is found that the MARS14 underestimates the number of neutrons of 100 - 200 MeV and overestimates that of 350 - 500 MeV.

In figure 2, the ratios of reaction rates of slots 2, 3, 4, and 5 to those of slot 1 were plotted as a function of the Q value of (n, xpyn) reaction. This shows a relative change of the spectra of the neutrons passing through the shield concrete indirectly. The ratios are constant over the wide energy range of the Q value. It is indicated that the profile of the neutron spectrum does not change in the concrete shield at the depth from 0 to 185 cm. That is consistent with the results of MARS14.

References

[1] N. Nakao *et al.*, *"Shielding Experiment at the High Energy Neutron Beam Course of KENS"*, ICANS-XVI, 16th Meeting of the International Collaboration on Advanced Neutron Sources, May 12 – 15, 2003, Düsseldorf-Neuss, Germany.

[2] N. Nakao *et al.*, *"KENS Shielding Experiment (1) - Measurement of Neutron Attenuation through 4m Concrete Shield Using a High Energy Neutron Irradiation Room"*, Proc. The 2ns iTRS International Symposium on Radiation Safety and Detection Technology (ISORD-2), July 24-25, 2003, Tohoku University, Sendai, JAPAN.

[3] Wang *et al.*, *"KENS Shielding Experiment (2) - Measurement of the Neutron Spatial Distribution inside and outside of a Concrete Shield using an Activation Foil and an Imaging Plate Technique"*, Proc. The 2ns iTRS International Symposium on Radiation Safety and Detection Technology (ISORD-2), July 24-25, 2003, Tohoku University, Sendai, JAPAN.

[4] H. Yashima and N. Nakao, *"Data Analysis for Neutron Reaction Rates Activation Detectors in KENS Shielding Experiment - Experiment on January 2003 -"*, KEK Internal 2003-10, February 2004.

[5] R. B. Firestone, *Table of Isotopes*, 8th ed., John Wiley and Sons, Inc., New York 1996.

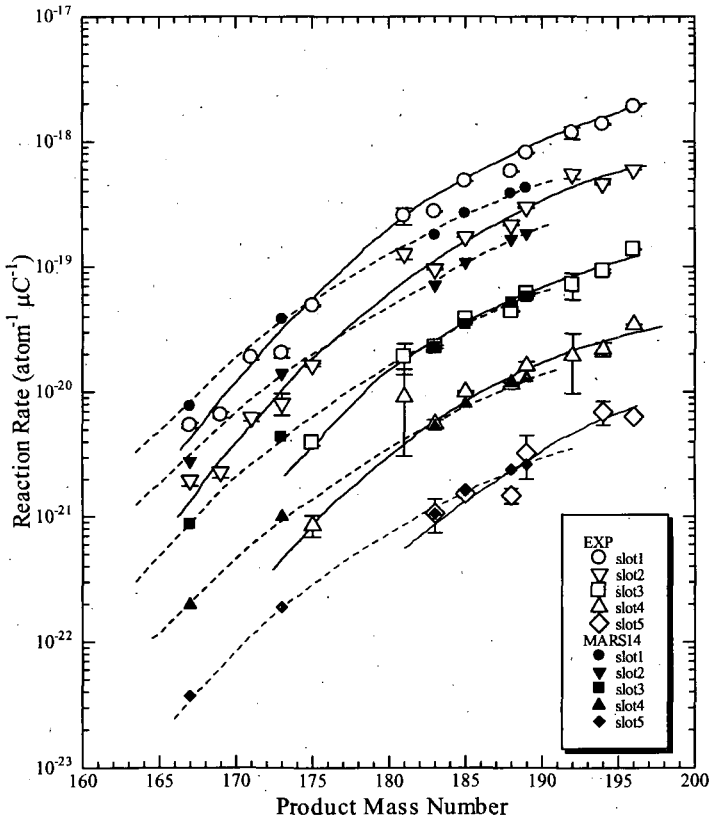

Figure 1. Reaction rates of spallation of ^{197}Au as a function of the mass number of products. Open symbols denote the experimental values obtained in this work and closed symbols denote the values by MARS14 code. See text for details.

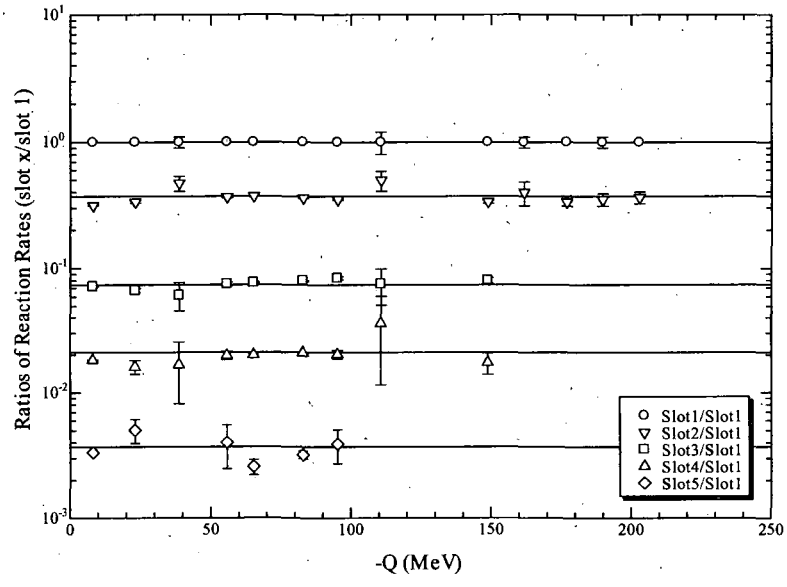

Figure 2. Ratios of the reaction rates of slots 2, 3, 4, and 5 to those of slot 1 as a function of the Q value of (n, xpyn) reaction. The solid lines indicate the average of the ratios.

III. Japan Atomic Energy Research Institute

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

III-A-1

Re-evaluation of Neutron Nuclear Data for ^{129}I and ^{143}Nd

Tsuneo NAKAGAWA and Akira HASEGAWA

A report on this subject was published as JAERI-Research 2003-020 with the following abstract.

The evaluated nuclear data for ^{129}I and ^{143}Nd stored in JENDL-3.3 were investigated comparing with other evaluated data and experimental data. New experimental data were available especially for the capture cross sections of both nuclides. The parameters used in theoretical calculations were modified so as to reproduce those experimental data. The statistical model calculation was performed using the revised parameters. The resonance parameters were also revised so that the cross sections measured in the thermal energy region were reproduced well. The present results were compiled in the ENDF-6 format.

III-A-2

Evaluations of Heavy Nuclide Data for JENDL-3.3

Toshihiko KAWANO[*1], Hiroyuki MATSUNOBU[*2], Toru MURATA[*3], Atsushi ZUKERAN[*4], Yutaka NAKAJIMA[*5], Masayoshi KAWAI[*6], Osamu IWAMOTO, Keiichi SHIBATA, Tsuneo NAKAGAWA, Takaaki OHSAWA[*7], Mamoru BABA[*8], Tadashi YOSHIDA[*9] and Makoto ISHIKAWA[*10]

A report on this subject was published as JAERI-Research 2003-026 with the following abstract.

New evaluations of neutron 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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*1 Kyushu University (present address, Los Alamos National Laboratory)
*2 Data Engineering, Inc.
*3 AITEL Corporation
*4 Hitachi Ltd.
*5 Research Organization for Information Science & Technology
*6 High Energy Accelerator Research Organization (KEK)
*7 Kinki University
*8 Tohoku University
*9 Musashi Institute of Technology
*10 Japan Nuclear Cycle Development Institute

III-A-3

Unified Description of Neutron-, Proton- and Photon-induced Fission Cross Sections in Intermediate Energy Region

Tokio FUKAHORI, Osamu IWAMOTO and Satoshi CHIBA

A paper on this subject was published in Proc. of the Seventh International Conference on Nuclear Criticality Safety (ICNC2003), Oct. 20-24, 2003, Techno Community Square RICOTTI, Tokai, Ibaraki, Japan (JAERI-Conf 2003-019) with the following abstract.

For an accelerator-driven nuclear waste transmutation system, it is very important to estimate sub-criticality of core system for feasibility and design study of the system. The fission cross section in the intermediate energy range has an important role. A program FISCAL has been developed to calculate neutron-, proton- and photon-induced fission cross sections in the energy region from several tens of MeV to 3 GeV. FISCAL adopts the systematics considering experimental data for Ag-^{243}Am. It is found that unified description of neutron-, proton- and photon-induced fission cross sections is available.

III-A-4

Development of a new code of coupled-channels optical model calculation

Osamu Iwamoto

A paper on this subject was published as JAERI-Data/Code 2003-020 with the following abstract with the title "Program CCOM -- Coupled-channels Optical Model Calculation with Automatic Parameter Search --".[1)]

A new program of coupled-channels optical model calculation has been developed for the evaluation of actinide nuclei. The code is composed of by the modules having high independency and large flexibility. The code is written by C++ language using object oriented techniques. The program has capability of fitting of the parameters even for the several nuclei at the same time. The formulae required in the calculation, details of the numerical treatments and the input parameters are described. The examples of the input file and the output are also shown.

References:

1) O. Iwamoto: JAERI-Data/Code 2003-020 (2003).

III-A-5

Evaluation of the $^{210m}Bi/^{210g}Bi$ Branching Ratio of the $^{209}Bi(n,\gamma)^{210}Bi$ Cross Section in the Neutron Energy Range from 200 keV to 3 MeV

A.Ichihara and K.Shibata

A paper on this subject was published in J. Nucl. Sci. Technol. **40**, 980 (2003) with the following abstract.

The $^{209}Bi(n,\gamma)^{210g,210m,210}Bi$ cross sections were evaluated by the statistical model with the γ-ray cascade calculation. The optical model potential developed by Koning and Delaroche and the level density formula developed by Mengoni and Nakajima were adopted in the calculation. The evaluated cross sections are in quantitative agreement with the recent experiments by Tokyo Institute of Technology.

B. Advanced Science Research Center

III-B-1

Analysis of Nucleon Scattering Data of ^{52}Cr with a Coupling Scheme Built with the Soft-rotator Model

Efrem Sh. Sukhovitskiĭ, Satoshi Chiba, Jeong-Yeon Lee, Byung-taik Kim and Seung-Woo Hong

A paper on this subject was published as J. Nucl. Sci. Technol. **40**, pp69-76(2003) with the following abstract:

A coupled-channel method based on a coupling scheme built with a wave function of the soft-rotator model was employed for an analysis of nucleon scattering data for ^{52}Cr. The parameters of the soft-rotator model were extracted to reproduce experimental collective levels of ^{52}Cr up to excitation energy of around 4.5 MeV. The optical model potential and deformation parameters were searched for. It was found that the present calculation can explain experimental nucleon interaction data up to 200 MeV very well.

III-B-2

Possibility of $\Lambda\Lambda$ pairing and its dependence on background density in relativistic Hartree-Bogoliubov model

T. Tanigawa, M. Matsuzaki and S. Chiba

A paper on this subject was published as Phys. Rev. C 68, 015801(2003) with the following abstract:

We calculate a $\Lambda\Lambda$ pairing gap in binary mixed matter of nucleons and Λ hyperons within the relativistic Hartree-Bogoliubov model. Λ hyperons to be paired up are immersed in background nucleons in a normal state. The gap is calculated with a one-boson-exchange interaction obtained from a relativistic Lagrangian. It is found that at background density $\rho_N = 2.5\rho_0$ the $\Lambda\Lambda$ pairing gap is very small, and that denser background makes it rapidly suppressed. This result suggests a mechanism, specific to mixed matter dealt with relativistic models, of its dependence on the nucleon density. An effect of weaker $\Lambda\Lambda$ attraction on the gap is also examined in connection with revised information of the $\Lambda\Lambda$ interaction.

C. Center for Proton Accelerator Facilities

III-C-1

Research Activities on Radiation Safety Design for J-PARC

Hiroshi NAKASHIMA[1], Nobuo SASAMOTO[1], Yoshihiro NAKANE[1], Fumihiro MASUKAWA[1], Yukihiro MIYAMOTO[1], Kouichi IKENO[1], Norihiro MATSUDA[1], Tomomi OGURI[1], Hideo NAKANO[1], Tokushi SHIBATA[2], Takenori SUZUKI[2], Hideo HIRAYAMA[2], Taichi MIURA[2], Shinichi SASAKI[2], Masaharu NUMAJIRI[2], Noriaki NAKAO[2] and Kiwamu SAITO[2]

A series of papers on this subject was submitted to the proceedings of the Second iTRS International Symposium On Radiation Safety and Detection Technology (ISORD-2) held at Tohoku University in 2003. The brief summary and titles are as follows.

A series of benchmark experiments and analyses on deep penetration and radiation streaming was carried out for J-PARC using high and intermediate energy accelerator facilities. As R&D for J-PARC, performance of low activationized concrete and shielding basic data such as cross section and dose conversion coefficient were also studied.

1. KENS Shielding Experiment
   (1): Establishment of High Energy Neutron Irradiation Facility and Measurement of Neutron Attenuation through 4m Concrete
2. KENS Shielding Experiment
   (2): Measurement of Neutron Spatial Distribution inside and outside the Concrete Shield using Activation Foil and Imaging Plate Technique
3. Analyses of Streamed Neutron Energy Spectra at TIARA Using DUCT-III
4. Benchmark Analyses of Neutron Streaming Experiments for Proton Accelerator Facilities
5. Analysis of Radiation Streaming Experiment through a Labyrinth in a Proton Accelerator Facility of Several Tens of MeV
6. Study of Radionuclides Induced in Low-Activation Concrete Using 12 GeV Proton Synchrotron Accelerator at KEK
7. A Study on Induced Radioactivity in a Low-Activationized Concrete for J-PARC
8. Benchmark Experiments of Dose Distributions in Phantom Placed Behind Iron and Concrete Shields at the TIARA Facility
9. Measurement of Differential Cross Sections for Evaluation of Radiation Dose of Ten's of MeV Neutrons

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1 Japan Atomic Energy Research Institute, Tokai, Ibaraki 319-1195, Japan
2 High Energy Accelerator Research Organization, Oho, Tsukuba, 305-0801 Japan

D. Department of Fusion Engineering Research

III-D-1

D-T Neutron Skyshine Experiments and the MCNP Analysis

Takeo NISHITANI, Kentaro OCHIAI, Shigeo YOSHIDA[1], Ryohei TANAKA[2], Masashi WAKISAKA[3],Makoto NAKAO, Satoshi SATO, Michinori YAMAUCHI, Jun-ichi HORI, Masayuki WADA, Akito TAKAHASHI[2], Jun-ichi KANEKO[3] and Teruko SAWAMURA[3]

A paper on this subject was submitted to J. Nucl. Sci. Tech., with the following abstract.

The D-T neutron skyshine experiments were carried out at the Fusion Neutronics Source (FNS) of JAERI with a port at the roof in March 2002 and March 2003. The concrete thickness of the roof and the wall of a FNS target room are 1.15 and 2 m, respectively. The FNS skyshine port with a size of 0.9×0.9 m^2 was open during the experimental period. The source neutron intensity was $\sim 1.7 \times 10^{11}$ n/s in those skyshine experiments. The highest total dose rate measured was about 0.5 μSv/h at a distance of 30 m from the D-T target point and the dose rate was attenuated to about 0.1 μSv/h at a distance of 100 m and 0.02μSv/h at a distance of 550 m. Those experimental results were analyzed by Monte Carlo code MCNP-4C with the nuclear data library JENDL-3.2, where the FNS building and the measurement field were modeled with a simplified cylindrical geometry, and the pine forest was modeled by homogenized cell with a height of 10m. The MCNP calculation agreed well both neutron and secondary gamma-ray dose rate distributions.

[2]*Tokai University, Hiratsuka, Kanagawa 259-1292, Japan*
[2]Osaka University, Suita, 565-0871, Japan
[3]Hokkaido University, Sapporo 060-0808, Japan

III-D-2

Measurement of Tritium Production Rate for Enriched Lithium-6 /Beryllium Assembly with D-T Neutron Source

Kentaro OCHIAI, Axel KLIX, Vury. M. VERZILOV, Satoshi SATO, Michinori YAMAUCHI, Masayuki WADA and Takeo NISHITANI

Two neutoronics experiments of fusion blanket have been carried out on JAERI/FNS. One was an integral experiment with lithium-6 enriched Li_2TiO_3 and beryllium assembly to evaluate tritium production rate by means of Li_2CO_3 pellet method. Another was a clean benchmark experiment of beryllium to evaluate the scattered neutron spectrum by means of slow down method using a BF3 detector. Also the weigh densities of main elements and impurities of materials used on the experiments were analyzed with ICP-mass spectroscopy. From these neutronics experiments and analysis, it is concluded that the C/E values of average TPR was about 1.1.

III-D-3

Experiments of (n, CP) Cross Sections with Penciled DT Neutron in JAERI/FNS

Kentaro OCHIAI, Takeo NISHITANI[1] Keitaro KONDO, Isao MURATA, Hiroyuki MIYAMARU and Akito TAKAHASHI[2]

JAERI and Osaka-univ. started to measure cross sections of (n, charged particle) reactions with penciled DT neutron beam in JAERI/FNS. The analyzing vacuum chamber was set up near the outlet of the penciled neutron beam. ΔE-E counter telescope with silicon semiconductor detectors was locate in the chamber to detect the charged particles. As the neutron flux monitor, Fission chamber (U-238) also set up at the backward of chamber and the average flux was 1 x 10^6 n/sec/cm^2. First of all, we carried out the measurements of the charged particle spectra of $^{27}Al(n,\alpha x)$, $^{27}Al(n,px)$ H(n,p) and $^{12}C(n,\alpha x)$ to calibrate the measurement system at various angles. After calibrations, we tried to measure the charged-particle spectrum from $^{9}Be(n,\alpha x)$ and $^{9}Be(n,t)$ and obtained the identified charged-particle spectra obviously. We currently intends to carry out the measurements to obtain the charged-particle cross sections with the penciled DT neutron beam.

[2] Osaka University, Suita 565-0871, Japan

III-D-4

Experimental Studies on W-armor Impact on Nuclear Responses of Solid Breeding Blanket

S. Sato, M. Nakao, Y. Verzilov, K. Ochiai, M. Wada, T. Nishitani

A paper on this subjest is to be presented at 20th IAEA Fusion Energy Coference, and submitted to Nuclear Fusion, with the following synopsis.

In fusion DEMO reactors, the blanket is required to provide a tritium breeding ratio (TBR) of more than unity by neutron induced reactions in lithium in the blanket. The solid breeder blanket being developed by JAERI for tokamak-type DEMO reactors consists of Li_2TiO_3 or other lithium ceramics as the tritium breeder material, beryllium as the neutron multiplier material, reduced activation ferritic steel F82H as the structural material and water as the coolant[1, 2]. In the blanket design proposed by JAERI, the local TBR is around 1.4 - 1.5 for the case without an armor on the first wall. From the view point of sputtering damage of the first wall, W armors are the effective protection. However, from the view point of nuclear response, W armors affect TBR negative. In case the W armors are installed, TBR might not satisfy the requirement in case[3]. There are a number of scattering and resonance capture reactions in the W. No experimental studies have been reported so far about the impact of the W armor on the TBR. Therefore experimental studies are very important for the evaluation of nuclear responses of the blanket in the presence of W armor. In order to evaluate this issue experimentally, neutronics experiments have been performed by using DT neutrons at Fusion Neutron Source (FNS) facility of JAERI.

DEMO blanket mockups, composed of a set of slabs of 16 mm thick F82H, 12 mm thick Li_2TiO_3 (^{6}Li enrichment of 40 %) and 200 mm thick Be with about 660 mm height and about 660 mm width each, were installed at about 450 mm distant from the DT neutron source, and DT neutron irradiation experiments were conducted by using FNS 80° beam line. In the experiments three types of mockups were tested: without the armor; with 12.6 mm thick W armor; and with 25.2 mm thick W armor. Figure 1 shows a configuration of the mockup for the case with the 25.2 mm thick W armor and the installation position of the detector. DT neutron yield at the target was about 1 x 10^{11} neutrons/s on average, which was monitored by the associated alpha particle measurement with a silicon surface barrier diode installed in the beam line. Three continuous irradiation experiments, each for ten hours, were performed, with the integrated irradiation period of 30 hours in total. Metal foils of Nb, Al, Au and Au, with 10 mm in diameter and 1 – 100 μm in thickness, with Cd cover, were installed at the boundary surfaces inside the mockup. After the irradiation, induced radioactivities were measured by decay gamma ray intensity with a high purity Ge detector, and neutron fluxes corresponding to each reaction rate were evaluated. Fifteen slices of Li_2CO_3 pellets, with a ^{6}Li enrichment of 40 %, 13 mm in diameter and 0.5 - 2 mm in thickness were embedded inside the Li_2TiO_3. After the irradiation, induced radioactivities were measured by beta ray intensity of these pellets with a liquid scintillation counter, and tritium production rate (TPR) was evaluated.

Figure 2 shows the experimental results of the Nb reaction rate which corresponds to the neutron flux with the energy above about 9 MeV. The circles denote the experimental data with 25.2 mm armor, the squares without armor, the solid line the ratio of those with 25.2 mm armor to without armor, and the

broken line the ratio of those with 12.6 mm armor to without armor. By installing the 25.2 mm thick W armor, the reaction rates of Nb, Al and Au inside the Li_2TiO_3 were reduced by 20 – 30, 30 and 10 – 30 %, respectively. Both of the fast and thermal neutron fluxes were reduced by installing the W armor. Figure 3 shows the experimental results of the TPR which corresponds to the ^{6}Li reaction rate. By installing the 25.2 and 12.6 mm thick W armors, the TPRs were reduced by 19 and 18 %, respectively, in maximum, and the integrated TPRs in the Li_2TiO_3 were reduced by 8 and 3 %, respectively.

Numerical analyses were conducted by using the Monte Carlo neutral particle transport code MCNP-4C and the fusion evaluated nuclear data library FENDL-2. The calculation results almost show the same tendency as the experiment ones. Figure 4 shows the neutron spectra at the front surface of the F82H without the armor and with 25.2 mm armor. Similarly to the experiment results, both of the fast and thermal neutron fluxes were reduced by installing the W armor at all boundary surfaces. It is expected that the fast neutron fluxes are reduced by the scattering of the W, therefore the thermal neutron fluxes are reduced by the reduction of neutron multiplying reactions between Be and the fast neutron. In addition, capture reactions of the W itself are also expected to contribute to reduction of thermal neutron fluxes. So, while W has large neutron multiplier reactions itself, it can be concluded that the TPRs were reduced by above-mentioned effects. In the blanket design proposed by JAERI, it is expected that the reduction of the TBR is less than 2 % as the thickness of the W armor is less than 5 mm. Further experiment is to be performed using the mockup with 5 mm thick W armor.

References

1) Y. Yanagi, et al., *J. Nucl. Sci. Technol.*, 38, 1014-1018 (2001).
2) M. Enoeda, et al., Proc. of 19th IAEA Fusion Energy Conf. (2002).
3) S. Sato, et al., *J. Nucl. Mat.*, 313-316 690-695 (2002).

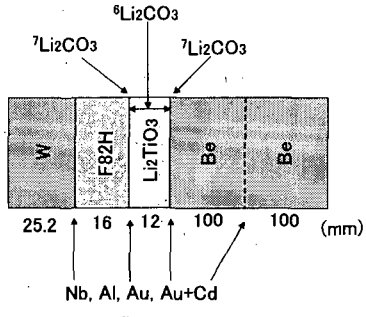

Fig. 1. The configuration of the mockup and the installation position of the detector.

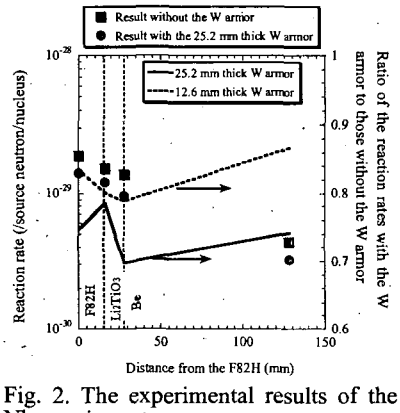

Fig. 2. The experimental results of the Nb reaction rate.

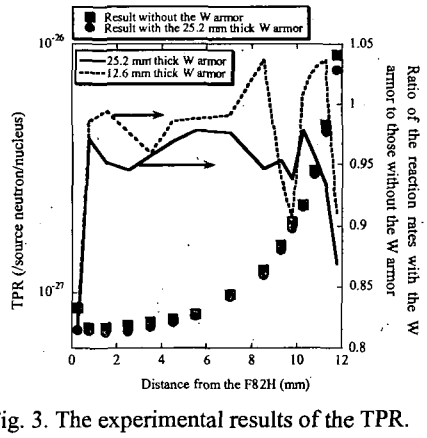

Fig. 3. The experimental results of the TPR.

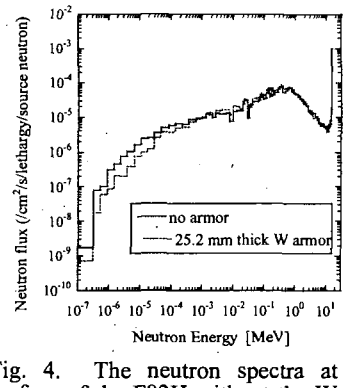

Fig. 4. The neutron spectra at the front surface of the F82H without the W armor and with the 25.2 mm thick one.

III-D-5

Non-Destructive Analysis of Impurities in Beryllium Affecting Evaluation of the Tritium Breeding Ratio

Yury Verzilov, Kentaro Ochiai, Axel Klix, Satoshi Sato, Masayuki Wada, Michinori Yamauchi and Takeo Nishitani

A paper on this subject was submitted to Journal of Nuclear Materials, with the following abstract.

The non-destructive, pulsed neutron method was used as the most effective one in analyzing the integral effect of impurities in beryllium, relevant to the tritium breeding ratio evaluation. The integral effect was evaluated from time behavior observations of the neutron density, following the injection of a burst of D-T neutrons into the beryllium assembly. The assembly was constructed from the structural beryllium grade S-200F (Brush Wellman Inc.). Experimental data was compared with the reference data and MCNP-4B calculations. Results show, that the measured absorption cross section of thermal neutrons in beryllium blocks is approximately 30% larger than the calculated value, based on the data, specified by the manufacturing company. Impurities in beryllium, such as the Li, B, Cd and others, affect the absorption cross section even if the content of impurities is less than 10 ppm.

III-D-6

Measurement of Deuteron-induced Activation Cross-Sections for Aluminum, Copper, and Tungsten in 22-34MeV Region

Jun-ichi HORI*, Makoto NAKAO, Kentaro OCHIAI, Michinori YAMAUCHI, Noriko S ISHIOKA and Takeo NISHITANI

A paper on this subject was submitted to JAERI CONF, with the following abstract.

Activation cross-sections for deuteron-induced reactions on aluminum, copper and tungsten were measured by using a stacked-foil technique at the AVF cyclotron in TIARA facility, JAERI. We irradiated three types of stacked-foil with 35 MeV deuteron beam and the activation cross sections for the $^{27}Al(d,x)^{27}Mg$, ^{24}Na, $^{nat}Cu(d,x)^{62,\ 63}Zn$, $^{61,\ 64}Cu$ and $^{nat}W(d,x)^{181-184,\ 186}Re$, ^{187}W reactions were obtained in 22-34 MeV region. The experimental cross sections were compared with other experimental ones and the data from ACSELAM library in the IRAC code system.

*Present address: Research Reactor Institute, Kyoto University, Kumatori-cho, Sennan-gun, Osaka 590-0494, Japan

IV. Japan Nuclear Cycle Development Institute

A. System Engineering Technology Division

IV-A-1

Validation of MA Nuclear Data by Sample Irradiation Experiments with the Fast Reactor "JOYO"

Shigeo OHKI

Japan Nuclear Cycle Development Institute is developing a commercialized fast reactor cycle system which involves the recycling of minor actinide (MA) nuclides. To develop a burnup calculation method and to validate MA nuclear data, we have launched the isotopic composition analysis of MA samples (^{237}Np, ^{241}Am, ^{243}Am, ^{244}Cm) irradiated at the experimental fast reactor "JOYO". The irradiation was performed for 200-250 EFPD during the period of 1994 to 1999. Post irradiation examination (PIE) of the first sample (one of ^{243}Am samples) was finished in October, 2003.

The preliminary C/E values for the ^{243}Am sample are listed in Table 1. The sample was initially composed of 12.2% of ^{241}Am and 87.8% of ^{243}Am. We focused on the production of ^{242m}Am from ^{241}Am, as well as that of ^{244}Cm from ^{243}Am. The main purpose of the former one was to validate the isomeric ratio (IR) of ^{241}Am capture reaction. There exist only two IR evaluations with the following large discrepancy: about 0.8 (ground/(ground + meta)) given from ENDF/B-VI under fast reactor spectrum, while about 0.7 from JENDL-3.3. This discrepancy influenced strongly on the production amount of ^{242m}Am. Assuming IR = 0.8 and using JENDL-3.2, we obtained the preliminary C/E value of 1.30 for the abundance ratio of ^{242m}Am/^{241}Am. In the case of IR = 0.85, the C/E value reduced to 1.00. To use other libraries (IR was set to 0.85) changed the C/E value no more than 6%. The experimental error was about 2% via mass spectroscopy, which was small enough. The above results implied the possibility that the IR of ^{241}Am capture reaction lies around 0.85. This is consistent with the independent PIE results with PFR[1] and PHENIX[2] as shown in Table 1. Necessity of re-evaluation of the IR both in ENDF/B-VI and in JENDL-3.3 is suggested.

For the abundance ratio of ^{244}Cm/^{243}Am, the present calculations underestimated the measurement systematically. We have met the difficulty in measuring the ratio of Cm/Am, in which relatively large experimental error (about 10%) arose from alpha spectroscopy. We now try to improve the measurement accuracy by means of the isotope dilution analysis.

We carry on the analyses for the remaining samples, increase the number of results, and apply detailed calculation modeling.

Table 1 Comparison of C/E values for the isotopic abundance ratio of irradiated MA samples

	PFR [Ref.1]	JOYO (preliminary result on the ^{243}Am sample)					PHENIX [Ref.2]
Nuclear data library	JENDL-3.2	JENDL-3.2	JENDL-3.2	JENDL-3.3	ENDF/B-VI.5	JEF-2.2	JEF-2.2
^{241}Am Isomeric ratio	0.80	0.80	0.85	0.85	0.85	0.85	0.85
^{242m}Am / ^{241}Am	1.29	1.30	1.00	1.02	0.94	1.03	1.03
^{244}Cm / ^{243}Am	0.95	0.84	0.84	0.84	0.83	0.88	0.96

References

1) K. Tsujimoto, *et al.*, *Nucl. Sci. Eng.*, **144**, 129 (2003).
2) R. Soule and E. Fort, Proc. GLOBAL '97, 1332 (1997).

B. Waste Management and Fuel Cycle Research Center

IV-B-1

Measurement of the Thermal Neutron Capture Cross Section and the Resonance Integral of the $^{109}Ag(n,\gamma)^{110m}Ag$ Reaction

S. NAKAMURA, H. WADA[1], O. SHCHERBAKOV,
K. FURUTAKA, H. HARADA and T. KATOH

A paper on this subject was published in J. Nucl. Sci. Technol., 40, 119 (2003) with the following abstract.

In order to develop a neutron flux monitor for long-term neutron irradiation, the thermal neutron (2,200 m/s neutron) capture cross section (σ_0) and the resonance integral (I_0) of the $^{109}Ag(n,\gamma)^{110m}Ag$ reaction were measured by the activation and γ-ray spectroscopic methods. Silver foils were irradiated with and without a Cd shield capsule at the Rikkyo Research Reactor. The Co/Al and Au/Al alloy wires were irradiated together with silver foils in order to monitor the thermal neutron flux and the fraction of the epi-thermal neutron part (Westcott's index). A high purity Ge detector was used for the γ-ray measurements of the irradiated samples. The σ_0 and the I_0 of the $^{109}Ag(n,\gamma)^{110m}Ag$ reaction are 4.12 ± 0.10 b and 67.9 ± 3.1 b, respectively. The σ_0 is 12% smaller than the tabulated one (4.7 ± 0.2 b). On the other hand, the I_0 is in agreement with the tabulated one (72.3 ± 4.0 b) within the limits of error.

*1 Present address: Nippon University

IV-B-2

Measurement of Thermal Neutron Capture Cross Section and Resonance Integral of the $^{237}Np(n, \gamma)^{238}Np$ Reaction

T. KATOH, S. NAKAMURA, K. FURUTAKA, H. HARADA, K. FUJIWARA[1], T. FUJII[2] and H. YAMANA[2]

A paper on this subject was published in J. Nucl. Sci. Technol., 40, 559 (2003) with the following abstract.

The thermal neutron capture cross section(σ_0) and the resonance integral(I_0) of ^{237}Np have been measured by an activation method to supply basic data for the study of transmutation of nuclear waste. The neutron irradiation of ^{237}Np samples have been done at the Research Reactor Institute, Kyoto University(KUR). Samples of ^{237}Np were irradiated between two Cd sheets or without a Cd sheet. Since ^{237}Np has a strong resonance at the energy of 0.49 eV, the Cd cut-off energy was adjusted at 0.358 eV(thickness of the Cd sheets: 0.125 mm). A high purity Ge detector was employed for activity measurement. The reaction rate to produce ^{238}Np from ^{237}Np was analyzed by the Westcott's convention. Results obtained were 141.7 $\pm$ 5.4 barns for σ_0 and 862 $\pm$ 51 barns for I_0 above 0.358 eV of ^{237}Np. By setting the Cd cut-off energy at 0.358 eV considering the resonance at 0.49 eV, a smaller value of σ_0 was obtained in this work than the values reported by the previous authors.

*1 Research Reactor Institute, Kyoto University
Present address: Japan Nuclear Cycle Development Institute
*2 Research Reactor Institute, Kyoto University

IV-B-3

A large BGO detector system for studies of neutron capture by radioactive nuclides

O. Shcherbakov, K. Furutaka, S. Nakamura, H. Harada, K. Kobayashi[1]

A paper on this subject was published in Nucl. Instru. Methods. A 517, 269 (2004) with the following abstract.

The 16-section BGO scintillation detector having a total volume of 8.54 l and the associated 40 MHz flash-ADC–based data taking system have been developed. This detector system is intended for the measurements of neutron capture cross sections of radioactive nuclei by the time-of-flight method. The detector response function, efficiency, gamma-ray and neutron energy resolution, backgrounds have been evaluated experimentally and by calculation. The neutron capture cross section measurements with ^{10}B, ^{197}Au and ^{237}Np samples have been carried out in the energy range 1 – 1000 eV to demonstrate the performance of the system.

*1 Research Reactor Institute, Kyoto University

IV-B-4

Measurement of Effective Capture Cross Section of ^{238}Np for Thermal Neutron

H. HARADA, S. NAKAMURA, T. FUJII[1], and H. YAMANA[1]

A paper on this subject was published in J. Nucl. Sci. Technol., 41, 1 (2004) with the following abstract.

The effective capture cross section ($\hat{\sigma}$) of ^{238}Np for thermal neutron has been measured as data for the burn-up analysis of irradiated fuels and for the study of nuclear transmutation of minor actinides. A sample of ^{237}Np was irradiated for 10 hours at the Kyoto University Reactor. Neptunium-238 and –239 were produced simultaneously via the double neutron capture reaction ^{237}Np(n, γ)^{238}Np(n, γ)^{239}Np. The neutron flux at the irradiation position was monitored using Au and Co monitor wires. The epithermal index $r\sqrt{T/T_0}$ in Westcott's convention was deduced as 0.03. To measure the activities of ^{238}Np and ^{239}Np, a high-purity Ge detector with a BGO ($Bi_4Ge_3O_{12}$) anti-coincidence shield has been developed. The $\hat{\sigma}$ of ^{238}Np was deduced from the ratio of these activities. The result obtained is 479 ± 24 b for the $\hat{\sigma}$ of ^{238}Np. The result is compared with data in evaluated nuclear data libraries, ENDL-86, ENDF/B-VI, and JENDL-3.3.

*1 Research Reactor Institute, Kyoto University

V. Kyoto University

A. Research Reactor Institute

V-A-1

Neutron Capture Cross Section Measurement of Praseodymium In the Energy Region from 0.003 eV to 140 keV

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

A paper on this subject was published in the Journal of Nuclear Science and Technology, Vol.40, No.7, 447-456 (2003) with the following abstract.

The neutron capture cross section of praseodymium (^{141}Pr) has been measured relative to the ^{10}B(n,$\alpha\gamma$) standard cross section in the energy region from 0.003 eV to 140 keV by the neutron time-of-flight (TOF) method with a 46-MeV electron linear accelerator (linac) of the Research Reactor Institute, Kyoto University (KURRI). An assembly of $Bi_4Ge_3O_{12}$ (BGO) scintillators was used for the capture cross section measurement. In addition, the thermal neutron cross section (2,200 m/s value) of the ^{141}Pr(n,γ)^{142}Pr reaction has been also measured by an activation method at the heavy water thermal neutron facility of the Kyoto University Reactor (KUR). The thermal neutron flux was monitored with the ^{197}Au(n,γ)^{198}Au standard cross section. The above TOF measurement has been normalized to the current activation data (11.6±1.3 b) at 0.0253 eV.

The evaluated data in JENDL-3.3, ENDF/B-VI, and JEF-2.2 have been in general agreement with the current result, except that the JENDL-3.3 and the JEF-2.2 values are clearly lower than the measurement in the cross section minimum region from about 10 to 500 eV.

[1] Dong-A University,
840 Hadan 2-dong, Saha-gu, Pusan, 604-714, Korea.
[2] Research Reactor Institute, Kyoto University,
Kumatori-cho, Sennan-gun, Osaka 590-0494, Japan.

V-A-2

Neutron Capture Cross Section Measurement of Technetium-99 By Linac Time-of-Flight Method and the Resonance Analysis

Katsuhei Kobayashi [1], Samyol Lee [1], Shuji Yamamoto [1], and Toshihiko Kawano [2]*

A paper on this subject will be published soon in the Nuclear Science and Engineering, with the following abstract.

The neutron capture cross section of ^{99}Tc has been measured relative to the $^{10}B(n,\alpha\gamma)$ standard cross section by the neutron time-of-flight (TOF) method in the energy range of 0.005 eV to 47 keV using a detection assembly of $Bi_4Ge_3O_{12}$ (BGO) scintillators and a 46 MeV electron linear accelerator (linac) at the Research Reactor Institute, Kyoto University (KURRI). The relative measurement has been normalized at 0.0253 eV to the reference value (22.9 ± 1.3 b) measured by Harada et al. The energy dependent experimental data and the evaluated data in ENDF/B-VI, JENDL-3.2, -3.3 and JEF-2.2 are in general agreement with the current measurement. Especially the JENDL-3.3 data, which have been recently released, show better agreement with the measurement in the lower energy region.

The resonance parameters at 5.6 and 20.3 eV have been analyzed by the KALMAN system using the current TOF data. The resonance integral calculated with the parameters obtained is derived to be 330 ± 19 b, which is close to the data obtained from JENDL-3.3 and evaluated by Mughabghab, although the resonance integrals from JENDL-3.2, ENDF/B-VI and JEF-2.2 are smaller by about 6 to 8 % than the current value. The resonance integral data measured by Harada et al. is larger by about 20 %.

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[1] Research Reactor Institute, Kyoto University,
Kumatori-cho, Sennan-gun, Osaka 590-0494, Japan.

[2] Interdisciplinary Graduate School of Engineering Sciences, Kyushu University
6-1 Kasuga Koen, Kasuga-shi, Fukuoka 816-8580, Japan

* Present address: T16, MS B243, Los Alamos National Laboratory,
Los Alamos, NM 87545, USA

VI. Kyushu University

A. Department of Advanced Energy Engineering Science

VI-A-1

Coupled-channels analysis of nucleon interaction data of ^{28,30}Si up to 200 MeV based on the soft rotator model

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

A paper on this subject was published in *J. Nucl. Sci. and Technol.*, **40**, 635–643 (2003) with the following abstract

A consistent analysis for nuclear level structure and nucleon scattering data up to 200 MeV was performed for sd-shell nuclei, ^{28,30}Si, using a unified framework of soft-rotator model and coupled-channels approach. The ^{28,30}Si were assumed to be deformed nuclei having oblate shapes. The soft-rotator model parameters were determined so as to reproduce measured collective levels of ^{28,30}Si up to an excitation energy of around 10 MeV. The relativistic kinematics and global optical potential form were taken into account in the coupled-channels optical model analysis, and the optical model parameters were derived. The calculation showed good agreement with experimental data for both collective levels and nucleon interaction data — neutron total cross sections, proton reaction cross sections, and nucleon scattering angular distributions.

[†]Institute of Applied Physics and Computational Mathematics, China
[‡]Joint Institute of Energy and Nuclear Research - Sosny, Belarus
[*]Japan Atomic Energy Research Institute

VI-A-2

Evaluation of cross sections for nucleons up to 3 GeV on ^{12}C

Y. Watanabe, O. Iwamoto[†], T. Fukahori[†], S. Chiba[†], E.Sh. Sukhovitskiĭ[‡]

A paper on this subject was published in Proc. of the 2002 Symposium on Nuclear Data, Nov. 21-22, 2002, JAERI, Tokai, Japan; JAERI-Conf 2003-006, p.183–188 (2003) with the following abstract:

We have performed an evaluation of cross sections on ^{12}C for both neutron and proton with energies between 20 MeV and 3 GeV. The evaluation is based on measured data as well as predictions from nuclear model calculations and some systematics. The results are compared with available experimental data and the LA150 evaluation. Thick target neutron production spectra for proton incident on carbon are analyzed using the evaluated double-differential (p, xn) cross sections.

[†]Japan Atomic Energy Research Institute
[‡]Joint Institute of Energy and Nuclear Research - Sosny, Belarus

VI-A-3

Analysis of cosmic ray neutron induced single-event phenomena

Y. Tukamoto, Y. Watanabe, H. Nakashima

A paper on this subject was published in Proc. of the 2002 Symposium on Nuclear Data, Nov. 21-22, 2002, JAERI, Tokai, Japan; JAERI-Conf 2003-006, p.265–270 (2003) with the following abstract:

We have developed a database of cross sections for the n+^{28}Si reaction in the energy range between 2 MeV and 3 GeV in order to analyze single-event upset (SEU) phenomena induced by cosmic-ray neutrons in semiconductor memory devices. The data are applied to calculations of SEU cross sections using the Burst Generation Rate (BGR) model including two parameters, critical charge and effective depth. The calculated results are compared with measured SEU cross-sections for energies up to 160 MeV, and the reaction products that provide important effects on SEU are mainly investigated.

VI-A-4

High-energy neutron and proton nuclear data for applications — Evaluation of cross sections on C and Si up to 3 GeV —

Y. Watanabe, W. Sun†, K. Kosako‡, E.S. Sukhovitskii*,
O. Iwamoto¶, S. Chiba¶, T. Fukahori¶

A paper on this subject was presented at XV Int. School on Nuclear Physics, Neutron Physics and Nuclear Energy, Sep. 9-13, 2003, Varna, Bulgaria with the following abstract:

We have performed an evaluation of cross sections on ^{12,13}C and ^{28,29,30}Si for both neutrons and protons in the incident energy range extended up to 3 GeV in order to meet nuclear data needs in accelerator-related applications. The evaluation is based on predictions from nuclear model calculations and systematics as well as measurements. A nuclear model calculation code system developed for this purpose is described. The evaluated cross sections contain the following data: neutron total cross sections, nucleon elastic scattering cross sections and angular distributions, non-elastic cross sections, production cross sections and double-differential cross sections of secondary light particles (n, p, d, t, ^{3}He, α, and π), and isotope production cross sections. The results are compared with available experimental data and the LA150 evaluation. For validation of these nuclear data, thick-target neutron production spectra from C target are calculated for bombardment of 113 MeV and 256 MeV protons using the MCNPX transport code and are compared with the measurements. An application of Si data to predictions of neutron-induced single-event upset phenomena in microelectronics is also presented. These evaluated nuclear data are included into the JENDL high-energy library in ENDF-6 format.

†Institute of Applied Physics and Computational Mathematics, China
‡Sumitomo Atomic Energy Industries, Ltd.
*Joint Institute of Energy and Nuclear Research - Sosny, Belarus
¶Japan Atomic Energy Research Institute

VI-A-5

Nuclear data relevant to single-event upsets (SEU) in microelectronics and their application to SEU simulation

Y. Watanabe, Y. Tukamoto, A. Kodama, H. Nakashima

A paper on this subject was presented at the 2003 Symposium on Nuclear Data, Nov. 27-28, 2003, JAERI, Tokai, Japan with the following abstract:

The radiation effects known as single-event upsets(SEUs) in microelectronics have recently been recognized as a key reliability concern for many current and future silicon-based integrated circuit technologies. Cosmic-ray neutrons with a wide energy range from MeV to GeV are regarded as one of the major sources of SEUs in the devices used on the ground or in airplanes. Therefore, nuclear reaction data to describe the interaction of neutrons with the nuclides contained in the devices are highly requested as a fundamental physical quantity necessary for SEU simulations. Under these circumstances, we have recently developed a cross section database for silicon, using evaluated nuclear data file (JENDL-3.3 and LA150) and QMD calculation for energies ranging from 2 MeV to 3000 MeV. So far, it has been applied successfully to SEU simulations.

In the present work, we propose a simple model of calculating SEU cross sections based on the Monte Carlo method. Using the model, we analyze the experimental data for SRAM and the simulation results for DRAM, in order to investigate the dependence of SEU cross sections on incident neutron energy and clarify the secondary ions generated by nuclear reactions with Si and incident energy range which have the most important effects on SEUs. In addition, the model calculations are compared with the calculations based on the Burst Generation Rate (BGR) method, and a consideration on the sensitive volume used in the BGR method is given.

VII. Nagoya University

A. Department of Energy Engineering and Science

VII-A-1

Measurement method of activation cross sections of reactions producing short-lived nuclei with 14-MeV neutrons

K. Kawade, H. Sakane, Y. Kasugai, M. Shibata,
T. Iida [1], A. Takahashi [1] and T. Fukahori[2]

A paper on this subject was published in Nucl. Instr. Meth. A496 (2003) 183-197, with the following abstract.

We describe a method for obtaining reliable activation cross sections in the neutron energy range between 13.4 and 14.9 MeV for the reactions producing short-lived nuclei with half-lives between 0.5 and 30 min. We noted neutron irradiation fields and measured induced activities, including (1) the contribution of scattered low-energy neutrons, (2) the fluctuation of the neutron fluence rate during the irradiation, (3) the true coincidence sum effect, (4) the random coincidence sum effect, (5) the deviation in the measuring position due to finite sample thickness, (6) the self-absorption of the γ-ray in the sample material and (7) the interference reactions producing the same radionuclides or the ones emitting the γ-ray with the same energy of interest. The cross sections can be obtained within a total error of 3.6%, when good counting statistics are achieved, including an error of 3.0% for the standard cross section of ^{27}Al (n, α) ^{24}Na. We propose here simple methods for measuring γ-rays efficiently at a close source-to-detector distance and for measuring β^+ activities emitting almost no γ-rays.

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[1] Osaka University, Yamadaoka, Suita-shi, Osaka 565-0871, Japan
[2]Japan Atomic Energy Research Institute, Tokai-mura, Ibaraki-ken, Japan

VII-A-2

Measurements of the (n, np+d) activation cross sections with 13.4 - 14.9 MeV neutrons using a Fusion Neutronics Source/JAERI

Hitoshi Sakane, Yoshimi Kasugai[1], Michihiro Shibata,
Hiroshi Takeuchi[1], and Kiyoshi Kawade

A paper on this subject was published in Annals of Nuclear Energy 30 (2003) 1847-1862, with the following abstract.

The activation cross sections for twenty (n, np+d) reactions were measured in the energy range between 13.4 and 14.9 MeV [by the activation method]. The mass-separated isotopes of ^{87}Sr, ^{95,100}Mo, ^{104}Ru, ^{106}Pd, ^{113,116}Cd, ^{118,119,120}Sn, ^{123,128,130}Te, ^{184,186}W, and ^{189,190}Os were irradiated. The sixteen cross sections, excepting those for ^{118}Sn, ^{128}Te and ^{184,186}W, were obtained for the first time.

The d-T neutron source of the Fusion Neutronics Source (FNS) at the Japan Atomic Energy Research Institute (JAERI) was used for irradiation. All cross section values were determined relative to that of the ^{27}Al (n, α) ^{24}Na reaction (ENDF/B-VI). To measure weakly induced activities, an efficiency calibration technique with a well-type HPGe detector was applied.

The present results were compared with the comprehensive evaluated data in the JENDL-3.3, the JENDL-Activation File, the ENDF/B-VI, and the FENDL/A-2.0. Most of the data in the JENDL-3.3 and the JENDL-Activation File were in good agreement with the present result. However, relative to our values, thirteen of the twenty evaluated data in FENDL/A-2.0 were overestimated more than 2 times or underestimated by more than one order.

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[1]Japan Atomic Energy Research Institute, Tokai-mura, Ibaraki-ken, Japan

VII-A-3

Measurements of activation cross sections of (n, p) and (n, α) reactions with d-D neutrons in the energy range of 2.1 to 3.1 MeV

Toshiaki Shimizu, Hitoshi Sakane, Michihiro Shibata,
Kiyoshi Kawade, and Takeo Nishitani[1]

A paper on this subject was submitted to Annals of Nuclear Energy in 2003 and in press, with the following abstract.

Activation cross sections for (n, p) and (n, α) reactions were measured by the activation method in the energy range of 2.1 to 3.1 MeV. The irradiated target isotopes were ^{27}Al, ^{41}K, ^{47}Ti, ^{51}V, ^{54}Fe, ^{59}Co, ^{58,61}Ni, ^{65}Cu, ^{67}Zn, ^{69}Ga, ^{79}Br, ^{92}Mo, ^{93}Nb, and ^{96}Ru. The cross sections for ^{41}K (n, p) ^{41}Ar, ^{61}Ni (n, p) ^{61}Co, ^{65}Cu (n, p) ^{65}Ni, ^{67}Zn (n, p) ^{67}Cu, ^{79}Br (n, p) ^{79m}Se, ^{96}Ru (n, p) $^{96m+g}$Tc, and ^{69}Ga (n, α) ^{66}Cu reactions were obtained for the first time.

Irradiation was from the d-D neutron source of the Fusion Neutronics Source at the Japan Atomic Energy Research Institute. All cross section values were determined relative to those of the ^{115}In (n, n') ^{115m}In reaction. To obtain reliable activation cross sections, careful attention was paid to correct neutron irradiation and to correct the measurement of induced activity as well as to determine the mean neutron energy at the irradiation positions. To measure weak activity levels, a highly efficient measuring technique with a well-type High Purity Germanium detector was applied to the activities.

The present results were compared against the comprehensive evaluated data in JENDL-3.3, -3.2, and -Activation File 96 as well as in ENDF/B-VI, and FENDL/A-2.0. We concluded that the evaluated data for ^{41}K (n, p) ^{41}Ar, ^{51}V (n, p) ^{51}Ti, ^{61}Ni (n, p) ^{61}Co, ^{79}Br (n, p) ^{79m}Se, ^{96}Ru (n, p) $^{96m+g}$Tc, ^{69}Ga (n, α) ^{66}Cu, and ^{93}Nb (n, α) ^{90m}Y reactions were overestimated or underestimated by more than 30%.

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[1]Japan Atomic Energy Research Institute, Tokai-mura, Ibaraki-ken, Japan

VII-A-4

An improved pneumatic sample transport system for measurement of activation cross sections with d-D neutrons in the energy range between 2.1 and 3.1 MeV

T. Shimizu, H. Sakane, S. Furuichi, M. Shibata, K. Kawade, and H. Takeuchi[1]

A paper on this subject was submitted to Nucl. Instr. Meth. A in 2003 and in press, with the following abstract.

We have improved a pneumatic sample transport system that enables activation cross sections to be measured by producing short-lived nuclei on the order of sub-millibarns. The irradiation distances between the d-D neutron source and the samples ranged from 20 to 65 mm at six angles of between 0° and 155°. The neutron fluence rates were between 1×10^8 and 5×10^6 n/cm^2/s in the 2.1 to 3.1-MeV range, and these values were between 24 and 3 times higher than those of the previous system, which used a distance of 100 mm, at the Fusion Neutronics Source at the Japan Atomic Energy Research Institute.

The energy spreads at the irradiation positions were calculated by taking into account the slowing of incident 350-keV deuterons, the self-loaded deuteron distribution in the Ti-target and the solid angle subtended by the irradiated sample. At each angle, the acceptably close distance was found to be about 20 mm under the condition of an energy spread of less than about 300 keV. The spreads at about 0° and 180° were determined mainly by the slowing of deuterons in the target, while those at about 90° were determined by the finite solid angle.

The activation cross sections of ^{27}Al (n, p) ^{27}Mg and ^{61}Ni (n, p) ^{61}Co reactions were obtained for test measurements. This was undertaken with the prospect of using the present system to systematically measure the activation cross sections down to a sub-millibarn level.

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[1]Japan Atomic Energy Research Institute, Tokai-mura, Ibaraki-ken, Japan

VIII. National Institute of Advanced Industrial Science and Technology

A. National Metrology Institute of Japan

VIII-A-1

Characterization of Gamma Rays Existing in The NMIJ Standard Neutron Field

H. Harano, T. Matsumoto, Y. Ito[1], G. Katano, A. Uritani and K. Kudo

National Metrology Institute of Japan,
National Institute of Advanced Industrial Science and Technology,
Tsukuba, 305-8568, Japan

A paper on this subject was submitted to the Proceeding of the Ninth Neutron Dosimetry Symposium, the Delft University of technology, the Netherlands, September 28 - October 3, 2003, Radiation Protection Dosimetry.

Introduction

Our laboratory provides national standards on fast neutron fluence. Neutron fields are always accompanied by gamma rays produced in neutron sources and surroundings. It is very important to quantitatively characterize these gamma rays for calibration of neutron detectors or sensing elements, because most of them are sensitive to both neutrons and gamma rays. We have characterized the gamma rays in the thermal neutron field [1]. In this paper, we describe characterization of the gamma rays in the 5.0 MeV standard neutron field.

Experimental

A Van de Graaff accelerator (4UH-HC Pelletron, Nuclear Electrostatic, USA) is used to produce the 5.0 MeV neutrons by the $D(d,n)^3He$ reaction, where 1.817 MeV deuteron beam impinges on the target consisting of Ti-D evaporated on a 0.5 mm thick copper backing. The mixed photon dose in the fast neutron field was measured with the NE213 liquid organic scintillation detector, 5.08 cm diameter x 5.08 cm thick, coupled to a photomultiplier tube (R329-02, Hamamatsu). The rise-time-related signal was collected with the pulse-height amplitude in a coincidence mode using a multiparameter data acquisition system (MPA-3, Fast ComTec). The pulse shape discrimination between gamma rays and neutrons was performed using the differences in the rise time. The irradiated fluence was determined at the calibration point with the count of a polyethylene long counter (PLC) situated at the angle of 45 degree.

The gamma-ray response spectra of the NE213 detector were measured using gamma-ray reference sources of ^{88}Y, ^{60}Co, ^{22}Na, ^{54}Mn, and ^{137}Cs. The energy resolution function and the scaling factor between the deposited electron-equivalent energy (MeVee) and the channel number were determined by comparing the spectra with the response function calculated by the EGS4 electron-photon transport Monte-Carlo code [2]. The response functions were prepared by calculating and tallying the energy deposition in the NE213 detector for the incident gamma rays up to 10 MeV by the EGS4 code. The response matrix for the unfolding codes was completed by folding these calculated response functions with the resolution function.

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[1] Present address, Japan Science and Technology Agency, Kawaguchi, 332-0012, Japan

Results and Discussions

Figure 1 shows the pulse height spectra measured in the 5.0 MeV standard neutron field. The NE213 detector was located at 50 cm and 100 cm from the target. Figure 2 shows the unfolded spectra obtained by the MIEKE code in the HEPRO program package [3] using the response matrix. The effective dose equivalents were evaluated for these spectral fluences using the conversion coefficients calculated for the MIRD phantoms [4]. Table 1 summarizes the results for the AP geometry (irradiation from the front to the back) and the LAT geometry (lateral irradiation from either side). These values however include the contribution of the neutron-induced gamma rays generated in the detector assembly. Figure 1 also shows the detector response to the self-produced gamma rays calculated using the MCNP4C code [5]. The corrected values of the effective dose equivalent are also shown in Table 1.

Conclusions

We have characterized the gamma rays existing in the 5.0 MeV neutron field for the national standard in Japan. Further characterization is in progress on the parasite gamma rays existing in the fast neutron field of the other energies such as 144 keV, 565 keV and 14.8 MeV.

References:
[1] K.Kudo, N.Takeda, S.Koshikawa, H.Toyokawa, H.Ohgaki and M.Matzke, Nucl. Instr. and Meth. A 476, 213-217 (2002).
[2] W.R.Nelson, H.Hirayama and D.W.O.Rogers, *The EGS4 Code System.* SLAC-265, Stanford University, 1985.
[3] M.Matzke, *Unfolding of pulse height spectra: the HEPRO program system.* PTB Report PTB-N-19, Braunschweig, 1994.
[4] ICRP *Data for Use in Protection Against External Radiation.* ICRP Publication 51, Ann. ICRP, 17(2/3), Pergamon Press, Oxford, (1987).
[5] J.F.Briesmeister (Editor), *MCNP - a general Monte Carlo n-particle transport code, version 4C.* LA-13709-M, Los Alamos National Laboratory, 2000.

Table 1: Effective dose equivalents of the gamma rays at 10^7 neutrons/cm^2 on the detector.

Position	Effective dose equivalent (Corrected) [μSv]	
	AP	LAT
50 cm	26.0 (24.1)	20.2 (18.9)
100 cm	29.2 (27.2)	22.7 (21.3)

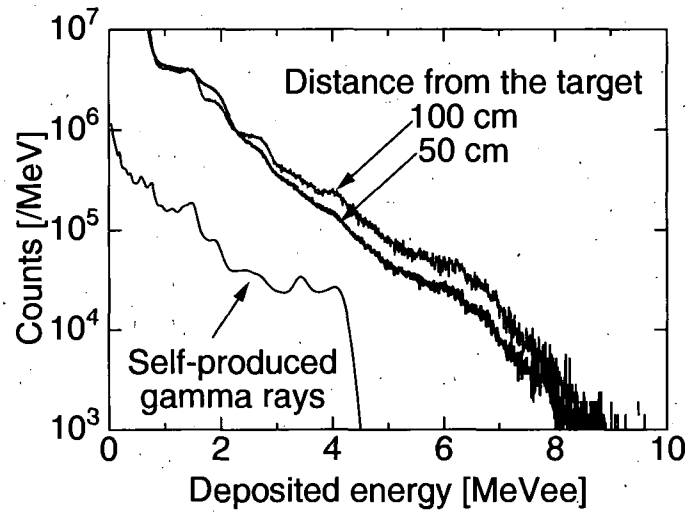

Figure 1: Pulse height spectra measured in the 5.0 MeV standard neutron field and calculated response to the neutron-induced gamma rays in the detector.

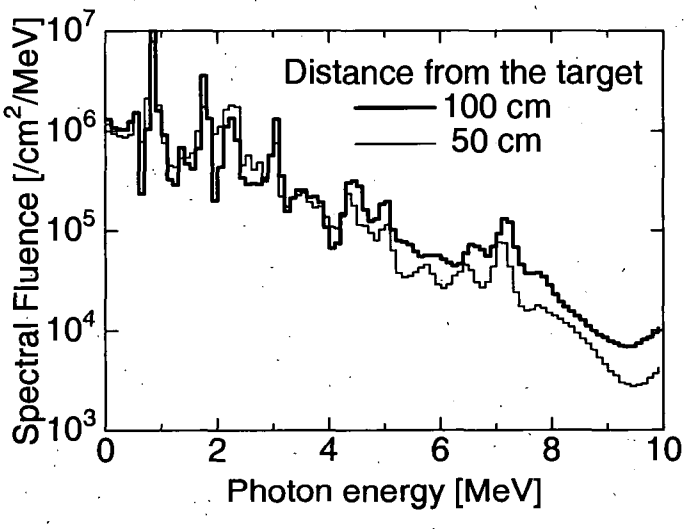

Figure 2: Photon energy spectra in the 5.0 MeV standard neutron field unfolded by the MIEKE code.

VIII-A-2

Development of a Tiny Neutron Probe with an Optical Fiber for BNCT

G. Katano, Y. Ito[1], H. Harano, T. Matsumoto, A. Uritani, K. Kudo,
K. Kobayashi[2], T. Yoshimoto[2], Y. Sakurai[2], T. Kobayashi[2] and C. Mori[3]

A paper on this subject was submitted to the Proceeding of the Ninth Neutron Dosimetry Symposium, the Delft University of technology, the Netherlands, September 28 - October 3, 2003, Radiation Protection Dosimetry.

We have developed a tiny neutron probe detector as a monitor of a thermal neutron flux for boron neutron capture therapy (BNCT) [1]. The detector consists of an optical fiber and a small neutron probe. We have used a film-like ZnS (Ag) scintillator and a ^{6}LiF neutron converter for the neutron probe. In order to improve the neutron-gamma discrimination ability, vacuum evaporation of ^{6}LiF onto the ZnS (Ag) film has been done. In order to improve the neutron detection efficiency, we have newly made use of a wavelength shifting (WLS) fiber [2] as the probe material. In this report, the characteristics of the two types of detector are shown.

The pulse height spectra of the detectors were measured at the thermal neutron field of the HWNIF of the KUR, and under the thermal neutron irradiation mode. The thermal neutron flux was measured with a gold activation method.

A ZnS (Ag) film is made on 12 μm cellulose acetate sheet. ^{6}LiF was evaporated onto the cellulose side. The ^{6}LiF thickness was about 5 μm. This neutron probe was stick on an optical fiber end. The pulse height spectrum of this detector is shown in Fig. 1. The thermal neutron flux was about 1.4×10^{5} n/cm^{2}·s. The cellulose acetate sheet fully stopped alpha particles. Alpha particles were never detected and only tritons contributed to the pulse height spectrum. As the result, the peak of the neutron events appears clearly as is seen in Fig. 1. This pulse height spectrum indicates the high neutron-gamma discrimination ability. It is easy to set the discrimination level at the valley. The sensitivity of the fiber detectors was 2.1×10^{-3} cm^{2}.

We made another type probe with the WLS fiber. The neutron probe sheet was attached on the side surface of the WLS fiber. The length of the films was 1cm. The pulse height spectrum of the detector is shown in Fig. 2. The thermal neutron flux was about 8.4×10^{4} n/cm^{2}·s. The gain of the amplifier was 10 times higher than that applied for the above type detector, because the intensity of the scintillation light decreased during the process of wavelength shifting. The sensitivity of the fiber probe detector was 9.5×10^{-2} cm^{2}, when the discrimination level was set at 70 channel. The sensitivity was 40 times higher than that of the above type detector at the sacrifice of the neutron-gamma discrimination ability and the spatial resolution. The spatial resolution became worse because of the long neutron probe.

The purpose of this research was to enhance the neutron-gamma discrimination ability and neutron detection efficiency of the neutron probe detectors. The pulse height spectrum that had the high neutron-gamma discrimination ability was obtained with a detector had the film-like neutron converter made by vacuum evaporation. For another purpose, we made use of the WLS fiber and expanded the effective detection area. The neutron sensitivity was 40 times higher than that of the first type.

[1] Present address, Japan Science and Technology Agency, Kawaguchi, 332-0012, Japan
[2] Research Reactor Institute, Kyoto University, Kumatori, 590-0494, Japan
[3] Faculty of Engineering, Aichi Institute of Technology, Toyota, 470-0392, Japan

References:
[1] Sakurai, Y. and Kobayashi, T. *Characteristics of the KUR Heavy Water Neutron Irradiation Facility as a neutron irradiation filed with variable energy spectra*, Nuclear Instr. & Meth. A453, 569-596 (2000).
[2] Gorin A., Kuroda K., Manuilov I., Morimoto K., Oku T., Ryazantsev A., Shimizu M. H., Suzuki J. and Tokanai F. *Development of Scintillation imaging device for cold neutrons*, Nuclear Instr. & Meth. A479, 456-460 (2002).

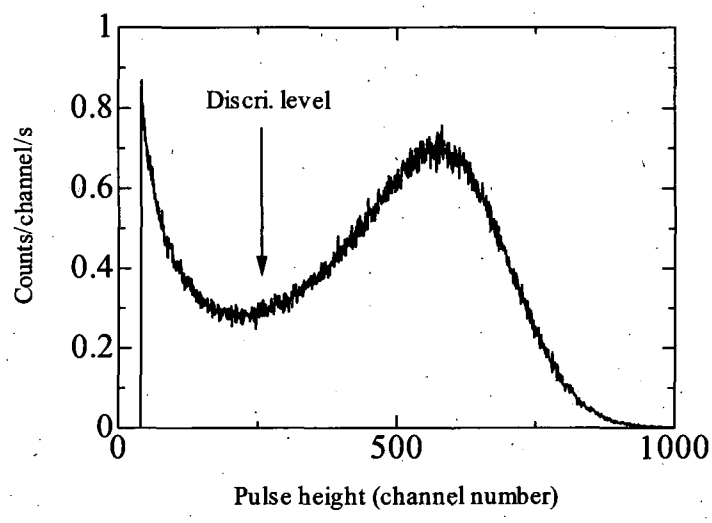

Figure 1: Pulse height spectrum of the thin ZnS(Ag) film probe detector.

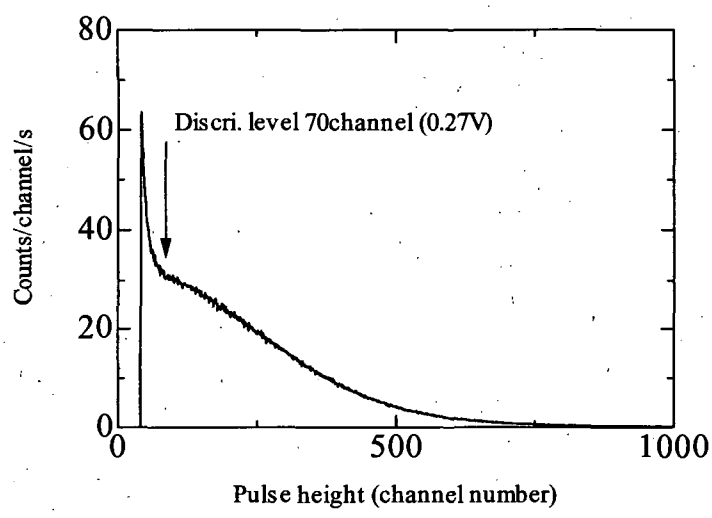

Figure 2: Pulse height spectrum of the WLS fiber probe detector.

VIII-A-3

Development of Fast Neutron Spectrometer Composed of Silicon-SSD and Position-Sensitive Proportional Counters

T. Matsumoto, H. Harano, Y. Ito[1], G.Katano, A. Uritani, K. Emi and K. Kudo

A paper on this subject was submitted to proceedings of the Ninth Neutron Dosimetry Symposium, the Delft University of Technology, the Netherlands, 28 September – 3 October, 2003; Radiat. Prot. Dosim. The content is as follows.

There are many types of fast neutron spectrometers for thermo-nuclear fusion plasma diagnostics. Mori *et al.* [1] developed a spectrometer with recoil-proton method several years ago. The spectrometer consisted of a silicon surface barrier detector (SSD) and an ordinary proportional counter with methane gas of which axis is parallel to an incident neutron beam. They achieved energy resolution of 2.4 % for 5 MeV neutrons and 2.1 % for 14 MeV neutrons. The energy resolution of the spectrometer was restricted by ambiguity of the recoil angle of the recoil protons. In the present study, we adopted three charge-division-type position-sensitive proportional counters(PSPCs) instead of the ordinary proportional counter. Figure 1 shows a schematic drawing of the present spectrometer. A collimator made of polyethylene with a thickness of 20 cm is placed in front of the spectrometer so as to fix the direction of the incident neutrons. Each PSPC with a quadratic prism of 3 cm each side and 15.5 cm length consists of a Nichrome wire of 10 μm diameter as an anode and methane gas working as counting gas and a radiator. The axes of the PSPCs are perpendicular to the collimated incident neutron direction. A stainless-steel mesh is put between the PSPCs for electrostatic shielding. The SSD with a sensitive area of 150 mm^2 and a depletion layer depth of 2000 μm is placed at 19 mm away from the center of the incident neutron beam in order to avoid radiation damage. Signals from both ends of all anode wires and the SSD are stored into a personal computer in a list mode. Coincidental signals are extracted from the list files using a computer program.

The recoil proton generated by collision of a collimated incident neutron with a hydrogen atom in the first PSPC passes through the second and third PSPCs and reaches the SSD. The energy of the recoil proton is measured with the PSPCs and the SSD. At the same time, position signals at A and B in Fig. 1 are obtained from the outputs of the second and the third PSPCs. The recoil angles are derived from the position information. Finally, the neutron energy is derived from the energy of the recoil proton and the recoil angle.

The characteristics of the spectrometer was evaluated using 5.0 MeV neutrons generated by a 4 MV Pelletron accelerator and $D(d,n)^3He$ neutron source at the National Institute of Advanced Industrial Science and Technology. Figure 2 shows the energy spectrum of 5.0 MeV neutrons. The FWHM of the spectrum is 2.6 %. Therefore, the energy resolution of the present spectrometer was estimated to be 1.8 % by taking it into account that the energy width (FWHM) of the incident neutrons is 90 keV [2]. This energy resolution is better than that of the spectrometer with the ordinary proportional counter.

[1] Present address, Japan Science and Technology Agency, Kawaguchi, 332-0012, Japan

References:
[1] Mori, C., Tojo, M., Yanagida, K., Goto, J., Uritani, A., Miyahara, H., Wu, Y., Kudo, K., Takeda, N., Ikeda, Y., Kasugai, Y., Iida, T., Sakuma, Y. and Sasao, M. *Development of fast neutron spectrometer of proportional counter and Si-detector telescope type.* Fusion Technology 30, 1134 (1996).
[2] Kudo, K., Uritani, A. and Takeda, N. *NMIJ report for CCRI key comparison of neutron fluence neasurements at energies of 144 keV, 5.0 MeV and 14.8 MeV.* AIST Bulletin of Metrology 2(1), 61 (2003).

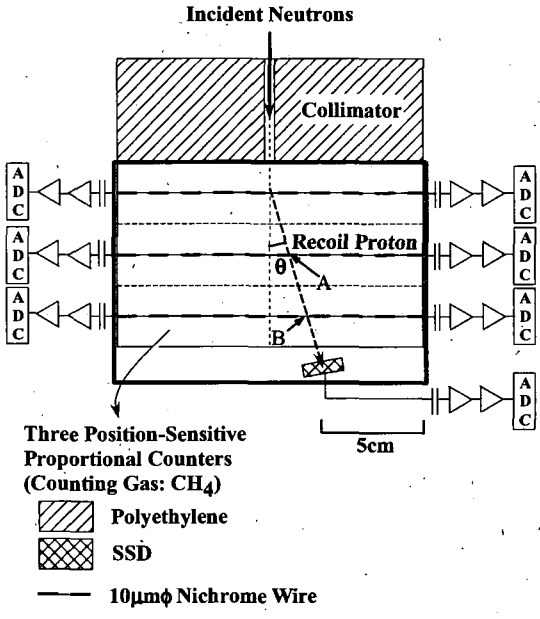

Figure 1: Schematic drawing of the present spectrometer

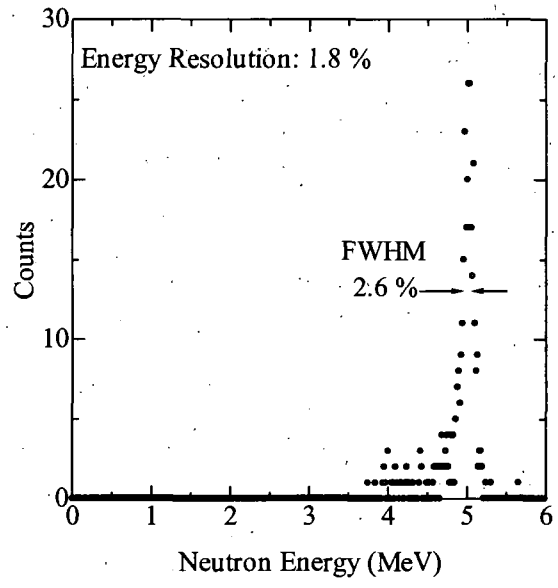

Figure 2: Derived the energy spectrum of 5.0 MeV neutrons

IX. Tokyo Institute of Technology

A. Research Laboratory for Nuclear Reactors

IX-A-1

Measurements of keV-Neutron Capture Cross Sections and Capture Gamma-Ray Spectra of ^{99}Tc

M. Igashira, T. Ohsaki and T. Matsumoto

A paper of the title was published in J. Nucl. Sci. Technol., **40**, 61 (2003) with the following abstract.

The capture cross sections of ^{99}Tc were measured in the incident neutron energy region from 8 to 90 keV and at 190, 330, and 540 keV. A neutron time-of-flight method was adopted with a ns-pulsed neutron source by the ^{7}Li(p,n)^{7}Be reaction and with a large anti-Compton NaI(Tl) gamma-ray spectrometer. A pulse-height weighting technique was applied to observed capture gamma-ray pulse-height spectra to derive capture yields. Using the standard capture cross sections of ^{197}Au, the capture cross sections of ^{99}Tc were obtained with the error of about 5%. The present results were compared with other measurements and the evaluated values of JENDL-3.2 and 3.3 and ENDF/B-VI. Capture gamma-ray spectra were obtained by unfolding observed capture gamma-ray pulse-height spectra. A change of slopes was observed at 2.2 MeV in the spectra. The mulitiplicities of observed gamma rays were obtained from the gamma-ray spectra.

IX-A-2

An Interpretation of the Anomalous Bump in keV-Neutron Capture γ-Ray Spectra of Lanthanide Nuclides

M. Igashira, T. Ohsaki and M. Kawasaki

A paper of the title was published in Proc. 11-th Int. Symp. on Capture Gamma-Ray Spectroscopy and Related Topics, Pruhonice near Prague, Czech Republic, 2002, ed. J.Kvasil, P.Cejnar and M.Krticka (World Scientific, 2003) 258 with the following abstract.

To investigate the origin of the anomalous bump or shoulder observed in the γ-ray energy region from 1.5 to 3.5 MeV in the keV-neutron capture γ-ray spectra of lanthanide nuclides, the spectra of ^{145}Nd, ^{161}Dy, and ^{167}Er were analyzed with the statistical model calculation from the viewpoint of the M1 scissors mode excitation, assuming the Brink hypothesis for the excitation. The values of $B(M1)$ for the excitation were derived from the analysis, and the derived values were in good agreement with those derived from the (γ, γ') reactions. From this agreement, the anomalous bump or shoulder in the keV-neutron capture γ-ray spectra of lanthanide nuclides may be ascribed to the M1 scissors mode excitation if we can assume the Brink hypothesis for the M1 scissors mode excitation.

IX-A-3

Measurement of the $^{18}O(n,\gamma)^{19}O$ Reaction Cross Sections by Prompt γ-Ray Detection Methods at Thermal and keV Energies

T. Ohsaki, M. Igashira, Y. Nagai, K. Kobayashi, T. Kobayashi and Y. Sakurai

A paper of the title was published in Proc. 11-th Int. Symp. on Capture Gamma-Ray Spectroscopy and Related Topics, Pruhonice near Prague, Czech Republic, 2002, ed. J.Kvasil, P.Cejnar and M.Krticka (World Scientific, 2003) 364 with the following abstract.

The $^{18}O(n,\gamma)^{19}O$ reaction cross section, which is important for studies on the nucleosyntheses in the non-standard inhomogeneous big-bang model and the s process in cool giant stars, was measured by prompt γ-ray detection methods at thermal and keV energies. In the measurement at thermal energy, ten primary and secondary γ-ray transitions were identified and the total capture cross section was obtained as 156 $\pm$ 16 μb, assuming a new ^{19}O neutron separation energy of 3.964 MeV. In the measurement at keV energies, three primary transitions were observed and the total capture cross sections were obtained as 8.5 $\pm$ 1.7 and 11.9 $\pm$ 1.8 μb at 42 and 65 keV, respectively.

IX-A-4

Measurements of Neutron Capture Cross Sections for Dy Isotopes in the Energy Region from 10 to 90 keV

M. Igashira, T. Ohsaki, S. Mizuno, G. N. Kim, Y. G. Min, T. I. Ro, H. D. Kim and J. K. Ahn

A paper of the title was published in Proc. 11-th Int. Symp. on Capture Gamma-Ray Spectroscopy and Related Topics, Pruhonice near Prague, Czech Republic, 2002, ed. J.Kvasil, P.Cejnar and M.Krticka (World Scientific, 2003) 722 with the following abstract.

The neutron capture cross sections of Dy isotopes (^{161}Dy, ^{162}Dy, ^{163}Dy, and ^{164}Dy) have been measured in the neutron energy range from 10 to 90 keV using the 3-MV Pelletron accelerator of the Research Laboratory for Nuclear Reactors at the Tokyo Institute of Technology. Pulsed keV neutrons were produced from the $^{7}Li(p,n)^{7}Be$ reaction by bombarding the 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, 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.

IX-A-5

Measurement of keV-Neutron Capture Cross Sections of I-129

M. Igashira, T. Ohsaki and T. Matsumoto

A paper of the title was published in Proc. 11-th Int. Symp. on Capture Gamma-Ray Spectroscopy and Related Topics, Pruhonice near Prague, Czech Republic, 2002, ed. J.Kvasil, P.Cejnar and M.Krticka (World Scientific, 2003) 761 with the following abstract.

The neutron cature cross sections of ^{129}I were measured in the energy region from 15 to 90 keV, using a 1.5-ns pulsed neutron beam and a Time-Of-Flight method. The capture γ rays were detected with a large anti-Compton NaI(Tl) spectrometer, and the capture yields were obtained by a pulse-height weighting technique. Using standard capture cross sections of ^{197}Au, the capture cross sections of ^{129}I were derived with the errors of about 7 %.

IX-A-6

Measurement of keV-Neutron Capture Cross Sections of ^{209}Bi

M. Igashira, T. Ohsaki, K. Saito, J. Kawakami, T.Obara and H. Sekimoto

A paper of the title was published in Proc. 11-th Int. Symp. on Capture Gamma-Ray Spectroscopy and Related Topics, Pruhonice near Prague, Czech Republic, 2002, ed. J.Kvasil, P.Cejnar and M.Krticka (World Scientific, 2003) 801 with the following abstract.

The capture cross sections of ^{209}Bi were measured in a neutron energy region from 10 to 100 keV and at 520 keV, using pulsed keV neutrons from the ^{7}Li(p,n)^{7}Be reaction and a time-of-flight method. The capture γ rays from a bismuth or standard gold sample were detected with a large anti-Compton NaI(Tl) spectrometer. The capture yield of the bismuth or gold sample was obtained by applying a pulse-height weighting technique to the corresponding capture γ-ray pulse-height spectrum. The derived capture cross sections from 10 to 100 keV were in good agreement with recent measurements, but that at 520 keV is about half to one third of previous measurements. This discrepancy was ascribed to the incorrect background-subtraction in the previous measurements.

X. Osaka University

A. Department of Nuclear Engineering

X-A-1

Measurement of alpha particle emission double differential cross sections of Be with a pencil beam DT neutron source

I. Murata, K. Kondo, S. Takaki, H. Miyamaru, A. Takahashi,
K. Ochiai[1], and T. Nishitani[1]

Charged particle emission double-differential cross sections (DDXc) are very important for estimation of PKA, KERMA in a fusion reactor design. However, only a few data have been accumulated because of difficulty of the experiment. Our group had measured DDXc of various materials for a fusion device at OKTAVIAN in Osaka University for several years, however it is very difficult experiment due to high background signals and small cross sections. So we have tried to develop a new spectrometer for measurement of DDXc using a pencil beam DT neutron source at FNS in JAERI. The pencil beam DT neutron source at FNS provides a perfectly collimated 2cm-ϕ neutron beam. Thus using this neutron source, background signals are kept to be quite low and a high S/N ratio can be achieved, even if a detector is arranged very close to a measuring sample. In the first, we measured α-particle emission DDX of aluminum in order to confirm the validity of the new method. In the present study, we have measured α-particle emission DDX of beryllium because of its importance for a fusion reactor design, especially in a blanket field, and from the standpoint of nuclear reaction theory of light nuclei.

In the measurement of DDXc, we have to discriminate types of charged particles. We chose a telescope system with two silicon SSDs of ΔE and E for particle discrimination since we can use it in a significantly low neutron background condition. Detection energies of ΔE and E silicon detectors change depending on charged- particle types and their energies due to difference of their stopping power. This fact discriminate charged-particle types. A two-dimensional MCA is thus used in order to distinguish signals of interest. True DDXc is obtained by collecting energy losses in a sample material.

In the present spectrometer, we can eliminate almost all noise signals using the coincidence detection technique (Only a few counts per hour were detected). Statistically accurate DDXc data could therefore be measured with relatively short measurement time and good energy resolution. Furthermore normally the measurable lower energy limit for α-particle is around several MeV. However, in the present spectrometer the lower measurable energy below 1 MeV has been successfully achieved by employing the anticoincidence alpha spectrum of E and ΔE detectors as the spectrum below the energy range of the standard limit of several MeV. We also observed tritium signals by ^{9}Be(n,t) reactions clearly distinguished from α signals by ^{9}Be(n,xα) reactions. This fact suggests the superiority of the present spectrometer to other conventional methods. We will continue measurements of DDXc using the present spectrometer and analysis of the obtained data.

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[1] Japan Atomic Energy Research Institute

X-A-2

Spectrum measurement of emitted neutrons from (n,2n) reaction with a pencil beam DT neutron source

I. Murata, S. Takaki, K. Kondo, A. Takahashi, K. Ochiai[1], T. Nishitani[1]

The (n,2n) reaction plays a very important role in the design of fusion reactor, because it is a neutron multiplication reaction and has a large cross section value in the energy range of several to 14 MeV. In the previous experiments, the cross section was measured mainly by the foil activation method or by using a large scintillation detector. However, with these methods, it is not possible to measure the neutron spectrum. Generally, it can be expected that the spectrum of the emitted neutrons from (n,2n) reaction is mostly expressed by an evaporation spectrum. But, for light elements, the spectrum might become complicated because evaporation process may not be assumed for a small cluster of nuclei. But the spectrum actually has crucial information to find out the nuclear reaction mechanism. Currently, however, it is still difficult to measure accurate spectrum especially for light nuclides.

Measurement of neutron spectrum emitted from (n,2n) reaction is possible in principle with the coincience detection method. However, an acceptable signal to noise (S/N) ratio could not be obtained so far because isotropically produced source neutrons, the great majority of which does not bombard the sample, act as a large amount of background signals in the measurement. The newly developed beam-type (2cm ϕ -collimated) DT neutron source at FNS can realize the measurement by using the coincidence detection method, because we can arrange neutron detectors very close to the sample. In the measurement, two spherical NE213(4cm ϕ) detectors were located at 20cm from the sample. The coincident neutron signals of the two detectors were extracted from the time spectrum obtained with anode signals of the detectors. Also, the n/γ pulse shape discrimination technique was used to exclude n/γ coincident signals emitted from nuclear reactions of (n,n'γ), (n,2nγ), (n,npγ) and so on. To cover the energy of emitted neutrons, two amplifiers were used to extend the dynamic neutron energy range, that is from 100keV to 10MeV. As for the neutron angular distribution, it is known that a slightly forward oriented distribution can be obtained. However, in the present measurement, the angular correlation of the emitted two neutrons should be taken into account to yield the cross section. Considering the symmetrical arrangement of the detectors, several measurements are carried out for one sample.

Until the previous fiscal year, the validity of the present method was confirmed through the measurement with a Mn sample which is regarded as a standard sample because the (n,2n) cross section was well measured with the activation method. Then from this year we began to carry out experiments with a Be sample, which is the most important light material in the fusion reactor. In the coming next year, we plan to continue measurement of Be and start measurement of deuterium, i.e., the lightest element of which the (n,2n) reaction occur. As for Be, we have also measured the α -particle emission DDX spectra in this year. We look forward to conducting a precise discussion of the reaction mechanism of Be(n,x) reaction by the use of these two experimental results.

1) Japan Atomic Energy Research Institute

X-A-3

Fusion-fission hybrid reactor analysis for ITER model

I. Murata Y. Yamamoto K. Kondo K. Umehara and A. Takahashi

The fusion-fission hybrid reactor with a blanket in which the fissile materials are loaded is useful for transmutation of high level wastes (HLW). The fissile materials are used under sub-criticality condition as a neutron and energy multiplier. As a result, this concept can reduce the neutron wall loading compared with the pure fusion reactor. Additionally the excess neutrons from the blanket can be used for transmutation of HLW or breeding of nuclear fuel.

In this study, 3-dimensional ITER model was used as a base fusion reactor. The calculation model is shown in Fig. 1. The following materials, i.e., nuclear fuel (reprocessing plutonium as the fissile materials mixed with natural uranium as the fertile materials), transmutation materials (minor actinides, i.e., Np-237, Am-241 and Am-243, and long-lived fission products, i.e., Zr-93, Tc-99, Pd-107, I-129 and Cs-135) and tritium breeder (90% Be and 10% Li_2ZrO_3 in which Li-6 was enriched to 30%), were loaded in the blanket. The neutronics and burn-up calculation was performed by MCNP-4B coupled with ORIGEN2.

For an example of calculation results, transmutation results and other nuclear performance after a year with plant factor of 70% were shown in Table 1.In this case, 24% of the blanket was used for transmutation and the transmutation materials were loaded with Be.

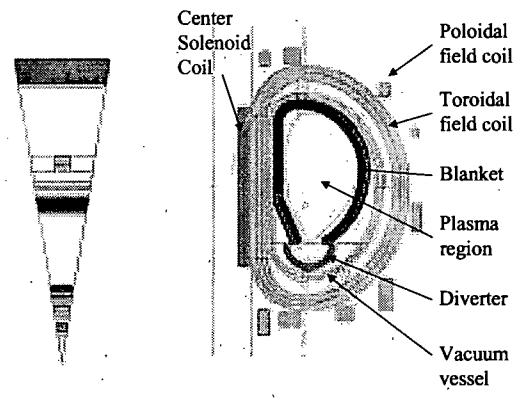

Fig. 1 Horizontal and Vertical Cross Section of Calculation Model
(18deg. Sector Model)

Table 1 Calculation Result

Be90%	transmutation efficiency(%/y)	transmutation (3.4GWty-PWR)	effective half-life(year)	half-life (year)
Zr-93	0.27	0.49	257.60	1530000
Tc-99	1.71	4.77	40.26	215000
Pd-107	1.27	14.58	54.32	6500000
I-129	0.92	2.41	75.34	15700000
Cs-135	0.91	1.32	75.61	2300000
Np-237	1.89	8.18	36.34	2140000
Am-241	1.88	18.04	36.58	432
Am-243	2.38	50.48	28.72	7370
max power density(W/cm3)		66.70		
TBR		1.10		
keff		0.62		

X-A-4

Skyshine Experiment with D-T neutron Source at FNS of JAERI

S. Yoshida[1], I. Murata, T. Nishitani[2], K. Ochiai[2], N. Mori, A. Takahashi

A paper on this subject was presented at the 2003 Fall Meeting of the Atomic Energy Society of Japan held at Shizuoka University, on Sep.24-26, 2003 with the following abstract.

D–T neutron skyshine experiments have been carried out at the Fusion Neutronics Source (FNS) of JAERI with the neutron yield of ~1.7×10^{11} n/s. The concrete thickness of the roof and the wall of a FNS target room are 1.15 and 2 m, respectively. The FNS skyshine port with a size of 0.9×0.9 m^2 was open during the experimental period. The radiation dose rate outside the target room was measured at the maximum distance of 550 m from the D–T target point with a spherical rem-counter. Measurement near the FNS building (3,6 and 10.5m from the skyshine plug along the north direction on the roof and 12m from the D–T target point the edge of shielding wall) was mainly performed and it aimed at solving the influence of building structure affecting generation / propagation mechanism of the skyshine secondary gamma-rays.

Secondary gamma-rays were measured with high purity Ge detectors and NaI scintillation counters. The highest gamma-ray dose was about 3.2×10^{-12} Sv/(source neutron) at a distance of 3 m from the skyshine plug and the dose rate was attenuated to 1.9×10^{-15} Sv/(source neutron) at a distance of 300 m from the D–T target point. The measured gamma-ray dose distribution shown in Fig. 1 was analyzed with Monte Carlo code MCNP-4C. The MCNP calculation results agree well with the experimental results within the distance of 300 m.

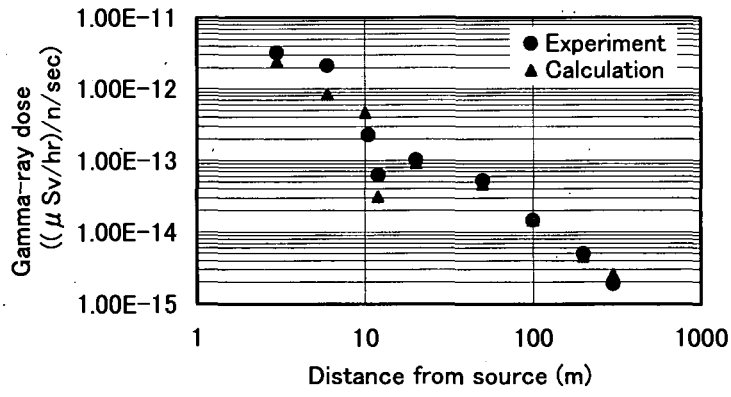

Fig.1 Gamma-ray dose distribution compared with MCNP calculation

1) Current address: Faculty of Engineering, Tokai University, Kita-Kaname 1117, Hiratsuka, Kanagawa, 259-1292 Japan
e-mail: neutron@keyaki.cc.u-tokai.ac.jp
2) Japan Atomic Energy Research Institute