IAEA 1-st RCM of CRP on FENDL-3, 2-5 Dec. 2008

Status of research activities on nuclear data relevant to ITER and IFMIF in Japan

Yukinobu Watanabe

Department of Advanced Energy Engineering Science,

Kyushu University

Contents

- High-energy nuclear data（above 20 MeV) related to accelerator applications including IFMIF:
  - deuteron, neutron, and proton-induced reactions
  - secondary particle emission
- Fusion neutronics related to ITER @ JAEA

Status of JENDL was reported by S. Kunieda (JAEA)

High-energy nuclear data related to IFMIF

- Measurement and Theoretical analysis -

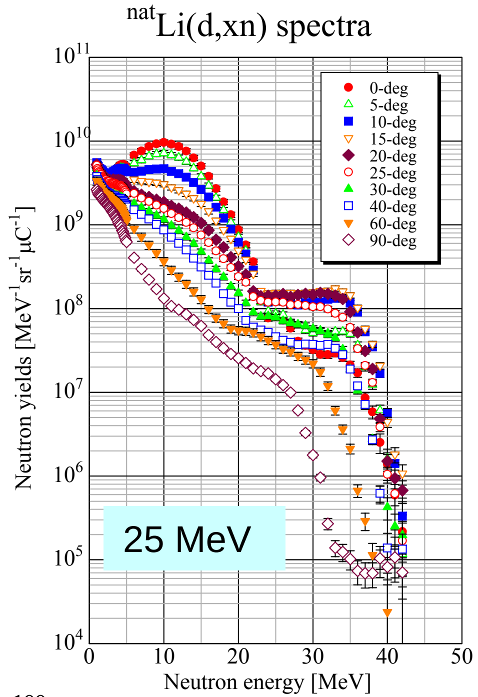
Deuteron induced reactions

- Measurement of thick target neutron yields (TTNY) and model analysis [Tohoku + Kyushu]
- Theoretical analysis of d+Li reactions [Kyushu]
- Measurement of d-induced activation cross sections [JAEA]

Measurements@Tohoku

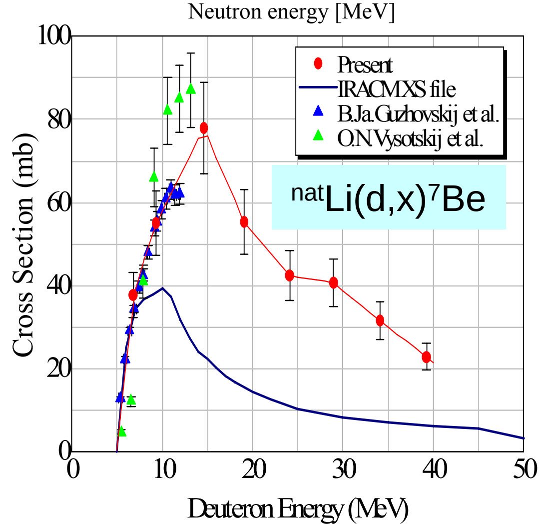
- **Measurements of neutron spectrum for (d,nx) reactions on thick targets :**

- Targets : Li, Be, C, Al, Fe, Cu, Ta
- Energies : Ed= 40, 25 MeV
- Angles : 0 to 110 deg

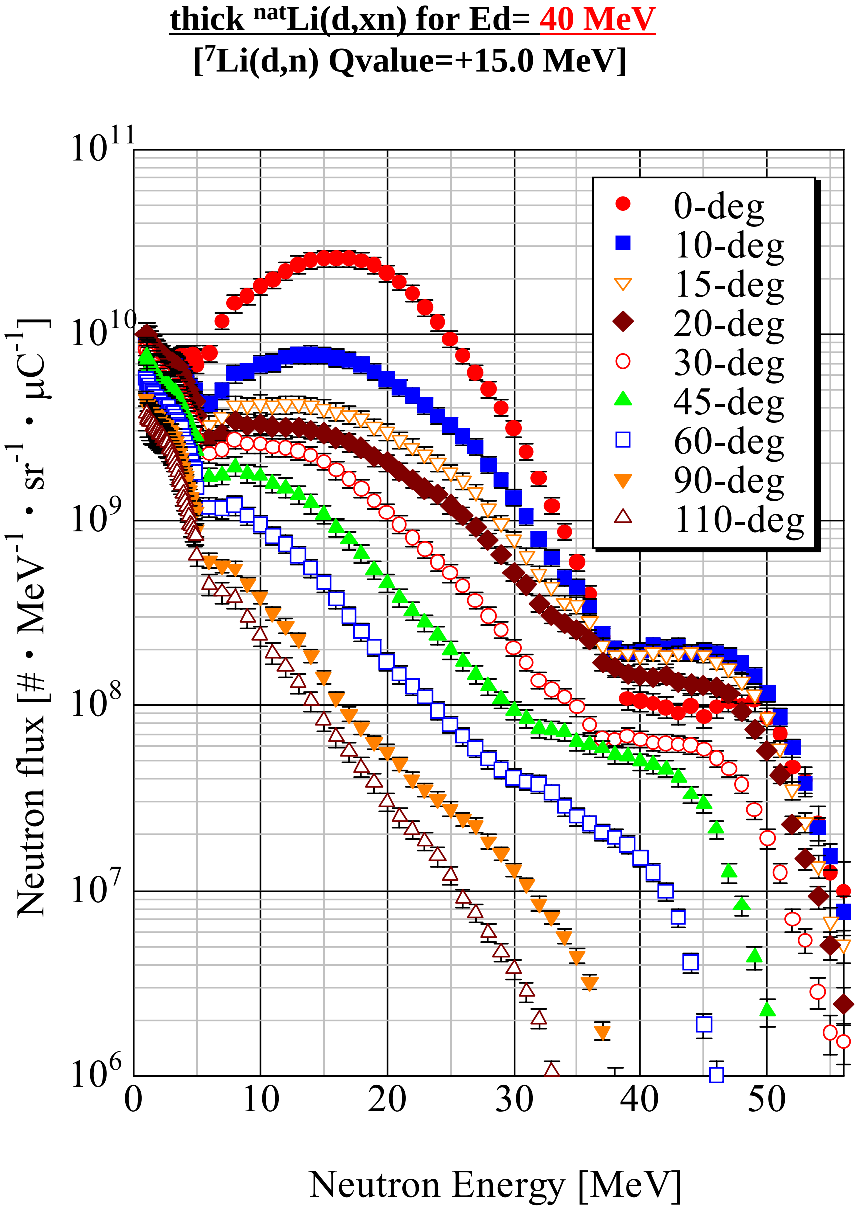


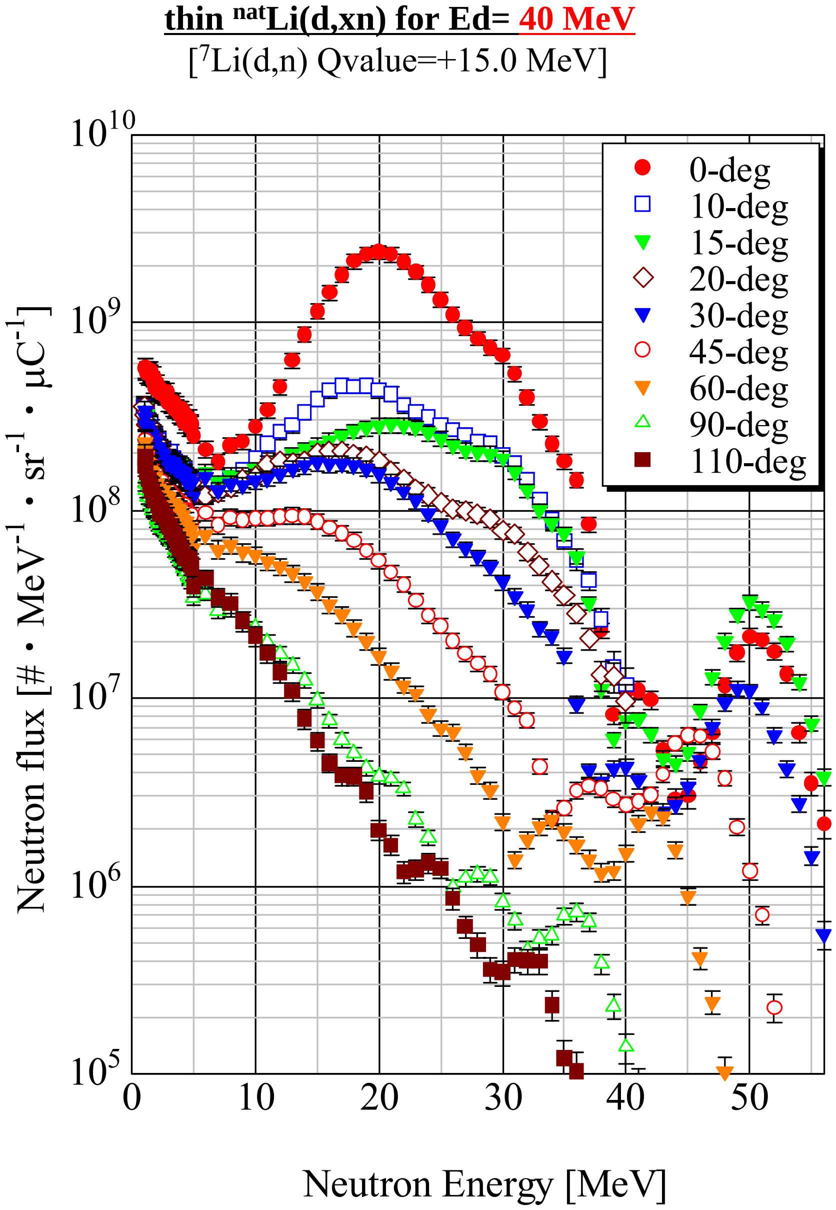
- **Production yields of radio-nuclides via (d,x) reaction:**

- Targets: Li, C, Al, Fe, Cu, Ta

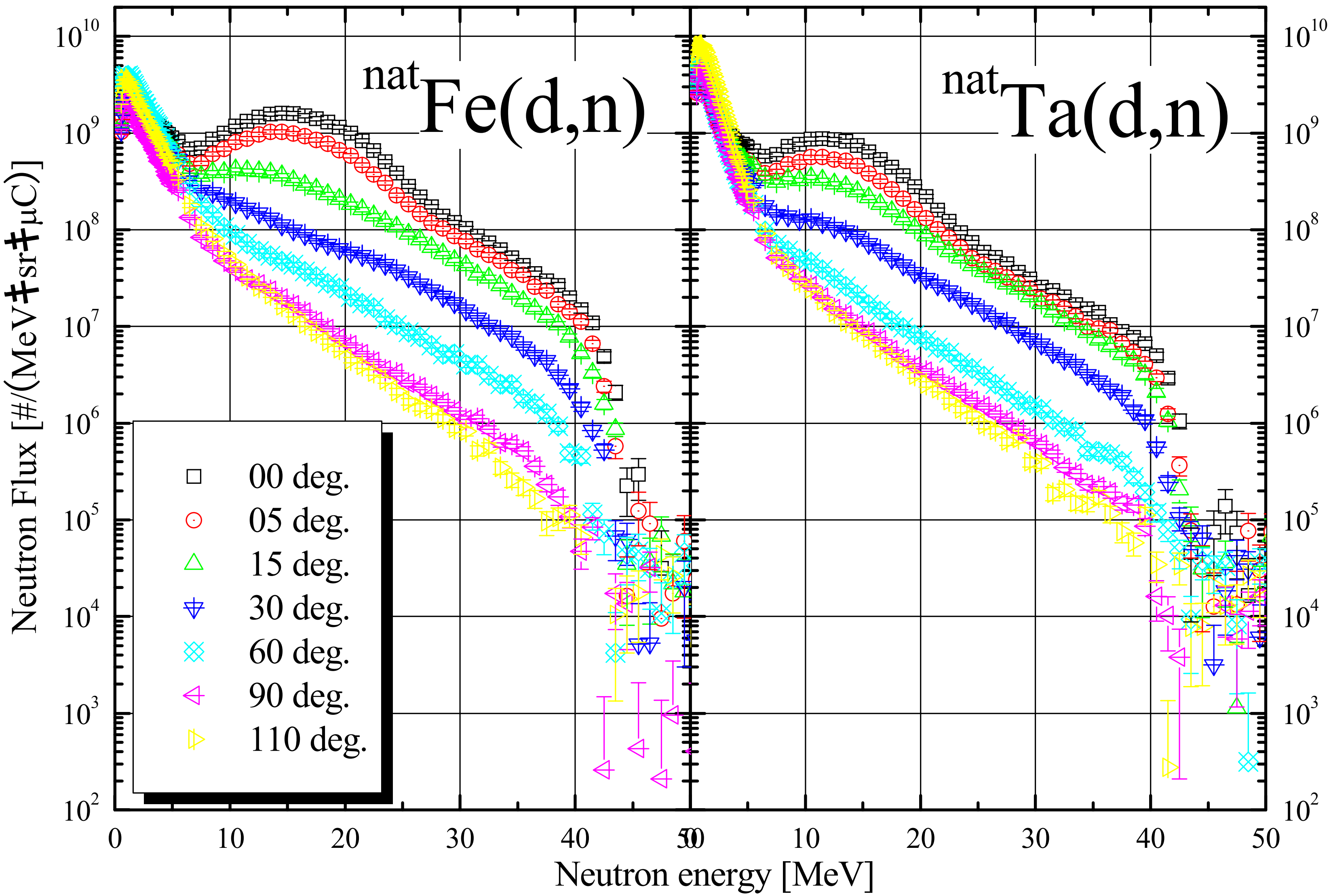


natLi(d,xn) Ed = 40 MeV Thick and thin lithium

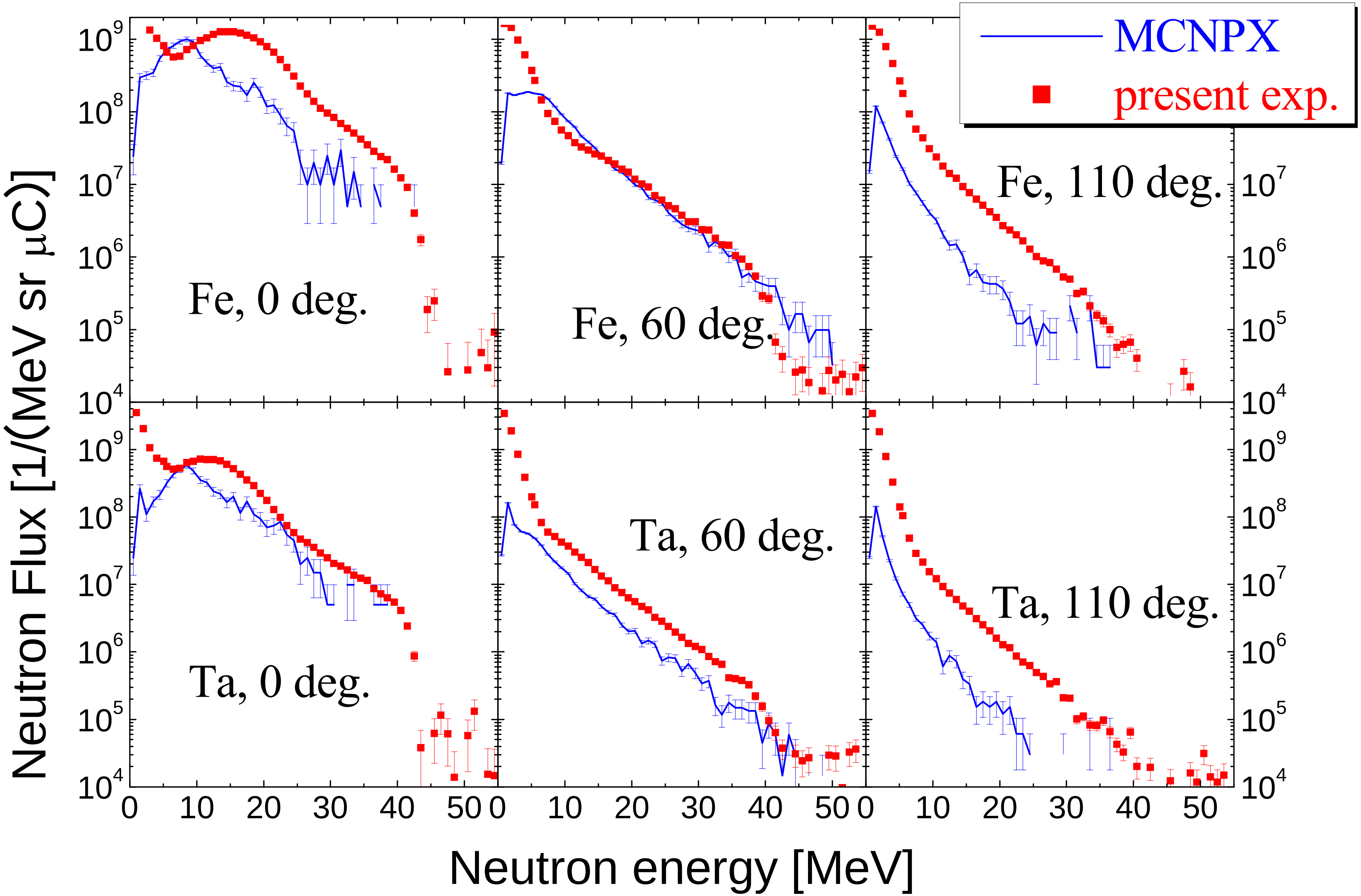




Fe, Ta(d,n) @ 40 MeV



Comparison with MCNPX; Fe, Ta (@Tohoku)



Analysis of d-TTY data using TALYS

$$\frac{d^2Y}{dE_n d\Omega_n} = N\int_0^{E_0}\left[\frac{d^2\sigma}{dE_n d\Omega_n}\right]_{(E_d,\theta_n)}\left[\frac{dE_d}{dx}\right]^{-1} exp\left(-\int_{E_d}^{E_0}\sum{}_{non}(E')\left[\frac{dE'}{dx}\right]^{-1} dE'\right)dE_d$$

DDX(d,xn)

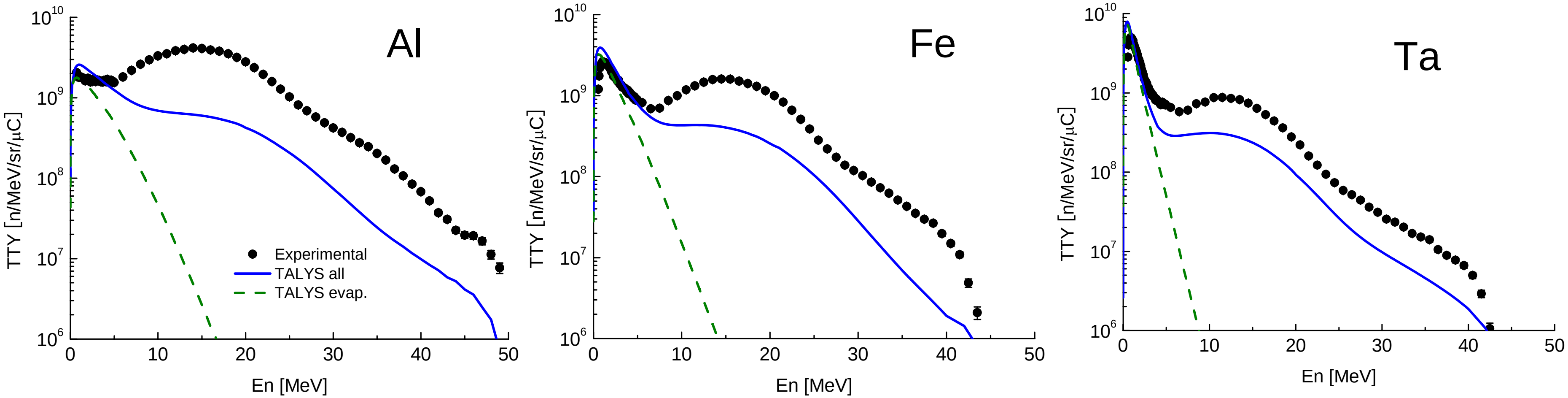
TALYS-1.0 with default parameters

Stopping power (SRIM2008)

Attenuation of incident deuteron

Remarkable underestimation is seen in the bump around 15 MeV

40 MeV 0 deg



by C. Motooka and Y. Watanabe (Kyushu)

Analysis of d-TTY data using TALYS

$$\frac{d^2Y}{dE_n d\Omega_n} = N\int_0^{E_0}\left[\frac{d^2\sigma}{dE_n d\Omega_n}\right]_{(E_d,\theta_n)}\left[\frac{dE_d}{dx}\right]^{-1} exp\left(-\int_{E_d}^{E_0}\sum\nolimits_{non}(E')\left[\frac{dE'}{dx}\right]^{-1}dE'\right)dE_d$$

DDX(d,xn)

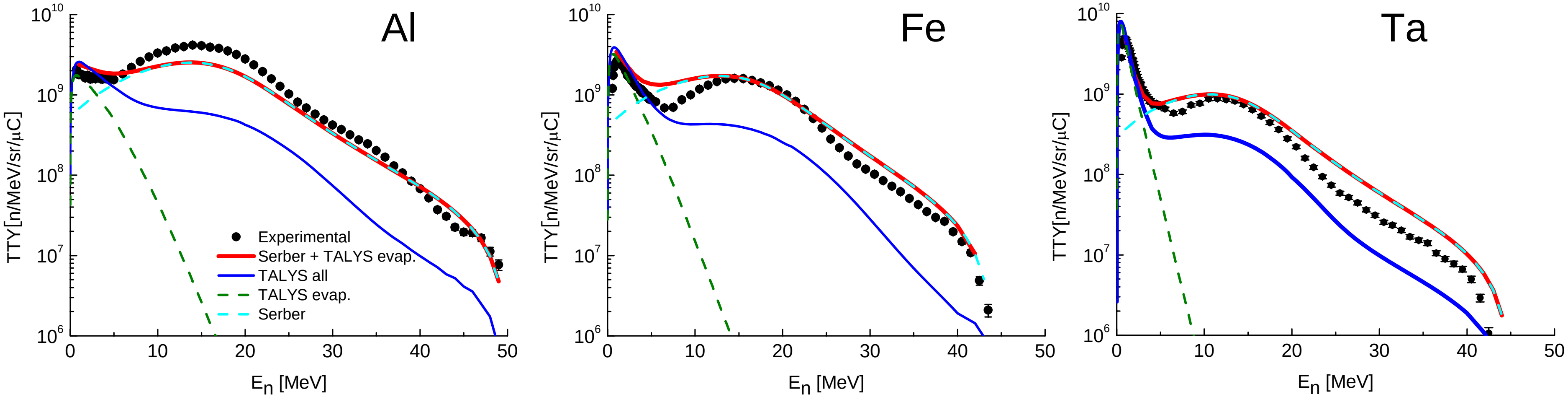
Stopping power (SRIM2008)

Attenuation of incident deuteron

Serber model (stripping)
+
TALYS evap.

Agreement with experimental data around the bump is improved.

40 MeV 0 deg Preliminary cal.



by C. Motooka and Y. Watanabe (Kyushu)

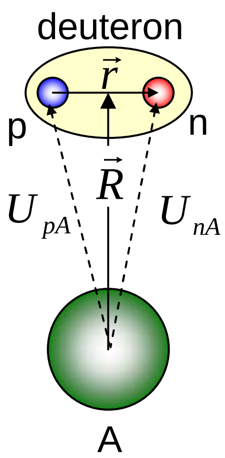
CDCC analysis of d+Li reactions

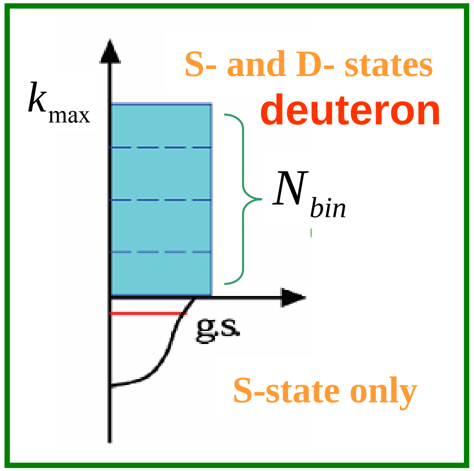
Application of **the CDCC method** to deuteron elastic scattering from ^{6,7}Li

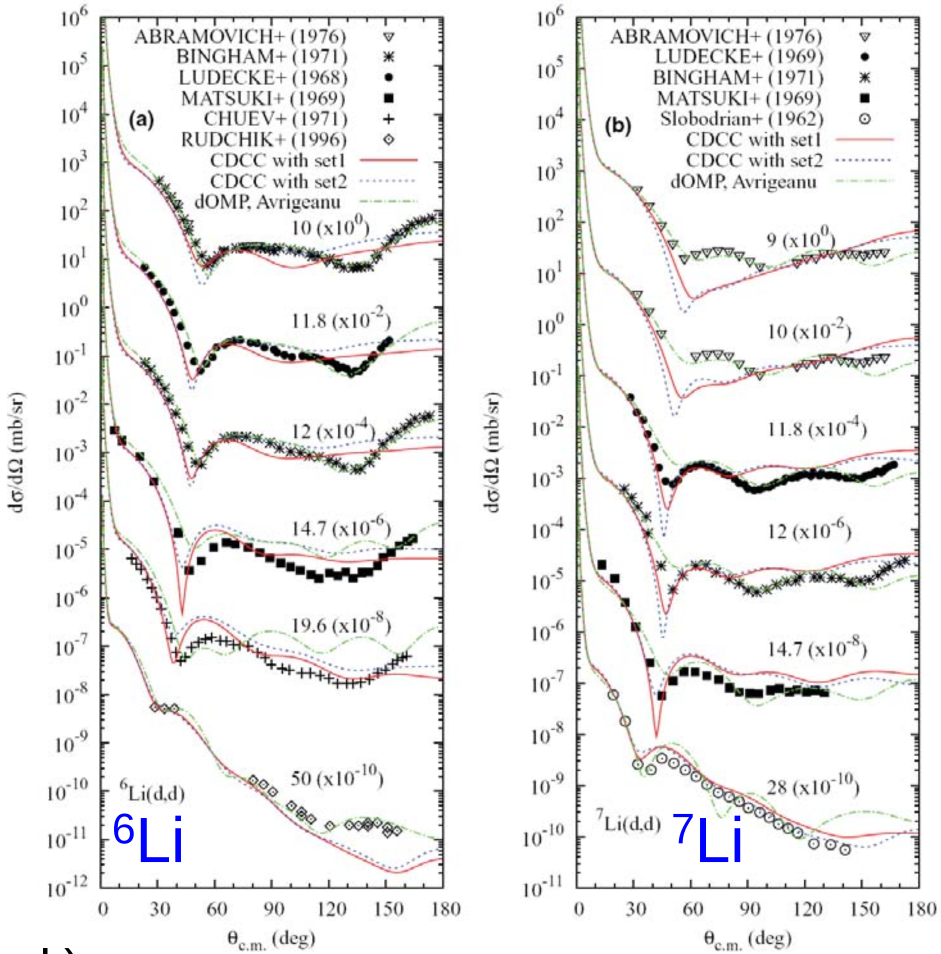
T. Ye, Y. Watanabe, K. Ogata, and S. Chiba, PRC 78, 024611 (2008).

The **CDCC** (**C**ontinuum **D**iscretaized **C**oupled-**C**hannels) method describes deuteron breakup process (A+2 body system) with following phenomenological three-body Hamiltonian :

$$H_{eff} = T_R + U_{pA}(\vec{r}_p, \vec{s}_p, E_d/2) + U_{nA}(\vec{r}_n, \vec{s}_n, E_d/2) + V_p^{(Coul)}(R) + H_{pn}(\vec{r}, \vec{s}_p, \vec{s}_n)$$



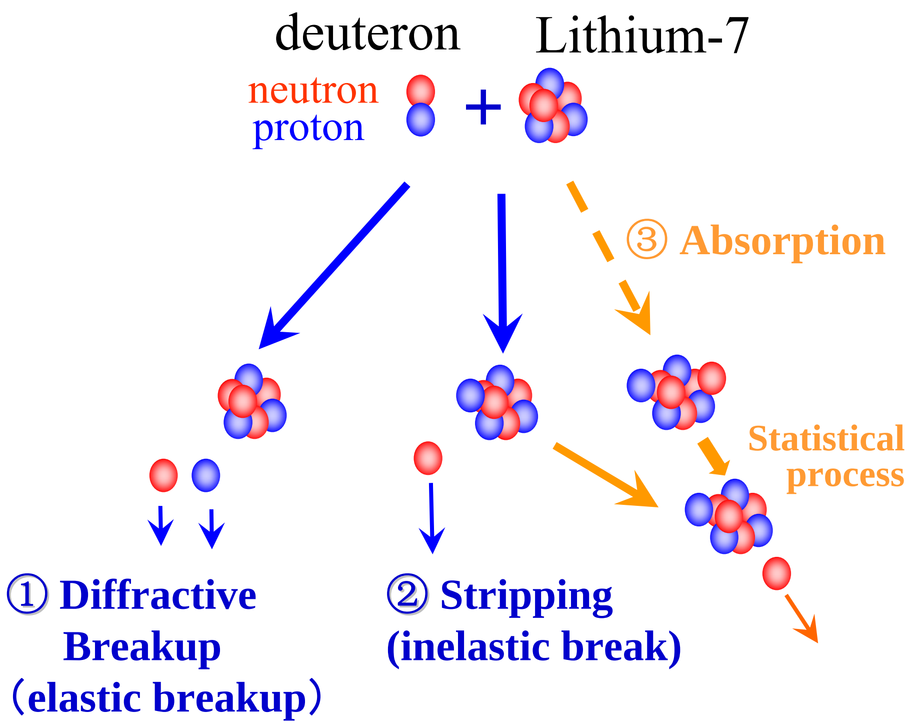




Code: CDCDEU+HICADEU (by Y. Iseri et al.)

CDCC+Glauber analysis of Li(d,nx) reactions

Schematic view of neutron production



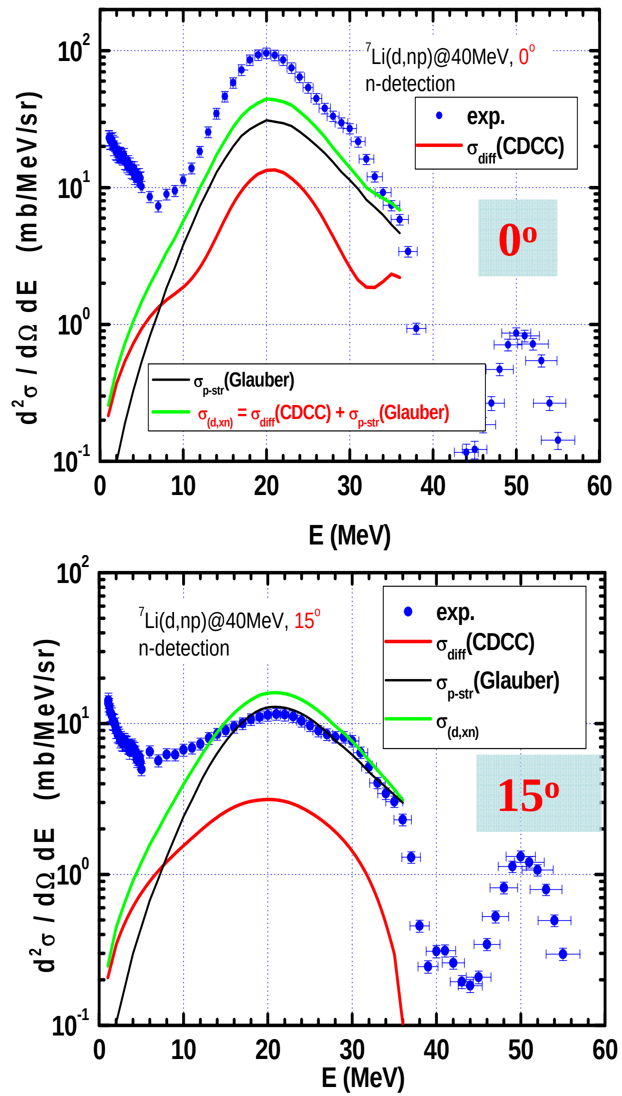
CDCC

S-matrices for d-breakup transition

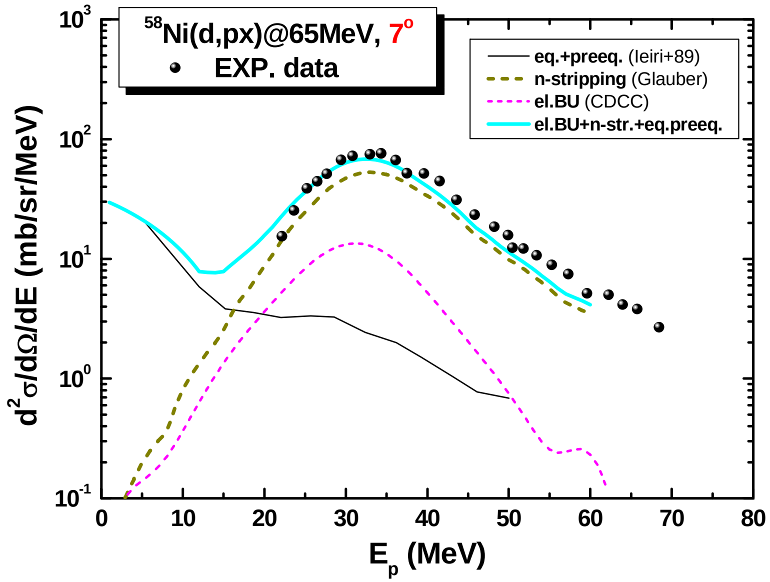
Glauber model

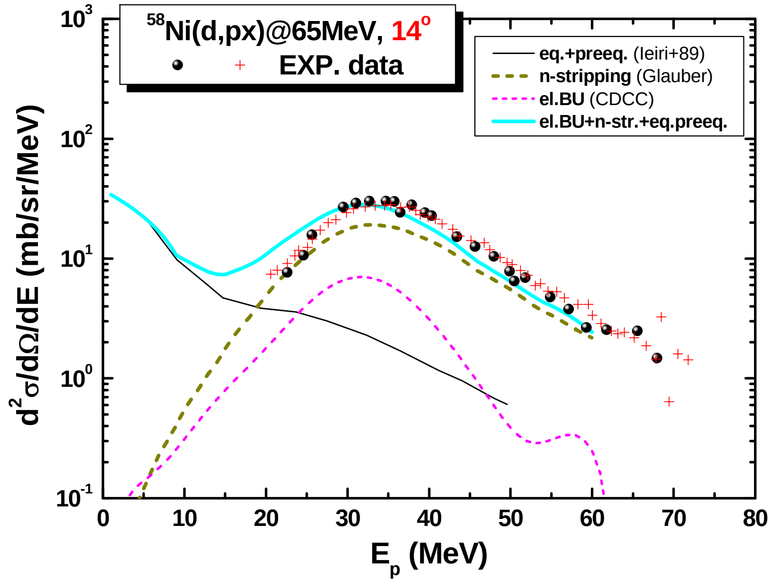
(eikonal approx.
+ adiabatic approx.)

7Li(d,nx)@40MeV



CDCC+Glauber analysis of ^{58}Ni(d,px) reactions

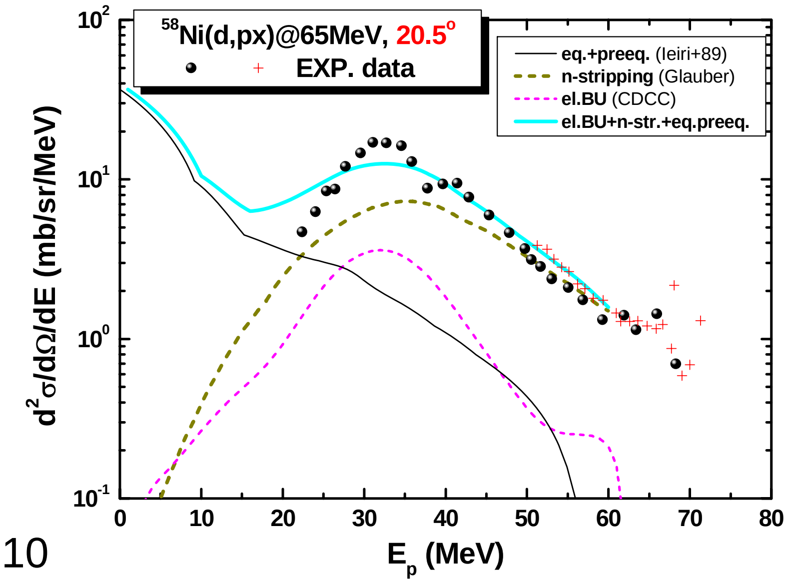




Our CDCC + Glauber calculation

+

Equilibrium and preequilibrium component (Ieiri et al.)



Ref.) M. Ieiri et al., Nucl. Phys. A504 (1989) 477-510

d-induced Activation Cross-sections
required for the IFMIF machine activation estimation

D-induced activation cross-sections for the IFMIF accelerator materials were measured at the AVF synchrotron at JAEA Takasaki.

Ed = 14 to 49 MeV

30 reactions

Table 1. Measured activation cross sections.

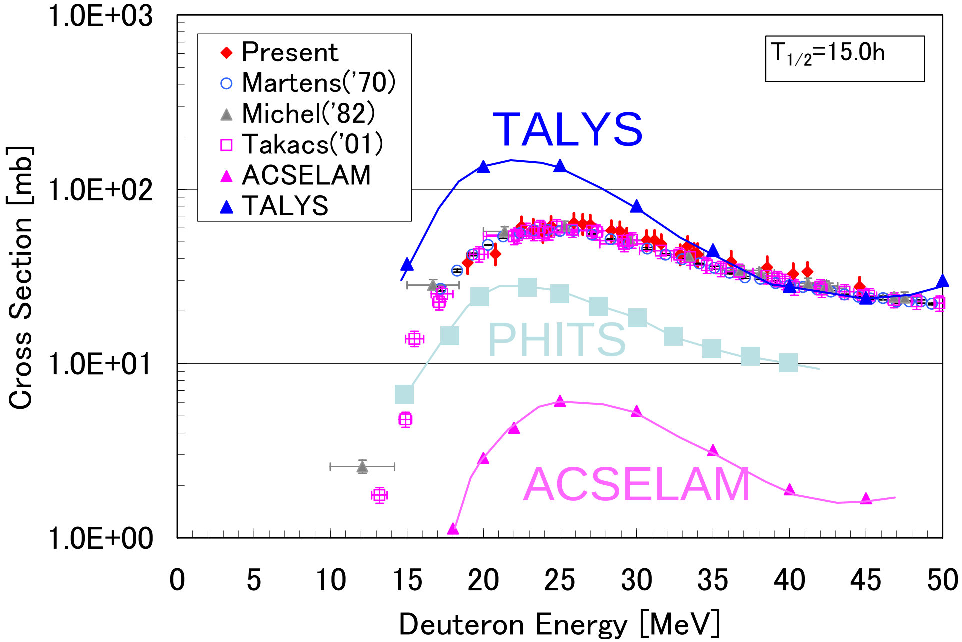
$^{27}Al(d,x)^{22}Na$,	$^{27}Al(d,x)^{24}Na$,	$^{27}Al(d,2p)^{27}Mg$,	$^{51}V(d,4n)^{49}Cr$,
$^{nat}Cr(d,x)^{48}V$,	$^{nat}Cr(d,x)^{52}Mn$,	$^{55}Mn(d,x)^{54}Mn$,	$^{nat}Fe(d,x)^{52}Mn$,
$^{nat}Fe(d,x)^{54}Mn$,	$^{nat}Fe(d,x)^{55}Co$,	$^{nat}Fe(d,x)^{56}Co$,	$^{nat}Fe(d,x)^{57}Co$,
$^{nat}Ni(d,x)^{55}Co$,	$^{nat}Ni(d,x)^{57}Co$,	$^{nat}Ni(d,x)^{56}Co$,	$^{nat}Ni(d,x)^{60}Cu$,
$^{nat}Ni(d,x)^{61}Cu$,	$^{nat}Cu(d,x)^{62}Zn$,	$^{nat}Cu(d,x)^{63}Zn$,	$^{nat}Cu(d,x)^{61}Cu$,
$^{nat}Cu(d,x)^{64}Cu$,	$^{nat}Ta(d,x)^{178}Ta$,	$^{nat}Ta(d,x)^{180}Ta$,	$^{nat}W(d,x)^{181}Re$,
$^{nat}W(d,x)^{182}Re$,	$^{nat}W(d,x)^{183}Re$,	$^{nat}W(d,x)^{184}Re$,	$^{nat}W(d,x)^{186}Re$,
$^{nat}W(d,x)^{187}W$,	$^{197}Au(d,x)^{194}Au$		

K. Ochiai et al., Proc. of ND2007, p.1011-1014

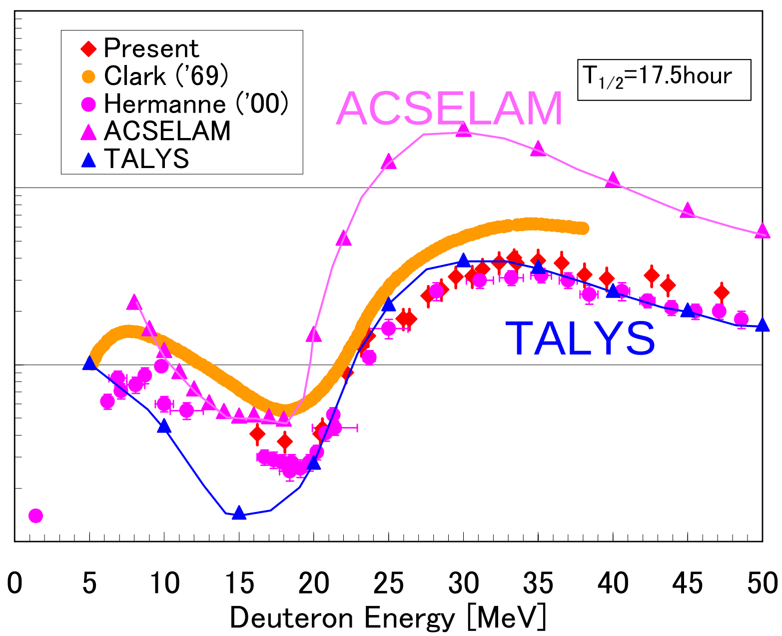
d-induced Activation Cross-sections
required for the IFMIF machine activation estimation

Measured data were compared with ACSELAM library (by ALICE), calculations by TALYS (ver.0.64) and PHITS

$^{27}Al(d,x)\ ^{24}Na$



$^{nat}Fe(d,x)^{55}Co$



K. Ochiai et al., Proc. of ND2007, p.1011-1014

High-energy nuclear data related to IFMIF

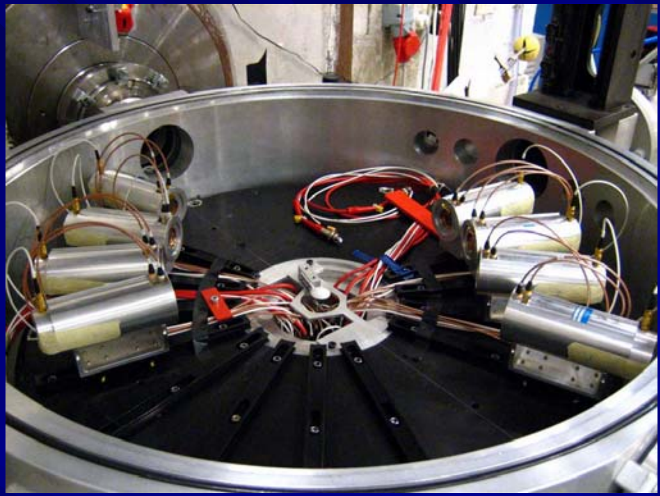
- Measurement and Benchmarking -

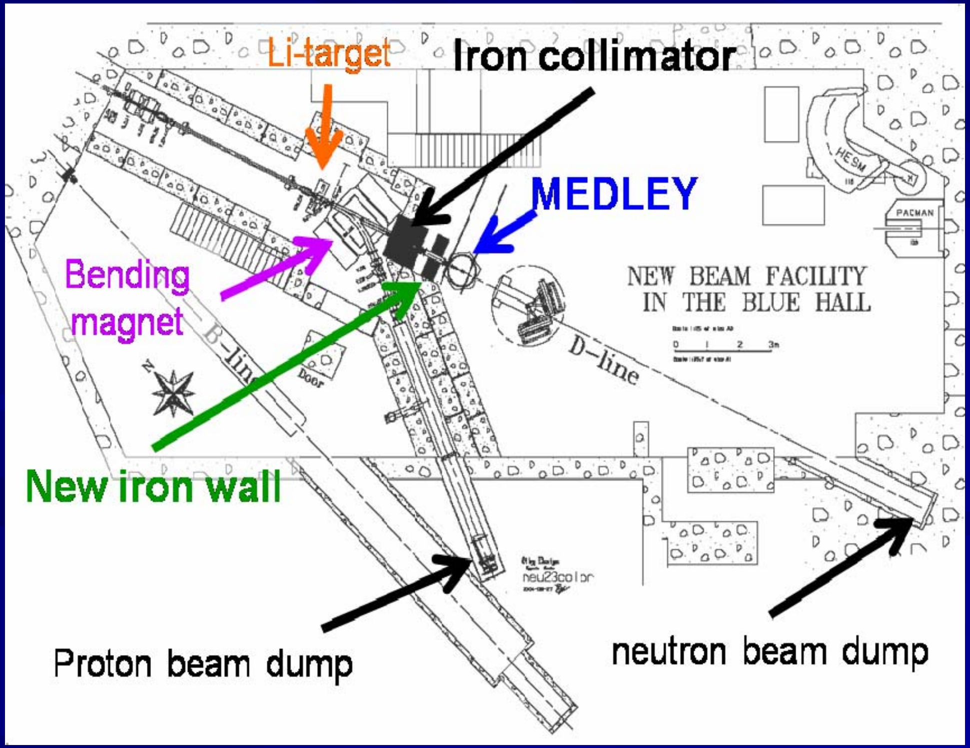
Neutron induced reactions

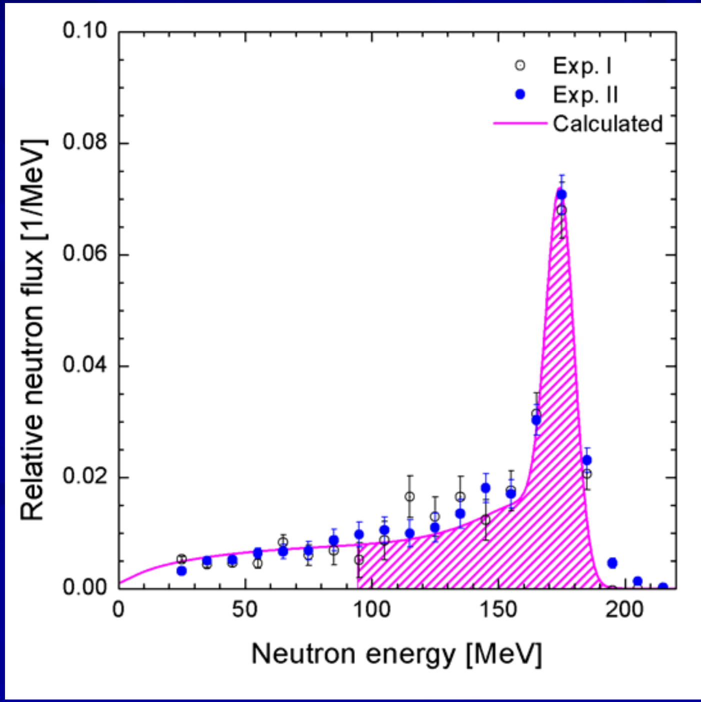
- Light-ion production from carbon bombarded by 175 MeV quasi-monoenergetic neutrons@TSL [Kyushu-Uppsala]
- (n,xn) DDX @ LANCE, LANL [Kyushu-LANL]

New neutron beam facility @ TSL, Uppsala

- Gustaf Warner Cyclotron
  - ✓ Proton energy ~180 MeV
- Neutron source
  - ✓ Quasi mono-energetic neutron source with Li(p,n) reaction
  - ✓ Neutron energy 11-175 MeV



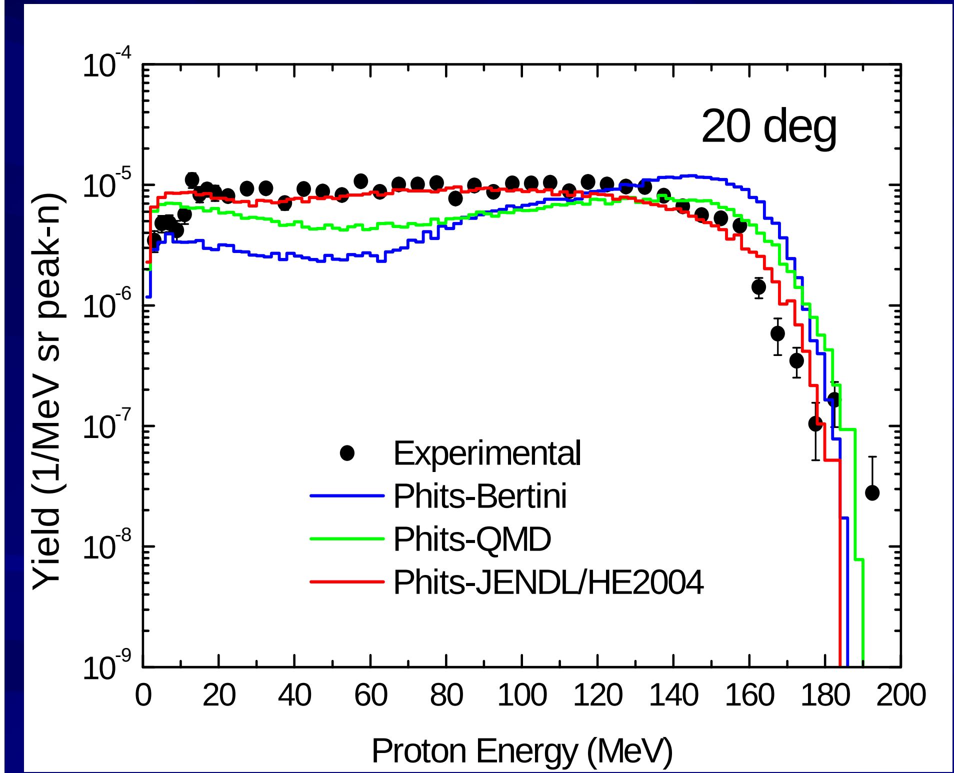


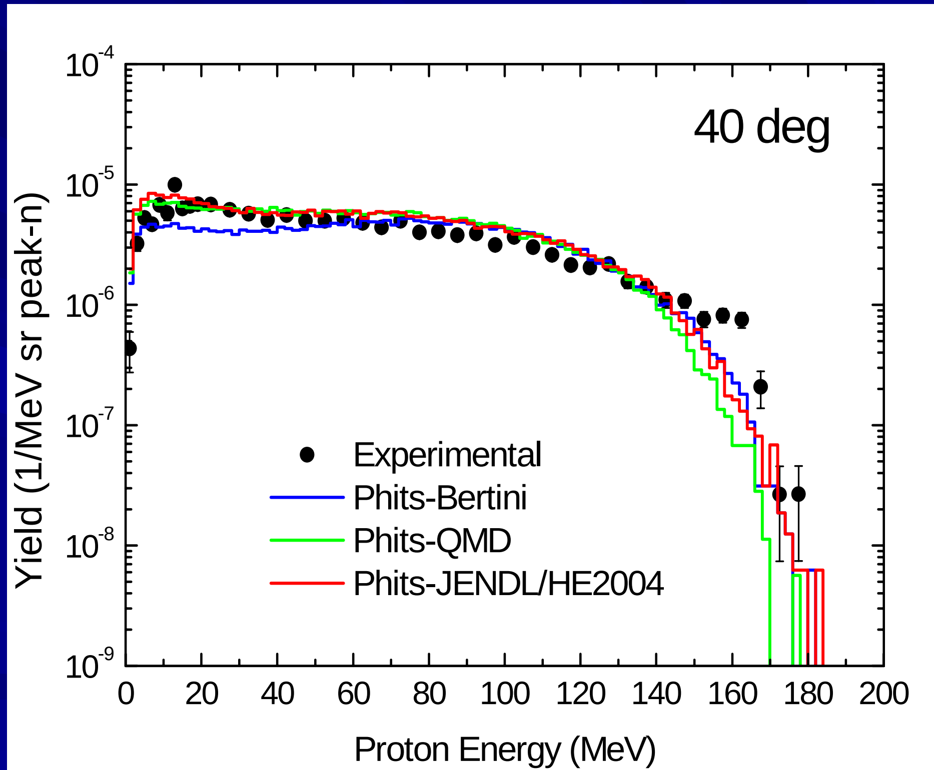


Comparison between Exp. & Cal. (1)

Proton production from Carbon

PHITS calculation with JENDL/HE, Bertini INC, and QMD



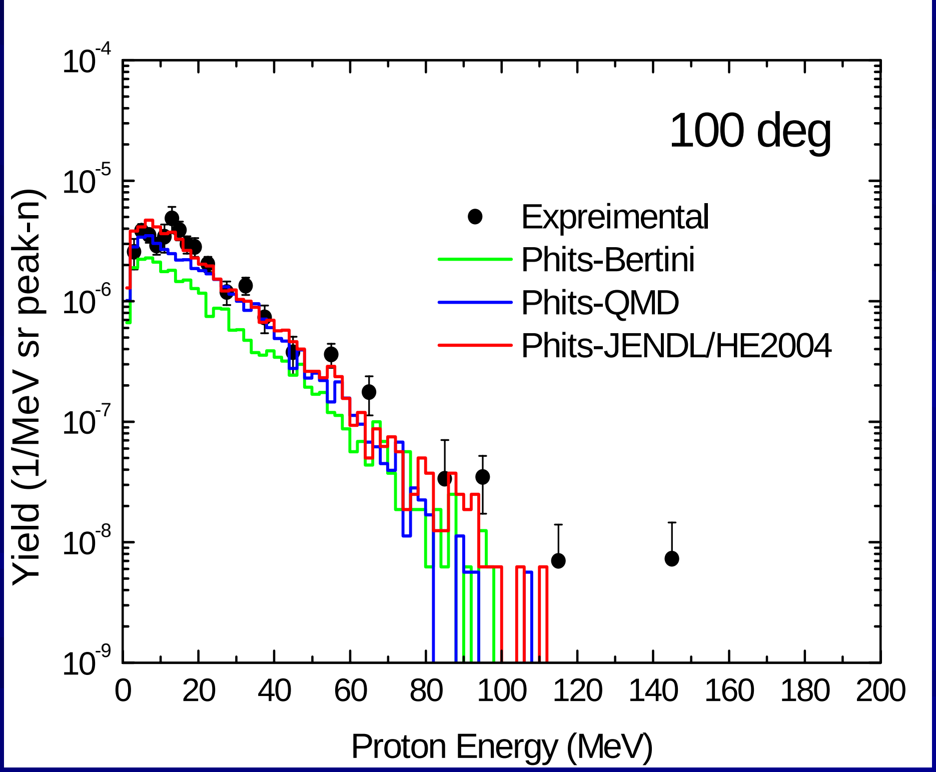


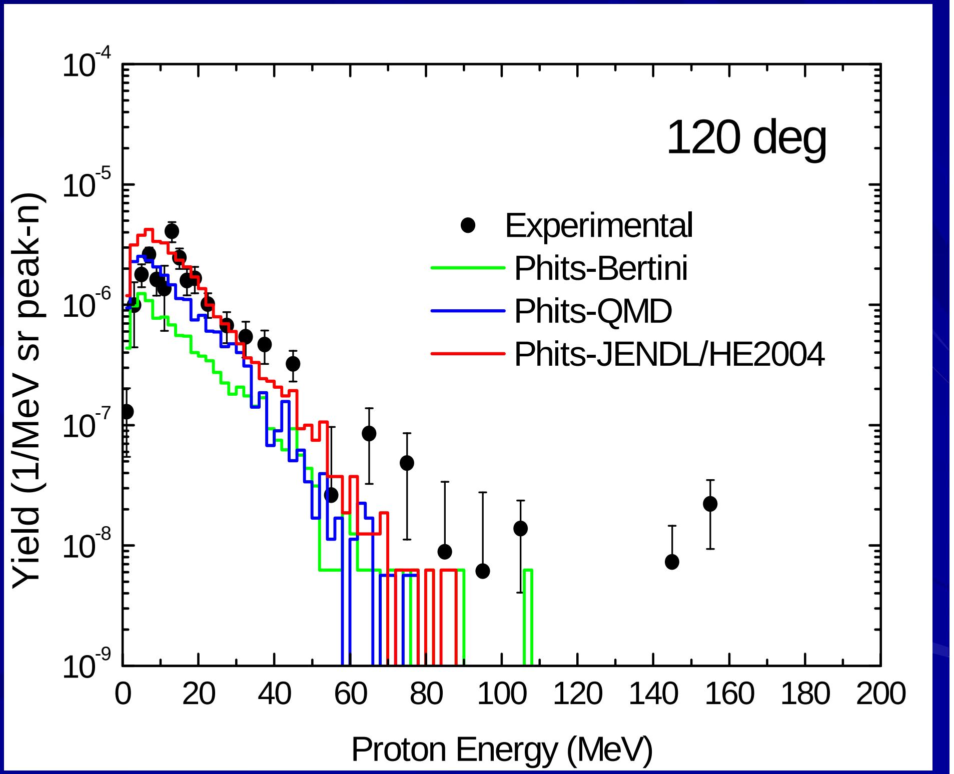
Ref.) M. Hayashi, Y. Watanabe, et al.,
Proc. of ND2007, p.1091, DOI: 10.105/ndata:07747

Comparison between Exp. & Cal. (2)

Proton production from Carbon

PHITS calculation with JENDL/HE, Bertini INC, and QMD





Ref.) M. Hayashi, Y. Watanabe, et al.,
Proc. of ND2007, p.1091, DOI: 10.105/ndata:07747

(n, xn) DDX @ LANSCE

Kyushu Univ.& LANL

LANSCE WNR: Spallation neutron source (< 800 MeV)

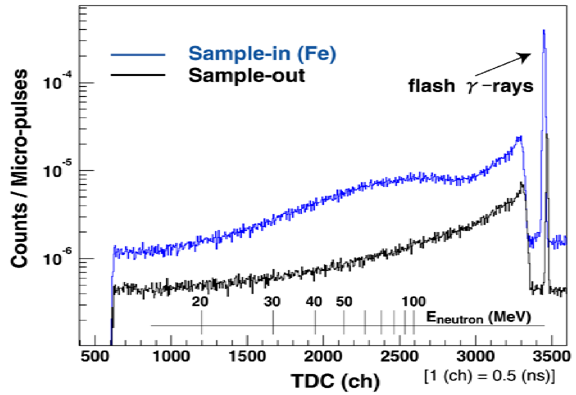
Sample: Thin C, Al, Fe, In, Pb
Thick Fe, Pb

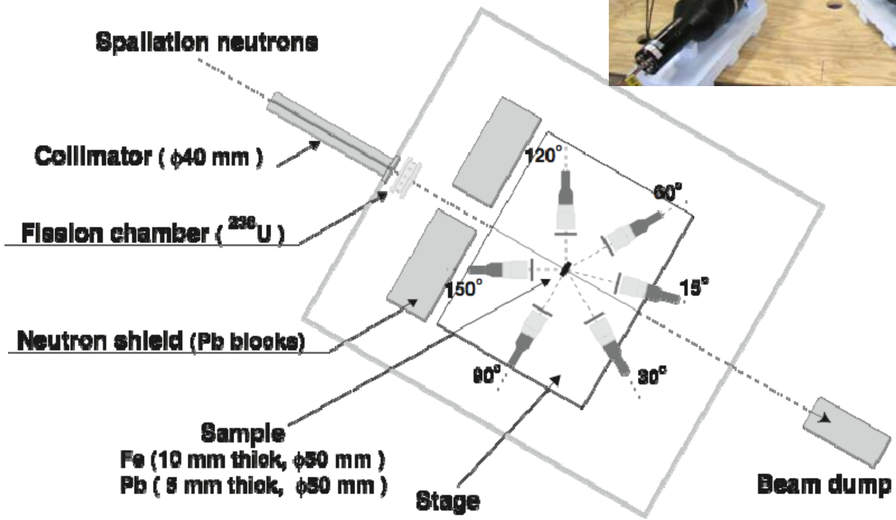
Detector: NE213, Phoswich type NaI(Tl)

Incident neutron: TOF

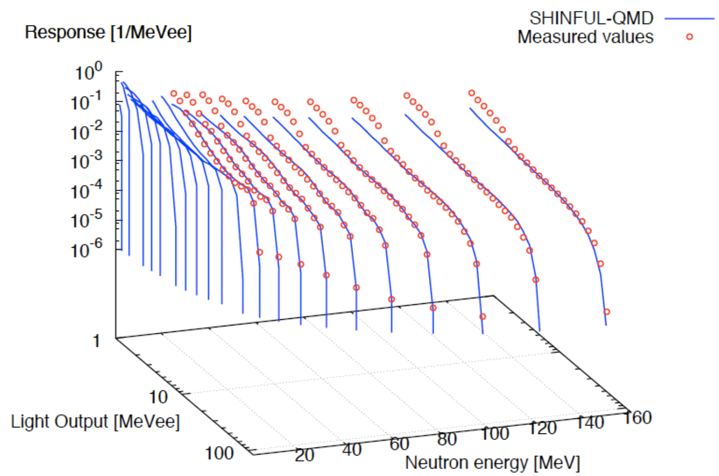
Outgoing neutron: Unfolding

TOF Spectra





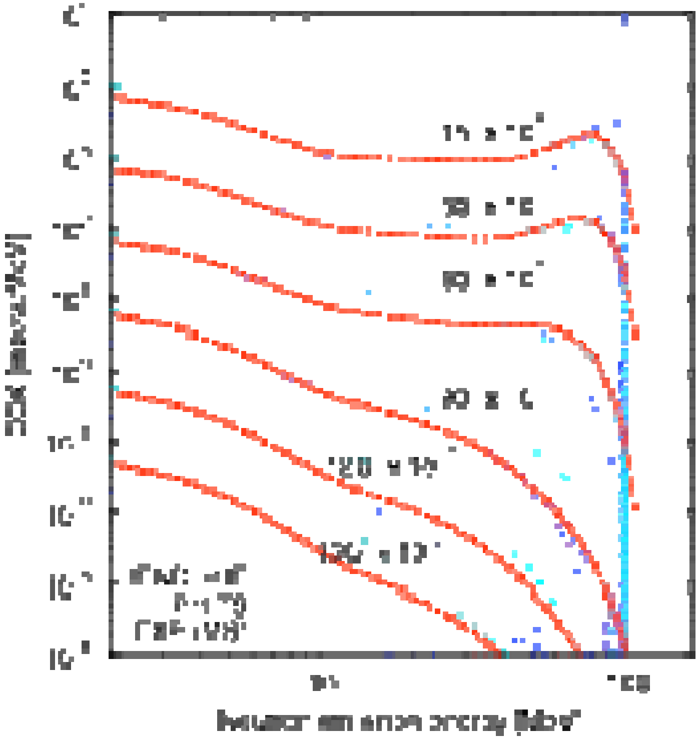
Detector Response



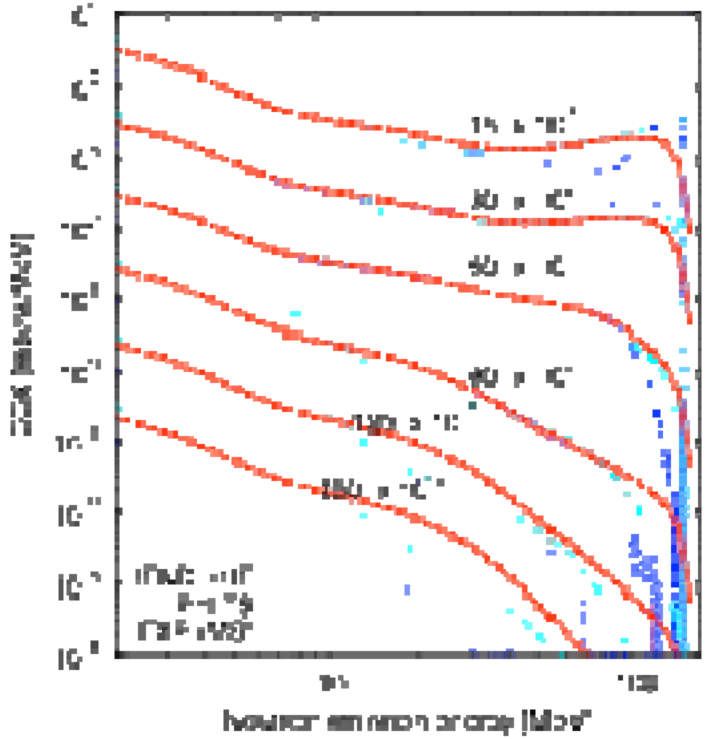
(n, xn) DDX @ LANSCE

Unfolding using moving source model

90 - 110 MeV, Al(n,xn)



140 - 160 MeV, Fe(n,xn)



N. Noda, et al., Proc. ND2007, 274 - 277 (2008).
N. Shigyo, et al., Proc. ND2004, 924 – 927 (2005).
S. Kunieda, et al., Proc. ND2004, 1058 – 1061 (2005).

High-energy nuclear data related to IFMIF
- Measurement and Benchmarking -

Proton induced reactions

- **TTY of neutron production**

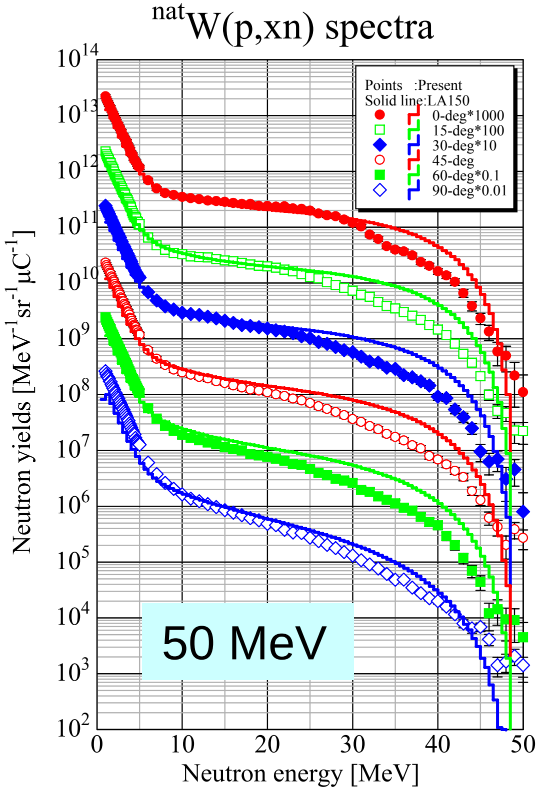
  @CYRIC(35, 50, 70MeV: C, Al, Fe, Cu, Ta, W) [Tohoku] ,
  @RCNP(140, 250, 350 MeV: C, Al, Fe, Pb) [JAEA]

  - T. Aoki et al., Nucl. Sci. Eng. 146, 200 (2004).
  - Y. Iwamoto et al., NIM A562, 789 (2006), A593, 298 (2008).

- **DDX of (p,LCPs) reactions**

  @RCNP (392MeV: Be, C, Al, etc.) [Kyushu]

  - Y. Uozumi et al., NIM A 571, *743-747* (2007).
  - T. Kin et al. PRC 72, 014606 (2005).



Japanese Activities on Fusion Neutronics

Prepared by C. Konno @ JAEA

Contents

JAEA/FNS

- Neutronics experiments for Japanese ITER test blanket module [JAEA]
- Angle-correlated neutron spectrum measurement for $^{nat}Zr(n,2n)$ reaction [Osaka Univ. + JAEA]
- Charged-particle emission DDX measurement at 14 MeV [Osaka Univ. + JAEA]
- Benchmark tests for nuclear data based on integral experiments with DT neurons at JAEA/FNS [JAEA]

Charged-particle emission DDX measurement at 14 MeV

Features of the spectrometer

JAEA/FNS

- Utilizing **a pencil DT neutron beam**
  - Low neutron background outside the beam:
    ϕ=50-70 [n/s/cm^2] !
    Detectors can be arranged close to samples without any radiation shield.
    As a result, high signal-to-noise ratio is achieved.

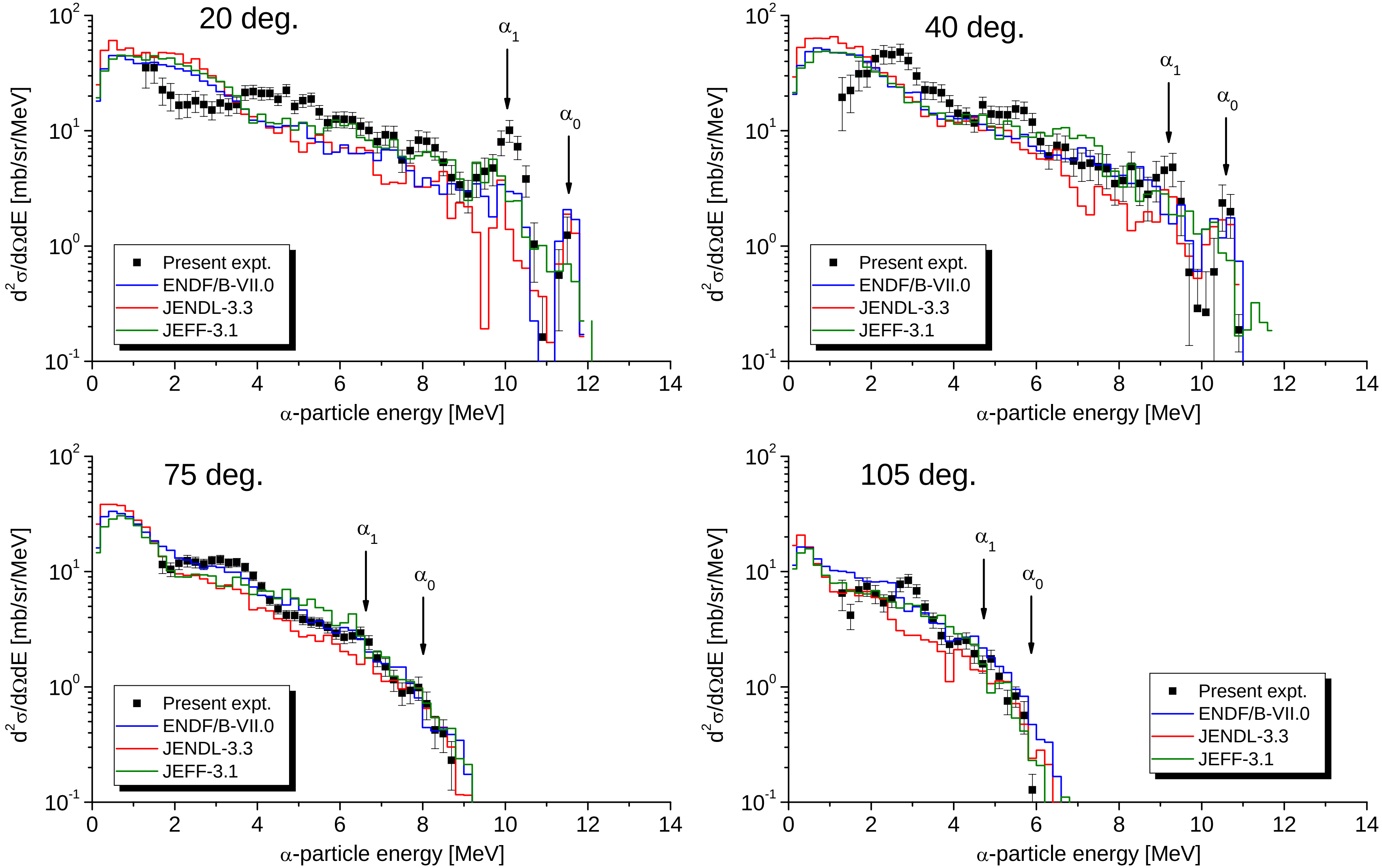
- E-ΔE counter telescope with SSBDs
  - Thin ΔE detector (9.6 μm)
    α-particle measurement down to 1.0 MeV
    (combining coincidence spectrum and anticoincidence spectrum of ΔE detector)

- Correction for energy loss in sample materials

K.Kondo et al., Nucl. Instrum. Methods A 568, 723 (2006)

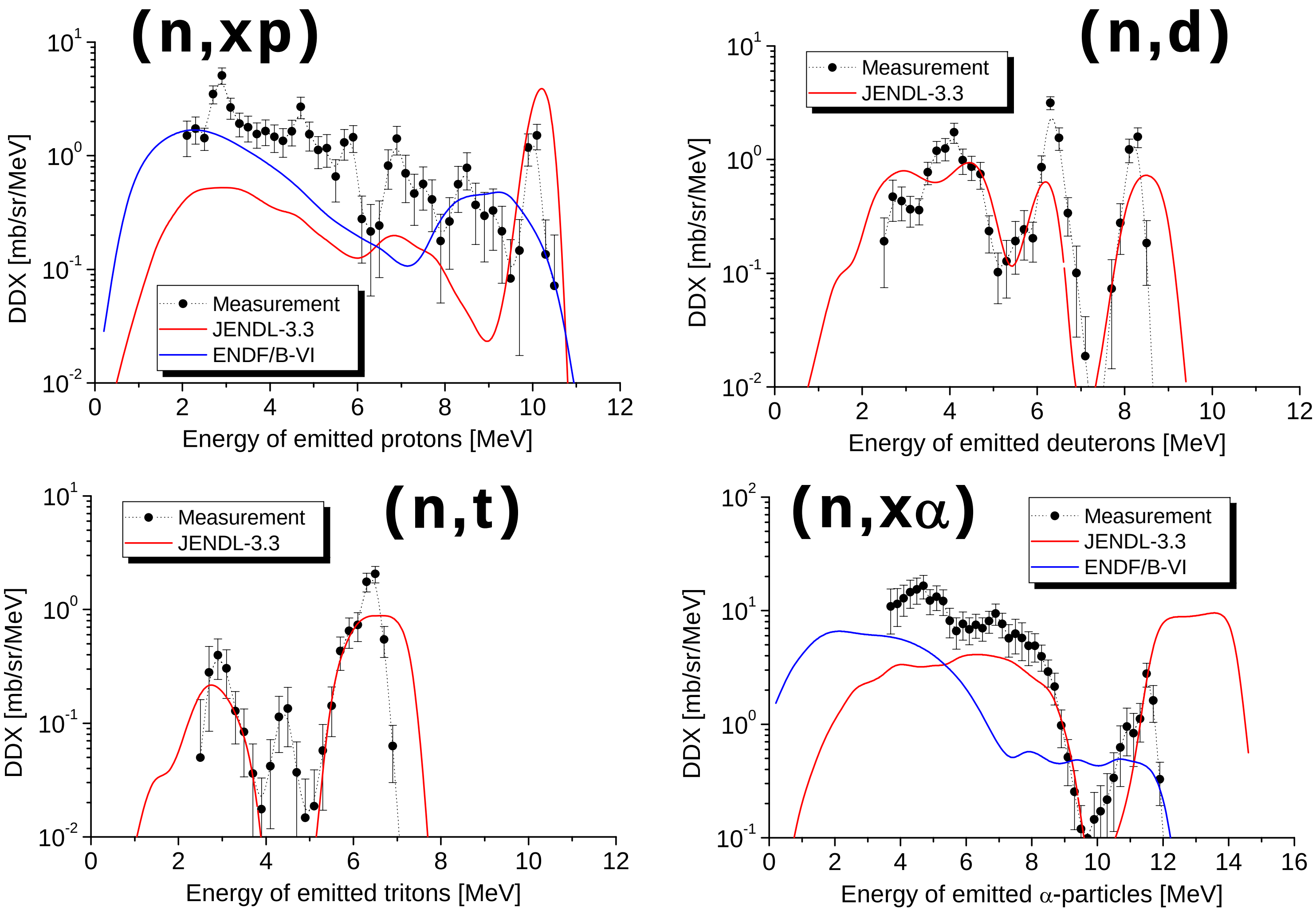
Comparison with evaluated DDX for $^{9}Be(n,x\alpha)$

JAEA/FNS



Comparison with evaluated data for ^{19}F

JAEA/FNS



Comparison of DDX at 30 deg. between measurement and evaluation

Benchmark tests for nuclear data based on integral experiments with DT neurons at JAEA/FNS

Many integral benchmark experiments at JAEA/FNS:

- **Simple Benchmark Experiments**

  Li_2O, Beryllium, Graphite, SiC, Vanadium, Iron, SS316, Copper, Tungsten, etc.

- **Time-Of-Flight (TOF) Experiments**

  Li_2O, Li_2TiO_3, Beryllium, Graphite, Nitrogen, Oxygen, Iron, Lead, etc.

Calculation conditions

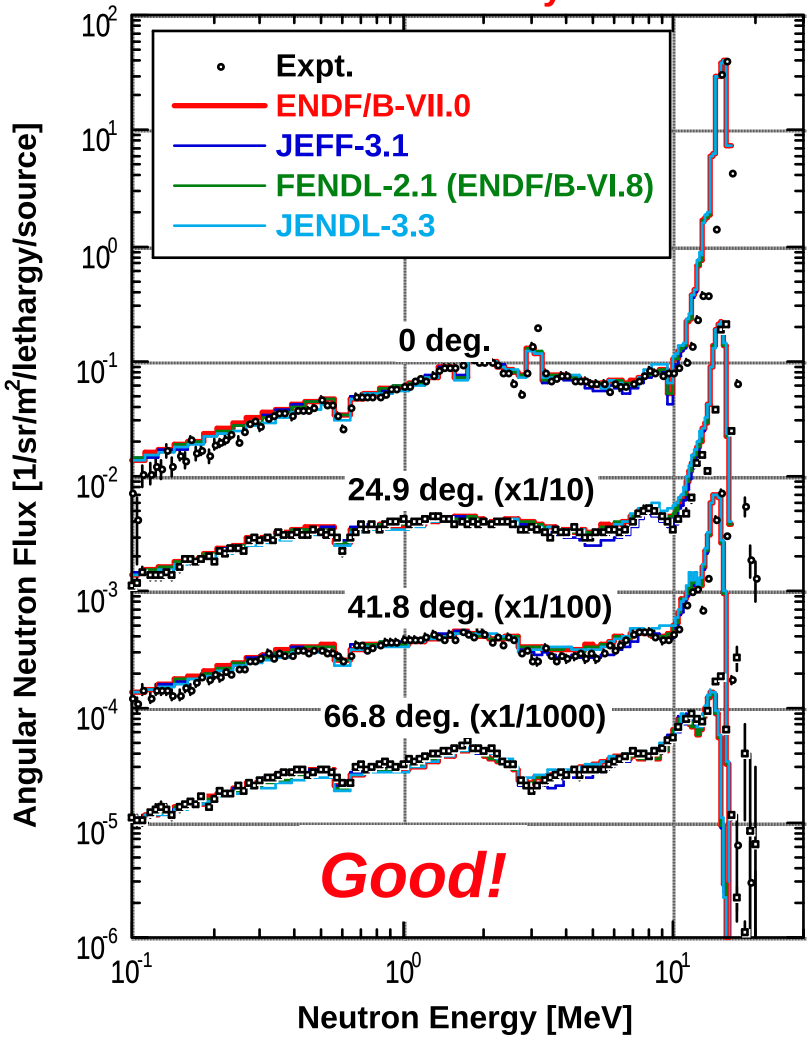
JAEA/FNS

- Code : MCNP4C
- Nuclear data library (ACE file)
  - FENDL-2.1
    (FENDL/MC-2.1 from IAEA)
  - JENDL-3.3
    (FSXLIB-J33 from Japanese Nuclear Data Center)
  - JEFF-3.1
    (MCJEFF3.1 from OECD/NEA Data Bank)
  - ENDF/B-VII.0
    (Processed with NJOY99.161 at JAEA/FNS)
- Experimental configuration is modeled in detail.

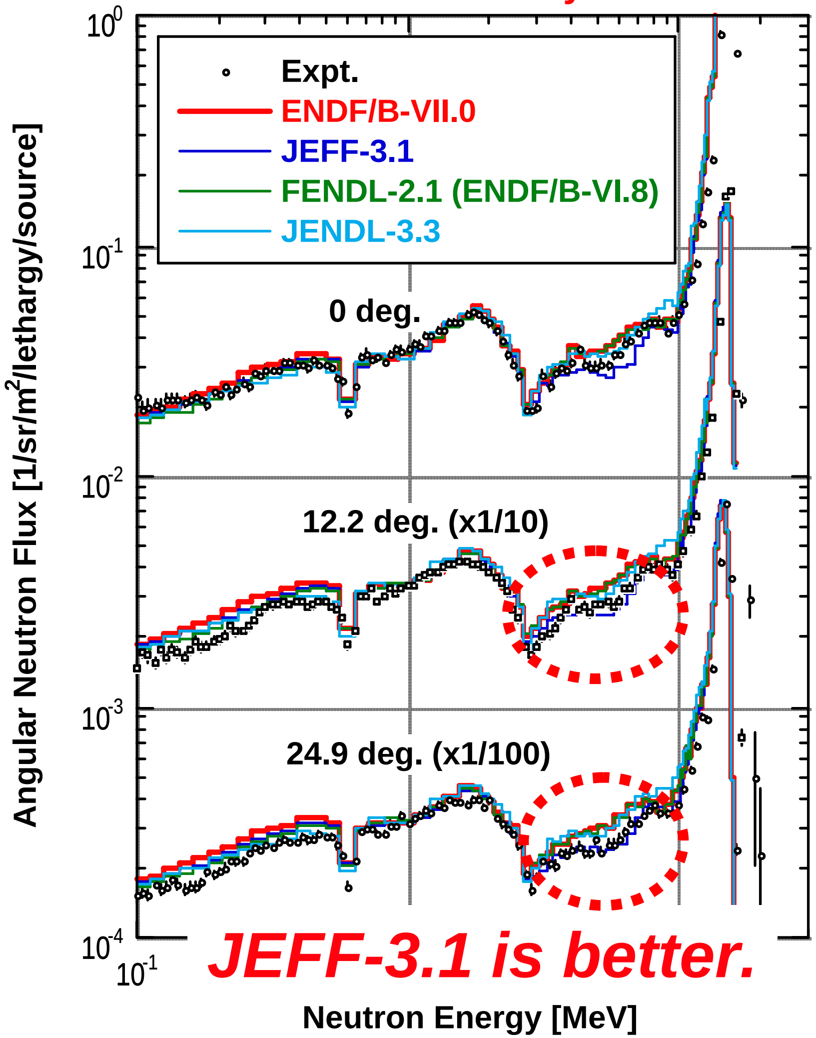
Beryllium (TOF Expt.) - (1)

JAEA/FNS

Leakage angular neutron spectra
from 51 mm thick Beryllium slab

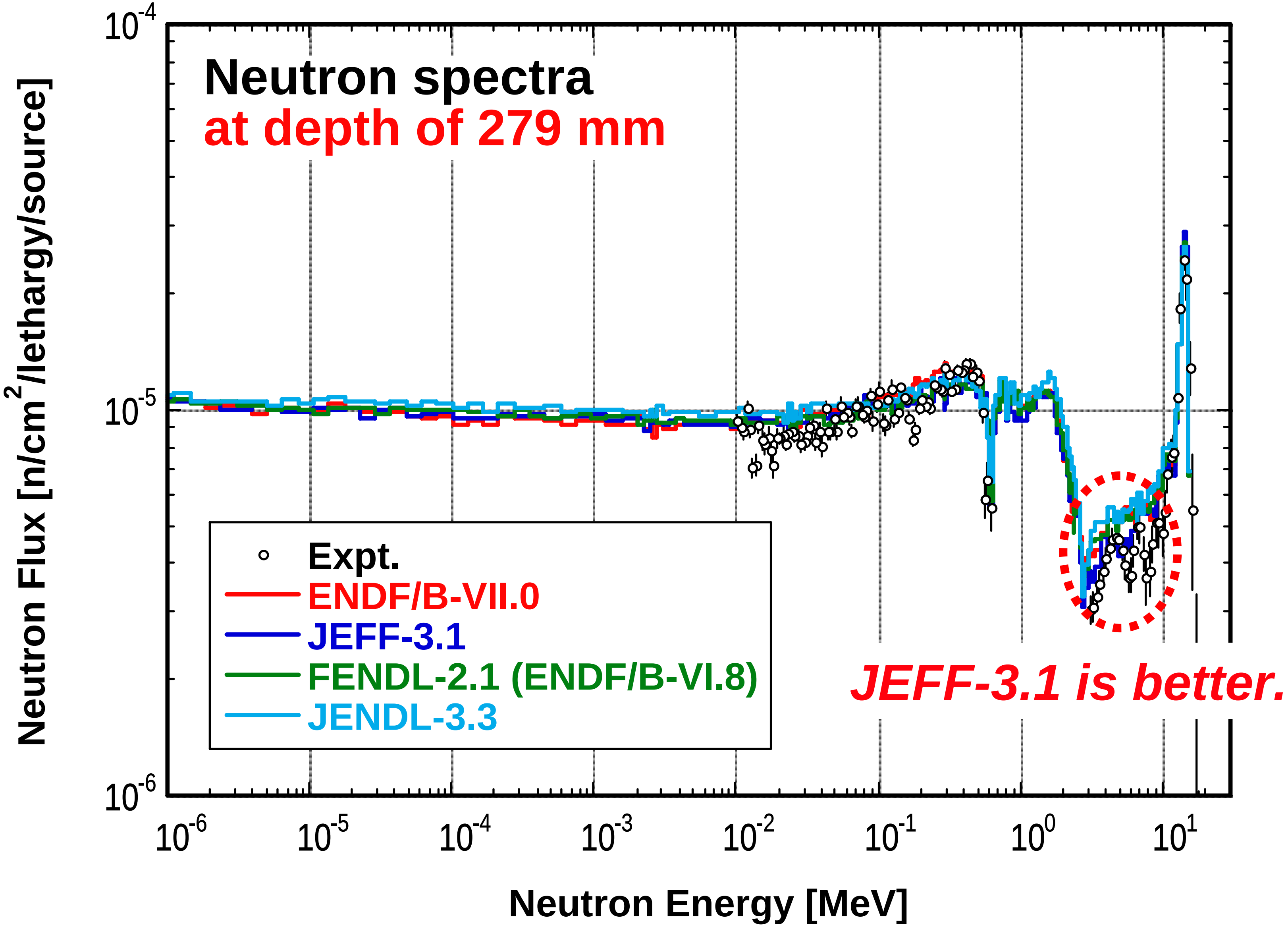


Leakage angular neutron spectra
from 152 mm thick Beryllium slab



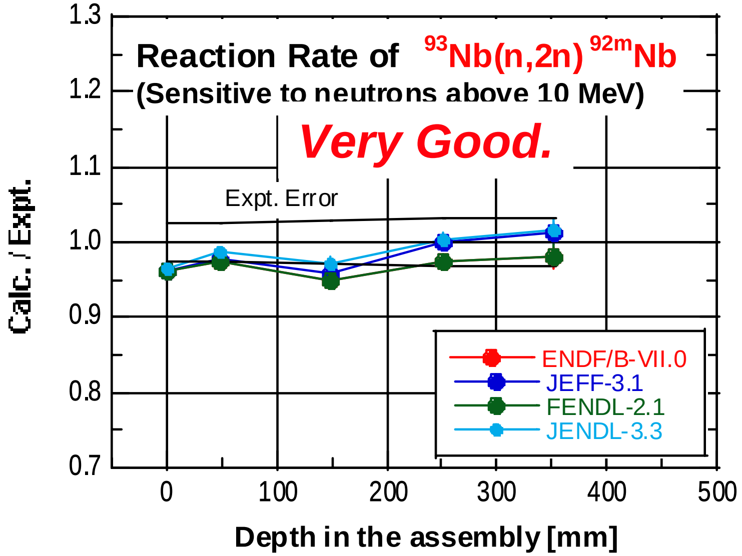
Beryllium (Simple Benchmark Expt.) - (2)

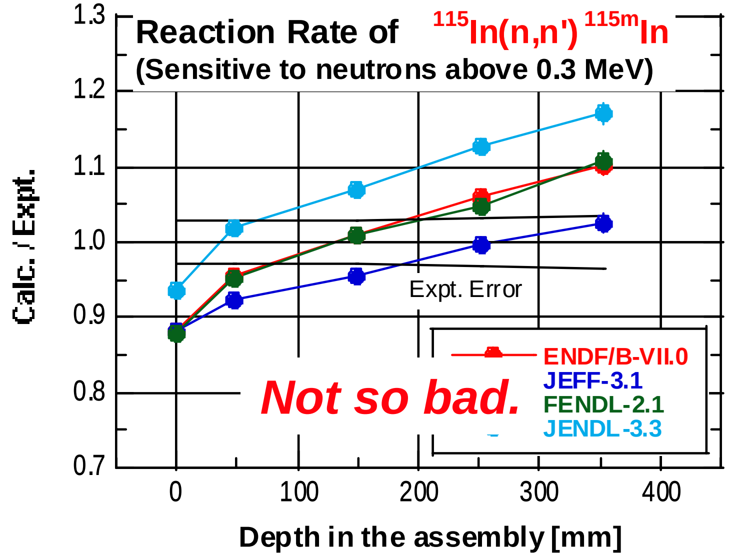
JAEA/FNS

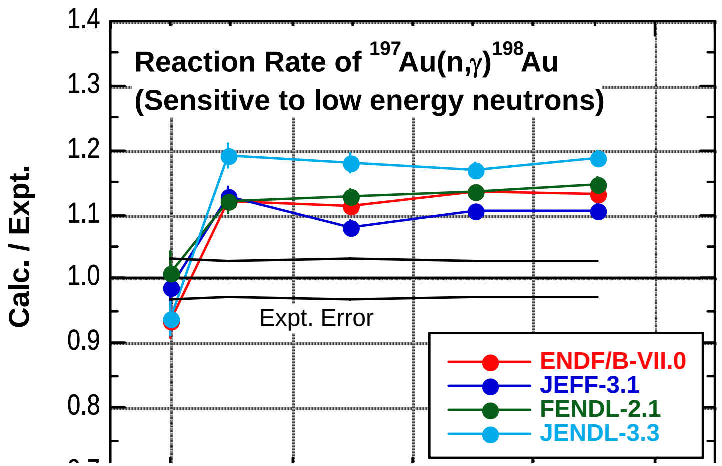


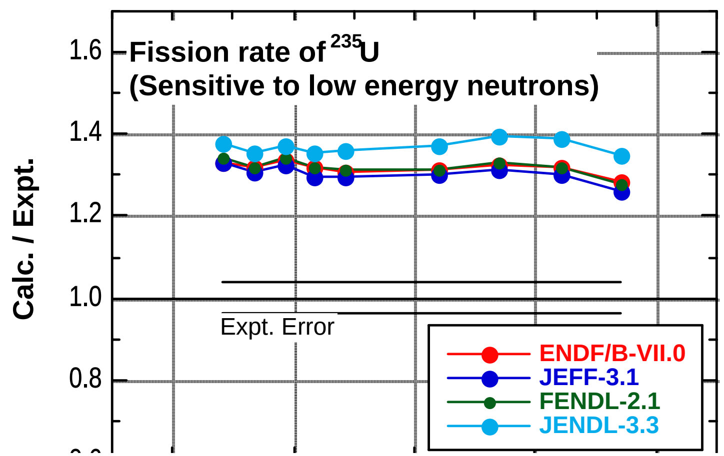
Beryllium (Simple Benchmark Expt.) - (3)

JAEA/FNS









All the calculations overestimate low energy neutrons.
This may overestimate tritium breeding ratio for blankets with beryllium.

Summary

Overview the status of Japanese nuclear data activities relevant to IFMIT and ITER

1. **High-energy nuclear data（above 20 MeV) related to accelerator applications including IFMIF**

   - Measurements of deuteron, neutron, and proton-induced reactions
   - Model analyses using CDCC, Glauber, and Serber models for d
   - Benchmarking of JENDL/HE and high-energy models for n and p

2. **Fusion neutronics related to ITER**

   - Measurements of charged-particle emission DDX for Be and F at 14 MeV
   - Benchmark tests for nuclear data based on integral experiments with DT neurons (e.g., Be)