COMPUTING THE ELECTRON DENSITY PROFILE FROM MICROWAVE INTERFEROMETER MEASUREMENTS

K.Baker

IPP 2/227 November 1974

MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK

GARCHING BEI MÜNCHEN

MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK

GARCHING BEI MÜNCHEN

COMPUTING THE ELECTRON DENSITY PROFILE FROM MICROWAVE INTERFEROMETER MEASUREMENTS

K.Baker

IPP 2/227 November 1974

Die nachstehende Arbeit wurde im Rahmen des Vertrages zwischen dem Max-Planck-Institut für Plasmaphysik und der Europäischen Atomgemeinschaft über die Zusammenarbeit auf dem Gebiete der Plasmaphysik durchgeführt.

IPP 2/227 Karen Baker, Computing the Electron Density Profile from Microwave Interferometer Measurements

November 1974 (in English)

Abstract - The plasma electron density profile can be deduced by measuring the phase change ψ over the plasma length using a multi-channel microwave interferometer. An APL program originally developed by J.G. Wegrove to calculate this density and which is used on WIIB by E. Wuersching[1] has been changed to provide a faster calculation time as well as modified to allow one to simulate the plasma numerically. The program was also enlarged to investigate various beam properties. The stellarator geometry prohibits the use of parallel probing beams which can be used with tokamaks. Moreover, the plasma cross section is closer to an ellipse than a circle which further complicates evaluation techniques. With the APL program, profiles can be produced quickly while experimental measurements are being taken. However, a FORTRAN translation primarily for use in Grenoble with Wega was made as the programs were further developed to include an error evaluation and an iteration technique in searching for an optimum beam spacing. Calculations using the geometrical configuration foreseen for Wega indicate that the mathematical technique used to deduce the density profile from a numerically simulated plasma yielded reasonable profiles even when 20% experimental error on phase measurements was included. There was found to be no unique optimum beam configuration. Dealing with each individual beam, it was found exact focusing is not critical. Assuming a fan-shaped microwave beam instead of an infinitely thin one, introduced an error of approximately 10%. The programs and their use is described in detail here. All are related to the FORTRAN program PROFILE in which one inputs experimental values of phase change ψ or ψ values deduced from an assumed density. It gives as output an approximation of the density profile.

CONTENTS

I. INTRODUCTION

II. MATHEMATICAL PROCEDURE
   A. Assumptions
   B. Mathematical Overview
   C. Detailed Explanation of Terms
      1. Input Parameters
      2. Calculated Plasma Parameters
      3. DEL - Beam Path Length
      4. PSIB1 - Phase Change
      5. NRF - Superposed Functions
      6. VARR - Comparing PSIB1 with PSIB2
      7. DENS - Finding Density
      8. Error Evaluations
      9. Representation of Results

III. FORTRAN PROGRAMS
   A. PROFILE - Density Profile
      1. How to Use
      2. Results - Error on Profiles
      3. Conclusions
   B. ITERATE - Optimum Beam Configuration
      1. Description
      2. How to Use
      3. Results

IV. APL PROGRAMS
   A. WORK2 - Corresponding to PROFILE
   B. WORK4 - Corresponding to ITERATE
   C. Beam Focusing
      1. SPREAD2
      2. SPREAD3

V. APPENDIX
   A. Figures
   B. Example Runs
      1. WORK2
      2. SPREAD2
      3. SPREAD3
   C. Listings
      1. PROFILE
      2. ITERATE
      3. WORK2
      4. WORK4
      5. SPREAD2
      6. SPREAD3

I. INTRODUCTION

First there is given a mathematical overview of the process used for finding the density profile. This includes the assumptions made and a general outline of technique followed by a more detailed definition of terms and derivation of formulas.

In section III the FORTRAN programs developed are discussed. How to use the program PROFILE for finding the density profile is explained in detail after which some results are given. The program ITERATE, designed to look for optimum beam angles, is mentioned.

Section IV deals with the APL programs. WORK2 corresponds to PROFILE; WORK4 corresponds to ITERATE. Further APL programs SPREAD2 and SPREAD3 deal with beam focusing. Finally the figures, example runs, and listings are given in the appendix.

II. MATHEMATICAL PROCEDURE

A. Assumptions

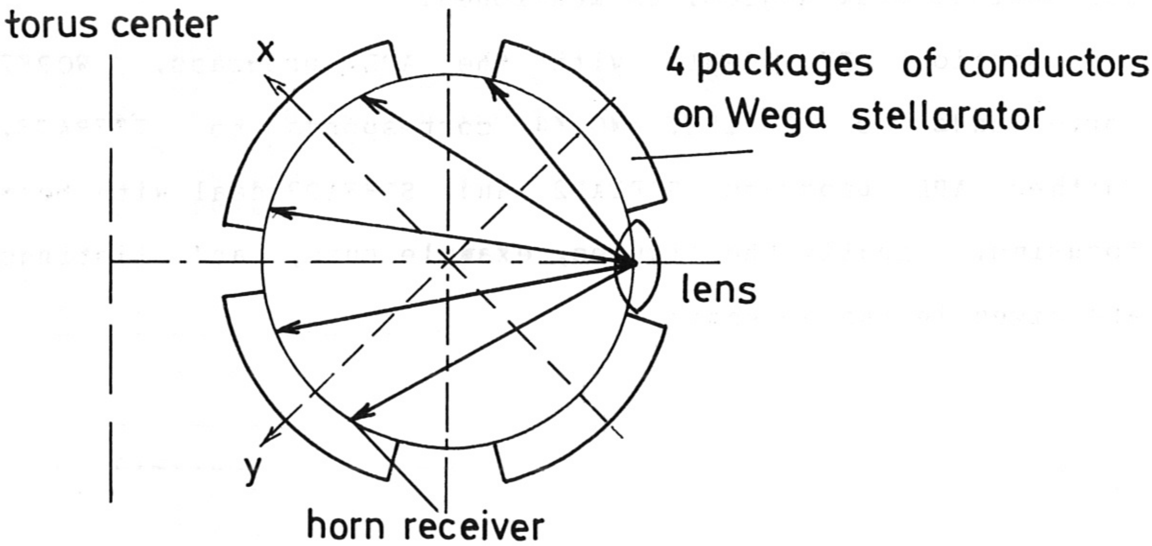
In developing the programs, the following assumptions have been made:

a) The interferometer beams are infinitely thin.

b) The cross sections of magnetic surfaces are approximated by ellipses whose ellipticity and position relative to the magnetic axes as a function of time are taken from numerical calculations.[2] These surfaces are lines of constant density.

c) The time dependent current causes a change in the ellipses' excentricity.[3]

d) The density is zero outside the last ellipse. This last ellipse has a major axis which is tangent to the given limiter radius.



The co-ordinate system used throughout this report has axes rotated 45° from the torus axis as shown above.

B. Mathematical Overview

The following outline of the FORTRAN program PROFILE is given with numbers (n*) corresponding to those appearing on the program listing in the last section. The APL programs use this same general plan. The chosen procedure uses a superpositon of smooth functions which gives a least square deviation from the measured phase angles of the different beams. This method is superior to the simple matrix inversion method which may be used if the number of beams equals the number of ellipses the plasma is divided into (NB=NE).

a) Input of known plasma parameters including the number of microwave beams used (NB) and the number of ellipses used to describe the plasma (NE).

b) Various plasma parameters such as effective limiter radius and excentricity are calculated.

c) Subroutine LONG calculates DEL(1*) which contains the piece length of each beam KNB in each ellipse KNE.

d) PSIB1 which is the phase change over the plasma length may be input directly from experimental measurements (2*) or may be deduced from an assumed density (3*).

e) To get the density at specific points we need to know ψ at specific points in the plasma so construct a function similar to ψ but which is well defined.

$$\psi_{KNB} = \sum l_{KNE,KNB} \sum \alpha_{KNF} f_{KNE,KNF}$$

PSIB1(KNB) = DEL(KNE, KNB) ALIF(KNF) NRF(KNE, KNF)

The NRF (4*) used is a superposition of NF=NB-1 test functions. The weighting factor ALIF can be found by using the method of least square solution(5*) to solve:

$$\psi_{KNB} = \sum \alpha_{KNF} \left(\sum \ell_{KNE,KNB} \, f_{KNE,KNF} \right)$$

PSIB1(KNB) = ALIF (KNF) PSIT (KNB, KNF)

which gives NR1(6*):

$$\left(\frac{\Delta\psi}{\Delta r}\right)_{KNE} = \sum \alpha_{KNF} \, f_{KNE,KNF}$$

NR1(KNE) = ALIF(KNF) NRF(KNE, KNF)

f) To see how accurately the superimposed functions approximate PSIB1, we can now calculate PSIB2(7*).

$$\psi'_{KNB} = \sum \ell_{KNE,KNB} \left(\frac{\Delta\psi}{\Delta r}\right)_{KNE}$$

PSIB2(KNB) = DEL(KNE, KNB) NR1 (KNE)

The subroutine VAR(8*) compares PSIB1 with PSIB2. If the variation between them is greater than EPS(9*) or if the specified number of iterations IMAX has not been exceeded(10*), then we can try to improve our approximation. Negative values of NR1 are unphysical so are automatically set to zero. Then the column of NRF most heavily weighted by ALIF is replaced by NR1(11*). With this 'improved' NRF the procedure is repeated from e).

g) The iteration continues until EPS or IMAX boundaries interpose. At this point the density at individual points is obtained by using the final NR1 in the function DENSIN(12*).

C. Detailed Explanation of Terms

1. Input Parameters

a. SHOT - shot number from 1 to 9999

b. TMS(ms) - time in discharge in milliseconds

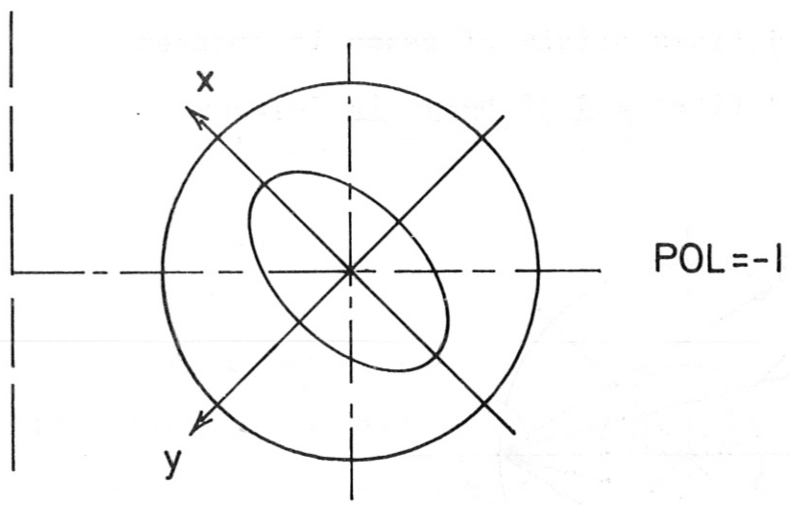
c. IOTC - stellarator rotational transform

d. IKA (ka) - plasma current in kiloamps

e. LIM (cm) - actual limiter radius in centimeters

f. POL - polarity equals +1 or -1 according to the following convention:

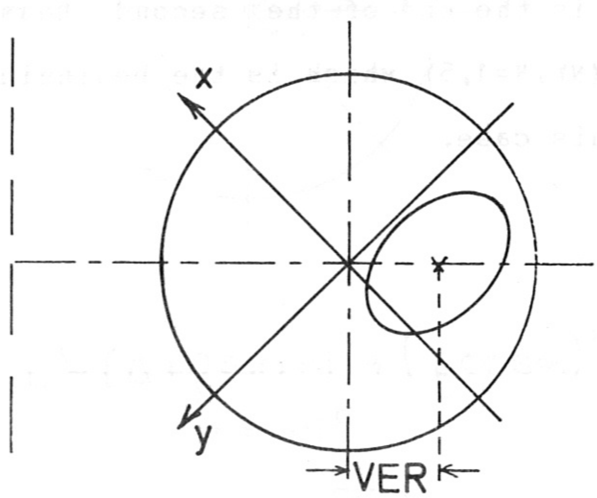
If major axis of ellipses coincides with x axis (as shown below), then POL=-1.



If major axis of ellipses coincides with y axis, then POL=+1.

g. VER (cm) -horizontal plasma displacement in centimeters

If VER>0, the translation is outwards.



h. NE - number of ellipses assumed (up to fifteen with present dimensions)

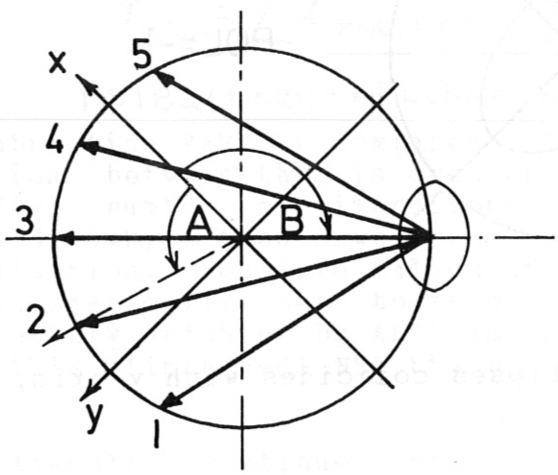
NB - number of beams used (from three to five)

-The minimum number of beams is three since using two beams means only one test function in used (NF=NB-1) which allows no superposition or weighting.

-The maximum number of beams is five but may be easily extended by enlarging the dimension statements.

i. PHI0(deg) - defines origin of beams in degrees

PHI1(deg) - defines end of beams in degrees



These angles are defined in terms of the angle through which one must rotate from the x(ϕ=0) axis. Angle A defines PHI1(2) which is the end of the second beam. Angle B defines (PHI0(N),N=1,5) which is the beginning of all the beams in this case.

j. Wega Parameters

RAD(cm) - torus minor (inner) radius in centimeters

$$RAD = 19.$$

LAM(cm) - free wavelength

$$\lambda = c/fr = 3.\times10^{10}/14.\times10^{10}$$

$$LAM = 3./14.$$

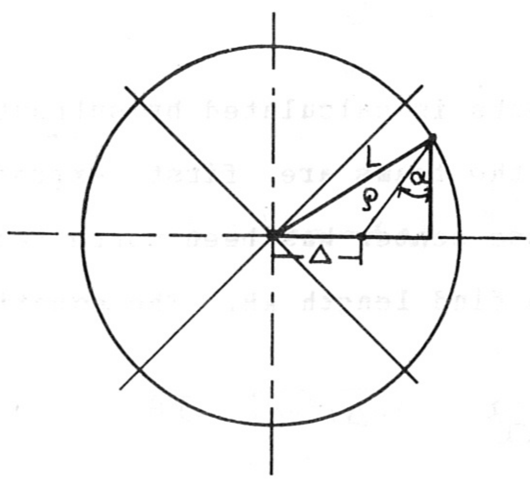
NC(1.E13 cm-3) - critical density

$$n_c = \frac{m_e \varepsilon_o (2\pi fr)^2}{e^2}$$

$$NC = 24.3$$

2. Calculated Plasma Parameters

a. Effective Limiter Radius - LIM is input as the actual limiter radius, but we wish to replace it with an effective limiter radius ρ:



$$L^2 = (\Delta + \rho\sin\alpha)^2 + (\rho\cos\alpha)^2$$

$$\alpha = 45^\circ$$

$$L^2 = \Delta^2 + \rho^2 + \sqrt{2}\Delta\rho$$

Finding the quadratic solution:

$$\rho = \frac{-\Delta}{\sqrt{2}} - \sqrt{L^2 - \frac{\Delta^2}{2}}$$

So in FORTRAN notation:

$$LIM \leftarrow \sqrt{LIM^2 - \frac{(VER)^2}{2}} - \left| \frac{VER}{\sqrt{2}} \right|$$

b. Excentrictiy

AS1 - excentricity A/B due to external field as given by numerical calculation

AS1=1.14 + 1.8*IOTO

AS - total excentricity as calculated by ref.(3)

$$R = \left(\frac{AS1^2 - 1}{AS1^2 + 1}\right)\left(1 - \frac{IKA}{20}\right)$$

$$AS = \sqrt{\frac{1+R}{1-R}}$$

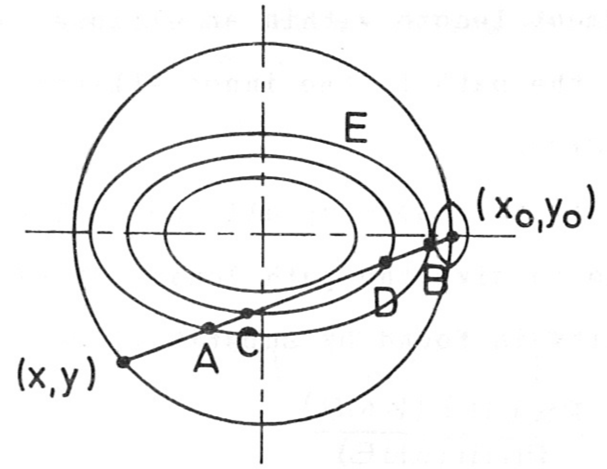
3. Beam Path Length

The length of beam segments is calculated by subroutine LONG. The origin and end of the beams are first expressed in Cartesian co-ordinates whose center has been corrected by VER. The first problem is to find length AB. The equations of ellipse E:

$$x^2 + \alpha^2 y^2 = a^2$$

$$a = \frac{LIM}{NE} \cdot KNE$$

$$\alpha = a/b$$



Equation of the beam path:

$$\frac{X - X_0}{X_1 - X_0} = \frac{y - y_0}{y_1 - y_0}$$

$$y = y_0 + K(x - x_0)$$

$$K = (y_1 - y_0)/(x_1 - x_0)$$

Solving for the intersection gives:

$$u x^2 + v x + w = 0$$

$$u = 1 + K^2 \alpha^2$$

$$v = 2 K \alpha^2 (y_0 - K x_0)$$

$$w = \alpha^2 (y_0^2 + K^2 x_0^2 - 2 y_0 K x_0) - a^2$$

So,

$$\Delta X = |X_B - X_A| = \frac{\sqrt{v^2 - 4uw}}{u}$$

But,

$$AB = \sqrt{\Delta x^2 + \Delta y^2} = \Delta x \sqrt{1 + K^2}$$

$$= \left(\frac{\sqrt{v^2 - 4uw}}{u}\right) \sqrt{1 + K^2}$$

This gives the segment length within an ellipse (i.e. AB). We now subtract the path in the inner ellipses so that we have the length (AC+DB).

The main program then sums up all the ellipse segment lengths of one beam to give the path length PATH(KNB).

The mean density is found by substituting:

$$\frac{\Delta\psi}{\Delta r} = \frac{PSIB1(KNB)}{PATH(KNB)}$$

into the density function DENSIN described in 7. below.

The integral density may be approximated:

$$\psi = \int \left\{ \sqrt{1-\frac{n_r}{n_c}} - 1 \right\} \frac{2\pi}{\lambda} dr \simeq \int \left\{ 1 + \frac{n_r}{2n_c} - 1 \right\} \frac{2\pi}{\lambda} dr$$

$$\int n_r dr \simeq \frac{\lambda n_c}{\pi} \psi$$

$$DENI(KNB) = NC \cdot LAM \cdot PSIB1(KNB)$$

4. PSIB1 - Phase Change

The phase change input takes two forms depending upon whether one choses ISEC=1 or ISEC=2:

ISEC=1 - a chosen assumed density function (i.e. Bessel or Gaussian) is put into the main program. It is chosen such that the density goes to zero at LIM. This allows one to find NR1A(KNE):

$$\frac{\Delta\psi}{\Delta r} = \left\{ \sqrt{1-\frac{n_r}{n_c}} - 1 \right\} \frac{2\pi}{\lambda}$$

which can be multiplied by the DEL(KNE,KNB) to give PSIA(KNB). To allow for experimental error a random error RD(KNE) is also read in from data and applied to PSIA(KNE) to give PSIB1(KNB).

ISEC=2 - means that the actual values of PSIB1 in radians are read in from the data.

5. NRF - Superimposed Functions

The following four sets of functions (IFUN=4) are used:

POLY:

$$NRF(KNE,KNF) = \left(\frac{RAD1R(KNE)}{LIM}\right)^{2(-1+KNF)}$$

COS:

$$NRF(KNE,KNF) = \cos\left[\left(\frac{\pi}{2}\frac{RAD1R(KNE)}{LIM}\right)(-2+2\cdot KNF)\right]$$

COO:

$$NRF(KNE,KNF) = \cos\left[\left(\frac{\pi}{2}\frac{RAD1R(KNE)}{LIM}\right)(0,-1+2(KNF-1))\right]$$

TCH:

$$NRF(KNE,1) = 1$$
$$NRF(KNE,2) = -1+2R^2$$
$$NRF(KNE,3) = 1-8R^2+8R^4$$
$$NRF(KNE,4) = -1+18R^2-48R^4+32R^6$$

$$R = [NRF(KNE,KNF)]_{POLY}$$

RAD1R is defined as:

$$RAD1R = \left(\frac{LIM}{NE}\right)(KNE-.5)$$

6. VARR - Comparing PSIB1 with PSIB2

$$VARR = \sqrt{\frac{\sum[PSIB1(KNB)-PSIB2(KNB)]^2}{\sum[PSIB1(KNB)+PSIB2(KNB)]^2}}$$

7. DENS - Finding Density

Once $\Delta\psi/\Delta r$ is known, the density is given by the function DENSIN$(\Delta\psi/\Delta r)$.

$$n_r = n_c \left[1 - \left(1 - \frac{\Delta\psi}{\Delta r}\frac{\lambda}{2\pi}\right)^2\right]$$

$$\text{DENS(IFUN,KNE)} = \text{NC}\left[1 - \left(1 - \frac{\text{NR1(KNE) LAM}}{2\pi}\right)^2\right]$$

8. Error Evaluation

If one has used the assumed density option (ISEC=1), then a comparison is made between this assumed density DENSA(KNE) and that deduced by the program DENS(IFUN,KNE). The gross deviations are double weighted by APP3. The last three points are dropped since they are usually unreliable approximations (NEM=NE-3).

$$\text{APP1} = \frac{|\text{DENS} - \text{DENSA}|}{\frac{\sum \text{DENSA}}{\text{NEM}}} \times 100.$$

$$\text{APP2} = \sum_{\text{NEM}} \text{APP1}$$

$$\text{APP3} = \sum_{3\ \text{max. APP1}} \text{APP1}$$

So the individual error (which appears on output in the appendix) is given by:

$$\text{APPSS} = \frac{\text{APP2} + \text{APP3}}{\text{NE}}$$

9. Representation of Results

The DENS matrix is printed out and may also be plotted as a function of the radial development along the major axis of the ellipse. The plotting is determined by the choice of IGRAF:

IGRAF=0 no graph

IGRAF=1 two or three graphs produced
a) seperate plot of each function (i.e. COS, COO, POLY, TCH)
b) all functions on one plot
c) plot of DENSA if ISEC=1

IGRAF=2 a graph with third dimension in time plotted

III. FORTRAN PROGRAMS

A. PROFILE - Density Profile

1. How to Use

If one is working with the Wega stellarator, the stellarator parameters listed at the beginning of the main program are correct. Therefore one only needs to change the data set which is explained below. Only the general form is explained since detailed explanations of the symbols is given in section II.

```
1                                                          (1)
002                                                        (2)
0001 01.00 00.30 00.00 14.00 -1.00 00.00 015               (3)
5 1                                                        (4)
-135.000 -135.000 -135.000 -135.000 -135.000               (5)   DATA SET I
 105.000   55.000   45.000   15.000   00.000               (6)
  20.0    -18.0    -14.0     15.0     08.0                 (7)
0001 01.00 00.30 00.00 14.00 -1.00 00.00 015               (3)'
4 1                                                        (4)'
-135.000 -135.000 -135.000 -135.000 -135.000               (5)'  DATA SET II
 105.000   61.000   57.000   18.000   09.000               (6)'
  20.0    -18.0    -14.0     15.0     008.0                (7)'
```

(1) ISEC=1 use assumed density section

=2 use experimentally measured PSIB1 values

(2) NDATA

The number of data sets to be read in (i.e. I and II here).

(3) SHOT TMS IOTO IKA LIM POL VER NE

(4) NB IGRAF

(5)PHIO(1) PHIO(2) . . . PHIO(NB)
The first NB entries are read.

(6)PHI1(1) PHI1(2) . . . PHI1(NB)
The first NB entries are read.

(7)If ISEC=1, random error should be entered.
RD(1) RD(2) . . . RD(NB)
The first NB entries are read.

If ISEC=2, PSIB1 should be entered.
PSIB1(1) PSIB1(2) . . . PSIB1(NB)
The first NB entries are read.

2. Results - Error on Profiles

The mathematical procedure itself can be tested by using an assumed density and taking the random error to be zero. Thus, if the procedure were perfect, it would exactly calculate the assumed density. This test showed that there were no noticeable errors introduced (always excepting the outside ellipses).

IMAX approximately equal to five seemed to be the optimum number of iterations. Increasing IMAX does not produce better results since the iteration procedure does not converge to a solution. EPS=10^{-2} was also found to be generally the best value.

The following assumed profiles are illustrated by figures in the appendix which are numbered correspondingly:

(1)Bessel

(2)Gaussian

(3)Straight Line

(4) Sin(x)+Cos(x/2)

(5) Hole

These are calculated using parameters IOTO=.3, IKA=0., LIM=14., POL=-1, VER=0., NE=15, NB=5. Two cases are taken:

(a) (RD=0 0 0 0 0)

(b) (RD=10 -9 -7 7 4).

One can see excellent agreement between the assumed and deduced curves in cases (a). When a 'random error' is introduced (b), the results still give the correct general shape of the assumed density profile. Figure (1a') shows the resultant four test function group approximations while figure (1a'') shows the assumed Bessel density profile. In the set of figures (1a,1b) to (5a,5b) the four test function groups and the assumed profile are all plotted on the same graph for easier comparison. With each figure is placed the printed out data about it including the input parameters, assumed density, resultant approximated density, and error.

It is necessary to look at some variations of the above normal cases in order to get an idea of how far the results can be trusted. The following variations on the Bessel case (1b) are illustrated:

(6) angle variation

(7) RD variation

(8) IOTO variation

(7), (9), (10) NB variation

With (6a) the new beam angles yield a total error of 157.68 as opposed to that of (1b) which was 40.65. On the other hand, the (6b) beam configuration gives an error of 29.22. One may find a best beam configuration (i.e. lowest total error) but only for one particular set of plasma parameters as is further explained in section (B. ITERATE).

Since it is not known how accurate the beam measurements in an experiment really are, it is important to look at various random error inputs which simulate the experimental error. In (7a) an error varying from +20% to -18% is introduced rather than the ≈10% of cases (1b) to (5b). The error is correspondingly 82.20 for (7a) as opposed to 40.65 for (1b) but the shape is still correct. Permuting the error of (7a) gives the result of (7b) where each function is shown seperately. TCH and POLY give the better results which is often the case because of the nature of the functions themselves. The error is high (162.22) which could be predicted from the fact that zeros appear in inside ellipses followed by nonzero values in the outer ones in the DENS print out. This usually indicates the attempt to reproduce the assumed profile has not been very successful. It is an important indication of the reliability of the results.

It is also important to know whether the hole appearing at the center of the plasma really exists. We know it does not in this case since the assumed test function was a Bessel shape. The nature of the superimposed test functions when five beams are used (NF=4 when NB=5) seems to produce this often erroneous 'minimum'. When the same case is investigated using four beams instead (NF=3), the 'minimum' disappears if it was not in the assumed profile as is shown in (7c). This is further illustrated in the next variations.

The stellarator rotational transform is changed from IOTO=.3 in (1a) to IOTO=.2 in (8a). The error is very small in this case with RD=0. When a RD=0 is used the erroneous hole appears if NB=5 as is illustrated in (8b'),(8b). The printed out DENS again shows zeros in the inner ellipses. When four beams are used as was previously suggested, the hole disappears and the error is much smaller (9a),(9b). The same case with NB=3 is illustrated in (9c).

If there is a hole in the assumed profile as is the case with (5b), it should remain when NB=4. (10a'), (10a), (10b) show it does remain. Again NB=3 is illustrated (10c) and is typical of the often inaccurate results with so few beams.

3. Conclusions

Experimentally when five or four beams are used one can usually predict the results will be quite reliable if

(a)the computed variance is less than .01

and

(b)the spread of the profile calculated with the different test functions is low.

If a hole is present in a profile obtained using five beams, it is best to confirm this plot using only four of these beams. Furthermore, the average error on each plot output is of the order of the random error appearing in one of the phase shift measurements.

B. ITERATE - Optimum Beam Configuration

1. Description

One might think that since the path length plays such an important part in the calculation that the 'more different' they are, the more new information they yield. To this end the beams were varied and the lengths tested by two APL programs - TEST2,TESTDET - but there was found to be no correlation between these tests and the results from the FORTRAN program ITERATE which would appear to be the most reliable.

The program ITERATE divides the space where the beams end into five fixed sections. An original beam configuration with one beam in each of these five sections is input. Then the first beam is varied within the first section and the postion which produces the lowest error after carrying out the PROFILE calculations is retained. Then the second beam is varied within the second fixed section and so forth until NB at which point IT=1 is finsihed. IT=2 would consist of then going backward from NB-1 to NB-2...to 1 each time carrying out the variation scheme. This continues until IT=IMAX is reached.

Instead of having five fixed sections, one could allow each section division size to vary only making sure none of the beams overlap at any time. This method was used in the APL program WORK4 which is otherwise basically the same as ITERATE.

2. How to Use

```
001 01.0 00.3 00.0 14.0 -1.0 00.0 015                  (1)
5                                                       (2)
  00.0      00.0      00.0      00.0      0.0           (3)
-135.00 -135.00 -135.00 -135.00 -135.00                 (4)
 100.00   60.00   55.00   20.00   -5.00                 (5)
04 0005.                                                (6)
 105.     80.     55.     35.     5.     -15.           (7)
```

(1) SHOT TMS IOTO IKA LIM POL VER NE

(2) NB

(3)RD(1) RD(2). . .RD(NB)

(4)PHIO(1) PHIO(2) . . .PHIO(NB)

(5)PHI1(1) PHI1(2) . . .PHI1(NB)

(6)ITMAX DELS

ITMAX - number of sweeps of beam

DELS - size of beam change

(7)DIV(1) DIV(2) . . .DIV(NB+1)

The first beam varies between DIV(1) and DIV(2).

The second beam varies between DIV(2) and DIV(3).

etc.

3. Results

There was found to be no unique optimum beam configuration since the end result depended upon each of the input plasma parameters as well as the starting beam configuration. One can only say that if the plasma will often be approximated as circular, it is best not to have a symmetric beam arrangement.

IV. APL PROGRAMS

A. WORK2 - Corresponding to PROFILE

Although APL calculations take a longer time on the computer, an APL terminal allows input and output to be used conveniently in the laboratory. A listing and a sample run are included in the appendix.

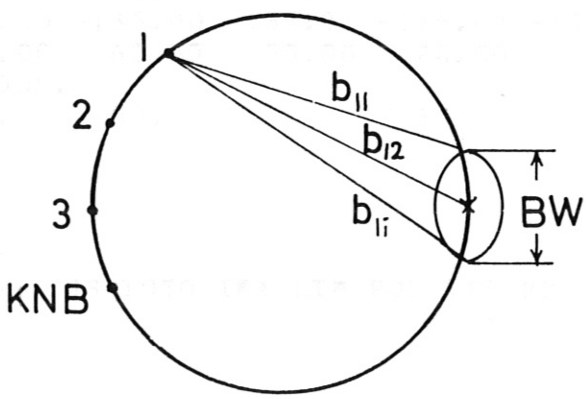
B. WORK4 - Corresponding to ITERATE

WORK4 is described in section (III.Fortran Programs B.ITERATE 1.Description).

C. Beam Focusing

1. SPREAD2

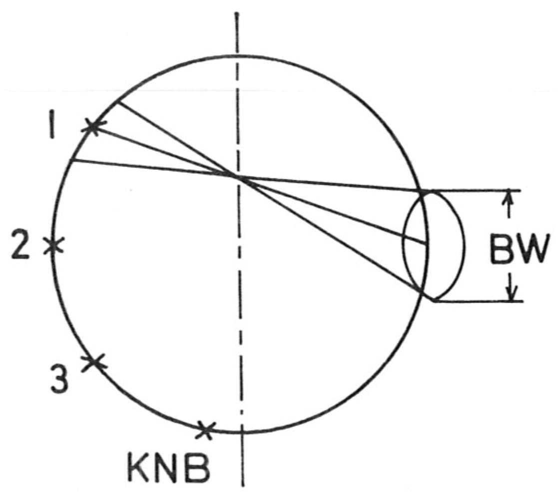
Instead of assuming an infinitely thin beam, an attempt was made to take into account the effect of the lens focusing the beam on the receiver as shown below.



An assumed density was used from which $\psi_{KNB,i}$ could be deduced. Then the scheme of PROFILE was followed but using $\psi_{KNB}=\langle\psi_{KNB}\rangle$ for each of the NB beams. A lens height of BW=6cm was used. The resultant density profile was essentially the same as when the lens effect was not included. An example of the output is given in the appendix.

2. SPREAD3

Instead of focusing of the receiver, SPREAD3 assumed the lens focused on a plane in the center of the plasma.



Using BW=6 led to a spread around each receiving point of about 15°. Assuming a density and using $\langle\psi_{KNB,i}\rangle$ again gave a resultant densiy profile never differing by more than 10% from the corresponding SPREAD2 results. This would indicate absolutely precise focusing on the receiver is not critical. The error due to spurious reflections of microwaves in the torus are ignored. An example of the output is given in the appendix.

V. APPENDIX

A. Figures

DATA RUN= 1 SHOT= 1 TMS= 1.0 IOTO= 0.3 IKA= 0.0
LIM=14.0 POL=-1.0 VER= 0.0 NE =15

BEAMS: 5

PHIE: -135.00 -135.00 -135.00 -135.00 -135.00

PHIB: 105.00 85.00 45.00 15.00 0.0

EFF LIM RAD(CM): 14.00

EXCENTRICITY DUE TO EXT FIELD: 1.68

TOTAL EXCENTRICITY: 1.68

PATH LENGTHS(CM): 12.3 15.4 20.3 20.2 15.7

PSIA:	3.251	8.673	20.053	11.490	2.560
RD:	0.0	0.0	0.0	0.0	0.0
PSIB1:	3.251	8.673	20.053	11.490	2.560

MEAN DENS:	0.437E 00	0.923E 00	0.161E 01	0.931E 00	0.269E 00
INT DENS:	0.538E 01	0.144E 02	0.332E 02	0.190E 02	0.424E 01

ITER:	1	1	1	1
VARI:	0.69E-05	0.14E-04	0.33E-05	0.24E-05

DENSITY(XE13)

COS	COO	POLY	TCH	ASS	RADIR
3.01	2.97	2.99	2.99	2.99	0.467
2.95	2.92	2.94	2.94	2.94	1.400
2.84	2.83	2.84	2.84	2.84	2.333
2.68	2.69	2.68	2.68	2.68	3.267
2.47	2.50	2.48	2.48	2.48	4.200
2.24	2.27	2.25	2.25	2.25	5.133
1.97	2.00	1.98	1.98	1.98	6.067
1.68	1.70	1.69	1.69	1.69	7.000
1.38	1.38	1.38	1.38	1.38	7.933
1.08	1.07	1.08	1.08	1.08	8.867
0.78	0.78	0.78	0.78	0.78	9.800
0.51	0.53	0.51	0.51	0.51	10.733
0.28	0.30	0.28	0.28	0.28	11.667
0.11	0.11	0.11	0.11	0.11	12.600
0.02	0.0	0.01	0.01	0.01	13.533

INDIV ERROR:	0.39	0.67	0.02	0.02
TOTAL ERROR:	1.10			

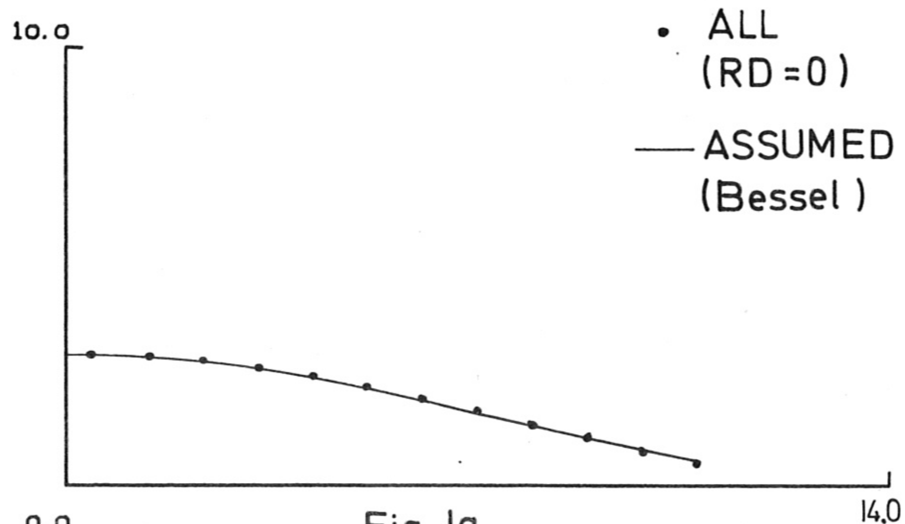


Fig. la

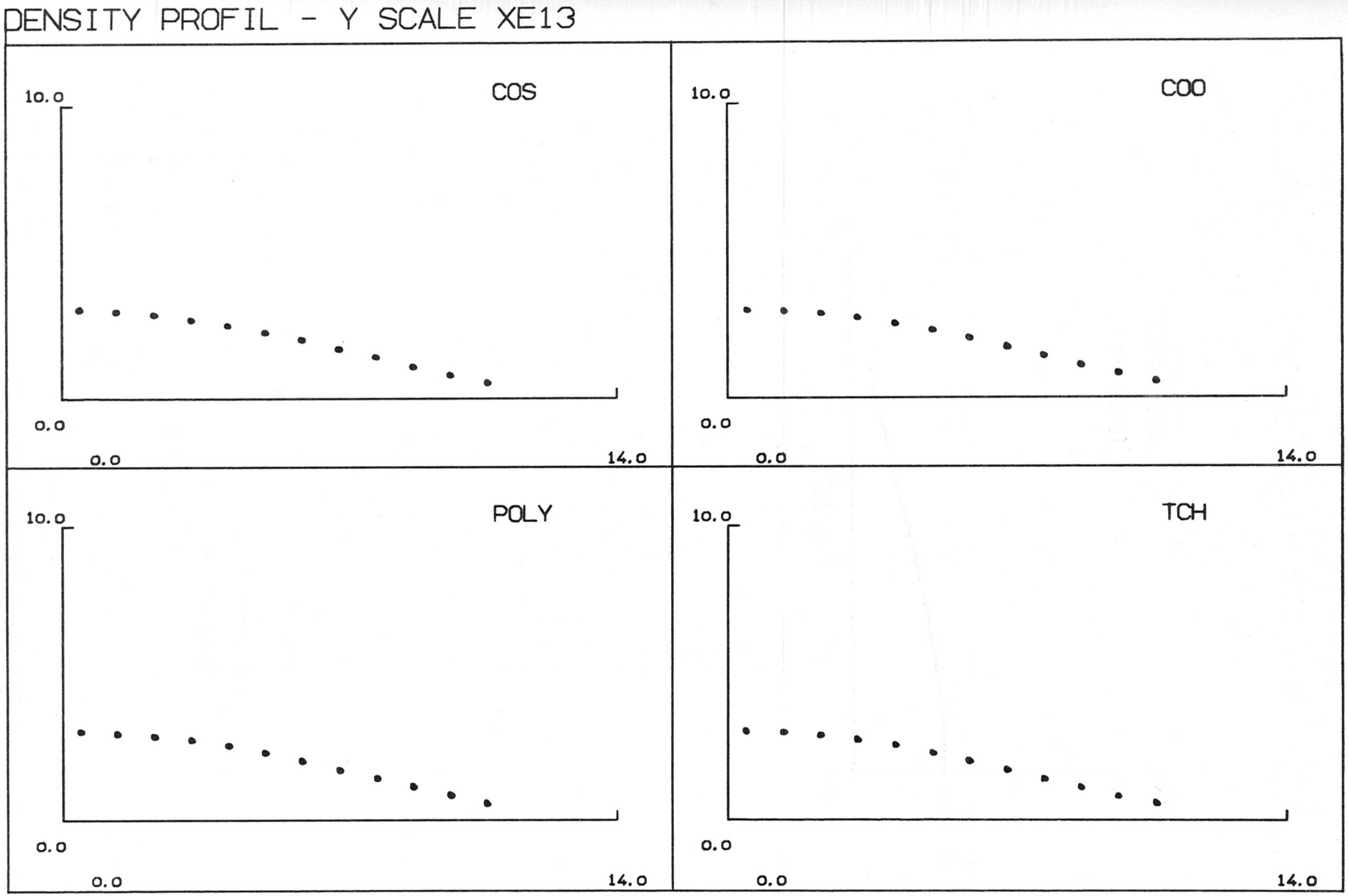

DENSITY PROFIL - Y SCALE XE13
COS
10.0
0.0
0.0
14.0
COO
10.0
0.0
0.0
14.0
POLY
10.0
0.0
0.0
14.0
TCH
10.0
0.0
0.0
14.0

Fig. 1a'

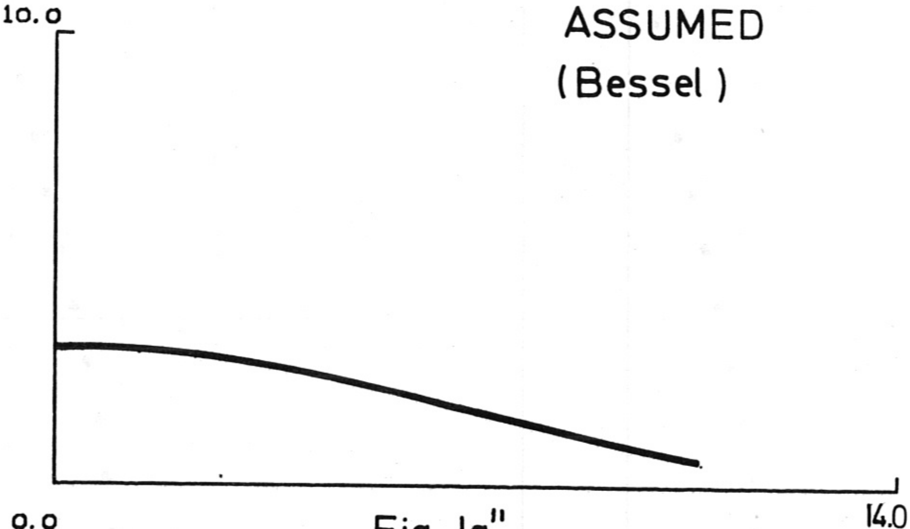


Fig. la''

```
DATA RUN=  1   SHOT=  1   TMS= 1.0   IOTO= 0.3   IKA= 0.0
               LIM=14.0   POL=-1.0   VER= 0.0    NE=15
BEAMS: 5
PHIE:-135.00 -135.00 -135.00 -135.00 -135.00
PHIB: 105.00   85.00   45.00   15.00    0.0


EFF LIM RAD(CM):   14.00
EXCENTRICITY DUE TO EXT FIELD:     1.68
           TOTAL EXCENTRICITY:     1.68

PATH LENGTHS(CM):    12.3    15.4    20.3    20.2    15.7


 PSIA:      3.251      8.673     20.053     11.490      2.560
   RD:     10.000     -9.000     -7.000      7.000      4.000
 PSIB1:     2.926      9.453     21.457     10.686      2.458


MEAN DENS:  0.393E 00  0.101E 01  0.172E 01  0.866E 00  0.258E 00
 INT DENS:  0.485E 01  0.157E 02  0.355E 02  0.177E 02  0.407E 01

ITER:   5         5         5         5
VARI: 0.21E-01  0.21E-01  0.21E-01  0.21E-01


DENSITY(XE13)                                      RADIR
```

COS	COD	POLY	TCH	ASS	RADIR
3.28	3.29	3.33	3.33	2.99	0.467
3.23	3.24	3.26	3.26	2.94	1.400
3.13	3.13	3.14	3.14	2.84	2.333
2.97	2.96	2.95	2.95	2.68	3.267
2.74	2.74	2.70	2.70	2.48	4.200
2.46	2.45	2.41	2.41	2.25	5.133
2.11	2.11	2.08	2.08	1.98	6.067
1.74	1.74	1.73	1.73	1.69	7.000
1.36	1.36	1.36	1.36	1.38	7.933
1.00	1.00	1.00	1.00	1.08	8.867
0.69	0.68	0.67	0.67	0.78	9.800
0.44	0.43	0.39	0.39	0.51	10.733
0.25	0.26	0.21	0.21	0.28	11.667
0.14	0.15	0.14	0.14	0.11	12.600
0.08	0.08	0.24	0.24	0.01	13.533

```
INDIV ERROR:    9.97    10.05    10.32    10.32
TOTAL ERROR:   40.65
```

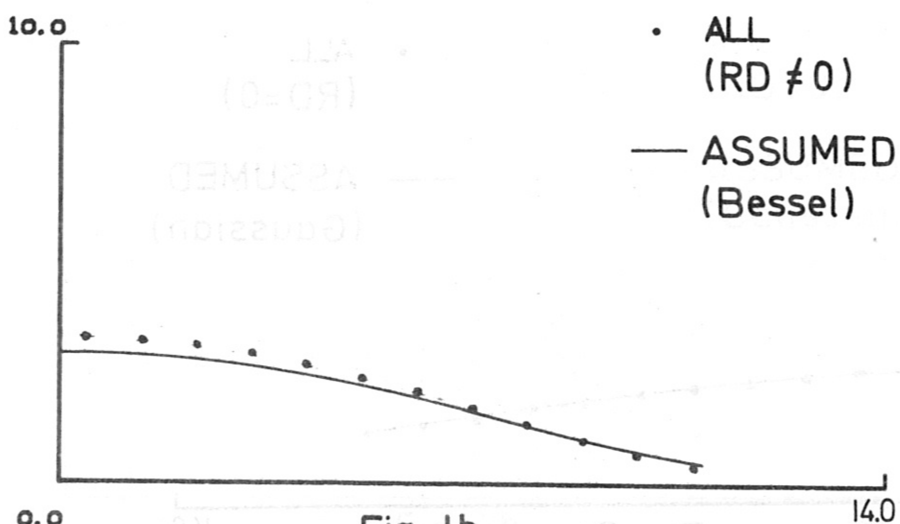


Fig. 1b

DATA RUN= 2 SHOT= 1 TMS= 1.0 IOTO= 0.3 IKA= 0.0
LIM=14.0 POL=-1.0 VER= 0.0 NE=15

BEAMS: 5
PHIE:-135.00 -135.00 -135.00 -135.00 -135.00
PHIB: 105.00 85.00 45.00 15.00 0.0

EFF LIM RAD(CM): 14.00
EXCENTRICITY DUE TO EXT FIELD: 1.68
TOTAL EXCENTRICITY: 1.68

PATH LENGTHS(CM): 12.3 15.4 20.3 20.2 15.7

PSIA:	11.921	17.810	28.121	23.450	14.072
RD:	0.0	0.0	0.0	0.0	0.0
PSIB1:	11.921	17.810	28.121	23.450	14.072

MEAN DENS:	0.158E 01	0.188E 01	0.224E 01	0.188E 01	0.146E 01
INT DENS:	0.197E 02	0.295E 02	0.466E 02	0.388E 02	0.233E 02

ITER:	1	1	1	1
VARI:	0.15E-04	0.22E-05	0.26E-05	0.23E-05

DENSITY(XE13)

COS	COO	POLY	TCH	ASS	RADIR
3.06	2.99	3.00	3.00	3.00	0.467
3.01	2.97	2.97	2.97	2.97	1.400
2.93	2.92	2.92	2.92	2.92	2.333
2.82	2.84	2.84	2.84	2.84	3.267
2.70	2.74	2.74	2.74	2.74	4.200
2.58	2.62	2.62	2.62	2.62	5.133
2.45	2.49	2.49	2.49	2.49	6.067
2.32	2.34	2.34	2.34	2.34	7.000
2.18	2.18	2.18	2.18	2.18	7.933
2.01	2.01	2.01	2.01	2.01	8.867
1.83	1.84	1.84	1.84	1.84	9.800
1.64	1.67	1.67	1.67	1.67	10.733
1.47	1,50	1.50	1.50	1.50	11.667
1.34	1.33	1.33	1.33	1.33	12.600
1.26	1.17	1.18	1.18	1.18	13.533

INDIV ERROR:	1.19	0.06	0.01	0.01
TOTAL ERROR:	1.28			

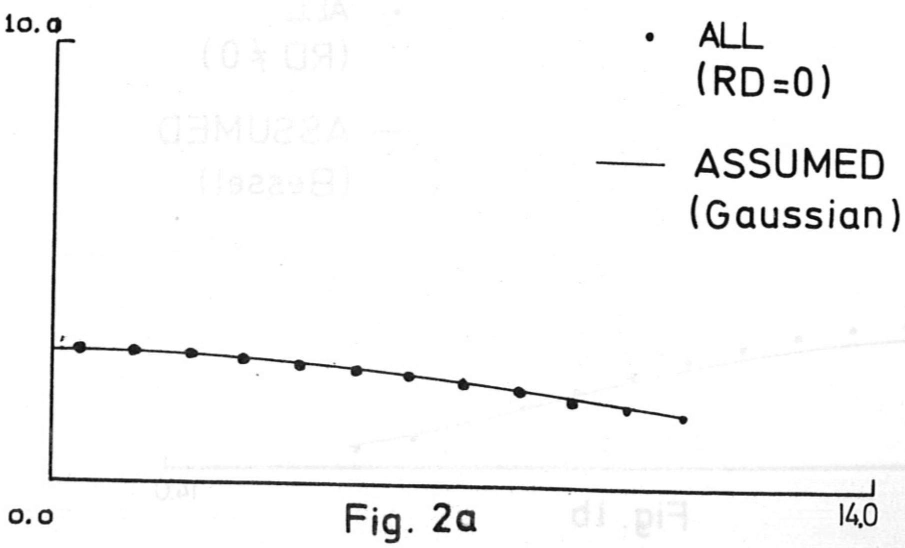


Fig. 2a

DATA RUN= 1 SHOT= 1 TMS= 1.0 IOTO= 0.3 IKA= 0.0
LIM=14.0 POL=-1.0 VER= 0.0 NE=15
BEAMS: 5
PHIE:-135.00 -135.00 -135.00 -135.00 -135.00
PHIB: 105.00 85.00 45.00 15.00 0.0

EFF LIM RAD(CM): 14.00
EXCENTRICITY DUE TO EXT FIELD: 1.68
TOTAL EXCENTRICITY: 1.68

PATH LENGTHS(CM): 12.3 15.4 20.3 20.2 15.7

PSIA:	11.921	17.810	28.121	23.450	14.072
RD:	10.000	-9.000	-7.000	7.000	4.000
PSIB1:	10.729	19.413	30.089	21.809	13.509

MEAN DENS:	0.143E 01	0.204E 01	0.240E 01	0.175E 01	0.140E 01
INT DENS:	0.178E 02	0.321E 02	0.498E 02	0.361E 02	0.224E 02

ITER:	5	5	5	5
VARI:	0.25E-01	0.25E-01	0.25E-01	0.25E-01

DENSITY(XE13)

COS	COO	POLY	TCH	ASS	RADIR
3.00	3.19	3.35	3.35	3.00	0.467
3.09	3.22	3.33	3.33	2.97	1.400
3.24	3.27	3.29	3.29	2.92	2.333
3.35	3.29	3.23	3.23	2.84	3.267
3.37	3.25	3.12	3.12	2.74	4.200
3.24	3.11	2.97	2.97	2.62	5.133
2.96	2.87	2.75	2.75	2.49	6.067
2.57	2.53	2.48	2.48	2.34	7.000
2.14	2.15	2.15	2.15	2.18	7.933
1.77	1.78	1.79	1.79	2.01	8.867
1.51	1.49	1.44	1.44	1.84	9.800
1.38	1.32	1.18	1.18	1.67	10.733
1.37	1.30	1.12	1.12	1.50	11.667
1.42	1.44	1.41	1.41	1.33	12.600
1.46	1.67	2.25	2.25	1.18	13.533

INDIV ERROR:	14.99	14.05	13.59	13.59
TOTAL ERROR:	56.21			

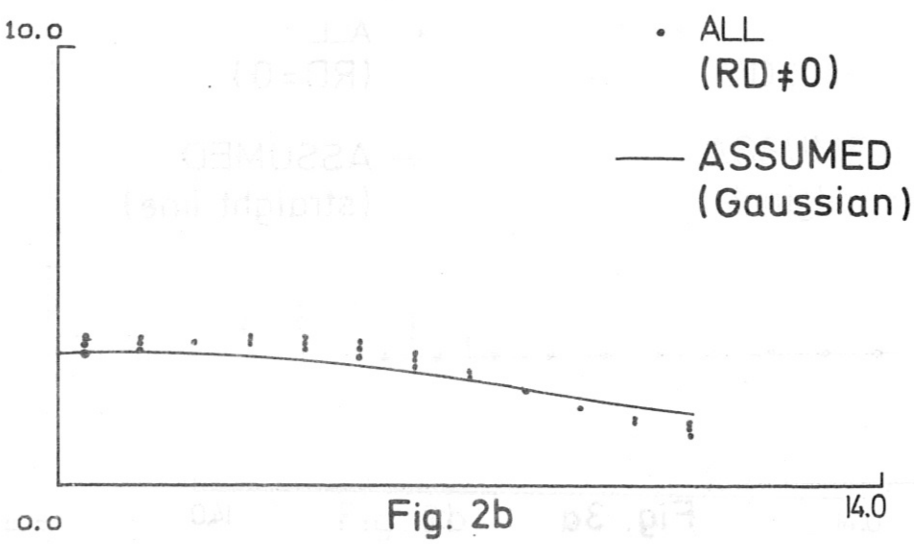


Fig. 2b

```
DATA RUN=   2   SHOT=  1   TMS= 1.0   IOTO= 0.3   IKA= 0.0
                LIM=14.0   POL=-1.0   VER= 0.0    NE =15
BEAMS: 5
PHIE:-135.00 -135.00 -135.00 -135.00 -135.00
PHIB: 105.00   85.00   45.00   15.00    0.0


EFF LIM RAD(CM):   14.00
EXCENTRICITY DUE TO EXT FIELD:    1.68
           TOTAL EXCENTRICITY:    1.68

PATH LENGTHS(CM):    12.3    15.4    20.3    20.2    15.7


 PSIA:    22.963    28.838    37.898    37.877    29.406
   RD:     0.0       0.0       0.0       0.0       0.0
 PSIB1:   22.963    28.838    37.898    37.877    29.406


MEAN DENS:  0.300E 01  0.300E 01  0.300E 01  0.300E 01  0.300E 01
 INT DENS:  0.380E 02  0.478E 02  0.628E 02  0.627E 02  0.487E 02

ITER:    1          1          1          1
VARI: 0.16E-05  0.16E-05  0.16E-05  0.15E-05
```

DENSITY(XE13)

COS	COO	POLY	TCH	ASS	RAD IR
3.00	3.00	3.00	3.00	3.00	0.467
3.00	3.00	3.00	3.00	3.00	1.400
3.00	3.00	3.00	3.00	3.00	2.333
3.00	3.00	3.00	3.00	3.00	3.267
3.00	3.00	3.00	3.00	3.00	4.200
3.00	3.00	3.00	3.00	3.00	5.133
3.00	3.00	3.00	3.00	3.00	6.067
3.00	3.00	3.00	3.00	3.00	7.000
3.00	3.00	3.00	3.00	3.00	7.933
3.00	3.00	3.00	3.00	3.00	8.867
3.00	3.00	3.00	3.00	3.00	9.800
3.00	3.00	3.00	3.00	3.00	10.733
3.00	3.00	3.00	3.00	3.00	11.667
3.00	3.00	3.00	3.00	3.00	12.600
3.00	3.00	3.00	3.00	3.00	13.533

```
INDIV ERROR:    0.00      0.00      0.00      0.00
TOTAL ERROR:    0.00
```

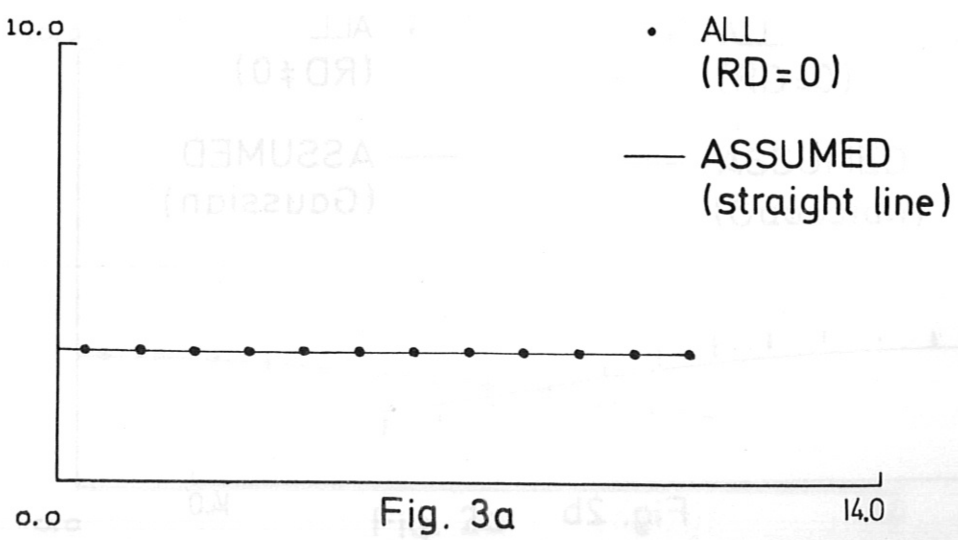


Fig. 3a

LIM=14.0 POL=-1.0 VER= 0.0 NE=15

BEAMS: 5
PHIE: -135.00 -135.00 -135.00 -135.00 -135.00
PHIB: 105.00 85.00 45.00 15.00 0.0

EFF LIM RAD(CM): 14.00
EXCENTRICITY DUE TO EXT FIELD: 1.68
TOTAL EXCENTRICITY: 1.68

PATH LENGTHS(CM): 12.3 15.4 20.3 20.2 15.7

PSIA:	22.963	23.838	37.898	37.877	29.406
RD:	10.000	-9.000	-7.000	7.000	4.000
PSIB1:	20.667	31.433	40.551	35.225	28.230

MEAN DENS:	0.271E 01	0.326E 01	0.320E 01	0.280E 01	0.288E 01
INT DENS:	0.342E 02	0.521E 02	0.672E 02	0.583E 02	0.468E 02

ITER:	5	5	5	5
VARI:	0.26E-01	0.26E-01	0.26E-01	0.26E-01

DENSITY(XE13)

COS	COO	POLY	TCH	ASS	RAD IR
2.52	3.02	3.36	3.36	3.00	0.467
2.83	3.17	3.40	3.40	3.00	1.400
3.32	3.41	3.47	3.47	3.00	2.333
3.83	3.66	3.53	3.53	3.00	3.267
4.16	3.83	3.58	3.58	3.00	4.200
4.20	3.86	3.57	3.57	3.00	5.133
3.94	3.70	3.47	3.47	3.00	6.067
3.48	3.38	3.27	3.27	3.00	7.000
2.95	2.98	2.97	2.97	3.00	7.933
2.55	2.59	2.60	2.60	3.00	8.867
2.40	2.34	2.25	2.25	3.00	9.800
2.51	2.34	2.06	2.06	3.00	10.733
2.81	2.62	2.25	2.25	3.00	11.667
3.13	3.17	3.12	3.12	3.00	12.600
3.35	3.90	5.04	5.04	3.00	13.533

INDIV ERROR: 23.28 18.16 17.84 17.84
TOTAL ERROR: 77.11

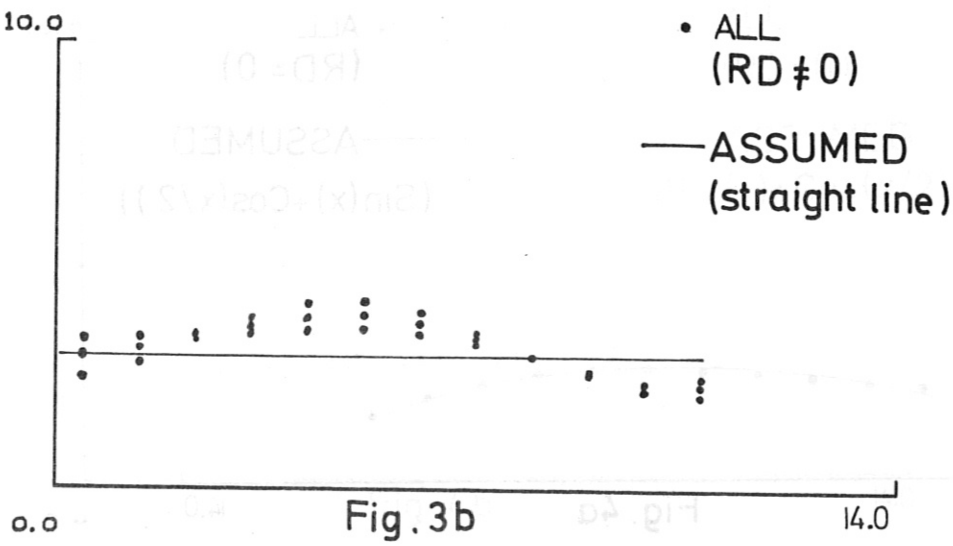


Fig. 3b

DATA RUN= 2 SHOT= 1 TMS= 1.0 IOTO= 0.3 IKA= 0.0
LIM=14.0 POL=-1.0 VER= 0.0 NE=15

BEAMS: 5

PHIE: -135.00 -135.00 -135.00 -135.00 -135.00

PHIR: 105.00 85.00 45.00 15.00 0.0

EFF LIM RAD(CM): 14.00

EXCENTRICITY DUE TO EXT FIELD: 1.68

TOTAL EXCENTRICITY: 1.68

PATH LENGTHS(CM): 12.3 15.4 20.3 20.2 15.7

PSIA:	9.744	17.164	23.934	22.630	9.731
RD:	0.0	0.0	0.0	0.0	0.0
PSIB1:	9.744	17.164	23.934	22.630	9.731

MEAN DENS:	0.130E 01	0.181E 01	0.192E 01	0.182E 01	0.101E 01
INT DENS:	0.161E 02	0.284E 02	0.396E 02	0.375E 02	0.161E 02

ITER:	1	1	1	1
VARI:	0.63E-04	0.13E-04	0.40E-04	0.40E-04

DENSITY(XE13)

COS	COO	POLY	TCH	ASS	RADIR
2.13	1.95	2.02	2.02	1.65	0.467
2.14	2.02	2.07	2.07	1.95	1.400
2.18	2.15	2.16	2.16	2.20	2.333
2.24	2.30	2.27	2.27	2.40	3.267
2.33	2.45	2.39	2.39	2.55	4.200
2.42	2.55	2.49	2.50	2.63	5.133
2.50	2.60	2.55	2.55	2.63	6.067
2.51	2.55	2.53	2.53	2.56	7.000
2.42	2.42	2.41	2.41	2.41	7.933
2.21	2.19	2.20	2.20	2.19	8.867
1.88	1.89	1.88	1.88	1.89	9.800
1.47	1.53	1.48	1.48	1.54	10.733
1.05	1.13	1.05	1.05	1.14	11.667
0.71	0.70	0.69	0.69	0.70	12.600
0.51	0.26	0.51	0.51	0.24	13.533

INDIV ERROR: 7.49 3.84 5.43 5.43

TOTAL ERROR: 22.18

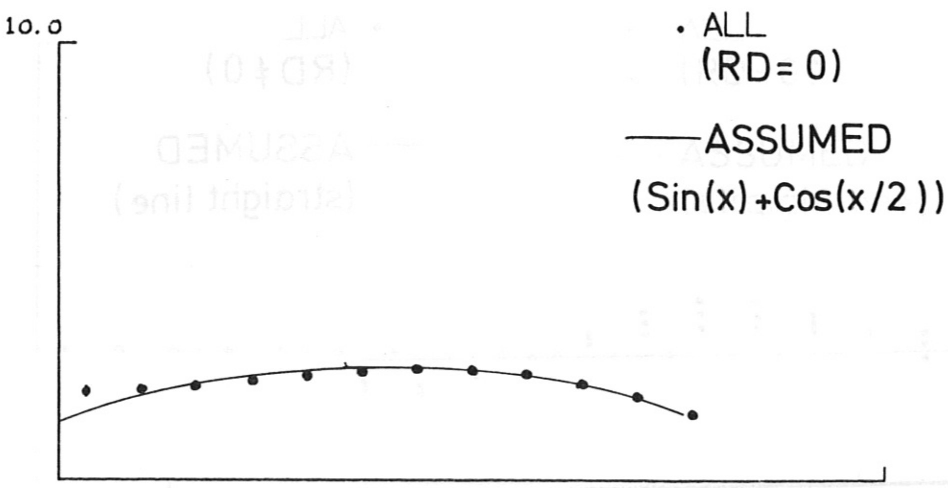


Fig. 4a

```
DATA RUN=  1   SHOT=  1   TMS= 1.0   IOTO= 0.3   IKA= 0.0
               LIM=14.0   POL=-1.0   VER= 0.0    NF=15
BEAMS: 5
PHIE:-135.00 -135.00 -135.00 -135.00 -135.00
PHIB: 105.00   85.00   45.00   15.00    0.00


EFF LIM RAD(CM):   14.00
EXCENTRICITY DUE TO EXT FIELD:      1.68
             TOTAL EXCENTRICITY:    1.68

PATH LENGTHS(CM):     12.3    15.4    20.3    20.2    15.7


 PSIA:      9.744      17.164      23.934      22.630      9.731
   RD:     10.000      -9.000      -7.000       7.000      4.000
 PSIB1:     8.769      18.709      25.609      21.046      9.341


MEAN DENS:  0.117E 01  0.197E 01  0.205E 01  0.169E 01  0.974E 00
 INT DENS:  0.145E 02  0.310E 02  0.424E 02  0.349E 02  0.155E 02

ITER:    5          5          5          5
VARI: 0.28E-01  0.28E-01  0.27E-01  0.27E-01


DENSITY(XE13)                                            RADIR
```

COS	COD	POLY	TCH	ASS	RADIR
2.10	2.13	2.33	2.33	1.65	0.467
2.23	2.25	2.39	2.39	1.95	1.400
2.45	2.45	2.49	2.49	2.20	2.333
2.70	2.68	2.61	2.61	2.40	3.267
2.89	2.87	2.72	2.72	2.55	4.200
2.97	2.95	2.78	2.78	2.63	5.133
2.91	2.90	2.76	2.76	2.63	6.067
2.70	2.70	2.63	2.63	2.56	7.000
2.38	2.38	2.38	2.38	2.41	7.933
2.00	1.99	2.00	2.00	2.19	8.867
1.60	1.59	1.54	1.54	1.89	9.800
1.25	1.24	1.07	1.07	1.54	10.733
0.97	0.97	0.74	0.74	1.14	11.667
0.79	0.80	0.77	0.77	0.70	12.600
0.69	0.70	1.44	1.44	0.24	13.533

```
INDIV ERROR:    12.95    12.98    14.37    14.37
TOTAL ERROR:    54.67
```

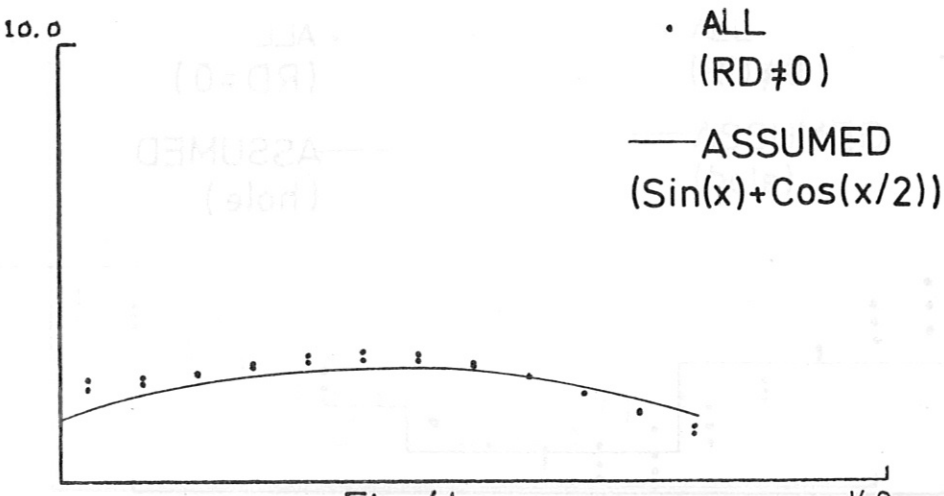


Fig. 4b

```
CATA RUN=  2  SHOT=  1  TMS= 1.0  IOTO= 0.3  IKA= 0.0
                LIM=14.0  POL=-1.0  VER= 0.0   NE=15
BEAMS: 5
PHIE:-135.00 -135.00 -135.00 -135.00 -135.00
PHIB: 105.00   85.00   45.00   15.00    0.0


EFF LIM RAD(CM):  14.00
EXCENTRICITY DUE TO EXT FIELD:     1.68
             TOTAL EXCENTRICITY:   1.68

PATH LENGTHS(CM):    12.3    15.4    20.3    20.2    15.7


 PSIA:    15.139    14.060    25.080    18.417    19.386
   RD:      0.0       0.0       0.0       0.0       0.0
 PSIB1:   15.139    14.060    25.080    18.417    19.386


MEAN DENS:  0.200E 01  0.149E 01  0.201E 01  0.148E 01  0.200E 01
 INT DENS:  0.251E 02  0.233E 02  0.415E 02  0.305E 02  0.321E 02

ITER:    1          1          1          1
VARI: 0.56E-03  0.43E-03  0.22E-03  0.22E-03


DENSITY(XE13)
```

COS	COO	POLY	TCH	ASS	RADIR
4.82	4.30	3.72	3.72	3.00	0.467
4.27	3.91	3.50	3.50	3.00	1.400
3.30	3.20	3.10	3.10	3.00	2.333
2.16	2.34	2.56	2.56	3.00	3.267
1.15	1.52	1.97	1.97	3.00	4.200
0.51	0.91	1.44	1.44	1.00	5.133
0.35	0.63	1.07	1.07	1.00	6.067
0.62	0.73	0.94	0.94	1.00	7.000
1.13	1.10	1.11	1.11	1.00	7.933
1.65	1.60	1.56	1.56	1.00	8.867
2.01	2.04	2.17	2.17	2.00	9.800
2.14	2.29	2.73	2.73	2.00	10.733
2.06	2.23	2.85	2.85	2.00	11.667
1.90	1.86	1.97	1.97	2.00	12.600
1.77	1.26	0.0	0.0	2.00	13.533

```
INDIV ERROR:  44.84    33.32    24.68    24.68
TOTAL ERROR: 127.53
```

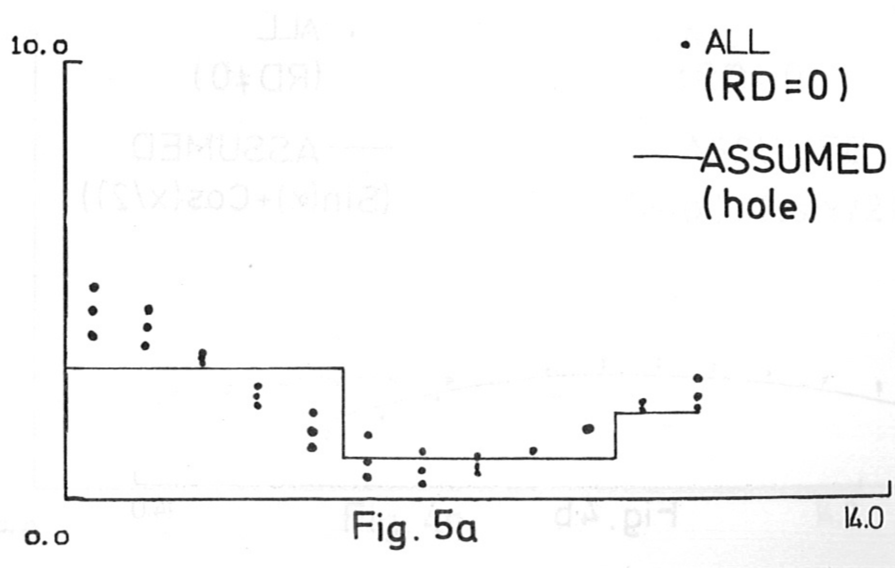


Fig. 5a

```
DATA RUN=  1   SHOT=  1   TMS= 1.0   IOTO= 0.3   IKA= 0.0
               LIM=14.0   PCL=-1.0   VER= 0.0    NE=15
BEAMS: 5
PHIE:-135.00 -135.00 -135.00 -135.00 -135.00
PHIB: 105.00   85.00   45.00   15.00    0.0


EFF LIM RAD(CM):   14.00
EXCENTRICITY DUE TO EXT FIELD:    1.68
           TOTAL EXCENTRICITY:    1.68

PATH LENGTHS(CM):    12.3    15.4    20.3    20.2    15.7


 PSIA:      15.139     14.060     25.080     18.417     19.386
   RD:      10.000     -9.000     -7.000      7.000      4.000
 PSIB1:     13.625     15.326     26.836     17.127     18.611


MEAN DENS:   0.180E 01   0.162E 01   0.214E 01   0.138E 01   0.192E 01
 INT DENS:   0.226E 02   0.254E 02   0.444E 02   0.284E 02   0.308E 02

ITER:    5           5           5           5
VARI:  0.21E-01   0.21E-01   0.21E-01   0.21E-01
```

DENSITY(XE13)

COS	COO	POLY	TCH	ASS	RADIR
4.46	4.28	3.93	3.93	3.00	0.467
4.11	3.99	3.75	3.75	3.00	1.400
3.49	3.46	3.39	3.39	3.00	2.333
2.73	2.79	2.91	2.91	3.00	3.267
1.98	2.10	2.37	2.37	3.00	4.200
1.39	1.52	1.84	1.84	1.00	5.133
1.05	1.15	1.40	1.40	1.00	6.067
0.98	1.01	1.14	1.14	1.00	7.000
1.10	1.09	1.10	1.10	1.00	7.933
1.34	1.32	1.29	1.29	1.00	8.867
1.60	1.59	1.66	1.66	2.00	9.800
1.80	1.83	2.09	2.09	2.00	10.733
1.93	1.97	2.34	2.34	2.00	11.667
2.00	1.99	2.06	2.06	2.00	12.600
2.02	1.91	0.74	0.74	2.00	13.533

```
INDIV ERROR:   31.59    28.88    25.04    25.04
TOTAL ERROR: 110.55
```

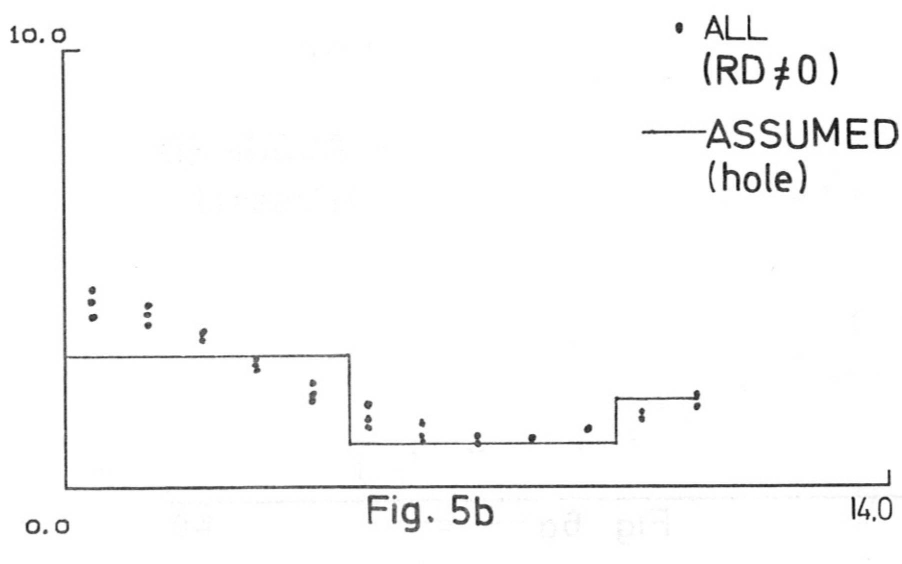


Fig. 5b

CATA RUN= 2 SHOT= 1 TMS= 1.0 IOTO= 0.3 IKA= 0.0
LIM=14.0 PGL=-1.0 VER= 0.0 NE=15

BEAMS: 5
PHIE:-135.00 -135.00 -135.00 -135.00 -135.00
PHIB: 105.00 95.00 55.00 30.00 0.0

EFF LIM RAD(CM): 14.00
EXCENTRICITY DUE TO EXT FIELD: 1.68
TOTAL EXCENTRICITY: 1.68

PATH LENGTHS(CM): 12.3 13.9 19.3 21.1 15.7

PSIA:	3.251	5.629	18.319	18.675	2.560
RD:	10.000	-9.000	-7.000	7.000	4.000
PSIB1:	2.926	6.135	19.602	17.367	2.458

MEAN DENS:	0.393E 00	0.725E 00	0.165E 01	0.135E 01	0.258E 00
INT DENS:	0.485E 01	0.102E 02	0.325E 02	0.288E 02	0.407E 01

ITER:	5	5	5	5
VARI:	0.14E-01	0.19E-01	0.26E-01	0.26E-01

DENSITY(XE13)

COS	COO	POLY	TCH	ASS	RADIR
5.30	5.01	4.36	4.32	2.99	0.467
4.87	4.66	4.14	4.11	2.94	1.400
4.11	4.03	3.74	3.71	2.84	2.333
3.20	3.24	3.20	3.18	2.68	3.267
2.34	2.44	2.59	2.57	2.48	4.200
1.69	1.77	1.99	1.98	2.25	5.133
1.33	1.33	1.48	1.49	1.98	6.067
1.20	1.12	1.15	1.16	1.69	7.000
1.19	1.08	1.01	1.01	1.38	7.933
1.15	1.10	1.03	1.02	1.08	8.867
0.96	1.01	1.08	1.06	0.78	9.800
0.61	0.71	0.93	0.87	0.51	10.733
0.16	0.09	0.15	0.05	0.28	11.667
0.0	0.0	0.0	0.0	0.11	12.600
0.0	0.0	0.0	0.0	0.01	13.533

INDIV ERROR: 47.14 43.76 33.93 32.86
TOTAL ERROR: 157.68

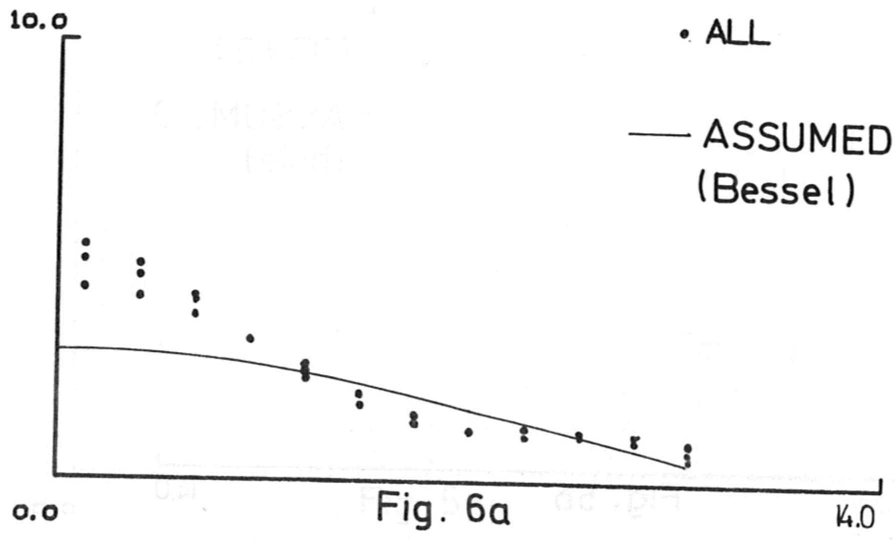


Fig. 6a

DATA RUN= 3 SHOT= 1 TMS= 1.0 ICTO= 0.3 IKA= 0.0
LIM=14.0 POL=-1.0 VER= 0.0 NE=15

BEAMS: 5

PHIE:-135.00 -135.00 -135.00 -135.00 -135.00

PHIB: 105.00 85.00 45.00 40.00 0.0

EFF LIM RAD(CM): 14.00

EXCENTRICITY DUE TO EXT FIELD: 1.68

TOTAL EXCENTRICITY: 1.68

PATH LENGTHS(CM): 12.3 15.4 20.3 20.6 15.7

PSIA:	3.251	8.673	20.053	20.192	2.560
RD:	10.000	-9.000	-7.000	7.000	4.000
PSIB1:	2.926	9.453	21.457	18.779	2.458

MEAN DENS:	0.393E 00	0.101E 01	0.172E 01	0.148E 01	0.258E 00
INT DENS:	0.485E 01	0.157E 02	0.355E 02	0.311E 02	0.407E 01

ITER:	5	5	5	5
VARI:	0.33E-01	0.35E-01	0.34E-01	0.34E-01

DENSITY(XE13)

COS	COD	POLY	TCH	ASS	RADIR
3.31	2.82	2.74	2.74	2.99	0.467
3.15	2.79	2.73	2.73	2.94	1.400
2.88	2.73	2.68	2.68	2.84	2.333
2.55	2.64	2.61	2.61	2.68	3.267
2.24	2.50	2.50	2.50	2.48	4.200
1.99	2.32	2.35	2.35	2.25	5.133
1.81	2.08	2.13	2.13	1.98	6.067
1.67	1.81	1.85	1.85	1.69	7.000
1.52	1.50	1.50	1.50	1.38	7.933
1.29	1.18	1.12	1.12	1.08	8.867
0.98	0.85	0.71	0.71	0.78	9.800
0.58	0.54	0.35	0.35	0.51	10.733
0.17	0.25	0.11	0.11	0.28	11.667
0.0	0.0	0.11	0.11	0.11	12.600
0.0	0.0	0.51	0.51	0.01	13.533

INDIV ERROR:	9.55	5.24	7.21	7.21
TOTAL ERROR:	29.22			

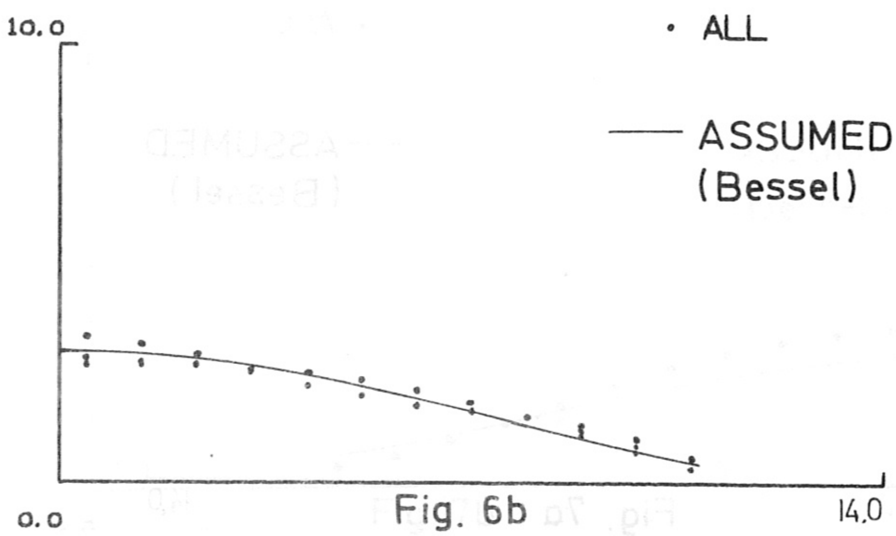


Fig. 6b

```
DATA RUN=  4   SHOT=  1   TMS=30.0   IOTO= 0.3   IKA= 0.0
               LIM=14.0   POL=-1.0   VER= 0.0    NE =15
BEAMS: 5
PHIE:-135.00  -135.00  -135.00  -135.00  -135.00
PHIB: 105.00    85.00    45.00    15.00     0.0

EFF LIM RAD(CM):   14.00
EXCENTRICITY DUE TO EXT FIELD:     1.68
             TOTAL EXCENTRICITY:   1.68

PATH LENGTHS(CM):    12.3    15.4    20.3    20.2    15.7

PSIA:      3.251      8.673     20.053     11.490      2.560
  RD:     20.000    -18.000    -14.000     15.000      8.000
PSIB1:     2.601     10.234     22.861      9.767      2.355

MEAN DENS:  0.350E 00   0.109E 01   0.183E 01   0.792E 00   0.248E 00
 INT DENS:  0.431E 01   0.169E 02   0.379E 02   0.162E 02   0.390E 01

ITER:    5           5           5           5
VARI: 0.43E-01   0.43E-01   0.43E-01   0.43E-01
```

DENSITY(XE13)

COS	COD	POLY	TCH	ASS	RADIR
3.57	3.63	3.68	3.68	2.99	0.467
3.53	3.57	3.60	3.60	2.94	1.400
3.43	3.44	3.45	3.45	2.84	2.333
3.26	3.24	3.22	3.22	2.68	3.267
3.00	2.97	2.92	2.92	2.48	4.200
2.66	2.62	2.57	2.57	2.25	5.133
2.24	2.21	2.18	2.18	1.98	6.067
1.78	1.77	1.75	1.75	1.69	7.000
1.32	1.33	1.33	1.33	1.38	7.933
0.92	0.92	0.92	0.92	1.08	8.867
0.60	0.58	0.56	0.56	0.78	9.800
0.37	0.34	0.29	0.29	0.51	10.733
0.23	0.21	0.14	0.14	0.28	11.667
0.16	0.18	0.18	0.18	0.11	12.600
0.14	0.21	0.43	0.43	0.01	13.533

```
INDIV ERROR:   20.08    20.45    20.83    20.83
TOTAL ERROR:   82.20
```

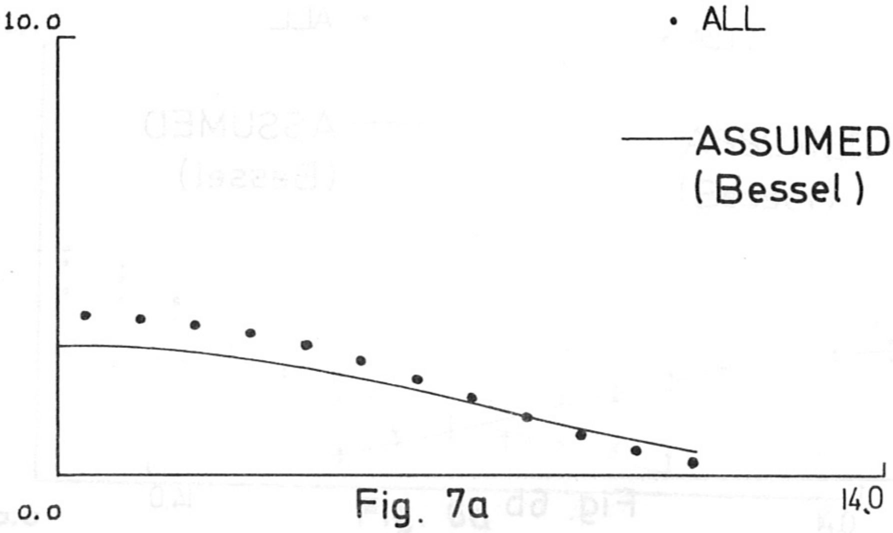


Fig. 7a

DATA RUN= 5 SHOT= 1 TMS=30.0 IOTO= 0.3 IKA= 0.0
LIM=14.0 POL=-1.0 VER= 0.0 NE=15
BEAMS: 5
PHIE:-135.00 -135.00 -135.00 -135.00 -135.00
PHIB: 105.00 85.00 45.00 15.00 0.0

EFF LIM RAD(CM): 14.00
EXCENTRICITY DUE TO EXT FIELD: 1.68
TOTAL EXCENTRICITY: 1.68

PATH LENGTHS(CM): 12.3 15.4 20.3 20.2 15.7

PSIA:	3.251	8.673	20.053	11.490	2.560
RD:	15.000	8.000	20.000	-18.000	-14.000
PSIB1:	2.763	7.979	16.043	13.558	2.918

MEAN DENS:	0.371E 00	0.850E 00	0.129E 01	0.110E 01	0.307E 00
INT DENS:	0.458E 01	0.132E 02	0.266E 02	0.225E 02	0.483E 01

ITER:	5	5	5	5
VARI:	0.39E-01	0.39E-01	0.39E-01	0.39E-01

DENSITY(XE13)

COS	COO	POLY	TCH	ASS	RADIR
0.62	1.05	1.50	1.50	2.99	0.467
0.97	1.26	1.58	1.58	2.94	1.400
1.54	1.62	1.71	1.71	2.84	2.333
2.14	2.01	1.87	1.87	2.68	3.267
2.58	2.31	2.02	2.02	2.48	4.200
2.73	2.44	2.09	2.09	2.25	5.133
2.53	2.33	2.06	2.06	1.98	6.067
2.07	1.99	1.87	1.87	1.69	7.000
1.46	1.48	1.51	1.51	1.38	7.933
0.88	0.93	1.00	1.00	1.08	8.867
0.46	0.45	0.41	0.41	0.78	9.800
0.26	0.16	0.01	0.01	0.51	10.733
0.26	0.14	0.0	0.0	0.28	11.667
0.35	0.37	0.08	0.08	0.11	12.600
0.43	0.79	1.60	1.60	0.01	13.533

INDIV ERROR: 48.02 41.68 36.25 36.27
TOTAL ERROR: 162.22

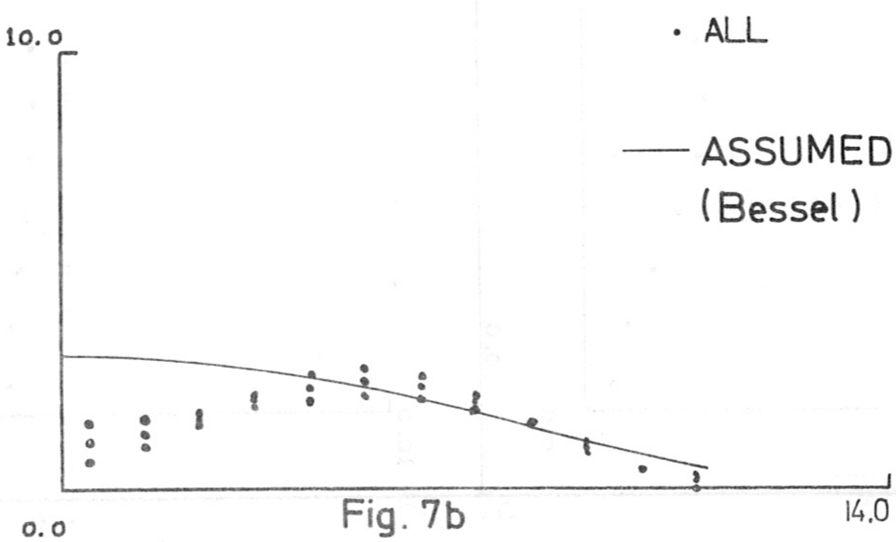


Fig. 7b

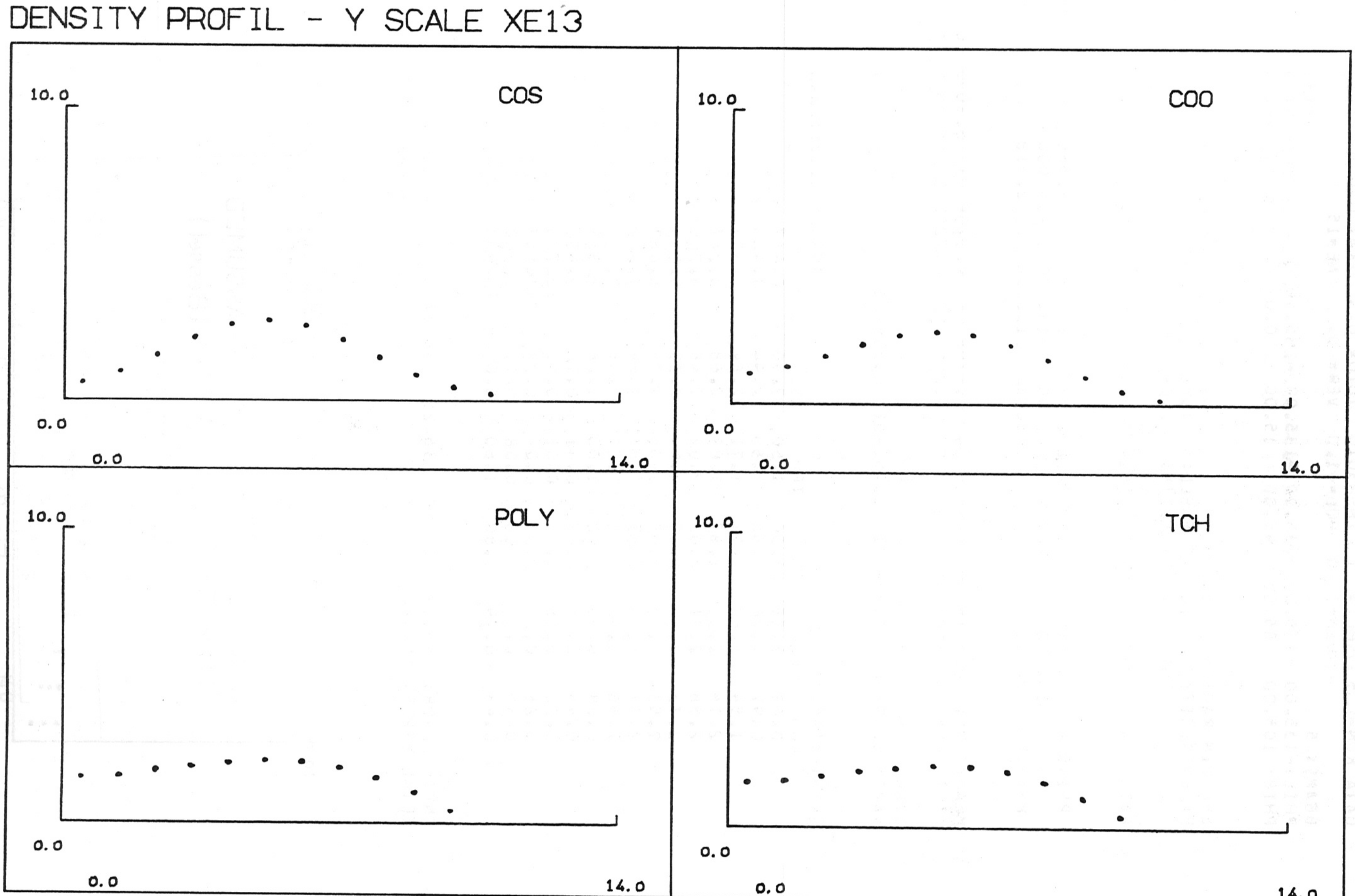


Fig. 7b'

DATA RUN= 1 SHOT= 1 TMS= 1.0 IOTO= 0.3 IKA= 0.0
LIM=14.0 POL=-1.0 VER= 0.0 NE=15
BEAMS: 4
PHIE:-135.00 -135.00 -135.00 -135.00
PHIB: 105.00 85.00 45.00 0.0

EFF LIM RAD(CM): 14.00
EXCENTRICITY DUE TO EXT FIELD: 1.68
TOTAL EXCENTRICITY: 1.68

PATH LENGTHS(CM): 12.3 15.4 20.3 15.7

PSIA:	3.251	8.673	20.053	2.560
RD:	15.000	8.000	20.000	-14.000
PSIB1:	2.763	7.979	16.043	2.918

MEAN DENS:	0.371E 00	0.850E 00	0.129E 01	0.307E 00
INT DENS:	0.458E 01	0.132E 02	0.266E 02	0.483E 01

ITER:	5	5	5	5
VARI:	0.14E-01	0.17E-01	0.16E-01	0.16E-01

DENSITY(XE13)

COS	COO	POLY	TCH	ASS	RADIR
2.16	2.25	2.26	2.26	2.99	0.467
2.15	2.22	2.23	2.23	2.94	1.400
2.11	2.15	2.16	2.16	2.84	2.333
2.05	2.06	2.07	2.07	2.68	3.267
1.96	1.93	1.94	1.94	2.48	4.200
1.83	1.78	1.79	1.79	2.25	5.133
1.67	1.61	1.61	1.61	1.98	6.067
1.47	1.42	1.42	1.42	1.69	7.000
1.23	1.22	1.21	1.21	1.38	7.933
0.98	1.00	0.99	0.99	1.08	8.867
0.73	0.78	0.76	0.76	0.78	9.800
0.49	0.55	0.53	0.53	0.51	10.733
0.29	0.31	0.31	0.31	0.28	11.667
0.14	0.07	0.11	0.11	0.11	12.600
0.07	0.0	0.0	0.0	0.01	13.533

INDIV ERROR:	24.08	23.19	23.07	23.08
TOTAL ERROR:	93.43			

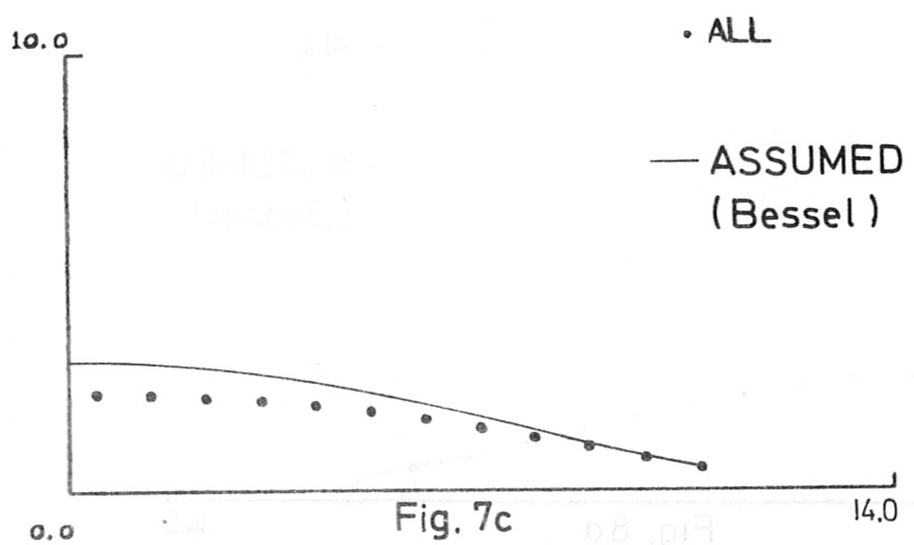


Fig. 7c

```
DATA RUN=  1  SHOT=  1  TMS= 1.0  IOTO= 0.2  IKA= 0.0
              LIM=14.0  POL=-1.0  VER= 0.0   NE=15
BEAMS: 5
PHIE:-135.00 -135.00 -135.00 -135.00 -135.00
PHIB: 105.00   85.00   45.00   15.00    0.0

EFF LIM RAD(CM):  14.00
EXCENTRICITY DUE TO EXT FIELD:    1.50
          TOTAL EXCENTRICITY:    1.50

PATH LENGTHS(CM):    13.7    17.2    22.0    21.7    18.0
```

PSIA:	3.668	9.739	21.748	13.279	4.291
RD:	0.0	0.0	0.0	0.0	0.0
PSIB1:	3.668	9.739	21.748	13.279	4.291

MEAN DENS:	0.440E 00	0.931E 00	0.161E 01	0.100E 01	0.394E 00
INT DENS:	0.607E 01	0.161E 02	0.360E 02	0.220E 02	0.711E 01

ITER:	1	1	1	1
VARI:	0.54E-04	0.12E-03	0.49E-05	0.46E-05

DENSITY(XE13)

COS	COO	POLY	TCH	ASS	RAD1R
3.00	2.98	2.99	2.99	2.99	0.467
2.94	2.93	2.94	2.94	2.94	1.400
2.84	2.84	2.84	2.84	2.84	2.333
2.68	2.69	2.68	2.68	2.68	3.267
2.48	2.50	2.48	2.48	2.48	4.200
2.24	2.26	2.25	2.25	2.25	5.133
1.98	1.99	1.98	1.98	1.98	6.067
1.69	1.69	1.69	1.69	1.69	7.000
1.38	1.39	1.38	1.38	1.38	7.933
1.07	1.08	1.08	1.08	1.08	8.867
0.78	0.79	0.78	0.78	0.78	9.800
0.50	0.53	0.51	0.51	0.51	10.733
0.28	0.30	0.28	0.28	0.28	11.667
0.11	0.10	0.11	0.11	0.11	12.600
0.03	0.0	0.01	0.01	0.01	13.533

```
INDIV ERROR:   0.21    0.57    0.02    0.02
TOTAL ERROR:   0.82
```

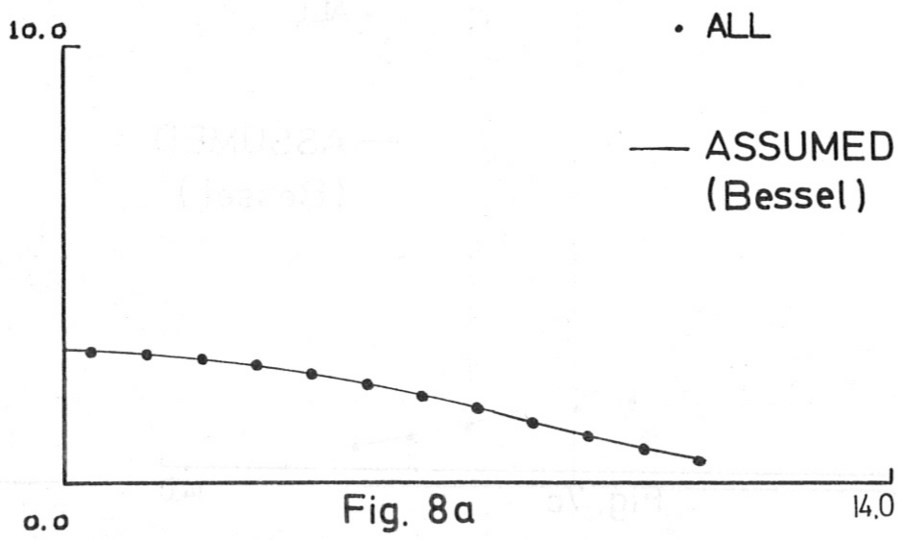


Fig. 8a

DATA RUN= 3 SHOT= 1 TMS= 1.0 IOTO= 0.2 IKA= 0.0
LIM=14.0 POL=-1.0 VER= 0.0 NE=15
BEAMS: 5
PHIE:-135.00 -135.00 -135.00 -135.00 -135.00
PHIB: 105.00 85.00 45.00 15.00 0.0

EFF LIM RAD(CM): 14.00
EXCENTRICITY DUE TO EXT FIELD: 1.50
TOTAL EXCENTRICITY: 1.50

PATH LENGTHS(CM): 13.7 17.2 22.0 21.7 18.0

PSIA:	3.668	9.739	21.748	13.279	4.291
RD:	10.000	-9.000	-7.000	7.000	4.000
PSIB1:	3.301	10.615	23.270	12.350	4.119

MEAN DENS:	0.396E 00	0.101E 01	0.172E 01	0.933E 00	0.378E 00
INT DENS:	0.547E 01	0.176E 02	0.385E 02	0.205E 02	0.682E 01

ITER:	5	5	5	5
VARI:	0.16E-01	0.19E-01	0.20E-01	0.22E-01

DENSITY(XE13)

COS	COO	POLY	TCH	ASS	RADIR
4.97	4.30	4.07	3.65	2.99	0.467
4.42	3.97	3.80	3.52	2.94	1.400
3.50	3.40	3.31	3.26	2.84	2.333
2.46	2.71	2.69	2.92	2.68	3.267
1.61	2.08	2.05	2.53	2.48	4.200
1.17	1.64	1.54	2.16	2.25	5.133
1.16	1.45	1.27	1.85	1.98	6.067
1.43	1.49	1.26	1.62	1.69	7.000
1.70	1.61	1.43	1.48	1.38	7.933
1.69	1.62	1.51	1.37	1.08	8.867
1.25	1.30	0.98	1.18	0.78	9.800
0.38	0.47	0.0	0.67	0.51	10.733
0.0	0.0	0.0	0.0	0.28	11.667
0.0	0.0	1.37	0.0	0.11	12.600
0.0	0.0	1.57	0.0	0.01	13.533

INDIV ERROR: 45.56 30.33 28.98 16.41
TOTAL ERROR: 121.28

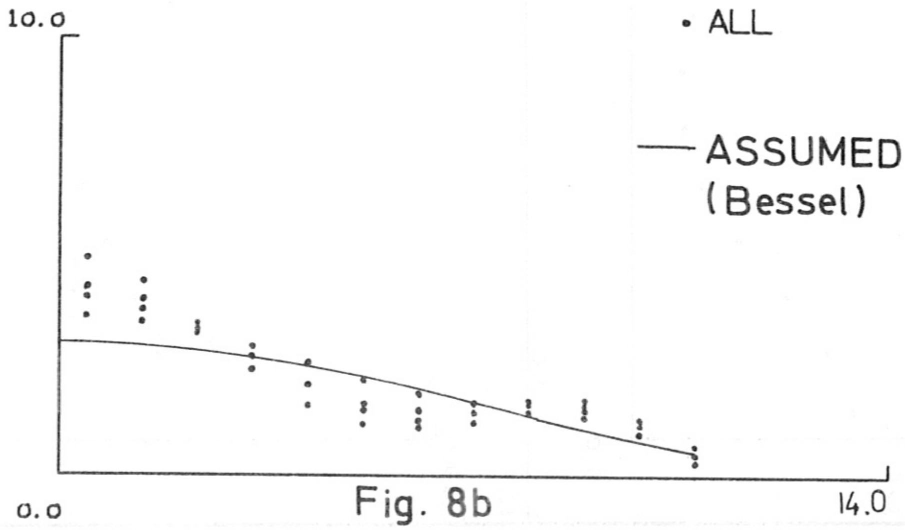


Fig. 8b

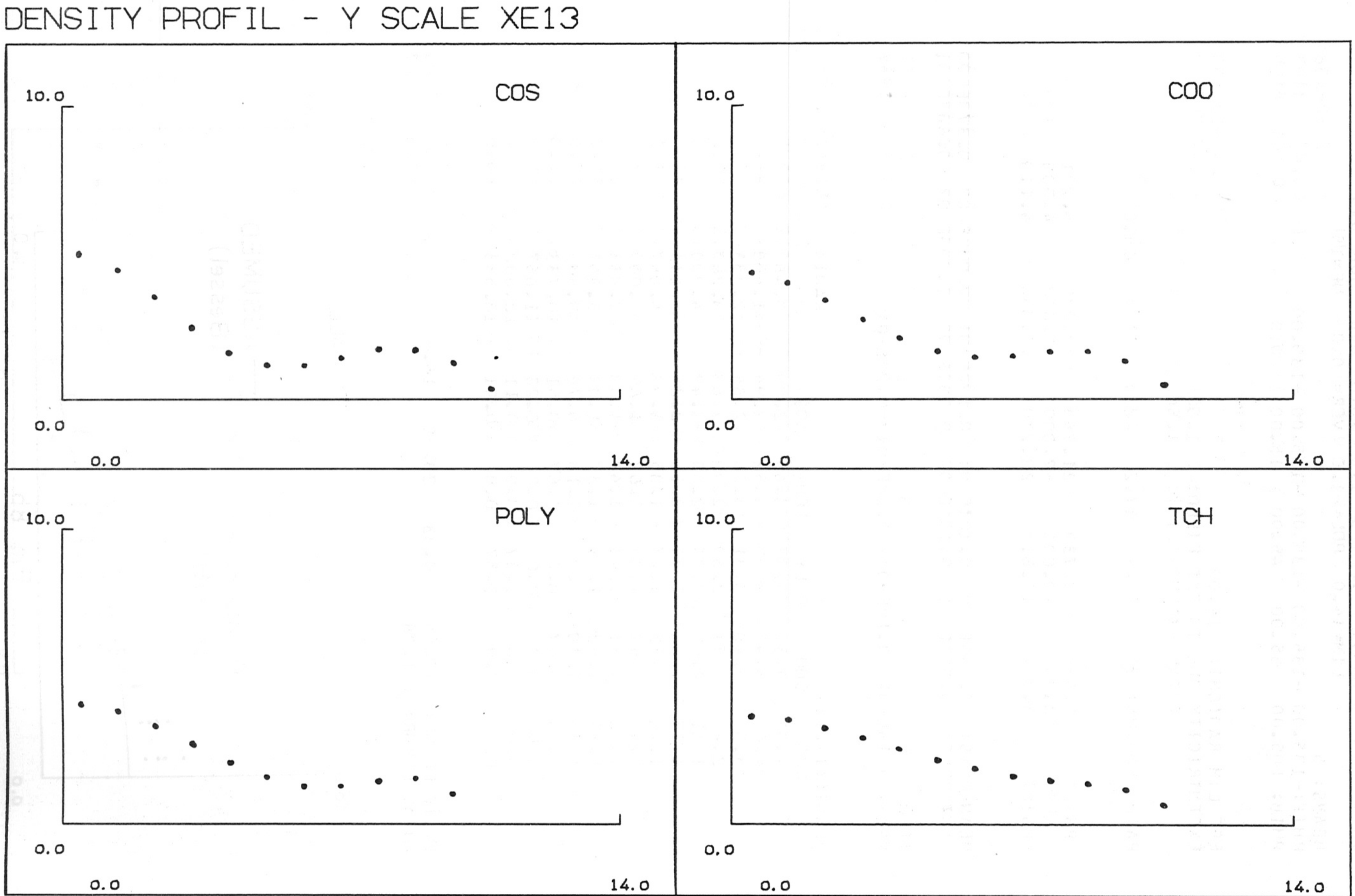


Fig. 8b′

DATA RUN= 4 SHOT= 1 TMS=30.0 IOTO= 0.2 IKA= 0.0
LIM=14.0 POL=-1.0 VER= 0.0 NE=15

BEAMS: 4
PHIE:-135.00 -135.00 -135.00 -135.00
PHIB: 105.00 85.00 45.00 0.0

EFF LIM RAD(CM): 14.00
EXCENTRICITY DUE TO EXT FIELD: 1.50
TOTAL EXCENTRICITY: 1.50

PATH LENGTHS(CM): 13.7 17.2 22.0 18.0

PSIA:	3.668	9.739	21.748	4.291
RD:	10.000	-9.000	-7.000	4.000
PSIB1:	3.301	10.615	23.270	4.119

MEAN DENS:	0.396E 00	0.101E 01	0.172E 01	0.378E 00
INT DENS:	0.547E 01	0.176E 02	0.385E 02	0.682E 01

ITER:	1	1	1	1
VARI:	0.49E-02	0.61E-02	0.57E-02	0.57E-02

DENSITY(XE13)

COS	COO	POLY	TCH	ASS	RADIR
3.11	3.19	3.17	3.17	2.99	0.467
3.07	3.13	3.12	3.12	2.94	1.400
2.99	3.03	3.02	3.02	2.84	2.333
2.88	2.88	2.88	2.88	2.68	3.267
2.71	2.68	2.69	2.69	2.48	4.200
2.49	2.45	2.46	2.46	2.25	5.133
2.22	2.19	2.19	2.19	1.98	6.067
1.91	1.90	1.90	1.90	1.69	7.000
1.56	1.59	1.58	1.58	1.38	7.933
1.20	1.27	1.24	1.24	1.08	8.867
0.83	0.94	0.90	0.90	0.78	9.800
0.50	0.60	0.57	0.57	0.51	10.733
0.22	0.26	0.24	0.24	0.28	11.667
0.02	0.0	0.0	0.0	0.11	12.600
0.0	0.0	0.0	0.0	0.01	13.533

INDIV ERROR: 8.82 9.81 9.36 9.36
TOTAL ERROR: 37.34

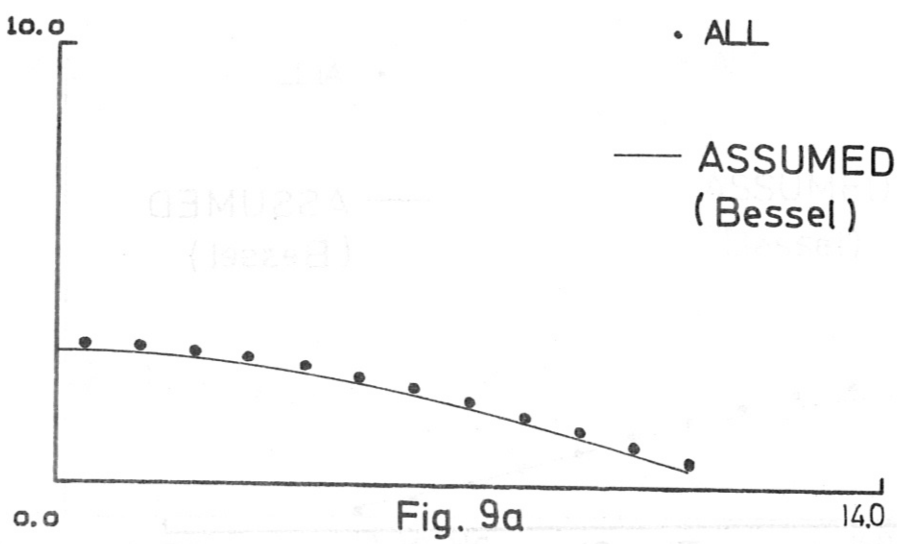


Fig. 9a

DATA RUN= 5 SHOT= 1 TMS=30.0 IOTO= 0.2 IKA= 0.0
LIM=14.0 POL=-1.0 VER= 0.0 NE=15

BEAMS: 4

PHIE:-135.00 -135.00 -135.00 -135.00

PHIB: 105.00 85.00 45.00 15.00

EFF LIM RAD(CM): 14.00

EXCENTRICITY DUE TO EXT FIELD: 1.50

TOTAL EXCENTRICITY: 1.50

PATH LENGTHS(CM): 13.7 17.2 22.0 21.7

PSIA:	3.668	9.739	21.748	13.279
RD:	10.000	-9.000	-7.000	7.000
PSIB1:	3.301	10.615	23.270	12.350

MEAN DENS:	0.396E 00	0.101E 01	0.172E 01	0.933E 00
INT DENS:	0.547E 01	0.176E 02	0.385E 02	0.205E 02

ITER:	5	5	5	5
VARI:	0.23E-01	0.23E-01	0.24E-01	0.24E-01

DENSITY(XE13)

COS	COO	POLY	TCH	ASS	RAD1R
3.37	3.38	3.33	3.33	2.99	0.467
3.30	3.31	3.27	3.27	2.94	1.400
3.15	3.16	3.13	3.13	2.84	2.333
2.95	2.95	2.94	2.94	2.68	3.267
2.69	2.68	2.69	2.69	2.48	4.200
2.39	2.38	2.40	2.40	2.25	5.133
2.05	2.05	2.06	2.06	1.98	6.067
1.70	1.71	1.71	1.71	1.69	7.000
1.36	1.38	1.34	1.34	1.38	7.933
1.02	1.06	0.99	0.99	1.08	8.867
0.72	0.76	0.67	0.67	0.78	9.800
0.46	0.49	0.40	0.40	0.51	10.733
0.25	0.24	0.22	0.22	0.28	11.667
0.11	0.02	0.15	0.15	0.11	12.600
0.04	0.0	0.23	0.23	0.01	13.533

INDIV ERROR:	10.13	9.91	10.17	10.17
TOTAL ERROR:	40.38			

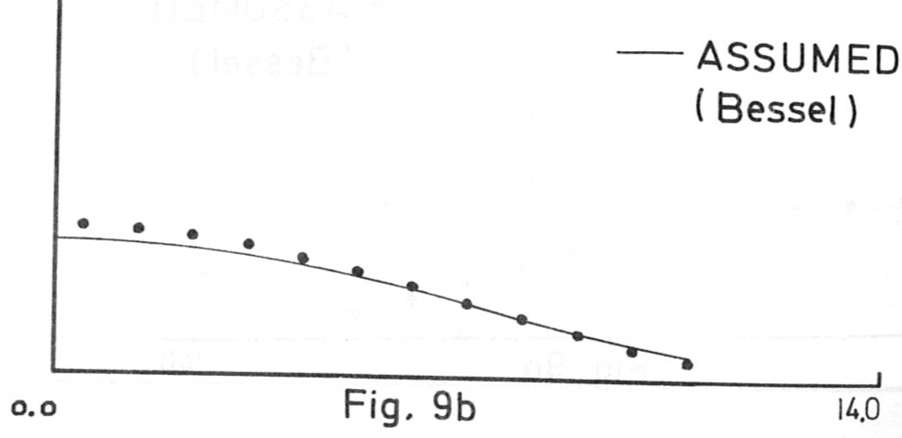


Fig. 9b

```
DATA RUN=  6   SHOT=  1   TMS=30.0   IOTO= 0.2   IKA= 0.0
               LIM=14.0   POL=-1.0   VER= 0.0    NE=15
BEAMS: 3
PHIE:-135.00 -135.00 -135.00
PHIB: 105.00   45.00    0.0


EFF LIM RAD(CM):   14.00
EXCENTRICITY DUE TO EXT FIELD:    1.50
           TOTAL EXCENTRICITY:    1.50

PATH LENGTHS(CM):    13.7    22.0    18.0


 PSIA:      3.668     21.748     4.291
   RD:     10.000     -9.000     4.000
 PSIB1:     3.301     23.705     4.119


MEAN DENS:   0.396E 00   0.175E 01   0.378E 00
 INT DENS:   0.547E 01   0.393E 02   0.682E 01

ITER:    1          1          1          1
VARI: 0.37E-02  0.79E-02  0.90E-02  0.90E-02
```

DENSITY(XE13)

COS	COO	POLY	TCH	ASS	RADIR
3.42	3.15	3.09	3.09	2.99	0.467
3.35	3.11	3.05	3.05	2.94	1.400
3.21	3.02	2.98	2.98	2.84	2.333
3.00	2.90	2.88	2.88	2.68	3.267
2.75	2.74	2.73	2.73	2.48	4.200
2.44	2.54	2.56	2.56	2.25	5.133
2.11	2.30	2.34	2.34	1.98	6.067
1.75	2.03	2.09	2.09	1.69	7.000
1.40	1.72	1.80	1.80	1.38	7.933
1.05	1.39	1.47	1.47	1.08	8.867
0.74	1.03	1.11	1.11	0.78	9.800
0.47	0.65	0.70	0.70	0.51	10.733
0.25	0.25	0.25	0.25	0.28	11.667
0.10	0.0	0.0	0.0	0.11	12.600
0.03	0.0	0.0	0.0	0.01	13.533

```
INDIV ERROR:   11.88    13.48    15.02    15.02
TOTAL ERROR:   55.40
```

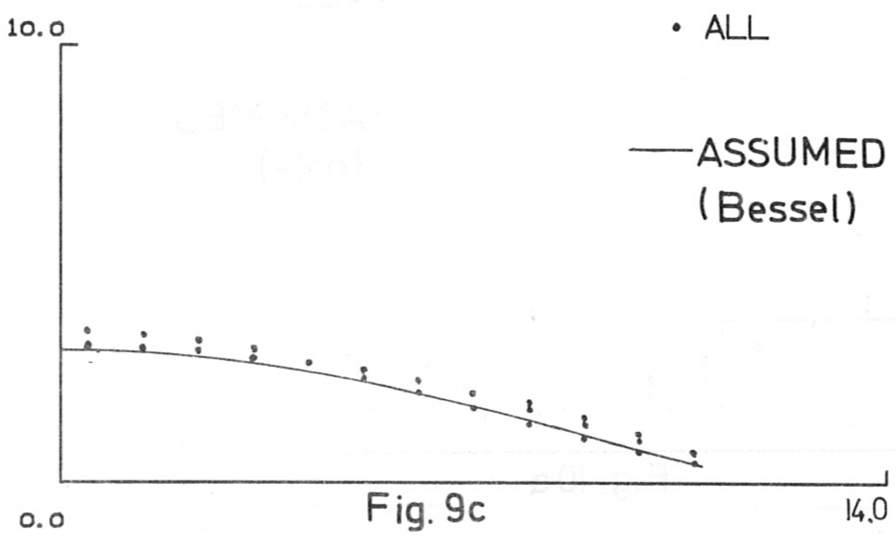


Fig. 9c

```
DATA RUN=  3   SHOT=  1   TMS= 1.0  IOTO= 0.3  IKA= 0.0
                LIM=14.0   POL=-1.0  VER= 0.0   NE=15
BEAMS: 4
PHIE:-135.00 -135.00 -135.00 -135.00
PHIB: 105.00    45.00    15.00     0.0

EFF LIM RAD(CM):  14.00
EXCENTRICITY DUE TO EXT FIELD:    1.68
          TOTAL EXCENTRICITY:    1.68

PATH LENGTHS(CM):    12.3    20.3    20.2    15.7

 PSIA:      15.139     25.080     18.417     19.386
   RD:      10.000     -7.000      7.000      4.000
PSIB1:      13.625     26.836     17.127     18.611

MEAN DENS:  0.180E 01   0.214E 01   0.138E 01   0.192E 01
 INT DENS:  0.226E 02   0.444E 02   0.284E 02   0.308E 02

ITER:    1          5          5          5
VARI: 0.87E-02  0.16E-01  0.23E-01  0.23E-01
```

DENSITY(XE13)

COS	COO	POLY	TCH	ASS	RADIR
4.10	3.78	3.51	3.51	3.00	0.467
3.88	3.63	3.40	3.40	3.00	1.400
3.47	3.33	3.19	3.19	3.00	2.333
2.92	2.93	2.89	2.89	3.00	3.267
2.32	2.45	2.52	2.52	3.00	4.200
1.75	1.96	2.10	2.10	1.00	5.133
1.29	1.50	1.66	1.66	1.00	6.067
1.00	1.13	1.25	1.25	1.00	7.000
0.91	0.90	0.91	0.91	1.00	7.933
1.01	0.84	0.70	0.70	1.00	8.867
1.26	0.97	0.69	0.69	2.00	9.800
1.59	1.29	0.94	0.94	2.00	10.733
1.93	1.77	1.52	1.52	2.00	11.667
2.20	2.37	2.51	2.51	2.00	12.600
2.35	3.04	3.94	3.94	2.00	13.533

```
INDIV ERROR:   27.41    29.04    33.07    33.07
TOTAL ERROR:  122.58
```

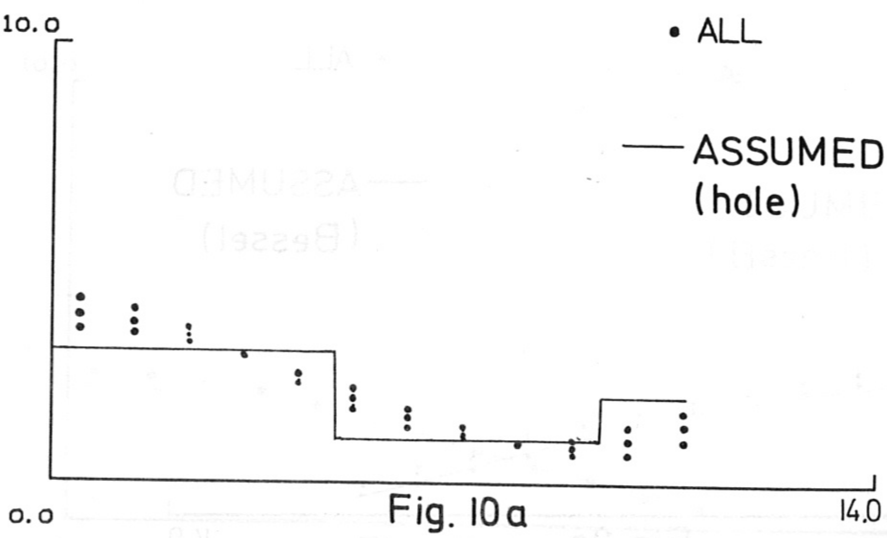


Fig. 10a

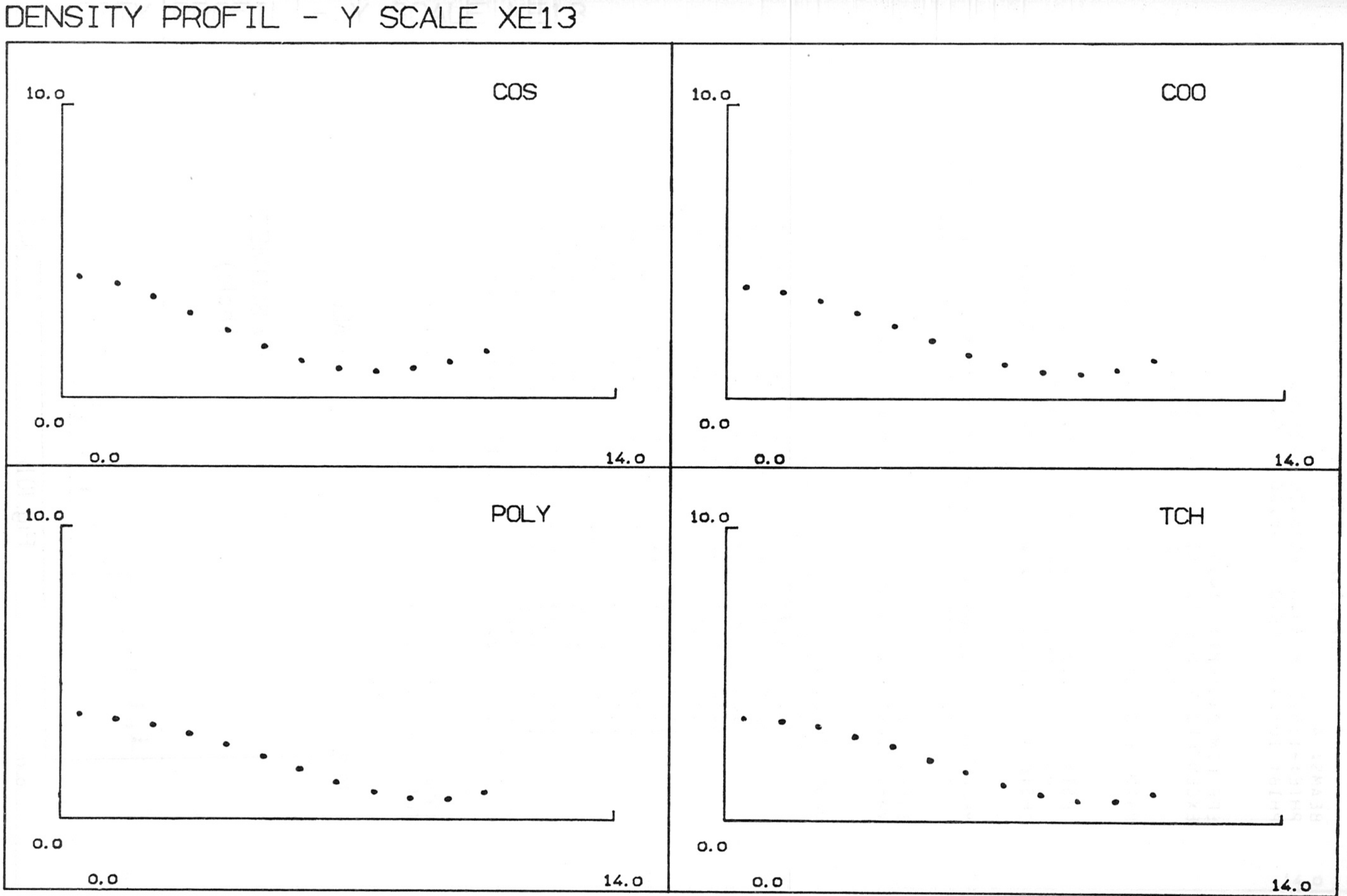


Fig. 10 a'

```
DATA RUN=  4   SHOT=  1   TMS=30.0   IOTO= 0.3   IKA= 0.0
               LIM=14.0   PCL=-1.0   VER= 0.0    NE=15
BEAMS: 4
PHIE:-135.00 -135.00 -135.00 -135.00
PHIB: 105.00   85.00   45.00    0.0

EFF LIM RAD(CM):  14.00
EXCENTRICITY DUE TO EXT FIELD:   1.68
          TOTAL EXCENTRICITY:   1.68

PATH LENGTHS(CM):    12.3    15.4    20.3    15.7

 PSIA:     15.139     14.060     25.080     19.386
   RD:     10.000     -9.000     -7.000      4.000
 PSIB1:    13.625     15.326     26.836     18.611

MEAN DENS:  0.180E 01  0.162E 01  0.214E 01  0.192E 01
 INT DENS:  0.226E 02  0.254E 02  0.444E 02  0.308E 02

ITER:    1          1         5         5
VARI: 0.11E-02  0.55E-02  0.10E-01  0.10E-01
```

DENSITY(XE13)

COS	COO	POLY	TCH	ASS	RADIR
3.49	3.29	3.10	3.10	3.00	0.467
3.35	3.18	3.03	3.03	3.00	1.400
3.08	2.99	2.89	2.89	3.00	2.333
2.72	2.72	2.69	2.69	3.00	3.267
2.33	2.41	2.45	2.45	3.00	4.200
1.95	2.08	2.17	2.17	1.00	5.133
1.64	1.77	1.88	1.88	1.00	6.067
1.43	1.52	1.60	1.60	1.00	7.000
1.35	1.36	1.37	1.37	1.00	7.933
1.39	1.30	1.22	1.22	1.00	8.867
1.52	1.36	1.19	1.19	2.00	9.800
1.71	1.53	1.32	1.32	2.00	10.733
1.91	1.81	1.66	1.66	2.00	11.667
2.07	2.17	2.26	2.26	2.00	12.600
2.16	2.58	3.15	3.15	2.00	13.533

```
INDIV ERROR:   25.50    26.60    28.97    28.97
TOTAL ERROR:  110.05
```

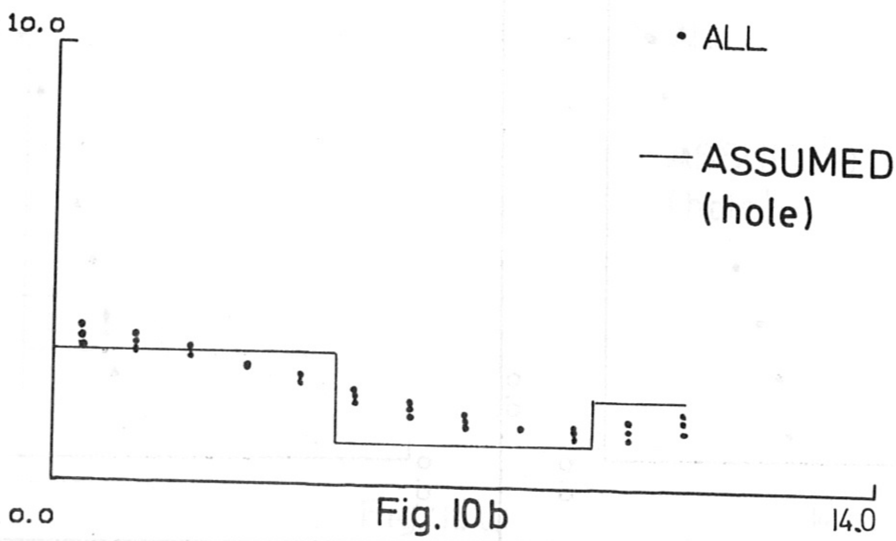


Fig. 10b

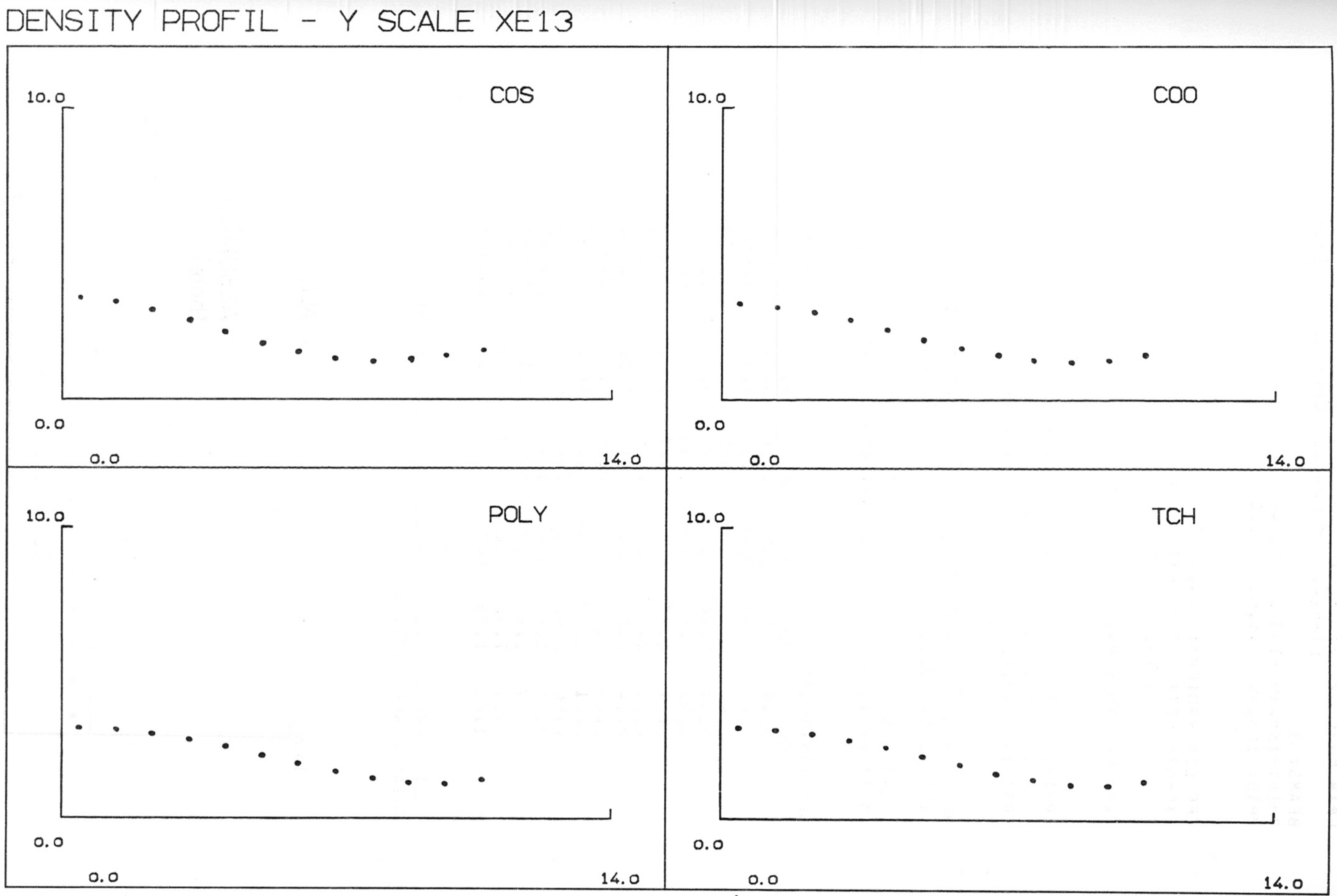


Fig. 10b'

DATA RUN= 5 SHOT= 1 TMS=30.0 IOTO= 0.3 IKA= 0.0
LIM=14.0 POL=-1.0 VER= 0.0 NE=15
BEAMS: 3
PHIE:-135.00 -135.00 -135.00
PHIB: 105.00 45.00 0.0

EFF LIM RAD(CM): 14.00
EXCENTRICITY DUE TO EXT FIELD: 1.68
TOTAL EXCENTRICITY: 1.68

PATH LENGTHS(CM): 12.3 20.3 15.7

PSIA:	15.139	25.080	19.386
RD:	10.000	-7.000	4.000
PSIB1:	13.625	26.836	18.611

MEAN DENS: 0.180E 01 0.214E 01 0.192E 01
INT DENS: 0.226E 02 0.444E 02 0.308E 02

ITER: 5 5 5 5
VARI: 0.13E-01 0.14E-01 0.15E-01 0.15E-01

DENSITY(XE13)

COS	COO	POLY	TCH	ASS	RADIR
2.45	2.38	2.36	2.36	3.00	0.467
2.44	2.37	2.36	2.36	3.00	1.400
2.41	2.36	2.35	2.35	3.00	2.333
2.37	2.34	2.33	2.33	3.00	3.267
2.32	2.31	2.30	2.30	3.00	4.200
2.27	2.27	2.27	2.27	1.00	5.133
2.21	2.23	2.24	2.24	1.00	6.067
2.14	2.18	2.19	2.19	1.00	7.000
2.08	2.13	2.14	2.14	1.00	7.933
2.01	2.08	2.09	2.09	1.00	8.867
1.96	2.02	2.03	2.03	2.00	9.800
1.91	1.95	1.96	1.96	2.00	10.733
1.87	1.88	1.89	1.89	2.00	11.667
1.84	1.82	1.81	1.81	2.00	12.600
1.83	1.75	1.72	1.72	2.00	13.533

INDIV ERROR: 41.54 43.00 43.37 43.37
TOTAL ERROR: 171.27

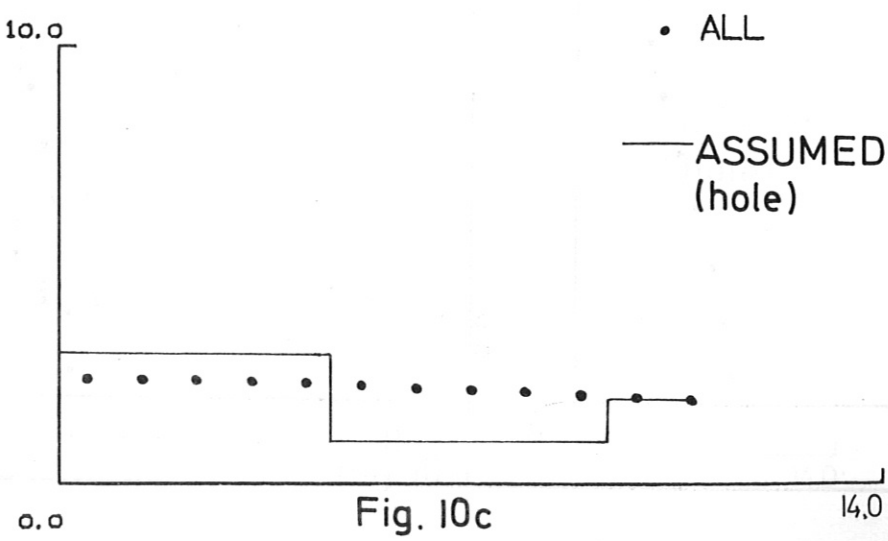


Fig. 10c

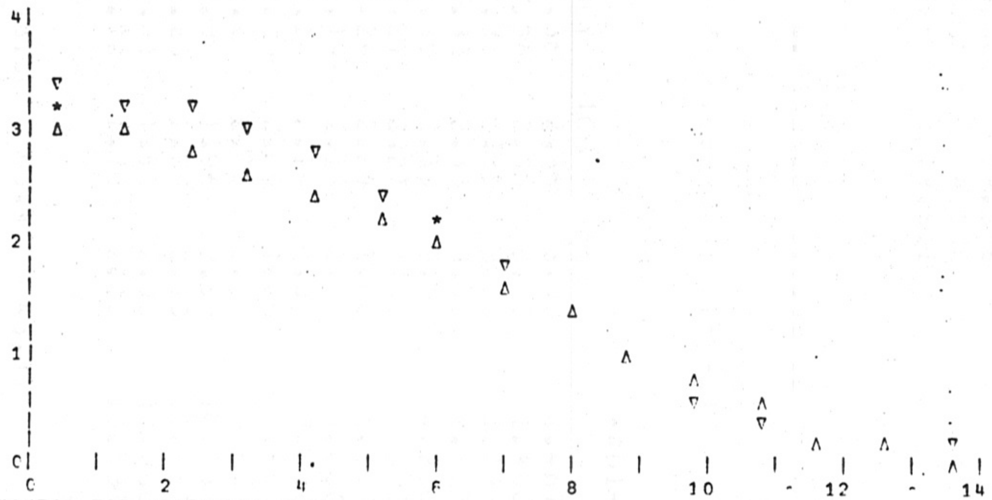
B. Example Runs

```
*KOPY2

PHI1+105 85 45 15 0

DENSASS
***************************************************************
     SHOT T/IS  10 I/YA LIN POL A NE BEAMS
 Γ    1 1 .3 0 14 ¯1 0 15 1 2 3 4 5
EFFECTIVE LIMITED RADIUS (CM):  14
EXCENTRICITY A/B DUE TO EXTERNAL FIELD: 1.68
TOTAL EXCENTRICITY:                      1.68
*
RANDOM ERROR:  10  ¯9  ¯7  7  4
PATH LENGTH (CM)             : 12.27208768   15.41167015   20.25372752   20.24244624   15.71531163
*
INTEGR.DENS. (CM¯2) : 4.845426931E13   1.565586095E14   3.553590036E14   1.769713833E14   4.070162296E13
MEAN DENS.   (CM¯3) : 3.932279807E12   1.005219125E13   1.722839465E13   8.663889374E12   2.583027522E12
*
       6   4.287559634E¯2
       6   4.286482166E¯2
       6   4.281168907E¯2
       6   4.281168907E¯2

PLOTSYMBOL 'COS COO POL TCH ASS'
             o   *   •   ∇   Δ
```



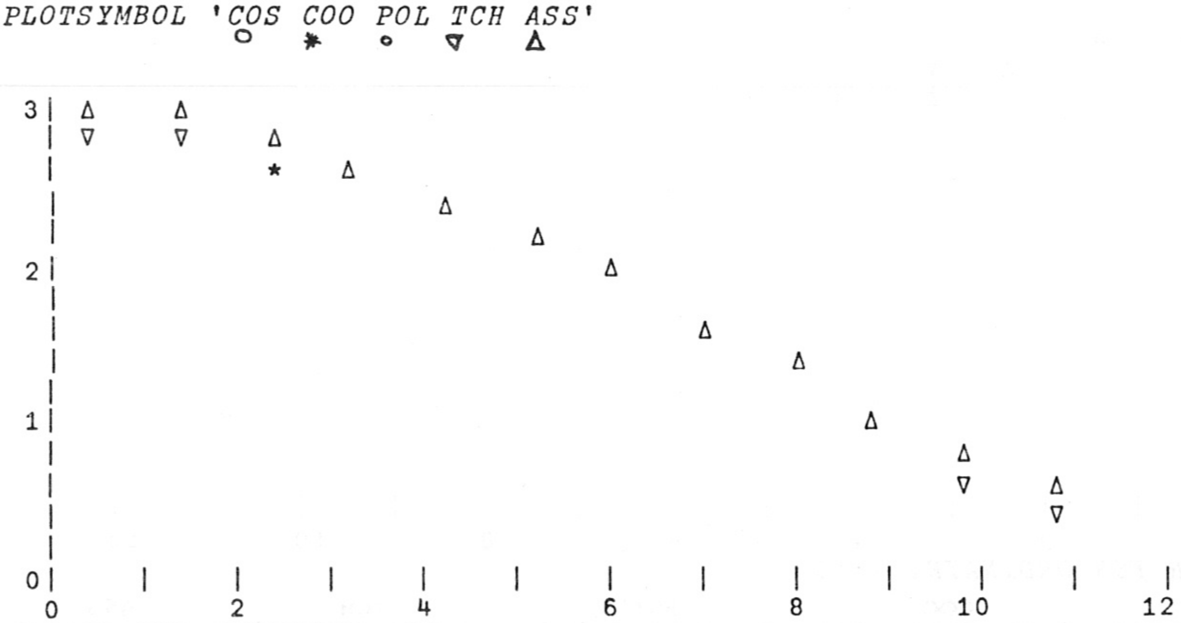
SCALE FACTOR FOR ORDINATE: 1E13

3.275390971E13	3.287025415E13	3.329574572E13	3.329574572E13	2.993337037E13
3.228204782E13	3.235548991E13	3.264592478E13	3.264592478E13	2.9403E13
3.128695958E13	3.129506837E13	3.136222191E13	3.136222191E13	2.835648148E13
2.969348808E13	2.964427721E13	2.947727099E13	2.947727099E13	2.682225926E13
2.744749092E13	2.737369194E13	2.704189532E13	2.704189532E13	2.4843E13
2.456118675E13	2.450161933E13	2.412730577E13	2.412730577E13	2.247559259E13
2.114200032E13	2.111975566E13	2.082793695E13	2.082793695E13	1.979114815E13
1.739323289E13	1.740291304E13	1.726482555E13	1.726482555E13	1.6875E13
1.358421667E13	1.359689991E13	1.358938067E13	1.358938067E13	1.382667037E13
9.998337148E12	9.983802378E12	9.987332083E12	9.987332083E12	1.076003704E13
6.876008098E12	6.830332715E12	6.682549399E12	6.682549399E12	7.803E12
4.372581722E12	4.330918761E12	3.940310334E12	3.940310334E12	5.097814815E12
2.546022574E12	2.560699639E12	2.069441347E12	2.069441347E12	2.800925926E12
1.377367824E12	1.452369871E12	1.422560682E12	1.422560682E12	1.083E12
8.135925241E11	8.047334668E11	2.393409996E12	2.393409959E12	1.289259259E11

∆SPREAD2

```
    PHI1
105  85  55  25  0
    DATA
1  1  .3  0  14  ¯1  0  15  1  2  3  4  5


    DENSASS
PHI2:    ¯130.476649
PHI2:    ¯125.953298
PHI2:    ¯139.523351
PHI2:    ¯144.046702
PHI2:    ¯135
PSIA:    3.25085434   8.672781975   18.31936849   16.92379375   2.560050104
PSIB1:   3.369509118   8.605049448   17.9094412   16.84499961   3.042810175
*        IT  VARI
         2   3.429975084E¯5
         2   7.04908516E¯4
         2   4.007178693E¯3
         2   4.007178693E¯3
    PLOTSYMBOL 'COS COO POL TCH ASS'
```



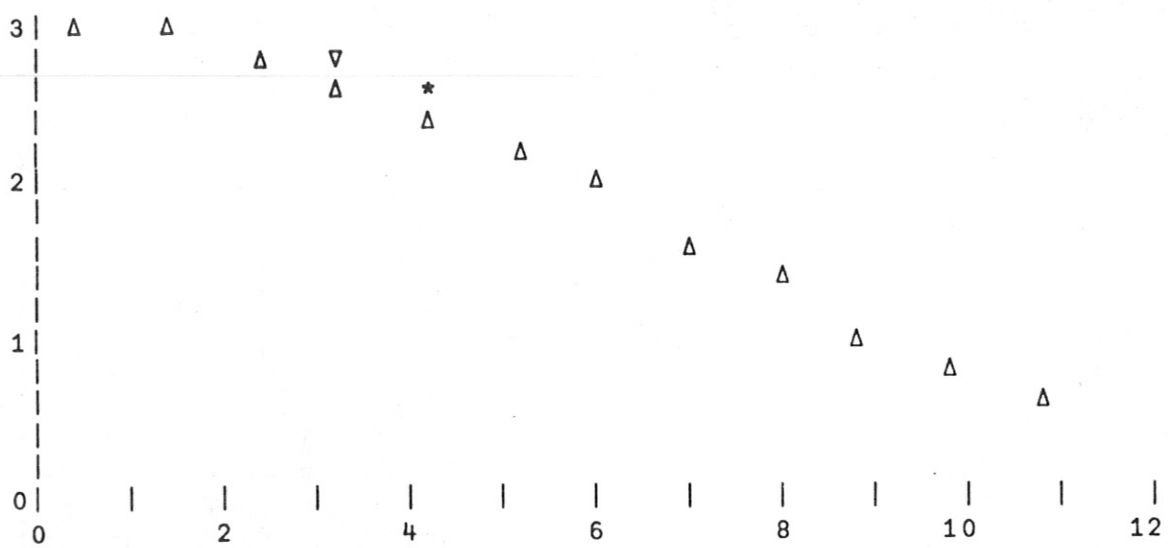
SCALE FACTOR FOR ORDINATE: 1E13

COS	COO	POLY	TCH	ASS
2.740853492E13	2.75770117E13	2.823616164E13	2.823616164E13	2.993337037E13
2.722228225E13	2.734189626E13	2.783207268E13	2.783207268E13	2.9403E13
2.675950191E13	2.680465959E13	2.701724835E13	2.701724835E13	2.835648148E13
2.58760389E13	2.585559137E13	2.578069168E13	2.578069168E13	2.682225926E13
2.443331E13	2.438380003E13	2.411170851E13	2.411170851E13	2.4843E13
2.235965243E13	2.232406504E13	2.200704534E13	2.200704534E13	2.247559259E13
1.969253674E13	1.969571078E13	1.948070614E13	1.948070614E13	1.979114815E13
1.658758966E13	1.662199827E13	1.657669722E13	1.657669722E13	1.6875E13
1.329137809E13	1.332279446E13	1.338496005E13	1.338496005E13	1.38267037E13
1.008687898E13	1.007937245E13	1.006066163E13	1.006066163E13	1.076003704E13
7.230168233E12	7.177477803E12	6.846735465E12	6.846735465E12	7.803E12
4.900406111E12	4.841849315E12	4.098980544E12	4.098980544E12	5.097814815E12
3.180196564E12	3.179749377E12	2.311967734E12	2.311967734E12	2.800925926E12
2.070983221E12	2.150249416E12	2.142259428E12	2.142259428E12	1.083E12
1.533542078E12	1.569300732E12	4.422754291E12	4.422754291E12	1.289259259E11

****

∆SPREAD3

```
    DENSASS
PHI2:   ¯130.476649
PHI1:    107   88   59.2   29.3   3.3
PHI2:   ¯125.953298
PHI1:    109   91   63.5   33.5   7
PHI2:   ¯139.523351
PHI1:    102.5   81.2   50   20.5   ¯3
PHI2:   ¯144.046702
PHI1:    100   77.5   46   17   ¯6
PHI2:   ¯135
PHI1:    105   85   55   25   0
PSIA:   3.25085434   8.672781975   18.31936849   16.92379375   2.560050104
PSIB1:   3.324300776   8.710565346   18.45989488   16.94327902   2.690254191
*
        IT  VARI
        2   3.487505155E¯4
        2   1.957812405E¯3
        2   1.58738428E¯3
        2   1.58738428E¯3
      PLOTSYMBOL 'COS COO POL TCH ASS'
                  ○   *   ∘   ∇   Δ
```



SCALE FACTOR FOR ORDINATE: 1E13

COS	COO	POLY	TCH	ASS
3.07440907E13	3.044795941E13	3.044009508E13	3.044009508E13	2.993337037E13
3.009076862E13	2.987920309E13	2.98644128E13	2.98644128E13	2.9403E13
2.883443988E13	2.875744261E13	2.873328009E13	2.873328009E13	2.835648148E13
2.706292798E13	2.711606381E13	2.708677385E13	2.708677385E13	2.682225926E13
2.488068554E13	2.500891143E13	2.498397247E13	2.498397247E13	2.4843E13
2.23877115E13	2.251243181E13	2.250152452E13	2.250152452E13	2.247559259E13
1.966641821E13	1.972526931E13	1.973145487E13	1.973145487E13	1.979114815E13
1.678166919E13	1.67637798E13	1.677801255E13	1.677801255E13	1.6875E13
1.379394882E13	1.375280669E13	1.375337287E13	1.375337287E13	1.38267037E13
1.078001816E13	1.081234218E13	1.077204305E13	1.077204305E13	1.076003704E13
7.851710498E12	8.042058552E12	7.943885366E12	7.943885366E12	7.803E12
5.163289407E12	5.506734166E12	5.365756759E12	5.365756759E12	5.097814815E12
2.901327177E12	3.225929153E12	3.111857751E12	3.111857751E12	2.800925926E12
1.257323139E12	1.170678754E12	1.222968158E12	1.222968158E12	1.083E12
3.901421371E11	0	0	0	1.289259259E11

****

C. Listings

```
*GRP:K1.PROFILE

// EXEC FORTRAN
//C.SYSIN DD *
C*******************************************
C
C     K1.PROFILE
C              -DENSITY PROFILE FROM MICROWAVE INTERFEROMETER DATA
C                                ,10/120
C*******************************************
C  NDATA   -NUMBER OF SETS OF DATA READ IN
C   SHOT -SHOT NUMBER
C   TMS  -TIME IN DISCHARGE
C   IOTO -STELLERATOR ROTAT. TRANSFORM
C   LIM  -ACTUAL LIMITER RADIUS (CM)
C   POL  -POLARITY OF +1 OR -1
C   VER  -DISPLACEMENT OF PLASMA
C   NE   -NUMBER OF ELLIPSES PLASMA DIVIDED INTO
C   NB   -NUMBER OF BEAMS THRU PLASMA
C   NF   -NUMBER OF FUNCTIONS USED (=NB-1)
C   PHIO -ANGLE OF LENS CENTER;I.E. START OF BEAMS
C   PHI1 -ANGLE OF END OF EACH BEAM
C   NC   -NUMBER PER CM**3
C   LAM  -FREE SPACE WAVELENGTH FOR WEGA
C   EPS  -FOR PSIB1,PSIB2 COMPARISION IN VAR SUBROUTINE
C   IMAX -NUMBER OF ITERATIONS;I.E. NUM OF TIMES NR1 REPLACES NRF COLUMN
C   ISEC -=1 USE ASSUMED PROFILE SECTION
C          =2 USE EXP. PSIB1 VALUES(IN RAD)
C   IGRAF -=0 NO GRAPH
C           =1 MAKES THREE GRAPHS
C           =2 TIME GRAPH
C
C *NOTE* PROGRAM DIMENSIONED FOR MAXIMUM OF 5BEAMS,MINIMUM OF 2 BEAMS
C ****************************************
      REAL*4 IOTO,IKA,LIM,NC,LAM,NRF,NRFF,NR1,NR1A,LO
      INTEGER*4 SHOT
      DIMENSION LO(2),YT(2),XT(2),X(15),APP1(15),KC(3),APPS(4)
      DIMENSION PHIO(5),PHI1(5),IBEAM(5),PATH(5),AUX(8),Y(15)
      DIMENSION PSIB1(5),SDEL(75),SDELT(75),SNRF(60),PSIT(5,4)
      DIMENSION SPSIB1(5),DEL(15,5),NRF(15,4),NRFF(15,4),IPIV(4)
      DIMENSION DENM(5),DENI(5),RADIR(15),NR1(15),ALIF(4)
      DIMENSION SPSIT(20),PSIB2(5),VARI(4),IT(4),DENS(6,15)
      DIMENSION RD(5),XA(15),DENSA(15),NR1A(15),PSIA(5)
C
      DENSIN(WX)=NC*(1.-(1.-WX*LAM/(2.*PI))**2)
C
C     DATA
      READ(5,31) ISEC
   81 FORMAT(I1)
      READ(5,30) NDATA
   30 FORMAT(I3)
      DO 310 ND=1,NDATA
      READ(5,31) SHOT,TMS,IOTO,IKA,LIM,POL,VER,NE
   31 FORMAT(I4,6(1X,F5.2),1X,I3)
      READ(5,32) NB,IGRAF
   32 FORMAT(I1,1X,I1)
      READ(5,33) (PHIO(I),I=1,NB)
      READ(5,33) (PHI1(I),I=1,NB)
   33 FORMAT(5(F8.3,1X))
```

```
*GRP:K1.PROFILE

      WRITE(6,6) ND,SHOT,TMS,IOTO,IKA,LIM,POL,VER,NE
    6 FORMAT('1','DATA RUN=',I3,2X,'SHOT=',I3,2X,'TMS=',F4.1,2X,'IOT',
     1 'O=',F4.1,2X,'IKA=',F4.1,/,' ',14X,'LIM=',F4.1,2X,'POL=',F4.1,2X
     2 ,'VER=',F4.1,3X,'NE=',I2)
      WRITE(6,7) NB,(PHIO(I),I=1,NB)
    7 FORMAT(' BEAMS:',I2,/,' PHIE:',5(F7.2,1X))
      WRITE(6,727) (PHI1(I),I=1,NB)
  727 FORMAT(' PHIB:',5(F7.2,1X))
C
C     STELLARATOR CONTANTS
      RAD=19.
      NC=24.28
      LAM=3./14.
C
      PI=3.14159265
      EPS=.01
      IMAX=5
      NF=-1+NB
C
C     EFFECTIVE LIMITER RADIUS
      LIM=SQRT(LIM*LIM-VER*VER/2.)-ABS(VER/1.4142)
      WRITE(6,8) LIM
    8 FORMAT(/,/,' EFF LIM RAD(CM):',F7.2)
C
C     EXCENTRICITY A/B DUE TO EXT FIELD - AS1
      AS1=1.14+1.8*IOTO
C
C     TOTAL EXCENTRICITY - AS
      R=(AS1*AS1-1.)*(1.-IKA/20.)/(AS1*AS1+1.)
      AS=SQRT((1.+R)/(1.-R))
      WRITE(6,9) AS1,AS
    9 FORMAT(' EXCENTRICITY DUE TO EXT FIELD:',F7.2,/,' ',11X,'TOTAL E
     1XCENTRICITY:',F7.2)
C
C
CCC   FINDING SEGMENT LENGTH IN EACH ELLIPSE - DEL(KNE,KNB)      (1*)-
      CALL LONG(PHI1,PHIO,AS,VER,NB,NE,RAD,LIM,POL,DEL,IBEAM)
      DO 1 KNB=1,NB
      PATH(KNB)=0.
      DO 2 KNE=1,NE
    2 PATH(KNB)=PATH(KNB)+DEL(KNE,KNB)
    1 CONTINUE
C     DO 201 KNF=1,NE
C 201 WRITE(6,10)(DEL(KNE,KNB),KNB=1,NB)
   10 FORMAT(' DEL:',5(2X,E9.3))
      WRITE(6,11) (PATH(KNB),KNB=1,NB)
   11 FORMAT(' ',/,' PATH LENGTHS(CM):',5(2X,F5.1))
      CALL ARRAY(2,NE,NB,15,5,SDEL,DEL)
      CALL GMTRA(SDEL,SDELT,NE,NB)
C
C
CCC   PSIB1 ASSUMED(ISEC=1) OR MEASURED(ISEC=2)
      IF(ISEC.EQ.2) GO TO 82
C     ************************************
C     ASSUMED PROFIL INPUT                                       (3*)
      READ(5,3)(RD(I),I=1,NB)
    3 FORMAT(5(F8.3,1X))
```

```
C
      DO 206 KNE=1,NE
C     BESSEL
      XA(KNE)=SQRT(8.)*(KNE-.5)/NE
      XA2=XA(KNE)*XA(KNE)
      DENSA(KNE)=3.    *(1.-XA2/4.+XA2*XA2/64.)
C     SIN X + COS X/2
C     XA(KNE)=PI*(KNE-.5)/NE
C     DENSA(KNE)=1.5*(SIN(XA(KNE))+COS(XA(KNE)/2.))
C     GAUSSIAN
C     XA(KNE)=(KNE-.5)/NE
C     DENSA(KNE)=3.*EXP(-XA(KNE)*XA(KNE))
C     HOLE
C     XA(KNE)=LIM*(KNE-.5)/NE
C     IF(XA(KNE).LE.(LIM*2./3.)) DENSA(KNE)=1.
C     IF(XA(KNE).LE.(LIM/3.)) DENSA(KNE)=3.
C     IF(XA(KNE).GT.(LIM*2./3.)) DENSA(KNE)=2.
C     SQUARE
C     XA(KNE)=LIM*(KNE-.5)/NE
C     IF(XA(KNE).LE.     LIM      ) DENSA(KNE)=3.
C     IF(XA(KNE).GT.     LIM      ) DENSA(KNE)=0.
      DENS(5,KNE)=DENSA(KNE)
      SQ=1.-SQRT(1.-DENSA(KNE)/NC)
C       WRITE(6,220) SQ
  220   FORMAT(' ',E9.2)
  206 NR1A(KNE)=2.*PI*SQ/LAM
C       WRITE(6,209) (NR1A(KNE),KNE=1,NE)
  209   FORMAT('   NR1A:',15(E7.2,1X))
C
      CALL MPRD(SDELT,NR1A,PSIA,NB,NE,0,0,1)
        WRITE(6,203)(PSIA(KNB),KNB=1,NB)
  203   FORMAT(' ',/,/,'   PSIA:',5(2X,F8.3))
        WRITE(6,204)(RD(KNB),KNB=1,NB)
  204   FORMAT('     RD:',5(2X,F8.3))
C
C     APPLYING RANDOM ERROR
      DO 215 KNB=1,NB
  215 PSIB1(KNB)=PSIA(KNB)-(PSIA(KNB)*RD(KNB)*.01)
      GO TO 83
C
(2*) C     MEASURED PSIB1 VALUES
   82 READ(5,542) (PSIB1(KNB),KNB=1,NB)
  542 FORMAT(5(F8.3,1X))
C
   83 CONTINUE
        WRITE(6,205)(PSIB1(KNB),KNB=1,NB)
  205   FORMAT('  PSIB1: ',5(F8.3,2X))
C     ***********************************
C
      DO 200 KNB=1,NB
C     MEAN DENSITY
      XZ=PSIB1(KNB)/PATH(KNB)
      DENM(KNB)=DENSIN(XZ)
C
C     INTEGER DENSITY
      DENI(KNB)=NC*LAM/PI*PSIB1(KNB)
  200 CONTINUE
```



```
        WRITE(6,5)(DENM(KNB),KNB=1,NB)
    5   FORMAT(' ',/,/,' MEAN DENS:',5(2X,E9.3))
        WRITE(6,202) (DENI(KNB),KNB=1,NB)
  202   FORMAT(' ',' INT DENS:',5(2X,E9.3))
C
C
(4*) CCC   FINDING NRF FOR EACH IFUN
      DO 130 IFUN=1,4
C
      DO 131 KNE=1,NE
      RAD1R(KNE)=LIM*(KNE-.5)/NE
      IF(ISEC.EQ.1) DENS(6,KNE)=RAD1R(KNE)
      IF(ISEC.EQ.2) DENS(5,KNE)=RAD1R(KNE)
      IF(IFUN.EQ.4) GO TO 136
C
      DO 132 KNF=1,NF
      GO TO (133,134,135),IFUN
C     COS FUNCTION
  133 NRF(KNE,KNF)=COS(PI*RAD1R(KNE)*(-2.+2.*KNF)/(2.*LIM))
      GO TO 132
C
C     COO FUNCTION
  134 KKNF=2.*KNF-3
      IF(KNF.EQ.1)KKNF=0.
      NRF(KNE,KNF)=COS(PI*RAD1R(KNE)*KKNF/(2.*LIM))
      GO TO 132
C
C     POLY FUNCTION
  135 NRF(KNE,KNF)=(RAD1R(KNE)/LIM)**(2.*(KNF-1))
      NRFF(KNE,KNF)=NRF(KNE,KNF)
  132 CONTINUE
C
C     TCH FUNCTION
      IF(IFUN.NE.4) GO TO 138
  136 CALL TCHEB(KNE,NF,NRFF,NRF)
C
  138 CONTINUE
  131 CONTINUE
C
C
CCC   FINDING PSIB2
      I=0
   37 I=I+1
      CALL ARRAY(2,NE,NF,15,4,SNRF,NRF)
      CALL MPRD(SDELT,SNRF,SPSIT,NB,NE,0,0,NF)
        IN=NB*NF
      CALL ARRAY(1,NB,NF,5,4,SPSIT,PSIT)
      DO 609 KL=1,NB
  609 SPSIB1(KL)=PSIB1(KL)
(5*)  CALL LLSQ(SPSIT,SPSIB1,NB,NF,1,ALIF,IPIV,1.E-44,IER,AUX)
      IF(IER.NE.0) GO TO 52
(6*)  CALL MPRD(SNRF,ALIF,NR1,NE,NF,0,0,1)
(7*)  CALL MPRD(SDELT,NR1,PSIB2,NB,NE,0,0,1)
C
C
CCC   MADE ANOTHER ITERATION TO BETTER APPROX PSIB1?
(8*)  CALL VAR(PSIB1,PSIB2,NB,VARR)
```

```
C
      DO 38 KNE=1,NE
   38 IF(NR1(KNE).LT.0.) NR1(KNE)=0.
(9*,10*)  IF(I.EQ.IMAX.OR.VARR.LT.EPS) GO TO 42
      ISAVE=1
      NFM=NF-1
      DO 39 KNF=1,NFM
      NFF=KNF+1
   39 IF(ABS(ALIF(NFF)).GT.ABS(ALIF(ISAVE))) ISAVE=NFF
C
      DO 40 KNE=1,NE
(11*)   40 NRF(KNE,ISAVE)=NR1(KNE)
      GO TO 37
C
C
CCC   ITERATING TO APPROX PSIB1 ENDED - FIND DENS
   42 IT(IFUN)=I
      VARI(IFUN)=VARR
      DO 41 KNE=1,NE
(12*)   41 DENS(IFUN,KNE)=DENSIN(NR1(KNE))
  130 CONTINUE
        WRITE(6,18) (IT(II),II=1,4)
   18   FORMAT(' ',/,' ITER: ',4(I3,7X))
        WRITE(6,193) (VARI(I),I=1,4)
  193   FORMAT(' VARI:',4(E9.2,1X))
      IF(ISEC.EQ.2) GO TO 828
        WRITE(6,829)
  829   FORMAT(/,/,' DENSITY(XE13)',31X,'RADIR',/,' ',6X,'COS',4X,'COO',
     14X,'POLY',3X,'TCH',4X,'ASS')
        DO 19 KNE=1,NE
   19   WRITE(6,119) (DENS(II,KNE),II=1,6)
  119   FORMAT(' ',6X,5(F5.2,2X),2X,F6.3)
      GO TO 826
  828 CONTINUE
        WRITE(6,825)
  825   FORMAT(/,/,' DENSITY(XE13)',24X,'RADIR',/,' ',6X,'COS',4X,'COO',
     14X,'POLY',3X,'TCH')
        DO 824 KNE=1,NE
  824   WRITE(6,823) (DENS(II,KNE),II=1,5)
  823   FORMAT(' ',6X,4(F5.3,2X),2X,F6.3)
      GO TO 921
C
C
CCC   ERROR EVALUATION
C     FINDING MEAN ASSUMED DENSITY
  326 ASSM=0.
      NEM=NE-3
      DO 90 KNE=1,NEM
   90 ASSM=ASSM+DENSA(KNE)
      ASSM=ASSM/NEM
C
C     APP1 INDIVIDUAL ERROR
C     APP2 AVERAGE ERROR
C     APP3 AVERAGE ERROR OF 3 MAX
C     APPS ERROR FOR ONE FUNCTION
C     APPSS TOTAL ERROR OF ALL FUNCTIONS
      DO 91 IFUN=1,4
```



```
      APP2=0.
      DO 92 KNE=1,NEM
      APP1(KNE)=100.*ABS(DENS(IFUN,KNE)-DENSA(KNE))/ASSM
   92 APP2=APP2+APP1(KNE)
      NEP=NEM+3
      APP2=APP2/NEP
C
C     FINDING 3 MAX ERROR VALUES SO CAN DOUBLE WEIGHT THEM
      KC(1)=0
      KC(2)=0
      DO 93 LC=1,3
      ST=0.
      DO 93 KNE=1,NEM
      IF(KNE.EQ.KC(1).OR.KNE.EQ.KC(2)) GO TO 93
      IF(APP1(KNE).LT.ST) GO TO 93
      ST=APP1(KNE)
      KC(LC)=KNE
   93 CONTINUE
      I1=KC(1)
      I2=KC(2)
      I3=KC(3)
      APP3=(APP1(I1)+APP1(I2)+APP1(I3))/NEP
      APPS(IFUN)=APP2+APP3
   91 CONTINUE
        WRITE(6,916) (APPS(IFUN),IFUN=1,4)
  916   FORMAT(/,/,' INDIV ERROR: ',4(F6.2,2X))
      APPSS=0.
      DO 94 IFUN=1,4
   94 APPSS=APPSS+APPS(IFUN)
        WRITE(6,936) APPSS
  936   FORMAT(' TOTAL ERROR: ',F6.2)
C
C
  921 IF(IGRAF.EQ.0) GO TC 310
      IF(IGRAF.EQ.2) GO TO 818
C*****
C     PLOTTING
      NEM=NE-3
      XMIN=0.
      XMAX=14.
      YMIN=0.
      YMAX=10.
C     ***GRAPHING EACH FUNCT AND ASS IN SEPERATE BOX
      DO 20 KNE=1,NEM
      X(KNE)=RADIR(KNE)
   20 Y(KNE)=DENS(1,KNE)
      CALL HORBOX(2,2)
      CALL GRAFE(X,Y,NEM,'P',XMIN,YMIN,XMAX,YMAX,'DENSITY PROFIL - Y SCA
     1LE XE13$','COS$')
      DO 22 IFUN=2,4
      DO 23 KNE=1,NEM
   23 Y(KNE)=DENS(IFUN,KNE)
      GO TO (771,771,772,773),IFUN
  771 CALL GRAFE(  X,Y,NEM,'P',XMIN,YMIN,XMAX,YMAX,'$','COO$')
      GO TO 22
  772 CALL GRAFE(  X,Y,NEM,'P',XMIN,YMIN,XMAX,YMAX,'$','POLY$')
      GO TO 22
```

```
  773 CALL GRAFE(   X,Y,NEM,'P',XMIN,YMIN,XMAX,YMAX,'$','TCH$')
   22 CONTINUE
      IF(ISEC.EQ.2) GO TO 347
      CALL GRAFE(FADIP,DENSA,KNE,'P',XMIN,YMIN,XMAX,YMAX,'$','ASS$')
C
C     ***GRAPHING ALL FUNCTION APPROXS IN ONE BOX
  347 DO 28 KNE=1,NEM
   28 Y(KNE)=DENS(1,KNE)
      CALL HORBOX(2,2)
      CALL GRAFER(   X,Y,NEM,'P',XMIN,YMIN,XMAX,YMAX,'DENSITY PROFIL$',
     1'ALL$')
      DO 29 IFUN=2,3
      DO 27 KNE=1,NEM
   27 Y(KNE)=DENS(IFUN,KNE)
      IF(IFUN.EQ.3) GO TO 782
  781 CALL GRAFES(   X,Y,NEM,'P',XMIN,YMIN,XMAX,YMAX)
      GO TO 29
  782 CALL GRAFES(   X,Y,NEM,'P',XMIN,YMIN,XMAX,YMAX)
   29 CONTINUE
      DO 26 KNE=1,NEM
   26 Y(KNE)=DENS(4,KNE)
      CALL GRAFET(   X,       Y,NEM,'P',XMIN,YMIN,XMAX,YMAX)
C
C*****
      GO TO 310
C*****
C     ***MAKING 3-DIM PLOT WITH TIME AS THIRD AXIS
  818 IF(ND.NE.1) GO TO 819
      TO=0.
C     BOUNDARIES OF FRAME
      XMINO=0.
      XMAXO=20.
      YMINO=0.
      YMAXO=20.
      LO(1)=0.
      LO(2)=0.
      CALL FRAME(XMINO,YMINO,XMAXO,YMAXO)
C
C     PUTTING IN TIME AXIS
      YT(1)=YMINO
      YT(2)=YMAXO/2.
      XT(1)=XMINO
      XT(2)=XMAXO
      CALL PLOTL(XT,YT,2)
C
C     PUTTING IN ZERO AXIS
      XT(1)=0.
      XT(2)=5.
      YT(1)=0.
      YT(2)=5.
      CALL PLOTL(XT,LO,2)
      CALL PLOTL(LO,YT,2)
C
C     SHIFTING ALONG TIME SCALE
  819 T=TMS-TO
      DX=(XMAXO-XMINO)/10.
      DY=(YMAXO-YMINO)/20.
```

*GRP:K1.PROFILE

```
      XMIN=XMINO-T*DX
      XMAX=XMAXO-T*DX
      YMIN=YMINO-T*DY
      YMAX=YMAXO-T*DY
      CALL SCALE(XMIN,YMIN,XMAX,YMAX)
C     SIZE OF AXIS DRAWN
      CALL PLOTL(XT,LO,2)
      CALL PLOTL(LO,YT,2)
      CALL PLOTQ(RADIR,DENSA,KNE)
C*****
      GO TO 310
C
   52 WRITE(6,53) IER,ND
   53 FORMAT(' ','IER OF LLSQ=',I3,5X,'ND=',I3)
C
C
  310 CONTINUE
      STOP
      END
      SUBROUTINE VAR(PSIB1,PSIB2,NB,VARI)
      DIMENSION PSIB1(5),PSIB2(5)
C
      AD=0.
      SU=0.
      DO 1 KNB=1,NB
      AD=AD+(PSIB1(KNB)+PSIB2(KNB))**2
    1 SU=SU+(PSIB1(KNB)-PSIB2(KNB))**2
C
      VARI=SQRT(SU/AD)
      RETURN
      END
      SUBROUTINE TCHEB(KNE,NF,NRF,NRFF)
      REAL*4 NRF,NRFF
      DIMENSION NRF(15,4),NRFF(15,4)
C
      NRFF(KNE,1)=1
      IF(NF.EQ.1) RETURN
      NRFF(KNE,2)=-NRF(KNE,1)+2.*NRF(KNE,2)
      IF(NF.EQ.2) RETURN
      NRFF(KNE,3)=NRF(KNE,1)-8.*NRF(KNE,2)+8.*NRF(KNE,3)
      IF(NF.EQ.3) RETURN
      NRFF(KNE,4)=-NRF(KNE,1)+18.*NRF(KNE,2)-48.*NRF(KNE,3)+32.*NRF(KNE,
     14)
      IF(NF.EQ.4) RETURN
      NRFF(KNE,5)=NRF(KNE,1)-32.*NRF(KNE,2)+160.*NRF(KNE,3)-256.*NRF(KNE
     1,4)+128.*NRF(KNE,5)
      RETURN
      END
      SUBROUTINE PONG(PHI1,PHIO,AS,VER,NB,NE,RAD,LIM,POL,DEL,IBEAM)
      REAL*4 LIM,K
      DIMENSION PHIO(5),PHI1(5),DEL(15,5),IBEAM(5)
      VVER=VER/1.414213
      DTR=4.*ATAN(1.)/180.
C
      DO 1 KNB=1,NB
C     DEFINING A NEW CENTER
      XO=RAD*COS(PHIO(KNB)*DTR)+VVER
```

*GRP:K1.PROFILE

```
      Y0=RAD*SIN(PHI0(KNB)*DTR)+VVER
      X1=RAD*COS(PHI1(KNB)*DTR)+VVER
      Y1=RAD*SIN(PHI1(KNB)*DTR)+VVER
C
      K=(Y0-Y1)/(X0-X1)
      SAVE=0.0
      DO 1 KNE=1,NE
      A=KNE*LIM/NE
      B=A/AS
      IF(POL.EQ.-1) GO TO 3
      A0=A
      A=B
      B=A0
C
    3 AA=(K*K/(B*B))+(1./(A*A))
      BB=K*(Y0-K*X0)/(B*B)
      CC=-1+((Y0*Y0)+(K*K*X0*X0)-(2.*K*X0*Y0))/(B*B)
C
      DEL(KNE,KNB)=BB*BB-AA*CC
      IF(DEL(KNE,KNB).LT.0.) DEL(KNE,KNB)=0.
      DEL(KNE,KNB)=(2./AA*SQRT(DEL(KNE,KNB)))*SQRT(K*K+1.)
      IF(KNE.EQ.1) GO TO 1
      KNEM=KNE-1
      SAVE=SAVE+DEL(KNEM,KNB)
      DEL(KNE,KNB)=DEL(KNE,KNB)-SAVE
    1 CONTINUE
C
      RETURN
      END
$$ WOS:WOS.GSYSLIB
//G.PLOTP DD DUMMY
//G.SYSIN DD *
1
002
0001 01.00 00.20 00.00 14.00 -1.00 00.00 015
5 0
-135.000 -135.000 -135.000 -135.000 -135.000
 105.000   85.000   45.000   15.000   00.000
  00.0     00.0     00.0     00.0     00.0
0001 01.00 00.30 00.00 14.00 -1.00 00.00 015
4 1
-135.000 -135.000 -135.000 -135.000 -135.000
 105.000   85.000   45.000   00.000   00.000
  15.0      8.0     20.0    -14.0      0.0
/*
```

*GRP:K1.ITERATE

```
// EXEC FORTRAN
//C.SYSIN DD *
C******************************************
C
C    K1.ITERATE
C                -DENSITY PROFILE FROM MICROWAVE INTERFEROMETER DATA
C                -VARYING PHI1 IN FIXED ZONES FINDS OPTIMUM CONFIGURATION
C                  (TRYS ANYWAY)
C                                          ,10/120
C******************************************
C  SHOT -SHOT NUMBER
C  TMS  -TIME IN DISCHARGE
C  IOTO -STELLERATOR ROTAT. TRANSFORM
C  LIM  -ACTUAL LIMITER RADIUS (CM)
C  POL  -POLARITY OF +1 OR -1
C  VER  -DISPLACEMENT OF PLASMA
C  NE   -NUMBER OF ELLIPSES PLASMA DIVIDED INTO
C  NB   -NUMBER OF BEAMS THRU PLASMA
C  NF   -NUMBER OF FUNCTICNS USED (=NB-1)
C  PHIO -ANGLE OF LENS CENTER;I.E. START OF BEAMS
C  PHI1 -ANGLE OF END OF EACH BEAM
C  NC   -NUMBER PER CM**3
C  LAM  -FREE SPACE WAVELENGTH FOR WEGA
C  EPS  -FOR PSIB1,PSIB2 COMPARISION IN VAR SUBROUTINE
C  IMAX -NUMBER OF ITERATIONS;I.E. NUM OF TIMES NR1 REPLACES NRF COLUMN
C
C *NOTE*PROGRAM DIMENSIONED FOR MAXIMUM OF 5BEAMS,MINIMUM OF 2 BEAMS
C
C     DELS-SIZE OF BEAM CHANGE INTERVAL
C     ITMAX-NUMBER OF SWEAPS THROUGH BEAMS WHERE EACH BEAM VARIED
C     IB-NUMBER OF BEAMS LOOKED AT IN ONE SWEAP
C     IBB-BEAM LOOKING AT
C     LI=1 FORWARD SWEAP THU BEAMS
C     LI=2 BACKWARD SWEAP THU BEAMS
C     DIV-(NB+1) DIVISIONS THRU WHICH BEAMS VARY
C     NT-NUMBER OF DELS CHANGES IN ONE DIV
C ****************************************
      REAL*4 IOTO,IKA,LIM,NC,LAM,NRF,NRFF,NR1,NR1A,LO
      INTEGER*4 SHOT
      DIMENSION DIV(6),APP1(15),KC(3),APPS(4,10),APPSS(10)
      DIMENSION LO(2),YT(2),XT(2),X(15)
      DIMENSION PHIO(5),PHI1(5),IBEAM(5),PATH(5),AUX(8),Y(15)
      DIMENSION PSIB1(5),SDEL(75),SDELT(75),SNRF(60),PSIT(5,4)
      DIMENSION SPSIB1(5),DEL(15,5),NRF(15,4),NRFF(15,4),IPIV(4)
      DIMENSION DENM(5),DENI(5),RADIR(15),NR1(15),ALIF(4)
      DIMENSION SPSIT(20),PSIB2(5),VARI(4),IT(4),DENS(4,15)
      DIMENSION RD(5),XA(15),DENSA(15),NR1A(15),PSIA(5)
C
      DENSIN(WX)=NC*(1.-(1.-WX*LAM/(2.*PI))**2)
C
C     DATA
      READ(5,31) SHOT,TMS,IOTO,IKA,LIM,POL,VER,NE
   31 FORMAT(I3,6(1X,F4.1),1X,I3)
      READ(5,32) NB
   32 FORMAT(I1)
      READ(5,3)(RD(I),I=1,NB)
    3 FORMAT(5(F7.2,1X))
```

*GRP:K1.ITERATE

```
      READ(5,33) (PHIO(I),I=1,NB)
      READ(5,33) (PHI1(I),I=1,NB)
   33 FORMAT(5(F7.2,1X))
      READ(5,988) ITMAX,DELS
  988 FORMAT(I2,1X,F7.2)
      NBC=NB+1
      READ(5,989) (DIV(I),I=1,NBC)
  989 FORMAT(6(F7.2,1X))
        WRITE(6,6) SHOT,TMS,IOTO,IKA,LIM,POL,VER,NE
    6   FORMAT('1','SHOT=  ',I3,2X,'TMS=',F4.1,2X,'IOT',
     1  'O=',F4.1,2X,'IKA=',F4.1,2X,'LIM=',F4.1,2(2X,F4.1),1X,I3)
        WRITE(6,7) NB,(PHIO(I),I=1,NB)
    7   FORMAT(' BEAMS:',I2,/,' PHIE:',5(F7.2,1X))
        WRITE(6,727) (PHI1(I),I=1,NB)
  727   FORMAT(' PHIB:',5(F7.2,1X))
        WRITE(6,940) ITMAX,DELS
  940   FORMAT(' ITMAX=',I2,2X,'DELS=',F7.2)
        WRITE(6,941)(DIV(IH),IH=1,NBC)
  941   FORMAT(' DIV=',6(F7.2,1X))
C
      RAD=19.
      NC=24.28
      LAM=3./14.
      PI=3.14159265
      EPS=.01
      IMAX=5
      NF=-1+NB
C
C     EFFECTIVE LIMITER RADIUS
      LIM=SQRT(LIM*LIM-VER*VER/2.)-ABS(VER/1.4142)
        WRITE(6,8) LIM
    8   FORMAT(/,/,' EFF LIM RAD:',F7.2)
C
C     EXCENTRICITY A/B DUE TO EXT FIELD - AS1
      AS1=1.14+1.8*IOTO
C
C     TOTAL EXCENTRICITY - AS
      R=(AS1*AS1-1.)*(1.-IKA/20.)/(AS1*AS1+1.)
      AS=SQRT((1.+R)/(1.-R))
        WRITE(6,9) AS1,AS
    9   FORMAT(' EXCENTRICITY DUE TO EXT FIELD:',F7.2,/,' TOTAL EXCENTRI
     1CITY:',F7.2)
C
C
CCC   VARYING BEAM
      LI=1
      DO 999 ITI=1,ITMAX
      NBB=NB-1
      IF(ITI.EQ.1) NBB=NB
C
      DO 998 IB=1,NBB
      NT=0
      IF(LI.EQ.1) IBB=IB+1
      IF(LI.EQ.0) IBB=NB-IB
      IF(ITI.EQ.1) IBB=IB
  995 NT=NT+1
C       WRITE(6,931) NT
```

```
*GRP:K1.ITERATE

  931   FORMAT(' ',/,' NT=',I2)
        PHI1(IBB)=DIV(IBB)-(NT-1)*DELS
C       WRITE(6,930) IBB,(PHI1(IW),IW=1,NB)
  930   FORMAT(' IBB=',I2,'PHI1=',5(F7.2))
C
C
CCC     FINDING SEGMENT LENGTH IN EACH ELLIPSE - DEL(KNE,KNB)
        CALL LONG(PHI1,PHIO,AS,VER,NB,NE,RAD,LIM,POL,DEL,IBEAM)
        DO 1 KNB=1,NB
        PATH(KNB)=0.
        DO 2 KNE=1,NE
      2 PATH(KNB)=PATH(KNB)+DEL(KNE,KNB)
      1 CONTINUE
C       WRITE(6,11) (PATH(KNB),KNB=1,NB)
   11   FORMAT(' PATH:',5(2X,E9.3))
        CALL ARRAY(2,NE,NB,15,5,SDEL,DEL)
        IN=NE*NB
        CALL GMTRA(SDEL,SDELT,NE,NB)
C
C
CCC     SECTION CAN BE REPLACED BY EXPERIMENT MEASURED PHASE CHANGE PSIB1
C       ***********************************
C       ASSUMED PROFIL INPUT
C
        DO 206 KNE=1,NE
C       BESSEL
        XA(KNE)=SQRT(8.)*(KNE-.5)/NE
        XA2=XA(KNE)*XA(KNE)
        DENSA(KNE)=3.    *(1.-XA2/4.+XA2*XA2/64.)
C       SIN X + COS X/2
C       XA(KNE)=PI*(KNE-.5)/NE
C       DENSA(KNE)=1.5*(SIN(XA(KNE))+COS(XA(KNE)/2.))
C       GAUSSIAN
C       XA(KNE)=(KNE-.5)/NE
C       DENSA(KNE)=3.*EXP(-XA(KNE)*XA(KNE))
        SQ=1.-SQRT(1.-DENSA(KNE)/NC)
  206   NR1A(KNE)=2.*PI*SQ/LAM
C       WRITE(6,207) (XA(KNE),KNE=1,NE)
  207   FORMAT(' ',/,/,' ASSUMED DENSITY',/,'        XA:',15(E7.2,1X))
C       WRITE(6,208) (DENSA(KNE),KNE=1,NE)
  208   FORMAT('  DENSA:',15(E7.2,1X))
C
        CALL MPRD(SDELT,NR1A,PSIA,NB,NE,0,0,1)
        WRITE(6,203)(PSIA(KNB),KNB=1,NB)
  203   FORMAT(' ',/,/,'  PSIA:',5(2X,F8.3))
C       WRITE(6,204)(RD(KNB),KNB=1,NB)
  204   FORMAT('     RD:',5(2X,F8.3))
C
C       APPLYING RANDOM ERROR
        DO 215 KNB=1,NB
  215   PSIB1(KNB)=PSIA(KNB)-(PSIA(KNB)*RD(KNB)*.01)
C       WRITE(6,205)(PSIB1(KNB),KNB=1,NB)
  205   FORMAT('  PSIB1:',5(2X,F8.3))
C       ***********************************
C
        DO 200 KNB=1,NB
C       MEAN DENSITY
```

```
*GRP:K1.ITERATE

        XZ=PSIB1(KNB)/PATH(KNB)
        DENM(KNB)=DENSIN(XZ)
C
C       INTEGER DENSITY
        DENI(KNB)=NC*LAM/PI*PSIB1(KNB)
  200   CONTINUE
C       WRITE(6,5)(DENM(KNB),KNB=1,NB)
    5   FORMAT(' ',/,/,' MEAN DENS:',5(2X,E9.3))
C       WRITE(6,202) (DENI(KNB),KNB=1,NB)
  202   FORMAT(' ',' INT DENS:',5(2X,E9.3))
C
C
CCC     FINDING NRF FOR EACH IFUN
        DO 130 IFUN=1,4
C
        DO 131 KNE=1,NE
        RADIR(KNE)=LIM*(KNE-.5)/NE
        IF(IFUN.EQ.4) GO TO 136
        DO 132 KNF=1,NF
        GO TO (133,134,135),IFUN
C
C       COS FUNCTION
  133   NRF(KNE,KNF)=COS(PI*RADIR(KNE)*(-2.+2.*KNF)/(2.*LIM))
        GO TO 132
C
C       COD FUNCTION
  134   KKNF=2.*KNF-3
        IF(KNF.EQ.1)KKNF=0.
        NRF(KNE,KNF)=COS(PI*RADIR(KNE)*KKNF/(2.*LIM))
        GO TO 132
C
C       POLY FUNCTION
  135   NRF(KNE,KNF)=(RADIR(KNE)/LIM)**(2.*(KNF-1))
        NRFF(KNE,KNF)=NRF(KNE,KNF)
  132   CONTINUE
C
C       TCH FUNCTION
        IF(IFUN.NE.4) GO TO 138
  136   CALL TCHEB(KNE,NF,NRFF,NRF)
  138   CONTINUE
  131   CONTINUE
C
C
CCC     FINDING PSIB2
        I=0
   37   I=I+1
        CALL ARRAY(2,NE,NF,15,4,SNRF,NRF)
        CALL MPRD(SDELT,SNRF,SPSIT,NB,NE,0,0,NF)
        CALL ARRAY(1,NB,NF,5,4,SPSIT,PSIT)
        DO 609 KL=1,NB
  609   SPSIB1(KL)=PSIB1(KL)
        CALL LLSQ(SPSIT,SPSIB1,NB,NF,1,ALIF,IPIV,0.000,IER,AUX)
        IF(IER.NE.0) GO TO 52
        CALL MPRD(SNRF,ALIF,NR1,NE,NF,0,0,1)
        CALL MPRD(SDELT,NR1,PSIB2,NB,NE,0,0,1)
C
C
```

```
CCC    MADE ANOTHER ITERATION TO BETTER APPROX PSIB1?
       CALL VAR(PSIB1,PSIB2,NB,VARR)
C
       DO 38 KNE=1,NE
    38 IF(NR1(KNE).LT.0.) NR1(KNE)=0.
       IF(I.EQ.IMAX.OR.VARR.LT.EPS) GO TO 42
       ISAVE=1
       NFM=NF-1
       DO 39 KNF=1,NFM
       NFF=KNF+1
    39 IF(ABS(ALIF(NFF)).GT.ABS(ALIF(ISAVE))) ISAVE=NFF
C
       DO 40 KNE=1,NE
    40 NRF(KNE,ISAVE)=NR1(KNE)
       GO TO 37
C
C
CCC    ITERATING TO APPROX PSIB1 ENDED - FIND DENS
    42 IT(IFUN)=I
       VARI(IFUN)=VARR
       DO 41 KNE=1,NE
    41 DENS(IFUN,KNE)=DENSIN(NR1(KNE))
   130 CONTINUE
C
C
CCC    ERROR EVALUATION
C      FINDING MEAN ASSUMED DENSITY
       ASSM=0.
       NEM=NE-3
       DO 90 KNE=1,NEM
    90 ASSM=ASSM+DENSA(KNE)
       ASSM=ASSM/NEM
C
C      APP1 INDIVIDUAL ERROR
C      APP2 AVERAGE ERROR
C      APP3 AVERAGE ERROR OF 3 MAX
C      APPS ERROR FOR ONE FUNCTION
C      APPSS TOTAL ERROR OF ALL FUNCTIONS
       DO 91 IFUN=1,4
       APP2=0.
       DO 92 KNE=1,NEM
       APP1(KNE)=100.*ABS(DENS(IFUN,KNE)-DENSA(KNE))/ASSM
    92 APP2=APP2+APP1(KNE)
       NEP=NEM+3
       APP2=APP2/NEP
C
C      FINDING 3 MAX ERROR VALUES SO CAN DOUBLE WEIGHT THEM
       KC(1)=0
       KC(2)=0
       DO 93 LC=1,3
       ST=0.
       DO 93 KNE=1,NEM
       IF(KNE.EQ.KC(1).OR.KNE.EQ.KC(2)) GO TO 93
       IF(APP1(KNE).LT.ST) GO TO 93
       ST=APP1(KNE)
       KC(LC)=KNE
    93 CONTINUE
```



```
       I1=KC(1)
       I2=KC(2)
       I3=KC(3)
       APP3=(APP1(I1)+APP1(I2)+APP1(I3))/NEP
       APPS(IFUN,NT)=APP2+APP3
C        WRITE(6,916) ASSM,APP2,APP3,APPS(IFUN,NT)
   916   FORMAT(' ASSM=',4(E12.4,2X))
    91 CONTINUE
       APPSS(NT)=0.
       DO 94 IFUN=1,4
    94 APPSS(NT)=APPSS(NT)+APPS(IFUN,NT)
C
C
CCC    VARYING BEAM
         WRITE(6,936) ITI,IB,IBB,PHI1(IBB),DIV(IBB+1),APPSS(NT)
   936   FORMAT(' IT=',3(I2,2X),2(F7.2,2X),E12.4)
       IF(PHI1(IBB).GT.(DIV(IBB+1)+DELS)) GO TO 995
       NTMAX=NT
       ST=1.E5
       DO 996 NT=1,NTMAX
       IF(APPSS(NT).GT.ST) GO TO 996
       ST=APPSS(NT)
       KP=NT
   996 CONTINUE
C
C        WRITE(6,915) ST,KP
   915   FORMAT(' ST=',E12.4,2X,'KP=',I2)
   998  PHI1(IBB)=DIV(IBB)-(KP-1)*DELS
          WRITE(6,950) ITI,IB,PHI1(IBB),APPSS(KP)
   950    FORMAT(' IT=',I2,'IB=',I2,2X,'PHI1=',F7.2,2X,'ERROR=',E12.4)
          WRITE(6,672) (PHI1(KIK),KIK=1,NB)
   672    FORMAT(' PHI1=',5(F7.2,2X))
       LI=LI+1
       IF(LI.GT.1) LI=0
   999 CONTINUE
       WRITE(6,951) (PHI1(I),I=1,NB)
   951 FORMAT(' PHI1=',5(F8.2,2X))
       GO TO 310
C
    52   WRITE(6,53) IER
    53   FORMAT(' ','IER OF LLSQ=',I3)
C
C
   310 CONTINUE
       STOP
       END
       SUBROUTINE VAR(PSIB1,PSIB2,NB,VARI)
       DIMENSION PSIB1(5),PSIB2(5)
C
       AD=0.
       SU=0.
       DO 1 KNB=1,NB
       AD=AD+(PSIB1(KNB)+PSIB2(KNB))**2
     1 SU=SU+(PSIB1(KNB)-PSIB2(KNB))**2
C
       VARI=SQRT(SU/AD)
       RETURN
```

```
      END
      SUBROUTINE TCHEB(KNE,NF,NRF,NRFF)
      REAL*4 NRF,NRFF
      DIMENSION NRF(15,4),NRFF(15,4)
C
      NRFF(KNE,1)=1
      IF(NF.EQ.1) RETURN
      NRFF(KNE,2)=-NRF(KNE,1)+2.*NRF(KNE,2)
      IF(NF.EQ.2) RETURN
      NRFF(KNE,3)=NRF(KNE,1)-8.*NRF(KNE,2)+8.*NRF(KNE,3)
      IF(NF.EQ.3) RETURN
      NRFF(KNE,4)=-NRF(KNE,1)+18.*NRF(KNE,2)-48.*NRF(KNE,3)+32.*NRF(KNE,
     14)
      IF(NF.EQ.4) RETURN
      NRFF(KNE,5)=NRF(KNE,1)-32.*NRF(KNE,2)+160.*NRF(KNE,3)-256.*NRF(KNE
     1,4)+128.*NRF(KNE,5)
      RETURN
      END
      SUBROUTINE LONG(PHI1,PHIO,AS,VER,NB,NE,RAD,LIM,POL,DEL,IBEAM)
      REAL*4 LIM,K
      DIMENSION PHIO(5),PHI1(5),DEL(15,5),IBEAM(5)
      VVER=VER/1.414213
      DTR=4.*ATAN(1.)/180.
C
      DO 1 KNB=1,NB
C     DEFINING A NEW CENTER
      XO=RAD*COS(PHIO(KNB)*DTR)+VVER
      YO=RAD*SIN(PHIO(KNB)*DTR)+VVER
      X1=RAD*COS(PHI1(KNB)*DTR)+VVER
      Y1=RAD*SIN(PHI1(KNB)*DTR)+VVER
C
      K=(YO-Y1)/(XO-X1)
      SAVE=0.0
      DO 1 KNE=1,NE
      A=KNE*LIM/NE
      B=A/AS
      IF(POL.EQ.-1) GO TO 3
      AO=A
      A=B
      B=AO
C
    3 AA=(K*K/(B*B))+(1./(A*A))
      BB=K*(YO-K*XO)/(B*B)
      CC=-1+((YO*YO)+(K*K*XO*XO)-(2.*K*XO*YO))/(B*B)
C
      DEL(KNE,KNB)=BB*BB-AA*CC
      IF(DEL(KNE,KNB).LT.0.) DEL(KNE,KNB)=0.
      DEL(KNE,KNB)=(2./AA*SQRT(DEL(KNE,KNB)))*SQRT(K*K+1.)
      IF(KNE.EQ.1) GO TO 1
      KNEM=KNE-1
      SAVE=SAVE+DEL(KNEM,KNB)
      DEL(KNE,KNB)=DEL(KNE,KNB)-SAVE
    1 CONTINUE
C
      RETURN
      END
$$ WOS:WOS.GSYSLIB
```



```
//G.PLOTP DD DUMMY
//G.SYSIN DD *
001 01.0 00.3 00.0 14.0 -1.0 00.0 015
5
  00.0     00.0     00.0     00.0      0.0
-135.00  -135.00  -135.00  -135.00  -135.00
 100.00    60.00    55.00    20.00    -5.00
04 0005.
 105.      80.      55.      35.       5.     -15.
/*
```

```
⍝WORK2 FUNCTION PLOT

      )FNS PLOT
 ∇ A PLOT B;B1;C;D;E;F;G;H;I;J;L;T;HZ;NB;VT;PT;ST;ISV;U
  [1] PC←'○⋆∘∇∆⎕'
  [2] HS←0
  [3] ST← 1 2 5
  [4] SM← 5 10
  [5] →((0=×/(2⍴A),⍴B), 3 2 1 <⍴⍴B)/0,PRKERR,PLOTL2,PLOTL3
  [6] →PLOTL3,⍴B←(D,2)⍴(⍉(2,D)⍴(⍳D←⍴B),B)
  [7] PLOTL2:B←((⍴B)[2],(⍴B)[3])⍴B[1;;]
  [8] PLOTL3:Y←1+⍳(⍴B)[2]-1
  [9] C←((⌈/⌈/B[;Y])-⌊/⌊/B[;Y]),(⌈/B[;1])-⌊/B[;1]
  [10] F←|(2⍴A)÷C+(C=0)×B[1; 2 1]+B[1; 2 1]=0
  [11] F←(ST[+/(⌊.0001+F×10⋆-G)∘.≥ST])×10⋆G←⌊10⍟F
  [12] G←(SM÷F)×⌊((⌊/⌊/B[;Y]),⌊/B[;1])×F÷SM←16⌊SM⌈ 1 4
  [13] B[;1]←⌊0.5+F[2]×B[;1]-G[2]
  [14] B[;Y]←⌊.5+F[1]×B[;Y]-G[1]
  [15] H←SM×⌈((⌈/⌈/B[;Y]),⌈/B[;1])÷SM
  [16] NB←G[1]+(SM[1]÷F[1])×0,⍳H[1]÷SM[1]
  [17] HZ←G[2]+(SM[2]÷F[2])×0,⍳H[2]÷SM[2]
  [18] 0⍴ST←6⍴~ISV←1≠U←9
  [19] PLOTL4:VT←∨/0>NB←NB×10⋆U-ST[6-ISV]←I←1+⌈/⌊10⍟|(NB≠0)/NB
  [20] PT←⌊1+10|PT-1|PT←((⍴NB),U)⍴1E¯5+(|NB)∘.÷10⋆¯1+⌽⍳U
  [21] L←U+1-(⌽((C←⍴NB)⍴1)∧.=PT)⍳0
  [22] →((U>T←VT+⌈/I,(L+L≠I),(I≤0)×2+L-I),ST[2-ISV]←ST[2-ISV]∨L≥U-VT+L>I)/ 3 2 +I
26
  [23] →(¯1+I26)×⍴⍴⍴ST[4-ISV]←I←1
  [24] →PLOTL4×⍴⍴NB←SM[1+~ISV]×¯1+⍳C
  [25] PT←(-VT+0⌈1-I)⌽PT
  [27] →(0≠VT⌈I-1)/L26
  [28] →L27,PT←(,PT)×J←(C×U+1-I+VT+I⌈I≤0)⍴1
  [29] L26:PT←(,PT)×J←,⍉(⌽⍴PT)⍴(,⍉(1≠PT)∨.∧(⍳U)∘.≤⍳VT⌈I-1),(C×U+1-I+VT+I⌈I≤0)⍴1
  [30] L27:→(~VT)/2+I26
  [31] PT[(U-+/(C,U)⍴J)+U×¯1+⍳C]←11×NB<0
  [32] PT←(~(⍳U+J)∊(I+J),⍳¯1+J+U-T)\(1 0 +C,U)⍴PT,U⍴0
  [33] PT[(⍳C);(I+J)]←12
  [34] PT←' 0123456789¯.'[1+PT[;⍳U-1]]
  [35] →PLOTL13×⍳~ISV
  [36] L←1,H[2]⍴0×C←H[1]
  [37] PLOTL8:L←(L×HS×C≠0)⌈1,H[2]⍴0
  [38] D←((⍴B)[1],⍴Y)⍴0×E←1
  [39] B1←((⍴B)[1],⍴Y)⍴C=B[;Y]
  [40] LOOP:D[E;]←B1[E;]×Y
  [41] →((⍴D)[1]≥E←E+1)/LOOP
  [42] L[1+(D≠0)/B[;1]]←(D≠0)/D,→L43×⍳0=⍴(D≠0)/D←⌈/D
  [43] L43:→(C≠0)/PLOTL11
  [44] L←L⌈0=(SM[2]÷2)|0,⍳H[2]
  [45] PLOTL11:PT[(((⍴PT)[1],1+C÷SM[1])[1+0=SM[1]|C]);],(' |',(⍴Y)⍴PC)[1+L]
  [46] →(0≤C←C-1)/PLOTL8
  [47] →(U=U←SM[2]-~ISV←~⍴⍴NB←,HZ)⍴PLOTL4
  [48] PLOTL13:(SM[2]-9)⌽(,(0 0 ,(U-1)⍴1)\PT),' '
  [49] →(ST[1 3 2 4])/L1,L2,L3,L4
  [50] →0
  [51] L1:('ORIGIN AND SCALE FACTOR FOR ORDINATE: ';G[1],÷F[1])
  [52] →(2+I26)×⍳0=ST[3]
  [53] L2:('SCALE FACTOR FOR ORDINATE: ';10⋆ST[5]-1)
  [54] →(2+I26)×⍳0=ST[2]
  [55] L3:('ORIGIN AND SCALE FACTOR FOR ABSCISSA: ';G[2],÷F[2])
  [56] →0×⍳0=ST[4]
  [57] L4:('SCALE FACTOR FOR ABSCISSA: ';10⋆ST[6]-1)
  [58] →0
  [59] PRKERR:'THE RIGHT ARGUMENT OF  PLOT  MUST HAVE RANK ≤ 3.'
 ∇
```

```
⍝WORK2 FUNCTION VS

      )FNS VS
 ∇ M←A VS B;C;D
  [1] →(((⍴⍴B←,B)<⍴⍴B), 2 1 0 <⍴⍴A)/ 8 8 4 3
  [2] A←((⍴B),1)⍴A
  [3] A←((×/⍴A),1)⍴A
  [4] →(∧/(⍴B)≠1,1⍴⍴A)/9
  [5] M←(0,(1⍴⌽⍴A)⍴1)\A
  [6] M[;⍳1]←B
  [7] →0×⍴⍴M←(1,⍴M)⍴M
  [8] →((⍴M←⍳0)≠⍴⎕←'AN ARGUMENT OF  VS IS OF IMPROPER RANK.')/0
  [9] 'ARGUMENTS OF  VS  ARE NOT CONFORMABLE.'
  [10] M←⍳0
 ∇
```

```
⍝WORK2 FUNCTION MASQUE

      )FNS MASQUE
 ∇MASQUE MAT
  [1]'90.999        '$MAT
 ∇
```

```
⍝WORK2 FUNCTION PLOTSYMBOL

      )FNS PLOTSYMBOL
 ∇ PLOTSYMBOL TEXT;V
  [1] V← (TEXT,' ')∊' '
  [2] (18⍴' '),(1, ¯1+V)\(+/V)↑PC
 ∇
```

```
⍝WORK2 FUNCTION VAR

      )FNS VAR
 ∇  Z←X VAR Y
   [1]XY←1
   [2]XY←0,→ONE×⍳((|(./(X-Y)))≥1E¯05)
   [3]ONE:XY←(+/(X-Y)⋆2),→TWO×⍳(XY=0)
   [4]TWO: Z←(XY÷+/X⋆2)⋆0.5
 ∇
```

⍝WORK2 FUNCTIONS

```
      )LOAD WORK2
SAVED 9.30/ 74.115/13384
      )FNS
PROFIL;I;J;COS;COO;POL;TCH
Z←DENSINDEX X
N←TCHEB NRF
L←A AND B;C;D
A PLOT B;B1;C;D;E;F;G;H;I;J;L;T;HZ;NB;VT;PT;ST;ISV;U
M←A VS B;C;D
MASQUE MAT
PLOTSYMBOL TEXT;V
Z←X VAR Y
DENSASS
Z←B ⌹ A
```

⍝WORK2 FUNCTION DENSASS

```
      )FNS DENSASS
∇ DENSASS
 [1] 60ρ'*'
 [2] ASBVERNE←1 1 1
 [3] '        SHOT T/MS  ⍳0 I/KA LIM POL Δ NF BEAMS'
 [4] SHOT←⎕
 [5] CHI←5ρ0
 [6] CHI[(8↑SHOT)]←1
 [7] LIM←(((SHOT[5]*2)-(SHOT[7]*2)÷2)*.5)-|(÷(2*.5))×SHOT[7]
 [8] POLARITY←SHOT[6]
 [9] ASBVERNE[2]←SHOT[7]
 [10] 'EFFECTIVE LIMITER RADIUS (CM):  ';LIM
 [11] DENSA←3E13×DENSA←1+(¯1×(XA*2)÷4)+(÷64)×(XA←((8*.5)÷NEA)×((⍳NEA←SHOT[8])-÷2))*4
 [12] LAM←3÷14∘NC←24.28E13
 [13] NR1A←(÷LAM)×○2×1-(1-DENSA÷NC)*.5
 [14] ASBVERNE[3]←NEA
 [15] ⍎')LOAD EXCENT'
 [16] EXCENT
 [17] ⍎')ERASE EXCENT'
 [18] PSIA←NR1A+.×DEL
 [19] ASBVERNE[3]←SHOT[8]
 [20] RD←20,¯18,¯14,15,8
 [21] PSIB1←PSIA-(PSIA×RD×.01)
 [22] 'RANDOM ERROR:  ';RD
 [23] PROFIL
∇
```

⍝WORK2 FUNCTION PROFIL

```
      )FNS PROFIL
∇ PROFIL; I;J;COS;COO;POL;TCH
 [1] ⍎')LOAD EXCENT'
 [2] EXCENT
 [3] ⍎')ERASE EXCENT'
 [4] 'PATH LENGTH (CM)              : ';+/[1]DFL
 [5] FAC←24.28E13×3÷14×○1
 [6] 1ρ'*'
 [7] 'INTEGR.DENS. (CM¯2) : ';FAC×PSIP1
 [8] 'MEAN DENS.    (CM¯3) : ';DENSINDEX(PSIP1÷(+/[1]DFL))
 [9] 1ρ'*'
 [10] NF←¯1 ++/CHI
 [11] →SIGM×⍳(NF=1)
 [12] ⍎ ')LOAD APPROXIT'
 [13] COS← NF APPROXIT 'COS'
 [14] VCOS←MV
 [15] COO← NF APPROXIT 'COO'
 [16] VCOO←MV
 [17] POL← NF APPROXIT 'POL'
 [18] VPOL←MV
 [19] TCH← NF APPROXIT 'TCH'
 [20] VTCH←MV
 [21] ⍎')ERASE APPROXIT'
 [22] 4 2 ρ(VCOS,VCOO,VPOL,VTCH)
 [23] ' '
 [24] '       PLOTSYMBOL ''COS COO POL TCH ASS'''
 [25] PLOTSYMBOL 'COS COO POL TCH ASS'
 [26] ASS←DENSA
 [27] DENS←DENSINDEX (COS AND COO AND POL AND TCH)
 [28] DENS←DENS AND ASS
 [29] 25 70 PLOT (DENS VS RAD1P)
 [30] ' '
 [31] DENS
 [32] ' '
 [33] ' '
 [34] ' '
 [35] 'PLOT OF |CALCULATED-ASSUMED DENS|'
 [36] DIFF←|(NE,4)↑(DENS-⍉(5,NE)ρDENS[;5])
 [37] '       PLOTSYMBOL ''COS COO POL TCH'''
 [38] PLOTSYMBOL 'COS COO POL TCH'
 [39] 25 70 PLOT DIFF VS RAD1P
 [40] 60ρ'*'
 [41] →END
 [42] SIGM: NRF← *-(RAD1P∘.÷LIM×0.25×⍳5)*2
 [43] PSIT←(⍉DEL)+.×NRF
 [44] I←1
 [45] VARI← AL1F←0×⍳5
 [46] ITER: AL1F[I]←PSIP1 ⌹ (2 1 ρPSIT[;I])
 [47] VARI[I]←PSIP1 VAR(AL1F[I]×PSIT[;I])
 [48] →ITER×⍳(5≥I←I+1)
 [49] 'APPROXIMATION: N=N0.EXP(-LIM/2.SIGMA)*2'
 [50] 'SIGMA = LIMITER/ ';0.125×J←¯1↑⍋VARI
 [51] 'N0 =                ';DENSINDEX(AL1F[J])
 [52] 'VARIANCE ';VARI[J]
 [53] END: 60ρ'*'
∇
```

⍝WORK2 FUNCTION DENSINDEX

```
      )FNS DENSINDEX
∇ Z←DENSINDEX X
 [1] NC← 6070000000000
 [2] LAM←3÷7
 [3] Z←NC×(1-(1-X×LAM÷○2)*2)
∇
```

⍝WORK2 FUNCTION TCHEB

```
      )FNS TCHEB
∇ N← TCHEB NRF
  [1] N←(ρNRF)ρ1
  [2] N[;2]← +/((ρNRF)ρ(NF↑¯1 2 0 0 0))×NRF
  [3] →0×⍳NF=2
  [4]N[;3]←+/((ρNRF)ρ(NF↑ 1 ¯8 8 0 0))×NRF
  [5] →0×⍳NF=3
  [6] N[;4]←+/((ρNRF)ρ(NF↑ ¯1 18 ¯48 32 0))×NRF
  [7] →0×⍳NF=4
  [8] N[;5]←+/((ρNRF)ρ(NF↑ 1 ¯32 160 ¯256 128))×NRF
∇
```

⍝WORK2 FUNCTION AND

```
      )FNS AND
∇ L←A AND B;C;D
 [1] →(((2<ρρA)∨3<ρρB),0≠ρρB)/ 17 3
 [2] B←,B
 [3] →(((3=ρρB)∧1≠1ρρB),2=ρρA)/ 17 7
 [4] A←,A
 [5] →(∧/((ρA)≠1,D),1≠D←1ρ¯2⌽ρB)/16
 [6] A←(((D×ρA)⌊D⌈ρA),1)ρA
 [7] →(1≠ρρB)/9
 [8] B←(((ρB)⌈(1=ρB)×1ρρA),1)ρB
 [9] →((∧/D≠1,1ρρA),1≠D←1ρ¯2⌽ρB)/ 16 11
 [10] B←(((3=ρρB)ρ1),(1ρρA),1ρ⌽ρB)ρB
 [11] →(3=ρρB)/14
 [12] L←(((C←1ρ⌽ρA)ρ0),(1ρ⌽ρB)ρ1)\B
 [13] →0×ρρL[;⍳C]←A
 [14] L←(1,((C←1ρ⌽ρA)ρ0),(¯1+1ρ⌽ρB)ρ1)\B
 [15] →0×ρρL[;;1+⍳C]←A
 [16] →18,ρ⍞←'ARGUMENTS OF  AND  ARE NOT CONFORMABLE.'
 [17] 'AN ARGUMENT OF  AND  IS OF IMPROPER RANK.'
 [18] L←⍳0
∇
```

⍝LIBRARY FUNCTION EXCENT

```
      )FNS EXCENT
∇ EXCENT;A;AS;B;V
 [1] TOTA←SHOT[3]+SHOT[4]÷10
 [2] A←ASBVERNE[1]
 [3] AS1←AS←1.14+1.8×SHOT[3]
 [4] AS←((1+B)÷((1-B←(((AS*2)-1)÷(AS*2)+1)×(1-SHOT[4]÷20))))*0.5
 [8] →0×⍳~((V<0.9)∨(1.1<V←A÷AS)∨((+/CHI=CHI0)≠5)∨(LIM≠LI)∨(POLARITY≠POSITIO
N)∨(ASBVERNE[2]≠SHIFT)∨(ASBVERNE[3]≠BZ))
 [9] BZ←ASBVERNE[3]
 [10] ASBVERNE← AS,ASBVERNE[2 3]
 [11] CHI0←CHI
 [12] ⍎ ')LOAD LONG1'
 [13] DEL←(CHI0←CHI) LONG1 ASBVERNE
 [14] ⍎ ')ERASE LONG1'
 [15] LI←LIM
 [16] POSITION←POLARITY
 [17] SHIFT←ASBVERNE[2]
 [18] 'EXCENTRICITY A/B DUE TO EXTERNAL FIELD: ';AS1
 [19] 'TOTAL EXCENTRICITY:                     ';AS
 [20] '*'
∇
```

⍝LIBRARY FUNCTION APPROXIT

```
      )FNS APPROXIT
∇ NR1←NF APPROXIT KIND;I;PSIT;PSIB2;VARI;S
 [.5] NE←ASBVERNE[3]
 [1] RAD1R←(LIM÷NE)×((⍳NF)-÷2)
 [3] I←1
 [4] →((4 3  ⍴'COSPOLCOOTCH')∧.=KIND)/CS,POLY,CO,TC
 [5] POLY: NRF←((÷LIM)×RAD1R)∘.*((¯1+⍳NF)×2)
 [7] →CAL×⍳(+/KIND ≠ 'TCH')
 [8] NRF← TCHEB NRF
 [10] →CAL
 [11] CO:NRF←2○((○÷2)×(÷LIM)×RAD1R∘.×(0,¯1+2×⍳NF-1))
 [13] →CAL
 [14] CS:NRF←2○((○÷2)×(÷LIM)×RAD1R∘.×(¯2+2×⍳NF))
 [16] →CAL
 [17] TC:→POLY
 [18] CAL:PSIT←(⍉DEL)+.×NRF
 [19] AL1F←PSIB1 ⌹ PSIT
 [21] NR1←NRF+.×(⍉AL1F-)
 [22] PSIB2←(⍉DEL)+.×NR1
 [23] VARI←PSIB1 VAR·PSIB2
 [24] NRF[;(1↑S←⍒|AL1F)]←NP1←NP1×NP1>0
 [25] →VVA×⍳((6≤I←I+1)∨(VARI<1E¯2))
 [26] →CAL
 [27] VVA:NV←I,VARI
∇
```

⍝LIBRARY FUNCTION LONG1

```
      )FNS LONG1
∇ Z←CHI LONG1 ASBVERNE;D;X;Y;A;B;AL;K;RO;AA;BB;CC;PHI;NB
 [1] PHI←(CHI,CHI)/(○1÷180)×(5⍴¯135),PHI1
 [2] Y←(D←ASBVERNE[2]÷2*.5)+19.×1○PHI
 [3] X←D+19.×2○PHI
 [4] B←(÷(AL←ASBVERNE[1]))×A←(LIM÷NE)×⍳NE←ASBVERNE[3]
 [5] AL←÷AL∘A←B,→POL×⍳(POLARITY=¯1)
 [6] POL:K←((Y←NB↑Y)-NB↓Y)÷(X←NB↑X)-(NB←+/CHI)↓X
 [7] AA←(RO←NE,NB)⍴(1+(K×AL)*2)
 [8] BB←RO⍴(K×AL×AL×(Y-K×X))
 [9] CC←(RO⍴((Y-K×X)×AL)*2)-⍉((NB,NE)⍴A*2)
 [10] DEL←(DEL>0)×(DEL←(BB*2)-AA×CC)
 [11] DEL←(÷AA)×2×(DEL×(RO⍴(1+K*2)))*.5
 [12] Z←DEL←DEL-RO↑((NB⍴0),[1]DEL)
∇
```

⍝WORK4 FUNCTIONS

```
      )LOAD WORK4
SAVED 12.50/ 74.318/10032
      )FNS
PROFIL;I;J;COS;COO;POL;TCH;VCOS;VCOO;VPOL;VTCH;NF;FAC;MV;NR1;NE;RAD1R;
VARI;PSIT;AS1F;NRF;IND
Z←DENSINDE X
N← TCHEB NRF
L←A AND B;C;D
MASQUE MAT
Z←X VAR Y
DENSASS;LAM;NEA;NR1A;PSIB1;DENSA;NC;XA;SHOT;CHI;POLARITY;NE;LI;POSITIO
N;SHIFT;CHI0;BZ;PHIC;PSIA
Z←B ⍎ A
ITERATE;RD;AS;AS1;LIM;APP3S;APP2S;ANGS;PHLL;APPS;PHLR;PHL;APP3;APP2;AP
PSS;DENS;APP1;IL;KE;ASSO;KI;ITERK;ASS;DEL
MASK MAT
```

⍝WORK4-FUNCTION DENSASS

```
      )FNS DENSASS
∇ DENSASS;LAM;NEA;NR1A;PSIB1;DENSA;NC;XA;SHOT;CHI;POLARITY;NE;LI;POSITION;S
HIFT;CHI0;BZ;PHIC;PSIA
 [.1] LI←POSITION←SHIFT←BZ←0
 [.2] CHI0←PHIC←0 0 0 0 0
 [.3]-ASBVERNE←1 1 1
 [1] SHOT←DATA
 [2] CHI←5⍴0
 [3]-CHI[(8↑SHOT)]←1
 [4] LIM←(((SHOT[5]*2)-(SHOT[7]*2)÷2)*.5)-|(÷(2*.5))×SHOT[7]
 [5] POLARITY←SHOT[6]
 [6] ASBVERNE[2]←SHOT[7]
 [7] DENSA←3E13×DENSA←1+(¯1×(XA*2)÷4)+(÷64)×(XA←((8*.5)÷NEA)×((1NEA←SHOT[8]
)-÷2))*4
 [8] LAM←3÷14○NC←24.28E13
 [9] NR1A←(÷LAM)×○2×1-(1-DENSA÷NC)*.5
 [10] ASBVERNE[3]←NEA
 [11] ⍎')LOAD EXCENT3'
 [12] EXCENT3
 [13] ⍎')ERASE EXCENT3'
 [14] PSIA←NR1A+.×DEL
 [15] ASBVERNE[3]←SHOT[8]
 [16] RD←20,¯18,¯14,15,8
 [17] PSIB1←PSIA-(PSIA×RD×.01)
 [18] PROFIL
∇
```

⍝WORK4 FUNCTION PROFIL

```
      )FNS PROFIL
∇ PROFIL;I;J;COS;COO;POL;TCH;VCOS;VCOO;VPOL;VTCH;NF;FAC;MV;NF1;NF;RAD1P;VAR
I;PSIT;AS1F;NRF;IND
 [1] ⍎')LOAD EXCENT3'
 [2] EXCENT3
 [3] ⍎')ERASE EXCENT3'
 [4] FAC←NC×LAM×○1
 [5] 1⍴'*'
 [6] NF←¯1 ++/CHI
 [7] →SIGM×⍳(NF=1)
 [8] ⍎')LOAD APPROXIT'
 [9] COS← NF APPROXIT 'COS'
 [10] VCOS←MV
 [11] COO← NF APPROXIT 'COO'
 [12] VCOO←MV
 [13] POL← NF APPROXIT 'POL'
 [14] VPOL←MV
 [15] TCH← NF APPROXIT 'TCH'
 [16] VTCH←MV
 [17] ⍎')ERASE APPROXIT'
 [18] ASS←DENSA
 [18.5] IND←COS AND COO AND POL AND TCH
 [19] DENS←DENSINDEX IND
 [20] →END
 [21] SIGM: NRF← *-(RAD1P∘.÷LIM×0.25×⍳5)*2
 [22] PSIT←(⍉REL)+.×NRF
 [23] I←1
 [24] VARI← AL1F←0×⍳5
 [25] ITER: AL1F[I]←PSIB1 ⌹ (2 1 ⍴PSIT[;I])
 [26] VARI[I]←PSIB1 VAR(AL1F[I]×PSIT[;I])
 [27] →ITER×⍳(5≥I←I+1)
 [28] 'APPROXIMATION: N=N0.EXP(-LIM/2.SIGMA)*2'
 [29] 'SIGMA = LIMITER/ ';0.125×J←¯1↑⍒VARI
 [30] 'N0 =                 ';DENSINDEX(AL1F[J])
 [31] 'VARIANCE ';VARI[J]
 [32] END:  →0
∇
```

⍝WORK4 FUNCTION ITERATE

```
      )FNS ITERATE
∇ ITERATE;RD;AS;AS1;LIM;APP3S;APP2S;ANGS;PHLL;APPS;PHLR;PHL;APP3;APP2;APPSS
;DENS;APP1;IN;KE;ASSO;KI;ITERK;ASS;PEL
 [1] ITERK←0
 [2] ⍝***GOING TO NEXT ITERATION***
 [3] IT: →END×⍳(ITER<ITERK←ITERK+1)
 [4] ⎕←'ITERATION ';ITERK∘⎕←' '∘⎕←' '∘⎕←' '∘KI←1
 [5] ⍝***GOING TO NEXT BEAM***
 [6] BEAM: →IT×⍳(5≤KI←KI+1)
 [7] ⎕←'BEAM ';KI∘⎕←' '∘⎕←' '
 [8] ANGS←0
 [9] APP←APPS←APP3S←APP2S←1 4⍴0
 [10] PHLR←PHI1[KI+1]+MAR
 [11] PHL←PHLL←PHI1[KI-1]+INTE-MAR
 [12] ⍝***SCANNING WHOLE BEAM***
 [13] VAR: ANGS←ANGS,PHI1[KI]←PHL←PHL-INTF
 [14] 'PHI1:  ';PHI1
 [15] DENSASS
 [16] NUP←ASBVERNE[3]-3
 [17] DENS←(NUP,4)↑DENS
 [18] ⍝***ERRORS***
 [19] ASSO←⍉(4,NUP)⍴(NUP↑ASS)
 [20] ASSM←(÷NUP)×+/(NUP↑ASS)
 [21] APP2S←APP2S,[1]APP2←(÷ASBVERNE[3])×+/[1]APP1←100×|(DENS-ASSO)÷ASSM
 [22] IN←0
 [23] OR: IN←IN+1
 [24] KE←⍋APP1[;IN]
 [25] APP1[;IN]←APP1[KE;IN]
 [26] →OR×⍳(IN<4)
 [27] APP3S←APP3S,[1]APP3←(÷ASBVERNE[3])×+/[1]APP33←3 4↑APP1
 [28] APPS←APPS,[1]APPSS←APP2+APP3
 [29] →VAR×⍳(PHL>PHLR)
 [30] ⍝***FINDING BEST ANGLE OF THE ONE BEAM SCANNED***
 [31] PHI1[KI]←PHLL-INTF×((1↓2↑⍋APPS[;4])-1)
 [32] ⎕←'APP2S  '
 [33] DUM←APP2S×ASBVERNE[3]÷NUP
 [34] MASK DUM
 [35] ⎕←'APP3S  '
 [36] DUM←APP3S×5
 [37] MASK DUM
 [38] ⎕←'APPS  '
 [39] MASK APPS
 [40] 'PHI1[KI]:  ';PHI1[KI]
 [41] →BEAM
 [42] END: 'EFFECTIVE LIMITER RADIUS (CM):  ';LIM
 [43] 'EXCENTRICITY A/F DUE TO EXT FIELD:  ';AS1
 [44] 'TOTAL EXCENTRICITY                  ';AS
 [45] 'RANDOM ERROR.  ';RD∘⎕←'*'
∇
```

⍝LIBRARY FUNCTION EXCENT3

```
      )VRS EXCENT3
∇ EXCENT3;A;B;V;ICTA
 [1] ICTA←SHOT[3]+SHOT[4]÷10
 [2] A←ASBVERNE[1]
 [3] AS1←AS←1.14+1.8×SHOT[3]
 [4] AS←((1+B)÷((1-B←(((AS*2)-1)÷(AS*2)+1)×(1-SHOT[4]÷20))))*0.5
 [5] →LI×ι(0≠+/(PHIC≠PHI1))
 [6] →0×ι~((V<0.9)∨(1.1<V←A÷AS)∨((+/CHI=CHI0)≠5)∨(LIN≠LI)∨(POLARITY≠POSITION)∨(ASB
 [8.5] LI: PHIC←PHI1
 [9] B2←ASBVERNE[3]
 [10] ASBVERNE← AS,ASBVERNE[2 3]
 [11] CHI0←CHI
 [12] ⍎ ')LOAD LONG1'
 [13] DEL←(CHI0←CHI) LONG1 ASBVERNE
 [14] ⍎ ')ERASE LONG1'
 [15] LI←LIN
 [16] POSITION←POLARITY
 [17] SHIFT←ASBVERNE[2]
∇
```

⍝SPREAD2 FUNCTIONS

```
      )FNS
PROFIL;I;J;CCS;COO;POL;TCH;VCOS;VCOO;VPOL;VTCH;NP;TAC;MV;NR1;NE;RAD1R;VARI;
PSIT;PS1P;NRF;IND
Z←[illegible] X
Z← [illegible] NRF
Z←A AND B;C;D
[illegible]
Z←X VAR Y
DENSASS;LAMUNFA;NR1A;PSIP1;DENSA;NC;XA;SHOT;CHI;POLARITY;NE;LI;POSITION;SHI
FT;CHI0;BZ;PHIC;PHICC;PSIA
Z←B & A
[illegible]
A PLOT B;B1;C;D;E;F;G;H;I;J;L;T;HZ;NP;VT;PT;ST;ISV;U
Z←A VS B;C;D
PLOTSYMBOL TEXT;V
```

⍝SPREAD2 FUNCTION DENSASS

```
      )FNS DENSASS
∇ DENSASS;LAM;NFA;NR1A;PSIP1;DENSA;NC;XA;SHOT;CHI;POLARITY;NE;LI;POSITION;S
HIFT;CHI0;BZ;PHIC;PHICC;PSIA
 [1] PHI2←¯135
 [2] BMWD←6
 [2.5] RAD←19.
 [3] LI←POSITION←SHIFT←BZ←PHICC←0
 [4] CHI0←PHIC←0 0 0 0 0
 [5] ASBVERNE←1 1 1
 [6] SHOT←DATA
 [7] CHI←5ρ0
 [8] CHI[(8↓SHOT)]←1
 [9] LIM←(((SHOT[5]*2)-(SHOT[7]*2)÷2)*.5)-|(÷(2*.5))×SHOT[7]
 [10] POLARITY←SHOT[6]
 [11] ASBVERNE[2]←SHOT[7]
 [12] DENSA←3E13×DENSA←1+(¯1×(XA*2)÷4)+(÷64)×(XA←((8*.5)÷NFA)×((⍳NFA←SHOT[8
])-÷2))*4
 [13] LAM←3÷14∘NC←24.28E13
 [14] NR1A←(÷LAM)×○2×1-(1-DENSA÷NC)*.5
 [15] ASBVERNE[3]←SHOT[8]
 [16] KT←0∘BMDEL←BMWD×45÷RAD×○1
 [17] PHIA←PHI2∘PSIAS←((+/CHI)ρ0)
 [18] ⍝LOOKING AT THE SPREAD OF A BEAM
 [19] REP:KT←KT+1
 [20] PHI2←((KT=5)×PHIA)+((KT=1)×(PHIA+BMDEL))+((KT=2)×(PHI2+BMDEL))+((KT=3
)×(PHIA-BMDEL))+((KT=4)×(PHI2-BMDEL))
 [21] 'PHI2:    ';PHI2
 [22] ⍎')LOAD EXCENT2'
 [23] EXCENT2
 [24] ⍎')ERASE EXCENT2'
 [25] PSIA←NR1A+.×DEL
 [26] PSIAS←PSIAS+PSIA
 [27] →SKI×⍳(KT≠5)
 [28] PSIAA←PSIA
 [29] SKI:→REP×⍳(KT<5)
 [30] ⍝TAKING MEAN
 [31] PSIB1←PSIAS÷5
 [32] 'PSIA:    ';PSIAA
 [33] 'PSIB1:    ';PSIB1
 [34] PROFIL
∇
```

```
⍝SPREAD2 FUNCTION PROFIL


      )FNS PROFIL
∇ PROFIL;I;J;COS;COO;POL;TCH;VCOS;VCOO;VPOL;VTCH;NF;FAC;MV;NR1;NF;RAD1R;VAR
I;PSIT;AS1F;NRF;IND
 [1] ⍎')LOAD EXCENT2'
 [2] EXCENT2
 [3] ⍎')ERASE EXCENT2'
 [4] FAC←NC×LAM×○1
 [5] 1ρ'*'
 [6] NF←¯1 ++/CHI
 [7] →SIGM×⍳(NF=1)
 [8] ⍎')LOAD APPROXIT'
 [9] COS← NF APPROXIT 'COS'
 [10] VCOS←MV
 [11] COO← NF APPROXIT 'COO'
 [12] VCOO←MV
 [13] POL← NF APPROXIT 'POL'
 [14] VPOL←MV
 [15] TCH← NF APPROXIT 'TCH'
 [16] VTCH←MV
 [17] ⍎')ERASE APPROXIT'
 [18] 4 2 ρ(VCOS,VCCO,VPOL,VTCH)
 [19] '      PLOTSYMBOL ''COS COO POL TCH-ASS'''
 [20] PLOTSYMBOL 'COS COO POL TCH ASS'
 [21] ⎕←' '
 [22] ASS←DENSA
 [23] IND←COS AND COO AND POL AND TCH
 [24] DENS←DENSINDEX IND
 [25] DENS←DENS AND DENSA
 [26] 20 60 PLOT (¯3 0 ↓DENS) VS (¯3↓RAD1R)
 [27] ⎕←' '
 [28] DENS
 [29] 60ρ'*'
 [30] →END
 [31] SIGM: NRF← *-(RAD1P∘.÷LIM×0.25×⍳5)*2
 [32] PSIT←(⍉DEL)+.×NRF
 [33] I←1
 [34] VARI← AL1F←0×⍳5
 [35] ITER: AL1F[I]←PSIR1 ⌹ (2 1 ρPSIT[;I])
 [36] VARI[I]←PSIR1 VAR(AL1F[I]×PSIT[;I])
 [37] →ITER×⍳(5≥I←I+1)
 [38] 'APPROXIMATION: N=N0.EXP(-LIM/2.SIGMA)*2'
 [39] 'SIGMA = LIMITER/ ';0.125×J←¯1↑⍋VARI
 [40] 'N0 =              ';DENSINDEX(AL1F[J])
 [41] 'VARIANCE ';VARI[J]
 [42] END: →0
∇
```

```
⍝SPREAD2 FUNCTION DENSINDE


      )FNS DENSINDE
∇ Z←DENSINDE X
 [1] Z←NC×(1-(1-X×LAM÷○2)*2)
∇
```

```
⍝SPREAD2 FUNCTION MASK


      )FNS MASK
∇ MASK MAT
 [1] '990.99    '⍕MAT
∇
```

⍝LIBRARY FUNCTION EXCENT2

```
      )FNS EXCENT2
∇ EXCENT2;A;B;V;IOTA
 [1] IOTA←SHOT[3]+SHOT[4]÷10
 [2] A←ASBVERNE[1]
 [3] AS1←AS←1.14+1.8×SHOT[3]
 [4] AS←((1+B)÷((1-P←(((AS*2)-1)÷(AS*2)+1)×(1-SHOT[4]÷20))))*0.5
 [5] →LI×ι((0≠+/(PHIC≠PHI1))∨(PHICC≠PHI2))
 [8] →0×ι~((V<0.9)∨(1.1<V←A÷AS)∨((+/CHI=CHI0)≠5)∨(LIN≠LI)∨(POLARITY≠POSITIO
N)∨(ASBVERNE[2]≠SHIFT)∨(ASBVERNE[3]≠BZ))
 [8.5] LI: PHIC←PHI1
 [8.7] PHICC←PHI2
 [9] BZ←ASBVERNE[3]
 [10] ASBVERNE← AS,ASBVERNE[2 3]
 [11] CHI0←CHI
 [12] ⍎ ')LOAD LONG2'
 [13] DEL←(CHI0←CHI) LONG2 ASBVERNE
 [14] ⍎ ')ERASE LONG2'
 [15] LI←LIN
 [16] POSITION←POLARITY
 [17] SHIFT←ASBVERNE[2]
∇
```

⍝LIBRARY FUNCTION LONG2

```
      )FNS LONG2
∇ Z←CHI LONG2 ASBVERNE;D;X;Y;A;B;AL;K;RO;AA;BB;CC;PHI;NP
 [1] PHI←(CHI,CHI)/(○1÷180)×(5ρPHI2),PHI1
 [2] Y←(D←ASBVERNE[2]÷2*.5)+RAD×1○PHI
 [3] X←D+RAD×2○PHI
 [4] B←(÷(AL←ASBVERNE[1]))×A←(LIN÷NF)×ιNF←ASBVERNE[3]
 [5] AL←÷AL∘A←B,→POL×ι(POLARITY=¯1)
 [6] POL:K←((Y←NB↑Y)-NP↓Y)÷(X←NB↑X)-(NB←+/CHI)↓X
 [7] AA←(RO←NF,NP)ρ(1+(K×AL)*2)
 [8] BB←ROρ(K×AL×AL×(Y-K×X))
 [9] CC←(ROρ((Y-K×X)×AL)*2)-⍉((NP,NF)ρA*2)
 [10] DEL←(DEL>0)×(DEL←(BB*2)-AA×CC)
 [11] DEL←(÷AA)×2×(DEL×(ROρ(1+K*2)))*.5
 [12] Z←DEL←DEL-RO↑((NBρ0),[1]DEL)
∇
```

⍝SPREAD3 FUNCTIONS

```
      )FNS
PROFIL;I;J;COS;COO;POL;TCH;VCOS;VCOO;VPOL;VTCH;NF;FAC;MV;NR1;NE;RAD1R;VARI;
PSIT;AS1F;NRF;IND
Z←DENSINDE X
N← TCHEB NRF
L←A AND B;C;D
MASQUE MAT
Z←X VAR Y
Z←B ∓ A
MASK MAT
A PLOT B;B1;C;D;E;F;G;H;I;J;L;T;FZ;NP;VT;PT;ST;TSV;U
M←A VS B;C;E
PLOTSYMBOL TEXT;V
EXCENT2;A;R;V;IOTA
DENSASS;LAM;NEA;NR1A;PSIB1;DENSA;NC;XA;SHOT;CHI;POLARITY;NF;LI;POSITION;SHI
FT;CHI0;BZ;PHIC;PHICC;PSIA
```

⍝SPREAD3 FUNCTION DENSASS

```
      )FNS DENSASS
∇ DENSASS;LAM;NEA;NR1A;PSIB1;DENSA;NC;XA;SHOT;CHI;POLARITY;NF;LI;POSITION;S
HIFT;CHI0;BZ;PHIC;PHICC;PSIA
 [1] PHI2←¯135
 [2] BMWD←6
 [3] P1←107 88 59.2 29.3 3.3
 [4] P2←109 91 63.5 33.5 7
 [5] P3←102.5 81.2 50 20.5 ¯3
 [6] P4←100 77.5 46 17 ¯6
 [7] P5←105 85 55 25 0
 [8] RAD←19.
 [9] LI←POSITION←SHIFT←BZ←PHICC←0
 [10] CHI0←PHIC←0 0 0 0 0
 [11] ASBVERNE←1 1 1
 [12] SHOT←DATA
 [13] CHI←5ρ0
 [14] CHI[(8↑SHOT)]←1
 [15] LIN←(((SHOT[5]*2)-(SHOT[7]*2)÷2)*.5)-|(÷(2*.5))×SHOT[7]
 [16] POLARITY←SHOT[6]
 [17] ASBVERNE[2]←SHOT[7]
 [18] DENSA←3E13×DENSA←1+(¯1×(XA*2)÷4)+(÷64)×(XA←((8*.5)÷NFA)×((NFA←SHOT[8
])-÷2))*4
 [19] LAM←3÷14∘NC←24.28E13
 [20] NR1A←(÷LAM)×○2×1-(1-DENSA÷NC)*.5
 [21] ASBVERNE[3]←SHOT[8]
 [22] KT←0∘BMDEL←BMWD×45÷RAD×○1
 [23] PHIA←PHI2∘PSIAS←((+/CHI)ρ0)
 [24] ⍝LOOKING AT THE SPREAD OF A BEAM
 [25] REP:KT←KT+1
 [26] PHI2←((KT=5)×PHIA)+((KT=1)×(PHIA+BMDEL))+((KT=2)×(PHI2+BMDEL))+((KT=3
)×(PHIA-BMDEL))+((KT=4)×(PHI2-BMDEL))
 [27] PHI1←(P5×KT=5)+(P1×KT=1)+(P2×KT=2)+(P3×KT=3)+(P4×KT=4)
 [28] 'PHI2:    ';PHI2
 [29] 'PHI1:     ';PHI1
 [30] ⍎')LOAD EXCENT2'
 [31] EXCENT2
 [32] ⍎')ERASE EXCENT2'
 [33] PSIA←NR1A+.×DEL
 [34] PSIAS←PSIAS+PSIA
 [35] →SKI×⍳(KT≠5)
 [36] PSIAA←PSIA
 [37] SKI:→REP×⍳(KT<5)
 [38] ⍝TAKING MEAN
 [39] PSIB1←PSIAS÷5
 [40] 'PSIA:    ';PSIAA
 [41] 'PSIB1:    ';PSIB1
 [42] PROFIL
∇
```

REFERENCES

(1) E.Wuersching; not yet published

(2) B.Streibl, S.Rehker; numerical calculations at IPP

(3) P.Barberio-Corsetti; IPP II/206(1972)