Japanese Activities in Nuclear Data Measurement

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on behalf of
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Activities at Japan Atomic Energy Agency (JAEA)

Research Group for Applied Nuclear Physics
Seven resonance peaks of $^{244}\text{Cm}$ are clearly observed.
The 7.67-eV and 16.77-eV resonance peaks are the first experimental results.

The neutron capture cross section ratios of $^{244}\text{Cm}$ resonances were reported in JNST [1].
Tentative results of $^{244}\text{Cm}$, $^{246}\text{Cm}$, $^{105}\text{Pd}$ and $^{107}\text{Pd}$ were presented at ND2010 conference.

Fast Neutron Capture Cross Section for the $^{129}$I$(n,\gamma)^{130}$I reaction

Irradiation Sample:
$^{129}$I 500 Bq (4x10$^{17}$個)

Monitors: $^{197}$Au foil 2.5mg
Sc, Co, Cu, Ti, In

Neutron Irradiation:
Yayoi Fast Neutron Reactor
@ Glory hole

Reactor Power: 2kW
Neutron Flux: 2x10$^{11}$ (n/cm$^2$/s)

Irrad. Time: 3H

$\sigma_{\text{cap}}$ (mb)
90 ± 10 @ 559 keV*
* Representative Energy

Gamma-ray spectrum for the irradiated I-129 sample
The photonuclear cross sections of Se isotopes were deduced using accurate energy distributions of LCS $\gamma$-rays systematically.

**Target:** Enriched Se isotopes
- $^{76}\text{Se}$ (99.67%)
- $^{77}\text{Se}$ (99.66%)
- $^{78}\text{Se}$ (99.39%)
- $^{80}\text{Se}$ (99.90%)

$LCS \gamma$-ray produced:
The electron storage ring (TERAS) at AIST

**Fig. 1** The experimental setup.

**Fig. 2** $^{80}\text{Se}$ and $^{78}\text{Se}$ cross section data corrected using energy distribution of LCS $\gamma$-ray with previous experimental data.
Activities at Japan Atomic Energy Agency (JAEA)

Gamma-ray Non-destructive Assay Research Group
Nuclear Data Measurement Activities at JAEA

Measurements of nuclear resonance fluorescence (NRF) using a monochromatic, linearly polarized LCS photon beam

Gamma-ray Non-destructive Assay Research Group

NRF measurements for closed-shell nuclei and their neighbors

NRF takes place via only electro-magnetic interaction:
- Model independent extraction of transition strength
- Selective excitation of dipole states
- Unambiguous parity determination ($1^-$ or $1^+$)

Experimental setup

Typical NRF spectrum

JAEA-AIST-Kyoto Univ. collaboration
Activities at Radiation Science Center, KEK

Hagiwara Group
Nuclear Data Measurement Activities at High Energy Accelerator Research Organization (KEK)

Systematic measurements of DDX on proton-induced fragment emission reactions for light-medium nuclei at intermediate energies from 40 – 300 MeV

**Experiment @ NIRS and RCNP**

**Incident proton:** 40, 50, 70, 80, 140, 200, 300 MeV

**Sample:** C (206 mg/cm²), Al (0.8 μm), Al₂O₃ (1.05 μm), AlN (0.91 μm), Ti (1 μm), Cu (1 μm)

**Particle identification results**

Ep = 80 MeV, C(p,x) at 30-deg.

This program is supported by members from universities and institutes
Nuclear Data Measurement Activities at High Energy Accelerator Research Organization (KEK)

Systematic measurements of DDX on proton-induced fragment emission reactions for light-medium nuclei at intermediate energies from 40 – 300 MeV

Experimental results are systematically compared with PHITS (ISOBAR+GEM, Bertini+GEM and QMD+GEM models) for incident energise from 40 to 200 MeV

This program is supported by members from universities and institutes
Nuclear Data Measurement Activities at High Energy Accelerator Research Organization (KEK)

Measurements of neutron and γ-ray production TTY from PET tracer and accelerator component materials induced by 18 MeV protons

**Experiment @ TIARA,**

- **Target:** ¹⁸O-, ¹⁶O-water, N as PET tracer targets
- **Accelerator components:** Be, C, Al, Cu, Ta, Pb
- **Detector:** NE213 (5.08 cm φ × 5.08 cm thick)
- **Detection Angles:** 9 angles (0 – 150 degrees)

This program is supported by members from universities and institutes
Activities at Tokyo Institute of Technology (Tokyo Tech)

Igashira Group
Capture Cross Sections and γ-ray Spectra in the keV Region

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>En = 15 – 100 keV</th>
<th>En = 550 keV</th>
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<tbody>
<tr>
<td>*Pd-104</td>
<td></td>
<td></td>
</tr>
<tr>
<td>105</td>
<td></td>
<td>2010/11</td>
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<tr>
<td>106</td>
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<td>107</td>
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<tr>
<td>108</td>
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<tr>
<td>110</td>
<td></td>
<td></td>
</tr>
<tr>
<td>**Nd-142</td>
<td>2008/1</td>
<td>2010/11</td>
</tr>
</tbody>
</table>

* Pd: Systematic measurements for Pd isotopes have been started.
** Nd-142: One of systematic measurements for N = 82 isotopes Measurements for La-139, Ce-140, and Pr-141 have been finished.
Capture Cross Sections of Pd-105 and Nd-142
Capture Gamma-Ray Spectra of Pd-105

\[ ^{105}\text{Pd}(n, \gamma)^{106}\text{Pd} \]

- \( B_n = 9.561 \text{ MeV} \)
- \( E_n = 15-100 \text{ keV} \)
- \( \langle E_n \rangle = 47 \text{ keV} \)

\( ^{108}\text{Pd} \)

\( 0.512 \text{ keV} \)

\( 2^+ \)

\( 0^+ \)
Activities at Kyoto University

KURRI Group
Neutron capture cross section measurements for Eu-151, 153

Motivation:
Neutron capture cross section data of fission products (FPs) play an important role in burn-up credit for criticality safety in the transportation, storage and treatment of spent nuclear fuel. Eu isotopes are important FPs for burn-up credit application.

Neutron Source: Electron Linear Accelerator + Ta Target, Flight path: 12m
Detector: A pair of C₆D₆,
Pulse-height weighting technique and TOF method were applied.
Neutron capture cross section measurements for Pd-107

Motivation:
Neutron capture cross section data of long-lived fission products (LLFPs) are greatly important for nuclear transmutation of radioactive waste. Pd-107 is one of the most important LLFPs.

Neutron Source: Electron Linear Accelerator + Ta Target, Flight path: 12.7 m
Detector: Total absorption BGO detectors, TOF method were applied.

$^{107}$Pd sample contains isotopic impurities of $^{105}$, $^{106}$, $^{108}$Pd. Therefore, the resonances of impurities were also observed.

The resonance parameters of $^{107}$Pd will be derived in future.

This work was supported by JSPS KAKENHI (22226016).
Activities at Konan University

Utsunomiya Group
Photoneutron cross section measurements
- Joint Activities With JAEA and AIST

LCS (laser-Compton scattering) $\gamma$-ray beams at AIST
Nd: YVO$_4$ Q-switch laser, 20 kHz
1064nm 40 W, 532nm 24W
80ms beam on, 20 ms beam off

Target Samples
- 99.6% $^{108}$Pd (731mg, 8mm dia)
- 98.4 % $^{106}$Pd (891mg, 8mm dia.)
- 98.4 % $^{105}$Pd (498mg, 6mm dia.)

2mm Pb collimator

Triple-ring Neutron Detector (Konan Univeristy)
three rings of 4, 8, and 8 $^3$He proportional counters embedded in a polyethylene moderator,
Neutron detection

High-resolution High-energy Spectrometer (JAEA)
Twin (2 X 334 cm$^3$) HPGe detectors with BGO anti-Compton Shield (23 pieces, total 11.8 X 10$^3$ cm$^3$)

NaI(Tl) monitor detector
8” diameter X 12” length
$^{107}$Pd($n,\gamma$) cross sections with the $\gamma$-ray strength function method

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STEP 1
High precision measurement of ($\gamma,n$) cross sections near neutron threshold

STEP 2
- Investigation of the $\gamma$SF by using the measured ($\gamma,n$) cross sections as experimental constraints
- Extrapolation of the $\gamma$SF to the energy region below $E_n$
- Justification of the adopted $\gamma$SF by reproducing known ($n,\gamma$) cross section in the statistical model calculation

$\gamma$-ray Strength Function: RMF (relativistic mean field) + QRPA model

SYEP 3
The statistical model calculation of ($n,\gamma$) cross sections for unstable nuclei with the $\gamma$SF adopted in STEP 2
Photoneutron cross sections

Radiative neutron capture cross sections

Unified description of \((\gamma,n)\) and \((n,\gamma)\) cross sections with HFB+QRPA E1 \(\gamma\)-ray strength function supplemented with a giant M1 resonance in Lorentz shape 
\(E_0 \sim 9\,\text{MeV}, \Gamma \sim 2.5\,\text{MeV}, \sigma_0 \sim 7\,\text{mb}\)
Activities at Kyushu University

Watanabe Group
Light-ion production from nuclear reactions induced by 175 MeV quasi-monoenergetic neutrons

Applied Nuclear and Radiation Physics Group
Department of Advanced Energy Engineering Science
Kyushu University

In collaboration with Uppsala University, Sweden and Chiang Mai University, Thailand
Neutron beam facility @ TSL, Uppsala

- **Gustaf Warner Cyclotron @ The Svedverg Laboratory (TSL)**
  - Proton energy ~180 MeV

- **Neutron source**
  - Quasi mono-energetic neutron (QMN) source with Li(p,n) reaction
  - Neutron energy 11-175 MeV

- **Detector system**
  - MEDLEY consisting of 8 counter telescopes composed of two Si detectors and CsI scintillator

- **Target**
  - Silicon, Oxygen

- **Detected light ions**
  - p, d, t, \(^3\)He, \(^4\)He

![Diagram of the neutron beam facility at TSL, Uppsala](image)
Results of Oxygen

- Comparison of measured double differential proton double differential cross sections for O with PHITS calculation with JENDL/HE-2007, Bertini INC, and QMD for benchmarking of high energy nuclear reaction models and evaluated data.

JENDL/HE-2007 is better at small angles than the others, but overestimates the measurement at backward angles.
Activities at Kyushu University

Ishibashi Group
(d,n) TTNY @ Kyushu

- Kyushu Univ. + JAEA
- IFMIF-EVEDA
  - 9 MeV d accelerator radiation safety
    - beam stopper, matching section...

- Kyushu Univ.,
  Tandem Accelerator Lab.

- 5 MeV (d,n) TTNY
  - Target: Cu, Ti, Nb
  - Angles: 0° - 140°
  - Detector: NE213
  - Unfolding

- Comparison with TALYS
Neutron Production DDX from Heavy-Ion Interactions @ NIRS

- Kyushu Univ, JAEA, KEK, NIRS
- Systematic cross-section data for elements constituting a human body’s tissue bombarded with heavy-ion beams

- HIMAC PH2 beam line
- Beam: 290 MeV/u C
- Target: O
- Detection: NE213 + TOF

- Gamma-ray production cross sections are also analyzing.

- A new Intra-Nuclear Cascade (INC) model is underdevelopment to reproduce the experimental data.
TTY for 120 GeV proton @ Fermilab

Under the program named **JASMIN**

- **Japanese-American Study of Muon Interactions and Neutron Detection** (JAEA, KEK, Kyushu, PAL, Kyoto, Shimizu, FNAL)
- Aiming to take **reference data for shielding of over 100 GeV accelerators**
- TTY as source term of the shielding data
- Precise data for physics models

- Systematic data taking
- NE213 + TOF with slow beam extraction
  - Targets: C, Al, Cu, W
  - 30°, 45°, 60°, 90°, 120°, 150°
- Comparison with PHITS, MARS, FLUKA

**Graph:**

Neutron yields from 120 GeV (p,xn)