Progress on Chinese Evaluated Nuclear Parameters Library And Nuclear Reaction Model Computation System*

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Abstract

The research projects on construction of a Chinese Evaluated Nuclear Parameter Library (CENPL) and development of a Nuclear Reaction Model Computation System (NRMCS) for nuclear model calculations were proposed and commenced. At present, the CENPL includes the atomic masses, discrete level schemes, average neutron resonance parameters, nuclear level densities, giant dipole resonance parameters, fission barrier parameters, and optical model parameters seven sub-libraries. The NRMCS contains the following three parts: the Nuclear Model Program Library, Nuclear Parameter Databases, and Analyses-Selection-Computation-Analyses System. The CENPL and NRMCS are the computerized libraries for storage, retrieval, optimization, calculations, evaluations and so on. The data and Programs of CENPL and NRMCS are taken from ones of different institutes and international organizations. Some of them were researched and estimated by Chinese scientists and our group. The CENPL has already been applied in researches of the nuclear physics, nuclear science and technology, and other fields widely.

* The project supported in part by the International Atomic Energy Agency and the Morrison & CO., LTD.

I. INTRODUCTION

In development of the nuclear physics, a lot of the nuclear basic data and nuclear model parameters have been accumulated. The nuclear basic data, such as the atomic mass, lives, energies, spins, parities of nuclear ground state and excited states, etc., are nucleus signs, They can reflect nuclear basic attributes and characteristics. In addition, an important feature in the nuclear physics is that various model theories have been presented and developed to follow its advance. These models are reflection of ability to understand and reproduce the abundant and complicated nuclear phenomena. These data and different model theories have widely been used in many research fields and application of the nuclear physics, nuclear science and technology and other subjects. In particular, many nuclear data, such as various nuclear reaction cross sections, angular distributions, spectra, and so on induced by neutron, proton, alpha, photon etc. are very necessary and important in nuclear power development, nuclear reactor physics, design and safety, medical radioisotope production, environmental protection and so on. The ever-higher demands for the nuclear data have been set in their accuracy and reliability. In addition, the resources of nuclear experimental data are very limited; therefore the nuclear model calculations have become an important source of evaluated nuclear data. Due to the widespread use of nuclear models in generating evaluated nuclear data there is a substantial demand for a large volume of precise nuclear basic data and reliable model parameters, that can cover still more nuclei and more extensive energy range to perform such calculations. The nuclear model theories and relevant model parameters should further be developed, and the research projects on construction of a Chinese Evaluated Nuclear Parameter Library (CENPL) and development of a Nuclear Reaction Model Computation System (NRMCS) for nuclear model calculations were proposed and commenced. The CENPL and NRMCS are the computerized libraries for storage, retrieval, optimization, calculations, evaluations and so on. The data and Programs of CENPL and NRMCS were taken from ones of different institutes and international organizations. Some of them were researched and estimated by Chinese scientists and our group, and they have been selected as the recommended parameters for including into the Starter Files of the Reference Input Parameter Library (RIPL)[1] of the International Atomic Energy Agency (IAEA). In this paper, the ENPL and NRMCS will be described.

II. CHINESE EVALUATED NUCLEAR PARAMETER LIBRARY

1. Scope and Composition

At present, CENPL includes the following seven sub-libraries (see Fig.1):

(1) The sub-library of atomic masses and characteristic constants for nuclear ground states (MCC);
(2) The sub-library of discrete level schemes and gamma radiation branching ratios (DLS);
(3) The sub-library of average neutron resonance parameters (ARP);
(4) The sub-library of nuclear level densities (NLD);
(5) The sub-library of giant resonance parameters for gamma-ray strength function (GRP);
(6) The sub-library of fission barrier parameters (FBP);
(7) The sub-library of optical model parameters (OMP).

Each sub-library consists of two parts: the data file and the management retrieval code system.

The evaluated nuclear basic data and model parameters are compiled in the data files of CENPL. And these files can cover nuclei as more as possible and contain various popular model parameters recommended by different authors in order to satisfy the demands of different users.

The management-retrieval code can provide the related information on the nuclear basic data and model parameters stored in the data files, and retrieve the required data. Besides the main functions mentioned above, there are other functions, such as deriving new data, supplementing the deficient parameters, making some nuclear model calculations and comparing the calculated results of different model parameters with the experimental results etc. to help users to choose and obtain the required parameters.

The management-retrieval code provides two retrieval ways. One is a retrieval for a single nucleus (SN) or single reaction channel (SC); another is for all relevant residual nuclei or reaction channels in a nuclear reaction model calculation (NR).

2. Contents and Progress

The CENPL-1 (the first version) was set up and collected into the Reference Input Parameter Library (RIPL) of the International Atomic Energy Agency (IAEA) as its Starter Files and recommended parameters. At present, we have commenced to develop the updated CENPL, i.e. CENPL-2 (the second version). The contents and progress of each sub-library are as follows:

2.1 MCC Sub-Library

For any nuclear reaction calculation nuclear masses are very basic data for getting binding energies and the Q-values of nuclear reaction. We also need the pricise nuclear masses in the researches on nuclear physics and some relevant subjects.

The MCC data file consists of the recentest measured, systematics, and calculated atomic masses [2,3], deformations [3] of nuclear ground states, etc. of 9066 nuclei ranging from Z=0, A=1 to Z=136, A=339. The few of these data were measured by Chinese scientists, and were collected, evaluated and compiled by us.

By using MCC management-retrieval code, not only the data listed in MCC data file can be retrieved, but also the others, such as total binding energies, separation energies of some particles and particle groups, $\beta^{\pm}$ decay energies, reaction energies and threshold energies etc. can be derived.

2.2 DLS Sub-Library

Discrete level schemes, including spins, parities, gamma-transitions and branching ratios are important for researches of nuclear structure, establishing of low-energy nuclear level densities and related cross section calculations.

The DLS data file contains the data on the both discrete levels and their gamma radiations. The data and information of this file were translated from the Evaluated Nuclear Structure Data File (ENSDF)[4]. The data were further checked and corrected. Some recentest discrete level schemes measured by Chinese scientists were supplemented in DLS data file. For each measured level, its energy, spin, parity, half-life, as well as branching ratios etc. of its gamma radiations are listed in DLS data file. At present, this file contains the data of 79461 levels and 93177 gamma rays for 1908 nuclides.

The management-retrieval code can help user select levels required from the whole level schemes.

2.3 ARP Sub-Library

The ARP data file contains S-wave average level spacing, neutron strength functions and average gamma radiative widths for 340 nuclides, which were estimated and recommended with using many kinds of statistical methods by our group [5].

The average neutron resonance parameters are the most important parameters describing average properties of the neutron resonance range and required for statistical model calculations of nuclear reactions. They are the most basic data in the researches of nuclear level density too.

2.4 NLD Sub-Library

The nuclear level densities are crucial ingredients in the statistical models of nuclear reaction and nuclear reaction cross section calculations. Many kinds of the level density formulae have been accumulated in the past, which are being used today, and there are many sets of related level density parameters for each formula. For the convenient use the eight sets of level density parameters for three popular used level density formulae (i.e. composite formula of constant temperature-Fermi gas model [6], back-shifted Fermi gas formula [7] and generalized superfluid model [8]) were compiled in NLD data file. There are level density parameters from our group [9-11] for each level density formula which were estimated and recommended by fitting our average neutron resonance spacing and cumulative number of low lying levels [5].

The management-retrieval code of NLD sub-library not only can retrieve the level density parameters, but also can calculate the relative data by different level density parameters and compare the calculated results.

At present, we are re-estimating and recommending the level density parameters by fitting the new relative data and expanding this sub-library.

2.5 GRP Sub-Library

Gamma-ray strength functions are important for description of the gamma emission channel in nuclear reactions. This is an almost universal reaction channel since gamma rays, in general, may accompany emission of any other emitted particle. The GRP data file contains the giant dipole resonance parameters (GDRP) of 102 nuclides ranging from ^{51}V to ^{239}Pu compiled by Dietrich et. al.[12] and GDRP of some A<50 nuclides, which have been extracted fitting the photonuclear reaction data by us [13].

Since there are no GDRP for most nuclides, we presented a treatment method including replacement, interpolation and calculation of systematics formulae [14], which could supplement GDRP for lack of ones in the GRP data file by using the management-retrieval code. In order to improve the systematics formulae, a semi-empirical formula for the peak

energy calculation of the giant dipole resonance was given [15].

2.6 FBP Sub-Library

Fission barrier parameters are very important to determine the fission character of a nucleus and to calculate fission cross sections. In the FBP data file there are five sets of fission barrier parameters, which are ones recommended by Lynn [16] (for 50 nuclides ranging from ^{230}Th to ^{255}Cf), Back et al. [17](for 46 nuclides ranging from ^{229}Th to ^{253}Cf), Ohsawa [18] (for 24 nuclides ranging from ^{232}Pa to ^{253}Cf), Smirenkin [19] (for 71 nuclides ranging from ^{232}Th to ^{253}Cf), and Maslov [20] (for 45 nuclides ranging from ^{230}Th to ^{249}Cm), respectively.

2.7 OMP Sub-Library

The optical model provides the basis for many theoretical analyses and evaluations of nuclear cross sections. In addition to offering the optical model cross sections directly, the optical model potentials are widely used in the direct reaction theory, statistical theory and quantum mechanical pre-equilibrium theory of nuclear reaction.

The OMP data file includes the following two parts:

(1) Global and regional optical model potential parameter sets, and
(2) Nucleus-specific optical model potential parameter sets.

The latter contains 75 sets of optimum optical model parameters of neutron, which were used in the neutron reaction data calculations in China. Its retrieval code not only could retrieve the required optical model parameter sets for a reaction channel and several related reaction channels in a realistic nuclear reaction, respectively, but also could calculate the optical model cross sections by retrieved optical model potential parameters and compare the calculated results.

At present, the OMP data file is further being expanded.

III. NUCLEAR REACTION MODEL COMPUTATION SYSTEM

The Nuclear Reaction Model Computation System (NRMCS) contains the following three parts (see Fig.2):

(1) Nuclear Model Program Library (MPL),

(2) Nuclear Parameter Databases (NPD),
(3) Analyses-Selection-Computation-Analyses System (ASCAS).

There are the functions of nuclear model calculations and nuclear model parameter evaluations in the NRMCS.

The various popular programs of the nuclear reaction model, for example SCAT2, GNASH, ALICE, TNG, DWUCK, ECIS, MUP, NDCP etc., are being collected and integrated in the MPL. These programs deal with the optical model, statistical theory of the compound nucleus reaction, pre-equilibrium emission model, direct reaction theory, theories on heavy ion reactions and so on, and they can calculate the various cross sections of neutron-, proton-, deuteron-, triton-, ^{3}He-, alpha-, photon- and heavy ion- induced nuclear reactions. The programs estimating nuclear model parameters, such as average neutron resonance parameters, nuclear level density parameters, giant resonance parameters and so on, are also contained in the MPL.

The NPD contains the following seven major input parameter sets:

(1) Atomic masses and related data,
(2) Discrete level schemes, their radiations and branching ratios,
(3) Average neutron resonance parameters,
(4) Nuclear level densities,
(5) Gamma-ray strength functions,
(6) Fission barrier parameters,
(7) Optical model parameters.

These data sets could be selected from CENPL.

The MPL and NPD will be connected and combined by ASCAS. There are the following functions in ASCAS. First of all, the ASCAS can analyze the input information on target nucleus, incident particle and energies, and computational functions required. Secondly, according to information analyzed above, it will select the suitable theoretical computation program from the MPL, retrieve the input parameters from NPD and generate input files required for the selected program. Thirdly, the nuclear model computations for required functions would be carried out. Fourthly, the calculated results will be analyzed and compared with the input experimental data. There is also the function of re-optimization of the model parameters in the ASCAS. Finally, the calculated results and used model parameters will be written respectively.

At present, there is NPD in the NRMCS. As the first step, we have commenced to set up MPL and to study on parameter re-optimization.

IV. CONCLUSIONS

The CENPL-1 (the first version) including its data files and management retrieval code systems was completed. Our group, as a member of the Co-ordinated Research Program on "Development of Reference Input Parameter Library on Nuclear Model Calculations of Nuclear Data (RIPL)" of the International Atomic Energy Agency (IAEA), submitted the CENPL-1 to the IAEA. These Files can be conveniently accessed using the Web interface or by using FTP. The address of the Web sits reads: http://www-nds.iaea.or.at/ripl/, while for FTP one should use: ftp iaeand.iaea.or.at. At present, we are developing the updated CENPL, i.e. CENPL-2 (the second version). The data files are being expanded and updated, some model parameters are being re-estimated and recommended. The management retrieval codes should further be developed and perfected for wider applications. We have commenced to develop the NRMCS too. As the first step, the current programs of the nuclear reaction model calculations and model parameter estimations are being collected and studied.

The following conclusions can be obtained.

1. It can be said that we have succeeded in developing an initial nuclear parameter library, the CENPL, and it has widely been used in many research fields and application of the nuclear engineering and technique. For example, we have provided a lot of nuclear parameters for nuclear data calculations, especially nuclear data calculations of many unstable nuclides, nuclear model analyses, researches on nuclear structure, nuclear fission and fusion, new nuclides etc., as well as in search of new Mossbauer's spectra and so on. The applied results show that CENPL is satisfactory and convenient, and the project of developing nuclear parameter library is of great worth.

2. All seven sub-libraries of the CENPL were recommended as the RIPL Starter Files of the IAEA. Some parameters, such as the nuclear level density parameters, giant dipole resonance parameters, which were estimated and recommended by our group, were taken as recommended parameters for the RIPL Starter Files [1]. The recommendations in the Third Research Co-ordination Meeting on Development of Reference Input Parameter Library for Nuclear Model Calculations of the IAEA are as follows [1]:

(1) "For the Gilbert-Cameron model the parameter of the Beijing group, based on a rather recent compilations of the neutron resonances and low-lying level densities and

included into the beijing_gc.dat file, are chosen as recommended", these parameters "seem to be the best ones". "They are recommended as the most reliable for the including into the Starter File of the level density parameters".

(2) "For the backed-shifted Fermi gas model the beijing_bs.dat file is selected as the recommended ones".

(3) For recommended giant resonance parameters, "they are extended by the Beijing group in later years especially for light nuclei", "and a tabular form of giant dipole resonance parameters for specific nuclei is given in recommended file beijing_gdr.dat".

Finally, we will quote the invited report [21] of Drs. D.W. Muir (Nuclear Data Section, the IAEA), P. Nagel, E. Sartori (Nuclear Energy Agency Data Bank, the OECD) et al., in International Conference on Nuclear Data for Science and Technology, held in Trieste, Italy, on 22 May, 1997. "It is important mention that the development of RIPL has benefited significantly from the complementary effort to develop the Chinese Evaluated Nuclear Parameter Library (CENPL)".

Acknowledgment: The authors would like to thank NDS/IAEA and NNDC/BNL for providing us the data tapes with mass excesses, ENSDF and so on.

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