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APPLICATION OF SENSITIVITY ANALYSIS TO A QUANTITATIVE ASSESSMENT OF NEUTRON CROSS-SECTION REQUIREMENTS FOR THE TFTR: AN INTERIM REPORT

by

S. A. W. Gerstl, D. J. Dudziak, and D. W. Muir

ABSTRACT

A computational method to determine cross-section requirements quantitatively is described and applied to the Tokamak Fusion Test Reactor (TFTR). In order to provide a rational basis for the priorities assigned to new cross-section measurements or evaluations, this method includes: quantitative estimates of the uncertainty of currently available data, the sensitivity of important nuclear design parameters to selected cross sections, and the accuracy desired in predicting nuclear design parameters. Perturbation theory is used to combine estimated cross-section uncertainties with calculated sensitivities to determine the variance of any nuclear design parameter of interest.

I. INTRODUCTION

A. Background

Nuclear design calculations have always been limited in their accuracy by both computational methods and uncertainties in cross-section data. After a period of extensive refinements in calculational methods* and computer codes, more emphasis in recent years has been directed toward improving cross-section data bases. Because quantitative and complete estimates of cross-section errors were not available in most cases, several ad hoc systems of nuclear design uncertainty analysis have evolved. One of the most fruitful for reactor core parameters has been the employment of integral experiments to measure directly such quantities as effective multiplication, central reactivity worths, etc., to compare with calculated results. However, the expense involved in such integral experiments normally precludes all but the most vital programmatic measurements. Even when such experiments are available, the designer is faced with an indeterminate problem of attributing the errors in his analysis of the experiment to individual cross sections (assuming

he is confident of the precision of his analytical tools). In the final analysis much of the deductive reasoning regarding possible cross-section errors depends upon qualitative judgement and a semiquantitative knowledge of the cross-section evaluations. That is, the designer must have an appreciation for the inherent errors in the cross-section measurements upon which the evaluated data are based if he wants to properly "adjust" his data to force agreement with experiment. Rather sophisticated methods of adjustment have evolved,² which depend upon the performance of integral experiments.

An alternative approach to the problem of determining accuracy of design calculations greatly reduces the need for integral experiments. Although this approach, called sensitivity analysis, never answers the absolute question of how computational results compare with experimental truth, it allows one to place quantitative error bands on these results. Sensitivity analysis does require that cross-section errors are quantified and formatted to the best of the evaluator's ability, but in return it allows one to analyze errors in calculated design parameters which would be extremely difficult and expensive to measure directly in an integral

*Confer, e.g., Ref. 1.

experiment. As a case in point, consider the dependence of radiation damage, e.g., displacements per atom (dpa), in the first wall or magnet coil of a fusion reactor on cross-section uncertainties, where measurements are essentially impossible. Even disregarding programmatic considerations such as the current lack of intense 14-MeV (2.25-pJ) neutron sources, cost considerations would allow measurement of only a few selected parameters.

From a cost-effectiveness point of view then, sensitivity analysis is particularly advantageous in studies of design parameters in complex systems not amenable to experiment; for parameters not easily measured directly (e.g., dpa); and, most important, for error analysis which is wide-ranging in the number of parameters and number of individual cross sections considered. This latter point is vividly illustrated below in the case of the Tokamak Fusion Test Reactor (TFTR), for which a conceptual design has been performed by Westinghouse Electric Corporation, under the technical direction of the Princeton Plasma Physics Laboratory.

A quantitative analysis of cross-section uncertainties and their effects on design parameters has been possible since nuclear analysis was first attempted. In fact, there is a literature based upon direct recomputation with alternate data sets (cf., e.g., Ref. 3). This approach can be characterized as one based upon "credibly deviant" cross-section data sets, starting with some estimates of the probable range of values, either at the pointwise or multigroup stage of energy dependence. However, such methods are limited in their information content, furnishing at best the magnitude of "typical" errors. But to make a truly quantitative estimate of cross-section errors, one must have considered in detail the variance of the cross-section data at all energies of interest. Just as importantly, one must consider correlations among energy bands and among partial cross sections. When such detailed evaluations of cross-section errors have been performed, the next logical step is to format⁴ them in computer-accessible files, as has been done for a few materials of CTR interest (C, N, O, and Al).

The versatile and powerful tools of generalized perturbation theory can be used to determine the sensitivity of design parameters to unit changes in

a cross section within, say, a particular energy group. The entirety of these sensitivities for all energy groups is often called a sensitivity profile for a particular partial cross section. Such profiles can then be combined with correlated error estimates, or covariances, to quantify the variances in integral design parameters.

B. Fusion Reactor Applications of Sensitivity Methods

Upon applying nuclear data developed for fission reactor, nuclear weapon, or accelerator applications to fusion reactors, a need for more accurate neutron cross sections in the MeV range becomes immediately apparent.⁵ Due to the large number of cross-section data needed for fusion reactor design calculations, it is clear that not all deficient data can be improved within a short time frame. Therefore, some reasonable criterion is sought to provide a rational basis for programmatic priority assignments for new cross-section measurements or evaluations. We feel that such a criterion should be based on a quantitative assessment of the uncertainties of presently available data, the sensitivity of important nuclear design parameters to such cross sections, and the accuracy desired in predicting nuclear design parameters at various stages of an evolving fusion reactor design. The development of such a quantitative criterion for priority assignments to new cross-section measurements and evaluations is an integral part of the CTR cross-section assessment program described in this report.

It is clear that the importance of a specific cross section for a specific fusion reactor design depends strongly on the details of that particular design. Also, the accuracy of an existing cross-section set may be fully satisfactory for the calculation of a certain design parameter R_A in a reactor design (A), while the same design parameter in another design (B), R_B , may be extremely sensitive to this particular cross section in question, so that its errors may introduce an unacceptably large uncertainty in R_B . This demonstrates that every cross-section assessment task must be seen within the context of a given reactor design, and that any statement about the quality of a given cross-section set must be related to its application. Such applications, however, may cover a generic class of designs.

C. Applications to the Tokamak Fusion Test Reactor (TFTR)

Our first application of the method described above has been to assess the cross-section requirements of the TFTR. Conceptual design of the TFTR has been completed,⁶ and prior to Title I design work the adequacy of existing cross-section data must be assessed. Specifically, nuclear data uncertainties have been analyzed to determine their effects upon activation of TFTR components. Because of the importance of accurately predicting dose rates in the reactor cell during maintenance operations, several important (dominant) activation reactions need to be considered. Errors in activation rates depend upon both errors in transport cross sections and in the response (activation) cross sections themselves. These studies have been limited in scope by the availability of cross-section error information, an area in which continuing effort is being placed. This interim report presents results available as of August 1975. It is believed by the authors that most major uncertainties in nuclear data have been identified for the TFTR, but further analysis will be performed on dose rate uncertainties outside the concrete cell walls.

II. THEORY

A. Basic Covariance Formulation

Our goal is to calculate the effect of a given cross-section uncertainty $\Delta\Sigma$ on a specific nuclear design parameter of interest R ; or in other words, to predict the uncertainty ΔR of a calculated integral parameter due to a given cross-section uncertainty $\Delta\Sigma$. In the following we assume that first-order perturbation theory is sufficiently accurate for our purposes.

Following a derivation by Perey,⁴ we denote with (Σ_i) a set of group cross sections and with R any design parameter of interest which is calculated as the result of some transport calculation which uses the group cross sections (Σ_i) . Then we can write

$$R = R(\Sigma_i) \quad (1)$$

and calculate any change in R due to small changes $\delta\Sigma$ in Σ_i as

$$\delta R \approx \sum_i \frac{\partial R}{\partial \Sigma_i} \delta \Sigma_i, \quad (2)$$

that is, by using first-order perturbation theory. However, what we really want is the standard deviation of R derived from the statistical population of possible cross-section values, which is defined as the positive square root

$$\Delta R = \sqrt{E\{\delta R^2\}} \equiv \sqrt{\text{Var}(R)}, \quad (3)$$

where $\text{Var}(R)$ denotes the variance of the calculated parameter R . $\text{Var}(R)$ is formally obtained as the expectation value of δR^2 and may be written as

$$\text{Var}(R) \equiv E\{\delta R^2\} = E\left\{\sum_{i,j} \frac{\partial R}{\partial \Sigma_i} \frac{\partial R}{\partial \Sigma_j} \delta \Sigma_i \delta \Sigma_j\right\}, \quad (4)$$

using Eq. (2). Since $\partial R/\partial \Sigma_i$ and $\partial R/\partial \Sigma_j$ are constants over the considered statistical ensemble, we can rewrite Eq. (4) as

$$\text{Var}(R) = \sum_{i,j} \frac{\partial R}{\partial \Sigma_i} \frac{\partial R}{\partial \Sigma_j} E\{\delta \Sigma_i \delta \Sigma_j\}. \quad (5)$$

The expectation value of the product of $\delta \Sigma_i$ and $\delta \Sigma_j$ is the definition of a matrix element of the covariance matrix for cross sections Σ_i and Σ_j over a joint probability density function $f(\Sigma_i, \Sigma_j)$:

$$\begin{aligned} \text{Cov}(\Sigma_i, \Sigma_j) &\equiv E\{\delta \Sigma_i \delta \Sigma_j\} \\ &= \iint_{-\infty}^{+\infty} f(\Sigma_i, \Sigma_j) (\Sigma_i - \hat{\Sigma}_i) (\Sigma_j - \hat{\Sigma}_j) d\Sigma_i d\Sigma_j, \end{aligned} \quad (6)$$

where $\hat{\Sigma}_i$ and $\hat{\Sigma}_j$ are the expectation values of Σ_i and Σ_j , respectively. Inserting this definition (6) into Eq. (5) we obtain our final result

$$\text{Var}(R) = \sum_{i,j} \frac{\partial R}{\partial \Sigma_i} \frac{\partial R}{\partial \Sigma_j} \text{Cov}(\Sigma_i, \Sigma_j), \quad (7)$$

which is the basis for our quantitative data assessment program.

The diagonal elements of the covariance matrix, $\text{Cov}(\Sigma_i, \Sigma_i)$, are the usual (uncorrelated) cross-section uncertainties expressed as the variance of Σ_i :

$$\text{Cov}(\Sigma_1, \Sigma_1) = \text{Var}(\Sigma_1) \equiv E\{\delta\Sigma_1^2\} \equiv \Delta\Sigma_1^2. \quad (8)$$

Cross-section variances have been compiled recently for a wide variety of CTR materials by the CTR Subcommittee of the USNDC.⁵ The off-diagonal terms of the covariance matrix indicate correlations between the cross sections Σ_i and Σ_j .

The quantities $\partial R / \partial \Sigma_i$ in Eq. (7) are the sensitivity coefficients which result from a sensitivity analysis of the particular transport problem of interest.^{7,8,9} It is convenient and useful to define a relative sensitivity coefficient

$$P_{\Sigma_i} = \frac{(\partial R / R)}{(\partial \Sigma_i / \Sigma_i)}, \quad (9)$$

which is called a sensitivity profile for cross section Σ_i when i is the group index of a multigroup cross-section set (Σ_i). P_{Σ_i} can be interpreted as the fractional (percentage) change of the design parameter R per fractional (percentage) change of cross section Σ_i . In order to derive a formula for the calculation of the sensitivity profile P_{Σ_i} , two cases must be considered according to the type of cross section Σ_i for which a sensitivity profile is desired. Let us denote with Σ_i^R the response function which is used to convert the neutron flux distribution ϕ into the nuclear design parameter of interest R , by

$$R = \langle \Sigma_i^R, \phi \rangle. \quad (9a)$$

The symbol $\langle, \rangle$ indicates integrations over all angles, neutron energies, and all spatial zones containing Σ_i^R . For example, Σ_i^R is the flux-to-dose conversion function when R is the dose rate, or, Σ_i^R is a macroscopic activation cross section when R is the production rate of a particular radioactive isotope. Therefore, since Σ_i^R can also be a reaction cross section, we must distinguish between the two cases where a sensitivity profile is required for a cross section Σ_i which may be equal or not equal to Σ_i^R :

1. If a sensitivity profile is desired for $\Sigma_i \neq \Sigma_i^R$

In this case the dependence $R = R(\Sigma_i)$, expressed

in Eq. (1), is exclusively due to radiation transport processes incorporated in the transport equation which must be solved to calculate the flux distribution ϕ . It has been shown^{7,8,9} that for the calculation of a sensitivity profile for Σ_i , the adjoint flux distribution ϕ^* is also required. The formula obtained for P_{Σ_i} is

$$P_{\Sigma_i} = \frac{\langle \phi^*, L_{\Sigma} \phi \rangle_i}{R}, \quad (10)$$

where L_{Σ} denotes that portion of the Boltzmann transport operator which contains the cross-section set (Σ_i).

2. If a sensitivity profile is desired for $\Sigma_i = \Sigma_i^R$

In this case, Eq. (1) is explicitly given by Eq. (9a) and a formula for $P_{\Sigma_i^R}$ can be established

by direct differentiation according to Eq. (9):

$$P_{\Sigma_i^R} = \frac{\Sigma_i^R \langle \phi \rangle_i}{R}, \quad (10a)$$

where $\langle \phi \rangle_i$ denotes the integrated angular flux ϕ over all angles and all spatial zones containing Σ_i^R ; usually, in a multigroup formulation, where i is the group index, $\langle \phi \rangle_i$ is the zone-integrated scalar flux for group i . It should be noted that in this case when Σ_i equals the response function Σ_i^R , and when Σ_i^R is also contained in the transport operator L , which is used to describe the nuclear design, then Σ_i^R also contributes to the process of radiation transport throughout the system, and a term calculated via Eq. (10) must be added to Eq. (10a). However, in most practical cases this additional term is negligible compared to the contribution from Eq. (10a), especially when Σ_i^R is an individual activation cross section as will be the case for all of the following computations.

While the sensitivity profile for a certain cross section contains much valuable detailed information, it is also convenient to define an integral cross-section sensitivity

$$S_{\Sigma} = \sum_i P_{\Sigma_i} \quad (11)$$

which reduces the sensitivity information about the whole cross-section set (Σ_i) to one number. S_{Σ} can be interpreted as the percentage change of the design parameter of interest, $(\partial R/R)$, resulting from a simultaneous 1% increase of the group cross sections Σ_i in all energy groups i (assuming full correlation, i.e., a correlation coefficient of +1).

With respect to Eq. (10a) an important observation can be made when that equation is summed over all energy groups i on both sides. Since

$$\sum_i \Sigma_i^R \langle \phi \rangle_i = \langle \Sigma_i^R \rangle, \quad \phi = R, \quad (10b)$$

the integral sensitivity for any response cross section Σ_i^R is always unity, as is physically obvious:

$$S_{\Sigma^R} = \sum_i P_{\Sigma_i^R} = 1. \quad (10c)$$

Also, since the zone-integrated scalar flux for any group i , $\langle \phi \rangle_i$, cannot be negative, it follows that the sensitivity profile $P_{\Sigma_i^R}$ must always be positive.

For convenience we transform our basic Eq. (7) into a form containing only fractional quantities. Inserting Eq. (9) into Eq. (7) and using Eq. (3) we obtain

$$\left(\frac{\Delta R}{R}\right)^2 = \sum_{i,j} P_{\Sigma_i} P_{\Sigma_j} \frac{\text{Cov}(\Sigma_i, \Sigma_j)}{\Sigma_i \Sigma_j}. \quad (12)$$

In Eq. (12) all cross-section uncertainty information is contained in the relative covariance matrix elements $\text{Cov}(\Sigma_i, \Sigma_j)/\Sigma_i \Sigma_j$ and all sensitivity information in the product of the profiles $P_{\Sigma_i} P_{\Sigma_j}$. It is seen from Eq. (10) that a sensitivity profile is highly problem-dependent and specific for a particular cross section Σ_i as well as a particular design parameter R . Hence, Eq. (12) combines the problem-dependent cross-section sensitivities of a particular nuclear design with the basic cross-section error information into a design-oriented quantity $\Delta R/R$ which is of immediate use for the designer.

The predicted uncertainty $\Delta R/R$ for a calculated design parameter R due to given uncertainties of a multigroup cross-section set (Σ_i) may be compared to a specified design criterion requiring a certain confidence limit for the parameter R . Such a confidence limit may be expressed as a maximum allowable standard deviation for the design parameter R , say $(\Delta R/R)_{\text{max,crit.}}$. Then three cases are possible.

$$a) \quad \Delta R/R < (\Delta R/R)_{\text{max,crit.}} \quad (13a)$$

$$b) \quad \Delta R/R \geq (\Delta R/R)_{\text{max,crit.}} \quad (13b)$$

$$c) \quad \Delta R/R \gg (\Delta R/R)_{\text{max,crit.}} \quad (13c)$$

For case (a) we conclude that the cross-section set (Σ_i) is adequate for the calculation of this particular design parameter in the underlying design, while in cases (b) and (c) we have identified situations where the cross-section set is either marginal or grossly inadequate for this application. After such a deficient cross-section set has been found, an inspection of the sensitivity profile P_{Σ_i} reveals in which energy range a cross-section improvement should be attempted to contribute most to a reduction of $\Delta R/R$.

B. Upper Limits for $\Delta R/R$

In cases where no complete error files are available but rough error estimates can be obtained for the cross sections of interest, it is useful to determine upper limits for $\Delta R/R$ based on calculated sensitivities and such rough estimates. The term "rough" should indicate that either cross-section correlations or energy dependencies or both are neglected when errors are estimated. Then certain conservative assumptions can be made about such correlations or energy dependencies to obtain upper limits for resulting response uncertainties $\Delta R/R$.

1. Uncorrelated Cross-Section Uncertainties

If cross sections Σ_i are assumed to be uncorrelated, then their uncertainties will also be uncorrelated, with the result that all off-diagonal elements of the covariance matrix vanish:

$$\text{Cov}(\Sigma_i, \Sigma_j)_{\text{uncorr.}} = \text{Cov}(\Sigma_i, \Sigma_j) \delta_{ij}. \quad (14)$$

Inserting Eq. (14) into Eq. (12) allows us to reduce the double sum to a single summation and we obtain

with Eq. (8)

$$\left(\frac{\Delta R}{R}\right)_{\text{uncorr.}}^2 = \sum_i \left(P_{\Sigma_i} \frac{\Delta \Sigma_i}{\Sigma_i} \right)^2. \quad (15)$$

2. Fully Correlated Cross-Section Uncertainties

A more conservative assumption about cross-section correlations than being uncorrelated is to assume a correlation of +1. This means that when a cross section in one specific energy group is increased by a certain amount, then the cross sections in all other groups are also increased by the same amount. Under this assumption all off-diagonal elements of the covariance matrix take on the maximum value allowed by the diagonal elements:¹⁰

$$\text{Cov}(\Sigma_i, \Sigma_j)_{\text{corr.}(+1)} = \sqrt{\text{Cov}(\Sigma_i, \Sigma_i)} \sqrt{\text{Cov}(\Sigma_j, \Sigma_j)}. \quad (16)$$

Inserting this into Eq. (12) and using again the notation of Eq. (8), we obtain

$$\left(\frac{\Delta R}{R}\right)_{\text{corr.}(+1)} = \left| \sum_i P_{\Sigma_i} \frac{\Delta \Sigma_i}{\Sigma_i} \right|. \quad (17)$$

3. Energy Independent Cross-Section Error Estimates

The simplest possible and most conservative error estimate is to assume that all uncertainties in an entire cross-section set are equal to the largest uncertainty in any of the individual cross sections, i.e.,

$$\frac{\Delta \Sigma_i}{\Sigma_i} = \text{const.} = \left(\frac{\Delta \Sigma}{\Sigma}\right)_{\text{max.}}. \quad (18)$$

If we further assume the group-by-group errors to be fully correlated, we obtain $\left(\frac{\Delta R}{R}\right)_{\text{max.}}$, the most conservative upper limit for $\Delta R/R$. Using a new definition for an always positive integral sensitivity [in contrast to S_Σ defined in Eq. (11)]:

$$\hat{S}_\Sigma = \sum_i |P_{\Sigma_i}|, \quad (11a)$$

and inserting Eq. (18) into Eq. (17) we obtain

$$\left(\frac{\Delta R}{R}\right)_{\text{max.}} = \hat{S}_\Sigma \cdot \left(\frac{\Delta \Sigma}{\Sigma}\right)_{\text{max.}}. \quad (19)$$

As long as the sensitivity profile P_{Σ_i} does not change sign it can be shown by comparing Eqs. (12), (17), and (19) that

$$\left(\frac{\Delta R}{R}\right) \leq \left(\frac{\Delta R}{R}\right)_{\text{corr.}(+1)} \leq \left(\frac{\Delta R}{R}\right)_{\text{max.}}. \quad (20)$$

To summarize then, the largest upper limit for $\Delta R/R$ is given by $\left(\frac{\Delta R}{R}\right)_{\text{max.}}$, where $\left(\frac{\Delta \Sigma}{\Sigma}\right)_{\text{max.}}$ is the largest error expected in any group of the entire energy region of interest. $\left(\frac{\Delta R}{R}\right)_{\text{corr.}(+1)}$ weights the energy-dependent error estimates with the energy-dependent sensitivities, and $\left(\frac{\Delta R}{R}\right)_{\text{uncorr.}}$ replaces the strong assumption of full correlation by the weaker assumption of no correlation at all. The last step to $\Delta R/R$ via Eq. (12) allows individual terms of the double sum to have differing signs and thereby account for the possible cancellation or accumulation of errors. Therefore, while $\left(\frac{\Delta R}{R}\right)_{\text{max.}}$ and, where P_{Σ_i} does not change sign, $\left(\frac{\Delta R}{R}\right)_{\text{corr.}(+1)}$ are real upper limits for $\Delta R/R$, the special case $\left(\frac{\Delta R}{R}\right)_{\text{uncorr.}}$ does not constitute any limit to the real $\Delta R/R$ from Eq. (12). The utility of the two different upper limits for $\Delta R/R$ is recognized when a numerical comparison is made with the design criterion $\left(\frac{\Delta R}{R}\right)_{\text{max, crit.}}$. If it is found that Eq. (13a) is satisfied already with one of the upper limits for $\Delta R/R$, then a further uncertainty evaluation of that cross-section set is not urgent for the design problem considered.

III. CROSS-SECTION UNCERTAINTIES

A. General Approach

As mentioned in Sec. I.A., formats have been developed which allow ENDF/B evaluators to enter numerical estimates of cross-section uncertainties directly into the ENDF/B system. Also, computer programs have been developed to process these error files into the form of multigroup covariance matrices. Unfortunately, formatted ENDF/B uncertainty files are available for only a few of the reactions of potential importance in TFTR activation studies. For this reason, emphasis has been placed on obtaining preliminary estimates of the errors and correlations from other sources. Of course, detailed error information provided by evaluators is used wherever possible.

The number of potentially important reactions is very large, so that fine details in the energy dependence of the cross-section uncertainties have not been treated. Furthermore, we have not attempted to assign correlations between separate reaction cross sections. The latter restriction leads to separate estimates of the variance in the integral quantity due to each reaction. These separate contributions can be summed linearly or quadratically at the completion of the sensitivity analysis, depending on whether the assumption of full correlation or no correlation is more appropriate.

In order to make these error estimates useful for setting upper bounds on the errors in integral design parameters, we have attempted to make them conservative. For example, when faced with a choice of two methods of estimating the cross-section variance, we have taken the route which gives the larger number. Further, it was shown in the preceding section that a conservative assumption on correlations is that the correlation is complete (at least for the great majority of cases, where the sensitivity profile does not change sign). Thus, full positive correlation was assigned in cases where there was no clear justification for weaker or negative correlations. Cases where the correlations are not complete are treated in one of two different ways, as described in Appendix A.

B. Availability of Experimental Data

The procedure used in this study to assign numerical error estimates is strongly dependent on the availability of experimental data for a given cross section in a given energy range. We describe below three general classes of data.

Class I data: Based on several independent measurements over a given energy range.

For this class of data, error bands were drawn on a composite plot of available data so as to include all credible data and, in most cases, the error bars assigned by the experimenter. In some instances, a few data points were allowed to fall outside the error band when there was reason to suspect the validity of these points. This procedure is clearly conservative.

Class II data: Based on a single measurement over a given energy range.

In this case, the errors assigned by the experimenter were generally increased to make them consistent

with the errors in energy ranges where Class I data exists, which in turn were obtained using the procedure described above.

Class III data: Based entirely on calculations or direct interpolation.

Often the energy regions in which no experimental data are available lie reasonably close to regions for which experimental data are available and for which error estimates can be made using the procedures described already. In these cases, the error estimate at nearby energies is increased (typically by a factor of two) and assigned to the region of interest. In those infrequent cases where no experimental data exist over the entire energy range from 2 to 14 MeV, the error is assigned using estimates of the accuracy of the nuclear model calculations used to generate the data.

C. Estimating Correlations

The degree of correlation of errors is difficult to estimate, and the correlation range parameters assigned (see Appendix A) were often rather arbitrary. A high degree of correlation was assumed over a given energy range when there was a single measurement spanning the range. The rationale for this is that systematic errors (such as normalization) would probably affect the cross section in a uniform way over the energy range. On the other hand, when separate measurements exist in two different energy ranges (for example, threshold to 8 MeV and 13 to 20 MeV) it is reasonable to assume little or no correlation between the errors in each range. Systematic uncertainties in one measurement are unlikely to be correlated with those of an independent measurement made in a different energy region.

D. Discussion of Individual Reactions

In this section we present background information on those reactions on which we have performed preliminary error evaluations as part of this study. Since only a limited number of reactions could be analyzed for these initial calculations, we have examined only those reactions involving an abundant target nucleus or a large cross section (or both).

1. Response function uncertainties

Adequate data exist at all energies except the region 8.5 to 12.5 MeV.¹¹ Energy bands were set up as described above for Class I data in

the regions for which adequate data exist. The error at 10 MeV (Class III data) was taken as twice the error at 8 MeV. Recently, Smith and Meadows¹² published new measurements extending up to 10 MeV. These data were not available when the error band was established, hence, the fact that they fall within our error bands enhances confidence in the method of estimating errors at energies where data are lacking. Figure 1, which shows the error bands on a plot of some of the older experimental data (taken from Ref. 11) and the new data above 3 MeV, illustrate this point.

$^{27}\text{Al}(n,p)^{27}\text{Mg}$ (9.5 m)

For the $^{27}\text{Al}(n,p)$ reaction, the evaluator's estimate of the errors as given in Ref. 5 was used above about 3 MeV and the error band was increased near threshold to account for the greater uncertainties associated with the smaller cross-section values.

$^{27}\text{Al}(n,\alpha)^{24}\text{Na}$ (15 h)

Above 8 MeV the error estimates⁵ of the aluminum evaluators again were used. Below 8 MeV, an error band was established as described for Class I data.

$^{55}\text{Mn}(n,2n)^{54}\text{Mn}$ (303 d)

Adequate data exist from ~ 12.5 to 20 MeV for the $^{55}\text{Mn}(n,2n)$ reaction and our error band was set up in this region as described above for Class I data. Near the threshold energy where data are

Fig. 1. Error bands shown on a plot of some data for $^{58}\text{Ni}(n,p)^{58}\text{Co}$ taken from Ref. 11 and recent results from Ref. 12 above 3 MeV.

lacking the error band was expanded to reflect the larger uncertainties (50 to 100%). The disagreement between two evaluated cross-section curves near threshold (curve from Ref. 11 and ENDF/B-IV Dosimetry file) is on this order. The ENDF/B-IV Dosimetry data are more consistent with the experimental data above 12.5 MeV, so the error band was established about this evaluated curve.

$^{54}\text{Fe}(n,p)^{54}\text{Mn}$ (303 d)

The procedure used to establish the error band was very similar to that described above for the $^{58}\text{Ni}(n,p)$ reaction. Likewise, the method of estimating this error band in the vicinity of 10 MeV, where data were lacking, seems to be validated by the recent measurements of Smith and Meadows¹² which extend to 10 MeV and fall within our error band. The data of Storey et al.¹³ at 15.7 MeV and the data of Singh¹⁴ at 14.5 MeV were discounted when establishing the error band since they were nearly a factor of two greater than a number of other measurements. Singh's measurements are also systematically higher for the $^{56}\text{Fe}(n,p)$ reaction near 14 MeV.

$^{56}\text{Fe}(n,p)^{56}\text{Mn}$ (2.58 h)

Error bands were established as described above for the "adequate data" situation (Class I). The composite plot was obtained from Ref. 11. A high degree of error correlation was specified since several data sets spanned the energy range, 5 to 20 MeV.

$^{63}\text{Cu}(n,2n)^{62}\text{Cu}$ (9.9 m)

There are about a dozen different experimental measurements available and several data sets span the range from near threshold to 20 MeV. The error band was established so as to include all of the experimental data given in Ref. 15.

$^{63}\text{Cu}(n,\alpha)^{60}\text{Co}$ (5.2 y)

The error band for the $^{63}\text{Cu}(n,\alpha)$ reaction was established using the experimental errors of Paulsen,¹⁶ where data span the range from threshold to 20 MeV and form the basis of the latest copper ENDF/B evaluation.¹⁵ The error band was assumed to be larger than the experimental errors of this single measurement in order to produce consistency with the spread of seven measurements in the vicinity of 14 MeV (i.e., except near 14 MeV we were dealing with Class II data).

There are adequate data for this reaction over the entire energy range from threshold to 20 MeV. The error band was drawn through a composite plot of the experimental data obtained from Ref. 15.

There are adequate (Class I) data near 14 MeV, but the spread leads to a large error estimate, about 40%, in that region. The data below 14 MeV¹⁷ are Class II and are assumed uncorrelated with the 14-MeV data.

A composite plot of experimental data¹⁸⁻²¹ supplementing data available in BNL-325²² formed the basis for the error band determination. Between 12 and 18 MeV the data were treated as Class I data and the error band was drawn so as to include the several measurements. Below 12 MeV and above 18 MeV, there were only single measurements available (Class II data).

The only experimental data available are at 14.1 MeV.²³ This measurement is a factor of three higher than model (THRESH) calculations in this energy range. Normalizing the shape of the predicted cross-section curve to the 14.1-MeV experimental data yielded nominal cross-section values. The error near 14 MeV was taken to be about a factor of two greater than the quoted measurement error. To account for inaccuracies in the shape of the calculated curve, errors for other energies were taken to be at least double the 14-MeV error. The small values of this cross section (2.7 mb at 14.1 MeV) probably makes more careful error estimation unnecessary.

2. Transport Cross-Section Uncertainties

The cross-section uncertainty assumed here is that estimated in Ref. 5. In order to be conservative, full positive correlation is assumed at all energies.

The cross-section uncertainty assumed here is a constant 30%, again following Ref. 5. Again, to be conservative, full positive correlation is assumed at all energies.

The cross-section uncertainty assumed here again follows Ref. 5. Full correlation is assumed at all energies. In this case, full correlation is quite realistic since this cross section has been measured only near 14 MeV, with those data being used to normalize a calculated excitation function.

IV. SENSITIVITY ANALYSIS

As described in Sec. II, cross-section sensitivity profiles are required to predict the uncertainties of calculated integral design parameters, $\Delta R/R$, due to estimated cross-section uncertainties. The sensitivity profiles P_{Σ_1} and P_{Σ_i} , together with the integral sensitivities S_{Σ_1} and $\hat{S}_{\Sigma_i}$, are the result of a sensitivity analysis where Eqs. (10), (10a), (11), and (11a) are evaluated. As pointed out in Sec. II, all sensitivities are problem-dependent and specific for a particular cross section Σ_i as well as a particular design parameter R . The problem dependence enters into Eqs. (10) and (10a) through ϕ and ϕ^* , which are the forward and adjoint angular flux distributions for the specific nuclear design model of interest. Therefore, and to assure the proper interpretation of calculated sensitivities, it is necessary to describe the nuclear design model for which the analysis is performed and to specify in detail which integral design parameters are considered.

A preliminary one-dimensional computational model for TFTR neutronics calculations has been supplied by the Princeton Plasma Physics Laboratory²⁴ and Westinghouse,²⁵ and is shown in Fig. 2, where R is the radial distance from the plasma centerline. Since the main objective of the TFTR is to demonstrate the scientific feasibility of a Tokamak

Fig. 2. One-dimensional computational model for TFTR cross-section sensitivity analysis.

fusion reactor, it is not required to breed tritium, and therefore does not employ a lithium blanket. The reactor is expected to operate in a pulsed mode yielding a maximum of 1 000 pulses per year, generating a maximum neutron fluence of 1.4×10^{19} fusion neutrons per m^2 per year on the first wall.²⁶ Due to this low neutron fluence, radiation damage or nuclear heating problems are not of major concern. However, the activation of magnet coils, structural materials, and instruments is considered a major neutronics problem area, in particular the generation of long-lived radioactive isotopes. Therefore, and for biological shielding reasons, a radiation shield is provided as close to the plasma as possible (Fig. 2). In cooperation with Princeton and Westinghouse we selected several threshold activation reactions in the structural steel (zones 9 and 11 in Fig. 2) and the main copper coil (zone 10 in Fig. 2) as important nuclear design parameters of interest (see Table I). Our objective is to estimate the uncertainties introduced in the calculation of these activation rates due to estimated errors in the neutron cross sections of the system. Of particular interest are uncertainties in the cross sections of the shield zone 7, the composition of which is given in Table II, and uncertainties in the activation cross sections themselves.

TABLE II
SHIELD CONSTITUENTS, "PERTURBED CROSS SECTIONS"
IN ZONE 7 OF TFTR

Lead-Borated-Polyethylene, $\rho = 4.4 \text{ g/cm}^3$

Element	(wt%)	(at/barn·cm)
H	1.8	0.04706
C	10.7	0.02363
Pb	80.0	0.01023
B	1.0	0.00245
$\emptyset$	6.5	0.0108

In order to calculate the sensitivity profiles P_{Σ_i} and $P_{\Sigma_i}^R$ according to Eqs. (10) and (10a), we performed a forward transport calculation for the TFTR model of Fig. 2 and an adjoint for each of the ten activation reactions listed in Table I, saving the angular fluxes ϕ and ϕ^* . All transport calculations were performed with the one-dimensional S_N code DTF-IV²⁷ in an S_8 approximation and slab geometry using 20-group P_3 neutron cross sections. This cross-section set was generated from the first 20 groups of the DLC-2E 100-group set distributed by RSIC.²⁸ It covers neutron energies between 2.02 and 14.92 MeV, which is sufficient for the activation reactions considered. Cross sections for the activation reactions listed in Table I were taken

TABLE I
ACTIVATION REACTIONS ("RESPONSES R_i ") OF INTEREST FOR THE TFTR

Symbol	Activation Reaction	In TFTR Zone No.	$T_{1/2}$ of Radioisotope	Number Density of Parent Isotope (at/b·cm)
R_1	$^{54}\text{Fe}(n,p)^{54}\text{Mn}$	9, 11	313 d	0.003415
R_2	$^{55}\text{Mn}(n,2n)^{54}\text{Mn}$	9, 11	313 d	0.00175
R_3	$^{56}\text{Fe}(n,p)^{56}\text{Mn}$	9, 11	2.6 h	0.05399
R_4	$^{58}\text{Ni}(n,p)^{58}\text{Co}$	9, 11	71 d	0.006727
R_5	$^{27}\text{Al}(n,\alpha)^{24}\text{Na}$	9, 11 ^a	15 h	0.06027
R_6	$^{27}\text{Al}(n,p)^{27}\text{Mg}$	9, 11 ^a	9.5 m	0.06027
R_7	$^{63}\text{Cu}(n,2n)^{62}\text{Cu}$	10	9.8 m	0.05755
R_8	$^{63}\text{Cu}(n,\alpha)^{60}\text{Co}$	10	5.2 y	0.05755
R_9	$^{65}\text{Cu}(n,2n)^{64}\text{Cu}$	10	12.7 h	0.02586
R_{10}	$^{65}\text{Cu}(n,p)^{65}\text{Ni}$	10	2.6 h	0.02586

^aAluminum is considered in zones 9 and 11 as potential alternative structural material.

from Ref. 29. The stored angular fluxes ϕ and ϕ^* from the transport calculations were then read into the LASL sensitivity code SENSIT-1D³⁰ to evaluate Eqs. (10), (10a), (11), and (11a), and to plot the sensitivity profiles of interest. The cross sections Σ_1 for which sensitivity profiles are calculated were generated from ENDF/B-IV with the LASL multigroup cross-section processing systems MINX and NJOY.³¹ For individual reactions which produce secondary neutrons, complete transfer matrices were also produced using the LASL processing systems.

Integral sensitivities, S_{Σ_1} , of all ten activation reactions to all significant transport cross sections in the TFTR are tabulated in Table III. This information can be used as an indicator to identify the most sensitive responses and the highest sensitivities to such responses. It is noted that all integral sensitivities are negative, indicating that an increase in such cross sections would cause the respective activation rate to decrease. The largest sensitivity shown in Table III is that of R_{10} to the copper cross sections which indicates that a 1% increase in the total cross section of copper would decrease the ⁶⁵Ni production in the coil by 2.05%. This and the other responses are even less sensitive to the total cross sections of the radiation shield (zone 7) and structural materials (zones

9 and 11), resulting from the fact that both the shield as well as the structures are relatively thin. Indeed, a hand calculation shows that the 16 cm of shield material corresponds to only 1.8 mean-free-paths for the 14-MeV fusion neutrons originating in the plasma. Nevertheless, the uncertainties in these cross sections with marginal sensitivities still could be high enough to produce an undesirably large uncertainty in the calculated activation rates, $\Delta R/R$. The sensitivity profiles for the total cross sections of all ten transport cross-section sets are plotted in Figs. B-I through B-X in Appendix B. These sensitivity profiles are given only for those response functions which show the largest integral sensitivities, as listed and circled in Table III. Also given in Appendix B are the sensitivity profiles $P_{\Sigma_1^R}$ for all ten activation cross sections listed in Table I; these are plotted in Figs. B-XI through B-XX. For completeness it may be recalled from Sec. II that the integral sensitivities for all activation cross sections are equal to +1 according to Eq. (10c).

V. PREDICTED RESPONSE UNCERTAINTIES

The sensitivity profiles P_{Σ_1} and $P_{\Sigma_1^R}$ are combined with the respective covariance matrices according to

TABLE III
INTEGRAL SENSITIVITIES, S_{Σ_1} , OF THE RESPONSES, R_i (ACTIVATION RATES),
TO THE NEUTRON TRANSPORT CROSS SECTIONS OF ALL MATERIALS CONSIDERED IN THE TFTR NUCLEAR DESIGN

"Perturbed" Cross Sections Σ_1	Integral Sensitivities, S_{Σ_1} , for									
	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_{10}
C	-0.87	-0.78	-0.79	-0.78	-0.78	-0.83	-0.63	-0.66	-0.64	-0.66
Pb	-1.52	-1.30	-1.34	-1.33	-1.32	-1.43	-1.06	-1.11	-1.07	-1.12
$\emptyset$	-0.47	-0.43	-0.44	-0.42	-0.43	-0.43	-0.35	-0.36	-0.36	-0.36
H	-1.08	-0.81	-0.86	-0.91	-0.84	-0.97	-0.65	-0.72	-0.66	-0.73
Fe	-0.70	-0.47	-0.53	-0.56	-0.53	-0.60	-0.87	-0.92	-0.88	-0.93
Cr	-0.20	-0.13	-0.14	-0.15	-0.14	-0.16	-0.23	-0.24	-0.23	-0.25
Ni	-0.12	-0.09	-0.10	-0.10	-0.10	-0.11	-0.16	-0.17	-0.16	-0.17
Mn	-0.02	-0.01	-0.02	-0.02	-0.02	-0.02	-0.03	-0.03	-0.03	-0.03
Al	-0.45	-0.33	-0.35	-0.36	-0.35	-0.38	-0.60	-0.61	-0.60	-0.62
Cu	-0.04	*	*	-0.02	*	-0.01	-1.93	-2.03	-1.96	-2.05

Footnote: "*" indicates that the calculated S_{Σ_1} is so close to zero that its numerical value is unreliable due to negative angular fluxes and Σ_1 round-off errors.

Eq. (12) to obtain the resulting uncertainties $\Delta R_1/R_1$ of the calculated ten activation reaction rates. Since explicit covariance matrices could be obtained only for a limited number of partial transport cross sections and the activation cross sections themselves (as described in Sec. III and listed in Appendix A), it was necessary to use upper-limit estimates for most transport cross-section errors, $(\Delta\Sigma/\Sigma)_{\max}$. Using Eq. (19) then, largest possible upper limits for the response uncertainties, $(\Delta R_1/R_1)_{\max}$, due to these transport cross-section uncertainties, are obtained.

Table IV lists the results from Eqs. (12) and (19) obtained with SENSIT-ID³⁰ for all estimated transport cross-section errors. Column 2 of Table

IV indicates which type of error estimate was used. "COV" stands for a complete covariance matrix, while a number indicates the maximum percentage error assumed for all individual cross sections of the respective element. Results in Table IV are listed only for responses R_1 and R_{10} because these two activation rates were identified as most sensitive of all (compare Table III). Note from Table IV that for any one element the $\Delta R_1/R_1$ obtained from Eq. (12) using estimated covariance matrices are considerably smaller than those obtained from Eq. (19) using rough upper-limit error estimates. In cases where practically all partial cross sections for one element were evaluated and, hence, where estimated covariance matrices were obtained for

TABLE IV
PREDICTED UNCERTAINTIES OF SELECTED ACTIVATION RATES R_1 AND R_{10}
DUE TO ESTIMATED ERRORS IN TRANSPORT CROSS SECTIONS Σ

"Perturbed" Transport Cross Sections	Error Estimates: COV or $(\frac{\Delta\Sigma}{\Sigma})_{\max}$ (in %)	Maximum Integral Sensitivity $\hat{S}$, and Predicted Activation Rate Uncertainty $\frac{\Delta R}{R}$			
		for R_1		for R_{10}	
		$\hat{S}$ (% per %)	$\frac{\Delta R}{R}$ or $(\frac{\Delta R}{R})_{\max}$ (in %)	$\hat{S}$ (% per %)	$\frac{\Delta R}{R}$ or $(\frac{\Delta R}{R})_{\max}$ (in %)
C	25	0.87	21.8	0.66	16.5
C(n,n' α)	COV	---	2.4	---	2.2
Pb	25	1.52	38.0	1.12	28.0
Pb(n,2n)	COV	---	18.3	---	14.8
ϕ	25	0.47	11.8	0.36	9.0
H	2	1.08	2.2	0.73	1.5
Fe	25	0.70	17.5	0.93	23.3
Fe(n,tot)	COV	---	2.2	---	3.2
Fe(n,abs.)	COV	---	0.71	---	1.7
Fe(n,n'cont.)	COV	---	4.4	---	7.4
Fe(n,elas.)	COV	---	2.5	---	3.7
Fe(n,incl.)	COV	---	3.5	---	6.7
Fe(n,2n)	COV	---	1.2	---	3.6
Cr	25	0.20	5.0	0.25	6.3
Ni	25	0.12	3.0	0.17	4.3
Mn	25	0.021	0.53	0.027	0.68
Al	25	0.45	11.3	0.62	15.5
Cu	25	0.039	0.98	2.05	51.3
Cu(n,elas.)	COV	---	0.12	---	5.0
Cu(n,incl.)	COV	---	0.13	---	6.8
Cu(n,2n)	COV	---	0.04	---	9.6
Cu(n,tot.)	COV	---	0.12	---	5.1
Cu(n,abs.)	COV	---	0.04	---	16.8

these partials (e.g., Fe and Cu), even the linear sum of all $\Delta R_1/R_1$ due to the estimated errors in these partials is smaller than the upper-limit estimate for this element. This confirms the conservatism built into the upper-limit estimates $(\Delta R_1/R_1)_{\max}$.

Table V summarizes the upper limits for the response uncertainties obtained for all ten activation rates due to estimated errors in all transport cross sections for material k according to

$$\frac{\Delta R_1^k}{R_1} = \left(\frac{\Delta R_1^k}{R_1} \right)_{\max} = \sum_1^k \left(\frac{\Delta \Sigma^k}{\Sigma^k} \right)_{\max}. \quad (21)$$

In order to obtain the uncertainty of a specific response due to the transport cross-section uncertainties of all materials it is assumed that the cross-section errors for each material are uncorrelated with those for all other materials. Thus we obtain

$$\frac{\Delta R_1^{\text{TRANS}}}{R_1} = \left[\sum_k \left(\frac{\Delta R_1^k}{R_1} \right)^2 \right]^{1/2}. \quad (22)$$

The results of Eq. (22) are shown in the two bottom lines of Table V, where for "SS-struct." only the uncertainties due to Fe, Cr, Ni, and Mn are counted in addition to the shield and coil materials, and for "Al-struct." the stainless steel materials are replaced by aluminum.

In Table VI the uncertainties due to errors in the activation cross sections are also incorporated. These activation cross-section error estimates are available in covariance form, $\text{Cov}(\Sigma_1^R, \Sigma_j^R)$, for all ten responses considered (as given in Appendix B). Therefore, Eq. (12) could be employed to calculate the uncertainty in the calculated activation rates due to estimated errors in the activation cross sections themselves, $\Delta R_1^{\text{ACT}}/R_1$. Again, in combining $\Delta R_1^{\text{ACT}}/R_1$ with $\Delta R_1^{\text{TRANS}}/R_1$ we assume the originating cross-section errors to be completely uncorrelated

TABLE V
SUMMARY OF PREDICTED UNCERTAINTIES OF ACTIVATION RATES R_1^k
DUE TO ERRORS IN TRANSPORT CROSS SECTIONS Σ^k

Transport Cross Sections		$\frac{\Delta R_1^k}{R_1}$, in %, for									
	Σ^k	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8	R_9	R_{10}
Shield	C	21.8	19.5	19.8	19.5	19.5	20.9	15.8	16.6	16.0	16.5
	Pb	38.0	32.5	33.5	33.3	33.0	35.8	26.5	27.8	26.8	28.0
	Ø	11.8	10.9	11.0	10.5	10.8	11.3	8.8	9.0	8.9	9.1
	H	2.2	1.6	1.7	1.8	1.7	1.9	1.3	1.4	1.3	1.5
Structure	Fe	17.5	11.9	13.3	13.9	13.1	14.9	21.7	23.0	21.9	23.1
	Cr	5.0	3.2	3.5	3.8	3.5	4.0	5.7	6.1	5.8	6.2
	Ni	3.0	2.2	2.4	2.5	2.4	2.7	3.9	4.1	3.9	4.2
	Mn	0.5	0.4	0	0.4	0.4	0.4	0.7	0.7	0.7	0.7
	Al	11.2	8.1	8.7	9.0	8.7	9.4	15.0	15.3	15.1	15.4
	---	---	---	---	---	---	---	---	---	---	---
Coil	Cu	1.0	---	---	0.6	---	0.4	48.3	50.8	49.0	51.3
All, with SS-struct.		49.1	41.4	42.8	42.6	42.2	45.7	62.3	65.5	63.1	66.1
All, with Al-struct.		46.8	40.3	41.4	41.0	41.0	44.0	59.9	62.8	60.7	63.3

and obtain

$$\frac{\Delta R_1}{R_1} = \sqrt{\left(\frac{\Delta R_1^{\text{TRANS}}}{R_1}\right)^2 + \left(\frac{\Delta R_1^{\text{ACT}}}{R_1}\right)^2} \quad (22a)$$

in columns 5 and 6 of Table VI. It is interesting to note from Table VI that all predicted response uncertainties are dominated by the uncertainties due to the estimated transport cross-section errors. This is largely due to the considerable conservatism inherent in the procedure used to estimate $\Delta R/R$ for these cases via Eq. (21).

At this point of our analysis a comparison of the predicted $\Delta R_1/R_1$ with specified maximum allowable standard deviations for these activation rates, according to Eqs. (13a) through (13c), would be in order. However, such detailed design criteria are presently not specified for the TFTR. Relative uncertainties of individual activation rates are not of immediate concern for the nuclear designer; rather, he must meet overall design criteria for the allowable maximum radiation exposure to operating person-

nel. Such biological shield design criteria have recently been specified for the TFTR.³² In order to apply our results to these design criteria we must further reduce our calculated data.

VI. APPLICATION TO TFTR BIOLOGICAL DOSE RATE CRITERIA

The entire torus of the TFTR will be contained in a test cell of large dimensions.³³ Access to all components of the torus inside the cell after D-T operation is planned to be via a shielded cab with remote handling equipment operated by personnel inside the cab.³⁴ The biological dose rate criteria inside the test cell at shut down conditions are summarized as follows:³²

$$\left. \begin{aligned} E^P &\leq 100 \frac{\text{mrem}}{h} & 2 \text{ h after shutdown, and} \\ E^P &\leq 10 \frac{\text{mrem}}{h} & 1 \text{ d after shutdown.} \end{aligned} \right\} \quad (23)$$

In Ref. 32 no confidence limit is specified for these criteria; however, we feel it is reasonable

TABLE VI
SUMMARY OF PREDICTED UNCERTAINTIES OF ACTIVATION RATES R_1
DUE TO ESTIMATED ERRORS IN ACTIVATION CROSS SECTIONS,
 $\text{Cov}(R_1^R, R_j^R)$, AND ALL TRANSPORT CROSS-SECTION UNCERTAINTIES

Activation Reaction R_1	Due to Act.-XS. Errors	$\frac{\Delta R_1}{R_1}$, in %, Due to Transp.-XS. Errors			
		Due to		Due to	
		SS-Str.	Al-Str.	SS-Str.	Al-Str.
$R_1 = {}^{54}\text{Fe}(n,p){}^{54}\text{Mn}$ in Z9 and Z11	15.7	49.1	---	51.5	---
$R_2 = {}^{55}\text{Mn}(n,2n){}^{54}\text{Mn}$ in Z9 and Z11	15.6	41.4	---	44.2	---
$R_3 = {}^{56}\text{Fe}(n,p){}^{56}\text{Mn}$ in Z9 and Z11	12.8	42.8	---	44.7	---
$R_4 = {}^{58}\text{Ni}(n,p){}^{58}\text{Co}$ in Z9 and Z11	20.7	42.6	---	47.4	---
$R_5 = {}^{27}\text{Al}(n,\alpha){}^{24}\text{Na}$ in Z9 and Z11	8.7	---	41.0	---	41.8
$R_6 = {}^{27}\text{Al}(n,p){}^{27}\text{Mg}$ in Z9 and Z11	5.5	---	44.0	---	44.3
$R_7 = {}^{63}\text{Cu}(n,2n){}^{62}\text{Cu}$ in Z10	24.3	62.3	59.9	66.9	64.6
$R_8 = {}^{63}\text{Cu}(n,\alpha){}^{60}\text{Co}$ in Z10	29.3	63.5	62.8	69.9	69.3
$R_9 = {}^{65}\text{Cu}(n,2n){}^{64}\text{Cu}$ in Z10	13.4	63.1	60.7	64.5	62.2
$R_{10} = {}^{65}\text{Cu}(n,p){}^{65}\text{Ni}$ in Z10	32.6	66.1	63.3	73.7	71.2

to attach a maximum allowable uncertainty (one standard deviation) to the predicted personnel exposure rates of

$$\left(\frac{\Delta E^P}{E^P}\right)_{\max, \text{crit.}} \leq 50\%. \quad (24)$$

The objective of our analysis is to predict the expected uncertainties ΔE^P of calculated personnel exposure rates at both shutdown conditions specified in the criteria (23), due to estimated cross-section uncertainties, and then test the accuracy requirement (24).

The activity produced by radionuclides i during 1 pulse of D-T operation of the TFTR may be calculated from

$$A_i(1 \text{ pulse}, t = 0) = K S \lambda_i R_i, \quad (25)$$

where R_i is the production rate of isotopes i per fusion neutron, λ_i the decay constant, S the neutron source strength per pulse ($S = 1.6 \times 10^{18}$ neutrons/pulse),²⁶ K a conversion factor ($K = 2.7 \times 10^{-11}$ Ci per disintegration/s), and A_i the generated activity in Ci/pulse. For operating times of 1 y or more we assume an equivalent time-averaged neutron source strength of $Q = 5.07 \times 10^{13}$ neutrons/s assuming 1 000 pulses per year.²⁶ With these assumptions we calculate the activity $A_i(T, t)$ due to radionuclides i after an operating time T and cooling-down time t after shutdown from³⁵

$$\left. \begin{aligned} A_i(T = 1 \text{ pulse}, t = 2 \text{ h}) &= K S \lambda_i R_i e^{-\lambda_i t} \quad (\text{Ci/pulse}) \\ A_i(T = 1 \text{ y}, t = 1 \text{ d}) &= K Q R_i (1 - e^{-\lambda_i T}) e^{-\lambda_i t} \quad (\text{Ci}) \end{aligned} \right\} \quad (26)$$

A useful measure for the exposure potential of a radionuclide is obtained by multiplying its activity with its specific gamma-ray constant Γ_i .³⁶ The result gives the dose rate expected from this activity at a fixed distance in vacuum (unshielded). Hence, the exposure rate from the activity A_i (considered to be concentrated at a point) at a distance of 1 m is

$$E_i = \frac{\Gamma_i}{10} A_i. \quad (27)$$

where $\Gamma_i/10$ is in (rem/h)/Ci at 1 m, and E_i in rem/h

unshielded. Values for Γ_i are tabulated in Ref. 36 and range from 1.2 to 18.4 for the radionuclides considered in our analysis. For the isotopes ^{62}Cu and ^{27}Mg no Γ -values are given in Ref. 36; these values were calculated to be approximately 7.0 and 5.0, respectively.

Since in the TFTR the handling of activated components inside the test cell is via the shielded cab, we have to incorporate the gamma shielding effectiveness of the cab when calculating dose rates to operating personnel:

$$E^P = \sum_i E_i e^{-\mu_i^Y x} \hat{=} C \sum_i E_i, \quad (28)$$

where μ_i^Y is an effective attenuation coefficient for the gamma rays emitted by the radionuclide i . Since no detailed information exists at this time regarding the design of the shielded cab, we replace all gamma-ray attenuation factors by a constant C which we shall adjust arbitrarily to meet the dose rate criteria (23).

In Tables VII and VIII we converted the $R_i \pm \Delta R_i$ to $E^P \pm \Delta E^P$ according to Eqs. (25) through (28). It should be noted that the originally calculated response uncertainties $\Delta R_i/R_i$, interpreted as percentage uncertainties in the calculated activation rates R_i , are now transformed into $\Delta E_i/E_i$ and interpreted as percentage uncertainties in the

calculated exposure rates E_i . The $\Delta R_i/R_i$ as well as the $\Delta E_i/E_i$ are relative uncertainties, and E_i is calculated from R_i via constant factors which are considered to have no uncertainties. Thus, all relative uncertainties are identical:

$$\frac{\Delta E_i}{E_i} = \frac{\Delta A_i}{A_i} = \frac{\Delta R_i}{R_i}. \quad (29)$$

Columns 5 through 8 in Tables VII and VIII list the calculated absolute exposure rates E_i together with their respective absolute uncertainties

TABLE VII
PREDICTED ABSOLUTE UNCERTAINTIES IN CALCULATED RADIATION EXPOSURE RATES
DUE TO ALL CROSS-SECTION UNCERTAINTIES - TFTR DESIGN WITH STEEL STRUCTURE

Radio-nuclide i	T _{1/2}	Production Mechanism	Production Rate, R _i (atoms per fusion neutron)	Exposure Rate E _i ± ΔE _i After				
				1 Pulse and 2 h		1 y and 1 d		
				E _i (rem/h)	ΔE _i (rem/h)	E _i (rem/h)	ΔE _i (rem/h)	
⁵⁴ Mn	313	d	⁵⁴ Fe(n,p)	1.35 E-3	7.05 E-4	3.63 E-4	4.38 E-1	2.26 E-1
⁵⁴ Mn	313	d	⁵⁵ Mn(n,2n)	4.80 E-4	2.49 E-4	1.10 E-4	1.72 E-1	7.60 E-2
⁵⁶ Mn	2.6	h	⁵⁶ Fe(n,p)	3.32 E-3	5.11 E+0	2.28 E+0	6.31 E-3	2.82 E-3
⁵⁸ Co	71	d	⁵⁸ Ni(n,p)	2.30 E-3	6.16 E-3	2.92 E-3	1.67 E+0	7.92 E-1
⁶² Cu	9.8	m	⁶³ Cu(n,2n)	9.89 E-3	6.94 E-1	4.64 E-2	< E-10	< E-10
⁶⁰ Co	5.2	y	⁶³ Cu(n,α)	1.03 E-3	2.30 E-4	1.61 E-4	2.19 E-1	1.53 E-1
⁶⁴ Cu	12.7	h	⁶⁵ Cu(n,2n)	9.55 E-3	6.66 E-1	4.29 E-1	4.26 E-1	2.75 E-1
⁶⁵ Ni	2.6	h	⁶⁵ Cu(n,p)	2.69 E-4	1.53 E-1	1.13 E-1	1.91 E-4	1.41 E-4
Total Exposure Rate (unshielded):				6.53	2.36	2.90	0.884	
$E = \sum_i E_i, \Delta E = \sqrt{\sum_i \Delta E_i^2}$				rem/h	rem/h	rem/h	rem/h	
Total Personnel Exposure (shielded):				22.5	8.14	10.0	3.05	
$(E^P \pm \Delta E^P) = 3.45 \times 10^{-3}(E \pm \Delta E)$				mrem/h	mrem/h	mrem/h	mrem/h	

$\Delta E_i = E_i(\Delta E_i/E_i) = E_i(\Delta R_i/R_i)$, for the two different shutdown conditions indicated in the criteria (23) and Eq. (26). The two bottom lines in Tables VII and VIII give the total unshielded exposure rates and the total personnel exposure rates inside the shielded cab due to all radionuclides. The shielding factor C for the cab, as defined in Eq. (28), is chosen so that from the two design criteria (23) the one that requires the most shielding is just met. It turns out that the most difficult criterion to meet is $E^P \leq 10$ mrem/h after 1 y of operation and 1 d shutdown for both the steel-structure and the aluminum-structure design. Since a detailed design was not available for the TFTR using aluminum structures, we have made the assumption that the aluminum zones would be neutronically equivalent to the steel zones they are replacing. For this reason the angular fluxes ϕ

and ϕ^* calculated for the stainless steel model have been used for both cases in this analysis.

VII. CONCLUSIONS

The results in the bottom lines of Tables VII and VIII can be directly compared with the design criteria (23) and (24). It is obvious that the biological dose rate criteria (23) can always be met as long as the attenuation factor C for the shielded cab can be arbitrarily chosen. However, relative uncertainties in the calculated personnel dose rates due to cross-section uncertainties cannot be made arbitrarily small. Our analysis predicts an uncertainty of the calculated maximum allowable personnel dose rate of 30.5% for the steel-structured TFTR and 36.1% when aluminum structures are chosen. To recall, these uncertainties are due to cross-section uncertainties only. Comparing this result with the accuracy requirement of $\leq 50\%$

TABLE VIII
PREDICTED ABSOLUTE UNCERTAINTIES IN CALCULATED RADIATION EXPOSURE RATES
DUE TO ALL CROSS-SECTION UNCERTAINTIES - TFTR DESIGN WITH ALUMINUM STRUCTURE

Radio-nuclide i	$T_{1/2}$	Production Mechanism	Production Rate, R_i (atoms per fusion neutron)	Exposure Rate $E_i \pm \Delta E_i$ After			
				1 Pulse and 2 h		1 y and 1 d	
				E_i (rem/h)	ΔE_i (rem/h)	E_i (rem/h)	ΔE_i (rem/h)
^{24}Na	15 h	$^{27}\text{Al}(n,\alpha)$	4.30 E-3	3.95 E+0	1.65 E+0	3.59 E+0	1.50 E+0
^{27}Mg	9.5 m	$^{27}\text{Al}(n,p)$	3.57 E-3	1.43 E-2	6.31 E-3	< E-10	< E-10
^{62}Cu	9.8 m	$^{63}\text{Cu}(n,2n)$	9.89 E-3	6.94 E-1	4.49 E-2	< E-10	< E-10
^{60}Co	5.2 y	$^{63}\text{Cu}(n,\alpha)$	1.03 E-3	2.30 E-4	1.60 E-4	2.19 E-1	1.52 E-1
^{64}Cu	12.7 h	$^{65}\text{Cu}(n,2n)$	9.55 E-3	6.66 E-1	4.14 E-1	4.26 E-1	2.65 E-1
^{65}Ni	2.6 h	$^{65}\text{Cu}(n,p)$	2.69 E-4	1.53 E-1	1.09 E-1	1.91 E-4	1.15 E-4
Total Exposure Rate (unshielded):				5.51	1.71	4.24	1.53
$E = \sum_i E_i, \Delta E = \sqrt{\sum_i \Delta E_i^2}$				rem/h	rem/h	rem/h	rem/h
Total Personnel Exposure (shielded):				13.0	4.04	10.0	3.61
$(E^P \pm \Delta E^P) = 2.36 \times 10^{-3}(E \pm \Delta E)$				mrem/h	mrem/h	mrem/h	mrem/h

as specified in Eq. (24), we conclude that all neutron transport and activation cross sections are adequately known for the TFTR activation analysis performed in this report.

It is interesting to note that the largest resulting overall uncertainty $\Delta E^P/E^P = 36.1\%$ is considerably below any of the relative uncertainties calculated for the individual activation rates $\Delta R_i/R_i$, as summarized in Table VI. This is due to two effects: (a) the large relative uncertainties per radionuclide are associated only with fractions of the total exposure rate, and (b) the uncertainties of the exposure rates due to individual radionuclides are assumed to be completely uncorrelated -- which is considered a reasonable assumption for the activation reactions included here. It is possible that other activation reactions or radiation streaming effects which were not considered in our present analysis may cause additional uncertainties in calculated personnel dose rates so that the confidence limit specified in Eq. (24) could be exceeded. In addition, in order to make a final

conclusion on the adequacy or inadequacy of all nuclear data for TFTR applications, this analysis must be extended to incorporate additional nuclear design criteria which may involve other radiation effects; e.g., radiation damage to insulators or biological dose rates due to direct radiation outside the test cell at operating conditions.

In summary, the nuclear data required for the TFTR activation analysis as outlined in this report have been found adequate for the specified criteria. For this reason, however, the TFTR model does not fully demonstrate all of the capabilities of the sensitivity methods employed. In particular the value of the sensitivity profiles is not shown. If more stringent accuracy requirements were specified so that certain cross-section sets were found deficient, then the sensitivity profiles could be used to determine where improvements in the data would be most effective. It is expected that the sensitivity methods outlined in this report can provide even more valuable information and guidance when applied to experimental power reactors (EPR's), materials testing reactors, and longer term fusion power systems.

Such systems are neutronicly thicker than the TFTR and will therefore give higher sensitivities. Due to the higher neutron source strengths, more and probably tighter shield design criteria will have to be met. Moreover, these devices will have additional nuclear performance requirements (for example, high tritium production and low radiation damage) which will place new requirements on the accuracy of the nuclear data base and the analytical methods used in fusion applications.

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APPENDIX A

MULTIGROUP COVARIANCE MATRICES

The preliminary cross-section uncertainty estimates described in Sec. III have been evaluated in continuous-energy form. Cross-section variances are represented by a series of $\{E, [\text{Var } \sigma(E)]\}$ pairs, with log-linear interpolation understood between energy points. A correlation range parameter $R(E)$ is specified in an identical manner. This correlation range is used to describe gradual loss of correlation between the cross section at E_1 and the cross section at E_2 as the energy difference increases. The correlation coefficient $C(E_1, E_2)$ is assumed to fall off exponentially

$$C(E_1, E_2) = \exp\{-|\log E_1 - \log E_2| / R_{\text{ave}}\}.$$

Here R_{ave} is the (geometric) mean of the correlation ranges at E_1 and E_2 . In addition to the correlation range $R(E)$, one also specifies correlation "bands." In case E_1 and E_2 lie in different bands, the value of $C(E_1, E_2)$ given above is overridden and

set to zero. For the purposes of this study, then, a complete error evaluation for a given reaction consists of a specification of (a) the energy-dependent variance, (b) the energy-dependent correlation range, and (c) the correlation band structure.

A short computer program COVMAT has been written to process information of this type into the form of full (group-to-group) covariance matrices. This code interpolates between the input data, performs the calculations described above, and punches the resulting matrices in a format compatible with the sensitivity analysis code SENSIT-1D.³⁰ The matrices used in this study are listed in Tables A-I through A-XXV, which follow. In terms of the multigroup notation of Sec. II, the data in these tables are constructed from the correlation coefficients C_{ij} and the variances $\Delta \Sigma_i^2$ as follows:

$$\frac{\text{Cov}(\Sigma_i, \Sigma_j)}{\Sigma_i \Sigma_j} = \frac{C_{ij} \Delta \Sigma_i \Delta \Sigma_j}{\Sigma_i \Sigma_j}.$$

TABLE A-I. TWENTY-GROUP COVARIANCE MATRIX FOR THE REACTION
AL-27(N,P)MG-27 (9 M) ERRORS EVALUATED BY V. ORPHAN, 10 MAY 1975

		GROUP INDEX																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.0100	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
2	.0000	.0100	.0028	.0009	.0003	.0001	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
3	.0000	.0028	.0100	.0033	.0012	.0005	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
4	.0000	.0009	.0033	.0100	.0037	.0015	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
5	.0000	.0003	.0012	.0037	.0100	.0041	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
6	.0000	.0001	.0005	.0015	.0041	.0100	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
7	.0000	.0000	.0000	.0000	.0000	.0000	.0100	.0058	.0037	.0016	.0019	.0015	.0013	.0011	.0009	.0008	.0007	.0019	.0016	.0013	.0013
8	.0000	.0000	.0000	.0000	.0000	.0000	.0058	.0100	.0070	.0041	.0036	.0032	.0029	.0026	.0023	.0021	.0020	.0060	.0053	.0047	.0047
9	.0000	.0000	.0000	.0000	.0000	.0000	.0037	.0070	.0100	.0059	.0052	.0046	.0042	.0038	.0034	.0031	.0029	.0080	.0071	.0060	.0059
10	.0000	.0000	.0000	.0000	.0000	.0000	.0026	.0053	.0075	.0100	.0078	.0070	.0062	.0056	.0051	.0046	.0043	.0125	.0111	.0099	.0099
11	.0000	.0000	.0000	.0000	.0000	.0000	.0019	.0041	.0059	.0078	.0100	.0089	.0080	.0072	.0066	.0060	.0055	.0162	.0144	.0129	.0129
12	.0000	.0000	.0000	.0000	.0000	.0000	.0015	.0036	.0052	.0070	.0089	.0121	.0109	.0098	.0090	.0082	.0076	.0223	.0199	.0178	.0178
13	.0000	.0000	.0000	.0000	.0000	.0000	.0013	.0032	.0046	.0062	.0080	.0109	.0142	.0128	.0117	.0107	.0099	.0293	.0261	.0235	.0235
14	.0000	.0000	.0000	.0000	.0000	.0000	.0011	.0029	.0042	.0065	.0072	.0098	.0128	.0162	.0148	.0136	.0126	.0372	.0332	.0299	.0299
15	.0000	.0000	.0000	.0000	.0000	.0000	.0009	.0026	.0038	.0051	.0066	.0090	.0117	.0148	.0183	.0168	.0156	.0460	.0412	.0371	.0371
16	.0000	.0000	.0000	.0000	.0000	.0000	.0008	.0023	.0034	.0045	.0060	.0082	.0107	.0136	.0168	.0204	.0189	.0558	.0500	.0450	.0450
17	.0000	.0000	.0000	.0000	.0000	.0000	.0007	.0021	.0031	.0043	.0055	.0076	.0099	.0126	.0156	.0189	.0225	.0666	.0597	.0530	.0530
18	.0000	.0000	.0000	.0000	.0000	.0000	.0019	.0060	.0091	.0123	.0162	.0223	.0293	.0372	.0460	.0558	.0666	.2500	.2239	.2016	.2016
19	.0000	.0000	.0000	.0000	.0000	.0000	.0016	.0053	.0080	.0111	.0144	.0199	.0261	.0332	.0412	.0500	.0597	.2239	.2500	.2255	.2255
20	.0000	.0000	.0000	.0000	.0000	.0000	.0013	.0047	.0071	.0099	.0129	.0178	.0235	.0299	.0371	.0450	.0530	.2016	.2255	.2500	.2500

TABLE A-II. TWENTY-GROUP COVARIANCE MATRIX FOR THE REACTION
AL-27(N,α)NA-24 (15 M) ERRORS EVALUATED BY V. ORPHAN, 10 MAY 1975

		GROUP INDEX																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.0100	.0071	.0048	.0031	.0018	.0011	.0007	.0004	.0003	.0002	.0002	.0003	.0002	.0001	.0001	.0000	.0000	.0000	.0000	.0000	.0000
2	.0071	.0142	.0096	.0063	.0037	.0022	.0013	.0009	.0006	.0004	.0004	.0004	.0004	.0002	.0001	.0001	.0000	.0000	.0000	.0000	.0000
3	.0048	.0096	.0183	.0120	.0071	.0042	.0025	.0017	.0011	.0007	.0008	.0012	.0007	.0004	.0003	.0001	.0001	.0000	.0000	.0000	.0000
4	.0031	.0063	.0120	.0225	.0133	.0079	.0047	.0031	.0020	.0011	.0015	.0023	.0013	.0008	.0005	.0003	.0002	.0001	.0001	.0000	.0000
5	.0018	.0037	.0071	.0133	.0225	.0133	.0079	.0053	.0034	.0021	.0026	.0038	.0023	.0013	.0008	.0005	.0003	.0002	.0001	.0001	.0001
6	.0011	.0022	.0042	.0079	.0133	.0225	.0133	.0089	.0058	.0037	.0044	.0055	.0038	.0023	.0013	.0008	.0005	.0003	.0002	.0001	.0001
7	.0007	.0013	.0025	.0047	.0079	.0133	.0225	.0150	.0097	.0061	.0074	.0109	.0065	.0038	.0023	.0013	.0008	.0005	.0003	.0002	.0002
8	.0004	.0009	.0017	.0031	.0053	.0089	.0150	.0283	.0184	.0111	.0148	.0207	.0123	.0073	.0043	.0025	.0015	.0009	.0005	.0003	.0003
9	.0003	.0006	.0011	.0020	.0034	.0058	.0097	.0184	.0342	.0211	.0260	.0384	.0220	.0135	.0080	.0047	.0028	.0017	.0010	.0006	.0006
10	.0002	.0004	.0007	.0013	.0022	.0037	.0062	.0118	.0219	.0140	.0174	.0270	.0162	.0096	.0051	.0030	.0018	.0010	.0006	.0004	.0004
11	.0002	.0004	.0008	.0015	.0026	.0044	.0076	.0140	.0260	.0167	.0200	.0370	.0140	.0082	.0049	.0029	.0017	.0010	.0006	.0004	.0004
12	.0003	.0006	.0012	.0023	.0038	.0065	.0109	.0207	.0384	.0211	.0270	.0499	.0220	.0135	.0080	.0047	.0028	.0017	.0010	.0006	.0006
13	.0002	.0004	.0007	.0013	.0023	.0038	.0065	.0123	.0220	.0141	.0180	.0324	.0160	.0096	.0051	.0030	.0018	.0010	.0006	.0004	.0004
14	.0001	.0002	.0004	.0008	.0013	.0023	.0038	.0065	.0135	.0084	.0082	.0300	.0160	.0096	.0051	.0030	.0018	.0010	.0006	.0004	.0004
15	.0001	.0001	.0003	.0005	.0008	.0013	.0023	.0038	.0065	.0084	.0082	.0300	.0160	.0096	.0051	.0030	.0018	.0010	.0006	.0004	.0004
16	.0000	.0001	.0001	.0003	.0005	.0008	.0013	.0023	.0038	.0065	.0084	.0082	.0300	.0160	.0096	.0051	.0030	.0018	.0010	.0006	.0004
17	.0000	.0000	.0001	.0002	.0003	.0005	.0008	.0013	.0023	.0038	.0065	.0084	.0082	.0300	.0160	.0096	.0051	.0030	.0018	.0010	.0006
18	.0000	.0000	.0000	.0001	.0002	.0003	.0005	.0008	.0013	.0023	.0038	.0065	.0084	.0082	.0300	.0160	.0096	.0051	.0030	.0018	.0010
19	.0000	.0000	.0000	.0000	.0001	.0002	.0003	.0005	.0008	.0013	.0023	.0038	.0065	.0084	.0082	.0300	.0160	.0096	.0051	.0030	.0018
20	.0000	.0000	.0000	.0000	.0001	.0001	.0002	.0003	.0005	.0008	.0013	.0023	.0038	.0065	.0084	.0082	.0300	.0160	.0096	.0051	.0030

TABLE A-III. TWENTY-GROUP COVARIANCE MATRIX FOR THE REACTION
MX-55(N=2)MN-54 (312 D) ERRORS EVALUATED BY V. ORPHAN, 10 MAY 1975

	GROUP INDEX																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.0225	.0226	.0426	.0641	.0483	.0364	.0274	.0206	.0156	.0117	.0088	.0066	.0050	.0038	.0028	.0021	.0016	.0012	.0009	.0007
2	.0226	.0400	.0753	.1135	.0455	.0644	.0485	.0366	.0275	.0207	.0156	.0118	.0089	.0067	.0050	.0038	.0029	.0021	.0016	.0012
3	.0426	.0753	.2500	.3766	.2437	.2137	.1610	.1213	.0914	.0681	.0518	.0391	.0294	.0222	.0167	.0126	.0095	.0071	.0054	.0040
4	.0641	.1135	.3766	.9999	.7533	.5675	.4275	.3220	.2426	.1827	.1377	.1037	.0781	.0588	.0443	.0334	.0252	.0190	.0143	.0107
5	.0483	.0855	.2437	.7533	.9999	.7533	.5675	.4275	.3220	.2426	.1827	.1377	.1037	.0781	.0588	.0443	.0334	.0252	.0190	.0143
6	.0364	.0644	.2137	.5675	.7533	.9999	.7533	.5675	.4275	.3220	.2426	.1827	.1377	.1037	.0781	.0588	.0443	.0334	.0252	.0190
7	.0274	.0485	.1610	.4275	.5675	.7533	.9999	.7533	.5675	.4275	.3220	.2426	.1827	.1377	.1037	.0781	.0588	.0443	.0334	.0252
8	.0206	.0366	.1213	.3220	.4275	.5675	.7533	.9999	.7533	.5675	.4275	.3220	.2426	.1827	.1377	.1037	.0781	.0588	.0443	.0334
9	.0156	.0275	.0914	.2426	.3220	.4275	.5675	.7533	.9999	.7533	.5675	.4275	.3220	.2426	.1827	.1377	.1037	.0781	.0588	.0443
10	.0117	.0207	.0688	.1827	.2426	.3220	.4275	.5675	.7533	.9999	.7533	.5675	.4275	.3220	.2426	.1827	.1377	.1037	.0781	.0588
11	.0088	.0156	.0518	.1377	.1827	.2426	.3220	.4275	.5675	.7533	.9999	.7533	.5675	.4275	.3220	.2426	.1827	.1377	.1037	.0781
12	.0066	.0118	.0391	.1037	.1377	.1827	.2426	.3220	.4275	.5675	.7533	.9999	.7533	.5675	.4275	.3220	.2426	.1827	.1377	.1037
13	.0050	.0089	.0294	.0781	.1037	.1377	.1827	.2426	.3220	.4275	.5675	.7533	.9999	.7533	.5675	.4275	.3220	.2426	.1827	.1377
14	.0038	.0067	.0222	.0588	.0781	.1037	.1377	.1827	.2426	.3220	.4275	.5675	.7533	.9999	.7533	.5675	.4275	.3220	.2426	.1827
15	.0028	.0050	.0167	.0443	.0588	.0781	.1037	.1377	.1827	.2426	.3220	.4275	.5675	.7533	.9999	.7533	.5675	.4275	.3220	.2426
16	.0021	.0038	.0126	.0334	.0443	.0588	.0781	.1037	.1377	.1827	.2426	.3220	.4275	.5675	.7533	.9999	.7533	.5675	.4275	.3220
17	.0016	.0029	.0095	.0252	.0334	.0443	.0588	.0781	.1037	.1377	.1827	.2426	.3220	.4275	.5675	.7533	.9999	.7533	.5675	.4275
18	.0012	.0021	.0071	.0190	.0252	.0334	.0443	.0588	.0781	.1037	.1377	.1827	.2426	.3220	.4275	.5675	.7533	.9999	.7533	.5675
19	.0009	.0016	.0054	.0143	.0190	.0252	.0334	.0443	.0588	.0781	.1037	.1377	.1827	.2426	.3220	.4275	.5675	.7533	.9999	.7533
20	.0007	.0012	.0040	.0107	.0143	.0190	.0252	.0334	.0443	.0588	.0781	.1037	.1377	.1827	.2426	.3220	.4275	.5675	.7533	.9999

TABLE A-IV. TWENTY-GROUP COVARIANCE MATRIX FOR THE REACTION
FE-54(N,P)MN-54 (312 D) ERRORS EVALUATED BY V. ORPHAN, 10 MAY 1975

GROUP INDEX																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.0625	.0435	.0723	.0242	.0176	.0104	.0060	.0034	.0018	.0009	.0007	.0005	.0003	.0002	.0002	.0001	.0001	.0001	.0001	.0000
2	.0435	.0625	.0439	.0374	.0271	.0161	.0093	.0053	.0028	.0014	.0011	.0008	.0005	.0004	.0003	.0002	.0001	.0001	.0001	.0001
3	.0723	.0439	.0450	.0713	.0517	.0306	.0178	.0100	.0053	.0027	.0020	.0014	.0010	.0007	.0005	.0004	.0003	.0002	.0002	.0001
4	.0242	.0374	.0713	.1275	.0925	.0547	.0318	.0179	.0095	.0047	.0036	.0025	.0018	.0013	.0009	.0007	.0005	.0004	.0003	.0002
5	.0176	.0271	.0517	.0925	.1400	.0947	.0550	.0310	.0165	.0087	.0062	.0044	.0031	.0022	.0016	.0012	.0009	.0007	.0005	.0004
6	.0104	.0161	.0306	.0547	.0947	.1336	.0777	.0437	.0233	.0107	.0087	.0062	.0044	.0030	.0023	.0017	.0012	.0010	.0007	.0005
7	.0060	.0093	.0178	.0318	.0550	.0777	.1076	.0606	.0323	.0157	.0121	.0086	.0061	.0042	.0032	.0024	.0017	.0014	.0010	.0008
8	.0034	.0053	.0100	.0179	.0310	.0437	.0606	.0813	.0433	.0208	.0162	.0116	.0082	.0057	.0043	.0032	.0023	.0018	.0014	.0010
9	.0018	.0028	.0053	.0095	.0165	.0233	.0323	.0433	.0551	.0257	.0207	.0148	.0104	.0072	.0055	.0040	.0029	.0023	.0018	.0013
10	.0009	.0014	.0025	.0045	.0077	.0109	.0151	.0203	.0258	.0294	.0231	.0165	.0116	.0081	.0062	.0045	.0032	.0026	.0020	.0014
11	.0007	.0011	.0020	.0036	.0062	.0087	.0121	.0162	.0207	.0233	.0141	.0085	.0021	.0154	.0118	.0086	.0062	.0050	.0038	.0027
12	.0005	.0008	.0016	.0025	.0044	.0062	.0086	.0116	.0148	.0165	.0035	.0037	.0026	.0022	.0021	.0147	.0105	.0085	.0064	.0046
13	.0003	.0005	.0010	.0018	.0031	.0044	.0061	.0082	.0104	.0111	.0021	.0037	.0043	.0044	.0037	.0027	.0017	.0142	.0107	.0078
14	.0002	.0004	.0007	.0013	.0022	.0030	.0042	.0057	.0077	.0094	.0014	.0026	.0040	.0029	.0058	.0040	.0023	.0034	.0178	.0129
15	.0002	.0003	.0005	.0009	.0016	.0023	.0032	.0043	.0054	.0064	.0018	.0021	.0037	.0058	.0019	.0048	.0035	.0031	.0025	.0036
16	.0001	.0002	.0004	.0007	.0012	.0017	.0024	.0032	.0040	.0047	.0028	.0047	.0027	.0040	.0010	.0048	.0030	.0027	.0025	.0043
17	.0001	.0001	.0003	.0005	.0009	.0012	.0017	.0023	.0029	.0033	.0022	.0040	.0027	.0035	.0009	.0048	.0030	.0027	.0025	.0043
18	.0001	.0001	.0002	.0004	.0007	.0010	.0014	.0018	.0023	.0027	.0020	.0038	.0025	.0034	.0009	.0048	.0030	.0027	.0025	.0043
19	.0001	.0001	.0002	.0003	.0005	.0007	.0010	.0014	.0018	.0022	.0020	.0038	.0025	.0034	.0009	.0048	.0030	.0027	.0025	.0043
20	.0000	.0001	.0001	.0002	.0004	.0005	.0008	.0010	.0013	.0016	.0027	.0046	.0028	.0029	.0023	.0043	.0035	.0036	.0025	.0043

TABLE A-V. TWENTY-GROUP COVARIANCE MATRIX FOR THE REACTION
FE-56(N,P)MN-56 (2.6 M) ERRORS EVALUATED BY V. ORPHAN, 14 APR 75

	GROUP 1 DEX																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.0225	.0140	.0107	.0094	.0084	.0075	.0068	.0062	.0057	.005	.0048	.0038	.0078	.0070	.0063	.0056	.0050	.0045	.0040	.0036
2	.0150	.0152	.0110	.0096	.0086	.0077	.0070	.0065	.0059	.005	.0102	.0093	.0084	.0076	.0068	.0062	.0056	.0050	.0045	.0041
3	.0107	.0110	.0109	.0088	.0078	.0071	.0065	.0059	.0055	.005	.0095	.0086	.0079	.0072	.0065	.0060	.0054	.0049	.0045	.0041
4	.0094	.0096	.0086	.0100	.0089	.0081	.0074	.0068	.0063	.005	.0109	.0100	.0092	.0084	.0077	.0071	.0065	.0059	.0054	.0050
5	.0084	.0085	.0078	.0084	.0100	.0090	.0083	.0076	.0073	.006	.0123	.0113	.0104	.0096	.0089	.0082	.0075	.0069	.0064	.0059
6	.0075	.0077	.0071	.0081	.0090	.0100	.0091	.0084	.0078	.007	.0136	.0126	.0116	.0108	.0100	.0092	.0086	.0079	.0073	.0068
7	.0068	.0070	.0065	.0074	.0083	.0091	.0100	.0092	.0085	.008	.0149	.0139	.0129	.0120	.0111	.0103	.0096	.0089	.0083	.0077
8	.0062	.0065	.0059	.0066	.0076	.0084	.0092	.0100	.0093	.008	.0162	.0151	.0141	.0131	.0122	.0114	.0106	.0099	.0092	.0086
9	.0057	.0059	.0055	.0063	.0070	.0078	.0085	.0093	.0100	.009	.0175	.0163	.0153	.0143	.0134	.0125	.0117	.0109	.0102	.0095
10	.0053	.0055	.0051	.0058	.0066	.0073	.0080	.0086	.0093	.010	.0188	.0176	.0165	.0154	.0145	.0136	.0127	.0119	.0112	.0105
11	.0048	.0102	.0095	.0109	.0123	.0136	.0149	.0162	.0175	.018	.0400	.0376	.0353	.0332	.0312	.0293	.0275	.0258	.0243	.0228
12	.0054	.0093	.0086	.0100	.0113	.0126	.0139	.0151	.0163	.017	.0376	.0400	.0376	.0353	.0332	.0312	.0293	.0275	.0258	.0243
13	.0078	.0084	.0079	.0092	.0104	.0116	.0129	.0141	.0153	.016	.0353	.0376	.0400	.0376	.0353	.0332	.0312	.0293	.0275	.0258
14	.0070	.0076	.0072	.0084	.0096	.0108	.0120	.0131	.0143	.015	.0332	.0353	.0376	.0400	.0376	.0353	.0332	.0312	.0293	.0275
15	.0063	.0065	.0065	.0077	.0089	.0100	.0111	.0122	.0134	.014	.0312	.0332	.0353	.0376	.0400	.0376	.0353	.0332	.0312	.0293
16	.0056	.0062	.0060	.0071	.0082	.0092	.0103	.0114	.0125	.013	.0293	.0312	.0332	.0353	.0376	.0400	.0376	.0353	.0332	.0312
17	.0050	.0056	.0054	.0065	.0075	.0086	.0096	.0106	.0117	.012	.0275	.0293	.0312	.0332	.0353	.0376	.0400	.0376	.0353	.0332
18	.0045	.0050	.0049	.0059	.0069	.0079	.0089	.0099	.0109	.011	.0258	.0275	.0293	.0312	.0332	.0353	.0376	.0400	.0376	.0353
19	.0040	.0046	.0045	.0054	.0064	.0073	.0083	.0092	.0102	.011	.0243	.0258	.0275	.0293	.0312	.0332	.0353	.0376	.0400	.0376
20	.0036	.0041	.0041	.0050	.0059	.0068	.0077	.0086	.0095	.010	.0228	.0243	.0258	.0275	.0293	.0312	.0332	.0353	.0376	.0400

TABLE A-VI. TWENTY-GROUP COVARIANCE MATRIX FOR THE REACTION
NI-58(N,P)CO-58 (71 D) ERRORS EVALUATED BY V. ORPHAN, 5 MAY 75

GROUP INDEX																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.0400	.0656	.0492	.0379	.0297	.0187	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
2	.0456	.0900	.0476	.0520	.0409	.0258	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
3	.0492	.0476	.0900	.0693	.0545	.0345	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
4	.0379	.0520	.0693	.0900	.0708	.0448	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
5	.0297	.0409	.0545	.0708	.0900	.0570	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
6	.0187	.0258	.0345	.0448	.0570	.0562	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
7	.0000	.0000	.0000	.0000	.0000	.0000	.0225	.0187	.0159	.0137	.0120	.0106	.0095	.0085	.0161	.0195	.0214	.0196	.0181	.0167
8	.0000	.0000	.0000	.0000	.0000	.0000	.0187	.0225	.0191	.0165	.0145	.0128	.0115	.0104	.0196	.0239	.0262	.0241	.0223	.0206
9	.0000	.0000	.0000	.0000	.0000	.0000	.0159	.0191	.0225	.0195	.0171	.0152	.0136	.0123	.0233	.0283	.0312	.0287	.0266	.0247
10	.0000	.0000	.0000	.0000	.0000	.0000	.0137	.0165	.0195	.0225	.0198	.0175	.0157	.0142	.0270	.0329	.0363	.0335	.0310	.0289
11	.0000	.0000	.0000	.0000	.0000	.0000	.0120	.0145	.0171	.0198	.0225	.0200	.0179	.0162	.0309	.0376	.0415	.0383	.0356	.0331
12	.0000	.0000	.0000	.0000	.0000	.0000	.0106	.0126	.0152	.0175	.0200	.0225	.0202	.0183	.0348	.0424	.0468	.0435	.0402	.0374
13	.0000	.0000	.0000	.0000	.0000	.0000	.0095	.0115	.0136	.0157	.0179	.0202	.0225	.0204	.0388	.0473	.0522	.0483	.0449	.0419
14	.0000	.0000	.0000	.0000	.0000	.0000	.0085	.0104	.0123	.0142	.0162	.0183	.0204	.0225	.0429	.0523	.0577	.0535	.0497	.0464
15	.0000	.0000	.0000	.0000	.0000	.0000	.0161	.0196	.0233	.0270	.0309	.0348	.0388	.0429	.0983	.1200	.1325	.1227	.1141	.1055
16	.0000	.0000	.0000	.0000	.0000	.0000	.0195	.0239	.0283	.0329	.0376	.0424	.0473	.0523	.1200	.1742	.1924	.1782	.1657	.1547
17	.0000	.0000	.0000	.0000	.0000	.0000	.0214	.0262	.0312	.0363	.0415	.0468	.0522	.0577	.1325	.1924	.2500	.2316	.2154	.2012
18	.0000	.0000	.0000	.0000	.0000	.0000	.0196	.0241	.0287	.0335	.0383	.0433	.0483	.0535	.1227	.1782	.2316	.2500	.2326	.2172
19	.0000	.0000	.0000	.0000	.0000	.0000	.0181	.0223	.0266	.0310	.0356	.0402	.0449	.0497	.1141	.1657	.2154	.2326	.2500	.2335
20	.0000	.0000	.0000	.0000	.0000	.0000	.0167	.0206	.0247	.0289	.0331	.0374	.0419	.0464	.1055	.1547	.2012	.2172	.2335	.2500

TABLE A-VII. TWENTY-GROUP COVARIANCE MATRIX FOR THE REACTION
CU-63(N,2N)CU-62 (10 M) ERRORS EVALUATED BY V. ORPHAN, 14 APR 75

	GROUP INDEX																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.0729	.0030	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
2	.0000	.0625	.2262	.2047	.1852	.1676	.1516	.1372	.1242	.1121	.1016	.0920	.0832	.0753	.0681	.0616	.0558	.0505	.0457	.0413
3	.0300	.2262	.9999	.9048	.8187	.7408	.6703	.6065	.5488	.4966	.4493	.4066	.3679	.3329	.3012	.2725	.2466	.2231	.2019	.1827
4	.0300	.2047	.9048	.9999	.9048	.8187	.7408	.6703	.6065	.5488	.4966	.4493	.4066	.3679	.3329	.3012	.2725	.2466	.2231	.2019
5	.0000	.1852	.8187	.9048	.9999	.9048	.8187	.7408	.6703	.6065	.5488	.4966	.4493	.4066	.3679	.3329	.3012	.2725	.2466	.2231
6	.0000	.1676	.7408	.8187	.9048	.9999	.9048	.8187	.7408	.6703	.6065	.5488	.4966	.4493	.4066	.3679	.3329	.3012	.2725	.2466
7	.0000	.1516	.6703	.7408	.8187	.9048	.9999	.9048	.8187	.7408	.6703	.6065	.5488	.4966	.4493	.4066	.3679	.3329	.3012	.2725
8	.0000	.1372	.6065	.6703	.7408	.8187	.9048	.9999	.9048	.8187	.7408	.6703	.6065	.5488	.4966	.4493	.4066	.3679	.3329	.3012
9	.0000	.1242	.5488	.6065	.6703	.7408	.8187	.9048	.9999	.9048	.8187	.7408	.6703	.6065	.5488	.4966	.4493	.4066	.3679	.3329
10	.0000	.1121	.4966	.5488	.6065	.6703	.7408	.8187	.9048	.9999	.9048	.8187	.7408	.6703	.6065	.5488	.4966	.4493	.4066	.3679
11	.0000	.1016	.4493	.4966	.5488	.6065	.6703	.7408	.8187	.9048	.9999	.9048	.8187	.7408	.6703	.6065	.5488	.4966	.4493	.4066
12	.0000	.0920	.4066	.4493	.4966	.5488	.6065	.6703	.7408	.8187	.9048	.9999	.9048	.8187	.7408	.6703	.6065	.5488	.4966	.4493
13	.0300	.0832	.3679	.4066	.4493	.4966	.5488	.6065	.6703	.7408	.8187	.9048	.9999	.9048	.8187	.7408	.6703	.6065	.5488	.4966
14	.0000	.0753	.3329	.3679	.4066	.4493	.4966	.5488	.6065	.6703	.7408	.8187	.9048	.9999	.9048	.8187	.7408	.6703	.6065	.5488
15	.0000	.0681	.3012	.3329	.3679	.4066	.4493	.4966	.5488	.6065	.6703	.7408	.8187	.9048	.9999	.9048	.8187	.7408	.6703	.6065
16	.0000	.0616	.2725	.3012	.3329	.3679	.4066	.4493	.4966	.5488	.6065	.6703	.7408	.8187	.9048	.9999	.9048	.8187	.7408	.6703
17	.0000	.0558	.2466	.2725	.3012	.3329	.3679	.4066	.4493	.4966	.5488	.6065	.6703	.7408	.8187	.9048	.9999	.9048	.8187	.7408
18	.0000	.0505	.2231	.2466	.2725	.3012	.3329	.3679	.4066	.4493	.4966	.5488	.6065	.6703	.7408	.8187	.9048	.9999	.9048	.8187
19	.0000	.0457	.2019	.2231	.2466	.2725	.3012	.3329	.3679	.4066	.4493	.4966	.5488	.6065	.6703	.7408	.8187	.9048	.9999	.9048
20	.0000	.0413	.1827	.2019	.2231	.2466	.2725	.3012	.3329	.3679	.4066	.4493	.4966	.5488	.6065	.6703	.7408	.8187	.9048	.9999

TABLE A-VIII. TWENTY-GROUP COVARIANCE MATRIX FOR THE REACTION
CU-63(N,2N)CU-60 (5.3 Y) ERRORS REVISED BY V. ORPHAN, 24 JUN 1975

	GROUP INDEX																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.1225	.0621	.0536	.0436	.0345	.0275	.0221	.0178	.0556	.0671	.0562	.0468	.0390	.0325	.0270	.0225	.0187	.0156	.0130	.0108
2	.0421	.0925	.0305	.0493	.0390	.0312	.0252	.0203	.0637	.0771	.0653	.0550	.0464	.0391	.0330	.0278	.0234	.0197	.0166	.0140
3	.0536	.0665	.0625	.0510	.0404	.0324	.0261	.0211	.0664	.0810	.0689	.0587	.0499	.0425	.0362	.0308	.0262	.0223	.0190	.0162
4	.0436	.0493	.0510	.0625	.0496	.0398	.0321	.0260	.0819	.1000	.0858	.0737	.0633	.0543	.0466	.0400	.0343	.0295	.0253	.0217
5	.0345	.0390	.0404	.0496	.0569	.0456	.0369	.0299	.0943	.1152	.0996	.0861	.0745	.0644	.0556	.0481	.0416	.0360	.0311	.0269
6	.0275	.0312	.0324	.0398	.0456	.0513	.0414	.0336	.1060	.1297	.1128	.0982	.0854	.0743	.0646	.0562	.0489	.0426	.0370	.0322
7	.0221	.0252	.0261	.0321	.0369	.0414	.0456	.0370	.1168	.1430	.1251	.1094	.0957	.0837	.0733	.0641	.0561	.0490	.0429	.0375
8	.0178	.0203	.0211	.0260	.0299	.0336	.0370	.0400	.1262	.1546	.1359	.1195	.1050	.0923	.0812	.0713	.0627	.0551	.0485	.0426
9	.0556	.0637	.0664	.0819	.0943	.1060	.1168	.1262	.5200	.6361	.5622	.4964	.4383	.3870	.3417	.3017	.2664	.2352	.2077	.1834
10	.0675	.0775	.0810	.1000	.1152	.1297	.1430	.1546	.6361	.9999	.8865	.7859	.6967	.6176	.5475	.4854	.4303	.3814	.3381	.2997
11	.0562	.0653	.0689	.0858	.0996	.1128	.1251	.1359	.5622	.8865	.9999	.8865	.7859	.6967	.6176	.5475	.4854	.4303	.3814	.3381
12	.0468	.0550	.0587	.0737	.0861	.0982	.1094	.1195	.4964	.7859	.8865	.9999	.8865	.7859	.6967	.6176	.5475	.4854	.4303	.3814
13	.0390	.0464	.0499	.0633	.0745	.0854	.0957	.1050	.4383	.6967	.7859	.8865	.9999	.8865	.7859	.6967	.6176	.5475	.4854	.4303
14	.0325	.0391	.0425	.0543	.0644	.0743	.0837	.0923	.3870	.6176	.6967	.7859	.8865	.9999	.8865	.7859	.6967	.6176	.5475	.4854
15	.0270	.0330	.0362	.0466	.0556	.0646	.0733	.0812	.3417	.5475	.6176	.6967	.7859	.8865	.9999	.8865	.7859	.6967	.6176	.5475
16	.0225	.0278	.0308	.0400	.0481	.0562	.0641	.0713	.3017	.4854	.5475	.6176	.6967	.7859	.8865	.9999	.8865	.7859	.6967	.6176
17	.0187	.0234	.0262	.0343	.0416	.0489	.0561	.0627	.2664	.4303	.4854	.5475	.6176	.6967	.7859	.8865	.9999	.8865	.7859	.6967
18	.0156	.0197	.0223	.0295	.0360	.0426	.0490	.0551	.2352	.3814	.4303	.4854	.5475	.6176	.6967	.7859	.8865	.9999	.8865	.7859
19	.0130	.0166	.0190	.0253	.0311	.0370	.0429	.0485	.2077	.3381	.3814	.4303	.4854	.5475	.6176	.6967	.7859	.8865	.9999	.8865
20	.0108	.0140	.0162	.0217	.0269	.0322	.0375	.0426	.1834	.2997	.3381	.3814	.4303	.4854	.5475	.6176	.6967	.7859	.8865	.9999

TABLE A-IX. TWENTY-GROUP COVARIANCE MATRIX FOR THE REACTION
CU-65(N+2N)CU-64 (13 H) ERRORS EVALUATED BY V. ORPHAN, 5 MAY 75

		GROUP INDEX																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.0149	.0182	.0195	.0650	.0650	.0650	.0650	.0650	.0650	.0650	.0650	.0650	.0650	.0650	.0650	.0650	.0650	.0650	.0650	.0650	.0650
2	.0182	.0197	.0211	.0702	.0702	.0702	.0702	.0702	.0702	.0702	.0702	.0702	.0702	.0702	.0702	.0702	.0702	.0702	.0702	.0702	.0702
3	.0195	.0211	.0225	.0750	.0750	.0750	.0750	.0750	.0750	.0750	.0750	.0750	.0750	.0750	.0750	.0750	.0750	.0750	.0750	.0750	.0750
4	.0650	.0702	.0750	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
5	.0650	.0702	.0750	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
6	.0650	.0702	.0750	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
7	.0650	.0702	.0750	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
8	.0650	.0702	.0750	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
9	.0650	.0702	.0750	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
10	.0650	.0702	.0750	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
11	.0650	.0702	.0750	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
12	.0650	.0702	.0750	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
13	.0650	.0702	.0750	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
14	.0650	.0702	.0750	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
15	.0650	.0702	.0750	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
16	.0650	.0702	.0750	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
17	.0650	.0702	.0750	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
18	.0650	.0702	.0750	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
19	.0650	.0702	.0750	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
20	.0650	.0702	.0750	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500

TABLE A-X. TWENTY-GROUP COVARIANCE MATRIX FOR THE REACTION
CU-65(N,P)NI-65 (2.5 H) ERRORS EVALUATED BY V. ORPHAN, 14 APR 75

	GROUP INDEX																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.1060	.1058	.0732	.0423	.0260	.0248	.0236	.0225	.0215	.0205	.0195	.0187	.0179	.0171	.0158	.0147	.0137	.0127	.0119	.0111
2	.1058	.1256	.0865	.0575	.0312	.0300	.0289	.0278	.0267	.0257	.0247	.0238	.0230	.0222	.0207	.0193	.0181	.0171	.0161	.0152
3	.0732	.0865	.0913	.0608	.0331	.0320	.0309	.0298	.0288	.0275	.0270	.0262	.0253	.0246	.0230	.0216	.0204	.0193	.0182	.0173
4	.0423	.0575	.0608	.0569	.0310	.0300	.0291	.0282	.0273	.0265	.0257	.0250	.0243	.0236	.0222	.0210	.0198	.0188	.0178	.0170
5	.0260	.0312	.0331	.0310	.0225	.0218	.0211	.0205	.0199	.0193	.0188	.0183	.0179	.0174	.0164	.0155	.0147	.0140	.0133	.0127
6	.0248	.0300	.0320	.0300	.0218	.0269	.0261	.0254	.0247	.0241	.0234	.0228	.0223	.0217	.0205	.0194	.0184	.0175	.0167	.0160
7	.0236	.0289	.0309	.0291	.0211	.0261	.0314	.0305	.0297	.0295	.0282	.0275	.0269	.0263	.0248	.0235	.0224	.0213	.0203	.0194
8	.0225	.0278	.0298	.0282	.0205	.0254	.0305	.0358	.0349	.0340	.0332	.0324	.0317	.0310	.0293	.0278	.0264	.0252	.0241	.0230
9	.0215	.0267	.0288	.0273	.0199	.0247	.0297	.0349	.0403	.0393	.0383	.0374	.0366	.0358	.0339	.0322	.0307	.0292	.0280	.0268
10	.0205	.0257	.0279	.0265	.0193	.0240	.0289	.0340	.0393	.0447	.0437	.0427	.0417	.0409	.0387	.0368	.0350	.0334	.0320	.0306
11	.0195	.0247	.0270	.0257	.0188	.0234	.0282	.0332	.0383	.0437	.0492	.0481	.0470	.0461	.0436	.0415	.0395	.0377	.0361	.0346
12	.0187	.0238	.0262	.0250	.0183	.0228	.0275	.0324	.0374	.0427	.0481	.0536	.0525	.0514	.0487	.0463	.0441	.0421	.0403	.0387
13	.0179	.0230	.0253	.0243	.0179	.0223	.0269	.0317	.0366	.0417	.0470	.0525	.0581	.0569	.0539	.0512	.0488	.0467	.0447	.0429
14	.0171	.0222	.0245	.0236	.0174	.0217	.0263	.0310	.0358	.0409	.0461	.0514	.0569	.0625	.0592	.0563	.0537	.0513	.0491	.0471
15	.0158	.0207	.0230	.0222	.0164	.0205	.0248	.0293	.0339	.0387	.0436	.0487	.0539	.0592	.0625	.0594	.0567	.0541	.0518	.0497
16	.0147	.0193	.0216	.0210	.0155	.0194	.0235	.0278	.0322	.0368	.0415	.0463	.0512	.0563	.0594	.0625	.0596	.0570	.0546	.0523
17	.0137	.0181	.0204	.0198	.0147	.0184	.0224	.0264	.0307	.0350	.0395	.0441	.0488	.0537	.0567	.0596	.0625	.0597	.0572	.0549
18	.0127	.0171	.0193	.0188	.0140	.0175	.0213	.0252	.0292	.0334	.0377	.0421	.0467	.0513	.0541	.0570	.0597	.0625	.0599	.0575
19	.0119	.0161	.0182	.0178	.0133	.0167	.0203	.0241	.0280	.0320	.0361	.0403	.0447	.0491	.0518	.0546	.0572	.0599	.0625	.0600
20	.0111	.0152	.0173	.0170	.0127	.0160	.0194	.0230	.0268	.0306	.0346	.0387	.0429	.0471	.0497	.0523	.0549	.0575	.0600	.0625

TABLE A-XI. TWENTY-GROUP COVARIANCE MATRIX FOR THE REACTION
PB-204(N,2N)PB-203 (52 M) ERRORS EVALUATED BY V. ORPHAN, 20 JUN 1975

		GROUP INDEX																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1		.0400	.0364	.0302	.0240	.0216	.0170	.0130	.0099	.0074	.0051	.0041	.0030	.0022	.0016	.0011	.0008	.0006	.0004	.0003	.0002
2		.0364	.0675	.0560	.0445	.0400	.0315	.0242	.0183	.0137	.0101	.0075	.0055	.0040	.0029	.0021	.0016	.0011	.0008	.0006	.0004
3		.0302	.0560	.0950	.0755	.0679	.0534	.0411	.0311	.0233	.0171	.0128	.0094	.0069	.0050	.0036	.0026	.0019	.0014	.0010	.0007
4		.0240	.0445	.0755	.1225	.1102	.0866	.0666	.0505	.0378	.028	.0208	.0152	.0111	.0081	.0059	.0043	.0031	.0022	.0016	.0011
5		.0216	.0400	.0679	.1102	.2025	.1592	.1224	.0927	.0695	.0511	.0381	.0280	.0205	.0149	.0108	.0079	.0057	.0041	.0029	.0021
6		.0170	.0315	.0534	.0866	.1592	.2557	.1966	.1489	.1116	.0821	.0612	.0450	.0329	.0240	.0174	.0126	.0091	.0066	.0047	.0034
7		.0130	.0242	.0411	.0666	.1224	.1966	.3088	.2339	.1753	.130	.0962	.0706	.0517	.0376	.0273	.0198	.0143	.0103	.0074	.0053
8		.0099	.0183	.0311	.0505	.0927	.1489	.2339	.3620	.2712	.2011	.1488	.1093	.0799	.0582	.0423	.0307	.0222	.0160	.0115	.0083
9		.0074	.0137	.0233	.0378	.0695	.1116	.1753	.2712	.4152	.3081	.2278	.1673	.1223	.0892	.0648	.0469	.0339	.0245	.0176	.0127
10		.0055	.0102	.0173	.0281	.0516	.0829	.1303	.2016	.3085	.4668	.3458	.2540	.1857	.1353	.0983	.0712	.0515	.0372	.0268	.0192
11		.0041	.0075	.0128	.0208	.0381	.0612	.0962	.1488	.2278	.3451	.5215	.3830	.2801	.2041	.1483	.1074	.0777	.0560	.0404	.0290
12		.0030	.0055	.0094	.0152	.0280	.0450	.0706	.1093	.1673	.2540	.3830	.5747	.4203	.3063	.2225	.1612	.1165	.0841	.0604	.0435
13		.0022	.0040	.0069	.0111	.0205	.0329	.0517	.0799	.1223	.1857	.2801	.4203	.6278	.4575	.3324	.2408	.1741	.1256	.0905	.0650
14		.0016	.0029	.0050	.0081	.0149	.0240	.0376	.0582	.0892	.1351	.2041	.3063	.4575	.6810	.4947	.3585	.2591	.1870	.1346	.0968
15		.0011	.0021	.0036	.0059	.0108	.0174	.0273	.0423	.0648	.0981	.1483	.2225	.3324	.4947	.7342	.5319	.3846	.2774	.1998	.1437
16		.0008	.0016	.0026	.0043	.0079	.0126	.0198	.0307	.0469	.0711	.1074	.1612	.2408	.3585	.5319	.7873	.5692	.4106	.2957	.2127
17		.0006	.0011	.0019	.0031	.0057	.0091	.0143	.0222	.0339	.0515	.0777	.1165	.1741	.2591	.3846	.5692	.8405	.6064	.4367	.3140
18		.0004	.0008	.0014	.0022	.0041	.0066	.0103	.0160	.0245	.0372	.0560	.0841	.1256	.1870	.2774	.4106	.6064	.8937	.6436	.4628
19		.0003	.0006	.0010	.0016	.0029	.0047	.0074	.0115	.0176	.0268	.0404	.0606	.0905	.1346	.1998	.2957	.4367	.6436	.9468	.6808
20		.0002	.0004	.0007	.0011	.0021	.0034	.0053	.0083	.0127	.0192	.0290	.0435	.0650	.0968	.1437	.2127	.3140	.4628	.6808	.9999

TABLE A-XII. TWENTY-GROUP COVARIANCE MATRIX FOR THE REACTION
PB-206(N,2N)PB-203 (47 D) ERRORS EVALUATED BY V. ORPHAN, 20 JUN 1975

		GROUP INDEX																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1		.0625	.0875	.0612	.0641	.0599	.0419	.0293	.0205	.0144	.010	.0070	.0049	.0034	.0024	.0017	.0012	.0008	.0006	.0004	.0003
2		.0875	.2500	.1749	.1832	.1713	.1198	.0838	.0587	.0410	.0281	.0201	.0141	.0098	.0069	.0048	.0034	.0024	.0016	.0011	.0008
3		.0612	.1749	.2500	.2618	.2448	.1713	.1198	.0838	.0587	.0411	.0287	.0201	.0141	.0098	.0069	.0048	.0034	.0024	.0016	.0011
4		.0641	.1832	.2618	.5600	.5236	.3663	.2563	.1793	.1255	.0879	.0614	.0430	.0301	.0210	.0147	.0103	.0072	.0050	.0035	.0025
5		.0599	.1713	.2448	.5236	.9999	.6997	.4895	.3425	.2397	.1677	.1173	.0821	.0574	.0402	.0281	.0197	.0138	.0096	.0067	.0047
6		.0419	.1198	.1713	.3663	.6997	.9999	.6997	.4895	.3425	.2397	.1677	.1173	.0821	.0574	.0402	.0281	.0197	.0138	.0096	.0067
7		.0293	.0838	.1198	.2563	.4895	.6997	.9999	.6997	.4895	.3425	.2397	.1677	.1173	.0821	.0574	.0402	.0281	.0197	.0138	.0096
8		.0205	.0587	.0838	.1793	.3425	.4895	.6997	.9999	.6997	.4895	.3425	.2397	.1677	.1173	.0821	.0574	.0402	.0281	.0197	.0138
9		.0144	.0410	.0587	.1255	.2397	.3425	.4895	.6997	.9999	.6997	.4895	.3425	.2397	.1677	.1173	.0821	.0574	.0402	.0281	.0197
10		.0101	.0287	.0410	.0878	.1677	.2397	.3425	.4895	.6997	.9999	.6997	.4895	.3425	.2397	.1677	.1173	.0821	.0574	.0402	.0281
11		.0070	.0201	.0287	.0614	.1173	.1677	.2397	.3425	.4895	.6997	.9999	.6997	.4895	.3425	.2397	.1677	.1173	.0821	.0574	.0402
12		.0049	.0141	.0201	.0430	.0821	.1173	.1677	.2397	.3425	.4895	.6997	.9999	.6997	.4895	.3425	.2397	.1677	.1173	.0821	.0574
13		.0034	.0098	.0141	.0301	.0574	.0821	.1173	.1677	.2397	.3425	.4895	.6997	.9999	.6997	.4895	.3425	.2397	.1677	.1173	.0821
14		.0024	.0069	.0098	.0210	.0402	.0574	.0821	.1173	.1677	.2397	.3425	.4895	.6997	.9999	.6997	.4895	.3425	.2397	.1677	.1173
15		.0017	.0048	.0069	.0147	.0281	.0402	.0574	.0821	.1173	.1677	.2397	.3425	.4895	.6997	.9999	.6997	.4895	.3425	.2397	.1677
16		.0012	.0034	.0048	.0103	.0197	.0281	.0402	.0574	.0821	.1173	.1677	.2397	.3425	.4895	.6997	.9999	.6997	.4895	.3425	.2397
17		.0008	.0024	.0034	.0072	.0138	.0197	.0281	.0402	.0574	.0821	.1173	.1677	.2397	.3425	.4895	.6997	.9999	.6997	.4895	.3425
18		.0006	.0016	.0024	.0050	.0096	.0138	.0197	.0281	.0402	.0574	.0821	.1173	.1677	.2397	.3425	.4895	.6997	.9999	.6997	.4895
19		.0004	.0011	.0016	.0035	.0067	.0096	.0138	.0197	.0281	.0402	.0574	.0821	.1173	.1677	.2397	.3425	.4895	.6997	.9999	.6997
20		.0003	.0008	.0011	.0025	.0047	.0067	.0096	.0138	.0197	.0281	.0402	.0574	.0821	.1173	.1677	.2397	.3425	.4895	.6997	.9999

TABLE A-XIII. TWENTY-GROUP COVARIANCE MATRIX FOR THE REACTION
C-12(N,N CONTINUUM) ERRORS EVALUATED BY D. W. MUIR, FEB 75.

		GROUP INDEX																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.0400	.0543	.0663	.0762	.0848	.0927	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000	.1000
2	.0548	.0750	.0908	.1043	.1162	.1270	.1369	.1369	.1369	.1369	.1369	.1369	.1369	.1369	.1369	.1369	.1369	.1369	.1369	.1369
3	.0663	.0908	.1100	.1263	.1407	.1538	.1658	.1658	.1658	.1658	.1658	.1658	.1658	.1658	.1658	.1658	.1658	.1658	.1658	.1658
4	.0762	.1043	.1263	.1450	.1616	.1766	.1904	.1904	.1904	.1904	.1904	.1904	.1904	.1904	.1904	.1904	.1904	.1904	.1904	.1904
5	.0848	.1162	.1407	.1616	.1800	.1967	.2121	.2121	.2121	.2121	.2121	.2121	.2121	.2121	.2121	.2121	.2121	.2121	.2121	.2121
6	.0927	.1270	.1538	.1766	.1967	.2150	.2318	.2318	.2318	.2318	.2318	.2318	.2318	.2318	.2318	.2318	.2318	.2318	.2318	.2318
7	.1000	.1369	.1658	.1904	.2121	.2318	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
8	.1000	.1369	.1658	.1904	.2121	.2318	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
9	.1000	.1369	.1658	.1904	.2121	.2318	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
10	.1000	.1369	.1658	.1904	.2121	.2318	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
11	.1000	.1369	.1658	.1904	.2121	.2318	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
12	.1000	.1369	.1658	.1904	.2121	.2318	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
13	.1000	.1369	.1658	.1904	.2121	.2318	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
14	.1000	.1369	.1658	.1904	.2121	.2318	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
15	.1000	.1369	.1658	.1904	.2121	.2318	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
16	.1000	.1369	.1658	.1904	.2121	.2318	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
17	.1000	.1369	.1658	.1904	.2121	.2318	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
18	.1000	.1369	.1658	.1904	.2121	.2318	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
19	.1000	.1369	.1658	.1904	.2121	.2318	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
20	.1000	.1369	.1658	.1904	.2121	.2318	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500

TABLE A-XIV. TWENTY-GROUP COVARIANCE MATRIX FOR THE REACTION
FE-NAT(N,N CONTINUUM) ERRORS EVALUATED BY D. W. MUIR, FEB 75.

		GROUP INDEX																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.0225	.0352	.0444	.0520	.0586	.0645	.0700	.0750	.0750	.0750	.0750	.0750	.0750	.0750	.0750	.0750	.0750	.0750	.0750	.0750
2	.0352	.0550	.0694	.0812	.0916	.1009	.1094	.1173	.1173	.1173	.1173	.1173	.1173	.1173	.1173	.1173	.1173	.1173	.1173	.1173
3	.0444	.0694	.0875	.1025	.1155	.1272	.1389	.1479	.1479	.1479	.1479	.1479	.1479	.1479	.1479	.1479	.1479	.1479	.1479	.1479
4	.0520	.0812	.1025	.1200	.1353	.1490	.1616	.1732	.1732	.1732	.1732	.1732	.1732	.1732	.1732	.1732	.1732	.1732	.1732	.1732
5	.0586	.0916	.1155	.1353	.1525	.1680	.1821	.1953	.1953	.1953	.1953	.1953	.1953	.1953	.1953	.1953	.1953	.1953	.1953	.1953
6	.0645	.1009	.1272	.1490	.1680	.1850	.2006	.2151	.2151	.2151	.2151	.2151	.2151	.2151	.2151	.2151	.2151	.2151	.2151	.2151
7	.0700	.1094	.1389	.1616	.1821	.2006	.2175	.2332	.2332	.2332	.2332	.2332	.2332	.2332	.2332	.2332	.2332	.2332	.2332	.2332
8	.0750	.1173	.1479	.1732	.1953	.2151	.2332	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
9	.0750	.1173	.1479	.1732	.1953	.2151	.2332	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
10	.0750	.1173	.1479	.1732	.1953	.2151	.2332	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
11	.0750	.1173	.1479	.1732	.1953	.2151	.2332	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
12	.0750	.1173	.1479	.1732	.1953	.2151	.2332	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
13	.0750	.1173	.1479	.1732	.1953	.2151	.2332	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
14	.0750	.1173	.1479	.1732	.1953	.2151	.2332	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
15	.0750	.1173	.1479	.1732	.1953	.2151	.2332	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
16	.0750	.1173	.1479	.1732	.1953	.2151	.2332	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
17	.0750	.1173	.1479	.1732	.1953	.2151	.2332	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
18	.0750	.1173	.1479	.1732	.1953	.2151	.2332	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
19	.0750	.1173	.1479	.1732	.1953	.2151	.2332	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
20	.0750	.1173	.1479	.1732	.1953	.2151	.2332	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500

TABLE A-XV. TWENTY-GROUP COVARIANCE MATRIX FOR THE REACTION
PB-NAT(N,2N) ERRORS EVALUATED BY D. W. MUIR, FEB 75.

[illegible]

TABLE A-XVI. TWENTY-GROUP COVARIANCE MATRIX FOR THE REACTION
 $Fe-NaT(N-TOT)$ ERRORS EVALUATED BY V. ORPHAN, 20 JUN 1975

	GROUP INDEX																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.0010	.0012	.0010	.0008	.0007	.0006	.0005	.0004	.0004	.0001	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003
2	.0012	.0010	.0013	.0010	.0009	.0007	.0006	.0005	.0005	.0004	.0004	.0004	.0004	.0004	.0004	.0004	.0004	.0004	.0003	.0003
3	.0010	.0013	.0016	.0013	.0011	.0009	.0008	.0007	.0006	.0004	.0005	.0005	.0005	.0005	.0005	.0005	.0005	.0005	.0004	.0004
4	.0008	.0010	.0013	.0016	.0013	.0011	.0010	.0009	.0008	.0007	.0007	.0007	.0006	.0006	.0006	.0006	.0006	.0006	.0005	.0005
5	.0007	.0009	.0011	.0013	.0016	.0013	.0012	.0010	.0009	.0008	.0008	.0008	.0007	.0007	.0007	.0007	.0007	.0007	.0006	.0006
6	.0006	.0007	.0009	.0011	.0013	.0016	.0014	.0012	.0011	.0011	.0009	.0009	.0009	.0008	.0008	.0008	.0008	.0008	.0007	.0007
7	.0005	.0006	.0008	.0010	.0012	.0014	.0016	.0014	.0013	.0012	.0011	.0010	.0010	.0009	.0009	.0009	.0008	.0008	.0008	.0007
8	.0004	.0005	.0007	.0009	.0010	.0012	.0014	.0017	.0015	.0014	.0013	.0012	.0011	.0011	.0011	.0010	.0010	.0009	.0009	.0008
9	.0004	.0005	.0006	.0008	.0009	.0011	.0013	.0015	.0018	.0019	.0015	.0014	.0013	.0013	.0012	.0011	.0011	.0011	.0010	.0010
10	.0003	.0004	.0006	.0007	.0008	.0010	.0012	.0014	.0016	.0016	.0017	.0016	.0015	.0014	.0014	.0014	.0013	.0013	.0012	.0011
11	.0003	.0004	.0005	.0007	.0008	.0009	.0011	.0013	.0015	.0017	.0020	.0018	.0017	.0016	.0016	.0015	.0014	.0014	.0013	.0013
12	.0003	.0004	.0005	.0007	.0008	.0009	.0010	.0012	.0014	.0016	.0018	.0020	.0019	.0018	.0018	.0017	.0016	.0016	.0015	.0014
13	.0003	.0004	.0005	.0006	.0007	.0009	.0010	.0011	.0013	.0015	.0017	.0019	.0021	.0020	.0020	.0019	.0018	.0017	.0016	.0016
14	.0003	.0004	.0005	.0006	.0007	.0008	.0009	.0011	.0013	.0014	.0016	.0018	.0020	.0022	.0021	.0020	.0020	.0019	.0018	.0017
15	.0003	.0004	.0005	.0006	.0007	.0008	.0009	.0011	.0012	.0014	.0016	.0018	.0020	.0021	.0023	.0022	.0022	.0021	.0020	.0019
16	.0003	.0004	.0005	.0006	.0007	.0008	.0009	.0010	.0011	.0012	.0015	.0017	.0019	.0020	.0022	.0024	.0023	.0022	.0021	.0020
17	.0003	.0004	.0005	.0006	.0007	.0008	.0008	.0010	.0011	.0012	.0014	.0016	.0018	.0020	.0022	.0023	.0025	.0024	.0023	.0022
18	.0003	.0004	.0005	.0005	.0006	.0007	.0008	.0009	.0011	.0012	.0014	.0016	.0017	.0019	.0021	.0022	.0024	.0025	.0024	.0023
19	.0003	.0003	.0004	.0004	.0005	.0006	.0007	.0008	.0009	.0010	.0011	.0013	.0015	.0016	.0018	.0020	.0021	.0023	.0024	.0024
20	.0003	.0003	.0004	.0004	.0005	.0006	.0007	.0007	.0008	.0010	.0011	.0013	.0014	.0016	.0017	.0019	.0020	.0022	.0023	.0024

TABLE A-4V11. Tenthry-Group Covariance Matrix for the Prediction
FE-NAT(40ELAS) FIELDS EVALUATED BY V. OMPHANO, 20 JUN 1975

GROUP INDEX																			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.0100	.0077	.0061	.0050	.0041	.0035	.0030	.0025	.0021	.0017	.0016	.0015	.0014	.0013	.0011	.0010	.0009	.0008	.0008
2	.0077	.0103	.0090	.0075	.0065	.0059	.0053	.0047	.0042	.0037	.0036	.0035	.0034	.0033	.0031	.0030	.0029	.0028	.0028
3	.0061	.0090	.0100	.0081	.0069	.0057	.0049	.0043	.0038	.0033	.0032	.0031	.0030	.0029	.0027	.0026	.0025	.0024	.0024
4	.0050	.0075	.0081	.0100	.0081	.0070	.0060	.0050	.0042	.0037	.0036	.0035	.0034	.0033	.0031	.0030	.0029	.0028	.0028
5	.0041	.0065	.0069	.0081	.0100	.0085	.0072	.0061	.0051	.0044	.0043	.0042	.0041	.0040	.0038	.0037	.0036	.0035	.0035
6	.0035	.0059	.0057	.0070	.0085	.0100	.0086	.0072	.0061	.0051	.0044	.0043	.0042	.0041	.0039	.0038	.0037	.0036	.0036
7	.0030	.0053	.0049	.0060	.0072	.0086	.0100	.0084	.0071	.0060	.0053	.0047	.0046	.0045	.0043	.0042	.0041	.0040	.0040
8	.0025	.0047	.0043	.0053	.0061	.0072	.0084	.0094	.0079	.0068	.0059	.0053	.0052	.0051	.0049	.0048	.0047	.0046	.0046
9	.0021	.0037	.0033	.0042	.0051	.0061	.0071	.0079	.0087	.0076	.0066	.0059	.0058	.0057	.0055	.0054	.0053	.0052	.0052
10	.0017	.0033	.0029	.0038	.0047	.0057	.0067	.0074	.0082	.0090	.0080	.0073	.0072	.0071	.0069	.0068	.0067	.0066	.0066
11	.0016	.0033	.0029	.0038	.0047	.0057	.0067	.0074	.0082	.0090	.0098	.0088	.0081	.0080	.0079	.0078	.0077	.0076	.0076
12	.0015	.0033	.0029	.0038	.0047	.0057	.0067	.0074	.0082	.0090	.0098	.0096	.0094	.0093	.0092	.0091	.0090	.0089	.0089
13	.0014	.0033	.0029	.0038	.0047	.0057	.0067	.0074	.0082	.0090	.0098	.0096	.0094	.0093	.0092	.0091	.0090	.0089	.0089
14	.0013	.0033	.0029	.0038	.0047	.0057	.0067	.0074	.0082	.0090	.0098	.0096	.0094	.0093	.0092	.0091	.0090	.0089	.0089
15	.0013	.0033	.0029	.0038	.0047	.0057	.0067	.0074	.0082	.0090	.0098	.0096	.0094	.0093	.0092	.0091	.0090	.0089	.0089
16	.0011	.0033	.0029	.0038	.0047	.0057	.0067	.0074	.0082	.0090	.0098	.0096	.0094	.0093	.0092	.0091	.0090	.0089	.0089
17	.0010	.0033	.0029	.0038	.0047	.0057	.0067	.0074	.0082	.0090	.0098	.0096	.0094	.0093	.0092	.0091	.0090	.0089	.0089
18	.0009	.0033	.0029	.0038	.0047	.0057	.0067	.0074	.0082	.0090	.0098	.0096	.0094	.0093	.0092	.0091	.0090	.0089	.0089
19	.0008	.0033	.0029	.0038	.0047	.0057	.0067	.0074	.0082	.0090	.0098	.0096	.0094	.0093	.0092	.0091	.0090	.0089	.0089
20	.0008	.0033	.0029	.0038	.0047	.0057	.0067	.0074	.0082	.0090	.0098	.0096	.0094	.0093	.0092	.0091	.0090	.0089	.0089

TABLE A-4V11. Tenthry-Group Covariance Matrix for the Prediction
FE-NAT(40ELAS) FIELDS EVALUATED BY V. OMPHANO, 20 JUN 1975

GROUP INDEX																			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.0025	.0073	.0096	.0241	.0273	.0144	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
2	.0073	.0025	.0082	.0051	.0071	.0241	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
3	.0096	.0082	.0025	.0082	.0096	.0051	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
4	.0241	.0051	.0082	.0109	.0065	.0044	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
5	.0273	.0071	.0096	.0065	.0012	.0029	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
6	.0144	.0241	.0082	.0044	.0029	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
7	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
8	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
9	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
10	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
11	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
12	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
13	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
14	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
15	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
16	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
17	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
18	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
19	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
20	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000

TABLE A-112. Factor-Product Correlation Matrix for the Recession
(1960-1970)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1.0000	.8224	.8503	.8123	.8374	.8532	.8452	.8312	.8283	.8215	.8203	.8104	.8125	.8111	.8091	.8075	.8061	.8050	.8041	.8030
2	.8224	1.0000	.8314	.8101	.8368	.8270	.8236	.8022	.8003	.8041	.8031	.8271	.8272	.8191	.8142	.8122	.8100	.8081	.8067	.8055
3	.8503	.8314	1.0000	.8372	.8244	.8207	.8036	.8019	.8012	.8010	.8009	.8227	.8227	.8154	.8094	.8070	.8044	.8024	.8004	.8000
4	.8123	.8101	.8372	1.0000	.8400	.8363	.8000	.8000	.8000	.8000	.8000	.8214	.8214	.8141	.8081	.8057	.8031	.8011	.8000	.8000
5	.8374	.8270	.8244	.8400	1.0000	.8363	.8000	.8000	.8000	.8000	.8000	.8214	.8214	.8141	.8081	.8057	.8031	.8011	.8000	.8000
6	.8532	.8452	.8363	.8363	.8363	1.0000	.8000	.8000	.8000	.8000	.8000	.8214	.8214	.8141	.8081	.8057	.8031	.8011	.8000	.8000
7	.8312	.8022	.8019	.8000	.8000	.8000	1.0000	.8000	.8000	.8000	.8000	.8214	.8214	.8141	.8081	.8057	.8031	.8011	.8000	.8000
8	.8283	.8003	.8012	.8000	.8000	.8000	.8000	1.0000	.8000	.8000	.8000	.8214	.8214	.8141	.8081	.8057	.8031	.8011	.8000	.8000
9	.8215	.8041	.8010	.8000	.8000	.8000	.8000	.8000	1.0000	.8000	.8000	.8214	.8214	.8141	.8081	.8057	.8031	.8011	.8000	.8000
10	.8203	.8031	.8009	.8000	.8000	.8000	.8000	.8000	.8000	1.0000	.8000	.8214	.8214	.8141	.8081	.8057	.8031	.8011	.8000	.8000
11	.8104	.8125	.8111	.8104	.8104	.8104	.8104	.8104	.8104	.8104	1.0000	.8214	.8214	.8141	.8081	.8057	.8031	.8011	.8000	.8000
12	.8125	.8125	.8125	.8125	.8125	.8125	.8125	.8125	.8125	.8125	.8125	1.0000	.8214	.8214	.8141	.8081	.8057	.8031	.8011	.8000
13	.8111	.8142	.8154	.8141	.8141	.8141	.8141	.8141	.8141	.8141	.8141	.8141	1.0000	.8214	.8214	.8141	.8081	.8057	.8031	.8011
14	.8091	.8075	.8094	.8081	.8081	.8081	.8081	.8081	.8081	.8081	.8081	.8081	.8081	1.0000	.8214	.8214	.8141	.8081	.8057	.8031
15	.8075	.8061	.8070	.8057	.8057	.8057	.8057	.8057	.8057	.8057	.8057	.8057	.8057	.8057	1.0000	.8214	.8214	.8141	.8081	.8057
16	.8061	.8050	.8044	.8031	.8031	.8031	.8031	.8031	.8031	.8031	.8031	.8031	.8031	.8031	.8031	1.0000	.8214	.8214	.8141	.8081
17	.8050	.8041	.8030	.8011	.8011	.8011	.8011	.8011	.8011	.8011	.8011	.8011	.8011	.8011	.8011	.8011	1.0000	.8214	.8214	.8141
18	.8041	.8030	.8024	.8004	.8004	.8004	.8004	.8004	.8004	.8004	.8004	.8004	.8004	.8004	.8004	.8004	.8004	1.0000	.8214	.8214
19	.8030	.8024	.8004	.8000	.8000	.8000	.8000	.8000	.8000	.8000	.8000	.8000	.8000	.8000	.8000	.8000	.8000	.8000	1.0000	.8214
20	.8024	.8011	.8000	.8000	.8000	.8000	.8000	.8000	.8000	.8000	.8000	.8000	.8000	.8000	.8000	.8000	.8000	.8000	.8000	1.0000

TABLE A-113. Factor-Product Correlation Matrix for the Recession
(1960-1970)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	1.0000	.8545	.8624	.8725	.8724	.8781	.8161	.8131	.8187	.8444	.8874	.8880	.8500	.8880	.8880	.8880	.8880	.8880	.8880	.8880
2	.8545	1.0000	.8642	.8644	.8644	.8644	.8314	.8275	.8213	.8174	.814	.8123	.8095	.8070	.8060	.8060	.8060	.8060	.8060	.8060
3	.8624	.8642	1.0000	.8644	.8644	.8644	.8314	.8275	.8213	.8174	.814	.8123	.8095	.8070	.8060	.8060	.8060	.8060	.8060	.8060
4	.8725	.8644	.8644	1.0000	.8644	.8644	.8314	.8275	.8213	.8174	.814	.8123	.8095	.8070	.8060	.8060	.8060	.8060	.8060	.8060
5	.8724	.8644	.8644	.8644	1.0000	.8644	.8314	.8275	.8213	.8174	.814	.8123	.8095	.8070	.8060	.8060	.8060	.8060	.8060	.8060
6	.8781	.8314	.8275	.8275	.8275	1.0000	.8644	.8314	.8275	.8213	.8174	.814	.8123	.8095	.8070	.8060	.8060	.8060	.8060	.8060
7	.8161	.8275	.8275	.8275	.8275	.8314	1.0000	.8644	.8314	.8275	.8213	.8174	.814	.8123	.8095	.8070	.8060	.8060	.8060	.8060
8	.8131	.8213	.8213	.8213	.8213	.8275	.8314	1.0000	.8644	.8314	.8275	.8213	.8174	.814	.8123	.8095	.8070	.8060	.8060	.8060
9	.8187	.8174	.8174	.8174	.8174	.8213	.8275	.8314	1.0000	.8644	.8314	.8275	.8213	.8174	.814	.8123	.8095	.8070	.8060	.8060
10	.8444	.8444	.8444	.8444	.8444	.8444	.8444	.8444	.8444	1.0000	.8644	.8314	.8275	.8213	.8174	.814	.8123	.8095	.8070	.8060
11	.8874	.8880	.8880	.8880	.8880	.8880	.8880	.8880	.8880	.8880	1.0000	.8644	.8314	.8275	.8213	.8174	.814	.8123	.8095	.8070
12	.8880	.8880	.8880	.8880	.8880	.8880	.8880	.8880	.8880	.8880	.8880	1.0000	.8644	.8314	.8275	.8213	.8174	.814	.8123	.8095
13	.8500	.8095	.8095	.8095	.8095	.8095	.8095	.8095	.8095	.8095	.8095	.8095	1.0000	.8644	.8314	.8275	.8213	.8174	.814	.8123
14	.8880	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	1.0000	.8644	.8314	.8275	.8213	.8174	.814
15	.8880	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	1.0000	.8644	.8314	.8275	.8213	.8174
16	.8880	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	1.0000	.8644	.8314	.8275	.8213
17	.8880	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	1.0000	.8644	.8314	.8275
18	.8880	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	1.0000	.8644	.8314
19	.8880	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	1.0000	.8644
20	.8880	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	.8060	1.0000

TABLE 3-131. T-EXIV-GROUP COVARIANCE MATRIX FOR THE REACTION
COMBUSTION (TOT) ERRORS (EVALUATED BY V. OGDEN, 20 JAN 1975)

[illegible]

TABLE 4-111. TABLE-GROUP COEFFICIENT MAINIA FOR THE REACTION
CUMENATIONELAS: ER-GHS EVALUATED BY V. GRPANO, 20 JUN 1975

	GROUP INDEX																			
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	.0036	.0024	.0017	.0013	.0010	.0009	.0007	.0006	.0005	.0011	.0004	.0003	.0003	.0003	.0003	.0002	.0002	.0002	.0002	.0002
2	.0024	.0036	.0026	.0020	.0014	.0013	.0011	.0009	.0008	.0011	.0006	.0005	.0005	.0005	.0005	.0004	.0004	.0004	.0004	.0004
3	.0017	.0026	.0036	.0028	.0022	.0018	.0015	.0013	.0011	.0011	.0009	.0008	.0008	.0007	.0007	.0006	.0006	.0006	.0006	.0006
4	.0013	.0020	.0028	.0036	.0029	.0024	.0020	.0017	.0015	.0011	.0011	.0011	.0010	.0010	.0009	.0009	.0008	.0008	.0008	.0008
5	.0010	.0014	.0022	.0029	.0036	.0030	.0025	.0021	.0018	.0011	.0014	.0014	.0013	.0012	.0012	.0011	.0011	.0011	.0010	.0010
6	.0008	.0013	.0018	.0024	.0030	.0036	.0030	.0026	.0023	.0021	.0018	.0017	.0016	.0015	.0014	.0014	.0013	.0013	.0013	.0013
7	.0007	.0011	.0015	.0020	.0025	.0030	.0036	.0031	.0027	.0021	.0020	.0019	.0018	.0017	.0016	.0016	.0016	.0016	.0016	.0016
8	.0006	.0009	.0013	.0017	.0021	.0026	.0031	.0036	.0031	.0021	.0024	.0023	.0022	.0021	.0020	.0019	.0018	.0019	.0018	.0018
9	.0005	.0008	.0011	.0015	.0018	.0023	.0027	.0031	.0036	.0031	.0028	.0027	.0026	.0024	.0023	.0022	.0021	.0021	.0021	.0021
10	.0004	.0007	.0010	.0013	.0016	.0020	.0024	.0028	.0032	.0031	.0032	.0030	.0029	.0028	.0027	.0025	.0024	.0025	.0024	.0024
11	.0004	.0006	.0009	.0011	.0014	.0018	.0021	.0024	.0028	.0031	.0036	.0034	.0033	.0031	.0030	.0029	.0027	.0028	.0028	.0028
12	.0003	.0005	.0008	.0011	.0014	.0017	.0020	.0023	.0027	.0031	.0034	.0041	.0039	.0037	.0035	.0034	.0033	.0033	.0033	.0033
13	.0003	.0005	.0008	.0010	.0013	.0016	.0019	.0022	.0026	.0021	.0033	.0039	.0045	.0043	.0041	.0040	.0038	.0039	.0039	.0038
14	.0003	.0005	.0007	.0010	.0012	.0015	.0018	.0021	.0024	.0021	.0031	.0037	.0043	.0050	.0048	.0046	.0044	.0044	.0045	.0044
15	.0003	.0005	.0007	.0009	.0012	.0014	.0017	.0020	.0023	.0021	.0030	.0035	.0041	.0048	.0055	.0052	.0050	.0051	.0051	.0051
16	.0002	.0004	.0006	.0009	.0011	.0014	.0016	.0019	.0022	.0021	.0029	.0034	.0040	.0046	.0052	.0059	.0057	.0058	.0058	.0057
17	.0002	.0004	.0006	.0008	.0011	.0013	.0016	.0018	.0021	.0021	.0027	.0033	.0038	.0044	.0050	.0057	.0064	.0065	.0065	.0065
18	.0002	.0004	.0006	.0008	.0011	.0013	.0016	.0019	.0021	.0021	.0028	.0033	.0039	.0044	.0051	.0058	.0065	.0076	.0076	.0076
19	.0002	.0004	.0006	.0008	.0010	.0013	.0016	.0018	.0021	.0021	.0028	.0033	.0039	.0045	.0051	.0058	.0065	.0076	.0088	.0088
20	.0002	.0004	.0006	.0008	.0010	.0013	.0016	.0018	.0021	.0021	.0028	.0033	.0039	.0044	.0051					

TABLE A-XXIII. TWENTY-GROUP COVARIANCE MATRIX FOR THE REACTION
CU-NATIN (INEL) ERRORS (EVALUATED BY V. ORPHAN, 28 JUN 1975)

		GROUP INDEX																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1		.0225	.0136	.0043	.0050	.0030	.0021	.0014	.0009	.0006	.0000	.0003	.0001	.0001	.0001	.0000	.0000	.0000	.0000	.0000	.0000
2		.0136	.0225	.0136	.0083	.0050	.0035	.0023	.0015	.0010	.0007	.0004	.0003	.0001	.0001	.0001	.0000	.0000	.0000	.0000	.0000
3		.0043	.0136	.0225	.0136	.0083	.0057	.0038	.0025	.0017	.0011	.0007	.0004	.0003	.0001	.0001	.0001	.0000	.0000	.0000	.0000
4		.0050	.0083	.0136	.0225	.0136	.0094	.0063	.0042	.0027	.0017	.0011	.0007	.0004	.0003	.0001	.0001	.0001	.0000	.0000	.0000
5		.0030	.0050	.0043	.0136	.0225	.0155	.0105	.0069	.0045	.0024	.0019	.0011	.0007	.0004	.0003	.0001	.0001	.0001	.0000	.0000
6		.0021	.0035	.0057	.0094	.0155	.0292	.0196	.0136	.0085	.0051	.0035	.0021	.0013	.0008	.0005	.0003	.0002	.0001	.0001	.0000
7		.0014	.0023	.0038	.0063	.0105	.0196	.0358	.0237	.0154	.0101	.0064	.0039	.0024	.0014	.0009	.0005	.0003	.0002	.0001	.0001
8		.0009	.0015	.0025	.0042	.0069	.0136	.0237	.0425	.0277	.0171	.0115	.0070	.0042	.0026	.0016	.0009	.0006	.0003	.0002	.0001
9		.0006	.0010	.0017	.0027	.0045	.0085	.0154	.0277	.0492	.0311	.0204	.0124	.0075	.0045	.0028	.0017	.0010	.0006	.0003	.0002
10		.0000	.0007	.0011	.0018	.0029	.0055	.0100	.0179	.0318	.0551	.0358	.0217	.0132	.0080	.0048	.0029	.0018	.0010	.0006	.0003
11		.0003	.0004	.0007	.0011	.0019	.0035	.0064	.0115	.0204	.0351	.0625	.0379	.0230	.0140	.0085	.0051	.0031	.0018	.0010	.0006
12		.0001	.0003	.0004	.0007	.0011	.0021	.0039	.0070	.0124	.0211	.0379	.0625	.0379	.0230	.0140	.0085	.0051	.0029	.0016	.0009
13		.0001	.0001	.0003	.0004	.0007	.0013	.0024	.0042	.0075	.0131	.0230	.0379	.0625	.0379	.0230	.0140	.0085	.0048	.0027	.0015
14		.0001	.0001	.0001	.0003	.0004	.0008	.0014	.0026	.0045	.0081	.0140	.0230	.0379	.0625	.0379	.0230	.0140	.0079	.0045	.0025
15		.0000	.0001	.0001	.0001	.0003	.0005	.0009	.0016	.0028	.0041	.0085	.0140	.0230	.0379	.0625	.0379	.0230	.0131	.0074	.0041
16		.0000	.0000	.0001	.0001	.0001	.0003	.0005	.0009	.0017	.0021	.0051	.0085	.0140	.0230	.0379	.0625	.0379	.0216	.0122	.0068
17		.0000	.0000	.0000	.0001	.0001	.0002	.0003	.0006	.0010	.0011	.0031	.0051	.0085	.0140	.0230	.0379	.0625	.0356	.0200	.0112
18		.0000	.0000	.0000	.0000	.0000	.0001	.0002	.0003	.0007	.0011	.0018	.0029	.0048	.0079	.0131	.0216	.0356	.0550	.0310	.0173
19		.0000	.0000	.0000	.0000	.0000	.0001	.0001	.0002	.0003	.0008	.0016	.0016	.0027	.0045	.0074	.0122	.0209	.0310	.0475	.0264
20		.0000	.0000	.0000	.0000	.0000	.0000	.0001	.0001	.0002	.0008	.0016	.0019	.0015	.0025	.0041	.0068	.0112	.0173	.0264	.0400

TABLE A-XXIV. TWENTY-GROUP COVARIANCE MATRIX FOR THE REACTION
CU-NAT (N,2N) ERRORS (EVALUATED BY V. ORPHAN, 28 JUN 1975)

		GROUP INDEX																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1		.0225	.0222	.0192	.0221	.0182	.0144	.0114	.0089	.0068	.0051	.0039	.0029	.0022	.0016	.0012	.0009	.0007	.0005	.0004	.0003
2		.0222	.0425	.0369	.0423	.0358	.0280	.0219	.0176	.0130	.0091	.0075	.0056	.0042	.0031	.0023	.0017	.0013	.0009	.0007	.0005
3		.0192	.0369	.0625	.0716	.0592	.0473	.0371	.0287	.0220	.0161	.0126	.0095	.0071	.0053	.0039	.0029	.0022	.0016	.0012	.0009
4		.0221	.0423	.0716	.1600	.1321	.1057	.0829	.0641	.0491	.0371	.0282	.0212	.0158	.0118	.0088	.0065	.0048	.0036	.0026	.0019
5		.0182	.0350	.0592	.1321	.2125	.1700	.1334	.1031	.0790	.0600	.0453	.0340	.0255	.0190	.0141	.0105	.0078	.0057	.0042	.0031
6		.0144	.0280	.0473	.1057	.1700	.2650	.2978	.1608	.1231	.0931	.0706	.0531	.0397	.0296	.0226	.0163	.0121	.0089	.0066	.0048
7		.0114	.0219	.0371	.0829	.1334	.2078	.3175	.2456	.1880	.1421	.1079	.0810	.0607	.0452	.0336	.0249	.0184	.0136	.0101	.0074
8		.0089	.0170	.0287	.0641	.1031	.1608	.2456	.3700	.2833	.2151	.1625	.1221	.0914	.0681	.0507	.0376	.0270	.0205	.0151	.0111
9		.0068	.0130	.0220	.0491	.0790	.1231	.1880	.2833	.4225	.3211	.2424	.1821	.1363	.1016	.0755	.0560	.0415	.0306	.0226	.0166
10		.0051	.0091	.0167	.0373	.0600	.0935	.1429	.2152	.3210	.4751	.3587	.2695	.2016	.1504	.1118	.0829	.0613	.0453	.0334	.0246
11		.0039	.0075	.0126	.0282	.0453	.0706	.1079	.1625	.2424	.3581	.5275	.3963	.2966	.2211	.1644	.1219	.0902	.0666	.0491	.0362
12		.0029	.0056	.0095	.0212	.0340	.0531	.0810	.1221	.1821	.2695	.3963	.5800	.4340	.3236	.2406	.1784	.1320	.0975	.0719	.0529
13		.0022	.0042	.0071	.0158	.0255	.0397	.0607	.0914	.1363	.2016	.2966	.4340	.6325	.4716	.3507	.2600	.1924	.1421	.1048	.0771
14		.0016	.0031	.0053	.0116	.0190	.0296	.0452	.0681	.1016	.1504	.2211	.3236	.4716	.6850	.5093	.3777	.2795	.2064	.1522	.1120
15		.0012	.0023	.0039	.0088	.0141	.0220	.0336	.0507	.0755	.1111	.1644	.2406	.3507	.5093	.7375	.5469	.4047	.2989	.2203	.1622
16		.0009	.0017	.0029	.0065	.0105	.0163	.0249	.0376	.0560	.0821	.1219	.1784	.2600	.3777	.5469	.7900	.5846	.4317	.3183	.2343
17		.0007	.0013	.0022	.0048	.0078	.0121	.0184	.0278	.0415	.0611	.0902	.1320	.1924	.2795	.4047	.5846	.8425	.6222	.4587	.3377
18		.0005	.0009	.0016	.0036	.0057	.0089	.0136	.0205	.0306	.0451	.0666	.0975	.1421	.2064	.2989	.4317	.6222	.8950	.6598	.4857
19		.0004	.0007	.0012	.0026	.0042	.0066	.0101	.0151	.0226	.0334	.0491	.0719	.1048	.1522	.2203	.3183	.4587	.6598	.9475	.6975
20		.0003	.0005	.0009	.0019	.0031	.0048	.0074	.0111	.0166	.0246	.0362	.0529	.0771	.1120	.1622	.2343	.3377	.4857	.6975	.9999

GROUP DATA																			
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

APPENDIX B CROSS-SECTION SENSITIVITY PROFILES

Figures B-I through B-X show the sensitivity profiles for the total neutron cross sections of all ten transport cross-section sets employed in our nuclear analysis of the TFR. According to the definition for P_{Σ_1} , Eq. (10), a sensitivity profile has been plotted by SENSIT-ID³⁰ for every cross section (total and partials) in the system, and for every response function R considered. For brevity we print in this report only those cross-section sensitivity profiles which apply to response functions showing largest integral sensitivities, as listed and circled in Table III. We also restrict ourselves to the total cross sections of an element rather than plotting the profiles for all partial cross sections contributing to the total.

All sensitivity profiles shown in Figs. B-I through B-X represent the sum of a loss-term and a gain-term:^{8,9}

$$P_{\Sigma_1} = -P_{\Sigma_{1,loss}}^{tot} + P_{\Sigma_{1,gain}}^{scat}$$

$P_{\Sigma_{1,loss}}^{tot}$ represents the sensitivity due to collision losses and is calculated from Eq. (10) with $L_{\Sigma_1} = \Sigma_1^{tot}$, while $P_{\Sigma_{1,gain}}^{scat}$ represents the increase in sensitivity due to scattering of neutrons into the energy group 1, and is calculated from Eq. (10) with L_{Σ_1} being the scattering integral operator of the transport equation. All sensitivity profiles are plotted per lethargy width

$$\Delta u_1 = \ln \frac{E_1}{E_{1+1}},$$

which, for our 20-group structure, is constant and equal to 0.1. The dashes (for negative sensitivities) and dots (for positive sensitivities) mark the group upper energy boundaries in the computer plots. These marks could be extended horizontally to the group lower energy boundaries if histograms for the sensitivity profiles were desired. All values with $|P_{\Sigma_1}| \leq 10^{-3}$ are plotted on the abscissa.

The sensitivity profiles for the ten activation cross sections used as response-functions R_i in this report are given in Figs. B-XI through B-XX. The plots are again per lethargy width, i.e., Eq.

(10a) is divided by $\Delta u_i = 0.1$ for every energy group, to remove the arbitrariness of the group structure from the plots.

Fig. B-II

TFTR-SENSITIVITY-RUN 101- R1 IN 29. LEAD IN 27

Fig. B-III

TFTR-SENSITIVITY-RUN 101- R1 IN 29. OXYGEN IN 27

Fig. B-IV

TFTR-SENSITIVITY=RUN 101+ R1 IN 29. HYDROGEN IN 27

Fig. B-V

TFTR-SENSITIVITY=RUN 120+ R10 IN 210. IRON IN 29

Fig. 3-VI

TFTR-SENSITIVITY-RUN 120-R10 IN Z10. CHROME IN Z9

Fig. 3-VII

TFTR-SENSITIVITY-RUN 120-R10 IN Z10. NICKEL IN Z9

Fig. B-VIII

TFTR-SENSITIVITY=RUN 120= R10 IN Z10. MANGAN. IN Z9

Fig. B-IX

TFTR-SENSITIVITY=RUN 120= R10 IN Z10. ALUMINUM IN Z9

Fig. B-X

TFTR-SENSITIVITY=RUN 130+ R10 IN Z10-COPPER IN Z10

Fig. B-XI

TFTR-SENSITIVITY=RUN 101+ R1 IN Z9.

Fig. B-XII

TFTR-SENSITIVITY-RUN 102- R2 IN 29.

Fig. B-XIII

TFTR-SENSITIVITY-RUN 103- R3 IN 29.

FIG. B-XV

FIG. B-XIV

Fig. B-XVI

TPTR-SENSITIVITY-RUN 106- R6 IN 29.

Fig. B-XVII

TPTR-SENSITIVITY-RUN 107- R7 IN 210.

Fig. B-XVIII

Fig. B-XIX

Fig. D-XX

WTR-SENSITIVITY-RUN 110- N10 IN 210.