Recent Nuclear Data Measurement, Evaluation and Calculation in China

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Recent nuclear data measurement, evaluation and calculation in China related to CENDL-3 are summarized. They include the measurements of secondary neutron and charged particle DDXs, activation CS, fission yields, neutron spectra and radiative capture gamma-rays; the evaluation and calculation.

I. Nuclear Data Measurement

1. Neutron Double Differential Cross Section (DDX)

The DDX are continuously measured at CIAE at 10 MeV incident neutron energy with Tandem by means of both normal and abnormal TOF spectrometers. The D(d,n) neutron source was used and the abnormal TOF spectrometer was used to separate the d-d breakup continuous neutron for measuring low energy part of the secondary neutron spectrum. The measurements for ^{6,7}Li are in progress.

The DDX of ^{9}Be(n,n emission) were measured at incident neutron energy 5.9 and 6.4 MeV at Peking University with Van de Graaf accelerator by using time of flight method at 10 angles between 25 and 150 degree for En=5.9 MeV and 11 angles between 15 and 150 degree for En=6.4 MeV. The energy resolution is about 5%, and the error of data is about 10%.

2. Charged-particle Double Differential Cross Section(CDDX)

The DDX of (n,x emission) were measured at Peking University with 4.5 MV Van de Graaff accelerator by means of gridded ionization chamber(GIC). The D(d,n) reaction was used as neutron source with a deuteron gas target. The DDX of ^{39}K(n,α) at 4.41, 5.46, 6.52 MeV and the differential cross section of ^{6}Li(n,t) at 3.67, 4.42 MeV were completed in last year. In addition, the DDX of ^{40}Ca(n,α) at 5.0, 6.0 MeV and ^{40}Ca(n,p) at 4.41 MeV were improved, which were measured in 1998.

3. Activation Cross Section

The excitation functions have been measured in China by several groups with activation method, such as CIAE, Peking University, Lanzhou University. The influence of the low energy neutrons was carefully paid attention and deducted by irradiating samples in the conditions of gas in and gas out, selecting a monitor with nearly same threshold and similar shape of excitation function as investigated or a group of monitors with different threshold.

4. Fission Product Yield

The fission product yield has been measured at CIAE by means of direct gamma spectrum method. Two HPGe gamma spectrometers with volume 110 cm^3 and 120 cm^3 were used. In last year, the chain yields of 8 products at light peak, 10 at heavy peak and 1 at valley were measured at incident neutron energy 5.5 MeV with HI-13 Tandem and 14.9 MeV with Cockcroft-Walton accelerator.

II. Nuclear Data Evaluation

1.General Purpose File

CENDL-3 was started in 1996 and will be accomplished by the end of 2000. It contains about 200 nuclides. Among them, the data of following nuclides will be newly or reevaluated: fissile nuclides 15, structure materials 18, light nuclides 5, fission products 91. It will contain consistent data between natural elements and their isotopes for structure material, newly evaluated data for fission products, much improved secondary neutron spectra for light nuclides and more gamma-production data(Files 12 ~ 15), double differential cross section(File 6).

1.1 Fissile Nuclides

The evaluation of ^{238}U complete data was completed at Peking University based on the available new experimental data and theory alculation by using codes APOM(automatically adjusting parameter optical model program), FMT(Hauser-Feshbach theory, exiton model), DWUCK and coupled channel optical model. The cross section of inelastic scattering was evaluated and calculated by using coupled channel optical code for first two levels and DWUCK for other higher levels,

the result is consistent with the newly measured data. The neutron double differential cross sections(File 6) were calculated and good agreement with the data measured by M.Baba and Shen was got by adjusting the parameters of FMT and DWUCK based on above experimental data.

The theoretical calculations have been completed for ^{239}Pu and the evaluation is under way. The results have been compared with the data from ENDF/B-6 and JENDL-3.2. The calculation and experimental data collecting are in progress for other Uranium and Plutonium isotopes.

1.2 Structure Material

The evaluation of complete data for natural Ni and its isotopes ^{58,60,61,62}Ni have been completed and improved. Due to the new experimental data are available in last years, the evaluated data have been considerably improved, especially the (n,p), (n,n'p), (n,α), (n,d), and inelastic scattering cross sections. The cross sections between natural Ni and its isotopes are consistent with each other, which was achieved by adjusting them with code CABEI. The energy balance was tested and the energy taken by outgoing particles and the available from the reaction are in balance within several percent.

Also the complete data have been completed for ^{63}Cu, and primary completed for ^{65}Cu. For natural Zr and its isotopes ^{90,91,92,94,96}Zr, the experimental data have been evaluated and the calculations are under way. For natural Fe and its isotopes ^{54,56,57,58}Fe, the calculations have been improved and the evaluations of the experimental data are in progress.

1.3 Light Nuclides

A new model for neutron induced reaction on light nucleus and corresponding code LUNF were developed. The key point of the model is the description of the particle emissions from discrete level to discrete levels in pre-equilibrium states. In the whole reaction processes the angular momentum and parity are conserved and the energy balance is taken into account. The level broadening effect and energy resolution are considered to fit experimental data. Using the code, the calculations for ^{9}Be and ^{12}C have been completed. The calculations for other light nuclei are under way.

1.4 Fission Product Nuclides

According to the plan, the files 1-5 will be included in CENDL-3 for 91 fission product nuclides. So far the evaluations have been completed for 40 nuclides, including theoretical calculation, experimental data evaluation, comprehensive adjusting and checking. The theoretical calculations have been completed for more than 80 nuclides.

2. Special Purpose File

According to the plan, also the special files for fission yield, activation cross section and photonuclear reaction data are being developed.

2.1 Fission Yield

The reference fission yield were continuously evaluated. The evalu-ations have been completed in last year for 15 product nuclides of ^{235}U fission and 25 nuclides of ^{238}U fission. They are as follows:

^{235}U fission: ^{85}As, ^{88,89,90,91}Br, ^{92}Sr, ^{97}Mo, ^{115g,115m}Cd, ^{135}Sb, ^{135,137}I, ^{136}Cs, ^{147,152}Sm;

^{238}U fission: ^{88,89}Br, ^{85g,85m,87,88}Kr, ^{91g}Y, ^{95}Zr, ^{99}Mo, ^{106}Ru, ^{105g}Rh, ^{111g}Ag, ^{115m}Cd, ^{125}Sb, ^{131,137}I, ^{133g,134g}Xe, ^{140}Ba, ^{144}Ce, ^{147,148}Nd, ^{151}Sm, ^{156}Eu, ^{161}Tb.

Taking into account of the special features of the retrieval and processing for fission yield data, a fission yield data evaluation system FYDES have been developed. The system includes data retrieval, data table standardization, data correction and data processing(average with weight, simultaneous evaluation and curve fitting etc.). The system has been used for above reference and other yield data evaluations.

2.2 Activation Cross Section

The activation cross sections were continuously evaluated for about 40 reaction channels to supplement and improve Chinese Evaluated Nuclear Data File CENDL-ACF. The evaluations were combined with experimental measurements closely, and the recommended data were determined with new measured data at CIAE or other laboratories in China, when the discrepancies were faced in the evaluations.

2.3 Photonuclear Reaction Data

The complete data of photonuclear reaction up to 30 MeV, including cross section, double differential cross section, gamma production data of all possible reactions, have been continuously evaluated and calculated by using code GUNF as the task of IAEA CRP. In last year, the evaluations have been completed for nuclides ^{54,56}Fe, ^{209}Bi, ^{63,65}Cu. The evaluations are in progress for nuclides ^{27}Al, ^{9}Be and Cr.

III. Theoretical Calculation

1. General Situation on Model Developing

To fit the needs to set up neutron files UNF program system has been established. This code system includes

- "UNF" code for neutron induced reactions on structure material below 20 MeV including file-6;
- "SUNF" code for neutron induced reactions on fission production below 20 MeV including file-5, which is the simplified edition of UNF code;
- "NUNF" code for neutron induced reactions on natural element below 20 MeV including file-6;
- "CUNF" code for charged particle induced reactions on structure material below 30 MeV;
- "FUNF" code for neutron induced reactions on fissile material below 20 MeV including file-6 or file-5;
- "GUNF" code for gamma-ray induced reactions on structure material below 30 MeV including file-6;

Beside the codes of nuclear reaction calculation some auxiliary codes are also established. "APMN" and "APFO" codes for adjusting optical model parameters of structure materials and fissile materials, respectively. The codes for retrieving experimental data, the codes for plotting and "DWUCK", "ECIS" for calculating direct reaction data have been developed.

To coordinate with the theoretical model calculations the input parameter data files have been established. The evaluated nuclear parameter library (CENPL) includes six sub-library. They are

- "MCC": the atomic masses and characteristic constants of the nuclear ground states;
- "GDP": the giant dipole resonance parameters for gamma-ray strength function;

- "FBP": the fission barrier parameters;
- "DLS": the discrete level schemes and gamma branching ratios;
- "NLD": the nuclear level density parameters;
- "OMP": the optical model parameters.

With the useful tools mentioned above the nuclides calculated for CENDL-3 are about 150.

China Nuclear Data Center joined the CRP on Compilation and Evaluation of Photonuclear Data for Applications, and the relevant data of some structure material and ^{9}Be have been calculated with GUNF and GLUNF codes.

2. Characteristic on Theoretical Model

In the theoretical model the nuclear structure effect is taken into account for multi-particle emission processes. The calculated data included the discrete levels not only for the neutron emission but also for the charged particle emission. The gamma production data can also be calculated. Since the recoil effect is taken into account exactly to maintain the energy balance both in C.M.S. and L.S. in the model, so the energy balance is fully satisfied in the output files. The recoil effect can expanse the spectra of the outgoing secondary particles. If the recoil effect were not taken into account, the spectra would have unseasonable shapes.

Since the method of the double differential cross sections have been developed, so that the file-6 data for all of kinds composed particle emissions can be obtained.

An new model has been developed for calculating all kinds of reaction cross sections and double differential cross sections for neutron induced reactions of light nuclei. Therefore the file-6 can given in CENDL-3. The LUNF code is developed, in which the reaction mechanisms of sequential two-body reaction, two body separation processes and three-body break-up processes are involved. Because the Legendre expansion can be employed in C.M.S. for the file-6 outputting. In this way it will reduce the size of file-6 obviously. Since the emission of the first particle has definite energy, while the secondary particle emissions have ringg-type spectra in C.M.S. So the histogram form is the suitable format to record the file-6.