CONF-800942--17

ORACLE: AN ADJUSTED CROSS-SECTION AND COVARIANCE LIBRARY FOR FAST-REACTOR ANALYSIS*

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ABSTRACT

Benchmark integral-experiment values from six fast critical-reactor assemblies and two standard neutron fields are combined with corresponding calculations using group cross sections based on ENDF/B-V in a least-squares data adjustment using evaluated covariances from ENDF/B-V and supporting covariance evaluations. The purpose is to produce an adjusted cross-section and covariance library which is based on well-documented data and methods and which is suitable for fast-reactor design. By use of such a library, data- and methods-related biases of calculated performance parameters should be reduced and uncertainties of the calculated values minimized. Consistency of the extensive data base is analyzed using the chi-square test. This adjusted library ORACLE will be available shortly. Feedback from designers, evaluators, experimentalists, and analysts is solicited.

INTRODUCTION

The purpose of this paper is to describe the specifications, software development and initial results of an Oak Ridge National Laboratory Program in cross-section adjustment for fast-reactor core-physics analysis, using information from fast-reactor and dosimetry integral experiments and from differential-data evaluations. The exposition of the proposed approach is mainly intended for review and criticism from integral experimentalists, from basic-data evaluators, from methods analysts, and from reactor

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*Research sponsored by the U.S. Department of Energy under Contract No. W-7405-eng-26 with Union Carbide Corporation.

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designers. Such feedback is essential since an integration of data from various disciplines is required for the success and ultimate acceptance of such a procedure. The combination of integral and differential data by means of least-squares adjustment is an attempt to make use of all available information in a consistent scheme based on logical probabilistic arguments. The fact that least-squares adjustment rests on a firm theoretical and mathematical foundation is a strong argument in support of the method. However, the validity and quality of the data used and the applicability of particular technical points need to be examined critically.

Data adjustments are widely used in the framework of many leading fast-breeder programs and were originated from techniques proposed as early as 1964. Since the original papers in this field, many improvements have been introduced, including the development of generalized perturbation theory for sensitivity calculations, a comprehensive statistical formulation with allowance for uncertainty correlations, the use of transport methods for sensitivity analysis, and the development of a procedure for basic parameter adjustment. A comprehensive review and extensive lists of related references will be found in References 1 and 2. However, to our knowledge, the present effort represents the first attempt in the United States to provide publicly-available adjusted libraries wherein the basic data are documented and available for critical review, and which include uncertainties (including correlations) in calculational methods, and in integral and differential data.

This major attempt to develop useful adjusted libraries is based on established benchmark integral data, accurate and well documented analysis techniques, sensitivities, and quantified uncertainties for nuclear data, integral experiment measurements, and calculational methodology. The adjustments are intended to produce an overall improvement (in a least-squares sense*) in the quality of the data libraries so that calculations of other similar systems using the adjusted data base with any credible method will produce results without much data related bias. We fully expect our adjusted libraries to evolve as the state of reactor physics information develops. However, any adjusted cross section library is intended to reflect the synthesis of our best information at a given point in time.

The output adjusted library (including adjusted and covariance estimates) will be used to estimate nominal parameter values with uncertainties for the Conceptual Design Studies, to analyze some experiments in PHENIX, and to apply to other LMFBR-related design studies such as supporting analyses for the Clinch River Breeder Reactor. The adjustments obtained should also aid in making specific recommendations to the cross-section measurement and evaluation programs. These recommendations need to be carefully considered in the light of newer measurements, the perceived need for cross-section information over a wider range of applied programs, and

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*We do not expect that any specific cross section parameter need necessarily be closer to its true value, because of the generally broad resolution with which integral experiments are measures of nuclear data.

the inherent scientific value of such information. The information obtained from the systematic combination of differential and integral data is equivalent to that sought in testing the adequacy of evaluated nuclear data sets (e.g. the data testing program of the Cross Section Evaluation Working Group). Finally, the adjustment process provides us with a more global view of analysis by forcing us to openly recognize and quantify what we are doing.

The following section outlines the procedure for generating the first version of ORACLE, the adjusted cross section library. The starting point is the newly generated VITAMIN-E 174-group cross section library[3] based on ENDF/B-V and a 26-energy-band[4] cross-section covariance library[5] also based on ENDF/B-V. The first adjusted 174-group cross section library is available in ORNL for in-house use in the AMPX master form. The first version to be transmitted to designers will be a 174-group cross-section library in ISOTXS format. In addition ORACLE includes a modified 26-energy-band cross-section covariance library available upon separate request. Every effort will be made in order to meet additional designers requests as far as commonly used formats and collapsed broad-group adjusted libraries are concerned.

Then the measured responses (benchmark integral measurements) used for the development of ORACLE, and their uncertainties and correlations are presented and discussed, followed by a brief discussion of the corresponding calculated values and their sensitivities to the input parameters. The input parameter covariances are the subject of the next section. The availability in ENDF/B-V and the efforts to fill the gaps are stressed in that section. After describing all the necessary ingredients of an adjustment, an analysis of the consistency of all the data (measured responses and differential input parameters) is presented, followed by a discussion of preliminary results, and a summary.

ADJUSTMENT PROCEDURE

The 174-group adjusted cross-section library part of ORACLE is based on VITAMIN-E. The self-shielding f factors are not modified, and the adjustment refers to the infinitely dilute multigroup cross sections of VITAMIN-E modified by multiplicative factors h_G. These factors, h_G, are different for every element and every reaction and refer to the 26 energy bands. For energy group g within a given energy band G the ORACLE infinitely dilute cross section σ'_g is given by

$$\sigma'_g = \sigma_g \cdot h_G \qquad g \in G \tag{1}$$

where σ_g is the corresponding VITAMIN-E cross section. This procedure and the software developed will be outlined in this section.

The modifying factors are obtained from the least-squares data adjustment code UNCOVER.[7] The input and output of this module of the FORSS system[6] are schematically given in Fig. 1. The input data classes are only identified here, and will be discussed later.

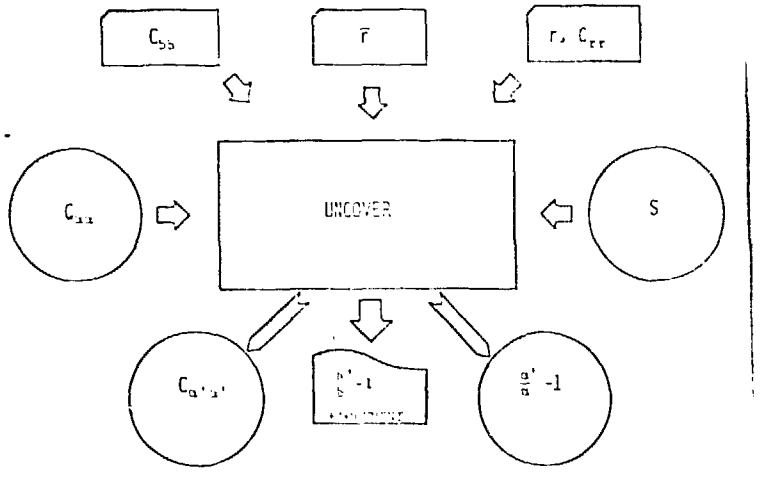

FIG. 1. THE INPUT AND OUTPUT DATA OF THE ADJUSTMENT MODULE UNCOVER.

The input consists of the following: measured values of integral responses $\bar{r}$ and their corresponding covariance matrix C_{rr}, calculated values r corresponding to the measured responses (these calculated values have been corrected by a series of calculated-response correctors to account for modeling and calculational deficiencies), and covariance matrices C_{bb}, for these calculated-response correctors. In addition, UNCOVER utilizes the sensitivities S of the calculated responses $\bar{r}$ to the differential input parameters α, and the covariance matrices of these parameters $C_{\alpha\alpha}$. The sensitivities are retrieved from a SENPRO[7] formatted file and the covariances from a COVERX[7] formatted file.

The suggested changes in the parameters are put on file to be used later by the recently-developed module ADJUST in addition to the regular printed output. These changes are calculated by UNCOVER according to the following formula

$$\alpha' - \alpha = - C_{\alpha\alpha} S^{\dagger} [C_{rr} + S C_{\alpha\alpha} S^{\dagger}]^{-1} (\bar{r} - r) \quad . \tag{2}$$

The changes in the calculated-response correctors resulting from the adjustment procedure (which changes are not handled automatically) will be documented separately for use in future computations utilizing ORACLE. The covariances of the adjusted parameters are also available to be used, for example, in the evaluation of the uncertainty in a calculated response using ORACLE data.

The role of the code ADJUST is demonstrated in Fig. 2. The code has as its input the original VITAMIN-E file and the file of relative changes generated by UNCOVER. The multiplicative modifiers h_G, defined as

$$h_G = 1 + \left(\frac{\alpha'}{\alpha} - 1 \right) \tag{3}$$

for each adjusted reaction cross section, are applied accordingly.

Reaction cross sections which are not adjusted are just transmitted from VITAMIN-E to ORACLE. The modified fission spectra are calculated explicitly by ADJUST using the proper ENDF/B-V formulation (Watt or Maxwellian) and modified parameters obtained manually from the UNCOVER printed output. The output of ADJUST is the ORACLE cross-section library in the AMPX master form.

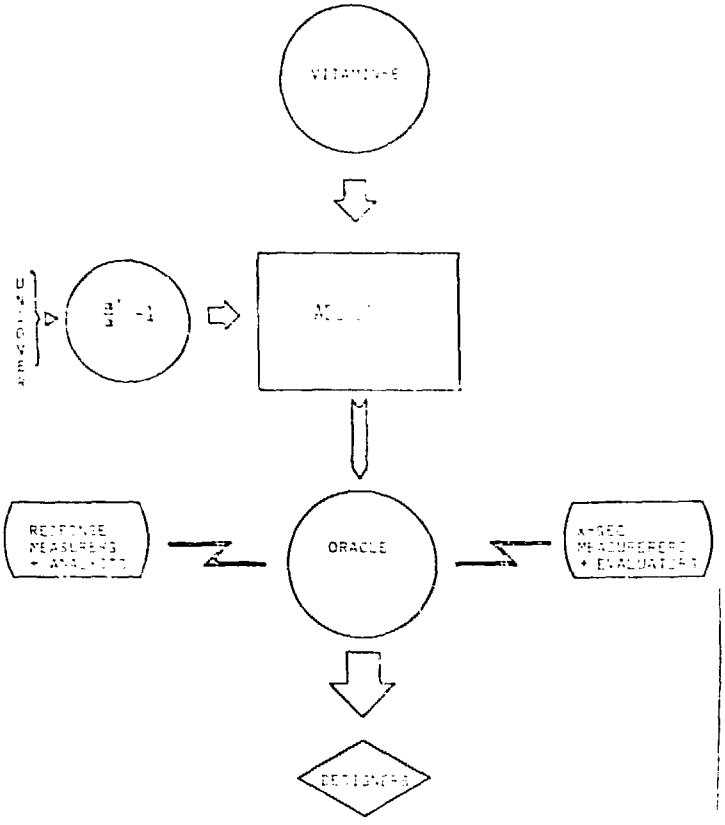

FIG. 2. THE INPUT AND OUTPUT DATA OF THE ADJUST MODULE WITH PROPOSED FEEDBACK CHANNELS.

EXPERIMENTAL RESPONSES

The general considerations in the selection of responses (integral experiments) to be included in meaningful adjustments in general, and the reasons for the specific choice for the first attempt to generate a viable adjusted library in particular, are discussed in great detail in Reference 4. In essence, the two dominant factors in the present selection are (a) to include responses measured in relatively simple assemblies and to exclude those of which the *calculational* uncertainties are not well understood, and (b) to include only those responses for which an adequate uncertainty analysis is available.

Thus, three sets of integral measurements are included in the present adjustment: fourteen responses in four of ANL's ZPR assemblies, eight in LASL's GODIVA and JEZEBEL, and seven in the NBS's Cf-252 and ISNF neutron fields. These twenty-nine responses are limited to the reactivities of the six critical assemblies and to central reaction-rate ratios only. The one exception is the absolute value of σ^f_{25} averaged over the Cf field spectrum, which was felt to be a particularly careful measurement, and for which the correlations with all the reaction-rate ratios measured at NBS were thoroughly analyzed.

These three sets of experiments are to a reasonable approximation independent of each other, so that the only non-vanishing sub-matrices in the accordingly partitioned 29 × 29 response-correlation matrix are the three diagonal sub-matrices, which are given in Tables I.1, 2, and 3.

Table I.1. Experimental Values, Standard Deviations and Correlations of Responses Measured in the ZPR Assemblies

Assembly	Response	Experimental Value	Standard Deviation (%)		Correlation Matrix
[illegible]	k	1.[illegible]	0.1	1	1
	28f/25f	0.8[illegible]	2.6	2	1
	37f/25f	0.13[illegible]	2.7	3	.25 1
ZPR-6/7	k	1.00[illegible]	0.1	4	1
	25f/[illegible]	1.0[illegible]	2.1	5	-.23 -.35 1
	28f/[illegible]	0.[illegible]	2.9	6	.44 .34 1
	37f/[illegible]	0.1[illegible]	2.3	7	.38 .40 .24 1
ZPR-6/11	k	1.[illegible]	0.1	8	1
	25f/[illegible]	1.[illegible]	2.4	9	-.26 -.15 .53 .24 .13 1
	28f/[illegible]	0.[illegible]	2.6	10	.37 .24 .57 .12 .46 1
	37f/[illegible]	0.[illegible]	2.3	11	.15 .09 .34 .21 .19 .17 1
[illegible]	k	1.[illegible]	0.1	12	1
	28f/[illegible]	0.[illegible]	2.9	13	.19 .16 1
	37f/[illegible]	0.[illegible]	2.[illegible]	14	.30 .[illegible] .26 .53 1

Table I.2. Experimental Values, Standard Deviations and Correlations of Responses Measured in GODIVA and JEZEBEL

Assembly	Response	Experimental Value	Standard Deviation (%)		Correlation Matrix
GODIVA	k	1.0000	0.1	15	1
	28f/25f	0.1[illegible]	1.1	16	1
	37f/25f	0.[illegible]	1.6	17	.5 1
	49f/25f	1.402	1.8	18	.5 .5 1
JEZEBEL	k	1.0000	0.2	19	1
	28f/25f	0.2[illegible]	1.1	20	1 .5 .5 1
	37f/25f	0.962	1.7	21	.5 1 .5 .5 1
	49f/25f	1.448	2.0	22	.5 .5 1 .5 .5 1

Table I.3. Experimental Values, Standard Deviations and Correlations of Responses Measured in the Standard Neutron Fields

Field	Response	Experimental Value	Standard Deviation (%)		Correlation Matrix
Ct-252	25f	1.205	2.1	23	1
	28f/25f	0.7644	1.1	24	.40 1
	37f/25f	1.105	2.1	25	-.09 .25 1
	49f/25f	1.500	1.3	26	-.19 .13 .32 1
ISNF	28f/25f	0.9920	0.6	27	.14 .65 .14 1
	37f/25f	0.5102	2.0	28	-.14 .16 .98 .32 .09 1
	49f/25f	1.155	1.3	29	-.21 .11 .32 .95 .02 .33 1

Table I.1 lists the fourteen ANL responses and gives all the relevant information regarding these measurements. Recall that the ZPR-6/6A fuel is U-235 and the other three ZPR's are Pu assemblies; and also that ZPR-6/6A and 6/7 are oxide-fuel assemblies and ZPR-9/31 and 3/48 have carbide fuel.

It should be mentioned that these LMFBR measurements were the first for which a relatively complete uncertainty analysis with correlations was published in the open literature. The authors of that analysis, Collins and Lineberry,[3] have since revised their original results, and the data we used given in Table I.1 were actually taken from Reference 1.

Table I.2 lists the eight LASL responses with their experimental values and standard deviations. These are their latest re-evaluation, as reported by Hansen and Paxton.[9] The correlation matrix should be considered as a rough approximation, however, reflecting a statement by Hansen[10] that "the central fission ratios are fully correlated between the different assemblies, and about 0.5 correlated in a particular benchmark."

The seven NBS responses are listed in Table I.3. The complete uncertainty analysis for these is reported in Reference 11, from which all the information in this table was taken.

CALCULATED RESPONSES

Although calculating the reactivity of a given assembly, or a central reaction-rate ratio in it, may seem a trivial problem, the accuracy of these calculated values must be carefully considered, since the input to an adjustment procedure requires the differences between these and the experimental values, as indicated in Eq. (2). Thus, seemingly negligible inaccuracies with respect to the calculated value of a given response might actually mean significant errors in the corresponding discrepancy. In evaluating the calculated responses it is therefore necessary to consider all factors which may result in possible errors.

The benchmark specifications include recommended calculational models and approximations, and also detailed "calculated-response correctors" (often referred to as "biases", an ambiguous term which we prefer to replace). The modelling correctors account for heterogeneity, dimensionality and the fact that the central reaction-rate ratios may be measured in special experimental cells which are different from the normal cells in the assembly considered. The calculational correctors compensate for such factors as the finite orders of the S_n and P_n approximations in the actual calculations. Clearly, not all the correctors are relevant to all our responses, and each, of course, was only applied in the calculation of the relevant responses.

The calculated-response values, with all correctors applied, are given in Table II. The Response Numbers refer to the corresponding experimental-response values listed in Tables I.1-3. Also given in Table II are the standard deviations of the calculated values and the discrepancies $(\bar{r}-r)$,

which are the really relevant quantities. The standard deviation of the calculated value $\bar{r}$ of a given response results from the uncertainties of the differential and other data, to which it is related by means of the sensitivities of $\bar{r}$ to the differential data. Let s be the sensitivity of $\bar{r}$ with respect to the data α, then the contribution to the variance of $\bar{r}$ from the uncertainties in α is $sC_{\alpha\alpha}s^{\dagger}$. The last two columns of Table II refer to the Data Consistency Analysis, and will be discussed in that section.

The calculated values of the responses in the fast critical assemblies were evaluated by R.Q. Wright[12] except for the three ZPR-3/48 responses and the 37f/25f ratios in GODIVA and JEZEBEL which were calculated by J. L. Lucius and C. C. Webster. The calculated values of the NBS-ISNF responses are from Reference 13.

[illegible] and their Uncertainties, [illegible] with Experimental Values and Consistencies with ENDF/B-IV Data

[illegible] Individual [illegible] and Overall [illegible] Explained in the Text.

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	[illegible]	1.0	0.41	[illegible]	14
2	[illegible]	4.1	1.10	[illegible]	7
3	[illegible]	2.0	-3.[illegible]	1.	15
4	[illegible]	1.0	0.11	[illegible]	1
5	1. [illegible]	3.0	-0.73	[illegible]	6
6	[illegible]	3.0	3.87	[illegible]	16
7	[illegible]	3.0	-5.[illegible]	1.[illegible]	14
8	1.[illegible]	1.0	-0.46	[illegible]	20
9	0.9	3.1	-4.1[illegible]	0.[illegible]	23
10	[illegible]	4.0	0.[illegible]	[illegible]	2
11	[illegible]	1.0	-4.[illegible]	1.	13
12	1.[illegible]	1.0	-0.[illegible]	[illegible]	22
13	[illegible]	5.0	-6.13	[illegible]	24
14	[illegible]	2.0	1.33	[illegible]	9
15	[illegible]	1.0	0.3[illegible]	[illegible]	11
16	[illegible]	3.0	-3.[illegible]	1.[illegible]	17
17	[illegible]	9.0	-6.[illegible]	[illegible]	28
18	1.[illegible]	2.0	[illegible]	[illegible]	4
19	1.[illegible]	2.0	-[illegible]	[illegible]	11
20	[illegible]	2.0	[illegible]	[illegible]	27
21	[illegible]	9.0	[illegible]	[illegible]	3
22	1.[illegible]	2.0	2.81	[illegible]	29
23	1.[illegible]	2.0	-2.[illegible]	[illegible]	12
24	[illegible]	1.0	[illegible]	[illegible]	25
25	1.[illegible]	9.0	1.10	[illegible]	4
26	1.[illegible]	2.0	3.66	[illegible]	22
27	[illegible]	4.1	[illegible]	[illegible]	26
28	[illegible]	10.2	1.[illegible]	[illegible]	5
29	1.[illegible]	2.0	1.67	[illegible]	12

SENSITIVITIES

In the analysis of each fast critical assembly, the forward and adjoint fluxes and the generalized adjoint flux were routinely calculated and stored, so that the necessary sensitivities could be generated by the JULIET code and added to the sensitivities collected in a file with SENPRO format.

CROSS-SECTION COVARIANCES

The differential data to be included in the adjustment procedure are discussed in great detail in Reference 4. Except for the Pu-241 data, all cross sections and fission spectra listed on p.46 of Reference 4 are participants in the adjustment reported in this paper. A major problem throughout the present effort to generate the first version of ORACLE has been to supplement the uncertainty data available from ENDF/B-V files.

The totality of the uncertainty information pertaining to a given adjustment problem is expressed in an extended covariance matrix, which is partitioned according to the natural grouping of the participating parameters. By convention, the first partition of this extended covariance matrix consists of the covariance of the integral experimental values and the second consists of the covariance of the calculated-response correctors. The other partitions refer to fission-spectrum parameters, and to the band (coarse-group) partial cross sections corresponding to specific reactions of each participating isotope. In our case, the central band-fluxes in the two NBS neutron fields were also included in the parameters to be adjusted, and their respective covariances each occupy one partition.

Most of the off-diagonal sub-matrices in the extended covariance matrix are, quite naturally, null matrices. It is therefore convenient to indicate explicit non-null information in a schematic representation of the extended matrix. This information is presented in Tables III.1, 2, and 3.

Table III.1. The Extended Covariance Matrix: Coolant and Structure Materials "Original" and Cross-reaction Covariances Available in ENDF/B-V Files

				8	9	10	11	12	13	14	15	16	17	18	19	20
Partition	8	C	elastic	V												
	9		inelastic	V	V											
	10		capture		V	V										
	11	O	elastic				V									
	12		inelastic				V	V								
	13	Na	elastic						V							
	14		inelastic							V						
	15		capture						V		V					
	16	Cr	capture									V				
	17	Fe	elastic										V			
	18		inelastic											V		
	19		capture										V	V	V	
	20	Ni	capture													V

Table III.2. The Extended Covariance Matrix: U and Pu Isotopes

V = previously from ENDF/B-V files.
A = ... "A" covariances.
H = ... "preliminary V" covariances.

Partition			21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
21	U-235	elastic	A																												
22		inelastic	A	A																											
23		capture	A	A	V																										
24		fission	A	A	H	V		26	27	28	29																				
25		$\bar{\nu}$				V																									
26	U-238	elastic					V																								
27		capture			H	H	V	V																							
28		fission			H	H	V	H	V		40	41	42	43	44																
29		$\bar{\nu}$				H			V																						
30	Pu-239	elastic								A																					
31		inelastic								A	A																				
32		capture			H	V			H	H		A	A	V																	
33		fission			H	V			H	H		A	A	V	V		45	46	47	48	49										
34		$\bar{\nu}$					H				H					V															
35	Pu-240	elastic															A														
36		inelastic															A	A													
37		capture															A	A	V												
38		fission															A	A	H	A											
39		$\bar{\nu}$					H				H					H					V										

Table III.3. The Extended Covariance Matrix: U-238 Inelastic Levels

V = Previously from ENDF/B-V files. H = Includes "preliminary V" covariances.

Partition			26	27	28	29	30	31	32	33	34	35	36
26	elastic		V										
27	inelastic level	1	V	V									
28		2	V	H	V								
29		3	V	H	H	V							
30		4	V	H	H	H	V						
31		5	V	H	H	H	H	V					
32		6	V	H	H	H	H	H	V				
33		7	V	H	H	H	H	H	H	V			
34		8-10		H	H	H	H	H	H	H	H		
35		11-13		H	H	H	H	H	H	H	H	H	
36		14,15 and Continuum		H	H	H	H	H	H	H	H	H	H

The covariances and cross-reaction covariances of the cross sections of the structural materials in the four ZPR's and of sodium, generated from the ENDF/B-V uncertainty files, are indicated in Table III.1. The available uncertainty information on the more important cross sections, those of the fissionable isotopes, is shown in Table III.2. It is seen that not too much is now available from ENDF/B-V, so this information was supplemented by (a) formerly available cross correlations from the ORNL in-house so-called "preliminary version V" compilation,[14] and by (b) U-238 covariances (from ENDF/B-V) which we assumed to more or less represent the missing covariances of some of the U-235, Pu-239, and Pu-240 cross sections.

Finally, the uncertainty information regarding the U-238 inelastic-scattering discrete levels which was used in our adjustment is indicated in Table III.3, and the fission spectra covariances are discussed in Reference 15. The ENDF/B-V covariances were generated by Smith and Broadhead.[5]

DATA CONSISTENCY ANALYSIS

In a major data-adjustment project such as this, a great deal of effort is invested in the preparation and careful examination of the extensive input-data requirements for the adjustment module UNCOVER. Each adjustment also requires a careful a-posteriori re-examination of the input data, and especially of the effect of particular data on χ^2 and on the contributions of the different partitions to the total χ^2.

Such analysis tests the a-priori overall consistency of the set, or of a subset, of experimental responses by which the cross sections are adjusted, the "participating" responses, with the given cross-section library, and also the consistency of the participating responses with each other. It also gives some indication of the integral experiments which are mainly responsible for the adjustment of a particular cross section. The procedure for this data re-examination has been elaborated elsewhere.[16]

The essence of systematic data testing is to perform least-squares adjustments using a sequence of subsets of the experimental responses. We start with just one response, that response for which the value of χ^2 is lowest. These so-called "individual χ^2's" are listed in Table II under the heading Individual Consistency. Obviously, the smaller the χ^2, the more consistent the corresponding experimental response is with the given cross-section library. Returning to our sequence of subsets, consecutive subsets are determined by adding to a subset of n responses that non-participating response which forms the n+1 subset with the lowest χ^2. The responses are thus ranked according to their consistency with both the cross sections and the preceding responses. The ranking of our 29 responses is also indicated in Table II, under Overall Consistency Rank.

Values of chi-square per degree of freedom, χ^2/n, corresponding to each of the response subsets in our sequence are shown in Figure 3. These values certainly constitute a valid measure of the joint consistency of each response subset with the cross-section library. However, the more proper consistency measure is the probability $p(\chi^2,n)$ associated with each value. This is the a-priori probability that χ^2, considered as a random variable, would fall at or above the actual χ^2 value. In order to appreciate the significance of the results of our consistency analysis, three equal-probability curves, for p=50, 90 and 99%, are also plotted in Figure 3.

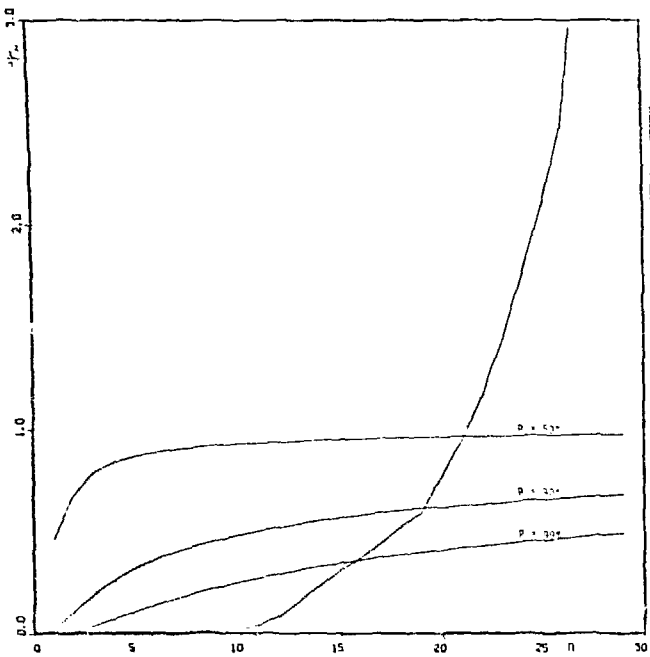

FIG. 3. JOINT CONSISTENCY CURVE. CHI SQUARED PER DEGREE OF FREEDOM χ^2/n, AS A FUNCTION OF PARTICIPATING RESPONSES, n, ALONG THE OPTIMAL SUBSET SEQUENCE.

The foregoing ranking procedure not only orders the experimental responses according to their consistency, and gives a quantitative measure for the joint consistency of each response subset with the given cross-section library. It also indicates how the adjustment of any partition (cross section) progresses with the addition of each non-participating response to the active subsets in the established consistency sequence. This aspect of the consistency analysis was also discussed in detail and illustrated in Reference 16. In the present work the emphasis is more on (a) compiling and processing the input data base, and (b) the *methodology* of the consistency analysis. We shall therefore not present these results here.

DISCUSSION

Although all measured responses that were considered in our procedure were carefully selected it is obvious from Figure 3 that the twenty-nine measured responses are not jointly consistent with each other and with the differential data base. Moreover, it is unacceptable to base ORACLE on an adjustment characterized by a value for χ^2/n of 5.5. It is therefore necessary to reject some measurements. It should be stressed that even if a given assembly or field qualifies to participate in the adjustment procedure ("clean" and good uncertainty analysis), some specific measurements which are not jointly consistent with the optimal response subset and the differential data base should be eliminated, but not necessarily all the measurements performed in that particular field, nor those measurements which indicate relative individual inconsistency (high individual χ^2). Although the first six measurements with lowest individual χ^2 ("individual consistency") are indeed also jointly the most consistent measurements, this pattern does change. For instance, the k value of ZPR-9/31 ranks as No. 20 in the joint consistency sequence, although its individual χ^2 is only 0.063 and it is the eleventh lowest individual χ^2. On the other hand, 28c/49f in ZPR-6/7 has a high individual χ^2 of 1.935 (25th individually), and yet ranks 19th in the joint consistency sequence. It should be pointed out that when χ^2/n approaches unity (i.e. $p(\chi^2,n) \simeq 50\%$) some cross section adjustments go well beyond one standard deviation. Pending further clarification of these inconsistencies the number of responses included in the adjustment for ORACLE is limited to twenty corresponding to $\chi^2/n \lesssim 1$.

SUMMARY AND CONCLUDING REMARK

The first version of an adjusted cross-section and covariance library ORACLE, developed explicitly for application to fast-reactor design, will be available in the Fall of 1980. This library is based on the gathering of a large array of well-documented data, including ENDF/B-5 nuclear data and covariances and benchmark integral data and covariances from six fast critical assemblies and two standard neutron fields, thereby covering a range of spectra. Some integral data were discarded on the basis of inconsistencies. The development of the library rests also on the existence of sophisticated methods for calculating not only integral values but also their sensitivities, a least-squares code capable of handling the large data base, and new computer software for incorporating the adjustments to form the library. Plans for using ORACLE for specific design purposes have been outlined in this paper. However, the value of such a library depends on the extent to which it can and will be used in actual applications. Accordingly, designers, evaluators experimentalists, and analysts are urged to examine and use the library and to provide feedback for guidance in developing a second version. This second version, in addition to reflecting such feedback, will incorporate additional integral experiments. For this purpose, inconsistent experiments which have been discarded will be reexamined.

ACKNOWLEDGEMENTS

The authors are very grateful to J.D. Drischler for his help in manipulating the covariance files, and to J.L. Lucius and C. C. Webster for generating the necessary sensitivity files, for developing and running the ADJUST module of FORSS, and for diverse neutronic calculations. Without their patience, perseverance and continuous help this work would have not been possible.

Special thanks are due to Ann Houston for her expert typing of the tables and last but not least, to Patty Boit for the professional and *patient* typing of several versions of this paper, while keeping us in good spirits.

REFERENCES

1. C. R. WEISBIN, R. W. PEELLE, J. H. MARABLE, G. DE SAUSSURE, P. J. COLLINS, E. KUJAWSKI, and E. GREENSPAN, "Sensitivity and Uncertainty Analysis of Reactor Performance Parameters." Advances in Nuclear Science and Technology, vol, 14 (to be published).

2. J. H. MARABLE, C. R. WEISBIN, and G. DE SAUSSURE, "Uncertainty in the Breeding Ratio of a Large Liquid-Metal Fast Breeder Reactor: Theory and Results," Nucl. Sci. Eng., 75, 30 (1980).

3. J. BARHEN, D. G. CACUCI, W. E. FORD, III, R. W. ROUSSIN, J. J. WAGSCHAL, C. R. WEISBIN, J. E. WHITE, AND R. Q. WRIGHT, "VITAMIN-E: A Multipurpose ENDF/B-V Coupled Neutron-Gamma Cross-Section Library," Nuclear Cross Sections and Technology (Knoxville, 1979), Conference Proceedings (to be published).

4. C. R. WEISBIN, J. H. MARABLE, P. J. COLLINS, C. L. COWAN, R. W. PEELLE, and M. SALVATORES, "Specifications for Adjusted Cross-Section and Covariance Libraries Based Upon CSEWG Fast-Reactor and Dosimetry Benchmarks." ORNL-5517 (1979).

5. J. D. SMITH, III and B. L. BROADHEAD, "Multigroup Covariance Matrices for Fast Reactor Studies." ORNL-TM-7389 (1980).

6. J. L. LUCIUS, C. R. WEISBIN, J. H. MARABLE, J. D. DRISCHLER, R. Q. WRIGHT, and J. E. WHITE, "A User's Manual for the FORSS Sensitivity and Uncertainty Analysis Code System." ORNL-5316 (1980).

7. The different modules and file names are all described in Reference 6.

8. P. J. COLLINS and M. J. LINEBERRY, "The Use of Cross-Section Sensitivities in the Analysis of Fast-Reactor Integral Experiments." ORNL/RSIC-42 (1978), pp.

9. G. E. HANSEN and H. C. PAXTON, "Specifications of Los Alamos Fast-Neutron Assemblies in the CSEWG Benchmark Format." LA-UR-79-2923 (1979).

10. G. E. HANSEN, Private Communication to J. J. Wagschal, (July 1980).

11. J. J. WAGSCHAL, R. E. MAERKER, and D. M. GILLIAM, "Detailed Error Analysis of Average Fission Cross Section Measurements in NBS Standard Neutorn Fields." Trans. Am. Nucl. Soc., 33, 823 (1979).

12. R. Q. WRIGHT, J. BARHEN, B. R. DIGGS, W. E. FORD,III, N. M. GREENE, J. R. KNIGHT, J. L. LUCIUS, J. H. MARABLE, C. C. WEBSTER, C. R. WEISBIN, and J. E. WHITE, "Fast Reactor Data Testing of ENDF/B-V." Report to CSEWG Fast Reactor Data Testing Subcommittee (May 15 1980).

13. B. L. BROADHEAD and J. J. WAGSCHAL, "The ISNF: A New CSEWG Dosimetry Benchmark (Computational Problems and Their Solution)." Trans. Am. Nucl. Soc. 35, (1980).

14. J. D. DRISCHLER and C. R. WEISBIN, "Compilation of Multigroup Cross Section Covariance Matrices for Several Important Reactor Materials." ORNL-5318 (rev.1), to be published.

15. R. E. MAERKER, J. H. MARABLE, and J. J. WAGSCHAL, "Estimation of the Uncertainties in the ENDF/B-V U-235 Fission Spectrum," Trans. Am. Nucl. Soc. 35, (1980).

16. Y. YEIVIN, J. J. WAGSCHAL, J. H. MARABLE, and C. R. WEISBIN, "Relative Consistency of ENDF/B-IV and V with Fast-Reactor Benchmarks." Nuclear Cross Sections and Technology (Knoxville, 1979), Conference Proceedings (to be published).