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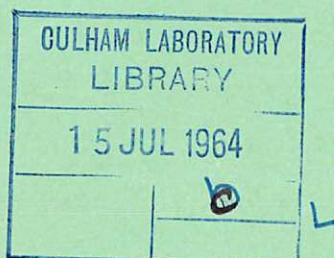
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RESEARCH GROUP

Report

COMPUTER PROGRAMS FOR THE
NUMERICAL STUDY AND GRAPHICAL
DISPLAY OF MAGNETIC FIELDS

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COMPUTER PROGRAMS FOR THE NUMERICAL STUDY AND
GRAPHICAL DISPLAY OF MAGNETIC FIELDS

by

F.M. LARKIN

A B S T R A C T

The report describes six computer programs which facilitate assessment of the plasma containment properties of a wide class of magnetic field configurations, including magnetic mirrors, cusps and Ioffe fields. As well as relevant printed output the programs can provide graphical output illustrating salient geometric features of the magnetic fields. This graphical output may be plotted automatically either on a Benson-Lehner Model J plotter or a Stromberg-Carlson 4020 microfilm recorder.

A complete worked example is given for every program and data input is described in detail so that the report may be used as an operating manual for the programs.

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1. INTRODUCTION

1. For a magnetic field to be capable of containing a plasma by the mirror effect it must be carefully designed. The complete requirements for containment are not yet properly understood, but if the plasma is so tenuous that its modifying effect on the magnetic field may be ignored it is possible to prescribe necessary conditions which must be satisfied before containment can be achieved⁽¹⁾. Moreover, theory indicates that certain types of plasma instability may also be suppressed if some further restrictions are imposed on the magnetic field⁽²⁾.
2. To a first approximation, the properties which the magnetic confining field \underline{B} should satisfy may be regarded as purely geometric, and the question of stable containment turns on the relation between the field lines and the spatial distribution of the field strength $|B|$. The computer programs described in this report make it possible to assess the mirror containment properties of a given magnetic field. In particular, they can be used to gain an insight into special features of existing experimental apparatus and also as 'design tools' for future experiments. Moreover, it turns out that many magnetic fields which are of interest as possible prototypes for controlled thermonuclear reactors have a rather complicated three dimensional structure and their salient features are most easily understood from a model or stereoscopic picture. The computer programs have therefore been equipped to provide enough geometric information to build a model, or to draw automatically a convenient stereoscopic picture of selected magnetic field lines.
3. In this report a magnetic field is considered to be generated by an arbitrary number of filamentary electric currents. There is no reason in principle why the field should not be defined analytically, or be generated by distributed electric currents, although the total computer time required for any calculation will increase if the magnetic field is defined in a more complex way.
4. The computer programs are all written in the S2 dialect of FORTRAN, and the results which are presented as examples were obtained with the IBM 7030 (Stretch) at A.W.R.E. Aldermaston, and a Benson-Lehner Model J automatic graph plotter at Culham. As often happens, these programs have undergone considerable modification since their initial conception. The result is that they are models neither of elegance nor efficiency although every effort has been made to ensure their accuracy and to make them as efficient as programming time permitted. Also, within the limits of the built-in options, the programs may be usefully and easily operated by people who are only marginally familiar with computing methods.

5. Where FORTRAN variable names are mentioned in the text these refer to definite data locations whose values the program user will assign; they are also described on the Data Sheets. Where FORTRAN subroutine names are mentioned, those subroutines must be supplied by the user.

6. It is hoped that this report describes the programs in sufficient detail for them to be usable by anyone with a nodding acquaintance with automatic computing. For those requiring more detailed information the FORTRAN listings are given in the appendix.

2. PROGRAM FOR PLOTTING CONTOURS OF $|B|$, PROGRAM I

SCOPE OF PROGRAM

7. This program supplies a picture of the spatial distribution of total field strength, in a magnetic field which is generated by a given configuration of filamentary conductors. The program user may specify any number of square plane regions intersecting the three-dimensional region of interest in the magnetic field, and selected contours of constant $|B|$ are plotted automatically in these planes. By combining properly chosen segments a three-dimensional, composite picture of the field strength distribution may be constructed.

ALLOWABLE TYPES OF FILAMENTARY CONDUCTORS

8. The basic arrangement for the filamentary conductors is an idealised generalisation of 'Ioffe geometry',⁽³⁾. It consists of any number of co-axial circles, whose axis is the z-axis of a rectangular, Cartesian co-ordinate system, and any number of infinitely long, straight conductors, parallel with the z-axis and intersecting an (x,y) plane at arbitrary points. The radii of the circles, their positions along the z-axis, and all currents are also arbitrary. Dimensions and currents specifying the configuration are read into the computer as part of the data. An example of this type of current configuration is shown in Fig.1.

9. In addition the user may specify any number of arbitrarily oriented, finite, straight conductors, also with arbitrary currents. These are defined by supplying the Cartesian co-ordinates of their end points, together with their currents, as data input.

10. To complete the list of allowable types of filamentary conductor, the user may specify an arbitrary number of completely general space curves, defined parametrically in a special subroutine which he must supply himself. Provision is made in the body of the program for the convenient input of supplementary defining data as well as the standard data for this type of conductor. For example, if a general curved conductor is specified by

$$\begin{aligned}x &= x(t) \\y &= y(t) \quad (t_1 \leq t \leq t_2) \\z &= z(t)\end{aligned} \dots (1)$$

then the functions $x(t)$, $y(t)$ and $z(t)$ must be defined in a subroutine, CURDEF, while the values of t_1 , t_2 and current, together with an integer specifying the number of integration steps along the curve, will be read in as standard data.

11. Any extra parameters required for the definition of $x(t)$, $y(t)$ and $z(t)$ must be read in CURDEF when a certain entry in its argument list is negative. The details of this should be evident from the complete example which follows in para.18 et seq.

ALLOWABLE TYPES OF CROSS SECTION

12. For plotting contours of $|B|$ the program user is allowed to specify two types of plane region intersecting the region of interest of the magnetic field. A plane region may be axial (lying in a plane containing the z -axis) or transverse (normal to the z -axis) and in either case it must be square. Axial regions have one pair of edges parallel to the z -axis, while transverse planes have their edges parallel to the x and y -axes (see Fig.2).

13. Each plane region is characterised in the data input by giving the co-ordinate values of its midpoint XMID, YMID, ZMID and edge-length L, and another parameter P which distinguishes between axial and transverse planes. A plane region will be treated as axial if

$$0 \leq P < 2\pi$$

and as transverse if P lies outside this range. However, note that θ , for the axial plane satisfies

$$\sin \theta = \frac{YMID_1}{\sqrt{XMID_1^2 + YMID_1^2}},$$

$$\cos \theta = \frac{XMID_1}{\sqrt{XMID_1^2 + YMID_1^2}},$$

except when $XMID_1 = YMID_1 = 0$, when $\theta = P$ radians.

OPERATION OF THE PROGRAM

14. Having read all the relevant data, the program will deal with each square, planar region in turn and, referring to the specified conductor configuration, will compute $|B|$ at every node of a regular, rectangular grid of points spanning the square. The values of $|B|$ are then regarded as spot heights in a $|B|$ surface and a standard subroutine, KONTUA (see appendix), interpolates contours of constant $|B|$ over the grid and effects the graphical output. The relevant contour heights are entirely at the disposal of the program user, and are read in as part of the input data. However, in any one case the contour heights

will be the same for all planes in which contours are plotted.

OUTPUT

15. The output from the program appears in two forms - printed and graphical. The printed output lists the input data for reference purposes, and also gives some diagnostic printing if this should be necessary. The graphical output, which is processed by an IBM 1401 computer and then used as input to a Benson-Lehner Model J automatic graph plotter, results in a square frame with the appropriate contour lines drawn in it. Each contour line is numbered with an integer (modulo 10) and the corresponding contour height may be found from a list in the printed output.

16. A composite picture of the surfaces of constant $|B|$ may be built up from as many axial and transverse planes as desired.

17. A steering parameter IGRID determines whether or not the array of $|B|$ values is to be printed out, (see Data Sheet).

A COMPLETE EXAMPLE

18. As a further guide to the use of the program we consider the following example which, although artificial, illustrates the main facilities available and can be used as a model, in conjunction with Data Sheet I, for cases of practical interest.

19. The conductor configuration is chosen as follows:

(a) Two co-axial circles with radii 1.0, normal to the z-axis, centred at $z = -1.5$, $z = +1.5$ and carrying currents -2.0 , $+2.0$ respectively. (i.e. a simple cusp configuration.)

(b) One infinitely long straight conductor, co-incident with the z-axis, carrying a current 1.0.

(c) Four finite, straight conductors forming a square of side 2.0, centred at the origin, whose plane is normal to the z-axis. A current of strength 3.0 flows anti-clockwise round the square, (as viewed in the positive z-direction).

(d) One conductor, curved rather like the seam on a tennis ball, whose parametric equation is

$$\left. \begin{aligned} x &= \lambda \left\{ a \cdot \cos \left(\theta + \frac{\pi}{4} \right) - b \cdot \cos 3\left(\theta + \frac{\pi}{4} \right) \right\}, \\ y &= \mu \left\{ a \cdot \sin \left(\theta + \frac{\pi}{4} \right) + b \cdot \sin 3\left(\theta + \frac{\pi}{4} \right) \right\}, \\ z &= c \cdot \sin (2\theta), \end{aligned} \right\} \quad \dots (2)$$

where

$$\left. \begin{aligned} \lambda &= 1 + d \cdot \sin (2\theta) = 1 + \frac{dz}{c} \\ \mu &= 1 - d \cdot \sin (2\theta) = 1 - \frac{dz}{c} \end{aligned} \right\} \quad \dots (3)$$

and

$$\theta = 2\pi t, \quad 0 \leq t < 1.0.$$

This curve actually lies on a sphere of radius $a+b$ if $d=0$ and $c^2=4ab \dots (4)$. In this example we take $a = 1$, $b = \frac{1}{2}$, $c = \sqrt{2}$, $d = 0$, and for the purposes of numerical integration we split the space curve into 32 elements. The current in the curve will be taken as 0.5. The complete FORTRAN subroutine defining this curve might appear as follows:-

```
SUBROUTINE CURDEF (T,X,Y,Z,J)
IF(J)1,1,2
1 READ 100,A,B,C,D
100 FORMAT(4F10.5)
PRINT 200,A,B,C,D
200 FORMAT(///,20X,4HA = ,F10.5,4HB = ,F10.5,4HC = ,F10.5,4HD = ,F10.5,///)
PIT2 = 2.0*3.14159265358979
PIB4 = 0.125*PIT2
RETURN
2 W = SIN(2.0*PIT2*T)
PHI = PIT2*T + PIB4
FLAM = 1.0 + D*W
FMU = 1.0 - D*W
X = FLAM*(A*COS(PHI) - B*COS(3.0*PHI)) }
Y = FMU*( A*SIN(PHI) + B*SIN(3.0*PHI) )
Z = C*W
RETURN
END
```

The name CURDEF and the form of the argument list are obligatory, but the actual details of the computation are at the discretion of the program user. Notice that J in the above subroutine is a function number which normally takes values 1, 2, ... NCUR; however after data specifying the conductor configuration has been read, and before any calculation is done, subroutine CURDEF is called NCUR times with J equal to -1, -2, ... -NCUR. This enables the program user, by testing the sign and magnitude of J, to read in any supplementary parameters required to define the curves. Alternatively he may specify them by FORTRAN statements and compile CURDEF afresh each time a different run is made. In the above example only one general, curved conductor is defined, and the supplementary parameters are A, B, C and D. Even if no general, curved conductors are required by the problem a dummy subroutine CURDEF is automatically included in the program to satisfy the computer operating system. This is ignored if the user inserts a version of his own.

20. Now suppose that we wish to plot contours of $|B| = 10, 15, 20, 25, 30, 35$ in the following regions:-

- A transverse square of side 1.0, centred at (0.5, 0.5, 0.5).
- An axial square of side 1.0, also centred at (0.5, 0.5, 0.5).

The two graphs are to be 10" square, and in order to plot the contours we instruct the program to compute $|B|$ on two regular, square meshes (21×21), one for each plane, so

that the mesh interval is 0.05. These computed values of $|B|$ are to be printed out for detailed study.

21. The data input is arranged as follows:-

2	1	4	1
2	21	21	1
6			
1			

EXAMPLE OF THE USE OF A PROGRAM FOR PLOTTING CONTOURS OF MAGNETIC FIELD STRENGTH

1.5	1.0	2.0
-1.5	1.0	-2.0
0.0	0.0	1.0
1.0	1.0	0.0
1.0	-1.0	0.0
-1.0	-1.0	0.0
-1.0	1.0	0.0
0.0	1.0	32
1.0	0.5	1.414
0.5	-1.0	0.0
0.5	1.0	2.0
10.0		
15.0		
20.0		
25.0		
30.0		
35.0		
10.0		
-1		

(Refer to Data Sheet I)

22. The corresponding printed output is shown in Fig.3. It is mainly concerned with listing the input data for reference purposes. The principal output is in graphical form and is shown in Figs.4 and 5. The total Stretch computer time required for this example was 2 minutes 30 seconds.

3. PROGRAM FOR PLOTTING STEREO PAIRS AND RADIAL EXCURSION OF MAGNETIC FIELD LINES, AND FOR EVALUATING INTEGRALS ALONG FIELD LINES BETWEEN MIRROR POINTS - PROGRAM II

SCOPE OF PROGRAM

23. This program was designed to facilitate the study of field lines, as opposed to field strength, in a magnetic field generated by a configuration of filamentary conductors. A field line is defined by specifying the Cartesian co-ordinates of any point which lies on the line. The program then numerically integrates the differential equations of the field line in two directions, using these co-ordinates as initial conditions. The integration terminates when either the magnetic field strength exceeds a prescribed value, or the line intersects the surface of a cylinder (e.g. the 'walls of the apparatus'), containing the specified region of interest. The differential equations of the field line are

$$\frac{dx}{ds} = \frac{B_x}{B}, \quad \frac{dy}{ds} = \frac{B_y}{B}, \quad \frac{dz}{ds} = \frac{B_z}{B}, \quad \dots (5)$$

where the magnetic field vector is denoted by (B_x , B_y , B_z),

$$B^2 = B_x^2 + B_y^2 + B_z^2 ,$$

and s is a distance measured along the length of the curved line. The numerical integration uses a 4th order Runge-Kutta⁽⁴⁾ method.

24. During the integration along a magnetic field line a number of options are available to the program user, viz:

- (a) A stereo pair of pictures of the field line may be automatically plotted.
- (b) The integral of a given function may be evaluated along the field line. The value of the integral will generally only be meaningful if the terminal points, and therefore the whole segment, lie strictly within the cylindrical region of interest.
- (c) A picture showing the radial excursion of the field lines, within the cylindrical region of interest, may be obtained by plotting $\sqrt{x^2 + y^2}$ against z .
- (d) As the integration proceeds along a field line, co-ordinates of points on the line may be printed out.

Any combination of these options is available by appropriately setting the steering parameters.

ALLOWABLE TYPES OF FILAMENTARY CONDUCTOR

25. The permitted conductor configuration for this program is precisely the same as for Program I.

THE CYLINDRICAL REGION OF INTEREST

26. Many magnetic field configurations which are of interest because of their possible use for confining plasma have an axis of symmetry, or at least a preferred axis of some description. The region of interest in the magnetic field is then usually a more or less cylindrical region centred on this preferred axis. The program user must specify the dimensions of this 'cylinder of interest' by supplying its radius RI, and semi-length ZTX. The cylinder will always be centred on the co-ordinate origin, with its axis coincident with the z-axis. Integration along a magnetic field line ceases as soon as it hits the surface of this cylinder.

NORMAL TERMINATION OF A MAGNETIC FIELD LINE

27. When investigating the stability of a plasma confined in a magnetic field it is sometimes of interest to evaluate certain integrals along field lines. The terminal points for such an integration are defined as the two nearest points along the field line, one on either side of the starting point, at which $|B|$ attains a prescribed value BREF. It will

be seen that this arrangement is convenient for a mirror field, which requires a local minimum of \underline{B} along any field line which is capable of confining plasma. The value of the integrand must be computed in a subroutine named INTGRD, supplied by the user, which is called by the operative part of the program when it is required.

28. Stereo pairs of field lines will be terminated at these 'mirror points', but plots of radial excursions of the field lines will only be terminated where they intersect the cylinder of interest.

THE STEREOSCOPIC PROJECTION SYSTEM

29. The eyes of a binocular observer are located at two points E_L and E_R lying in a horizontal plane (Fig.6), and converge to a centre of interest X_0 , which need not be in the same horizontal plane as the eyes. The z-axis is vertical, and X_1 is an unnormalised vector pointing from X_0 towards the midpoint of $E_L E_R$. A spherical region of interest is chosen with radius R_0 and centre X_0 , but the image may be dilated or contracted at will by applying a magnification factor XMAG. The magnified sphere may then be rotated azimuthally about the axis of vector X_1 through an angle PSI radians. After magnification and rotation, points within the sphere of interest are projected from E_L and E_R onto a plane distant F from $E_L E_R$, the separation between this plane and centre of the sphere being adjusted to minimise the strain on the eyes of the user. Finally the two images are drawn automatically, each one fitting into a square of side GSIZ inches, separated horizontally on one piece of paper by DISP inches.

30. The magnitude of vectors X_0 and X_1 , as well as the parameters R_0 , XMAG, PSI, F, D, DISP and GSIZ must be specified by the program user, and should be chosen to fit the binocular viewing apparatus which he will use to examine the pictures. These particular parameters have been placed at the disposal of the program user in order to give him a large degree of flexibility in 'mental manipulation' of the mathematical object, before finally viewing it from the selected aspect.

31. For routine use this flexibility may be an embarrassment, and the example given later in this section can be used as a guide.

THE STEERING PARAMETERS

32. The parameter ISTER has the following effect:-

ISTER

- ≤ -2 Suppresses both field line integrals and stereo pairs.
- -1 Field line integrals only are computed.
- 0 Both field line integrals and stereo pairs are computed.
- ≥ 1 Stereo pairs only are drawn.

Note that the stereoscopic projection data (see Data Sheet II) must be included only if
ISTER ≥ 0 ; otherwise it must be omitted.

33. The parameter IPLOT is concerned with drawing a graph of the radial excursions of the field lines.

IPLOT

≤ -1 Plotting of field lines' radial excursions suppressed.
 ≥ 0 Radial excursions of all field lines are plotted.

34. In addition, parameter IP, associated with each individual magnetic field line, determines whether or not the successive co-ordinate values along the line are printed out as integration of equations (5) proceeds:

IP

0 No co-ordinate values printed.
#0 Co-ordinate values printed.

Co-ordinate values are printed in cylindrical polar form as well as rectangular Cartesian form, and the current value of $|B|$ is also printed.

OUTPUT

35. There are two kinds of output - printed and graphical. The printed output lists the input data for reference purposes and also the co-ordinates of points along a field line if these have been requested. Some types of error condition also result in a printed warning.

36. The graphical output may be either a stereo pair of pictures of the specified magnetic field lines, or a graph of the radial excursions of these field lines. The stereo pair will also show any finite, straight conductors and general, curved conductors which lie inside the spherical region of interest (this should not be confused with the cylindrical region of interest assumed in integrating along field lines). In addition a circle is drawn, indicating the intersection of the plane $z = 0$ with the cylindrical region of interest. Coaxial circular conductors will not be shown but short lengths of the infinite straight conductors will be drawn.

37. The field of view of the stereo pair will just cover the sphere of interest of radius R_0 . The picture showing radial excursions of the field lines will exactly cover one half of an axial cross-section through the cylinder of interest, i.e. its dimensions will be $2(ZTX)$ horizontally, and RI vertically.

38. Although it is possible to obtain both types of graphical output simultaneously, the program was actually designed to provide them on separate runs. However, if the two types

are required together, notice that the same value of GSIZE will apply to both, i.e. the larger dimension of both the radial-excursion graph, and a single member of the stereo pair, will be scaled to GSIZE inches.

A COMPLETE EXAMPLE

39. As an example we consider the magnetic field to be generated by a unit electric current flowing in a single continuous loop around eight edges of a cube of side 2, centred on the origin of co-ordinates (Fig. 7). We run the program only once, but let it operate on two successive cases, the first case drawing a stereo pair and evaluating $\int \frac{ds}{B}$ along selected field lines, and the second case plotting radial excursions of these field lines with a detailed print-out of co-ordinates along one of them.

40. For the first case we set ISTER = 0, IPLOT = -1, GSIZE = 4.0, and for the second case ISTER = -2, IPLOT = 0, GSIZE = 10.0.

The following parameters will be common to both cases:-

NC = 0, NL = 0, NFB = 8, NCUR = 0.
NPB = 8, the number of field lines considered.
NBDS = 100, maximum allowed number of integration steps.
ZTX = 1.0, RI = 1.414.
DS = 0.05, integration step length.
BREF = 3.1.

41. The starting points of the eight magnetic field lines will be in the plane $z = 0$, equispaced around a circle, radius 0.3, centred on the origin. In case 2 we print out co-ordinates along the field line passing through the point (0.3, 0.0, 0.0). For case 1 we take the stereoscopic projection data as

$$\begin{aligned} \underline{X_0} &= (0.0, 0.0, 0.0) \\ \underline{X_1} &= (4.0, 2.0, 1.0) \\ R_0 &= 1.732, XMAG = 2.0, PSI = 0.0, F = 20.0, D = 1.25, DISP = 5.0. \end{aligned}$$

42. This choice of parameters results in an observer whose eyes are 2.5" apart viewing an object of $2 \times 1.732 \times 2.0 \approx 7"$ diameter from a distance of 20", and this 'natural' situation has been found to be satisfactory for most purposes.

43. The printed output resulting from this data input is shown in Fig.8, the stereo pair in Fig.9 and the radial excursion graph in Fig.10. The total Stretch computer time for this example was 1 min. 30 sec. Fig.10 shows that the graphs of radial excursions of field lines have been superimposed in three groups; this is due to the symmetry of the magnetic field and the starting points of the field lines.

4. PROGRAM FOR ASSESSING THE HYDROMAGNETIC STABILITY OF A LOW
β PLASMA CONFINED BY THE MIRROR EFFECT - PROGRAM III

PREAMBLE

44. In many cases of interest, the motion of a charged particle in a magnetostatic field⁽⁵⁾ may be analysed into three parts: a rapid rotation about a 'guiding centre', in a plane normal to the field; an oscillation of this guiding centre along a magnetic field line between two 'mirror points' with equal values of $|\underline{B}|$, and a relatively slow drift in the direction $\underline{B} \wedge \nabla B$, (where $B = |\underline{B}|$) .

45. If the spatial variation of \underline{B} is sufficiently slow then the quantities

$$\mu = \frac{E_{\perp}}{B} , \quad \dots (6)$$

and

$$J = \int_{M_1}^{M_2} \sqrt{2m(E - \mu B)} \cdot ds , \quad \dots (7)$$

are both constants of the motion, where E_{\perp} is the energy of the particle normal to the magnetic field, m is the mass of the particle, and the integral is evaluated along a field line between the mirror points M_1 and M_2 .

46. Equations (6) and (7) may be regarded as defining a function

$$E = E(\mu, J, a, \beta) , \quad \dots (8)$$

where (a, β) signify the 'co-ordinates of a field line' in a direction transverse to the magnetic field. J.B. Taylor⁽²⁾ has discussed the importance of the surfaces.

$$E(\mu, J) = \text{constant} \quad \dots (9)$$

in assessing the hydromagnetic stability of a plasma whose pressure is small compared with the magnetic pressure.

SCOPE OF THE PROGRAM

47. Working with a fixed E and μ , and a specified magnetic field, the program evaluates a matrix of J values, computed according to equation (7), from starting points at the nodes of a regular rectangular grid. This grid spans a given square, planar region normal to the z -axis, called the 'J-plane'. A contour of specified height J_0 is then drawn. It represents a 'drift curve', i.e. the intersection between the J-plane, and the three-dimensional surface on which the guiding centre of a particle with constants of motion (E, μ, J_0) is constrained to move. The complete surface may be obtained by projecting the drift curve in both directions, along the magnetic field lines passing through it, as far as the surface

$$B(x, y, z) = \frac{E}{\mu} . \quad \dots (10)$$

49. This procedure may now be repeated for different values of E , but the same values of μ and J_0 , resulting in a series of energy contours in the transverse plane. The hydromagnetic stability of a plasma in the prescribed magnetic field turns on whether a depression occurs in the corresponding 'energy surface', for values of E, J which are represented in the plasma distribution. A localised depression in this energy surface represents a localised region where the plasma will be confined and be stable against interchange instabilities⁽²⁾.

ALLOWABLE TYPES OF FILAMENTARY CONDUCTOR

49. The permitted conductor configuration for this program is precisely the same as that for Program I.

SPECIFICATION OF THE CONSTANTS OF MOTION

50. Two options are available for setting up the initial constants μ and J_0 , as follows:

- (a) For the first option one can regard the program as simulating the injection, and subsequent ionization by the Lorentz force⁽¹⁾, of an energetic neutral particle. A particle of unit mass is assumed to be injected, with kinetic energy EK , in some plane

$$x = XPAR \quad \dots (11)$$

Fig.11 shows a projection, onto the plane $x = 0$, of the geometry involved. The velocity of the neutral particle is

$$v = \sqrt{2EK} , \quad \dots (12)$$

and ionization is assumed to occur when

$$|v \wedge B| \geq EI , \quad \dots (13)$$

EI being a prescribed value of electric field required to produce ionization. At the point of ionization the transverse energy is computed, from the local angle between the magnetic field and the injection line, and μ is then found from equation (6). The basic contour height J_0 is then evaluated according to equation (7), starting the integration from the ionization point. This value J_0 is used for all the ancillary energies which are read in, as well as for the injection kinetic energy. This first option is assumed to be required if EI is set greater than or equal to zero in the input data.

(b) The second option, which is obtained by setting $EI < 0$ in the input data, makes it possible to prescribe an ionization position and a value of μ , without reference to any injection system. In this case the ionization position is $(XPAR, YPAR, ZPAR)$ and the given value of μ is FMU, on the data sheet. Subsequent calculations are identical with the first option.

SOME REMARKS ON THE EVALUATION OF J

51. As in Program II, the user of the present program must define a cylindrical region of interest, radius RI, semi-length ZTX. Values of $|B|$ are computed at intervals along the whole section of a field line which is contained within the cylinder of interest, and in general there may be several mirror points along the line.

52. In Fig.12, $|B|$ is plotted as a function of distance along the magnetic field; the two upper horizontal lines represent two different values of $\frac{E}{\mu}$. S_1 and S_2 are the points where the field line is truncated by the cylinder of interest. If the starting point for the J integral is S_0 , then the region of integration in the case of $\frac{E}{\mu} = P$ is between the mirror points G and H. However, in the case $\frac{E}{\mu} = Q$, the region between mirror points A and B may be a valid integration region, as well as that between the points C and D, since a particle may start in the latter region and finish up in the former during the course of its drift in the $B \wedge \nabla B$ direction. Whether or not this transfer is in fact possible depends on the topology of the surfaces $|B| = \text{constant}$, relative to the field lines themselves.

53. The computer program is not capable of assessing topological properties of fields directly and is designed to cope only with the case of a single mirror region, within the cylinder of interest, on any magnetic field line. However, it will count the number of integration regions along any field line which it examines, and print out a 'matrix of puddle counts', every component of which corresponds to a component of the matrix of values of J which is also printed out. The puddle count only includes complete puddles, not those of the form EF in Fig.12. The final energy surfaces, therefore, will only provide an indication of plasma stability in the region of the J -point where the 'puddle counts' are all unity. In practice this limitation does not appear to be serious, since magnetic fields of the type for which the program was intended are usually designed to have either one single minimum, or several widely separated local minima, in $|B|$. Note that a component in any J matrix will be set to zero unless its associated 'puddle count' is unity.

THE J -PLANE PARAMETERS

54. The J-plane, containing the rectangular grid of points which form starting positions for the purpose of evaluating $J(E, \mu, \alpha, \beta)$, is a square region normal to the z-axis, with sides parallel with the x and y axes. The edge length is EDGE, in Data Sheet III, and the x and y co-ordinates respectively of the mid point of the plane are XMID and YMID in the Data Sheet. The z position of the J-plane is taken as the z co-ordinate of the point of ionization of the original, neutral, injected particle. This value is computed

by the program in the first option and specified by the user in the second option. The dimensions of the rectangular grid are NX by NY.

OUTPUT

55. Output from the program is in two forms - printed and graphical. The printed output lists the input data for reference purposes and also some quantities which are computed prior to the main calculations. These include the integration step length, which is taken as

$$DS = 0.02 \sqrt{R_i^2 + ZTX^2} \quad \dots (14)$$

the magnetic moment μ , and the constant J_0 , at the point of ionization, the components and magnitude of the magnetic field at the point of ionization and the magnitude of the field at the mirror points. This last quantity is found simply from the relation

$$|B| = \frac{E_K}{\mu}, \text{ at reflection.} \quad \dots (15)$$

56. The matrix of J values is printed out for every energy, together with its associated matrix of 'puddle counts', if the steering parameter IGRID is set different from zero. If IGRID is zero this print out will take place only for the injection kinetic energy.

57. The graphical output consists of a picture of the contours, all drawn at height J_0 , in the J surfaces corresponding to the different specified energies, as described in paragraphs 47 and 48. The contour corresponding to the injection kinetic energy is numbered 1, and the other contours are numbered 2, 3, ... etc., in order of input of the remaining energies. Thus the contours represent contours in an 'energy surface' for given μ and J_0 .

A COMPLETE EXAMPLE

58. In order to illustrate the use of this program we consider an idealised, quadrupole Ioffe apparatus, consisting of a pair of co-axial coils, radius 1.0 and separation 2.0, together with four infinitely long conductors parallel with the z-axis, regularly disposed about the axis of the circles. The currents in the two circular conductors are in the same sense and of magnitude 1.0, while the currents in the four infinite, straight conductors are of magnitude 2.0, adjacent currents being anti-parallel.

59. We shall consider a J-plane of edge length 0.35, in the plane $z = 0$, centred on the point (0.175, 0.175), and start the calculation by injecting a neutral particle along the y-axis in a positive direction, set to ionize when $|v \wedge B| = 4.35$. Grid dimensions will be 20 by 20 and the matrices will be printed out only for the injection kinetic energy.

60. The kinetic energy of the injected particle will be 0.5, and contours will also be

drawn in the energy surface at heights corresponding to $E = 0.492, 0.496, 0.504, 0.508, 0.512, 0.516, 0.520, 0.524, 0.528, 0.532$ and 0.536 . The radius of the cylinder of interest will be 1.0 , and its total length will be 2.0 . The final graph size will be 17.5 cm. or 6.89 inches.

61. The printed output for this example is shown in Fig.13 and the graphical output in Fig.14.

62. The total Stretch computer time required for this example was 12 mins. 12 secs. Notice that, referring to the matrix of 'puddle counts' in the printed output, the irregularities around the top and right hand edges are due to puddle counts of 0 and 2 in these regions.

5. PROGRAM FOR ASSESSING THE HYDROMAGNETIC STABILITY OF A
LOW β PLASMA CONFINED BY THE MIRROR EFFECT IN A
CYLINDRICALLY SYMMETRIC MAGNETIC FIELD - PROGRAM IV

SCOPE OF PROGRAM

63. The purpose and scope of this program are exactly the same as for Program III except for a restriction upon the type of magnetic field considered. In cases where Program IV is applicable it will be much more economical with computer time than will Program III.

64. As in Program III, values of $\frac{J}{\mu^{\frac{1}{2}}}$, defined by

$$\frac{J}{\mu^{\frac{1}{2}}} = \sqrt{2} \int \sqrt{\frac{E}{\mu} - B \cdot ds} \quad \dots (16)$$

are computed by integrating along field lines in a region of relatively low $|B|$ between pairs of mirror points. The starting points for the integrations lie in the plane $z = ZSTART$, and are equispaced between the radial positions RMIN and RMAX. It should be noted that RMIN must be greater than zero in order for the program to work. The J integrals are evaluated for a range of energies, equispaced between EMIN and EMAX. The result is that values of $\frac{J}{\mu^{\frac{1}{2}}}$ are evaluated at the nodal points of a uniform rectangular grid, of dimensions NR by NE, spanning a rectangular region in the radius-energy plane. Contours of constant $\frac{J}{\mu^{\frac{1}{2}}}$ are now drawn in the surface defined by the spot heights at the nodal points, the graphical output being effected automatically. The heights of these contour lines, NJ in number, are equispaced between the values FJMIN and FJMAX.

65. Remarks on the cylindrical region of interest and normal termination of magnetic field lines, made in previous sections, also apply to this program.

ALLOWABLE TYPES OF FILAMENTARY CONDUCTOR

66. The only conductors allowed are an arbitrary number of circles co-axial with the z-axis, and an infinite line current of arbitrary magnitude along the z-axis itself. The radii of the circles, and their currents, are completely arbitrary.

OUTPUT

67. Output from the program is in two forms, printed and graphical. The printed output lists the input data for reference purposes, and can also contain some diagnostic information in case of an input error. The computed matrix of values of $\frac{J}{\mu^2}$, together with its associated matrix of 'puddle counts' (see previous programme), is also printed out.

68. The graphical output, as mentioned previously, consists of a contour map of the $\frac{J}{\mu^2}$ surface over the specified rectangular region in the radius-energy plane. A special problem of scaling arises here because $(EMAX-EMIN)$ may be a different numerical order of magnitude from $(RMAX-RMIN)$. However, the user may specify a constant FMU, which represents the magnetic moment μ , and by a suitable choice of FMU he can ensure that the interesting range of energy is of the same order of magnitude as $(RMAX-RMIN)$. This is possible because only $\frac{E}{\mu}$ enters in the integral for J .

69. Unlike the previous program a component of the $\frac{J}{\mu^2}$ matrix is not set to zero if its associated 'puddle count' is greater than one; however, it will be zero if its 'puddle count' is zero. Notice also that this program prints matrices of $\frac{J}{\mu^2}$ values, whereas the previous program prints matrices of J values.

A COMPLETE EXAMPLE

70. To illustrate the use of this program we consider a magnetic field generated by a pair of equal, co-axial coils carrying equal, antiparallel currents, together with an infinite line current along the common axis. The radii of the coils will be 1.0, their separation 1.0 and their currents ± 1.0 ; the axial current will be 0.1. The grid dimensions in the radius-energy plane will be 20 by 20, with RMIN = 0.05, RMAX = 0.75 and EMIN = 0.3, EMAX = 1.0. Ten contours will be drawn in the $\frac{J}{\mu^2}$ surface between the values FJMIN = 0.0 and FJMAX = 2.0. FMU will be taken as 0.2.

71. The radius and semi-length of the cylinder of interest will be 0.8 and 0.4 respectively, and the starting points for the J integrals will lie in the plane ZSTART = 0.1. The integration step length, along the field lines, will be 0.05 and we shall take GSIZE = 10.0.

72. The printed output from this example is shown in Fig.15 and the graphical output

appears in Fig.16. Total Stretch computer time required for this example was about 2 minutes.

73. Once again irregularities around the edge of the picture are due to puddle counts other than unity. The region of stable containment, indicated by contours of positive slope, is concentrated more or less towards the centre of the picture.

6. PROGRAM FOR STUDYING THE IONIZATION OF NEUTRAL ATOMS INJECTED INTO A MAGNETIC TRAP - PROGRAM V

SCOPE OF PROGRAM

74. This program simulates the trapping, by Lorentz ionization, of neutral atoms injected into a magnetic field⁽¹⁾. Neutral atoms of unit mass are injected with unit velocity along a straight line into the field. The point at which ionization occurs may be specified by the user or may be computed as that point at which the Lorentz electric field $|v \wedge B|$, first exceeds a prescribed value. Once ionized the particle may then oscillate between a pair of mirror points along a magnetic field line. The strength of the magnetic field at the mirror points is given by

$$B_m = B_i \cdot \left(\frac{v}{v_{\perp}}\right)^2 \quad \dots (17)$$

where B_i is the field strength, and v_{\perp} the component of velocity of the particle perpendicular to the field at the point of ionization; v , the injection velocity of the particle is taken as unity. The Larmor radius of the ionized particle is assumed to be negligibly small.

75. The program evaluates $|v \wedge B|$ at a sequence of points along that part of the injection trajectory which lies inside a cylinder of interest, of radius R_I and semi-length Z_{TX} . It also draws a graph of radial excursion, between the mirror points, of the ionized particle, plotted against the z co-ordinate of its position.

76. A number of neutral particles may be injected consecutively along the same, or different, path and their subsequent radial excursions will be superimposed on the same graph.

ALLOWABLE TYPES OF FILAMENTARY CONDUCTOR

77. The permitted conductor configuration is precisely the same as that for Program I.

GEOMETRY OF THE INJECTION SYSTEM

78. Apart from restriction of the injected particles to unit velocity, the injection

system is precisely the same as described in para.50. An injection line must lie in the plane $x = XP$, and the impact parameters d and θ are referred to in the Data Sheet as DP and TP respectively.

79. The steering parameter INJ controls the choice of ionization option as follows:

(a) $INJ < 0$

The quantity ER, appearing on the same card as XP, DP and TP, is interpreted at the critical value of $|v \wedge B|$ at which ionization of the injected particle must occur. As soon as this value is exceeded the subsequent path of the ionized particle is determined by the magnetic field.

(b) $INJ \geq 0$

In this case the quantity ER will be interpreted as the radius (i.e. perpendicular distance from the z-axis) at which the particle is to be ionized. Fig.17 shows an axial view of the injection system which illustrates this. Again, after ionization the subsequent path of the particle between its mirror points is completely determined by the magnetic field.

OUTPUT

80. The output from this program is of two types - printed and graphical. The printed output lists the input parameters for reference purposes and if $INJ \geq 0$ it also includes a table, for each separate particle, of $|v \wedge B|$ at intervals of $\frac{RI}{20}$. Some ancillary computed parameters, such as the co-ordinates of ionization and mirror points, and components and strength of the magnetic field at the ionization point, are also printed out.

81. The graphical output consists of a picture of the radial excursion of each ionized particle as it oscillates along a magnetic field line between its mirror points. This, of course, is only the initial stage of its motion subsequent to ionization. These graphs are superimposed, and each separate line is numbered so that tracks of separate particles may be distinguished. The ionization and mirror points for each particle are indicated on the picture by dots.

A COMPLETE EXAMPLE

82. In order to illustrate the use of this program we consider again the magnetic field configuration described in para. 58. We inject four neutral particles, along an injection line defined by the impact parameters $XP = 0.05$, $DP = 0.1$ and $TP = 0.15$ radians, and specify that these particles be ionized at radii 0.1 , 0.2 , 0.3 and 0.4 respectively. The radius and semi-length of the cylinder of interest will be 0.7 and 0.6 respectively. Fig.18 illustrates the printed output from this input data, and the graph

of the radial excursions of the ionized particles is shown in Fig.19. The total Stretch computer time required for this example was about 2 minutes.

7. PROGRAM FOR PRODUCING TEMPLATES OF MAGNETIC FIELD LINES IN AN IDEALISED, SYMMETRIC IOFFE APPARATUS - PROGRAM VI

SCOPE OF PROGRAM

83. The purpose of this program is to produce pictures of transverse, plane cross-sections through a Ioffe-type magnetic field, showing the points of intersection between a prescribed set of magnetic field lines and these planes. The pictures may then be used as working templates from which transverse sections, for example in perspex, may be made and stacked together to form a three dimensional model of the magnetic field.

ALLOWABLE TYPES OF FILAMENTARY CONDUCTOR

84. The magnetic field with which this program operates is much more restricted than that of the previous programs described in this report, since only circles co-axial with the z-axis, and infinite lines parallel with the z-axis, are allowed as conductors, and an implicit assumption that the field is of the Ioffe type is written into the program. That is, every circular coil must have a 'mirror image' coil, the reflection plane being $z = 0$, and there must be an even number of infinite conductors, equispaced on the surface of a circular cylinder whose axis is the z-axis, with adjacent lines carrying equal, anti-parallel currents. A schematic transverse cross-section of such a configuration, with six infinite conductors, is shown in Fig.20. Curved arrows indicate the general direction of the magnetic field.

85. Notice that any given field line must lie wholly within one single sector (i.e. region between two adjacent planes of symmetry containing exactly one infinite line conductor) and cannot cross a plane of symmetry. The program makes use of the assumed symmetry by computing a field line only in the sector of the given starting point and then effectively reflecting the whole line into adjacent sectors until all are accounted for. This results in a considerable economy in computing time at the expense of flexibility.

86. Although the above assumptions are implicit in the main body of the program they are not implicit in the input data and the relevant dimensions for all circular and linear conductors of the symmetric configuration must be explicitly entered. This is to ensure compatibility of conductor data with any of the other previous programs.

THE TRANSVERSE SECTIONS

87. As in the previous programs the region of interest is supposed bounded by a cylinder, co-axial with the z-axis, of radius RI and semi-length ZTX, centred on the origin. The number of transverse sections plotted is 2.NZT - 1, equispaced along the axis of the cylinder of interest, so that NZT sections occupy a length ZTX. These cross-sections are in the form of squares, of edge length 2.RB, centred on the z-axis with edges parallel with the x- and y-axes. Thus RB is the radius of the largest circle which can be inscribed in the plotted region of the cross-sections.

THE FIELD LINES

88. The magnetic field lines considered by the program are specified by giving the x and y co-ordinates of their intersections with the plane $z = 0$. Co-ordinates of points along the lines are then found by numerically integrating equations (5), in both directions away from these starting points, by a 4th order Runge-Kutta method using an integration step length DS. Field lines are terminated at their points of intersection with the cylinder of interest.

89. Because of the assumed symmetry of the system it is necessary to specify starting points of field lines in only one sector; the resulting field lines will then be duplicated into adjacent sectors by reflection in the planes of symmetry. The number of field line starting points in any one sector is NPB, so the final total number of field lines will be NL.NPB, since the number of sectors is equal to NL, the number of infinite straight conductors.

OUTPUT

90. The output from this program consists of two forms - printed and graphical. The printed output lists the input data for reference purposes, prints the z positions of all the transverse planes on which the field line positions are to be plotted and can also indicate some types of input error.

91. The graphical output consists of pictures of the transverse, square regions considered. Each picture is numbered with a reference between -NZT and +NZT and its z position may be found by referring to the printed output. The positions of the infinite straight conductors are marked on every picture and lines indicating the planes of symmetry are also drawn. Numbered points printed on the pictures indicate the places where field lines intersect the planes, and the track of any one of the field lines considered may be found by tracing the point marked by the reference number of that line as it alters from picture to picture.

Reference numbers are assigned to field lines in the order in which the starting points are read into the machine. Line numbers appearing in any one symmetry sector will all be different but will be repeated in other sectors by the reflection process described earlier. If a field line leaves the cylinder of interest through the curved surface another one, bearing the same number, is 'injected' at the opposite side of the same sector.

92. If RB is chosen to be so small that a point to be plotted falls outside the allowed area (a square of side $2.RB$) this fact will be indicated in the printed output.

A COMPLETE EXAMPLE

93. The magnetic field for the example will again be taken as generated by the conductor configuration described in para. 58. The total number of transverse cross-sections will be 9, so that NZT is 5, and the radius and semi-length of the cylinder of interest will both be 1.0. We take $RB = 1.001$, to be sure of just including the infinite straight conductors at the four corners, and the final graph size will be 10 inches square. The integration step length will be 0.02.

94. We shall plot the positions of 5 field lines in one quadrant starting from positions
 $(0.227, 0.115)$, $(0.115, 0.227)$, $(0.155, 0.580)$, $(0.424, 0.424)$, $(0.580, 0.155)$
in the plane $z = 0$.

95. The printed output from this example is shown in Fig.21, and Figs.22, 23 and 24 show transverse cross-sections at $z = 0.0$, 0.25 and 0.5 respectively. The process of automatic re-injection of field lines is illustrated by lines 4 and 5. These are lost from the lower right of the first quadrant and appear again in the top left, and the other quadrants are treated correspondingly. Total Stretch computer time for this example was about 1 minute.

8. MODELS OF A REPRESENTATIVE 'MINIMUM B' MAGNETIC FIELD

96. The idealised, quadrupole Ioffe conductor configuration described in para. 58 and used as an example on subsequent occasions is representative of the main features of a general type of magnetic field, viz. a field containing a local minimum in $|B|$. The magnetic field lines and surfaces of constant $|B|$ have a spatial distribution which is sufficiently complex for a three dimensional model to be a valuable means of displaying geometric details of the system.

97. The computer programs described in this report have been used, among other things, for the purpose of studying this standard, simple configuration and two models have been built to display the essential features of the magnetic field. Plate I is a photograph of a

model made in thin cardboard. The transverse (horizontal) sections and the axial (vertical) sections are fitted together in eggbox fashion and are bounded by a surface, $|B| = \text{constant}$, which is just not closed. Closed $|B| = \text{constant}$ surfaces are indicated by intersections drawn on the cardboard. Magnetic field lines are represented by coloured wires threaded through holes in the cardboard, and these have been chosen to display drift surfaces, i.e. surfaces whereon the guiding centres of particles with given energy and adiabatic invariants μ and J must be constrained to lie. The inner drift surface, whose ends are truncated at the surface of constant $|B|$ where the particles would be reflected, lies in a region of stable plasma confinement, and the outer surfaces lie in unstable regions.

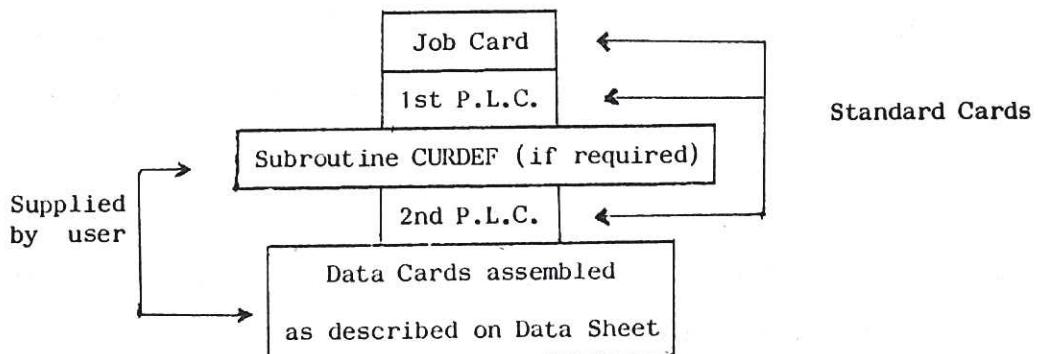
98. The conductors are not shown in this model, but the mirror coils may be imagined to lie, concentric with the vertical supporting rod, a little below and above the lowest and highest planes of which the model is constructed. The infinite, straight conductors may be imagined to be vertical and situated roughly between the 'ears' which are disposed tetrahedrally about the centre.

99. A rather more detailed model of the same magnetic field configuration has been constructed of thin perspex sheets. This also shows surfaces of constant $|B|$, magnetic field lines and drift surfaces, thus illustrating stable and unstable regions of plasma confinement. A picture of this perspex model would serve only to indicate its complexity, so one has not been included in this report.

100. The cardboard model in Plate I was made by Dr. K.V. Roberts and the author.

9. OPERATION USING THE CULHAM PROGRAM LIBRARY SYSTEM

101. The easiest way of using the programs described in this report is to assemble card input decks from Program Library Cards and data cards, rather than from actual program cards. As far as a program user is concerned a Program Library Card is the logical equivalent of a complete computer program, or part of a program. This system results in the elimination of a great deal of unnecessary card handling. The present programs are each represented by two Program Library Cards, and the card input decks should be assembled as follows:-



Every Program Library Card has its own permanent reference number (the first number on the card); the reference numbers appropriate to the present programs are listed in Table 1.

102. Except in the case of stereo pairs in Program II all graphical output may be automatically transferred to the Stromberg-Carlson 4020 microfilm recorder (situated at A.W.R.E. Aldermaston) by the simple expedient of including Program Library Cards 001, 127, and 153 immediately before the '2nd P.L.C.' in the diagram. The stereo pairs in Program II will automatically appear on the S-C 4020 if input parameter F is ≤ 0 . Note that if S-C 4020 output is expected the appropriate control cards should be inserted before the first Program Library Card.

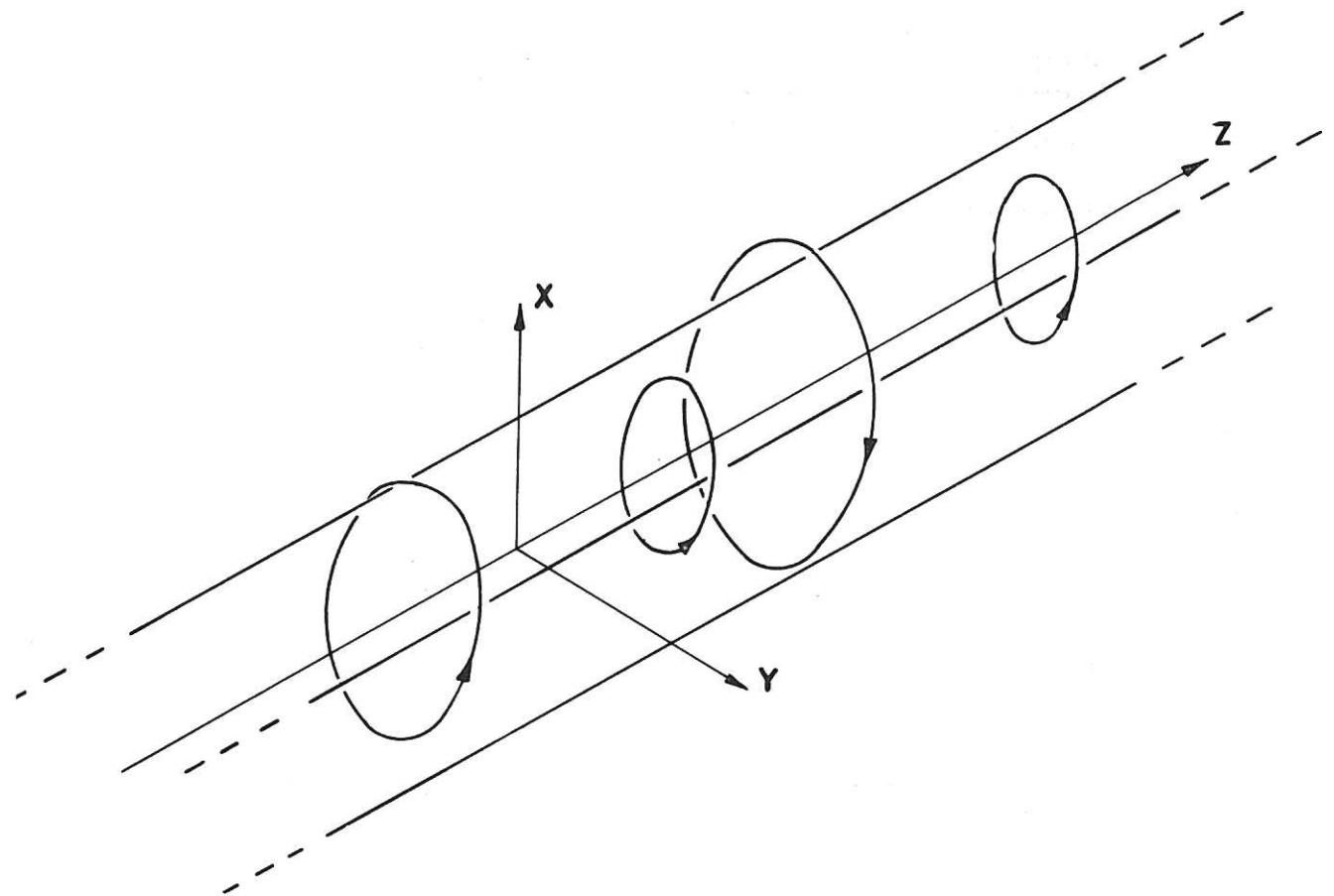
TABLE 1

Number	Program Description	Reference Numbers	
		1st P.L.C.	2nd P.L.C.
I	Contours of constant $ B $	261	267
II	Stereo pictures and/or field line integrals and/or radial excursions of field lines.	262	267
III	Energy surfaces in a general magnetic field.	263	267
IV	Energy surfaces in a cylindrically symmetric magnetic field.	264	267
V	Injection of neutral particles into a magnetic trap.	265	267
VI	Production of templates of field lines in a Ioffe apparatus.	266	267

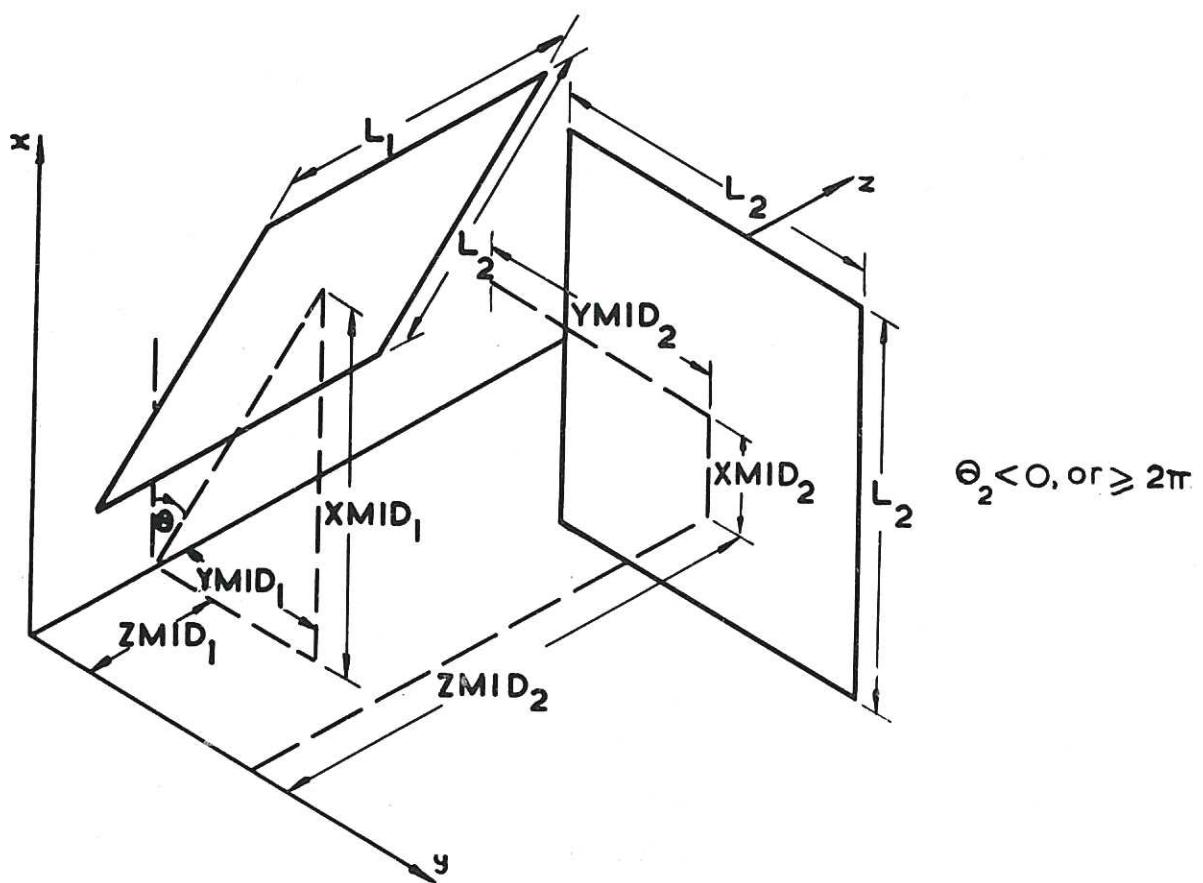
103. A dummy subroutine CURDEF comprises part of the first Program Library Card (except in the case of Program VI), so the system operating requirements will be satisfied even if the user does not load his own subroutine. If the user does load his own subroutine CURDEF, which must be preceded by a standard (S2) card, it will supersede the dummy.

10. REFERENCES

1. See, for example, 'THOMPSON, W.B. An introduction to plasma physics. Oxford, Pergamon Press, 1962'.
2. TAYLOR, J.B. Equilibrium and stability of plasma in arbitrary mirror fields. CLM - P 36, January, 1964.
3. GOTTL, Yu.V., IOFFE, M.S. and TELKOVSKY, V.G. Some new results on confinement in magnetic traps. I.A.E.A. Conference on Plasma Physics and Controlled Nuclear Fusion Research, Salzburg, September, 1961. Proceedings, Nuclear Fusion 1962 Supplement, part 3, pp.1045 - 1047, 1962.
4. See, for example, 'LEVY, H. and BAGGOTT, E.A. Numerical solutions of differential equations. New York, Dover Publications, 1950'
5. See, for example, 'SPITZER, L. Physics of fully ionized gases. 2nd ed. New York, Intersciences, 1962'.



CLM - R31 Figure 1: Example of basic conductor configuration. (See paragraph 8)



CLM - R31 Figure 2: Examples of allowable types of cross-section. (See paragraph 12)

SPECIFICATION OF CIRCULAR CONDUCTORS

H(CENTRE)	RADIUS	CURRENT
1.5000000	1.0000000	2.0000000
-1.5000000	1.0000000	-2.0000000

SPECIFICATION OF LINEAR CONDUCTORS

X	Y	CURRENT
0.	0.	1.0000000

SPECIFICATION OF FINITE, STRAIGHT CONDUCTORS

X1	Y1	Z1	X2	Y2	Z2	CURRENT
1.0000	1.0000	0.	1.0000	-1.0000	0.	3.0000
1.0000	-1.0000	0.	-1.0000	-1.0000	0.	3.0000
-1.0000	-1.0000	0.	-1.0000	1.0000	0.	3.0000
-1.0000	1.0000	0.	1.0000	1.0000	0.	3.0000

DATA RELEVANT TO GENERAL CURVED CONDUCTORS

T1	T2	NT	CURRENT
0.	1.0000000	32	0.5000000

A = 1.00000 B = 0.500000 C = 1.41400 D = 0.

SPECIFICATION OF PLANES OF INTEREST

Z	THETA	SIZE	X MID	Y MID
0.5000000	-1.0000000	2.0000000	0.5000000	0.5000000
0.5000000	1.0000000	2.0000000	0.5000000	0.5000000

ROW

1 0.7909E C1 0.8104E 01 0.8236E 01 0.8313E 01 0.8341E 01 0.8323E 01 0.8264E 01 0.8165E 01 0.8028E 01 0.7850E 01
C.7628E C1 0.7352E 01 0.7011E 01 0.6589E 01 0.6078E 01 0.5490E 01 0.4862E 01 0.4247E 01 0.3685E 01 0.3196E 01
2 0.9597E 01 0.9791E 01 0.9916E 01 0.9982E 01 0.9997E 01 0.9967E 01 0.9895E 01 0.9784E 01 0.9636E 01 0.9449E 01
0.9218E 01 0.8930E 01 0.8560E 01 0.8073E 01 0.7433E 01 0.6641E 01 0.5768E 01 0.4922E 01 0.4178E 01 0.3557E 01
3 0.1156E C2 0.1172E 02 0.1182E 02 0.1186E 02 0.1185E 02 0.1180E 02 0.1172E 02 0.1160E 02 0.1146E 02 0.1128E 02
0.1107E 02 0.1081E 02 0.1046E 02 0.9958E 01 0.9189E 01 0.8105E 01 0.6849E 01 0.5667E 01 0.4691E 01 0.3921E 01
4 0.1364E C2 0.1373E 02 0.1378E 02 0.1378E 02 0.1374E 02 0.1367E 02 0.1357E 02 0.1346E 02 0.1333E 02 0.1319E 02
0.1305E 02 0.1288E 02 0.1263E 02 0.1219E 02 0.1131E 02 0.9791E 01 0.7958E 01 0.6361E 01 0.5153E 01 0.4252E 01
5 0.1553E C2 0.1552E 02 0.1549E 02 0.1543E 02 0.1535E 02 0.1525E 02 0.1514E 02 0.1504E 02 0.1495E 02 0.1489E 02
0.1484E 02 0.1481E 02 0.1471E 02 0.1431E 02 0.1313E 02 0.1099E 02 0.8531E 01 0.6745E 01 0.5465E 01 0.4512E 01
6 0.1681E 02 0.1670E 02 0.1659E 02 0.1646E 02 0.1633E 02 0.1620E 02 0.1609E 02 0.1601E 02 0.1597E 02 0.1598E 02
0.1604E 02 0.1613E 02 0.1609E 02 0.1541E 02 0.1327E 02 0.1008E 02 0.7967E 01 0.6665E 01 0.5595E 01 0.4694E 01
7 0.1721E 02 0.1703E 02 0.1685E 02 0.1667E 02 0.1649E 02 0.1634E 02 0.1622E 02 0.1616E 02 0.1616E 02 0.1623E 02
0.1635E 02 0.1645E 02 0.1625E 02 0.1503E 02 0.1206E 02 0.8785E 01 0.7267E 01 0.6492E 01 0.5668E 01 0.4842E 01
8 0.1676E 02 0.1658E 02 0.1637E 02 0.1615E 02 0.1594E 02 0.1576E 02 0.1562E 02 0.1557E 02 0.1560E 02 0.1570E 02
0.1581E 02 0.1579E 02 0.1530E 02 0.1371E 02 0.1090E 02 0.8484E 01 0.7349E 01 0.6627E 01 0.5833E 01 0.5009E 01
9 0.1577E 02 0.1563E 02 0.1542E 02 0.1519E 02 0.1496E 02 0.1474E 02 0.1459E 02 0.1452E 02 0.1456E 02 0.1468E 02
0.1478E 02 0.1469E 02 0.1409E 02 0.1265E 02 0.1063E 02 0.8980E 01 0.7927E 01 0.7030E 01 0.6109E 01 0.5214E 01
10 0.1460E 02 0.1449E 02 0.1432E 02 0.1410E 02 0.1385E 02 0.1360E 02 0.1341E 02 0.1332E 02 0.1337E 02 0.1352E 02
0.1366E 02 0.1365E 02 0.1325E 02 0.1232E 02 0.1104E 02 0.9776E 01 0.8634E 01 0.7521E 01 0.6436E 01 0.5440E 01
11 0.1350E 02 0.1341E 02 0.1329E 02 0.1314E 02 0.1291E 02 0.1262E 02 0.1236E 02 0.1222E 02 0.1227E 02 0.1246E 02
0.1271E 02 0.1287E 02 0.1280E 02 0.1235E 02 0.1155E 02 0.1040E 02 0.9250E 01 0.7973E 01 0.6750E 01 0.5656E 01
12 0.1259E 02 0.1253E 02 0.1252E 02 0.1254E 02 0.1245E 02 0.1213E 02 0.1170E 02 0.1144E 02 0.1144E 02 0.1167E 02
0.1201E 02 0.1236E 02 0.1256E 02 0.1245E 02 0.1192E 02 0.1097E 02 0.9705E 01 0.8329E 01 0.7008E 01 0.5838E 01
13 0.1193E 02 0.1189E 02 0.1208E 02 0.1255E 02 0.1303E 02 0.1281E 02 0.1189E 02 0.1119E 02 0.1100E 02 0.1119E 02
0.1158E 02 0.1204E 02 0.1242E 02 0.1252E 02 0.1215E 02 0.1127E 02 0.9999E 01 0.8572E 01 0.7191E 01 0.5971E 01
14 0.1146E 02 0.1146E 02 0.1193E 02 0.1337E 02 0.1635E 02 0.1738E 02 0.1376E 02 0.1163E 02 0.1097E 02 0.1101E 02
0.1137E 02 0.1188E 02 0.1233E 02 0.1253E 02 0.1225E 02 0.1142E 02 0.1015E 02 0.8703E 01 0.7294E 01 0.6045E 01
15 0.1123E 02 0.1117E 02 0.1178E 02 0.1424E 02 0.2581E 02 0.5436E 02 0.1730E 02 0.1241E 02 0.1121E 02 0.1106E 02
0.1134E 02 0.1182E 02 0.1228E 02 0.1250E 02 0.1225E 02 0.1144E 02 0.1018E 02 0.8730E 01 0.7314E 01 0.6057E 01
16 0.1114E 02 0.1097E 02 0.1139E 02 0.1326E 02 0.1975E 02 0.2583E 02 0.1627E 02 0.1262E 02 0.1149E 02 0.1127E 02
0.1148E 02 0.1188E 02 0.1228E 02 0.1245E 02 0.1217E 02 0.1135E 02 0.1009E 02 0.8656E 01 0.7253E 01 0.6007E 01
17 0.1124E 02 0.1096E 02 0.1105E 02 0.1181E 02 0.1343E 02 0.1447E 02 0.1351E 02 0.1235E 02 0.1176E 02 0.1163E 02
0.1178E 02 0.1207E 02 0.1235E 02 0.1239E 02 0.1202E 02 0.1116E 02 0.9901E 01 0.8486E 01 0.7112E 01 0.5895E 01
18 0.1156E 02 0.1125E 02 0.1116E 02 0.1140E 02 0.1195E 02 0.1245E 02 0.1253E 02 0.1235E 02 0.1220E 02 0.1219E 02
0.1230E 02 0.1245E 02 0.1252E 02 0.1236E 02 0.1182E 02 0.1086E 02 0.9597E 01 0.8218E 01 0.6894E 01 0.5724E 01
19 0.1217E 02 0.1190E 02 0.1177E 02 0.1184E 02 0.1211E 02 0.1246E 02 0.1270E 02 0.1283E 02 0.1290E 02 0.1298E 02
0.1305E 02 0.1305E 02 0.1286E 02 0.1238E 02 0.1156E 02 0.1045E 02 0.9172E 01 0.7851E 01 0.6603E 01 0.5499E 01
20 0.1306E 02 0.1287E 02 0.1275E 02 0.1278E 02 0.1295E 02 0.1321E 02 0.1347E 02 0.1369E 02 0.1386E 02 0.1399E 02
0.1404E 02 0.1390E 02 0.1344E 02 0.1252E 02 0.1126E 02 0.9913E 01 0.8618E 01 0.7388E 01 0.6246E 01 0.5230E 01

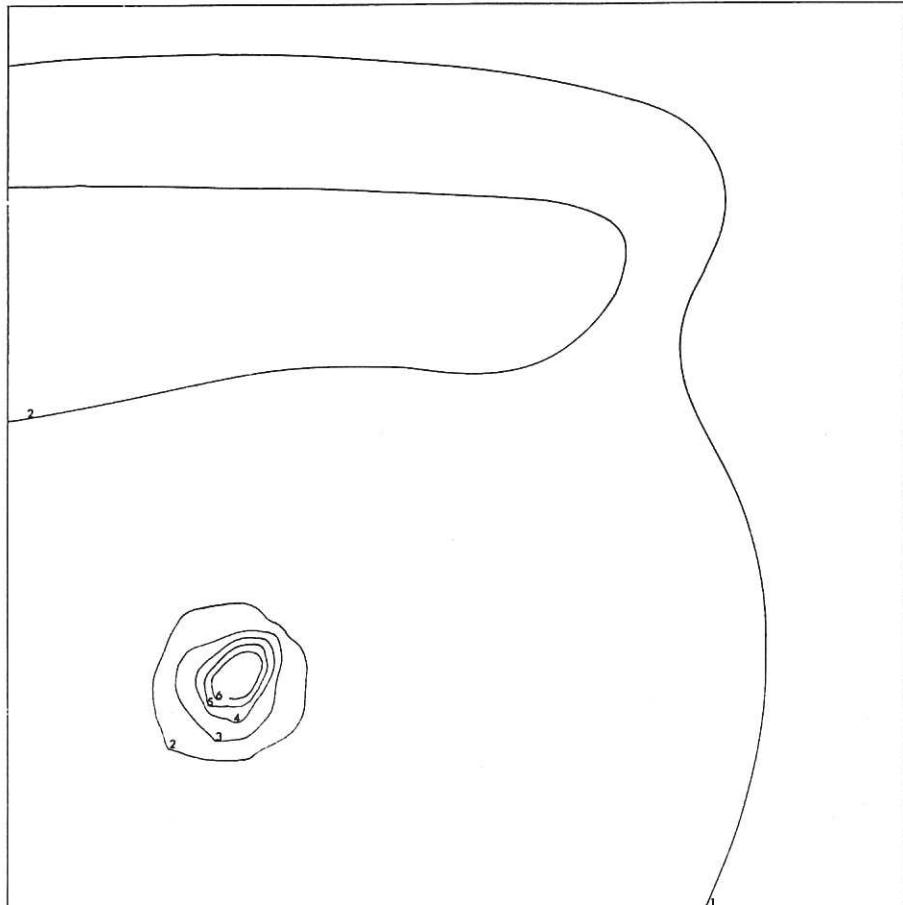
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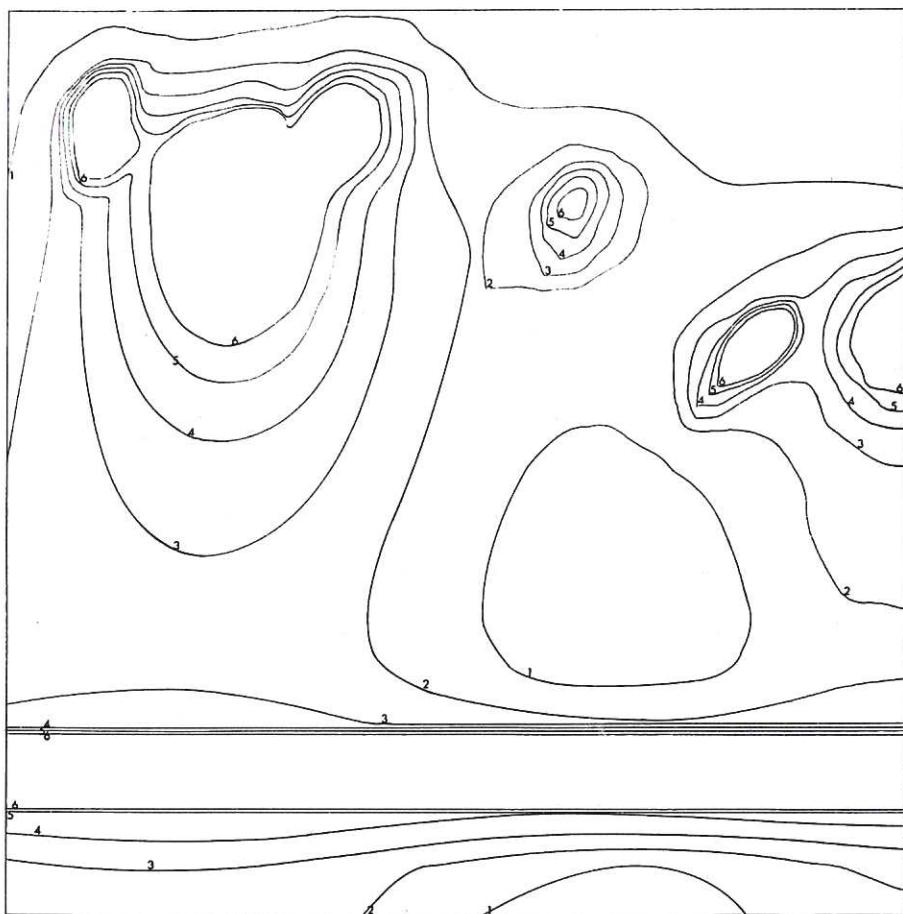
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CONTOUR HEIGHT	0.15000E 02	CONTOUR NUMBER	2
CONTOUR HEIGHT	0.20000E 02	CONTOUR NUMBER	3
CONTOUR HEIGHT	0.25000E 02	CONTOUR NUMBER	4
CONTOUR HEIGHT	0.30000E 02	CONTOUR NUMBER	5
CONTOUR HEIGHT	0.35000E 02	CONTOUR NUMBER	6

ROW

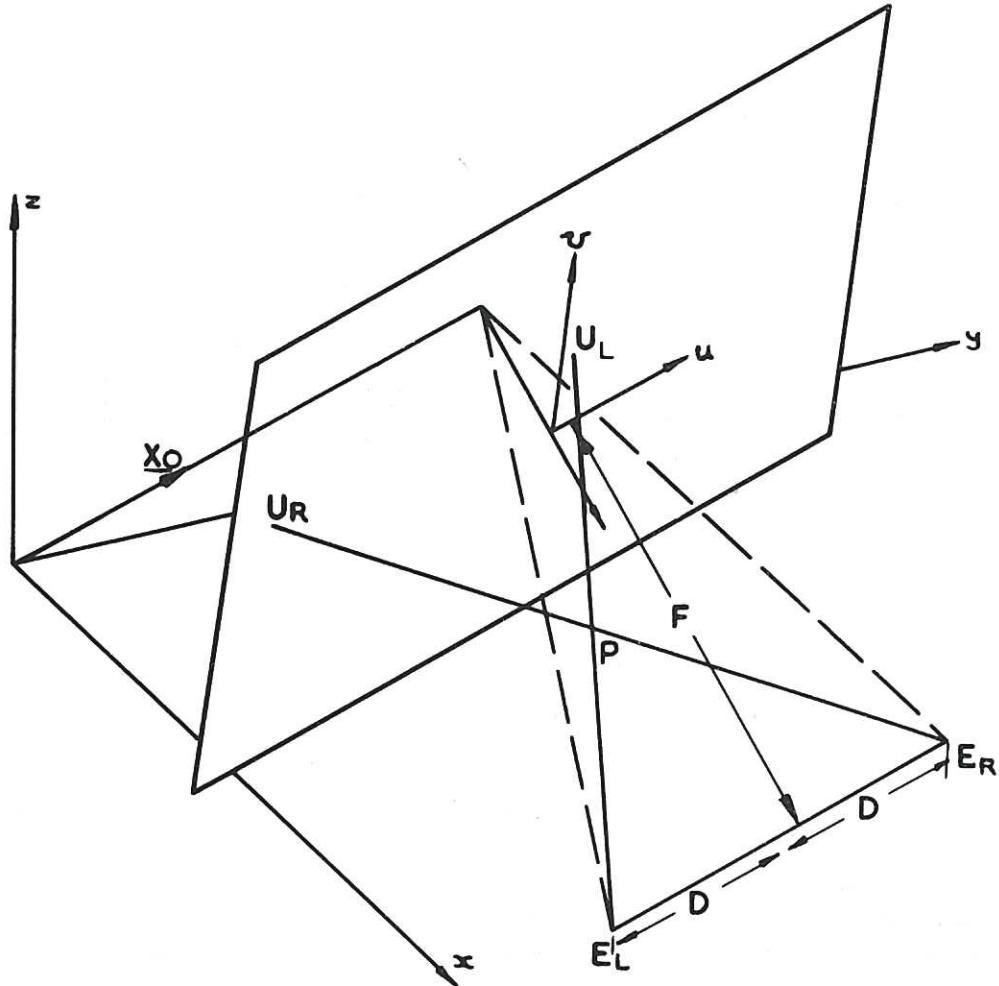
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2	0.6150E 01 0.9798E 01 0.1467E 02 0.1198E 02 0.1109E 02 0.1219E 02 0.1296E 02 0.1620E 02 0.1506E 02 0.1061E 02 0.8634E 01 0.7857E 01 0.7498E 01 0.7122E 01 0.6639E 01 0.6179E 01 0.5785E 01 0.5417E 01 0.5023E 01 0.4583E 01
3	0.7461E 01 0.1517E 02 0.7009E 02 0.2113E 02 0.2220E 02 0.2802E 02 0.2196E 02 0.5142E 02 0.3429E 02 0.1355E 02 0.1036E 02 0.9695E 01 0.9832E 01 0.9294E 01 0.8236E 01 0.7481E 01 0.7026E 01 0.6668E 01 0.6259E 01 0.5729E 01
4	0.8730E 01 0.1551E 02 0.5962E 02 0.3289E 02 0.6380E 02 0.2302E 03 0.4051E 02 0.5646E 02 0.3189E 02 0.1508E 02 0.1210E 02 0.1267E 02 0.1640E 02 0.1400E 02 0.1032E 02 0.8992E 01 0.8591E 01 0.8412E 01 0.8120E 01 0.7524E 01
5	0.1043E 02 0.1482E 02 0.2301E 02 0.3414E 02 0.7267E 02 0.1088E 03 0.4983E 02 0.3052E 02 0.2195E 02 0.1598E 02 0.1391E 02 0.1817E 02 0.4384E 02 0.2133E 02 0.1197E 02 0.1052E 02 0.1055E 02 0.1122E 02 0.1072E 02
6	0.1183E 02 0.1545E 02 0.2202E 02 0.3391E 02 0.5457E 02 0.6391E 02 0.4488E 02 0.2932E 02 0.2109E 02 0.1654E 02 0.1430E 02 0.1860E 02 0.2921E 02 0.1660E 02 0.1216E 02 0.1200E 02 0.1304E 02 0.1470E 02 0.1710E 02 0.1792E 02
7	0.1274E 02 0.1635E 02 0.2223E 02 0.3120E 02 0.4187E 02 0.4545E 02 0.3757E 02 0.2777E 02 0.2088E 02 0.1664E 02 0.1444E 02 0.1422E 02 0.1448E 02 0.1285E 02 0.1243E 02 0.1405E 02 0.1724E 02 0.1936E 02 0.2943E 02 0.4676E 02
8	0.1350E 02 0.1691E 02 0.2177E 02 0.2800E 02 0.3389E 02 0.3556E 02 0.3160E 02 0.2546E 02 0.2012E 02 0.1629E 02 0.1363E 02 0.1249E 02 0.1186E 02 0.1183E 02 0.1365E 02 0.2463E 02 0.8057E 02 0.2200E 02 0.3894E 02 0.1433E 03
9	0.1417E 02 0.1714E 02 0.2094E 02 0.2520E 02 0.2865E 02 0.2948E 02 0.2714E 02 0.2307E 02 0.1866E 02 0.1561E 02 0.1316E 02 0.1156E 02 0.1076E 02 0.1095E 02 0.1359E 02 0.3237E 02 0.1989E 02 0.1915E 02 0.2824E 02 0.3613E 02
10	0.1471E 02 0.1715E 02 0.2000E 02 0.2295E 02 0.2506E 02 0.2543E 02 0.2381E 02 0.2091E 02 0.1768E 02 0.1475E 02 0.1238E 02 0.1067E 02 0.9693E 01 0.9629E 01 0.1090E 02 0.1361E 02 0.1450E 02 0.1678E 02 0.2070E 02 0.2284E 02
11	0.1512E 02 0.1707E 02 0.1923E 02 0.2123E 02 0.2253E 02 0.2261E 02 0.2134E 02 0.1909E 02 0.1643E 02 0.1383E 02 0.1155E 02 0.9742E 01 0.8568E 01 0.8230E 01 0.8913E 01 0.1050E 02 0.1262E 02 0.1519E 02 0.1762E 02 0.1846E 02
12	0.1545E 02 0.1698E 02 0.1858E 02 0.1995E 02 0.2074E 02 0.2042E 02 0.1952E 02 0.1765E 02 0.1536E 02 0.1298E 02 0.1076E 02 0.8868E 01 0.7514E 01 0.6991E 01 0.7556E 01 0.9201E 01 0.1178E 02 0.1504E 02 0.1733E 02 0.1705E 02
13	0.1577E 02 0.1697E 02 0.1815E 02 0.1910E 02 0.1954E 02 0.1928E 02 0.1827E 02 0.1662E 02 0.1457E 02 0.1236E 02 0.1019E 02 0.8246E 01 0.6758E 01 0.6102E 01 0.6626E 01 0.8292E 01 0.1088E 02 0.1401E 02 0.1603E 02 0.1576E 02
14	0.1627E 02 0.1720E 02 0.1809E 02 0.1873E 02 0.1894E 02 0.1859E 02 0.1763E 02 0.1613E 02 0.1427E 02 0.1222E 02 0.1015E 02 0.8258E 01 0.6770E 01 0.6093E 01 0.6537E 01 0.8024E 01 0.1019E 02 0.1253E 02 0.1415E 02 0.1449E 02
15	0.1742E 02 0.1815E 02 0.1880E 02 0.1924E 02 0.1931E 02 0.1891E 02 0.1801E 02 0.1667E 02 0.1502E 02 0.1321E 02 0.1141E 02 0.9801E 01 0.8600E 01 0.8064E 01 0.8372E 01 0.9469E 01 0.1108E 02 0.1279E 02 0.1410E 02 0.1467E 02
16	0.2175E 02 0.2227E 02 0.2272E 02 0.2299E 02 0.2299E 02 0.2263E 02 0.2190E 02 0.2087E 02 0.1963E 02 0.1834E 02 0.1712E 02 0.1611E 02 0.1541E 02 0.1512E 02 0.1528E 02 0.1588E 02 0.1681E 02 0.1786E 02 0.1873E 02 0.1921E 02
17	0.8865E 02 0.8878E 02 0.8888E 02 0.8894E 02 0.8893E 02 0.8884E 02 0.8866E 02 0.8841E 02 0.8814E 02 0.8786E 02 0.8762E 02 0.8742E 02 0.8730E 02 0.8725E 02 0.8728E 02 0.8738E 02 0.8755E 02 0.8775E 02 0.8793E 02 0.8803E 02
18	0.2862E 02 0.2900E 02 0.2933E 02 0.2953E 02 0.2951E 02 0.2923E 02 0.2867E 02 0.2790E 02 0.2700E 02 0.2608E 02 0.2524E 02 0.2457E 02 0.2412E 02 0.2394E 02 0.2404E 02 0.2442E 02 0.2503E 02 0.2573E 02 0.2633E 02 0.2667E 02
19	0.1853E 02 0.1918E 02 0.1975E 02 0.2011E 02 0.2014E 02 0.1974E 02 0.1889E 02 0.1765E 02 0.1614E 02 0.1451E 02 0.1291E 02 0.1152E 02 0.1053E 02 0.1009E 02 0.1033E 02 0.1122E 02 0.1255E 02 0.1400E 02 0.1514E 02 0.1570E 02
20	0.1663E 02 0.1747E 02 0.1825E 02 0.1879E 02 0.1893E 02 0.1855E 02 0.1761E 02 0.1618E 02 0.1440E 02 0.1243E 02 0.1046E 02 0.8650E 01 0.7256E 01 0.6615E 01 0.7005E 01 0.8345E 01 0.1028E 02 0.1233E 02 0.1382E 02 0.1431E 02



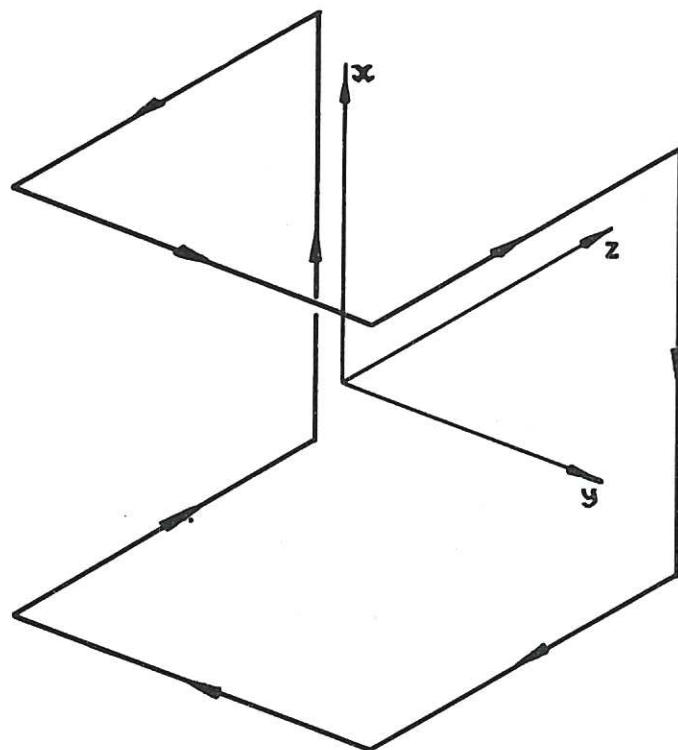
CLM - R31 Figure 4: Transverse section through magnetic field, showing contours of constant IBI (See paragraph 22)



CLM - R31 Figure 5: Axial section through magnetic field, showing contours of constant IBI (See paragraph 22)



CLM - R31 Figure 6: The stereoscopic projection system. (See paragraph 29)



CLM - R31 Figure 7: Conductor configuration for a complete example. (See paragraph 39)

SAMPLE PROBLEM, STEREO PICTURE OF, AND INTEGRALS ALONG MAGNETIC FIELD LINES.
CASE 1

SPECIFICATION OF FINITE, STRAIGHT CONDUCTORS

X1	Y1	Z1	X2	Y2	Z2	CURRENT
1.0000	1.0000	1.0000	1.0000	1.0000	-1.0000	1.0000
1.0000	1.0000	-1.0000	1.0000	-1.0000	-1.0000	1.0000
1.0000	-1.0000	-1.0000	1.0000	-1.0000	1.0000	1.0000
1.0000	-1.0000	1.0000	-1.0000	-1.0000	1.0000	1.0000
-1.0000	-1.0000	1.0000	-1.0000	-1.0000	-1.0000	1.0000
-1.0000	-1.0000	-1.0000	-1.0000	1.0000	-1.0000	1.0000
-1.0000	1.0000	-1.0000	-1.0000	1.0000	1.0000	1.0000
-1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

SEMI-LENGTH CONSIDERED 1.0000000
 INTEGRATION STEP-LENGTH 0.0500000
 MAGNETIC FIELD AT REFLECTION 3.1000000
 RADIUS OF VACUUM VESSEL 1.4140000
 CO-ORDINATES OF CENTRE OF INTEREST (0. , 0. , 0.)
 VIEW VECTOR (4.0000000, 2.0000000, 1.0000000)
 RADIUS OF SPHERE OF INTEREST 1.7320000
 MAGNIFICATION FACTOR 2.0000000
 AZIMUTHAL ROTATION 0.
 VIEWING DISTANCE 20.0000000
 SEMI-INTEROCULAR DISTANCE 1.2500000
 DISPLACEMENT BETWEEN IMAGES 5.0000000
 XMIN = -3.4210663 XMAX = 3.4210663
 YMIN = -3.4145922 YMAX = 3.4145922

STARTING POINTS OF FIELD LINES

X	Y	Z
0.300000	0.	0.
0.	0.300000	0.
-0.300000	0.	0.
0.	-0.300000	0.
0.212100	0.212100	0.
-0.212100	0.212100	0.
-0.212100	-0.212100	0.
0.212100	-0.212100	0.

TABLE OF FIELD LINE INTEGRALS

K	X(START)	Y(START)	Z(START)	INTEGRAL	NRI
1	0.30000E 00	0.	0.	0.450784E 00	1
2	0.	0.30000E 00	0.	0.450784E 00	1
3	-0.30000E 00	0.	0.	0.450784E 00	1
4	0.	-0.30000E 00	0.	0.450784E 00	1
5	0.212100E 00	0.212100E 00	0.	0.450784E 00	1
6	-0.212100E 00	0.212100E 00	0.	0.450784E 00	1
7	-0.212100E 00	-0.212100E 00	0.	0.450784E 00	1
8	0.212100E 00	-0.212100E 00	0.	0.450784E 00	1

CLM - R31 Figure 8

SAMPLE PROBLEM. RADIAL EXCURSIONS OF, AND CO-ORDINATES ALONG, MAGNETIC FIELD LINES.
CASE 2

SPECIFICATION OF FINITE, STRAIGHT CONDUCTORS

X1	Y1	Z1	X2	Y2	Z2	CURRENT
1.0000	1.0000	1.0000	1.0000	1.0000	-1.0000	1.0000
1.0000	1.0000	-1.0000	1.0000	-1.0000	-1.0000	1.0000
1.0000	-1.0000	-1.0000	1.0000	-1.0000	1.0000	1.0000
-1.0000	-1.0000	1.0000	-1.0000	-1.0000	-1.0000	1.0000
-1.0000	-1.0000	-1.0000	-1.0000	1.0000	-1.0000	1.0000
-1.0000	1.0000	-1.0000	-1.0000	1.0000	1.0000	1.0000
-1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000

SEMI-LENGTH CONSIDERED 1.0000000
 INTEGRATION STEP-LENGTH 0.0500000
 MAGNETIC FIELD AT REFLECTION 3.1000000
 RADIUS OF VACUUM VESSEL 1.4140000

STARTING POINTS OF FIELD LINES

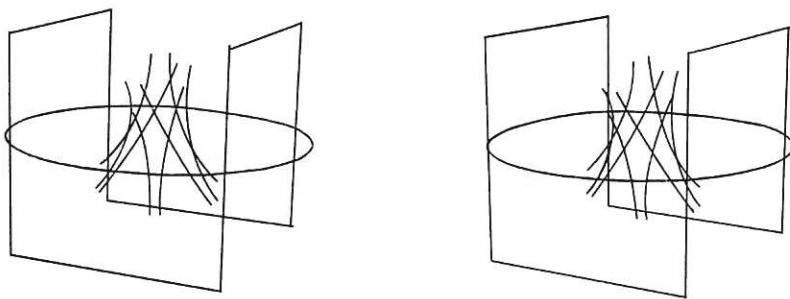
X	Y	Z
0.300000	0.	0.
0.	0.300000	0.
-0.300000	0.	0.
0.	-0.300000	0.
0.424200	0.424200	0.
-0.424200	0.424200	0.
-0.424200	-0.424200	0.
0.424200	-0.424200	0.

CO-ORDINATES OF POINTS ALONG FIELD LINE

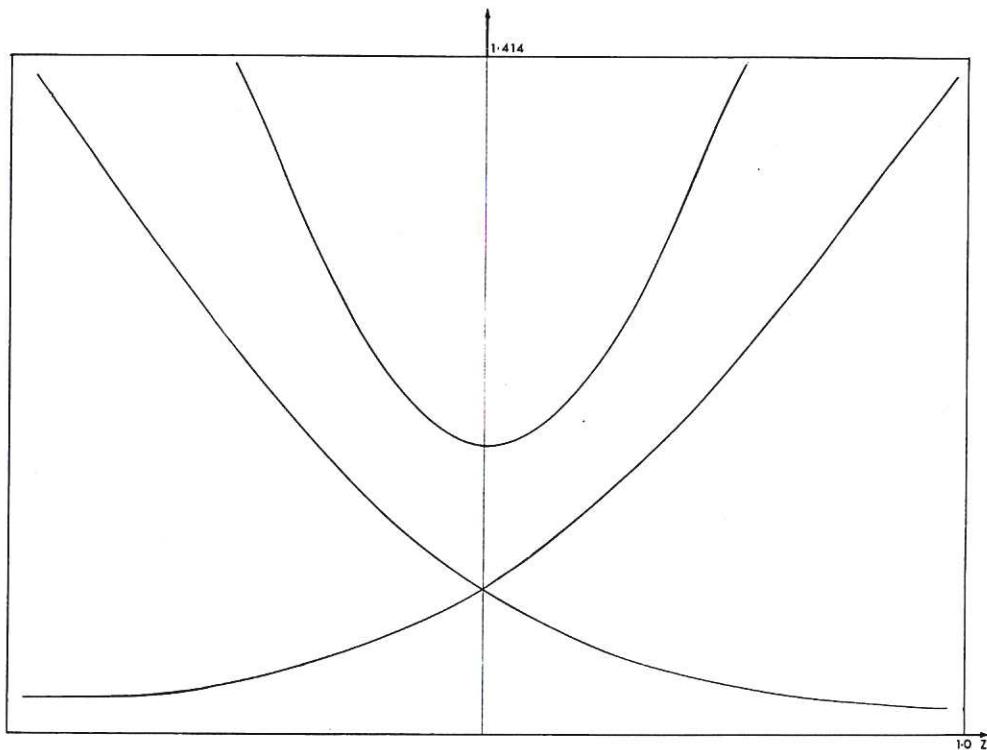
X	Y	Z	R LINE NUMBER	THETA I	DS =	MOC(B)
0.300000	0.	0.	0.300000	-0.		-0.0500000
0.3272853	-0.0000000	0.0418958	0.3272853	-0.0000000		2.6573301
0.3559690	-0.0000000	0.0628473	0.3559690	-0.0000000		2.7022925
0.3859488	-0.0000000	0.1228599	0.3859488	-0.0000000		2.7523068
0.4171206	-0.0000000	0.1619514	0.4171206	-0.0000000		2.8059416
0.4493813	-0.0000000	0.2001494	0.4493813	-0.0000000		2.8617332
0.4826321	-0.0000000	0.2374891	0.4826321	-0.0000000		2.9182061
0.5167795	-0.0000000	0.2746109	0.5167795	-0.0000000		2.9738861
0.5517369	-0.0000000	0.3097584	0.5517369	-0.0000000		3.0273081
0.5874245	-0.0000000	0.3447772	0.5874245	-0.0000000		3.0770236
0.6237694	-0.0000000	0.3791135	0.6237694	-0.0000000		3.1216087
0.6607052	0.0000000	0.4128135	0.6607052	0.0000000		3.1596781
0.6981715	-0.0000000	0.4459227	0.6981715	-0.0000000		3.1899045
0.7361136	0.0000000	0.4784658	0.7361136	0.0000000		3.2110456
0.7744816	-0.0000000	0.5105462	0.7744816	-0.0000000		3.2219784
0.8132298	-0.0000000	0.5421460	0.8132298	-0.0000000		3.2217385
0.8523168	-0.0000000	0.5733259	0.8523168	-0.0000000		3.2095630
0.8917046	-0.0000000	0.6041250	0.8917046	0.0000000		3.1849321
0.9313585	-0.0000000	0.6345808	0.9313585	-0.0000000		3.1476061
0.9712468	-0.0000000	0.6647290	0.9712468	-0.0000000		3.0976522
1.0113406	-0.0000000	0.6946033	1.0113406	-0.0000000		3.0354571
1.0516138	0.0000000	0.7242354	1.0516138	0.0000000		2.9617230
1.0920429	-0.0000000	0.7536545	1.0920429	-0.0000000		2.8774443
1.1326068	0.0000000	0.7828875	1.1326068	0.0000000		2.7838667
1.1732870	-0.0000000	0.8119585	1.1732870	-0.0000000		2.6824321
1.2140671	-0.0000000	0.8408891	1.2140671	-0.0000000		2.5747117
1.2549333	-0.0000000	0.8696980	1.2549333	-0.0000000		2.4623369
1.2958737	-0.0000000	0.8984013	1.2958737	-0.0000000		2.3469294
1.3368785	0.0000000	0.9270125	1.3368785	0.0000000		2.2300406
1.3779400	0.0000000	0.9555425	1.3779400	0.0000000		2.1131001

CO-ORDINATES OF POINTS ALONG FIELD LINE

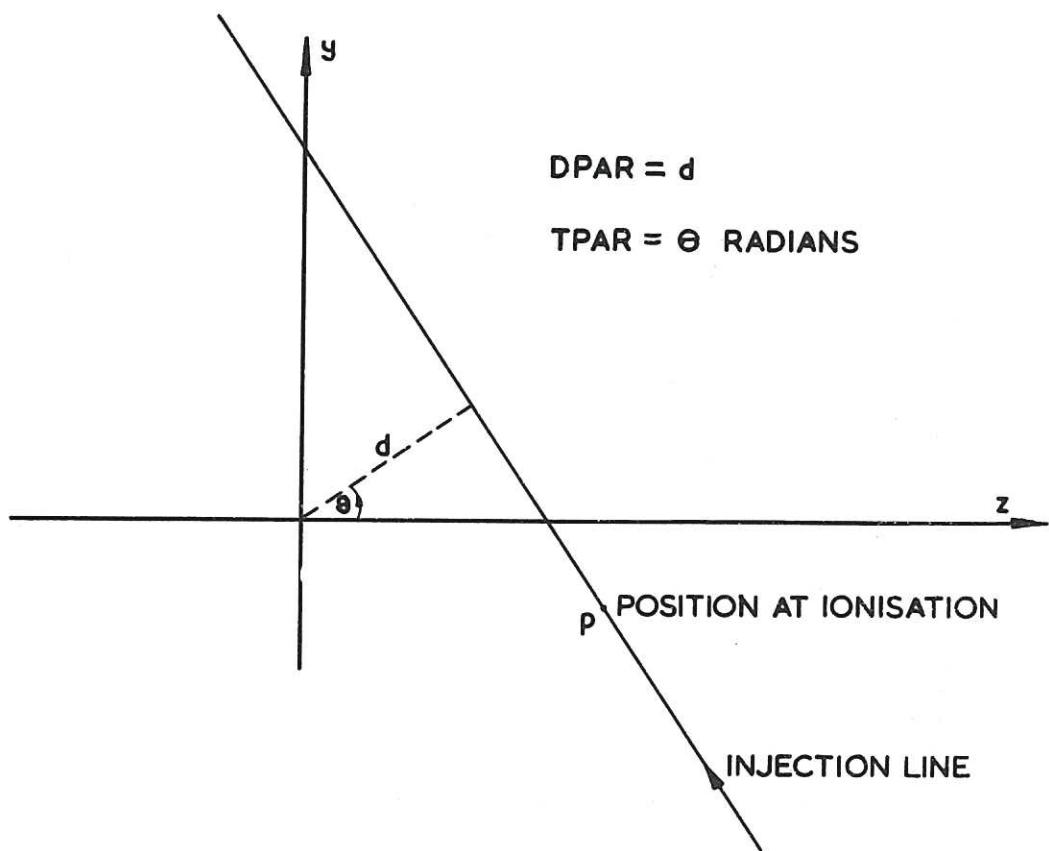
X	Y	Z	R LINE NUMBER	THETA I	DS =	MOC(B)
0.300000	0.	0.	0.300000	-0.		0.0500000
0.2742082	0.0000000	-0.0428312	0.2742082	0.0000000		2.5879277
0.2499932	0.0000000	-0.0665731	0.2499932	0.0000000		2.5658562
0.2274208	0.0000000	-0.1311847	0.2274208	0.0000000		2.5534658
0.2065348	0.0000000	-0.1766102	0.2065348	0.0000000		2.5513812
0.1873532	0.0000000	-0.2227815	0.1873532	0.0000000		2.5599111
0.1698668	0.0000000	-0.2696211	0.1698668	0.0000000		2.5790154
0.1540394	0.0000000	-0.3170474	0.1540394	0.0000000		2.6082876
0.1398110	0.0000000	-0.3649778	0.1398110	0.0000000		2.6449538
0.1271017	0.0000000	-0.4133336	0.1271017	0.0000000		2.6938846
0.1158171	0.0000000	-0.4620418	0.1158171	0.0000000		2.7476160
0.1058539	0.0000000	-0.5110377	0.1058539	0.0000000		2.8063778
0.0971048	0.0000000	-0.5602651	0.0971048	0.0000000		2.8681290
0.0894629	0.0000000	-0.6096767	0.0894629	0.0000000		2.9306012
0.0828248	0.0000000	-0.6592333	0.0828248	0.0000000		2.9913565
0.0770936	0.0000000	-0.7089031	0.0770936	0.0000000		3.0478587
0.0721794	0.0000000	-0.7586605	0.0721794	0.0000000		3.0975645
0.0680008	0.0000000	-0.8084852	0.0680008	0.0000000		3.1380278
0.0644848	0.0000000	-0.8583611	0.0644848	0.0000000		3.1670171
0.0615667	0.0000000	-0.9082756	0.0615667	0.0000000		3.1826325
0.0591895	0.0000000	-0.9582189	0.0591895	0.0000000		3.1834139



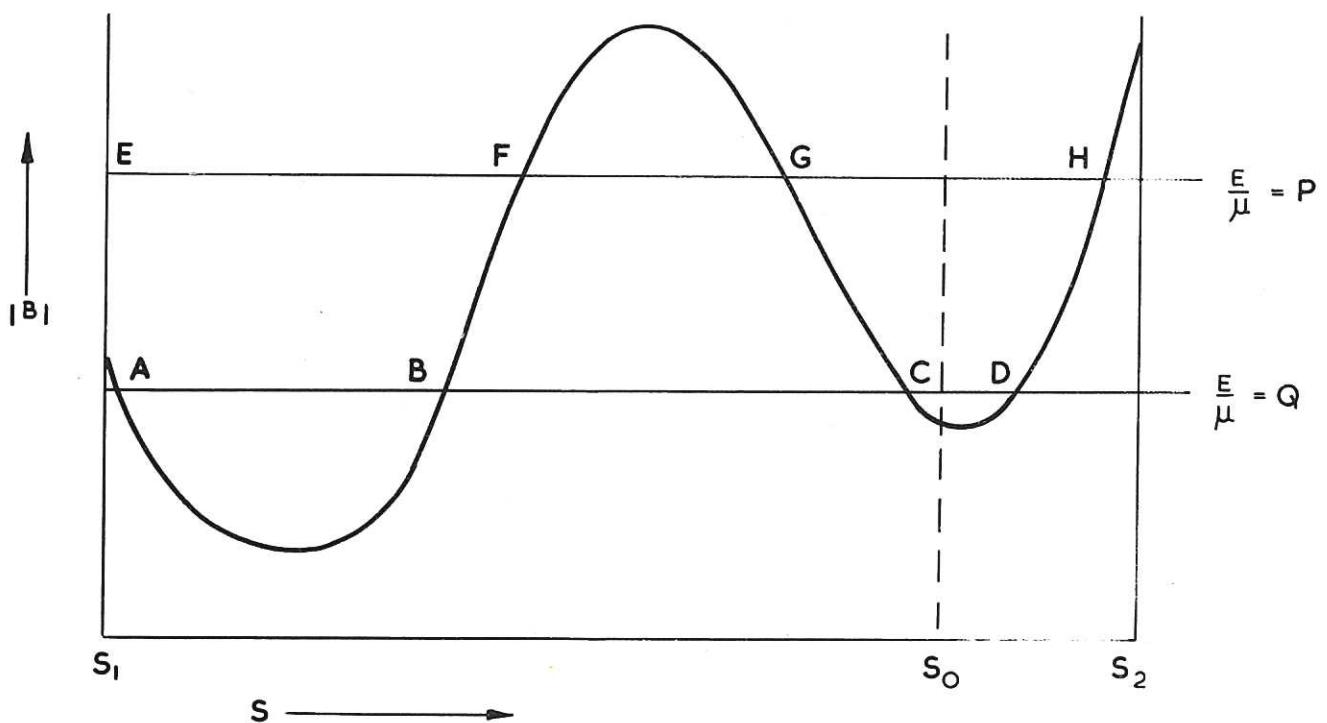
CLM - R31 **Figure 9:** Stereoscopic pictures of field lines due to a cube-edge arrangement of filamentary conductors. The 3-dimensional effect should be obtainable by viewing with the eyes diverged to infinity while focussed on the figure. (See paragraph 43).



CLM - R31 **Figure 10:** Radial excursions of magnetic field lines. (See paragraph 43).



CLM - R31 Figure 11: Plan of neutral particle injection system. (See paragraph 50)



CLM - R31 Figure 12: Variation of IBI along a magnetic field line. (See paragraph 52)

SAMPLE PROBLEM. ENERGY SURFACE IN AN IDEALISED QUADRUPOLE IOFFE APPARATUS.
CASE 1

SPECIFICATION OF CIRCULAR CONDUCTORS

H(CENTRE)	RADIUS	CURRENT
1.0000000	1.0000000	1.0000000
-1.0000000	1.0000000	1.0000000

SPECIFICATION OF LINEAR CONDUCTORS

X	Y	CURRENT
1.0000000	1.0000000	2.0000000
-1.0000000	1.0000000	-2.0000000
-1.0000000	-1.0000000	2.0000000
1.0000000	-1.0000000	-2.0000000

MID POINT OF PLANE LIES AT (0.1750000, 0.1750000)

EDGE LENGTH OF TRANSVERSE PLANE IN REAL SPACE 0.3500000
EDGE LENGTH OF GRAPH 6.8900000 INCHES

RADIUS CYLINDER OF INTEREST = 1.000000
SEMI-LENGTH OF CYLINDER = 1.000000
INTEGRATION STEP LENGTH = 0.0282843
INJECTION KINETIC ENERGY = 0.5000000

CONTOURS OF CONSTANT J ARE DRAWN AT THE FOLLOWING ENERGIES, AS WELL AS AT THE INJECTION ENERGY

KE	ENERGY
2	0.4920000
3	0.4960000
4	0.5000000
5	0.5080000
6	0.5120000
7	0.5160000
8	0.5200000
9	0.5240000
10	0.5280000
11	0.5320000
12	0.5360000

NEUTRAL INJECTION PARAMETERS

INJECTION LINE PARAMETERS		POSITION AT IONISATION			CRITICAL V*B, MOU(B) AT TURN	
D	THETA	X	Y	Z	E1	BRM
0.	0.	0.	-0.1910000	0.	4.3500000	5.1810950
MAGNETIC MOMENT OF ION		0.9650470E-01				
		J	0.5734517E-01			

BXION = 0.
BYION = 0.1527492E 01
BZION = 0.4350961E 01
MBION = 0.4611301E 01

NEW PAGE ON GRAPH-PLOTTER. SCALE = 0.196857E 02 INCHES PER UNIT VARIABLE.

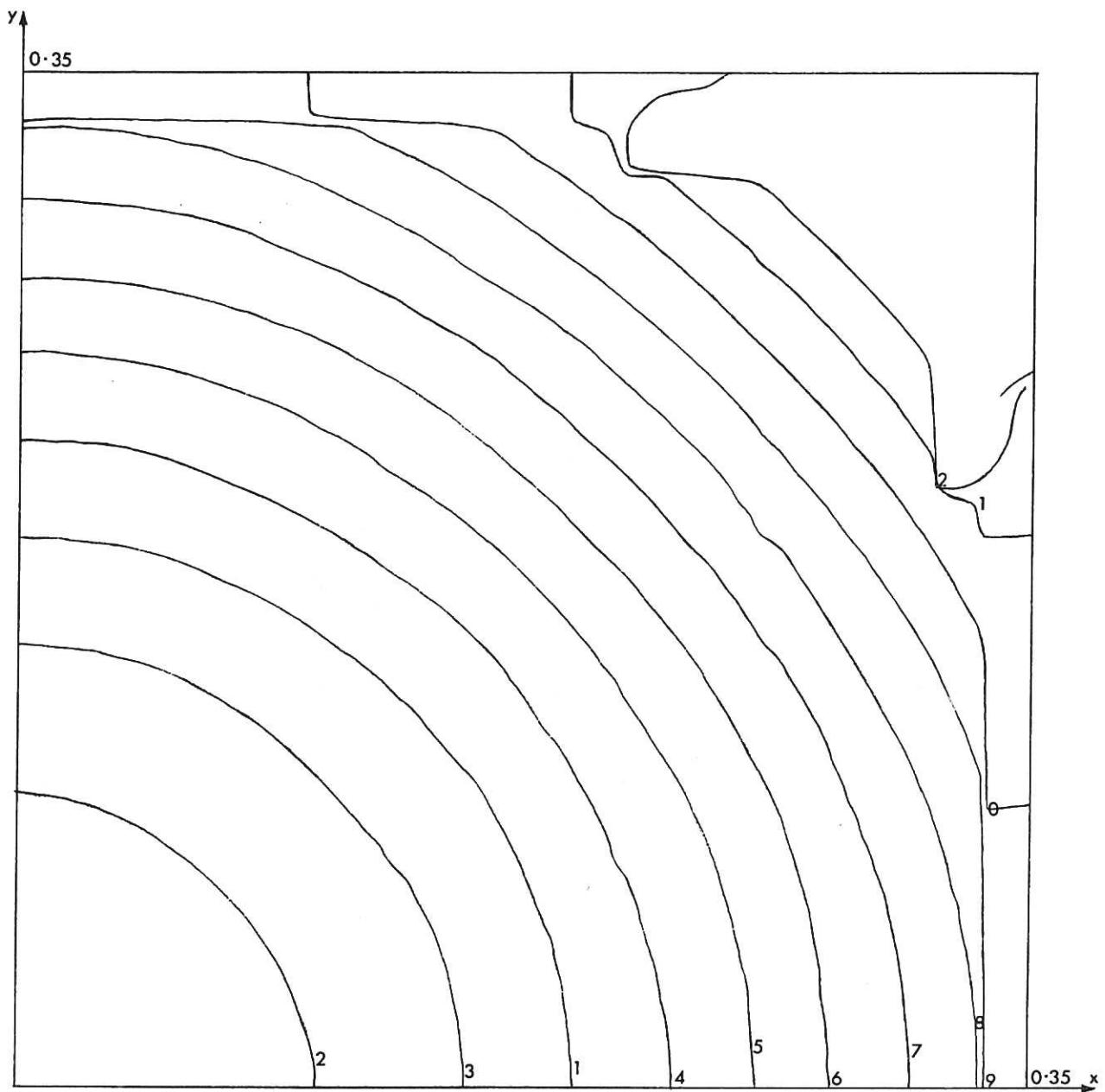
CONTOUR HEIGHT 0.573452E-01 CONTOUR NUMBER 1

CLM - R31 Figure 13

MATRIX FOR INJECTION ENERGY

ROW	1	0.2675E-01	0.2660E-01	0.2614E-01	0.2532E-01	0.	0.	0.	0.	0.	0.
	2	0.3122E-01	0.3108E-01	0.3067E-01	0.2996E-01	0.2892E-01	0.2748E-01	0.2540E-01	0.2326E-01	0.2068E-01	0.1762E-01
	3	0.3605E-01	0.3586E-01	0.3523E-01	0.3431E-01	0.3336E-01	0.3208E-01	0.3039E-01	0.2790E-01	0.2561E-01	0.2278E-01
	4	0.4013E-01	0.3999E-01	0.3955E-01	0.3878E-01	0.3753E-01	0.3633E-01	0.3479E-01	0.3278E-01	0.3003E-01	0.2760E-01
	5	0.4407E-01	0.4394E-01	0.4353E-01	0.4282E-01	0.4176E-01	0.4027E-01	0.3880E-01	0.3690E-01	0.3452E-01	0.3192E-01
	6	0.4762E-01	0.4749E-01	0.4708E-01	0.4639E-01	0.4539E-01	0.4396E-01	0.4217E-01	0.4055E-01	0.3856E-01	0.3586E-01
	7	0.5057E-01	0.5045E-01	0.5008E-01	0.4946E-01	0.4856E-01	0.4735E-01	0.4562E-01	0.4404E-01	0.4210E-01	0.3965E-01
	8	0.5341E-01	0.5329E-01	0.5291E-01	0.5226E-01	0.5129E-01	0.5008E-01	0.4861E-01	0.4696E-01	0.4510E-01	0.4297E-01
	9	0.5596E-01	0.5588E-01	0.5550E-01	0.5491E-01	0.5408E-01	0.5298E-01	0.5157E-01	0.4967E-01	0.4788E-01	0.4562E-01
	10	0.5810E-01	0.5799E-01	0.5766E-01	0.5710E-01	0.5631E-01	0.5527E-01	0.5395E-01	0.5218E-01	0.5041E-01	0.4846E-01
	11	0.5959E-01	0.5948E-01	0.5925E-01	0.5899E-01	0.5823E-01	0.5723E-01	0.5597E-01	0.5437E-01	0.5249E-01	0.5064E-01
	12	0.6194E-01	0.6183E-01	0.6150E-01	0.6095E-01	0.6017E-01	0.5914E-01	0.5778E-01	0.5618E-01	0.5426E-01	0.5249E-01
	13	0.6358E-01	0.6348E-01	0.6316E-01	0.6264E-01	0.6190E-01	0.6092E-01	0.5970E-01	0.5819E-01	0.5618E-01	0.5437E-01
	14	0.6495E-01	0.6483E-01	0.6452E-01	0.6401E-01	0.6329E-01	0.6234E-01	0.6116E-01	0.5970E-01	0.5778E-01	0.5597E-01
	15	0.6604E-01	0.6599E-01	0.6564E-01	0.6514E-01	0.6443E-01	0.6356E-01	0.6234E-01	0.6092E-01	0.5914E-01	0.5723E-01
	16	0.6699E-01	0.6680E-01	0.6654E-01	0.6604E-01	0.6534E-01	0.6444E-01	0.6329E-01	0.6190E-01	0.6017E-01	0.5823E-01
	17	0.6763E-01	0.6753E-01	0.6723E-01	0.6674E-01	0.6604E-01	0.6514E-01	0.6401E-01	0.6246E-01	0.6095E-01	0.5899E-01
	18	0.6812E-01	0.6802E-01	0.6772E-01	0.6723E-01	0.6654E-01	0.6554E-01	0.6452E-01	0.6316E-01	0.6150E-01	0.5952E-01
	19	0.6841E-01	0.6831E-01	0.6802E-01	0.6753E-01	0.6664E-01	0.6594E-01	0.6485E-01	0.6348E-01	0.6183E-01	0.5984E-01
	20	0.7120E-01	0.6841E-01	0.6612E-01	0.6476E-01	0.6464E-01	0.6460E-01	0.6493E-01	0.6458E-01	0.6194E-01	0.5995E-01

MATRIX OF PUDDLE COUNTS FOR INJECTION ENERGY



CLM - R31 Figure 14: Contours of an energy surface in a transverse section, at $z=0$, through a quadrupole Ioffe magnetic field.

$E = 0.5$, $u = 0.0965$, $J = 0.0573$.
(See paragraph 61)

SAMPLE PROBLEM. ENERGY SURFACES IN A CUSP WITH AXIAL CURRENT.

CASE . 1

SPECIFICATION OF CIRCULAR CONDUCTORS

H(CENTRE)	RADIUS	CURRENT
0.5000000	1.0000000	1.0000000
-0.5000000	1.0000000	-1.0000000

SPECIFICATION OF LINEAR CONDUCTORS

X	Y	CURRENT
0.	0.	0.1000000

DS = 0.0500000
 FJMIN = 0. FJMAX = 2.5000000
 RHOMIN = 0.0500000 RHOMAX = 0.7500000
 EMIN = 0.3000000 EMAX = 1.0000000
 MU = 0.2000000 ZTX = 0.4000000 RADIUS = 0.8000000
 ZSTART = 0.1000000
 NC = 2 NL = 1 NRHO = 20 NE = 20 NJ = 6 NAS = 2000
 DE = 0.0368421 DRHO = 0.0368421 DJ = 0.5000000

J/MU**1/2 MATRIX

ROW	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0.2357E 01 0.2189E 01 0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	
2	0.2206E 01 0.2049E 01 0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	
3	0.2066E 01 0.1900E 01 0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	
4	0.1926E 01 0.1760E 01 0.1623E 01 0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	
5	0.1791E 01 0.1629E 01 0.1478E 01 0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	
6	0.1670E 01 0.1477E 01 0.1365E 01 0.1229E 01 0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	
7	0.1515E 01 0.1366E 01 0.1226E 01 0.1127E 01 0.1024E 01 0.9267E 00 0.8331E 00 0.7407E 00 0.6484E 00 0.5563E 00 0.4824E 00 0.3982E 00 0.3126E 00 0.2226E 00 0.1540E 00 0.4008E-01 0. 0.																			
8	0.1389E 01 0.1238E 01 0.1118E 01 0.1003E 01 0.8929E 00 0.P034E 00 0.7257E 00 0.6446E 00 0.5593E 00 0.4708E 00 0.3774E 00 0.2956E 00 0.2185E 00 0.1586E 00 0.6297E-01 0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	
9	0.1249E 01 0.1113E 01 0.1003E 01 0.8940E 00 0.8042E 00 0.7141E 00 0.6262E 00 0.5394E 00 0.4532E 00 0.3808E 00 0.3036E 00 0.2233E 00 0.1489E 00 0.7286E-01 0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	
10	0.1107E 01 0.1001E 01 0.8785E 00 0.7914E 00 0.6910E 00 0.6042E 00 0.5236E 00 0.4441E 00 0.3652E 00 0.2877E 00 0.2131E 00 0.1440E 00 0.7726E-01 0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	
11	0.9917E 00 0.8691E 00 0.7845E 00 0.6723E 00 0.5998E 00 0.5177E 00 0.4366E 00 0.3566E 00 0.2779E 00 0.2116E 00 0.1315E 00 0.6127E-01 0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	
12	0.8560E 00 0.7783E 00 0.6629E 00 0.5903E 00 0.5020E 00 0.4218E 00 0.3467E 00 0.2740E 00 0.2035E 00 0.1363E 00 0.7530E-01 0.6072E-02 0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	
13	0.7340E 00 0.6593E 00 0.5794E 00 0.4782E 00 0.4126E 00 0.3391E 00 0.2660E 00 0.1942E 00 0.1232E 00 0.5894E-01 0.7486E-02 0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	
14	0.6160E 00 0.5802E 00 0.4683E 00 0.4040E 00 0.3255E 00 0.2533E 00 0.1867E 00 0.1233E 00 0.6258E-01 0.1137E-01 0.0. 0.	0. 0.																		
15	0.5092E 00 0.4751E 00 0.3907E 00 0.3035E 00 0.2435E 00 0.1797E 00 0.1150E 00 0.4932E-01 0.8142E-02 0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	
16	0.3902E 00 0.3746E 00 0.2976E 00 0.2348E 00 0.1587E 00 0.9932E-01 0.4547E-01 0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	
17	0.2887E 00 0.2706E 00 0.2292E 01 0.1547E 00 0.9223E-01 0.3732E-01 0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	
18	0.1942E 00 0.1781E 00 0.1504E 00 0.9054E-01 0.4104E-01 0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	
19	0.9700E-01 0.8887E-01 0.6239E-01 0.1509E-01 0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	
20	0.4023E-02 0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	0. 0.	

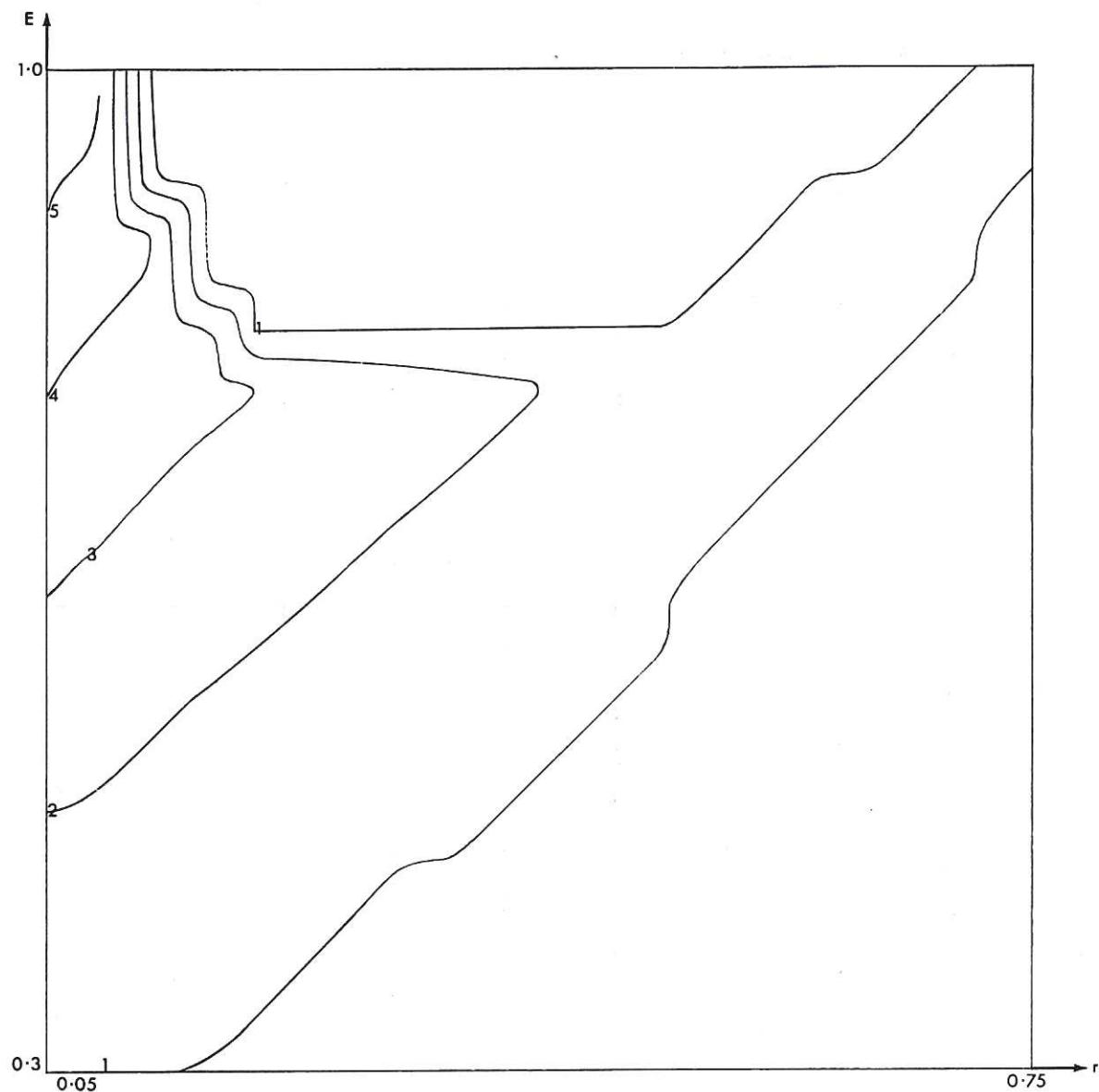
MATRIX OF PUDDLE COUNTS

ROW

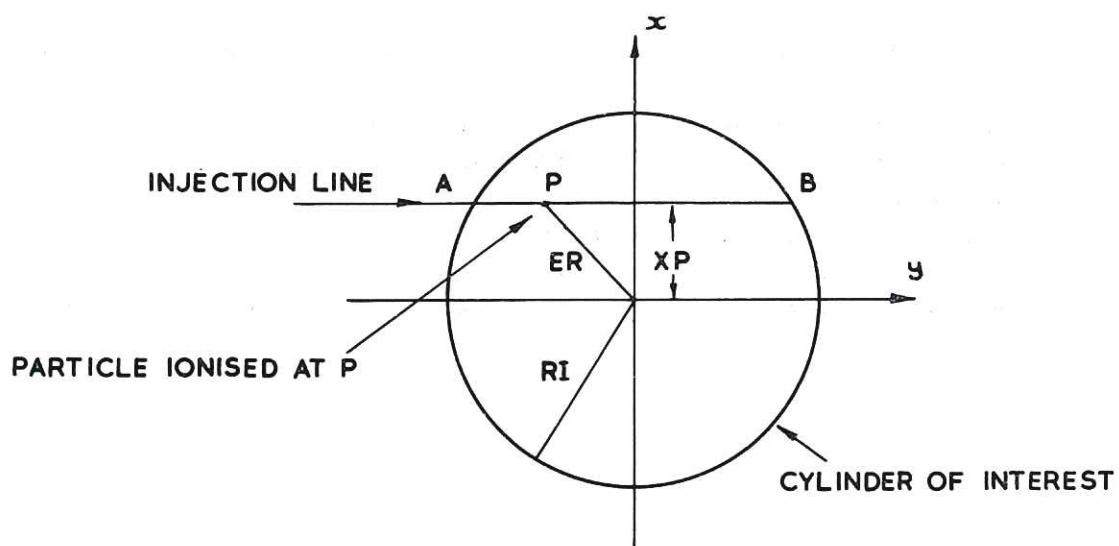
1	1	1	0	0	0	0	0	0	0	0	0
2	1	1	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	1	0	0
4	1	1	1	0	0	0	1	1	0	0	0
5	0	0	0	0	1	0	1	1	0	0	0
6	1	1	1	1	0	0	0	0	0	0	0
7	1	1	1	1	1	1	1	0	1	0	1
8	1	1	1	1	1	1	0	0	1	0	0
9	1	1	1	1	0	0	0	0	1	0	1
10	1	1	1	0	0	0	0	0	1	0	0
11	1	1	0	0	0	0	0	0	1	0	1
12	1	1	0	0	0	0	0	0	1	0	0
13	1	0	0	0	0	0	0	0	1	0	1
14	0	0	0	0	0	0	0	0	1	0	0
15	0	0	0	0	0	0	0	0	1	0	0
16	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0

NEW PAGE ON GRAPH-PLOTTER. SCALE = 1.00000E 01 INCHES PER UNIT VARIABLE.

CONTOUR HEIGHT	0.10000E-13	CONTOUR NUMBER	1
CONTOUR HEIGHT	0.50000E 00	CONTOUR NUMBER	2
CONTOUR HEIGHT	0.10000E 01	CONTOUR NUMBER	3
CONTOUR HEIGHT	0.15000E 01	CONTOUR NUMBER	4
CONTOUR HEIGHT	0.20000E 01	CONTOUR NUMBER	5
CONTOUR HEIGHT	0.25000E 01	CONTOUR NUMBER	6
			**** NO INTERSECTION ****



CLM - R31 Figure 16: Representation of energy surfaces in a cylindrically symmetric magnetic field. (See paragraph 72)



CLM - R31 Figure 17: Transverse view of neutral particle injection system. (See paragraph 79)

SAMPLE PROBLEM RADIAL EXCURSIONS OF PARTICLES IONISED BY LORENTZ FORCE

CASE

SPECIFICATION OF CIRCULAR CONDUCTORS

H(CENTRE)	RADIUS	CURRENT
1.0000000	1.0000000	1.0000000
-1.0000000	1.0000000	1.0000000

SPECIFICATION OF LINEAR CONDUCTORS

X	Y	CURRENT
1.0000000	1.0000000	1.0000000
-1.0000000	1.0000000	-1.0000000
-1.0000000	-1.0000000	1.0000000
1.0000000	-1.0000000	-1.0000000

RADIUS OF CYLINDER OF INTEREST = 0.7000000

SEMI-LENGTH OF CYLINDER = 0.6000000

DS = 0.0070000

XMIN = -0.6000000 XMAX = 0.6000000 YMINT = 0. YMAX = 0.7000000

TABLE OF MOD(V*B)

X	Y	Z	R	THETA	MOD(V*B)
0.0500000	-0.6982120	0.2066601	0.7000000	-85.9059562	3.8333667
0.0500000	-0.6636050	0.2014297	0.6654860	-85.6911323	3.9312664
0.0500000	-0.6289980	0.1961994	0.6309822	-85.4550292	4.0204762
0.0500000	-0.5943910	0.1907691	0.5964903	-85.1916161	4.1012202
0.0500000	-0.5597841	0.1857387	0.5620126	-84.8958769	4.1737768
0.0500000	-0.5251171	0.1605084	0.5275518	-84.5614912	4.2380577
0.0500000	-0.4905701	0.1752781	0.4931115	-84.1803021	4.2955892
0.0500000	-0.4559631	0.1700477	0.4586963	-83.7820632	4.3454979
0.0500000	-0.4213561	0.1646174	0.4243123	-83.2326722	4.3885001
0.0500000	-0.3867491	0.1595671	0.3896978	-82.6335024	4.4248929
0.0500000	-0.3521421	0.1543567	0.3556741	-81.9186988	4.4549493
0.0500000	-0.3175351	0.1491264	0.3214476	-81.0515162	4.4789137
0.0500000	-0.2829281	0.1436961	0.2873123	-79.977980	4.4970004
0.0500000	-0.2463212	0.1386657	0.2533050	-78.6155041	4.5093923
0.0500000	-0.2137142	0.1334154	0.2194852	-76.8320754	4.5162408
0.0500000	-0.1791072	0.1292950	0.1859553	-74.4022628	4.5176665
0.0500000	-0.1445002	0.1229747	0.1529062	-70.9133419	4.5137602
0.0500000	-0.1096932	0.1177444	0.1207333	-65.5350743	4.5045841
0.0500000	-0.0752862	0.1125140	0.0903771	-64.4105857	4.4901739
0.0500000	-0.0406792	0.1072937	0.0644577	-39.1312747	4.4705400
0.0500000	-0.0060722	0.1026534	0.0503677	-6.9245739	4.4456705
0.0500000	0.0265347	0.0966230	0.0575694	29.7131782	4.4155327
0.0500000	0.0631417	0.0915927	0.0805912	51.6253760	4.3800762
0.0500000	0.0977447	0.0863624	0.1097944	62.9095442	4.3392360
0.0500000	0.1325557	0.0811320	0.1414851	69.3049446	4.2929545
0.0500000	0.1669627	0.0759017	0.1742887	71.3287191	4.2410895
0.0500000	0.2015697	0.0706714	0.2076784	76.0687876	4.1836100
0.0500000	0.2361767	0.0654410	0.2414113	78.0466391	4.1204087
0.0500000	0.2707037	0.0602107	0.2753612	79.5382143	4.0514034
0.0500000	0.3055906	0.0549804	0.309567	80.7017696	3.9765225
0.0500000	0.3399976	0.0497509	0.3436545	81.6340564	3.8957114
0.0500000	0.3746046	0.0445197	0.3779267	82.397434	3.8089381
0.0500000	0.4092116	0.0392094	0.4125249	83.0337783	3.7161998
0.0500000	0.4438116	0.0340590	0.4466262	83.5722375	3.6175293
0.0500000	0.4704256	0.0282287	0.4810312	84.0337077	3.5130011
0.0500000	0.5130326	0.0235984	0.5151633	84.4335502	3.4027378
0.0500000	0.5476396	0.0183680	0.5499173	84.7833053	3.2869158
0.0500000	0.5822465	0.0131577	0.5845895	85.0916078	3.1657697
0.0500000	0.6168535	0.0079074	0.6168766	85.3659347	3.0395967
0.0500000	0.6514605	0.0026770	0.6533765	85.6111176	2.9087594
0.0500000	0.6860675	-0.025553	0.6878871	85.8317031	2.7736669
0.0500000	0.7206745	-0.0077837	0.722069	86.0312101	2.6348748

CO-ORDINATES OF MIRROR POINTS

XREF	YREF	ZREF	RREF	TREF	ZREF
0.505279e-01	-0.853726e-01	0.130185e 00	0.992046e-01	-0.103639e 01	0.130185e 00
0.394979e-01	-0.108838e 00	-0.141580e 00	0.115783e 00	-0.122267e 01	-0.141580e 00

BXION = 0.1710491

BYION = 0.3965545

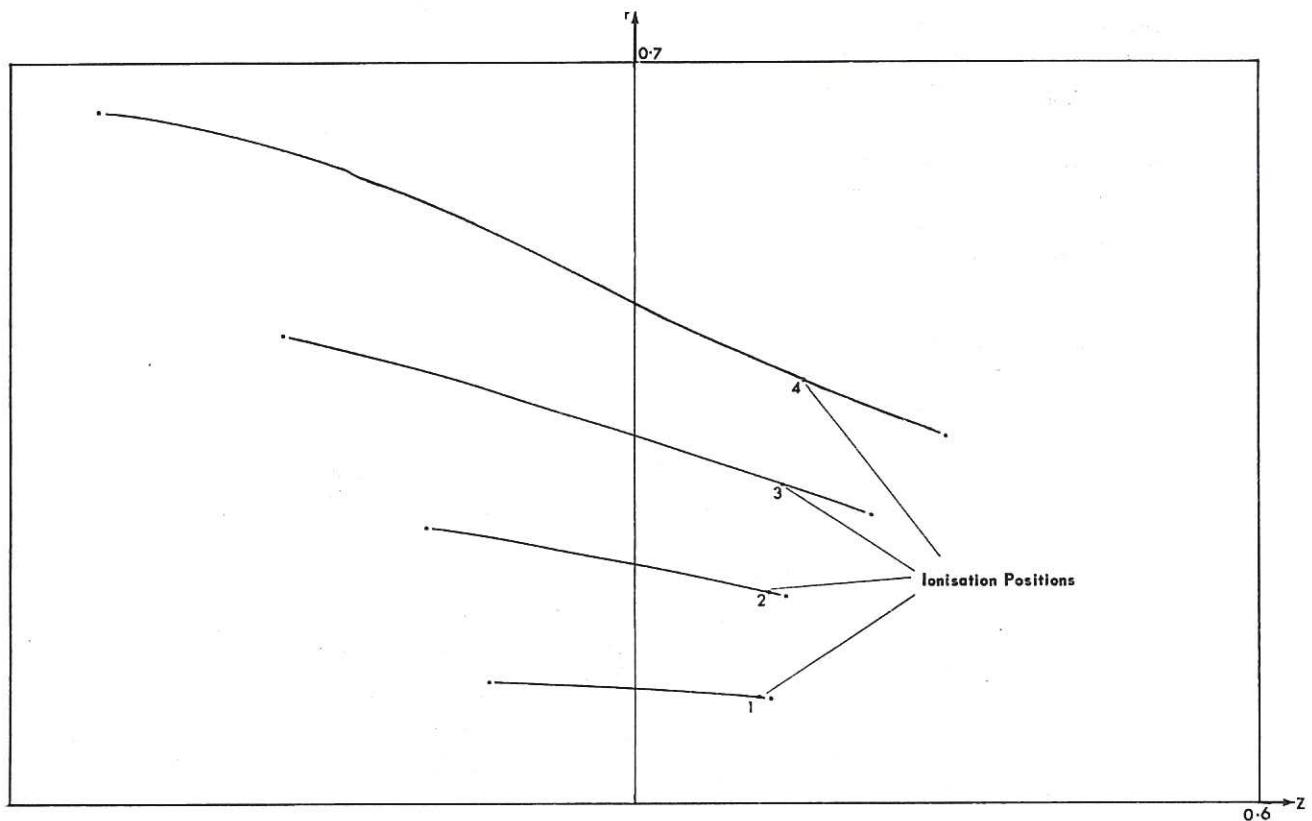
BZION = 4.4857340

MBION = 4.5064757

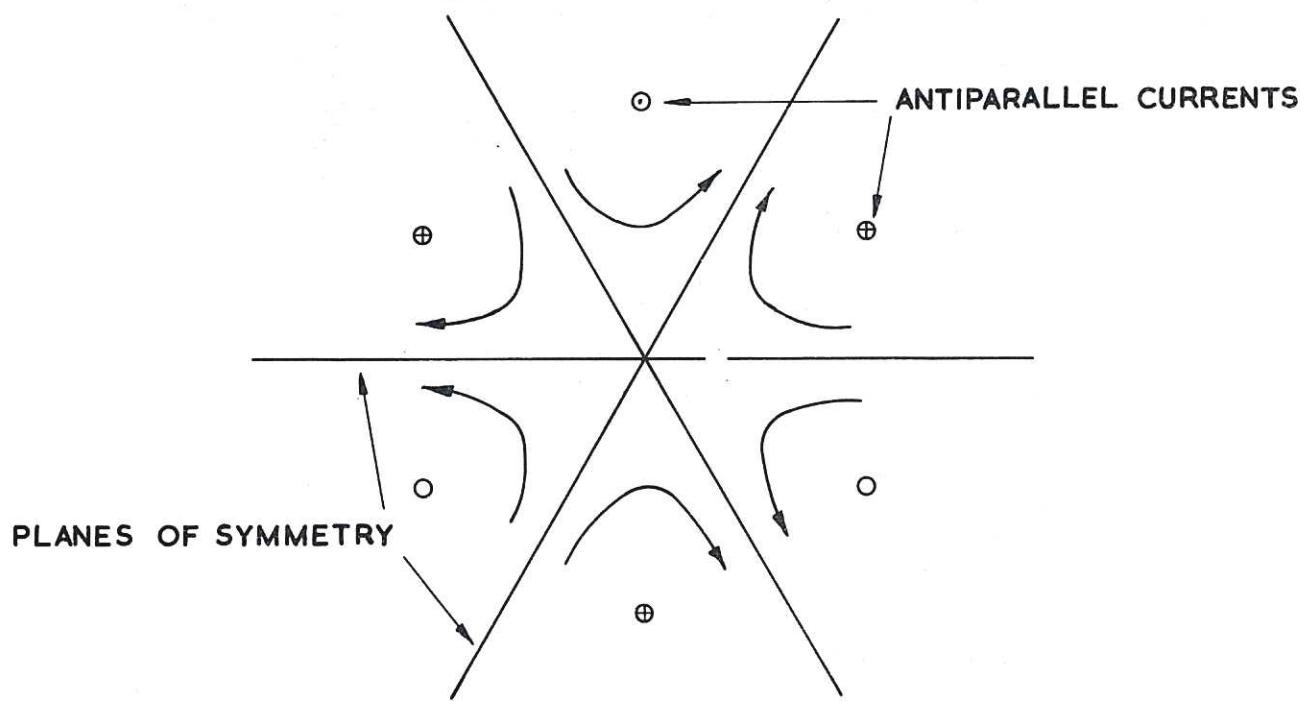
NEUTRAL INJECTION PARAMETERS

INJECTION LINE PARAMETERS		POSITION AT IONISATION			RADIUS	MOD(B) AT TURN
D	THETA	X	Y	Z	R	BRM
0.1000000	0.1500000	0.0500000	-0.0866025	0.1162492	0.1000000	4.5237204

AND SO ON FOR THE OTHER THREE INJECTED PARTICLES.



CLM - R31 Figure 19: Radial excursions, between mirror points, of particles trapped by Lorentz ionisation. (See paragraph 82)



CLM - R31 Figure 20: Example of the type of magnetic field assumed by Program VI, illustrating the symmetry. (See paragraph 84)

SAMPLE PROBLEM. TRANSVERSE TEMPLATES FOR MODEL OF MAGNETIC FIELD LINES.

SPECIFICATION OF CIRCULAR CONDUCTORS

H(CENTRE)	RADIUS	CURRENT
1.0000000	1.0000000	1.0000000
-1.0000000	1.0000000	1.0000000

SPECIFICATION OF LINEAR CONDUCTORS

X	Y	CURRENT
1.0000000	1.0000000	2.0000000
-1.0000000	1.0000000	-2.0000000
-1.0000000	-1.0000000	2.0000000
1.0000000	-1.0000000	-2.0000000

SEMI-LENGTH CONSIDERED 1.0000000

NUMBER OF TEMPLATES 9

INTEGRATION STEP-LENGTH 0.0200000

RADIUS OF VACUUM VESSEL 1.0000000

RADIUS OF PLOTTED REGION 1.0010000

STARTING POINTS OF FIELD LINES (Z=0)

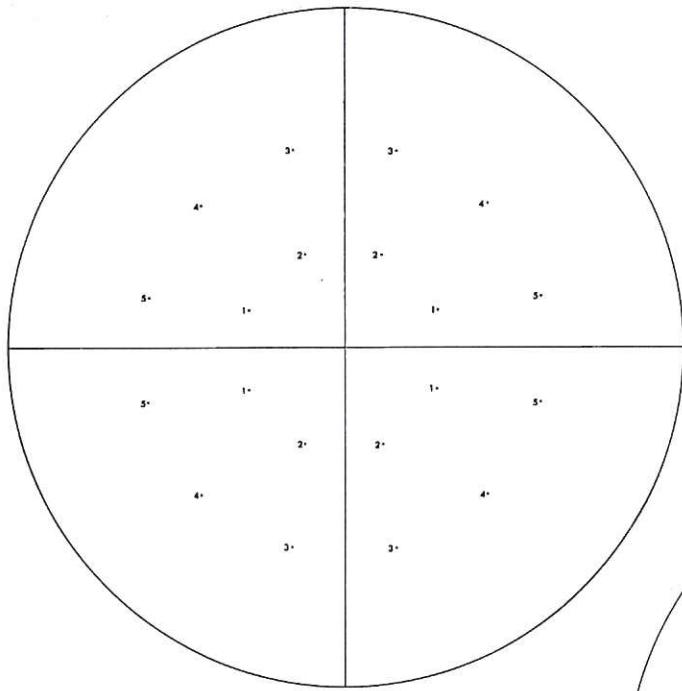
X	Y
0.277000	0.115000
0.115000	0.277000
0.155000	0.580000
0.424000	0.424000
0.580000	0.155000

Z ORDINATES OF TEMPLATES

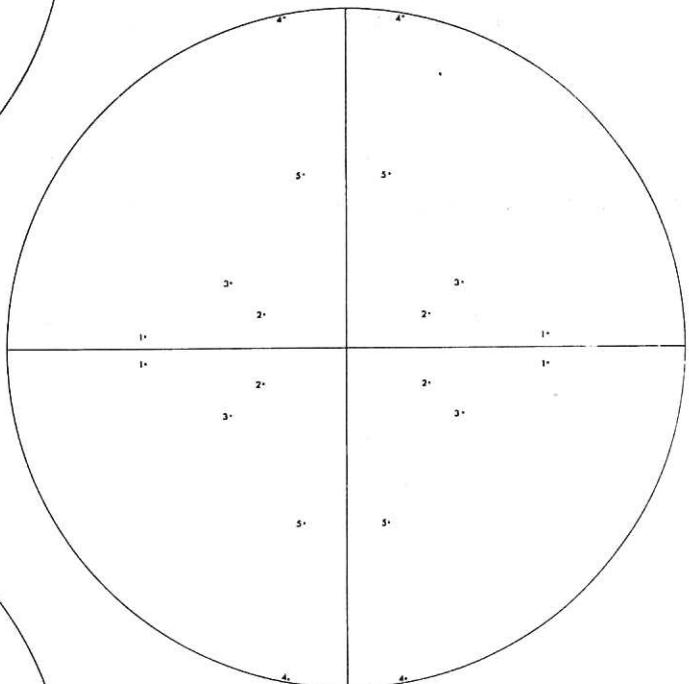
TEMPLATE NUMBER	POSITION
0	-0.
-1	-0.2500000
-2	-0.5000000
-3	-0.7500000
-4	-1.0000000

Z ORDINATES OF TEMPLATES

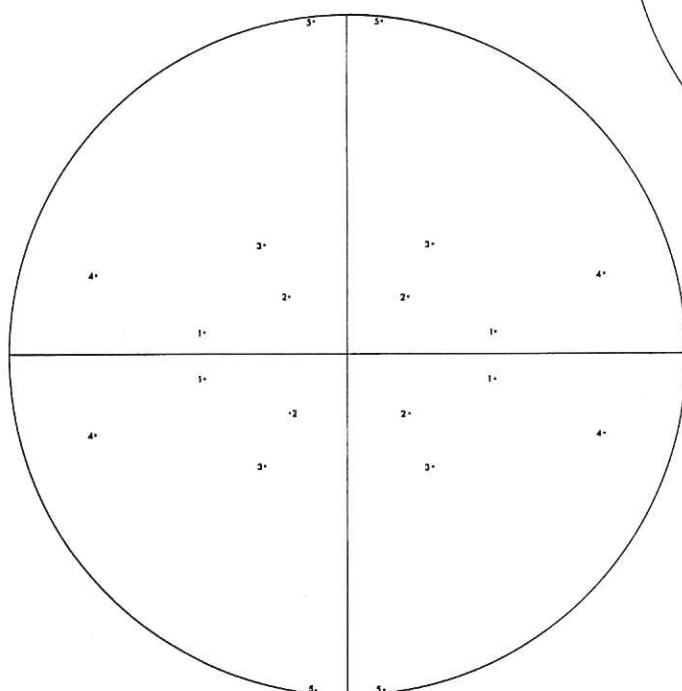
TEMPLATE NUMBER	POSITION
-0	0.
1	0.2500000
2	0.5000000
3	0.7500000
4	1.0000000



CLM-R31 Figure 22: Transverse section, at $z=0$, through loffe field showing intersections with field lines. (See paragraph 95)



CLM-R31 Figure 24: Transverse section, at $z=0.5$, through loffe field showing intersections with field lines. (See paragraph 45)



CLM-R31 Figure 23: Transverse section, $z=0.25$, through loffe field showing intersections with field lines. (See paragraph 95)

CLM - R31 Plate 1: Cardboard model of a quadrupole Ioffe magnetic field. (See paragraph 97)

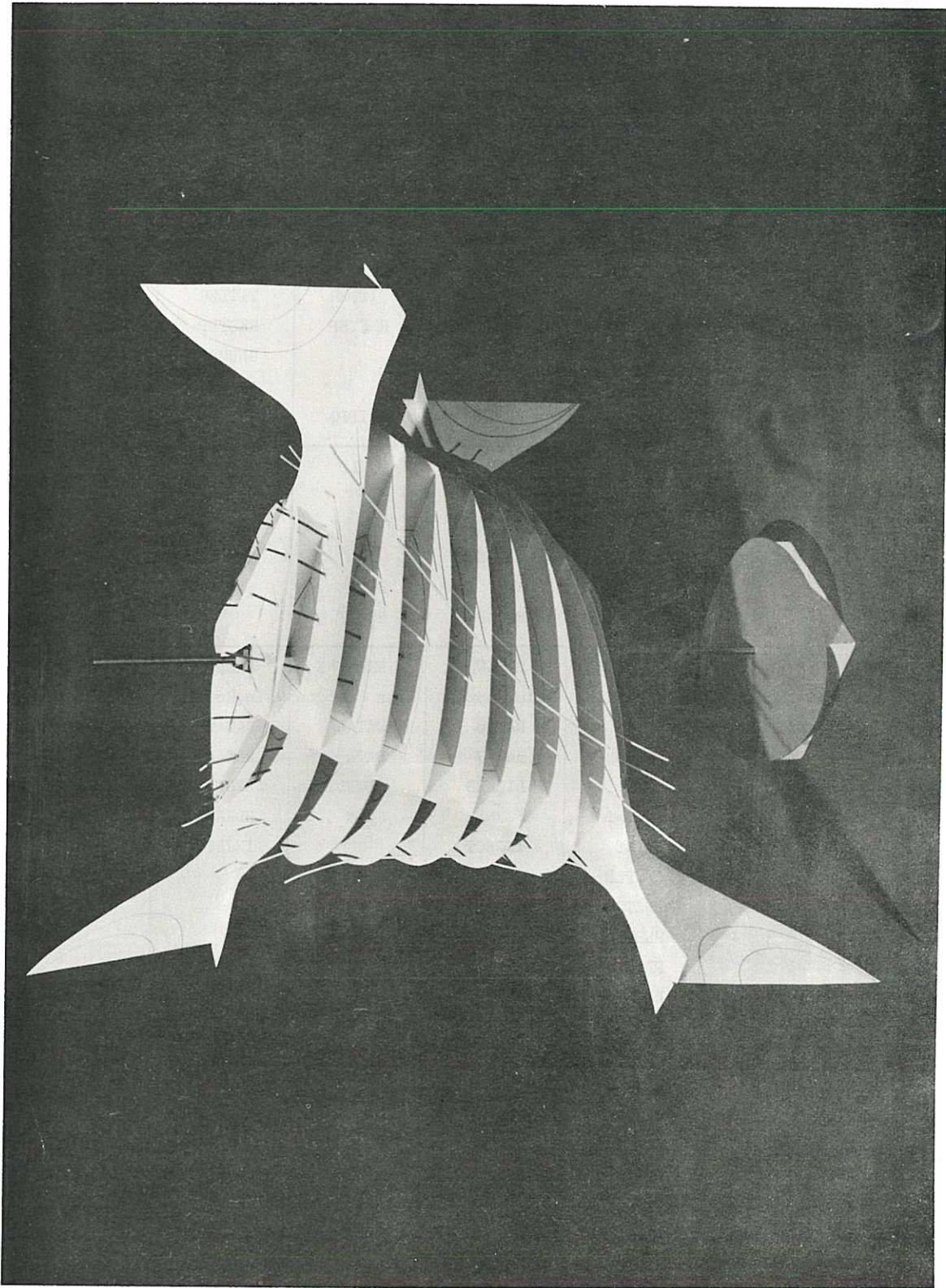


TABLE 2

Program Type of Subroutine \ Program	Program I B Contours	Program II Stereo pairs etc.	Program III Energy Surfaces, General	Program IV Energy Surfaces, Symmetric	Program V Neutral Injection	Program VI Field line Templates
Type (a) Standard	MAGCUR	MAGCUR	MAGCUR		MAGCUR	
	MAGLIN	MAGLIN	MAGLIN		MAGLIN	
	PLOT	PLOT	PLOT	PLOT	PLOT	PLOT
	KONTUA		KONTUA	KONTUA		
	ATANFQ	ATANFQ	ATANFQ		ATANFQ	ATANFQ
	TITLER	TITLER	TITLER	TITLER	TITLER	TITLER
	RKSTEP	RKSTEP	RKSTEP	RKSTEP	RKSTEP	RKSTEP
	GNUMB				GNUMB	GNUMB
	FRAME				FRAME	
	GRIDPQ		GRIDPQ	GRIDPQ		
Type (b) Similar	FIELD	FIELD	FIELD	FIELD	FIELD	FIELD
	DATAFB	DATAFB	DATAFB		DATAFB	
	DATCUR	DATCUR	DATCUR		DATCUR	
	CURDEF	CURDEF	CURDEF		CURDEF	
	BLINT	BINT	BINT			
	BLCOMP	BCOMP	BCOMP			
Type (c) Specialised	PRELUDE	PRELUDE	PRELUDE	PRELUDE	PRELUDE	PRELUDE
	Main Routine	Main Routine	Main Routine	Main Routine	Main Routine	Main Routine
	DATAB	DATA1	DATA6	DATA4	DATAB	DATA1
		DATA8	DATA7	DATA5	DATANI	DATA2
	MODB	BORG	LIONES	OUTPUT	LION	TMPLTS
		MIRINT	JGENER	JGEN	BDRAW	TEMPLT
		BLINE	INJECT		INJECT	
		SYMPLE				
		PLSTCR				
		PLSTFB				
		PLOST				
		BPLOST				
		STEREO				
		ROTMAT				
		ROTATE				
		STEROP				
		TRNSPT				
		GRIND				
		INTGRD				

Two dummy subroutines PHOTBG and ENDBQQ are also included in all six programs, in order to satisfy the Operating System. These will be overwritten if the Program Cards are included which cause graphical output to appear on the Stromberg-Carlson 4020 microfilm recorder. These library cards will also cause the inclusion of other standard subroutines concerned with graphical output.

A P P E N D I X

104. The subroutines which make up the programs described in this report may conveniently be classified into the following groups:

- (a) Standard subroutines used as self contained logical units in some, or all, of the programs.
- (b) Subroutines similar, but not identical, to those in the other programs.
These are mostly Input-Output routines.
- (c) Specialised subroutines peculiar to individual programs.

105. Table 2 lists these subroutines according to the above classification. Every program has a PRELUDE, which organises the layout of common storage, and a main routine, which initiates the computation proper and exercises broad control. The subroutine listings which follow are classified in the same way and in the interests of brevity only the specialised subroutines are listed under individual programs. One each of the standard and similar subroutines is listed separately, except for the small standard subroutines ATANFQ, TITLER, GNUMB and FRAME which are merely described, as follows.

<u>Subroutine</u>	<u>Function</u>
ATANFQ(X,Y)	Evaluates the angle θ which satisfies the relations
	$\cos \theta = \frac{X}{\sqrt{X^2 + Y^2}}$
	$\sin \theta = \frac{Y}{\sqrt{X^2 + Y^2}}$
	$0 \leq \theta < 2\pi$
TITLER	Reads and prints the contents of a title card supplied as input data.
GNUMB	Plots a given number at a specified position on the graph paper.
FRAME	Draws a rectangular frame of specified dimensions, forming a border to the plotting region.

106. The comment cards which appear in the following listings should be sufficient to indicate the purpose and methods of the various routines.

Data Sheet I. Contours of Constant $|B|$ in a Magnetic Field

General Description	Information on Card	Format	Notes and Comments																								
Prelude data. Sets dimensions of arrays and determines whether or not the $ B $ matrix is printed out.	<table border="1"> <tr> <td>NC</td><td>NL</td><td>NPF</td><td>NCUR</td></tr> <tr> <td>NP</td><td>NPX</td><td>NPY</td><td>IGRID</td></tr> <tr> <td colspan="4">NCONT</td></tr> </table>	NC	NL	NPF	NCUR	NP	NPX	NPY	IGRID	NCONT				4I7 4I7 I7	NC, number of circles. NL, number of infinite, parallel conductors. NPF, number of finite, straight conductors. NCUR, number of general curved conductors. NP, number of plane regions where contours are drawn. NPX, NPY, dimensions of grid. NCONT, number of $ B $ contours. To print $ B $ matrix set IGIRD ≥ 1 .												
NC	NL	NPF	NCUR																								
NP	NPX	NPY	IGRID																								
NCONT																											
A																											
Case number	<input type="text" value="NK"/>	I7	Normally NK ≥ 0 , set NK = -1 to terminate calculation																								
Variable title	Title : across 80 columns of card	10A8	e.g. Job description																								
Data for Co-axial circles	<table border="1"> <tr> <td>HC(1)</td><td>RC(1)</td><td>CC(1)</td><td></td></tr> <tr> <td>HC(2)</td><td>RC(2)</td><td>CC(2)</td><td></td></tr> <tr> <td>HC(NC)</td><td>RC(NC)</td><td>CC(NC)</td><td></td></tr> </table>	HC(1)	RC(1)	CC(1)		HC(2)	RC(2)	CC(2)		HC(NC)	RC(NC)	CC(NC)		3F14.7	HC, Z co-ordinate of centre of circle. RC, radius of circle. CC, current in circle. This is positive in the direction of a right hand screw moving along the Z axis in a positive direction.												
HC(1)	RC(1)	CC(1)																									
HC(2)	RC(2)	CC(2)																									
HC(NC)	RC(NC)	CC(NC)																									
Data for infinite, straight lines parallel to Z axis	<table border="1"> <tr> <td>XL(1)</td><td>YL(1)</td><td>CL(1)</td><td></td></tr> <tr> <td>XL(2)</td><td>YL(2)</td><td>CL(2)</td><td></td></tr> <tr> <td>XL(NL)</td><td>YL(NL)</td><td>CL(NL)</td><td></td></tr> </table>	XL(1)	YL(1)	CL(1)		XL(2)	YL(2)	CL(2)		XL(NL)	YL(NL)	CL(NL)		3F14.7	XL, YL, co-ordinates of the intersection of the conductor with the plane Z = 0. CL, current in the conductor. This is positive in the positive direction of the Z axis.												
XL(1)	YL(1)	CL(1)																									
XL(2)	YL(2)	CL(2)																									
XL(NL)	YL(NL)	CL(NL)																									
Data for finite, straight lines	<table border="1"> <tr> <td>X1(1)</td><td>Y1(1)</td><td>Z1(1)</td><td>X2(1)</td><td>Y2(1)</td><td>Z2(1)</td><td>CF(1)</td><td></td></tr> <tr> <td>X1(2)</td><td>Y1(2)</td><td>Z1(2)</td><td>X2(2)</td><td>Y2(2)</td><td>Z2(2)</td><td>CF(2)</td><td></td></tr> <tr> <td>X1(NFB)</td><td>Y1(NFB)</td><td>Z1(NFB)</td><td>X2(NFB)</td><td>Y2(NFB)</td><td>Z2(NFB)</td><td>CF(NFB)</td><td></td></tr> </table>	X1(1)	Y1(1)	Z1(1)	X2(1)	Y2(1)	Z2(1)	CF(1)		X1(2)	Y1(2)	Z1(2)	X2(2)	Y2(2)	Z2(2)	CF(2)		X1(NFB)	Y1(NFB)	Z1(NFB)	X2(NFB)	Y2(NFB)	Z2(NFB)	CF(NFB)		7F14.14	(X1, Y1, Z1) are the co-ordinates of end 1 of the finite, straight conductor. (X2, Y2, Z2) are the co-ordinates of end 2. CF is the current in the conductor. This is positive moving in the direction from end 1 towards end 2.
X1(1)	Y1(1)	Z1(1)	X2(1)	Y2(1)	Z2(1)	CF(1)																					
X1(2)	Y1(2)	Z1(2)	X2(2)	Y2(2)	Z2(2)	CF(2)																					
X1(NFB)	Y1(NFB)	Z1(NFB)	X2(NFB)	Y2(NFB)	Z2(NFB)	CF(NFB)																					
Data for general curved conductors	<table border="1"> <tr> <td>T1(1)</td><td>T2(1)</td><td>NT(1)</td><td>CR(1)</td><td></td></tr> <tr> <td>T1(2)</td><td>T2(2)</td><td>NT(2)</td><td>CR(2)</td><td></td></tr> <tr> <td>T1(NCUR)</td><td>T2(NCUR)</td><td>NT(NCUR)</td><td>CR(NCUR)</td><td></td></tr> </table>	T1(1)	T2(1)	NT(1)	CR(1)		T1(2)	T2(2)	NT(2)	CR(2)		T1(NCUR)	T2(NCUR)	NT(NCUR)	CR(NCUR)		2F14.7,I7,F14.7	T1, T2, respectively are the initial and final values of the parameter T. NT is the number of integration intervals between T1 and T2. CR is the current in the conductor. This is positive in the direction of T increasing from T1 to T2.									
T1(1)	T2(1)	NT(1)	CR(1)																								
T1(2)	T2(2)	NT(2)	CR(2)																								
T1(NCUR)	T2(NCUR)	NT(NCUR)	CR(NCUR)																								

Data Sheet I. (Continued)

General Description	Information on Card	Format	Notes and Comments															
Supplementary data for general curved conductors	Supplementary parameters																	
Data specifying square regions for the purpose of plotting $ B $ contours.	<table border="1"> <tr><td>ZMD(1)</td><td>P(1)</td><td>PL(1)</td><td>XMD(1)</td><td>YMD(1)</td></tr> <tr><td>ZMD(2)</td><td>P(2)</td><td>PL(2)</td><td>XMD(2)</td><td>YMD(2)</td></tr> <tr><td>ZMD(NP)</td><td>P(NP)</td><td>PL(NP)</td><td>XMD(NP)</td><td>YMD(NP)</td></tr> </table>	ZMD(1)	P(1)	PL(1)	XMD(1)	YMD(1)	ZMD(2)	P(2)	PL(2)	XMD(2)	YMD(2)	ZMD(NP)	P(NP)	PL(NP)	XMD(NP)	YMD(NP)	5F14.7	(XMD, YMD, ZMD) are the co-ordinates of the midpoint of the square region over which $ B $ contours are plotted. PL is the edge length of that square. $0 \leq P < 2\pi$ denotes an axial plane, and $0 > P$ or $2\pi \leq P$ denotes a transverse plane.
ZMD(1)	P(1)	PL(1)	XMD(1)	YMD(1)														
ZMD(2)	P(2)	PL(2)	XMD(2)	YMD(2)														
ZMD(NP)	P(NP)	PL(NP)	XMD(NP)	YMD(NP)														
Values of $ B $ at which contour heights are plotted.	<table border="1"> <tr><td>H(1)</td></tr> <tr><td>H(2)</td></tr> <tr><td>H(NCONT)</td></tr> </table>	H(1)	H(2)	H(NCONT)	F14.7	$ B $ contours are plotted, in all square regions specified, at heights H(1), H(2), ..., H(NCONT).												
H(1)																		
H(2)																		
H(NCONT)																		
Graph size	GSIZE	F14.7	Edge length, in inches, of final pictures.															
Data for next case	Repeat AA-BB as often as required	as above	No array dimensions may exceed those specified in the Prelude Data															
Closing card	-1	I7	This is precisely equivalent to starting Case Number "-1". EXIT follows.															

B

B

In the above table each line represents one card, and the format description adheres to standard FORTRAN convention.

If any array dimension is zero all subsequent blocks of data associated with that dimension must simply be left out. For example, if NFB in the Prelude data is set equal to zero the data block described as "Data for finite, straight lines" will not appear at all. Similarly, if the definition of the general curved conductors does not call for any supplementary parameters the corresponding data block will also be left out. However, even if no general curved conductors are used, a subroutine CURDEF must appear in the program input deck.

For a more precise description of the various categories of data refer to the text or the example.

Data Sheet II. Stereoscopic Pictures of Magnetic Field Lines and/or Field Line Integrals

General Description	Information on Card	Format	Notes and Comments																																
Prelude Data. Sets dimensions of arrays.	<table border="1"> <tr> <td>NC</td> <td>NL</td> <td>NFB</td> <td>NCUR</td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> </tr> </table> <table border="1"> <tr> <td>NFB</td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> </tr> </table> <table border="1"> <tr> <td>NBDS</td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> </tr> </table>	NC	NL	NFB	NCUR					NFB								NBDS								4I7 I7 I7	NC, number of co-axial circles. NL, number of infinite, straight lines. NFB, number of finite, straight conductors. NCUR, number of general curved conductors. NPB, number of field lines considered. NBDS, maximum permissible number of integration steps along any field line.								
NC	NL	NFB	NCUR																																
NFB																																			
NBDS																																			
A																																			
Case number	<table border="1"> <tr> <td>NRK</td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> </tr> </table>	NRK								I7	Normally NRK > 0; set NRK = -1 to terminate calculation.																								
NRK																																			
Variable title	<table border="1"> <tr> <td colspan="4">Title : across 80 columns of card</td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> </tr> </table>	Title : across 80 columns of card								10A8	e.g. Job description.																								
Title : across 80 columns of card																																			
Data for Co-axial circles.	<table border="1"> <tr> <td>HC(1)</td> <td>RC(1)</td> <td>CC(1)</td> <td></td> </tr> <tr> <td>HC(2)</td> <td>RC(2)</td> <td>CC(2)</td> <td></td> </tr> <tr> <td>HC(NC)</td> <td>RC(NC)</td> <td>CC(NC)</td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> </tr> </table>	HC(1)	RC(1)	CC(1)		HC(2)	RC(2)	CC(2)		HC(NC)	RC(NC)	CC(NC)						3F14.7	HC, Z co-ordinate of centre of circle. RC, radius of circle. CC, current in circle. This is positive in the direction of a right hand screw moving along the Z-axis in the positive direction.																
HC(1)	RC(1)	CC(1)																																	
HC(2)	RC(2)	CC(2)																																	
HC(NC)	RC(NC)	CC(NC)																																	
Data for infinite, straight lines parallel to Z-axis.	<table border="1"> <tr> <td>XL(1)</td> <td>YL(1)</td> <td>CL(1)</td> <td></td> </tr> <tr> <td>XL(2)</td> <td>YL(2)</td> <td>CL(2)</td> <td></td> </tr> <tr> <td>XL(NL)</td> <td>YL(NL)</td> <td>CL(NL)</td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> </tr> </table>	XL(1)	YL(1)	CL(1)		XL(2)	YL(2)	CL(2)		XL(NL)	YL(NL)	CL(NL)						3F14.7	XL, YL are the co-ordinates of the intersection of the conductor with the plane Z = 0. CL, current in the conductor. This is positive in the positive direction of the Z-axis.																
XL(1)	YL(1)	CL(1)																																	
XL(2)	YL(2)	CL(2)																																	
XL(NL)	YL(NL)	CL(NL)																																	
Data for finite, straight lines.	<table border="1"> <tr> <td>X1(1)</td> <td>Y1(1)</td> <td>Z1(1)</td> <td>X2(1)</td> <td>Y2(1)</td> <td>Z2(1)</td> <td>CR(1)</td> <td></td> </tr> <tr> <td>X1(2)</td> <td>Y1(2)</td> <td>Z1(2)</td> <td>X2(2)</td> <td>Y2(2)</td> <td>Z2(2)</td> <td>CR(2)</td> <td></td> </tr> <tr> <td>X1(NFB)</td> <td>Y1(NFB)</td> <td>Z1(NFB)</td> <td>X2(NFB)</td> <td>Y2(NFB)</td> <td>Z2(NFB)</td> <td>CF(NFB)</td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> </table>	X1(1)	Y1(1)	Z1(1)	X2(1)	Y2(1)	Z2(1)	CR(1)		X1(2)	Y1(2)	Z1(2)	X2(2)	Y2(2)	Z2(2)	CR(2)		X1(NFB)	Y1(NFB)	Z1(NFB)	X2(NFB)	Y2(NFB)	Z2(NFB)	CF(NFB)										7F11.4	(X1, Y1, Z1) are the co-ordinates of end 1 of the finite, straight conductor. (X2, Y2, Z2) are the co-ordinates of end 2. CF is the current in the conductor. This is positive moving from end 1 to end 2.
X1(1)	Y1(1)	Z1(1)	X2(1)	Y2(1)	Z2(1)	CR(1)																													
X1(2)	Y1(2)	Z1(2)	X2(2)	Y2(2)	Z2(2)	CR(2)																													
X1(NFB)	Y1(NFB)	Z1(NFB)	X2(NFB)	Y2(NFB)	Z2(NFB)	CF(NFB)																													
Data for general curved conductors.	<table border="1"> <tr> <td>T1(1)</td> <td>T2(1)</td> <td>NT(1)</td> <td>CR(1)</td> <td></td> </tr> <tr> <td>T1(2)</td> <td>T2(2)</td> <td>NT(2)</td> <td>CR(2)</td> <td></td> </tr> <tr> <td>T1(NCUR)</td> <td>T2(NCUR)</td> <td>NT(NCUR)</td> <td>CR(NCUR)</td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> </table>	T1(1)	T2(1)	NT(1)	CR(1)		T1(2)	T2(2)	NT(2)	CR(2)		T1(NCUR)	T2(NCUR)	NT(NCUR)	CR(NCUR)							2F14.7,I7,F14.7	Specified by the user. T1, T2, respectively are the initial and final values of the parameter, T. NT is the number of integration regions between T1 and T2. CR is the current in the conductor. This is positive in the direction of T increasing from T1 to T2.												
T1(1)	T2(1)	NT(1)	CR(1)																																
T1(2)	T2(2)	NT(2)	CR(2)																																
T1(NCUR)	T2(NCUR)	NT(NCUR)	CR(NCUR)																																
Supplementary data for general curved conductors.	<table border="1"> <tr> <td colspan="5">Supplementary parameters</td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> </table>	Supplementary parameters											These may be required in order to complete the definitions of the general, curved conductors. The user will arrange them in the order specified by his own input instructions in subroutine CURDEF.																						
Supplementary parameters																																			
Graph: size	<table border="1"> <tr> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td></td> <td></td> <td></td> <td></td> </tr> </table>									F14.7	Length, in inches, of the longer side of any resulting picture.																								

Data Sheet II. (Continued)

General Description	Information on card	Format	Notes and Comments
Steering parameters	ISTER IPLOT	2I7	ISTER < -2 suppresses both integrals and stereo pairs. ISTER = -1, integrals only. ISTER > 0, stereo pair only. ISTER = 0, both integrals and stereo pair. Set IPLOT = -1 to suppress radius plotting.
Boundary parameters	ZTX RI	2F14.7	ZTX, RI, respectively, are semi-length and radius of the cylindrical region of interest centred on the origin, for the purpose of following field lines.
Field line parameters	DS BREF	2F14.7	DS, integration step length along field line. BREF, value of $ \underline{B} $ at terminal points of field line.
Stereoscopic projection Data. Leave out if ISTER < 0.	X0(1) X0(2) X0(3) X1(1) X1(2) X1(3) RO XMAG PSTI F D DISP	3F14.7 3F14.7 3F14.7 5F14.7 F14.7	\underline{X}_0 is the position of a "centre of interest", for the purpose of stereoscopic examination. \underline{X}_1 is a vector defining the direction along which the centre of interest is viewed. RO, radius of spherical region of interest. XMAG, a magnification factor which can be applied to this region. PSTI, azimuthal angle through which the region of interest may be rotated (i.e. about line of sight) before viewing. F, distance of projection points from projection plane. D, semi-distance between projection points. DISP, distance, in inches, between left and right pictures.
Starting points of magnetic field lines	XB(1) YB(1) ZB(1) IP(1) XB(2) YB(2) ZB(2) IP(2) XR(NPB) YR(NPB) ZR(NPB) IP(NPB)	3F14.7,I7	(XB, YB, ZB) is the starting point of a field line (i.e. any point along that field line). If IP = 0 no printing will occur. If IP ≠ 0 co-ordinates of all points computed along field line will be printed out.
Data for next case	Repeat AA : BB as often as required	as above	No array dimensions may exceed those specified in Prelude data.
Closing card	-1	I7	This is equivalent to starting "case -1". Exit follows immediately.

In the above table each line represents one card, and the format adheres to standard FORTRAN convention.
 If any array dimension is zero all subsequent blocks of data associated with that dimension must simply be left out. For example, if NFB in the Prelude data is set equal to zero the data block described as "Data for finite, straight lines" will not appear at all. Similarly, if the definition of the general, curved conductors does not call for any supplementary parameters, the corresponding data block will be left out. However, even if no general, curved conductors are used, a subroutine CURDBP must appear in the program input deck.

For a more precise description of the various categories of data refer to the text or the example.

Data Sheet III. Energy Surfaces in a Magnetic Field with a Minimum in |B|

General Description	Information on Card				Format	Notes and Comments																								
Prelude data. Sets dimensions of arrays and determines whether or not the J matrix will be printed out.	<input type="text"/> NC <input type="text"/> NL <input type="text"/> NFB <input type="text"/> NCUR <input type="text"/> NX <input type="text"/> NY <input type="text"/> IGRID <input type="text"/> NE <input type="text"/> NAS				4I7	NC, number of co-axial circles. NL, number of infinite straight lines. NFB, number of finite, straight lines. NCUR, number of general, curved conductors.																								
					3I7																									
					I7	Set IGRID = 0 to suppress printing of J matrices for all energies except injection kinetic energy.																								
					I7	NAS, maximum permissible number of integration steps along a field line.																								
A																														
Case number	<input type="text"/> NK				I7	Normally NK ≥ 0; set NK = -1 to terminate calculation.																								
Variable title		Title : across 80 columns of card			10A8	e.g. Job description																								
Data for co-axial circles	<table border="1"><tr><td>HC(1)</td><td>RC(1)</td><td>CC(1)</td></tr><tr><td>HC(2)</td><td>RC(2)</td><td>CC(2)</td></tr><tr><td></td><td></td><td></td></tr><tr><td>HC(NC)</td><td>RC(NC)</td><td>CC(NC)</td></tr></table>	HC(1)	RC(1)	CC(1)	HC(2)	RC(2)	CC(2)				HC(NC)	RC(NC)	CC(NC)				3F14.7	HC, Z co-ordinate of centre of circle. RC, radius of circle.												
HC(1)	RC(1)	CC(1)																												
HC(2)	RC(2)	CC(2)																												
HC(NC)	RC(NC)	CC(NC)																												
						CC, current in circle. This is positive in the direction of a right hand screw moving along the Z-axis in a positive direction.																								
Data for infinite, straight lines, parallel to Z-axis	<table border="1"><tr><td>XL(1)</td><td>YL(1)</td><td>CL(1)</td></tr><tr><td>XL(2)</td><td>YL(2)</td><td>CL(2)</td></tr><tr><td></td><td></td><td></td></tr><tr><td>XL(NL)</td><td>YL(NL)</td><td>CL(NL)</td></tr></table>	XL(1)	YL(1)	CL(1)	XL(2)	YL(2)	CL(2)				XL(NL)	YL(NL)	CL(NL)				3F14.7	XL, YL are the co-ordinates of the intersection of the conductor with the plane Z = 0. CL, current in the conductor. This is positive in the positive direction of the Z-axis.												
XL(1)	YL(1)	CL(1)																												
XL(2)	YL(2)	CL(2)																												
XL(NL)	YL(NL)	CL(NL)																												
Data for finite, straight lines	<table border="1"><tr><td>X1(1)</td><td>Y1(1)</td><td>Z1(1)</td><td>Y2(1)</td><td>Z2(1)</td><td>CF(1)</td></tr><tr><td>X1(2)</td><td>Y1(2)</td><td>Z1(2)</td><td>Y2(2)</td><td>Z2(2)</td><td>CF(2)</td></tr><tr><td></td><td></td><td></td><td></td><td></td><td></td></tr><tr><td>X1(NFB)</td><td>Y1(NFB)</td><td>Z1(NFB)</td><td>Y2(NFB)</td><td>Z2(NFB)</td><td>CF(NFB)</td></tr></table>	X1(1)	Y1(1)	Z1(1)	Y2(1)	Z2(1)	CF(1)	X1(2)	Y1(2)	Z1(2)	Y2(2)	Z2(2)	CF(2)							X1(NFB)	Y1(NFB)	Z1(NFB)	Y2(NFB)	Z2(NFB)	CF(NFB)				7F14.4	(X1, Y1, Z1) are the co-ordinates of end 1 of the finite, straight conductor. (X2, Y2, Z2) are the co-ordinates of end 2. CF is the current in the conductor. This is positive moving from end 1 to end 2.
X1(1)	Y1(1)	Z1(1)	Y2(1)	Z2(1)	CF(1)																									
X1(2)	Y1(2)	Z1(2)	Y2(2)	Z2(2)	CF(2)																									
X1(NFB)	Y1(NFB)	Z1(NFB)	Y2(NFB)	Z2(NFB)	CF(NFB)																									
Data for general, curved conductors	<table border="1"><tr><td>T1(1)</td><td>T2(1)</td><td>NT(1)</td><td>CR(1)</td></tr><tr><td>T1(2)</td><td>T2(2)</td><td>NT(2)</td><td>CR(2)</td></tr><tr><td></td><td></td><td></td><td></td></tr><tr><td>T1(NCUR)</td><td>T2(NCUR)</td><td>NT(NCUR)</td><td>CR(NCUR)</td></tr></table>	T1(1)	T2(1)	NT(1)	CR(1)	T1(2)	T2(2)	NT(2)	CR(2)					T1(NCUR)	T2(NCUR)	NT(NCUR)	CR(NCUR)				2F14.7,I7, F14.7	T1, T2, respectively are the initial and final values of the parameter T. NT is the number of integration regions between T1 and T2. CR is the current in the conductor. This is positive in the direction of T increasing from T1 to T2.								
T1(1)	T2(1)	NT(1)	CR(1)																											
T1(2)	T2(2)	NT(2)	CR(2)																											
T1(NCUR)	T2(NCUR)	NT(NCUR)	CR(NCUR)																											

Data Sheet III. (Continued)

General Description	Information on Card	Format	Notes and Comments
Supplementary data for general, curved conductors	Supplementary parameters	Specified by the user.	These may be required in order to complete the definitions of the General, curved conductors. The user will arrange them in the order specified by his own input instructions in subroutine CURDEF.
J-plane parameters	EDGE XMD YMD	3F14.7	EDGE is the edge length of the square J-plane which is normal to the Z-axis. (XMD, YMD) are the (x, y) co-ordinates of its mid point.
Graph size	GSIZE	F14.7	Edge length, in inches, of all resulting square pictures.
Boundary parameters	RI ZTX	2F14.7	RI, ZTX, respectively, are radius and semi-length of the region of interest, for the purpose of following field lines, centred on the origin.
Ionisation field	EI	F14.7	Injected particle is ionised where $ V_A = EI$. Set EI = -1 to ionise at prescribed place.
Injection parameters	DPAR TPAR YPAR ZPAR	5F14.7 blank (one card)	Injection line lies in plane x = XPAR. DPAR is the impact parameter w.r.t. origin, and TPAR is angle, in radians, which injection line makes with y-axis. EK is injection kinetic energy of neutral particle. YPAR, ZPAR are co-ordinates of point where particle is required to be ionised (as opposed to injection); FMU is the magnetic moment in this case. If EI > 0, upper interpretation used; if EI < 0, lower interpretation is used.
Kinetic energies	E(2) E(3) E(NE)	E(1) = EK F14.7	The E are energies used, in addition to EK, in the computation of values of J.
B Data for next case	Repeat AA : BB as often as required	as above	No array dimensions may exceed those specified in Prelude data.
Closing card	-1	I7	This is equivalent to starting "Case -1". Exit follows immediately.
B			
In the above table each line represents one card, and the format description adheres to standard FORTRAN convention. Five numbers only appear on the card described as "Injection parameters", but the 2nd, 3rd and 5th, are interpreted in two different ways according as the ionisation potential is positive or negative.			
If any array dimension is zero all subsequent blocks of data associated with this dimension must simply be left out. For example, if NFB is set equal to zero in the data block described as "Data for finite, straight lines" will not appear at all. Similarly, if the definition of the General, curved conductors does not call for any supplementary parameters, the corresponding data block will be left out. However, even if no General, curved conductors are used, a subroutine CURDEF must appear in the program input deck.			
For a more precise description of the various categories of data refer to the text or the example.			

Data Sheet IV. Energy Surfaces in a Cylindrically Symmetric Apparatus

General Description	Information on Card		Format	Notes and Comments
Prelude data. Sets dimensions of all arrays.	<input type="text"/> NC <input type="text"/> NL		2I7	NC, number of co-axial circles. NL, number of infinite, straight lines; this may only be either 0 or 1.
	<input type="text"/> NR <input type="text"/> NE		2I7	NR, NE, dimensions of rectangular mesh spanning a region in the radius: energy plane.
	<input type="text"/> NJ		I7	NJ, number of contours of constant $J/\mu^{\frac{1}{2}}$.
	<input type="text"/> NAS		I7	NAS, maximum allowed number of integration steps along a magnetic field line.
<hr/>				
A				
Case number	<input type="text"/> NK		I7	Normally NK > 0. Set NK = -1 to terminate calculation.
Variable title	<input type="text"/> Title : across 80 columns of card		10A8	e.g. Job description
Data for co-axial circles	<input type="text"/> RC(1) <input type="text"/> RC(1) <input type="text"/> CC(1) <input type="text"/> RC(2) <input type="text"/> RC(2) <input type="text"/> CC(2)		3F14.7	HC, Z co-ordinate of centre of circle. RC, radius of circle.
Data for current along Z-axis	<input type="text"/> RC(NC) <input type="text"/> RC(NC) <input type="text"/> CC(NC)		3F14.7	CC, current in circle. This is positive in the direction of a right hand screw moving positively along the Z axis.
Graph size	<input type="text"/> 0.0 <input type="text"/> 0.0 <input type="text"/> CL		3F14.7	CL, current in positive direction along Z-axis. Leave out this card if NL = 0.
Integration step	<input type="text"/> DS		F14.7	Length, in inches, of the longer side of resulting rectangular graph.
Boundary values of $J/\mu^{\frac{1}{2}}$.	<input type="text"/> RJMIN <input type="text"/> RJMAX		2F14.7	Integration step length along a magnetic field line.
Boundary values of radius	<input type="text"/> RMIN <input type="text"/> RMAX		2F14.7	$J/\mu^{\frac{1}{2}}$ contours are equispaced between values RJMIN and RJMAX.
Boundary values of energy	<input type="text"/> EMIN <input type="text"/> EMAX		2F14.7	RMIN, RMAX, respectively, denote lower and upper bounds to the radius.
Position of starting plane	<input type="text"/> RMU <input type="text"/> RTX <input type="text"/> RADIUS <input type="text"/> ZSTART		2F14.7	EMIN, EMAX, respectively, denote lower and upper bounds to the energy.
B	Data for next case	Repeat AA:BB as often as required	as above	No array dimensions may exceed those specified in Prelude data.
Closing card	<input type="text"/> -1		I7	This is equivalent to starting "case -1". Exit follows immediately.
<hr/>				
B				
For a more precise description of the various categories of data refer to the text of the example.				

Data Sheet V. Injection of Neutral Particles into a Magnetic Trap

General Description	Information on Card	Format	Notes and Comments																												
Prelude data. Sets dimensions of arrays.	<table border="1"> <tr><td>NC</td><td>NL</td><td>NFB</td><td>NCUR</td></tr> <tr><td></td><td></td><td></td><td></td></tr> <tr><td>NPAR</td><td></td><td></td><td></td></tr> </table>	NC	NL	NFB	NCUR					NPAR				IIT	NC, number of circular conductors. NL, number of infinite, parallel lines. NFB, number of finite, straight lines. NCUR, number of general, curved conductors. NPAR, number of neutral particles injected.																
NC	NL	NFB	NCUR																												
NPAR																															
A																															
Case number	<table border="1"> <tr><td>NK</td></tr> </table>	NK	I7	Normally NK > 0; set NK = -1 to terminate calculation.																											
NK																															
Variable title	Title : across 80 columns of card	10A8	e.g. Job description																												
Data for co-axial coils	<table border="1"> <tr><td>HC(1)</td><td>RC(1)</td><td>CC(1)</td></tr> <tr><td>HC(2)</td><td>RC(2)</td><td>CC(2)</td></tr> <tr><td></td><td></td><td></td></tr> <tr><td>HC(NC)</td><td>RC(NC)</td><td>CC(NC)</td></tr> </table>	HC(1)	RC(1)	CC(1)	HC(2)	RC(2)	CC(2)				HC(NC)	RC(NC)	CC(NC)	3F14.7	HC, Z co-ordinate of centre of circle. RC, radius of circle. CC, current in circle. This is positive in the direction of a right hand screw moving along the Z-axis in a positive direction.																
HC(1)	RC(1)	CC(1)																													
HC(2)	RC(2)	CC(2)																													
HC(NC)	RC(NC)	CC(NC)																													
Data for infinite, straight lines, parallel to Z-axis.	<table border="1"> <tr><td>XL(1)</td><td>YL(1)</td><td>CL(1)</td></tr> <tr><td>XL(2)</td><td>YL(2)</td><td>CL(2)</td></tr> <tr><td></td><td></td><td></td></tr> <tr><td>XL(NL)</td><td>YL(NL)</td><td>CL(NL)</td></tr> </table>	XL(1)	YL(1)	CL(1)	XL(2)	YL(2)	CL(2)				XL(NL)	YL(NL)	CL(NL)	3F14.7	XL, YL, co-ordinates of the intersection of the conductor with the plane Z = 0. CL, current in the conductor. This is positive in the positive direction of the Z axis.																
XL(1)	YL(1)	CL(1)																													
XL(2)	YL(2)	CL(2)																													
XL(NL)	YL(NL)	CL(NL)																													
Data for finite, straight lines.	<table border="1"> <tr><td>X1(1)</td><td>Y1(1)</td><td>Z1(1)</td><td>X2(1)</td><td>Y2(1)</td><td>Z2(1)</td><td>CF(1)</td></tr> <tr><td>X1(2)</td><td>Y1(2)</td><td>Z1(2)</td><td>X2(2)</td><td>Y2(2)</td><td>Z2(2)</td><td>CF(2)</td></tr> <tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr> <tr><td>X1(NFB)</td><td>Y1(NFB)</td><td>Z1(NFB)</td><td>X2(NFB)</td><td>Y2(NFB)</td><td>Z2(NFB)</td><td>CF(NFB)</td></tr> </table>	X1(1)	Y1(1)	Z1(1)	X2(1)	Y2(1)	Z2(1)	CF(1)	X1(2)	Y1(2)	Z1(2)	X2(2)	Y2(2)	Z2(2)	CF(2)								X1(NFB)	Y1(NFB)	Z1(NFB)	X2(NFB)	Y2(NFB)	Z2(NFB)	CF(NFB)	7F11.4	(X1, Y1, Z1) are the co-ordinates of end 1 of the finite, straight conductor. (X2, Y2, Z2) are the co-ordinates of end 2. CF is the current in the conductor. This is positive moving in the direction from end 1 to end 2.
X1(1)	Y1(1)	Z1(1)	X2(1)	Y2(1)	Z2(1)	CF(1)																									
X1(2)	Y1(2)	Z1(2)	X2(2)	Y2(2)	Z2(2)	CF(2)																									
X1(NFB)	Y1(NFB)	Z1(NFB)	X2(NFB)	Y2(NFB)	Z2(NFB)	CF(NFB)																									
Data for general, curved conductors	<table border="1"> <tr><td>T1(1)</td><td>T2(1)</td><td>NT(1)</td><td>CR(1)</td></tr> <tr><td>T1(2)</td><td>T2(2)</td><td>NT(2)</td><td>CR(2)</td></tr> <tr><td></td><td></td><td></td><td></td></tr> <tr><td>T1(NCUR)</td><td>T2(NCUR)</td><td>NT(NCUR)</td><td>CR(NCUR)</td></tr> </table>	T1(1)	T2(1)	NT(1)	CR(1)	T1(2)	T2(2)	NT(2)	CR(2)					T1(NCUR)	T2(NCUR)	NT(NCUR)	CR(NCUR)	2F14.7, I7,F14.7	T1, T2, respectively are the initial and final values of the parameter T. NT is the number of integration intervals between T1 and T2. CR is the current in the conductor. This is positive in the direction of T increasing from T1 to T2.												
T1(1)	T2(1)	NT(1)	CR(1)																												
T1(2)	T2(2)	NT(2)	CR(2)																												
T1(NCUR)	T2(NCUR)	NT(NCUR)	CR(NCUR)																												

Data Sheet V. (Continued)

General Description	Information on Card	Format	Notes and Comments												
Supplementary parameters for general, curved conductors	<input type="text"/> Supplementary parameters	Specified by the user.	These may be required in order to complete the definitions of the general, curved conductors. The user will arrange them in the order specified by his own input instructions in subroutine CURDEF.												
Graph size	<input type="text"/> GSIZE	F14.7	Length, in inches, of longer side of final rectangular picture.												
Steering parameter	<input type="text"/> INJ	I7	Specifies type of injection; for details see below: "injected particles".												
Boundary parameters	<input type="text"/> ZTX <input type="text"/> FI	2F14.7	ZTX, RI, respectively, are semi-length and radius of the cylindrical region of interest which is centred on the origin.												
Data specifying injected particles.	<table border="1"> <tr> <td>XP(1)</td><td>DP(1)</td><td>TP(1)</td><td>ER(1)</td></tr> <tr> <td>XP(2)</td><td>DP(2)</td><td>TP(2)</td><td>ER(2)</td></tr> <tr> <td>XP(NPAR)</td><td>DP(NPAR)</td><td>TP(NPAR)</td><td>ER(NPAR)</td></tr> </table>	XP(1)	DP(1)	TP(1)	ER(1)	XP(2)	DP(2)	TP(2)	ER(2)	XP(NPAR)	DP(NPAR)	TP(NPAR)	ER(NPAR)	4F14.7	Injection line lies in the plane $x = XP$. DP is the impact parameter, and TP is the angle, in radians, which the injection line makes with the y-axis. ER is regarded as the ionisation field of the injected particle if INJ<0 and as the radius at ionisation if INJ>0.
XP(1)	DP(1)	TP(1)	ER(1)												
XP(2)	DP(2)	TP(2)	ER(2)												
XP(NPAR)	DP(NPAR)	TP(NPAR)	ER(NPAR)												
B Data for next case	Repeat AA-BB as often as required	as above	No array dimensions may exceed those specified in the Prelude Data.												
Closing card	<input type="text"/> -1	I7	This is equivalent to starting "Case -1". Exit follows immediately.												

In the above table each line represents one card, and the format description adheres to standard FORTRAN convention.

If any array dimension is zero all subsequent blocks of data associated with that dimension must simply be left out. For example, if NFB in the Prelude Data is set equal to zero the data block described as "Data for finite, straight lines" will not appear at all. Similarly, if the definition or the general, curved conductors does not call for any supplementary parameters, the corresponding data block will also be left out. However, even if no general, curved conductors are used, a subroutine CURDEF must appear in the program input deck.

For a more precise description of the various categories of data refer to the text or the example.

Data Sheet VI. Magnetic Field Templates in Idealised, Symmetric Lofte Machine

General Description	Information on Card	Format	Notes and Comments									
Prelude data. Sets dimensions of all arrays.	<table border="1"> <tr><td>NC</td><td>NL</td></tr> <tr><td>NZT</td><td>NPB</td></tr> </table>	NC	NL	NZT	NPB	2I7 2I7	NC, number of co-axial circles. NL, number of infinite, straight lines parallel to Z-axis. NZT, number of transverse templates along semi-length of bounding cylinder. NPB, number of magnetic field lines considered.					
NC	NL											
NZT	NPB											
A—												
Case number	<table border="1"> <tr><td>NK</td></tr> </table>	NK	I7	Normally, NK≥0; set NK = -1 to terminate calculation.								
NK												
Variable title	Title : across 80 columns of card	10A8	e.g. Job description									
Data for co-axial circles	<table border="1"> <tr><td>HC(1)</td><td>RC(1)</td><td>CC(1)</td></tr> <tr><td>HC(2)</td><td>RC(2)</td><td>CC(2)</td></tr> <tr><td>HC(NC)</td><td>RC(NC)</td><td>CC(NC)</td></tr> </table>	HC(1)	RC(1)	CC(1)	HC(2)	RC(2)	CC(2)	HC(NC)	RC(NC)	CC(NC)	3F14.7 3F14.7	HC, Z co-ordinate of centre of circle. RC, radius of circle. CC, current in circle. This is positive in the direction of a right hand screw moving along the Z-axis in a positive direction.
HC(1)	RC(1)	CC(1)										
HC(2)	RC(2)	CC(2)										
HC(NC)	RC(NC)	CC(NC)										
Data for infinite, straight lines parallel to Z-axis.	<table border="1"> <tr><td>XL(1)</td><td>YL(1)</td><td>CL(1)</td></tr> <tr><td>XL(2)</td><td>YL(2)</td><td>CL(2)</td></tr> <tr><td>XL(NL)</td><td>YL(NL)</td><td>CL(NL)</td></tr> </table>	XL(1)	YL(1)	CL(1)	XL(2)	YL(2)	CL(2)	XL(NL)	YL(NL)	CL(NL)	3F14.7 3F14.7	XL, YL, are the co-ordinates of the intersection of the infinite, straight conductor with the plane Z = 0. CL, current in the conductor. This is positive in the positive direction of the Z-axis.
XL(1)	YL(1)	CL(1)										
XL(2)	YL(2)	CL(2)										
XL(NL)	YL(NL)	CL(NL)										
Graph size	<table border="1"> <tr><td>GSIZE</td></tr> </table>	GSIZE	F14.7	Length, in inches, of the side of the resulting square pictures.								
GSIZE												
Semi-length of cylinder	<table border="1"> <tr><td>ZTX</td></tr> </table>	ZTX	F14.7	Semi-length of the cylinder of interest.								
ZTX												
Starting points of field lines	<table border="1"> <tr><td>XB(1)</td><td>YB(1)</td></tr> <tr><td>XB(2)</td><td>YB(2)</td></tr> <tr><td>XB(NPB)</td><td>YB(NPB)</td></tr> </table>	XB(1)	YB(1)	XB(2)	YB(2)	XB(NPB)	YB(NPB)	2F14.7	(XB, YB, 0.0) is the starting point of a magnetic field line.			
XB(1)	YB(1)											
XB(2)	YB(2)											
XB(NPB)	YB(NPB)											
Integration step length	<table border="1"> <tr><td>DS</td></tr> </table>	DS	F14.7	Integration step length along a magnetic field line.								
DS												
Boundary radii	<table border="1"> <tr><td>RI</td><td>RB</td></tr> </table>	RI	RB	2F14.7	RI, radius of cylindrical region of interest. RB, radius of plotted region.							
RI	RB											
B—	Repeat AA : BB as often as required	as above	No array dimensions may exceed those specified in Prelude data.									
Closing card	<table border="1"> <tr><td>-1</td></tr> </table>	-1	I7	This is equivalent to starting "case -1". Exit follows immediately.								
-1												

For a more precise description of the various categories of data refer to the text or the example.

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(S2)          PROGRAM I
C
C      MOD(B) CONTOURS IN GENERAL MAGNETIC FIELD
C
C      SURROUNTING PRELUDE
COMMON HC,RC,CC,XL,YL,CL,XP,YP,ZP,NC,NL,NP
COMMON CKAO,CKA1,CKA2,CKA3,CKAN,CKB0,CKB1,CKB2,CKB3,CKB4,CEA1,
ICEA2,CEA3,CEA4,CEB1,CEB2,CEB3,CEB4
COMMON NCUR,CCUR,T1,T2,NT,NSIZE
COMMON XHD,YMID,IGRID
COMMON NFB,XF01,YFB1,ZFB1,XFB2,YFB2,ZFB2,CFB
READ 100,NC,NL,NP,NCUR
READ 100,NP,NP,NCUR,NPY,IGRID
100 FORMAT(1I7)
      L=79*9
      L=L+NC
      HC=L
      L=L+NC
      RC=L
      L=L+NC
      CC=L
      L=L+NL
      XL=L
      L=L+NL
      YL=L
      L=L+NL
      CL=L
      L=L+NP
      XP=L
      ZP=L
      L=L+NP
      YP=L
      L=L+NP
      YMID=L
      NTX=2*(NPX-1)
      NTY=NPY-1
      READ 100,NCONT
      L=L-9-NP*NPY
      XPL=L
      YPL=L
      L=L-NP*NPY
      ZPL=L
      L=L-NTX*NTY
      LD=L
      L=L-NCONT
      MB=L
      L=L-NFB
      XFB1=L
      L=L-NFB
      YFB1=L
      L=L-NFB
      ZFB1=L
      L=L-NFB
      XFB2=L
      L=L-NFB
      YFB2=L
      L=L-NFB
      ZFB2=L
      L=L-NFB
      CFB=L
      L=L-NCUR
      CCUR=L
      L=L-NCUR
      T1=T
      L=L-NCUR
      T2=T
      L=L-NCUR
      NT=L
      RETURN
END

(S2)          MAIN ROUTINE + MOD(B) CONTOURS IN GENERAL MAGNETIC FIELD
      DIMENSION HC(NC),RC(NC),CC(NC),XL(NL),YL(NL),CL(NL),XP(NP),YP(NP),
      ZP(NP),XMID(NP),YMID(NP)
      DIMENSION XPL(NPX,NPY),YPL(NPX,NPY),ZPL(NPX,NPY),LD(NTX,NTY),HB
      I(NCONT)
      DIMENSION XFB1(NFB),YFB1(NFB),ZFB1(NFB),XFB2(NFB),YFB2(NFB),
      ZFB2(NFB),CFB(NFB)
      DIMENSION CCUR(NCUR),T1(NCUR),T2(NCUR),NT(NCUR)
COMMON HC,RC,CC,XL,YL,CL,XP,YP,ZP,NC,NL,NP
COMMON CKAO,CKA1,CKA2,CKA3,CKAN,CKB0,CKB1,CKB2,CKB3,CKB4,CEA1,
ICEA2,CEA3,CEA4,CEB1,CEB2,CEB3,CEB4
COMMON XHD,YMID,IGRID
COMMON NFB,XF01,YFB1,ZFB1,XFB2,YFB2,ZFB2,CFB
COMMON NCUR,CCUR,T1,T2,NT,NSIZE
COMMON XHD,YMID,IGRID
COMMON NFB,XF01,YFB1,ZFB1,XFB2,YFB2,ZFB2,CFB
COMMON NCUR,CCUR,T1,T2,NT,NSIZE
100 FORMAT(1I7)
      IF(NK1).LT.2
2 CALL TILER(-3)
      PRINT 200,NK
200 FORMAT(1X,4HCASE,1I)
      CALL DATAFB(1,1)
      CALL DATAFB
      CALL MOOR
      GO TO 3
1 CALL ENDIO
STOP
100 FORMAT(1I7)
      END

(S2)          SUBROUTINE DATAFB
C      DATA INPUT ROUTINE FOR MOD(B) CONTOURS
      DIMENSION HC(NC),RC(NC),CC(NC),XL(NL),YL(NL),CL(NL),XP(NP),YP(NP),
      ZP(NP),XMID(NP),YMID(NP)
      DIMENSION XPL(NPX,NPY),YPL(NPX,NPY),ZPL(NPX,NPY),LD(NTX,NTY),HB
      I(NCONT)
      DIMENSION XFB1(NFB),YFB1(NFB),ZFB1(NFB),XFB2(NFB),YFB2(NFB),
      ZFB2(NFB)
      DIMENSION CCUR(NCUR),T1(NCUR),T2(NCUR),NT(NCUR)
COMMON HC,RC,CC,XL,YL,CL,XP,YP,ZP,NC,NL,NP
COMMON CKAO,CKA1,CKA2,CKA3,CKAN,CKB0,CKB1,CKB2,CKB3,CKB4,CEA1,
ICEA2,CEA3,CEA4,CEB1,CEB2,CEB3,CEB4
COMMON XHD,YMID,IGRID
COMMON NFB,XF01,YFB1,ZFB1,XFB2,YFB2,ZFB2,CFB
COMMON NCUR,CCUR,T1,T2,NT,NSIZE
      SEI COEFFICIENTS FOR FIELD DUE TO CIRCULAR CONDUCTORS
      (SEE ELLIPTIC INTEGRALS IN C-HASTINGS)
      CKAO=1.3662914587
      CKA1=0.-0.6966334259
      CKA2=0.-0.3590092383
      CKA3=0.-0.3742563713
      CKA4=0.-0.04451196212
      CKB0=0.5
      CKB1=0.1200853597
      CKB2=0.0802942376
      CKB3=0.-0.5129353116
      CKB4=0.-0.0441767012
      CEA1=0.-0.4325141463
      CEA2=0.-0.0260601220
      CEA3=0.-0.675738356
      CEA4=0.-0.1736506451
      CEB1=0.-0.0000000000
      CEB2=0.-0.0200000037
      CEB3=0.-0.004497526
      CEB4=0.-0.00526449639
      IF(NC1).LT.2,3
      READ AND PRINT DATA FOR CO-AXIAL CIRCLES
101 FORMAT(1I7,1X,4H3HSPECIFICATION OF CIRCULAR CONDUCTORS,13X,9HM
      ICHNTR1,4H,4HRADIUS,6X,7HCURRENT,1)
      DO 4 KC=1,NC
      READ 102,HC(KC),RC(KC),CC(KC)
102 FORMAT(5F14.7)
      PRINT 103,HC(KC),RC(KC),CC(KC)
103 FORMAT(10X,5F14.7)
      4 CONTINUE
      2 IF(NL).LT.6,7
      READ AND PRINT DATA FOR INFINITE, STRAIGHT CONDUCTORS
      7 PRINT 104
104 FORMAT(1I7,1X,4H3HSPECIFICATION OF LINEAR CONDUCTORS,13X,9HM
      IX,IHY,1IX,7HCURRENT,1)
      DO 5 KL=1,NL
      READ 105,XL(KL),YL(KL),CL(KL)
      PRINT 103,XL(KL),YL(KL),CL(KL)
      S CONTINUE
      READ AND PRINT DATA FOR FINITE, STRAIGHT CONDUCTORS
      6 CALL DATAFB
      READ AND PRINT DATA FOR GENERAL, CURVED CONDUCTORS
      7 CALL DATCUR
      READ AND PRINT DATA SPECIFYING PLANES OF INTEREST
      PRINT 106
      106 FORMAT(1I7,1X,4H3HSPECIFICATION OF PLANES OF INTEREST,13X,1H2,
      1IX,5HSHETA,1IX,5HHSIZE,10X,4HNMID,10X,4HNMID,1)
      DO 8 KP=1,NP
      READ 107,XP(KP),YP(KP),ZP(KP),XMID(KP),YMID(KP)
      8 CONTINUE
      IF(NC1).LT.10,11
      READ CONTOURS HEIGHTS
      11 DO 9 KC=1,NCONT
      READ 105,HB(KC)
      9 CONTINUE
      10 READ 105,NSIZE
      105 FORMAT(F14.7)
      10 PRINT 107
      107 FORMAT(37HG1 F. M. LARKIN CULHAN.)
      PRINT 108
      108 FORMAT(34HGI PLEASE MOUNT DIGIT PRINTER.)
      1 STOP
      END
(S2)          PRINCIPAL COMPUTING SUBROUTINE
      SUBROUTINE MOD(B)
      DIMENSION HC(NC),RC(NC),CC(NC),XL(NL),YL(NL),CL(NL),XP(NP),YP(NP),
      ZP(NP),XMID(NP),YMID(NP)
      DIMENSION XPL(NPX,NPY),YPL(NPX,NPY),ZPL(NPX,NPY),LD(NTX,NTY),HB
      I(NCONT)
      DIMENSION XFB1(NFB),YFB1(NFB),ZFB1(NFB),XFB2(NFB),YFB2(NFB),
      ZFB2(NFB)
      DIMENSION CCUR(NCUR),T1(TCUR),T2(TCUR),NT(NCUR)
COMMON HC,RC,CC,XL,YL,CL,XP,YP,ZP,NC,NL,NP
COMMON CKAO,CKA1,CKA2,CKA3,CKAN,CKB0,CKB1,CKB2,CKB3,CKB4,CEA1,
ICEA2,CEA3,CEA4,CEB1,CEB2,CEB3,CEB4
COMMON XPL,YPL,ZPL,LH,HU,NP,NPY,NTX,NTY,NCNT
COMMON XHD,YMID,IGRID
COMMON NFB,XF01,YFB1,ZFB1,XFB2,YFB2,ZFB2,CFB
COMMON NCUR,CCUR,T1,T2,NT,NSIZE
      DO 3 KP=1,NP
      EVALUATE X AND Y GRID INCREMENTS
      HX=ZP(KP)/FLCAT(PNPX-1)
      HY=ZH(KP)/FLCAT(PNPY-1)
      XM1=0.0
      YM1=XMIN
      YM2=YMIN
      DO 2 KX=1,NPX
      DO 1 KY=1,NPY
      IF(CY(PKP1)).LT.5.5
      5 IF(CY(PKP1)).GT.2.0*3.141592653589/916.4
      4 XD=HX*FLOAT(X(KX-1)-U)+5*ZP(KP)+XM1(DKP)
      YD=HY*FLOAT(Y(KY-1))-C.5*ZP(KP)+YM1(DKP)
      ZD=ZP(KP)
      GO TO 7
      6 RX=1.02*XP(KP)+2.*YM1(DKP)*2
      IF(RM(ID2-1,OE)-79120,20,21
      21 TYPATAFO(XM1(DKP),YM1(DKP))
      GO TO 22
      20 TYP(YH(KP))
      22 RM10=5*ZP(KP)
      RD=HY*FLOAT(X(KY-1))-0.5*ZP(KP)+RH
      EVALUATE CO-ORDINATES OF POINT ON AXIAL PLANE
      XD=RDX*COS(F1Y)
      YD=RDX*SIN(F1Y)
      ZD=RD*FLOAT(X(KX-1))-C.5*ZP(KP)+XP(KP)
      7 CALL 1ELDX(XD,YD,ZD,RX,RY,RZ,ZL(X,KY))
      1 CONTINUE
      2 CONTINUE
      IF(IGRID).NE.1,2,3
      10 CALL GRIDPO(ZL,NPX,NPY,1)
      9 DO 6 KC=1,NCNT
      6 CALL KONTAUX(XMIN,XMAX,YMIN,YMAX,ZL,NP,NPY,LD,VFX,NTY,HB(KC),KC,G
      ISIZL)
      8 CONTINUE
      3 CONTINUE
      RETURN
END

(S2)          SUBROUTINE YIELD(X,Y,Z,BX,BY,BZ)
      EVALUATES MAGNETIC FIELD AT (X,Y,Z)
      DIMENSION HC(NC),RC(NC),CC(NC),XL(NL),YL(NL),CL(NL),XP(NP),YP(NP),
      ZP(NP),XMID(NP),YMID(NP)
      DIMENSION XPL(NPX,NPY),YPL(NPX,NPY),ZPL(NPX,NPY),LD(NTX,NTY),HB
      I(NCONT)
      DIMENSION XFB1(NFB),YFB1(NFB),ZFB1(NFB),XFB2(NFB),YFB2(NFB),
      ZFB2(NFB)
      DIMENSION CCUR(NCUR),T1(NCUR),T2(NCUR),NT(NCUR)
COMMON HC,RC,CC,XL,YL,CL,XP,YP,ZP,NC,NL,NP
COMMON CKAO,CKA1,CKA2,CKA3,CKAN,CKB1,CKB2,CKB3,CKB4,CEA1,
ICEA2,CEA3,CEA4,CEB1,CEB2,CEB3,CEB4
COMMON XHD,YMID,IGRID
COMMON NFB,XF01,YFB1,ZFB1,XFB2,YFB2,ZFB2,CFB
COMMON NCUR,CCUR,T1,T2,NT,NSIZE
      DSURTF(X**2*Y**2)
      SDR=0.0
      BZ=U.J
      IF(NC1).LT.2,3
      1 STOP
      2 CONTINUE
      3 DO 4 KC=1,NC
      GZ=HC(KC)
      W=(RC(KC))+D*2.6**2
      U=(PC(KC))-D*2.6**2
      E=1.0+D*RC(KC))+D/1/W
      V=LCG(F1)
      CK=(CKAO+E*(CKA1)+E*(CKA3+E*(CKA1)))-(CKB0+E*(CKB1)+E*(CKB2+E*
      (CKB3+E*(CKB1))))+V
      CE=1.0+E*(CEA1)+E*(CEA2+E*(CEA3+E*(CEA1)))-E*(CEB1+E*(CEB2+E*(CEB3+E*
      (CEB4+E*(CEB1))))+V
      BZ=2.0*(C(KC)+K1+(RC(KC))+2*D+2*G**2)*CE/U1/(DSURTF(W)+DZ
      SDR*(C(KC)+G1+K1+(RC(KC))+2*D+2*G**2)*CE/U1)/(DSURTF(W)+D)
      4 CONTINUE
      2 IF(U-D*1518.B,12
      B BX=0.0
      DYC=0.0
      GO TO 9
      12 BX=(C(KC)+G1+K1)/D
      BY=(C(KC)+G1)/D
      9 BXL=0.0
      BYL=0.0
      IF(NL).LT.5,6
      5 BX=DXC+XL
      DY=BYC+YL
      IF(NFB).LT.15,14
      14 COMPUTE FIELD DUE TO CO-AXIAL CIRCLES
      6 DO 7 KL=1,NL
      R2=(X-XL(KL))*2+(Y-YL(KL))*2
      AV=(X-XL(KL))
      BXL=BXL-(AV*(Y-YL(KL)))/R2
      BYL=BYL-(AV*(X-XL(KL)))/R2
      7 CONTINUE
      5 BX=DXC+XL
      DY=BYC+YL
      IF(NFB).LT.15,14
      14 COMPUTE FIELD DUE TO FINITE, STRAIGHT CONDUCTORS
      15 CALL MAGLIN(XFB1,YFB1,ZFB1,XFB2,YFB2,ZFB2,CFB,NFB,X,Y,Z,BX,DYD,
      BZD)
      BX=BX+BZD
      BY=BY+BZD
      BZ=BZ+BZD
      15 B=DSURTF(BX+2*BY+2*BZ**2)
      RETURN
END

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PROGRAM I Continued

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(S2)      SUBROUTINE DATAFA
C          READS AND PRINTS DATA FOR FINITE, STRAIGHT CONDUCTORS.
C          DIMENSION HC(NC), RC(NC), CC(NC), XL(NL), YL(NL), CL(NL), XPNP, YPNP,
C          ZPNP, XMDINP, YMIDINP
C          DIMENSION XPL(NPX, NPY), YPL(NPX, NPY), LDINTX, NTY, HB
C          (CONT)
C          DIMENSION XFB1(NFB), YFB1(NFB), ZFB1(NFB), XFB2(NFB), YFB2(NFB),
C          ZFB2(NFB), CCUR(NCUR), T1(NCUR), T2(NCUR), NTNLUR
C          COMMON HC, RC, CC, XL, YL, CL, XPNP, YPNP, ZPNP, NC, NL, NP
C          COMMON CKA0, CKA1, CKA2, CKA3, CKA4, CKB0, CKR1, CKB2, CKB3, CKB4, CEAI,
C          ICEA2, CEAS, CEAN, CEB1, CEB2, CEB3, CEB4
C          COMMON XPL, YPL, ZPL, LD, HB, NPX, NPY, NTX, NTY, NCNT
C          COMMON XMID, YMID, IGRD
C          COMMON XFB1, YFB1, ZFB1, XFB2, YFB2, ZFB2, CFB
C          COMMON NCUR, CCUR, T1, T2, NT, GSIZE
C          IF(FIN01).LT.2
C          RETURN
C          2 PRINT 200
200 FORMAT(//, 3BX, 4HSPECIFICATION OF FINITE, STRAIGHT CONDUCTORS, //, 1
19X, 2H1X, 12X, 2HY1, 12X, 2H2X, 12X, 2HY2, 12X, 2H2Z, 10X, 7HCURRENT
2X, 1)
DO 3 KFB=1,NFB
READ 100, XFB1(NFB), YFB1(NFB), ZFB1(KFB), XFB2(KFB), YFB2(KFB), ZFB2(KF
1D), CFB(KFB)
100 FORMAT(7F14.4)
PRINT 201, XFB1(KFB), YFB1(KFB), ZFB1(KFB), XFB2(KFB), YFB2(KFB), ZFB2(K
1FB), CFB(KFB)
201 FORMAT(10X, 7F14.4)
3 CONTINUE
RETURN
END
(S2)      SUBROUTINE DATCUR
C          READS AND PRINTS DATA FOR GENERAL, CURVED CONDUCTORS
C          DIMENSION HC(NC), RC(NC), CC(NC), XL(NL), YL(NL), CL(NL), XPNP, Y
C          ZPNP, XMDINP, YMIDINP
C          DIMENSION XPL(NPX, NPY), YPL(NPX, NPY), ZPL(NPX, NPY), LDINTX, NTY, HB
C          (CONT)
C          DIMENSION XFB1(NFB), YFB1(NFB), ZFB1(NFB), XFB2(NFB), YFB2(NFB) +
1ZFB2(NFB), CCUR(NCUR)
C          DIMENSION CCUR(NCUR), T1(NCUR), T2(NCUR), NTNLUR
C          COMMON HC, RC, CC, XL, YL, CL, XPNP, YPNP, ZPNP, NC, NL, NP
C          COMMON CKA0, CKA1, CKA2, CKA3, CKA4, CKR1, CKB2, CKB3, CKB4, CEAI,
C          ICEA2, CEAS, CEAN, CEB1, CEB2, CEB3, CEB4
C          COMMON XPL, YPL, ZPL, LD, HB, NPX, NPY, NTX, NTY, NCNT
C          COMMON XMID, YMID, IGRD
C          COMMON YFB1, XFB1, YFB1, ZFB1, XFB2, YFB2, ZFB2, CFB
C          COMMON NCUR, CCUR, T1, T2, NT, GSIZE
C          IF(NCUR).LT.2
1E10
2 PRINT 200
200 FORMAT(//, 1IX, 2H2D DATA RELEVANT TO GENERAL, CURVED CONDUCTORS, //, 1
1X, 2H1X, 13X, 2H2Z, 12X, 2HNT, 6X, 7HCURRENT, /)
DO 3 KCUR=1, NCUR
READ 101, T1(NCUR), T2(NCUR), NTNLUR, CCUR(NCUR)
101 FORMAT(10I, 7I, 7F14.7)
PRINT 231, T1(NCUR), T2(NCUR), NTNLUR, CCUR(NCUR)
231 FORMAT(10I, 2F15.7, 1B, F15.7)
3 CONTINUE
C          READ SUPPLEMENTARY PARAMETERS FOR GENERAL, CURVED CONDUCTORS
DO 4 KCUR=1, NCUR
J=KCUR
CALL CUREDF(T, X, Y, Z, J)
4 CONTINUE
RETURN
END

(S2)      PROGRAM II
C          STEREO PAIRS-FIELD LINE INTEGRALS AND RADIAL EXCURSIONS
C          PRELUDE
COMMON HC, RC, CC, XL, YL, CL, NC, NL
COMMON GSIZ, THETA, XM1N, XMAX, YM1N, YMAX, DS
COMMON CKA0, CKA1, CKA2, CKA3, CKA4, CKR0, CKR1, CKB2, CKB3, CKB4, CEAI,
ICEA2, CEAS, CEAN, CEB1, CEB2, CEB3, CEB4
COMMON XPL, YPL, ZPL, LD, HB, NPX, NPY, NTX, NTY, NCNT
COMMON XMID, YMID, IGRD
COMMON YFB1, XFB1, YFB1, ZFB1, XFB2, YFB2, ZFB2, CFB, T1, T2, NT,
CCUR, X, X0, X1, RC, XMAG, PSI, F, D, DISP, R, NK, XB, YR, ZB, NB
COMMON BREF, ISTER, BS, IPRT, IPLOT
READ 10, NC, NL, NB, NCUR
READ 100, XFB1(NFB), YFB1(NFB), ZFB1(NFB), XFB2(NFB), YFB2(NFB), ZFB2(NFB),
CFC(NFB), XMID(NFB), YMID(NFB), NTNLUR, CCUR(NCUR)
100 FORMAT(10I, 7I, 7F14.7)
READ 101, NPB
READ 102, NCDS
L=7*499
L=L+NC
HC=L
L=L+NC
RC=L
L=L+NC
CC=L
L=L+NL
XL=L
L=L+NL
YL=L
L=L+NL
CL=L
L=L+LPD
L=L+YPD
XPL=L
L=L+YPM
YPL=L
L=L+NPB
ZPL=L
L=L+NPD
L=L+NPB
ZFB1=L
L=L+NPB
XFR1=L
L=L+NPB
YFB1=L
L=L+NPB
XFR2=L
L=L+NPB
YFB2=L
L=L+NPB
ZFB2=L
L=L+NPB
CFB=L
L=L+NCUR
T1=L
L=L+NCUR
T2=L
L=L+NCUR
NT=L
L=L+NCUR
CCUR=L
RETURN
END

(S2)      MAIN ROUTINE FOR STEREO PAIRS-FIELD LINE INTEGRALS, ETC
DIMENSION HC(NC), RC(NC), CC(NC), XL(NL), YL(NL), CL(NL)
DIMENSION XPL(NPB), YPL(NPB), ZPL(NPB), IPRT(NPB)
DIMENSION X(3), X0(3), X1(3), XB(NBDS), YB(NBDS), ZB(NBDS), BS(NBDS)
DIMENSION YFR1(NFB), YFB1(NFB), ZFB1(NFB), XFB2(NFB), YFB2(NFB),
ZFB2(NFB), CCUR(NCUR), T1(NCUR), T2(NCUR), NTNLUR, CCUR(NCUR)
COMMON HC, RC, CC, XL, YL, CL, NC, NL
COMMON GSIZ, THETA, XM1N, XMAX, YM1N, YMAX, DS
COMMON CKA0, CKA1, CKA2, CKA3, CKA4, CKR0, CKR1, CKB2, CKB3, CKB4, CEAI,
ICEA2, CEAS, CEAN, CEB1, CEB2, CEB3, CEB4
COMMON ZTX, XPL, YPL, ZPL, LD, HB, NPX, NPY, NTX, NTY, NCNT
COMMON YDS, XFB1, YFB1, ZFB1, XFB2, YFB2, ZFB2, CFB, T1, T2, NT,
CCUR, X, X0, X1, RC, XMAG, PSI, F, D, DISP, R, NK, XB, YR, ZB, NB
COMMON BREF, ISTER, BS, IPRT, IPLOT

```

COMMON BREF, ISTER, BS, IPRT, IPLOT

3 READ 100, NC
1FNK1=1, 2
2 CALL TITLER(-3)
PRINT 200, NC
200 FORMAT(10I, 7I, 7F14.7)
CALL PHCTB(1, 1)
CALL DATA1
CALL DATA2
IF(ISTER).NE.5, 5
C DRAW STEREO PAIR OF CONDUCTOR CONFIGURATION
5 CALL SYMPLE
C ORGANISE REST OF STEREO PICTTING
CALL BORG
4 IF(ISTER).EQ.6, 6
C ORGANISE INTEGRALS BETWEEN MIRROR POINTS, AND RADIAL
EXCURSIONS
6 CALL MIRINT
GO TO 3
1 CALL ENBOD
STOP
100 FORMAT(17)
END

(S2) SUBROUTINE DATA1
DIMENSION HC(NC), RC(NC), CC(NC), XL(NL), YL(NL), CL(NL)
DIMENSION XPL(NPB), YPL(NPB), ZPL(NPB), IPRT(NPB)
DIMENSION X(3), X0(3), X1(3), XB(NBDS), YB(NBDS), ZB(NBDS)
DIMENSION YFR1(NFB), YFB1(NFB), ZFB1(NFB), XFB2(NFB), YFB2(NFB),
ZFB2(NFB), CCUR(NCUR)
COMMON HC, RC, CC, XL, YL, CL, NC, NL
COMMON GSIZ, THETA, XM1N, XMAX, YM1N, YMAX, DS
COMMON CKA0, CKA1, CKA2, CKA3, CKA4, CKR0, CKR1, CKB2, CKB3, CKB4, CEAI,
ICEA2, CEAS, CEAN, CEB1, CEB2, CEB3, CEB4
COMMON ZTX, XPL, YPL, ZPL, LD, HB, NPX, NPY, NTX, NTY, NCNT
COMMON XMID, YMID, IGRD
COMMON YFB1, XFB1, YFB1, ZFB1, XFB2, YFB2, ZFB2, CFB
COMMON NCUR, CCUR, T1, T2, NT, GSIZE
1FNK1=1, 2

C SET COEFFICIENTS FOR FIELD DUE TO CIRCULAR CONDUCTORS
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PROGRAM II Continued

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1 CONTINUE
R12=R1+R1
R8=R1
IF(IPL0T19,10,10)
10 CALL FRAMEI-ZTX,ZTF,X,0.0,R1,GSIZE)
9 RETURN
END

(S2) SUBROUTINE BORG
DIMENSION HC(1NC),RC(1NC),CC(1NC),XL(1NL),YL(1NL),CL(1NL)
DIMENSION XPB1(NPB1),YPB1(NPB1),ZPB1(NPB1),IPRINT(NPB1)
DIMENSION X(3),X0(3),K1(3),X0(NBDS),Y0(NBDS),Z0(NBDS),BS(NBDS)
DIMENSION XFB1(NFB1),YFB1(NFB1),ZFB1(NFB1),XF2(NFB1),YF2(NFB1),
ZFB2(NFB1),CFB1(NFB1),T1(NCUR),T2(NCUR),NT(NCUR),CCUR(NCUR)
COMMON HC,RC,CC,XL,YL,CL,NC,NL
COMMON GSIZ,E,THETA,XMAX,YMIN,YMAX,DS
COMMON XPAK,YPAK,ZPAK,XPAK,YMIN,YMAX,DS
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CE4A188,CE4B188,CE4C188
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PROGRAM II Continued

PROGRAM III Continued

PROGRAM III Continued

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1 PRINT 20,NAME
2 FORMAT(1H1,///,20X,17H==> WARNING ==,/,15X,31HNUMBER OF INT
ITEGRATION REGIONS =,I7)
   RETURN          EVALUATE J-MATRIX
2 CALL JGENER
   PRINT 202
202 FORMAT(1H1,///,20X,29H J MATRIX FOR INJECTION ENERGY,/)
   RECOVER J-MATRIX AND PUDDLE COUNTS FOR INJECTION ENERGY
   DO 10 KX=1,NX
   DO 11 KY=1,NY
   FJMAT(KX,KY)=FJMAT0(KX,KY,1)
   IJ(KX,KY)=IJ0(KX,KY,1)
11 CONTINUE
10 CONTINUE          PRINT J-MATRIX AND PUDDLE COUNTS FOR INJECTION ENERGY
   CALL GRIDPQFJMAT,NX,NY,0)
   PRINT 203
203 FORMAT(1H1,///,20X,49HMATRIX OF PUDDLE COUNTS FOR INJECTION ENER
GY,/)
   CALL GRIDPQIJ(NX,NY,1)
   DRAW CONTOUR FOR INJECTION ENERGY
   CALL KONTUA(XMIN,XMAX,YMIN,YMAX,FJMAT,NX,NY,LD,NTX,NTY,FK,I,GSIZE)
   IF(FN=11)FN=14,15
15 DO 3 KX=2,NX
   DO 12 KX=1,NX
   DO 13 KY=1,NY
   RECOVER J-MATRIX AND PUDDLE COUNTS FOR ANOTHER ENERGY
   FJMAT(KX,KY)=FJMAT0(KX,KY,KE)
   IJ(KX,KY)=IJ0(KX,KY,KE)
13 CONTINUE
12 CONTINUE          IF((GRID0)16,17,16
   PRINT 207,E(KE))
207 FORMAT(1H1,///,20X,19H J MATRIX FOR ENERGY,FIN,7,/)
   PRINT J-MATRIX AND PUDDLE COUNTS FOR THIS OTHER ENERGY
   CALL GRIDPQFJMAT,NX,NY,0)
   PRINT 208,E(KE)
208 FORMAT(1H1,///,20X,39HMATRIX OF PUDDLE COUNTS FOR ENERGY,FIN,7,/
1)
   CALL GRIDPQIJ(NX,NY,1)
   DRAW CONTOUR FOR THIS OTHER ENERGY
17 CALL KONTUA(XMIN,XMAX,YMIN,YMAX,FJMAT,NX,NY,LD,NTX,NTY,FK,KE,GSIZE
1)
3 CONTINUE
14 RETURN
END

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PROGRAM IV

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      PROGRAM 14
      ENERGY SURFACES IN SYMMETRIC MAGNETIC FIELD

SUBROUTINE PRELUDE
COMMON HC,RC,CC,XL,YL,CL,NL,GSIZE,DS
COMMON LD,NIX,NY,NRHO,NE,NJ,NAS
COMMON FJMIN,FJMAX,RHOMIN,RHOMAX,EMIN,EMAX,FLJ,IJ,DJ,DRHO,DE,FMU,
     IBS,ZTX,RADIUS,R12
COMMON CKAK,CKA1,CKA2,CKA3,CKAN,CKBO,CBK1,CBK2,CBK3,CBK4,CEA1,
     ICEA2,CEA3,CEA4,CEB1,CEB2,CEB3,CEB4
COMMON ZSTART
READ 100,NX,NL
100 FORMAT(1I7)
1 IF(NL1,1,2
2 NL=1
1 L=79999
4 L=L-NC
5 HC=L
6 L=L-NC
7 RL=L-NC
8 RC=L
9 L=L-NC
10 L=L-NL
11 L=L-NL
12 L=L-NL
13 CL=L
14 READ 100,NRHO,NE
15 REAU 100,NJ
16 L=L-NRHO+NE
17 FLJ=L
18 L=L-NRHO+NE
19 IJ=L
20 NTX=2*(NRHO-11)
21 NTY=NE-1
22 L=L-NTX-NTY
23 L=L
24 READ 100,NAS
25 L=L-NAS
26 BS=L
27 RETURN
28 END

(S21)      MAIN ROUTINE = ENERGY SURFACES IN SYMMETRIC MAGNETIC FIELD
1 DIMENSION H(NC),RC(NC),CC(NC),XL(NL),YL(NL),CL(NL)
2 DIMENSION FLJ(NRHO,NE),LJ(NRHO,NE),RS(NAS)
3 COMMON HC,RC,CC,XL,YL,CL,NL,GSIZE,DS
4 COMMON LD,NIX,NY,NRHO,NE,NJ,NAS
5 COMMON FJMIN,FJMAX,RHOMIN,RHOMAX,EMIN,EMAX,FLJ,IJ,DJ,DRHO,DE,FMU,
     IBS,ZTX,RADIUS,R12
6 COMMON CKAK,CKA1,CKA2,CKA3,CKAN,CKBO,CBK1,CBK2,CBK3,CBK4,CEA1,
     ICEA2,CEA3,CEA4,CEB1,CEB2,CEB3,CEB4
7 COMMON ZSTART
8 READ 100,NK
9 FORMAT(1I7)
10 IF(NK)1,2,2
11 CALL ENDB00
12 STOP
13 CALL TITLER(-3)
14 PRINT 200,NK
200 FORMAT(1F,90X,SHCASE +17)
15 CALL PHOTB0(1,1)
16 CALL DATA1
17 CALL DATA2
18 CALL OUTPUT
19 GO TO 3
20 END

(S22)      SUBROUTINE DATAN
1 DIMENSION H(NC),RC(NC),CC(NC),XL(NL),YL(NL),CL(NL)
2 DIMENSION FLJ(NRHO,NE),LJ(NRHO,NE),RS(NAS)
3 COMMON HC,RC,CC,XL,YL,CL,NL,GSIZE,DS
4 COMMON LD,NIX,NY,NRHO,NE,NJ,NAS
5 COMMON FJMIN,FJMAX,RHOMIN,RHOMAX,EMIN,EMAX,FLJ,IJ,DJ,DRHO,DE,FMU,
     IBS,ZTX,RADIUS,R12
6 COMMON CKAK,CKA1,CKA2,CKA3,CKAN,CKBO,CBK1,CBK2,CBK3,CBK4,CEA1,
     ICEA2,CEA3,CEA4,CEB1,CEB2,CEB3,CEB4
7 COMMON ZSTART
8 SET COEFFICIENTS FOR FIELD DUE TO CIRCULAR CONDUCTORS
9 (SEE ELLIPTIC INTEGRALS IN C.HASTINGS)
10 CKAO=1.3862493477
11 CKAI=0.19646334259
12 CKAQ=0.45590092383
13 CKAK=0.05742563713
14 CKAW=0.01451196212
15 CKBO=0.5
16 CKB1=0.12499523597
17 CKB2=0.04880246576
18 CKR3=0.03328355346
19 CKBW=0.00441787012
20 CEA1=0.14432541463
21 CEA2=0.06260601220
22 CEA3=0.04757383546
23 CEA4=0.017362461
24 CEB1=0.003848310
25 CEB2=0.0292016037
26 CEB3=0.04064967526
27 CEBW=0.0052649939
28 IF(NC)1,2,3
29 READ AND PRINT DATA FOR CO-AXIAL CIRCLES
3 PRINT 10
40 IF(NC)1,10,40,PRINTSPECIFICATION OF CIRCULAR CONDUCTORS,13,9HHE
5 COMMON H(1:6X),AHRH(1:6X),RS(1:6X),THCURRENT,1
6 DO 10 K=1,NC
7 READ 102,KCK1,RC(KC1),CC(KC1)
8 READ 102,F5F14,T1
9 PRINT 103,H(1KC1),RC(KC1),CC(KC1)
103 FORMAT(10F,5F14.7)
11 CONTINUE
12 IF(NL1,1,6,7
13 READ AND PRINT DATA FOR SINGLE, INFINITE, STRAIGHT CONDUCTOR
14 PRINT 104

```

PROGRAM V Continued


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S2) SUBROUTINE MAGCUR(T1,T2,N1,CCUR,NCUR,X,Y,Z,BX,BY,BZ)
  DIMENSION T1(NCUR),T2(NCUR),NT(NCUR),NCUR(NCUR)
  I1(NCUR),I3,4
  BX=0.0
  BY=0.0
  BZ=0.0
  DO 1 KCUR=1,NCUR
  NDT=NT(KCUR)
  DT=(T2(KCUR)-T1(KCUR))/FLOAT(NDT)
  CALL CURDEF(I1(KCUR),X1,Y1,Z1,KCUR)
  DO 2 NOD=1,NDT
  I2=T1(KCUR)+FLOAT(NOD)*DT
  CALL CURDEF(I2,X2,Y2,Z2,KCUR)
  RX=0.5*(X1+X2)-X
  RY=0.5*(Y1+Y2)-Y
  RZ=0.5*(Z1+Z2)-Z
  R3=SQR((X1-X)*(X2-X)+(Y1-Y)*(Y2-Y)+(Z1-Z)*(Z2-Z))
  BX=(X1-X2)*(Z2-Z1)-(Z1-Z)*(X2-X1))/CCUR(KCUR)/R3
  BY=(Y1-Y2)*(Z2-Z1)-(Z1-Z)*(Y2-Y1))/CCUR(KCUR)/R3
  BZ=B2*(RX-(Y2-Y1))-RY*(X2-X1))/CCUR(KCUR)/R3
  X1=X2
  Y1=Y2
  Z1=Z2
  2 CONTINUE
  1 CONTINUE
  3 RETURN
  END

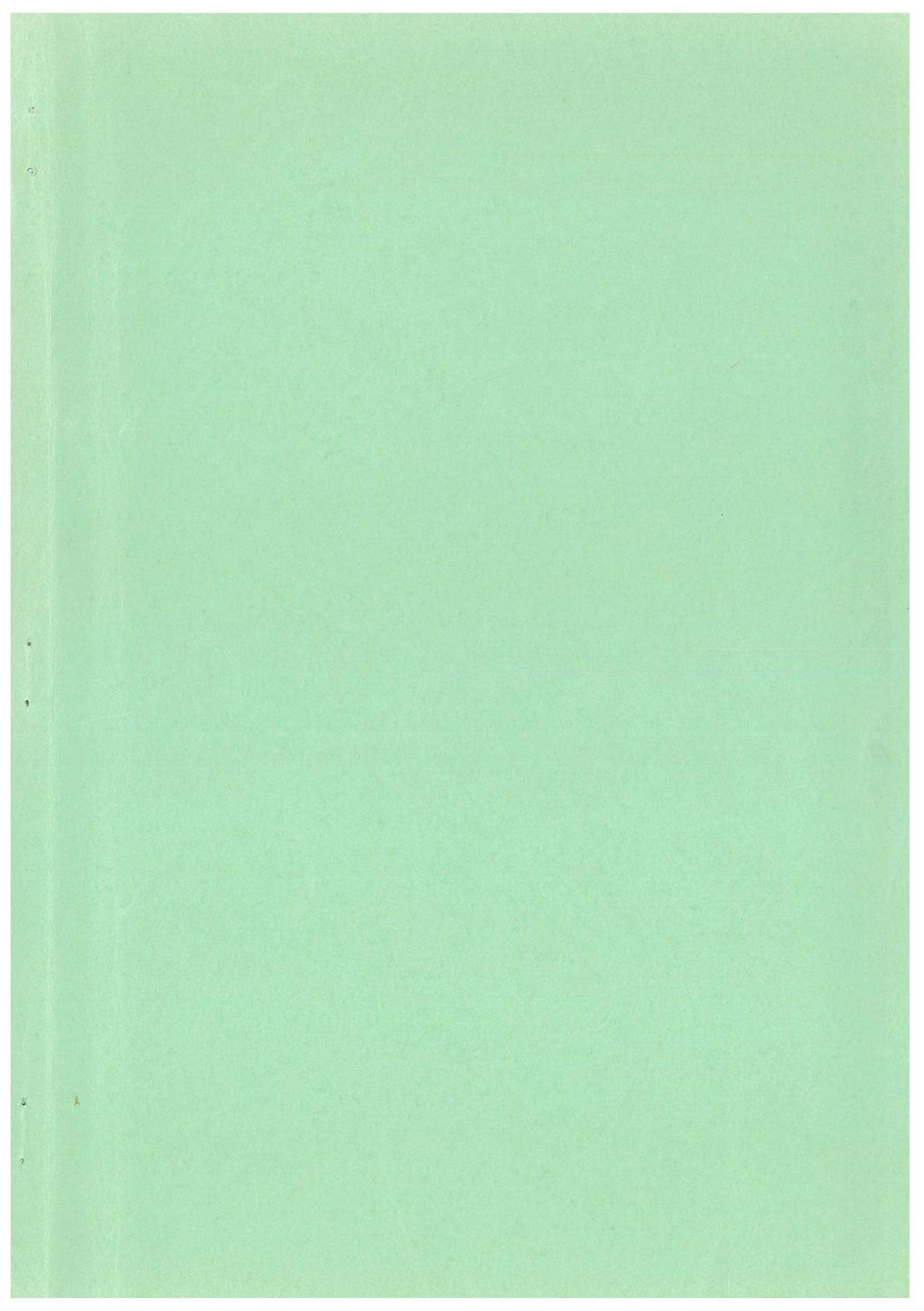
(S2) SUBROUTINE MAGLIN(X1,Y1,Z1,X2,Y2,Z2,CN,N,X,Y,Z,BX,BY,BZ)
  COMPUTES MAGNETIC FIELD DUE TO FINITE, STRAIGHT CONDUCTORS
  DIMENSION X1(N),Y1(N),Z1(N),X2(N),Y2(N),Z2(N),CN(N)
  BX=0.0
  BY=0.0
  BZ=0.0
  DO 1 I=1,N
  BL=X-X1(K)
  DH=Y-Y1(K)
  CN=Z-Z1(K)
  B=SQR(FLOAT(BL+BM+BN+BN))
  CL=X-K2(X)
  CH=Y-K2(Y)
  CN=Z-K2(Z)
  C=SQR(FLOAT(CL+CH+CM+CN+CN))
  AL=BL-CL
  AH=BM-CH
  AN=BN-CN
  VL=BM*CN-BN*CM
  VM=VN*CL-BL*CN
  VN=BL*CM-BM*CL
  MCN(K)=1+(AL+BL+AH+BM+AN+BN)/B-(AL+CL+AH+CH+AN+CN)/C1/(VL+VL+VM+VN)
  1+VN*VN
  BX=BX+AL*VL
  BY=BY+AH*VM
  BZ=BZ+AN*VN
  1 CONTINUE
  RETURN
  END

(S2) SUBROUTINE PLOT(X,Y,XMIN,XMAX,YMIN,YMAX,GSIZE,NLP,MODE)
  WRITES SINGLE POINT GRAPHICAL INFORMATION ONTO OUTPUT TAPE
  SET MARKER TO CALL NEW PAGE ON GRAPH-PLOTTER IF
  SUBROUTINE ENTERED FOR FIRST TIME
  IF(NLPNPL115,6,5
  5 IF(NLPNPL17,6,7
  7 NLP=-1
  8 NLPNPLP
  GO TO 9
  10 IF(NLPNPL19,8,9 TEST WHETHER OR NOT POINT LIES ON GRAPH
  9 IF(X-KMIN150,-1,1
  1 IF(X-KMAX150,-2,2
  2 IF(Y-YMIN150,-3,3
  3 IF(YMAX-Y150,4,4 POINT DOES LIE ON GRAPH
  COMPUTE SCALE FACTOR
  4 XX=XMAX-XMIN
  YX=YMAX-YMIN
  MAKE SURE GSIZE IS POSITIVE
  GSIZE=HSIZE(GSIZE)
  SCALE=GSIZE/MAX1F(XX,YX)
  COMPUTE GRAPH-PLOTTER CO-ORDINATES (IN INCHES)
  XXG=SCALE*XX
  YXG=SCALE*YX
  IF(XXG<0)GO TO 80
  80 IF(YXG<0)GO TO 81
  81 XXG=XX
  YXG=YX
  82 XXG=SCALE*(X-XMIN)
  YXG=SCALE*(Y-YMIN)
  TRANSFORM THESE CO-ORDINATES INTO COUNTS
  IX=XINTF(400,0*XG)
  YX=YINTF(400,0*YX)
  69 IF(NLPNPL11,12,13 NEW PAGE ON GRAPH-PLOTTER REQUIRED
  11 PRINT 100,SCALE
  100 FORMAT(1H1//,1/2X,24HNEW PAGE ON GRAPH-PLOTTER.+10X,8HSCALE +,
  IE1N,6,27H INCHES PER UNIT VARIABLE,+//)
  SET GRAPH COUNTER
  11 IF(MKG)36,37,37
  37 MKG
  38 MKG=0
  GO TO 39
  39 MKG=MKG-1
  PRINT 102
  102 FORMAT(12HGEND OF FILE) PRINT GRAPH-NUMBER IN LIEU OF JOB NUMBER
  36 KG=-MKG
  PRINT 101,KG
  101 FORMAT(1SHGIG,14,3X,19HIS THE GRAPH-NUMBER)
  CALL FOR NEW PAGE ON GRAPH-PLOTTER
  PRINT 103
  103 FORMAT(1HGHG001N+006NC) DUMMY DATA RECORD
  PRINT 127
  127 FORMAT(1HGD 0 OJ) NEW PAGE AND/OR NEW LINE
  CHECK THAT MODE LIES BETWEEN -1 AND 13
  13 IF(MODE+11)>15,15
  15 IF(MODE-13)>14,16
  16 J=MODE+2
  17 IF(NLPNPL19,70,70
  70 IF(MODE+11)>19,29,19 END FREE RUN POINT IN LONG LINE MODE
  29 PRINT 129,IX,IY
  129 FORMAT(2HGD,15,IX,15,IH1) REMEMBER MODE
  19 MODE=M-MODE PRINT POINT IN SPECIFIED MODE
  GO TO 120,21,22,22,22,22,22,22,22,23,24,25,26,1,J
  IN PRINT 114,MODE
  114 FORMAT(1//,20X,7HMODE =,15,5,39HSHOULD BE BETWEEN -1 AND 13, INCL
  INCLUSIVE.) MODE=12
  GO TO 16
  16 BEGIN FREE RUN WITH POINT IN LONG LINE MODE
  20 PRINT 121,IX,IY BEGIN FREE RUN PROPER
  PRINT 120,IX,IY
  120 FORMAT(2HGD,15,IX,15,IHS) GO TO 17
  21 PRINT 121,IX,IY
  121 FORMAT(2HGD,15,IX,15,IHL) GO TO 17
  22 PRINT 122,IX,IY,MODE
  122 FORMAT(2HGD,15,IX,15,I11) GO TO 17
  23 PRINT 123,IX,IY
  123 FORMAT(2HGD,15,IX,15,IHO

```

```

21=Z(LX1,LY1)
22=L(LX2,LY2)
23=Z(LX3,LY3)
C      HTX=KTX
      HTY=KY
      KEEP THIS TRIANGLE
C      FIND FIRST POINT OF INTERSECTION
      AND SET LT1
198 IF(Z1=H122,124,23
22 IF(Z2=H125,124,26
23 IF(Z2=H126,124,25
26 XP1=X1+(X2-X1)*(H-Z1)/(Z2-Z1)
      YP1=Y1+(Y2-Y1)*(H-Z1)/(Z2-Z1)
      LT1=1
      GO TO 69
25 IF(Z1=H127,124,28
27 IF(Z3=H131,124,29
28 IF(Z3=H129,124,32
29 XP1=X1+(X3-X1)*(H-Z1)/(Z3-Z1)
      YP1=Y1+(Y3-Y1)*(H-Z1)/(Z3-Z1)
      LT1=1
      GO TO 69
31 IF(Z2=H140,124,33
32 IF(Z2=H133,124,30
33 XP1=X2+(X3-X2)*(H-Z2)/(Z3-Z2)
      YP1=Y2+(Y3-Y2)*(H-Z2)/(Z3-Z2)
      LT1=1
69 XN1=XP1+0.005*(XMAX-XMIN)
      YN1=YP1+0.005*(YMAX-YMIN)
      IF(XN1>XMAX160,181,181
181 XN1=XP1-0.005*(XMAX-XMIN)
180 IF(YN1>YMAX182,183,183
183 YN1=YP1-0.005*(YMAX-YMIN)
182 NHD=XP0F1N1,101+1
      CALL PLOT(XN1,YN1,XMIN,XMAX,YMIN,YMAX,OSIZE,0,NHD)
      CALL PLOT(XP1,YP1,XMIN,XMAX,YMIN,YMAX,OSIZE,1,-1)
      FIND SECOND POINT OF INTERSECTION
      AND SET LT2
C      70 IF(LT1=171,91,B1
71 IF(Z3=H172,124,73
72 IF(Z2=H175,124,74
73 IF(Z2=H174,124,76
75 IF(L1=H176,124,77
76 IF(L1=H177,124,80
01 IF(Z2=H182,124,83
b2 IF(Z1=H185,124,77
83 IF(Z1=H177,124,86
85 IF(Z3=H140,124,86
00 IF(Z3=H141,124,80
91 IF(Z1=H192,124,93
92 IF(Z3=H195,124,86
93 IF(Z3=H188,124,96
95 IF(Z2=H140,124,76
96 IF(Z2=H174,124,80
78 XP2=X1+(X2-X1)*(H-Z1)/(Z2-Z1)
      YP2=Y1+(Y2-Y1)*(H-Z1)/(Z2-Z1)
      LT2=0
      GO TO 3d
77 XP2=X1+(X2-X1)*(H-Z1)/(Z2-Z1)
      YP2=Y1+(Y2-Y1)*(H-Z1)/(Z2-Z1)
      LT2=0
      GO TO 3d
64 XP2=X1+(X3-X1)*(H-Z1)/(Z3-Z1)
      YP2=Y1+(Y3-Y1)*(H-Z1)/(Z3-Z1)
      LT2=-1
      CALL PLOT(XP2,YP2,XMIN,XMAX,YMIN,YMAX,OSIZE,0,-1)
      STORE LD IN MD AND THEN PUT LD=0
C      (MEANING-THIS TRIANGLE IS FINISHED)
C      PD=LD(KTX,KTY)
197 LD(KTX,KTY)=0
C      FIND NEXT TRIANGLE
196 KTX=KTX+LT2-MD+1-LT2
      KTY=KY+(LT2+LT2*(LT2-MD)/2)
C      LOOK TO SEE IF THIS TRIANGLE
      IS OFF EDGE OF MESH
53 IF(KTX-NTX)54,54,55
54 IF(KTX)55,55,56
56 IF(KTY)55,55,57
57 IF(KTY-NY)60,60,55
C      IF IT IS - GO BACK TO START OF LINE
      AND FIND NEXT BRANCH
55 KTX=HTX+1
      KY=HTY
192 IF(HTX-NTX)58,58,40
C      UPDATE LT1 AND VERTICES OF TRIANGLES
      UNLESS LD=0
60 IF(LD(KTX,KTY))61,40,61
61 LT1=-LT2
193 LX1=(KTX+1)/2
      LY1=KY
      LX2=LX1+1
      LY2=LY1+1
      *****SUBROUTINE BINT(D,NS,EDUM,FMU,DS,FJ,NR1)*****
      DIMENSION BNS1
      E=EDUM/FMU
      FJ=0.0
      NSM1=NS-1
      NR1=1
      DO 1 K=1,NSM1
      F1=-B(K)
      IF(F1)1,2,2,1
      2 F2=E-B(K+1)
      IF(F2)2,1,1,3
      3 NS1=K5+1
      DC=J5-NS1,NSM1
      F1=F2-DC
      IF(F1)1,1,1,5
      5 F2=E-B(J5+1)
      IF(F2)5,6,6,4
      6 NR1=NR1+1
      NS2=JS
      GO TO 7
      4 CONTINUE
      9 RETURN
      7 DC=J5-NS1,NS2
      FJ=FJ+SORTF(E-B(J5))
      8 CONTINUE
      KS=NS2
*****PARAMETER HAS CHANGED*****1
      1 CONTINUE
      FJ=J5*DS*SORTF(2.0*FMU)
      RETURN
      END
```



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