Whereas Ganesan[1] may have a valid point for low-energy Doppler broadening in thermal reactors, his remarks are misleading when applied to Doppler broadening in fast reactors. He implies that his remarks apply to fast as well as thermal reactors by quoting from Ref. 2.

Ganesan's quote comes from a paragraph on Doppler-broadened resonance absorption in fast reactors. The treatment of Doppler broadening presented in the book is the "psi-chi" method, which is the approximate method based on the Breit-Wigner single-level formula for resonance cross sections. The infinitely dilute group absorption cross section for absorber m is a value proportional to the reaction rate per atom of m, $\int_g \sigma_{am}(E)\,dE/E$, divided by $\int_g dE/E$. The contribution to this reaction rate integral from each resonance in the group, when calculated by the psi-chi method, is indeed independent of temperature, as stated in our text. The Cullen-Weisbin[3] paper referenced by Ganesan shows that the psi-chi method represents an excellent approximation for the calculation of Doppler-broadened cross sections for heavy elements like ^{238}U in the energy range of importance in fast reactors and for fuel temperatures involved in fast reactor safety. For resonances in fast reactors, the concept that the integral $\int \sigma_{am}(E)\,dE/E$ is unaffected by Doppler broadening is accurate, rather than erroneous as suggested by Ganesan.

It is emphasized in Ref. 2 that Doppler broadening of absorption resonances in a fast reactor must be combined with self-shielding of the neutron flux in order for there to be any variation of the effective group absorption cross section with temperature. Without self-shielding there would be no Doppler reactivity effect from changes in fuel temperature in a fast reactor.

Reference 2 describes methods applicable to fast reactors. We clearly had no intention of generalizing our remarks on Doppler broadening either to low-energy resonances where, according to Cullen and Weisbin,[3] the "psi-chi" approximation deviates from exact methods for calculating Doppler broadening or to $1/v$ absorbers, which are also treated in detail by those authors.

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[1]S. GANESAN, *Nucl. Sci. Eng.*, **86**, 118 (1984).
[2]A. E. WALTAR and A. B. REYNOLDS, *Fast Breeder Reactors*, Pergamon Press, New York (1981).
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Comment on "Error Due to Nuclear Data Uncertainties in the Prediction of Large Liquid-Metal Fast Breeder Reactor Core Performance Parameters"

In a recent paper by Kamei and Yoshida[1] on the use of mock-up experiments to correct calculated performance parameters of planned power reactors and to estimate the errors in these predicted parameters, the authors state, among other things, that "There are, in principle, two different approaches to utilize the information from the mock-up experiments in the core design calculations. One is the cross-section adjustment method, and the second is the so-called bias-factor method." This, hyperbolically, corresponds to the statement that there are two approaches to treating a bacterial infection: one is to use the right antibiotics, and the other, to take a couple of aspirins. Undeniably, some people *are* allergic to antibiotics, and indeed aspirin *may* bring some (temporary) relief. Still, aspirin is certainly not the treatment of choice for infections.

As the authors of Ref. 1 state, "The (cross-section adjustment) methodology rests on a firm theoretical and mathematical foundation." They may be familiar with the paper on generalized bias operators by Ronen et al.[2] in which this statement is made and which further elaborates on the fact that the adjustment technique requires a great deal of input data, which generally necessitates expensive and time-consuming work to obtain and of which the quality and validity are sometimes still open to question. Thus, only when this information is lacking or is seriously in doubt, may the recourse to the bias-factor method be justified. And yet, in their paper, Kamei and Yoshida derive a prescription for the evaluation of the uncertainties in reactor performance parameters derived by the bias-factor method, a prescription based on the very data only the lack or deficiency of which would have justified the employment of the method in the first place.

The primary purpose of this Letter is to demonstrate how the uncertainties in power reactor performance parameters *should* be evaluated. In other words, we propose to establish the way in which the uncertainties in a given nuclear data ("cross sections") set, the results of any relevant integral experiment (mock-up, benchmark, etc.), and the necessary sensitivity profiles should be properly combined to produce the actual "error" in any performance parameter of a given reactor design and the correlations between the different parameters, i.e., the complete uncertainty matrix of the evaluated performance parameters. We shall also show that the prescription of Ref. 1 is a problematic approximation of the correct expression for the uncertainty matrix of the performance parameters, even in the special case discussed in that paper, the rather unrealistic case of absolutely precise mock-up measurements, the case of integral data of which the associated uncertainty matrix vanishes.

We should, first of all, call attention to the fact that the problem under discussion is mathematically identical to that of extrapolating surveillance dosimetry information to predict radiation damage in power reactor pressure vessels. Traditionally, the bias-factor method was being applied in the latter extrapolation. But more recently, the objective advantages of the adjustment approach have been recognized, so much so that the American Society for Testing and Materials is now considering a new draft standard on the subject.[3] Apparently we could have just quoted the relevant reference,[4] of which the formulas (with the right notation) in fact express the complete and correct solution to extrapolating the mock-up results to the reactor design. However, we feel that the very effort to evaluate the uncertainties in the values of the reactor

[1]T. KAMEI and T. YOSHIDA, *Nucl. Sci. Eng.*, **84**, 83 (1983).
[2]Y. RONEN, D. G. CACUCI, and J. J. WAGSCHAL, *Nucl. Sci. Eng.*, **77**, 426 (1981).
[3]F. B. K. KAM, Private Communication.
[4]J. J. WAGSCHAL, R. E. MAERKER, and Y. YEIVIN, *Trans. Am. Nucl. Soc.*, **34**, 631 (1980).

performance parameters, calculated with a given (unadjusted) cross-section library and modified by bias factors derived from the mock-up measurements, affords a golden opportunity to underscore the telling advantage of the adjustment approach, provided of course that the cross-section uncertainties and the mock-up and reactor sensitivities are available. It is hoped that the following exposition will shed light on the mismatch arising from the blending of the bias-factor method with sensitivity analysis and will, at the same time, further elucidate the adjustment technique.

We shall now first review the proper way to make the most of the cross-section and mock-up information in order to obtain both the most likely values of the performance parameters of the actual reactor and their associated uncertainties. Given a cross-section library $\sigma \equiv (\sigma_i)$, $i = 1, 2, \ldots, N$, with its uncertainty (covariance) matrix $\mathbf{C}_\sigma \equiv \mathrm{cov}(\sigma_i,\sigma_j)$, and a set of mock-up measurements $I_0 \equiv (I_{0k})$, $k = 1, 2, \ldots, n$, with their uncertainty matrix $\mathbf{C}_0 \equiv \mathrm{cov}(I_{0k},I_{0l})$; and given the corresponding set of the calculated mock-up parameters $\bar{I}_0 = \bar{I}_0(\sigma)$ and their sensitivity profiles $\mathbf{S}_0 \equiv (\partial \bar{I}_{0k}/\partial\sigma_i)$; the adjusted library, i.e., the cross sections adjusted by the integral (mock-up) data, is

$$\sigma' = \sigma + x \ , \quad x = -\mathbf{C}_\sigma \mathbf{S}_0^+ (\mathbf{C}_0 + \mathbf{S}_0 \mathbf{C}_\sigma \mathbf{S}_0^+)^{-1} (\bar{I}_0 - I_0) \ , \qquad (1)$$

where $\mathbf{S}_0^+$ denotes the transpose of the matrix $\mathbf{S}_0$. Note that $\mathbf{S}_0\mathbf{C}_\sigma\mathbf{S}_0^+$ is just the uncertainty matrix of $\bar{I}_0$, resulting from the uncertainties in the cross sections that enter into the calculation of $\bar{I}_0$. Since, by the very definition of sensitivities, $\delta\bar{I}_0 = \mathbf{S}_0\delta\sigma$, it trivially follows that $\langle(\delta\bar{I}_0)(\delta\bar{I}_0)^+\rangle = \mathbf{S}_0\langle(\delta\sigma)(\delta\sigma)^+\rangle\mathbf{S}_0^+ = \mathbf{S}_0\mathbf{C}_\sigma\mathbf{S}_0^+$. This is the so-called "sandwich rule," which is so useful throughout the adjustment formalism. Anyway, $\mathbf{C}_0 + \mathbf{S}_0\mathbf{C}_\sigma\mathbf{S}_0^+$ is the sum of the uncertainties of the experimental and the calculated mock-up parameters, and thus it is, in fact, the uncertainty matrix $\mathbf{C}_d$ of the difference $d = \bar{I}_0 - I_0$, provided I_0 and $\bar{I}_0$, i.e., I_0 and σ(!), are uncorrelated. Under the same provision, the uncertainty matrix of the adjusted cross-section library is

$$\mathbf{C}_{\sigma'} = \mathbf{C}_\sigma - \mathbf{C}_x \ , \quad \mathbf{C}_x = \mathbf{C}_\sigma \mathbf{S}_0^+ (\mathbf{C}_0 + \mathbf{S}_0 \mathbf{C}_\sigma \mathbf{S}_0^+)^{-1} \mathbf{S}_0 \mathbf{C}_\sigma \ . \qquad (2)$$

A didactic, neat, and easy derivation of Eqs. (1) and (2) can be found in Ref. 5.

Now, let $I \equiv (I_k)$, $k = 1, 2, \ldots, n'$ be the performance parameters of the power reactor that we wish to evaluate. These need not necessarily correspond, one to one, to the n input mock-up parameters, which incidentally is another advantage of adjustment. And let $\mathbf{S}$ be the sensitivity matrix of the parameters I with respect to the input cross sections. Then, obviously, the best estimate of the reactor performance parameters is

$$I' = \bar{I}(\sigma') = \bar{I}(\sigma + x) = \bar{I}(\sigma) + \mathbf{S}x \ , \qquad (3)$$

and their uncertainty matrix, by the sandwich rule, is

$$\mathbf{C}' = \mathbf{S}\mathbf{C}_{\sigma'}\mathbf{S}^+ = \mathbf{S}(\mathbf{C}_\sigma - \mathbf{C}_x)\mathbf{S}^+ = \mathbf{S}\mathbf{C}_\sigma\mathbf{S}^+ - \mathbf{S}\mathbf{C}_x\mathbf{S}^+ \ , \qquad (4)$$

where x and $\mathbf{C}_x$ are respectively given in Eqs. (1) and (2).

This is a convenient point at which to note that, whereas Eqs. (1) through (4) are formulated in terms of absolute (dimensional) quantities, the equivalent formulation in terms of the corresponding relative (dimensionless) quantities is quite common. In fact, Ref. 1 is an example of the use of relative quantities and thus an excuse for this digression. Fortunately, the transition from one formulation to the other is *almost* trivial. If we denote relative quantities by placing a tilde over the respective symbols, then the relative adjustment $\tilde{x} \equiv (x_i/\sigma_i)$, for instance, is given by an expression identical to the one for x in Eq. (1) in which each quantity is replaced by its relative counterpart:

$$\mathbf{C}_\sigma \to \tilde{\mathbf{C}}_\sigma \equiv \mathrm{cov}\left(\frac{\delta\sigma_i}{\sigma_i}, \frac{\delta\sigma_j}{\sigma_j}\right) \ , \quad \mathbf{S}_0 \to \tilde{\mathbf{S}}_0 \equiv \left(\frac{\partial\tilde{\bar{I}}_{0k}}{\partial\tilde{\sigma}_i}\right) = \left(\frac{\sigma_i}{\bar{I}_{0k}}\frac{\partial\bar{I}_{0k}}{\partial\sigma_i}\right) \ . \qquad (5)$$

There is, however, an exception to this simple rule. The relative experimental values of the integral (mock-up) parameters and their associated relative uncertainty matrix should be modified before applying the transition rule. Let $\mathbf{R}_0$ be the diagonal matrix (of order n)

$$\mathbf{R}_0 \equiv \mathrm{diag}\left(\frac{I_{01}}{\bar{I}_{01}}, \frac{I_{02}}{\bar{I}_{02}}, \ \ldots, \frac{I_{0n}}{\bar{I}_{0n}}\right) \ . \qquad (6)$$

Then the transition from the absolute to the relative formulation, in addition to Eq. (5), necessitates the substitutions

$$I_0 \to \mathbf{R}_0\tilde{I}_0 \ , \quad \mathbf{C}_0 \to \mathbf{R}_0\tilde{\mathbf{C}}_0\mathbf{R}_0 \ . \qquad (7)$$

The same rules apply to $\mathbf{C}_{\sigma'}$, given in Eq. (2), provided we adopt the convention

$$\mathbf{C}_{\sigma'} \to \left(\frac{\mathrm{cov}(\sigma_i',\sigma_j')}{\sigma_i\sigma_j}\right) \ , \quad \mathbf{C}_x \to \left(\frac{\mathrm{cov}(x_i,x_j)}{\sigma_i\sigma_j}\right) \ , \qquad (8)$$

and to I', Eq. (3), and its uncertainty matrix $\mathbf{C}'$, Eq. (4), if

$$I' \to \left(\frac{I_k'}{\bar{I}_k}\right) \ , \quad \mathbf{C}' \to \left(\frac{\mathrm{cov}(I_k',I_l')}{\bar{I}_k\bar{I}_l}\right) \ . \qquad (9)$$

In short, the relative formulation is formally identical to the absolute formulation, Eqs. (1) through (4), with the convention that all relative differential (cross-section) quantities are relative with respect to the given cross sections σ, and all relative integral (performance-parameter) quantities are relative with respect to their corresponding *calculated* values.

Trivial as the foregoing paragraph may be, employment of the relative-quantity formulation is indeed somewhat confusing. Negligence of Eq. (7) is a notorious and rather commonplace pitfall in the application of adjustment, and we are aware of instances in which it has indeed led to erroneous results in actual adjustments. The transition rules might have been documented in some obscure internal notes or technical reports, but, to the best of our knowledge, not in a readily available formal journal article.

Let us now return to Ref. 1. Our first comment refers to the derivation of its principal result, the uncertainty matrix in Eq. (7), and (from a methodical point of view at least) is almost as important as our general reservation regarding the very application of the bias-factor method under the circumstances defined in the paper. Anyway, if one does choose to modify the calculated performance parameters $\bar{I}$ by the prescription

$$I_k' = \bar{I}_k \times (I_{0k}/\bar{I}_{0k}) \ , \qquad (10)$$

then it *trivially* follows that

$$\frac{\delta I_k'}{I_k'} = \frac{\delta\bar{I}_k}{\bar{I}_k} + \frac{\delta I_{0k}}{I_{0k}} - \frac{\delta\bar{I}_{0k}}{\bar{I}_{0k}} = \frac{\delta I_{0k}}{I_{0k}} + \sum_{i=1}^{N} (\tilde{S}_{ki} - \tilde{S}_{0ki})\frac{\delta\sigma_i}{\sigma_i} \ . \qquad (11)$$

And so, bearing in mind that $\tilde{\mathbf{C}}' \equiv \langle(\delta I_k'/I_k')(\delta I_l'/I_l')\rangle$ and that the cross sections σ and the mock-up measurements I_0 are mutually independent, we immediately obtain

[5] J. J. WAGSCHAL and Y. YEIVIN, *Trans. Am. Nucl. Soc.*, **34**, 776 (1980).

$$\tilde{\mathbf{C}}' = \tilde{\mathbf{C}}_0 + (\tilde{\mathbf{S}} - \tilde{\mathbf{S}}_0)\tilde{\mathbf{C}}_\sigma(\tilde{\mathbf{S}} - \tilde{\mathbf{S}}_0)^+ \ . \qquad (12)$$

This, in fact, is just Eq. (7) of Ref. 1, except that $\tilde{\mathbf{C}}_0$ is missing in that equation. We note in passing that this disappearance of $\tilde{\mathbf{C}}_0$ is rather disturbing, since, to quote from Ref. 1 again, "The mock-up experiments are used to estimate the errors in the prediction of neutronic parameters . . . ," and experiments, by their very nature, always involve uncertainties. Certainly the ZPPR-10D experiment, from which the bias factors were obtained for the Ref. 1 illustrative example, is no exception. The actual argument, however, concerns the rather lengthy, definitely cumbersome, and very foggy derivation of Eq. (7), whereas the result, in fact, is elementary, immediate, and crystal clear.

Our second and main comment, unlike the first that dealt with *form*, concerns the very *substance* of Ref. 1. We shall compare the result we have discussed, Eq. (12) of this Letter or Eq. (7) of Ref. 1, with Eq. (4), which is the true and correct uncertainty matrix associated with the values of the performance parameters of the target reactor, evaluated with *proper* consideration of the mock-up information. We shall adhere to the relative-uncertainty-and-sensitivity formulation, disregard the fine distinction between the relative uncertainties proper and the ones required by the rules of the correct transition from the absolute to the relative formulation, and from now on omit the tilde that we had used to denote relative quantities.

For the sake of simplicity and clarity in the course of this comparison, we shall also assume that the experimental mock-up uncertainties, $\mathbf{C}_0$, may be neglected. Under this assumption, Eq. (2) becomes

$$\mathbf{C}_{\sigma'} = \mathbf{C}_\sigma - \mathbf{C}_x \ , \quad \mathbf{C}_x = \mathbf{C}_\sigma \mathbf{S}_0^\dagger (\mathbf{S}_0 \mathbf{C}_\sigma \mathbf{S}_0^\dagger)^{-1} \mathbf{S}_0 \mathbf{C}_\sigma \ , \qquad (13)$$

and, defining $\Delta\mathbf{S} = \mathbf{S} - \mathbf{S}_0$, Eq. (4) reduces to

$$\mathbf{C}' = (\mathbf{S}_0 + \Delta\mathbf{S})\mathbf{C}_{\sigma'}(\mathbf{S}_0 + \Delta\mathbf{S})^+ = \ldots = \Delta\mathbf{S}\mathbf{C}_{\sigma'}\Delta\mathbf{S}^+ \ . \qquad (14)$$

That the other three terms do indeed vanish, easily follows on substituting Eq. (13) for $\mathbf{C}_{\sigma'}$:

$$\mathbf{S}_0\mathbf{C}_{\sigma'}\mathbf{S}_0^\dagger = \mathbf{S}_0\mathbf{C}_\sigma\mathbf{S}_0^\dagger - \mathbf{S}_0\mathbf{C}_\sigma\mathbf{S}_0^\dagger(\mathbf{S}_0\mathbf{C}_\sigma\mathbf{S}_0^\dagger)^{-1}\mathbf{S}_0\mathbf{C}_\sigma\mathbf{S}_0^\dagger = 0 \ , \qquad (15)$$

and similarly for the two remaining terms.

On the other hand, under the same assumptions Eq. (12) now becomes

$$\mathbf{C}' = \Delta\mathbf{S}\mathbf{C}_\sigma\Delta\mathbf{S}^+ \ , \qquad (16)$$

which is identical to Eq. (7) of Ref. 1. The difference between this equation and the actual $\mathbf{C}'$ of Eq. (14) is manifest and unmistakable: the "bias-factor-method" $\mathbf{C}'$ hangs on the uncertainty matrix $\mathbf{C}_\sigma$ of the original, given, cross-section library, whereas the proper "adjustment" $\mathbf{C}'$ derives from $\mathbf{C}_{\sigma'}$, the uncertainty matrix of the adjusted library, adjusted that is by the very same integral data I_0 that the authors of Ref. 1 had only used to generate their bias factors.

We cannot, at this point, resist the temptation to recall, again, that ever since sensitivity analysis became so fashionable with the neutronics community, we have been preaching the gospel of adjustment.[6] The paper by Kamei and Yoshida[1] provides yet another convincing argument, if one were still necessary, that the logical conclusion of sensitivity analysis, and in particular any such analysis with practical pretensions, should indeed be adjustment. Adjustment, one might say, is the fulfillment of sensitivity analysis.

And so, in conclusion, we propose to epitomize our main critique in four observations:

1. By the rules of our game, namely the simplifying assumptions we have adopted for the sake of the foregoing comparison, the mock-up measurements are *absolute* reference points for the target reactor parameters we wish to evaluate. Thus the uncertainties in I' depend on how far a target assembly is from the reference mock-up. More precisely, they are dependent on how different the sensitivity profiles of the former are from those of the latter. Indeed, in both Eqs. (14) and (16), $\mathbf{C}'$ is dependent on $\Delta\mathbf{S}$ rather than on the individual sensitivity matrices. The other factor in the two expressions for $\mathbf{C}'$ is the cross-section uncertainty matrix, which is sandwiched between $\Delta\mathbf{S}$ and $\Delta\mathbf{S}^+$. Now, in Eq. (16) the uncertainty matrix $\mathbf{C}_\sigma$ of the given cross-section library is used. However, the mock-up measurements I_0 are not just reference values for the derived performance parameters. They also constitute valuable information on the cross sections, which especially under our particular assumptions is of high quality. Failure to *fully* use this information is just extravagant wastefulness. But this is precisely what has happened in Ref. 1, where sensitivity analysis was only carried half-way. In Eq. (14), on the other hand, full use of the I_0 data is expressed in the appearance of $\mathbf{C}_{\sigma'}$ between $\Delta\mathbf{S}$ and $\Delta\mathbf{S}^+$. Here, then, these data are exploited both as references for the I' and as further cross-section information used to improve the given library and reduce $\mathbf{C}_\sigma$ to $\mathbf{C}_{\sigma'}$.

2. From a purely practical point of view, any investment in setting up a critical-assembly experiment is only justified by the substantial cost savings expected in the construction of the power reactor, the core of which the critical assembly purports to be a mock-up. These expected savings should derive from reduced design safety margins which, in turn, would result from diminished uncertainties in any predicted reactor parameter. Further, the authors of Ref. 1 have, over and above, invested great efforts in the compilation of the $\mathbf{C}_\sigma$ data and then in the evaluation of the sensitivities. And for all that, they end up reducing the reactor-parameter uncertainty matrix from $\mathbf{S}\mathbf{C}_\sigma\mathbf{S}^+$ to $\Delta\mathbf{S}\mathbf{C}_\sigma\Delta\mathbf{S}^+$. Surely, inasmuch as $\mathbf{S}$ is close enough to $\mathbf{S}_0$, this would be a very impressive reduction. The actual uncertainty matrix, however, is still smaller by $\Delta\mathbf{S}\mathbf{C}_x\Delta\mathbf{S}^+$. Thus, the prescription of Ref. 1 falls short of achieving the maximum in savings in return for all the investments.

3. Considering $\mathbf{C}'$ of Eq. (16) as an approximation of the actual $\mathbf{C}'$ given in Eq. (14), we now observe that as such it is not much to be proud of. By this we mean that the additional reduction in $\mathbf{C}'$, namely $\Delta\mathbf{S}\mathbf{C}_x\Delta\mathbf{S}^+$, is not generally negligible, nor is it even significantly smaller, compared to the "approximate" $\mathbf{C}'$, not even when $\Delta\mathbf{S}$ approaches zero. On the contrary, as is plain and clear, this reduction in $\mathbf{C}'$ is of the same order in $\Delta\mathbf{S}$ as the approximate result itself. And further, insofar as the mock-up data are really good, which obviously is the case with our assumption of vanishing $\mathbf{C}_0$, the expected uncertainties in the adjusted cross sections would be substantially smaller than those in the unadjusted library, i.e., we may in fact expect that the matrix $\mathbf{C}_{\sigma'} = \mathbf{C}_\sigma - \mathbf{C}_x$ represent uncertainties that are much smaller than those represented by $\mathbf{C}_\sigma$. Thus if, on one hand, $\Delta\mathbf{S}$ is small enough, then the further decrease in $\mathbf{C}'$ is "by a factor" and independent of $\Delta\mathbf{S}$; and if, on the other hand, $\Delta\mathbf{S}$ is not that small (compared to $\mathbf{S}$), then evidently the "approxmate" $\mathbf{C}'$ is not any improvement over the uncertainty $\mathbf{S}\mathbf{C}_\sigma\mathbf{S}^+$ of the "unbiased" parameters $\bar{I}$, whereas, the actual, adjusted $\mathbf{C}'$ is still reduced by that same "factor."

[6] J. J. WAGSCHAL, A. YA'ARI, and Y. YEIVIN, "Cross-Section Sensitivities, Adjustments and All That," *Proc. Conf. Advanced Reactors: Physics, Design and Economics*, Atlanta, Georgia, September 9-13, 1974, Pergamon Press (1975).

4. We have extensively discussed the uncertainties in the predicted target reactor performance parameters. This, of course, is the main subject of Ref. 1, which provoked the present deliberation. In this final remark we wish to recall that important as the uncertainties are, the very parameter values about which these uncertainties are spread are at least just as important. And as far as the parameter predictions are concerned, by our discursive reasoning and by the force of all our arguments, it should by now be quite clear that the predictions by the bias-factor method are definitely less reliable than the adjusted parameter values, which, to return to an early quotation, indeed "rest on a firm theoretical and mathematical foundation."

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Response to "Comment on 'Error Due to Nuclear Data Uncertainties in the Prediction of Large Liquid-Metal Fast Breeder Reactor Core Performance Parameters'"

Wagschal and Yeivin[1] assert that the predictions by the bias-factor method are definitely less reliable than by the adjusted parameter values and state that the recourse to the bias-factor method would have been justified only when the covariance and sensitivity data are lacking or are seriously in doubt. "The bias-factor method or the adjustment" has been a theme of years of argument in the neutronics community.

We believe that the adjustment is a very powerful tool to improve the predictive accuracy of performance parameters, but the method is not always almighty. We also believe that the bias-factor method is also an indispensable tool in design work for the following reasons.

The measured sample worths are not free from the problem of the "central discrepancy." The control rod worth inevitably involves the uncertainty associated with the delayed neutron data (β_{eff}). The use of these data as input for the adjustment might distort the adjusted cross sections and consequently degrade the accuracy of predictions of other performance parameters such as criticality, power distribution, etc. In order to avoid this degradation, it is possible to lessen the weights for these data. This is, however, equivalent to discarding the information from the experiment. On the other hand, the bias-factor method can utilize this information without affecting other parameters, although uncertainties associated with β_{eff} and others are included in the predicted values.

It is desirable that the cross-section library be unchanged during the design once it has been started. The library may be either nonadjusted or adjusted. In any case, we have to cope with the addition of new integral data and the revision of old data. This is accomplished by the bias-factor method. These are the reasons why we believe that the bias-factor method will not be abandoned even in the future. As long as the bias-factor method continues to be used, it is necessary to provide a method of error evaluation after the bias factor is applied.

The method presented in Ref. 2 can also be utilized in the selection of the best mock-up system. Let us assume that there are many candidates for the mock-up of a future power reactor. The best mock-up system is the one that minimizes the variance of performance parameter, namely the diagonal term of matrix $\mathbf{V}$ of Eq. (7) in Ref. 2.

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[1] J. J. WAGSCHAL and Y. YEIVIN, *Nucl. Sci. Eng.*, **86**, 121 (1984).

[2] T. KAMEI and T. YOSHIDA, *Nucl. Sci. Eng.*, **84**, 83 (1983).