III DATA EVALUATION

TECHNIQUES USED FOR CHARGED PARTICLE NUCLEAR DATA EVALUATION AT CNDC

Zhuang Youxiang Sun Zuxun

(CHINESE NUCLEAR DATA CENTER, IAE)

ABSTRACT

The methods and techniques used for Charged Particle Nuclear Data (CPND) evaluation at Chinese Nuclear Data Center (CNDC) are summarized in this report, including compilation and evaluation of experimental data, nuclear reaction theory and model calculation, systematics research and comprehensive recommendation etc..

INTRODUCTION

Charged Particle Nuclear Data (CPND) have been widely used in basic scientific researches on nuclear force, nuclear structure, nuclear reaction mechanism and nuclear astrophysics etc.; also used in engineering and technology such as space radiation effects, neutron sources, biomedical isotope production, radiation therapy, activation analyses, radiation processing, accelerator shielding and fusion reactor designs.

Due to Coulomb repulsion between incident charged particle and target nucleus, the cross sections of charged particle nuclear reaction are much smaller than those of neutron, they are in about millibarn region; besides, there is a Coulomb threshold, which is dependent upon Coulomb barrier, when incident charged particle energy is less than the Coulomb threshold, the nuclear reaction can not be induced, even if reaction energy $Q>0$. But in general, the threshold for a reaction of $Q>0$ equals to zero. These are the two characters of charged particle nuclear reaction.

Compared with neutron experimental data, CPND are scarce and existing data are scattered, usually the measured data are not enough to do an evaluation. Therefore, Chinese Nuclear Data Center (CNDC) puts the stress on the establishment of nuclear reaction theory and model calculation codes for CPND.

By the end of fifties, the measurements of CPND with light particle incident were started in China Institute of Atomic Energy. About ten years later, the studies of nuclear reactions induced by heavy ion have been performed. From 1975 on, the evaluations[1] of CPND on light, intermediate, heavy and fissionable nuclides have been carried out at CNDC in the energy region from threshold to 20 MeV or above.

In general, data are generated from experiment, theory and systematics. The experiment is the first and direct source, and the base of both the latters.

The main task of evaluators consists in the collection, comparison, critical assessment and selection of experimental data and associated covariances; nuclear model calculations and systematics must be used to fill gaps and remove inconsistencies in the available experimental data; followed by the derivation of preferred values by appropriate combination procedures, or self–consistent sets of those if necessary.

1 EVALUATION OF EXPERIMENTAL DATA

1.1 Compilation and Collection of CPND

The measured data need to be compiled in EXFOR format for preserving, exchanging and using. CNDC has compiled the CPND measured in China, and sent to NDS / IAEA.

It is high important to make full use of all the available information on nuclear data. This is one of cardinal principles of nuclear data evaluation; because the more information is utilized, the more reliable and accurate recommendation is obtained. Therefore the related experimental data must be collected as complete as possible.

The bibliographies and indexes to CPND used at CNDC are as follows :

Nuclear Science Abstracts; Nuclear Data Table; Atomic Data and Nuclear Data Table; INIS Atomindex; USRL–50400, BNL–NCS–50640, BNL–NCS–51771; CPND EXFOR Master–File Index.

The numeral data can be got from EXFOR entries, some papers and their authors sometimes; however, it is necessary for this purpose to read graph, because parts of the experimental data have not been compiled in EXFOR entries yet. A part of numeral data used for CPND evaluation at CNDC were taken from the figures of related articles and reports. The error of reading graph is about 1~5%.

1.2 Comparison and Evaluation of CPND

The first step, experimental data are analysed on the basis of measuring method and instrument, correction factors and covariance matrixes etc.

The main methods used in measurements of CPND are as follows :

(1) Measurement of outgoing particles : "$E/\Delta E$" and "E/t" measurements, magnetic deflection, mass—separator, pulse—height discrimination;

(2) Measurement of production nucleus : activation, chemical separation, collection of recoil nucleus, and their combination.

In a complex reaction, the method with particle identification is better than the others, and the more the instrumental resolution is high, the more the measured result is accurate.

In absolute determination, the incident charged particle flux is often measured by beam current integration. The unstability of beam current integrator is one of important sources for data difference sometimes, because there are usually some interferences in experiment, if they are not noticed and eliminated. In addition, the background due to big elastic scattering is also a factor not to be ignored.

In relative measurement, if the standard data of monitor are renewed, the result should be renormalized.

When any correction and covariance in evaluated experiments are unreasonable or omitted, we adjust or supplement them, if possible; otherwise, such experimental data shouldn't be adopted.

After this process, available experimental data have been selected.

The second step, all chosen data are plotted in different figures according to data categories respectively, in order to compare each other. If the discrepancy among them is large, a further and refined analysis is needed to decide which should be accepted or rejected. If it is difficult to do this, the basic principle is that the minority is subordinate to the majority, or equal—weight average can be adopted.

Currently, simultaneous evaluation is proposed and applied to estimate cross sections, especially for important ones. It is advanced in comparison with individual evaluation usually adopted in many works because of the following reasons. In the former method, it can be expected to reduce contribution of systematic errors in experiments to uncertainties of evaluated results, and original values of experimental data are used without renormalizing even ratio data.

Simultaneous evaluation method has been used in neutron data evaluation at CNDC. It will be utilized for evaluating CPND.

1.3 Data Processing

The data fit programs with Legendre polynomials[2] for angular distribution, orthogonal polynomials[3] and spline functions[4] with knot optimization are used at CNDC. Both the latters can estimate not only the evaluated cross sections but also the covariances associated with them. The both quantities can be estimated taking account of correlation on the cross section measurements.

Model theory is also used to fit experimental data[5], as shown in Fig. 1. Sometimes, eye–guide is convenient and useful for this purpose.

Because of large systematic errors and discrepancies between different experimental results which in many cases are very difficult to disclose and eliminate, or lack of experiment data, the further and more precise measurement is necessary, if possible.

If evaluated experimental data are not quite enough for application requirement, theoretical model calculation, systemstics research or comprehensive recommendation are required.

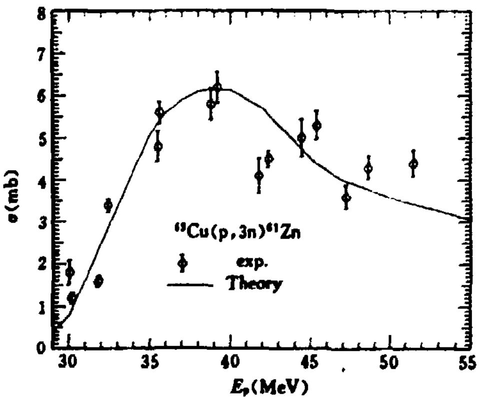

Fig. 1 The excitation function of $^{63}Cu(p,3n)^{61}Zn$ reaction

2 NUCLEAR REACTION THEORY AND MODEL CALCULATION

Many CPND needed for application are either very difficult to measure or have to wait for being measured for unpredictable time delays. To a large extent due to the practical requirements, nuclear reaction theories and models have been developed to the extent, that with appropriate parameters based on related available experimental data the required limited accuracies for some of those "unmeasurable" data can approximately be met. These developments concern particularly the theoretical description of fission process, improvement in the statistical and optical models of nuclear reaction, the introduction of pre-equilibrium and multistep processes in the description of nuclear reaction and a further understanding of the physical foundations of nuclear model parameters. Parallel to these theoretical developments powerful computer codes have been developed which allow very detailed calculations of nuclear reaction data for structural and fissionable materials.

The present power of appropriately parameterised nuclear reaction theories and nuclear model calculation can be described as follows :

(1) They can be employed for inter– and extra–polation of experimental results[5], see Fig. 2;

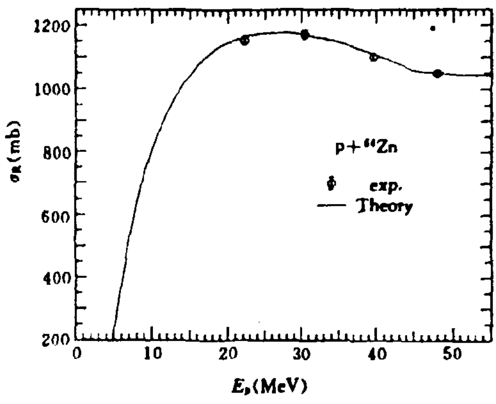

Fig. 2 The reaction cross sections of p+^{64}Zn

— CMUP2 calculation

(2) They can be used for the prediction of unknown nuclear data such as reaction cross section, angular and energy distributions as well as double differential cross section etc.[6], see Fig. 3;

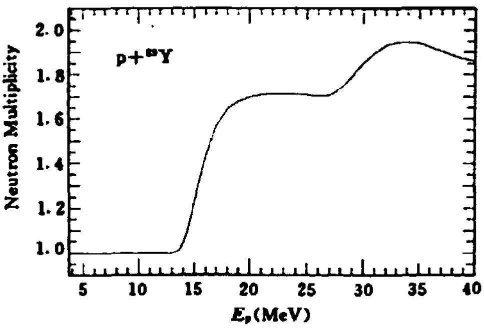

Fig. 3 The calculated neutron multiplicity of ^{89}Y induced by proton below 40 MeV

(3) They can be used to check the internal consistency between measurements of different nuclear data of the same nuclides or neighboring nuclides and can occasionally help in deciding among discrepant experimental results[7], as shown in Fig. 4;

The isomeric cross section ratios for reaction ^{55}Mn(α,n)^{58}Co were determined by S. Iwata (1962)[8], T. Matuso (1965)[9] and Long Xianguan et al. (1989)[7]. The theoretical calculation was performed with Huizenga and Vandenbosch method[10], it trends towards the experimental data of S. Iwata[8] and Long Xianguan et al.[7]. The latter is a newer and more accurate measurement, because high resolution γ-spectrometry technique was used.

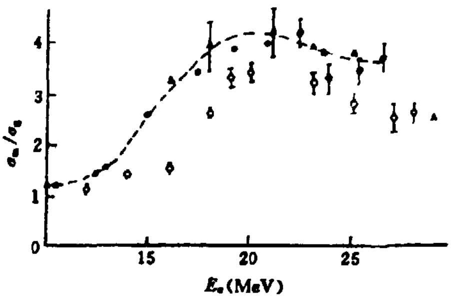

Fig. 4 Isomeric cross section ratios for ^{55}Mn(α,n)^{58}Co reaction

— Theoretical calculation; ▲ Iwata (1963); ○ Matuso (1965); ● Long Xianguan et al. (1989).

(4) They can be used to calculate the cross sections of numerous charged particle nuclear reactions with medium and high incident energy.

Some general and united codes for CPND have been set up at CNDC. For instance, a comprehensive R–matrix analysis RCA code[11] based on the multichannel and multilevel R–matrix theory[12] is for light nuclei; model calculation codes CMUP2[13] based on the optical model and the unified treatment of exciton model and evaporation model is for medium and heavy weight nuclei and CFUP1[14] based on MUP2[15] code for fissile ones, they can be used to calculate the related CPND in the energy region from threshold to 50 MeV, and will to 100 MeV according to the plan of 1993. See Fig. 5[16].

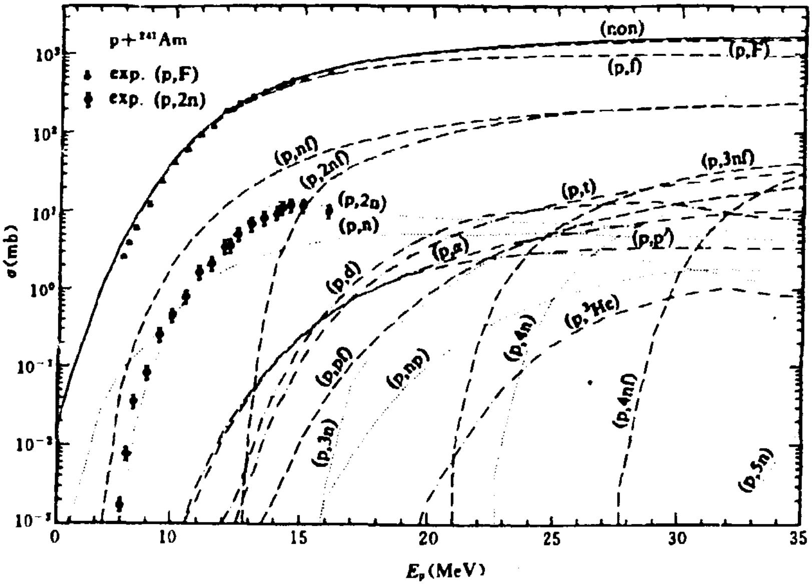

Fig. 5 The calculated particle emission cross sections in reaction p+^{241}Am below 35 MeV

— CFUP1 calculation

3 SYSTEMATICS RESEARCH

The CPND of the nuclides which have a short life time or very low abundance are either scarce or scattered, some of these data can complemented by systematics.

The method settled a problem by from individuality to generality such as systematics has been applied in many sciences.

If systematical behavior can be found out from existing experimental data of other nuclei, unknown physical quantities can be derived from known ones with the aid of systematics research.

A series of systematics research on neutron data have been done at CNDC, such as average total radiative widths[17], thermal fission cross sections of actinides[18], (n,2n)[19], (n,charged–particle) and (n,γ) cross sections[20~23].

The systematicses of (p,n), (p,2n) and (d,n), (d,2n) reaction cross sections are being studied by means of simplified model formulas and empirical parameters at CNDC. The results will be published in "Communication of Nuclear Data Progress".

4 COMPREHENSIVE RECOMMENDATION

A final comprehensive recommendation is usually necessary after the evaluations for various channels accomplished individually, when a complete set of all the partial reaction data is required.

(1) Generally, the comprehensive recommendation is mainly based on the evaluated measured data, the model theory calculation and systematics results are usually used to make up the deficiencies of experimental data;

(2) A comprehnsive reevaluation must be done in the case that the individual evaluations do not meet the physical constraint condition, i. e. the nonelastic scattering cross section is not equal to the sum of all the partial cross sections.

In this case, some cross sections were reevaluated and adjusted firstly to make them to be self–consistent in the experimental errors. Then the reevaluated data of various reaction channels were fitted jointly to a self–consistent data set by measns of one of the following methods.

(1) To obtain the cross section of a specified reaction channel from other various channels according to certain physical relation. For example, a reaction cross section (usually they are deficient in measured data or with poor accuracy) can be deduced from the nonelastic scattering cross section minus the sum of all the other partial reaction cross sections;

(2) To make the excitation functions of various reaction channels self–consistent by the aid of simulteneously fitting of the various individual evaluations with the B–spline function or polynomial.

If there is a need for the data of a specific reaction channel but not for a complete set of all the partial reaction channels, the basic principles of comprehensive recommendation can be given as follows:

(1) There are more accurate and enough experimental data, the recom-

mended values are taken from evaluated ones;

(2) If experimental data are scarce, theoretical model calculation or systematics can represent them well, model or systematics calculation can be accepted, see Fig. 6[5].

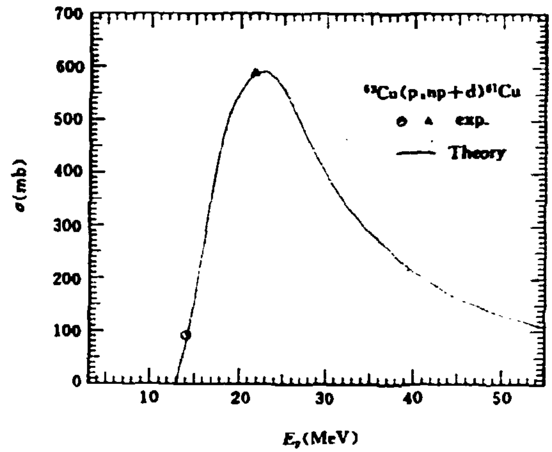

Fig. 6 The excitation function of $^{63}Cu(p,np+d)^{61}Cu$ reaction

5 SUMMARY

Using mentioned–above charged–particle evaluation techniques, CNDC has evaluated thermal nuclear reaction cross sections for fusion application and activation cross sections of intermediate and heavy nuclei for isotopes production and activation analysis, such as $^{2}H(d,n)^{3}He$, $^{2}H(d,p)^{3}H$, $^{3}H(d,n)^{4}He$, $^{3}He(d,p)^{4}He$, $d+^{6,7}Li$, $t+^{6,7}Li$, $^{3}He+^{6,7}Li$ and $^{56}Fe(p,\gamma)^{57}Co$, $^{57}Fe(p,n)^{57}Co$, $^{235}U(d,2n)^{235}Np$, $^{235}U(p,n)^{235}Np$. The evaluated results have satisfied the needs of the users.

However, the model calculation program for light nuclides still need to be set up at CNDC. The existing codes CMUP2 and CFUP1 will be developed in the energy region from threshold to 100 MeV or more. It is necessary for CNDC to make a further research on the systematics and covariance of CPND. A problem awaiting solution in the world is how to establish a set of standard data of monitor for CPND measurements.

Authors are very grateful to Drs. C. L. Dunford and R. M. White of U. S. A. for giving a chance to summarize the CPND work at CNDC, and Dr. Wang Dahai of IAEA for his helpful advices.

REFERENCES

[1] Zhuang Youxiang et al., hsj–CPND–1–(bp) (1976) ~ hsj–CPND–41 (bp) (1992)

[2] Yu Baosheng et al., At. Energy Sci. and Tech., 3, 281(1983) (in Chinese)

[3] Zhao Zhixiang et al., At. Energy Sci. and Tech., 6, 16(1989) (in Chinese)

[4] Liu Tingjin et al., CNDP, 2, 58(1989)

[5] Han Yinlu et al., Communication of Nuclear Data Progress (CNDP) 7, 45(1992)

[6] Shen Qingbiao et al., to be published in Nucl. Sci. and Eng., (1992)

[7] Long Xianguan et al., Chinese J. of Nucl. Phys., 11, 25(1989) (in Chinese)

[8] S. Iwata, J. Phys. Soc. Jpn., 17, 1323(1962)

[9] T. Matuso et al., Phys. Rev., B139, 886(1965)

[10] J. Huizenga et al., Phys. Rev., 120, 1305(1960)

[11] Chen Zhengpeng et al., CNDP 4, 20(1990)

[12] A. M. Lane et al., Rev. Mod. Phys., 30, 257(1958)

[13] Cai Chonghai et al., CNDP 3, 29(1990); CNDP 4, 18(1990)

[14] Shen Qingbiao, CNDP 5, 36(1991)

[15] Cai Chonghai et al., MUP2 (IAEA–0907 / 01), News from the NEA Data Bank, No. 1, 7(1986)

[16] Zhuang Youxiang et al., CNDP 8(1992)

[17] Zhuang Youxiang et al., At. Energy Sci. and Tech., 1, 34(1985) (in Chinese)

[18] Gu Fuhua et al., At. Energy Sci. and Tech., 1, 39(1985)

[19] Zhang Jin et al., Proc. of Inter. Conf. on Nucl. Data for Basic and Applied Sci., Santa Fe, p. 1611, 1985; IAEA–TECDOC–457 p. 159, (1989)

[20] Zhao Zhixiang et al., Nucl. Sci. and Eng., 99, 367(1988)

[21] Zhao Zhixiang et al., Proc. of Inter. Conf. on Nucl. Data for Sci. and Tech., Mito, Japan, p. 513, 1988

[22] Zhao Zhixiang et al., Chinese J. of Nucl. Phys., 11, 71(1989) (in Chinese)

[23] Zhao Zhixiang et al., Chinese J. of Nucl. Phys., 13, 139(1991) (in Chinese)