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COVARIANCE ANALYSIS OF n + 7Li DATA FOR ENDF/B-VI

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Abstract: A new covariance analysis of n+^{7}Li experimental data has been completed for Version VI of ENDF/B. The analysis basically updates our 1981 work for ENDF/B-V.2 to include new data that has become available since that time and to incorporate cross correlations between different experiments. The bulk of the new measured data consists of some 10 new (or newly revised) tritium-production measurements involving about 70 new data points. The new analysis results in only small changes in the previous evaluation of the tritium-production cross section but significantly reduces the magnitudes of uncertainties due to the more extensive and accurate data base that was used.

(Keywords: ^{7}Li, neutron reactions, data evaluation, tritium production, covariance analysis)

Introduction

The major interest in ^{7}Li for fusion energy applications results from its potential use as a breeding material for tritium.[1] Additionally, because large amounts of ^{7}Li will be required in fusion blankets for this purpose, it is important to accurately describe all neutron-producing reactions for neutronic calculations, as well as charged-particle- and γ-ray-producing reactions for energy deposition studies. In 1981 a major re-analysis of ^{7}Li data was completed for Revision 2 of ENDF/B-V.[2] Since that time, a number of new measurements, mainly of tritium-production cross sections, elastic scattering angular distributions, and neutron-emission spectra, have been completed. Consequently, a new evaluation of n+^{7}Li cross section and covariance data has been performed for Version VI of ENDF/B to reflect the new information in the experimental data base.

Analysis Description

As was the case with the ENDF/B-V.2 evaluation, covariance analyses have been performed of each of the major n+^{7}Li cross-section types for which experimental data exist. The GLUCS code system[3] was utilized to determine evaluated energy-dependent cross sections and covariances for each reaction type from inputted experimental cross sections with their associated uncertainties and correlations. In addition to energy-dependent correlations within individual experiments, cross correlations between different measurements from common flux standards and half life in tritium-counting experiments were included. The results of the GLUCS analysis were combined using the ALVIN code,[4] under the constraint that all partial reactions sum to the total cross section, with full account being taken of all covariances from the GLUCS analysis.

Using a constant 49-point energy grid, independent covariance analyses were carried out with GLUCS for the following four reactions or combinations of reactions:

1. total cross section;
2. elastic plus (n,n_1') cross section to the first excited state of ^{7}Li;
3. (n,n't) tritium-production cross section;
4. (n,2n) plus (n,2nd) plus (n,3np) plus (n,d) cross sections.

Reactions (1)-(4) include all the partial reaction and scattering cross sections that must sum to reaction (1), the total cross section. The data adjustment code, ALVIN, was then used to combine the cross sections and covariances from the independent GLUCS analyses, under the constraint that $\sigma_1 = \sigma_2 + \sigma_3 + \sigma_4$. The results on the 49-point energy grid were smoothed, where necessary, and fit with spline curves for the final evaluated results.

In addition to the above combined analysis, the individual ^{7}Li(n,n') cross sections to the 1st and 2nd excited states of ^{7}Li were obtained from separate GLUCS analyses of the individual reactions. Because the 0.478-MeV first excited state of ^{7}Li is bound, the experimental data base for the ^{7}Li(n,n_1) reaction consists mainly of (n,n'γ) measurements. The second excited state at E_x = 4.63 MeV is unbound by 2.16 MeV, and direct measurements of inelastic neutrons are available for the (n,n_2) reaction.

To perform the above analyses, it was necessary to obtain covariance matrices for each experimental data measurement. In many cases, sufficient information was available to infer the correlations in the experimental data, and occasionally the correlation matrices were even provided directly by the experimenters. For several measurements, however, it was necessary to make simple generic assumptions regarding the correlations present in different types of experiments. For example, modern total cross-section measurements were generally assumed to have a normalization uncertainty of the order of 0.3-0.5% due to sample thickness and composition uncertainty. Greater normalization uncertainty was assumed for older measurements. The final GLUCS/ALVIN cross sections were not found to be highly sensitive to the exact assumptions made, although it was observed that significant overestimates of correlations can distort results, especially in energy regions where measured data were scarce.

A simple error doubling procedure was followed for measurements that differed by more than two standard deviations from trial results from GLUCS. That is, if the results from a particular experiment differed from the GLUCS combination of all other experiments such that χ^2/point was greater than 4, then the uncertainties on all the data from that experiment were doubled. Such a procedure was necessary for some 10 experiments out of the 50 used in the analysis. It should be noted that some 7 of the 10 experiments with doubled errors were reported prior to 1965. The uncertainties on more recent measurements were generally found to be more self-consistent..

Experimental Data

All available experimental data for which reasonable error estimates were feasible were included in the GLUCS analyses. A total of some 3400 experimental data points were considered, although the initial 3200 total cross section points were averaged down to about 500 points in order to simplify the analysis. The new experimental data on tritium production[5-13], completed or revised since the previous ENDF/B-V.2 analysis, are summarized in Table I. Other new experimental data included in the analysis were the elastic cross section results of Chiba et al.,[11] Shen et al.,[14] Alfimenkov et al.,[15] and Drosg et al.,[16] a new 14-MeV (n,2n) data point from the work of Chiba et al., and new results on the (n,n_2) cross section from Chiba et al., Drosg et al., Schmidt et al.,[17] and Dekempeneer and Liskien.[18]

The only experimental data available in the energy range 16-20 MeV are the total and (n,n'γ) cross sections. Therefore, in order to permit an accurate separation of the partial cross sections at these energies, an optical-model analysis was performed covering the energy range 10-20 MeV. The elastic angular distribution measurements of Hogue et al.[19] and Shen et al.,[14], together with an average of the total cross section measurements[20] from 10-20 MeV were fit using the SCATOPT spherical optical model code.[21] The results were used to compute elastic cross sections from 15-20 MeV for inclusion in the GLUCS/ALVIN analysis.

Table 1. Summary of ^{7}Li(n,n't) Cross Section Results Since the 1981 ENDF/B-V.2 Evaluation*

Reference	No. Points	Energy Range (MeV)	First Author and Laboratory	Covariance Information
5	26	4.99-16.03	Liskien, Geel	Correlations inferred
6	1	14.9	Maekawa, JAERI	——
7	1	14.74	D.L. Smith, ANL	Correlations with 1981 measurements supplied
8a	6	13.31-14.88	Maekawa, FNS(JAERI)	Correlations estimated
8b	6	13.40-14.79	Maekawa, Tokyo Univ.	Correlations estimated
9	12	13.35-14.83	Takahashi, Osaka Univ.	Correlations estimated
10	1	14.94	Goldberg, LLNL	——
11	3	5.40-14.2	Chiba, Tohoku Univ.	Correlations inferred
12	8	4.57-14.1	Swinhoe, Harwell	Revision of '79 measurements & covariances
13	6	7.945-10.48	Qaim, Jülich	Correlations inferred

*Cross sections and covariances for the new measurements were supplied by D. L. Smith of Argonne National Laboratory, October, 1986.

Results

The total cross section that resulted from the analysis is compared in Fig. 1 with white neutron source measurements[20] between 2 and 18 MeV. The evaluated curve was obtained by passing a spline curve directly through the ALVIN results on the 49-point energy grid. The resulting curve is virtually indistinguishable from our earlier ENDF/B-V.2 evaluation, which is not surprising as the same total cross section data base was used in both analyses.

The (n,n't) cross sections that resulted from the ALVIN analysis were not as smooth as the total cross section, primarily because of the smaller and less consistent experimental data base that went into the (n,n't) analysis, so some smoothing of those results was necessary. The smoothed results are compared in the left half of Fig. 2 to the experimental (n,n't) data[5-13] that have been obtained since the ENDF/B-V.2 analysis , as well as to the older measurements[22] (right half of the figure) and to the earlier ENDF/B-V.2 analysis[2] (dashed curves). Clearly the tritium-production cross section from the present analysis differs only slightly from the 1981 evaluation. The new results lie higher than the earlier analysis between 6 and 10 MeV, fall somewhat lower above 15 MeV, and are within ~1% near 14 MeV It should be noted, however, that the covariance matrix for the (n,n't) reaction is changed substantially. In particular, the standard deviations are significantly reduced because of the additional data in the analysis. A total uncertainty of about ±2.1% is obtained for the 14-15 MeV region as compared to ~4% for ENDF/B-V.2.

The results for the combined elastic plus (n,n'γ) cross section are compared in Fig. 3 to the available experimental data base[22], and to the ENDF/B-V.2 evaluation. The new analysis represents the experimental data quite well and differs only slightly from the earlier evaluation.

Finally, the ^{7}Li(n,n_1) and ^{7}Li(n,n_2) cross sections that result from the independent GLUCS analyses are compared to experimental data and to ENDF/B-V.2 in Figs. 4 and 5, respectively. The new (n,n_1) results are identical with the earlier evaluation because the same experimental data base was used. The new (n,n_2) evaluation lies higher than ENDF/B-V.2 at neutron energies below 10 MeV and falls lower at higher neutron energies, primarily reflecting the influence of the new Dekempeneer and Liskien[18] data and the fact that a covariance analysis was not used for the (n,n_2) reaction in ENDF/B-V.2 .

Summary Remarks

The ^{7}Li cross sections and covariances for the ENDF/B-VI evaluated data file have been improved over the previous evaluation by consideration of new experimental data since 1981 in a covariance analysis. The usefulness of this type analysis is highlighted by the fact that the resulting ^{7}Li(n,n't) cross section differs little from that of the previous covariance analysis, despite the availability of much more accurate and consistent data. The major impact of the new measurements on the evaluation is to significantly reduce uncertainties in the evaluated data and to improve the associated covariances.

The angular distribution data in the ENDF/B-VI evaluation will be based mainly on the previous ENDF/B-V.2 evaluation, updated to include the new measurements mentioned above. Representation of the energy-angle correlated neutron-emission spectra will be accomplished using the sequential breakup analysis of Beynon.[23]

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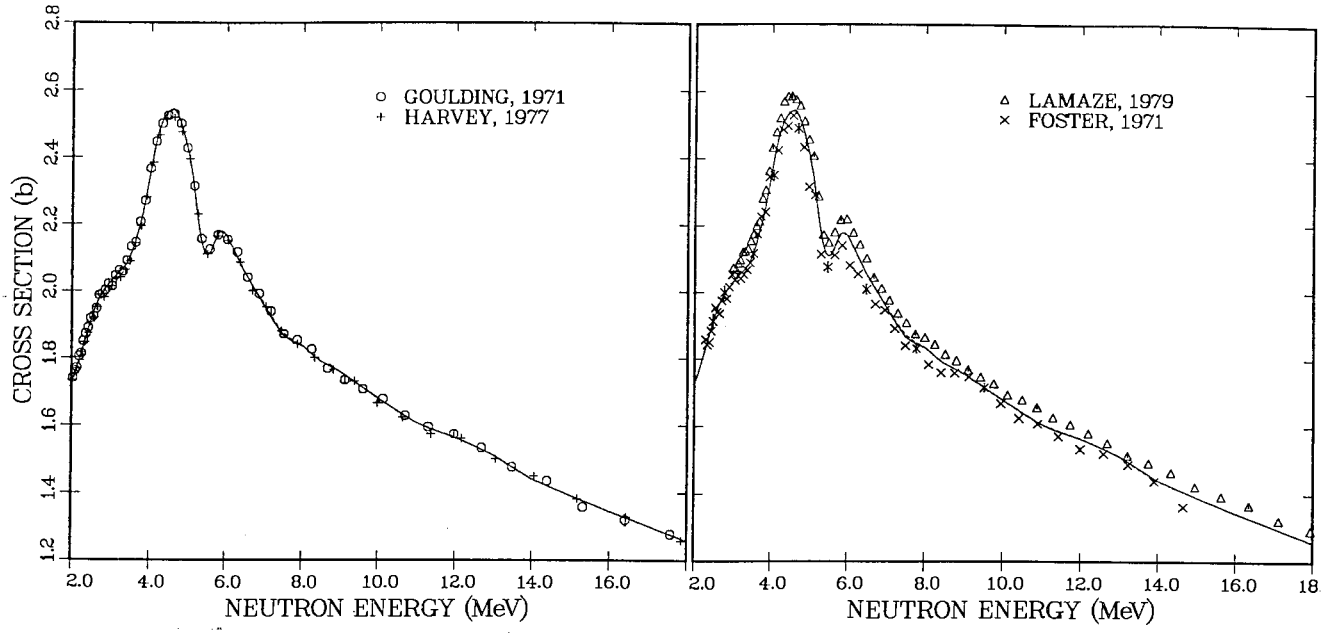

Fig. 1. Neutron total cross section of ^{7}Li. The solid curves are from the present covariance analysis; the points are experimental data.[20]

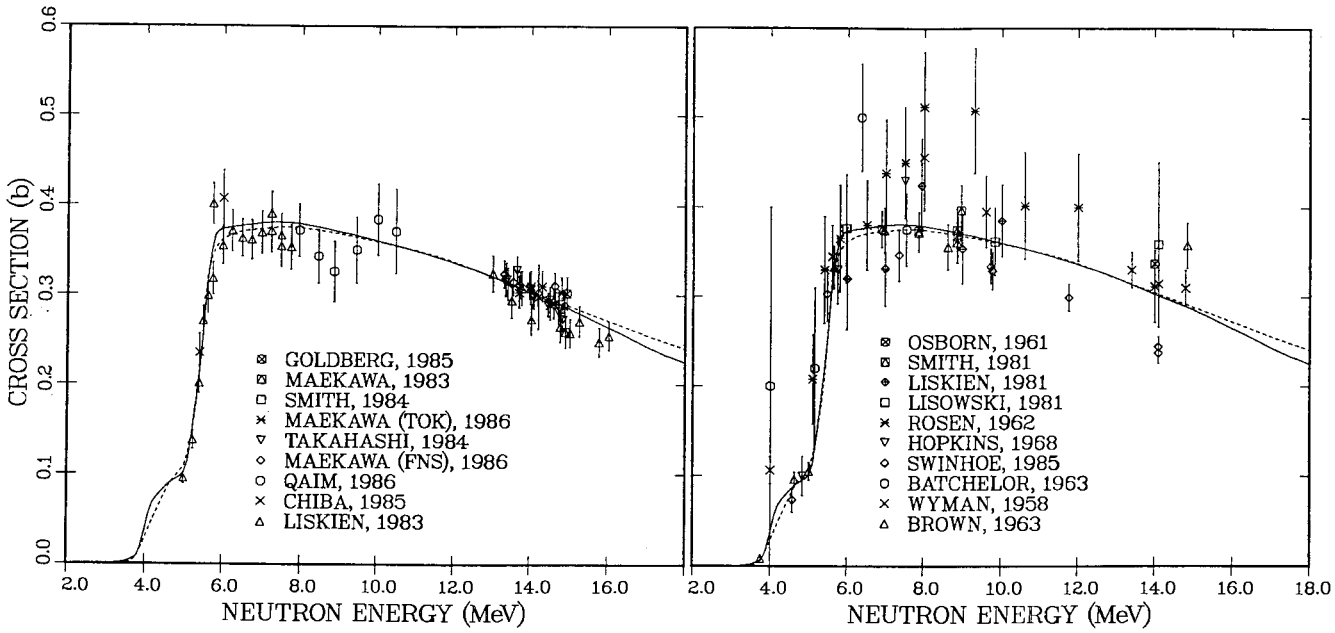

Fig. 2. The ^{7}Li(n,n't) cross section. The solid curves are from the present analysis and the dashed curves are ENDF/B-V.2. The experimental data in the right half[22] of the figure were available for the ENDF/B-V.2 analysis; the experimental data in the left half[5-13] became available after the ENDF/B-V.2 analysis.

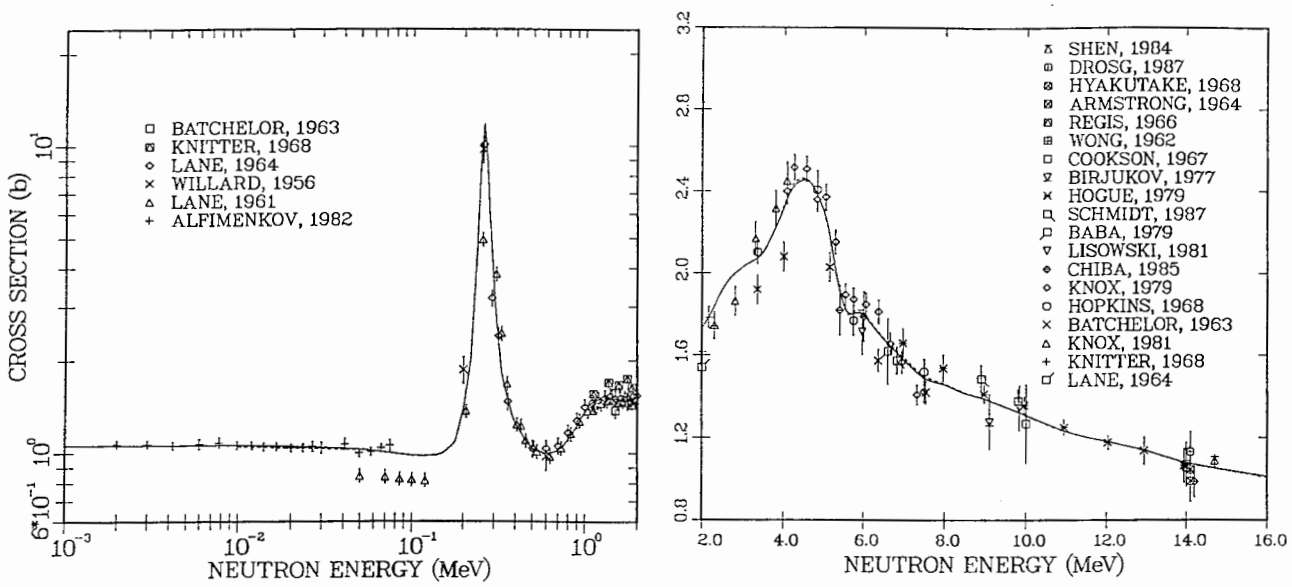

Fig. 3. Neutron elastic scattering cross section of ^{7}Li. The solid curve is from the present analysis; the points are experimental data.[22]

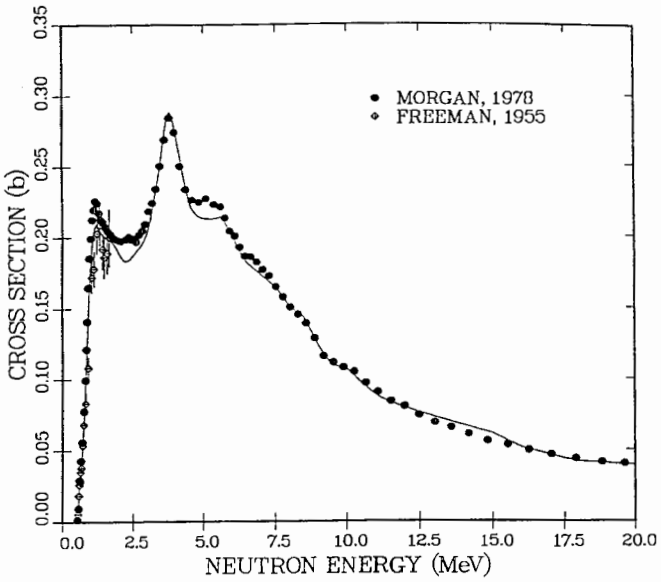

Fig. 4. Evaluated and measured[22] cross sections for the ^{7}Li(n,n'γ) reaction, corresponding to the ^{7}Li(n,n$_1$) reaction to the 0.478-MeV first excited state of ^{7}Li.

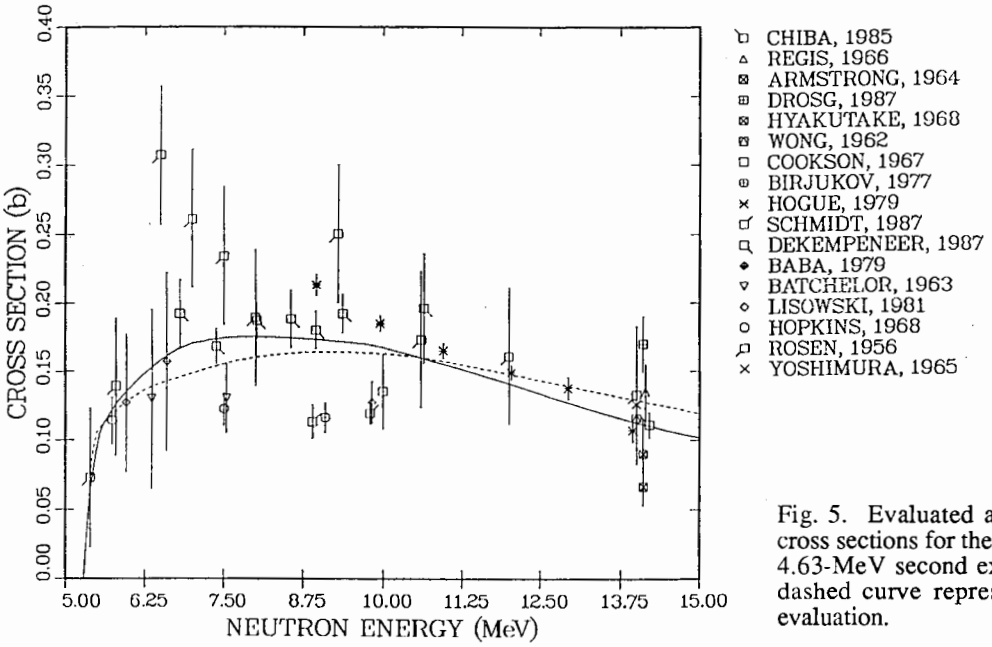

Fig. 5. Evaluated and measured[11,17,18,22] cross sections for the ^{7}Li(n,n$_2$) reaction to the 4.63-MeV second excited state of ^{7}Li. The dashed curve represents the ENDF/B-V.2 evaluation.