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Impacts of Data Covariances on the Calculated Breeding Ratio for CRBRP

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In the design and analysis of a nuclear reactor, it is highly desirable to have each performance parameter calculated with a minimum of uncertainty. Such a goal can be achieved, in principle, by consistently combining all available relevant integral experiment data with differential nuclear data by means of least-squares adjustment techniques.[1] However, practical difficulties do exist in both integral and differential data areas where complete and consistent information regarding the uncertainties and their correlations are usually lacking.[2] In order to establish our confidence on the data adjustment methodology as applied to LMFBR design, and to estimate the importance of data correlations in that respect, we have initiated an investigation on the impacts of data covariances on the calculated reactor performance parameters. This paper summarizes the results and findings of such an effort specifically related to the calculation of breeding ratio for CRBRP as an illustration.

Thirty-nine integral parameters and their covariances, including k_{eff} and various capture and fission reaction rate ratios, from the ZEBRA-8 series and four ZPR physics benchmark assemblies were used in the least-squares fitting processes.[3] Multigroup differential data and the sensitivity coefficients of those 39 integral parameters were generated by standard 2-D diffusion theory neutronic calculational modules at ANL. Three differential data covariance libraries, all based on ENDF/B-V evaluations, were tested in this study. The first one labeled <u>ORNL</u> is a 52-group library originally processed by PUFF-II code at ORNL and supplied to us by the Engineering Physics Information Center (EPIC).[4] The second one labeled <u>HEDL</u> is a 29-group library originally processed by FERRET code at HEDL.[5] These two libraries were later condensed to a 7-group structure at ANL and then used in this study. The third one labeled ANL is a 7-group library processed by NJOY code[6] at ANL. Although these libraries were all processed from the same ENDF/B evaluations, we found quite different multigroup covariances exist for some material and reaction types. It is probably due to the differences in processing methodology as well as the capability of these codes in handling various types and components of the ENDF/B-V error files. Since our current interest emphasizes the impacts of these processed covariances from the end-user's point of view, no attempts were taken to reveal the sources of these discrepancies.

The calculational sequences in this study start with a least-squares fitting of those 39 integral parameters by adjusting the differential data. After the least-squares fitting is done, the adjusted differential data is then used to calculate the breeding ratio and k_{eff} for CRBRP via their sensitivity coefficients. The impacts of both integral and differential data covariances can be seen by either including or excluding their correlations (off-diagonal matrix elements) during the calculational sequences. Four different cases of covariance data variations were studied. Each case again can use one of the three differential covariance data libraries. The results of such calculations for CRBRP breeding ratio and k_{eff} are summarized in Table I.

In Table I, $B\hat{R}$ and $\delta B\hat{R}$ is the calculated breeding ratio and its uncertainty (in %) respectively using the adjusted data, δBR_o is the breeding ratio uncertainty using the unadjusted data, and $\hat{\chi}^2$ is the chi-squares per degree of freedom after adjustment. (Notations for k_{eff} are likewise). Without data adjustment, nominal values for the breeding ratio is 1.2547, for the k_{eff} is 0.9766, and for the chi-squares per degree of freedom is 9.86. From the $\hat{\chi}^2$ results shown in Table I, we can clearly see the least-square fitting process

TABLE I. Comparison of CRBRP Breeding Ratio and k_{eff} Calculations with Variations of Covariance Data in the Adjustment Process

			Differential Data Covariance Library											
			ORNL[(a)]				HEDL[(b)]				ANL[(c)]			
Case	ID[(d)] XR	DD XR	$\hat{BR}$	$\delta\hat{BR}$	δBR_o	$\hat{\chi}^2$	$\hat{BR}$	$\delta\hat{BR}$	δBR_o	$\hat{\chi}^2$	$\hat{BR}$	$\delta\hat{BR}$	δBR_o	$\hat{\chi}^2$
1	Yes	Yes	1.209	1.71	3.45	1.11	1.205	1.39	4.26	0.92	1.206	1.72	4.10	1.21
2	Yes	No	1.217	1.48	2.24	1.17	1.210	1.22	2.86	0.97	1.221	1.45	2.45	1.19
3	No	No	1.222	1.10	2.24	1.05	1.217	0.86	2.86	0.83	1.224	1.09	2.45	1.07
4	No	Yes	1.217	1.25	3.45	0.99	1.214	0.97	4.26	0.78	1.213	1.25	4.10	1.08
			$\hat{k}$	$\delta\hat{k}$	δk_o		$\hat{k}$	$\delta\hat{k}$	δk_o		$\hat{k}$	$\delta\hat{k}$	$\delta\hat{k}_o$	
1	Yes	Yes	0.9871	0.32	1.85		0.9856	0.28	2.91		0.9865	0.34	2.62	
2	Yes	No	0.9873	0.32	1.42		0.9866	0.27	2.59		0.9872	0.33	2.58	
3	No	No	0.9873	0.29	1.42		0.9869	0.23	2.59		0.9872	0.30	2.58	
4	No	Yes	0.9873	0.29	1.85		0.9863	0.24	2.91		0.9867	0.31	2.62	

Note: (a) The original data is processed from ENDF/B-V by PUFF-II code at ORNL (See Reference 4).
(b) Data processed from ENDF/B-V by FERRET code at HEDL.
(c) Data processed from ENDF/B-V by NJOY code at ANL.
(d) Yes or No indicates whether integral data (ID) and differential data (DD) correlation is used or not in the data adjustment process.

worked and it had significantly reduced χ^2 from an initial value of 9.86 to final values around 1.0 for most cases. The calculated breeding ratio stays rather stationary between 1.20 and 1.22 for all cases. The calculated k_{eff} also stays rather stationary between 0.985 and 0.986 for all cases. However, the uncertainties of both breeding ratio and k_{eff} are quite sensitive to the data correlations and the libraries used. The reduction from δBR_0 to $\delta \hat{BR}$ is almost a factor of 2 with both ORNL and ANL libraries and greater than 3 with HEDL library. The reductions from δk_0 to δk are even greater, a factor of 5 with ORNL library and a factor > 8 with HEDL and ANL libraries. The exclusion of differential data correlation in the calculation resulted in a substantial reduction of uncertainty estimates (~40% in δBR and ~20% in δk). The exclusion of integral data correlation in the calculation resulted in a slightly better least-squares fitting and a larger reduction in the uncertainty estimates.

According to the results and findings in this study, we concluded that the calculated integral parameters ($\hat{BR}$ and $\hat{k}$) are rather insensitive to the choices of differential data covariance libraries. The main reason for this is because the integral parameters (especially k_{eff}) used in this study have rather small uncertainties which tend to dominate the least-squares fitting processes.[7] The impacts of the integral data uncertainty are reported in another paper of this meeting.[8] We found that the accuracy of the input integral data is the major controlling factor in the whole data adjustment process. This is a rather fortunate situation since the covariance files in ENDF/B-V evaluations are at their developmental stages and the accuracy, consistency, and completeness of these data are not guaranteed by any means. Even under such an unfavorable environment, the data adjustment techniques can still be used in combining the integral experiment data with differential data to improve the overall accuracy of calculated reactor parameters. However, the uncertainties of these parameters ($\delta B\hat{R}$ and $\delta\hat{k}$) are very sensitive to the correlations as well as the covariance libraries being used. An important task confronting us now is to compare and assess the accuracy of those uncertainty estimates by going into the details of the processing methodology of those codes and the covariance files in ENDF/B-V evaluations.

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