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THE RFSP PROGRAMME FOR UNFOLDING NEUTRON SPECTRA FROM ACTIVATION DATA

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ABSTRACT

The authors describe the RFSP programme for unfolding neutron spectra from activation data. With spectra satisfying the activation equations they use the programme to unfold that spectrum for which the functional characterizing deviations from the initial spectrum is at a minimum. The RFSP programme is an advanced and more rapid version of the SPECTRA code. The results obtained with the codes are identical, but RFSP requires less computer time. In this report the authors describe the algorithm of the method, the input/output specifications and typical results.

I. Introduction

When unfolding neutron spectra from activation data, one measures the integrals

$$A_i = \int_0^\infty \phi(E)\, \sigma_i(E) dE \quad , \qquad /i = 1,2,\ldots,n/ \tag{1}$$

where A_i represents the measured activities of the i-th foil,

$\phi(E)$ is the differential neutron spectrum,

$\sigma_i(E)$ is the cross-section for the reaction occurring during activation of the i-th foil, as a function of energy,

and the spectrum $\phi(E)$ has to be determined for known $\sigma_i(E)$ and A_i.
Since we are here dealing with the solution of mathematically indeterminate systems of equations (the number of points at which the spectrum is determined is greater than the amount of measurement data available to us), certain initial information is required for the solution in addition to the measurement data.

The published theoretical methods differ mainly in the form that this initial information takes; in practice, these methods can be divided into two groups. The first group comprises methods for which it is assumed that one is dealing with a spectrum given in a simple analytical form and that it is only the parameters of the analytical form that are unknown. In the case of the second group, an initial spectrum given in purely numerical form is varied in the course of an iterative process until the activities agree with the measured values.

The method described in this report belongs to the second group. The problem is formulated as follows: the initial spectrum $\phi_o(E)$ is given, and from spectra satisfying the activation equations (i.e. those reproducing the measurement results) we determine the spectrum for which the functional characterizing the difference between the initial spectrum and the derived spectrum is at a minimum.

$$\int_{E_{min}}^{E_{max}} \left[\frac{\phi_o(E) - \phi(E)}{\phi_o(E)} \right]^2 dE = \text{minimum} \tag{2}$$

(E_{min} and E_{max} stand for the energy values above and below which the spectrum is taken as zero). At this point the question arises as to what accuracy should be stipulated when solving the activation equations. If the derived spectrum is required to satisfy the activation equations exactly, the problem can be solved by applying Lagrange's method of multipliers. The cross-sections of the foils used for the measurements (first and foremost those of the threshold detectors) are known only to within ± 10%, so it is not always advisable to stipulate that the activation equations should be satisfied exactly. Greer and co-workers [1] have described an iterative method of which the result agrees with that obtained by using Lagrange's method of multipliers. During the iteration process the spectrum is varied in such a way that the difference between the measured and theoretical activities gradually decreases. The iterations thus result in a spectrum satisfying the activation equations only within the limits of the measurement accuracy (taking into account the degree of indeterminacy of the cross-sections). As will be demonstrated further on, the spectrum derived as the iteration limit may be obtained directly, without iteration, by Greer's method. The question as to which variant is best used in which particular case and the overall questions involved in applying the programme are discussed in Ref. [2].

The method developed by us is a more advanced and faster version of Greer's method.

II. Mathematical principles underlying the RFSP code

1. The problem is to find the spectrum in a form such that the product of the spectrum and energy $E\phi(E)$ is a piecewise linear function of the energy; in such a case, the system of activation equations can be transformed into the matrix equation

$$a = Q\phi \tag{3}$$

where a is a column vector consisting of n elements, the measured activities A_i being the elements;

ϕ is a column vector consisting of m elements, these being the spectrum values sought at individual energy - and hence lethargy - points;

Q is a matrix of size n x m, the elements of which are definite integrals of the cross-sections, m being greater than n (see Appendix I).

If we divide the rows of the matrix Q into the corresponding elements of the vector a, we arrive at the system of equations

$$C\phi = (1_n) \tag{4}$$

where (1_n) is a column vector consisting of n elements, each element being equal to 1.

Assuming an initial spectrum (a vector consisting of m elements) that does not satisfy Eq. (3), let us normalize it so that the sum of the squares of the deviations of the elements of the vector $C\phi_o$ from unity is at a minimum (see Appendix II).

Let us now formulate a function that will characterize the deviations of the measured activities from the activities calculated in the unknown spectrum, on one hand, and of the initial from the unknown spectrum, on the other:

$$\Delta_1 = \left(a_1 - (1_n)\right)^T F^2 \left(a_1 - (1_n)\right) + \left(\phi_1 - \phi_o\right)^T G^2 \left(\phi_1 - \phi_o\right) \qquad (5)$$

where $a_1 = C\phi_1$

G^2 and F^2 are diagonal matrices used for normalization:

$$\det(G) \neq 0 \ , \ \det(F) \neq 0$$

It is advisable, though not essential, to select these matrices in such a way that the elements of the matrix G represent the reciprocals of the corresponding elements of the initial spectrum, while those of the matrix F represent the reciprocals of the relative errors in measuring the activity of the corresponding foils; the superscript T is used to designate the transposition operation.

Let us now attempt to find the spectrum for which this function is at a minimum. To do so we shall differentiate expression (5) with respect to ϕ_1, and then equate it to zero; from which we obtain

$$\phi_1 = \left(C^T F^2 C + G^2\right)^{-1} \left(C^T F^2 (1_n) + G^2 \phi_o\right) \qquad (6)$$

where the superscript -1 is used to designate the matrix inversion operation.

We now introduce the notation

$$\underline{C} = FCG^{-1}$$

$$\text{and } \underline{B} = \left(\underline{C}^T \underline{C} + I\right)^{-1}$$

where this time I designates a unit matrix of the order m. On the basis of a brief computation it can easily be seen that expression (6) now assumes the following form:

$$\phi_1 = G^{-1} \underline{B} \left(\underline{C}^T F(1_n) + G\phi_o\right) \qquad (7)$$

It can be demonstrated (see Appendix III) that the matrix $\partial^2\Delta_1/\partial\phi_1^2=C^TF^2C+G^2$ is positive and therefore transformable; hence, there is a solution of expression (6), and with this solution the function Δ_1 does assume a minimum value. It can also be demonstrated [1] that, if ϕ_o is not a solution of Eq. (3), neither is ϕ_1.

As with expression (5), we can now formulate a new function in which we write ϕ_1 instead of ϕ_o and ϕ_2 instead of ϕ_1. If this process is repeated several times, we arrive, after k steps, at the following expression for the next spectrum approximation:

$$\phi_{k+1} = G^{-1}\,\underline{B}\left(\underline{C}^T F(1_n) + G\,\phi_k\right) \tag{8}$$

Here we have derived a formula which is suitable for the iteration process, and by applying formula (8) several times we obtain progressively better spectrum approximations. These approximations tend to a limit. Further calculations are required for a direct determination of the limit. If we express ϕ_k in Eq. (8) by means of the iteration spectra referred to, we arrive at the expression

$$\phi_{k+1} = G^{-1}\left(I+\underline{B}+\underline{B}^2+\ldots+\underline{B}^k\right)\underline{B}\,\underline{C}^T F(1_n) + G^1\,\underline{B}^{k+1}\,G\phi_o \tag{9}$$

It can be demonstrated (see Appendix III) that, if some vector is an eigenvector of the matrix $\underline{C}^T\underline{C}$ and it has an eigenvalue λ, then this vector is at the same time an eigenvector of the matrix $\underline{B}$, and in this case the eigenvalue is $1/(1+\lambda)$. Since the rank of the matrix $\underline{C}^T\underline{C}$ is equal to n, zero is its m-n-fold eigenvalue. Thus, 1 is the m-n-fold eigenvalue of the matrix $\underline{B}$, while the other eigenvalues lie between 0 and 1 (see Appendix III).

The matrix $\underline{B}$ is symmetric, so that its right-hand and left-hand eigenvectors are identical and it can be written in the form PLP^T, where L is the diagonal matrix containing eigenvalues and P is the matrix containing the orthonormalized eigenvectors as column vectors. Let us arrange the elements of the matrix L in ascending order and let the order of the column vectors in the matrix P follow the same order. Equation (9) can be rewritten in the following form:

$$\phi_{k+1} = G^{-1}\,P\left(I+L+L^2+\ldots+L^k\right)P^T\underline{BC}^T\,F(1_n) + G^{-1}\,PL^{k+1}\,P^TG\phi_o \tag{10}$$

(here we have made use of the identity resulting from the fact that the eigenvectors have been orthonormalized: $P^T = P^{-1}$, so $PP^T = 1$).

Let us determine the limit of this expression for $k \to \infty$. It is easy to determine the limit of the second term: $\lim_{k\to\infty} L^{k+1} = H$, where H represents a diagonal matrix, of which the first n diagonal elements are equal to 0 and the others equal to 1.

To determine the limit of the first term in expression (10) let us look at the matrix product $P^T \underline{BC}^T$. Since the matrix $\underline{B}$ is symmetric, $\underline{B} = \underline{B}^T$, so that $P^T \underline{BC}^T = P^T \underline{B}^T \underline{C}^T = (\underline{CBP})^T$. In the last of the (m-n) columns of the matrix $\underline{CBP}$ there are only zeros (see Appendix IV), so that, if we take the diagonal matrix L_o, the first n elements of which coincide with the corresponding elements of the matrix L, while the other elements are equal to zero, then the following relationship is valid for any k:

$$L^k P^T \underline{BC}^T = L_o^k P^T \underline{BC}^T$$

Consequently, we can everywhere write L_o instead of L in the first term of expression (10) without affecting the result. The limit of the expression in brackets, $(I+L_o+L_o^2+\ldots+L_o^k)$, for $k\to\infty$ can easily be determined; the individual diagonal elements are the sums of infinite geometric series. If in this case, as above, the non-zero eigenvalues of the matrix $\underline{C}^T\underline{C}$ are designated by $\lambda_1, \lambda_2, \ldots, \lambda_n$, then the non-zero diagonal elements of the matrix L_o will be $1/(1+\lambda_1)$, $1/(1+\lambda_2)\ldots$, $1/(1+\lambda_n)$, while the elements of the matrix K corresponding to the limit of the matrix sequence will be $(1+\lambda_1)/\lambda_1$, $(1+\lambda_2)/\lambda_2$, ..., $(1+\lambda_n)/\lambda_n$).

Thus, the spectrum limit for $k \to \infty$ is

$$\phi = \lim_{k\to\infty} \phi_k = G^{-1} PKP^T \underline{BC}^T F(1_n) + G^{-1} PHP^T G\phi_o \qquad (11)$$

It can be demonstrated that this spectrum satisfies either Eq. (3) or Eq. (4) and agrees with the solution obtained by Lagrange's method of multipliers; i.e. for this spectrum the integral (2) does assume its minimum value. However, the proof is complicated and, as it is fully described in Ref. [1], we do not include it here.

2. Complicated and laborious matrix operations are required to determine the limit by means of Eq. (11). Later on we shall show that there is a simpler but rapid method of determining it. By appropriate conversion of the iteration formula one obtains a formula with which, after only one iteration, one can find the limit with the desired accuracy (if necessary, the convergence rate can be adjusted to the desired value).

Let us write the result of the first iteration and the limit expression of the iteration process, with the restriction that matrix G contains the reciprocals of the initial spectrum ϕ_o; the diagonal elements of matrix G^{-1} then coincide with the elements of the vector ϕ_o. The fact that the problem concerns a diagonal matrix rather than a vector is underscored by designating the matrix by ϕ_o^M. In this case, the product $G\phi_o$ appearing in Eqs (7) and (11) is a column vector with each element equal to unity. We will denote this vector by (1_m). Formulas (7) and (11) can then be written in the following form:

$$\phi_1 = \phi_o^M\left(PIP^T\underline{B}^T\underline{C}^TF(1_n) + PLP^T(1_m)\right) \tag{12}$$

$$\phi = \phi_o^M\left(PKP^T\underline{B}^T\underline{C}^TF(1_n) + PHP^T(1_m)\right) \tag{13}$$

The difference between the two spectra is

$$\phi - \phi_1 = \phi_o^M\left(P\left(L_o+L_o^2+\ldots\right)\ P^T\underline{B}^T\underline{C}^TF(1_n) + P(H-L)\ P^T(1_m)\right) \tag{14}$$

Further on we will describe a method by means of which, without affecting the flux ϕ, the difference $\phi - \phi_1$ can be reduced in such a way that the flux can be derived with sufficient accuracy after only one iterative step.

Let us go back to Eq. (4). Physically, this equation means that, when multiplied by the corresponding cross-sections, the flux should give the measured activities. If both sides of the equation - i.e. all the elements of the matrix C and of the vector (1_n) - are multiplied by the same number ω, there will be no change in the physical meaning of the equation; i.e. the spectrum obtained as the iteration limit remains unchanged. This operation comes to the same thing as writing $C' = \omega\,\underline{C}$ in Eqs (5)-(14) instead of the matrix C, $\underline{B}' = (\underline{C}'^T\underline{C}'+1)^{-1}$ instead of $\underline{B}$, and the column vector (ω_n) - all the elements of which are equal to ω - instead of the vector (1_n).

If we multiply all the elements of some matrix by the same number, the eigenvectors of the matrix remain unchanged, while the eigenvalues are multiplied by the same number. Having multiplied the matrix $\underline{C}$ by ω, we multiply each element of the matrix $\underline{C}^T\underline{C}$ by ω^2; accordingly, the eigenvalues of $\underline{C}'^T\underline{C}'$ will be ω^2-fold values of the eigenvalues of $\underline{C}^T\underline{C}$, and the eigenvalues of $\underline{B}'$ will therefore be $1/(1+\omega^2\lambda_i)/i=1, 2, \ldots n/$. As was pointed out, the introduction of these changes does not affect ϕ, but ϕ_1, and therefore $\phi - \phi_1$, are changed. In this case the difference will be

$$\phi - \phi_1' = \phi_o^M \left[P\left(L_o' + L_o'^2 + \ldots\right) P^T \underline{B}'^T \underline{C}'^T F(\omega_n) + P(H-L')\ P^T(1_m) \right] \tag{15}$$

where the matrix L' contains all the eigenvalues of $\underline{B}'$, while the matrix L_o' contains only the first n of these values.

After multiplication and addition, the square brackets in Eq. (15) contain one column vector of m elements. As this column vector is multiplied from the left by the diagonal matrix ϕ_o^M, any element of the column vector can be multiplied by only one corresponding element of the initial spectrum; each element of the column vector $\phi - \phi_1'$ is therefore obtained as a result of only <u>one</u> multiplication of this kind.

In Appendix V it is demonstrated that for any positive ε there will be a ω for which the absolute value of the largest element of the column vector standing in square brackets in expression (15) will be smaller than ε. In other words, if we use a large enough value of ω, then the difference $\phi - \phi_1$ can be reduced to the desired value. Appendix V also contains formula (V-11), which can be used to determine the required value of ω for a given value of ε.

Hence, if we multiply the matrix C by ω according to formula (V-11) at the very beginning of the computation, ϕ is determined with an accuracy of the order ε in the first iteration step. It should be pointed out here that the phrase "with an accuracy of the order ε" does not in this case mean that the following expression is satisfied for any element of the vectors ϕ, ϕ_1, ϕ_o:

$$\left| \frac{\phi_s - \phi_{1s}}{\phi_s} \right| \leq \varepsilon \tag{16}$$

but that only

$$\left| \frac{\phi_s - \phi_{1s}}{\phi_{os}} \right| \leq \varepsilon \tag{17}$$

is satisfied, since the s-th element of the exact solution ϕ_s may be very small or equal to zero, in which case the inequality (16) cannot be satisfied, even if $\phi_s - \phi_{1s}$ is very small.

It should also be noted that, when calculating ω, we always took into account the most unfavourable conditions as regards the accuracy of the result. In practice, the accuracy of this method is much better than it would seem from Eqs (V-11) and (V-12).

3. With the method described by Greer [1], the limit is determined with the help of Eq. (11), in which one has to calculate all the eigenvalues and eigenvectors of a matrix whose dimensions coincide with those of matrix $\underline{C}^T\underline{C}$; one must then still orthogonalize the eigenvectors belonging to the eigenvalue 0.

Examining the sequence of the calculations, we see that, when our method is used, after forming the matrix $\underline{C}^T\underline{C}$ we have to calculate its n non-zero eigenvalues and from this determine the multiplier ω; we can then determine the limit of the iteration process by multiplying the matrix $\underline{C}$ by this multiplier, using the simple formula (7). Thus, the use of our method helps to save a considerable number of cells in the computer's internal memory and a great deal of computer time.

III. RFSP code

The RFSP code, which is written in FORTRAN IV, was developed for the translator of our Institute's ICT-1905 computer. Two regimes (modes of operation) are possible with the code; in the first it determines the neutron spectrum using the method described in Section II, while in the second it performs functions connected with the storing of cross-sections:

(a) It compiles a new magnetic tape;

(b) It records new cross-sections on library tape already available;

(c) It erases the cross-section for a particular reaction from the tape;

(d) It prints out the cross-section for a particular reaction on a line printer.

At present, the cross-sections are stored on "RFSP LIBRARY" tape.

In the first regime, the sequence of operations is as follows:

After compiling the matrix $\underline{C}^T\underline{C}$, the code determines ω. The value ω may sometimes be too large, in which case some elements of the matrix $\underline{C}'^T\underline{C}'$ exceed 10^{12} and in the sum $\underline{C}'^T\underline{C}' + 1$ the addition is not performed accurately. To avoid this situation, the programme (after determining ω) checks whether or not this value is too high. If it is, the highest value of ω not leading to inaccuracy is determined. Then, on the basis of formula (V-12), the programme determines the number of iteration steps required to calculate the limit with the desired accuracy using the new value of ω.

It may sometimes prove necessary to study the way in which a spectrum varies as one approaches an exact solution. In such a case, of course, the method we

describe (i.e. determining ω and multiplying the matrix $\underline{C}^T\underline{C}$ by ω^2 is not applicable, since it gives the limit at once. However, bearing in mind that the rate of convergence is determined by ω, we can take some value ω' such that $1 < \omega' < \omega$, multiply the matrix $\underline{C}^T\underline{C}$ by ω'^2, and thereby vary the rate of convergence which would be obtained by using Greer's method - i.e. if we used $\omega' = 1$.

As part of the input information we have to indicate whether we want to apply this iteration method (see further on). If we do, the rate of convergence is controlled by means of keys. If neither the third nor the fourth key is inserted then $\omega' = \sqrt{\omega}$; if only the third key is inserted, then $\omega' = 1$; if the fourth key is inserted, then $\omega' = \frac{1}{\sqrt{\omega}}$ (the latter may be required if the iteration process converges very rapidly even for $\omega' = 1$; i.e. for $\omega' = 1$ a solution that is "too good" is obtained after the first step).

In certain cases it may prove necessary not to normalize the initial flux - i.e. not to make the calculation described in Appendix II. There is no normalization when key 1 is inserted. When key 2 is inserted, the code - before calculation begins - prints out the response functions of the individual foils in a given spectrum - i.e. the elements of the matrix $C\phi_o^M$. Questions connected with calculating a specific spectrum, using the different regimes and interpreting the results are described in detail in Ref. [2].

When compiling the RFSP code we drew considerably on the SPECTRA code. The input data for both codes are virtually identical, but our code nevertheless differs greatly from the SPECTRA code. Apart from the mathematical differences described in Section II, the two codes are dissimilar in the following respects:

(a) In the RFSP code $E\phi(E)$, and not $\phi(E)$, is the piecewise linear energy function. In the case of conventional reactors, $\phi(E)$ varies within eight orders of magnitude and we have to describe the spectrum by a limited number of points (a maximum of 50 in this case). Taking $\phi(E)$ as the piecewise linear function, we can permit an error of up to 10-12% in the activities. If $E\phi(E)$ is taken as the piecewise linear function, the error is virtually eliminated, but this is only a slight modification from the standpoint of programming and mathematics;

(b) As already mentioned in Section II, with the SPECTRA code we calculate all the eigenvectors of a matrix of size m x m and then orthogonalize some of them, whereas there is no calculation of eigenvectors with the

RFSP code. As a result of this difference, the number of cells in the computer's internal memory required to accommodate the RFSP programme is considerably smaller than for the SPECTRA programme. With the ICT-1905 computer programmed with the RFSP code, a spectrum can be unfolded at 50 points, whereas the SPECTRA code can be accommodated in the computer only when the number of points drops to 25.

The RFSP programme occupies 25 500 cells in the computer's internal memory. The computer time required to solve one problem is a function of the size of the matrix $\underline{C}$ and - when an iteration process is used - of the number of iterations. In the case of 10 foils and 50 energy points it takes ~ 250 seconds to solve one problem, i.e. to determine the limit.

Introduction of the input data

The input data are introduced on punched tape or punched cards in the form described below, as required by the rules for using FORTRAN; each format corresponds to one line.

Format I/10A8/ - This line stipulates the operational regime for the programme. The information recorded in this line consists of only one of the following words and has to be recorded at the beginning of the line.

RUN - Unfolding of neutron spectra by the method described in Section II.

NEWTAPE - Compilation of a new magnetic tape library storing the cross-section data.

ADD - Recording of new reactions and cross-sections on existing magnetic tape.

DELETE - Erasure of any reaction or cross-section from the tape.

EDIT - Print-out of any reaction or cross-section on a line printer.

ENDEND - End of punched tape containing input data.

The information given after this line depends on the operational regime set in the first line.

(a) In the case of RUN

Format II/10A8/ - Any text; 80 alphanumerical symbols; the title of the problem may be put in here. The programme prints out this line at the beginning of each page on the line printer.

Format III /3I3,E12.5,I5,I2/ - IFOIL - Number of foils $\leqslant 30$

IENER - Number of energy points $\leqslant 50$

MODE - May have the following meanings:

(i) If the LIMIT regime is used by itself, only the three variables mentioned (IFOIL, IENER and MODE) need be given in this line, while the other spaces remain empty; in this case, if MODE = 1, the code produces a linear representation of the spectrum, while if MODE = 2, the mode represents it logarithmically (this only relates to a schematic representation of the spectrum and does not affect the code's operation);

(ii) If the REPETE regime is used, then the value of the remaining variables must be given and, furthermore, one must indicate whether the REPETE regime is being used by itself or whether the REPETE and LIMIT regimes are being used in sequence. If MODE = 1, the spectrum is unfolded only during the REPETE regime; if MODE = 2, it is unfolded in both regimes. The remaining variables are

$$\text{ERRE} = \frac{1}{n} \sum_{i=1}^{n} \left| \frac{A_i^k - A_i}{A_i} \right|$$

or the permissible mean error, where A_i^k is the activity of the i-th foil at the k-th iteration step:

MITE - Maximum number of iterations

IPLT - If it is equal to 1, the spectrum is represented linearly; if it is equal to 2, it is represented logarithmically. The REPETE regime is terminated when the mean deviation of the activities is less than ERRE, or when the number of iterations attains MITE. If a separate

error is given for the foils (see type V), the operation is also terminated when each activation error is less than the corresponding measurement error.

(iii) If MODE = 4 and we do not assign a value to the variables ERRE, MITE and IPLT, the programme determines only the mean cross-section for the reactions under consideration in the spectrum given as the programme input; in this case, the activation values have to be given a value of unity (see type V).

Format IV/6E12.5/ - E_1, $\phi(E_1)$,...E_m, $\phi(E_m)$, in all 2 x IENER variables; energy and input flux values. The energy should be given in ascending order. This format is fed in as many times as the IENER value requires.

Format V/2A8, E12.5, E13.5/ - The first two variables contain the foil designation, which should tally with the name of the reaction given in Table 1. This is followed by the measured foil activity and by the measurement error, which does not necessarily have to be determined; if the measurement error is not stipulated the diagonal elements of the matrix F are equal to unity. The measurement error has to be stipulated for all the foils or for none of them. This type is inserted IFOIL times. Then comes the line in which the next regime is given (Format I).

(b) **In the case of NEWTAPE or ADD**

Format VI/2A8,14/ - The first two variables contain the foil designation, after which comes the number of data (i.e. a number twice the number of energy points used to determine the cross-sections); it should not exceed 3500.

Format VII/6E12.5/ - The foil cross-sections in the sequence E_1, $\sigma(E_1)$, E_2, $\sigma(E_2)$, ...; the energy is given in ascending order. This type of punched card is inserted in numbers corresponding to the number of points.

This is followed either by the line giving the regime (Format I) or again by a line of Format IV.

(c) In the case of DELETE or ADD

Format VIII/2A8/ - The name of the reaction that it is intended to erase or to print-out on the line printer.

This is followed either by a line of Format VIII or by the line of Format I giving the regime.

The programme enables separate regimes to be run one after the other, following the order of the input data. After the final data the punched tape or card bearing the data should be terminated with the line of Format I containing the word ENDEND.

The input data

In the NEWTAPE, ADD and DELETE versions of the RFSP programme, the input data include the name of a given reaction, while for EDIT they also contain the reaction cross-section at all points.

In the RUN version, the title of the problem is followed by the designations of the foils, their measured activities and (if stipulated) the activity measurement errors. After this, the initial flux, $\phi(E)$ and $E\phi(E)$, and then the activity ratios, are printed out.

After the normalization described in Appendix II, there come the normalized fluxes and the corresponding normalized activity ratios. This is followed by ω and then (if there are any) by the results of the LIMIT version - i.e. the theoretical fluxes $\phi(E)$ and $E\phi(E)$, the activity ratios and the percentage errors.

In the case of the REPETE version, the output is the same as for LIMIT; each of the first ten iterations is printed out, after which every fifth iteration up to 100 and then every hundredth iteration. However, when REPETE is used, not more than 50 iterations are usually required.

Appendices VI and VII describe the set of input data and the result as calculated and printed out by the RFSP programme.

APPENDIX I: DETERMINATION OF THE ELEMENTS OF THE MATRIX C

As pointed out, the flux is given in such a way that $E\phi(E)$ is a piecewise linear energy function. Let E_1, E_2, ..., E_m be the corresponding energy values,

and $\phi_1, \phi_2, \ldots, \phi_m$ the corresponding fluxes. The flux values between E_j and E_{j+1} are then

$$E\phi(E) = \phi_{j+1} E_{j+1} \frac{E - E_j}{E_{j+1} - E_j} + \phi_j E_j \frac{E_{j+1} - E}{E_{j+1} - E_j} \tag{I-1}$$

Let us assume that below E_1 and above E_m the flux is zero, i.e. that $\phi_1 = \phi_m = 0$. Substituting the expression given above into Eq. (1) for the activity of the i-th foil, we get the following equation:

$$A_i = \int_{E_1}^{E_2} E\phi(E) \frac{\sigma_i(E)}{E} dE + \int_{E_2}^{E_3} E\phi(E) \frac{\sigma_i(E)}{E} dE + \ldots + \int_{E_{m-1}}^{E_m} E\phi(E) \frac{\sigma_i(E)}{E} dE =$$

$$= \int_{E_1}^{E_2} \left[\phi_2 E_2 \frac{E-E_1}{E_2-E_1} + \phi_1 E_1 \frac{E_2-E}{E_2-E_1} \right] \frac{\sigma_i(E)}{E} dE + \ldots + \int_{E_{m-1}}^{E_m} \left[\phi_m E_m \frac{E-E_{m-1}}{E_m-E_{m-1}} + \right.$$

$$\left. + \phi_{m-1} E_{m-1} \frac{E_m-E}{E_m-E_{m-1}} \right] \frac{\sigma_i(E)}{E} dE \tag{I-2}$$

If the integral sign is removed from $E_1, E_2, \ldots, E_m$ and $\phi_1, \phi_2, \ldots, \phi_m$, which are independent of the variable of integration, we get the following expression:

$$A_i = \phi_1 E_1 \left[\int_{E_1}^{E_2} \frac{E_2-E}{E_2-E_1} \frac{\sigma_i(E)}{E} dE \right] + \phi_2 E_2 \left[\int_{E_1}^{E_2} \frac{E-E_1}{E_2-E_1} \frac{\sigma_i(E)}{E} dE + \int_{E_2}^{E_3} \frac{E_3-E}{E_3-E_2} \frac{\sigma_i(E)}{E} dE \right] + \ldots$$

$$\ldots + \phi_j E_j \left[\int_{E_{j-1}}^{E_j} \frac{E-E_{j-1}}{E_j-E_{j-1}} \frac{\sigma_i(E)}{E} + \int_{E_j}^{E_{j+1}} \frac{E_{j+1}-E}{E_{j+1}-E_j} \frac{\sigma_i(E)}{E} dE \right] + \ldots + \phi_m E_m \left[\int_{E_{m-1}}^{E_m} \frac{E-E_{m-1}}{E_m-E_{m-1}} \frac{\sigma_i(E)}{E} dE \right] \tag{I-3}$$

The values in square brackets are the corresponding elements of the matrix Q. When one actually calculates these matrix elements, the functions $\sigma_i(E)$ are given at very closely grouped points, while linear interpolation is applied between points. Since the points are very close together, linear interpolation provides satisfactory accuracy.

APPENDIX II: NORMALIZATION OF THE INITIAL FLUXES AND SOME PROPERTIES OF NORMALIZED ACTIVITIES

Let us assume we are given an initial flux ϕ'_o and let it produce the activities d_1, d_2, ..., d_n when multiplied by matrix C. If each element of the flux vector is reduced by the constant x, then the activities are multiplied by this constant. It is desirable to normalize the flux in such a way that the following condition is satisfied:

$$\sum_{i=1}^{n} (xd_i - 1)^2 = \text{minimum} \tag{II-1}$$

Differentiating this expression with respect to x and then equating it to zero, after simple transformations we arrive at the following result:

$$x = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} d_i^2} \tag{II-2}$$

In this report the normalized flux is designated by ϕ_o, i.e. $x\phi'_o$.

Let us see what can be said of the activities derived with the aid of the normalized flux. We shall calculate the sum of the normalized activities and the sum of their squares

$$\sum_{i=1}^{n} xd_i = x \sum_{i=1}^{n} d_i = \frac{\left(\sum_{i=1}^{n} d_i\right)^2}{\sum_{i=1}^{n} d_i^2} \tag{II-3}$$

$$\sum_{i=1}^{n} (xd_i)^2 = x^2 \sum_{i=1}^{n} d_i^2 = \frac{\left(\sum_{i=1}^{n} d_i\right)^2}{\sum_{i=1}^{n} d_i^2} \tag{II-4}$$

This means that the two values are equal. If we substitute x from Eq. (II-2) into expression (II-1), then after the corresponding transformations we arrive at the following expression:

$$n - \frac{\left(\sum_{i=1}^{n} d_i\right)^2}{\sum_{i=1}^{n} d_1^2} \tag{II-5}$$

If we bear in mind that in Eq. (II-1) this value is derived as a sum of squares, it is clear that

$$\frac{\left(\sum_{i=1}^{n} d_i\right)^2}{\sum_{i=1}^{n} d_i^2} < n \qquad \text{(II-6)}$$

On the left-hand side we have the sum of the normalized activities. If both sides are divided by the number of foils (i.e. by n), we find that both the arithmetic mean and the arithmetic mean of the squares of the normalized activities are less than unity.

APPENDIX III: THEOREMS CONCERNING AND PROOF OF THE EXISTENCE OF THE MATRIX $\underline{B}$ AND ITS EIGENVALUES

Let us first demonstrate that each matrix of the form $\underline{C}^T\underline{C}$ is a positive semi-definite matrix.

We know that the scalar product of any vector multiplied by itself cannot be negative: $(V,V) = V^TV \geq 0$. Let V be an eigenvector of the matrix $\underline{C}^T\underline{C}$ and λ the eigenvalue pertaining to that vector. Then $\lambda(V,V) = \lambda(V,V) = (\underline{C}^T\underline{C}V,V) = V^T\underline{C}^T\underline{C}V = (\underline{C}V)^T(\underline{C}V) = (\underline{C}V, \underline{C}V) \geq 0$.

Thus, $\lambda(V,V) \geq 0$, and therefore $\lambda \geq 0$. We have thereby proved that the eigenvalue of $\underline{C}^T\underline{C}$ cannot be negative, i.e. that this matrix is a positive semi-definite one.

If V is an eigenvector of the matrix $\underline{C}^T\underline{C}$, then it must at the same time be an eigenvector of the matrix $\underline{C}^T\underline{C} + I$, and the corresponding eigenvalue will be $\lambda + 1$, for if

$$\underline{C}^T\underline{C}V = \lambda V$$

then

$$(\underline{C}^T\underline{C} + I)V = \lambda V + V = (\lambda + 1)$$

If $\lambda \geq 0$, it follows that $\lambda + 1 > 0$, i.e. the matrix $\underline{C}^T\underline{C} + I$ is a positive definite matrix.

On the other hand (see determination of the matrix $\underline{C}$),

$$\frac{\partial^2 \Delta_1}{\partial^2 \phi_1^2} = C^T F^2 C + G^2 = G(\underline{C}^T\underline{C} + I)G \qquad \text{(III-1)}$$

If we multiply any positive definite matrix by a diagonal matrix whose diagonal contains only positive elements, we again obtain a positive definite matrix, so that $\underline{C}^T\underline{C} + I$ is positive definite.

Let us now go back to the matrix $\underline{C}^T\underline{C} + I$. It is positive definite with an inverse matrix that can be designated as $\underline{B}$.

Let V again be one of the eigenvectors of the matrix $\underline{C}^T\underline{C} + I$ and let the corresponding eigenvalue be $\lambda + 1$, i.e.

$$(\underline{C}^T\underline{C} + I)V = (\lambda+1)V \tag{III-2}$$

Let us multiply from the left both sides of this equation by the matrix $\underline{B}$:

$$\underline{B}(\underline{C}^T\underline{C} + I)V = (\lambda+1)\underline{B}V \tag{III-3}$$

from which we get

$$V = (\lambda+1)\ \underline{B}\ V, \quad \underline{B}\ V = 1/(\lambda+1)V \tag{III-4}$$

Consequently, the vector that is an eigenvector of $\underline{C}^T\underline{C}$ and $\underline{C}^T\underline{C} + I$ is also an eigenvector of $\underline{B}$, and the corresponding eigenvalue will be $1/(\lambda + 1)$. It follows from the relationship $\lambda \geqslant 0$ that any eigenvalue $1/(\lambda + 1)$ of the matrix $\underline{B}$ is less than or equal to unity.

APPENDIX IV: ONE OF THE PROPERTIES OF EIGENVECTORS OF THE MATRIX $\underline{C}^T\underline{C}$ AND THE FORM OF THE PRODUCT $P\underline{B}C$

1. As already pointed out, the rank of $\underline{C}^T\underline{C}$ is n, so that in the m-dimensional space of the flux vectors there is a subspace containing all the linear combinations of m-n linearly independent vectors which, when multiplied by $\underline{C}^T\underline{C}$, give us zero. The matrix $\underline{C}$ also possesses a subspace with the property indicated above. If we consider any element of the subspace of the matrix $\underline{C}$, we find that this element is also an element of the subspace belonging to the matrix $\underline{C}^T\underline{C}$, for if $\underline{C}\phi = 0$, then $\underline{C}^T\underline{C}\phi = 0$.

Both the above subspaces are m-n-dimensional. Hence, if for any element of the first subspace there is one, and only one, corresponding element in the second subspace, the opposite statement (i.e. if $\underline{C}^T\underline{C}\phi = 0$, then $\underline{C}\phi = 0$) will also be true.

2. Let us now consider the product $P\underline{B}C$.

The matrix P consists of eigenvectors of $\underline{B}$, so that the columns of the matrix $\underline{B}P$ contain eigenvectors of $\underline{B}$ multiplied by the corresponding eigenvalues. The last m-n columns simply contain eigenvectors, since the corresponding eigenvalues of $\underline{B}$ are equal to unity.

These eigenvectors are also eigenvectors of matrix $\underline{C}^T\underline{C}$, and the corresponding eigenvalues are equal to zero. Hence, it can be stated on the basis of the theorem proved in the first part of Appendix IV that, if these vectors are multiplied by the matrix $\underline{C}$, the result will be zero; consequently, there are zeros in the last m-n columns of the matrix $P\underline{B}C$.

APPENDIX V: CALCULATION OF THE MULTIPLIER ω

For any positive ε there will be a ω for which even the absolute value of the element with the greatest absolute value of the column vector - in square brackets in expression (15) - will be less than ε; in other words, if a high enough ω is used, $\phi - \phi_1$ can be reduced to the desired value.

To prove this statement let us consider separately the two terms of the sum in square brackets in expression (15). In the first term we shall write out the matrix $\underline{C}'^T$ in greater detail: $\underline{C}'^T = \phi_o^M C^T F(\omega_n)$. Since F and ϕ_o^M are diagonal matrices, i.e. $F = F^T$ and $\phi_o^M = \phi_o^{MT}$ we do not designate the transposition operation for these matrices. In that case, the first term becomes

$$P\left(L_o' + L_o'^2 + \ldots\right) P^T \underline{B}'^T \phi_o^M \underline{C}^T F^2(\omega_n^2) \qquad (V\text{-}1)$$

The sum of the infinite geometric series contained in brackets is a diagonal matrix of which the elements are in sequence $1/(\lambda_1\omega^2)$, $1/(\lambda_2\omega^2)$, ..., $1/(\lambda_n\omega^2)$. Each element of the vector (ω_n^2) is equal to ω^2, so that multiplication by this vector can also be performed in such a way that each element of the diagonal matrix obtained as the sum of the matrix series is multiplied by ω^2, and instead of the column vector (ω_n) we write (1_n). In this case, the first term can be written as

$$P\bar{L}_o P^T \underline{B}'^T \phi_o^M \underline{C}^T F^2(1_n) \qquad (V\text{-}2)$$

where the elements of the diagonal matrix $\bar{L}_o$ are in sequence $1/\lambda_1$, $1/\lambda_2$, ..., $1/\lambda_n$.

Let us now consider the individual components of this product.

1. As the matrix P consists of eigenvectors of the matrix $\underline{B}'$ and as $P^T \underline{B}'^T = L'P^T$, we can multiply the diagonal matrix L' directly by $\bar{L}_o$, while the diagonal matrix $\bar{L}_o L'$ contains the following elements:

$$\frac{1}{\lambda_1(1+\omega^2\lambda_1)}, \quad \frac{1}{\lambda_2(1+\omega^2\lambda_2)}, \ldots, \quad \frac{1}{\lambda_n(1+\omega^2\lambda_n)} \tag{V-3}$$

2. The i-th column of the matrix $\phi_o^M C^T$ contains the following elements

$$c_{i1}\phi_{o1}, \; c_{i2}\phi_{o2}, \ldots, \; c_{im}\phi_{om}$$

The sum of these elements is equal to xd_i, i.e. to the normalized activity ratio pertaining to the i-th foil. If we divide each column by the corresponding activity ratio, then in the i-th column of the new matrix (designated C_d^T) we will find the elements

$$\frac{c_{i1}\phi_{o1}}{xd_i}, \; \frac{c_{i2}\phi_{o2}}{xd_i}, \ldots, \; \frac{c_{im}\phi_{om}}{xd_i} \tag{V-4}$$

Thus, the sum of the elements in any column is equal to unity, so that the sum of the squares of the elements cannot be greater than unity:

$$\sum_{j=1}^{m} \left(\frac{c_{ij}\,\phi_{oj}}{xd_i} \right)^2 \leq 1 \tag{V-5}$$

for all the elements are positive and less than unity, so that their squares are smaller than the numbers themselves. For this reason, the sum of their squares is greater than their sum.

To obtain the matrix $\phi_o^M C^T$, the matrix C_d^T has to be multiplied by a diagonal matrix of size n x n whose elements are the corresponding normalized activity ratios xd_i. This diagonal matrix is designated by D. In this case the expression (V-2) takes the following form:

$$P\bar{L}_o L' P^T C_d^T D F^2 (1_n) \tag{V-6}$$

3. The matrices D and F^2 are diagonal matrices of the order n. Let us use f^2 to designate the sum of the squares of the elements in the diagonal of the matrix DF^2. The sum of the squares of the elements of the column vector

$DF^2(1_n)$ is then also equal to f^2. It should be noted that, if the errors of the individual activation measurements are taken as identical (i.e. if no weight is attributed to the foils), the elements of the matrix F are equal to unity, and then $f^2 \leqslant n$, since the sum of the squares of the normalized activity ratios cannot exceed n (see Appendix II).

Let us now multiply together the products considered separately in paragraphs 1-3.

P^T is an orthonormalized matrix, so that, when we multiply $\bar{L}_o L'$ from the right by P^T, the lengths of the row vectors of the matrix $\bar{L}_o L' P^T$ will be equal to the lengths of the corresponding row vectors of the matrix $\bar{L}_o L'$, i.e. to the values of its corresponding diagonal elements. Hence, the sum of the squares of the elements of the i-th row of the matrix $\bar{L}_o L' P^T$ is not greater than the square of the i-th diagonal element of matrix $\bar{L}_o L'$, and if the matrix $\bar{L}_o L' P^T$ is multiplied by C_d^T, no element of the i-th row of the matrix $\bar{L}_o L' P^T C_d^T$ can be greater than $1/(\lambda_i(1+\lambda_i \omega^2))$, and for $i > n$ all the elements are equal to zero. In view of the fact that in this matrix there are n elements in one row, the sum of the squares of the elements of the i-th row is not greater than

$$\frac{n}{\lambda_i^2 (1 + \lambda_i \omega^2)^2}$$

If the matrix $\bar{L}_o L' P^T C_d^T$ is multiplied by the column vector $DF^2(1_n)$, the elements of the resulting column vector of m elements are equal to the scaler products of the rows of the matrix $\bar{L}_o L' P^T C_d^T$ as vectors and the column vector $DF^2(1_n)$. Because of the properties of the scalar product, the i-th element of this vector cannot be greater than

$$\frac{f\sqrt{n}}{\lambda_i (1 + \lambda_i \omega^2)}$$

and for $i > n$ the value of the elements is zero.

Thus, the sum of the squares of the elements of this vector is not greater than

$$f^2 n \sum_{i=1}^{n} \frac{1}{\lambda_i^2 (1 + \lambda_i \omega^2)^2}$$

while its length is not greater than

$$f \sqrt{n \sum_{i=1}^{n} \frac{1}{\lambda_i^2 (1 + \lambda_i \omega^2)^2}} \qquad \text{(V-7)}$$

P is an orthonormalized matrix, so that, when the matrix is multiplied by any vector, the vector length remains unchanged. The maximum value of the element with the greatest absolute value cannot exceed the length of the vector, so that the absolute value of the largest element of the first column vector in square brackets in Eq. (15) cannot be greater than the value of expression (V-7).

Let us now consider the second term in square brackets in Eq. (15):

$$P(H - L')\, P^T(1_m) \tag{V-8}$$

The diagonal elements of the matrix H-L' are

$$-\frac{1}{1 + \lambda_1\omega^2}, \quad -\frac{1}{1 + \lambda_2\omega^2}, \ldots, \quad -\frac{1}{1 + \lambda_n\omega^2}$$

The sum of the squares of the elements of the vector (1_m) is m, which fact remains unchanged when the vector is multiplied by the orthonormalized matrix P^T; consequently, the sum of the squares of the elements of a column vector consisting of m elements, $P^T(1_m)$, will also be m. Thus, by multiplying it by the diagonal matrix $-L_o'$, the maximum value of the sum of the squares for the resulting column vector consisting of m elements cannot exceed

$$m \sum_{i=1}^{n} \frac{1}{\left(1 + \lambda_i\omega^2\right)^2}$$

Multiplication by matrix P does not alter the sum of the squares in this case either so that the length - and at the same time the element with the greatest value - of the vector $P(H-L')\, P^T(1_m)$ cannot exceed

$$\sqrt{m \sum_{i=1}^{n} \frac{1}{\left(1 + \lambda_i\omega^2\right)^2}} \tag{V-9}$$

The absolute value of the largest element of the column vector in square brackets in Eq. (15) cannot be greater than the sum of expressions (V-7) and (V-9).

Let us now determine which value of ω is required for known n, m, f and $\lambda_1, \lambda_2, \ldots, \lambda_n$ for this sum to be less than a certain ε. This condition can be written in the following form:

$$\varepsilon > f\sqrt{n\sum_{i=1}^{n}\frac{1}{\lambda_i^2\left(1+\lambda_i\omega^2\right)^2}} + \sqrt{m\sum_{i=1}^{n}\frac{1}{\left(1+\lambda_i\omega^2\right)^2}} \qquad (V\text{-}10)$$

If we regard the unity in each denominator as negligible compared to $\lambda_i\omega^2$, the square root sign can be removed from ω^2 and we arrive directly at the required value of ω:

$$\omega > \sqrt{\frac{1}{\varepsilon}\left[f\sqrt{n\sum_{i=1}^{n}\frac{1}{\lambda_i^4}} + \sqrt{m\sum_{i=1}^{n}\frac{1}{\lambda_i^2}}\right]} \qquad (V\text{-}11)$$

It should be noted that, if we wish to find out what the greatest error can be after the k-th iterative step, by disregarding the unity in each denominator we arrive at an inequality similar to expression (V-10)

$$\varepsilon > \frac{1}{\omega^{2k}}\left[f\sqrt{n\sum_{i=1}^{n}\frac{1}{\lambda_i^{2k+2}}} + \sqrt{m\sum_{i=1}^{n}\frac{1}{\lambda_i^{2k}}}\right] \qquad (V\text{-}12)$$

REFERENCES

1. C.L. Greer, J.A. Halbleib, J.V. Walker, "A Technique for Unfolding Neutron Spectra from Activation Measurements" SC-RR-67-746, Nov. 1967

2. A. Fischer, L. Turi, to be published

Table 1

Reactions recorded on RFSP LIBRARY MAGNETIC TAPE
and their energy limits in MeV

U235/NF/FP-CD	$0{,}7.10^{-8}$ - 18
U235/NF/FP-CD	$1{,}0.10^{-8}$ - 18
PU239/NF/FP-CD	$0{,}6.10^{-8}$ - 18
NA23/NG/NA24-CD	$0{,}5.10^{-8}$ - 18
MG24/NP/NA24	0,05 - 18
IN115/NN/IN115M	0,05 - 18
S32/NP/P32	0,05 - 18
AL27/NP/MG27	0,05 - 18
AL27/NHE/NA24	0,05 - 18
RH103/NN/RH103M	0,05 - 18
FE56/NP/MN56	0,05 - 18
NI58/NP/CO58	0,05 - 18
P31/NP/SI31	0,05 - 18
PU239/NF/FP	$0{,}5.10^{-10}$ - 10^{-5}
DY164/NG/DY165	$0{,}33.10^{-10}$ - 10^{-5}
LU176/NG/LU177	$0{,}5.10^{-10}$ - 10^{-5}
EU151/NG/EU152	$0{,}5.10^{-10}$ - 10^{-5}
IN115/NG/IN116	$0{,}5.10^{-10}$ - 10^{-5}
AU197/NG/AU198	$0{,}5.10^{-10}$ - 2.10^{-5}

APPENDIX VI: Set of input data

```
RUN
TEST CASE FOR RFSP - REPORT.
  9 50  2
 5.00000E-04 0.00000E 00 1.00000E-03 5.50000E+10 1.40000E-03 5.50000E+10
 2.10000E-03 5.50000E+10 3.10000E-03 5.50000E+10 4.60000E-03 3.00000E+10
 5.50000E-03 1.57000E+10 6.50000E-03 1.53000E+10 8.50000E-03 1.30000E+10
 1.00000E-02 3.00000E+09 1.20000E-02 2.50000E+09 1.40000E-02 2.50000E+09
 1.80000E-02 2.50000E+09 2.10000E-02 3.00000E+09 4.60000E-02 9.50000E+09
 1.00000E-01 9.00000E+09 1.20000E-01 8.50000E+09 1.40000E-01 8.20000E+09
 1.80000E-01 7.50000E+09 2.00000E-01 7.30000E+09 2.80000E-01 6.60000E+09
 4.00000E-01 5.70000E+09 6.00000E-01 4.80000E+09 8.00000E-01 4.20000E+09
 9.00000E-01 2.70000E+09 9.50000E-01 1.70000E+09 1.06000E-00 1.30000E+09
 1.20100E-00 9.92000E+08 1.35100E-00 9.59300E+08 1.51900E 00 9.09674E+08
 1.70900E 00 8.48295E+08 1.92300E 00 7.66264E+08 2.16300E 00 6.54626E+08
 2.43300E 00 5.19910E+08 2.73700E 00 3.49759E+08 3.07900E 00 1.95804E+08
 3.46300E 00 1.69401E+08 3.89600E 00 9.77683E+07 4.38300E 00 5.33872E+07
 4.93000E 00 4.34825E+07 5.54600E 00 4.44581E+07 6.23900E 00 3.36522E+07
 7.01900E 00 1.79139E+07 7.89600E 00 8.45628E+06 8.88200E 00 4.52701E+06
 9.99200E 00 1.88431E+06 1.12400E+01 6.61172E+05 1.26400E+01 2.02586E+05
 1.42200E+01 5.39000E+04 1.80000E+01 0.00000E 00
IN115(NN)IN115M  3.69900E 08  5.-2
NI58(NP)CO58     1.87500E 08  5.E2
AL27(NHE)NA24    1.38100E 06  5.E2
MG24(NP)NA24     2.91160E 06  5.E2
FE56(NP)MN56     2.21020E 06  5.E2
AL27(NP)MG27     6.56420E 06  5.E2
RH103(NN)RH103M  1.97220E 09  5.E2
U235(NF)FP-CD    9.68650E+09  5.E2
NA23(NG)NA24-CD  1.28500E 07  5.E2
ENDEND      E                 E
```

TEST CASE FOR RFSP - REPORT

MG24(NP)NA24	2.91160E 06	5.00000E-02
IN115(NN)IN115M	3.69900E 08	5.00000E-02
AL27(NP)MG27	6.56420E 06	5.00000E-02
AL27(NNE)NA24	1.38100E 06	5.00000E-02
RH103(NN)RH103M	1.97220E 09	5.00000E-02
FE56(NP)MN56	2.21020E 06	5.00000E-02
NI58(NP)CO58	1.87500E 08	5.00000E-02
U235(NF)FP-CD	9.68650E 09	5.00000E-02
NA23(NG)NA24-CD	1.28500E 07	5.00000E-02

APPENDIX VII: Results printed out by RFSP code (page 1)

INITIAL FLUX F(E)

5.00000E-04	0.00000E-01	1.00000E-03	5.50000E 10	1.40000E-03	5.50000E 10	2.10000E-03	5.50000E 10
3.10000E-03	5.50000E 10	4.60000E-03	3.00000E 10	5.50000E-03	1.57000E 10	6.50000E-03	1.53000E 10
8.50000E-03	1.30000E 10	1.00000E-02	3.00000E 09	1.20000E-02	2.50000E 09	1.40000E-02	2.50000E 09
1.80000E-02	2.50000E 09	2.10000E-02	3.00000E 09	4.60000E-02	9.50000E 09	1.00000E-01	9.00000E 09
1.20000E-01	8.50000E 09	1.40000E-01	8.20000E 09	1.80000E-01	7.50000E 09	2.00000E-01	7.30000E 09
2.80000E-01	6.60000E 09	4.00000E-01	5.70000E 09	6.00000E-01	4.80000E 09	8.00000E-01	4.20000E 09
9.00000E-01	2.70000E 09	9.50000E-01	1.70000E 09	1.06000E 00	1.30000E 09	1.20100E 00	9.92000E 08
1.35100E 00	9.59300E 08	1.50900E 00	9.09674E 08	1.70900E 00	8.48795E 08	1.92300E 00	7.66264E 08
2.16300E 00	6.54626E 08	2.43300E 00	5.19910E 08	2.73700E 00	3.49759E 08	3.07900E 00	1.95804E 08
3.46300E 00	1.69401E 08	3.89600E 00	9.77683E 07	4.38300E 00	5.33872E 07	4.93000E 00	4.34825E 07
5.54600E 00	4.44581E 07	6.23900E 00	3.36522E 07	7.01900E 00	1.79139E 07	7.89600E 00	8.45628E 06
8.88200E 00	4.52701E 06	9.99200E 00	1.88631E 06	1.12400E 01	6.61172E 05	1.26400E 01	2.02586E 05
1.42200E 01	5.39000E 04						

INITIAL FLUX F(U)

5.00000E-04	0.00000E-01	1.00000E-03	5.50000E 07	1.40000E-03	7.70000E 07	2.10000E-03	1.15500E 08
3.10000E-03	1.70500E 08	4.60000E-03	1.38000E 08	5.50000E-03	8.63500E 07	6.50000E-03	9.94500E 07
8.50000E-03	1.10500E 08	1.00000E-02	3.00000E 07	1.20000E-02	3.00000E 07	1.40000E-02	3.50000E 07
1.80000E-02	4.50000E 07	2.10000E-02	6.30000E 07	4.60000E-02	4.37000E 08	1.00000E-01	9.00000E 08
1.20000E-01	1.02000E 09	1.40000E-01	1.14800E 09	1.80000E-01	1.35000E 09	2.00000E-01	1.46000E 09
2.80000E-01	1.84800E 09	4.00000E-01	2.28000E 09	6.00000E-01	2.88000E 09	8.00000E-01	3.36000E 09
9.00000E-01	2.43000E 09	9.50000E-01	1.61500E 09	1.06000E 00	1.37800E 09	1.20100E 00	1.19139E 09
1.35100E 00	1.29601E 09	1.50900E 00	1.38179E 09	1.70900E 00	1.44974E 09	1.92300E 00	1.47353E 09
2.16300E 00	1.41596E 09	2.43300E 00	1.26494E 09	2.73700E 00	9.57290E 08	3.07900E 00	6.02881E 08
3.46300E 00	5.86636E 08	3.89600E 00	3.80905E 08	4.38300E 00	2.33996E 08	4.93000E 00	2.14369E 08
5.54600E 00	2.46565E 08	6.23900E 00	2.09956E 08	7.01900E 00	1.25738E 08	7.89600E 00	6.67708E 07
8.88200E 00	4.02089E 07	9.99200E 00	1.88280E 07	1.12400E 01	7.43157E 06	1.26400E 01	2.56069E 06
1.42200E 01	7.66458E 05						

INITIAL CALCULATED ACTIVITY RATIOS

MG24(NP)NA24	1.02067E 00
IN115(NN)IN115M	1.12167E 00
AL27(NP)MG27	9.89249E-01
AL27(NHE)NA24	9.87434E-01
RH103(NN)RH103M	1.22215E 00
FE56(NP)MN56	9.91607E-01
NI58(NP)CO58	1.03413E 00
U235(NF)FP-CD	1.19182E 00
NA23(NG)NA24-CD	1.12186E 00

APPENDIX VII: Results printed out by RFSP code (page 2)

NORMALIZED INITIAL FLUX F(U)

5.00000E-06	0.00000E-01	1.00000E-03	5.08099E 07	1.40000E-03	7.11338E 07	2.10000E-03	1.06701E 08
3.10000E-03	1.57511E 08	4.60000E-03	1.27687E 08	5.50000E-03	7.97715E 07	6.50000E-03	9.18735E 07
8.50000E-03	1.02082E 08	1.00000E-02	2.77145E 07	1.20000E-02	2.77145E 07	1.40000E-02	3.23336E 07
1.80000E-02	4.15717E 07	2.10000E-02	5.82004E 07	4.60000E-02	4.03708E 08	1.00000E-01	8.31434E 08
1.20000E-01	9.42292E 08	1.40000E-01	1.06054E 09	1.80000E-01	1.24715E 09	2.00000E-01	1.34877E 09
2.80000E-01	1.70721E 09	4.00000E-01	2.10630E 09	6.00000E-01	2.66059E 09	8.00000E-01	3.10402E 09
9.00000E-01	2.24487E 09	9.50000E-01	1.49196E 09	1.06000E 00	1.27302E 09	1.20100E 00	1.10063E 09
1.35100E 00	1.19728E 09	1.51900E 00	1.27652E 09	1.70900E 00	1.33929E 09	1.92300E 00	1.36127E 09
2.16300E 00	1.30808E 09	2.43300E 00	1.16857E 09	2.73700E 00	8.84360E 08	3.07900E 00	5.56951E 08
3.46300E 00	5.41943E 08	3.89600E 00	3.51886E 08	4.38300E 00	2.16169E 08	4.93000E 00	1.98037E 08
5.54600E 00	2.27780E 08	6.23900E 00	1.93961E 08	7.01900E 00	1.16158E 08	7.89600E 00	6.16839E 07
8.88200E 00	3.71456E 07	9.99200E 00	1.73936E 07	1.12400E 01	6.86541E 06	1.26400E 01	2.36560E 06
1.42200E 01	7.08066E 05						

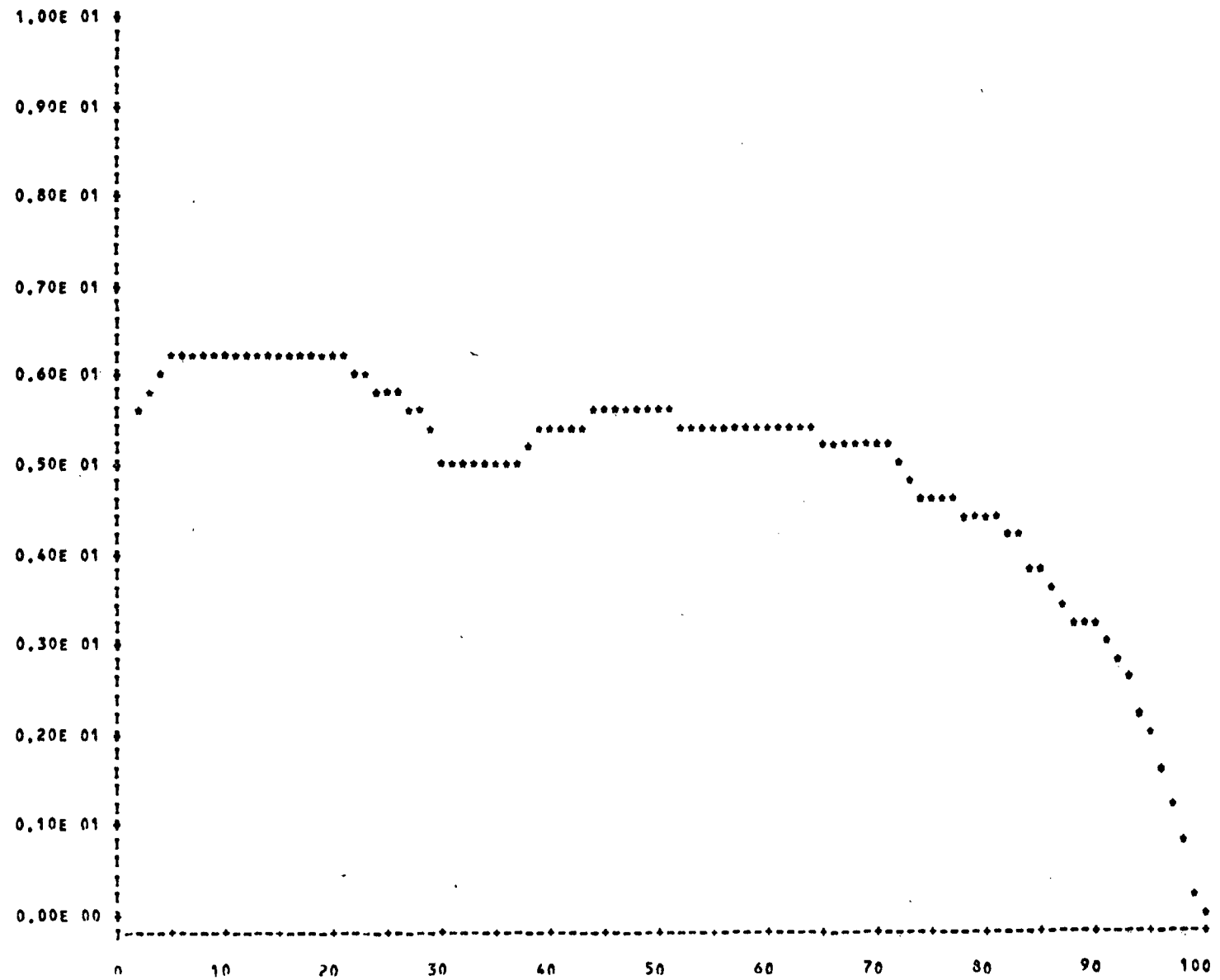
NORMALIZED INITIAL FLUX F(F)

5.00000E-06	0.00000E-01	1.00000E-03	5.08099E 10	1.40000E-03	5.08099E 10	2.10000E-03	5.08099E 10
3.10000E-03	5.08099E 10	4.60000E-03	2.77145E 10	5.50000E-03	1.45039E 10	6.50000E-03	1.41344E 10
8.50000E-03	1.20096E 10	1.00000E-02	2.77145E 09	1.20000E-02	2.30954E 09	1.40000E-02	2.30954E 09
1.80000E-02	2.30954E 09	2.10000E-02	2.77145E 09	4.60000E-02	8.77425E 09	1.00000E-01	8.31434E 09
1.20000E-01	7.85244E 09	1.40000E-01	7.57529E 09	1.80000E-01	6.92862E 09	2.00000E-01	6.74386E 09
2.80000E-01	6.09719E 09	4.00000E-01	5.26575E 09	6.00000E-01	4.43432E 09	8.00000E-01	3.88003E 09
9.00000E-01	2.49430E 09	9.50000E-01	1.57049E 09	1.06000E 00	1.20096E 09	1.20100E 00	9.16425E 08
1.35100E 00	8.86217E 08	1.51900E 00	8.40371E 08	1.70900E 00	7.83469E 08	1.92300E 00	7.07887E 08
2.16300E 00	6.04754E 08	2.43300E 00	4.80301E 08	2.73700E 00	3.23113E 08	3.07900E 00	1.80887E 08
3.46300E 00	1.56495E 08	3.89600E 00	9.03199E 07	4.38300E 00	4.93200E 07	4.93000E 00	4.01698E 07
5.54600E 00	4.10711E 07	6.23900E 00	3.10884E 07	7.01900E 00	1.65491E 07	7.89600E 00	7.81205E 06
8.88200E 00	6.18212E 06	9.99200E 00	1.74076E 06	1.12400E 01	6.10801E 05	1.26400E 01	1.87152E 05
1.42200E 01	4.97937E 04						

NORMALIZED INITIAL CALCULATED ACTIVITY RATIOS

MG24(NP)NA24	9.42914E-01
IN115(NN)IN115M	1.03622E 00
AL27(NP)MG27	9.13884E-01
AL27(NHE)NA24	9.12207E-01
RH103(NN)RH103M	1.12904E 00
FE56(NP)MN56	9.16062E-01
NI58(NP)CO58	9.55343E-01
U235(NF)FP-CD	1.10102E 00
NA23(NG)NA24-CD	1.03639E 00

APPENDIX VII: Results printed out by RFSP code (page 3)



APPENDIX VII: Results printed out by RFSP code (page 4)

THE RESPONSE FUNCTIONS ARE

MG24(NP)NA24

0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01
0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01
0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01
0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 6.35087E-07 3.90896E-03
1.00692E-01 2.34090E-01 2.78606E-01 2.00542E-01 1.08121E-01 4.96348E-02 1.93897E-02 5.01553E-03

IN115(NN)IN115M

0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01
0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 6.63312E-06
5.97515E-04 4.49706E-03 1.52504E-02 2.00198E-02 2.05502E-02 2.61478E-02 3.34036E-02 5.11332E-02 7.18880E-02 9.03910E-02
1.06321E-01 1.17063E-01 1.21077E-01 9.71559E-02 5.81229E-02 5.38196E-02 3.32011E-02 1.90244E-02 1.54371E-02 1.49356E-02
1.28435E-02 8.07500E-03 4.43570E-03 2.70914E-03 1.25176E-03 4.68286E-04 1.43389E-04 2.95212E-05

AL27(NP)MG27

0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01
0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01
0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01
0.00000E-01 0.00000E-01 2.62768E-03 1.65615E-02 2.29264E-02 6.64157E-02 5.38878E-02 5.74742E-02 8.77277E-02 1.78997E-01
1.87638E-01 1.36666E-01 8.73340E-02 5.69871E-02 2.80583E-02 1.14789E-02 4.02317E-03 1.19678E-03

AL27(NNE)NA24

0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01
0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01
0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01
0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 1.15307E-05 2.80202E-03 2.06104E-02
8.69282E-02 1.79568E-01 2.22546E-01 2.33605E-01 1.48234E-01 7.13066E-02 2.70457E-02 7.30286E-03

APPENDIX VII: Results printed out by RFSP code (page 5)

RH103(NN)RH103M

0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01
0.00000E-01 0.00000E-01 0.00000E-01 2.42894E-05 2.92592E-04 7.72675E-04 1.25794E-03 1.95054E-03 3.59308E-03 7.56665E-03
1.62456E-02 3.61356E-02 8.47048E-02 7.96067E-02 5.73807E-02 5.06699E-02 4.51209E-02 5.17110E-02 5.84203E-02 6.55528E-02
7.13404E-02 7.22279E-02 6.71671E-02 5.30975E-02 3.66996E-02 3.47139E-02 2.30286E-02 1.47737E-02 1.43619E-02 1.75379E-02
1.59016E-02 9.87633E-03 5.31557E-03 3.15915E-03 1.34081E-03 3.84969E-04 7.78325E-05 1.16721E-05

FE56(NP)MN56

0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01
0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01
0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01
0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 5.85937E-04 1.93707E-02 1.10266E-01
2.23248E-01 2.17227E-01 1.65929E-01 1.29816E-01 7.71277E-02 3.72875E-02 1.49914E-02 4.14924E-03

NI58(NP)CO58

0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01
0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01
0.00000E-01 0.00000E-01 0.00000E-01 0.00000E-01 1.04602E-04 1.71611E-03 4.72083E-03 1.01416E-02 1.77443E-02 2.77410E-02
4.05075E-02 5.62877E-02 7.35952E-02 9.77999E-02 9.98173E-02 9.22544E-02 7.90219E-02 6.29171E-02 6.76994E-02 8.72740E-02
7.96494E-02 4.88750E-02 2.61102E-02 1.54415E-02 6.99007E-03 2.63094E-03 8.24749E-04 1.35380E-04

U235(NF)FP-CD

2.29995E-03 1.12447E-02 1.56981E-02 1.79219E-02 1.12942E-02 5.93745E-03 6.72851E-03 7.12790E-03 1.98823E-03 1.85800E-03
1.92013E-03 2.26445E-03 3.43297E-03 1.91622E-02 2.98506E-02 3.35094E-02 3.67427E-02 3.94186E-02 4.31114E-02 4.97235E-02
5.73983E-02 6.72035E-02 7.54799E-02 5.57143E-02 3.84840E-02 3.33202E-02 2.92754E-02 3.18785E-02 3.45403E-02 3.69715E-02
3.75324E-02 3.62647E-02 3.24626E-02 2.40273E-02 1.50794E-02 1.45393E-02 9.08339E-03 5.49953E-03 4.96028E-03 5.56863E-03
5.25039E-03 3.64193E-03 2.20627E-03 1.37552E-03 6.38072E-04 2.54967E-04 8.78747E-05 2.66612E-05

APPENDIX VII: Results printed out by RFSP code (page 6)

NA23(NG)NA24-CD

1.92666E-03 1.85227E-02 1.41829E-01 4.57683E-01 2.70089E-02 6.24466E-03 5.31452E-03 4.25951E-03 8.83152E-04 7.14248E-04

6.66756E-04 6.63200E-04 1.40729E-03 1.21059E-02 8.13685E-03 1.57704E-02 2.13413E-02 2.45482E-02 2.56865E-02 2.66678E-02

2.69592E-02 2.21597E-02 2.03689E-02 1.28671E-02 7.97775E-03 6.85970E-03 6.40049E-03 7.53952E-03 8.62149E-03 9.61379E-03

1.02708E-02 1.02265E-02 9.28540E-03 6.95597E-03 4.17150E-03 3.63518E-03 1.88977E-03 7.67058E-04 6.02982E-04 7.62643E-04

7.13143E-04 4.67255E-04 2.70240E-04 1.76307E-04 8.77133E-05 3.44101E-05 1.11798E-05 2.76811E-06

THE EIGENVALUES OF (C-T)*C ARE

1.96379E 02 1.39947E 02 7.27580E 01 3.16061E 01 1.89923E 01 5.65952E 00
3.05063E 00 1.45731E 00 6.24265E-01

NUMBER OF ITERATION STEPS IS 4

OMEGA = 2.88646E 01

APPENDIX VII: Results printed out by RFSP code (page 7)

CALCULATED DIFFERENTIAL FLUX F(U)

5.00000E-04	0.000000E-01	1.000000E-03	5.09876E 07	1.40000E-03	7.13869E 07	2.10000E-03	1.05984E 08
3.10000E-03	1.53093E 08	4.600000E-03	1.27662E 08	5.50000E-03	7.98286E 07	6.50000E-03	9.19741E 07
8.50000E-03	1.02205E 08	1.000000E-02	2.77222E 07	1.20000E-02	2.77216E 07	1.40000E-02	3.23440E 07
1.80000E-02	4.15878E 07	2.100000E-02	5.82772E 07	4.60000E-02	4.08195E 08	1.00000E-01	8.38370E 08
1.20000E-01	9.43298E 08	1.400000E-01	1.05949E 09	1.80000E-01	1.24233E 09	2.00000E-01	1.33008E 09
2.80000E-01	1.61038E 09	4.000000E-01	1.79888E 09	6.00000E-01	1.86357E 09	8.00000E-01	1.81962E 09
9.00000E-01	1.88477E 09	9.500000E-01	1.33599E 09	1.06000E 00	1.11919E 09	1.20100E 00	9.95376E 08
1.35100E 00	1.09369E 09	1.500000E 00	1.18008E 09	1.70900E 00	1.24871E 09	1.92300E 00	1.28363E 09
2.16300E 00	1.20081E 09	2.463000E 00	1.16437E 09	2.73700E 00	9.10165E 08	3.07900E 00	5.78613E 08
3.46300E 00	5.67405E 08	3.896000E 00	3.67015E 08	4.38300E 00	2.25274E 08	4.93000E 00	2.13636E 08
5.54600E 00	2.82150E 08	6.239000E 00	2.24644E 08	7.01900E 00	1.08592E 08	7.89600E 00	5.41236E 07
8.88200E 00	4.75993E 07	9.992000E 00	2.20207E 07	1.12400E 01	7.81871E 06	1.26400E 01	2.48485E 06
1.42200E 01	7.23745E 05						

DIFFERENTIAL FLUX F(E)

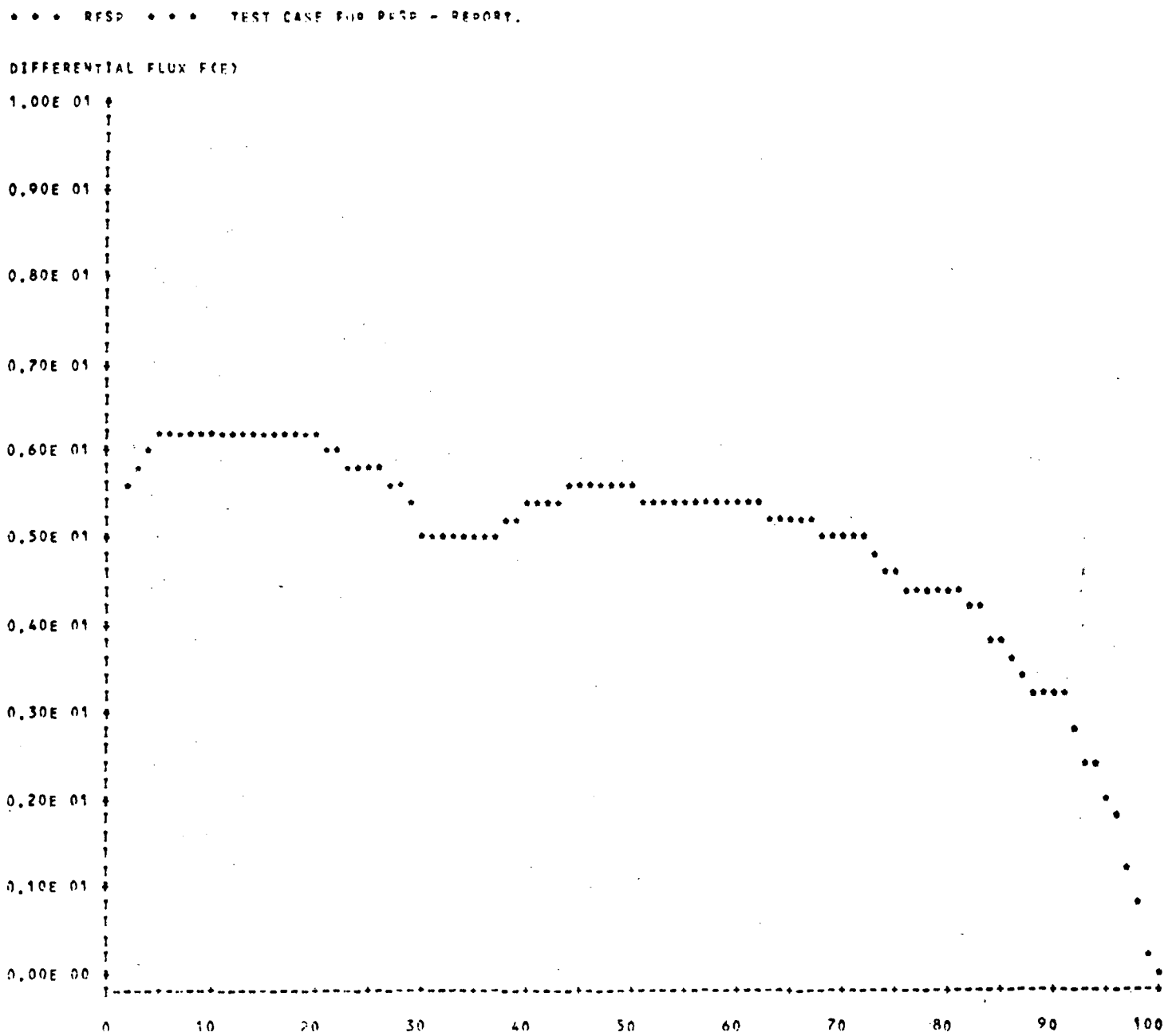
5.00000E-04	0.000000E-01	1.000000E-03	5.09876E 10	1.40000E-03	5.09935E 10	2.10000E-03	5.04686E 10
3.10000E-03	4.93848E 10	4.600000E-03	2.77527E 10	5.50000E-03	1.45143E 10	6.50000E-03	1.41699E 10
8.50000E-03	1.20241E 10	1.000000E-02	2.77222E 09	1.20000E-02	2.31014E 09	1.40000E-02	2.31029E 09
1.80000E-02	2.31043E 09	2.100000E-02	2.77511E 09	4.60000E-02	8.87380E 09	1.00000E-01	8.38370E 09
1.20000E-01	7.86082E 09	1.400000E-01	7.56781E 09	1.80000E-01	6.90183E 09	2.00000E-01	6.65041E 09
2.80000E-01	5.75135E 09	4.000000E-01	4.49721E 09	6.00000E-01	3.10595E 09	8.00000E-01	2.27452E 09
9.00000E-01	2.09419E 09	9.500000E-01	1.40631E 09	1.06000E 00	1.05584E 09	1.20100E 00	8.28790E 08
1.35100E 00	8.09542E 08	1.500000E 00	7.76882E 08	1.70900E 00	7.30468E 08	1.92300E 00	6.67316E 08
2.16300E 00	5.82809E 08	2.463000E 00	4.78572E 08	2.73700E 00	3.32541E 08	3.07900E 00	1.87922E 08
3.46300E 00	1.63871E 08	3.896000E 00	9.42030E 07	4.38300E 00	5.13973E 07	4.93000E 00	4.33336E 07
5.54600E 00	5.08745E 07	6.239000E 00	3.60064E 07	7.01900E 00	1.56712E 07	7.89600E 00	6.85454E 06
8.88200E 00	5.35907E 06	9.992000E 00	2.20383E 06	1.12400E 01	6.95415E 05	1.26400E 01	1.96586E 05
1.42200E 01	5.08962E 04						

CALCULATED ACTIVITIES, ACTIVITY RATIOS AND PERCENTAGE ERRORS

MG24(NP)NA24	2.91160E 06	1.0000	-0.0000
IN115(NN)IN115M	3.69900E 08	1.0000	0.0001
AL27(NP)MG27	6.56420E 06	1.0000	0.0000
AL27(NME)NA24	1.33100E 06	1.0000	-0.0000
RH103(NN)RH103M	1.97220E 09	1.0000	0.0000
FE56(NP)MN56	2.21020E 06	1.0000	-0.0000
NI58(NP)CO58	1.87500E 08	1.0000	0.0000
U235(NF)FP-CD	9.66650E 09	1.0000	0.0000
NA23(NG)NA24-CD	1.28500E 07	1.0000	0.0000

THE AVERAGE ACTIVITY ERROR IS 2.87626E-07

APPENDIX VII: Results printed out by RFSP code (page 8)



APPENDIX VII: Results printed out by RFSP code (page 9)

CALCULATED DIFFERENTIAL FLUX F(U)

5.00000E-04	0.00000E-01	1.00000E-03	5.09876E 07	1.40000E-03	7.13869E 07	2.10000E-03	1.05984E 08
3.10000E-03	1.53093E 08	4.60000E-03	1.27662E 08	5.50000E-03	7.98286E 07	6.50000E-03	9.19741E 07
8.50000E-03	1.02205E 08	1.00000E-02	2.77222E 07	1.20000E-02	2.77216E 07	1.40000E-02	3.23440E 07
1.80000E-02	4.15878E 07	2.10000E-02	5.82773E 07	4.60000E-02	4.08195E 08	1.00000E-01	8.38370E 08
1.20000E-01	9.43298E 08	1.40000E-01	1.05949E 09	1.80000E-01	1.24233E 09	2.00000E-01	1.33008E 09
2.80000E-01	1.61078E 09	4.00000E-01	1.79888E 09	6.00000E-01	1.86357E 09	8.00000E-01	1.81962E 09
9.00000E-01	1.88477E 09	9.50000E-01	1.33599E 09	1.06000E 00	1.11919E 09	1.20100E 00	9.95376E 08
1.35100E 00	1.09369E 09	1.50000E 00	1.18008E 09	1.70900E 00	1.24871E 09	1.92300E 00	1.28363E 09
2.16300E 00	1.26081E 09	2.40300E 00	1.16437E 09	2.73700E 00	9.10165E 08	3.07900E 00	5.78613E 08
3.46300E 00	5.67405E 08	3.86600E 00	3.67015E 08	4.38300E 00	2.25274E 08	4.93000E 00	2.13636E 08
5.54600E 00	2.82150E 08	6.25900E 00	2.24644E 08	7.01900E 00	1.08592E 08	7.89600E 00	5.41236E 07
8.88200E 00	4.75993E 07	9.97200E 00	2.20207E 07	1.12400E 01	7.81871E 06	1.26400E 01	2.48685E 06
1.42200E 01	7.23745E 05						

DIFFERENTIAL FLUX F(E)

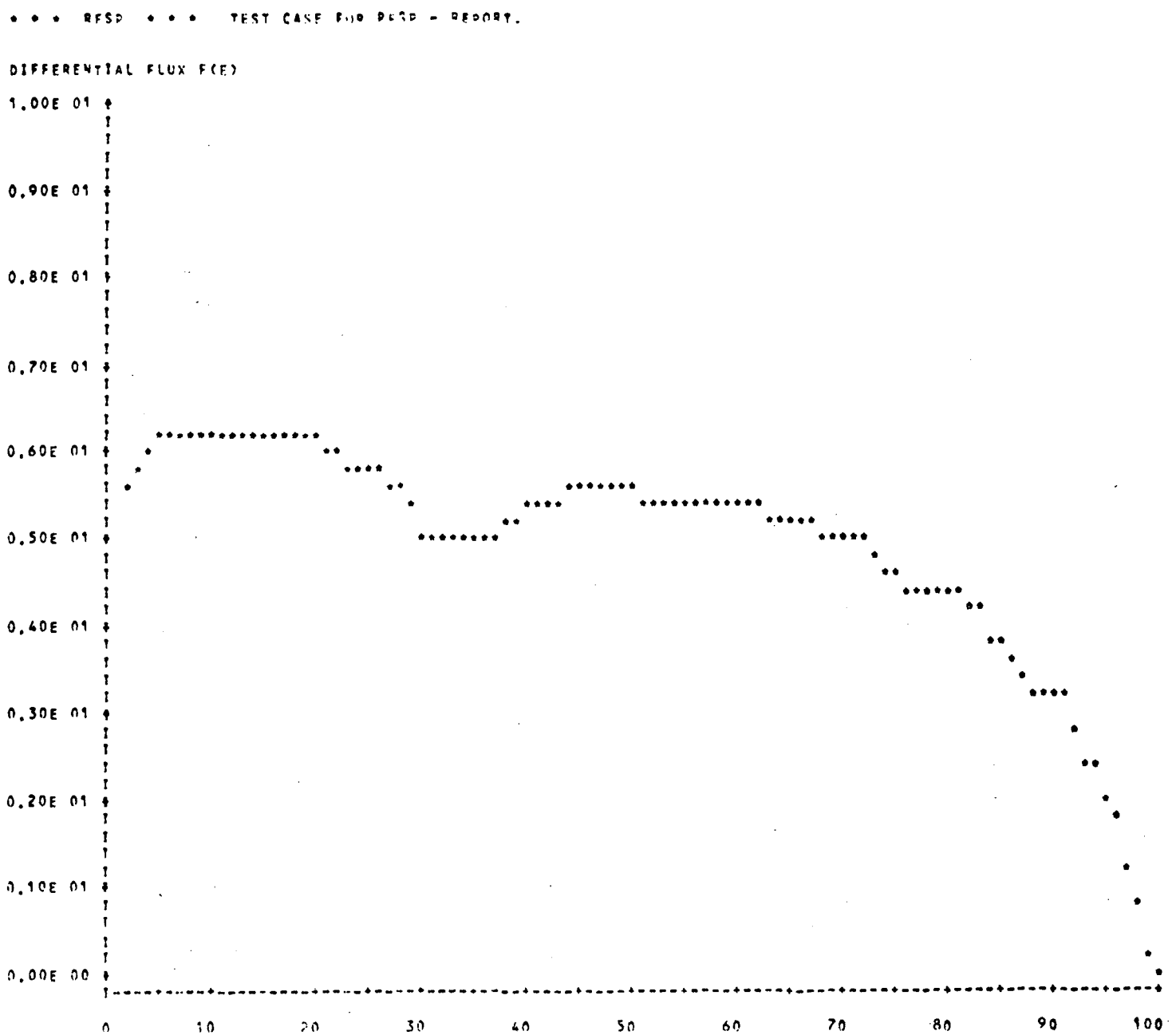
5.00000E-04	0.00000E-01	1.00000E-03	5.09876E 10	1.40000E-03	5.09335E 10	2.10000E-03	5.04686E 10
3.10000E-03	4.93848E 10	4.60000E-03	2.77527E 10	5.50000E-03	1.45143E 10	6.50000E-03	1.41499E 10
8.50000E-03	1.20241E 10	1.00000E-02	2.77222E 09	1.20000E-02	2.31014E 09	1.40000E-02	2.31029E 09
1.80000E-02	2.31043E 09	2.10000E-02	2.77511E 09	4.60000E-02	8.87380E 09	1.00000E-01	8.38370E 09
1.20000E-01	7.86002E 09	1.40000E-01	7.56781E 09	1.80000E-01	6.90183E 09	2.00000E-01	6.65041E 09
2.80000E-01	5.75135E 09	4.00000E-01	4.49721E 09	6.00000E-01	3.10595E 09	8.00000E-01	2.27452E 09
9.00000E-01	2.09419E 09	9.50000E-01	1.40631E 09	1.06000E 00	1.05584E 09	1.20100E 00	8.28790E 08
1.35100E 00	8.09542E 08	1.50000E 00	7.76882E 08	1.70900E 00	7.30468E 08	1.92300E 00	6.67916E 08
2.16300E 00	5.82809E 08	2.40300E 00	4.78572E 08	2.73700E 00	3.32541E 08	3.07900E 00	1.87922E 08
3.46300E 00	1.63871E 08	3.86600E 00	9.42030E 07	4.38300E 00	5.13973E 07	4.93000E 00	4.33336E 07
5.54600E 00	5.08745E 07	6.25900E 00	3.60064E 07	7.01900E 00	1.56712E 07	7.89600E 00	6.85454E 06
8.88200E 00	5.35907E 06	9.97200E 00	2.20383E 06	1.12400E 01	6.95415E 05	1.26400E 01	1.96586E 05
1.42200E 01	5.08962E 04						

CALCULATED ACTIVITIES, ACTIVITY RATIOS AND PERCENTAGE ERRORS

MG24(NP)NA24	2.91160E 06	1.0000	-0.0000
IN115(NN)IN115M	3.69000E 08	1.0000	0.0001
AL27(NP)MG27	6.56420E 06	1.0000	0.0000
AL27(NME)NA24	1.33100E 06	1.0000	-0.0000
RH103(NN)RH103M	1.97220E 09	1.0000	0.0000
FE56(NP)MN56	2.21020E 06	1.0000	-0.0000
NI58(NP)CO58	1.87500E 08	1.0000	0.0000
U235(NF)FP-CD	9.60650E 09	1.0000	0.0000
NA23(NG)NA24-CD	1.20500E 07	1.0000	0.0000

THE AVERAGE ACTIVITY ERROR IS 2.87626E-07

APPENDIX VII: Results printed out by RFSP code (page 8)



APPENDIX VII: Results printed out by RFSP code (page 9)