Japanese Activities in Nuclear Data Measurement

Atsushi Kimura
Japan Atomic Energy Agency
Nuclear Data Measurement in Japan

Nuclear Data Measurements have been performed at several accelerator and reactor facilities in Japan.

- New Subaru
- RIBF@RIKEN
- TIARA @ QST
- CYRIC@Tohoku Univ.
- RCNP
- Osaka Univ.
- OKTAVIAN
- Tandem@Kyusyu Univ.
- Tandem
- KUR
- LINAC
- Kyoto Univ.
- JRR-3
- JAEA
- HIMAC@QST
- OECD/NEA WPEC 2020
Activities by J-PARC・MLF・ANNRI collaboration in 2019

Japan Atomic Energy Agency
Tokyo Institute of Technology
Kyoto Univ.

Contact:
Nuclear Data Center
Nuclear and LWR Engineering Division
Nuclear Science and Engineering Center
Japan Atomic Energy Agency
Facility

J-PARC : Japan Accelerator Research Complex

LINAC 180MeV

RCS 3GeV

MR 30GeV

Hadron physics

MLF (neutron exp.)

Neutrino experiment

J-PARC: Japan Accelerator Research Complex
ANNRI (Accurate Neutron Nucleus Measurement Instrument)

- **Ge Spectrometer**
- **NaI(Tl) Spectrometer**
- **6 and 7 Li Glass detectors**

Graph shows intensity versus neutron energy for different reactors and instruments:
- ANNRI 300kW
- ANNRI 1MW (Future)
- DANCE
- n_TOF (EAR-1)
Total and Capture cross section of $^{243}$Am

Sample: $^{243}$Am 67.3, 155.8m, 281.8 [MBq]

Absolute capture cross section at the 1.356 eV resonance was derived by taking ratios of the capture yields.

Capture: 10meV $\sim$ 100eV
$\sigma_{25.3\text{meV}} = 87.7 \pm 5.4 \,(\text{b})$
$\Rightarrow 10\%$ Higher than JENDL 4.0
$\Rightarrow$ Activation Experiment ongoing!

Total: 10meV $\sim$ 2eV
$\sigma_{25.3\text{meV}} = 91 \pm 11 \,(\text{b})$
$\Rightarrow$ Neutron Intensity: 7.4b


Capture (with Ge detectors)

$\sigma_{25.3\text{meV}} = 87.7 \pm 5.4 \,(\text{b})$
Neutron capture cross section of $^{237}$Np

The capture cross-section of $^{237}$Np has been measured in the energy range from 10 to 500 eV.

Sample: $^{237}$Np 200mg  5[MBq]  

Interpreted data:

- Averaged radiation width: 40.3 ± 0.5meV
- s-wave mean level spacing: 0.60 ± 0.2eV
- Neutron strength function ($10^4S_0$): 1.02 ± 0.12

The present values are in agreement with the previous literature.


https://doi.org/10.1080/00223131.2019.1651231
Activities at the other beam lines.

Noboru (BL10)

Neutron Total cross section of powder diamond for cold neutrons

Sample:
Powder of Diamond  
Size: 5.1nm  
weight: 0.0375g

Result:
Set up:

![Image of experimental setup](Inside BL10)  
B$_4$C collimator  
Specimen holder  
Neutron beam  
$^3$He detector with B$_4$C resin

Total cross sections of nano-diamond. The cross sections of carbon (JENDL-4.0) and graphite (C. D. Bowman et al.) are shown for comparison.

M. Teshigawara, Y. Tsuchikawa, G. Ichikawa et al.  
NIM, A 929 (2019) 113–120
Activities at JAEA Tandem Accelerator Facility

Contact:
Katsuhisa Nishio
Advanced Science Research Center
Japan Atomic Energy Agency

JAEA

20 MV
Equipment at the JAEA Tandem Accelerator Facility

(1) Stable, high resolution, and sharp pencil beam
(2) Many radioactive target materials can be used

【Available】$^{232}$Th, $^{233,235,238}$U, $^{237}$Np, $^{239,240,244}$Pu, $^{241,243}$Am, $^{248}$Cm, $^{249}$Bk, $^{249,250,251}$Cf, $^{254}$Es

【Planned】$^{226}$Ra, $^{232}$U, $^{252}$Cf

(3) Unique setups

Isotope Separator On-Line
Spontaneous fission, $\alpha$-$\gamma$ decay study

Recoil Mass Separator
Search for N=Z nuclei beyond $^{100}$Sn

Magnetic spectrograph
Astrophysical $^7$Li problem

Prompt Fission Setup
In-beam fission measurement
Surrogate Reactions for Fission Data

Method

- Populate excited compound nuclides using multi-nucleon transfer reactions. Identification of fissioning nucleus and its excitation energy is given by silicon ΔE-E detectors.
- Detect both fission fragments (double-velocity measurement) using multi-wire proportional counters and micro-channel plate (MCP) based timing detectors.
- Coincidence with prompt neutrons (liquid scintillation detectors with n/g discrimination technique).

Obtained Data

- Fission cross sections
- Fission fragment mass and angular distribution
- Prompt neutron multiplicity and energy spectra

Fission Fragment Mass Distributions (FFMDs) obtained in $^{18}$O + $^{237}$Np

Fission data for 23 nuclides are obtained in the single experiment.

M.J. Vermeulen et al., submitted to Phys. Rev. C.
Experimental Data in Comparison with Langevin Calculation

\[234, 235, 236, 237, 238, 239, 240\] \( \text{U} \)

\[236, 237, 238, 239, 240, 241, 242\] \( \text{Np} \)

\[238, 239, 240, 241, 242, 243, 244\] \( \text{Pu} \)

Excitation Energy (MeV)

40-50
30-40
20-30
10-20

Yield (%)

Fragment Mass (u)

“The first chance fission only

With multi-chance fission

Experimental data

Data from \(^{18}\text{O} + ^{232}\text{Th}, \, ^{238}\text{U}, \, ^{237}\text{Np}\)

“Effects of multichance fission on isotope dependence of fission fragment mass distribution at high energies”
Prompt neutron multiplicity at low energy fissions, $E_{ex} \sim B_n$

- Analysis to find out the origin of prompt neutrons is ongoing.
  - (1) Pre-scission neutrons
  - (2) Neutrons from fragments.

**Selected Results**

### Present

- $^{18}\text{O} + ^{232}\text{Th}$
- $^{18}\text{O} + ^{238}\text{U}$
- $^{18}\text{O} + ^{237}\text{Np}$
- $^{18}\text{O} + ^{243}\text{Am}$
- $^{18}\text{O} + ^{248}\text{Cm}$

**JENDL-4.0**

- Literature Data

**Preliminary**

**Neutron**

- Backward
- Forward

33 Liquid scintillator detectors ($\phi 5'' \times 2''$)
Neutron Capture Cross Section Measurements at KURNS
(Institute for Integrated Radiation and Nuclear Science, Kyoto University)

Team:
Japan Atomic Energy Agency
Kyoto Univ.

Contact:
Shoji Nakamura, JAEA
Activation Measurement of Cs-135

Utilizing Cs-135 contained in a Cs-137 standard sol.
Derive of the capture cross section of Cs-135 by measuring decay γ-rays emitted from 2 nuclides

\[
\begin{align*}
\text{Cs-137 std. sol. (Japan RI Association)}
\end{align*}
\]

\[
\begin{align*}
\text{Cs-135/137 Cs Isotope ratio} & \quad 0.868 \pm 0.004 \\
& \quad 0.5\% \text{ Uncertainty with TIMS}
\end{align*}
\]
Experimental Results


- The present result of thermal–neutron capture cross section $\sigma_0$ was in agreement with the past reported data by Katoh (1997).
- The resonance integral $I_0$ was 25% smaller than the evaluated value adopted in JENDL–4.0.

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<tbody>
<tr>
<td>$\sigma_0$ (b)</td>
<td>8.57±0.25</td>
<td>8.302</td>
<td>8.3±0.3</td>
<td>8.7±0.5</td>
<td>14.5±4*</td>
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<tr>
<td>$I_0$ (b)</td>
<td>45.3±3.2</td>
<td>53.52</td>
<td>37.9±2.7</td>
<td>61.7±2.3</td>
<td></td>
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<tr>
<td>Cut–off Energy (eV)</td>
<td>0.133</td>
<td>0.5</td>
<td>0.55</td>
<td>0.5</td>
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*Effective Cross–Section*
Neutron Production DDX from Heavy-Ion Interactions @ NIRS-HIMAC

Team:
  a) Department of Applied Quantum Physics and Nuclear Engineering, Kyushu University
  b) Hiroshima University
  c) National Institute of Radiological Sciences of National Institute for Quantum and Radiological Science and Technology
  d) Sungkyunkwan University

Contact:
  Nobuhiro SHIGYO, Kyushu University
Neutron DDX from Heavy-Ion Interactions @ QST-NIRS-HIMAC

- Kyushu U., Hiroshima U.,
  QST-NIRS, Sungkyunkwan U,
  Myongji U

- Systematic neutron cross sections
  for shielding design

- HIMAC PH2 beam line
- Beam: 290 MeV/u $^{132}$Xe $\approx 10^5$ pps
- Target: Nb, Bi
- Detection: NE213, EJ301 + TOF
- Directions: 15° - 90°
Charged particle emission reactions induced by 100-MeV/u $^{12}$C ions@ HIMAC

Contact:

Y.Uozumi, Kyushu University
Telescope for particles heavier than $\alpha$-particle.

DDXs of $^{27}\text{Al}(^{12}\text{C},\alpha x)$ reaction.

Setup of vacuum chamber and detectors at PH2 course of HIMAC experimental hall.
Isotope production in proton-, deuteron-, and carbon-induced reactions on $^{93}$Nb at 113 MeV/nucleon in Riken RI beam

Contact person:
Yukinobu Watanabe, Kyushu University

In collaboration with the members from RIKEN, Tokyo Institute of Tech., U. of Tokyo, U. of Miyazaki, Hokkaido U., and Rikkyo U., under ImPACT Program of Council for Science, Technology and Innovation (Cabinet Office, Government of Japan)

Measurement of isotope production cross section for spallation reactions using the inverse kinematic method:

- Facility: RIKEN RI Beam Factory (RIBF)
- Primary beam: $^{93}\text{Nb}$
- Secondary targets: CH$_2$, CD$_2$, C
- Experimental apparatus: BigRIPS, ZeroDegree Spectrometer
- Particle identification: TOF-$B\rho$-$\Delta E$ method
Experimental Result (I)

Measured isotope-production cross sections for $^{93}$Nb + $p$, $d$, and $C$ reactions at 113 MeV/nucleon.
Experimental Result (II)

Comparison between data measured by the inverse kinematics method and by the activation method (Titarenko et al.) for the production cross sections of the \( p + ^{93}\text{Nb} \) reaction. The black lines connect the activation data denoted by black squares with cubic spline functions.
Activities at National Institutes for Quantum and Radiological Science and Technology (QST)

LCS Gamma-Ray Research Group
Contact: Toshiyuki Shizuma
shizuma.toshiyuki@qst.go.jp
Measurements of nuclear resonance fluorescence (NRF) using polarized and unpolarized photon beams

Facilities:

NewSUBARU (Univ. of Hyogo), HIγS (Duke University), γELBE (HZDR)

NRF takes place via only electro-magnetic interaction:

✓ Model independent extraction of transition strength
✓ Selective excitation of dipole states
✓ Unambiguous spin and parity determination (1− or 1+) using a polarized photon beam
Experimental Setup at NewSUBARU

Example

Electrons
Energy: 600-1500MeV
Current: Max. 250mA

Laser
Nd:YVO$_4$ l=1064nm
Power: 20W

LCS $\gamma$-ray beam
Max. energy: 6-39MeV
Ave. flux: $\sim 6 \times 10^5 /s$
NRF measurements at NewSUBARU

Typical NRF spectrum for $^{52}$Cr

Measured M1 strength compared with RPA calculations

$\Sigma B(M1)=5.8(3) \, \mu^2_N$

Exp.

$\Sigma B(M1)=5.4 \, \mu^2_N$

RPA +2p−2h +Tensor

$T. Shizuma et al., PRC 96, 044316 (2017)$. 

Measured M1 strength compared with RPA calculations
Status of photo neutron spectrum measurement for mono-energetic polarized photon

T. Sanami\textsuperscript{1,2}, Tran Kim Tuyet\textsuperscript{2}, H. Yamazaki\textsuperscript{1,2}, T. Itoga\textsuperscript{3}, Y. Kirihara\textsuperscript{4}, Y. Namito\textsuperscript{1,2}, H. Nakashima\textsuperscript{4}, S. Miyamoto\textsuperscript{5}, Y. Asano\textsuperscript{5}

\textsuperscript{1}KEK, \textsuperscript{2}SOKENDAI, \textsuperscript{3}JASRI, \textsuperscript{4}JAEA, \textsuperscript{5}University of Hyogo
Target and detector setup

Plastic scintillator
5 mm thick with Al rad.

LCS γ-ray
Circular polarized
13.9, 16.9 MeV

90 degrees,
70 cm flight path

Liquid organic scintillator
5 in. diam. - 5 in. length

Targets (Au, Pb, Cu, Fe, Ti, Sn)
10 mm diam.
• Two components, evaporation and non-evaporation, were observed

• Strong anisotropy was observed for non-evaporation component

• The anisotropy was described as a function of angle between polarization and neutron emission
Activities at Teikyo University

Ayano Makinaga

Collaboration with Ronald Schwengner at Helmholtz-Zentrum Dresden-Rossendorf (HZDR)

Photon scattering cross section data at HZDR

Partly supported by Hokkaido University
Experimental set up at HZDR

The bremsstrahlung facility at the electron accelerator gELBE

- Maximum electron energy: \( \sim 18 \text{MeV} \)
- Maximum average current: \( \sim 0.8 \text{mA} \)
- Micro-pulse rate: \( \sim 13 \text{MHz} \)
- Micro-pulse length: \( \sim 5 \text{ps} \)

By R. Massarczyk

R. Schwengner et al., NIM A 555, 211(2005)
Result:
\( \gamma \text{SF (\( \gamma \)-ray strength function)} \) for \(^{115}\text{In}\)

There is enhanced strength around 6 MeV, 8 MeV and 9 MeV.

- Present data
Thank you