# 2018/19 Status Report of China Nuclear Data Center

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## 1. General Information of China Nuclear Data Center

China Nuclear Data Center (CNDC) was established in 1975 and joined the nuclear data activities of IAEA as the national nuclear data center of China since 1984.

### 1-1. Staff and student information

1) 20 official staff + 5 students (Master 3, Ph.D 2)
2) Director: Prof. Ge Zhigang
3) Deputy Directors: Dr.Qian Jing and Dr.Wu Haicheng

| | | |
|---|---|---|
| Evaluation Unit | Head: Dr. Huang Xiaolong | 3 official staff |
| Theory Unit | Head: Dr. Xu Ruirui | 6 official staff |
| Macroscopic Data Unit | Head: Dr. Liu Ping | 6 official staff |
| Data Library Unit | Head: Dr. Shu Nengchuan | 4 official staff |
| Secretary Office | | 1 official staff |

### 1-2. Mainly Tasks of CNDC in 2018/2019

1) New evaluations and re-evaluations for neutron data file for CENDL.
2) Nuclear structure and decay data evaluation.
3) Fission yield data evaluation.
4) Photonuclear data evaluations.
5) The fundamental studies of nuclear data evaluations and measurements.
6) Methodological studies of nuclear data evaluation.
7) Nuclear data processing code development.
8) Experimental data compilations for EXFOR.
9) The regular update and maintenance of IAEA/NDS mirror-site in China.
10) Nuclear data services is providing to all the nuclear data users.
11) ND2019 preparation.

## 2. Nuclear Data Evaluation

### 2-1. CENDL-3.1

1) Light nuclei evaluation and model study

Some efforts have been contributed in the past to update the neutron data of light nuclei. The n-n and n-d colliding systems are calculated by considering the microscopic NN interactions, as shown in follows.

As regards the n-n system, due to the absence of neutron target, neutron-neutron scattering cannot be determined directly from experimental data. In our work, based on the microscopic CD-Bonn one-boson-exchange nuclear force, Lippmann-Schwinger equation in momentum coordinate is solved to provide T matrix elements and phase shifts in various partial waves. The neutron-neutron scattering cross section is calculated within S matrix theory. Results show that when incident energy up to about $10^4$eV, cross sections almost keep constant. Compared with ENDF, our results are larger about 1b in low energy region. Below 10 MeV, angle distribution is near isotropy.

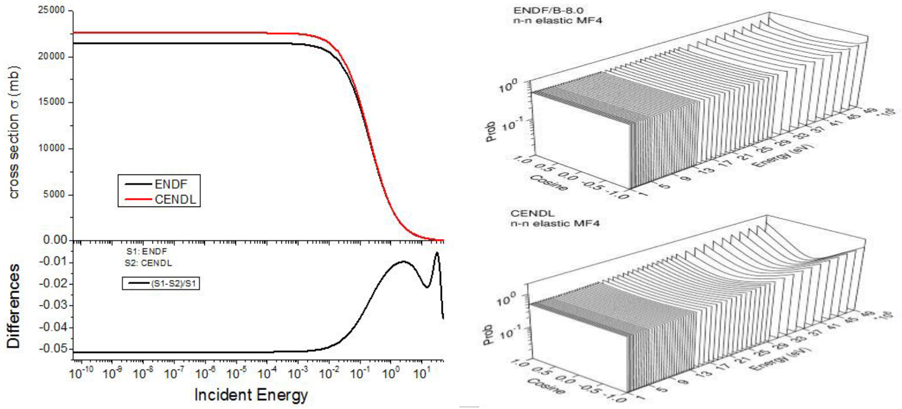



**Fig.1** The n-n elastic scattering cross sections based on the CD-Bonn force (left pad) and the processed elastic scattering angular distributions via the NJOY code(right pad).

2) Medium-heavy nuclei evaluation

The neutron reaction data of medium-heavy nuclei (mass number around 100~200) are systematically updated in CENDL. All the modifications are based on the calculations with the UNF code. Parts of them are new evaluations concerning the latest measurements. The others are the systematic reproductions to the previous CENDL library, some odd structures are removed from previous CENDL. The new evaluations for La-139 (n,tot),(n,inl) are shown in Figure 2.

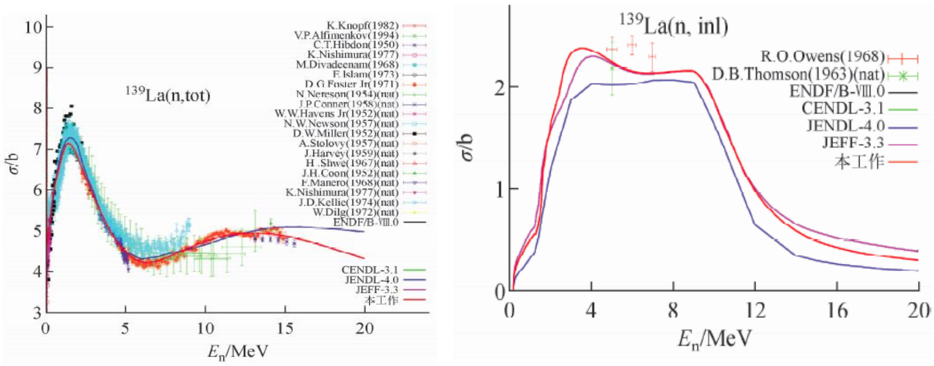



**Fig. 2** The new evaluation for n+$^{139}$La

Secondly, with the help of MINUIT, we have adjusted the parameters of the UNF program, such as the parameter of the level density, pairing interaction and Giant dipole resonance of (n, gamma) channel. As we have shown in Figure 3, the dotted line is the results of the CENDL3.1, the solid line is the cross sections we have calculated with the new parameter set. For the (n,n1) and (n,n2) channel, the new parameter set gives the reasonable cross section at 8 to 10 MeV.

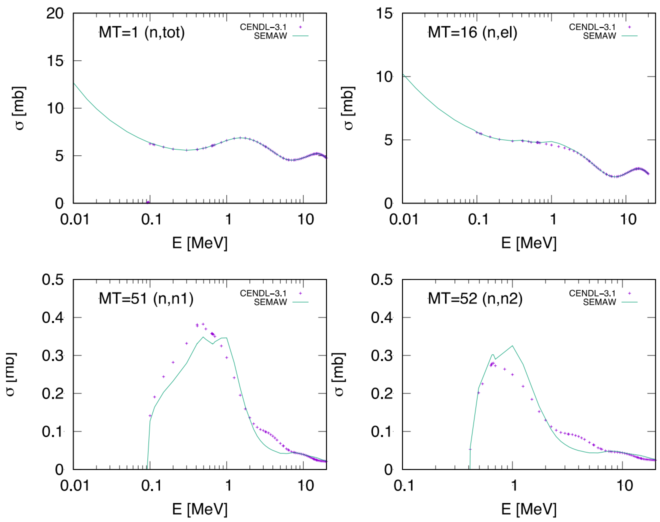



**Fig. 3** The cross section of CENDL3.1 and the new results for n-$^{147}$Pm reactions.

3) The photonuclear data evaluation at CNDC

Under the support of the CRP Contract No. 20466, 12 medium-heavy nuclei in the contract are finished using the new developed MEND-G code in 2018. The entire evaluation scheme in this work is shown in figure 4.Meanwhile, a sub-library of photonuclear in the coming CENDL is also being studied recently, and 274 nuclei are contained. The obtained absorption cross sections for Be-9 are shown in figure 5.

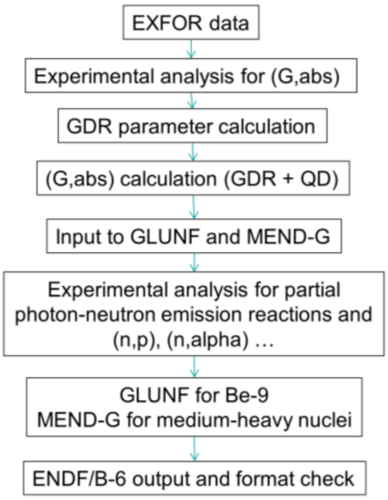



**Fig. 4** Scheme of photonuclear data evaluation at CNDC

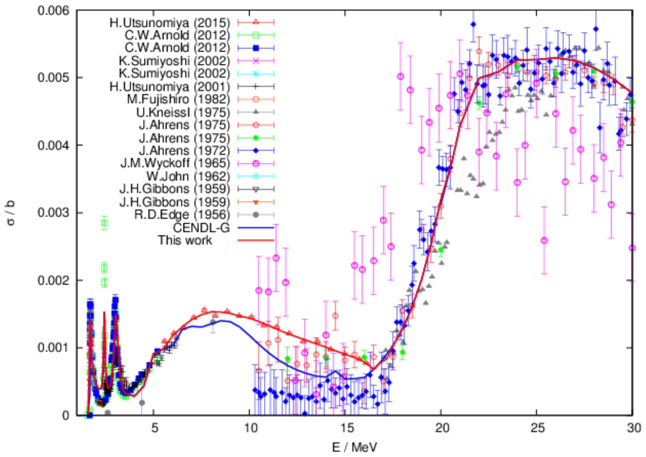



**Fig.5** The absorption cross section of g+Be-9

## 3. The fundamental studies related to the nuclear data

### 3-1.The microscopic optical model potential

Some microscopic nuclear reaction and structure studies are also paralleled studied at CNDC. The microscopic a-nucleus optical model potential and the nuclear structure results based on the Dirac-Brueckner Hartree Fock approach are successfully obtained. As shown in Fig. 6, in our scheme, the nucleus experimental data are reproduced systematically from $^{12}$C-$^{208}$Pb

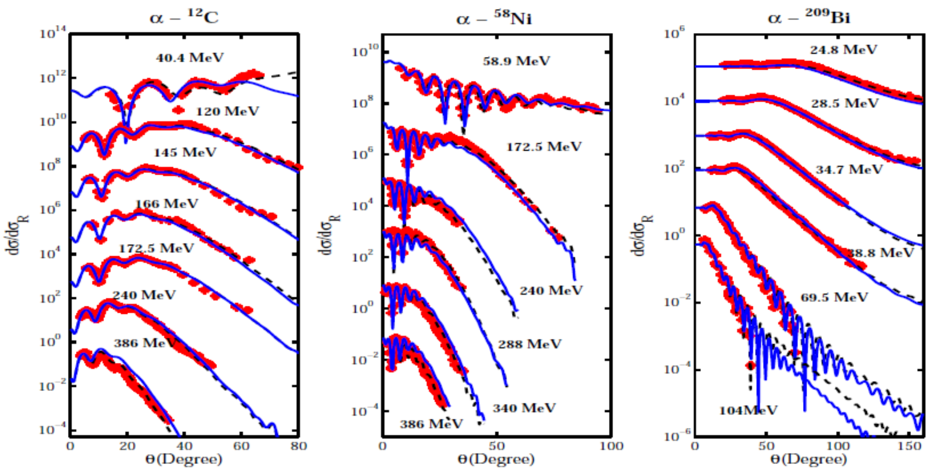



**Fig. 6** The comparisons between the calculations of $^{12}$C, $^{58}$Ni, $^{209}$Bi and measurement.

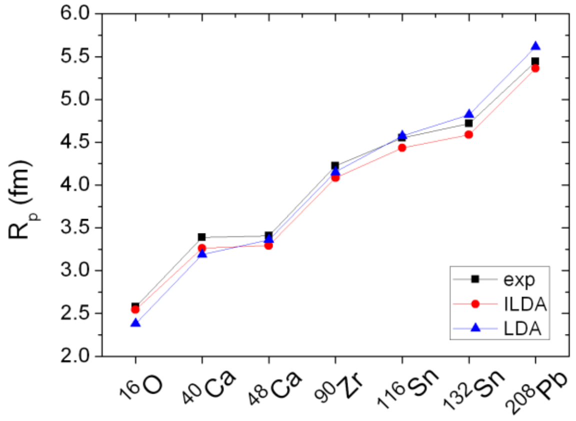



**Fig. 7** Calculations of finite nuclei binding energy and proton radius with DBHF approach.

## 3-2. Phenomenological Method of Fission Yield and Macro-benchmark Test

There are 49 experimental yields of $^{99}$Mo, $^{99}$Tc and chain yield, mainly from the United States, China and Europe. The experimental data were modified by gamma ray intensity and standard yield. After weighted averaging, the yields at thermal energy is 6.12E-2 (7.38E-4), consistent with that of ENDF/V-II.1. The yields at fission spectrum energy are quite different, ranging from 5.5 to 6.4%. Six of them are ratio, and have good consistency, which were adopted to deduced the yields, resulted 6.25 (1.8%) to 6.13 (1.8%) over the energy range of 0.2 MeV to 2 MeV, which are in accordance with the values of Selby 2011. The yield at 14 MeV has only measured datum 6.27%, and was corrected to 5.08E-2 (9.66E-4) by normalizing with its yield at thermal energy, which is consistent with ENDF/BVII-1 and JEFF-3.1 within the uncertainties, as shown in Fig 8.

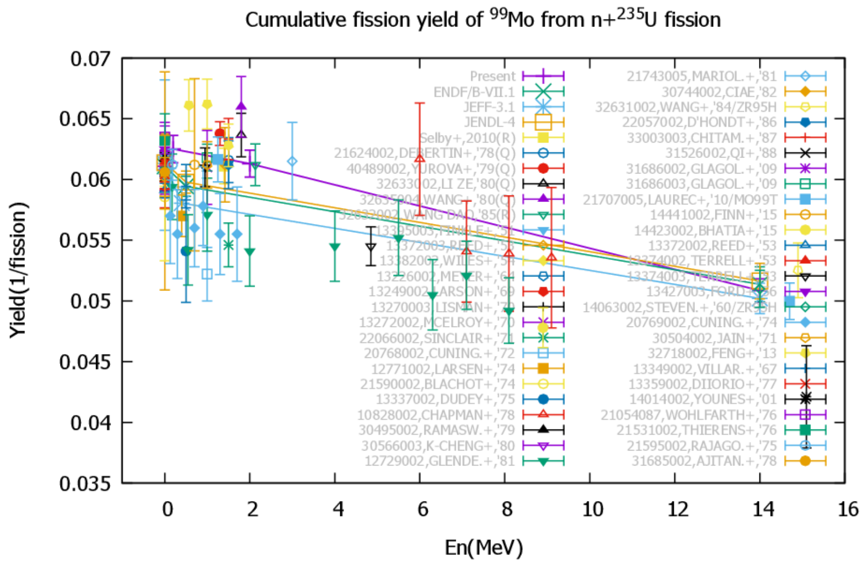



**Fig.8** Accumulated yield of fission$^{99}$Mo for n+$^{235}$U

GEF is a phenomenological model calculation program for simulating nuclear fission process. It can calculate the nuclide yield, angular momentum distribution, isonuclear yield, prompt neutron yield and neutron spectrum,prompt gamma spectrum and some other physical quantities of the pre- and post-neutron fragments of the extensive fission nuclei from Po to Se in spontaneous fission and neutron-induced fission. The model considers four fission channels. For all fission systems, the strength of the shell at fission Valley is the same, and the average position of heavy debris in the asymmetric fission channel is basically constant in atomic number. The fragments are Gauss distributed at the breakpoints. The calculation shows that the GEF model calculation program can reproduce the experimental data better and has good universality. However, in the peak area of mass distribution, there is still a 10-20% difference compared with the experimental data.

The relative sensitivity coefficients of Keff for various fission yields of major fission nuclides

($^{235}U$, $^{239}Pu$, $^{241}Pu$) are calculated by direct numerical perturbation method. For the three main fission nuclides, the absolute values of relative sensitivity coefficients, i.e., the fission yields which have great influence on Keff. The fission yields of $^{135}I$ in$^{235}U$ fission systemhave obvious effects on Keff, and it should be noted that the fission yields of $^{135}I$in $^{239}Pu$ fission, while the fission yields of$^{241}Pu$ have little effects on Keff.

### 3-3. Calculations of multi-dimensional potential energy surfaces within a macroscopic-microscopic model and the study of fission dynamic processes

In the macroscopic-microscopic model, two sets of shapes are used to describe the nuclear shape. One is three-quadrature surface, which can independently describe the deformation of fragment. The other is the generalized Lawrence shape, and parameters have clearer meaning. Each of these two sets of shape parameters contains five independent variables.

For these two shape descriptions, the LSD formula (Lublin-Strasburg Drop Model) was used in the macroscopic model, and the single-particle levels are calculated by Woods-Saxon potential and folded Yukawa potential, respectively. Considering the shell structure and paring of the nucleus, the Strutinsky method was used to calculate the microscopic shell correction energy, and BCS method was used to calculate the paring correction energy. Based on the above macroscopic-microscopic model, the calculations of potential energy surface of actinide are carried out.

Potential energy surfaces of isotopes of U and Pu elements were calculated in the five-dimensional deformation space. Based on the five-dimensional potential energy surface, the optimal fission path and key physical parameters such as ground state point, saddle point and scission point are obtained by using two search algorithms of simulated flooding method and simulated precipitation method, and the asymmetric and symmetrical fission modes of actinide are obtained. From Figure 9 (a), it can be seen that the symmetrical fission path and the asymmetrical fission path basically overlap from the ground state to the first barrier (inner barrier), but rapidly separate with the increase of deformation after the second minimum. The height of the second barrier of symmetrical fission is about 2.8 MeV higher than that of asymmetrical fission. Fig.9(b) shows that the difference between symmetrical fission and asymmetrical fission nuclei increases as the fission nuclei continue to elongate. The symmetrical fission path and asymmetrical fission path are clearly separated on the two-dimensional potential energy surface, which can qualitatively explain why $^{236}U$ asymmetrical fission dominates at low excitation energy, and the symmetrical yield does not gradually increase until the excitation energy is relatively high enough.

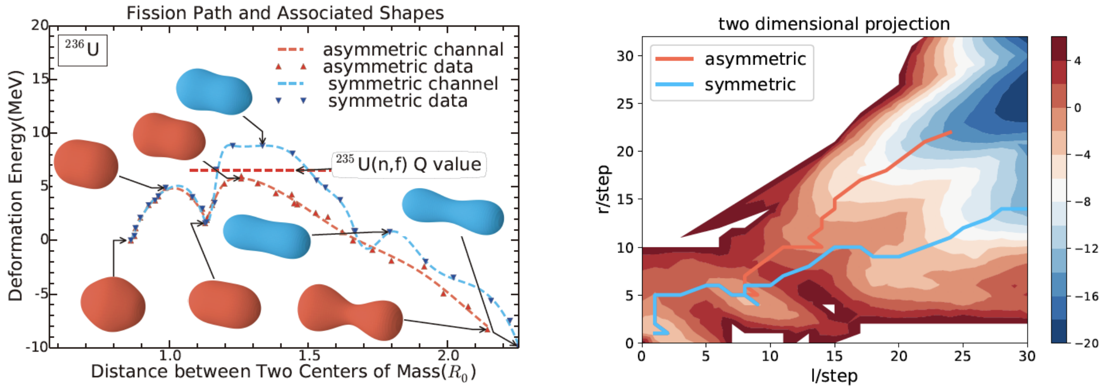



**Fig.9** Multi-modal fission paths of $^{236}U$(a left) and its projections on 2D PES(b right).

The mass distributions of 14MeV neutron induced $^{233, 235, 238}U$ and $^{239}Pu$ fission were calculated with Langevin equation, and the results were compared with the evaluated data of ENDF/B-VII.0 library (post-neutronmass distribution) and the results of pre-neutron mass distribution calculated by GEF in figure 10. From the calculated results, it can be seen that the results of Langevin equation agree well with those of GEF model, especially the peak positions of light and heavy fragments. This agreement also shows that our method is reliable.

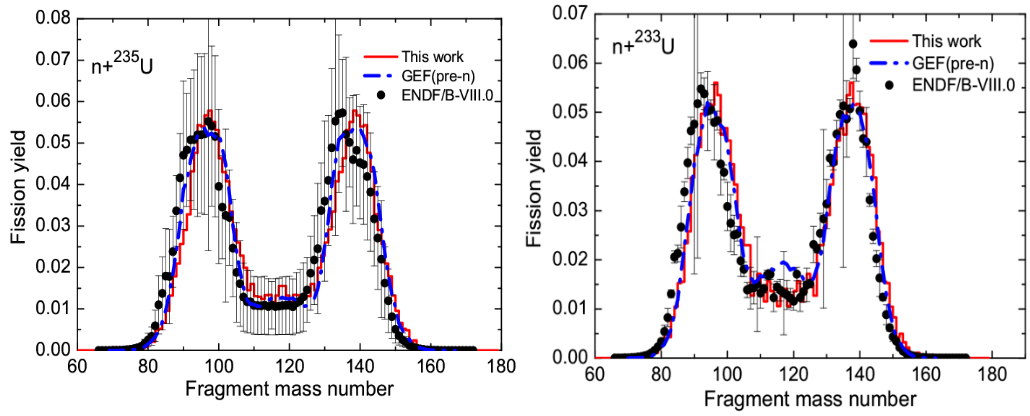


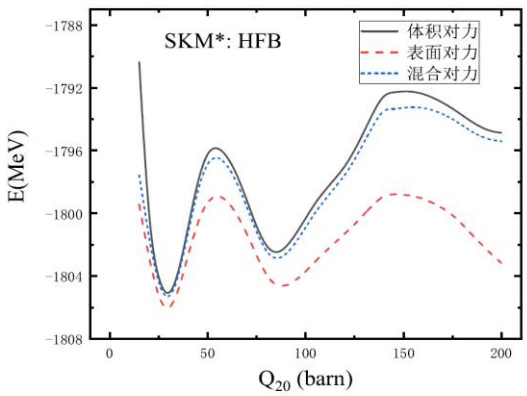

**Fig.10** Simulation and evaluation results of n(14MeV) +$^{235,233}$U

## 3-4. The studies on the mechanism of nuclear fission in Actinide nuclei with microscopic theories

The objective of microscopic theory research of actinide fission mechanism is to develop a self-consistent theoretical model which is based on the nucleon-nucleon effective interaction and used to calculate fission observable quantities. Combining with experiments and nuclear energy applications needs, microscopic theoretical results can provide reliable predictions for energy regions lacking experimental data. The basic frontier research on fission mechanism can be used to explore the relationship between microscopic model and phenomenological model, and can provide theoretical support for the calculation and evaluation of high-quality fission data.

Using the constrained Hartee-Fock-Bogoliubov (CHFB) method based on non-relativistic energy density functional, the method and program for calculating the multidimensional potential energy surface are developed. The effects of different paring models and different paring strength on the potential energy surface are analyzed.

Figure 11 gives a comparison of the calculated $^{240}$Pu potential energy surface for three different pairing modes (volume paring, surface paring and mixed paring). Figure 11 shows the HFB approximation (effective nuclear force is zero-range Skyrme force) using the mixed paring model and the comparison of the calculated results of potential energy surface adjusted by 5% of the paring strength. As can be seen from Figure 11, different pairing models have an effect on the energy of the ground state and isomeric states of fission nuclei. Figure 12 shows that the absolute value of the potential energy surface can be shifted by pairing strength. Finally, we will use fission-related experimental data, such as fission yield, to determine which pair model is closer to the real nuclei under the large-scale collective motion mode of nuclei.



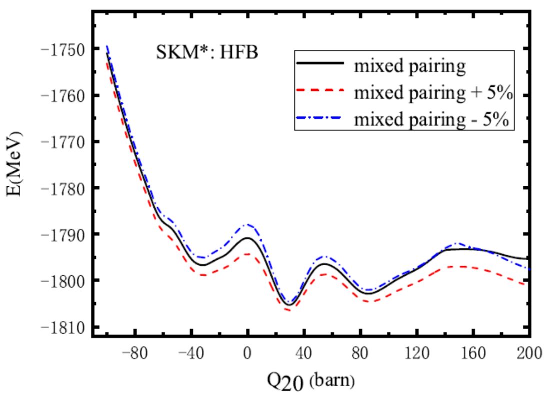




**Fig.11** Potential energy surfaces under HFB approximation with different paring models(left). **Fig.12** The potential energy surface with the change of paring strength of 5% in the case of mixed pairing(right).

On the other hand, the time-dependent generated coordinate method (TDGCM) based on covariant density functional is used to study the dynamic properties of $^{240}$Pu fission. The multi-dimensional fission potential energy surface and fission barrier structure are given. Figure 13 shows the potential energy surface of $^{240}$Pu on ($\beta_2$,$\beta_3$) plane calculated by PC-PK1 relativistic density functional theory. The ground state deformation of $^{240}$Pu is ($\beta_2$,$\beta_3$) ≈ (0.29, 0.09) and energy

= **-** 1813.82 MeV, see the blue arrow in the picture. It can be seen that there are two fission barriers (inner barrier and outer barrier) in the symmetrical fission direction of reflection(the red cross in the figure 8), i.e. the octupole deformation $\beta_3$=0, and $\beta_2$ = 0.53 and 1.89, respectively, and the barrier heights are 7.08 MeV and 7.93 MeV, respectively. After considering the octupole deformation, i.e. $\beta_3 \neq 0$, the outer barrier decreases to 3.53 MeV, and see the blue cross in the figure, where there is a distinct asymmetric fission valley, as shown in the red solid line in figure 13.

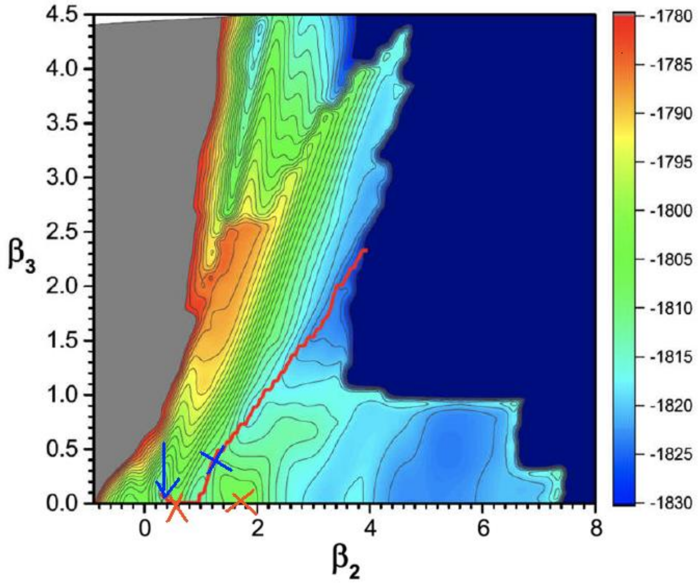



**Fig 13** $^{240}$Pu potential energy surface in ($\beta_2$,$\beta_3$) plane calculated with self-consistent relativistic mean field + BCS

## 4. EXFOR activities at CNDC during 2018/2019

### 4-1. Compilation activities of EXFOR

Since 2010, CNDC has compiled 217 EXFOR entries, which included 105 neutron and 112 charged particle entries, feedback & correction performed for more than 60 entries.

Since the last NRDC meeting (2018-5-1), 32 new entries have been finalized and 22 entries have been revised, more than 30 articles under compiling.

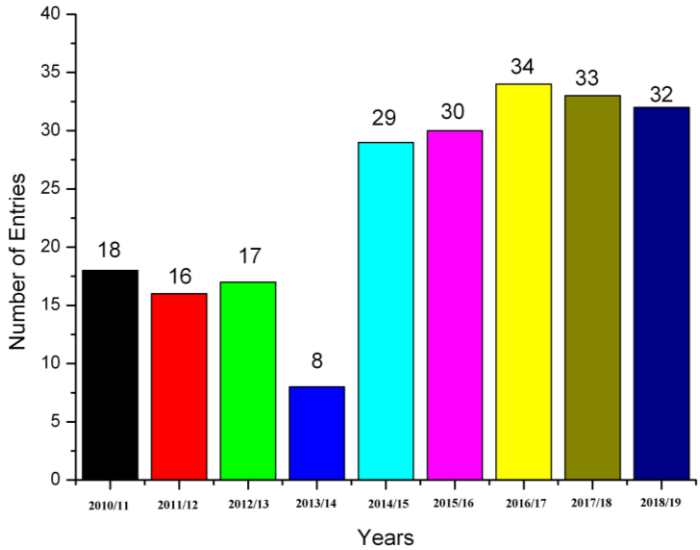



**Fig. 14** The number of the finalized EXFOR entries

### 4-2.Software NDPlot

NDPlot is an efficient plotting tool for nuclear data, developed by Dr. Yongli Jin (CNDC). It is not only a plotting tool for nuclear data, but also integrated application software. The latest version 0.93 beta was released in Dec.24, 2018.

The new features added to NDPlot include:

1) The ratio of cross sections can now be treated.
2) Plot the chain yields and energy dependent fission yields
3) Filter fission yield data and correct the data with new gamma data.
4) Special treatment on discrete level excitation cross sections.

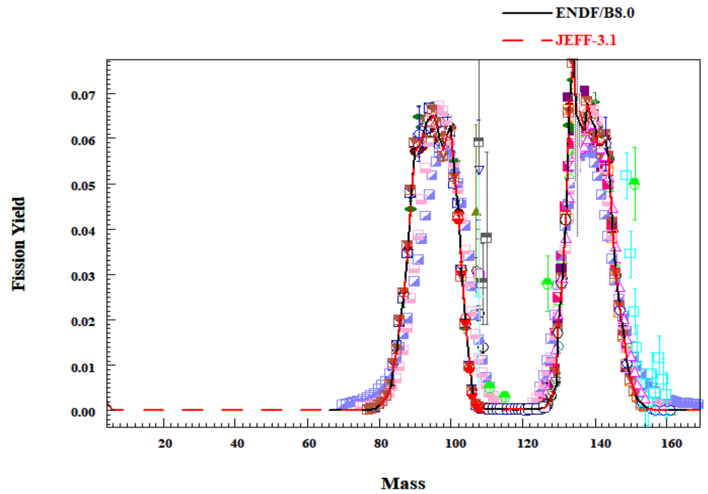



**Fig. 15** Chain Yield of U-235 (Thermal Energy)

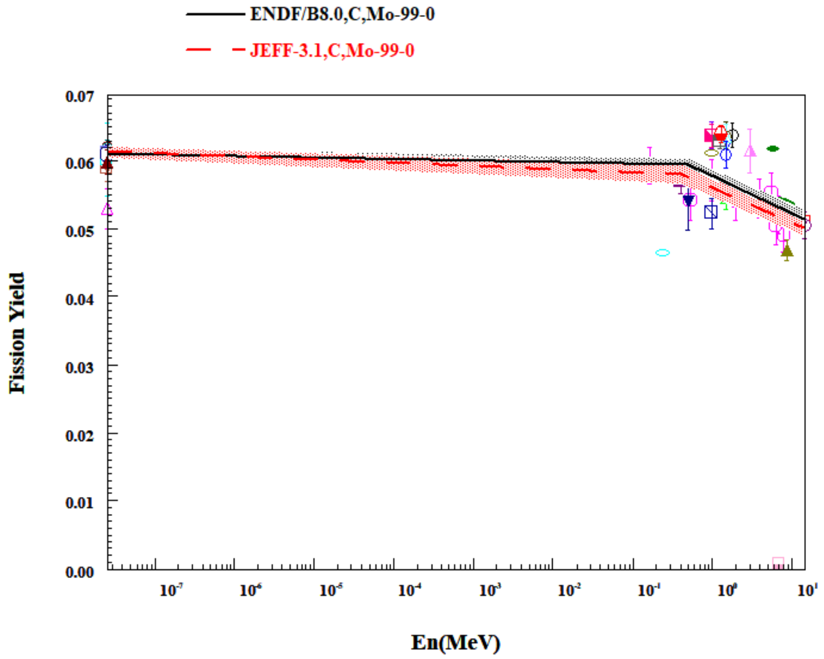



**Fig.16** Energy Dependent Fission Product Yields U-235 (N,F)42-Mo-99,CUM,FY

## 4-3. Communication and Co-opetation

- Dr. Qian Jing, Dr.Wang Jimin and Dr. Jin Yongli participated in the Workshop on the Compilation of Experimental Nuclear Reaction Data, 22-25 October 2018, Vienna, Austria.
- Dr.Wang Jimin and Dr. Jin Yongli participated in the 9th Asian Nuclear Reaction Database Development Workshop, 12-15 November 2018, Gyeongju, Korea.
- Dr. Otsuka visited CNDC, 18-24 November 2018. More than 10 new entries were finalized, the earlier issues of “Atomic Energy Science and Technology” were scaned and the candidates of EXFOR compilation were identified.

**Fig. 17** Participants of the EXFOR Workshop


**Fig. 18** Participants of the 9th Asian Nuclear Reaction Database Development Workshop


**Fig. 19** Dr. Naohiko Otsuka and Dr. Andrej Trkov at CNDC

## 4-4. Nuclear Data Services

CNDC provides the nuclear data service for institutes, universities or other requirements in

China. CNDC joined the developing of Chinese basic database and established the Website of "The Database of Nuclear Physics" including experimental data (EXFOR), evaluated data, nuclear structure and decay data, astrophysical data and nuclear data for medical applications, etc. Some software can be downloaded from the website, such as GDGraph, NDPlot, and so on.


**Fig.20** Homepage of "The Database of Nuclear Physics"