Update of PHOENIX-P 42 Group Library from CENDL-2

Zhang Baocheng
(China Nuclear Data Center, CIAE)

Introduction

PHOENIX-P is a lattice physics code system, developed by the Westinghouse Electric Corporation (WEC), which was transplanted and used at Dayabay Nuclear Power Plant (DNPJVC). The associated multi-group (42-group) library was derived from the evaluated nuclear data of ENDF/B-5. Some modifications were made to the library according to the results of validation calculations. In most cases, calculations with the library can give a satisfactory results. Since the original library is from the old evaluated nuclear data, it can not meet all the requirements of reactor physics calculations of the nuclear power plant, especial the burnup calculations for fresh fuel, though the library was modified somewhere. So it is necessary to update the library with the latest version of evaluated nuclear data. To do so, based on the investigation of the old library and the information about the library[1], some programs were developed at China Nuclear Data Center (CNDC) to produce PHOENIX-P format data sets mainly from CENDL-2 and the new data were used to supersede the old ones of the PHOENIX-P library.

1 The Proceeding of Update

The generation of PHOENIX–P format data is done with the NJOY91.91 code system[2], in which the modules MODER, RECONR, BROADR, UNRESR, THERMR and GROUPR were used to produce 42-group data file GENDF from ENDF/B format evaluaed nuclear data library according to the temperatures, weighting function and so on. GENDF data file contains all necessary data, which are designated in the input file of GROUPR. Clearly GENDF is not the PHOENIX-P format data file, also some special data, like transport cross sections and resonance integral etc., can not be given directly in the GENDF file. Therefore a new module PHENR was written with the reference of the module WIMSR to convert the GENDF data into the PHOENIX–P format data and produce some additional data which are not included in the GENDF file. Besides, the structure of the PHOENIX-P 42-group library is too complicate to substitute the new data for the old ones without a proper code. JOSPH is the code, developed at CNDC, to complete the substitution.

So the code system for the update of the PHOENIX-P 42-group library was set up. The proceeding of producing and substitution of PHOENIX-P library is shown in Fig.1.

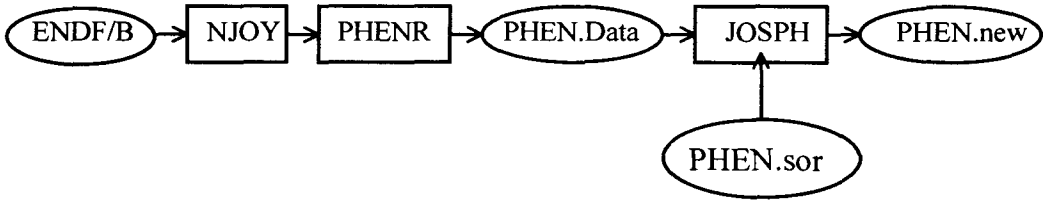

Fig.1 The update proceeding of PHOENIX-P library

Where the PHEN.sor and PHEN.new stand for the old and new PHOENIX-P library, respectively. The comparison of data among the new, old library and GENDF output file as well, shows that the code system is reliable. And that is also proved by validation calculations at Dayabay Nuclear Power Plant.

Besides substitution, the code JOSPH can be used for adding new nuclides, output of the readable list file of the library if necessary, which is easy for the user to analyze the values of cross-section.

2 PHENR Module

As mentioned above, some special data should be produced or recalculated in the PHENR module.

2.1 Resonance Integral

In the GENDF, for resonance absorber nuclide, the cross sections are given corresponding to different temperatures and σ_0s. In the PHOENIX–P library, the resonance integral tabulations are given instead, to describe the effect of self-shielding. The resonance integral can be calculated as following:

$$I_X = \int_{\Delta E} IR \frac{dE}{E} = \int_{\Delta E} \frac{\sigma_0 + \lambda \sigma_p^A}{\sigma_a^A + \lambda \sigma_p^A + \sigma_0} \sigma_X \frac{dE}{E}$$

Where λ is the Cohn-Goldstein constants, σ_0 is the parameter given through input file, σ_a^A and σ_p^A are absorption and potential scattering cross section of the absorber, respectively, σ_x is the effective cross section after self-shielding correction (the index a stands for absorption and f for fission). For the non-fissile resonance nuclide, only resonance integral of absorption is present.

2.2 Absorption and Transport Cross Section

The diffusion equation consists of three items, i.e. absorption, production and leakage item. None of them refers to the (n,2n) and (n,3n) cross sections directly. Different approximate methods are used in different codes, since the reactions are happened in the fast region (~MeV). In order to be consistent with original library, in the PHENR module, (n,2n) and (n,3n) are treated as negative and double negative capture, respectively. So the absorption cross section is corrected as follow:

$$\sigma_a^* = \sigma_a - \sigma_{n,2n} - 2\times\sigma_{n,3n}$$

Here, σ_a^* is the corrected absorption cross section. The same correction is made for the transport cross section by using σ_a^* instead of σ_a.

2.3 Scattering Matrix

PHOENIX-P 42-group library contains P_0 and P_1 scattering matrices, and the P_1 scattering matrix data is given for hydrogen, deuterium, oxygen and carbon. The scattering matrix is written in the order of destination groups. And no upscatter data is allowed above 4 eV. That means the neutron can be scattered up to 4 eV due to thermalization. Normally, the energy of thermalized incident neutron is limited by the NJOY input file, and the energy range of the destination neutron depends on the property of the nuclide, which could be over 4 eV. To meet the requirement of the PHOENIX-P data format, a special treatment of the scattering cross section should be done for the group, from which the neutron can upscatter to the group over 4 eV. If $\sigma_{i,j}$ is neutron scattering cross section from group i to group j ($E_i < E_j$ and $E_j > 4$ eV), ϕ_i is the neutron flux in the group i, the net neutron current from group j to group i is $\sigma_{j,i}\phi_j - \sigma_{i,j}\phi_i$. To keep the net neutron current consistent from high energy group j to group i, the following modification was made in the PHENR module.

$$\sigma_{j,i}^* = \sigma_{j,i} - \frac{\phi_i}{\phi_j}\sigma_{i,j}$$

Where $\sigma_{j,i}^*$ is the corrected cross section which is given in the PHOENIX-P library.

3 Generation and Substitution of Group Cross Section

For the resonance absorber, the resonance self–shielding affects not only on the absorption and fission but also on the scattering. But in the PHOENIX-P library, the

resonance integral tabulations are presented for absorption and fission only. That means the scattering cross sections do not change with the σ_0. It is very important to choose a suitable value of σ_0 to cater to the requirements of applications[3]. Therefore, σ_0 has been calculated according to the geometry and composition of typical PWR using following formula,

$$\sigma_0 = \frac{\sum_{j \neq i} N_j \sigma_j}{N_i} + \sigma_e$$

Where N_j is the concentration of nuclide j, σ_j is its total cross section, and $\sigma_e = (N_i \bar{l})^{-1}$ is the escape cross section which is introduced for heterogeneous correction ($\bar{l}$ is the mean chord length of absorption region). So the calculated value of σ_0 was given in the input file of the PHENR module. And according to σ_0 value, a self-shielding treated scattering cross section was selected in the output file of the PHOENIX-P format data.

Based on CENDL-2 and ENDF/B-6, and according to the need of DNPJVC, 42-group nuclear data sets of 9 nuclides, including ^{238}U, ^{239}Pu and ^{240}Pu etc., were updated with the code system shown in Fig.1. Here 4 isotopes of plutonium and the file of scattering law of hydrogen were derived from ENDF/B-6, and the others from CENDL-2. It should be pointed out that the Cohen-Goldstein constants of the original library and WIMS 69 library[4] were used for reference. No modification was done for the fission neutron spectrum and fission products.

4 Validation of the Updated Library

The calculations with the updated library were carried out for 4 fuel cycles of 2 units at Dayabay Nuclear Power Plant. The comparison of results among calculations with different libraries and experimental values was made.

Fig.2 to 8 show the change of critical concentration of boron with burnup. The "wec.lib results" stands for the results from the original PHOENIX-P library, and the "Framatome results" for the results calculated with Framatome code system.

From the curves of boron concentration, a significant improvement of the results, especially for the first fuel cycle, can be found due to the update of the PHOENIX-P 42-group library. Also it is notable that no adjustment was done in this work. That means these data can be used in a wide scope and its accuracy in the different calculation is stable.

The above results show the fact that the updated library is reliable and can meet the need of reactor physics calculation. Also it can be concluded that the code system, used in the generation and substitution of PHOENIX-P library, is correct.

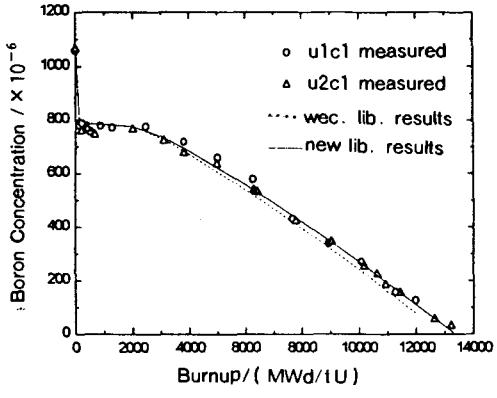

Fig.2 Boron concentration as a function of burnup for cycle 1 of units 1&2

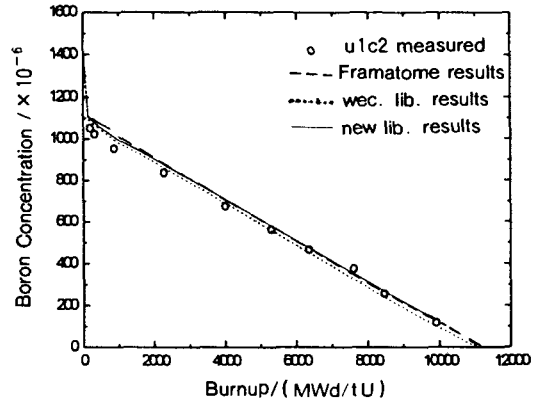

Fig.3 Boron concentration as a function of burnup for cycle 2 of unit 1

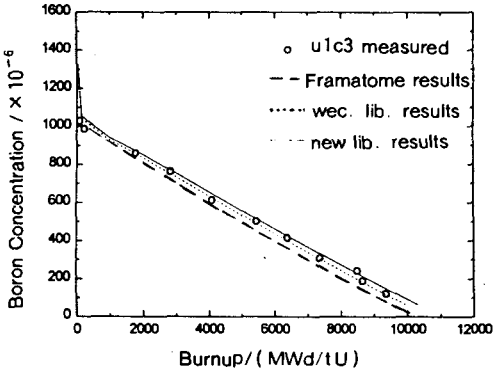

Fig.4 Boron concentration as a function of burnup for cycle 3 of unit 1

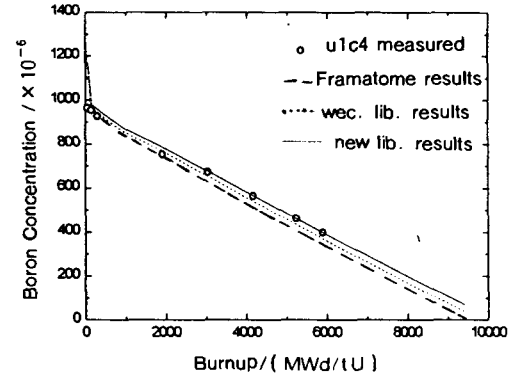

Fig.5 Boron concentration as a function of burnup for cycle 4 of unit 1

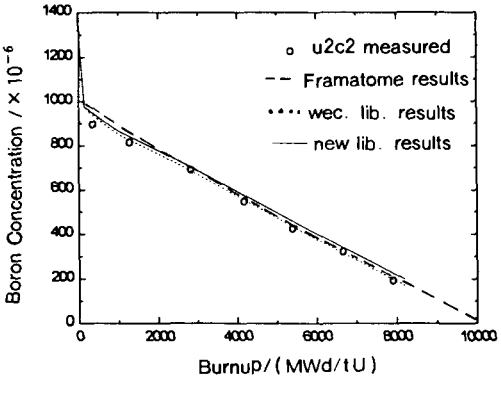

Fig.6 Boron concentration as a function of burnup for cycle 2 of unit 2

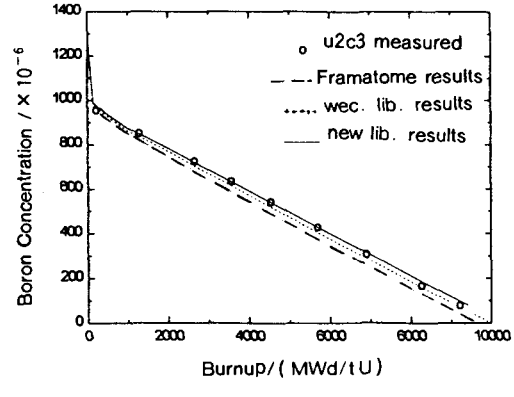

Fig.7 Boron concentration as a function of burnup for cycle 3 of unit 2

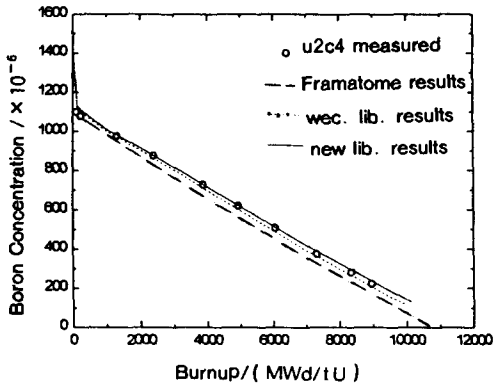

Fig.8 Boron concentration as a function of burnup for cycle 4 of unit 2

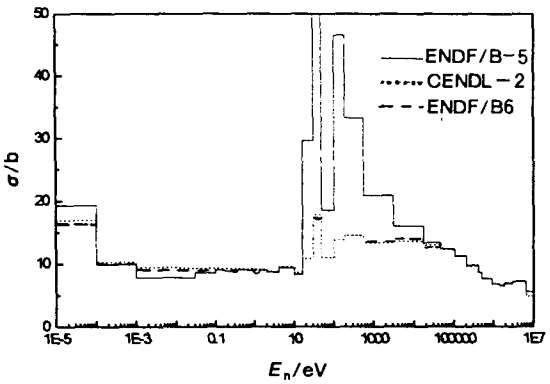

Fig.9 The comparison of ^{238}U scattering cross sections

5 Discussion and Conclusion

It is obvious that different evaluation nuclear data library is the cause of the difference of the results between old and new PHOENIX-P 42-group library. As mentioned above, the old library is based on ENDF/B-5, and the new one is based on CENDL-2 and ENDF/B-6. In general, the latter is more reliable than the former. It is well-known that ^{238}U data strongly affects on the calculated results of reactor physics parameters and their trend, due to high concentration in the uranium fuel reactors. Through comparison of group cross sections between old and new library, no obvious difference was found for fission and absorption.

The Fig.9 gives the comparison of scattering cross sections. A big difference is shown in the picture. In the resonance energy region, the value of the old library is much bigger than that of the new ones. The difference arises from the evaluation data and resonance self-shielding treatment for scattering cross sections as well. As seen in Fig.9, the bigger scattering cross section caused relative lower possibility of absorption, higher slowdown power and therefore softer neutron spectrum. All of these lead to an overestimated burnup rate of ^{235}U and overpredicted k_∞ at the beginning of fuel cycle. It also results in a lower production of ^{239}Pu and lower k_∞ at the end of fuel cycle, just like what is shown in Fig.2.

Clearly, the results could be influenced by other nuclear data. For instance, the influence of the nuclear data of plutonium would get stronger along with its

accumulation. According to the benchmark calculations for plutonium, the data of ENDF/B-6 are considered as the best one so far.

It is the first time that the Chinese evaluated nuclear data library (CENDL) is used in the nuclear power plant directly. As shown in Fig.2 to Fig.8, the calculated results from the new library, mainly deived from CENDL-2, are well consistent with the experimental results. In view of the fact that the consistency of the results, and their trend also, has been shown in every fuel cycle, it can be concluded that CENDL-2 is reliable.

As far as we know, some modifications were made in the lattice physics code PHOENIX-P at WEC and a new 70-group library has been generated for the code by WEC and Mitsubishi Heavy Industries, Ltd[5]. With the experience from this work, we can carry out the same developmental programme if necessary.

Acknowledgments

All the validation calculations were made by Dr. Yao Zenghua. The author would like to thank him for his supports and help, and thank Prof. Liu Guisheng for his helpful suggestions.

References

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