Recent Nuclear Data Research Progress in China

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China Nuclear Data Center
China Institute of Atomic Energy

Outline

- **ND measurement activities at different institutions**
- **Chinese Evaluated Nuclear Data Library(CENDL) status**

Most of the slides are taken from the WPEC-2021 reports, thank all colleagues for providing the slides.

Only part of the ND measurement progress are collected in this presentation

- **China Institute of Atomic Energy (CIAE)**
- **Shanghai Institute of Applied Physics (SINAP)**
- **Institute of Modern Physics (IMP)**
- **Inner Mongolia University for Nationalities (IMUN)**
- **China Academy of Engineering Physics**

China Institute of Atomic Energy

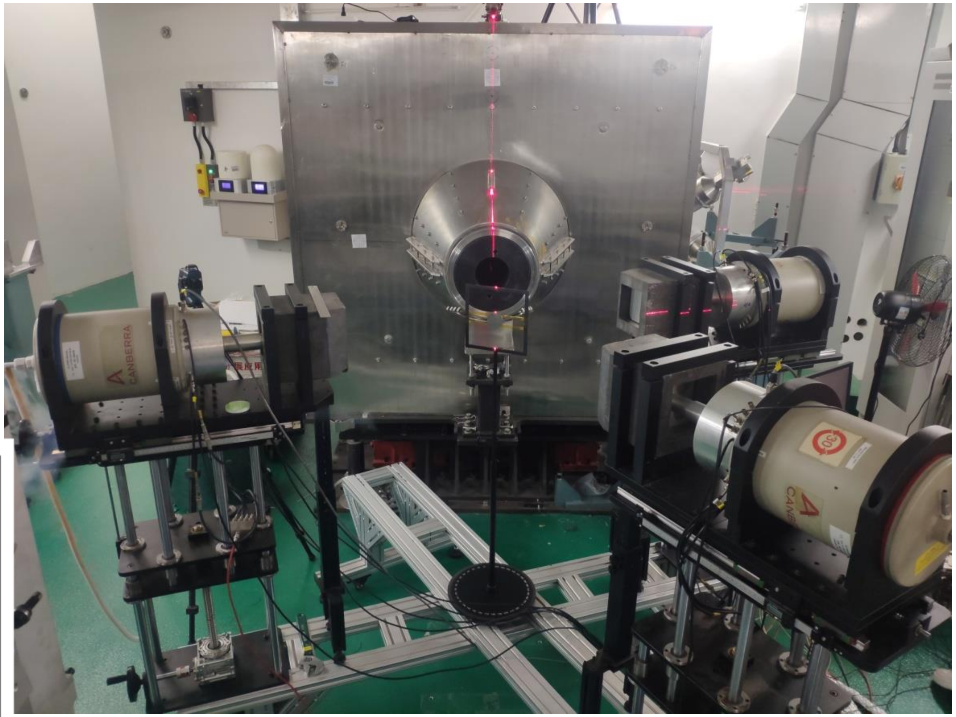
1. (n,n'g) and (n,2ng) cross section measurement

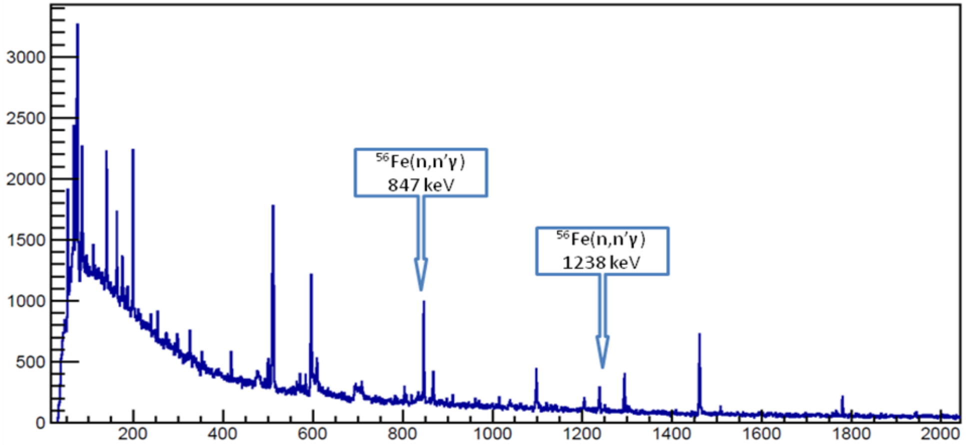
Neutron source:

1) 2×1.7 MV tandem: 1 – 3 MeV
2) HI-13 tandem: 8 – 12 MeV
3) Neutron generator: 14 MeV

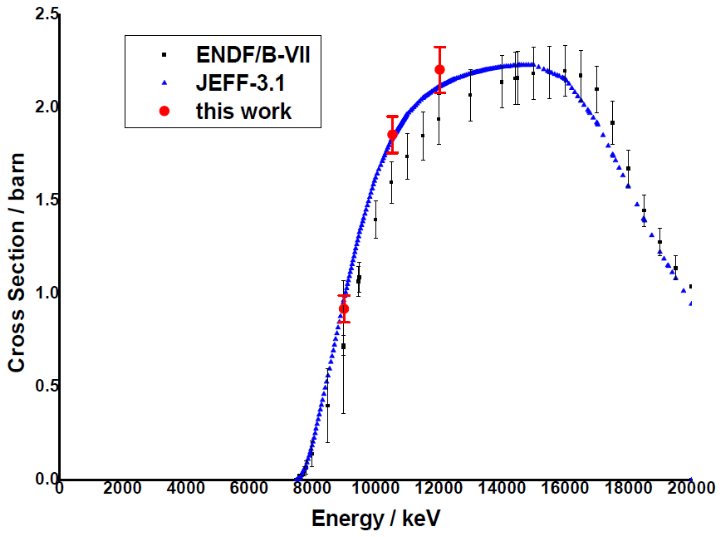
Detector:

HPGe and CLOVER detector

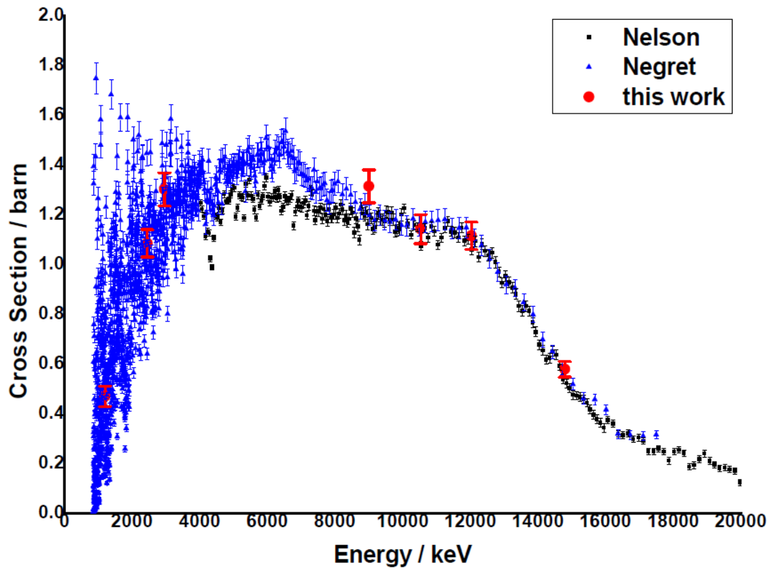




Preliminary results for (n,2ng) of ^{209}Bi and (n,n'g) of ^{56}Fe



(n,2ng) of ^{209}Bi @ 601.6 keV



(n,n'g) of ^{56}Fe

2. Neutron leakage spectrum measurement for d-D and d-T neutron sources

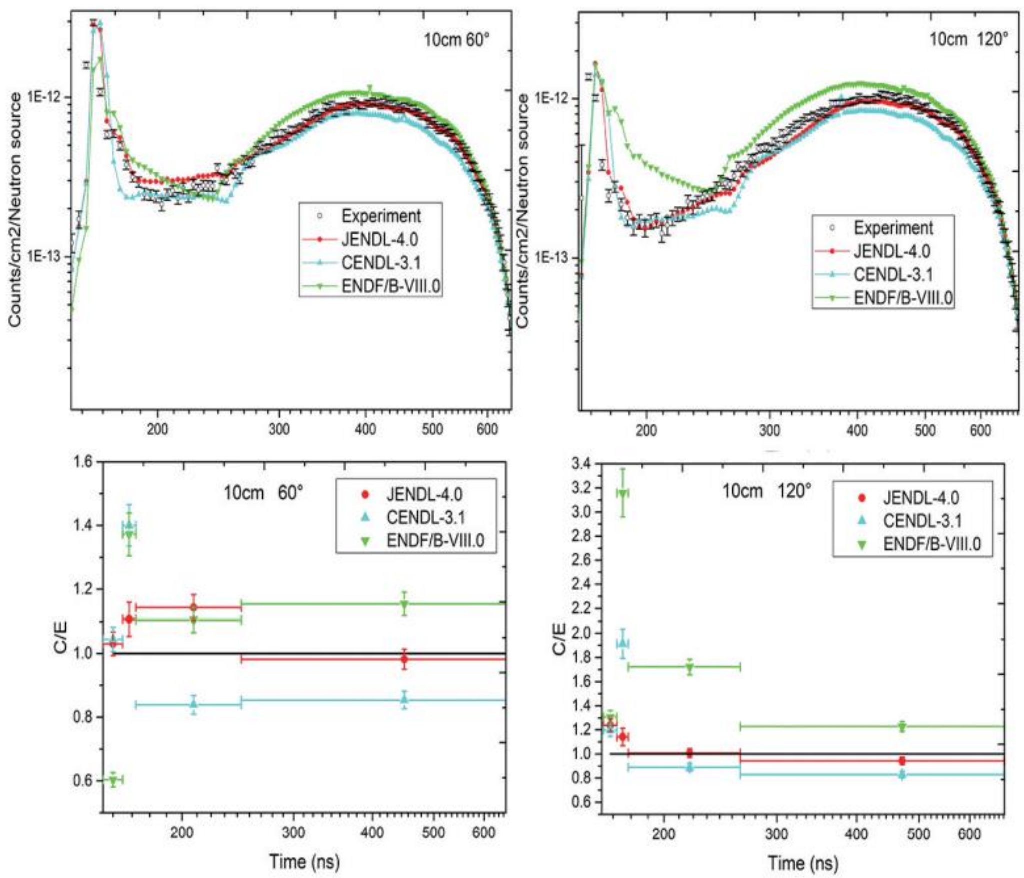


Figure 7: The results of experiment on the niobium sample with 10 cm

^{209}Bi, d-T neutrons

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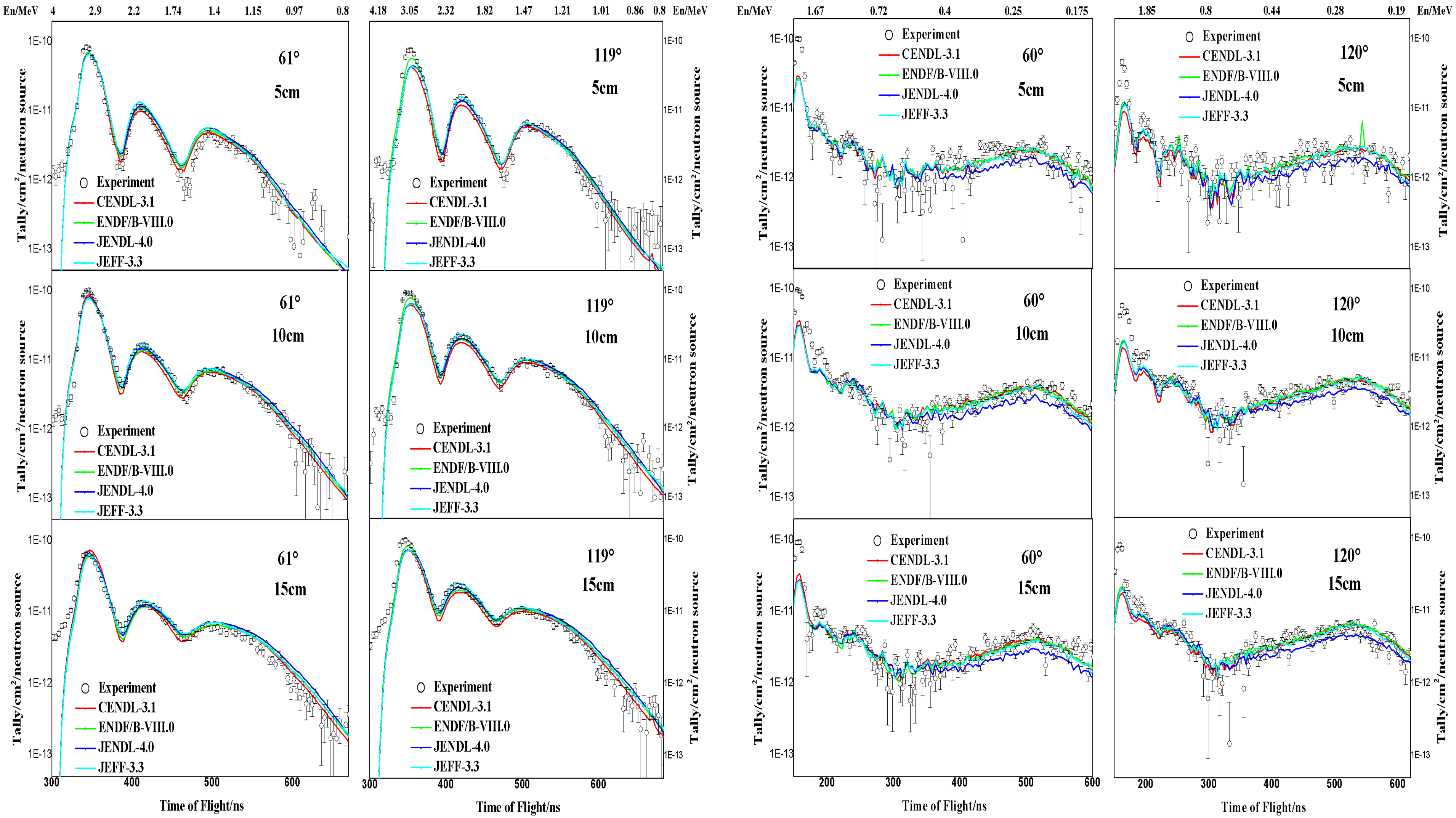
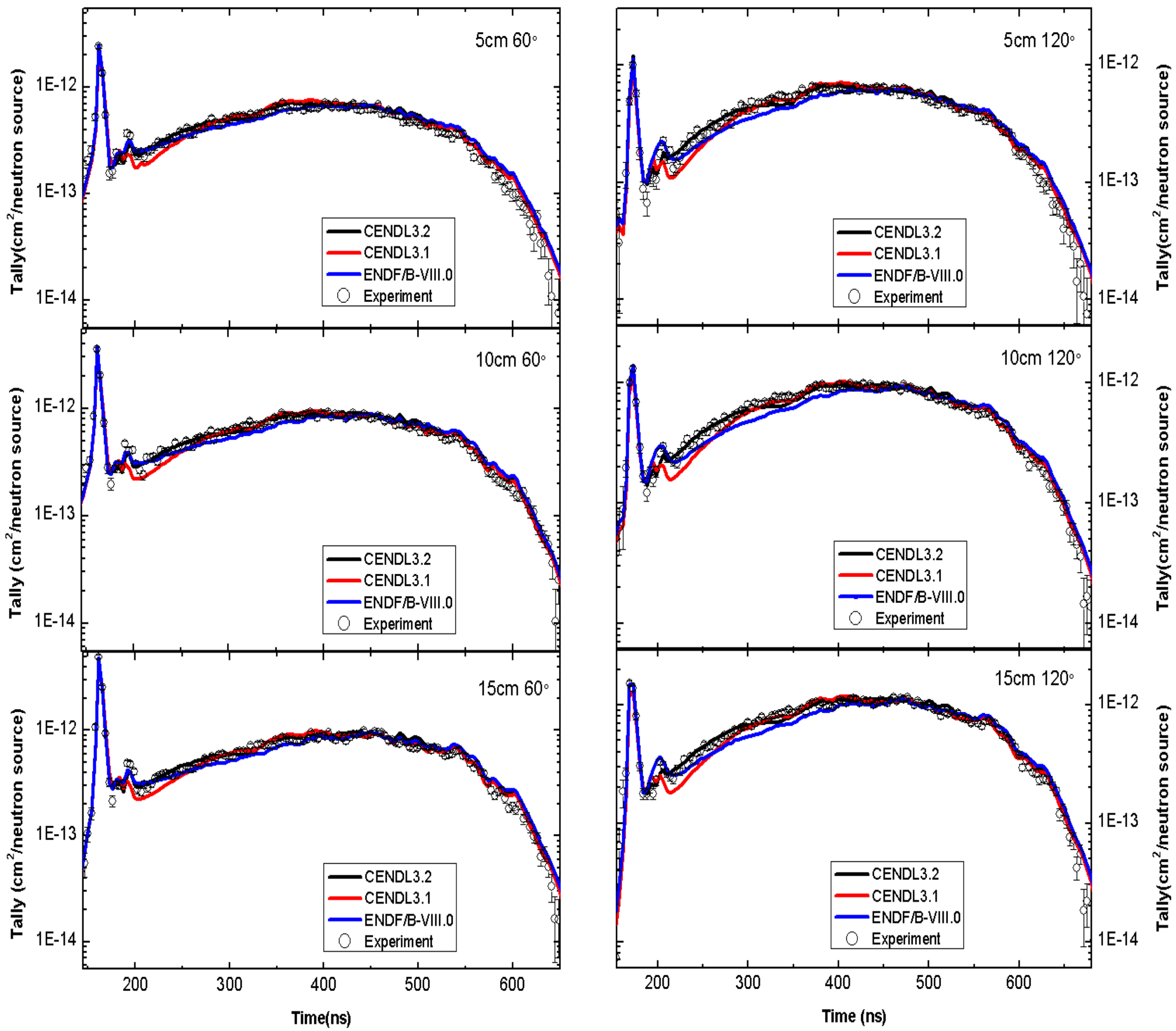


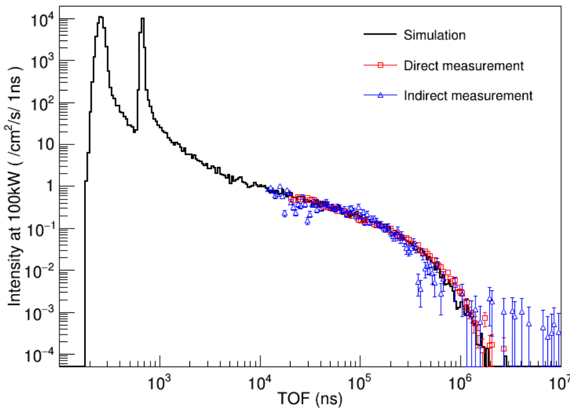
^{209}***Bi, d-D neutrons（left: BC501A; right: CLYC）***



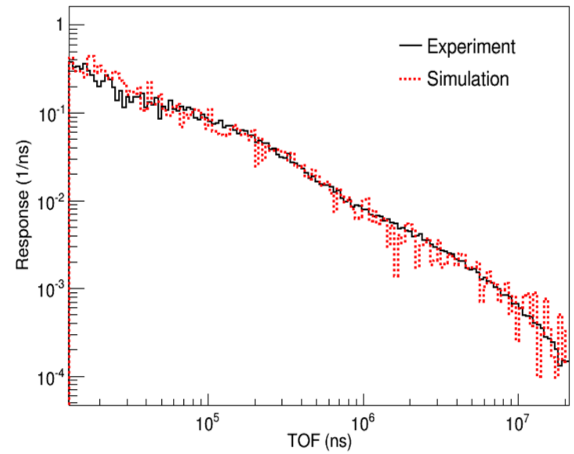
Iron data was used for improvement of CENDL data

3. Neutron capture cross section measurements at CSNS

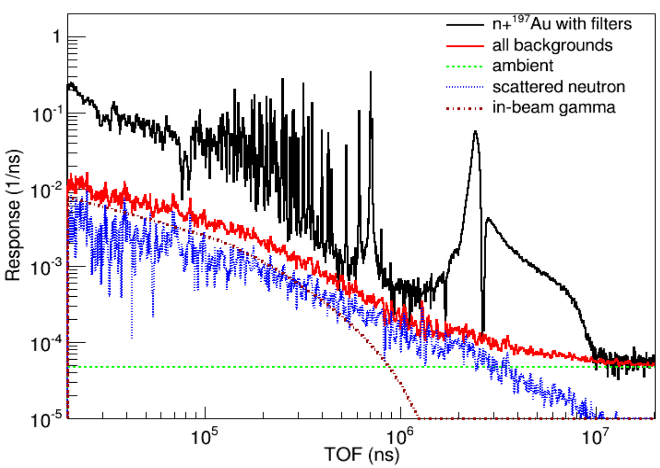
（1）Background study



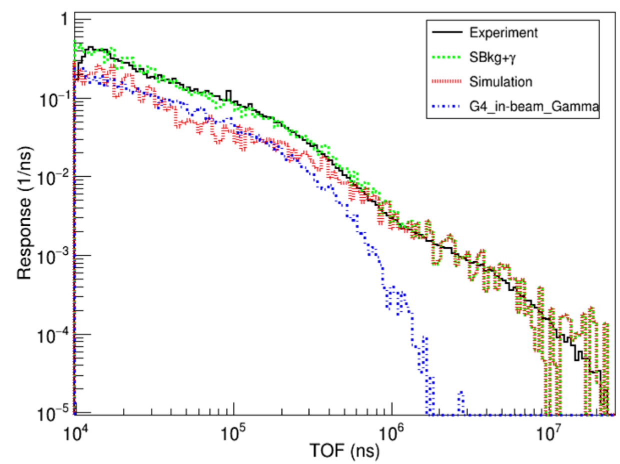
In beam gamma BG



Scattered neutron BG (Carbon)

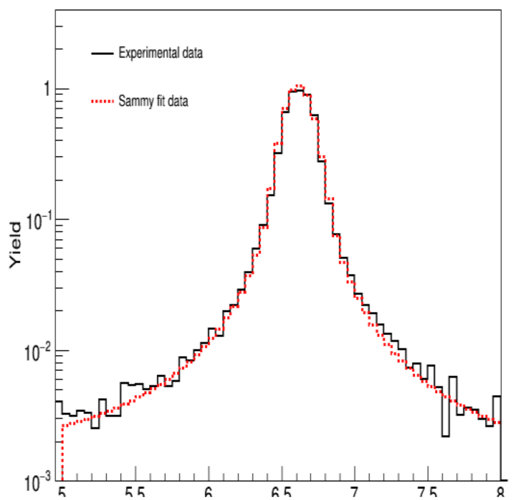


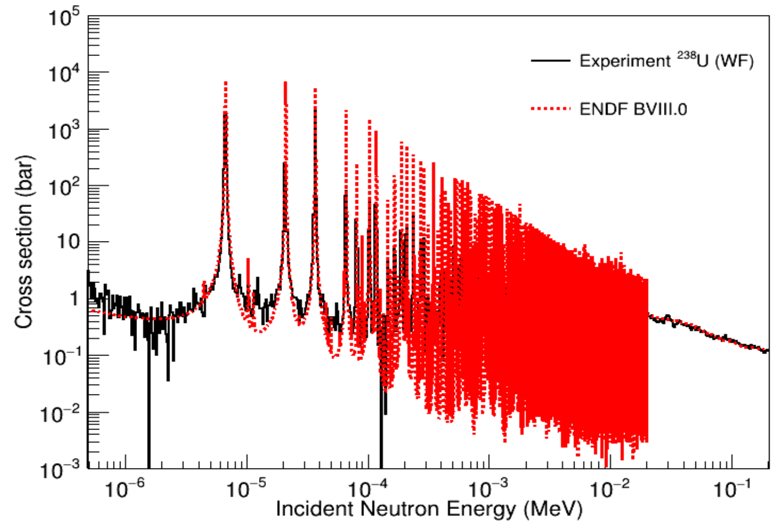
BG subtraction



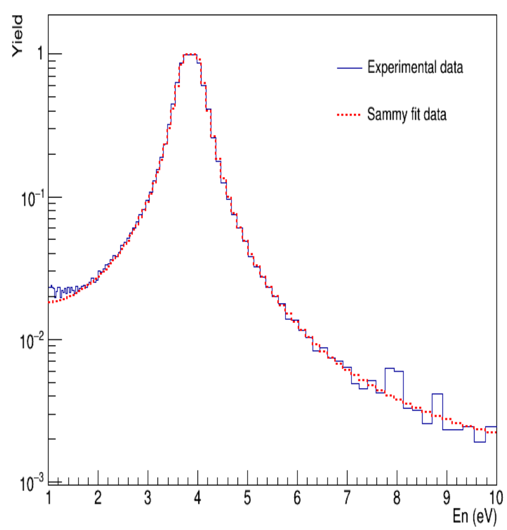
BG with Pb sample

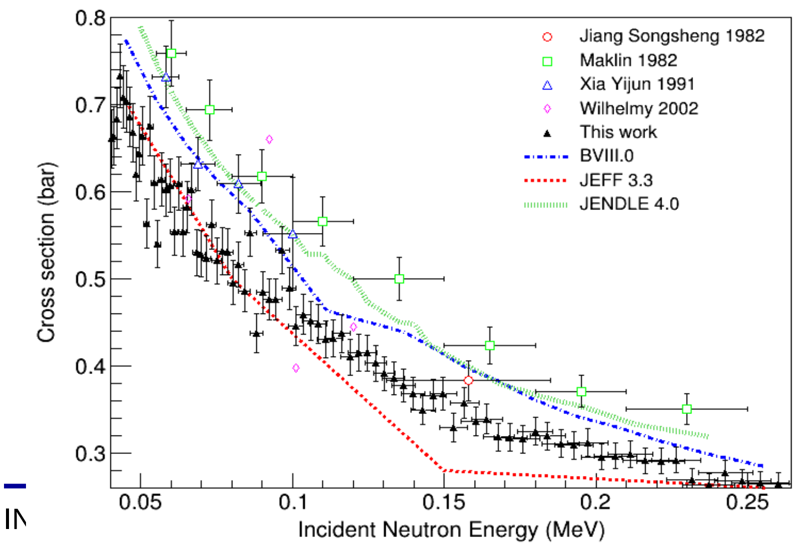
（2）Preliminary results





^{238}U and ^{169}Tm data are nearly ready for publication





Shanghai Institute of Applied Physics (SINAP)

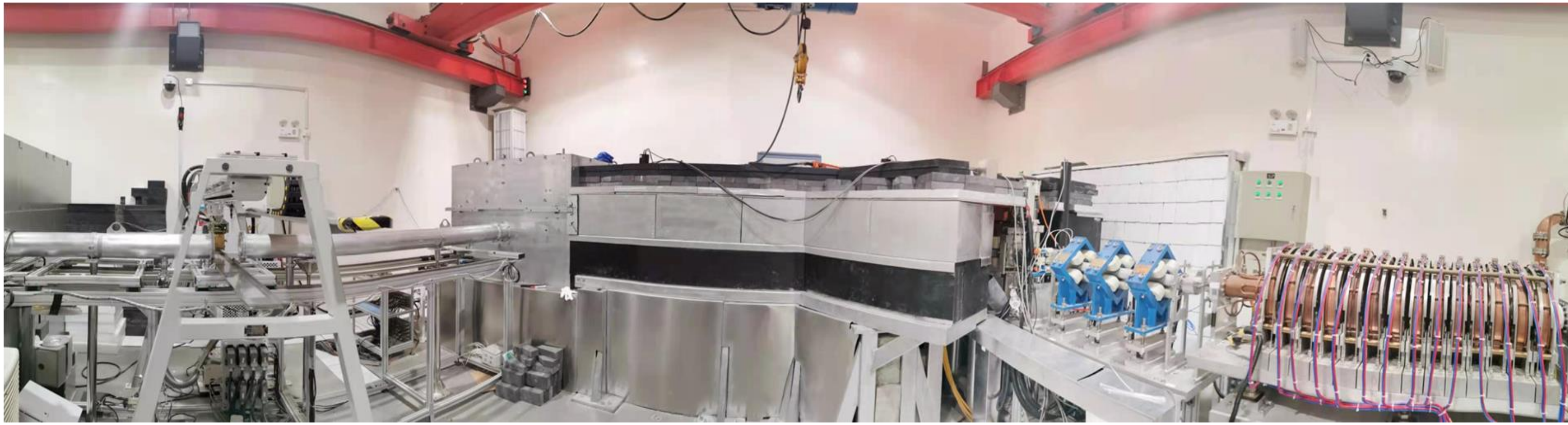
Nuclear data measurements of key nuclides for TMSR

TMSR Photo-Neutron Source (TMSR-PNS)

TMSR-PNS is a compact electron-linac-driven neutron source at the Shanghai Institute of Applied Physics, Chinese Academy of Sciences (SINAP, CAS).

- Electron-beam energy: 15 MeV;
- Pulse width: 3-10 ns, 15-30 ns, 0.5-3 μs;
- Pulse frequency: 1-260 Hz;
- Average beam current: 0.1 mA;
- Neutron yield: ~10^{11} n/s.

- Neutron nuclear data measurements;
- Boron equivalent measurements;
- Material irradiation;
- Measurement of Th-U fuel conversion ratio.



Nuclear data measurements of key nuclides for TMSR

To meet the neutron nuclear data requirements of thorium-uranium fuel cycle, the key nuclear data have been measured at TMSR-PNS and Back-n facility, respectively, which provide important supports for the physical design of Thorium Molten Salt Reactor (TMSR).

TMSR-PNS

- Thermal Neutron Scattering (TNS) effect for Ni ,Fe, GH3535;
- $^{nat.}$Li(n, tot)

Measurement Data of TMSR

Back-n

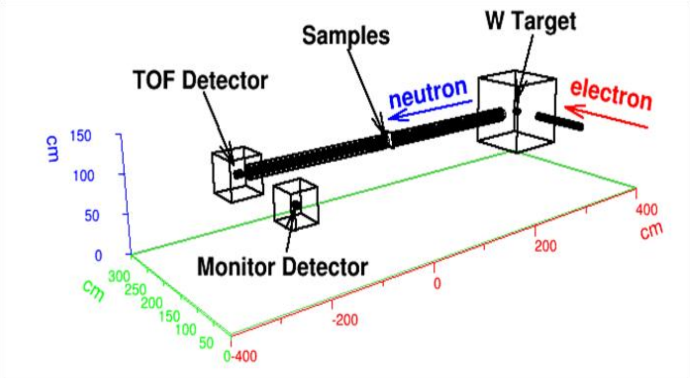
- ^{232}Th (n, γ)
- $^{nat.}$Li(n, tot)

Back-n at CSNS & TMSR-PNS at SINAP

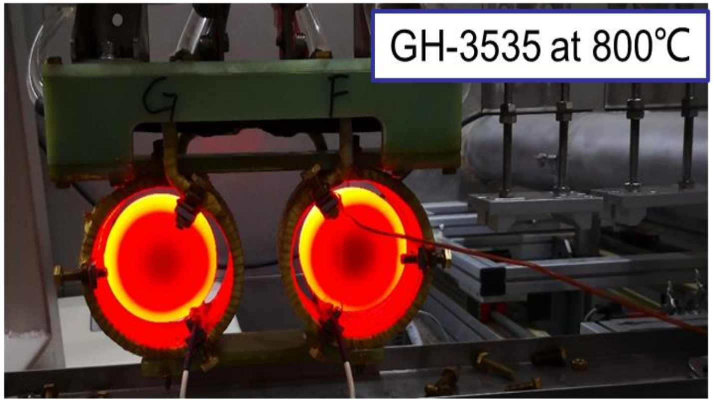
Measurements of TCS for Ni ,Fe, GH3535 at TMSR-PNS

Measurements of Total Cross Section (TCS) provide important data for the study of (Thermal Neutron Scattering)TNS effect

- Spectrometer: Time-of-flight spectrometer
- Method : Transmission method
- Detector: ^{6}LiF (EJ-426)
- Samples: Ni ,Fe, GH3535



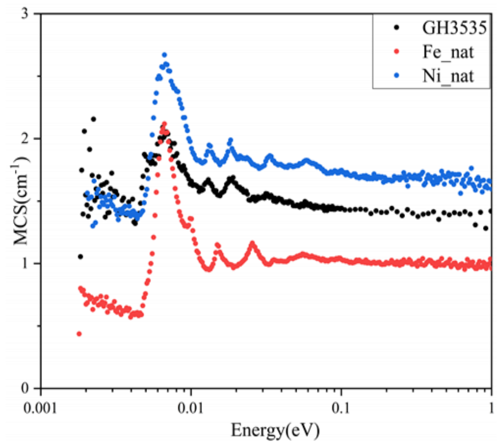
Samples	Diameter:mm	Thickness:mm	Temperature:℃
nat-Ni	60	8	20
nat-Fe	60	8	20
GH-3535	70	7.9	20/400/800

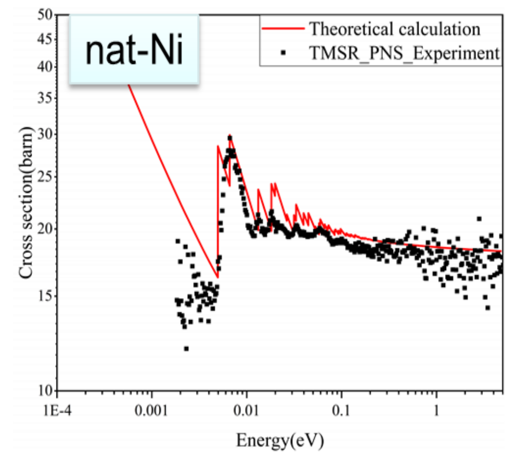


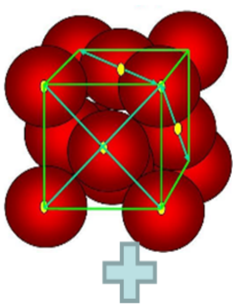
Measurements of TCS for Ni, Fe and GH3535 at TMSR-PNS

Measurement results

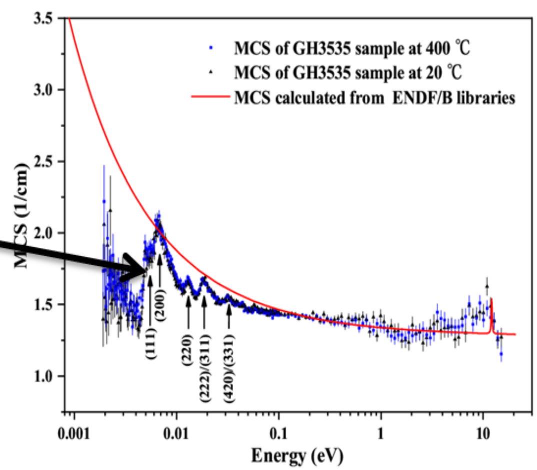
- The experimental data of TCS for Ni ,Fe and GH3535 are measured, respectively.
- The theoretical thermal neutron scattering cross-sections for nat-Ni are obatined from NJOY
- Comparison between the theory and the experiment was performed.







$\lambda = 2d(hkl)$

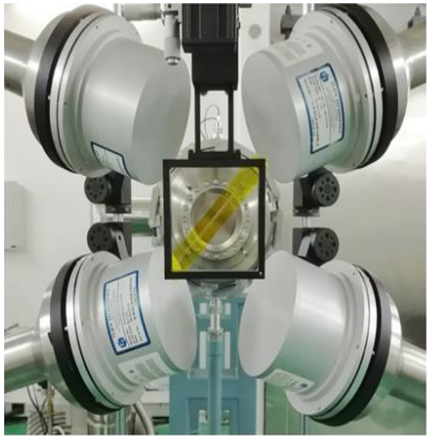


- It can be observed that the energy positions of Bragg-edges, and the Miller indices corresponding to the micro crystal structure (FCC) of the sample GH3535 are shown for each distinguishable Bragg-edge.

Measurement of ^{232}Th (n,γ) at Back-n

Experimental details

- **γ-detection**
- **Spectrometer:** CSNS Back-n time-of-flight spectrometer
- **Detector:** four hydrogen-free deuterated benzene C6D6 liquid scintillation detectors
- **Method:** total energy detection principle in combination with the Pulse Height Weighting Technique (PHWT)

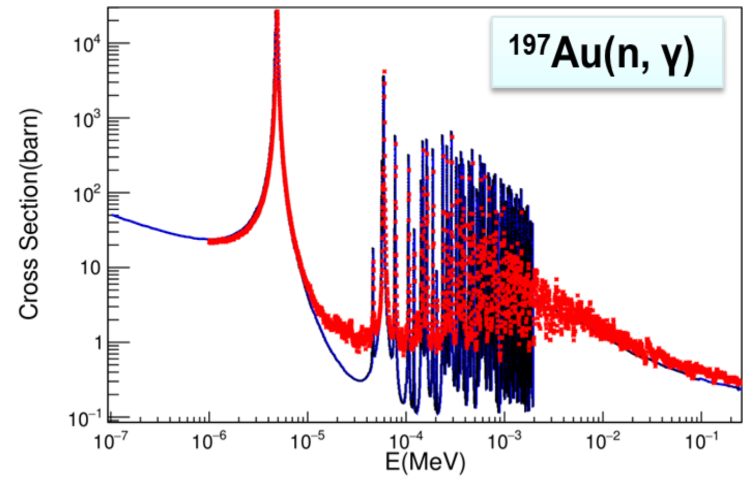


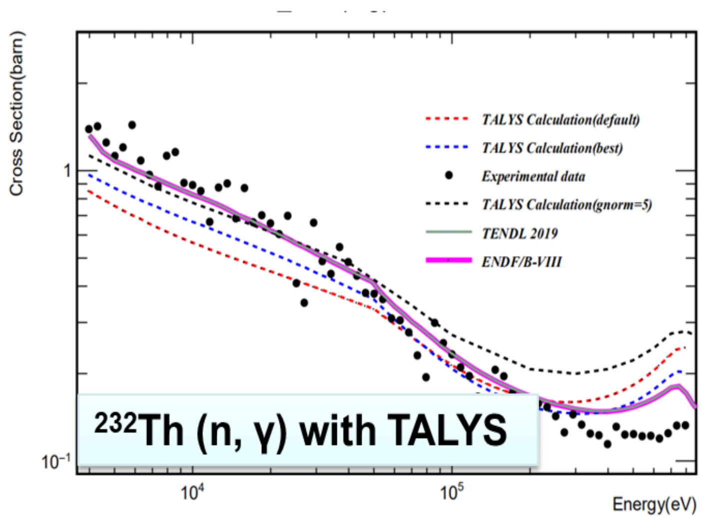
- **Samples & Background deduction**
- **^{197}Au:** to verify the data analysis procedure and to use for normalization
- **^{232}Th:** disk-shaped ^{232}Th sample with a diameter of 30mm and a thickness of 1mm
- **^{nat}C:** to evaluate the background resulting from sample scattered neutrons
- **^{nat}Pb:** to evaluate the background resulting from in-beam γ-rays
- **Empty holder**

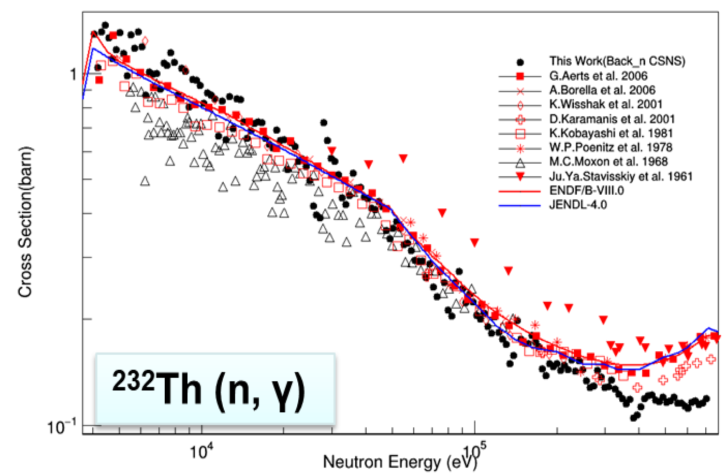
Measurement of ^{232}Th (n,γ) at Back-n

□ Measurement result

- Comparison of measured ^{232}Th /^{197}Au(n, γ) cross section with evaluated data from ENDF/B-VIII.0
- Calculation of ^{232}Th(n,γ) cross section with TALYS, and comparison with various measurements

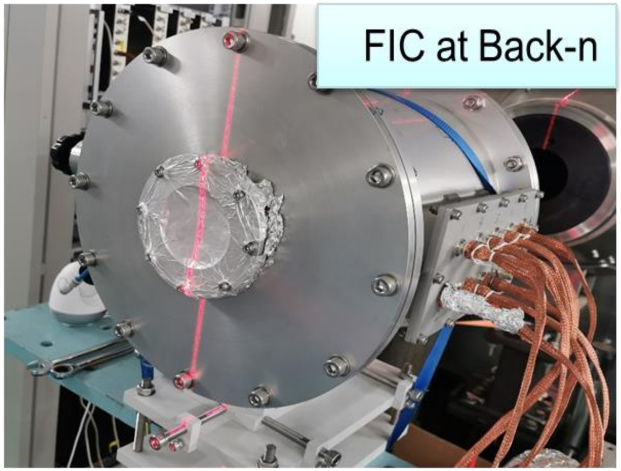


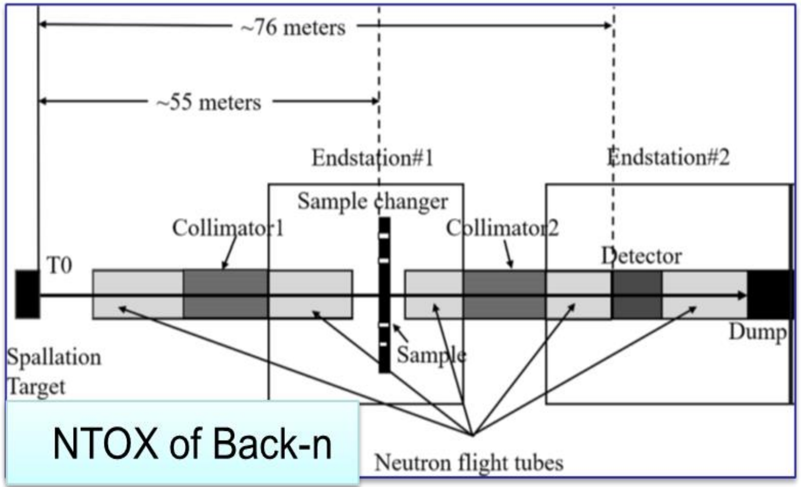




Measurement of TCS for ^{nat}Li at TMSR-PNS & Back-n

- **Spectrometer:** Time-of-flight spectrometer
- **Method :** Transmission method
- **Detector:** ^{6}LiF at TMSR-PNS， Multilayer fast ionization chamber (FIC) at Back-n
- **Samples:** Natural lithium (92.5% ^{7}Li, 7.5% ^{6}Li, Φ=50 mm, h=15 mm & 8 mm） is covered with aluminum to avoid oxidation


FIC at Back-n



NTOX of Back-n


Natural lithium samples

Measurement of TCS for ^{nat}Li at TMSR-PNS & Back-n

□ Data analysis

◆ TMSR-PNS

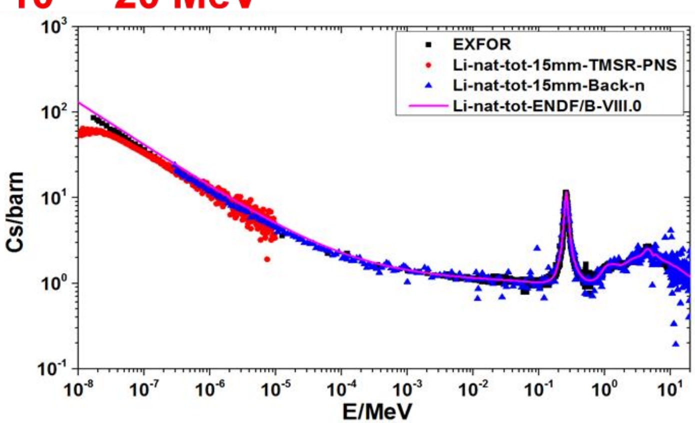
- ➢ **Background**
- ➢ **Neutron energy calibration**
- ➢ **Discrimination of n/γ :** PSD

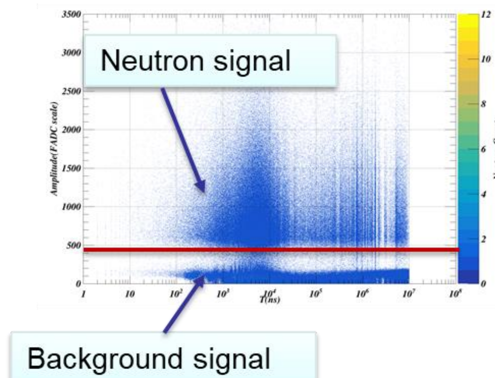
◆ Back-n

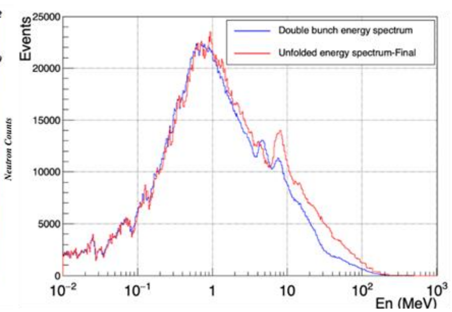
- ➢ **Neutron signal:** Threshold discrimination
- ➢ **Neutron energy calibration:** 8.77 eV resonance of ^{235}U
- ➢ **Double bunch spectrum unfolding**

□ Measurement result:

10^{-8} ~20 MeV







Institute of Modern Physics

Charged particle induced reaction measurements

中国原子能科学研究院
CHINA INSTITUTE OF ATOMIC ENERGY

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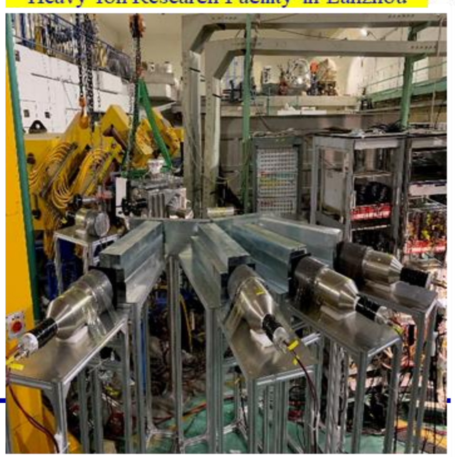
Double differential neutron yields from thick targets

- ☐ Measurements were carried out at the first Radioactive Ion Beam Line in Lanzhou (HIRFL-RIBLL1).
- ☐ BC501A liquid organic scintillator scintillation (5 inch thick and 5 inch in diameter) was used as a neutron detector.
- ☐ The experimental results were compared with GEANT4, FLUKA and PHITS calculations.

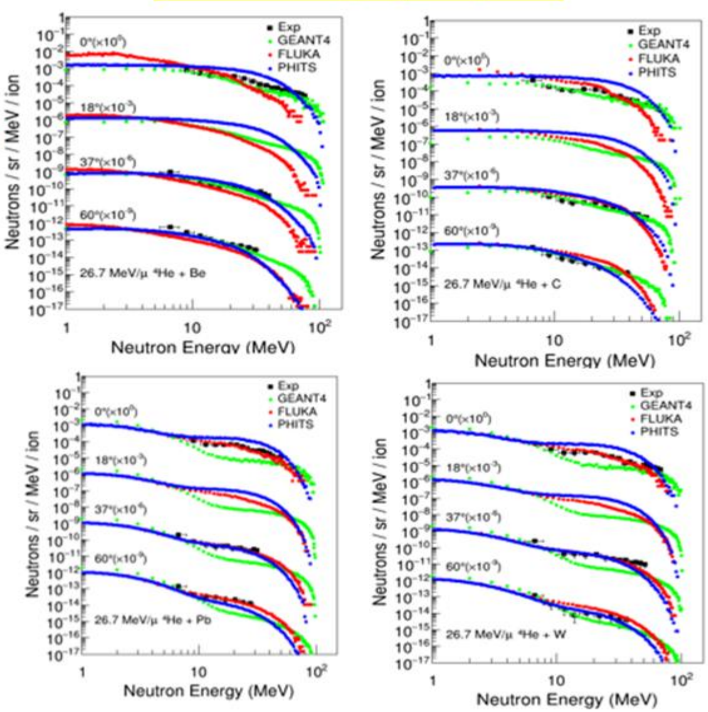
① 26.7 MeV/u ^{4}He + Be, C, Pb, W

② 80.5 MeV/u ^{12}C + Be, C, Pb, W

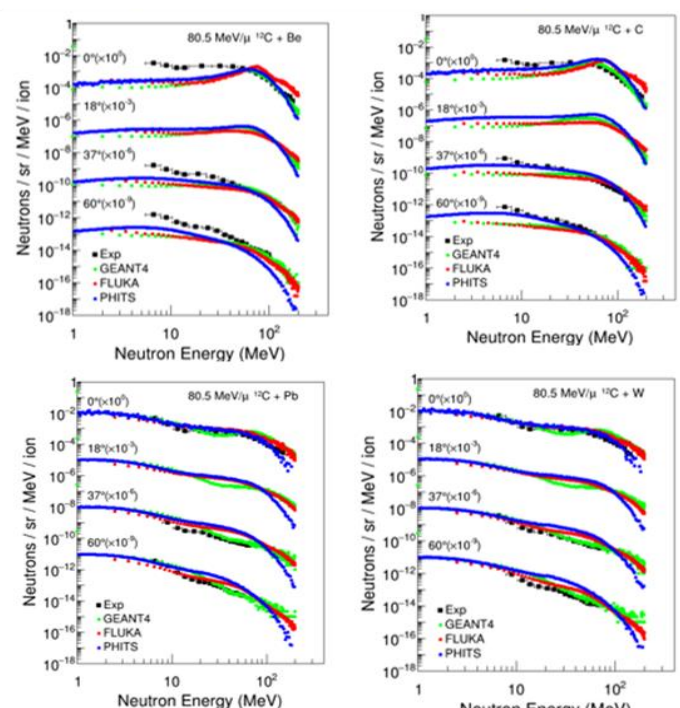
Heavy Ion Research Facility in Lanzhou



^{4}He + Be, C, Pb, W

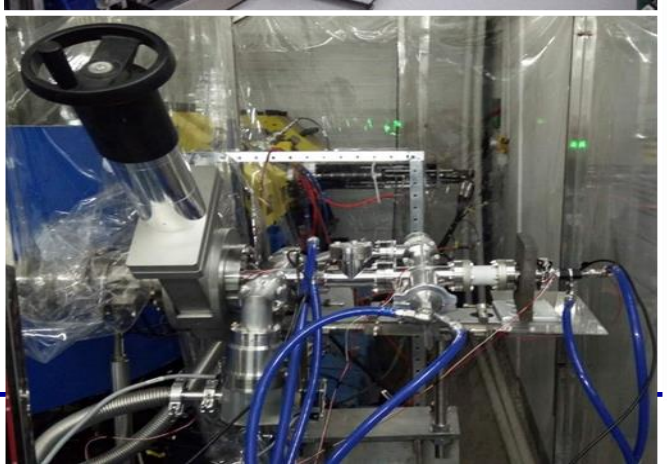


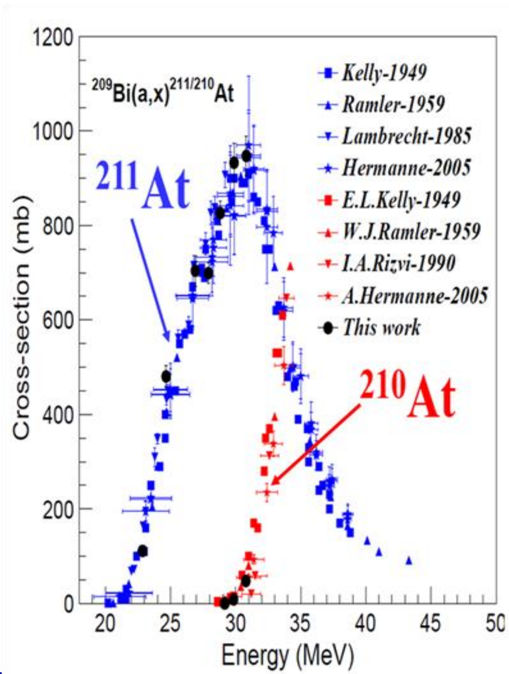
^{12}C + Be, C, Pb, W

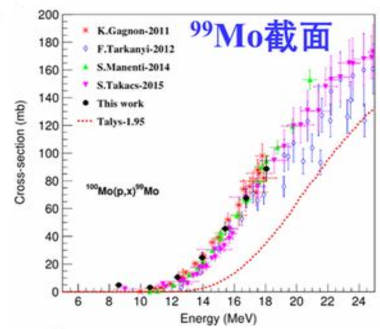


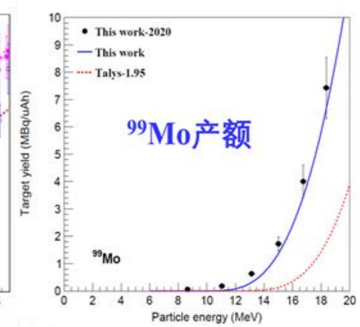
Excitation functions of ^{4}He and proton induced reactions for medical radioisotopes production

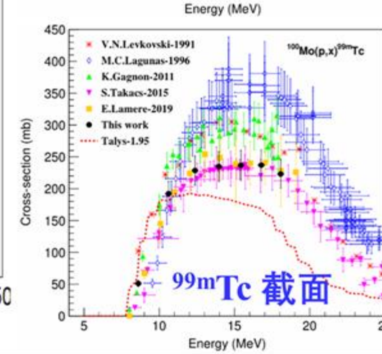
- Excitation functions of the ^{209}Bi(^{4}He, x)^{210,211}At and ^{nat}Mo(p, x) ^{99}Mo/^{99m}Tc reactions were measured.
- The irradiation was carried out at the superconducting linac at IMP,CAS.

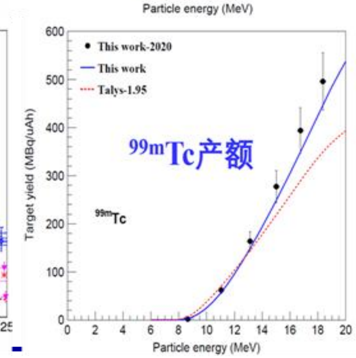






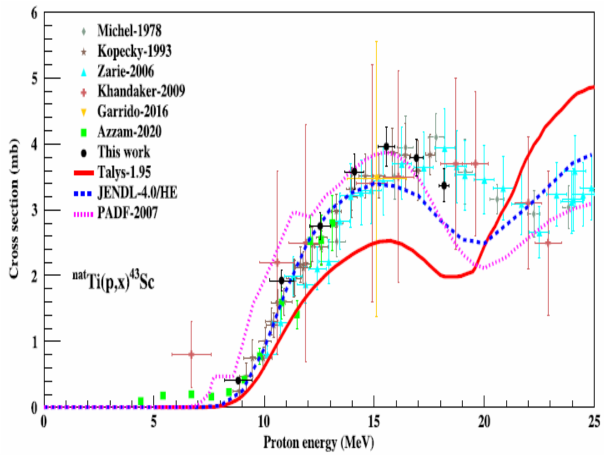


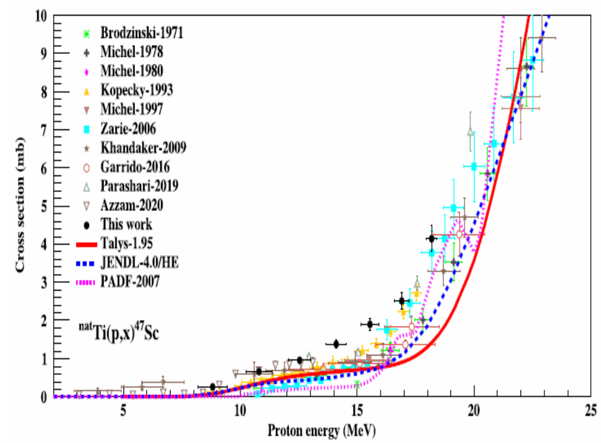


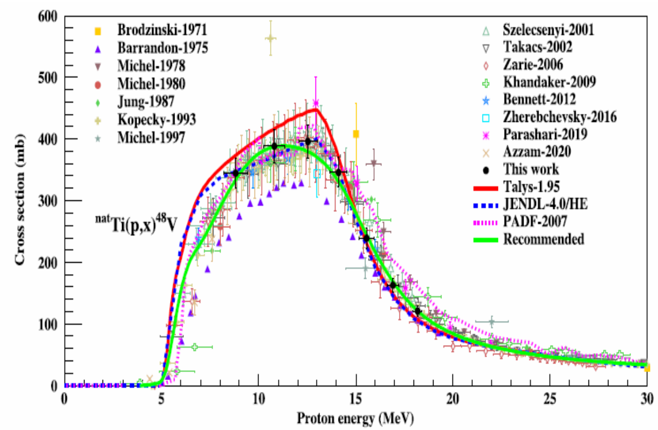


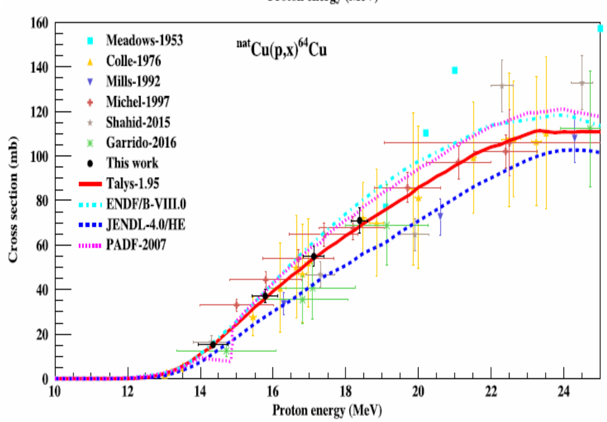
Excitation functions of proton induced reactions

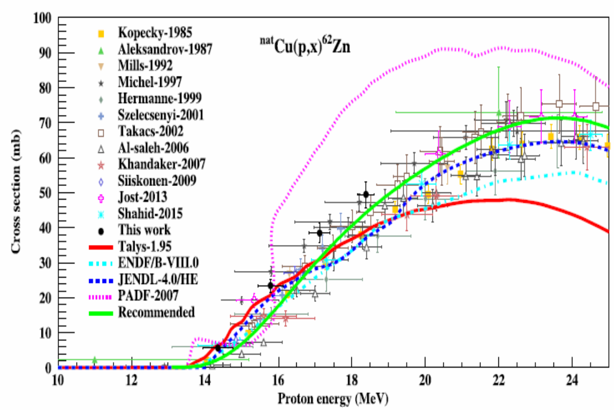
- Excitation functions of the $^{nat}Ti(p, x)^{43,47}Sc$, ^{48}V and $^{nat}Cu(p, x)^{64}Cu$, $^{62,65}Zn$ reactions were measured in the energy range of 8.8–18.4 MeV.
- The stacked-foil activation technique and off-line gamma spectroscopy were used.
- The irradiation was carried out at the superconducting linac at the Institute of Modern Physics, Chinese Academy of Sciences.
- The experimental results were compared with TALYS calculations, IAEA recommended data and evaluated nuclear data of the ENDF/B-VIII.0, JENDL-4.0/HE and PADF-2007 libraries.

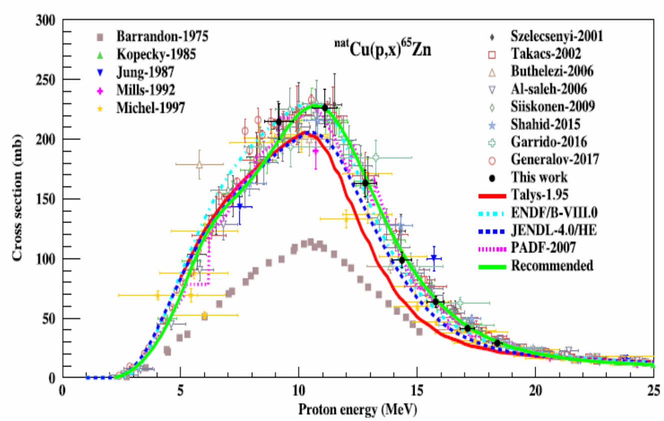












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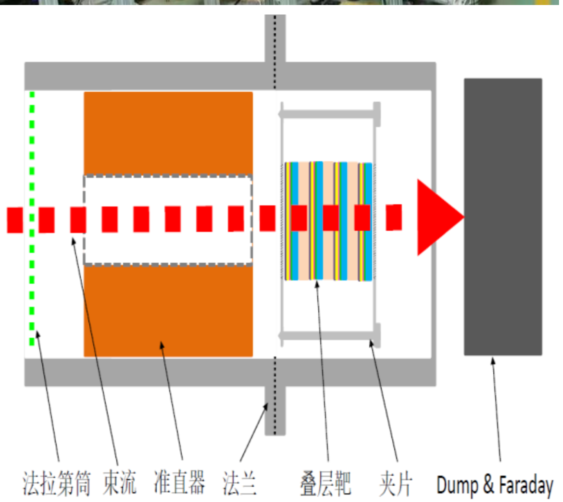
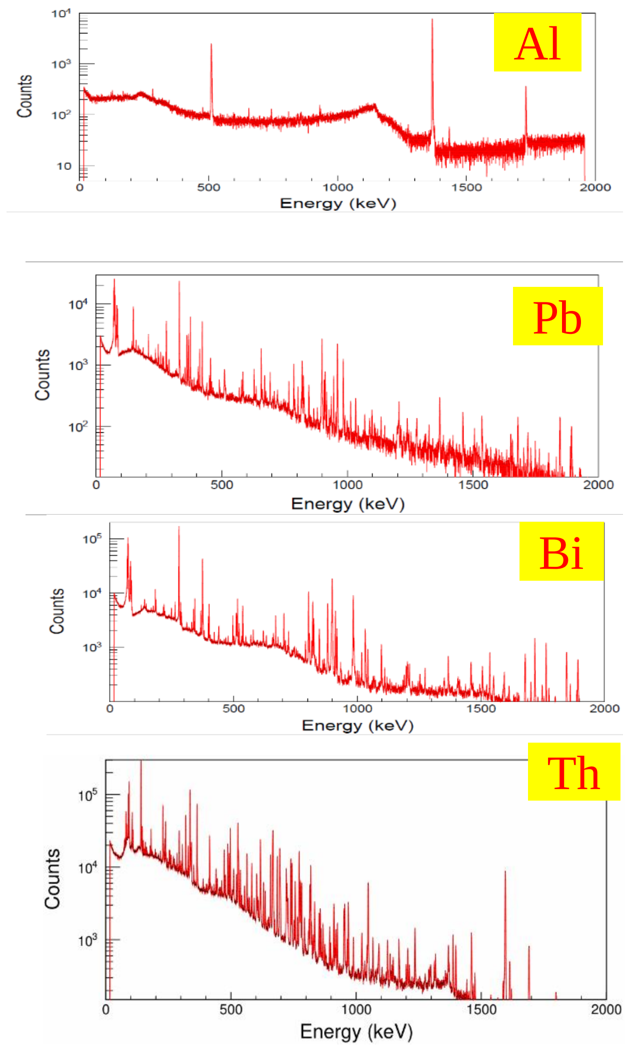
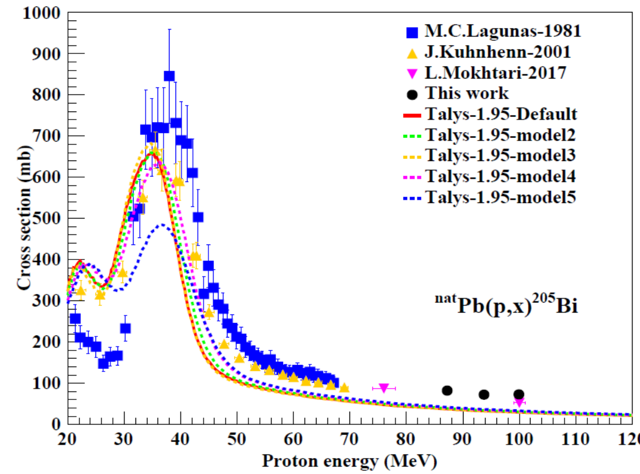
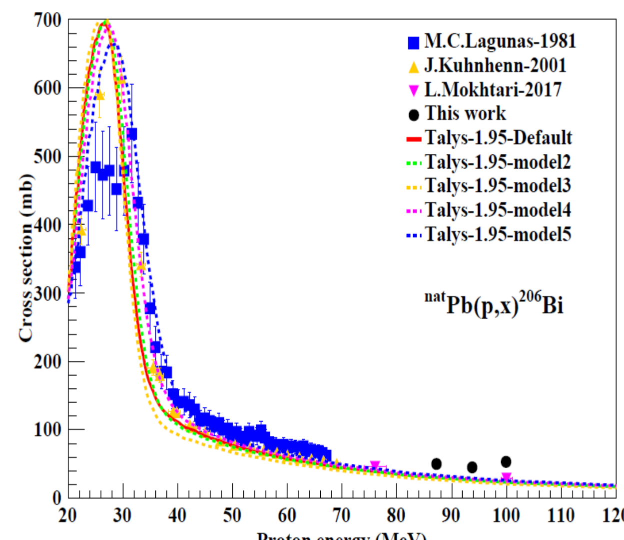
Measurements of spallation products induced by 100 MeV proton

- Spallation products induced by 100 MeV proton on Pb, Bi, Th targets were measured.
- The stacked-foil activation technique and off-line gamma spectroscopy were used.
- The irradiation was carried out at HIRFL-SSC at IMP, CAS.
- The experimental data are under analyzing.









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Measurement of leakage neutron spectra for ^{nat}Zr, ^{nat}Al with D-T neutrons at CIAE

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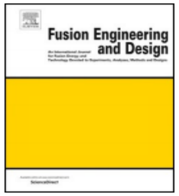

^{nat}Zr

Measurement of leakage neutron spectra for zirconium with D-T neutrons and validation of evaluated nuclear data

Check for updates

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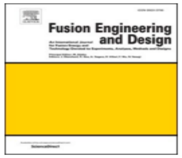

^{nat}Al

Measurement of leakage neutron spectra for aluminium with D-T fusion neutrons and validation of evaluated nuclear data

Check for updates

S. Zhang[a,b,c,*], D. Niu[a,c], D.X. Wang[a,c], Y. Nie[b], N. Song[a,c], J.C. Wang[a,c], X. Ruan[b], M. Huang[a,c], R. Wada[d], J. Ren[b], Y. Ding[b], K. Zhang[b], X. Tang[c,e], R. Han[f], B. Liu[f], L. Lu[c], W. Jiang[f]

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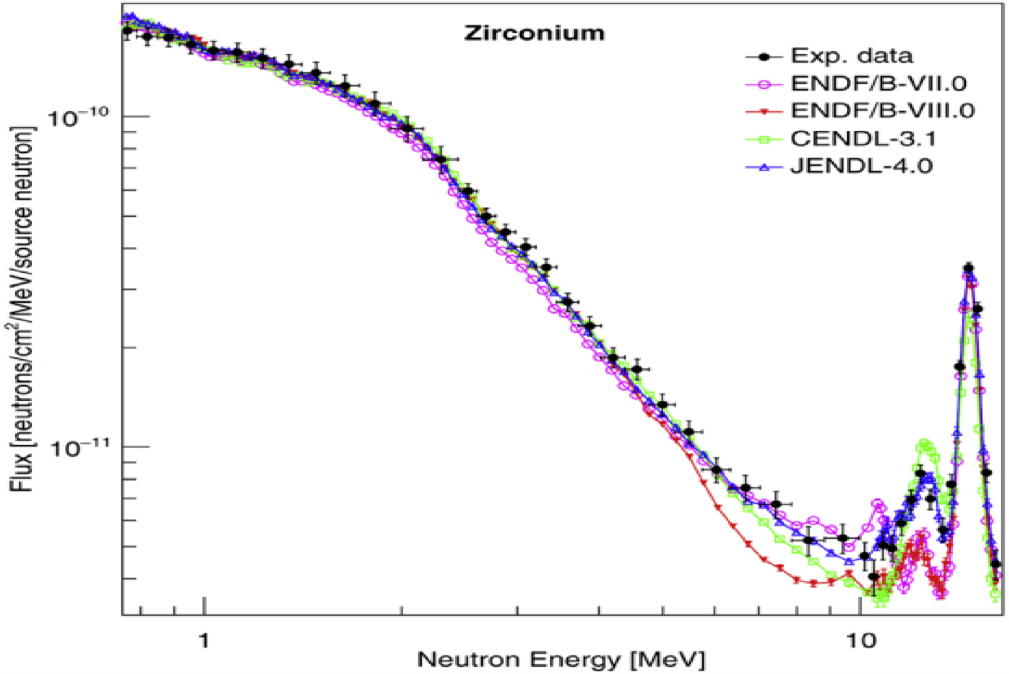
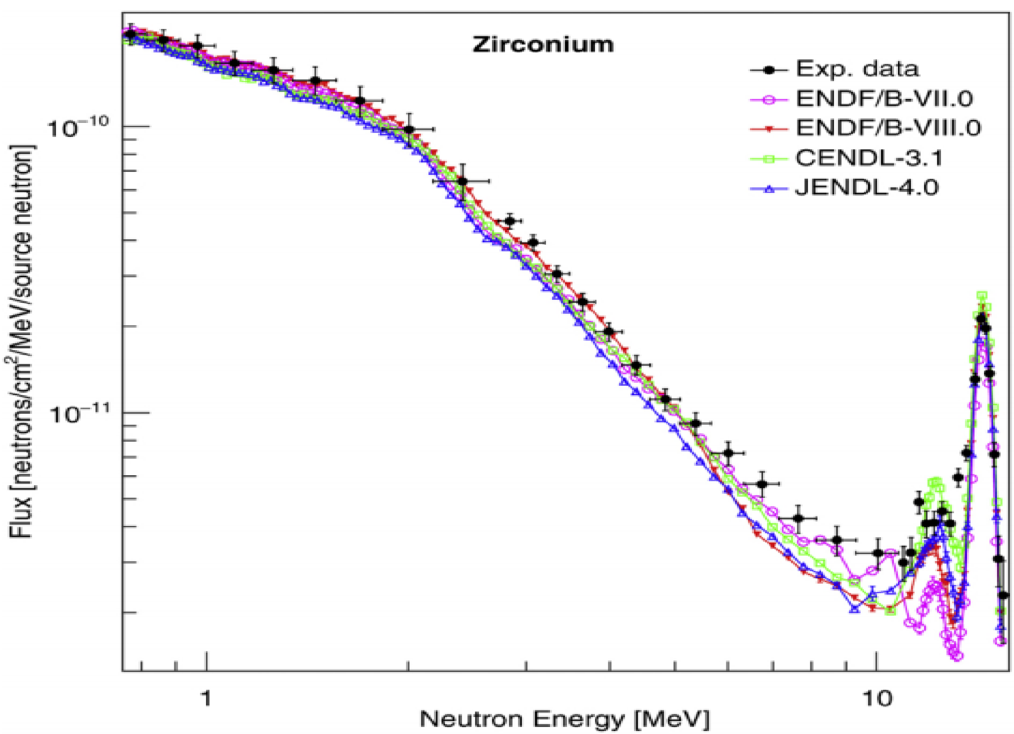
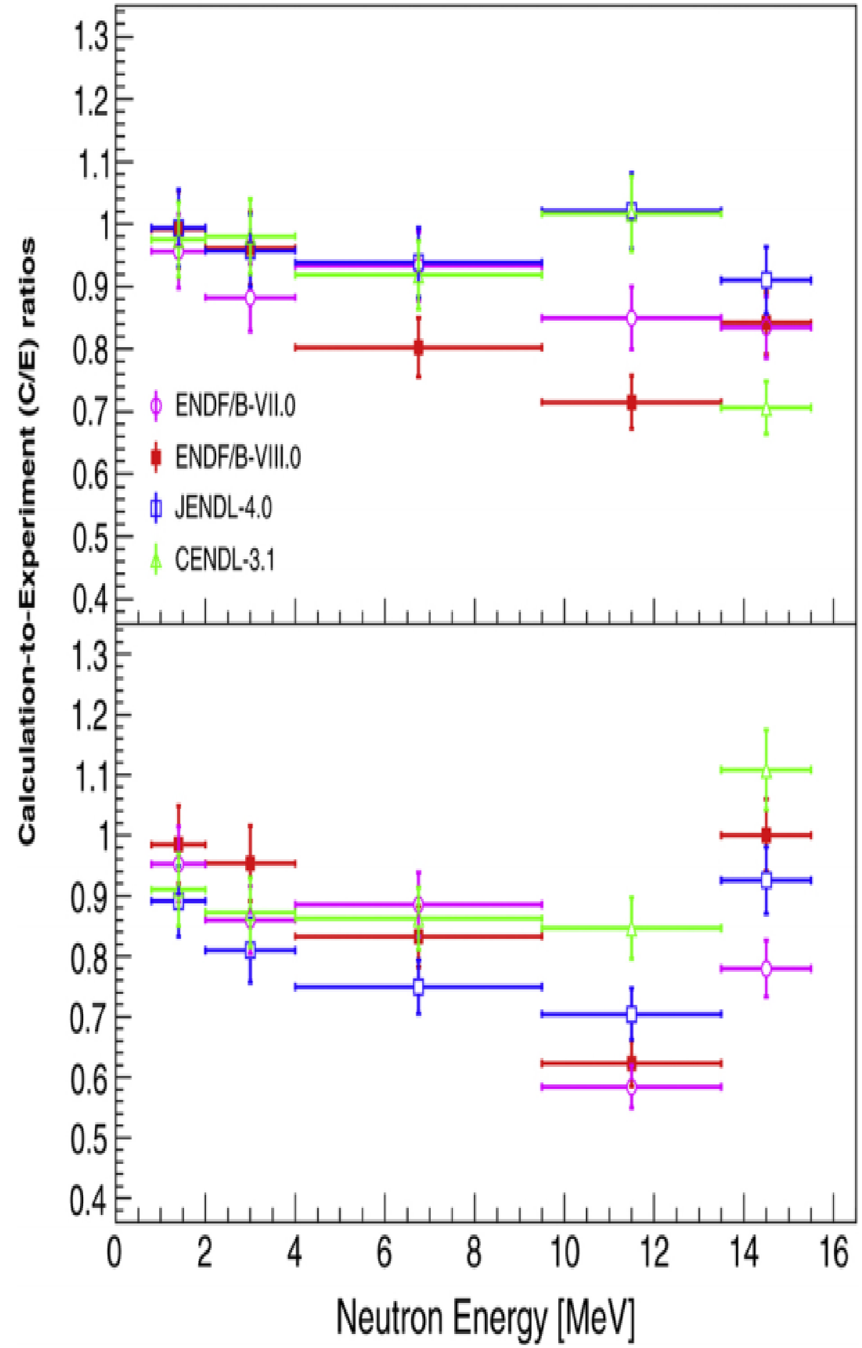
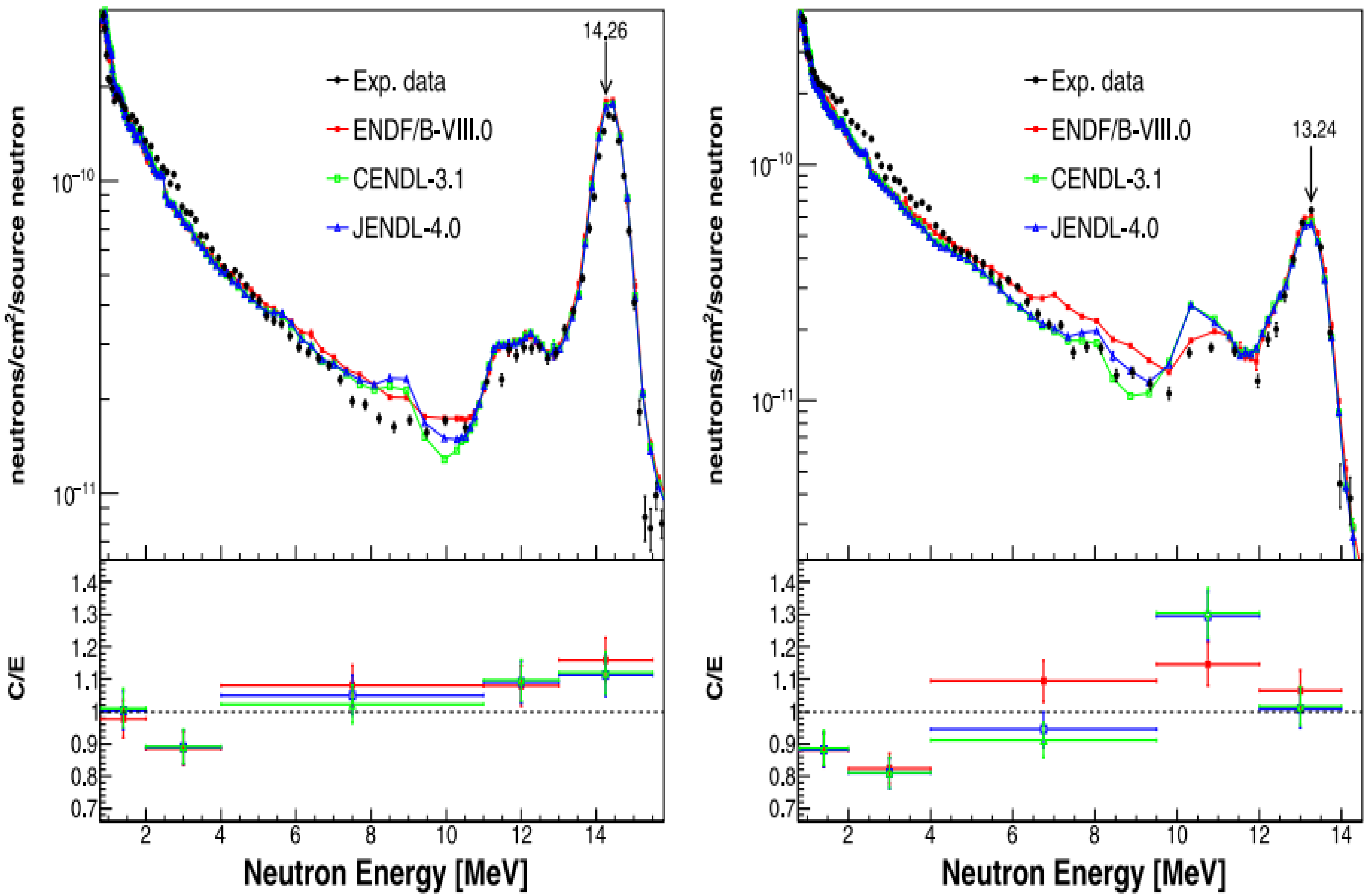

Zirconium
Exp. data
ENDF/B-VII.0
ENDF/B-VIII.0
CENDL-3.1
JENDL-4.0
Flux [neutrons/cm^2/MeV/source neutron]
10^{-10}
10^{-11}
1
10
Neutron Energy [MeV]


Zirconium
Exp. data
ENDF/B-VII.0
ENDF/B-VIII.0
CENDL-3.1
JENDL-4.0
Flux [neutrons/cm^2/MeV/source neutron]
10^{-10}
10^{-11}
1
10
Neutron Energy [MeV]


Calculation-to-Experiment (C/E) ratios
ENDF/B-VII.0
ENDF/B-VIII.0
JENDL-4.0
CENDL-3.1
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0
2
4
6
8
10
12
14
16
Neutron Energy [MeV]

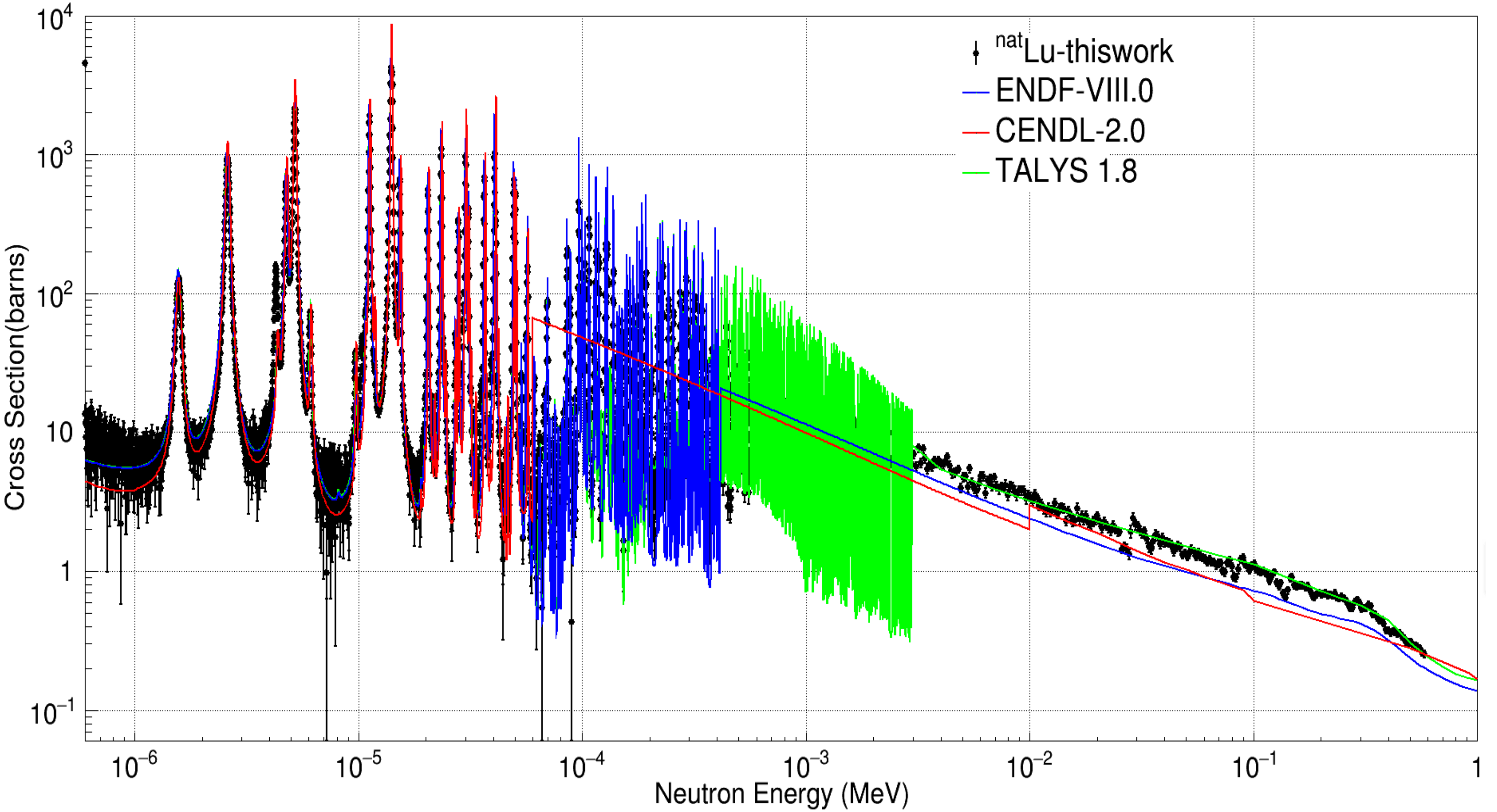
^{nat}Al case



14.26
Exp. data
ENDF/B-VIII.0
CENDL-3.1
JENDL-4.0
neutrons/cm²/source neutron
C/E
Neutron Energy [MeV]
13.24
Exp. data
ENDF/B-VIII.0
CENDL-3.1
JENDL-4.0
neutrons/cm²/source neutron
C/E
Neutron Energy [MeV]

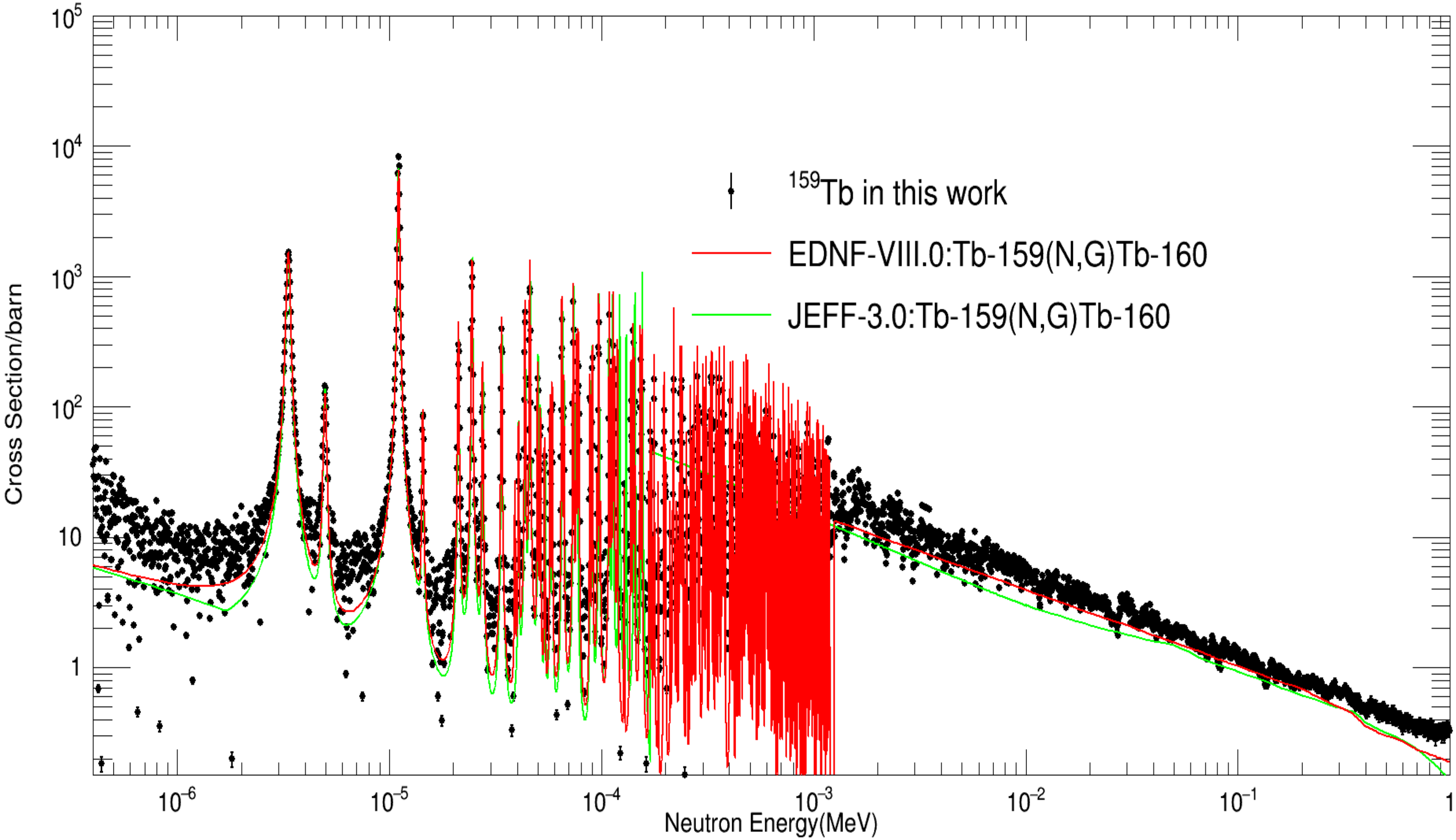
Neutron Capture Cross Section Measurement for ^{nat}Lu, ^{nat}Hf, ^{nat}Tb, ^{nat}Ho with CSNS Back-n

Preliminary result for ^{nat}Lu case



Neutron Capture Cross Section Measurement for ^{nat}Lu, ^{nat}Hf, ^{nat}Tb, ^{nat}Ho with CSNS Back-n

Preliminary result for ^{nat}Tb case



中国原子能科学研究院
CHINA INSTITUTE OF ATOMIC ENERGY

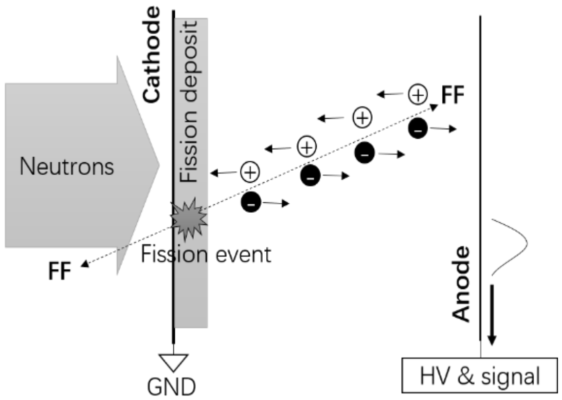
CHINA NUCLEAR DATA CENTER

Fission cross section measurement at CSNS by China Academy of Engineering Physics

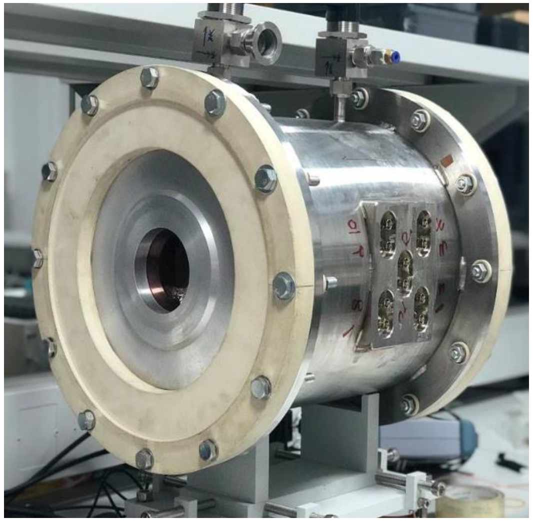
Dr. Yiwei Yang
winfield1920@126.com

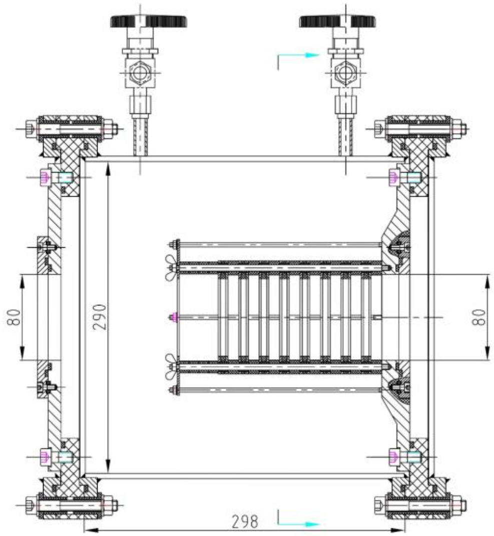
Fast Ionization Chamber for Fission Cross Section Measurement (FIXM)

- Ionization chamber**: simple** and **fast enough** for current operation mode of CSNS.
- Signal rise time about 40 ns.



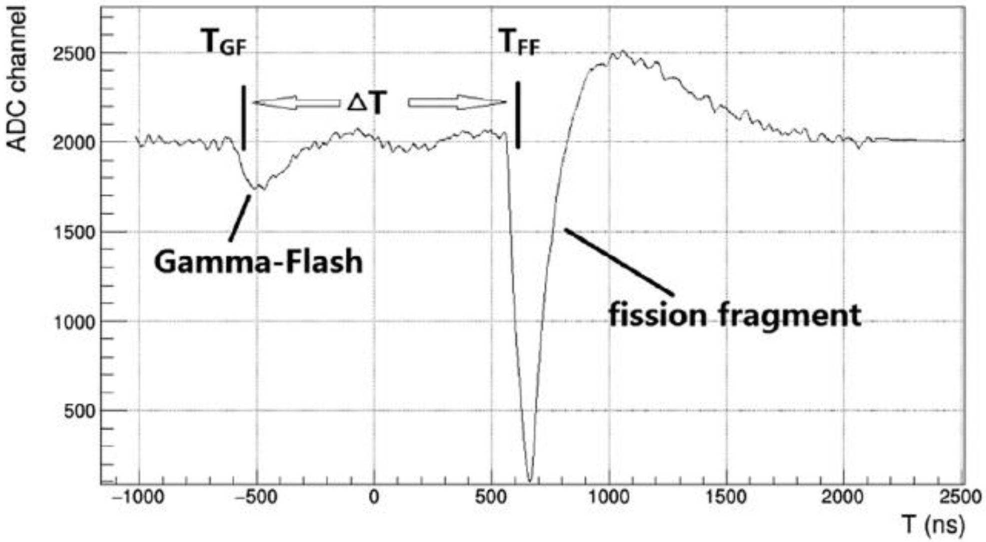
Basic principle diagram



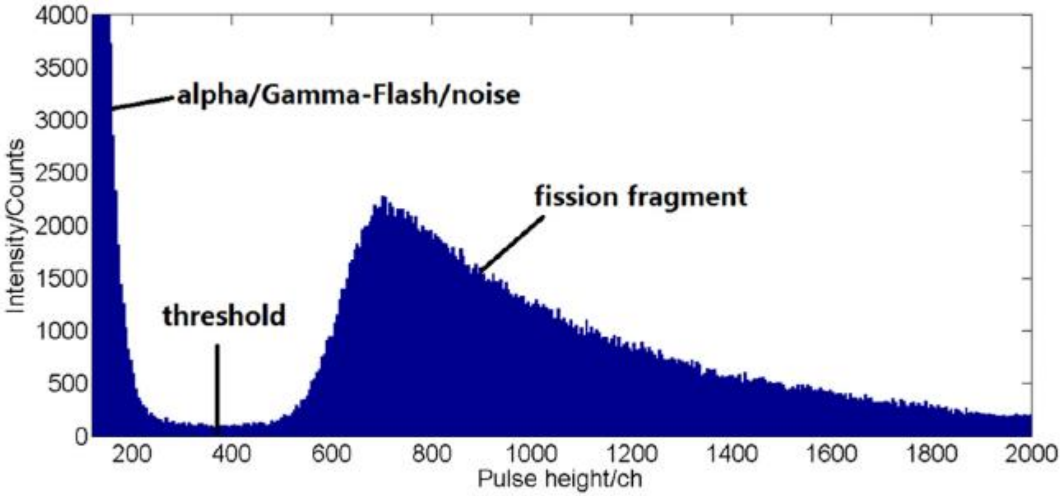


Measurement of the U-238/U-235 fission cross section ratio at CSNS – Back-n WNS

Annals of Nuclear Energy 140 (2020) 107301



Fission signal



PH spectrum

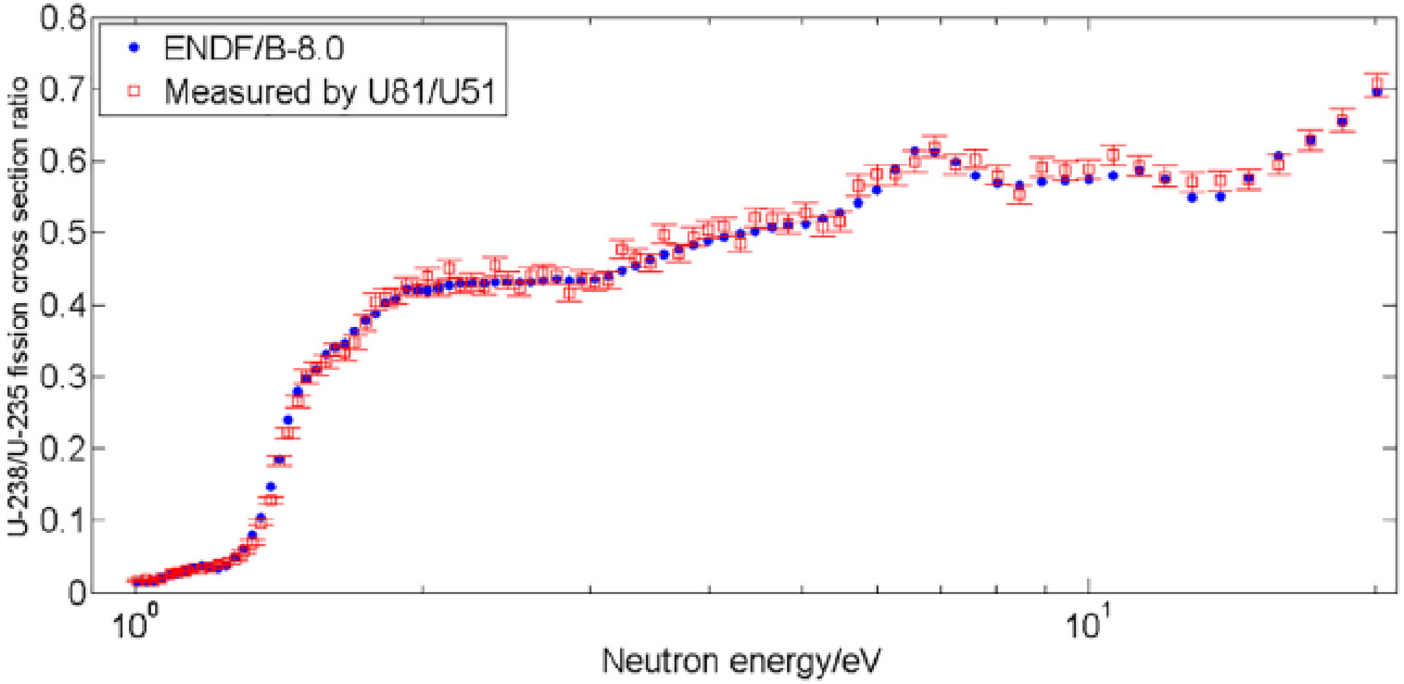
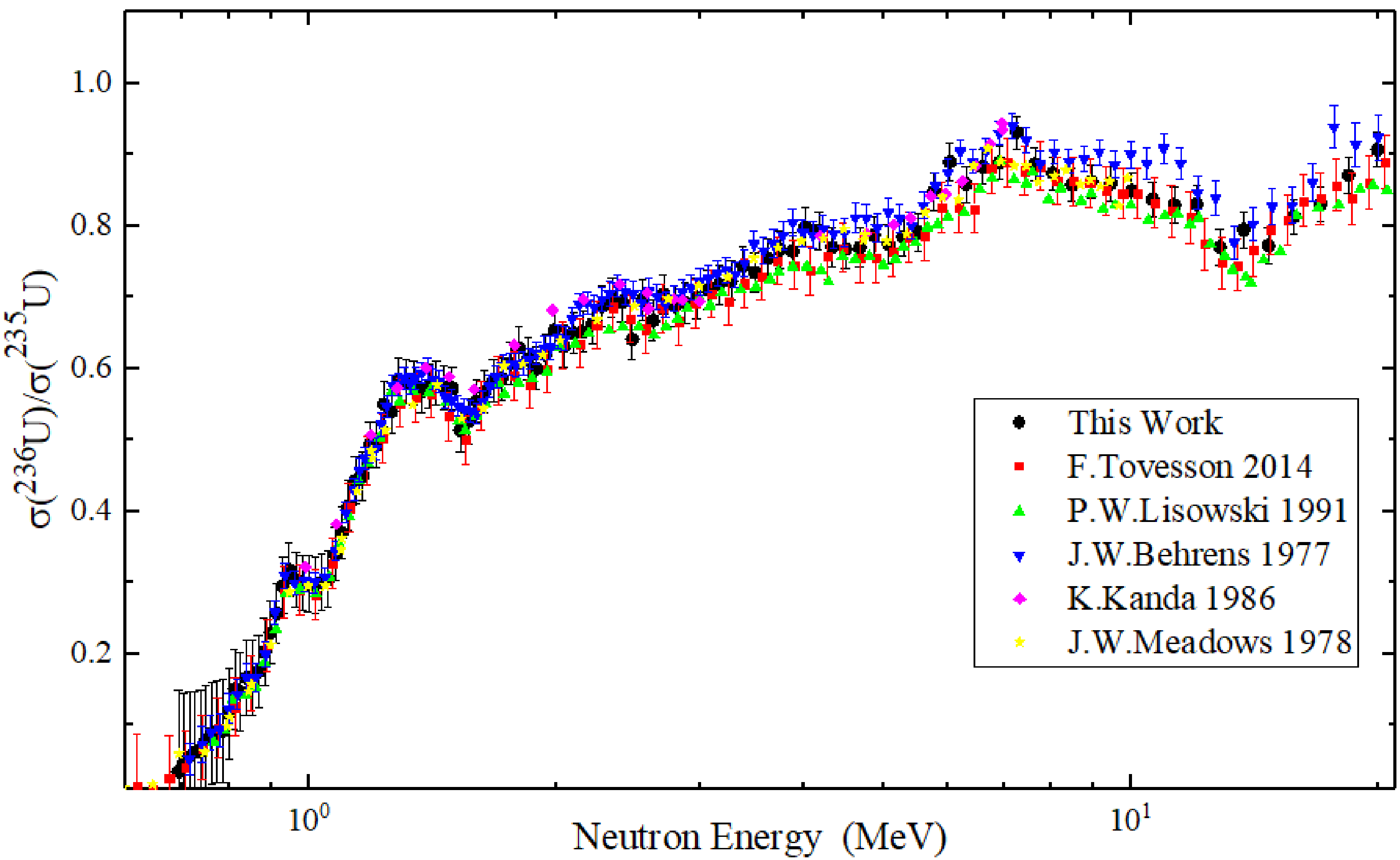


Fig. 13. The measured U-238/U-235 fission cross section ratios in 1–20 MeV region.

Measured U-238/U-235 ratio

Annals of Nuclear Energy 140 (2020) 107301



236U fission cross section result

PHYSICAL REVIEW C 102, 034604 (2020)

Status of CENDL

I. General Information of CNDC

CNDC

- ✓ China Nuclear Data Center (CNDC) was established in 1975,
- ✓ Joined the nuclear data activities of IAEA as the national nuclear data center of China since 1984.

The current main task of CNDC:

- ✓ CENDL library development and maintenance
- ✓ Nuclear data evaluations, nuclear reaction theory study and nuclear data benchmarking.
- ✓ Nuclear data measurement.
- ✓ The exchange of nuclear data activities with IAEA, foreign nuclear data centers and agencies.
- ✓ The services for domestic and foreign nuclear data application users.

II. The latest version CENDL-3.2 released on June 12.2020

As a general purpose evaluated nuclear database, Chinese Evaluated Nuclear Data Library (CENDL) is not only an output of more-than-forty-year domestic cooperation under the name of CENDL Library Project via China Nuclear Data Coordination Network (CNDCN), but also a product of international collaborations, especially under the multi-lateral framework of IAEA and OECD/NEA/WPEC.

Coordinated by China Nuclear Data Center (CNDC) during 2015-2019, CENDL-3.2 is the latest release of CENDL. With ENDF-6 formatted neutron reaction data for **a total number of 272 materials**, CENDL-3.2 is expected to meet general requirements for diversified scenarios of peaceful use of nuclear power and nuclear technology application.

The data for **135 materials are totally new or partly updated evaluations**, while the other 137 materials were inherited and adopted as it was from previous version, CENDL-3.1.

Table 1. Nuclides List and Major Updates for CENDL-3.2

Newly Evaluated and Partly Updated (135 Nuclides)
Newly Evaluated (58 Nuclides): n-1, H-1, Na-23, Al-27, S-32, S-33, S-34, S-36, Ca-40, Fe-56, Ni-58, Zn-64, Zn-66, Zn-67, Zn-68, Zn-70, Se-74, Se-76, Se-77, Se-78, Se-79, Se-80, Se-82, Kr-87, Kr-88, Mo-93, Mo-99, Sn-126, Sn-128, Sb-124, Sb-127, I-130, I-131, Xe-123, Xe-124[b], Xe-129, Xe-131, Xe-132[b], Xe-133, Xe-134[b], Xe-135[b], Xe-136, La-139[b], Ce-140, Ce-141[b], Ce-142, Ce-144[b], Ho-165, W-180, W-182, W-183, W-184, W-186, U-236, U-240, Np-236, Pu-238, Am-241.
Partly Updated (77 Nuclides): H-2, Li-7, Ti-48, Ga-69[b], Ga-71[b], Ge-71[b], Ge-73[b], Ge-74[b], Ge-75[b], Ge-76[b], Ge-77[b], Ge-78[b], As-75[b], As-77[b], As-79[b], Sr-89[b], Y-89[b], Y-91[b], Zr-93[b], Zr-95[b], Nb-93, Nb-95[b], Tc-99[b], Ru-99[b], Ru-100[b], Ru-101[b], Ru-103[b], Ru-104[b], Ru-105[b], Rh-103[b], Rh-105[b], Pd-105[b], Pd-108[b], Cd-113[b], Sb-121[b], Sb-125[b], I-127[b], I-129[b], I-135[b], Cs-133[b], Cs-135[b], Cs-137[b], Ba-130[b], Ba-134[b], Ba-135[b], Ba-136[b], Ba-137[b], Ba-138[b], Pr-141[b], Nd-143[b], Nd-145[b], Nd-146[b], Nd-148[b], Pm-147[b], Pm-148[b], Pm-149[b], Sm-150[b], Sm-151[b], Eu-151[b], Eu-153[b], Eu-155[b], Gd-154[b], Gd-155[b], Gd-156[b], Gd-157[b], Gd-158[b], Gd-160[b], Th-232, U-233, U-235[c], U-237, U-238[c], U-239, Np-237, Np-239, Pu-240, Pu-241[c].
Inherited from CENDL-3.1 (137 Nuclides):
H-3, He-3, He-4, Li-6, Be-9, B-10, B-11, C-12, N-14, O-16, F-19, Mg-24, Mg-25, Mg-26, Si-28, Si-29, Si-30, P-31, Cl-0, K-0, Ca-0, Ti-46, Ti-47, Ti-49, Ti-50, V-0, Cr-50, Cr-52, Cr-53, Cr-54, Mn-55, Fe-54, Fe-57, Fe-58, Co-59, Ni-60, Ni-61, Ni-62, Ni-64, Cu-0, Cu-63, Cu-65, Ge-0, Ge-70, Ge-72, Kr-83, Kr-84, Kr-85, Kr-86, Rb-85, Rb-87, Sr-88, Sr-90, Zr-90, Zr-91, Zr-92, Zr-94, Zr-96, Mo-92, Mo-94, Mo-95, Mo-96, Mo-97, Mo-98, Mo-100, Ru-102, Ag-0, Ag-107, Ag-109, Cd-0, In-113, In-115, Sn-0, Sn-112, Sn-114, Sn-115, Sn-116, Sn-117, Sn-118, Sn-119, Sn-120, Sn-122, Sn-124, Sb-123, Te-130, Cs-134, Ba-132, Ce-136, Ce-138, Nd-142, Nd-144, Nd-147, Nd-150, Pm-148m, Sm-144, Sm-147, Sm-148, Sm-149, Sm-152, Sm-154, Eu-154, Gd-152, Dy-164, Hf-174, Hf-176, Hf-177, Hf-178, Hf-179, Hf-180, Ta-181, Au-197, Hg-0, Tl-0, Pb-204, Pb-206, Pb-207, Pb-208, Bi-209, U-232, U-234, U-241, Np-238, Pu-236, Pu-237, Pu-239, Pu-242, Pu-243, Pu-244, Pu-245, Pu-246, Am-240, Am-242, Am-242m, Am-243, Am-244, Bk-249, Cf-249.

a. Total data size of CENDL-3.2: 392MB.
b. Covariance added.
c. Beta-delayed fission gamma spectrum (MT=460) added.

In order to verify the physical rationality, systematic comparisons between CENDL-3.2 and other major evaluated libraries (ENDF, JENDL, JEFF and TENDL…) as well as experimental data available have been implemented. Moreover, the benchmarking test of CENDL-3.2 was performed with ENDITS-1.0, an integrated **<u>benchmarking test system including 1233 criticality benchmark configurations</u>**.

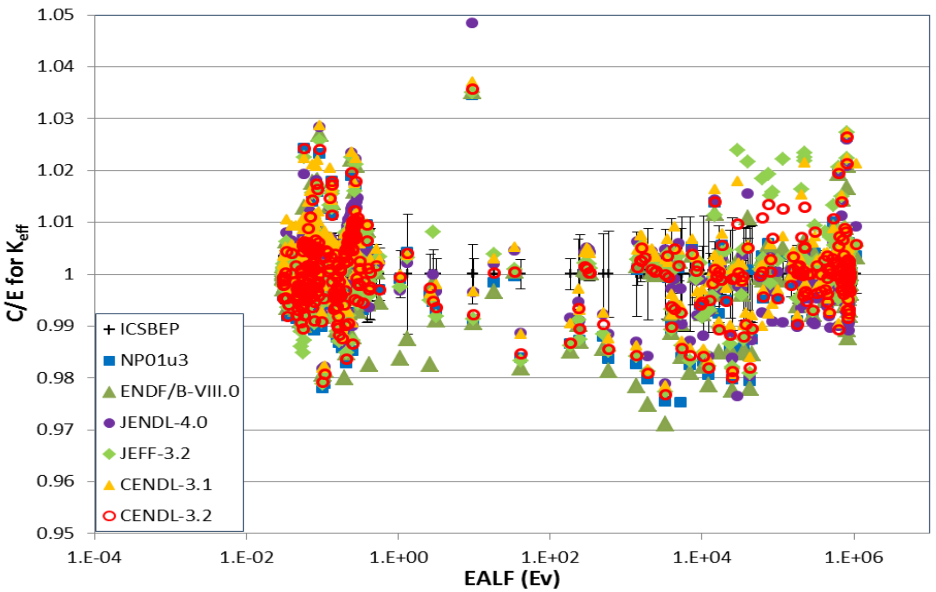


Fig. 1 Results for HEU systems

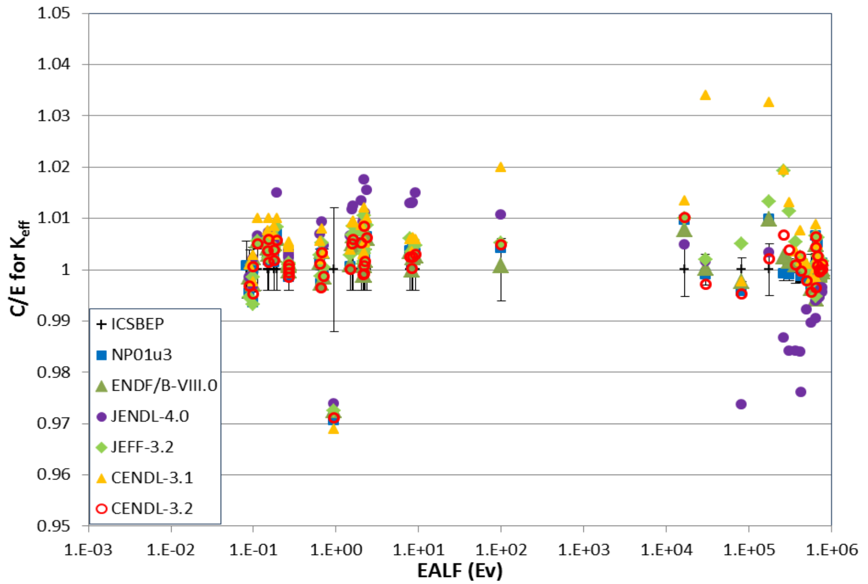


Fig. 2 Results for IEU systems

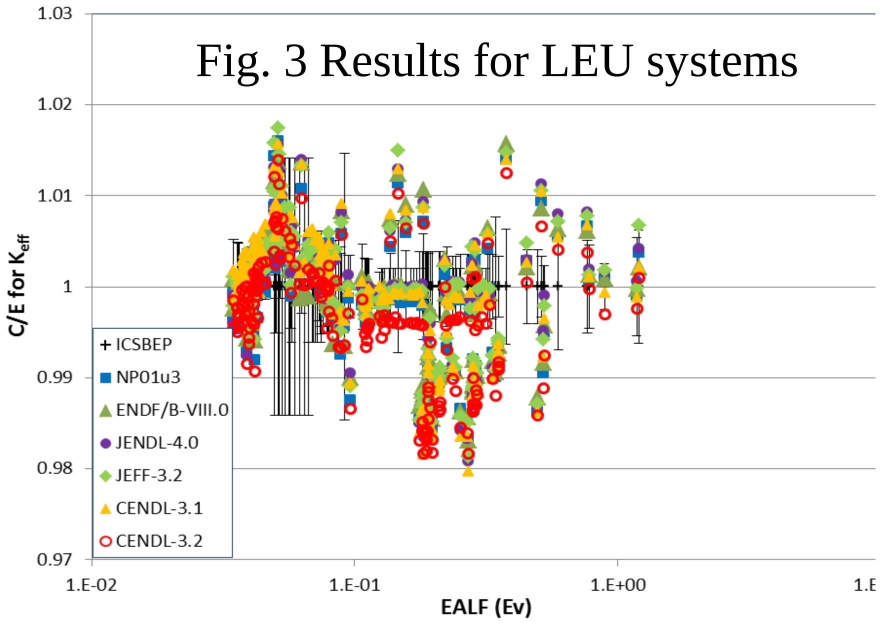


Fig. 3 Results for LEU systems
C/E for K_{eff}
EALF (Ev)
1.03
1.02
1.01
1
0.99
0.98
0.97
1.E-02
1.E-01
1.E+00
+ ICSBEP
NP01u3
ENDF/B-VIII.0
JENDL-4.0
JEFF-3.2
CENDL-3.1
CENDL-3.2

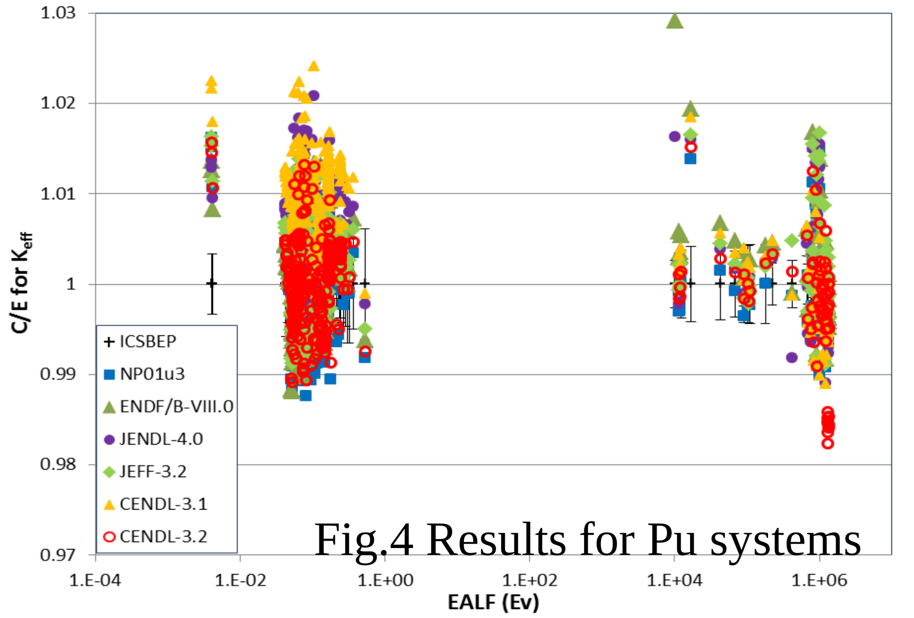


Fig.4 Results for Pu systems
C/E for K_{eff}
EALF (Ev)
1.03
1.02
1.01
1
0.99
0.98
0.97
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
+ ICSBEP
NP01u3
ENDF/B-VIII.0
JENDL-4.0
JEFF-3.2
CENDL-3.1
CENDL-3.2

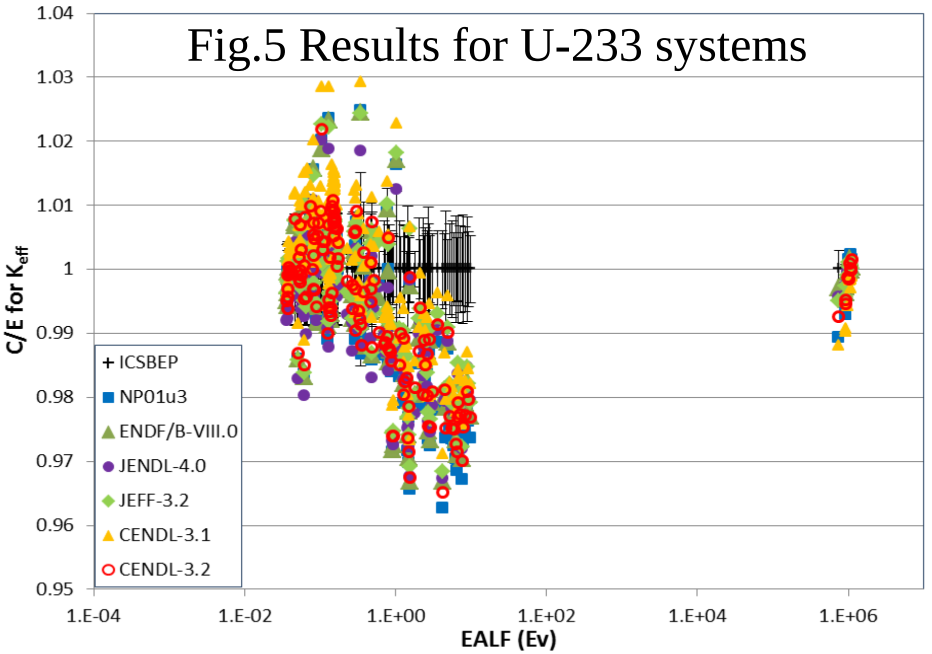


Fig.5 Results for U-233 systems
C/E for K_{eff}
EALF (Ev)
1.04
1.03
1.02
1.01
1
0.99
0.98
0.97
0.96
0.95
1.E-04
1.E-02
1.E+00
1.E+02
1.E+04
1.E+06
+ ICSBEP
NP01u3
ENDF/B-VIII.0
JENDL-4.0
JEFF-3.2
CENDL-3.1
CENDL-3.2

Table 2. The average values of C/E-1, standard deviation and χ^2

Type	Casess	Quantity	ENDF/B-VIII.0	JENDL-4.0	JEFF-3.2	CENDL-3.1	CENDL-3.2
U-235	686	C/E-1 (pcm)	-20	26	62	182	-84
		STDEV	703	772	750	779	758
		χ^2	12.32	13.56	12.41	23.94	9.66
U-Pu	7	C/E-1 (pcm)	-170	-1233	122	-36	88
		STDEV	225	572	414	285	283
		χ^2	5.89	249.26	35.51	11.89	16.81
Pu	376	C/E-1 (pcm)	93	554	210	764	4
		STDEV	488	561	504	769	554
		χ^2	2.26	4.91	2.80	9.05	3.27
U-233	164	C/E-1 (pcm)	-547	-653	-378	-42	-579
		STDEV	1127	1031	1091	1197	1139
		χ^2	4.81	4.77	4.27	6.49	5.30
All	1233	C/E-1 (pcm)	-56	89	49	328	-119
		STDEV	745	849	762	892	782
		χ^2	8.21	11.09	8.53	17.01	7.17

Feedback from applications

Progress in Nuclear Energy 136 (2021) 103727

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PROGRESS IN NUCLEAR ENERGY

Performance of CENDL-3.2 evaluated nuclear data library for t
shielding benchmarks

Wenyu Shu, Tiejun Zu *, Liangzhi Cao, Hongchun Wu

School of Nuclear Science and Technology, Xi'an Jiaotong University, Xi'an, Shaanxi, 710049, China

A R T I C L E I N F O

Keywords:
CENDL-3.2
Iron-88
PCA-Replica
HBR-2
NECP-Atlas
NECP-Hydra

A B S T R A C T

The latest CENDL-3.2 evaluated nuclear data library was releasec
CENDL-3.2 in shielding benchmarks, a broad-group shielding libr

Hindawi
Science and Technology of Nuclear Installations
Volume 2021, Article ID 6633366, 13 pages
https://doi.org/10.1155/2021/6633366

Hindawi

Research Article

Verification of CENDL-3.2 Nuclear Data on VENUS-3 Shielding Benchmark by ARES Transport Code

Jiaju Hu, Bin Zhang, Zhiwei Zong, Cong Liu, and Yixue Chen

School of Nuclear Science and Engineering, North China Electric Power University, Beijing 102206, China

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/ 2021; Published 5 February 2021

ibrary is deemed as an important achievement in the field of nuclear data research
ıry to the shielding calculation of PWR and analyze the influence of multigroup
lation, ARES-MACXS module is used to process the MATXS format multigroup
igroup working cross sections for PWR shielding calculation. VENUS-3 exper-
ry. It is often used to test the ability of the advanced transport calculation method
luate the accuracy of cross-section library. Different cross-section parameters are
ark, and equivalent neutron flux of ^{58}Ni(n,p)^{58}Co, ^{115}In(n,n′)^{115m}In and ^{27}Al(n,α)
ata provided by the benchmark report. The numerical results demonstrate that
ılculated results and the experimental results are within 20%, which satisfies the
3.2 is suitable for PWR shielding calculation. The comparison of various cross-

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Application of CENDL-3.2 and ENDF/B-VIII.0 on the reactor physics simulation of PWR

Check for updates

Tiejun Zu, Yihan Huang, Qichen Teng, Fenglin Han, Xing Huang, Chenghui Wan *, Liangzhi Cao, Hongchun Wu

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A R T I C L E I N F O

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Keywords:
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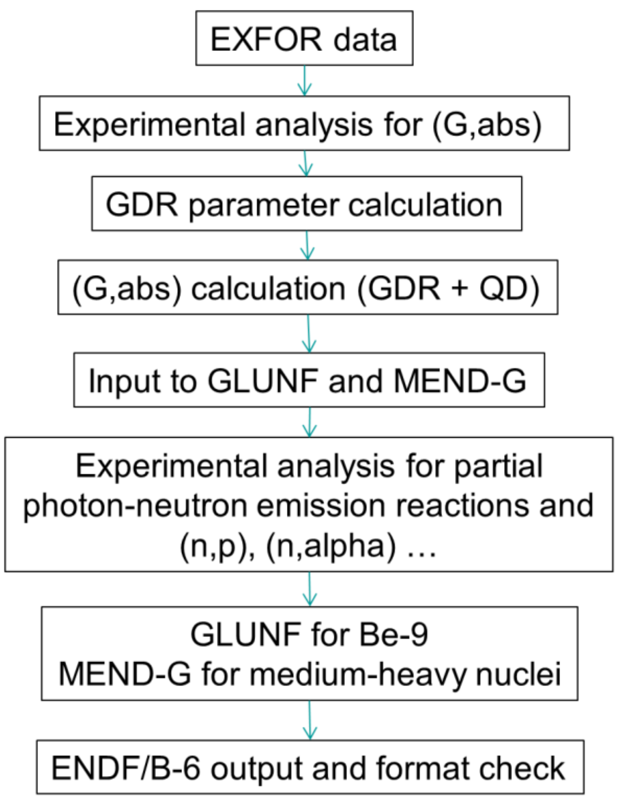
ENDF/B-VIII.0
CNP-1000
NECP-Atlas
LOCUST/SPARK

A B S T R A C T

The latest CENDL and ENDF/B evaluated nuclear data libraries was released in 2020 and 2018, respectively. To apply CENDL-3.2 and ENDF/B-VIII.0 in the reactor physic simulations of pressurized water reactor (PWR), the CNP-1000 PWR, which is an improved GEN-II PWR and operated in Fuqing Nuclear Power Plant in China, is simulated using these two libraries. The key parameters during the startup physics tests and power operation in the first three fuel cycles of the CNP-1000 reactor have been simulated and compared with corresponding measurement values. The numerical results show that ENDF/B-VIII.0 performs better in several parameters of the startup physics tests than ENDF/B-VII.0; the cross-section data in CENDL-3.2 is competent in the engineering application of PWR.

III. CENDL-PD for the photonuclear data will be released soon

1. CENDL-PD has been evaluated and it will be released soon, which contained photonuclear data for 266 nuclei.
2. The global estimation based on various Lorentzian model for all elements is performed;
3. The calculation for the competing photonuclear data is performed based on MEND-G and GUNF codes for light nuclei.



Scheme of photonuclear data evaluation at CNDC.

Reaction scheme

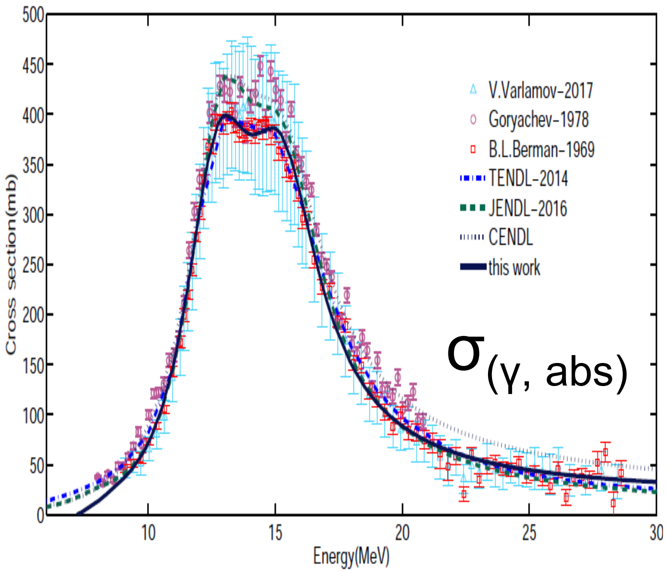
次数	Particles	Total reaction number
1	n,p,α,d,t,He-3	6
2	n,p,α,d,t,He-3	6^2=36
3	n,p,α,d,t,He-3	6^3=216
4	n,p,α,d,t,He-3	6^4=1296
5	n,p,α,d	6^4X4=5184
6	n,p,α,d	6^4X4^2=20736
7	n,p,α,d	6^4X4^3=82944
8	n,p,α	6^4X4^3X3=248832
9	n,p,α	6^4X4^3X3^2=746496
10	n,p,α	6^4X4^3X3^3=2239488
11	n,p	6^4X4^3X3^3X2=4478976
12	n,p	6^4X4^3X3^3X2^2=8957952
13	n,p	6^4X4^3X3^3X2^3=17915904
14	n,p	6^4X4^3X3^3X2^4=35831808
15	n,p	6^4X4^3X3^3X2^5=71663616
16	n,p	6^4X4^3X3^3X2^6=143327232
17	n,p	6^4X4^3X3^3X2^7=286654464
18	n,p	6^4X4^3X3^3X2^8=573308928

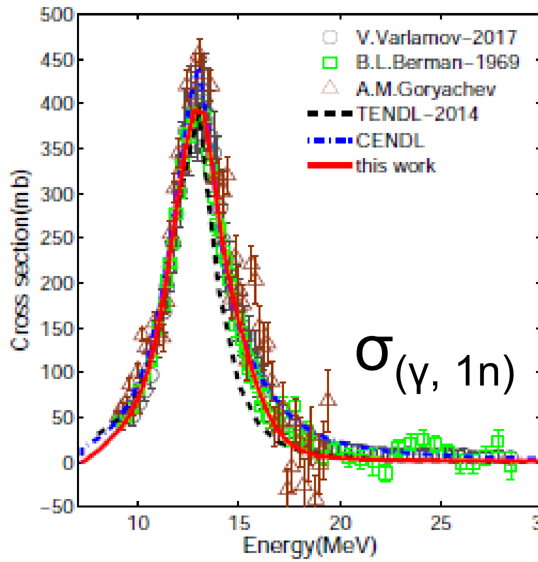
The evaluation for photonuclear data -W isotopes

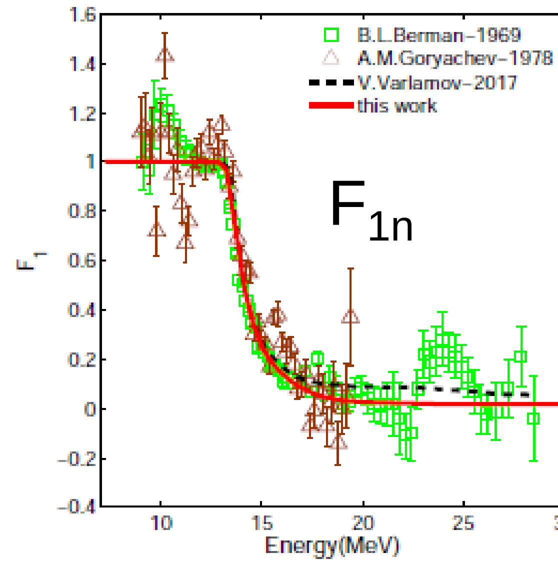
The experimental data of $\gamma + {}^{180,182,183,184,186}W$

Nuclide	Author/Ref.	Reaction Type	Energy(MeV)	Year
^{182}W	G.M.Gurevich+	(γ, abs)	8.53 - 20.7	1981
	A.M.Goryachev+	(γ, n)+(γ, np)+(γ, 2n)	8.02 - 20.8	1978
^{184}W	G.M.Gurevich+	(γ, abs)	8.53 - 20.7	1981
	A.M.Goryachev+	(γ, x)n	9.0 - 19.4	1973
	A.M.Goryachev+	(γ, n)+(γ, np)+(γ, 2n)	8.02 - 20.8	1978
^{186}W	Berman+	(γ, x)n	9.1 - 28.5	1969
		(γ, x)n,unw.	9.1 - 28.5	1969
		(γ, n)+(γ, np)	9.1 - 28.5	1969
		(γ, 2n)+(γ, 2np)	9.1 - 28.5	1969
		(γ, 3n)	9.1 - 28.5	1969
	A.M.Goryachev+	(γ, x)n	9.0 - 19.4	1973
		(γ, x)n,unw.,deriv.	9.0 - 19.0	1973
	A.M.Goryachev+	(γ, n)+(γ, np)+(γ, 2n)	8.02 - 20.8	1978
	G.M.Gurevich+	(γ, abs)	8.67 - 19.7	1981
	P.Mohr+	(γ, n)	7.26 - 10.9	2004

Experimental data for γ + W isotopes are measured mainly for ^{186}W below 30MeV.

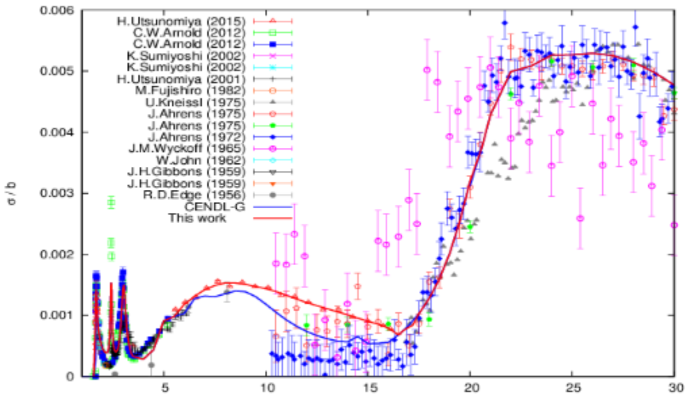




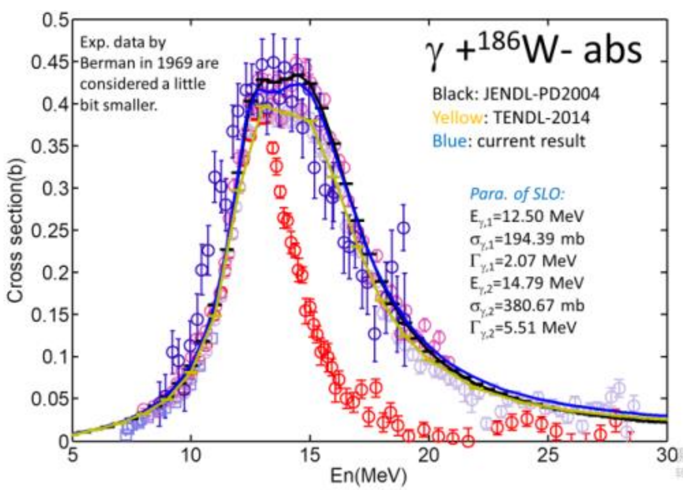


- The evaluated (γ, abs) with SMLO are based on the data by Berman and Varlamov's;
- The competing photonuclear reactions are calculated with MEND-G, and separate photon-neutron cross sections and physics criteria Fi are estimated.

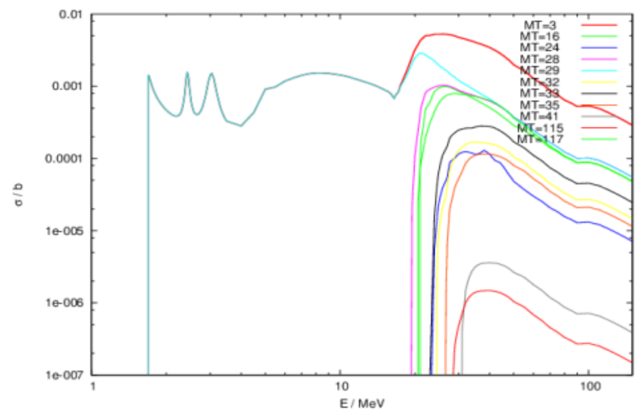
^{9}Be — ^{209}Bi   266 nuclei

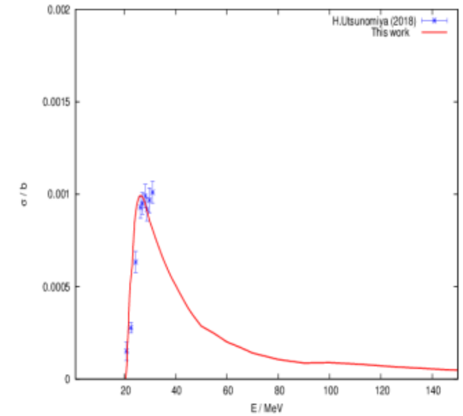


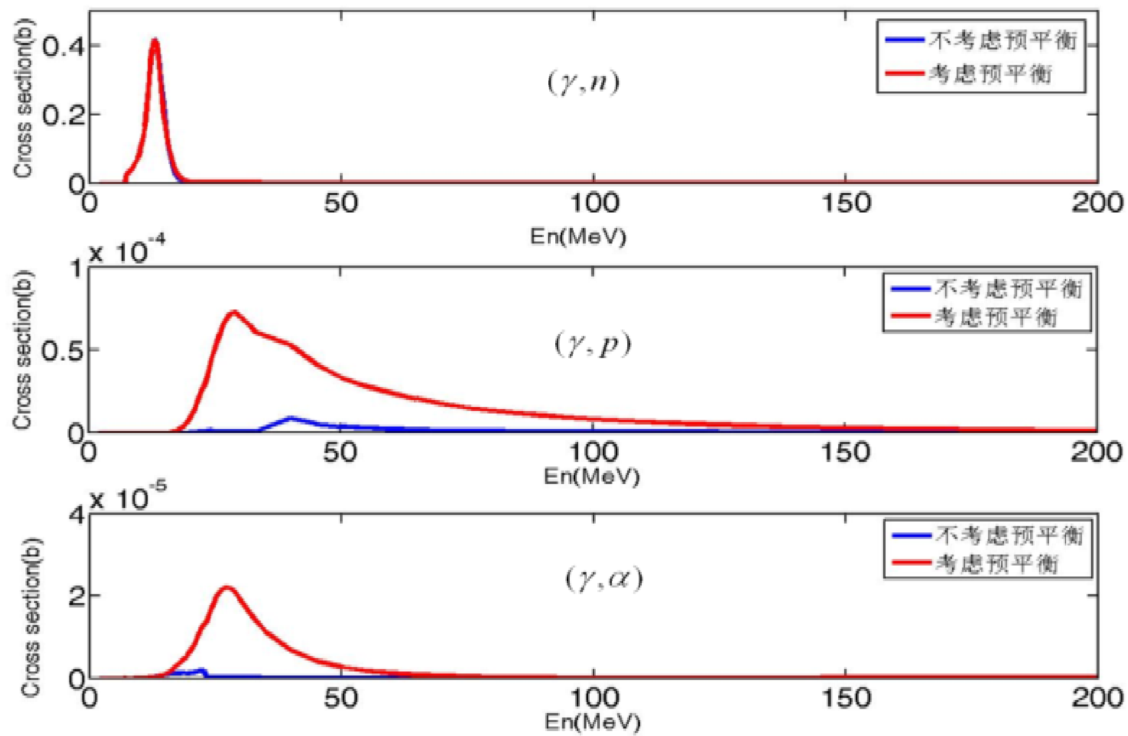
^{9}Be



^{186}W







IV. Improvement of UNF code for medium heavy & and fission nuclei

A function of the batch calculations of UNF for the medium heavy nuclei has been added

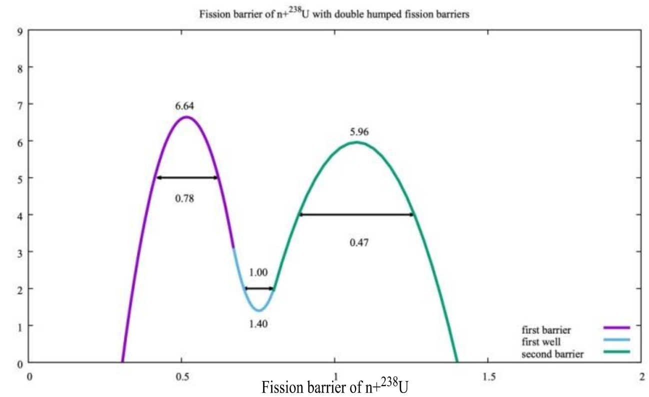
Calculation system for FP nuclei (CENDL-3.1 to 3.2)	
sunf2unf.pl	Convert sunf->unf
Batchcal	Produce unf.newunf
batchmincard.pl	Auto-produce inputs SEMAW.in, DPPMI.in, Min.in， sys.dat, exp
Correctmin	Correct the energy margin of min.in
get14MevCSInl	Produce the direct reaction cross section based on
batchmincard14.pl	Adjust DWUCK para. to fit 14MeV
NDPlot	Plot the figures for 10 reactions

核素	输入卡	核素	输入卡	核素	输入卡	核素	输入卡
12-MG-24	UNF	32-GE-70	UNF	39-Y-89	SUNF	44-RU-102	SUNF
12-MG-25	UNF	32-GE-71	UNF	39-Y-91	SUNF	44-RU-103	SUNF
12-MG-26	UNF	32-GE-72	UNF	40-ZR-90	UNF	44-RU-104	SUNF
14-SI-28	UNF	32-GE-73	UNF	40-ZR-91	UNF	44-RU-105	SUNF
20-CA-40	UNF	32-GE-74	UNF	40-ZR-92	UNF	44-RU-99	SUNF
22-TI-46	UNF	32-GE-75	UNF	40-ZR-93	SUNF	45-RH-103	SUNF
22-TI-47	UNF	32-GE-76	UNF	40-ZR-94	UNF	45-RH-105	SUNF
22-TI-48	UNF	32-GE-77	UNF	40-ZR-95	SUNF	46-PD-105	SUNF
22-TI-49	UNF	32-GE-78	UNF	40-ZR-96	UNF	46-PD-108	SUNF
22-TI-50	UNF	33-AS-75	UNF	41-NB-93	SUNF	48-CD-113	SUNF
28-NI-58	UNF	33-AS-77	UNF	41-NB-95	SUNF	49-IN-113	UNF
28-NI-60	UNF	33-AS-79	UNF	42-MO-100	UNF	49-IN-115	UNF
28-NI-61	UNF	36-KR-83	SUNF	42-MO-92	UNF	51-SB-121	SUNF
28-NI-62	UNF	36-KR-84	SUNF	42-MO-94	UNF	51-SB-123	SUNF
28-NI-64	UNF	36-KR-85	SUNF	42-MO-96	UNF	51-SB-125	UNF
29-CU-63	UNF	36-KR-86	SUNF	42-MO-98	UNF	52-TE-130	SUNF
29-CU-65	UNF	38-SR-88	SUNF	43-TC-99	SUNF	53-I-127	SUNF
31-GA-69	UNF	38-SR-89	SUNF	44-RU-100	SUNF	53-I-129	UNF
31-GA-71	UNF	38-SR-90	SUNF	44-RU-101	SUNF	53-I-135	SUNF

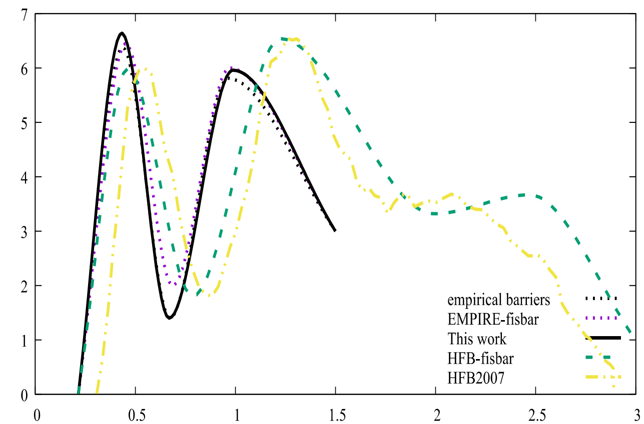
核素	输入卡	核素	输入卡	核素	输入卡
54-XE-123	SUNF	57-LA-139	SUNF	62-SM-149	SUNF
54-XE-124	SUNF	58-CE-141	SUNF	62-SM-150	SUNF
54-XE-129	SUNF	58-CE-144	SUNF	62-SM-151	SUNF
54-XE-131	SUNF	59-PR-141	SUNF	62-SM-152	SUNF
54-XE-132	SUNF	60-ND-142	SUNF	62-SM-154	SUNF
54-XE-134	SUNF	60-ND-143	SUNF	63-EU-151	SUNF
54-XE-135	SUNF	60-ND-144	SUNF	63-EU-153	SUNF
54-XE-136	SUNF	60-ND-145	SUNF	63-EU-154	SUNF
55-CS-133	SUNF	60-ND-146	SUNF	63-EU-155	SUNF
55-CS-134	SUNF	60-ND-147	SUNF	64-GD-152	SUNF
55-CS-135	SUNF	60-ND-148	SUNF	64-GD-154	SUNF
55-CS-137	SUNF	60-ND-150	SUNF	64-GD-155	SUNF
56-BA-130	SUNF	61-PM-147	SUNF	64-GD-156	SUNF
56-BA-132	SUNF	61-PM-148	SUNF	64-GD-157	SUNF
56-BA-134	SUNF	61-PM-148m	UNF	64-GD-158	SUNF
56-BA-135	SUNF	61-PM-149	SUNF	64-GD-160	SUNF
56-BA-136	SUNF	62-SM-144	SUNF	66-DY-164	SUNF
56-BA-137	SUNF	62-SM-147	SUNF		
56-BA-138	SUNF	62-SM-148	SUNF		

New fission reaction code — FUNF-2020 + Multi-humped fission

The multiple humped fission barrier((phenomenological) , have successfully incorporated recently into nuclear reaction code FUNF-2020, and some preliminary results for n+238U are obtained based on this code, FUNF-2020 will be used for the actinides modeling in our future neutron data evaluation according to the present results



n+^{238}U



The chief model parameters are listed as follows:

	n,inl	n,2n	n,3n	n,gamma
Level Density	23.87	28.62	31.73	28.16
Paring Correction	0.409	0.201	0.0283	0.0283

Table 1 The parameter of level density and pairing correction for (n,inl), (n,2n), (n,3n) and (n,gamma) channels

	Height	Width	Level density	Pairing correction
(n,f) inner	6.64	0.78	34.77	-0.997
(n,f) outer	5.96	0.47	26.83	-0.149
(n,f) well	1.40	1.00		
(n,nf)	5.13	0.15	25.10	1.014
(n,2nf)	6.07	1.39	41.39	0.560

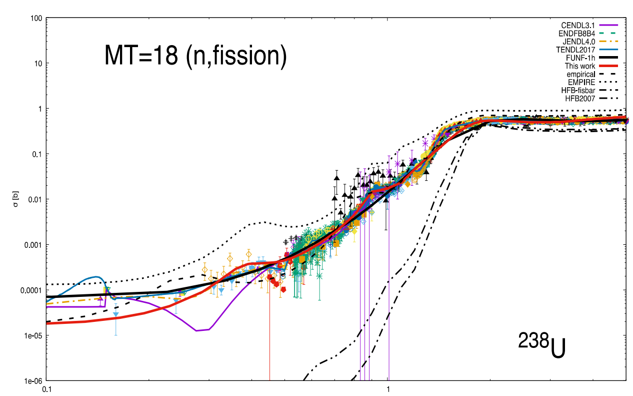
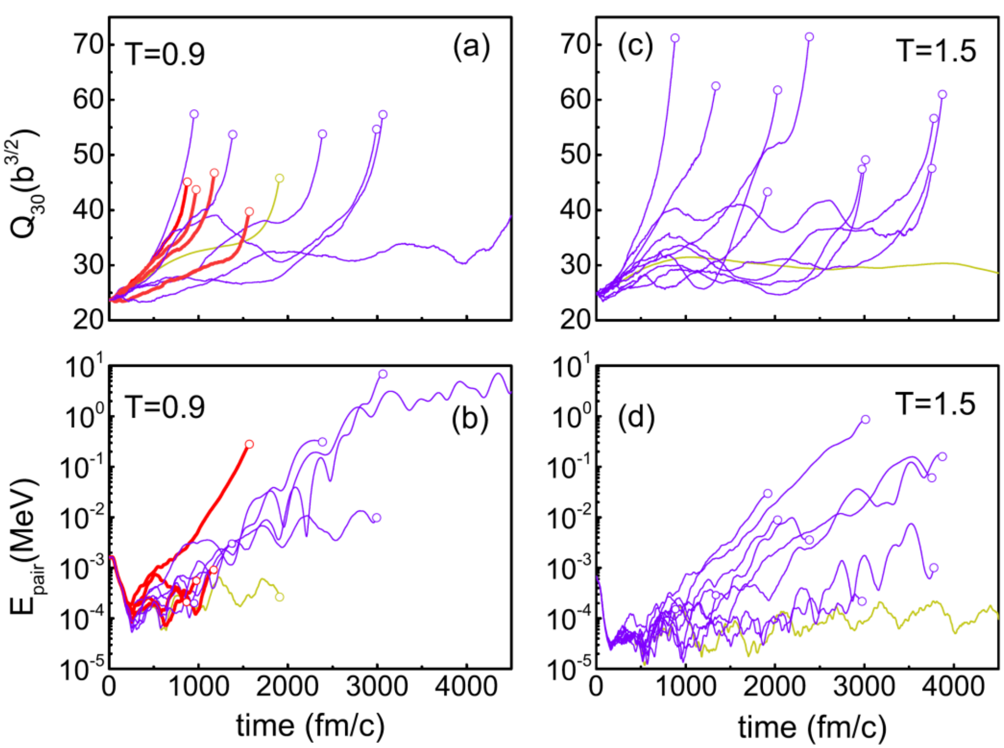


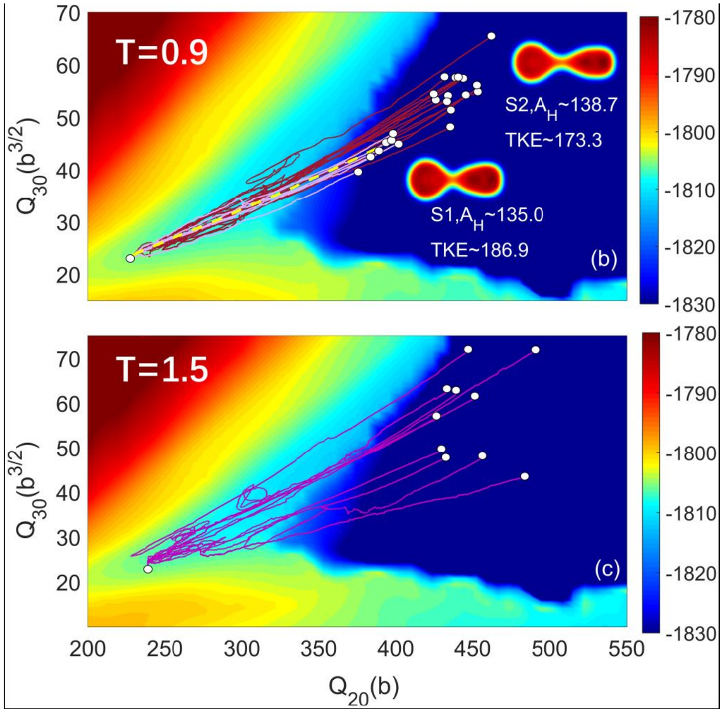
Table 2 The parameters of fission barriers and level density for (n,f), (n,nf) and (n,2nf) channels.

V. Theoretical study for fission data

The real-time fission dynamics from low-energy to high excitations in the compound nucleus ^{240}Pu with the TD-Hartree-Fock + BCS +thermal fluctuations was studied.



At high excitations, the random thermal fluctuations is indispensable to drive fission.



The obtained FY and TKE with fluctuations can be divided into two asymmetric scission channels, namely, S1 and S2, which explain well experimental results and give microscopic support to the Brosa model.

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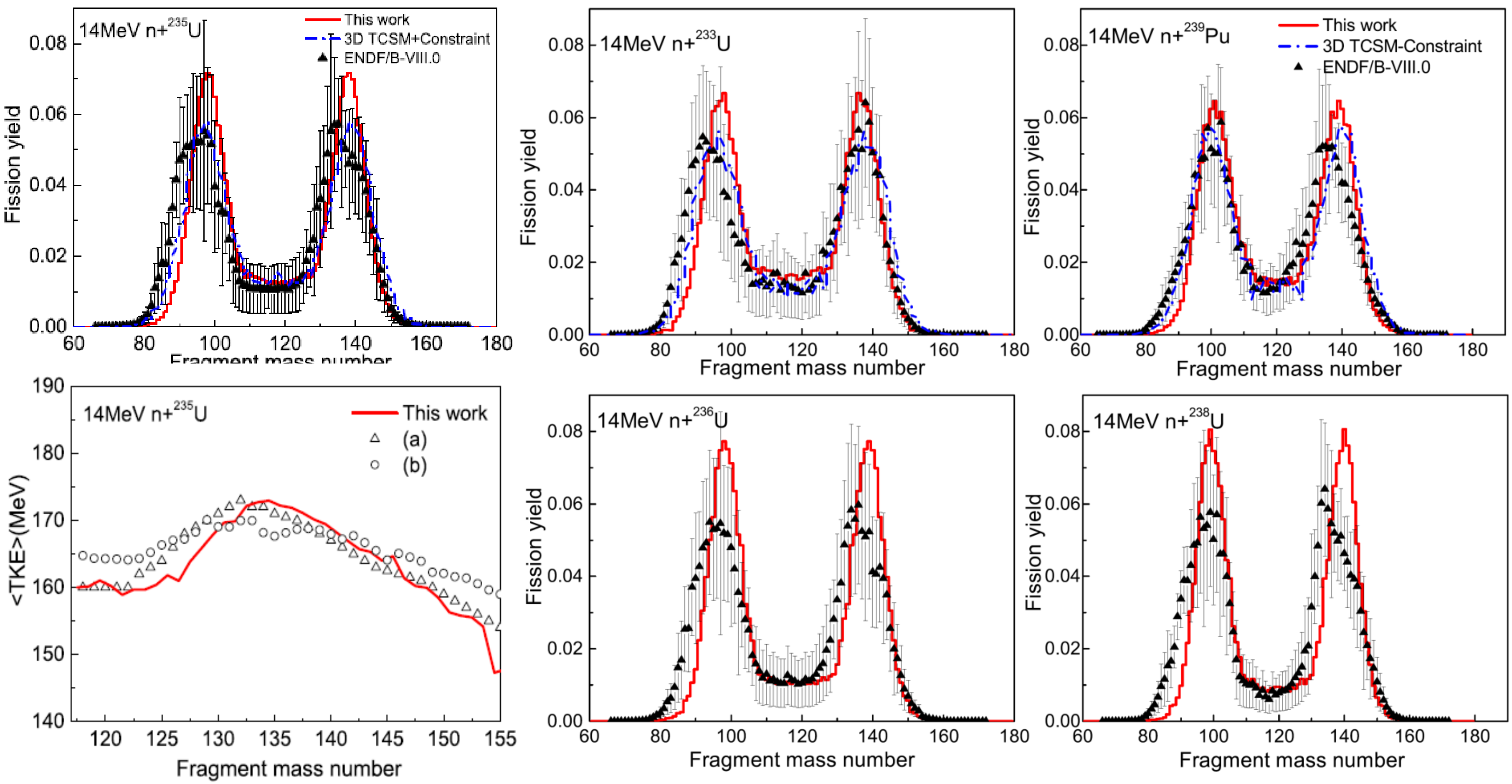
The Langevin approach is extendedly applied to study the dynamical process of nuclear fission within the Fourier shape parametrization.



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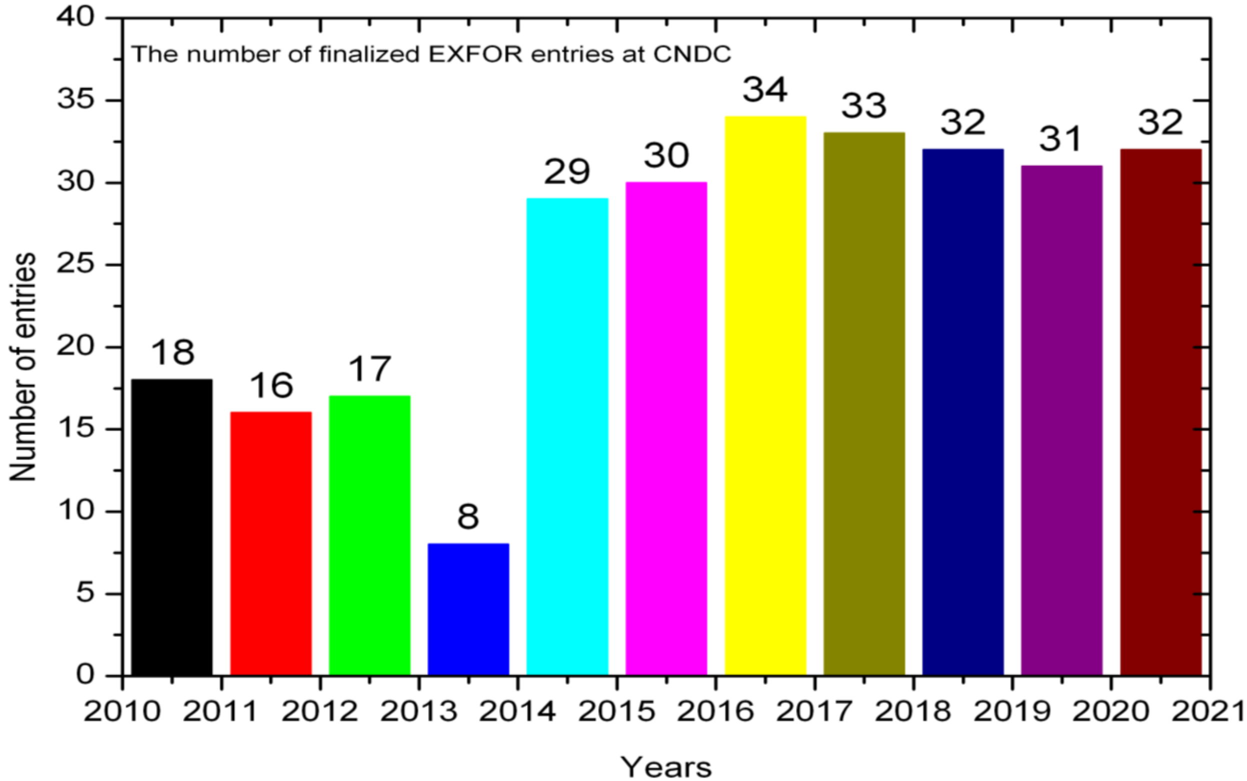
VI. EXFOR compilation

- more than 410 entries were compiled at CNDC. Since 2010, more than 280 entries were finalized, which included 142 neutron and 138 charged particle entries. Feedback and correction performed for more than 100 entries.
- Since the last NRDC meeting (April 2019), 63 new entries have been finalized and 26 entries have been revised, more than 87 articles under compiling.



Thank you for your attention !