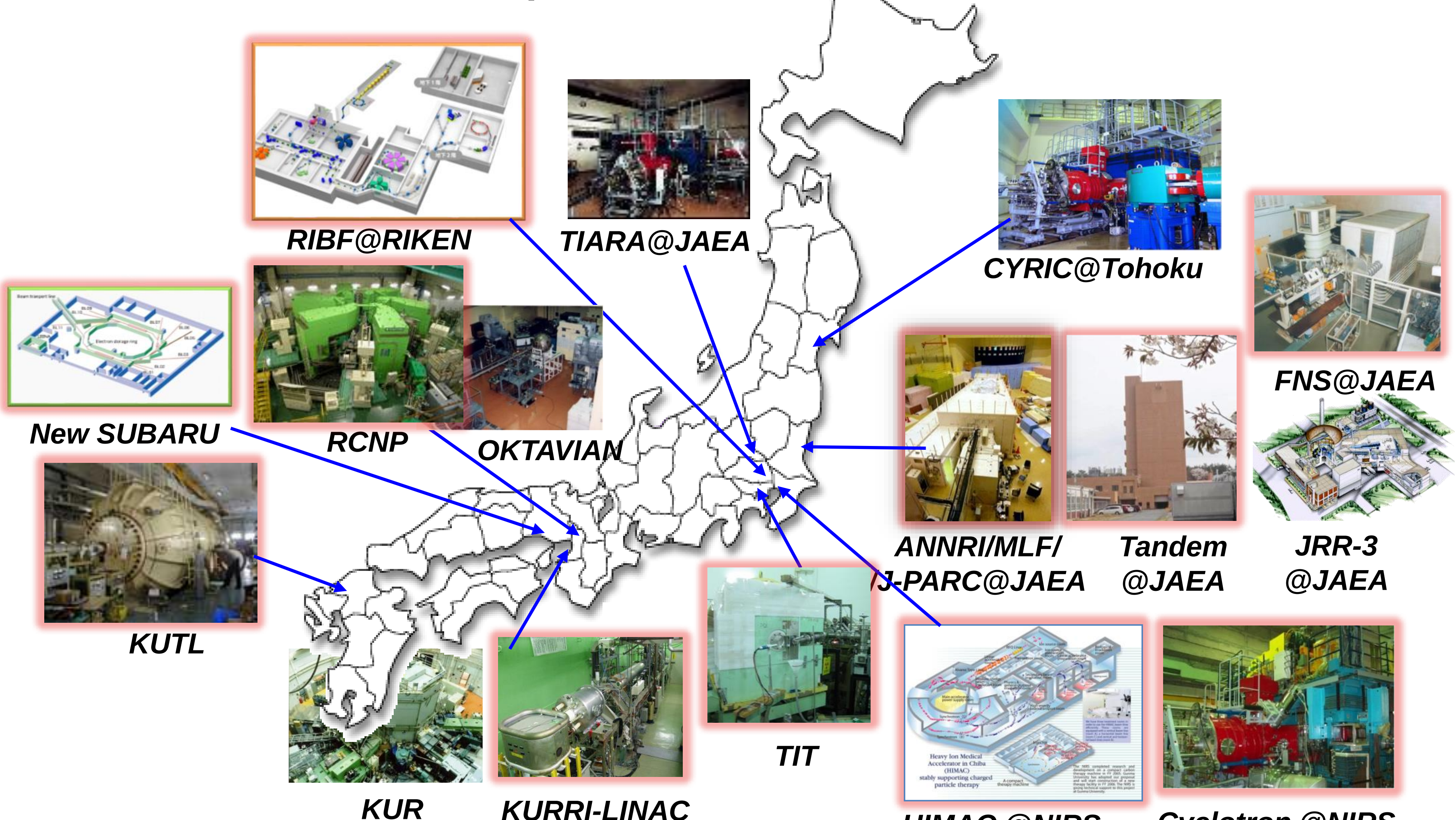
Japanese Activities in Nuclear Data Measurement

Hideo HARADA

Japan Atomic Energy Agency

Nuclear Data Measurement in Japan

Nuclear data measurements are being performed at several accelerator and reactor facilities in Japan:

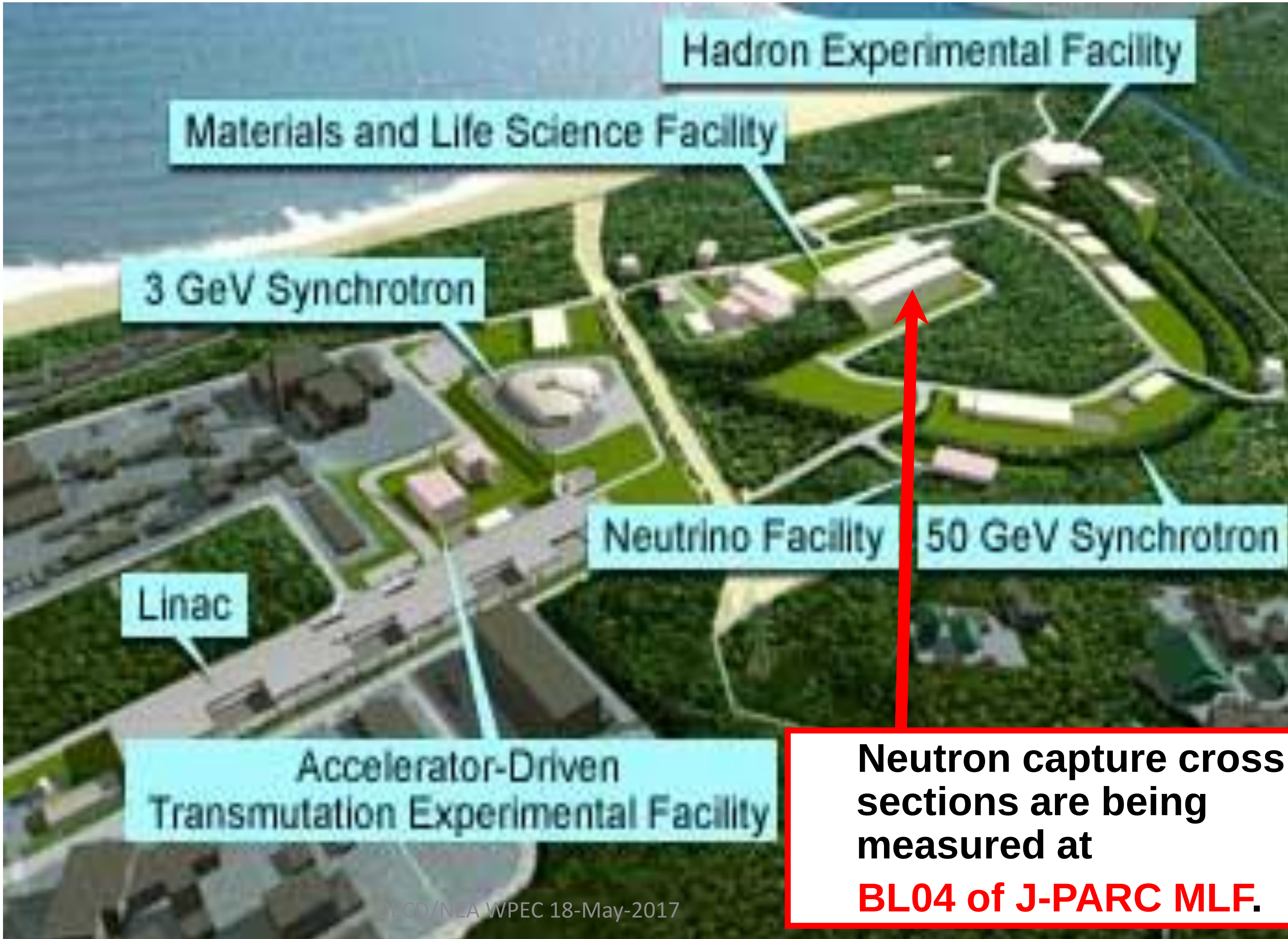


Activities by J-PARC/MLF/ANNRI collaboration in 2016JFY

Japan Atomic Energy Agency
Tokyo Institute of Technology
Kyoto University

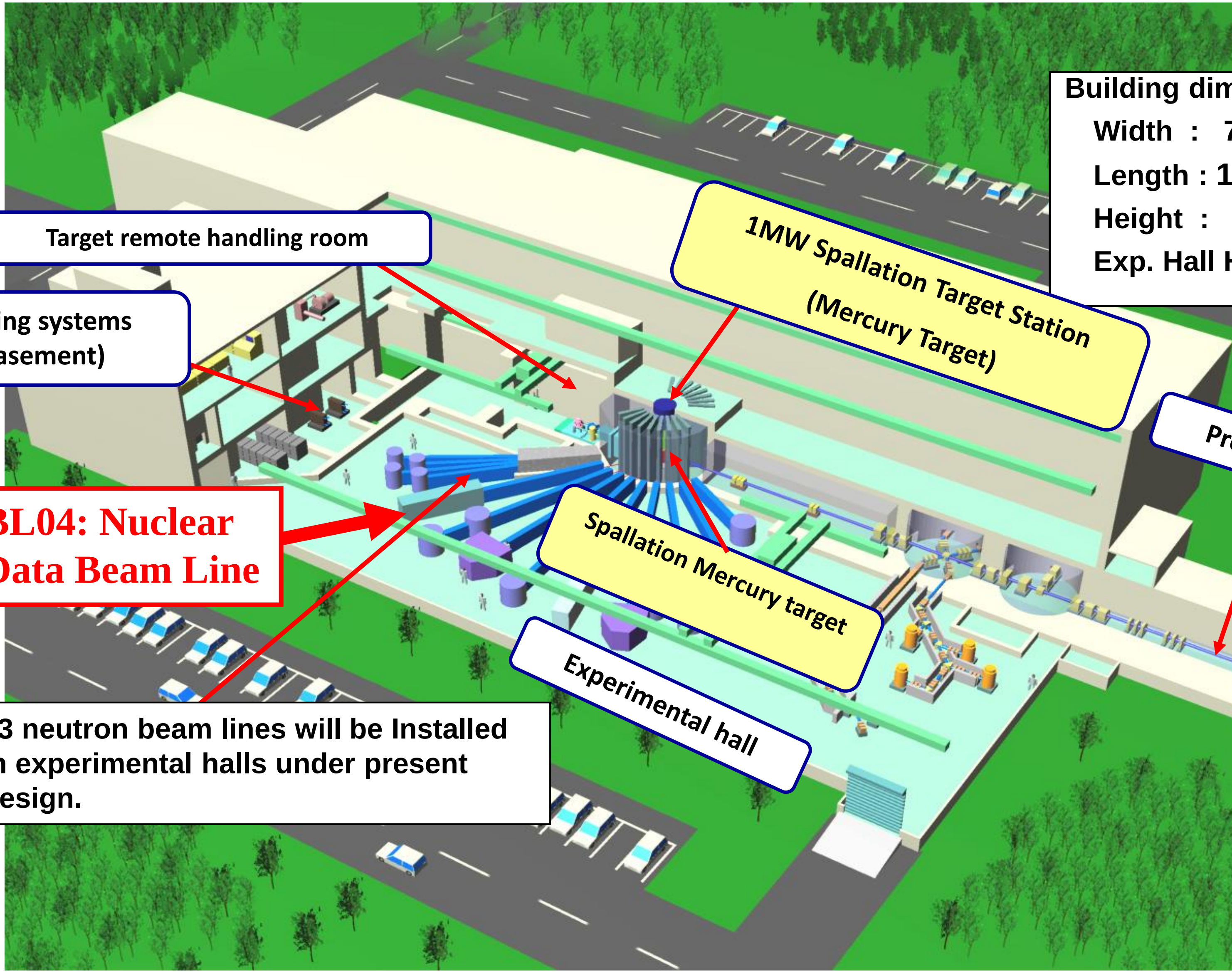
Contact :
Nuclear Data Center
Nuclear Data and Reactor Engineering Division
Nuclear Science and Engineering Center
Japan Atomic Energy Agency

Nuclear Data Projects in Japan



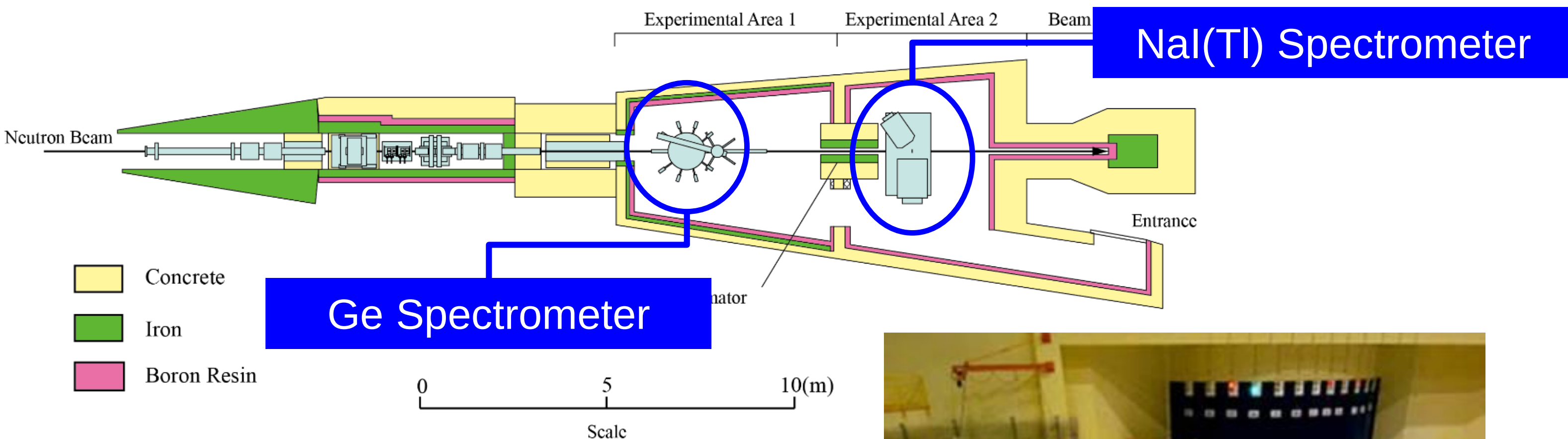
Neutron capture cross sections are being measured at BL04 of J-PARC MLF.

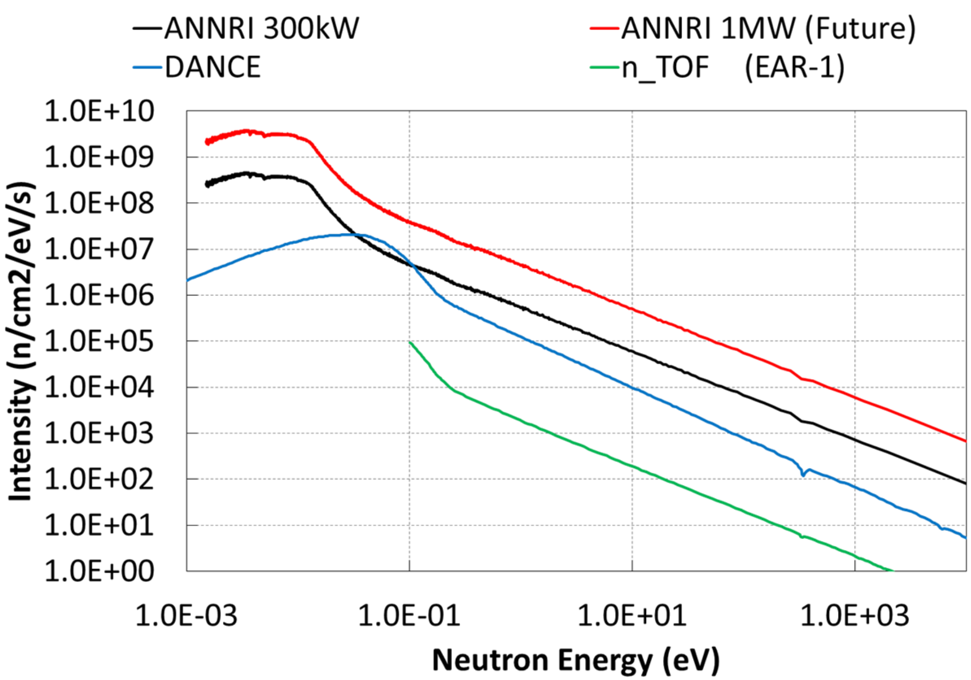
J-PARC Materials and Life Science Experimental Facility



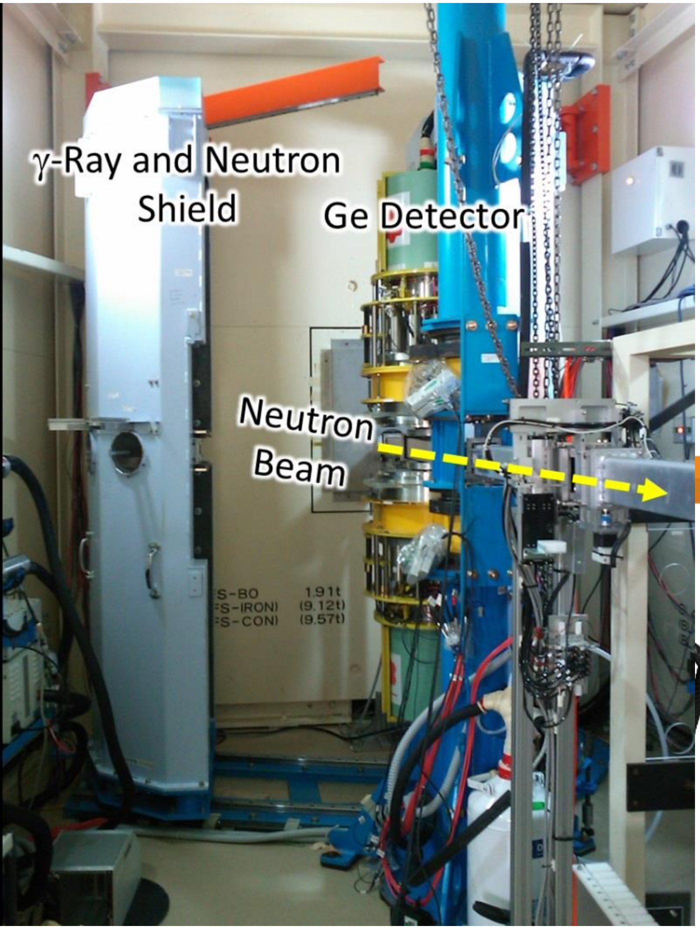
ANNRI

ANNRI (Accurate Neutron Nucleus Measurement Instrument)





Ge Spectrometer



Our spectrometer has

- 2 cluster-Ge detectors
  (7 Ge crystals are installed in the detector)
- 8 coaxial-Ge detectors
- Compton suppressing BGO detectors

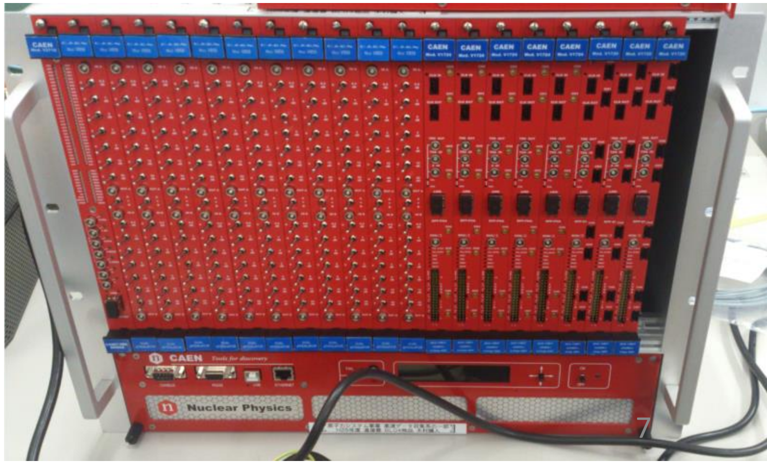
⇒22 Ge Crystals.

Peak efficiency for 1.33MeV γ-rays:

3.64 ± 0.11 %

DAQ is replaced to new one.

(CAEN 1724,1720)

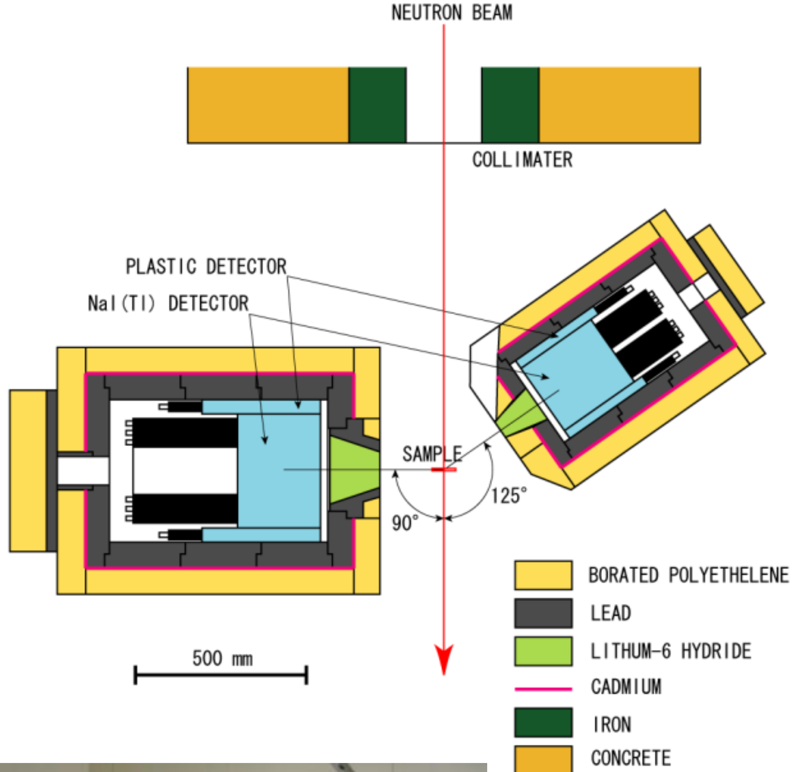


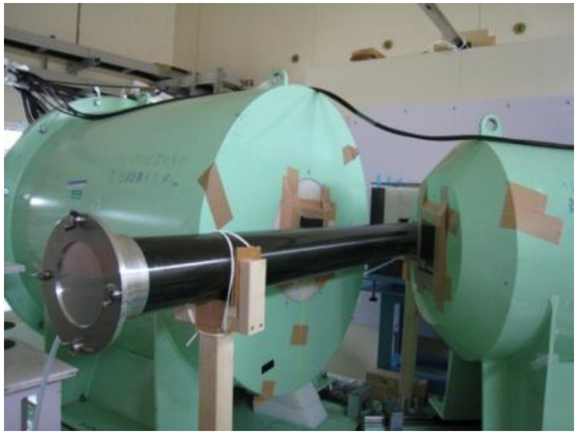
NaI(Tl) Spectrometer

- Use for:
  - Complementary use to Ge array
  - Measurement in the high energy range
- Detectors
  - 90° detector: 13” diam. × 8” long
  - 125° detector: 8” diam. × 8” long
- Shielding
  - Borated polyethylene, Pb, ^{6}LiH, Cd
- Data acquisition

(T. Katabuchi)

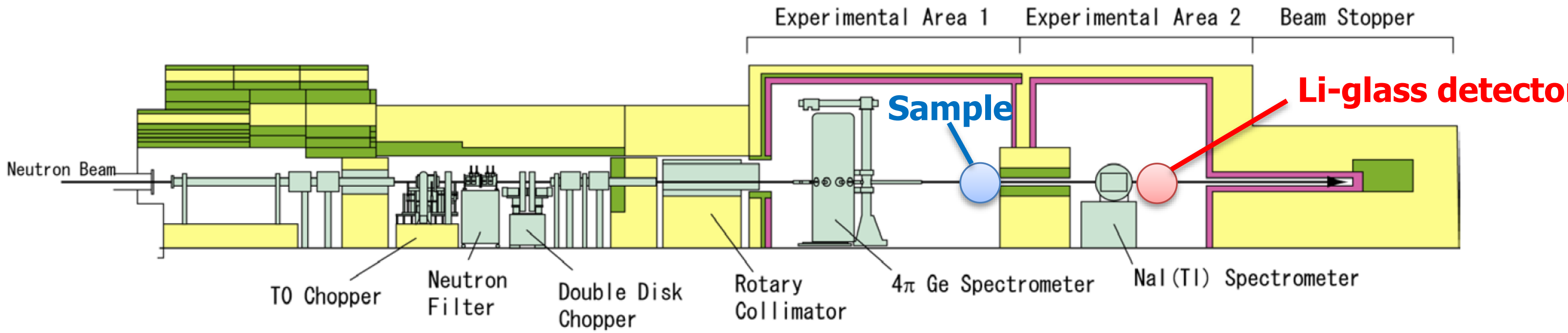
  - Multi-stop time digitizer
  - TOF, pulse height, pulse width are recorded sequentially



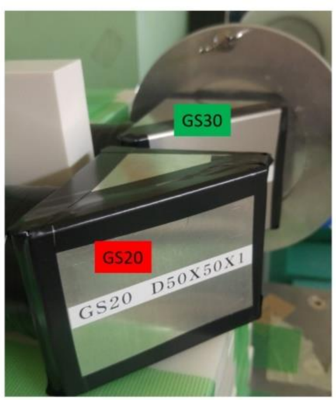


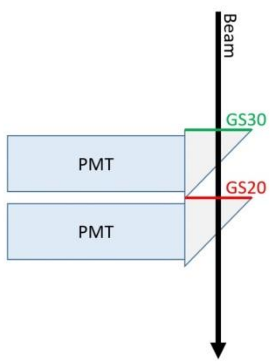
Measurement of neutron total cross sections

To determine the absolute value of the capture cross sections of MAs accurately, total cross section experimental setup combining capture measurement is under development.



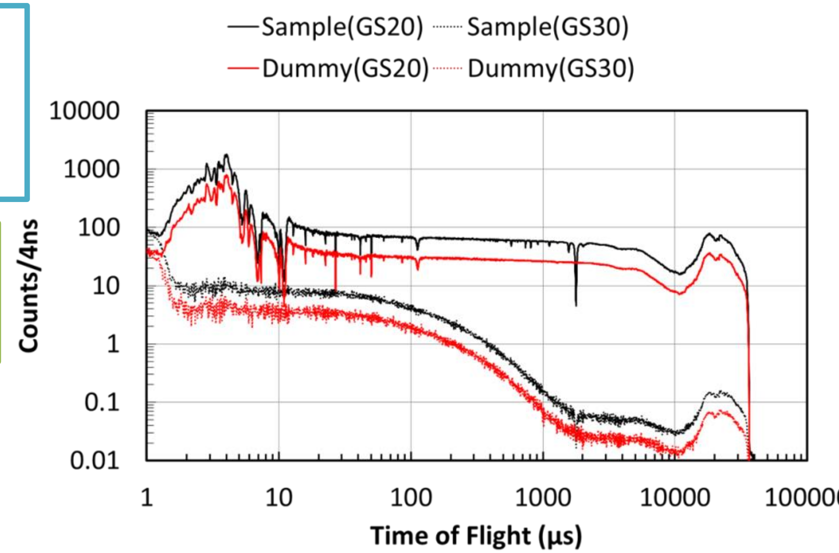
- Measurements of neutron total cross sections of ^{241,243}Am have been performed.
- Data analysis is in progress.





Experimental Set-up

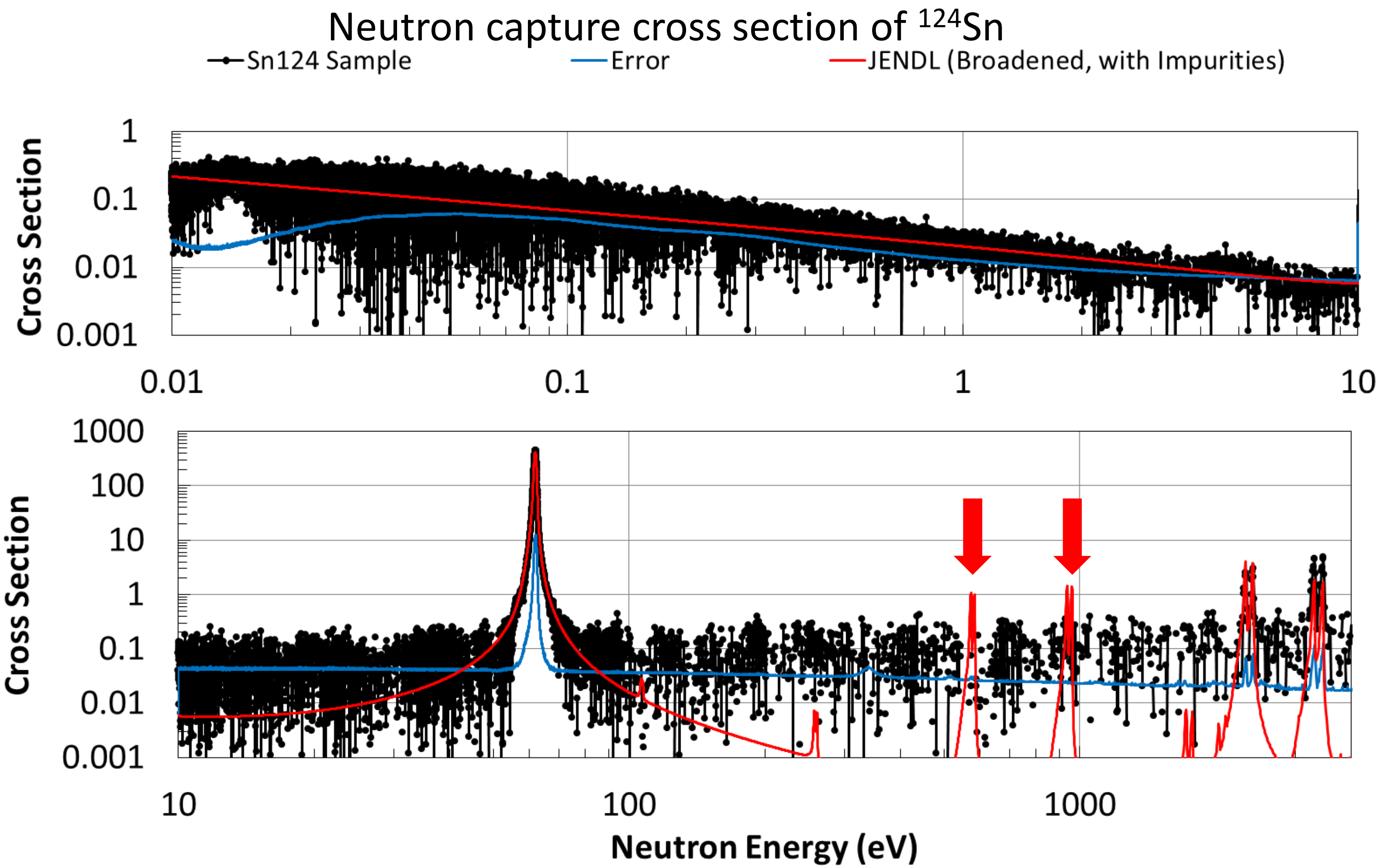
DAQ
(CAEN V1720)



TOF spectra for ^{243}Am

Neutron capture cross section of Sn stable isotopes

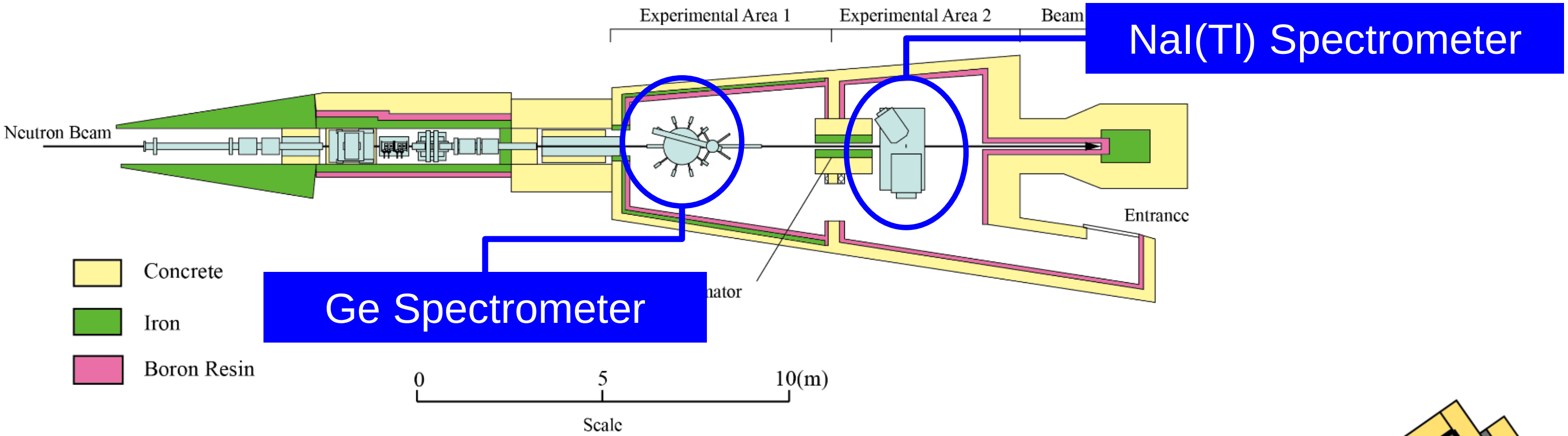
Neutron capture cross section of ^{120}Sn, ^{122}Sn and ^{124}Sn were obtained in the energy range from 10 meV to 4 keV with the array of germanium detectors in ANNRI.



The 579- and 950-eV resonances were not observed.
These resonances were reported by V. Adamchuk and Fuketa, and are listed in both JENDL-4.0 and ENDF/B VII.1.

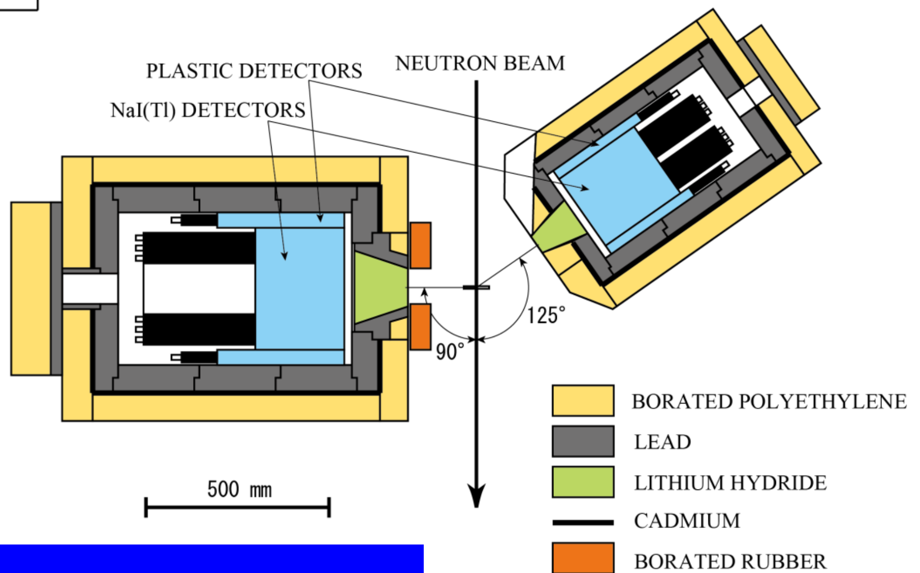
ANNRI

ANNRI (Accurate Neutron Nucleus Measurement Instrument)



NaI(Tl) Spectrometer

- Pulse-height weighting technique
- To reduce systematic uncertainties by combining measurement with Ge spectrometer
- Measurement in the high energy region



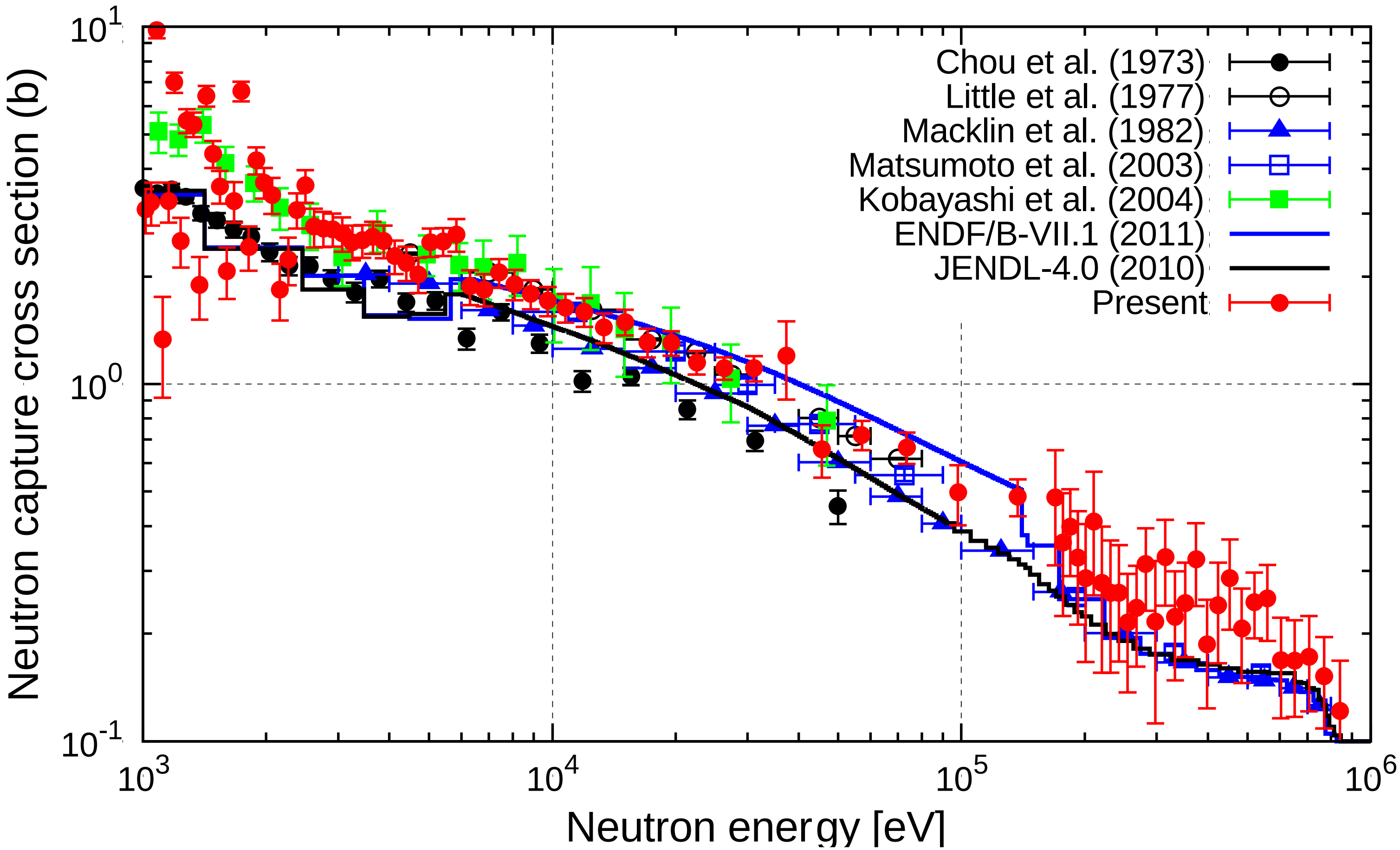
NaI(Tl) Crystal Size
90º: 330 mm × 203 mm, 125º: 203 mm × 203 mm

Neutron capture cross section of ^{99}Tc

■ Tc-99 sample

78 mg (52 MBq)

Sealed in Al container



Neutron capture cross section of ^{35}Cl

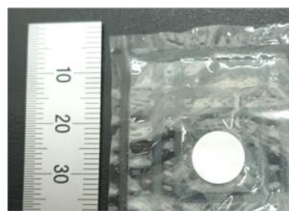
K.Y. Hara (Hokkaido Univ.)

*JSPS KAKENHI (26820411)

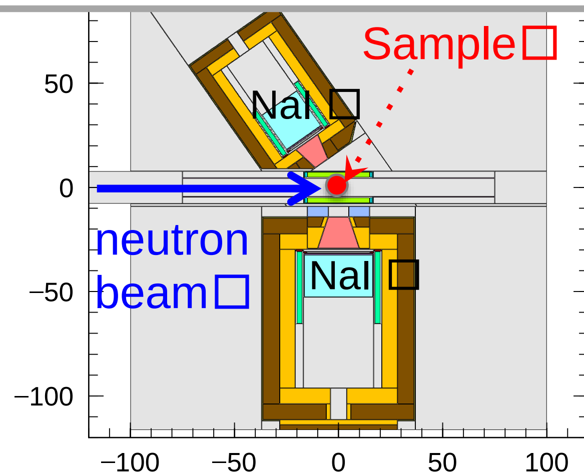
- Measurements were performed using 3 NaCl samples to obtain the cross section of ^{35}Cl(n,γ)^{36}Cl reaction in the energy range of 0.02 eV-1 keV.
- Production of long-lived radioactive waste **^{36}Cl (half-life 3×10^5 yr)** is concerned in some applications.

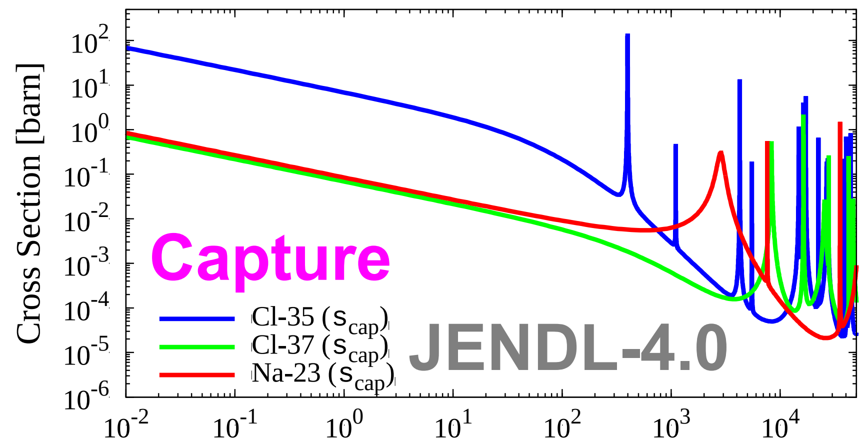
NaCl sample 0.15 g

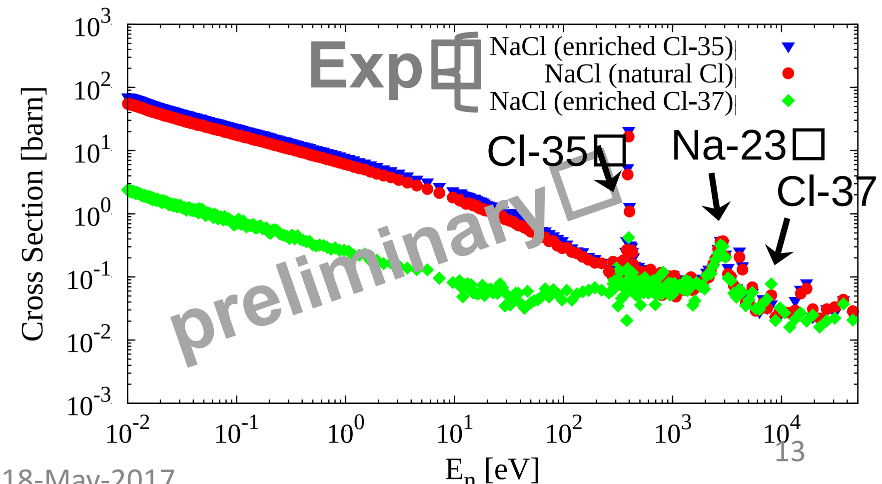
- ✓ 99% ^{35}Cl enriched
- ✓ natural Cl (^{23}Na 100%, ^{35,37}Cl 76, 24%)
- ✓ 98% ^{37}Cl enriched



NaI(Tl) detector in ANNRI at J-PARC







AIMAC collaboration

Research and Development for Accuracy Improvement of Neutron Nuclear Data on Minor ACtinides

H. Harada[1], O. Iwamoto[1], N. Iwamoto[1], A. Kimura[1], K. Terada[1], T. Nakao[1], S. Nakamura[1], K. Mizuyama[1], M. Igashira[2], T. Katabuchi[2], T. Sano[3], Y. Shibahara[3], Y. Takahashi[3], K. Takamiya[3], C. H. Pyeon[3], S. Fukutani[3], T. Fujii[3]*, J. Hori[3], H. Yashima[3]

[1]Japan Atomic Energy Agency,

[2]Tokyo Institute of Technology, [3]Kyoto University

Present study includes the result of "Research and Development for accuracy improvement of neutron nuclear data on minor actinides" entrusted to the Japan Atomic Energy Agency by the Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT).

* Present address: Osaka University, Osaka, Japan

Highlights of the AIMAC

① Precise characterization of sample
② Activation measurement
③ TOF measurement
④ Evaluation and Bias effect Correction

① Precise characterization of sample
- For isotopic purity characterization -

The same materials with TOF samples were prepared for destructive analyses: Mass (TIMS) and α-ray spectroscopy

Sample for analyses

The Same Sample material

A few hundred MBq

TOF sealed sample

Info in specification sheets:

No uncertainty information

Am-241 sample (130 kBq/mL)

Isotopic purity: Am-241：99.9%

Chemical purity: 99.9%（Pu-239：0.09%, Np-237：0.01%）

Am-243 sample (10 kBq/mL）

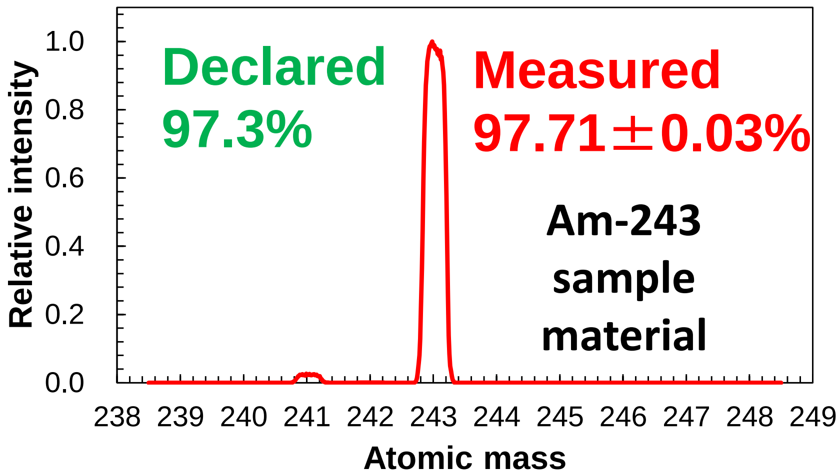
Isotopic purity: Am-243：97.3%, Am-241：2.7%

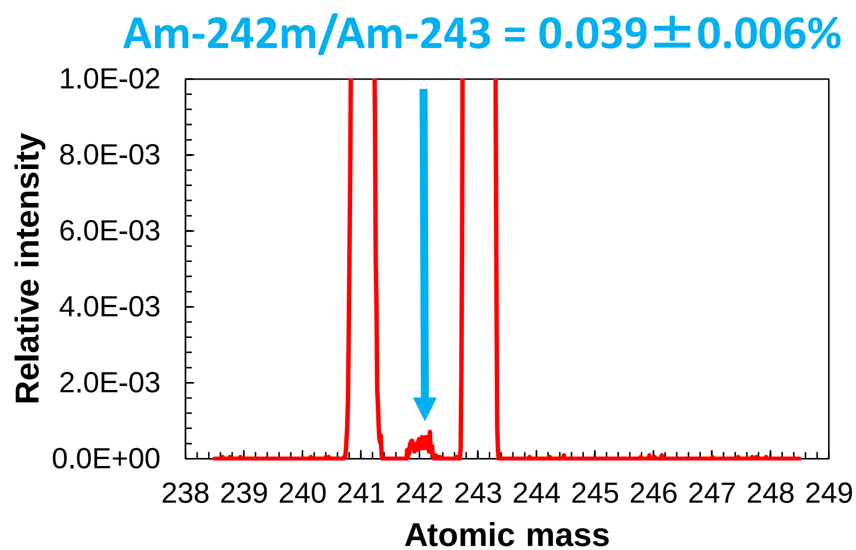
Chemical purity: 99.58%

（Fe, Ca, Na：0.07%, B: 0.09%, Gd: 0.03%etc）

① Precise characterization of sample

Thermal ionization mass spectroscopy (TIMS)





	Am-241	Am-243
Run-1	2.29±0.03%	97.71±0.03%
Run-2	2.28±0.03%	97.72±0.03%
Run-3	2.29±0.05%	97.71±0.05%

Non-declared isotope was identified.

0.03% precision !

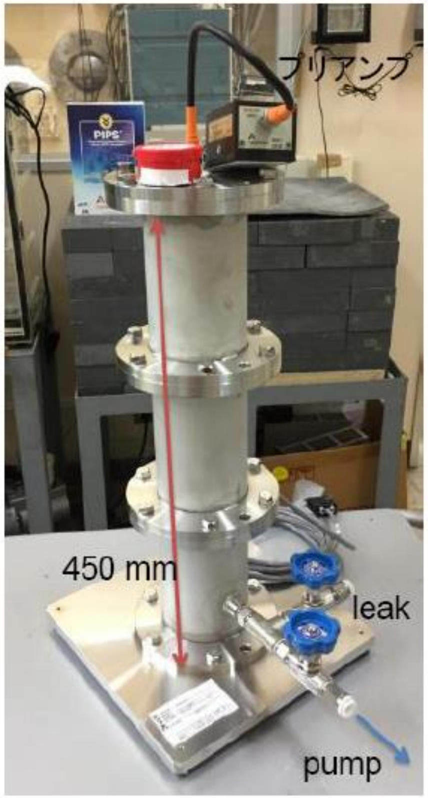
Details S301 by Dr. Y. Shibahara

Note: Pu contamination under investigation

Ref: Y. Shibahara, J. Radioanal. Nucl. Chem. 307, 2281 (2016)

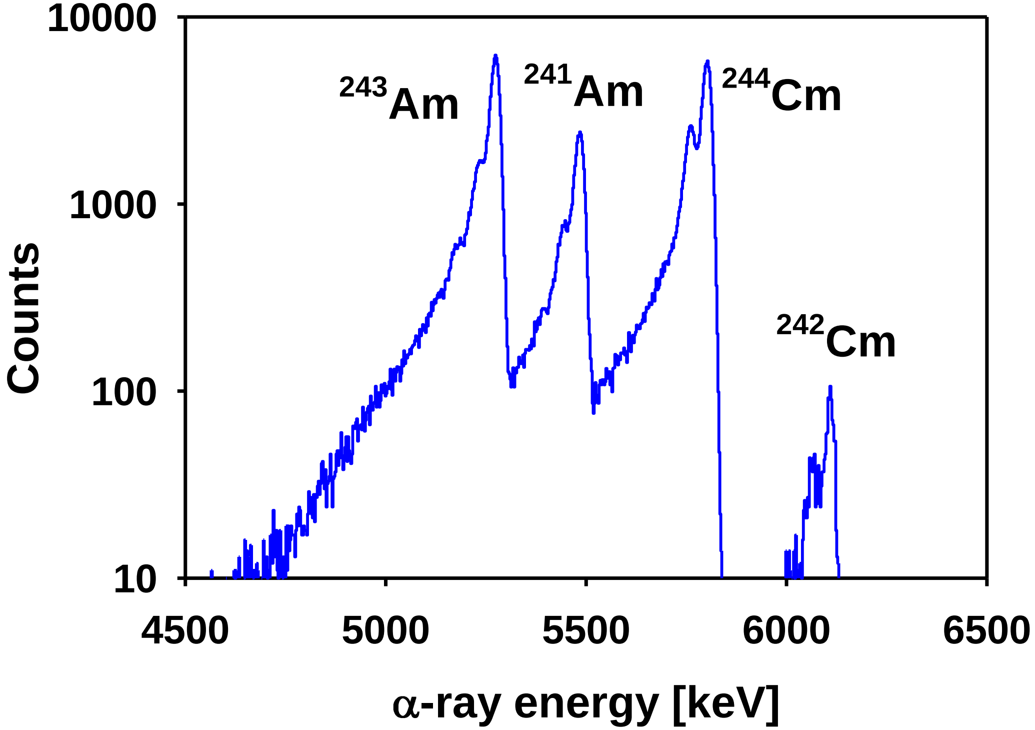
① Precise characterization of sample

α-ray spectroscopy



Setup for α-ray spectroscopy

α-ray from **Am-243** sample material



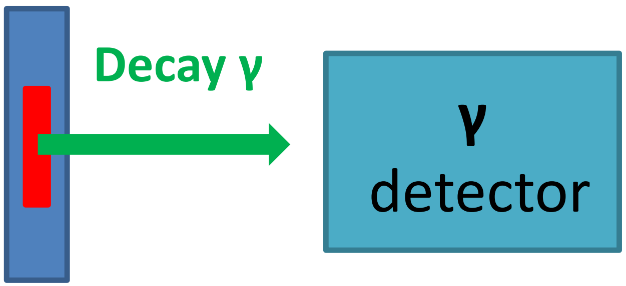
Cm-242&244 quantified

Feedback to Micro Calorimetry

① Precise characterization of sample

No uncertainty information for sealed sample amounts
(decay γ-ray rate is given by 10% uncertainty)
Two non-destructive methods developed

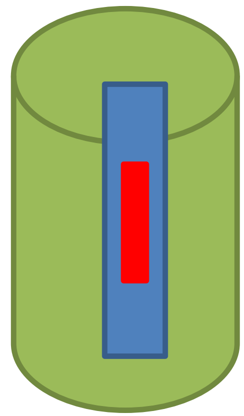
① Determination of decay γ-ray intensity

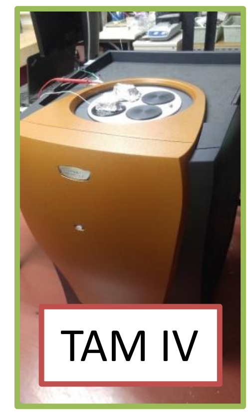


Precise determination of γ-detector's peak efficiency
Fine interpolation method was developed by utilizing Monte Carlo

Precise determination of γ-ray emission probability

② Utilization of Micro Calorimetry





Independent amounts
Cross-check

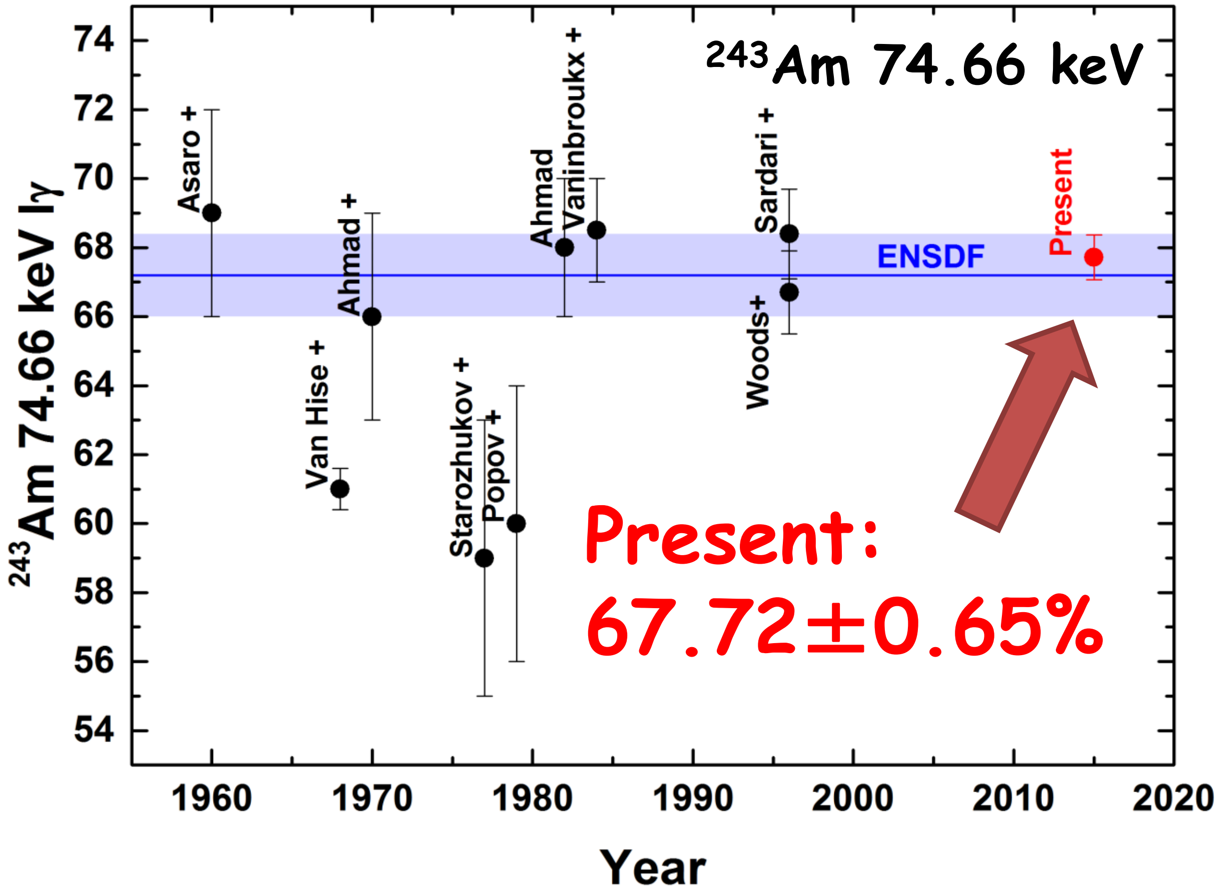
① Precise characterization of sample

- Precise determination of γ-ray emission probability -

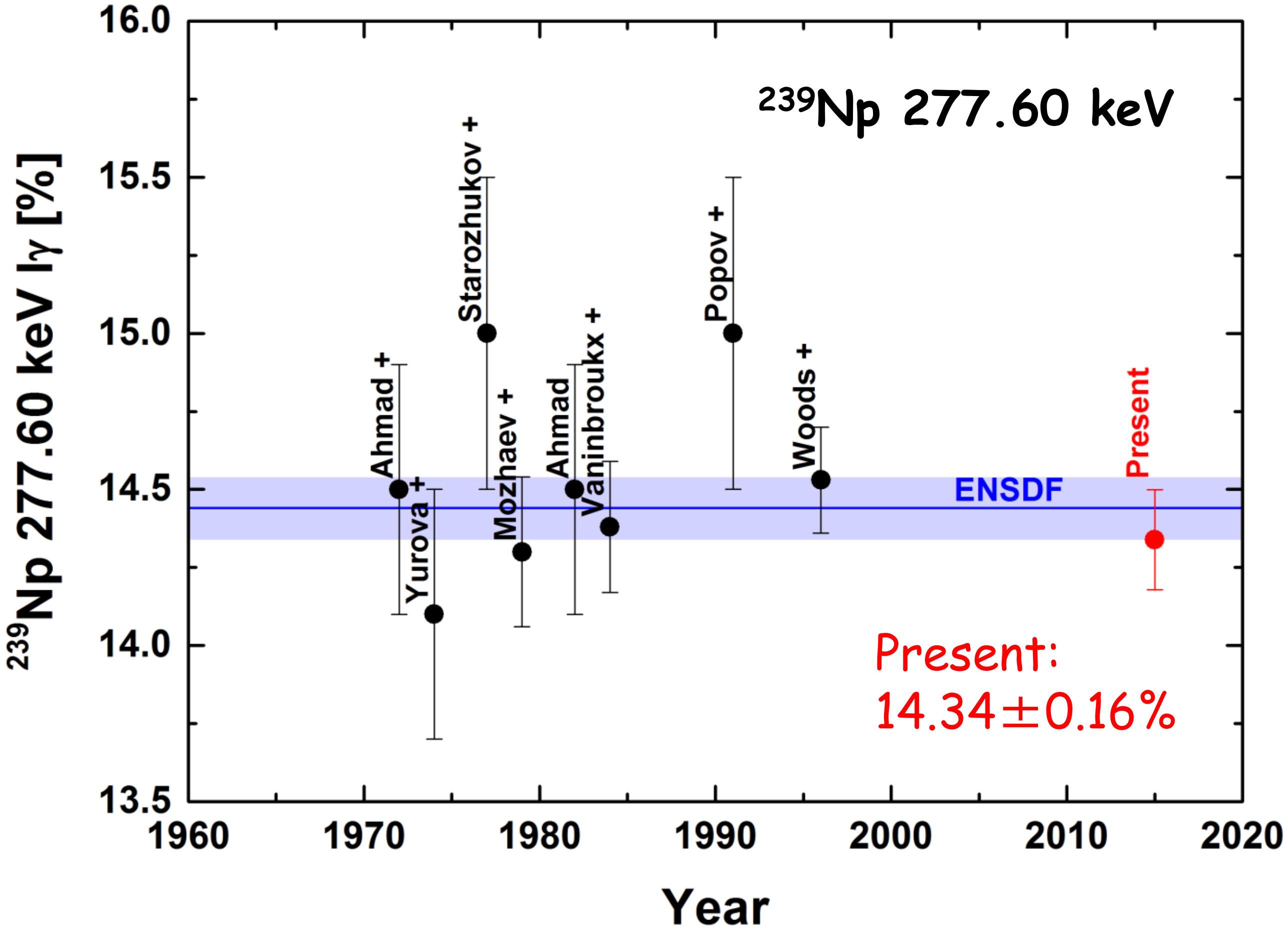
Precise determination of γ-detector's peak efficiency

Fine interpolation method was developed by utilizing Monte Carlo

Dr. K. Terada, *J. Nucl. Sci. Technol.* **53** (2016)



The gamma-ray emission probabilities of $^{241,243}Am$, $^{237,239}Np$, ^{233}Pa were derived with uncertainties about 1.2%.



① Precise characterization of sample

Comparison of two independent measurements

Declared Activity	Am-241 480 MBq	Am-241 950 MBq	Am-243 60 MBq	Am-243 120 MBq	Am-243 240 MBq
γ-ray Spectroscopy	511±10	962±19	66.7±1.3	155±3	286±6
Micro Calorimetry	510.7±0.5	957.4±0.5	67.3±0.3*	155.8±0.3*	281.8±0.3*

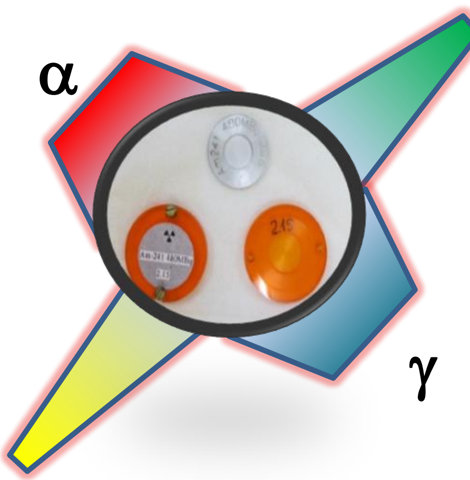
2% uncertainty

0.1% uncertainty

* Pu correction: small but to be checked

Cross-check, OK
Discrepancy between Declared and Measured

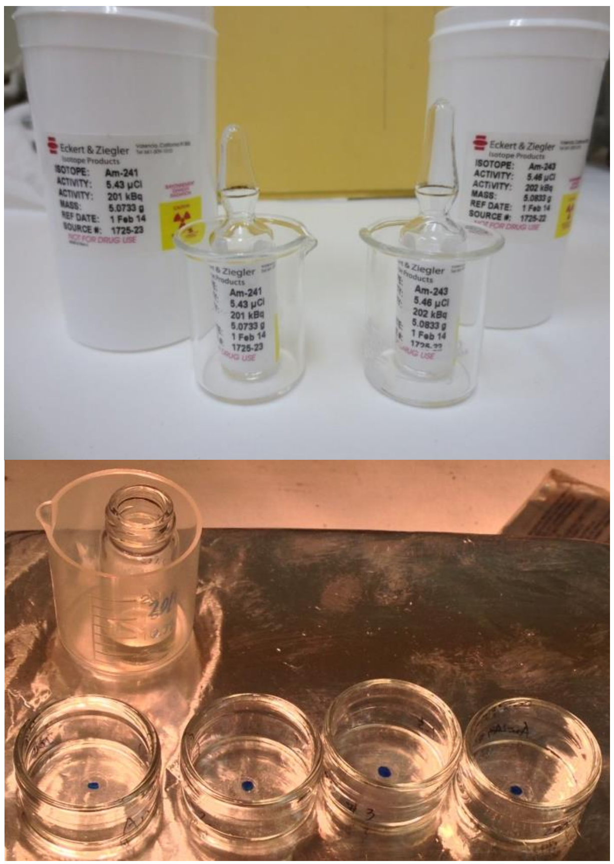
Details R300 by Dr. K. Terada

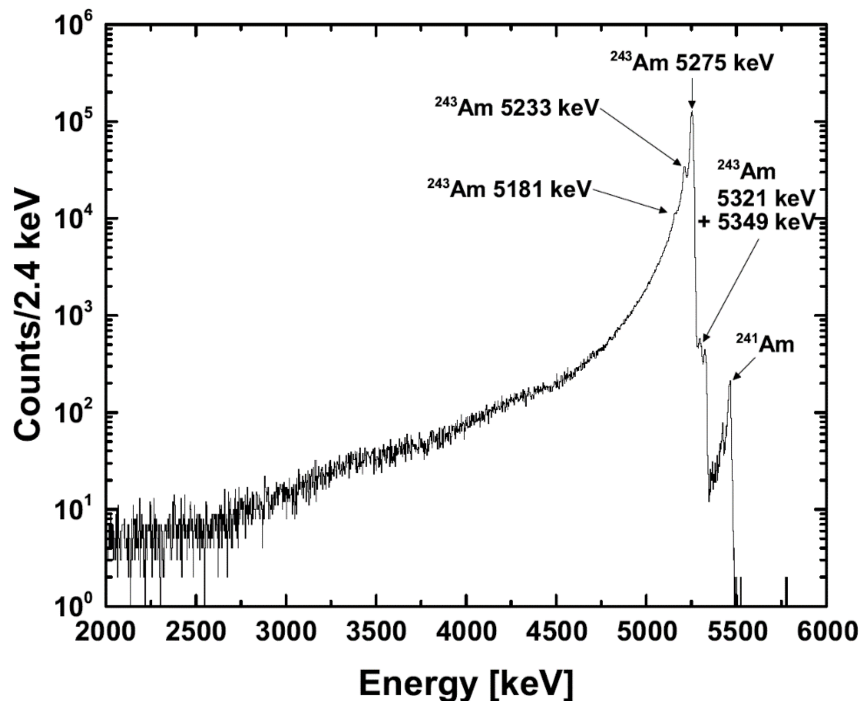


Effectiveness of integrating independent methods
α&γ ray spectroscopy,
Micro Calorimetry,
Mass spectroscopy

Measurements of gamma-ray emission probability

- We have measured gamma-ray emission probabilities of ^{241,243}Am and ^{239}Np for accurate quantitative determination of ^{241,243}Am samples used for TOF measurements.
- Standard solution sources were used to prepare measuring samples, and their activities were determined by counting alpha-rays with a Si detector.





Alpha-ray spectrum of ^{243}Am sample.

Activities at Tokyo Institute of Technology (Tokyo Tech)

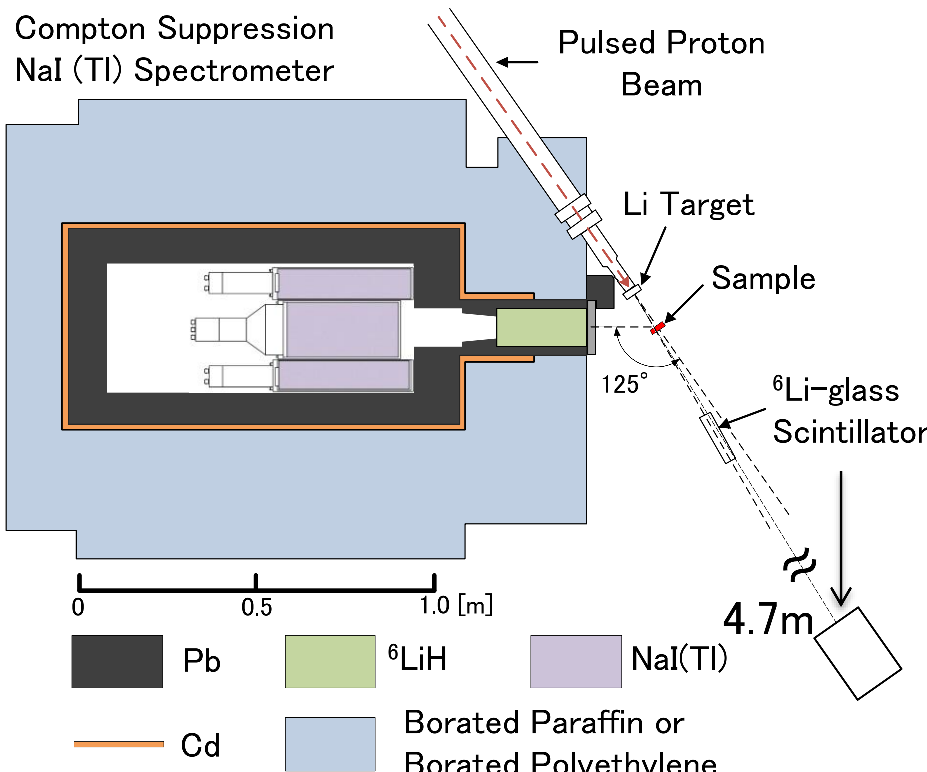
Capture Cross Sections and Gamma-ray Spectra in the keV Region (<100 keV)

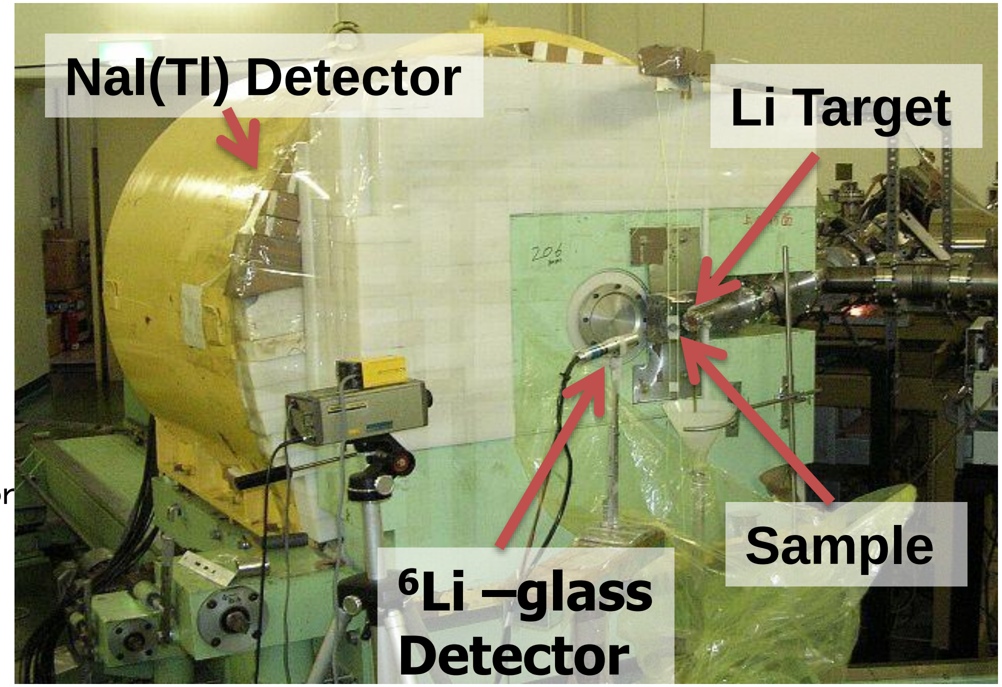
Nuclide	Method	
Re-185	TOF	σ, γ spectrum
Re-185, Re-187	Activation	σ

Experimental setup

3-MV Pelletron accelerator
Pulsed proton beam
- **Repetition rate : 4 MHz**
- **Beam width : 1.5 ns**
- **Average current : 10 μA**

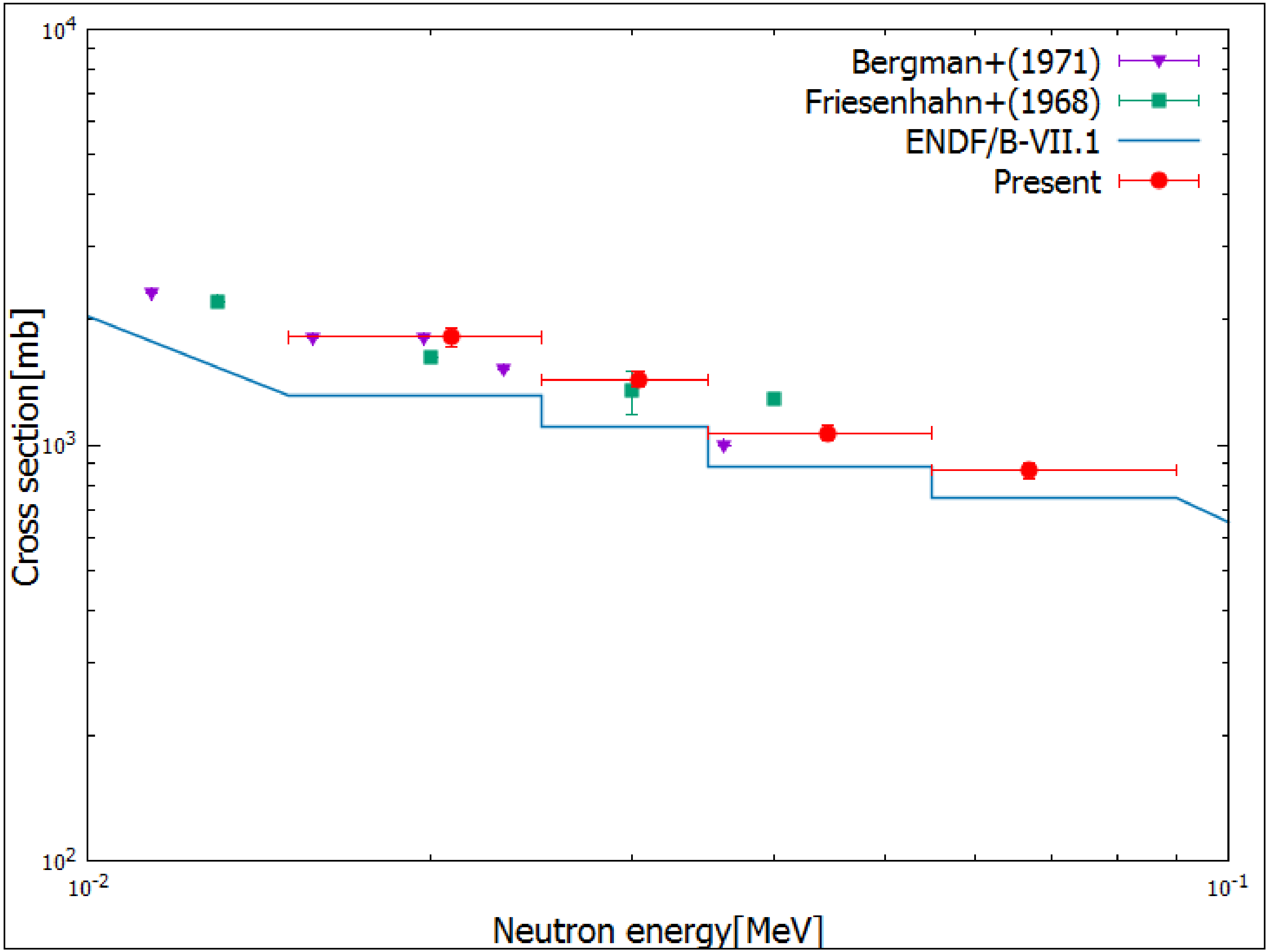
Neutron source : $^{7}Li(p,n)^{7}Be$
Flight path length :
- **12 cm for 15-100 keV neutrons**
- **20 cm for 550 keV neutrons**





NaI(Tl) Spectrometer
- **Two Dimensional Data: TOF x PH**

Neutron Capture Cross Section of ^{185}Re



Activities at National Institutes for Quantum and Radiological Science and Technology (QST)

LCS Gamma-Ray Research Group
Contact: Toshiyuki Shizuma
toshiyuki.shizuma@qst.go.jp

Measurements of nuclear resonance fluorescence (NRF) using polarized photon beams

Facilities:

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

NRF takes place via only electro-magnetic interaction:

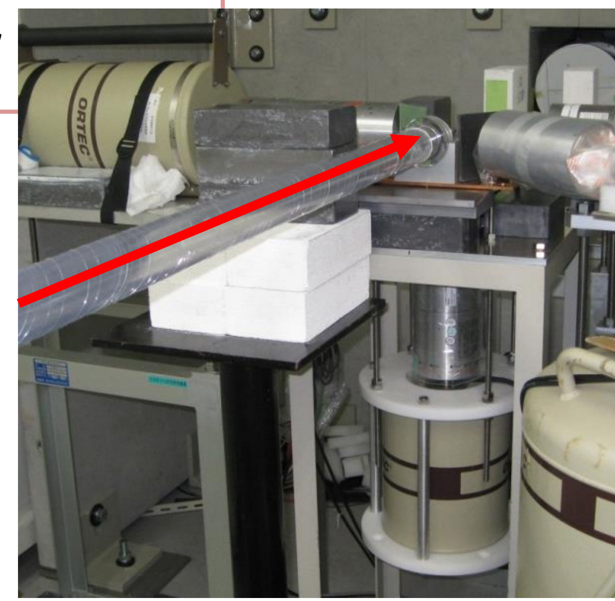
- ✓Model independent extraction of transition strength
- ✓Selective excitation of dipole states
- ✓Unambiguous parity determination (1^- or 1^+)

Experimental Setup at NewSUBARU

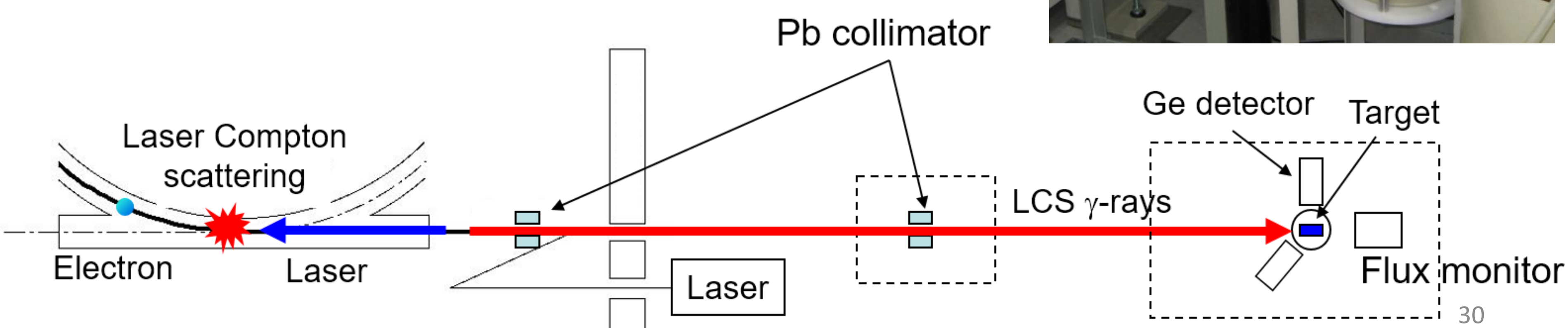
Example

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

Laser
- $Nd:YVO_4$ l=1064nm
- Power: 20W

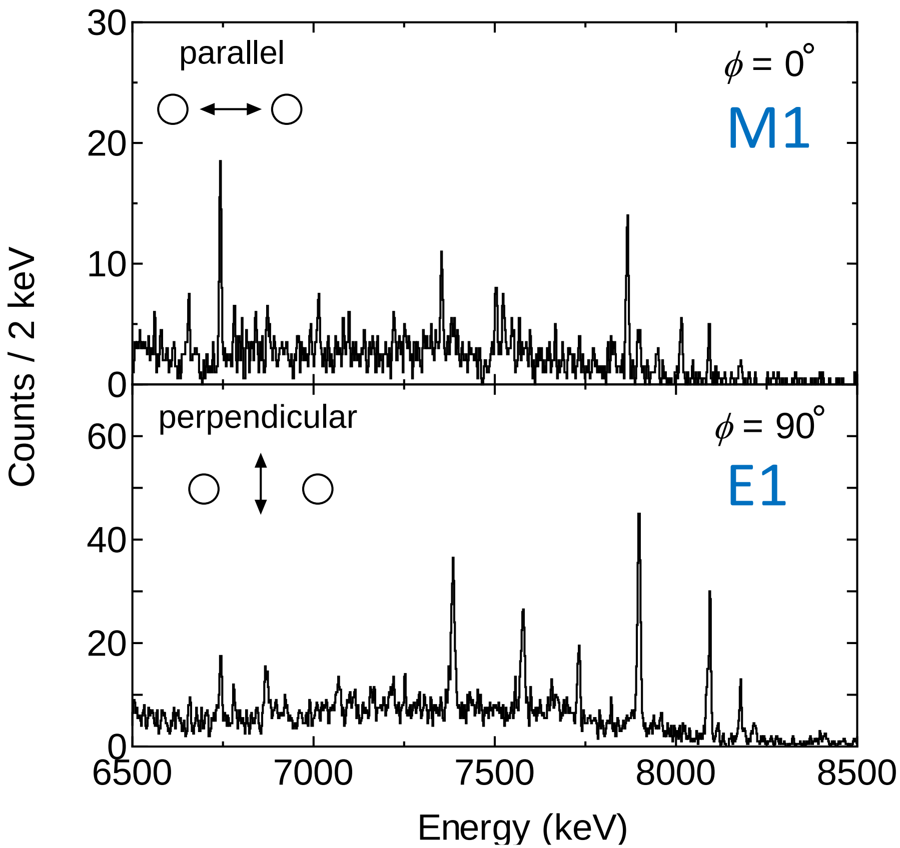


→ **LCS γ-ray beam**
- Max. energy: 6.3-39MeV
- Ave. flux: $\sim 6 \times 10^5$ /s

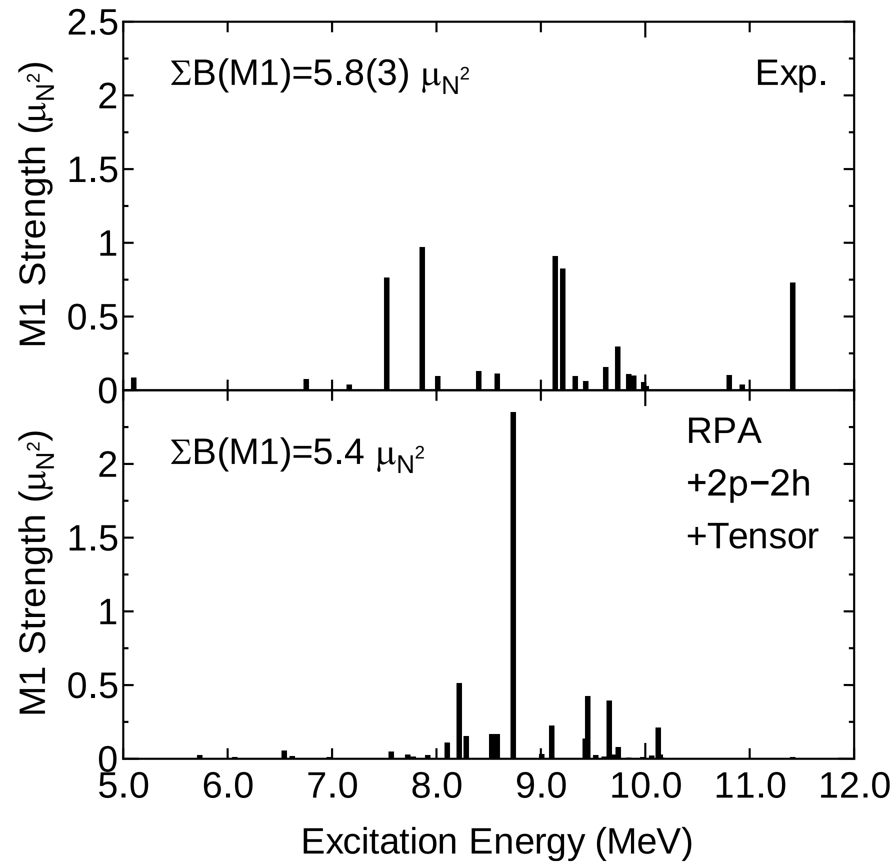


Results of NRF measurements for ^{52}Cr

Typical NRF spectrum



Measured M1 strength compared with RPA calculations



Activities at Hokkaido University

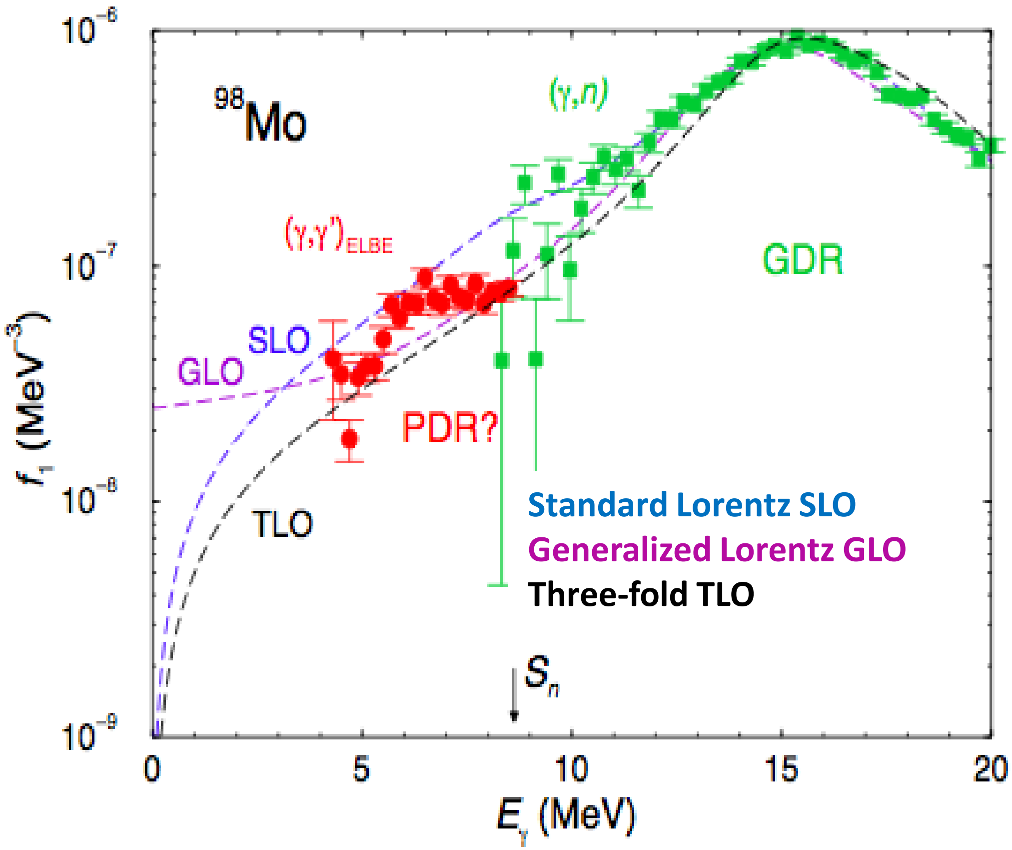
Ayano Makinaga

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

Photon scattering cross section data at HZDR

Photon strength function below neutron threshold

Photo absorption cross section



Measured intensity of a γ transition:

$$I_\gamma(E_\gamma, \Theta) = I_s(E_x)\phi_\gamma(E_x)\epsilon(E_\gamma)N_{at}W(\theta)\Delta\Omega$$

Integrated scattering cross section:

$$I_s = \int \sigma_{\gamma\gamma}\, dE = \frac{2J_x + 1}{2J_0 + 1}\left(\frac{\pi\hbar c}{E_x}\right)^2 \frac{\Gamma_0}{\Gamma}\Gamma_0$$

Absorption cross section:

$$\sigma_\gamma = \sigma_{\gamma\gamma}\left(\frac{\Gamma_0}{\Gamma}\right)^{-1}$$

E1 strength:

$$B(E1) \backsim \Gamma_0 / E_\gamma^3$$

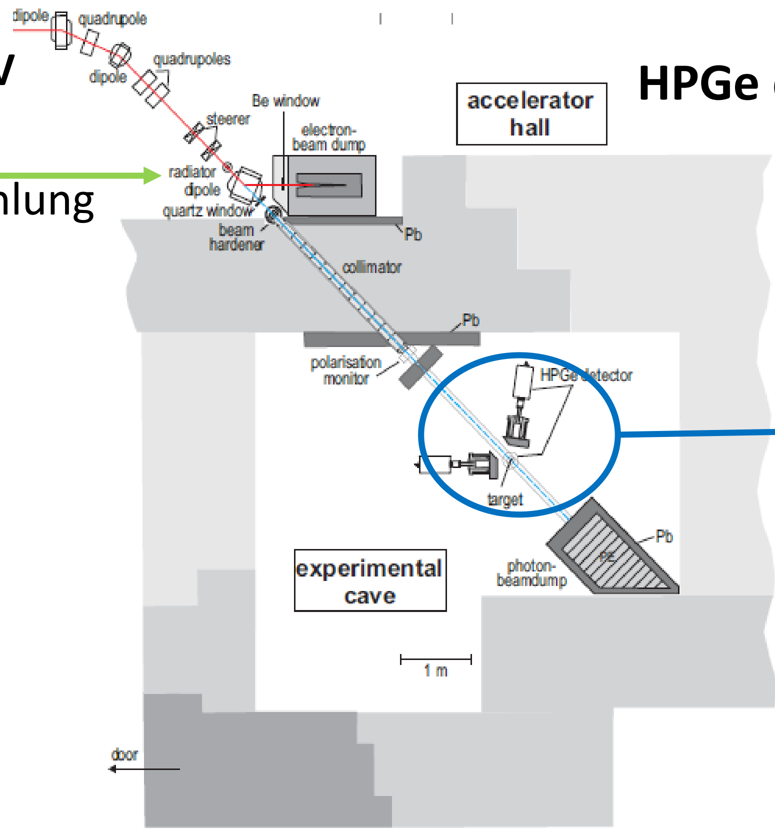
Implications for
astrophysics, nuclear technology, medical physics

Experimental set up at HZDR

electron

Ee :11.5 MeV

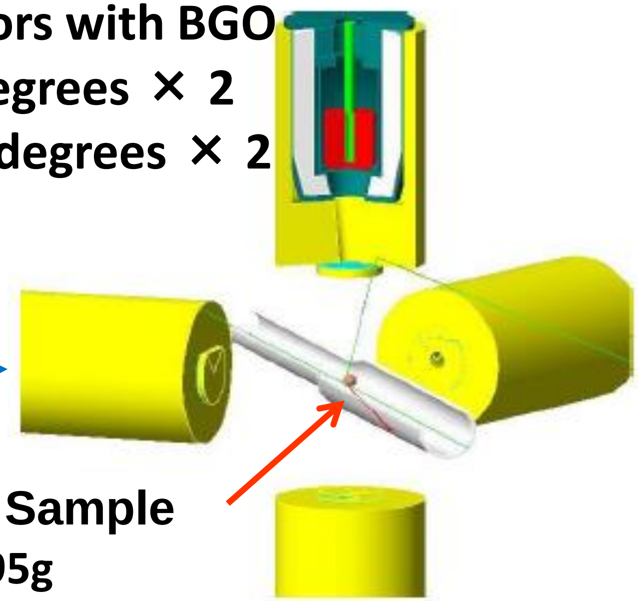
Bremsstrahlung



HPGe detectors with BGO

90 degrees × 2

127 degrees × 2



^{80}Se Sample

1.95g

99.9 % enriched

By R.Massarczyk

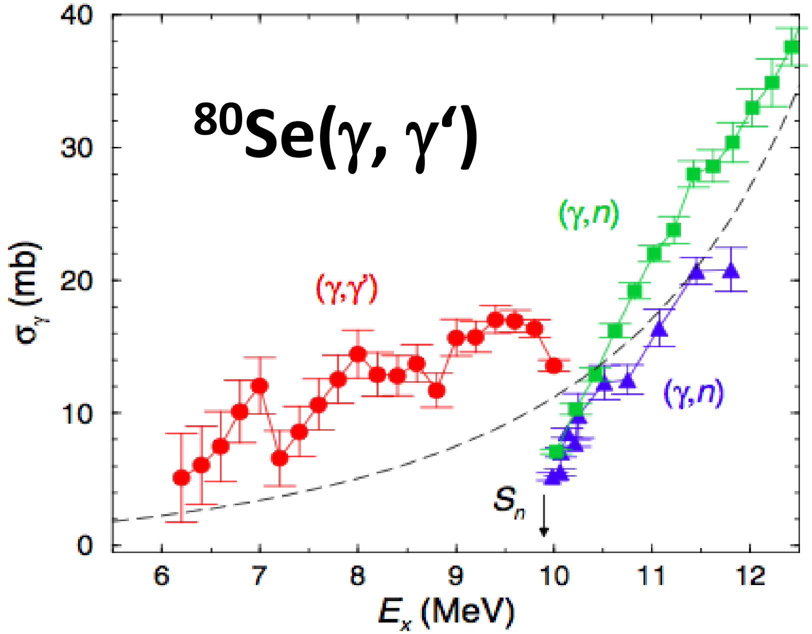
<u>The bremsstrahlung facility at the electron accelerator gELBE</u>

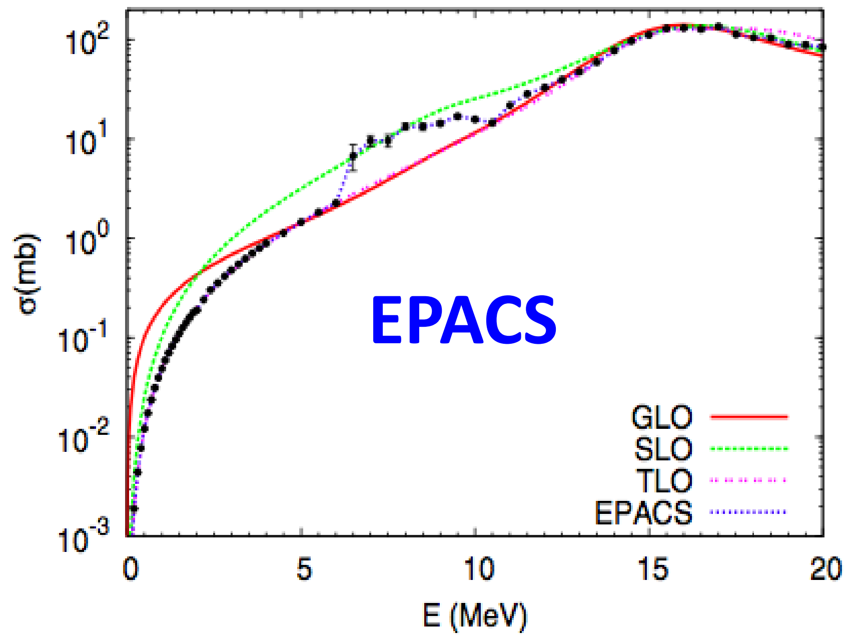
Maximum electron energy ~18MeV Maximum average current ~0.8mA

Micro-pulse rate ~13MHz Micro-pulse length ~5ps

R.Schwengner et.al., NIM A 555, 211(2005)

Result: γSF (γ-ray strength function) for ^{80}Se



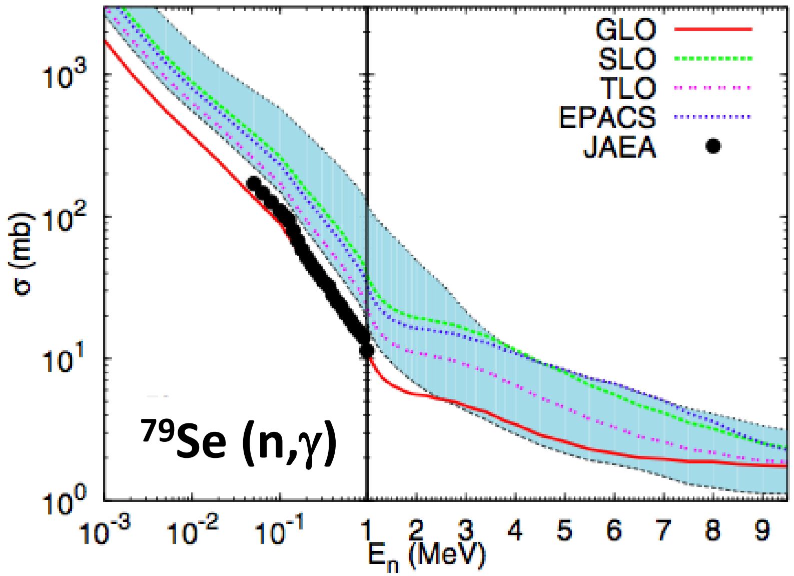


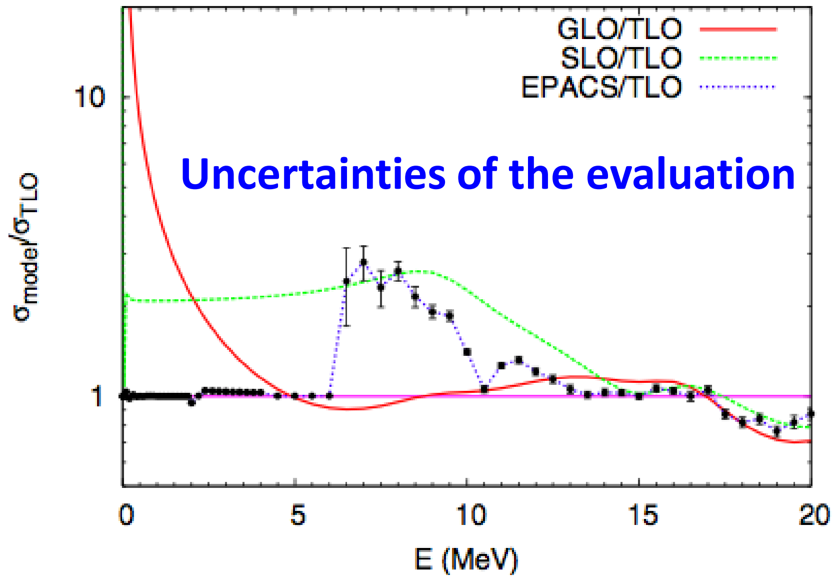
EPACS(Experimental photoabsorption cross section)

(i) 0 < Eγ < 6.2 MeV : TLO model (*because of no experimental data)
(ii) 6.2 MeV < Eγ <10.0 MeV : experimental (γ, γ') and (γ, n)
(iii) Eγ > 10.0 MeV : experimental (γ, n)

A. Makinaga, et. al., PRC94,044304 (2016).

Result:
Evaluation of ^{79}Se(n, γ)^{80}Se cross section





Uncertainties of the evaluation

For a better visibility of the differences, they are plotted relative to the TLO.

- **The SLO overestimates (between 6 and 15 MeV)**
- **The GLO and TLO agree well with the EPACS results (except for the region of the extra enhancement between about 6 and 10 MeV).**
- **Below 6 MeV, all results have still uncertainties because of the lack of experimental data.**

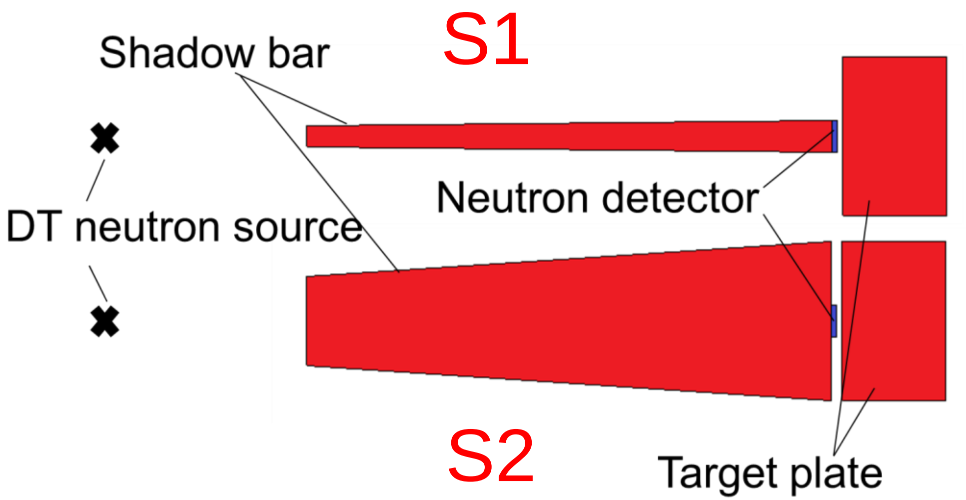
A. Makinaga, et. al., PRC94,044304 (2016).

Activities at OKTAVIAN of Osaka University

Benchmarking of Large Angle Neutron Scattering Reaction Cross Section at 14 MeV

Isao Murata

Introduction



Schematic experimental system arrangement.

・At FNS, it was confirmed that there might exist some problems in large angle back scattering cross sections from benchmark experiments for 14 MeV neutrons.

・At OKTAVIAN facility of Osaka University, some preliminary experimental studies have hence been carried out for the last 5 years on this matter.

・Basically a shadow bar was used to extract back scattering contribution. However, room return neutrons can seriously affect experimental results, if the contribution of interest (back scattering) is small.

・<u>**A new experimental system was thus proposed with two shadows bars as shown above to determine the contribution of large angle scattered neutrons accurately, removing the contribution of room return neutrons at the same time.**</u>

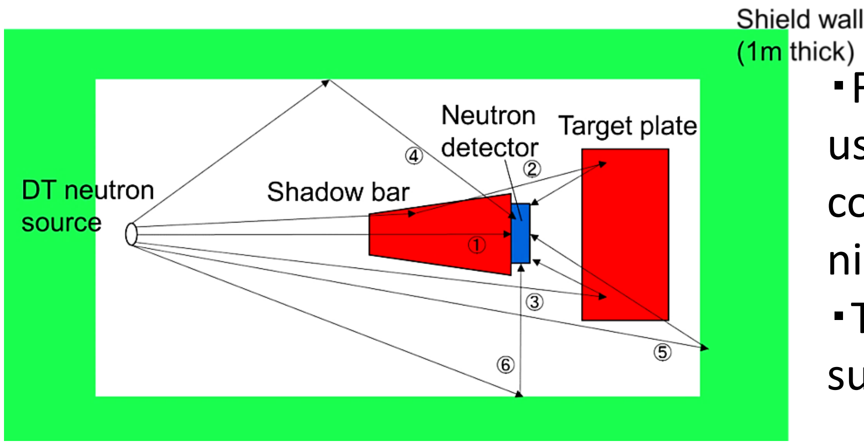
・Two shadow bars

First shadow bar (S1): To measure all the contribution.

Second shadow bar (S2): To measure the contribution of the room return neutrons.

Simulation

- We at first examined a procedure to evaluate back scattering contribution of ③ as shown in the left figure.
- From the numerical studies, it was found that by using two shadow bars we could extract only the contribution of back scattering neutrons by using a niobium foil.
- Table below shows an example of calculation summary in case of using JENDL-4.0.
  (Suffix “it” and “nt” mean experiments with and without the target plate, respectively.)



Reaction rate in each experiment (unit: 10^{-9} reaction/source neutron).

	S1it	S2it	S1nt	S2nt	S1it-S2it-(S1nt-S2nt)
①	0.02	0.12	0.01	0.12	0.01
②	0.10	0.01	0	0	0.09
③	4.04	0	0	0	4.04
④	1.01	0.57	1.02	0.56	-0.02
⑤	1.05	1.06	2.98	2.97	-0.02
⑥	0.75	0.23	0.81	0.23	-0.06
sum	6.97	1.99	4.82	3.88	4.04

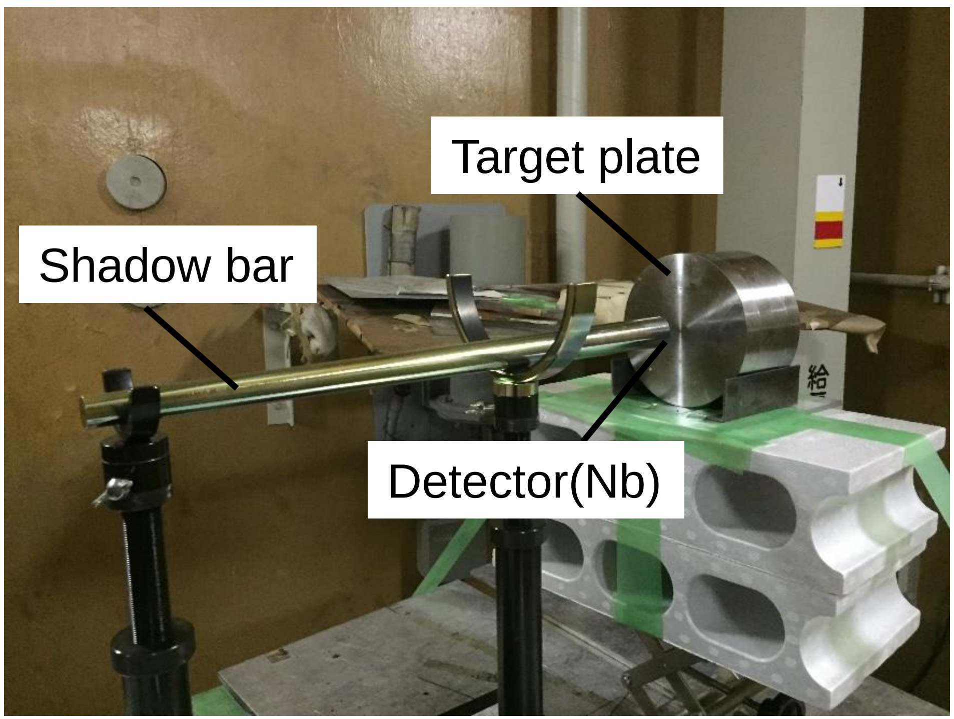
Experimental setup

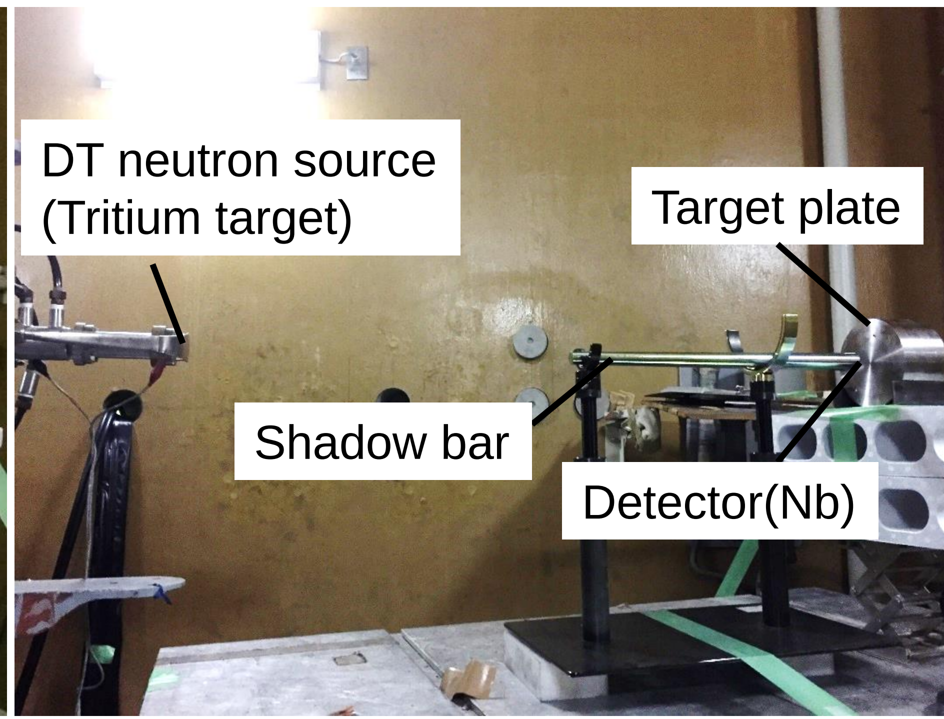
・We carried out four experiments, S1it, S1nt, S2it and S2nt at the 14 MeV neutron source facility, OKTAVIAN of Osaka University, Japan.

・Irradiation time: 15 hours

・Detector: Nb foil (Weight:30 g)

・14 MeV neutron source intensity: $5 \times 10^{9} \sim 1 \times 10^{10}$ n/s





Photos of the experimental system(S1).

Experimental result

・The table below shows the experimental result compared with the results of numerical experiments using JENDL-4.0, ENDF/B-VII and JEFF-3.1.

Reaction rate in each experiment compared with the result of numerical experiment.
(Unit: 10^{-9} reaction/source neutron)

	S1it	S2it	S1nt	S2nt	S1it-S2it-(S1nt-S2nt)
Experiment	8.31	1.68	6.92	3.83	3.54
JENDL-4.0	7.00	1.98	4.82	3.93	4.04
ENDF/B-VII	9.32	2.06	4.80	3.91	6.31
JEFF-3.1	6.83	2.07	4.83	3.98	3.90

・From the present preliminary experiment, there may be a significant difference observed between ENDF/B-Ⅶ and others. It means ENDF/B-VII may show a little higher cross section values in backward angles than others.

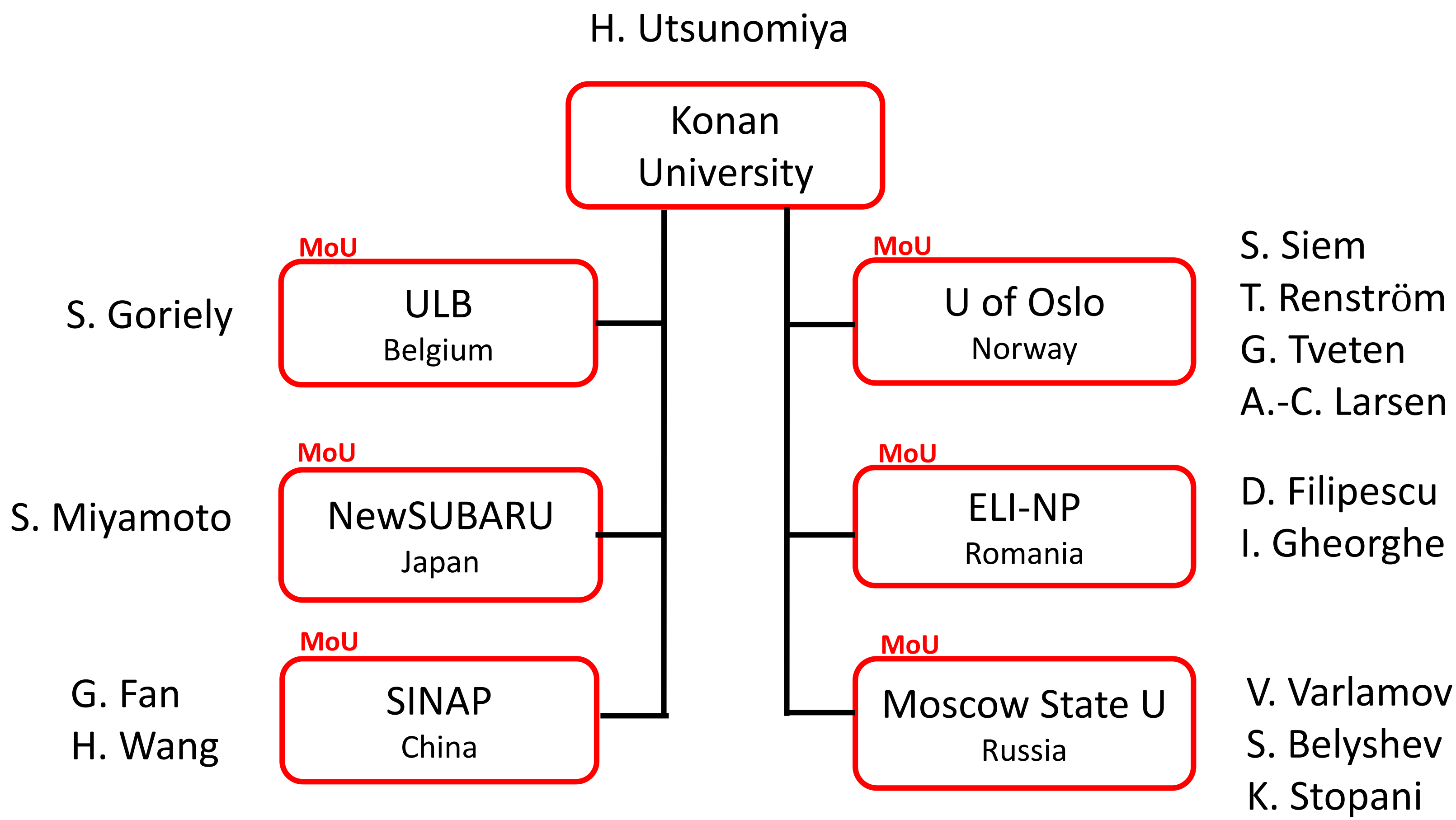
・We are planning to do additional experiments to confirm the above result and feedback it to the nuclear data library.

Activities at Konan University

Utsunomiya Group

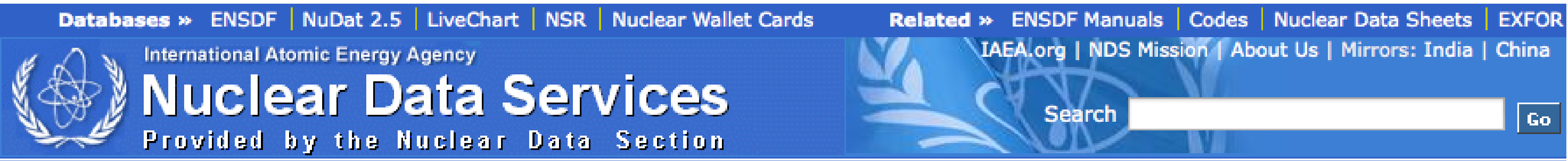
PHOENIX* Collaboration of the Konan Premier Project

*Photo-excitation and neutron emission Cross (x) sections



International Atomic Energy Agency Coordinated Research Project F41032

https://www-nds.iaea.org/CRP-photonuclear/index_1RCM.html



IAEA-CRP F41032 5 year-project (2016-2020)

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V. Varlamov (Moscow State University, Russian Federation)
N. Iwamoto (JAEA, Japan)
Y-S. Cho (KAERI, S. Korea)
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M. Wiedeking (iThemba LABS, S. Africa)
S. Siem (University of Oslo, Norway)
M. Krticka (Charles University in Prague, Czech Rep.)

Publication of two compilations in 2020

Updated photonuclear data library

Reference database of photon strength functions

Data Acquisition in the PHOENIX Collaboration for the IAEA-CRP F41032

	Updated photonuclear data library – (γ,xn) cross sections	Reference database of photon strength functions
2015	209Bi, 9Be	203Tl, 205Tl, 89Y
2016	197Au, 169Tm, 89Y	192Os, 185Re, 138Ba, 137Ba, 64Ni, 61Ni, 60Ni, 58Ni, 13C
2017	181Ta, 165Ho, 59Co	184W, 183W, 182W, 68Zn, 66Zn, 64Zn
2018	159Tb, 139La, 103Rh	160Gd, 158Gd, 157Gd, 156Gd

Nuclei underlined

Done

Activities at Kyushu University

Measurement of double-differential neutron production cross sections for deuteron-induced reactions

Team:

Dept. of Advanced Energy Engineering Science, Kyushu University
Japan Atomic Energy Agency
High Energy Accelerator Research Organization (KEK)
Research Reactor Institute, Kyoto University
Research Center for Nuclear Physics (RCNP), Osaka University

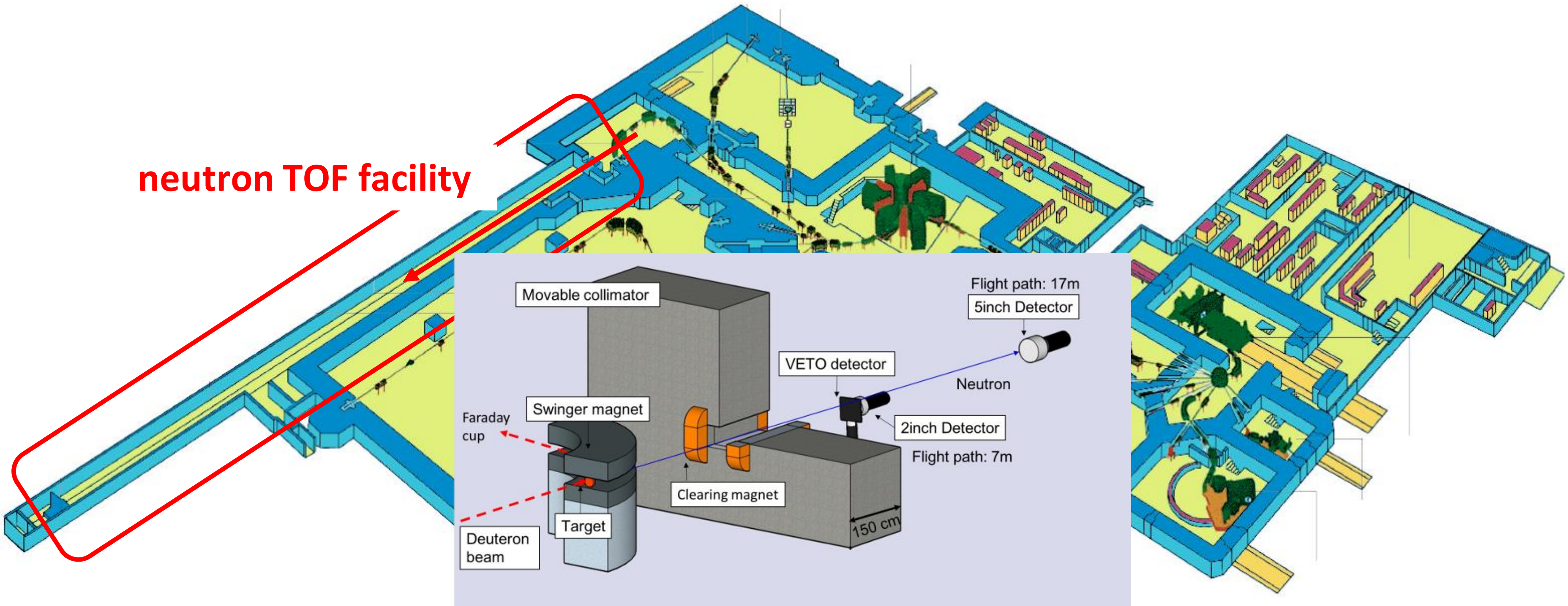
Contact:

Yukinobu Watanabe, Kyushu University

Experiment @RCNP, Osaka U.

Systematic measurement of double-differential (d,xn) cross sections at 102 MeV using conventional TOF method

- **Experimental Facility: Neutron TOF facility at RCNP, Osaka U.**
- **Targets: Li, Be, C, Al, Cu, and Nb**
- **Emission angles : 0, 5, 10, 25, 20, 25 degrees**

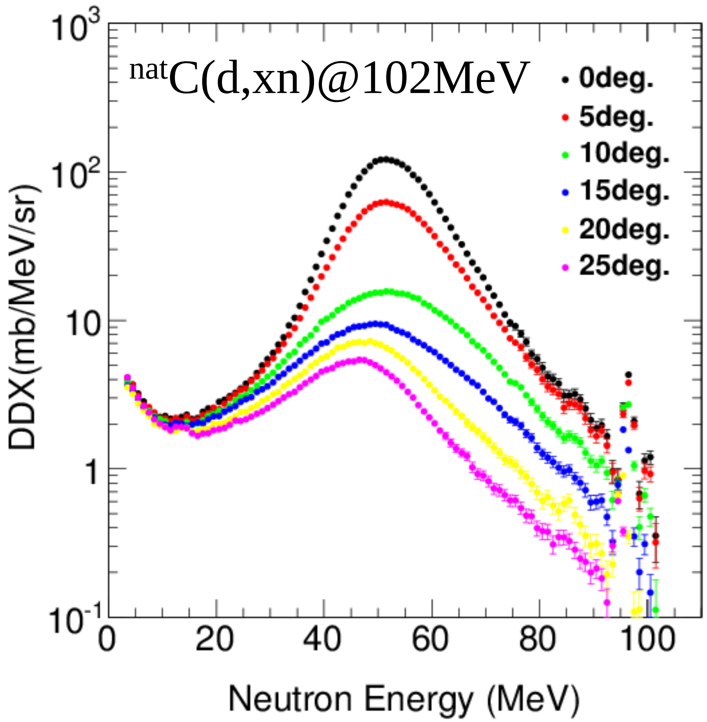


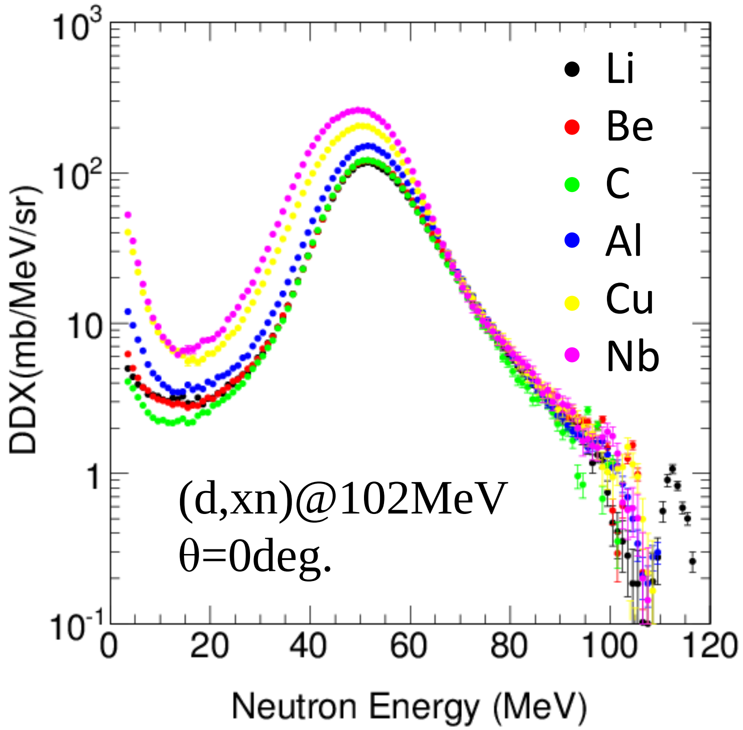
Experimental setup in the neutron TOF facility @ RCNP, Osaka U

Results

Double-differential (d,xn) cross sections

- **Incident energy : 102 MeV**
- **Targets: Li, Be, C, Al, Cu, and Nb**
- **Emission angles : 0, 5, 10, 25, 20, 25 degrees** （**0, 10 degrees for Li, Cu, Nb**）





For details, S. Araki, Y. Watanabe, et al., NIMA 842 (2017) 62-70.

Neutron Production DDX from Heavy-Ion Interactions @ NIRS-HIMAC

Team:

a) Department of Applied Quantum Physics and Nuclear Engineering, Kyushu University
b) Japan Atomic Energy Agency
c) Hiroshima University
d) High Energy Accelerator Research Organization
e) Shimizu Corporation
f) National Institute of Radiological Sciences of National Institute for Quantum and Radiological Science and Technology
g) Korea Atomic Energy Research Institute
h) Sungkyunkwan University
i) Myongji University

Contact:

Nobuhiro SHIGYO, Kyushu University

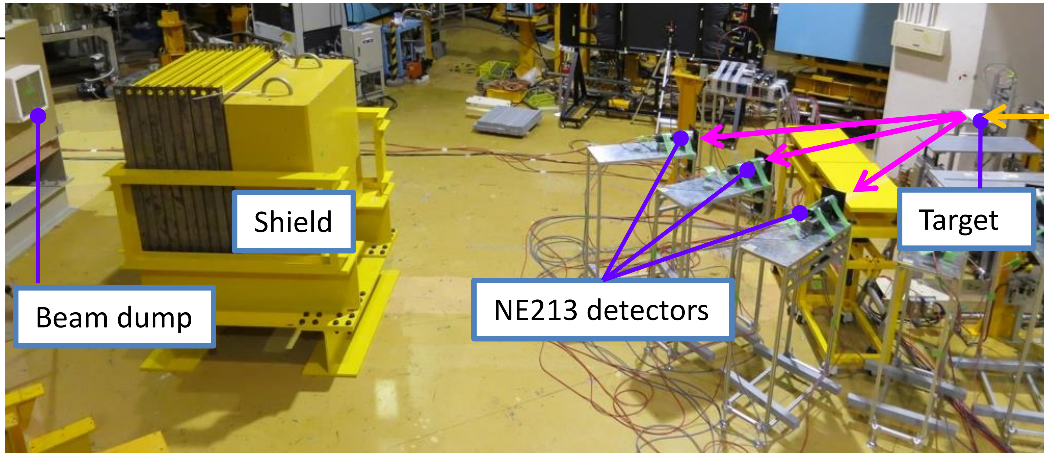
Neutron DDX and TTY from Heavy-Ion Interactions @ QSTNIRS-HIMAC

- Kyushu U., Hiroshima U., JAEA, KEK, Shimizu, QST-NIRS, KAERI, Sungkyunkwan U, Myongji U

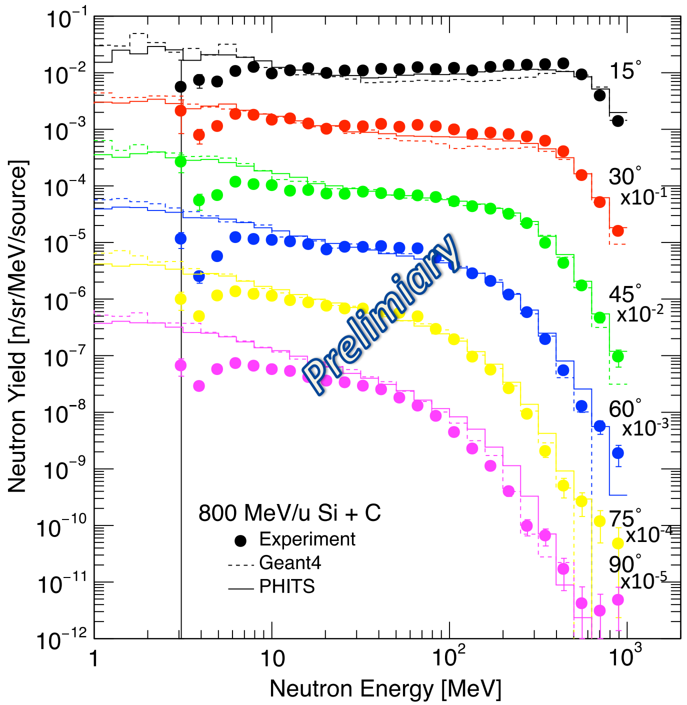
- Systematic cross-section data for elements constituting a human body's tissue bombarded with heavy-ion beams

- HIMAC PH2 beam line
- Beam: 800 MeV/u Si
- Target: C
- Detection: NE213 (2 sizes) + TOF
- Direction: 0˚, 15˚, 30˚, 45˚, 60˚, 75˚, 90˚

- PHITS reproduces experimental data



Experimental setup at HIMAC



800MeV/u Si(C, xn) TTY