Present Status of Fission Yield Data

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Fission yield data of minor actinides are needed for transmutation of nuclear waste by an ADS system. The yield data, however, are not enough for the application. The present status of the yield data is presented in this report.

1 Introduction

In the study of transmutation systems of minor actinides using accelerator driven system (ADS), fission yields data are needed for the calculation of neutron economy, reactor kinetics, decay heat and inventory. The yields needed for the application are those by high energy neutron- or proton-induced fission. The high energy means here that exceeds the range of traditional reactor application. In the reactor application neutrons are produced by fission and the maximum energy is below 20 MeV. In an ADS system, however, the primary neutrons are produced by spallation reaction by protons of energy of a few GeV. The energy of the spallation neutrons exceeds much higher than 20 MeV. Then the fission yields as a function of incident energy above 20 MeV are needed for such ADS application.

In this report the present status of fission yields data are described. First the situation of evaluated nuclear data file is described. After that the status of systematics and nuclear model for high energy fission is presented.

2 Status of Evaluated Nuclear Data File

There are several evaluated fission yield data, ENDF/B, JENDL, JEFF and so on. The number of types of fission yield data is 60 for ENDF/B-VI [1] which has the most plentiful data. The JENDL-3.3 file [2] has 20 types of fission yield and the JEF-2.2 file [3] has 39 types. The number of fissile nuclides is 38 for ENDF/B-VI, 11 for JENDL-3.3 and 21 for JEF-2.2 respectively. As an example the data in the ENDF/B-VI file are listed in Table 1. The data included in the file are designated as circle symbol.

Table 1 Fission yield data in ENDF/B-VI

Nuclides	Energy			
	Thermal	Fission	High Energy	Spontaneous
^{227}Th	○			
^{229}Th	○			
^{232}Th		○	○	
^{231}Pa		○		
^{232}U	○			
^{233}U	○	○	○	
^{234}U		○	○	
^{235}U	○	○	○	
^{236}U		○	○	
^{237}U		○		
^{238}U		○	○	○
^{237}Np	○	○	○	
^{238}Np		○		

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Nuclides	Energy			
	Thermal	Fission	High Energy	Spontaneous
^{238}Pu		○		
^{239}Pu	○	○	○	
^{240}Pu	○	○	○	
^{241}Pu	○	○		
^{242}Pu	○	○	○	
^{241}Am	○	○	○	
^{242m}Am	○			
^{243}Am		○		
^{242}Cm		○		
^{243}Cm	○	○		
^{244}Cm		○		○
^{245}Cm	○			
^{246}Cm		○		○
^{248}Cm		○		○
^{249}Cf	○			
^{250}Cf				○
^{251}Cf	○			
^{252}Cf				○
^{253}Es				○
^{254}Es	○			
^{254}Fm				○
^{255}Fm	○			
^{256}Fm				○

As seen in this table, the yield data are categorized as thermal, fission, high energy and spontaneous fission. The therms of "thermal", "fission" and "high energy" mean that the energy of neutrons which cause fission. The high energy means 14.7 MeV for traditional application. These categories are common even for other evaluated data. The fission yield data by neutrons of much higher energy than 14.7 MeV are needed for the field of innovative nuclear technology like ADS to reduce high level nuclear waste. These data, however, are not included in the evaluated nuclear data files available now.

For the ADS application it is reported that the yield data of the minor actinides from ^{237}Np through ^{245}Cm are needed for the incident energy up to 150 MeV[4]. The nuclides listed in table 1 cover the needed nuclides but the energy is not enough for the application. Then systematics or nuclear models are needed to be developed to estimate the fission yield of high energy fission.

IAEA organized in 1997 a Coordinated Research Program (CRP) entitled "Fission Product Yield Data Required for Transmutation of Minor Actinide Nuclear Waste" to develop fission yield systematics or nuclear models as a tool for an evaluation of energy dependent fission yields up to 150 MeV. As the scope of the CRP covers the ADS application, the benchmark tests proposed in the IAEA CRP are briefly described in the next section.

3 IAEA Benchmark Test

The purpose of the CRP is to develop systematics or nuclear model which is applicable to transmutation of nuclear waste. During the term of the CRP some systematics and model calculations had been presented by the participants. The CRP was first planned to be 4 years term. At the planned last meeting, benchmark calculations using the systematics and theoretical models presented in the CRP were proposed and the CRP was extended for one year to accomplish the proposed benchmark calculations. In the benchmark calculations, two kinds of comparisons were performed. One is the comparison with experimental mass distribution which is called Type A comparison. The other is the comparison among the calculations using the proposed systematics and theoretical models. The second type comparison is called Type B. The proposed benchmark calculations are listed in Table 2.

As the Type B comparisons are performed among calculations only, it is a good demonstration of the present status of the fission yield prediction.

Table 2 Benchmark Calculation

Type A		Type B	
Nuclide	Energy (MeV)	Nuclide	Energy (MeV)
^{233}U	Thermal, 1.0	^{237}Np	13, 28, 50, 100, 160
^{237}Np	Thermal, 5.0+5.5, 16.5	^{241}Am	13, 28, 50, 100, 160
^{245}Cm	Thermal	^{245}Cm	13, 28, 50, 100, 160
^{238}U	1.6, 5.5, 8, 10, 14-15, 21		
	13, 28, 50, 100, 160		
	E_p= 20, 50		
^{239}Pu	0.17, 7.9, 14-15		
^{242}Pu	15.1		

The comparisons were performed for the mass distributions of post- and pre-neutron emissions. As the systematics we proposed [5] is that can calculate only the mass distribution of post-neutron emission, the comparisons of the mass distribution of post-neutron emission are shown.

As examples of Type A comparisons, some of the mass distributions of low energy fission, intermediate energy and high energy fission are shown here. These comparisons are those presented at the CRP meeting in 2002. The result of the comparison of the low energy fission is shown in Fig. 1.

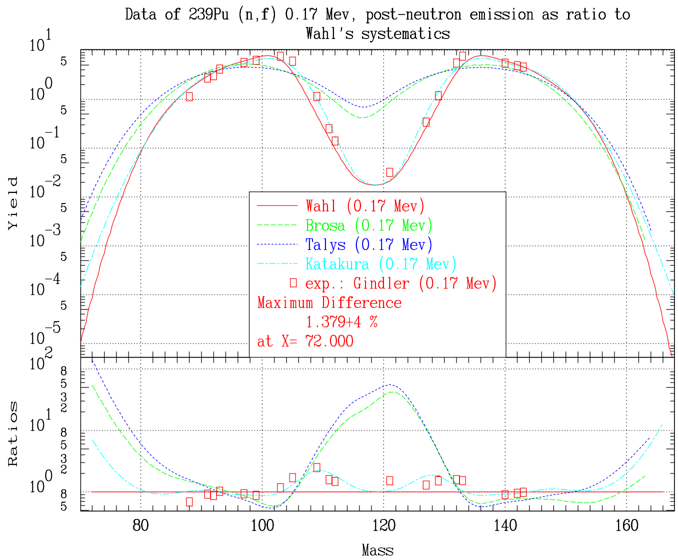

Fig. 1 Mass distribution of ^{239}Pu fission by 0.17 MeV neutrons

The lines in the figure are the mass distributions calculated by participants using systematics or theoretical models. The upper part shows the mass distributions and the lower part the ratios to Wahl's systematics. Two calculations by systematics designated as Wahl and Katakura seem to be consistent with the measured data designated by square. The calculations by theoretical model designated as Brosa and Talys show large deviation at the valley part of the distribution. Figure 2 shows the comparison of the mass distribution of ^{238}U fission by 160 MeV neutrons. The energy of 160 MeV is close to the limit in the CRP scope.

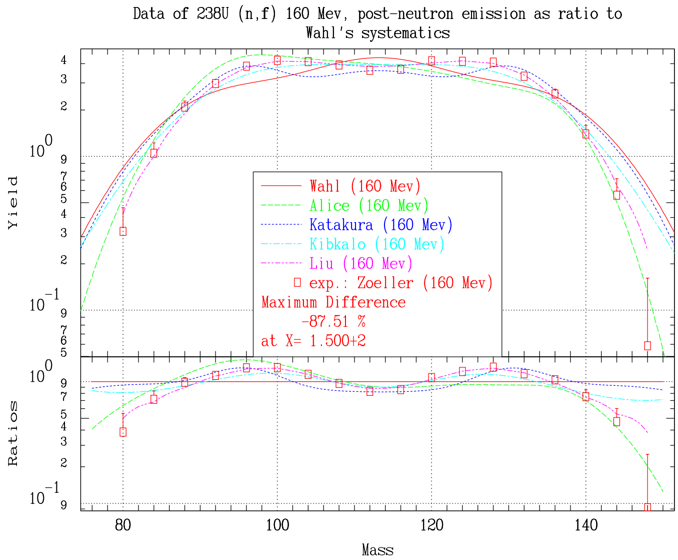

Fig. 2 Mass distribution of ^{238}U fission by 160 MeV neutrons

As seen in these figures the deviation among the calculations of high energy fission seems to be less than that of low energy fission but the descrepancy still remain at valley and the wing part.

As other examples, the comparisons of intermediate energy fission are shown in Figs. 3 and 4.

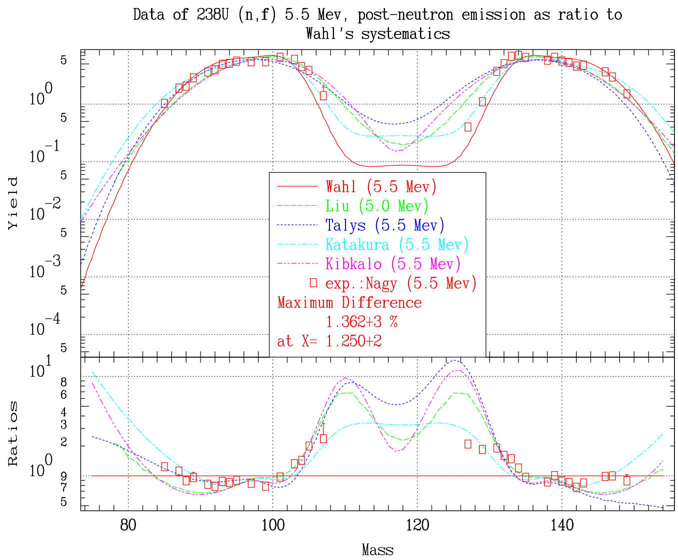

Fig. 3 Mass distribution of ^{238}U fission by 5.5 MeV neutrons

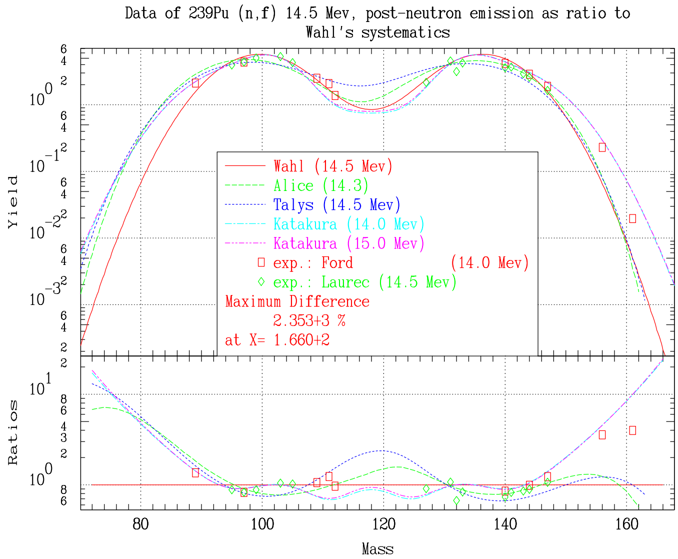

Fig. 4 Mass distribution of ^{239}Pu fission by 14.5 MeV neutrons

These comparisons show the degree of the reproduction of the systematics or nuclear models used. The reproduction of the proposed systematics and nuclear models seems to be still not enough.

For Type B comparisons, the mass distributions of ^{237}Np, ^{241}Am and ^{244}Cm by 13 MeV and 160 MeV are shown in Figs. 5, 6 and 7. The left-hand side in these figure shows the mass distribution by 13 MeV neutrons and the left-hand side the mass distribution by 160 MeV.

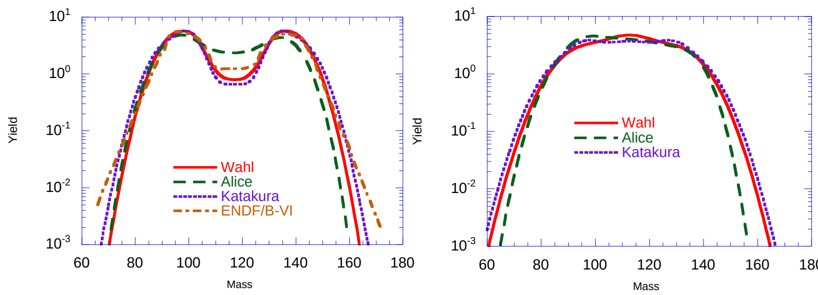

Fig. 5 Mass distributions of ^{237}Np fission by 13 and 160 MeV neutrons

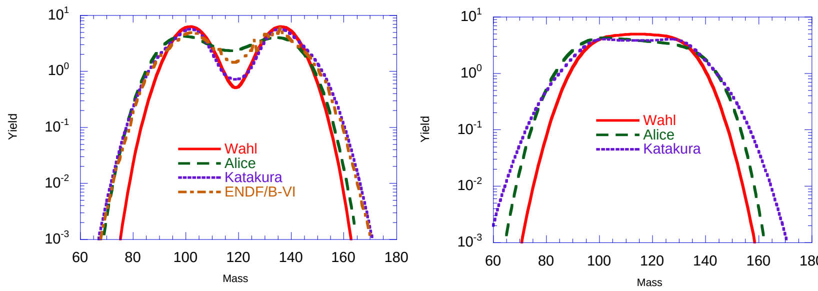

Fig. 6 Mass distributions of ^{241}Am fission by 13 and 160 MeV neutrons

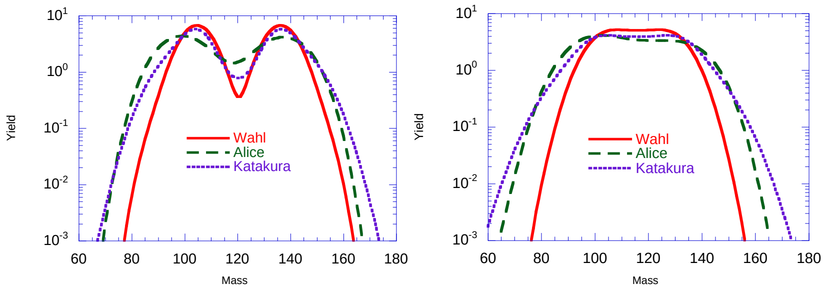

Fig. 7 Mass distributions of ^{244}Cm fission by 13 and 160 MeV neutrons

In these figures, the evaluated data of ENDF are also shown for ^{237}Np and ^{241}Am fission by 13 MeV neutrons. In the ENDF file, mass distributions by "high energy" neutrons are given for ^{237}Np and ^{241}Am. As the term of "high energy" means 14.7 MeV in the ENDF file which is close to 13 MeV, those data are shown for comparison. As there are no experimental data comparable for these yield, these comparisons only show the difference among different types of systematics and theoretical models. We can not say which one is good or bad. These figures show just the present status of fission yield prediction. In order to develop more reliable systematics or theoretical model, more data of minor actinides by high energy fission are strongly required.

4 Summary

The status of fission yield data was presented in this report. The evaluated data of fission yield are restricted in the region of traditional nuclear energy application. For the application to ADS system, fission yield data by higher energy neutrons than 100 MeV are needed. For such high energy fission, the present systematics or theoretical models are not alway give reliable estimation. In the technological application, it is important to know the accuracy of the estimated values. In order to have reliable accuracy, measured data of minor actinides in high energy region are indispensable. Although the measurement using minor actines seems to be difficult, it would be a challenging task for experimentalists interested in ADS or advance nuclear energy systems.

References

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[4] 'Overview of Physics Aspects of Different Transmutation Concepts', report NEA/NSC/DOC(94)11 (1994).

[5] J. KATAKURA, *A Systematics of Fission Product Mass Yields with 5 Gaussian Functions*, JAERI-Research 2003-004 (2003).