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**LERFCM—A Computer Code for
Spatial Reconstruction of
Volume Emission from Chord
Measurements in Plasmas**

A. P. Navarro
V. K. Paré
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FUSION ENERGY DIVISION

LERFCM — A COMPUTER CODE FOR SPATIAL RECONSTRUCTION OF VOLUME
EMISSION FROM CHORD MEASUREMENTS IN PLASMAS

A. P. Navarro,* V. K. Paré, and J. L. Dunlap

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ABSTRACT

Local Emissivity Reconstruction From Chord Measurements (LERFCM) is a package of computer programs used to determine the two-dimensional spatial distribution of the emission intensity of radiation in a plasma from line integral data, which represents signals from arrays of collimated detectors looking through the plasma along different chords in a plane. The method requires data from only a few detector arrays and assumes that the emission distribution in the plane of observation has a smooth angular dependence that can be represented by a few low-order harmonics. The intended application is a reconstruction of plasma shape and MHD instabilities, using data from arrays of soft x-ray detectors on the Impurity Study Experiment Tokamak.

In another paper by Navarro, Paré, and Dunlap entitled "Two-Dimensional Spatial Distribution of Volume Emission from Line Integral Data," the algorithms are derived in detail, and the results of simulation tests of the LERFCM package are shown. In this report the algorithms are summarized, and the functions and relationships of the programs are described, with the aid of a flow chart. The programs that were written specifically for the reconstruction calculations are listed fully. The package is written in FORTRAN and runs on a Digital Equipment Corporation PDP-10 computer. Modification of input/output statements would, in most cases, be sufficient to enable the programs to be run on another computer; however, the user would have to add the graphics capability appropriate to the facilities available to him.

1. INTRODUCTION

Several types of plasma diagnostics employ detectors that are collimated to receive radiation from the vicinity of a straight line through the plasma. For radiation not attenuated by the plasma, such as soft x-rays, the intensity reaching the detector is proportional to the line integral of volume emission intensity along the viewing line. In toroidal plasma devices, detectors are typically installed in arrays with all the viewing lines in a poloidal plane. There is an increasing interest in using the signals from such arrays to reconstruct two-dimensional (2-D) emission distributions that are not cylindrically symmetric in the viewing plane.

In a plasma device, the number of viewing ports is usually severely limited, so one cannot install the large number of arrays needed to reconstruct arbitrary emission distributions. However, reconstruction is still possible with a small number of arrays if the emission distribution satisfies sufficiently restrictive assumptions. An assumption that will probably prove suitable for many plasma studies is that the angular dependence of emission intensity is relatively smooth (i.e., it can be represented by a few low-order harmonics). We have developed and tested reconstruction algorithms based on this assumption; the derivation is described in detail, and the results of tests are presented in another paper.¹

In this report, we describe and list the computer programs that implement the algorithms used in our tests. The programs are designed to process data from three fan-shaped arrays of detectors in an arrangement similar to that of the soft x-ray system being built for the Impurity Study Experiment (ISX-B) tokamak.^{2,3} A summary of the algorithms is given in Sect. 2. Section 3 provides a brief functional description of the programs, which are (except for utilities and mathematical subroutines) listed fully in the Appendix. The package of programs is known as Local Emissivity Reconstruction From Chord Measurements (LERFCM).

2. ALGORITHMS

Assuming several fan-configuration arrays of detectors, we distinguish the arrays by subscript $i = 1, 2, \dots, N$, with all detectors viewing the emission distribution in the same plane. The geometry of one such array is shown in Fig. 1. The detectors are mounted on a circular arc A with a center at the collimating slit S, at a distance a_i from the origin. The x-ray emission intensity E (in units of power per unit volume of plasma) within the passband of the detectors is represented by a 2-D distribution within the circle of radius a_0 :

$$E = \begin{cases} f(r, \theta) , & r < a_0 \\ 0 , & r \geq a_0 \end{cases} . \quad (1)$$

The power received by a detector at D is proportional to the line integral of E along the viewing chord L_1, L_2 :

$$S_i(\beta_i) = \int_{L_1}^{L_2} f(r, \theta) d\ell , \quad (2)$$

where ℓ is a coordinate measured along the chord, with $\ell = 0$ at the center L_0 .

We assume that the angular dependence of $f(r, \theta)$ is relatively smooth (i.e., it can be represented by a small number of harmonics). We therefore make the expansion

$$f(r, \theta) = \sum_m [f_m(r) \cos m\theta + g_m(r) \sin m\theta] . \quad (3)$$

It is shown in Ref. 1 that under this assumption, the line integrals are given by

Fig. 1. Details of the measurement geometry.

$$\left. \begin{aligned}
 S_i(\beta_i) &= \sum_m [F_m(\rho) \cos m(\delta_i + \beta_i) + G_m(\rho) \sin m(\delta_i + \beta_i)] \\
 \text{and} \\
 S_i(-\beta_i) &= \sum_m (-1)^m [F_m(\rho) \cos m(\delta_i - \beta_i) + G_m(\rho) \sin m(\delta_i - \beta_i)] ,
 \end{aligned} \right\} \quad (4)$$

where β_i and the tangent radius ρ are considered as taking only positive values, and the harmonic contributions to the line integrals (i.e., to the detector signals) are related to the harmonic coefficients defined in Eq. (3) by

$$\left. \begin{aligned}
 F_m(\rho) \\
 G_m(\rho)
 \end{aligned} \right\} = 2 \int_{|\rho|}^a \left\{ \begin{aligned} f_m(r) \\ g_m(r) \end{aligned} \right\} T_m\left(\frac{\rho}{r}\right) \frac{r \, dr}{\sqrt{r^2 - \rho^2}} . \quad (5)$$

Here, $T_m(x)$ is the Chebyshev polynomial⁴ of order m .

There are N each of Eqs. (4); thus, at each value of tangent radius, they can be solved to obtain $F_m(\rho)$ and $G_m(\rho)$ for N poloidal harmonics (values of m). Generally, the harmonics for which solutions are sought would be $m = 0$ through $m = N - 1$. For a given tangent radius, the angle β_i must be chosen for each array so that it satisfies

$$\beta_i = \sin^{-1}\left(\frac{\rho}{u_i}\right) . \quad (6)$$

Because these angles will not, in general, correspond to detector locations in all the arrays, the needed values of $S_i(\beta_i)$ will usually be derived from the actual detector signals by interpolation and/or smoothing.

In many cases it may be valid to assume that the plasma is symmetric about one of its midplanes. Then, in general, more harmonics can be determined, but the potential for singularities in Eqs. (4) also arises. For example, consider symmetry about the horizontal midplane (i.e.,

about $\theta = 0$): $g_m(r) = G_m(\rho) = 0$, and, in principle, $2N$ harmonics can be determined. However, if one of the arrays is on the horizontal midplane ($\delta_i = -90^\circ$), Eqs. (4) are identical for that array; in that case, only $2N - 1$ harmonics can be determined. Other potential singularities of the system are discussed in Ref. 1.

A numerical difficulty, which is not strictly a singularity, arises from the fact that $F_m(0) = G_m(0) = 0$ for odd values of m . Thus, large relative errors may occur in the solutions of Eqs. (4) for the harmonic contributions near $\rho = 0$. The errors are minimized by smoothing $F_m(\rho)$ and $G_m(\rho)$ with, for odd m , the condition that the smoothed functions pass through zero at $\rho = 0$.

Once the harmonic contributions of the detector signals, $F_m(\rho)$ and $G_m(\rho)$, have been obtained, the emission intensity distribution can be reconstructed by inverting Eqs. (5) to get $f_m(r)$ and $g_m(r)$. We henceforth consider that r and ρ are normalized by the radius a_0 . To write these equations explicitly for the first five harmonics, we substitute the expressions for the Chebyshev polynomials $T_m(\rho/r)$ and define an Abel integral of a function $c(r)$ as

$$A(\rho) = a_0 \bar{A}[c(r)] = 2a_0 \int_0^1 c(r) \frac{r dr}{\sqrt{r^2 - \rho^2}}. \quad (7)$$

The relations between $F_m(\rho)$ and $f_m(r)$ [an identical set exists for $G_m(\rho)$ and $g_m(r)$] are then

$$\frac{1}{a_0} F_0(\rho) = \bar{A}[f_0(r)], \quad (8a)$$

$$\frac{1}{a_0 \rho} F_1(\rho) = \bar{A}\left[\frac{f_1(r)}{r}\right], \quad (8b)$$

$$\frac{1}{a_0} F_2(\rho) = 2\rho^2 \bar{A}\left[\frac{f_2(r)}{r^2}\right] - \bar{A}[f_2(r)], \quad (8c)$$

$$\frac{1}{a_0 \rho} F_3(\rho) = 4\rho^2 \bar{A} \left[\frac{f_3(r)}{r^3} \right] - 3\bar{A} \left[\frac{f_3(r)}{r} \right] , \quad (8d)$$

$$\frac{1}{a_0} F_4(\rho) = 8\rho^4 \bar{A} \left[\frac{f_4(r)}{r^4} \right] - 8\rho^2 \bar{A} \left[\frac{f_4(r)}{r^2} \right] + \bar{A}[f_4(r)] , \quad (8e)$$

and

$$\frac{1}{a_0 \rho} F_5(\rho) = 16\rho^4 \bar{A} \left[\frac{f_5(r)}{r^5} \right] - 20\rho^2 \bar{A} \left[\frac{f_5(r)}{r^3} \right] + 5\bar{A} \left[\frac{f_5(r)}{r} \right] . \quad (8f)$$

The inversion procedure is described briefly here (see Ref. 1 for a more detailed discussion). We symbolically represent the functions $f_m(r)$ and $g_m(r)$ as polynomials in r and fit certain functions involving $F_m(\rho)$ and $G_m(\rho)$ with polynomials in ρ . In the simpler cases, Eqs. (8a) and (8b), we substitute the latter polynomials into the inversion formula for Eq. (7):

$$c(r) = - \frac{1}{\pi a_0} \int_r^1 \frac{dA}{dn} \cdot \frac{d\rho}{\sqrt{\rho^2 - r^2}} . \quad (9)$$

This integral can be obtained by differentiation from one given by Arfken.⁵ Equations (8c)-(8f) are inverted by direct symbolic substitution of both sets of polynomials and matching of coefficients.

The relations between the coefficients in the polynomial expansions of $F_m(\rho)$ and $f_m(r)$ derived by these methods are given below for $m = 0$ through $m = 5$. In these equations, ρ and r are normalized to a_0 , and the index i is not the same as the one that distinguishes the arrays. Identical expressions are valid for the (G, g) pairs.

(1) m = 0 Inversion

With

$$\frac{F_0(\rho)}{a_0} = \sum_{j=0}^k c_{2j} \rho^{2j} \quad (10a)$$

and

$$f_0(r) = \sqrt{1 - r^2} \sum_{i=0}^{k-1} b_{2i} r^{2i}, \quad (10b)$$

the coefficients are related by

$$b_{2i} = -\frac{1}{\pi} \sum_{j=i+1}^k c_{2j} \frac{2j(2j-2) \dots (2j-2i)}{(2j-1)(2j-3) \dots (2j-2i-1)}. \quad (10c)$$

(2) m = 1 Inversion

Equation (10c) also applies to

$$\frac{F_1(\rho)}{a_0 \rho} = \sum_{j=0}^k c_{2j} \rho^{2j} \quad (11a)$$

and

$$f_1(r) = \sqrt{1 - r^2} \sum_{i=0}^{k-1} b_{2i} r^{2i+1}. \quad (11b)$$

(3) m = 2 Inversion

With

$$\frac{F_2(\rho)}{a_0 \sqrt{1 - \rho^2}} = \sum_{j=0}^k c_{2j} \rho^{2j} \quad (12a)$$

and

$$f_2(r) = \sum_{i=1}^k b_{2i} r^{2i}, \quad (12b)$$

$$c_0 = 2 \sum_{i=1}^k -b_{2i} \frac{1}{(2i+1)}$$

$$c_2 = 2 \sum_{i=1}^k b_{2i} \frac{2i+2}{(2i+1)(2i-1)} \quad (12c)$$

$$c_{2j} = 2 \sum_{i=j}^k b_{2i} \frac{(2i+2)(2i-2)(2i-4) \dots [2i-2(j-1)]}{(2i+1)(2i-1)(2i-3)(2i-5) \dots [2i-2(j-1)-1]} \cdot$$

From these equations one needs to obtain the coefficients b_{2i} in terms of c_{2j} . Note that the sum for $j = k$ consists of only one term. Thus, b_{2k} can easily be found in terms of c_{2k} . This result is then used in the equation for $j = k - 1$, etc. Similar procedures apply to Eqs. (13c), (14c), and (15c).

(4) m = 3 Inversion

With

$$\frac{F_3(\rho)}{a_0 \rho \sqrt{1-\rho^2}} = \sum_{j=0}^k c_{2j} \rho^{2j} \quad (13a)$$

and

$$r_3(r) = \sum_{i=1}^k b_{2i} r^{2i+1}, \quad (13b)$$

$$c_0 = 2 \sum_{i=1}^k -b_{2i} \frac{3}{(2i+1)}$$

$$c_2 = \sum_{i=1}^k b_{2i} \frac{2i+4}{(2i+1)(2i-1)} \quad (13c)$$

$$c_{2j} = 2 \sum_{i=j}^k b_{2i} \frac{(2i+4)(2i-2)(2i-4) \dots [2i-2(j-1)]}{(2i+1)(2i-1)(2i-3)(2i-5) \dots [2i-2(j-1)-1]}$$

(5) m = 4 Inversion

With

$$\frac{F_4(\rho)}{a_0 \sqrt{1 - \rho^2}} = \sum_{j=0}^k c_{2j} \rho^{2j} \quad (14a)$$

and

$$f_4(r) = \sum_{i=2}^k b_{2i} r^{2i}, \quad (14b)$$

$$c_0 = 2 \sum_{i=2}^k b_{2i} \frac{1}{(2i+1)}$$

$$c_2 = 2 \sum_{i=2}^k -b_{2i} \frac{14i+8}{(2i+1)(2i-1)} \quad (14c)$$

$$c_4 = 2 \sum_{i=2}^k b_{2i} \frac{(2i+4)(2i+2)}{(2i+1)(2i-1)(2i-3)}$$

$$c_{2j} = 2 \sum_{i=j}^k b_{2i} \frac{(2i+4)(2i+2)(2i-4)(2i-6) \dots [2i-2(j-1)]}{(2i+1)(2i-1)(2i-3)(2i-5)(2i-7) \dots [2i-2(j-1)-1]}.$$

(6) m = 5 Inversion

With

$$\frac{F_5(\rho)}{a_0 \sqrt{1 - \rho^2}} = \sum_{j=0}^k c_{2j} \rho^{2j} \quad (15a)$$

and

$$f_5(r) = \sum_{i=2}^k b_{2i} r^{2i+1}, \quad (15b)$$

$$\begin{aligned}
c_0 &= 10 \sum_{i=2}^k b_{2i} \frac{1}{(2i+1)} \\
c_2 &= -20 \sum_{i=2}^k b_{2i} \frac{3i+2}{(2i+1)(2i-1)} \\
c_4 &= 2 \sum_{i=2}^k b_{2i} \frac{(2i+6)(2i+4)}{(2i+1)(2i-1)(2i-3)} \\
c_{2j} &= 2 \sum_{i=j}^k b_{2i} \frac{(2i+6)(2i+4)(2i-4)(2i-6) \dots [2i-2(j-1)]}{(2i+1)(2i-1)(2i-3)(2i-5)(2i-7) \dots [2i-2(j-1)-1]} \quad j \geq 2
\end{aligned} \tag{15c}$$

To make use of these formulas, it is necessary first to evaluate the polynomial coefficients c_{2j} in Eqs. (10a), (11a), (12a), etc., according to the number of usable harmonics. We denote the left side of any of these equations by $H(\rho)$; in each case this function is known at each value of ρ and at each harmonic for which Eqs. (4) have been solved. Because of the parity properties of the Chebyshev polynomials appearing in Eqs. (5), $H(\rho)$ is always an even function. Thus, the polynomials on the right sides of Eqs. (10a), (11a), (12a), etc., need contain only even powers of ρ . We take advantage of the fact that if $H(\rho)$ is known at appropriately chosen values of ρ , it can be fitted by a finite series of Chebyshev polynomials without the computational complexity of integrations or least-squares calculations. The coefficients c_{2j} can then be obtained from the coefficients $[a_{2p}$ in Eq. (16) below] of the Chebyshev polynomial expansion.

The fitting just described is possible because it can be shown⁶ that the series

$$h(\rho) = \sum_{p=0}^k a_{2p} T_{2p}(\rho) \tag{16}$$

is, in a restricted sense, a least-squares approximation to $H(\rho)$ if the coefficients are given by

$$a_0 = \frac{1}{L} \sum_{\ell=0}^{L-1} H(\rho_\ell) \quad (17)$$

$$a_{2p} = \frac{2}{L} \sum_{\ell=0}^{L-1} H(\rho_\ell) T_{2p}(\rho_\ell), \quad p > 0$$

where $H(\rho)$ is known at the points

$$\rho_\ell = \cos \phi_\ell = \cos \left(\pi \frac{2\ell + 1}{2L} \right), \quad (18)$$

$$\ell = 0, 1, 2, \dots, L - 1.$$

The above formulas are given in terms of even-order Chebyshev polynomials but would be valid for all orders from 0 up to $L - 1$.

If we define an angle

$$\beta_\ell = \frac{\pi}{2} - \phi_\ell, \quad (19)$$

then from Eq. (18)

$$\rho_\ell = \sin \beta_\ell. \quad (20)$$

From Eq. (6) the corresponding detector angle in the i th array is

$$\beta_{i\ell} = \sin^{-1} \left(\frac{a_0}{a_i} \sin \beta_\ell \right); \quad (21)$$

note that ρ_ℓ in Eq. (20) is normalized to a_0 , but ρ in Eq. (6) was not. As can be seen from Eq. (18), the values of the angles β_ℓ and $\beta_{1\ell}$ are controlled by the choice of L . In the general case, interpolation could be used to obtain the detector signals corresponding to the angles $\beta_{1\ell}$ in the various arrays for input into the solution of Eqs. (4).

If all the collimating slits are at the same distance from the origin, one can use the same value for a_0 and each a_1 so that $\beta_{1\ell} = \beta_\ell$ for every array. Equation (19) then maps the argument range $(-1 \leq \rho \leq 1)$ of the Chebyshev polynomials into the detector angle range $(-\frac{\pi}{2} \leq \beta_\ell \leq \frac{\pi}{2})$. The function $H(\rho)$ is taken to be zero in those parts of the range where there are no detectors.

Once the coefficients in Eqs. (10b), (11b), (12b), etc., have been evaluated, the distribution of x-ray emission intensity is reconstructed by substitution into Eq. (3). The results are plotted in the form of a set of contours of constant emission intensity. If the contours obtained from data on a tokamak plasma resemble those derived from magnetohydrodynamic (MHD) equilibrium calculations, their shapes may be represented by the following equation:⁷

$$\left(\frac{x - x_0}{p}\right)^2 + \left(\frac{y}{q}\right)^2 (1 + D^2) - 2D \frac{(x - x_0)}{p} \left(\frac{y}{q}\right) = 1. \quad (22)$$

Here, x and y are measured from the origin, which is the point of intersection of the central axes of the detector arrays. The shift x_0 is the horizontal midpoint of the contour, the radius is p , and the ellipticity is $\epsilon = q/p$. These parameters are determined from the horizontal and vertical extrema. The triangularity D is obtained by a method that does not depend on a precise fit of Eq. (22) to the contour. The formula used is

$$D = 0.24 \frac{A_1 - A_2}{A_1 + A_2}, \quad (23)$$

where A_1 and A_2 are the areas within the contour and to the right and left of x_0 , respectively. It can be shown that for $|D| \leq 0.3$, this formula is accurate within 2% for a contour obeying Eq. (22). The contour structure can be characterized by plotting x_0 , ϵ , and D versus p .

3. PROGRAMS

We describe here the computer programs that were used¹ to test the algorithms summarized in the preceding section. The input data consisted of sets of detector signals derived from MHD equilibrium calculations⁸ for plasmas in a tokamak with the parameters of ISX-B. The locations and lines of sight of the detector arrays assumed in the tests are illustrated in Fig. 2. The arrangement is a simplified version of the system being built for ISX-B. The arrays are located at $\delta = 0^\circ$, -20° , and -90° ; each assumed array has 30 detectors covering an angular range of $\pm 45^\circ$; and the collimating slits are all at $a = 56.76$ cm. The angular positions are, of course, determined by the access ports available on ISX-B.

The programs would have to be generalized somewhat [incorporating, for instance, Eq. (21)] in order to use them with a system of arrays with collimating slits at different radii a_i . In addition, an input program module would have to be provided to generate the input data file. We do not describe such a module here because it would be specialized to a particular data acquisition scheme and detector array configuration. Also, since graphics capabilities vary among sites, we have not included any plotting commands or programs. All the programs are written in FORTRAN and have been run on a Digital Equipment Corporation PDP-10. The programs have not been checked for portability, but we believe that — except for input and output statements and file naming conventions — minimal revision would be needed to run the programs on another computer.

The functions and interrelationships of the programs in the system are indicated in Fig. 3. The name of each program (a file name) appears above the block containing it; if there is a second name in parentheses, it is the FORTRAN name. The authorship of the programs is shown in Table 1. All the programs are listed fully in the Appendix, except that only the comment sections are given for PLOTEx, an installation-dependent utility; for the bicubic interpolation routines, which are described elsewhere;⁹ and for the IMSL routines,¹⁰ which are proprietary.

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Fig. 2. Arrangement of the detectors used in the simulation tests.

Fig. 3. Flow chart for the LERFCM package.

The main program is TOMGEN or TOMSYM, depending on the symmetry assumed for the plasma. In TOMGEN no particular symmetry is assumed, and harmonic components for $m = 0, 1$, and 2 are determined. In TOMSYM the plasma is assumed symmetric about the horizontal midplane. The detector configuration of Fig. 2 contains an array on the horizontal midplane; thus, as noted in the discussion following Eq. (6), five harmonics can be determined. TOMSYM determines the harmonic contributions $F_m(\rho)$ to the detector signals for $m = 0, 1, 2, 3$, and 4 . However, it was found in a number of tests that $F_4(\rho)$ was always very small. Thus, the programs as listed here only perform inversions for $m = 0, 1, 2$, and 3 .

In either case the main program reads the operator's option selections and then the data file containing the detector angles and detector signals. The detector signals may be smoothed if desired. The program assumes that arrays 1 and 3 in Fig. 2 are located as shown at $\delta = 0^\circ$ and -90° , and it reads from the data file the angular position of array 2. The integer L in Eq. (18) is selected so that the angles β_ℓ in Eqs. (19) and (20) fall at the locations of the detectors. The main program then sets up the matrix of coefficients of Eqs. (4) and calls a subroutine to solve them to obtain $F_m(\rho_\ell)$ and (in TOMGEN) $G_m(\rho_\ell)$ for each value of ρ_ℓ given by Eq. (20). These harmonic contributions are smoothed if the operator has so specified, with the contributions of the odd modes being constrained to pass through zero at $\rho = 0$. The program then calculates the functions on the left sides of Eqs. (10a), (11a), (12a), etc. Subroutine CHEBIN is then called, once for each harmonic contribution, to perform the Chebyshev polynomial fitting described by Eqs. (16)-(18) and to do the inversions (i.e., calculate the coefficients c_{2i}) according to Eqs. (10), (11), (12), etc. CHEBIN uses a value of nine for the summation limit k in Eq. (16), since tests showed no significant improvement from using polynomials of an order higher than 18.

The emission distribution is reconstructed on a grid, using Eq. (3), by subroutine REC2DE, which calls PLOTEx to make a contour plot of the reconstructed distribution. PLOTEx is actually a package of seven subroutines that generate Calcomp¹¹ graphics calls. Finally, an option

is available to analyze each contour by determining the parameters of Eq. (22). This analysis is done by subroutine CONTAN. Since the contours generated by PLOTX are not in a suitable form, CONTAN uses only the emission values corresponding to the contours and locates them by a series of radial searches from the point of highest emission intensity. These searches are done by subroutine SEAR, which uses Gaffney's bicubic interpolation package⁹ with the grid of emission values calculated by REC2DE to find where on a particular radius vector a specified value of emission intensity occurs. As noted in Fig. 3, various searches are performed to obtain the quantities, indicated in the discussion following Eq. (22), from which the radius, shift, ellipticity, and triangularity are derived. CONTAN also uses these parameters to calculate, for comparison, a set of contours from an equation that is written in polar form and is a very close approximation to Eq. (22).

Table 1. Sources of programs

Programs	Author or source
TOMGEN	A. P. Navarro
TOMSYM	
CHEBIN	
REC2DE	
CONTAN	
SEAR	
SIGSM	
PLOTEX	ORNL staff
DERIVS	P. W. Gaffney
COEFF	
BICUBE	
ICSSCU	IMSL
ICSMOU	
LEQT2F	

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APPENDIX

Listing of Computer Programs for Spatial Reconstruction

```

C   T O M G E N
C   *****
C
C   PROGRAM FOR SPATIAL RECONSTRUCTION OF LOCAL VOLUME
C   EMISSION FROM CHORD MEASUREMENTS IN PLASMAS
C
C   TO BE USED IN PLASMA SHAPE ANALYSIS AND
C   MHD FLUCTUATIONS STUDIES.
C   (A.P.NAVARRO . OCT/78)
C
      DIMENSION WK(40),C0(13),C1(13),C2(13),C3(13),C4(13)
      DIMENSION SD(40),V(40),T(40),S(40),SP(40),A(5,5),BC(5)
      DIMENSION BETA(40),F0(20),F1(20),F2(20),G1(20),G2(20)
      COMMON /PARAM/ K1,IN,N,PI,ICON
      COMMON W(40,80),VX(40),VY(80),UX(40,80),UY(40,80)
      1,UXY(40,80)
      COMMON /TITLE/ COMENT(20)
      COMMON /MAINC/ SX,SY,NX,NY,
&      ID,NUMB,FF(75),JQ,DECK(2)
C
C   SETUP OF ANALYSIS CONDITIONS
C
      TYPE 1
1     FORMAT(10X,'ANALYSIS CONDITIONS',/,2X,
1     'DATA FILE #',/,2X,'SIGNAL SMOOTHING PRESS 1'
2     ,/,2X,'EVEN MODES SMOOTHING PRESS 1',/,2X,
3     'ODD MODES SMOOTHING PRESS 1',
4     ,/,2X,'NUMBER OF CONTOURS TO PLOT',/,10X,
5     'GRID DIMENSIONS (MAX.40*80)',/,2X,'NX',/,2X,'NY',
6     ,/,2X,'FOR CONTOUR ANALYSIS PRESS 1')
      ACCEPT 3002,IN
      ACCEPT 3002,ISM
      ACCEPT 3002,I3M0
      ACCEPT 3002,ISM1
      ACCEPT 3002,NUMB
      ACCEPT 3002,NX
      ACCEPT 3002,NY
      ACCEPT 3002,ICON
3002  FORMAT(I10)
      PI=3.14159
C
C   READOUT OF DETECTOR SIGNALS
C   -----
C   (THREE ARRAYS WITH COLLIMATION SLITS AT 0, DELTA, AND 90 DEG.)
C   (EACH ARRAY WITH N DETECTORS LOOKING THROUGH THE PLASMA
C   AT ANGLES BETA(J) )
C   MAXIMUM VALUES N=40, NUMBER OF HARMONICS=5
C   FOR26.DAT IS A FILE WITH INTERMEDIATE RESULTS FOR
C   PLOTTING PURPOSES
C
      READ(IN,2017) N,BM,DELTA

```

```

WRITE(26,2017) N,BM,DELTA
2017  FORMAT(I10,2F10.5)
      DO 29 J=1,N
      READ(IN,2007) J1,BETA(J),A2,S(J),SD(J),SP(J)
      WRITE(26,2007) J1,BETA(J),A2,S(J),SD(J),SP(J)
      WRITE(6,2007) J1,BETA(J),A2,S(J),SD(J),SP(J)
29    CONTINUE
C
C  OPTIONAL SIGNAL SMOOTHING
C
      IF(ISM.NE.1) GO TO 107
      CALL SIGSM(BETA,S,N,IER)
      CALL SIGSM(BETA,SD,N,IER)
      CALL SIGSM(BETA,SP,N,IER)
      WRITE(26,2007) (J,BETA(J),A2,S(J),SD(J),SP(J),J=1,N)
C
C  CALCULATION OF HARMONICS CONTRIBUTIONS (FM(BETA) AND GM(BETA))
C-----
C
107   CONTINUE
      WRITE(6,2010) N,BM,DELTA
2010  FORMAT(1H1,2X,'NUMBER OF DETEC.',I10,/,2X,'APERTURE (DEG.)',
1F10.2,/,2X,'DISTANCE BETW. SLITS (DEG.)',F10.2)
      K1=IFIX(180./BM)
      N2=N*K1
      TNORM=1.
      DO 10 J=1,N
      BETA(J)=BETA(J)*PI/180.
10    CONTINUE
2007  FORMAT(I5,5F12.5)
1007  FORMAT(I5,7F12.5)
1009  FORMAT(/,10X,'F0',9X,'F1',9X,'G1',9X,'F2',9X,'G2')
1006  FORMAT(I5,5F10.5)
      N3=N/2
      DELTA=DELTA*PI/180.
      DO 30 J=1,N3
      L=N-J+1
C
C  COEFFICIENTS FOR THE LINEAR EQUATION SYSTEM
C  WE USE HERE MODES 0,1, AND 2
C
      B1=BETA(J)
      A(1,1)=1.
      A(1,2)=COS(B1)
      A(1,3)=SIN(B1)
      A(1,4)=COS(2*B1)
      A(1,5)=SIN(2*B1)
      A(2,1)=1.
      A(2,2)=-A(1,2)
      A(2,3)=A(1,3)
      A(2,4)=A(1,4)

```



```

A(2,5)=-A(1,5)
B1=BETA(J)-DELTA
A(3,1)=1.
A(3,2)=COS(B1)
A(3,3)=SIN(B1)
A(3,4)=COS(2*B1)
A(3,5)=SIN(2*B1)
B1=BETA(J)+DELTA
A(4,1)=1.
A(4,2)=-COS(B1)
A(4,3)=SIN(B1)
A(4,4)=COS(2*B1)
A(4,5)=-SIN(2*B1)
B1=BETA(J)-PI/2.
A(5,1)=1.
A(5,2)=-COS(B1)
A(5,3)=SIN(B1)
A(5,4)=COS(2*B1)
A(5,5)=-SIN(2*B1)
BC(1)=S(J)
BC(2)=S(L)
BC(3)=SD(J)
BC(4)=SD(L)
BC(5)=SP(L)
C
C  LINEAR EQ. SYSTEM SOLUTION
C
      CALL LEQT2F(A,1,5,5,BC,4,V,IERR)
      IF(IERR.NE.0) TYPE 3003,IERR
3003  FORMAT(2X,'ERROR',I5,'TRYING TO SOLVE LINEAR EQ. SYSTEM')
      F0(J)=BC(1)
      F1(J)=BC(2)
      G1(J)=BC(3)
      F2(J)=BC(4)
      G2(J)=BC(5)
30    CONTINUE
      WRITE(6,1009)
      WRITE(6,2008) (F0(J),F1(J),G1(J),F2(J),G2(J),J=1,N3)
      WRITE(26,2008) (F0(J),F1(J),G1(J),F2(J),G2(J),J=1,N3)
2008  FORMAT(5F12.5)
C
C  FM(BETA) AND GM(BETA) SMOOTHING
C
      DO 46 I=1,N3
      J=N3-I+1
      V(I)=BETA(J)
      S(I)=F0(J)
      SD(I)=F1(J)
      SP(I)=G1(J)
      T(I)=F2(J)
46    VX(I)=G2(J)

```

```

      NP=N3+3
      B1=V(N3)-V(N3-1)
      V(N3+1)=V(N3)+B1
      V(N3+2)=V(N3)+2*B1
      V(N3+3)=V(N3)+3*B1
      DO 501 J=N3+1,NP
      S(J)=0.
      SD(J)=0.
      SP(J)=0.
501    VX(J)=0.
C
C    EVEN MODES SMOOTHING
C
      IF(ISMO.NE.1) GO TO 126
      CALL ICSMOU(V,S,NP,1.,0.,MAXIT,WK,IER)
      IF(IER.NE.0) TYPE 3004,IER
3004   FORMAT(2X,'ERROR',I5,'SMOOTHING EVEN MODES')
      CALL ICSMOU(V,T,NP,1.,0.,MAXIT,WK,IER)
      IF(IER.NE.0) TYPE 3004,IER
      CALL ICSMOU(V,VX,NP,1.,0.,MAXIT,WK,IER)
      IF(IER.NE.0) TYPE 3004,IER
126    CONTINUE
      DO 502 K=1,NP
      J=NP+2-K
      SD(J)=SD(J-1)
      SP(J)=SP(J-1)
502    V(J)=V(J-1)
      V(1)=0.
      SD(1)=0.
      SP(1)=0.
      NP=NP+1
C
C    ODD MODES SMOOTHING
C
      IF(ISM1.NE.1) GO TO 127
      CALL ICSMOU(V,SD,NP,1.,0.,MAXIT,WK,IER)
      IF(IER.NE.0) TYPE 3005,IER
3005   FORMAT(2X,'ERROR',I5,'SMOOTHING ODD MODES')
      CALL ICSMOU(V,SP,NP,1.,0.,MAXIT,WK,IER)
      IF(IER.NE.0) TYPE 3004,IER
127    CONTINUE
      DO 47 I=1,N3
      J=N3-I+1
      J2=J+1
      F0(I)=S(J)
      F1(I)=SD(J2)
      G1(I)=SP(J2)
      F2(I)=T(J)
47     G2(I)=VX(J)
      WRITE(26,2008) (F0(J),F1(J),G1(J),F2(J),G2(J),J=1,N3)
      WRITE(6,1006) (J,F0(J),F1(J),G1(J),F2(J),G2(J),J=1,N3)

```

```

C
C   INVERSION OF THE DIFFERENT HARMONICS CONTRIBUTIONS
C-----
C
      DO 504 J=1,N3
      F1(J)=F1(J)/SIN(BETA(J))
      G1(J)=G1(J)/SIN(BETA(J))
      F2(J)=F2(J)/COS(BETA(J))
504    G2(J)=G2(J)/COS(BETA(J))
      CALL CHEBY(F0,C0,0)
      CALL CHEBY(F1,C1,0)
      CALL CHEBY(G1,C2,0)
      CALL CHEBY(F2,C3,1)
      CALL CHEBY(G2,C4,1)
      WRITE(6,2011)
2011   FORMAT(1H1,2X,'RADIAL FUNCTIONS COEFF. ')
      WRITE(6,1011) (I,C0(I),C1(I),C2(I),C3(I),C4(I),I=1,10)
      WRITE(26,1011) (I,C0(I),C1(I),C2(I),C3(I),C4(I),I=1,10)
1011   FORMAT(I5,5F15.5)
C
C   TWO-DIMENSIONAL RECONSTRUCTION
C-----
C
      CALL RES(C0,C1,C2,C3,C4,0)
      STOP
      END

```

```

C   T O M S Y M
C   *****
C
C   PROGRAM FOR SPATIAL RECONSTRUCTION OF LOCAL VOLUME
C   EMISSION FROM CHORD MEASUREMENTS IN PLASMAS
C   WITH UP-DOWN SYMMETRICAL EMISSION DISTRIBUTIONS
C
C   TO BE USED IN PLASMA SHAPE ANALYSIS AND
C   MHD FLUCTUATIONS STUDIES.
C   (A.P.NAVARRO OCT/78)
C
      DIMENSION WK(40),C0(13),C1(13),C2(13),C3(13),C4(13)
      DIMENSION SD(40),V(40),T(40),S(40),SP(40),A(5,5),BC(5)
      DIMENSION BETA(40),F0(20),F1(20),F2(20),F3(20),F4(20),F13(20)
      COMMON /PARAM/ K1,IN,N,PI,ICON
      COMMON W(40,80),VX(40),VY(80),UX(40,80),UY(40,80)
1, UXY(40,80)
      COMMON /TITLE/ COMENT(20)
      COMMON /MAINC/ SX,SY,NX,NY,
&      ID,NUMB,FF(75),JQ,DECK(2)
C
C
C   SETUP OF ANALYSIS CONDITIONS
C
      TYPE 1
1   FORMAT(2X,'ANALYSIS CONDITIONS',/
1,2X,'DATA FILE #',/,2X,'SIGNAL SMOOTHING PRESS 1'
2,/,2X,'EVEN MODES SMOOTHING PRESS 1',/,2X
3,'ODD MODES SMOOTHING PRESS 1',
4/,2X,'NUMBER OF CONTOURS TO PLOT',/,10X,
5'GRID DIMENSIONS (MAX. 40*40)',/,2X,'NX',/,2X,'NY',
6/,2X,'FOR CONTOUR ANALYSIS PRESS 1')
      ACCEPT 3002,IN
      ACCEPT 3002,ISM
      ACCEPT 3002,ISM0
      ACCEPT 3002,ISM1
      ACCEPT 3002,NUMB
      ACCEPT 3002,NX
      ACCEPT 3002,NY
      ACCEPT 3002,ICON
3002  FORMAT(I10)
      PI=3.14159
C
C   READOUT OF DETECTOR SIGNALS
C   -----
C   (THREE ARRAYS WITH COLLIMATION SLITS AT 0, DELTA, AND 90 DEG.)
C   (EACH ARRAY WITH N DETECTORS LOOKING THROUGH THE PLASMA
C   AT ANGLES BETA(J) )
C   MAXIMUM VALUES N=40, NUMBER OF HARMONICS=5
C   FOR26.DAT IS A FILE WITH INTERMEDIATE RESULTS FOR
C   PLOTTING PURPOSES

```

```

C
      READ(IN,2017) N,BM,DELTA
      WRITE(26,2017) N,BM,DELTA
2017  FORMAT(I10,2F10.5)
      DO 29 J=1,N
      READ(IN,2007) J1,BETA(J),A2,S(J),SD(J),SP(J)
      WRITE(26,2007) J1,BETA(J),A2,S(J),SD(J),SP(J)
      WRITE(6,2007) J1,BETA(J),A2,S(J),SD(J),SP(J)
29    CONTINUE
C
C  OPTIONAL SIGNAL SMOOTHING
C
      IF(ISM.NE.1) GO TO 107
      CALL SIGSM(BETA,S,N,IER)
      CALL SIGSM(BETA,SD,N,IER)
      CALL SIGSM(BETA,SP,N,IER)
      WRITE(26,2007) (J,BETA(J),A2,S(J),SD(J),SP(J),J=1,N)
C
C  FM(BETA)  CALCULATION
C-----
C
107  CONTINUE
      WRITE(6,2010) N,BM,DELTA
2010  FORMAT(1H1,2X,'NUMBER OF DETEC.',I10,/,2X,'APERTURE (DEG.)',
1F10.2,/,2X,'DISTANCE BETW. SLITS (DEG.)',F10.2)
      K1=IFIX(180./BM)
      N2=N*K1
      TNORM=1.
      DO 10 J=1,N
      BETA(J)=BETA(J)*PI/180.
10    CONTINUE
2007  FORMAT(I5,5F12.5)
1007  FORMAT(I5,7F12.5)
1009  FORMAT(/,10X,'F0',9X,'F1',9X,'F2',9X,'F3',9X,'F4')
1006  FORMAT(I5,5F10.5)
      WRITE(6,1009)
      N3=N/2
      DELTA=DELTA*PI/180.
      DO 30 J=1,N3
      L=N-J+1
C
C  COEFFICIENTS FOR THE LINEAR EQUATION SYSTEM
C-----
C  WE USE HERE MODES 0,1,2,3,4 FOR COSINE TERMS
C  OTHER COMBINATIONS OF MODES REQUIRE ONLY
C  A CHANGE IN THE MATRIX A COEFFICIENTS
C
      DO 110 I=1,5
      A(1,I)=COS((I-1)*BETA(J))
      A(2,I)=A(1,I)*(-1)**(I+1)
      B1=BETA(J)-DELTA

```

```

      A(3,I)=COS((I-1)*B1)
      B1=BETA(J)+DELTA
      A(4,I)=COS((I-1)*B1)*(-1)**(I+1)
      B1=BETA(J)+PI/2.
      A(5,I)=COS((I-1)*B1)*(-1)**(I+1)
110  CONTINUE
      BC(1)=S(J)
      BC(2)=S(L)
      BC(3)=SD(J)
      BC(4)=SD(L)
      BC(5)=SP(L)

C
C  LINEAR EQ. SYSTEM SOLUTION
C
      CALL LEQT2F(A,1,5,5,BC,4,V,IERR)
      IF(IERR.NE.0) TYPE 3003,IERR
3003  FORMAT(2X,'ERROR',I5,'SOLVING LINEAR EQ. SYSTEM')
      F0(J)=BC(1)
      F1(J)=BC(2)
      F2(J)=BC(3)
      F3(J)=BC(4)
      F4(J)=BC(5)
      F13(J)=BC(2)+BC(4)
30  CONTINUE
      WRITE(26,2008) (F0(J),F1(J),F2(J),F3(J),F4(J),J=1,N3)
2008  FORMAT(5F12.5)

C
C  FM(BETA)  SMOOTHING
C-----
C
      IF(ISM0.NE.1) GO TO 127
      DO 46 I=1,N3
      J=N3-I+1
      V(I)=BETA(J)
      S(I)=F0(J)
      SD(I)=F1(J)
      SP(I)=F2(J)
      T(I)=F3(J)
      VY(I)=F13(J)
46  VX(I)=F4(J)
      NP=N3+3
      B1=V(N3)-V(N3-1)
      V(N3+1)=V(N3)+B1
      V(N3+2)=V(N3)+2*B1
      V(N3+3)=V(N3)+3*B1
      DO 501 J=N3+1,NP
      S(J)=0.
      SD(J)=0.
      SP(J)=0.
      VY(J)=0.
501  VX(J)=0.

```

```

      CALL ICSMOU(V,S,NP,1.,0.,5,WK,IER)
      TYPE 3002,IER
      CALL ICSMOU(V,VY,NP,1.,0.,5,WK,IER)
      TYPE 3002,IER
      CALL ICSMOU(V,SP,NP,1.,0.,5,WK,IER)
      TYPE 3002,IER
      CALL ICSMOU(V,VX,NP,1.,0.,5,WK,IER)
      TYPE 3002,IER
C
C  SMOOTHING OF ODD MODES NEAR BETA=0
C
127    CONTINUE
      IF(ISM1.NE.1) GO TO 126
      DO 502 K=1,NP
      J=NP+2-K
      SD(J)=ED(J-1)
      VY(J)=VY(J-1)
502    V(J)=V(J-1)
      V(1)=0.
      SD(1)=0.
      VY(1)=0.
      NP=NP+1
      CALL ICSMOU(V,SD,NP,1.,0.,5,WK,IER)
      TYPE 3002,IER
      DO 503 J=1,NP
503    T(J)=VY(J)-SD(J)
      DO 47 I=1,N3
      J=N3-I+1
      J2=J+1
      F0(I)=S(J)
      F1(I)=SD(J2)
      F2(I)=SP(J)
      F3(I)=T(J2)
      F13(I)=VY(J2)
47    F4(I)=VX(J)
126    CONTINUE
      WRITE(26,2008) (F0(J),F1(J),F2(J),F3(J),F4(J),J=1,N3)
      WRITE(6,1006) (J,F0(J),F1(J),F2(J),F3(J),F4(J),J=1,N3)
C
C  INVERSION OF THE DIFFERENT USED HARMONICS
C-----
C
      DO 504 J=1,N3
      F1(J)=F1(J)/SIN(BETA(J))
      F2(J)=F2(J)/COS(BETA(J))
504    F3(J)=F3(J)/SIN(2*BETA(J))
      CALL CHEBY(F0,C0,0)
      CALL CHEBY(F1,C1,0)
      CALL CHEBY(F2,C2,1)
      CALL CHEBY(F3,C3,-1)
      WRITE(6,2011)

```

```
2011  FORMAT(1H1,2X,'RADIAL FUNCTIONS COEFF.')
```

```
      WRITE(6,1011) (I,C0(I),C1(I),C2(I),C3(I),I=1,10)
```

```
      WRITE(26,1011) (I,C0(I),C1(I),C2(I),C3(I),I=1,10)
```

```
1011  FORMAT(I5,4F15.5)
```

```
C
```

```
C  TWO-DIMENSIONAL RECONSTRUCTION
```

```
C-----
```

```
C
```

```
      CALL RES(C0,C1,C2,C3,C4,1)
```

```
      STOP
```

```
      END
```



```

C  C H E B I N
C  *****
C  SUBROUTINE TO CALCULATE RADIAL FUNCTIONS F(R) AND G(R)
C  BY INVERSION OF THE HARMONIC CONTRIBUTIONS
C
      SUBROUTINE CHEBY(Y,C2,IND)
      COMMON /PARAM/ K1,IN,N,PI,ICON
      DIMENSION C2(13),X(20),Y(20),T(13,20),B(13),A(26)
C  M IS THE MAXIMUM ORDER OF CHEBYSHEV POLY. TO BE USED
C  (MAXIMUM M VALUE IS 18)
      M=18
      N2=N*K1
      K3=(K1-2)*N-2
      N4=N/2
C
C  EVALUATE CHEBYSHEV POLYNOMIALS AT RHO(L)=X(J)
C
      DO 20 J=1,N4
      X(J)=COS((K3+4*J)*PI/(2*N2))
      T(1,J)=1.
      F1=1.
      F2=X(J)
      IL=M+1
      DO 10 I=3,IL
      I1=I/2+1
      F3=2.*X(J)*F2-F1
      F1=F2
      F2=F3
      T(I1,J)=F3
10      CONTINUE
20      CONTINUE
C
C  CALCULATE COEFFICIENTS OF CHEBYSHEV POLYNOMIAL SERIES
C  THAT FITS THE FUNCTION Y(RHO)
C
      M=M/2+1
      WRITE(6,11)
11      FORMAT(1H1,' CHEB COEFF. F(X)=A(I)*TI(X) ',10X,
1' POLYN. COEFF. F(X)=C(I)*X**2I ',/)
      DO 40 I=1,M
      A(I)=0.
      DO 50 J=1,N4
50      A(I)=A(I)+Y(J)*T(I,J)
      A(I)=A(I)*8./N2
40      CONTINUE
      A(1)=A(1)/2.
C
C  CHANGE TO POLYNOMIALS IN RHO
C
      C2(7)=2048*A(7)
      C2(6)=-6144*A(7)+512*A(6)

```

```

C2(5)=6912*A(7)-1280*A(6)+128*A(5)
C2(4)=-3584*A(7)+1120*A(6)-256*A(5)+32*A(4)
C2(3)=840*A(7)-400*A(6)+160*A(5)-48*A(4)+8*A(3)
C2(2)=-72*A(7)+50*A(6)-32*A(5)+18*A(4)-8*A(3)+2*A(2)
C2(1)=A(7)-A(6)+A(5)-A(4)+A(3)-A(2)+A(1)
C2(10)=131072.*A(10)
C2(9)=32768.*A(9)-589824.*A(10)
C2(8)=8192.*A(8)-131072.*A(9)+1105920.*A(10)
C2(7)=C2(7)-28672.*A(8)+212992.*A(9)-1118208.*A(10)
C2(6)=C2(6)+39424.*A(8)-180224.*A(9)+658944.*A(10)
C2(5)=C2(5)-26880.*A(8)+84480.*A(9)-228096.*A(10)
C2(4)=C2(4)+9408*A(8)-21504*A(9)+44352.*A(10)
C2(3)=C2(3)-1568*A(8)+2688*A(9)-4320*A(10)
C2(2)=C2(2)+98*A(8)-128*A(9)+162*A(10)
C2(1)=C2(1)-A(8)+A(9)-A(10)
C
WRITE(6,4) (A(I),C2(I),I=1,M)
4  FORMAT(15X,F10.5,20X,F15.5)
WRITE(6,12)
12  FORMAT(/,20X,' X ',10X,' EXP ',10X,' ADJUST ')
DO 60 J=1,N4
R=0.
DO 70 I=1,M
R=R+A(I)*T(I,J)
70  CONTINUE
WRITE(26,5) X(J),Y(J),R
60  WRITE(6,5) X(J),Y(J),R
5    FORMAT(10X,3F15.6)
C
C  INVERSE TRANSFORM CALCULATION
C
Y(1)=1.
X(1)=1.
M2=M+2
DO 67 I=2,M2
X(I)=2*(I-1)*X(I-1)
Y(I)=(2*I-3)*Y(I-1)
67  CONTINUE
DO 71 I=1,M
71  A(I)=C2(I)
M1=M-1
IF(IND) 95,91,99
C
C  MODES 0 AND 1 INVERSION
C
91  CONTINUE
DO 74 I=1,M1
C2(I)=0.
JM=M-I
DO 74 J=1,JM
C2(I)=C2(I)+A(I+J)*X(I+J)*Y(J)/(Y(I+J)*X(J))

```

```

74      CONTINUE
        DO 75 J=1,M1
75      C2(J)=-C2(J)/PI
        C2(M)=0.
        GO TO 999

C
C  MODE 2 INVERSION
C
99      CONTINUE
        DO 101 I1=1,M1
          I=M-I1+1
          JM=M-I
          C2(I)=A(I)
          IF(JM) 103,103,104
104     CONTINUE
          DO 105 J=1,JM
            C2(I)=C2(I)-C2(I+J)*X(I+J+1)*Y(J+1)/(Y(I+J+1)*X(J+1)*2*(I+J-1))
105     CONTINUE
103     C2(I)=C2(I)*Y(I+1)*2*(I-1)/X(I+1)
101     CONTINUE
          C2(1)=0.
          DO 107 J=2,M
107     C2(J)=C2(J)/2.
          GO TO 999

C
C  MODE 3 INVERSION
C
95      CONTINUE
        DO 301 I1=1,M1
          I=M-I1+1
          JM=M-I
          C2(I)=A(I)
          IF(JM) 303,303,304
304     CONTINUE
          DO 305 J=1,JM
            C2(I)=C2(I)-C2(I+J)*X(I+J+2)*Y(J+1)/(X(J+1)*Y(I+J+1)*4*(I+J)*
1(I+J-1))
305     CONTINUE
303     C2(I)=C2(I)*Y(I+1)*4*I*(I-1)/X(I+2)
301     CONTINUE
          C2(1)=0.
          DO 108 J=2,M
108     C2(J)=C2(J)/2.
999     CONTINUE
        RETURN
        END

```

```

C   R E C 2 D E
C   *****
C
C   SUBROUTINE TO GENERATE 2-DIMENSIONAL DISTRIBUTIONS
C   OF VOLUME EMISSION USING THE RADIAL FUNCTIONS CALCULATED
C   WITH CHEBIN
C
C   ISYM.EQ.1 ASSUMES MODES 0,1,2 AND 3 (UP-DOWN SYMMETRY)
C   ISYM.NE.1 ASSUMES MODES 0,1,2
C
      SUBROUTINE RES(C0,C1,C2,C3,C4,ISYM)
      COMMON /PARAM/K1,IN,N,PI,ICON
      COMMON W(40,80),VX(40),VY(80),UX(40,80),UY(40,80)
1, UXY(40,80)
      COMMON /MAIN/ SX,SY,NX,NY,
&      ID,NUMB,FF(75),JQ,DECK(2)
      DIMENSION F(40,80),WK(80),C0(10),C1(10),C2(10),C3(10),C4(10)
      DIMENSION WP(40,80)
C
      WRITE(6,106)
106  FORMAT(/,60X,'RECONST. EMISS.',/,2X,
1 'HORIZ. RESOL.=1.36 CM',/)
C
C   GRID DEFINITION
C   (MAXIMUM GRID 40*80)
C   COLDIS=COLLIMATOR RADIUS
C
      COLDIS=56.76
      SX=6.
      SY=6.
      X0=-0.506
      DX=-2*X0/(NX-1)
      Y0=2*X0
      DY=2*DX*(NX-1)/FLOAT((NY-1))
      IF(ISYM.NE.1) GO TO 200
      DY=DY/2
      Y0=Y0-DY/2
200  CONTINUE
C
C   EMISSION INTENSITY CALCULATION
C
      DO 40 J9=1,NY
      J=NY-J9+1
      Y=Y0+(J-1)*DY
      DO 30 I=1,NX
      X=X0+(I-1)*DX
      R2=X**2+Y**2
      IF(R2-1.) 11,31,31
11  F0=0.
      F1=0.
      F2=0.

```

```

      F3=0.
      G1=0.
      G2=0.
      A1=SQRT(1.-R2)
      A2=2*X**2/R2-1.
      A3=4*X**3/R2-3*X
      IF(ISYM.NE.1) GO TO 32
      DO 25 I1=1,10
      R3=R2** (I1-1)
      F0=F0+C0(I1)*R3
      F1=F1+C1(I1)*R3
      F2=F2+C2(I1)*R3
25    F3=F3+C3(I1)*R3
      F(I,J)=F0*A1+F1*X*A1+F2*A2+F3*A3
      GO TO 30
32    A4=2*X*Y/R2
      DO 26 I1=1,10
      R3=R2** (I1-1)
      F0=F0+C0(I1)*R3
      F1=F1+C1(I1)*R3
      G1=G1+C2(I1)*R3
      F2=F2+C3(I1)*R3
26    G2=G2+C4(I1)*R3
      F(I,J)=F0*A1+F1*X*A1+G1*Y*A1+F2*A2+G2*A4
      GO TO 30
31    F(I,J)=0.
30    CONTINUE
C
C  RESULTS PRINTOUT AND PLOTTING
C  (FOR25.DAT IS A FILE TO BE USED BY PLOTTING SUBROUTINE)
C
      Y1=Y*COLDIS
      WRITE(25,310) (F(I,J),I=1,NX)
      WRITE(6,105) Y1
105    FORMAT(/,2X,'Y=',F6.1,' CM')
      WRITE(6,1300) (F(I,J),I=1,NX)
40    CONTINUE
1300   FORMAT(20F6.3)
310   FORMAT(2X,5E14.5)
334   FORMAT(F10.5)
C
      CALL PLOTX
C
C  ABOVE PROGRAM RETURNS CONTOUR VALUES IN ARRAY FF(I)
C
C  CONTOUR ANALYSIS
C
      WRITE(26,126) ICON
126    FORMAT(I10)
      IF(ICON.NE.1) GO TO 99
      DO 211 I=1,NX

```

```
211      VX(I)=(X0+(I-1)*DX)*COLDIS
        DO 2111 J=1,NY
2111     VY(J)=(Y0+(J-1)*DY)*COLDIS
        DO 247 I=1,NX
        DO 247 J=1,NY
247      W(I,J)=F(I,J)
        IF(1SYM.NE.1) GO TO 400
        NYT=2*NY
        DO 212 J9=1,NY
        J=NYT-J9+1
212     VY(J)=-VY(J9)
        DO 248 J=1,NY
        J9=NYT-J+1
        DO 248 I=1,NX
248     W(I,J9)=W(I,J)
        NY=NYT
400     CONTINUE
        CALL SPECT(WP,NX,NY)
99      CONTINUE
        RETURN
        END
```

```

C   C O N T A N
C   *****
C   SUBROUTINE TO ANALYZE CONTOURS OF CONSTANT EMISSION
C   BY DETERMINATION OF THEIR SHIFT,ELLIPTICITY AND  $\frac{1}{2}D_2$ 
C   CONTOUR VALUES ARE AT FF(I). WE USE HERE FF(I) VALUES
C   FROM THE PLOTTING SUBROUTINE PLOTX
C
      SUBROUTINE SPECT(WP,N1,N2)
      COMMON /MAINC/SX,SY,NX,NY,ID,
1 NUMB,FF(75),JQ,DECK(2)
      COMMON W(40,80),VX(40),VY(80),UX(40,80),UY(40,80)
1,UXY(40,80)
      COMMON /SEARCH/D2,D3,NX2,NY2,DX,DY
      DIMENSION A1(20),X0(20),EL(20),DI2(20)
      DIMENSION C(4,4),WK(480),YD(40),SUM(8),XD(40)
      DIMENSION WP(N1,N2)
      DO 300 I=1,NX
      DO 300 J=1,NY
300   WP(I,J)=W(I,J)
      NT=6*MAX0(NX,NY)
C   CALCULATE DERIVATIVES FOR BICUBIC INTERPOLATION
      CALL DERIVS(NX,NY,VX,VY,WP,NT,WK,UX,UY,UXY)
      DX=ABS(VX(NX)-VX(NX-1))
      DY=ABS(VY(NY)-VY(NY-1))
      D2=DX/2.
      D3=DY/2.
      NX2=NX/2+1
      NY2=NY/2+1
      INF=51
      WRITE(6,2002)
      WRITE(INF,4) NUMB
4      FORMAT(I10)
2002   FORMAT(1H1,50X,'CONTOUR ANALYSIS',//,4X,'#',4X,
2 'A1 (CM)',4X,'EMIS3',4X,'SHIFT',6X,
3 'ELLIPT.',4X,'D (%)',/)
      AM=0.
      INET=39
      WRITE(INET,4) NUMB
C   FIND X-COORDINATE OF HIGHEST EMISSION
      DO 301 I=1,NX
      IF(W(I,NY2).LT.AM) GO TO 301
      IMAX=I
      AM=W(I,NY2)
301   CONTINUE
C   FIND SHIFT
      DO 10 I1=1,NUMB
      I2=I1
      CALL SEAR(WP,N1,N2,VX(IMAX),FF(I1),0.,1,XB,YB)
      CALL SEAR(WP,N1,N2,VX(IMAX),FF(I1),180.,-1,XA,YA)
5      FORMAT(2F12.5)

```

```

      X0(I2)=(XA+XB)/2.
C  GENERATE ENTIRE CONTOUR IN POLAR COORDINATES
      DO 400 I=1,36
      PD=(I-1)*5.+2.5
      IF(PD-90.) 401,401,402
401      IT=1
      GO TO 403
402      IT=-1
403      CALL SEAR(WP,N1,N2,X0(I2),FF(I1),PD,IT,XD(I),YD(I))
400      CONTINUE
      A1(I2)=(XB-XA)/2.
      AD=10.
      PD=70.
      B2=0.
      B3=0.
C  FIND ELONGATION
      DO 500 J=1,40
      PD=PD+AD
      IF(PD-90.) 501,501,502
501      IT=1
      GO TO 503
502      IT=-1
503      CALL SEAR(WP,N1,N2,X0(I2),FF(I1),PD,IT,XC,B1)
      IF(B1-B2) 520,520,510
520      PD=PD-2*AD
      B2=B3
      AD=AD/2.
      IF(AD-0.1) 530,500,500
510      B3=B2
      B2=B1
500      CONTINUE
      TYPE 1,I2,FF(I1),PD
1      FORMAT(2X,'MORE ITERATIONS NEEDED FOR CONTOUR #',I3,
1'EMIS.',F12.5,'ANGLE=')
530      CONTINUE
      EL(I2)=B1/A1(I2)
      S1=0.
      S2=0.
C  FIND TRIANGULARITY
      DO 535 I=1,18
      J9=I+18
      R1=(XD(I)-X0(I2))**2+YD(I)**2
      R2=(XD(J9)-X0(I2))**2+YD(J9)**2
      S1=S1+R1
      S2=S2+R2
535      CONTINUE
      DI2(I2)=2.4*(S1-S2)/(S1+S2)
C
C  FOR COMPARISON, CALCULATE A CONTOUR FROM ANALYTICAL
C  FORMULA, USING THE PARAMETERS OBTAINED ABOVE
C

```



```

DO 25 I=1,36
PD=((I-1)*5.+2.5)*3.14159/180.
Y=B1*SIN(PD)
X=X0(I2)+A1(I2)*COS(PD-DI2(I2)*SIN(PD))
25  WRITE(INET,3111) XD(I),YD(I),X,Y
3111 FORMAT(2X,4F12.5)
TYPE 2001,I2,A1(I2),FF(I1),X0(I2),EL(I2),DI2(I2)
WRITE(6,2001) I2,A1(I2),FF(I1),X0(I2),EL(I2),DI2(I2)
WRITE(INF,2001) I2,A1(I2),FF(I1),X0(I2),EL(I2),DI2(I2)
10  CONTINUE
2001 FORMAT(2X,I3,6F10.3)
RETURN
END

```

```

C S E A R
C *****
C SUBROUTINE TO LOCATE POINTS ON A CONTOUR BY
C RADIAL SEARCHES
C
C COEFF AND BICUBE ARE GAFFNEY'S INTERPOLATION SUBROUTINES
C
      SUBROUTINE SEAR(WP,N1,N2,X0,FF0,PD,IT,X1,Y1)
      COMMON /MAINC/SX,SY,NX,NY,ID,
1 NUMB,FF(75),JQ,DECK(2)
      COMMON W(40,80),VX(40),VY(80),UX(40,80),UY(40,80)
1,UXY(40,80)
      COMMON /SEARCH/D2,D3,NX2,NY2,DX,DY
      DIMENSION WP(N1,N2),C(4,4)
      X=X0
      IF(ABS(PD-90.)-0.1) 700,700,801
801  CONTINUE
      A1=DX*IT
      PDR=(PD*3.14159/180.)
      PD2=SIN(PDR)/COS(PDR)
      DO 602 J=1,40
71  X=X+A1
      Y=(X-X0)*PD2
      IF(Y-50.) 73,73,72
72  X=X-A1
      A1=A1/2.
      GO TO 71
73  L=IFIX((X-D2)/DX)
      L1=L+NX2
      IF(X-D2) 64,74,74
74  L1=L1+1
      IF(L1.GT.NX) L1=NX
64  L=IFIX((Y-D3)/DY)
      L2=L+NY2
      IF(Y-D3) 65,75,75
75  L2=L2+1
      IF(L2.GT.NY) L2=NY
65  CALL COEFF(NX,NY,VX,VY,WP,UX,UY,UXY,L1,L2,C)
      CALL BICUBE(C,X,Y,S1,SX,SY,SXY,SXX,SYY)
      IF(S1-FF0) 601,600,602
601  X=X-A1
      A1=A1/2.
      IF(ABS(A1)-0.001) 600,600,602
602  CONTINUE
      TYPE 1
600  X1=X
      Y1=Y
      GO TO 999
1  FORMAT(2X,'MORE ITER. NEEDED IN SEAR')
700  L=IFIX((X0-D2)/DX)
      L1=L+NX2

```

```
      IF(X0-D2) 66,76,76
76      L1=L1+1
66      Y=0.
      A2=DY
      DO 702 J=1,40
      Y=Y+A2
      L=IFIX((Y-D3)/DY)
      L2=L+NY2
      IF(Y-D3) 67,77,77
77      L2=L2+1
67      CALL COEFF(NX,NY,VX,VY,WP,UX,UY,UXY,L1,L2,C)
      CALL BICUBE(C,X0,Y,S1,SX,SY,SXY,SXX,SYY)
      IF(S1-FF0) 701,710,702
701     Y=Y-A2
      A2=A2/2.
      IF(ABS(A2)-0.001) 710,710,702
702     CONTINUE
      TYPE 1
710     Y1=Y
      X1=X0
999     RETURN
      END
```

```

SUBROUTINE SIGSM(BETA,S,N,IER)
DIMENSION C(40,3),BETA(40),S(40),DY(40),WK(300),T(40),X(40)
DIMENSION SIG(40)
DO 100 J=1,N
  I=N-J+1
  X(I)=BETA(J)
  T(I)=S(J)
100  DY(I)=0.05
     CALL ICSSCU(X,T,DY,N,2.,SIG,C,N,WK,IE)
     IF(IE.EQ.0) GO TO 150
     TYPE 2,IE
2     FORMAT(2X,'ERROR IN SMOOTHING',I5)
150  CONTINUE
     DO 200 I=1,N
       J=N-I+1
200  S(J)=SIG(I)
     RETURN
END

```

```

C      PLOTX
C      *****
C
C      SUBROUTINE TO MAKE CONTOUR PLOTS OF
C      TWO-DIMENSIONAL DISTRIBUTIONS
C
C      DISTRIBUTION FUNCTION VALUES ARE READ
C      FROM UNIT 25 (A DISK FILE)
C
C      INPUT DATA IN COMMON BLOCK /MAINC/:
C
C      SX, SY = PLOT SIZE IN INCHES
C      NX, NY = NUMBER OF GRID POINTS
C              IN X, Y DIRECTIONS
C      NUMB   = NUMBER OF CONTOURS
C
C      OUTPUT IN /MAINC/:
C
C      FF(I)  = CALCULATED CONTOUR VALUES
C
C      *****
C
C      SUBROUTINE PLOTX
C      DIMENSION PSI(2500),BUFFER(3000)
C      COMMON /TITLE/ COMENT(20)
C      COMMON /MAINC/ SX,SY,NX,NY,
&      ID,NUMB,FF(75),JQ,DECK(2)
C
C      .
C      .
C      .
C      .

```

SUBROUTINE DERIVS(N, M, X, Y, LDU, U, IWK, WK, UX, UY,	DER	10
* UXY, IFAIL)	DER	20
INTEGER N, M, LDU, IWK	DER	30
REAL X(N), Y(M), U(LDU,M), WK(IWK), UX(N,M), UY(N,M),	DER	40
* UXY(N,M)	DER	50
C *****	DER	60
C	DER	70
C **SUBROUTINE DERIVS**	DER	80
C	DER	90
C THE PURPOSE OF THIS SUBROUTINE IS TO COMPUTE APPROXIMATIONS	DER	100
C TO THE DERIVATIVES OF A FUNCTION U(X,Y) GIVEN VALUES OF THE	DER	110
C FUNCTION AT THE GRID POINTS OF A RECTANGULAR MESH R:	DER	120
C	DER	130
C X(1).LE.X.LT.X(N)	DER	140
C Y(1).LE.Y.LT.Y(M).	DER	150
C	DER	160
C THE SUBROUTINE MAY BE USED FOR COMPUTING A BICUBIC SPLINE	DER	170
C FUNCTION WHICH INTERPOLATES THE GIVEN DATA. IN THIS	DER	180
C CASE IT SHOULD ONLY BE CALLED ONCE FOR EACH MESH R.	DER	190
C	DER	200
C **METHOD**	DER	210
C	DER	220
C THE APPROXIMATIONS ARE COMPUTED USING CUBIC SPLINE	DER	230
C INTERPOLATION IN THE X AND Y DIRECTIONS.	DER	240
C	DER	250
C **NOTE**	DER	260
C	DER	270
C THIS IS A DRIVER SUBROUTINE WHICH CALLS DERIVZ IN ORDER	DER	280
C TO COMPUTE THE NECESSARY DERIVATIVES AT THE MESH POINTS,	DER	290
C OF THE RECTANGULAR GRID.	DER	300
C	DER	310
C **INPUT**	DER	320
C	DER	330
C N IS THE NUMBER OF DATA POINTS IN THE X-DIRECTION.	DER	340
C RESTRICTION: N.GE.4 N IS NOT ALTERED BY THE SUBROUTINE.	DER	350
C M IS THE NUMBER OF DATA POINTS IN THE Y-DIRECTION.	DER	360
C RESTRICTION: M.GE.4 M IS NOT ALTERED BY THE SUBROUTINE.	DER	370
C X IS A LINEAR ARRAY WHICH CONTAINS THE N DATA POINTS	DER	380
C X(1) TO X(N).	DER	390
C RESTRICTIONS:	DER	400
C X(1).LT.X(2),...,LT.X(N),	DER	410
C X(2)-X(1) = X(3)-X(2) = X(4)-X(3)	DER	420
C X(N-2)-X(N-3) = X(N-1)-X(N-2) = X(N)-X(N-1)	DER	430
C X IS NOT ALTERED BY THE SUBROUTINE.	DER	440
C Y IS A LINEAR ARRAY WHICH CONTAINS THE M DATA POINTS	DER	450
C Y(1) TO Y(M).	DER	460
C RESTRICTIONS:	DER	470
C Y(1).LT.Y(2),...,LT.Y(M),	DER	480
C Y(2)-Y(1) = Y(3)-Y(2) = Y(4)-Y(3)	DER	490
C Y(M-2)-Y(M-3) = Y(M-1)-Y(M-2) = Y(M)-Y(M-1)	DER	500
C Y IS NOT ALTERED BY THE SUBROUTINE.	DER	510

C	LDU IS THE LEADING DIMENSION OF THE ARRAY U. LDU IS NOT	DER	520
C	ALTERED BY THE SUBROUTINE.	DER	530
C	U IS A TWO DIMENSIONAL ARRAY WHICH CONTAINS THE GIVEN	DER	540
C	FUNCTION VALUES U(X(I),Y(J)) I=1 TO N, J=1 TO M.	DER	550
C	U IS NOT ALTERED BY THE SUBROUTINE.	DER	560
C	IWK IS THE LENGTH OF THE WORK ARRAY WK. THE VALUE OF IWK	DER	570
C	SHOULD BE AT LEAST 6 * MAX(N,M). IWK IS NOT ALTERED	DER	580
C	BY THE SUBROUTINE.	DER	590
C	WK IS A WORK ARRAY OF LENGTH IWK.	DER	600
C		DER	610
C	**OUTPUT**	DER	620
C		DER	630
C	UX,UY, AND UXY ARE TWO-DIMENSIONAL ARRAYS WHICH MUST BE	DER	640
C	DIMENSIONED N BY M.	DER	650
C	UX CONTAINS DU/DX AT THE MESH POINTS	DER	660
C	UY CONTAINS DU/DY AT THE MESH POINTS	DER	670
C	UXY CONTAINS DU/DXDY AT THE MESH POINTS	DER	680
C	IFAIL IS AN ERROR FLAG. ON OUTPUT FROM THE	DER	690
C	SUBROUTINE IT HAS ONE OF THE FOLLOWING VALUES:	DER	700
C	IFAIL=0 SUCCESSFUL ENTRY	DER	710
C	IFAIL=1 N OR M IS TOO SMALL	DER	720
C	IFAIL=2 THE X DATA POINTS ARE NOT IN ASCENDING ORDER	DER	730
C	IFAIL=3 THE FIRST FOUR X DATA POINTS ARE NOT EQUALLY	DER	740
C	SPACED.	DER	750
C	IFAIL=4 THE LAST FOUR X DATA POINTS ARE NOT EQUALLY	DER	760
C	SPACED.	DER	770
C	IFAIL=5 THE Y DATA POINTS ARE NOT IN ASCENDING ORDER	DER	780
C	IFAIL=6 THE FIRST FOUR Y DATA POINTS ARE NOT EQUALLY	DER	790
C	SPACED.	DER	800
C	IFAIL=7 THE LAST FOUR Y DATA POINTS ARE NOT EQUALLY	DER	810
C	SPACED.	DER	820
C	IFAIL=8 IWK IS NOT .GE. 6*MAX(N,M)	DER	830
C		DER	840
C	**QUALITY ASSURANCE AND SOFTWARE STANDARD**	DER	850
C		DER	860
C	THIS SUBROUTINE HAS BEEN WRITTEN TO CONFORM	DER	870
C	TO THE FORTRAN IV ANSI STANDARD 1966, AND	DER	880
C	IT HAS BEEN VERIFIED USING THE BELL	DER	890
C	TELEPHONE LABORATORIES FORTRAN VERIFIER:	DER	900
C	PFOR.	DER	910
C	THE SUBROUTINE HAS RUN SUCCESSFULLY ON	DER	920
C	A VARIETY OF TEST PROBLEMS, AND IT HAS	DER	930
C	BEEN ANALYSED FOR ERRORS USING THE	DER	940
C	DAVE SYSTEM FROM THE UNIVERSITY OF	DER	950
C	COLORADO.	DER	960
C		DER	970
C		DER	980
C	P.W.GAFFNEY 1ST. MARCH 1979	DER	990
C		DER	1000
C	*****	DER	1010

SUBROUTINE COEFF(N, M, LDU, U, UX, UY, UXY, I, J, HX, HY,	COE	10
C, IFAIL)	COE	20
INTEGER N, M, LDU, I, J	COE	30
REAL U(LDU,M), UX(N,M), UY(N,M), UXY(N,M), HX, HY, C(4,4)	COE	40
C *****	COE	50
C	COE	60
C **SUBROUTINE COEFF**	COE	70
C	COE	80
C	COE	90
C THIS SUBROUTINE CALCULATES THE 16 COEFFICIENTS OF	COE	100
C THE INTERPOLATING BICUBIC POLYNOMIAL FOR THE	COE	110
C RECTANGLE R(I,J):	COE	120
X(I-1).LE.X.LT.X(I)	COE	130
Y(J-1).LE.Y.LT.Y(J)	COE	140
C	COE	150
C **METHOD**	COE	160
C	COE	170
C THE MATRIX OF COEFFICIENTS IS OBTAINED FROM THE	COE	180
C EXPRESSION:	COE	190
C	COE	200
C = A(HX)*K(I,J)*AT(HY)	COE	210
C	COE	220
C WHERE AT IS THE TRANSPOSE OF THE MATRIX A WHICH	COE	230
C TOGETHER WITH K(I,J) IS DEFINED IN THE REPORT:	COE	240
C "FORTRAN SUBROUTINES FOR BICUBIC SPLINE INTERPOLATION"	COE	250
C BY P/W/GAFFNEY, ORNL/CSD/TM-67.	COE	260
C	COE	270
C **INPUT**	COE	280
C	COE	290
C N IS THE NUMBER OF DATA POINTS IN THE X-DIRECTION.	COE	300
C RESTRICTION: N.GE.4 N IS NOT ALTERED BY THE SUBROUTINE.	COE	310
C M IS THE NUMBER OF DATA POINTS IN THE Y-DIRECTION.	COE	320
C RESTRICTION: M.GE.4 M IS NOT ALTERED BY THE SUBROUTINE.	COE	330
C LDU IS THE LEADING DIMENSION OF THE ARRAY U. LDU IS NOT	COE	340
C ALTERED BY THE SUBROUTINE.	COE	350
C U IS A TWO DIMENSIONAL ARRAY WHICH CONTAINS THE GIVEN	COE	360
C FUNCTION VALUES U(X(IR),Y(JR)), IR=1 TO N, JR=1 TO M.	COE	370
C U IS NOT ALTERED BY THE SUBROUTINE.	COE	380
C UX IS A TWO DIMENSIONAL ARRAY WHICH CONTAINS THE	COE	390
C DERIVATIVE OF U WITH RESPECT TO X EVALUATED AT	COE	400
C THE GRID POINTS X(IR),Y(JR). UX IS NOT ALTERED BY	COE	410
C THE SUBROUTINE.	COE	420
C UY IS A TWO DIMENSIONAL ARRAY WHICH CONTAINS THE	COE	430
C DERIVATIVE OF U WITH RESPECT TO Y EVALUATED AT	COE	440
C THE GRID POINTS X(IR),Y(JR). UY IS NOT ALTERED BY	COE	450
C THE SUBROUTINE.	COE	460
C UXY IS A TWO DIMENSIONAL ARRAY WHICH CONTAINS THE	COE	470
C DERIVATIVE OF U WITH RESPECT TO X AND Y EVALUATED	COE	480
C AT THE GRID POINTS X(IR),Y(JR). UXY IS NOT ALTERED BY	COE	490
C THE SUBROUTINE.	COE	500
C I,J ARE THE INTEGERS WHICH SPECIFY THE RECTANGLE R(I,J).	COE	510
C SPECIFICALLY IF XO.NE.X(N) THEN I IS THE UNIQUE	COE	520
C INTEGER WHICH SATISFIES THE INEQUALITIES	COE	530
X(I-1).LE.XO.LT.X(I)..	COE	540
C OTHERWISE I=N.	COE	550

SUBROUTINE BICUBE(C, XIM1, YJM1, XO, YO, S, SX, SY, SXY,	BIC	10
* SXX, SY, IFAIL)	BIC	20
REAL C(4,4), XIM1, YJM1, XO, YO, S, SX, SY, SXY, SXX, SY	BIC	30
C *****	BIC	40
C	BIC	50
C **SUBROUTINE BICUBE**	BIC	60
C	BIC	70
C	BIC	80
C THIS SUBROUTINE EVALUATES A BICUBIC POLYNOMIAL S, AND ITS	BIC	90
C DERIVATIVES THROUGH ORDER 2. SPECIFICALLY, GIVEN VALUES	BIC	100
C X=XO AND Y=YO IN THE SUBRECTANGLE:	BIC	110
C R(I,J): X(I-1).LE.X.LT.X(I)	BIC	120
C Y(J-1).LE.Y.LT.Y(J)	BIC	130
C OF THE GRID WHICH IS DEFINED BY THE VERTICAL LINES X=X(1)	BIC	140
C TO X=X(N), AND THE HORIZONTAL LINES Y=Y(1) TO Y=Y(M),	BIC	150
C AND GIVEN THE 16 COEFFICIENTS OF THE BICUBIC INTERPOLATING	BIC	160
C POLYNOMIAL ASSOCIATED WITH R(I,J), THIS SUBROUTINE COMPUTES	BIC	170
C THE VALUE:	BIC	180
C S = S(XO,YO)	BIC	190
C AND THE DERIVATIVES:	BIC	200
C SX = DS/DX	BIC	210
C SY = DS/DY	BIC	220
C SXY = DS/DXDY	BIC	230
C SXX = DDS/DXDX	BIC	240
C SY Y = DDS/DYDY	BIC	250
C EVALUATED AT THE POINT XO,YO.	BIC	260
C	BIC	270
C **METHOD**	BIC	280
C	BIC	290
C THE BICUBIC POLYNOMIAL IS EXPRESSED IN THE FORM:	BIC	300
C S(XBAR,YBAR) = XBAR*C*YBAR	BIC	310
C	BIC	320
C WHERE XBAR IS A ROW VECTOR WITH COMPONENTS:	BIC	330
C	BIC	340
C XBAR(L) = (X-X(I-1))**(L-1) L=1 TO 4	BIC	350
C	BIC	360
C AND YBAR IS A COLUMN VECTOR WITH COMPONENTS:	BIC	370
C	BIC	380
C YBAR(L) = (Y-Y(J-1))**(L-1) L=1 TO 4.	BIC	390
C	BIC	400
C THE RESPECTIVE DERIVATIVES ARE OBTAINED BY DIFFERENTIATING	BIC	410
C THE COMPONENTS OF THE APPROPRIATE VECTORS XBAR AND YBAR.	BIC	420
C	BIC	430
C NOTE THAT THIS ROUTINE DOES NOT EXPLICITLY REQUIRE THE	BIC	440
C VALUE OF I AND J. IT IS ONLY NECESSARY TO SUPPLY THE	BIC	450
C VALUE OF X(I-1) AND Y(J-1).	BIC	460
C	BIC	470
C **INPUT**	BIC	480
C	BIC	490
C C IS A 4 BY 4 ARRAY WHICH CONTAINS THE COEFFICIENTS OF	BIC	500
C THE BICUBIC POLYNOMIAL S. C IS NOT ALTERED BY THE	BIC	510
C SUBROUTINE.	BIC	520
C XIM1 IS THE VALUE OF X(I-1) WHERE I IS DEFINED ABOVE.	BIC	530
C IF XO=X(N) THEN XIM1=X(N-1). THE VALUE OF XIM1 IS NOT	BIC	540
C ALTERED BY THE SUBROUTINE.	BIC	550

C	YJM1	IS THE VALUE OF Y(J-1) WHERE J IS DEFINED ABOVE.	BIC	560
C		IF YO=Y(M) THEN YJM1=Y(M-1). THE VALUE OF YJM1 IS NOT	BIC	570
C		ALTERED BY THE SUBROUTINE.	BIC	580
C	XO	IS THE VALUE OF THE X-ARGUMENT AT WHICH S IS TO BE	BIC	590
C		EVALUATED. RESTRICTION: THE VALUE OF XO MUST BE	BIC	600
C		CONSISTENT WITH THE VALUE OF I AS DEFINED ABOVE.	BIC	610
C		XO IS NOT ALTERED BY THE SUBROUTINE.	BIC	620
C	YO	IS THE VALUE OF THE Y-ARGUMENT AT WHICH S IS TO BE	BIC	630
C		EVALUATED. RESTRICTION: THE VALUE OF YO MUST BE	BIC	640
C		CONSISTENT WITH THE VALUE OF J AS DEFINED ABOVE.	BIC	650
C		YO IS NOT ALTERED BY THE SUBROUTINE.	BIC	660
C	**OUTPUT**		BIC	670
C			BIC	680
C	S, SX, SY, SXY, SXX, SYX	AS DEFINED ABOVE.	BIC	690
C	IFAIL	IS AN ERROR FLAG. ON OUTPUT FROM THE	BIC	700
C		SUBROUTINE IT HAS ONE OF THE FOLLOWING VALUES:	BIC	710
C		IFAIL=0 SUCCESSFUL ENTRY	BIC	720
C		IFAIL=1 XIM1 OR YJM1 IS NOT CORRECT	BIC	730
C			BIC	740
C	**QUALITY ASSURANCE AND SOFTWARE STANDARD**		BIC	750
C			BIC	760
C	THIS SUBROUTINE HAS BEEN WRITTEN TO CONFORM		BIC	770
C	TO THE FORTRAN IV ANSI STANDARD 1966, AND		BIC	780
C	IT HAS BEEN VERIFIED USING THE BELL		BIC	790
C	TELEPHONE LABORATORIES FORTRAN VERIFIER:		BIC	800
C	PFORT.		BIC	810
C	THE SUBROUTINE HAS RUN SUCCESSFULLY ON		BIC	820
C	A VARIETY OF TEST PROBLEMS, AND IT HAS		BIC	830
C	BEEN ANALYSED FOR ERRORS USING THE		BIC	840
C	DAVE SYSTEM FROM THE UNIVERSITY OF		BIC	850
C	COLORADO.		BIC	860
C			BIC	870
C	P.W.GAFFNEY	1ST. MARCH 1979	BIC	880
C			BIC	890
C	*****		BIC	900

IMSL ROUTINE NAME - ICSSCU

PURPOSE - CUBIC SPLINE DATA SMOOTHER

USAGE - CALL ICSSCU (X,F,DF,NX,SM,Y,C,IC,WK,IER)

ARGUMENTS

X	- VECTOR OF LENGTH NX CONTAINING THE ABSCISSAE OF THE NX DATA POINTS (X(I),F(I)) I=1,..., NX. (INPUT) X MUST BE ORDERED SO THAT X(I) .LT. X(I+1).
F	- VECTOR OF LENGTH NX CONTAINING THE ORDINATES (OR FUNCTION VALUES) OF THE NX DATA POINTS. (INPUT)
DF	- VECTOR OF LENGTH NX. (INPUT) DF(I) IS THE RELATIVE WEIGHT OF DATA POINT I (SEE PARAMETER SM BELOW).
NX	- NUMBER OF ELEMENTS IN X, F, DF, AND Y. (INPUT) NX MUST BE .GE. 2.
SM	- A NON-NEGATIVE NUMBER WHICH CONTROLS THE EXTENT OF SMOOTHING. (INPUT) THE SPLINE FUNCTION S IS DETERMINED SUCH THAT THE SUM FROM 1 TO NX OF $((S(X(I))-F(I))/DF(I))^{**2}$ IS LESS THAN OR EQUAL TO SM, WHERE EQUALITY HOLDS UNLESS S DESCRIBES A STRAIGHT LINE.
Y,C	- SPLINE COEFFICIENTS. (OUTPUT) Y IS A VECTOR OF LENGTH NX. C IS AN NX-1 BY 3 MATRIX. THE VALUE OF THE SPLINE APPROXIMATION AT T IS $S(T) = ((C(I,3)*D+C(I,2))*D+C(I,1))*D+Y(I)$ WHERE X(I) .LE. T .LT. X(I+1) AND $D = T-X(I).$
IC	- ROW DIMENSION OF MATRIX C EXACTLY AS SPECIFIED IN THE DIMENSION STATEMENT IN THE CALLING PROGRAM. (INPUT)
WK	- WORK AREA VECTOR OF LENGTH 7*NX+14.
IER	- ERROR PARAMETER. (OUTPUT) TERMINAL ERROR IER = 129, IC IS LESS THAN NX-1 IER = 130, NX IS LESS THAN 2 IER = 131, INPUT ABSCISSAE ARE NOT ORDERED SO THAT X(1) .LT. X(2)LT. X(NX)

PRECISION/HARDWARE - SINGLE AND DOUBLE/H32
 - SINGLE/H36,H48,H60

REQD. IMSL ROUTINES - UERTST,UGETIO

IMSL ROUTINE NAME - ICSMOU

PURPOSE - ONE-DIMENSIONAL DATA SMOOTHING BY ERROR DETECTION

USAGE - CALL ICSMOU (X,Y,NX,DIS,SC,MAXIT,WK,IER)

ARGUMENTS

X	- VECTOR OF LENGTH NX CONTAINING THE ABSCISSAE OF THE NX DATA POINTS (X(I),Y(I)), I=1,..., NX. (INPUT) X MUST BE ORDERED SO THAT X(I) .LT. X(I+1).
Y	- VECTOR OF LENGTH NX CONTAINING THE ORDINATES (OR FUNCTION VALUES) OF THE NX DATA POINTS. (INPUT) ON OUTPUT Y CONTAINS THE SMOOTHED ORDINATES. NOTE - FOR PURPOSES OF NUMERICAL STABILITY, THE ROUTINE ASSUMES THAT Y(I), I=1,2,3,NX-2,NX-1,NX ARE NOT IN ERROR. THE ROUTINE NEVER MOVES THESE POINTS.
NX	- NUMBER OF ELEMENTS IN X AND Y. (INPUT) NX MUST BE .GE. 7.
DIS	- PROPORTION OF THE DISTANCE THE ORDINATE IN ERROR IS MOVED TO ITS INTERPOLATING CURVE. (INPUT) 0.0 .LE. DIS .LE. 1.0. A SUGGESTED VALUE IS DIS=1.0. SEE PROGRAMMING NOTES FOR FURTHER DETAILS.
SC	- STOPPING CRITERION. (INPUT) IF THE ABSOLUTE VALUE OF THE DISTANCE FROM Y(I) TO ITS INTERPOLATING CURVE IS LESS THAN OR EQUAL TO SC*((X(I+3)-X(I-3))/6.0) THEN Y(I) IS NOT MOVED, FOR I=4,...,NX-3. A SUGGESTED VALUE IS SC=0.0. SEE PROGRAMMING NOTES FOR FURTHER DETAILS.
MAXIT	- MAXIMUM NUMBER OF ITERATIONS ALLOWED. (INPUT) ON OUTPUT MAXIT CONTAINS THE ACTUAL NUMBER OF ITERATIONS TAKEN. A SUGGESTED VALUE IS MAXIT=ESTIMATED NUMBER OF POINTS IN ERROR. SEE PROGRAMMING NOTES FOR FURTHER DETAILS.
WK	- WORK AREA. WK IS A VECTOR OF DIMENSION 2*NX-12.
IER	- ERROR PARAMETER. (OUTPUT) TERMINAL ERROR IER = 129, NX IS LESS THAN 7. IER = 130, INPUT ABSCISSAE ARE NOT ORDERED SO THAT X(1) .LT. X(2)LT. X(NX).

PRECISION/HARDWARE - SINGLE AND DOUBLE/H32
- SINGLE/H36,H48,H60

REQD. IMSL ROUTINES - ICSEVU,IQHSCU,UERTST,UGETIO

IMSL ROUTINE NAME - LEQT2F

PURPOSE - LINEAR EQUATION SOLUTION - FULL STORAGE
MODE - HIGH ACCURACY SOLUTION

USAGE - CALL LEQT2F (A,M,N,IA,B,IDGT,WKAREA,IER)

ARGUMENTS

A	- INPUT MATRIX OF DIMENSION N BY N CONTAINING THE COEFFICIENT MATRIX OF THE EQUATION $AX = B$.
M	- NUMBER OF RIGHT-HAND SIDES. (INPUT)
N	- ORDER OF A AND NUMBER OF ROWS IN B. (INPUT)
IA	- ROW DIMENSION OF A AND B EXACTLY AS SPECIFIED IN THE DIMENSION STATEMENT IN THE CALLING PROGRAM. (INPUT)
B	- INPUT MATRIX OF DIMENSION N BY M CONTAINING THE RIGHT-HAND SIDES OF THE EQUATION $AX = B$. ON OUTPUT, THE N BY M MATRIX OF SOLUTIONS REPLACES B.
IDGT	- INPUT OPTION. IF IDGT IS GREATER THAN 0, THE ELEMENTS OF A AND B ARE ASSUMED TO BE CORRECT TO IDGT DECIMAL DIGITS AND THE ROUTINE PERFORMS AN ACCURACY TEST. IF IDGT EQUALS 0, THE ACCURACY TEST IS BYPASSED. ON OUTPUT, IDGT CONTAINS THE APPROXIMATE NUMBER OF DIGITS IN THE ANSWER WHICH WERE UNCHANGED AFTER IMPROVEMENT.
WKAREA	- WORK AREA OF DIMENSION GREATER THAN OR EQUAL TO $N^2 + 3N$.
IER	- ERROR PARAMETER. (OUTPUT) WARNING ERROR IER = 34 INDICATES THAT THE ACCURACY TEST FAILED. THE COMPUTED SOLUTION MAY BE IN ERROR BY MORE THAN CAN BE ACCOUNTED FOR BY THE UNCERTAINTY OF THE DATA. THIS WARNING CAN BE PRODUCED ONLY IF IDGT IS GREATER THAN 0 ON INPUT. (SEE THE CHAPTER L PRELUDE FOR FURTHER DISCUSSION.) TERMINAL ERROR IER = 129 INDICATES THAT THE MATRIX IS ALGORITHMICALLY SINGULAR. (SEE THE CHAPTER L PRELUDE). IER = 131 INDICATES THAT THE MATRIX IS TOO ILL-CONDITIONED FOR ITERATIVE IMPROVEMENT TO BE EFFECTIVE.

PRECISION/HARDWARE - SINGLE AND DOUBLE/H32
- SINGLE/H36,H48,H60

REQD. IMSL ROUTINES - SINGLE/LUDATF,LUELMF,LUREFF,VERTST,UGETIO
- DOUBLE/LUDATF,LUELMF,LUREFF,VERTST,UGETIO,
VXADD,VXMUL,VXSTO

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