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EVALUATION AND TESTING OF n + ^{239}Pu DATA FOR ENDF/B-VI IN THE keV AND MeV ENERGY REGION

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Abstract: A new analysis of neutron-induced reactions on ^{239}Pu above E_n = 20 keV was performed as part of the evaluation activity for Version VI of ENDF/B. This study merges results from a new theoretical analysis of n + ^{239}Pu reactions with covariance analyses of experimental data for the ^{239}Pu total and (n,f) cross sections and for the prompt fission neutron multiplicity. The results of this study are combined with a new analysis of the resolved and unresolved resonance regions of ^{239}Pu to produce a new evaluation spanning the incident neutron energy range 10^{-5} eV to 20 MeV. Preliminary data testing calculations for several fast critical assemblies were performed in conjunction with the evaluation.

(Keywords: ^{239}Pu, neutron reactions, data evaluation, covariance analysis, benchmark data testing)

Introduction

Significant new experimental data [1] for ^{239}Pu became available in the keV and MeV neutron energy ranges since the previous update of the ENDF/B data base (ENDF/B-V.2). Especially important are new measurements of the neutron total cross section, the (n,f) cross section, and the prompt fission neutron multiplicity $\bar{\nu}_p(E_n)$. Additionally, as part of the ENDF/B-VI standards evaluation, the Cross Section Evaluation Working Group's Standards Subcommittee released in 1987 a comprehensive covariance analysis [2] that incorporated a large body of experimental data in a simultaneous analysis of standards and related cross section data, including measurements of the ^{239}Pu(n,f) cross section. To consolidate and incorporate the new ^{239}Pu experimental results as well as to check and update results for the ^{239}Pu(n,f) cross section from the simultaneous standards analysis, we performed new covariance analyses of the σ_{tot}, σ_{nf}, and $\nu_p(E_n)$ data, including consideration of uncertainties and correlations within and among a variety of experiments. The results were combined with a recent analysis of the resolved and unresolved resonance parameters for ^{239}Pu [3] and with calculations of (n,n), (n,n'), and (n,xn) reactions from a new theoretical analysis.[4]

The assembled evaluation was tested by calculating several critical assemblies, including the Los Alamos fast criticals JEZEBEL, JEZEBEL-PU, and FLATTOP-PU, and the Argonne fast reactor critical ZPR-6/7.

Covariance Analyses and Results

For the ^{239}Pu(n,f) cross section, we initially planned to simply adopt results from the simultaneous covariance analysis of standards reactions for ENDF/B-VI. In addition to the actual standards cross section measurements, this thorough analysis included ^{238}U(n,γ), ^{238}U(n,f), and ^{239}Pu(n,f) cross sections together with interconnecting ratio data. However, the standards analysis was completed before results from two new measurements of the ^{239}Pu(n,f)/^{235}U(n,f) cross section ratio were available.[5,6] The new measurements and the ^{239}Pu(n,f) cross section from the standards analysis were found to disagree above E_n ~ 6 MeV, as is shown in Fig. 1. Furthermore, it was discovered that use of the standards ^{239}Pu(n,f) cross section in a preliminary version of the ENDF/B-VI evaluation led to an underprediction of k_{eff} by ~1% in the JEZEBEL ^{239}Pu bare sphere critical assembly.[7] Accordingly, it was decided to perform a new covariance analysis of the ^{239}Pu(n,f) ratio and absolute cross section data, along with new analyses of $\nu_p(E_n)$ and the neutron total cross section of ^{239}Pu.

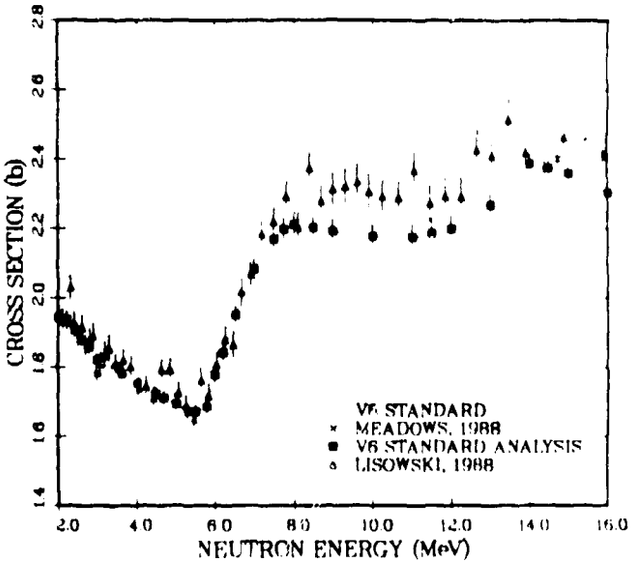

Fig. 1. Comparison of ENDF/B-VI standards evaluation of the ^{239}Pu(n,f) cross section with recent ratio measurements by Lisowski *et al.* and Meadows, converted to absolute cross sections. The dotted curve connects the solid squares, which are the covariance analysis results from the standards analysis.

All available experimental data and standard deviations were included in the analyses.[1] Where necessary, the $\nu_p(E_n)$ and σ_{nf} data were converted to ENDF/B-VI standards prior to the analyses. Approximate correlation matrices were constructed based on the details of the various experiments. In the case of ^{239}Pu(n,f) cross section, separate analyses were performed of the absolute cross section data and of the cross section ratio data relative to ^{235}U fission. All covariance analyses were performed using the Bayman analysis code GLUCS.[8]

Results from the covariance analysis of the ^{239}Pu(n,f)/^{235}U(n,f) ratio data (labeled ENDF/B-VI) are compared to a sampling of experimental data in Fig. 2, including the newer measurements.[5,6] In Fig. 3 the final ENDF/B-VI results for the ^{239}Pu(n,f) cross section are compared to ENDF/B-V, together with results of the present and the standards covariance analyses. Note that the two covariance analyses and their uncertainties are quite consistent at neutron energies below ~6 MeV. At higher energies the new analysis lies above the standards values due to influence of the new measurements.[5,6]

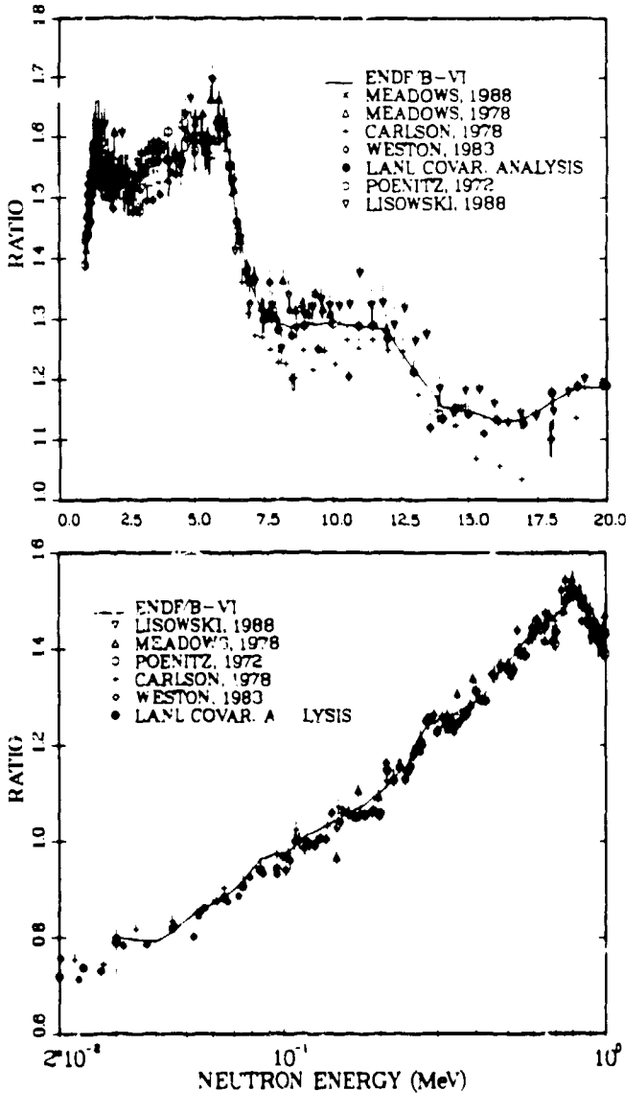

Fig. 2. Evaluated and measured neutron-induced $^{239}Pu(n,f)/^{235}U(n,f)$ fission cross section ratio from 20 keV to 20 MeV. The solid circles are the results of the LANL covariance analysis, and the curve is the ENDF/B-VI evaluation. A small selection of experimental data is compared.

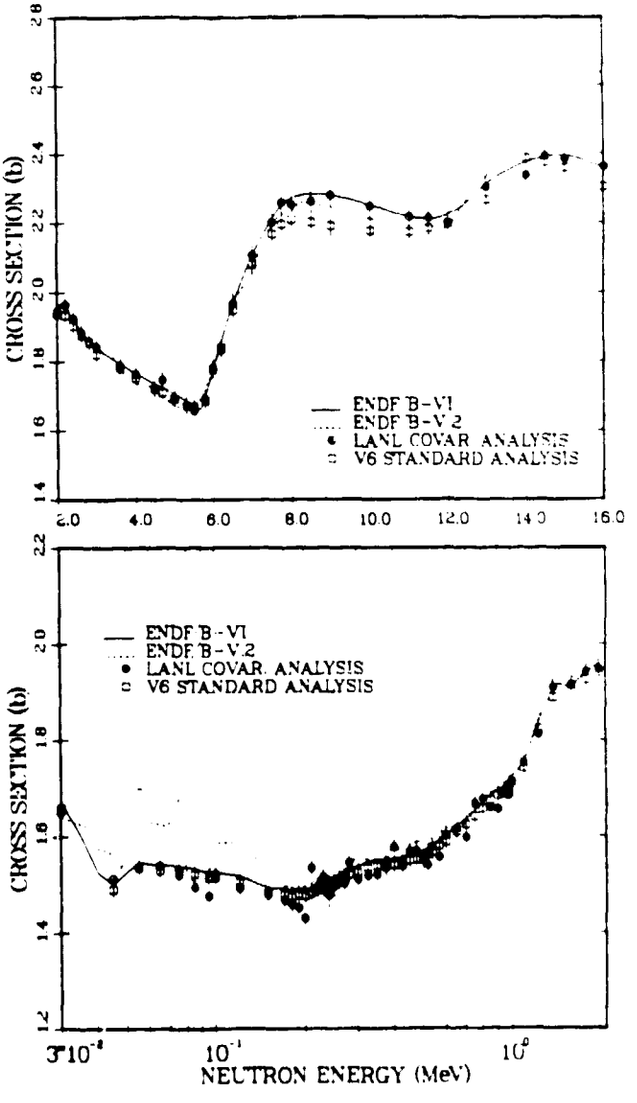

Fig. 3 Comparison of the LANL covariance analysis of the $^{239}Pu(n,f)$ cross section with the Version VI standards analysis and with the ENDF/B-VI and ENDF/B-V evaluations.

The ^{239}Pu neutron total cross section that resulted from the present covariance analysis is compared to ENDF/B-V.2 in Fig. 4. Similarly, results from the $\nu_p(E_n)$ covariance analysis are given in Fig. 5 along with ENDF/B-V.2 and assorted experimental data. Much of the available data were measured relative to ν_p for ^{252}Cf, and the data shown have been corrected for the ENDF/B-VI standard.

Integral Data Comparisons and Conclusions

To begin testing the new evaluations in ENDF/B-VI, preliminary calculations were made of several fast critical experiments that are ENDF/B benchmarks. [7] Results are presented here for the bare uranium and plutonium spheres GODIVA and JEZEBEL, the "dirty" plutonium sphere JEZEBEL-PU, the uranium-reflected plutonium sphere FLATTOP-PU, and liquid-metal fast breeder reactor benchmark ZPR-6/7. Homogeneous, one-dimensional, spherical calculations were made using transport theory for the small assemblies and diffusion theory for ZPR-6/7. Eighty-group cross section libraries were generated for these calculations using the NJOY nuclear data processing system. [9]

Results of these preliminary calculations of the integral assemblies are given in Table I. Dramatic changes are not seen in the calculated k_{eff} eigenvalues and reaction rate ratios, although some improvements over ENDF/B-V can be noted. k_{eff} is slightly improved for three of the four ^{239}Pu assemblies shown, and there appears to be a small improvement in the reaction ratios generally. A more noticeable improvement is seen in comparing the $^{238}U/^{235}U$ and $^{237}Np/^{235}U$ fission reaction ratios for GODIVA and JEZEBEL. In particular, the asymmetry or bias between the ^{235}U and ^{239}Pu assemblies that was apparent with ENDF/B-V libraries appears to be reduced. Overall, the calculations indicate somewhat greater consistency among the integral calculations with ENDF/B-VI libraries than was the case with ENDF/B-V.

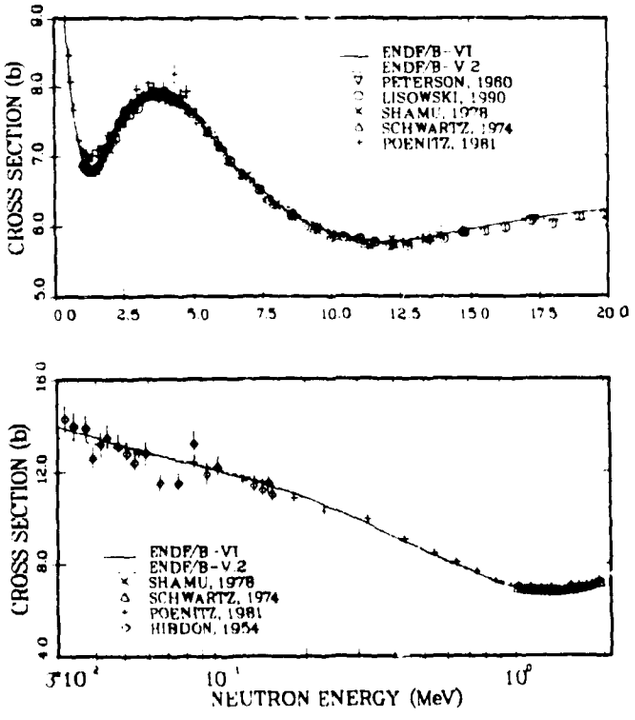

Fig. 4. Measured and evaluated neutron total cross section of ^{239}Pu from 30 keV to 20 MeV. The solid curve is ENDF/B-VI, based on the present covariance analysis, and the dashed curve is the ENDF/B-V evaluation. Only a selection of experimental data are shown.

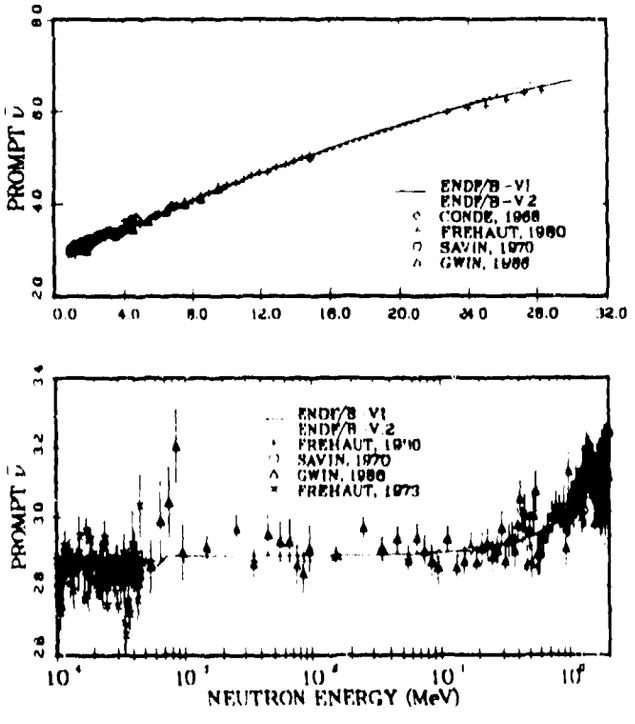

Fig. 5. Comparison of evaluated $\nu_p(E_n)$ for n + ^{239}Pu reactions between 100 eV and 30 MeV with a selection of experimental data.

Table 1. Preliminary Critical Assembly Performance Parameters for ^{239}Pu.

Parameter[a]	ENDF/B-V.2[b]	ENDF/B-VI[b]	Assembly
k_{eff}	0.9990	0.9980	GODIVA
f^{28}/f^{25}	1.037	0.971	
f^{37}/f^{25}	1.043	0.960	
f^{49}/f^{25}	0.985	0.976	
f^{23}/f^{25}	0.986	1.000	
k_{eff}	0.9982	0.9988	JEZEBEL
f^{28}/f^{25}	0.961	0.975	
f^{37}/f^{25}	0.979	0.969	
f^{49}/f^{25}	0.966	0.975	
f^{23}/f^{25}	0.985	1.000	
k_{eff}	0.9918	0.9916	JEZEBEL-PU
f^{28}/f^{25}	0.954	0.969	
f^{37}/f^{25}	1.009	0.998	
k_{eff}	1.0064	1.0069	FLATTOP-PU
f^{28}/f^{25}	0.973	0.983	
f^{37}/f^{25}	1.000	0.985	
k_{eff}	0.9857	0.9935	ZPR-6/7
f^{28}/f^{49}	1.045	1.055	
f^{25}/f^{49}	1.009	1.034	
c^{28}/f^{49}	1.106	1.079	

[a]Ratios are calculated result divided by experimental result.
[b]Transport-corrected P_3S_{16}.

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