Japanese Activities in Nuclear Data Measurement

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Japan Atomic Energy Agency
on behalf of
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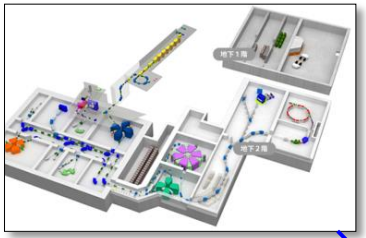
[1]*Tokyo Institute of Technology*
[2]*Japan Atomic Energy Agency*

Nuclear Data Measurement in Japan

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

QST:

National Institutes for Quantum and Radiological Science and Technology



RIBF@RIKEN

TIARA@QST

CYRIC@Tohoku

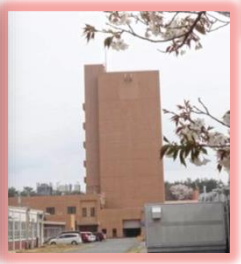
FNS@JAEA

New SUBARU

RCNP

OKTAVIAN

ANNRI/MLF/ J-PARC@JAEA



Tandem @JAEA

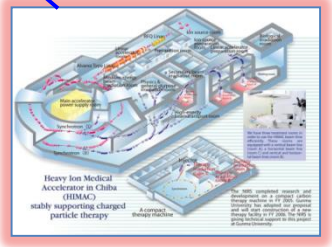
JRR-3 @JAEA

KUTL

KUR

KURRI-LINAC

TIT



HIMAC @QST

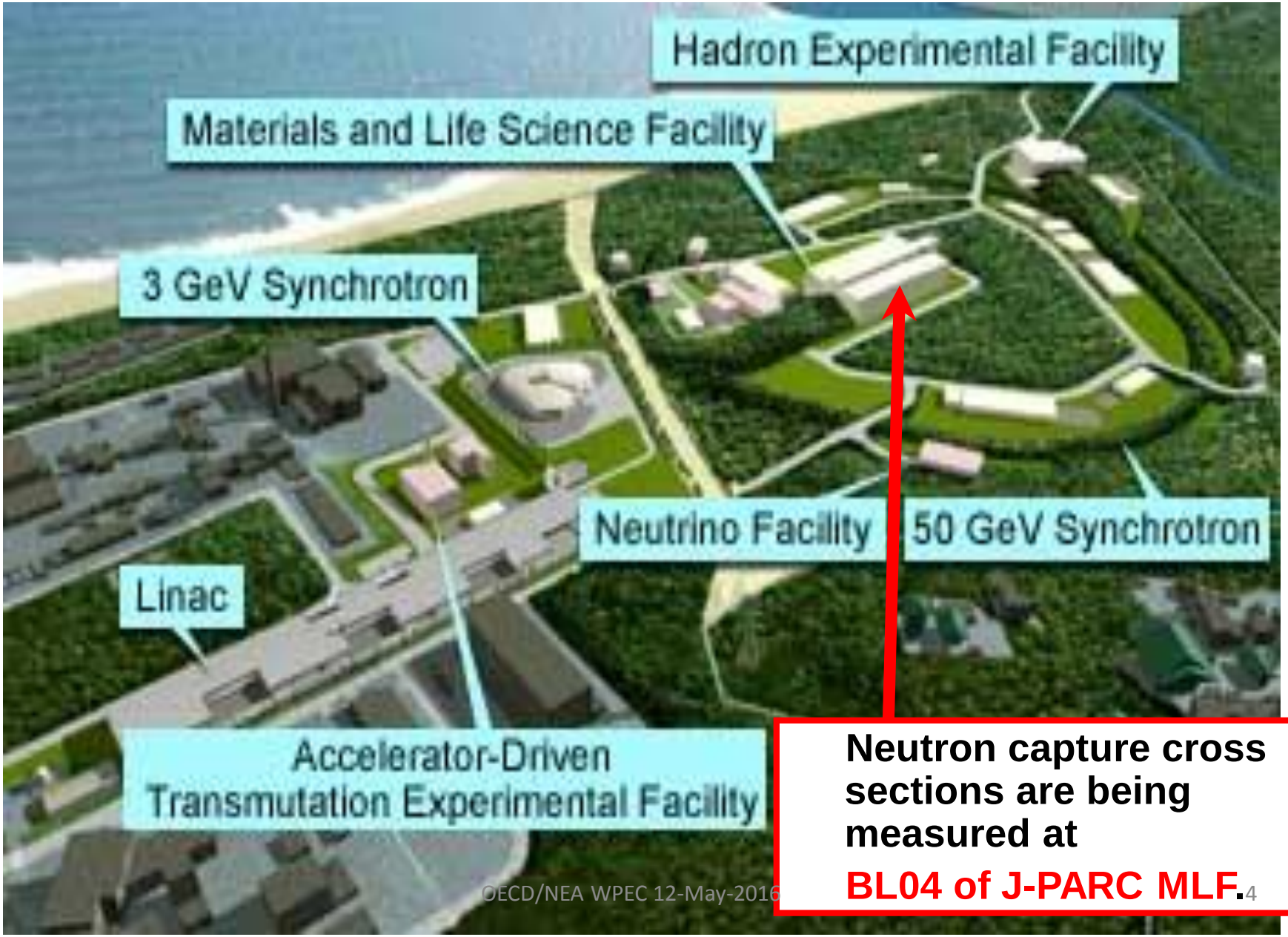
Cyclotron @QST

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

Japan Atomic Energy Agency
Tokyo Institute of Technology
Kyoto Univ.

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

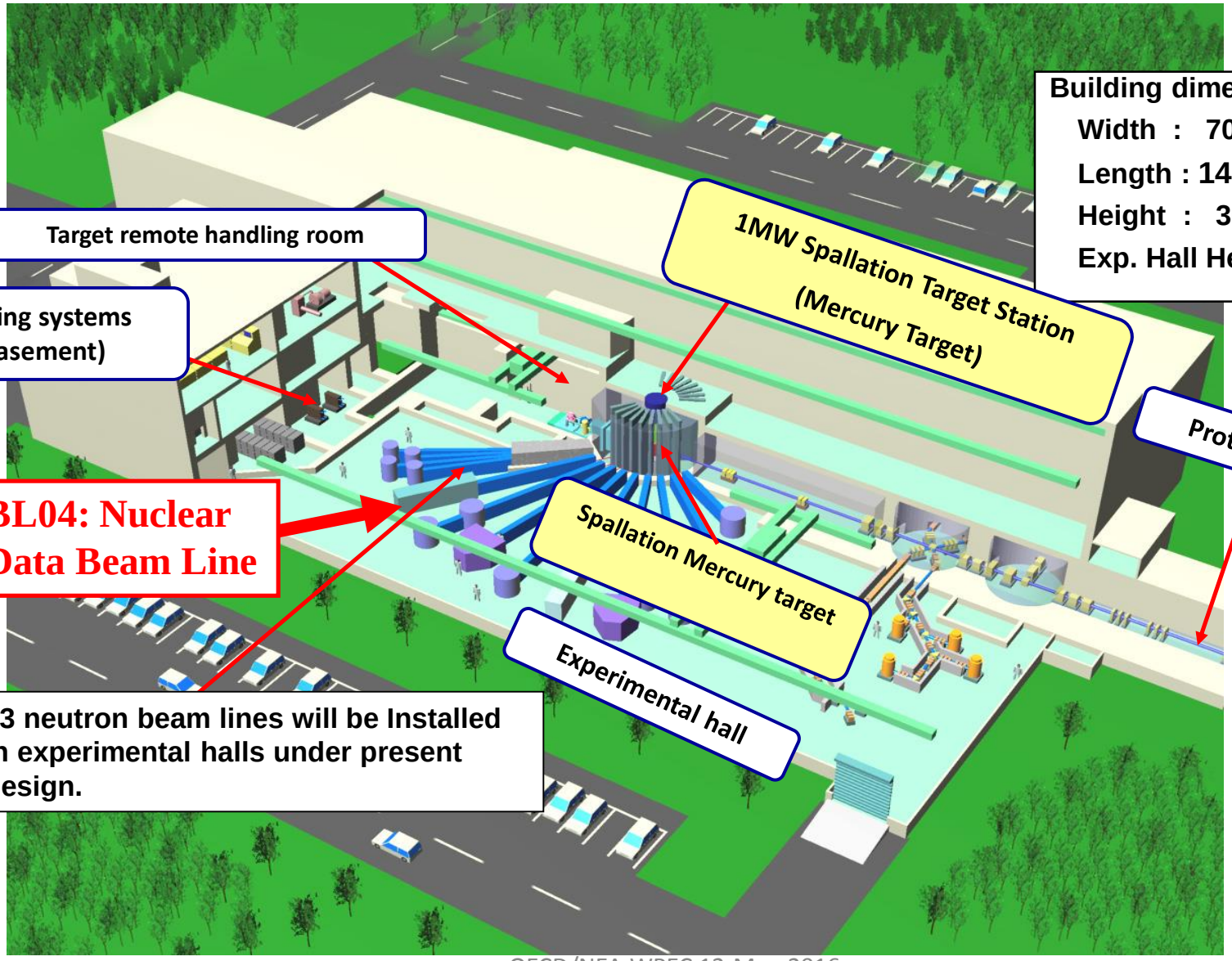
Nuclear Data Projects in Japan



Neutron capture cross sections are being measured at

BL04 of J-PARC MLF.

J-PARC Materials and Life Science Experimental Facility

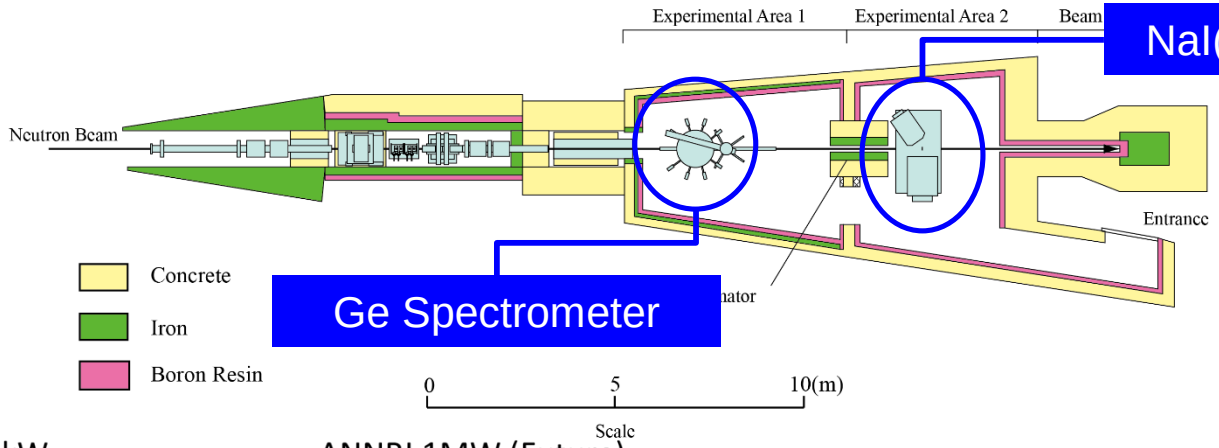


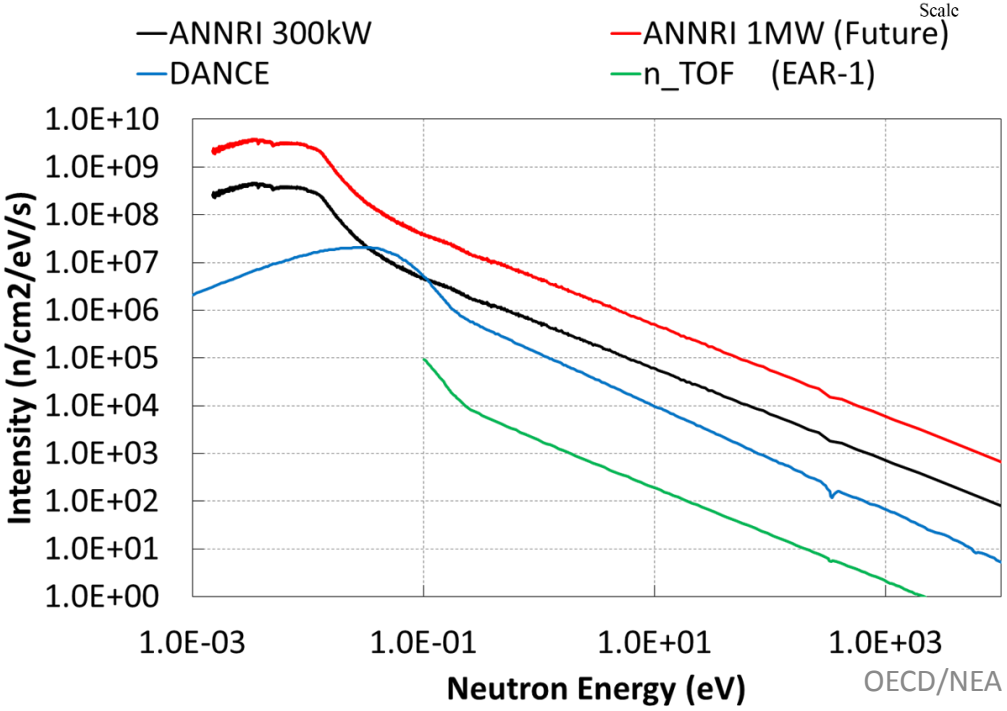
Building dimension :
- **Width : 70m**
- **Length : 146m**
- **Height : 30m**
- **Exp. Hall Height : 22m**

J-PARC MLF, Taken from HP of J-PARC

ANNRI

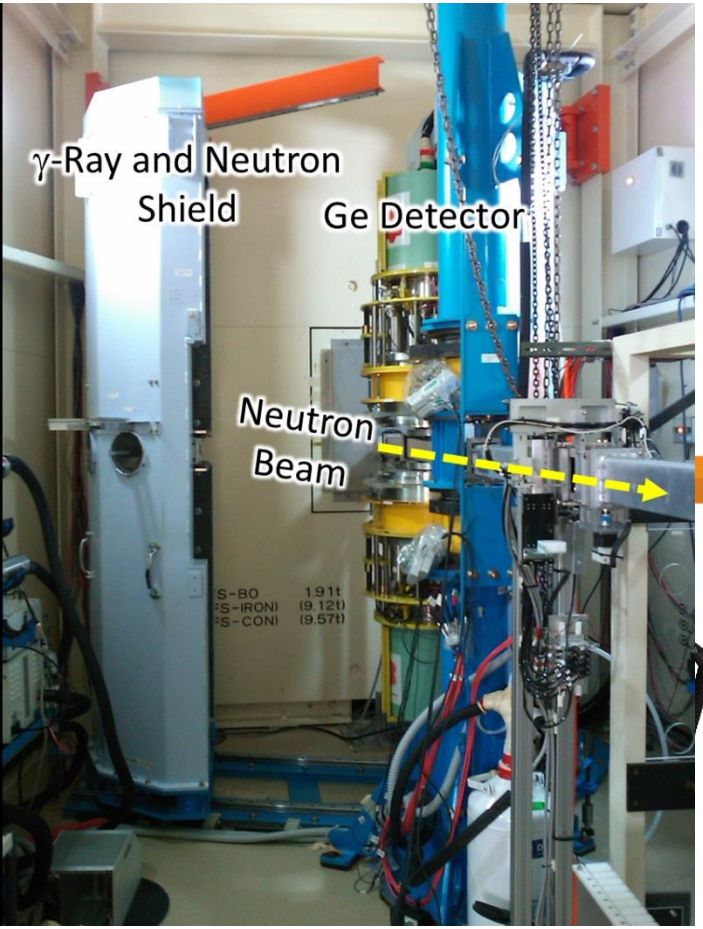
ANNRI (Accurate Neutron Nucleus Measurement Instrument)





Due to troubles in the mercury target, operation had been stopped from May 2015 to Sep. 2015 and Nov. 2015 to Feb. 2016.

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.

Energy resolution for 1.33MeV γ-rays:

5.8keV (for 200kevents/s),

2.4keV (for 20kevents/s) [1]

Peak efficiency for 1.33MeV γ-rays:

3.64 ± 0.11 %

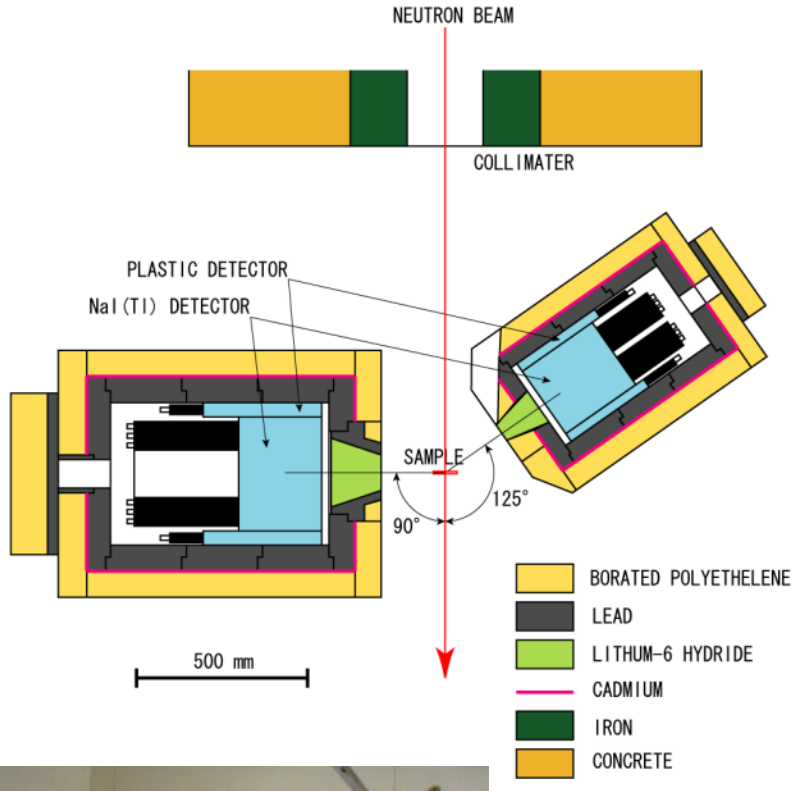
[1] T. Kin et. al., *the 2009 NSS-MIC Conf. Rec.* , N24-2, (2009).

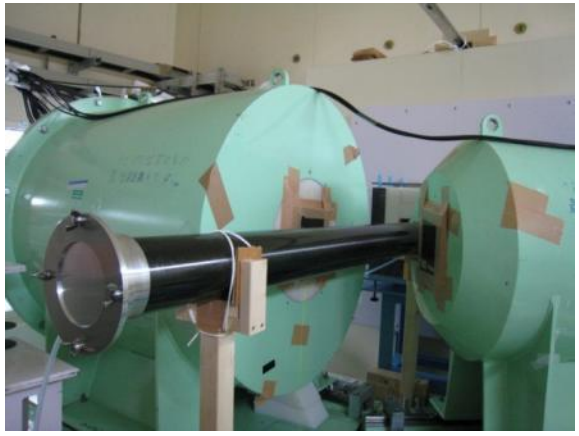
NaI(Tl) Spectrometer

- 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

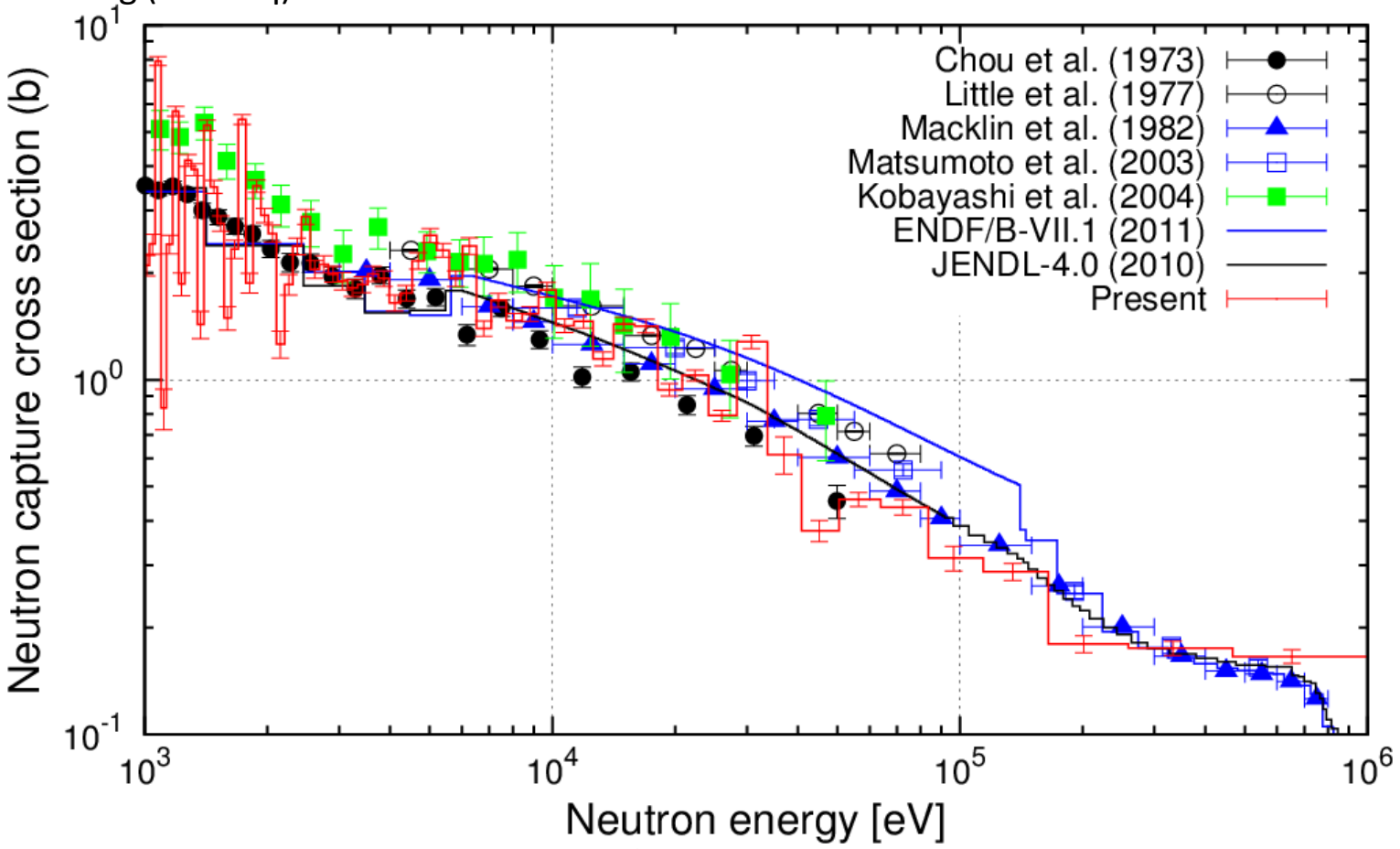




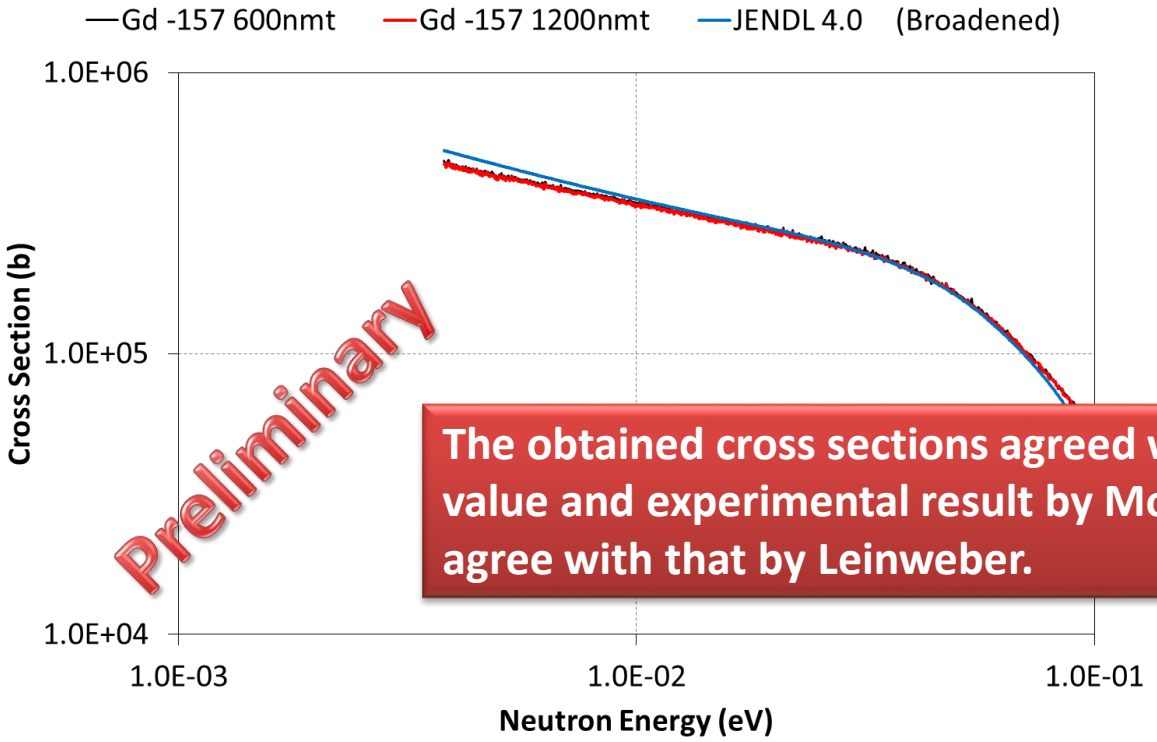
Neutron capture cross section of ^{99}Tc

Tc-99 sample (NaI (Tl) Spectrometer)

78 mg (52 MBq)Sealed in Al container



Neutron capture cross section of ^{157}Gd



Sample

- Enriched Gadolinium nitrate ($Gd(NO_3)_3$)
- Crystalized on Al foils (24μmt, 1200nmt and 600nmt)

The obtained cross sections agreed with evaluated value and experimental result by Moller but do not agree with that by Leinweber.

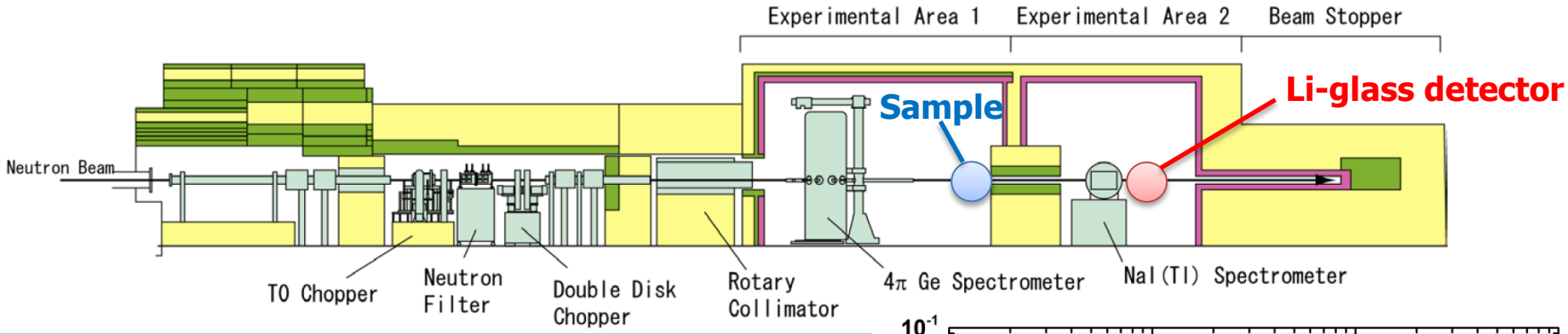
By taking the ratio, efficiencies of the detector and the incident neutron intensities are cancelled out and the absolute cross section is calculated accurately.

$$R(E_n) = \frac{\varphi(E_n) \times k_{Gd} \times \left(1 - exp(-\sigma(E_n)N_{thin})\right)}{\varphi(E_n) \times k_{Gd} \times \left(1 - exp(-\sigma(E_n)N_{thick})\right)} = \frac{1 - exp(-\sigma(E_n)N_{thin})}{1 - exp(-\sigma(E_n)N_{thick})}$$

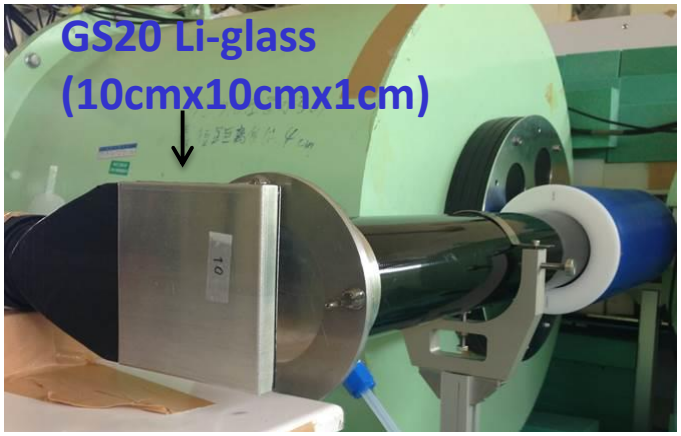
E_n : Neutron Energy, $\varphi(E_n)$: Neutron Flux, k_{Gd} : Detector Efficiency,
$\sigma(E_n)$: Capture Cross Section

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.

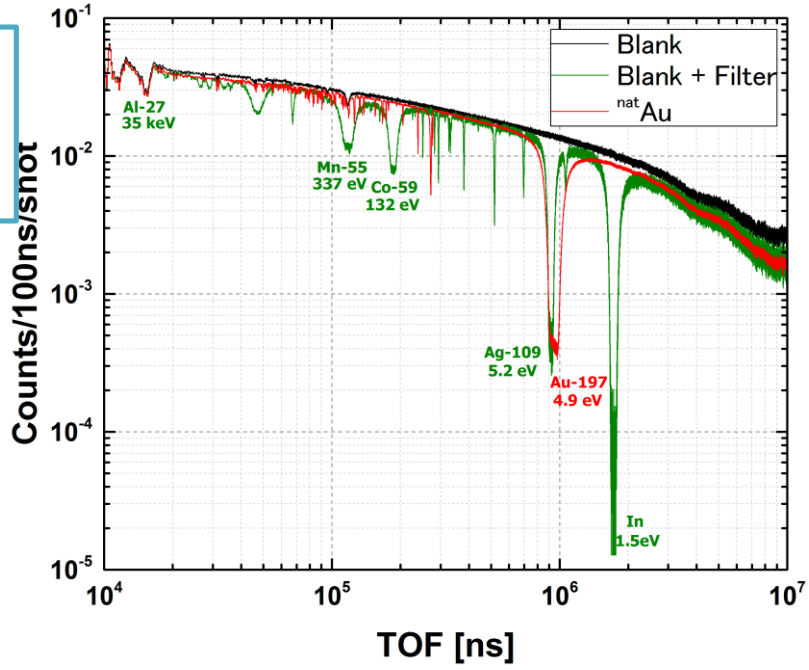


- Measurements of neutron total cross sections of ^{nat}Au, ^{241}Am, $^{155,157}Gd$ have been performed.
- Data analysis is in progress.



experimental setup

DAQ
(CAEN V1724)



TOF spectra for Blank (+Filter) and Au

AIMAC project

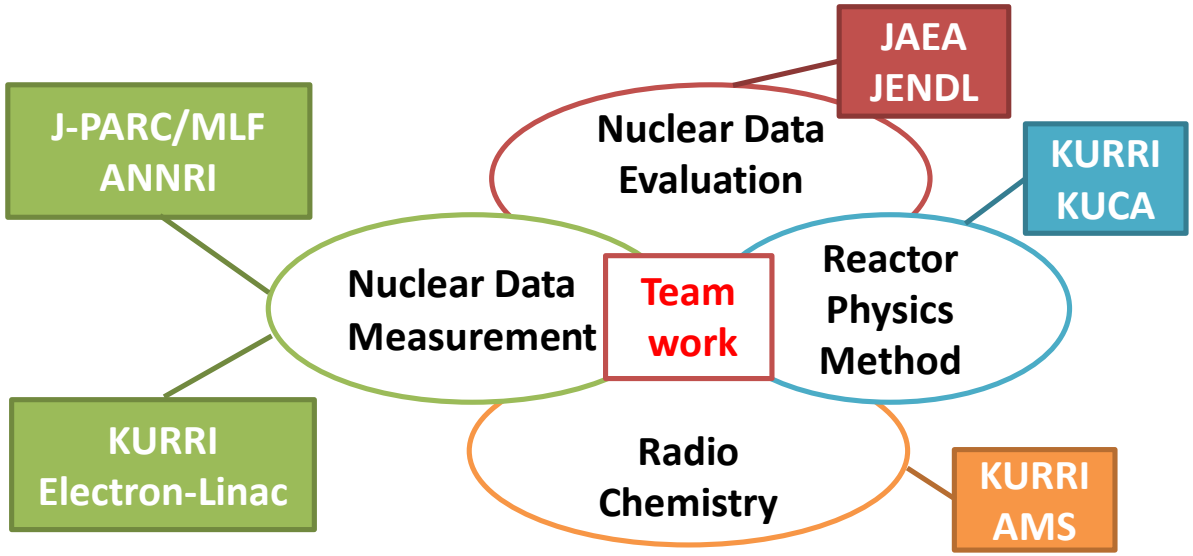
“Accuracy Improvement of Neutron Nuclear Data on Minor Actinides”

- One of the "Innovative Nuclear Research and Development Program" in Japan -

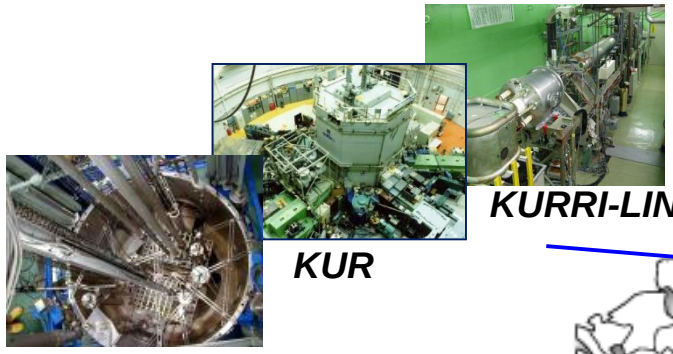
October 2013 – March 2017

Ref.: EPJ Web of Conferences, **93**, 06001 (2015)

AIMAC collaboration



Collaboration by researchers from 4 different research fields



KURRI-LINAC

KUR

KUCA

ANNRI (J-PARC) @JAEA

TIT

AIMAC Project

① Accurate measurements of
thermal neutron capture cross-sections

② High-precision quantification of
sample amount used for TOF measurement

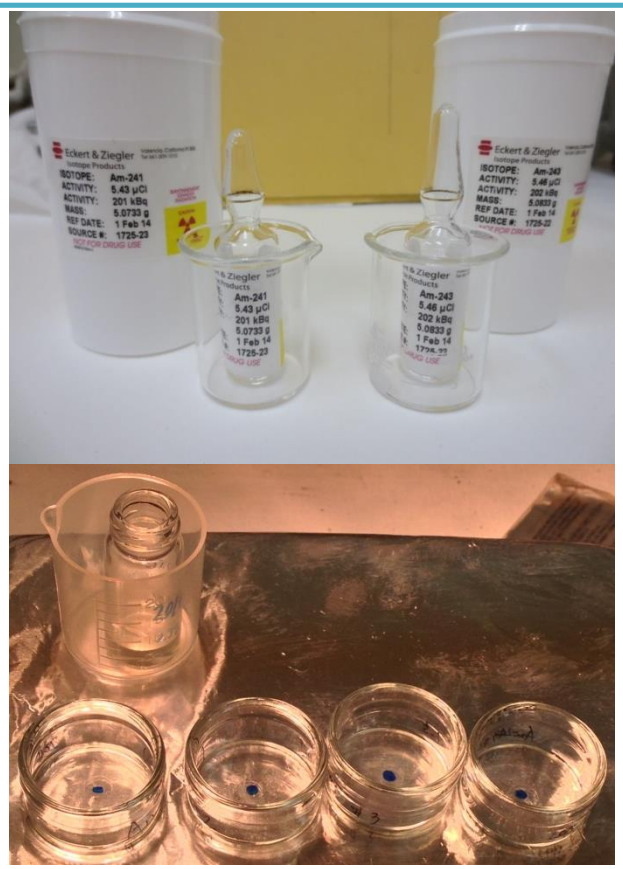
③ Resonance parameter determination
by combining total and capture cross sections

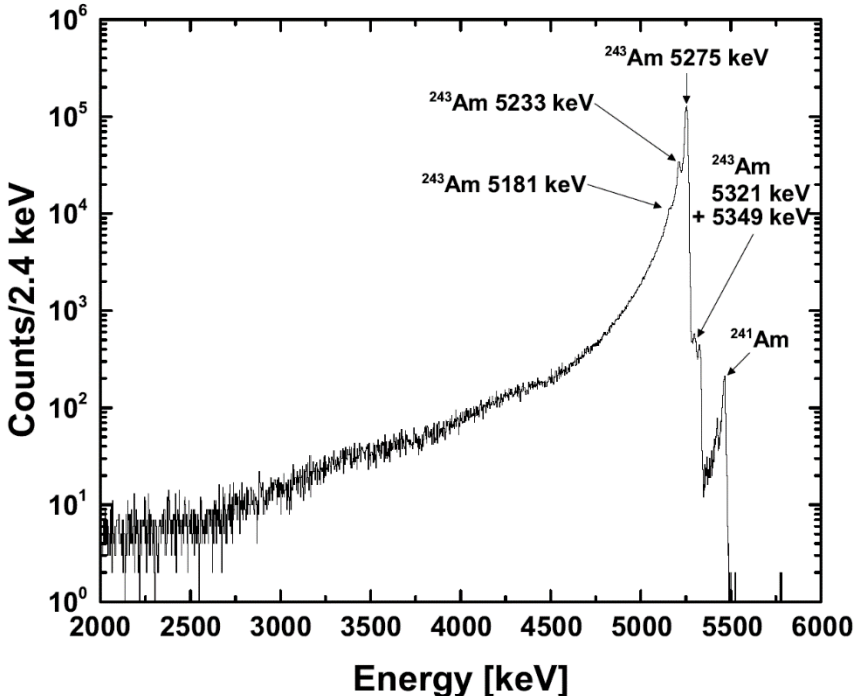
④ Extension of capture cross sections
to high energy neutrons

⑤ High quality evaluation based on
iterative communication with experimenters

Measurements of gamma-ray emission probability

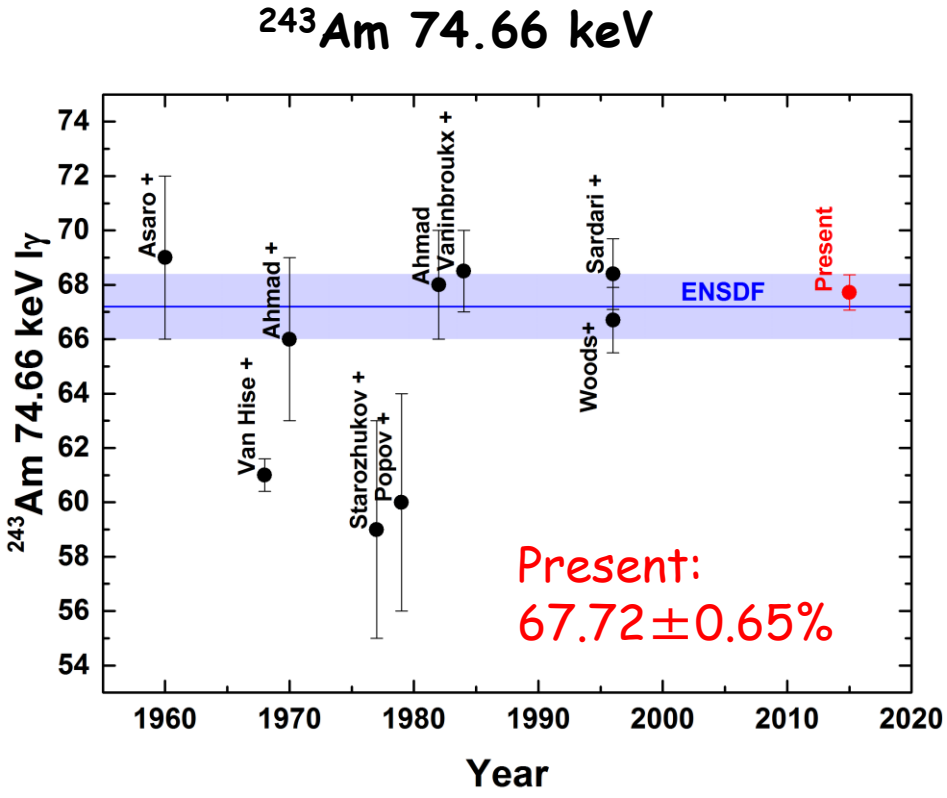
- We have measured gamma-ray emission probabilities of ^{241,243}Am and ^{239}Np for accurate quantitative determination of ^{241,243}Am samples used for TOF measurements.
- Standard solution sources were used to prepare measuring samples, and their activities were determined by counting alpha-rays with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

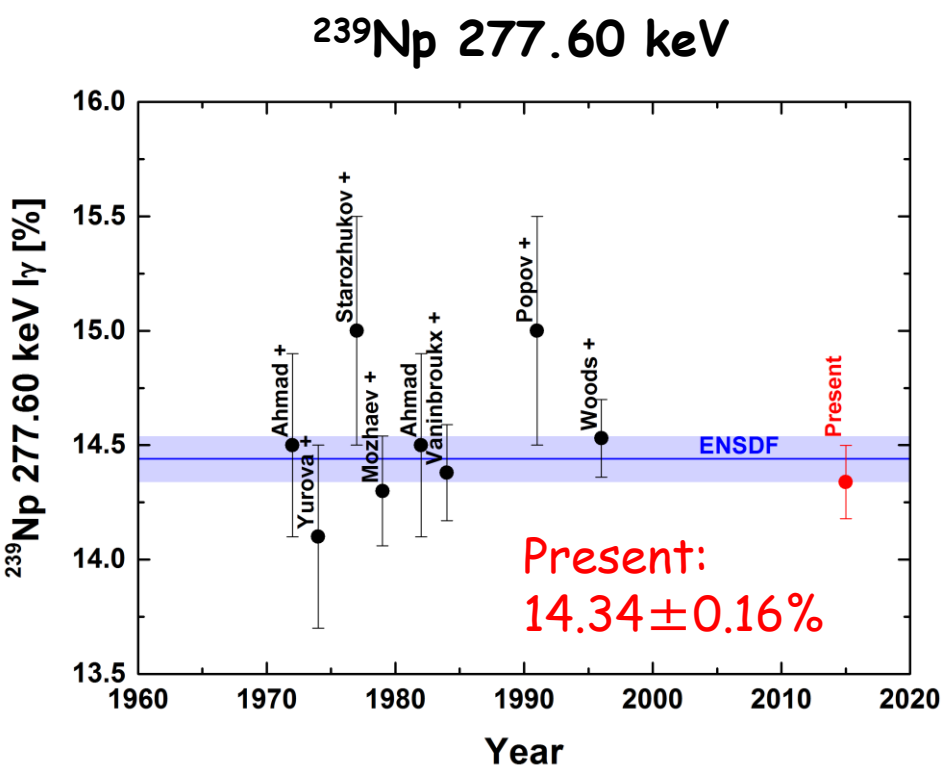




Alpha-ray spectrum of ^{243}Am sample.

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





To be published in JNST http://dx.doi.org/10.1080/00223131.2016.1174167.

Nuclear Data Activities at Tandem Accelerator Facility of Japan Atomic Energy Agency

Contact :
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Advanced Science Research Center
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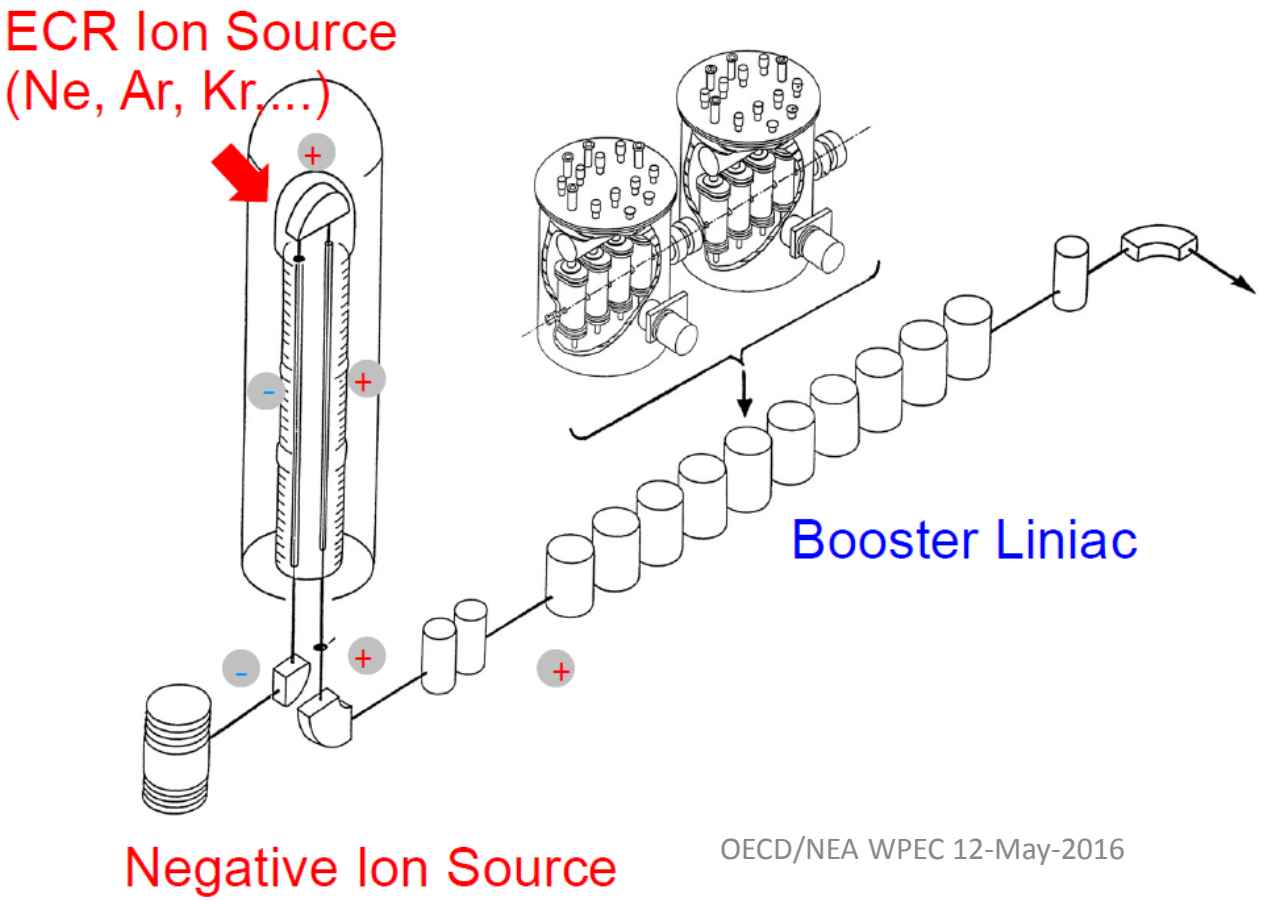
JAEA Tandem facility

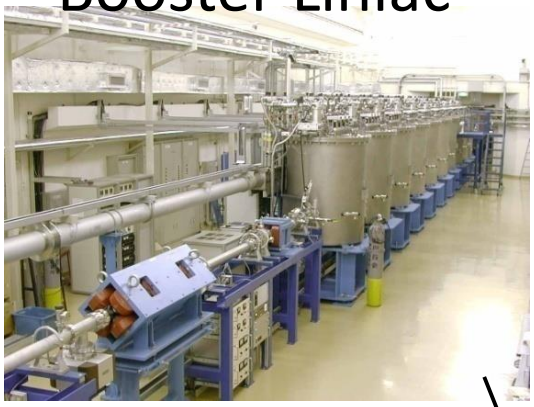
Development :

1982 : 20 MV Tandem accelerator in operation
1994 : Super-conducting Booster Liniac
2008 : ECR Ion Source on the terminal



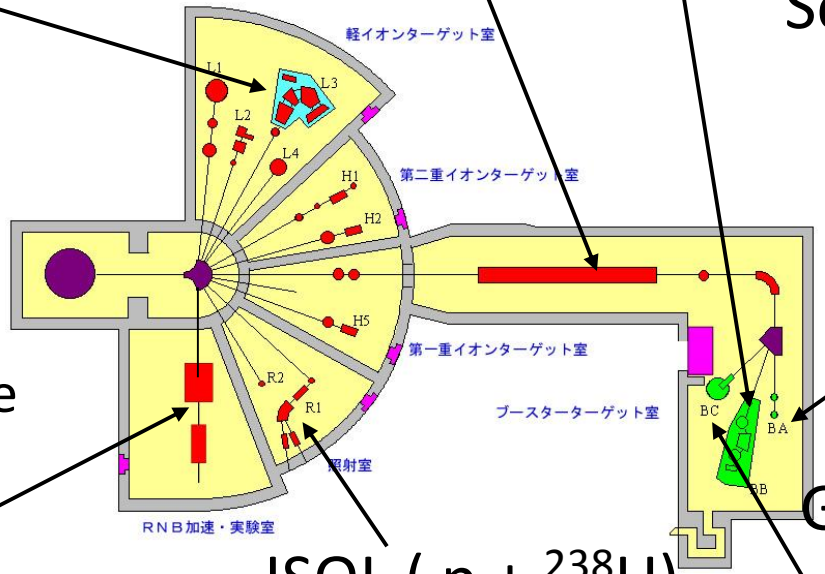
Magnetic Spectrometer

Booster Liniac



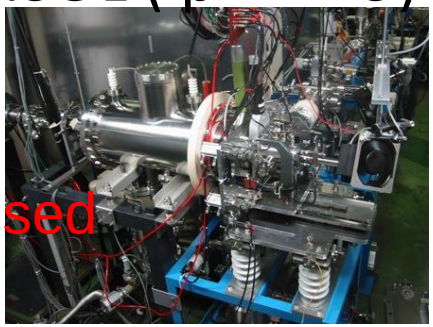
Recoil Mass Separator

Scattering Chamber

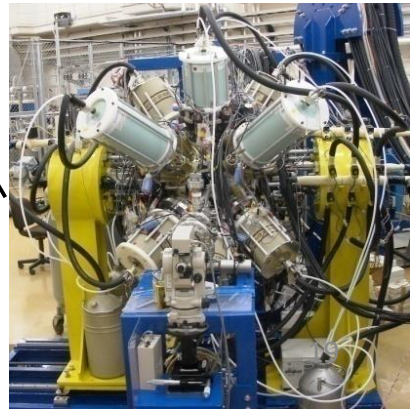


Surrogate reaction line

ISOL (p + ^{238}U)



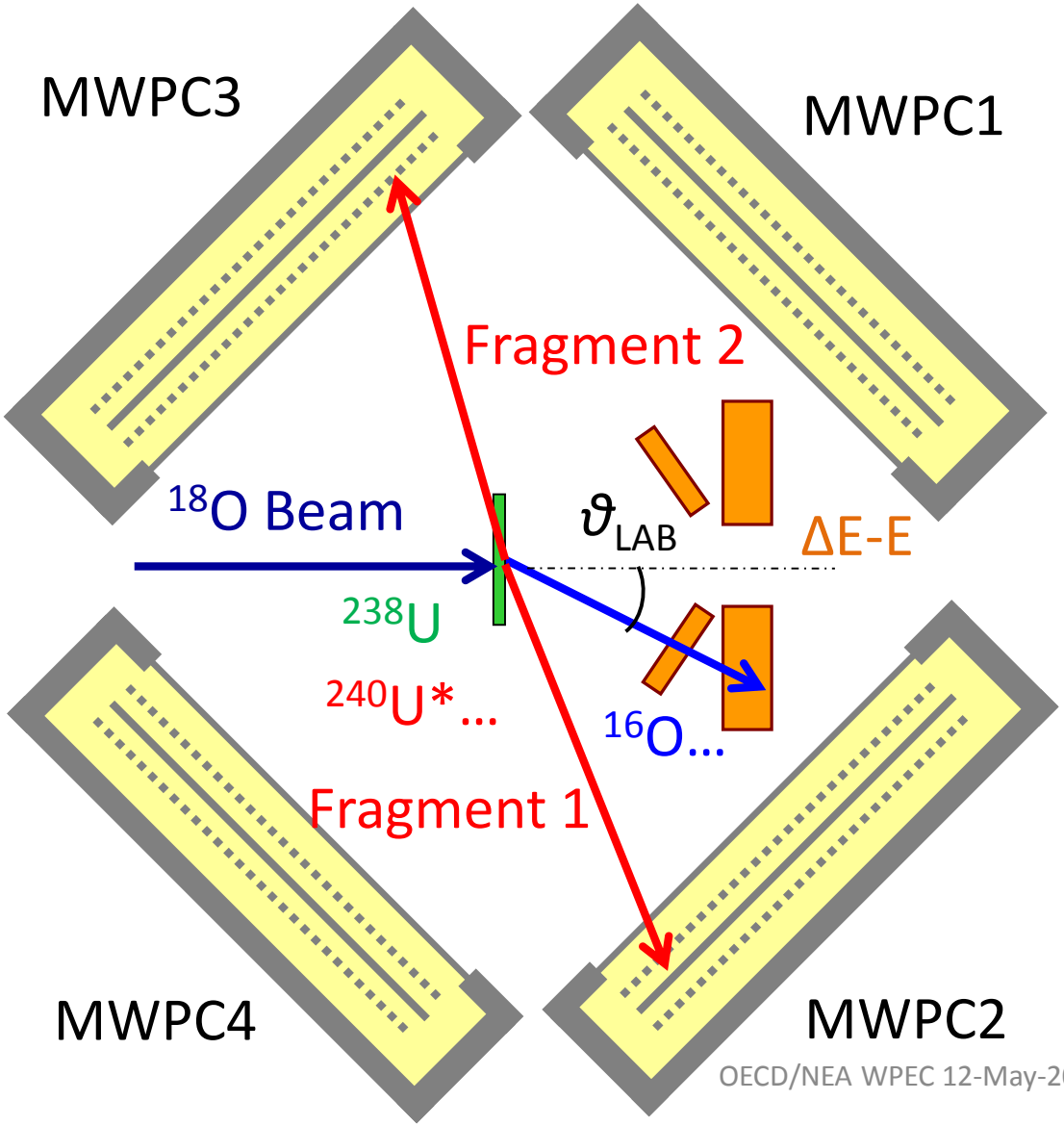
Ge-detector array



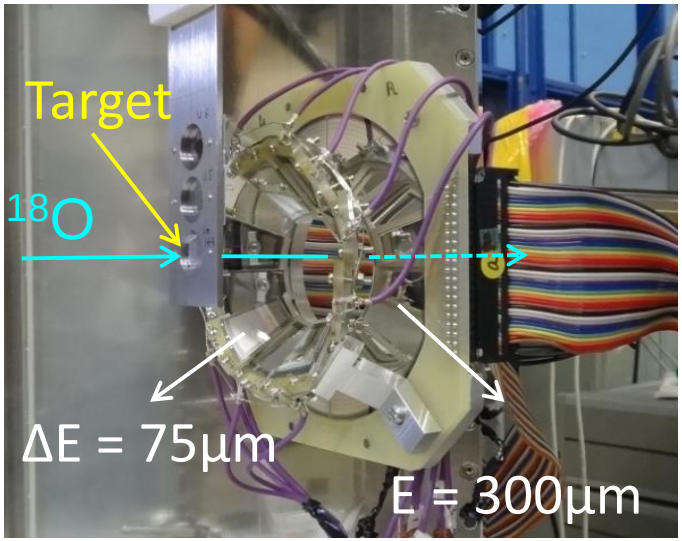
Radioactive materials can be used

Th, U, Np, Pu, Am, Cm, Cf

Fission Fragment Mass Distributions

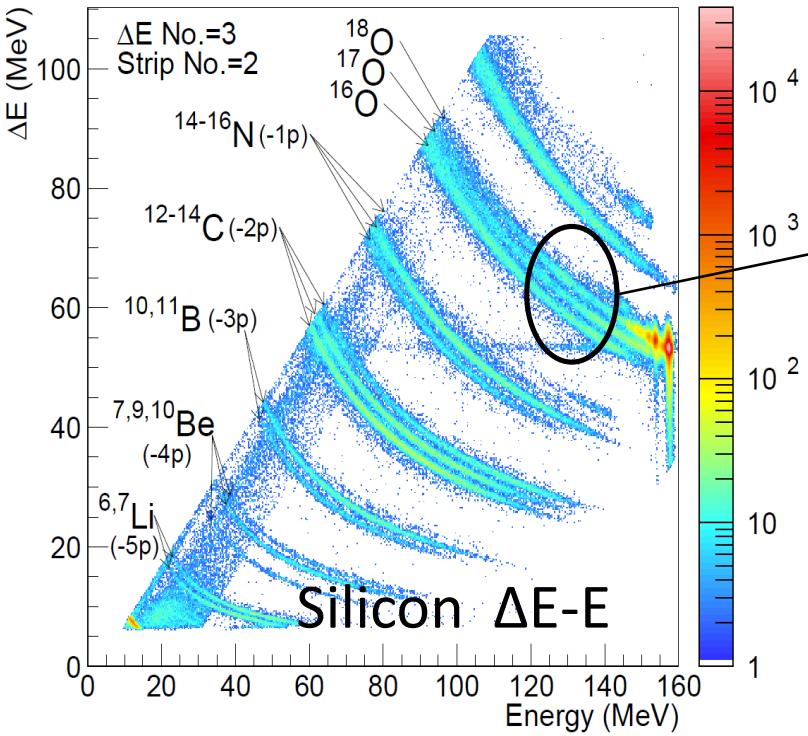


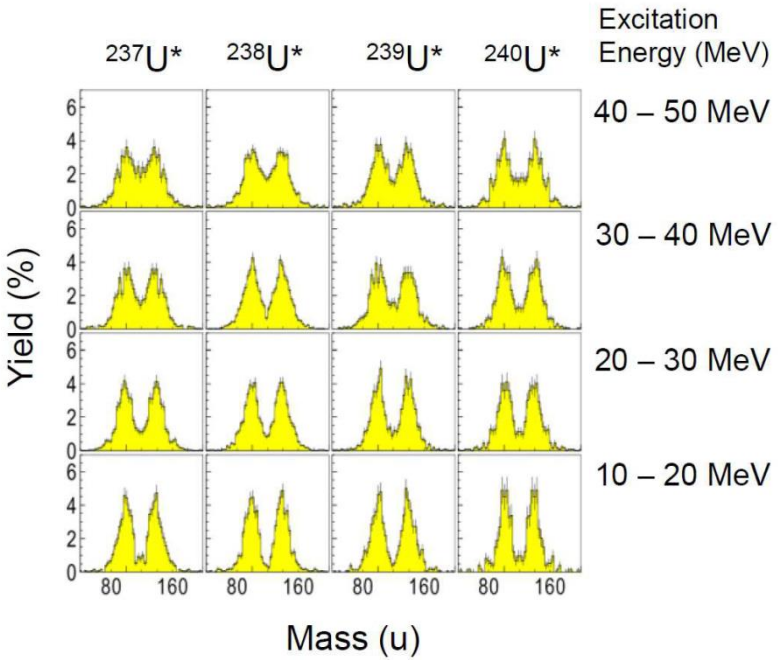
ΔE-E detector Array



Fission fragment mass distributions

$^{18}O + ^{238}U$ (E_{beam} = 157.5 MeV)





Example

- $^{18}O + ^{238}U \rightarrow ^{16}O + ^{240}U^*$
- $^{18}O + ^{238}U \rightarrow ^{15}N + ^{241}Np^*$
- $^{18}O + ^{238}U \rightarrow ^{12}C + ^{244}Pu^*$

Data takin finished

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

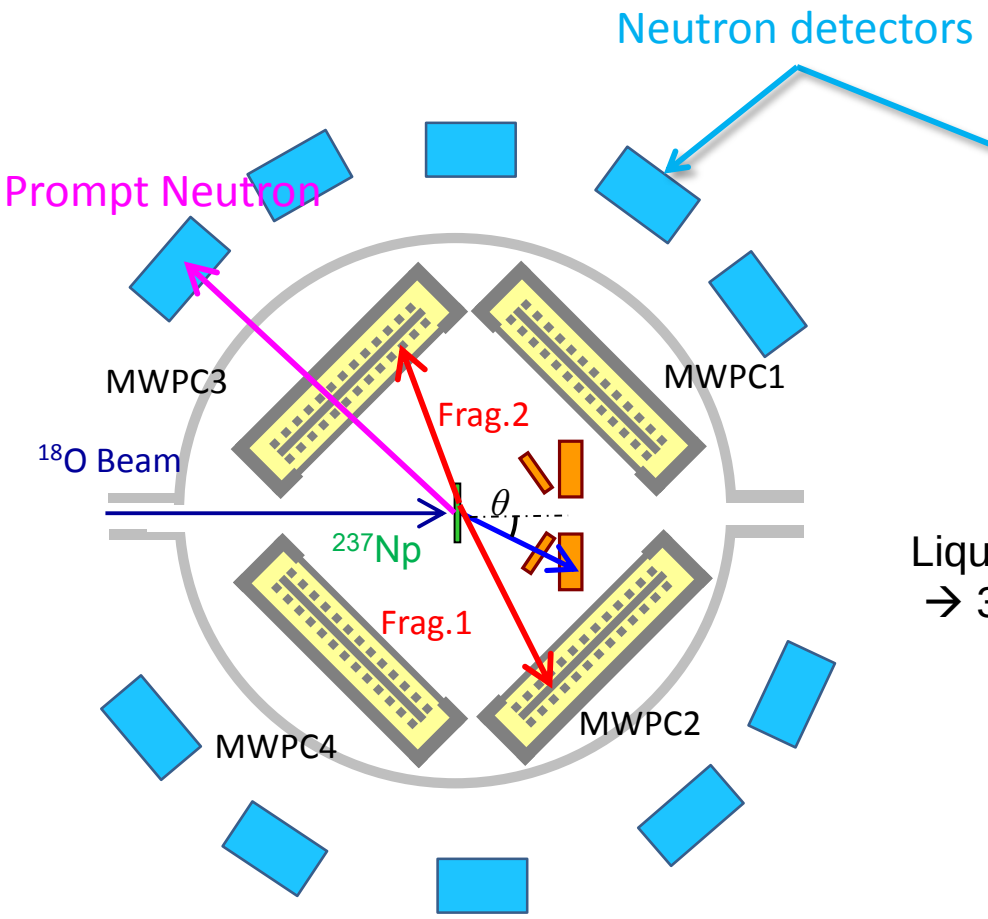
Planning

- $^{18}O + ^{249}Cf$
- $^{18}O + ^{243}Am$
- $^{18}O + ^{254}Es^{\#}$

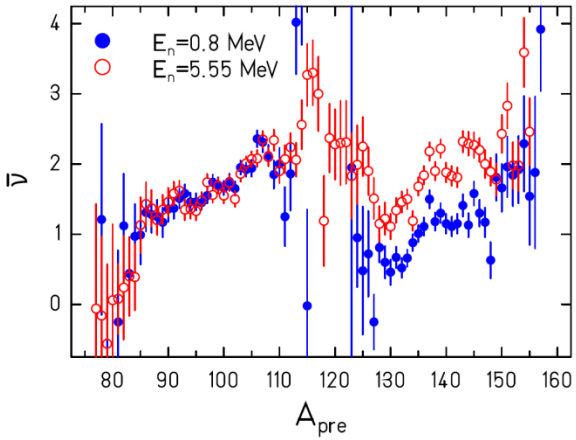
K. Nishio et al., Physics Procedia 64, 140 (2015).

if available from ORNL

Prompt neutrons in fission and neutron emission channel



Liquid Organic Scintillator (Φ5" x *t* 2")
→ 33 detectors mounted (~10% of solid angle)



Neutron multiplicity from fragments, $\nu(m)$

Energy spectrum $\chi(E_n)$

A. Naqvi *et al.*, Phys. Rev. C 34 (1986) 21.

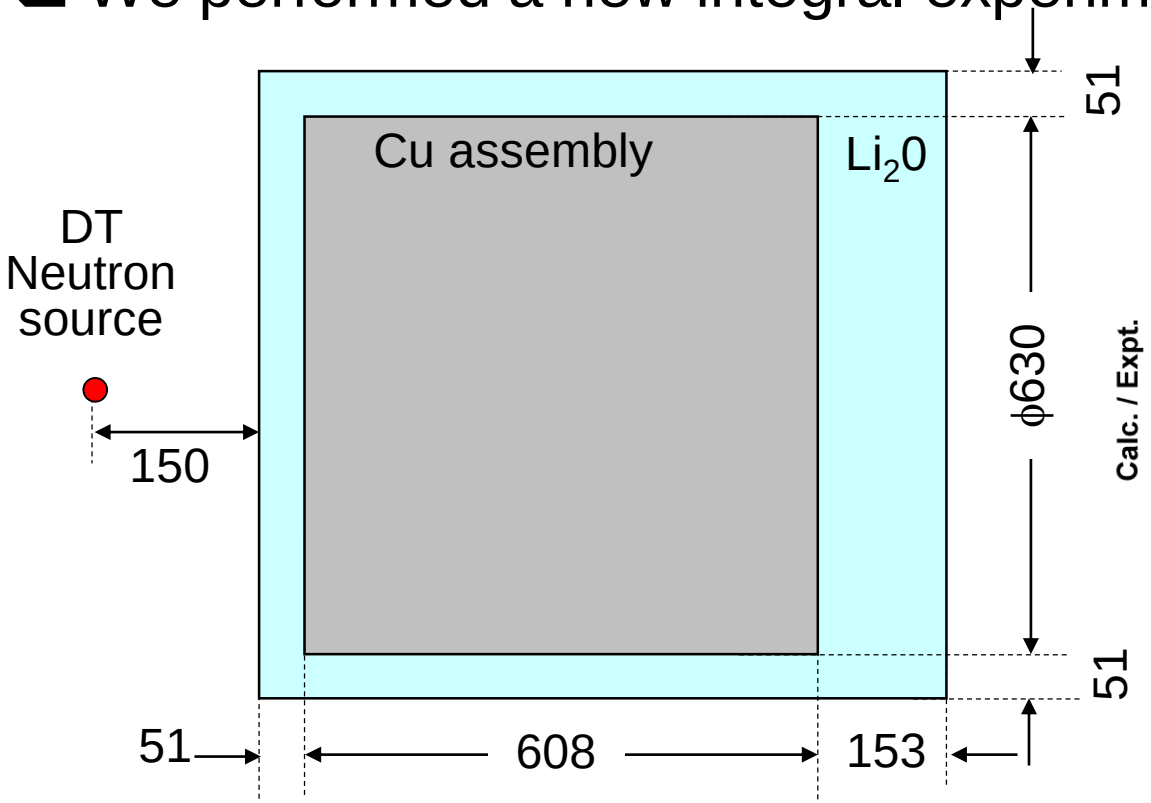
Activities at JAEA/FNS

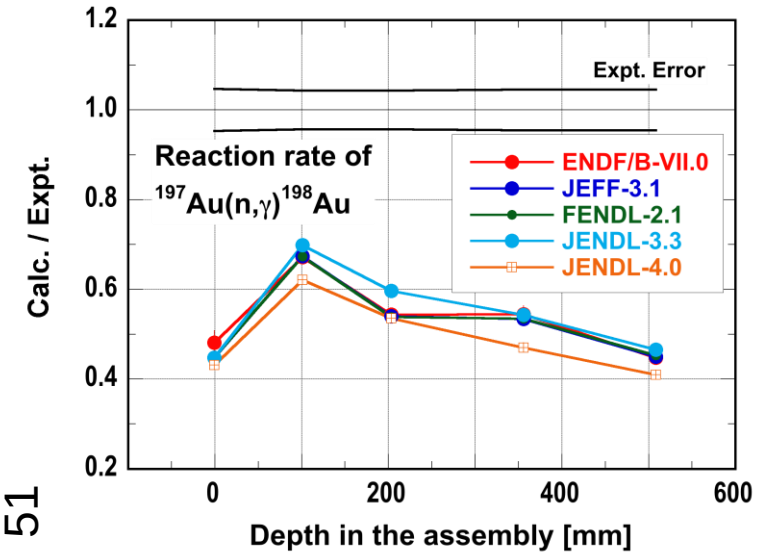
Cu and Mo benchmark experiments with DT neutrons at JAEA/FNS

Japan Atomic Energy Agency

Benchmark experiment on Cu-(1)

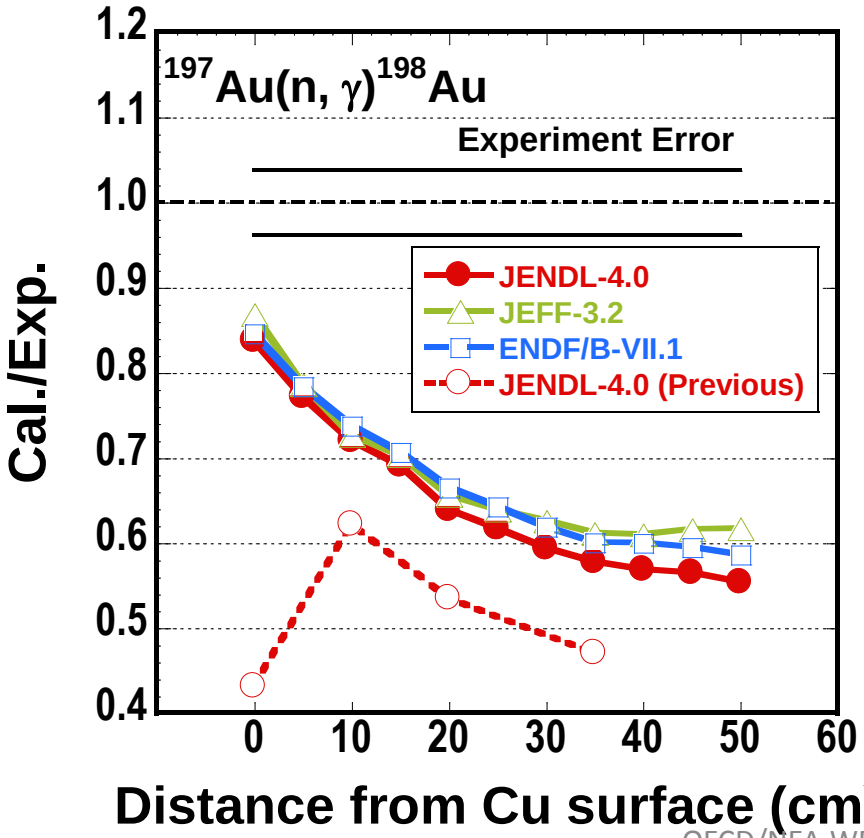
- Over 20 years ago, an integral experimental on copper had been carried at JAEA/FNS.
- The calculated results drastically underestimated the measured ones related to lower energy neutrons.
- We performed a new integral experiment on copper.

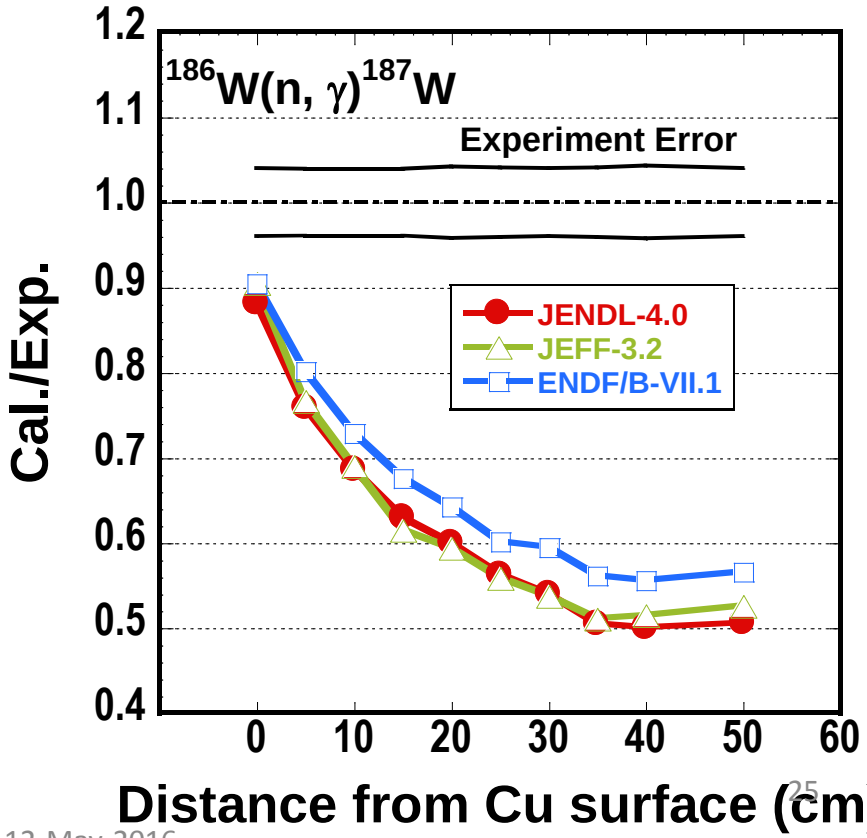




Benchmark experiment on Cu -(2)

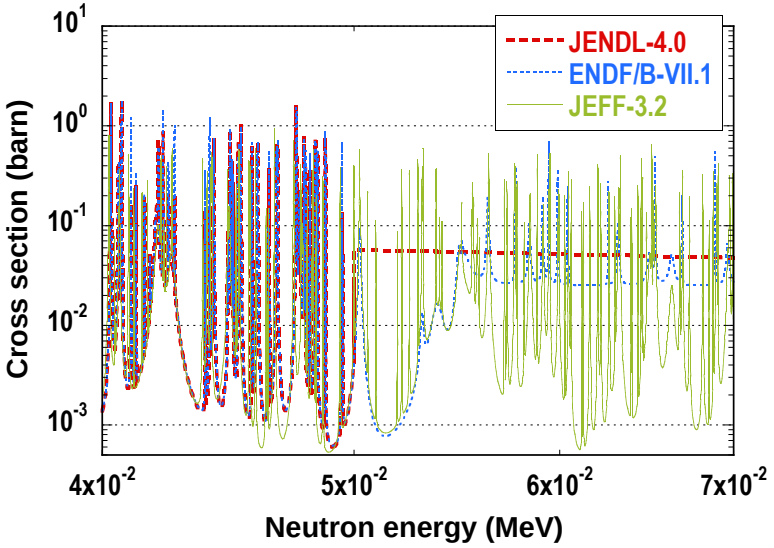
- We focus on the reaction rates sensitive to lower energy neutrons.
- The Li_2O layers reduce the influence of the background neutrons and improve the C/E by over 10%.
- The underestimation tendency still remains around 40%.

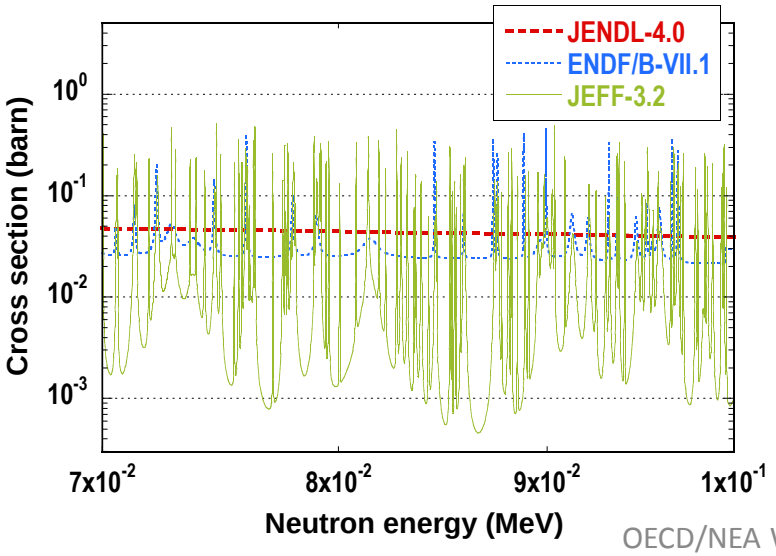


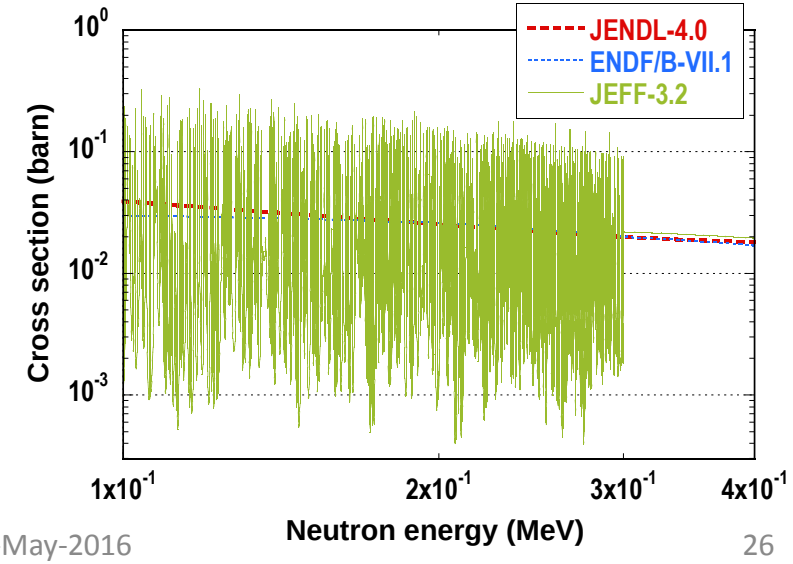


Benchmark experiment on Cu -(3)

- Large differences among the cross section of the $^{63}Cu(n,\gamma)$ reaction in the nuclear data libraries.
- We adopted JEFF-3.2 ^{63}Cu data.
- We changed the copper cross section data as a trial.

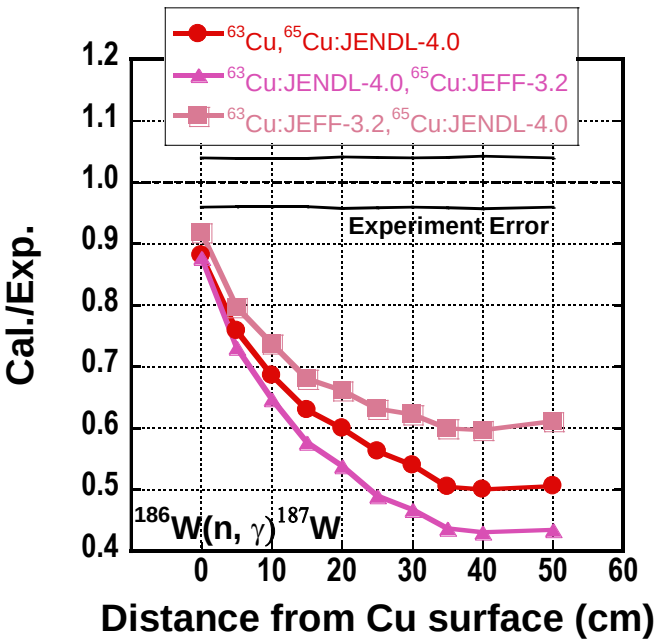


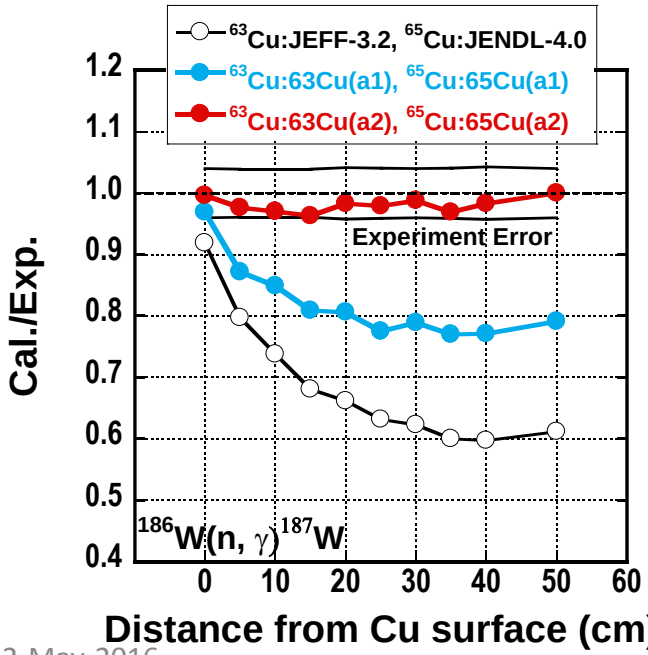




Benchmark experiment on Cu -(4)

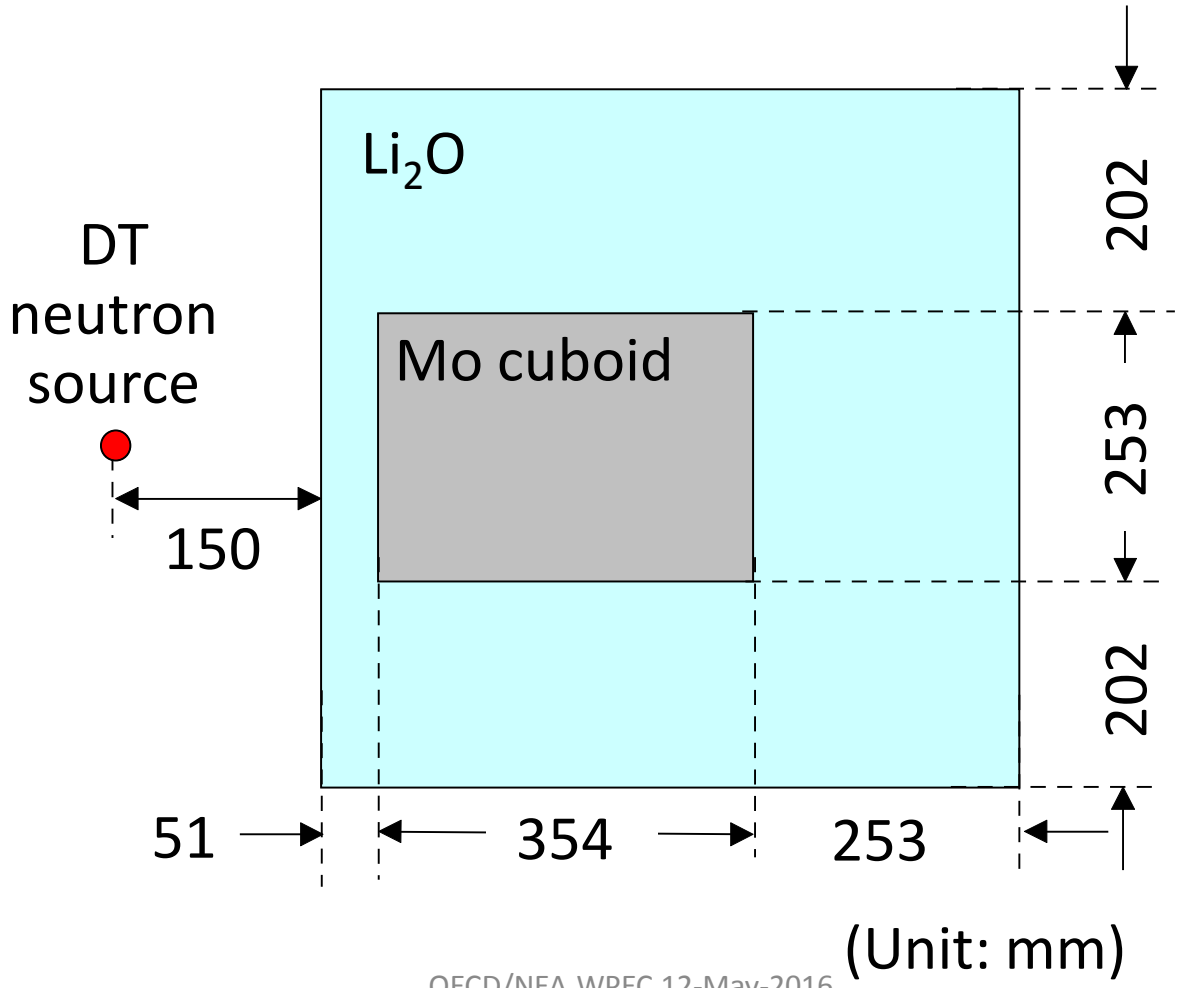
- Combination of ^{63}Cu : JEFF-3.2, ^{65}Cu : JENDL-4.0 is best.
- Larger elastic scattering cross section → larger fluxes
- Larger capture cross section → smaller fluxes
- (a1) : elastic 5% up, capture 5% down between 100 eV and 0.3 MeV (^{63}Cu : JEFF-3.2, ^{65}Cu : JENDL-4.0)
- (a2) : elastic 10% up, capture 10% down between 100 eV and 0.3 MeV → Underestimation is improved.



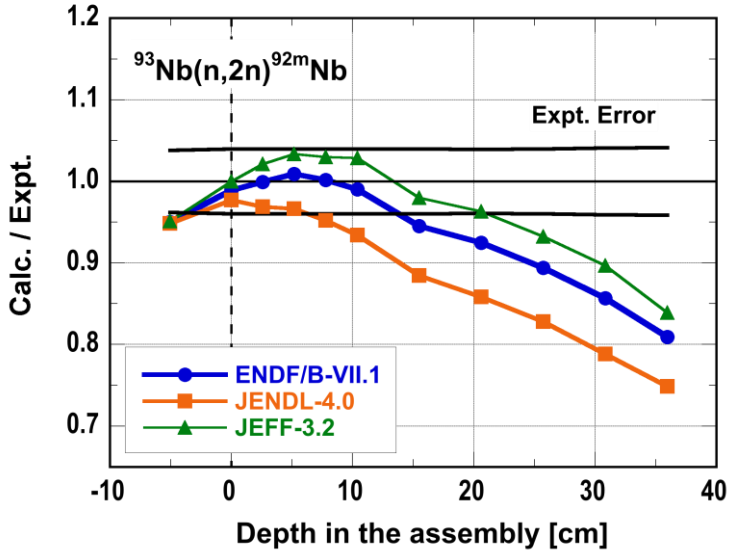


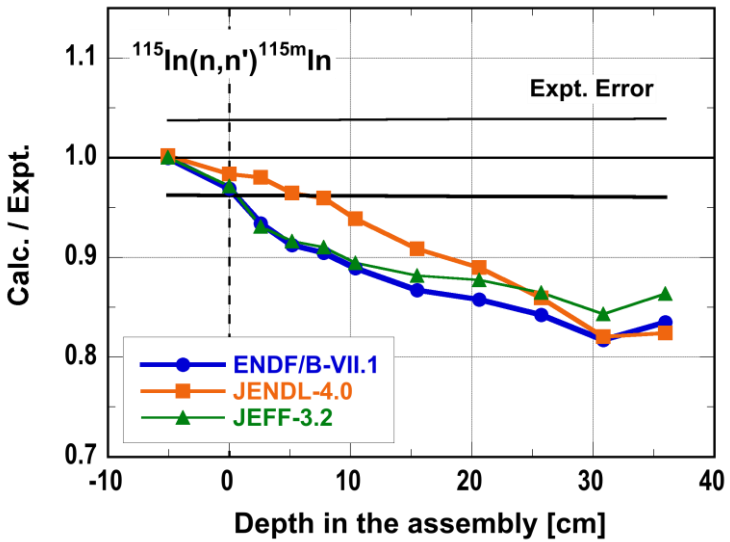
Benchmark experiment on Mo -(1)

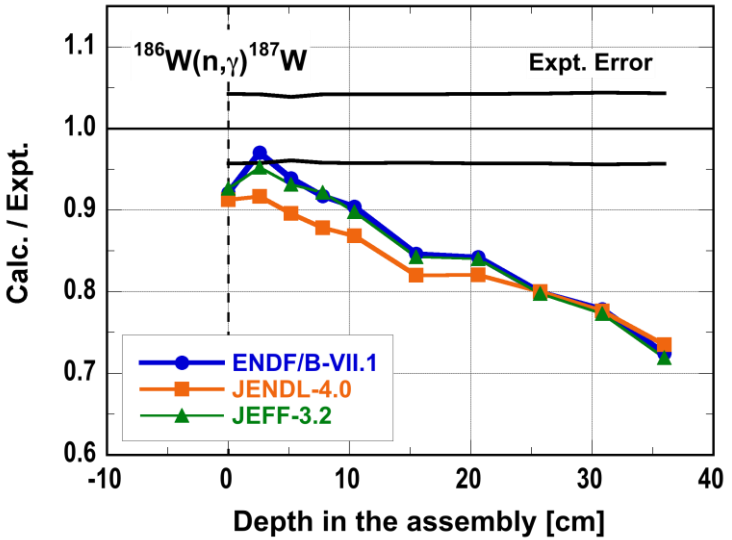
- We carried out a benchmark experiment on Mo in order to validate nuclear data libraries of Mo.

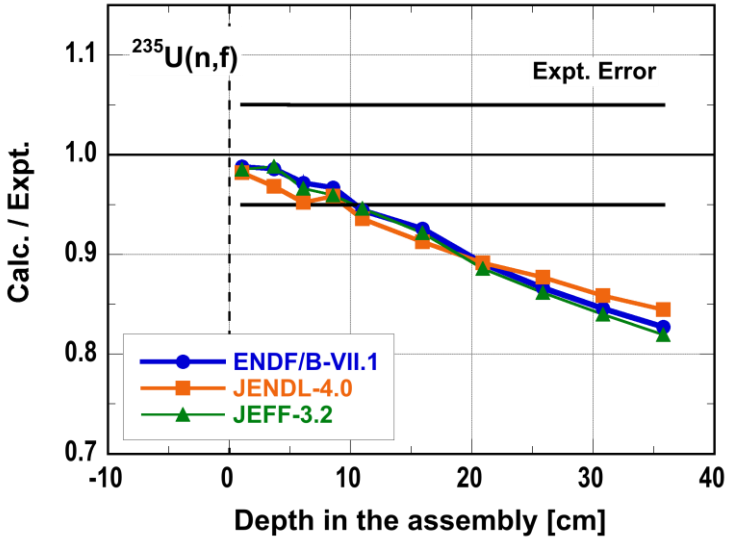


Benchmark experiment on Mo -(2)



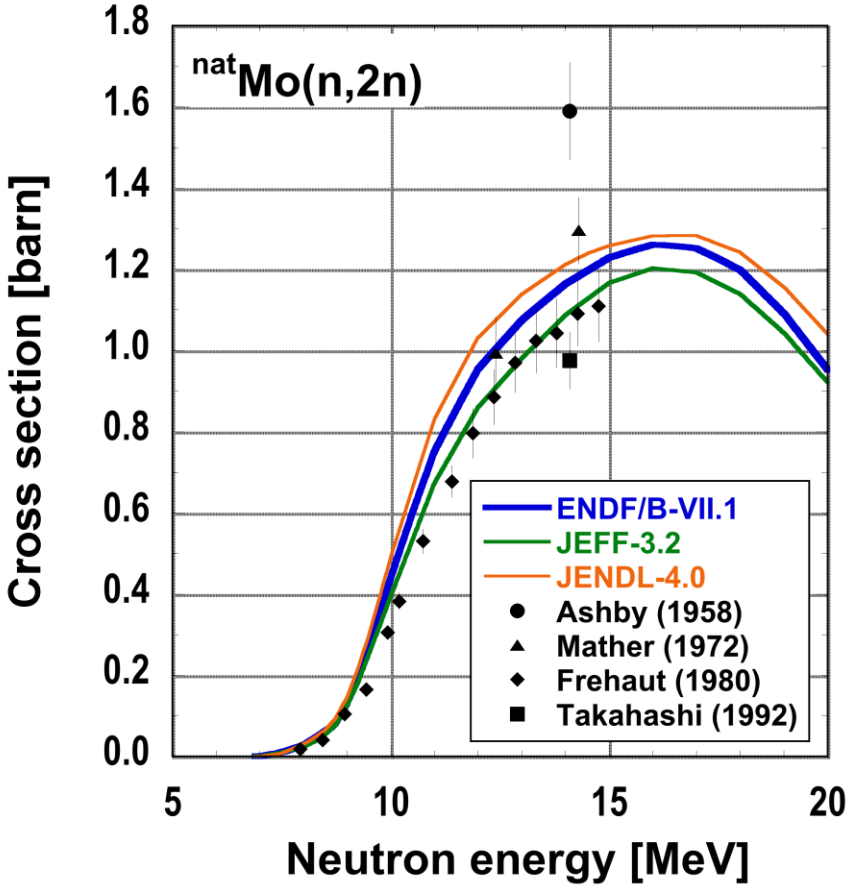


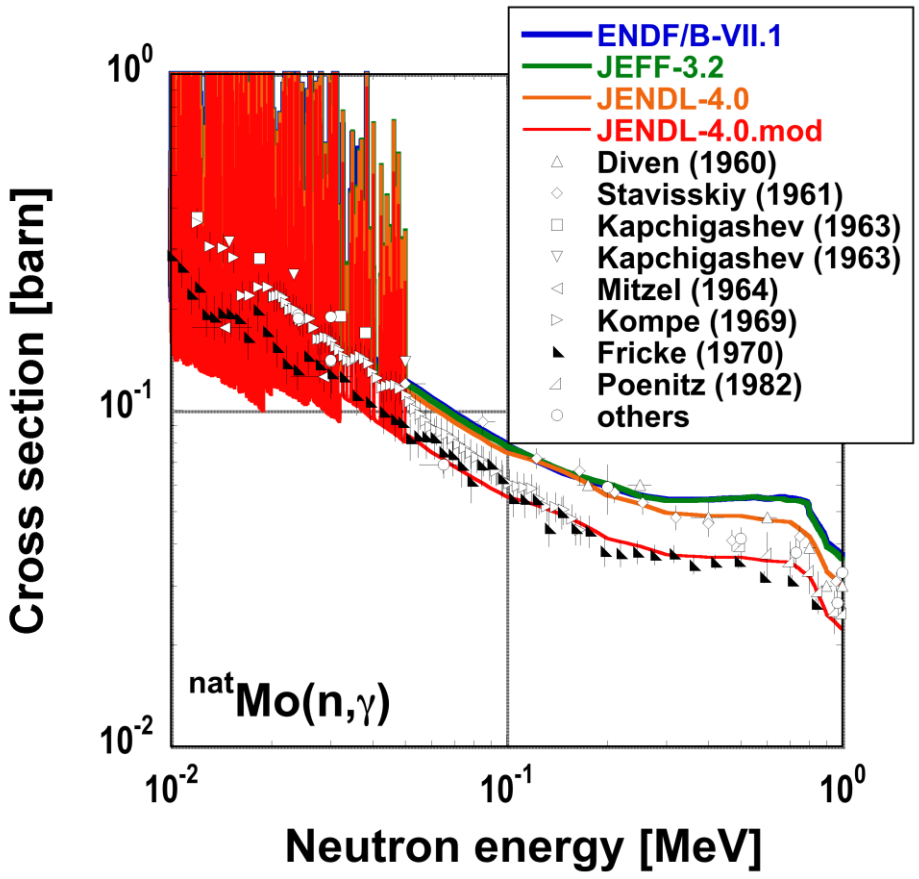




Calculation results tend to underestimate measured ones.

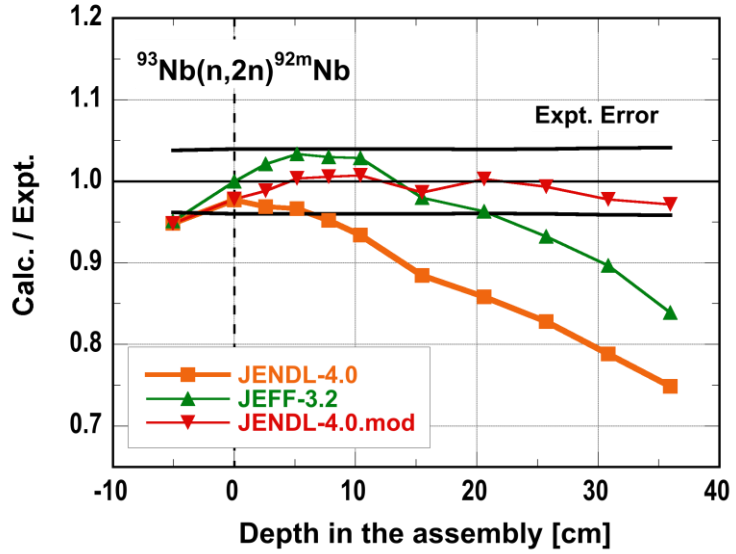
Benchmark experiment on Mo -(3)

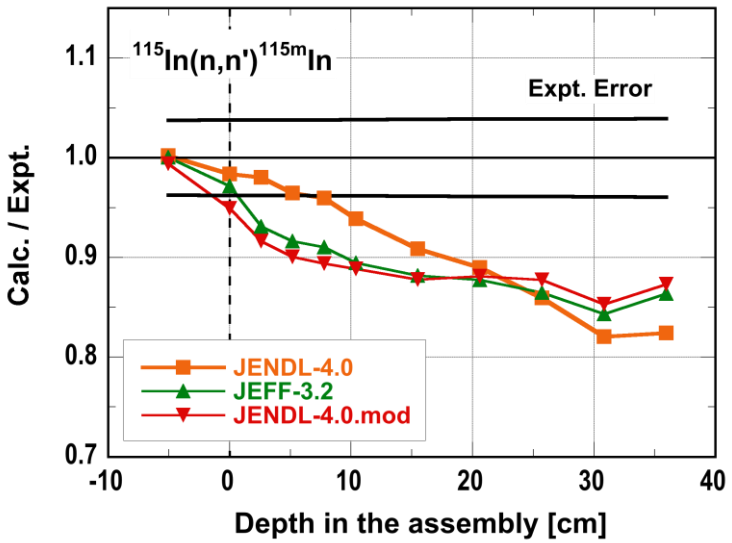


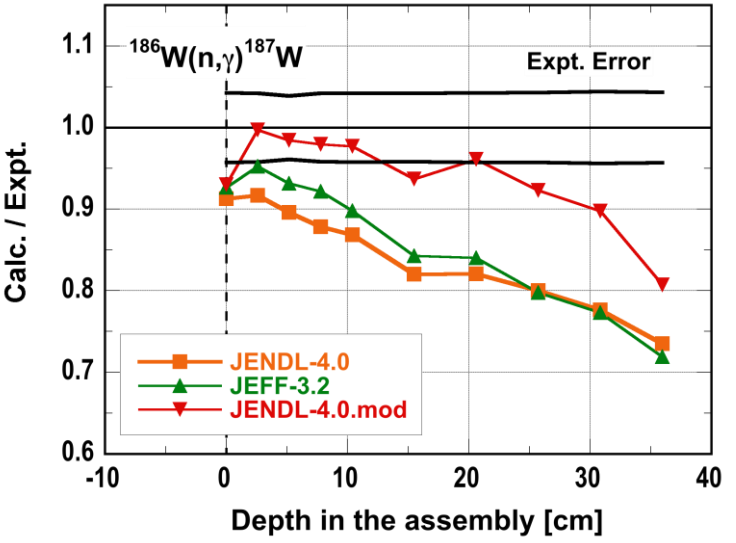


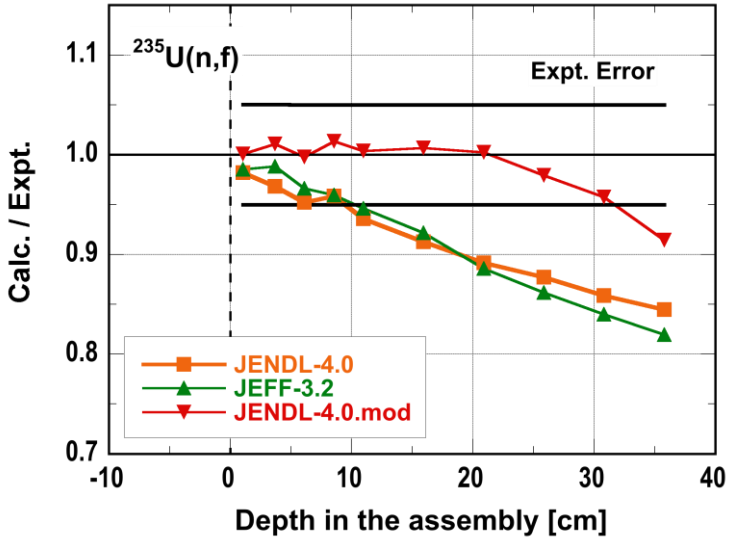
- We modified Mo data in JENDL-4.0. [JENDL-4.0.mod]
  - (n,2n) reaction cross section data are replaced with those in JEFF-3.2.
  - (n,g) reaction cross section data are reduced by 30 % based on Fricke's experimental data.

Benchmark experiment on Mo -(4)









Calculation result with JENDL-4.0.mod agrees with the measured one well.

JAEA/FNS shutdown

At 14:30, 5th February, 2016

National Institutes for Quantum and Radiological Science and Technology

Laser Compton Gamma-Ray Research Group

Nuclear Data Measurement Activities at QST

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

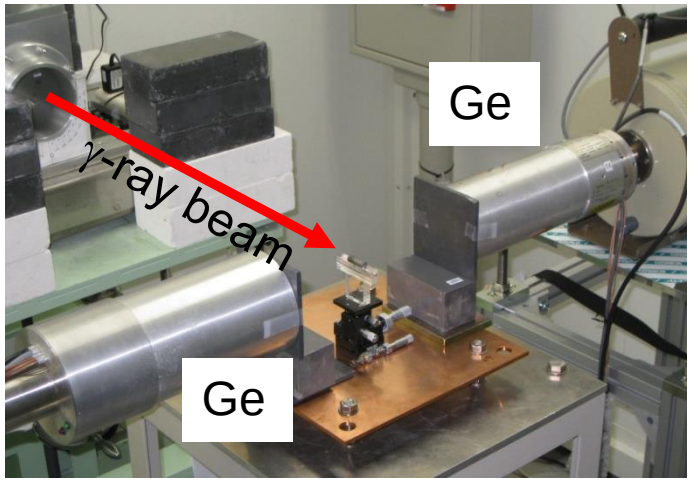
Laser Compton Gamma-Ray Research Group
National Institutes for Quantum and Radiological Science and Technology

NRF measurements for closed-shell nuclei and their neighbors at NewSUBARU

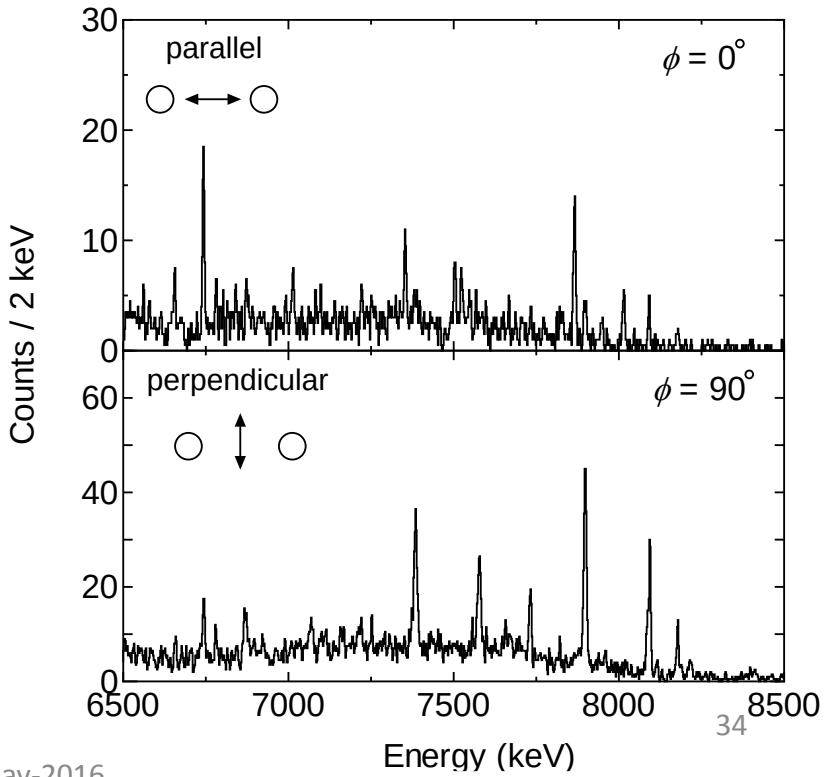
NRF takes place via only electro-magnetic interaction:

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

Experimental setup



Typical NRF spectrum



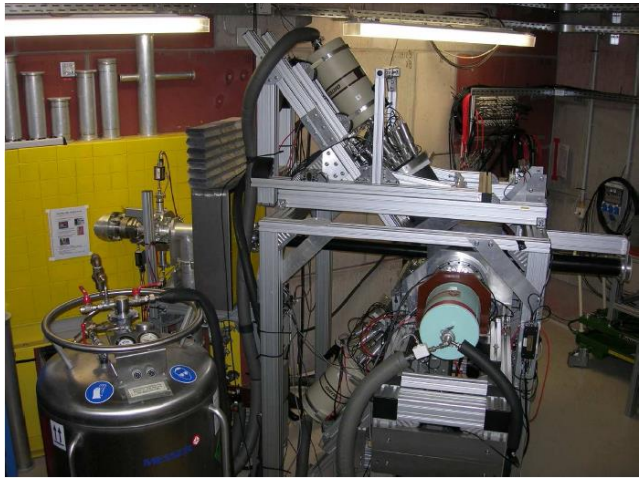
Collaboration of QST, Univ. of Hyogo, and Kyoto Univ.

Activities at Hokkaido University

Ayano Makinaga

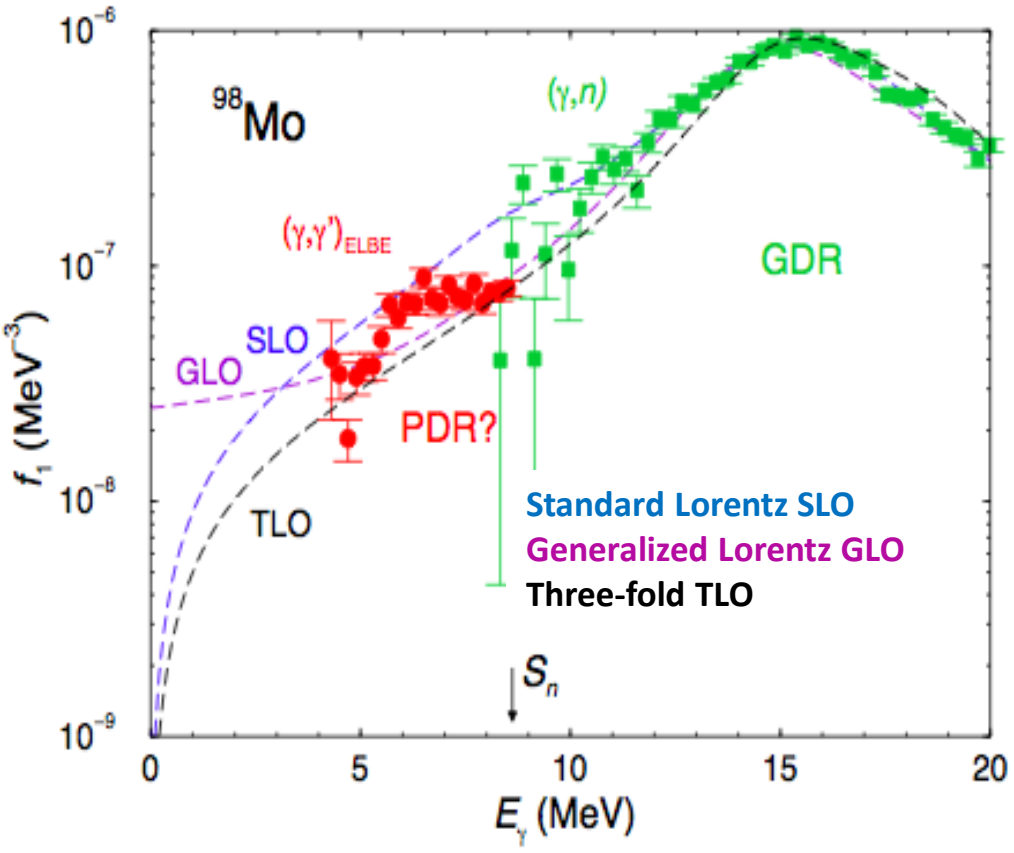
Collaboration with Ronald Schwengner
at Helmholtz-Zentrum Dresden-Rossendorf (HZDR)

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:

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

Absorption cross section:

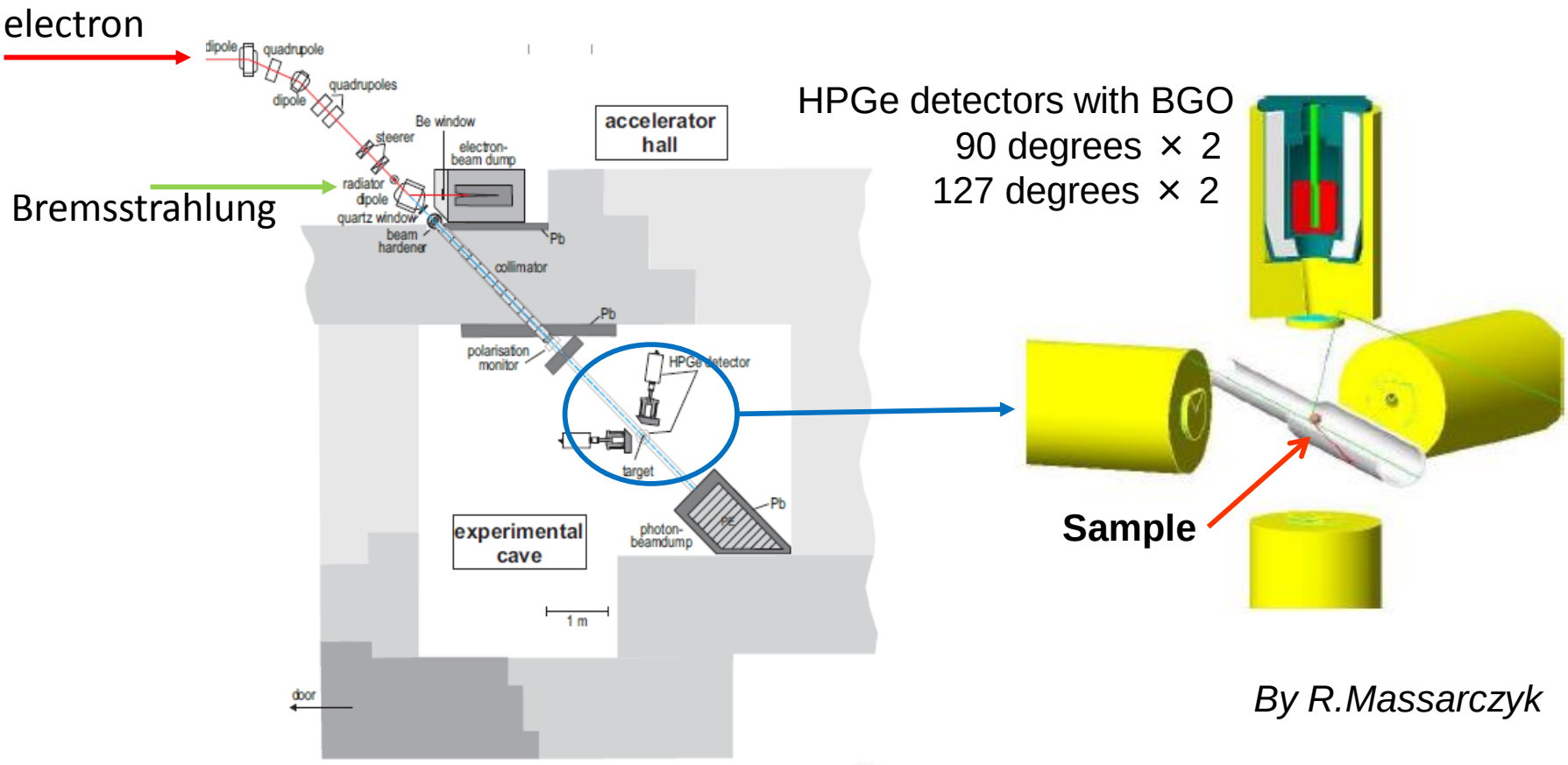
$$\sigma_\gamma = \sigma_{\gamma\gamma}\left(\frac{\Gamma_0}{\Gamma}\right)^{-1}$$

E1 strength:

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

Implications for
astrophysics, nuclear technology, medical physics

Experimental set up at HZDR

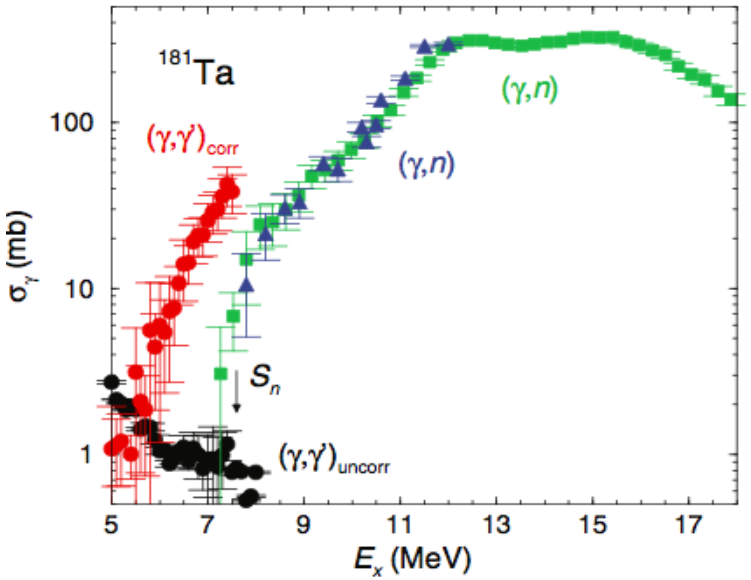


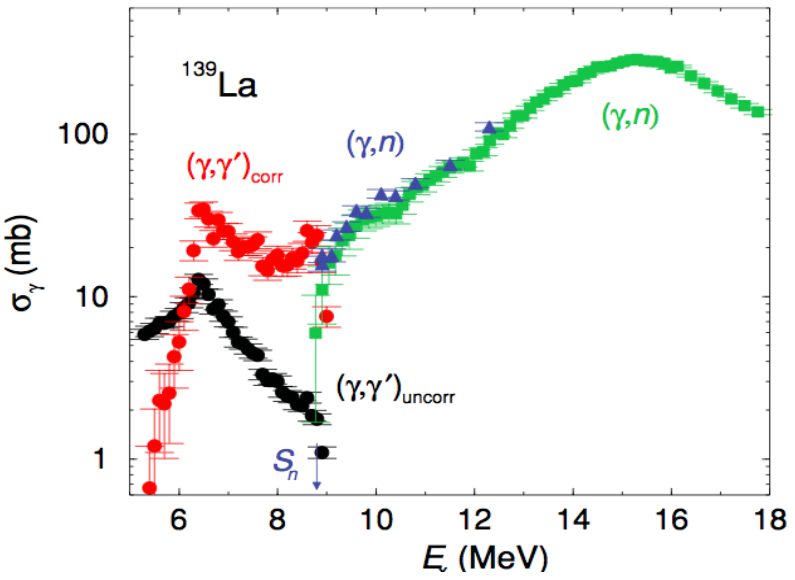
The bremsstrahlung facility at the electron accelerator gELBE

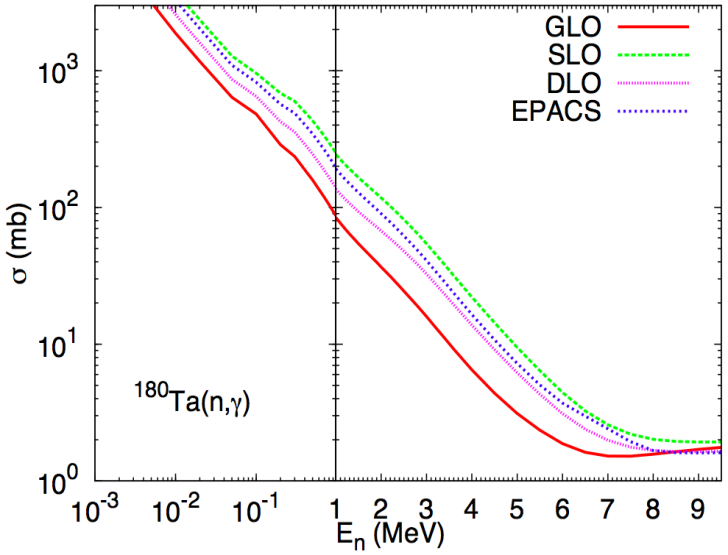
Maximum electron energy	~18MeV	Maximum average current	~0.8mA
Micro-pulse rate	~13MHz	Micro-pulse length	~5ps

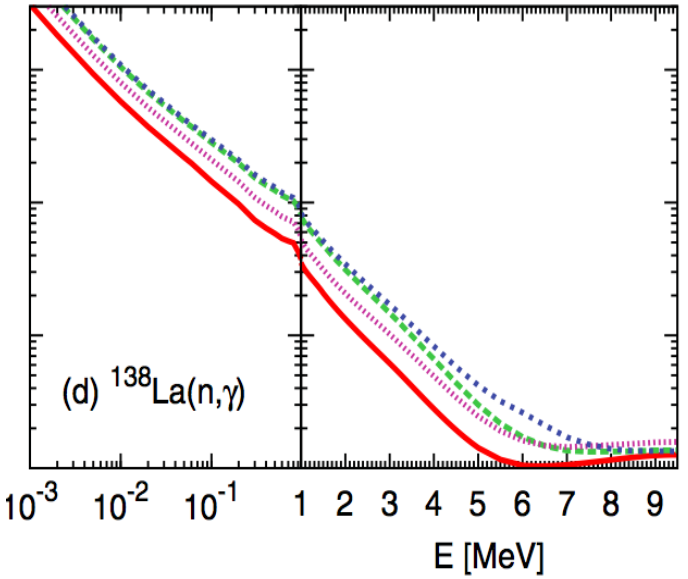
R.Schwengner et.al., NIM A 555, 211(2005)

Result









A. Makinaga, et. Al., PRC90,044301(2014).

A. Makinaga, et. Al., PRC90,044301(2014).
M. Beard, et. Al., PRC85,065808(2012).

Activities at Tokyo Institute of Technology (Tokyo Tech)

Igashira Group

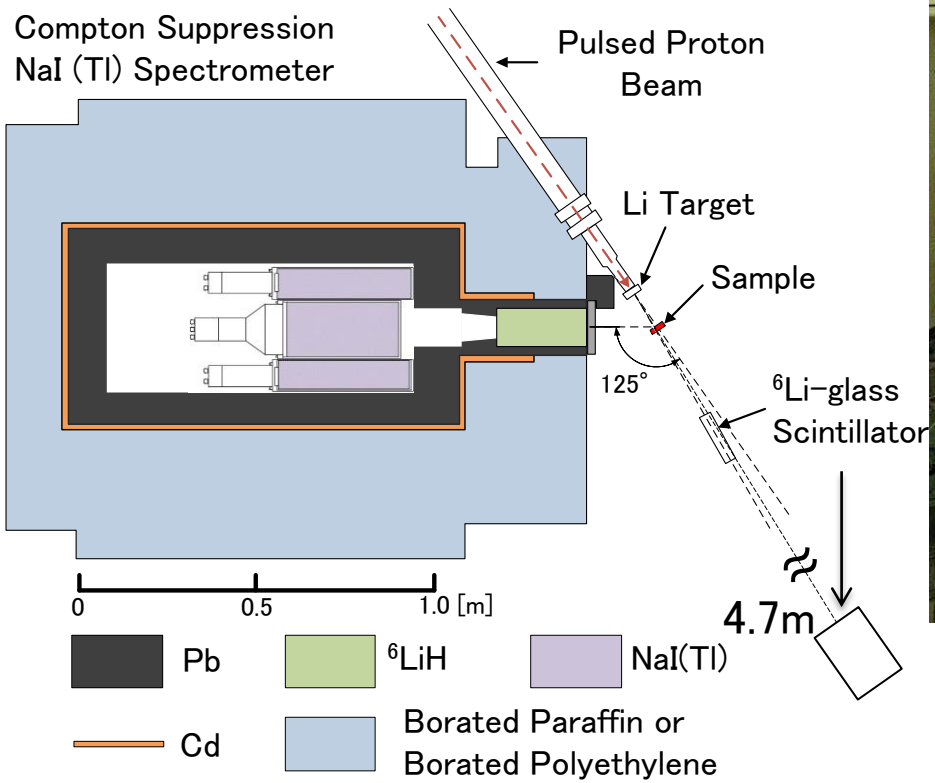
Capture Cross Sections and Gamma-ray Spectra in the keV Region

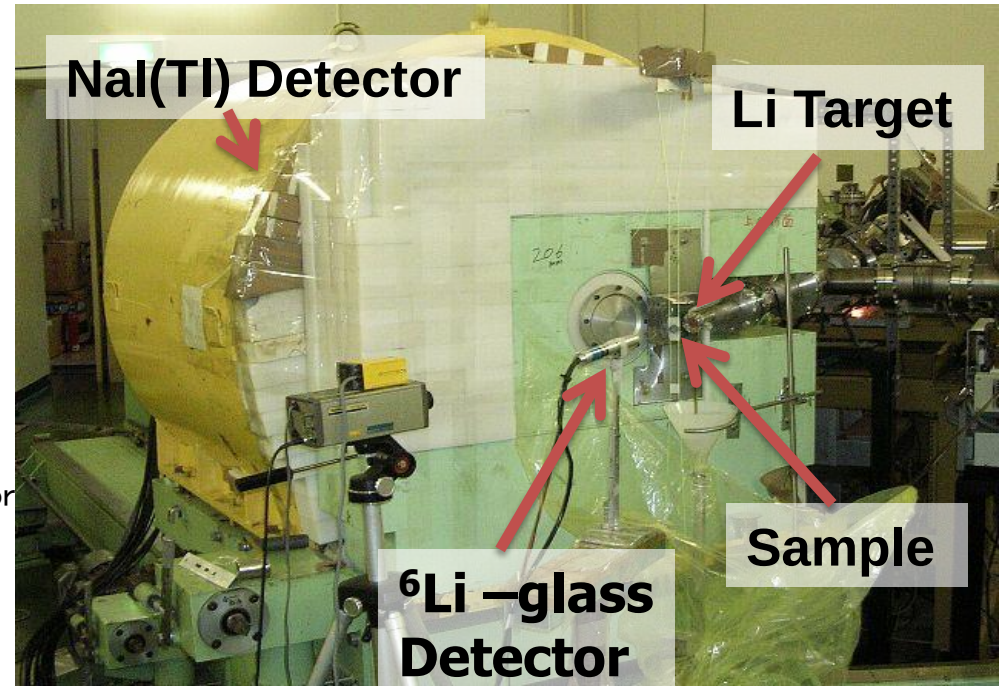
Nuclide	En = 15 - 100 keV	En = 550 keV
Y-89	2014/5	2015/6
Te-128	2014/7	2015/5

Experimental setup

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

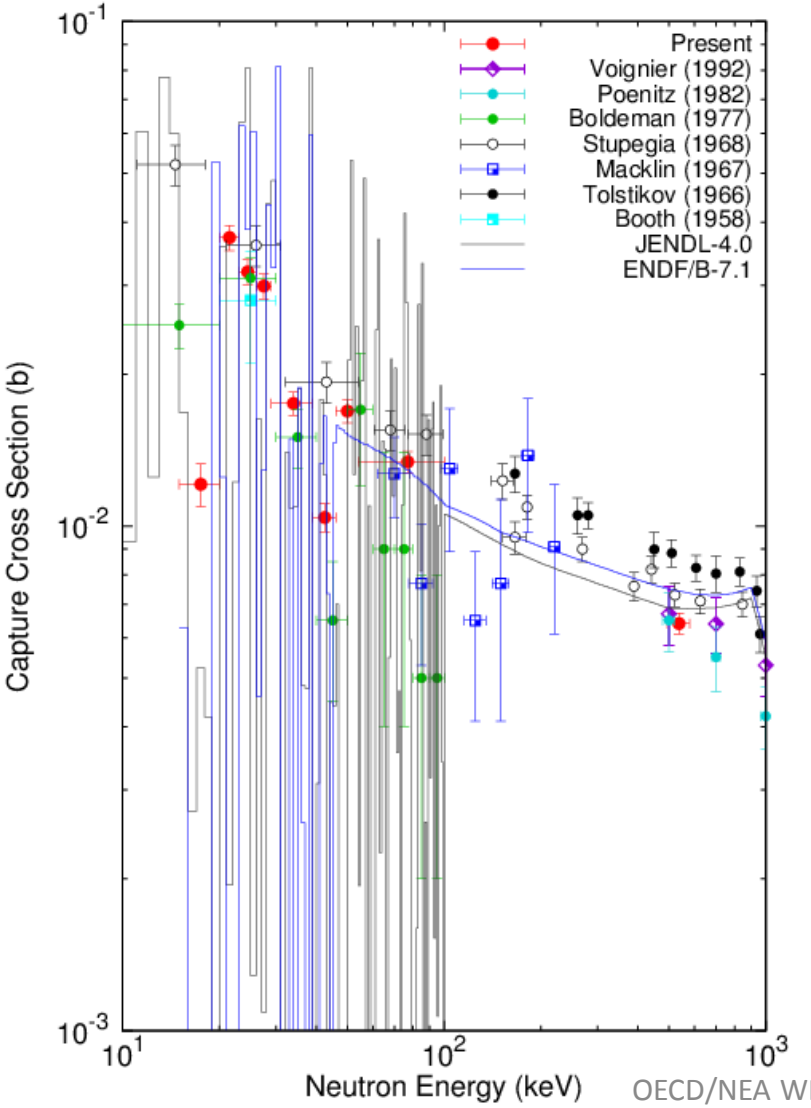
Neutron source : $^{7}Li(p,n)^{7}Be$
Flight path length :
- **12 cm for 15-100 keV neutrons**
- **20 cm for 550 keV neutrons**

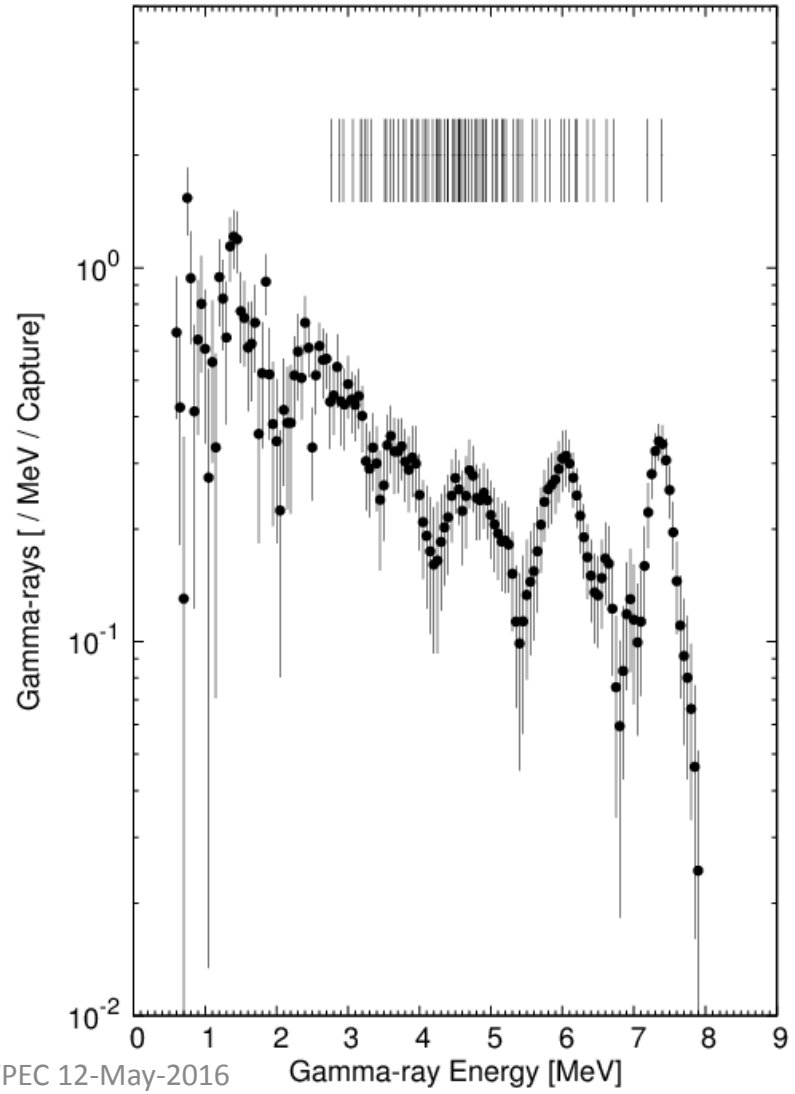




NaI(Tl) Spectrometer
- **Two Dimensional Data: TOF x PH**

Capture Cross Sections and Gamma-Ray Spectra of ^{89}Y





Neutron Production DDX from Heavy-Ion Interactions @ NIRS (QST) -HIMAC

Team:

Department of Applied Quantum Physics and Nuclear Engineering,
Kyushu University
Japan Atomic Energy Agency
Hiroshima University
High Energy Accelerator Research Organization
Shimizu Corporation
National Institute of Radiological Sciences
Korea Atomic Energy Research Institute

Contact:

Nobuhiro SHIGYO, Kyushu University

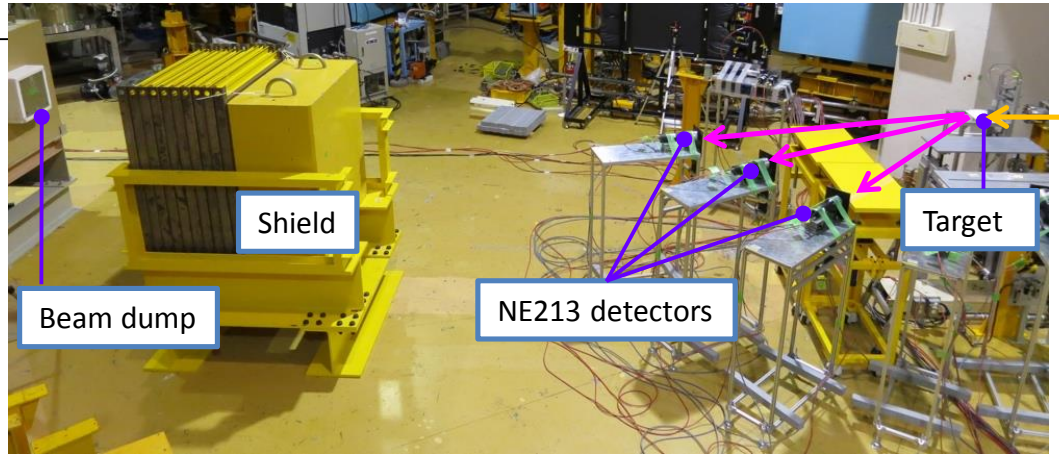
Neutron DDX and TTY from Heavy-Ion Interactions @ NIRS-HIMAC

- Kyushu U., JAEA, Hiroshima U., KEK, NIRS, KAERI

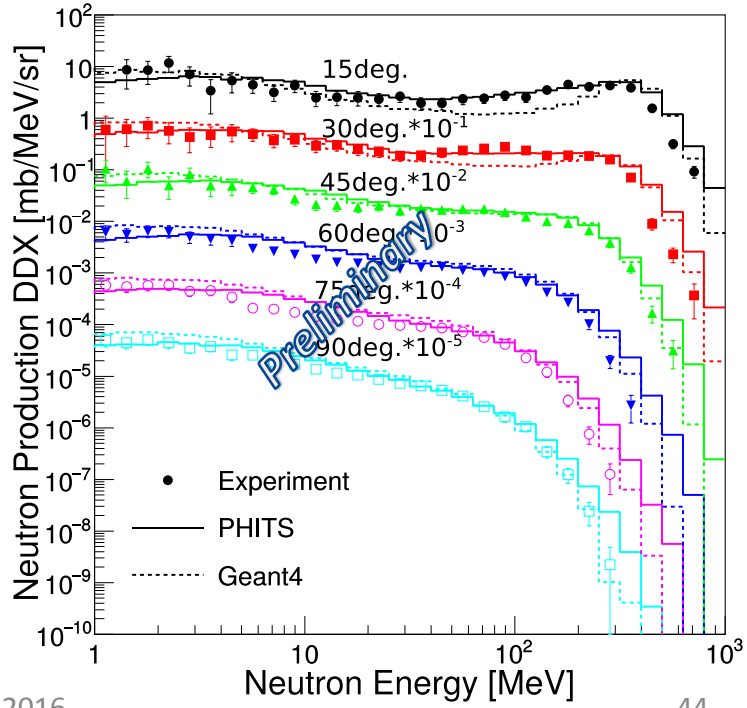
- Systematic cross-section data for elements constituting a human body's tissue bombarded with heavy-ion beams

- HIMAC PH2 beam line
- Beam: 430 MeV/u C, N, O
  290 MeV/u Ar
- Target: C, water
- Detection: NE213 (2 sizes) + TOF
- Direction: 0˚, 15˚, 30˚, 45˚, 60˚, 75˚, 90˚

- PHITS reproduces experimental data



Experimental setup at HIMAC



430MeV/u C(C, xn) DDX