TEMPERATURE DISTRIBUTION IN A COAXIAL RING TUBE DUCT FOR HTR APPLICATIONS

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ABSTRACT

A computer program has been developed to help optimize the design of a coaxial ring tubes type hot gas duct to be used in high temperature reactors (HTR). In this design, the hot helium (950°C) flows in a large ceramic pipe and the cold helium returns to the reactor through the holes made in the pipe wall, thus cooling the ceramic. The program provides a finite difference solution of the steady state conduction equation with proper boundary conditions in polar coordinates. The finite difference grid, containing many irregular points because at the convective boundary conditions on the cold gas holes, is prepared in a subroutine to allow running the program easily many times with different configurations.

I – INTRODUCTION

For nuclear process heat applications, high temperature reactors (HTR) must operate at a mean helium outlet temperature of 950°C or more. One of the most important technical problems associated with operation at such high temperatures is the transportation of helium from the core to the heat exchangers. Five possible HTR hot-gas duct designs have been reviewed by Kugeler et al [1] as follows:

1. **Double walled piping with insulation in the annular space**: the outer steel pipe which carries the pressure load (40 bar) is kept at about 50°C. Fibres, metallic foil or ceramic can be used as insulation materials. The inner pipe, which operates at a high temperature (950°C) does not carry any pressure load. In this design, an inner liner for the hot gas is necessary, and this creates problems because the performance of possible liner materials over a long service life has not at present been adequately tested. This type of duct, with fibrous insulation in the annular space, will be studied in the second test section of the IEA helium loop and a computer program has been developed[2] to predict its performance. The hot helium duct of the loop is of the same type as well.

2. **Coaxial duct without insulation**: Countercurrent cold helium (250°C) flows in the annular duct between the inner and outer pipes. The outer wall again carries the pressure load, and is maintained at about 250°C. The maximum inner wall temperature is limited to 550°C. The vibrations and thermal expansion are considered to be problematic in this duct design.

3. **Coaxial duct with insulated hot gas duct**: This is a combination of the two previous designs. It operates with an inner hot gas pipe insulated on the inside. Although the temperature of the inner wall is thus reduced, a liner which can withstand an operating temperature of 950°C is again necessary. The IEA helium loop presently has a test section to investigate this type of duct where the insulation consists of layers of metallic foil.

The dimensions and temperature profiles for the above hot gas ducts are shown in Figure 1 taken from reference[1].

4. **Coaxial Ring Tubes Duct**: This design is the subject of this report. It consists of a coaxial duct (Figure 2) made completely from a ceramic material. The problem of liner, vibrations and thermal expansion encountered in the previous designs are avoided in this one. The ceramic material would be carbon stone, and the temperature gradients in carbon stone are high, but can be tolerated[1].

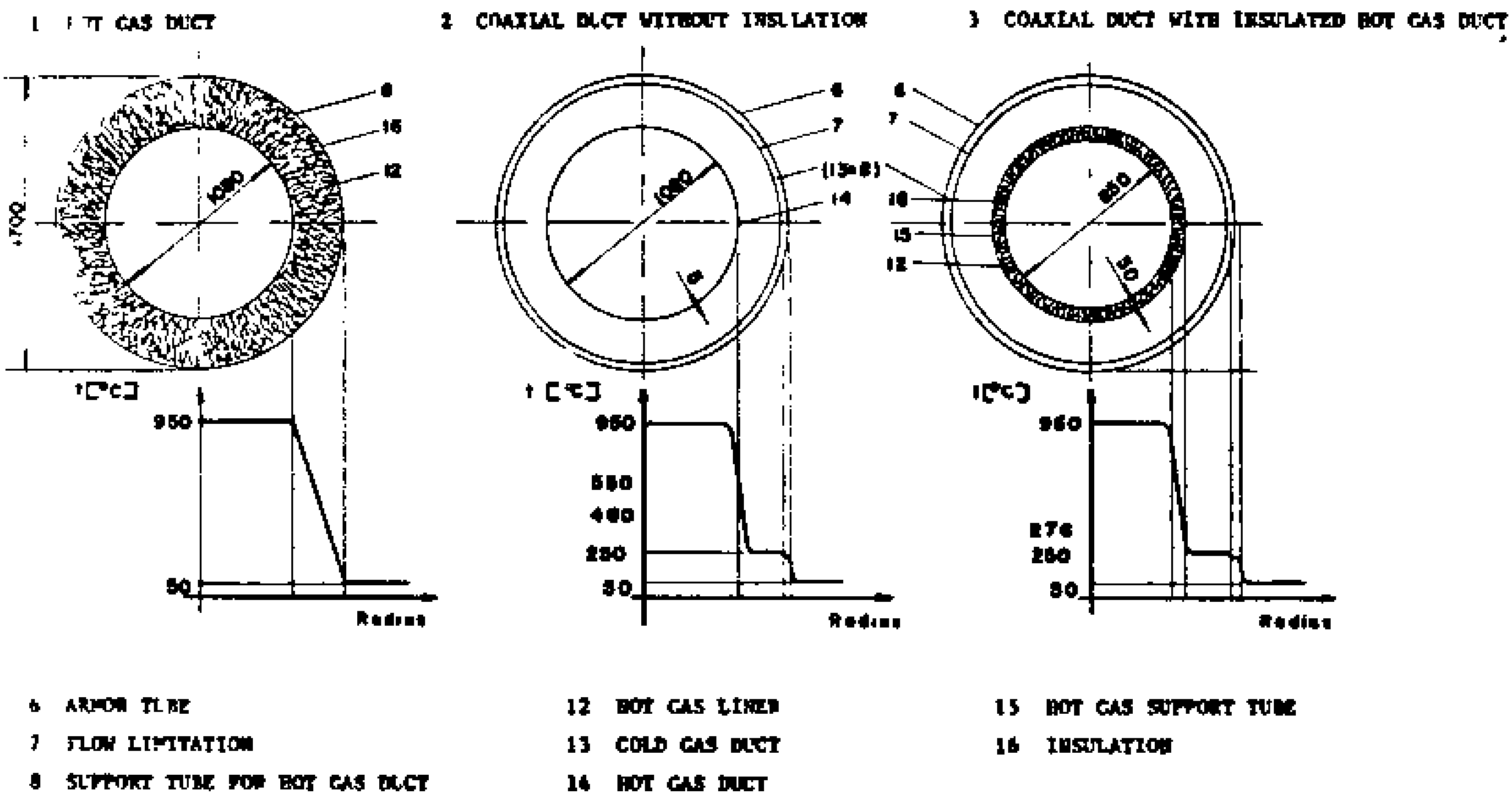

Figure 1 — Hot gas ducts.

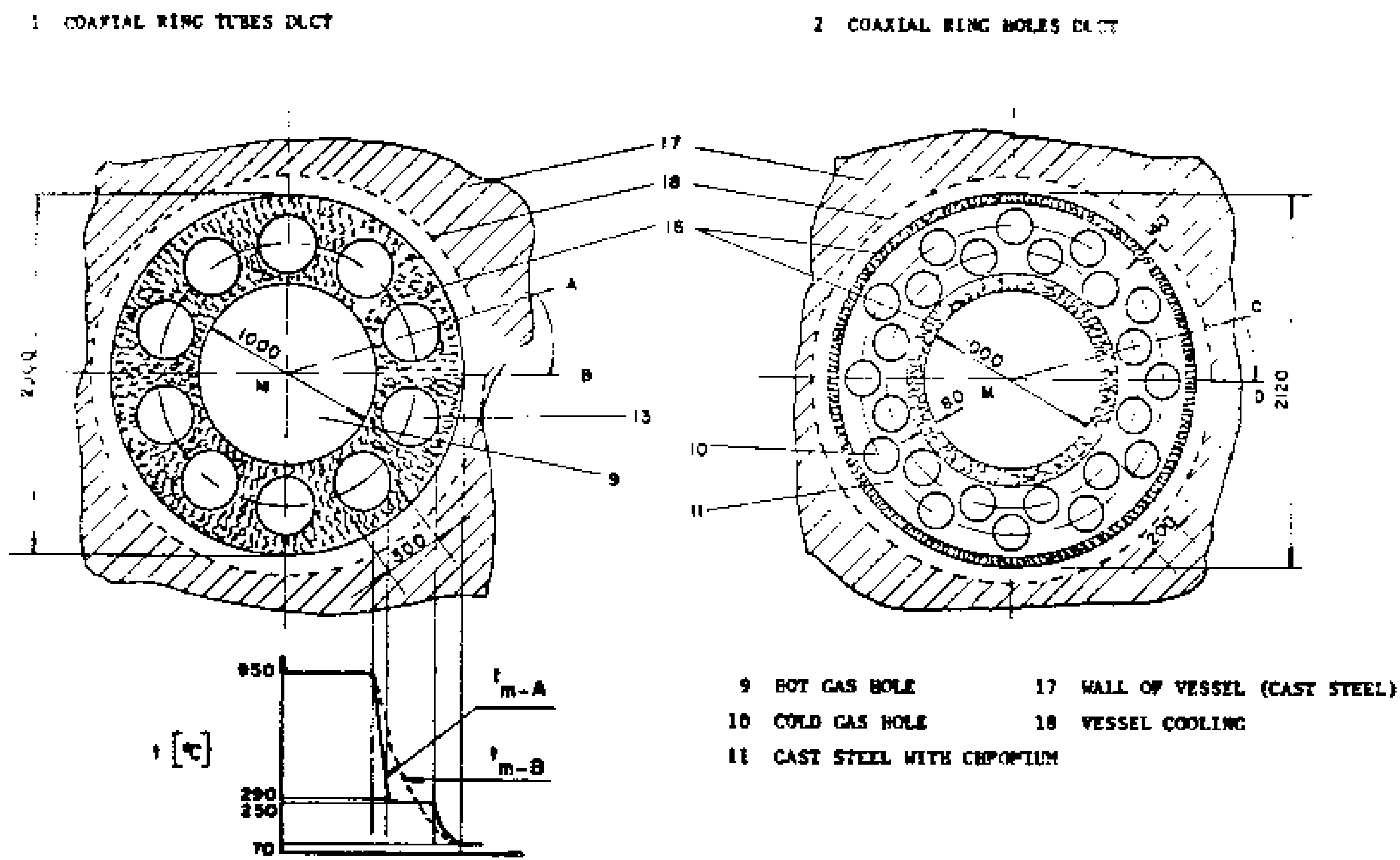

Figure 2 — Hot gas ducts

5 **Coaxial Ring Holes Duct** This design shown in Figure 2 has the cold gas ducting made of cast material with a carbon stone liner for the hot gas duct

The object of this report is to obtain the temperature distribution in a coaxial ring tubes duct made of ceramic material to help optimize the duct design The resulting temperature distribution is necessary to calculate the thermal stresses in the ceramic material The heat conduction equation in polar coordinates has been solved numerically using finite difference methods

The parameters to be considered in the optimal design are the number of loops the HTR would have and the dimensions of the duct The variables in the dimensions of the duct are the diameters of the hot gas duct and of the cold gas holes, the number of cold gas holes the wall thickness of the ceramic material and the distance of the center of the cold gas hole to the center of the hot gas duct To optimize the duct dimensions temperature profiles would have to be obtained for many different duct configurations Since the finite difference grid contains many irregular points on and near the wall of the cold gas holes each configuration leads to a different grid To avoid time consuming manual construction of the grid a subroutine has been written to prepare the grid configuration using only the duct dimensions as input The output in the form of a table is used by the subroutine which mounts the coefficient matrix of the finite difference equations Thus a computer program suitable for optimization studies has been obtained The method of solution is discussed in detail in section II, and in section III some results are shown to illustrate the use of the program Section IV contains the conclusions

II — FINITE DIFFERENCE EQUATIONS

1 — The Heat Conduction Equation and the Boundary Conditions

The steady state heat conduction equation in 2 dimensions (radial and angular) with no heat generation term is

$$\frac{\partial}{\partial r}\left(rK \frac{\partial T}{\partial r}\right) + \frac{1}{r} \frac{\partial}{\partial \theta} \left(K \frac{\partial T}{\partial \theta}\right) = 0 \qquad (1)$$

with

- r radial coordinate
- θ angular coordinate
- T temperature
- K thermal conductivity $= f(T)$

The symmetry of the system allows modeling of the section shown in Figure 3 to obtain the temperature distribution in the hot gas duct considered

The boundary conditions (Figure 3) for the section modeled are

$r = r_1$ (at the inside surface of the duct)

$$K \frac{\partial T}{\partial r} + h_h \left(T_h - T\right) = 0 \qquad (2)$$

$r = r_2$ (at the outside surface of the duct)

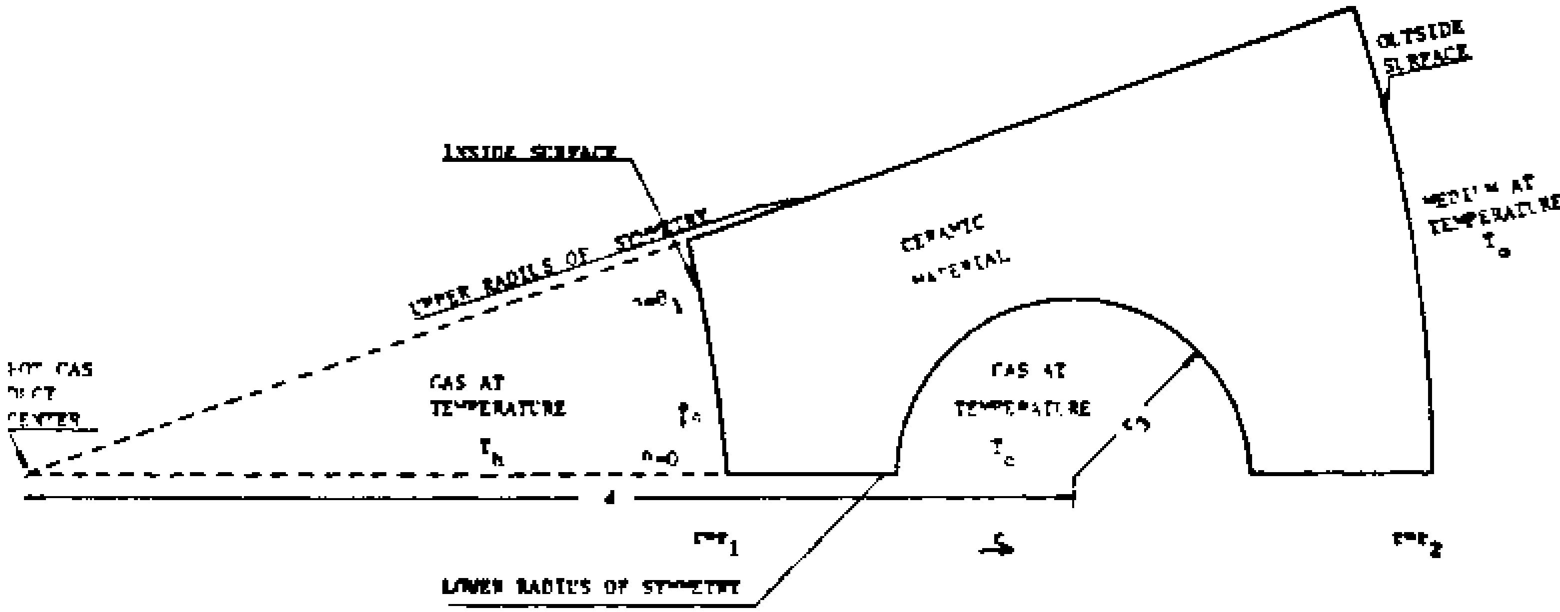

Figure 3 — Section modeled

$$K \frac{\partial T}{\partial r} - h_o (T_o - T) = 0 \tag{3-a}$$

Eq (3) is a convective boundary condition which really does not exist at the outside surface of the duct, but it is used to simulate either a prescribed outside wall temperature T_s or an insulated outside wall

Eq (3) is reduced to

$$\text{at } r = r_2 \quad T = T_s \tag{3 b}$$

by letting $T_o = T_s$ and choosing a value for h_o which is much larger than K

The boundary condition which corresponds to an insulated outside surface ($\frac{\partial T}{\partial r}$ at surface = 0) is obtained from eq (3) by choosing h much smaller than K Than eq (3) gives

$$\text{at } r = r_2 \quad (\frac{\partial T}{\partial r}) = 0 \tag{3-c}$$

$\theta = 0$ (lower diameter of symmetry) and $\theta = \theta_1$ (upper diameter of symmetry)

$$K \frac{\partial T}{\partial \theta} = 0 \tag{4}$$

The boundary condition at the surface of the cold helium hole can not be readily expressed in terms of the coordinates r and θ Instead, it is written in terms of s the normal to the surface

Thus on the surface of the cold helium hole

$$K \frac{\partial T}{\partial s} + h_c (T_c - T) = 0 \tag{5}$$

The terms in the boundary condition equations are defined as

- r_1 r_2 internal and external radii of the duct respectively
- h_h h_c heat transfer coefficientes for the hot and cold gas respectively
- h_o heat transfer coefficient between the outer surface of the duct and the medium surrounding it
- T_h T_c temperature of the hot and cold gas respectively
- T_o temperature of the medium surrounding the duct
- T_s temperature of the outside surface of the duct
- θ_1 Π/n where n is the number of cold gas holes

2 — Finite Difference Grid

A finite difference grid with 20 radial and 6 axial divisions is shown in Figure 4. The geometrical configuration of the grid is prepared in a subroutine whose inputs are the internal and external radii of the duct (r_1 and r_2), the radius (r_3) of the cold gas hole, the distance from the center of the cold gas hole to the center of the duct (d), the angle θ_1, and the number of radial (m) and angular (n) divisions. The subroutine does the following (Table I):

a) Numbers the grid points in a systematic way, counting from left to right, beginning on the lower radius of symmetry and going upward. Points on the cold gas hole and on a circle (such as points 43, 63, 75, etc) are numbered after points 42, 62 and 74.

b) Determines the type of each point, such as points on the cold gas hole (16, 28, 43,), on the hot gas duct surface (11, 23,), regular internal points (39, 77,) etc. Each type of point has a different finite difference equation.

c) Identifies the neighbors of each point, specifying the direction of each neighbor and its radial distance or angle to the point. For example, for point 27, points 28, 41, 26 and 15 are listed as its righthand, upper, lefthand and lower neighbors. For points on the cold gas hole, such as point 28, the neigbors are points 27 and 41, because the radius of the cold gas hole passing through 28 intersects the nearest radius or circle (in this case a circle) between points 27 and 41, at point 28. The distance of point 28 to point 28 and the angular distance of point 28 to points 41 and 27 are calculated using trigonometric relations. For point 61, neighbors are points 60 and 59, because the radius of the cold gas duct passing through 61 cuts the nearest grid radius or circle (in this case a radius) between points 60 and 59. The distance between points 61 and 61 and the distance of point 61 to points 59 and 60 are calculated again using trigonometric relations.

An other finite grid example with 18 radial and 5 angular divisions is shown in Figure 4 and Table II.

3 — Finite Difference Equations

The finite difference form of eq. (1) is derived considering the different type of points of the finite difference grid.

a. **Regular internal points.** The finite difference equations are derived using central differences. At point p(i,j), where p(i,j) is a regular point, the finite difference form of eq. (1) is (see Figure 5):

$$\frac{1}{\Delta r^2}\left[r^{i+1/2}K^{i+1/2,j}\left(T^{i+1,j}-T^{i,j}\right)-r^{i-1/2}K^{i-1/2,j}\left(T^{i,j}-T^{i-1,j}\right)\right]$$

$$+\frac{1}{r^i\Delta\theta^2}\left[K^{i,j+1/2}\left(T^{i,j+1}-T^{i,j}\right)-K^{i,j-1/2}\left(T^{i,j}-T^{i,j-1}\right)\right]=0 \qquad (6)$$

where

$$r^{i+1/2}=r^i+\frac{\Delta r}{2} \qquad (7.1)$$

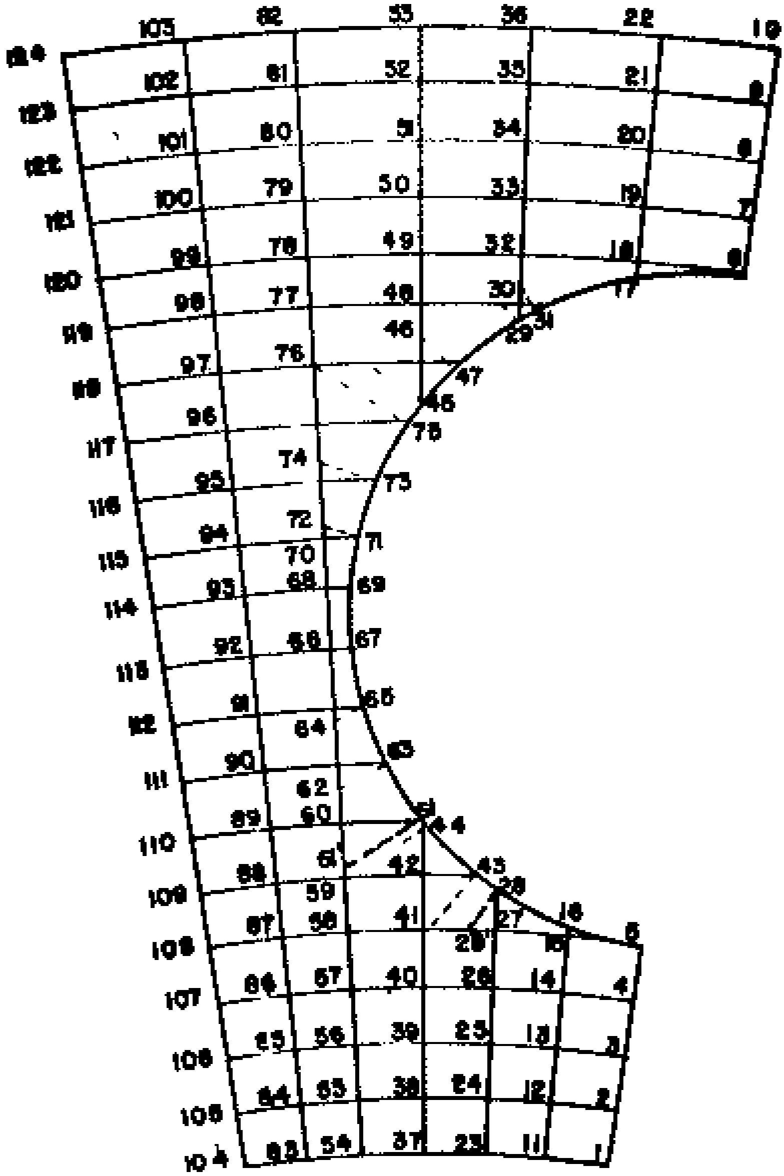

Figure 4 — Finite difference grid

r_1 = 50 cm r_2 = 100 cm r_3 = 15 cm d = 75 cm

10 Cold gas holes

20 Radial and 6 angular divisions

Table I

(Sheet 1 of 3)

GRID CONFIGURATION

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
1	6	2	11	0	0	2 00	3 000	0 000	0 000	50 000	0 000
2	4	3	12	1	0	2 500	3 000	2 500	0 000	52 500	0 000
3	4	4	13	2	0	2 500	2 000	2 00	0 000	55 000	0 000
4	4	5	14	3	0	2 00	1 000	2 00	0 000	57 500	0 000
5	17	0	14	0	4	0 000	3 000	0 000	0 000	0 000	2 500
6	17	0	19	0	7	0 000	3 000	0 000	0 000	0 000	2 500
7	4	8	19	6	0	2 500	2 000	2 00	0 000	92 500	0 000
8	4	9	20	7	0	2 00	3 000	2 500	0 000	95 000	0 000
9	4	10	21	8	0	2 00	2 000	2 00	0 000	97 500	0 000
10	9	0	22	9	0	0 000	2 000	2 500	0 000	100 000	0 000
11	2	12	22	0	1	2 00	3 000	0 000	3 000	50 000	0 000
12	1	13	24	11	2	2 500	3 000	2 500	3 000	52 00	0 000
13	1	14	25	12	3	2 500	2 000	2 500	3 000	55 000	0 000
14	1	15	26	13	4	2 500	2 000	2 500	3 000	57 500	0 000
15	10	16	27	14	5	0 420	2 000	2 00	3 000	60 000	0 000
16	17	0	27	0	15	0 000	2 [illegible]41	0 000	0 1[illegible]	0 000	0 437
17	17	0	32	0	15	0 000	2 [illegible]42	0 000	0 1[illegible]	0 000	0 650
18	11	19	32	17	6	2 00	3 000	0 625	3 000	90 000	0 000
19	1	20	33	18	7	2 500	3 000	2 00	3 000	92 00	0 000
20	1	21	34	19	8	2 500	3 000	2 00	3 000	95 000	0 000
21	1	22	35	20	9	2 500	2 000	2 500	3 000	97 00	0 000
22	3	0	36	21	10	0 000	2 000	2 00	3 000	100 000	0 000
23	2	24	37	0	11	2 500	2 000	0 000	3 000	50 000	0 000
24	1	25	38	23	12	2 500	3 000	2 500	3 000	52 500	0 000
25	1	26	39	24	13	2 500	3 000	2 00	3 000	55 000	0 000
26	1	27	40	25	14	2 500	3 000	2 500	3 000	57 500	0 000
27	10	28	41	26	15	1 41	3 000	2 500	3 000	60 000	0 000
28	17	0	41	0	27	0 000	1 333	0 000	1 061	0 000	2 125
29	17	0	48	0	30	0 000	2 351	0 000	0 043	0 000	0 145
30	16	32	48	29	31	2 500	[illegible] 000	0 123	0 133	97 500	0 000
31	18	32	0	30	0	2 157	0 000	0 342	0 000	0 000	0 399
32	1	33	49	30	18	2 500	3 000	2 500	3 000	90 000	0 000
33	1	34	50	32	19	2 500	3 000	2 500	3 000	92 500	0 000
34	1	35	51	33	20	2 500	3 000	2 500	3 000	95 000	0 000
35	1	36	52	34	21	2 500	3 000	2 500	3 000	97 500	0 000
36	3	0	53	35	22	0 000	3 000	2 500	3 000	100 000	0 000
37	2	38	54	0	23	2 500	3 000	0 000	3 000	50 000	0 000
38	1	39	55	37	24	2 500	3 000	2 500	3 000	52 500	0 000
39	1	40	56	38	25	2 500	3 000	2 500	3 000	55 000	0 000
40	1	41	57	39	26	2 500	3 000	2 500	3 000	57 500	0 000
41	1	42	58	40	27	2 00	3 000	2 500	3 000	60 000	0 000
42	15	44	9	41	43	2 231	3 000	2 500	2 457	62 500	0 000
43	18	0	41	0	27	0 000	0 [illegible]	0 000	2 777	0 000	3 177
44	17	0	33	0	42	0 000	0 [illegible]	0 000	2 645	0 000	3 683
45	17	0	[illegible]	0	46	0 000	1 [illegible]	0 000	1 [illegible]	0 000	2 496

Table I

(Sheet 2 of 3)

T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
46	16	43	76	45	47	2 100	3 000	1 577	0 371	85 000	0 000
47	18	48	0	46	0	0 347	0 000	1 513	0 000	0 000	2 034
48	1	49	77	46	48	2 500	3 000	2 500	3 000	87 500	0 000
49	1	0	78	48	32	2 100	3 000	2 500	3 000	90 000	0 000
50	1	51	79	49	33	2 500	3 000	2 500	3 000	92 500	0 000
51	1	52	80	44	34	2 100	3 000	2 500	3 000	95 000	0 000
52	1	52	1	51	35	2 500	3 000	2 500	3 000	97 500	0 000
53	3	0	[illegible]	52	36	0 000	3 000	2 500	3 000	100 000	0 000
54	2	55	43	0	37	2 500	3 000	0 000	3 000	50 000	0 000
55	1	56	44	54	38	2 500	3 000	2 500	3 000	52 500	0 000
56	1	57	[illegible]	55	39	2 500	3 000	2 000	3 000	55 000	0 000
57	1	58	56	56	40	2 500	3 000	4 000	3 000	57 000	0 000
58	1	59	8	57	41	2 500	3 000	2 500	3 000	60 000	0 000
59	1	60	58	53	42	2 500	3 000	2 500	2 000	62 500	0 000
60	12	62	89	59	61	2 500	3 000	2 500	2 516	65 000	0 000
61	18	60	0	59	0	2 251	0 000	0 244	0 000	0 000	1 362
62	12	64	90	60	63	2 500	3 000	2 500	1 525	67 500	0 000
63	18	62	0	60	0	0 790	0 000	1 710	0 000	0 000	1 253
64	12	66	91	62	65	2 500	3 000	2 500	0 799	70 000	0 000
65	18	64	0	62	0	0 232	0 000	2 269	0 000	0 000	1 002
66	12	69	92	64	67	2 500	3 000	2 500	0 433	72 500	0 000
67	18	66	0	64	0	0 033	0 000	2 462	0 000	0 000	0 613
68	12	70	93	66	69	2 500	3 000	2 500	0 522	75 000	0 000
69	18	70	0	65	0	2 423	0 000	0 072	0 000	0 000	0 687
70	12	72	94	68	71	2 500	3 000	2 500	0 367	77 500	0 000
71	18	72	0	70	0	2 172	0 000	0 327	0 000	0 000	1 220
72	12	74	95	70	73	2 500	3 000	2 500	1 525	80 000	0 000
73	18	74	0	72	0	1 484	0 000	1 016	0 000	0 000	2 371
74	12	76	96	72	75	2 500	3 000	2 500	2 527	82 500	0 000
75	18	0	76	0	46	0 000	0 156	0 000	2 344	0 000	4 272
76	1	77	97	74	46	2 500	3 000	2 500	3 000	35 000	0 000
77	1	78	98	76	43	2 500	3 000	2 500	3 000	37 500	0 000
78	1	79	99	77	49	2 500	3 000	2 500	3 000	90 000	0 000
79	1	80	100	78	50	2 500	3 000	2 500	3 000	92 500	0 000
80	1	81	101	79	51	2 500	3 000	2 500	3 000	35 000	0 000
81	1	82	102	80	52	2 500	3 000	2 500	3 000	97 500	0 000
82	3	0	103	81	53	0 000	3 000	2 500	3 000	100 000	0 000
83	2	84	104	0	54	2 500	3 000	0 000	3 000	50 000	0 000
84	1	85	105	83	55	2 500	3 000	2 500	3 000	52 500	0 000
85	1	86	106	84	56	2 500	3 000	2 500	3 000	55 000	0 000
86	1	87	107	85	57	2 500	3 000	2 500	3 000	57 500	0 000
87	1	88	108	86	58	2 500	3 000	2 500	3 000	60 000	0 000
88	1	89	109	87	59	2 500	3 000	2 500	3 000	62 500	0 000
89	1	90	110	86	60	2 100	3 000	2 500	3 000	65 000	0 000
90	1	91	111	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3 000	67 500	0 000

Table I

(Sheet 3 of 3)

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
91	1	92	112	90	64	2 500	3 000	2 500	3 000	70 000	0 000
92	1	93	113	91	66	2 500	3 000	2 500	3 000	72 500	0 000
93	1	94	114	92	68	2 500	3 000	2 500	3 000	75 000	0 000
94	1	95	115	93	70	2 500	3 000	2 500	3 000	77 500	0 000
95	1	96	116	94	72	2 500	3 000	2 500	3 000	80 000	0 000
96	1	97	117	95	74	2 500	3 000	2 500	3 000	82 500	0 000
97	1	98	118	96	76	2 500	3 000	2 500	3 000	85 000	0 000
98	1	99	119	97	77	2 500	3 000	2 500	3 000	87 500	0 000
99	1	100	120	98	78	2 500	3 000	2 500	3 000	90 000	0 000
100	1	101	121	99	79	2 500	3 000	2 500	3 000	92 500	0 000
101	1	102	122	100	80	2 500	3 000	2 500	3 000	95 000	0 000
102	1	103	123	101	81	2 500	3 000	2 500	3 000	97 500	0 000
103	3	0	124	102	82	0 000	3 000	2 500	3 000	100 000	0 000
104	7	105	0	0	83	2 500	0 000	0 000	3 000	50 000	0 000
105	5	106	0	104	84	2 500	0 000	2 500	3 000	52 500	0 000
106	5	107	0	105	85	2 500	0 000	2 500	3 000	55 000	0 000
107	5	108	0	106	86	2 500	0 000	2 500	3 000	57 500	0 000
108	5	109	0	107	87	2 500	0 000	2 500	3 000	60 000	0 000
109	5	110	0	108	88	2 500	0 000	2 500	3 000	62 500	0 000
110	5	111	0	109	89	2 500	0 000	2 500	3 000	65 000	0 000
111	5	112	0	110	90	2 500	0 000	2 500	3 000	67 500	0 000
112	5	113	0	111	91	2 500	0 000	2 500	3 000	70 000	0 000
113	5	114	0	112	92	2 500	0 000	2 500	3 000	72 500	0 000
114	5	115	0	113	93	2 500	0 000	2 500	3 000	75 000	0 000
115	5	116	0	114	94	2 500	0 000	2 500	3 000	77 500	0 000
116	5	117	0	115	95	2 500	0 000	2 500	3 000	80 000	0 000
117	5	118	0	116	96	2 500	0 000	2 500	3 000	82 500	0 000
118	5	119	0	117	97	2 500	0 000	2 500	3 000	85 000	0 000
119	5	120	0	118	98	2 500	0 000	2 500	3 000	87 500	0 000
120	5	121	0	119	99	2 500	0 000	2 500	3 000	90 000	0 000
121	5	122	0	120	100	2 500	0 000	2 500	3 000	92 500	0 000
122	5	123	0	121	101	2 500	0 000	2 500	3 000	95 000	0 000
123	5	124	0	122	102	2 500	0 000	2 500	3 000	97 500	0 000
124	8	0	0	123	103	0 000	0 000	2 500	3 000	100 000	0 000

DEFINITIONS (Distances in cm angles in degrees)

C1 Grid point identification number
C2 Type of point
C3 Identification number of the right hand neighbor
C4 Identification number of the upper neighbor
C5 Identification number of the left hand neighbor
C6 Identification number of the lower neighbor
C7 Distance between the point and the right hand neighbor
C8 Angle between the point and the upper neighbor
C9 Distance between the point and the left hand neighbor
C10 Angle between the point and the lower neighbor
C11 Radial coordinate (r') of the point
C12 Distance Δs (Figures 7 A and 7 B)

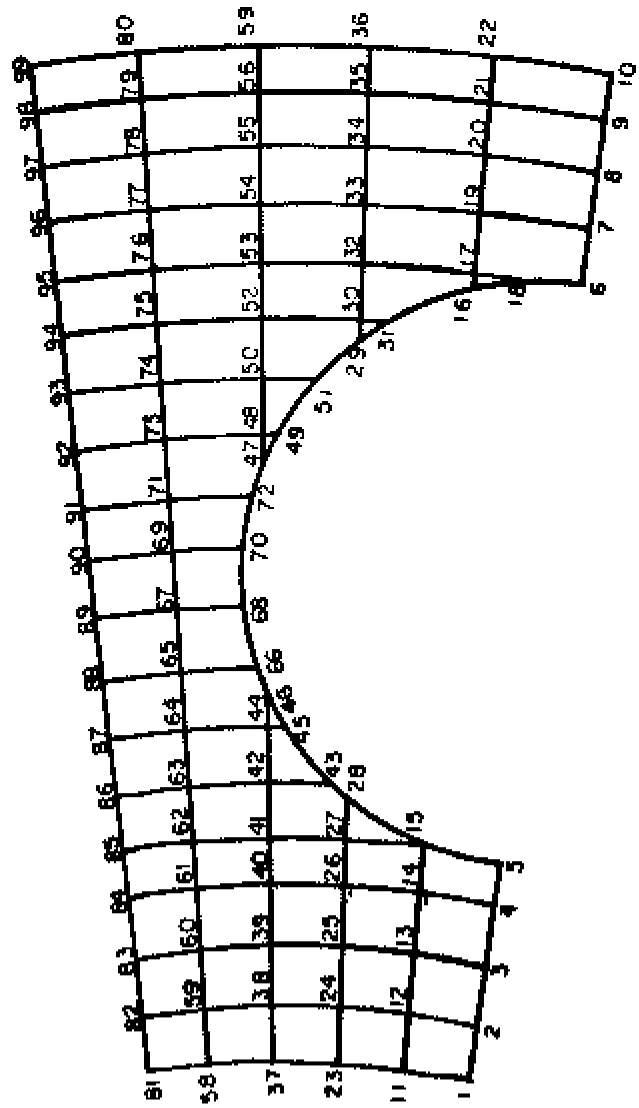

Figure 4 — Fini

Table II
(Sheet 1 of 3)

GRID CONFIGURATION

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
1	6	2	11	0	0	2 500	3 000	0 000	0 000	52 500	0 000
2	4	3	12	1	0	2 500	3 000	2 500	0 000	55 000	0 000
3	4	4	13	2	0	2 500	3 000	2 500	0 000	57 500	0 000
4	13	5	11	3	0	2 000	3 000	2 500	0 000	60 000	0 000
5	17	0	14	0	4	0 000	3 000	0 000	0 000	0 000	2 000
6	17	0	19	0	7	0 000	3 000	0 000	0 000	0 000	2 000
7	14	8	19	6	0	2 500	3 000	2 000	0 000	90 000	0 000
8	4	9	20	7	0	2 500	3 000	2 500	0 000	92 500	0 000
9	4	10	21	8	0	2 500	3 000	2 500	0 000	95 000	0 000
10	9	0	22	9	0	0 000	3 000	2 500	0 000	97 500	0 000
11	2	12	23	0	1	2 500	3 000	0 000	3 000	52 500	0 000
12	1	13	24	11	2	2 500	3 000	2 500	3 000	55 000	0 000
13	1	14	25	12	3	2 500	3 000	2 500	3 000	57 500	0 000
14	1	15	26	13	4	2 500	3 000	2 500	3 000	60 000	0 000
15	17	0	26	0	14	0 000	2 [illegible]11	0 000	0 75[illegible]	0 000	2 634
16	17	0	3[illegible]	0	16	0 000	[illegible]	0 000	0 044	0 000	2 [illegible]2
17	16	19	32	16	16	2 [illegible]00	3 000	0 210	0 4[illegible]1	67 500	0 000
18	16	0	19	0	7	0 000	0 [illegible]	0 000	2 944	0 000	2 525
19	1	20	33	17	7	2 500	3 000	2 500	3 000	90 000	0 000
20	1	21	34	19	8	2 500	3 000	2 500	3 000	92 500	0 000
21	1	22	35	20	9	2 500	3 000	2 500	3 000	95 000	0 000
22	3	0	36	21	10	0 000	3 000	2 500	3 000	97 500	0 000
23	2	24	37	0	11	2 500	3 000	0 000	3 000	52 500	0 000
24	1	25	38	23	12	2 500	3 000	2 500	3 000	55 000	0 000
25	1	26	39	24	13	2 500	3 000	2 500	3 000	57 500	0 000
26	1	27	40	25	14	2 500	3 000	2 500	3 000	60 000	0 000
27	10	26	41	26	15	1 719	3 000	2 500	3 000	62 500	0 000
28	17	0	41	0	27	0 000	1 799	0 000	1 201	0 000	2 173
29	17	0	52	0	30	0 000	2 974	0 000	0 0[illegible]1	0 000	0 052
30	16	32	52	29	31	2 500	3 000	0 041	0 0[illegible]	85 000	0 000
31	18	32	0	30	0	2 425	0 000	0 072	0 000	0 000	0 090
32	1	33	53	30	17	2 500	3 000	2 500	3 000	87 500	0 000
33	1	34	54	32	19	2 500	3 000	2 500	3 000	90 000	0 000
34	1	35	55	33	20	2 500	3 000	2 500	3 000	92 500	0 000
35	1	36	56	34	21	2 500	3 000	2 500	3 000	95 000	0 000
36	3	0	57	35	22	0 000	3 000	2 500	3 000	97 500	0 000
37	2	38	58	0	23	2 500	3 000	0 000	3 000	52 500	0 000
38	1	39	59	37	24	2 500	3 000	2 500	3 000	55 000	0 000
39	1	40	60	38	2[illegible]	2 500	[illegible] 000	2 500	3 000	57 500	0 000
40	1	41	61	39	2[illegible]	[illegible] 500	3 000	2 500	[illegible] 000	60 000	0 000
41	1	42	62	40	[illegible]	[illegible] 500	[illegible] 000	2 500	3 000	62 500	0 000
42	12	41	[illegible]	41	[illegible]	[illegible] 500	[illegible] 000	2 500	[illegible] 1[illegible]0	65 000	0 000
43	18	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible] 000	[illegible] 018	0 000	0 000	3 470
44	1[illegible]	[illegible]	[illegible]4	4	[illegible]	[illegible]	[illegible] 000	2 500	0 441	67 500	0 000
4[illegible]	18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] 000	[illegible]	[illegible] 000	0 000	0 [illegible]02

Table II
(Sheet 2 of 3)

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
46	17	0	64	0	44	0 000	1 2[illegible]0	0 000	1 600	0 000	2 349
47	17	0	73	0	46	0 000	2 517	0 000	0 403	0 000	0 74[illegible]
48	16	50	73	47	49	2 500	3 000	0 325	0 115	80 000	0 000
49	18	50	0	48	0	2 418	0 000	0 082	0 000	0 000	0 1[illegible]0
50	12	52	74	48	51	2 500	3 000	2 500	1 260	62 500	0 000
51	18	52	0	50	0	0 984	0 000	1 516	0 000	0 000	2 377
52	1	53	75	50	30	2 500	3 000	2 500	3 000	85 000	0 000
53	1	54	76	52	32	2 500	3 000	2 500	3 000	87 500	0 000
54	1	55	77	53	33	2 500	3 000	2 500	3 000	90 000	0 000
55	1	56	78	54	34	2 500	3 000	2 500	3 000	92 500	0 000
56	1	57	79	55	35	2 500	3 000	2 500	3 000	95 000	0 000
57	3	0	80	56	36	0 000	3 000	2 500	3 000	97 500	0 000
58	2	59	81	0	37	2 500	3 000	0 000	3 000	52 500	0 000
59	1	60	82	58	38	2 500	3 000	2 500	3 000	55 000	0 000
60	1	61	83	59	39	2 500	3 000	2 500	3 000	57 500	0 000
61	1	62	84	60	40	2 500	3 000	2 500	3 000	60 000	0 000
62	1	63	85	61	41	2 500	3 000	2 500	3 000	62 500	0 000
63	1	64	86	62	42	2 500	3 000	2 500	3 000	65 000	0 000
64	1	65	87	63	44	2 500	3 000	2 500	3 000	67 500	0 000
65	12	67	88	64	66	2 500	3 000	2 500	2 500	70 000	0 000
66	18	65	0	64	0	0 901	0 000	1 599	0 000	0 000	3 165
67	12	69	89	65	68	2 500	3 000	2 500	2 075	72 500	0 000
68	18	67	0	65	0	0 231	0 000	2 269	0 000	0 000	2 632
69	12	71	90	67	70	2 500	3 000	2 500	2 056	75 000	0 000
70	18	71	0	69	0	2 217	0 000	0 283	0 000	0 000	2 711
71	12	73	91	69	72	2 500	3 000	2 500	2 401	77 500	0 000
72	18	73	0	71	0	1 498	0 000	1 002	0 000	0 000	3 419
73	1	74	92	71	46	2 500	3 000	2 500	3 000	80 000	0 000
74	1	75	93	73	50	2 500	3 000	2 500	3 000	82 500	0 000
75	1	76	94	74	52	2 500	3 000	2 500	3 000	85 000	0 000
76	1	77	95	75	53	2 500	3 000	2 500	3 000	87 500	0 000
77	1	78	96	76	54	2 500	3 000	2 500	3 000	90 000	0 000
78	1	79	97	77	55	2 500	3 000	2 500	3 000	92 500	0 000
79	1	80	98	78	56	2 500	3 000	2 500	3 000	95 000	0 000
80	3	0	99	79	57	0 000	3 000	2 500	3 000	97 500	0 000
81	7	82	0	0	56	2 500	0 000	0 000	3 000	52 500	0 000
82	5	83	0	81	59	2 500	0 000	2 500	3 000	55 000	0 000
83	5	84	0	82	60	2 500	0 000	2 50[illegible]	3 000	57 500	0 000
84	5	85	0	83	61	2 500	0 000	2 500	[illegible]	[illegible] 000	0 000
85	5	86	0	84	62	2 500	0 000	2 500	[illegible]	[illegible] 500	0 000
86	5	[illegible]	0	85	63	2 500	0 000	[illegible]	3 [illegible]	[illegible] 000	0 000
87	5	[illegible]	0	86	64	[illegible] 500	0 000	[illegible]	[illegible]	[illegible] 500	0 000
88	5	[illegible]	0	87	65	[illegible]	0 000	[illegible]	[illegible]	0 000	0 000
89	5	[illegible]	0	[illegible]	[illegible]	[illegible]	0 000	[illegible]	[illegible]	[illegible]	0 000
90	5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0 000

Table II

(Sheet 3 of 3)

C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
91	5	92	0	90	71	2 500	0 000	2 500	3 000	77 500	0 000
92	5	93	0	91	73	2 500	0 000	2 500	3 000	80 000	0 000
93	5	94	0	92	74	2 500	0 000	2 500	3 000	82 500	0 000
94	5	95	0	93	75	2 500	0 000	2 500	3 000	65 000	0 000
95	5	96	0	94	76	2 500	0 000	2 500	3 000	87 500	0 000
96	5	97	0	95	77	2 500	0 000	2 500	3 000	90 000	0 000
97	5	98	0	96	76	2 500	0 000	2 500	3 000	92 500	0 000
98	5	99	0	97	79	2 500	0 000	2 500	3 000	95 000	0 000
99	8	0	0	98	80	0 000	0 000	2 500	3 000	97 500	0 000

DEFINITION OF THE VARIABLES IS GIVEN IN TABLE - I

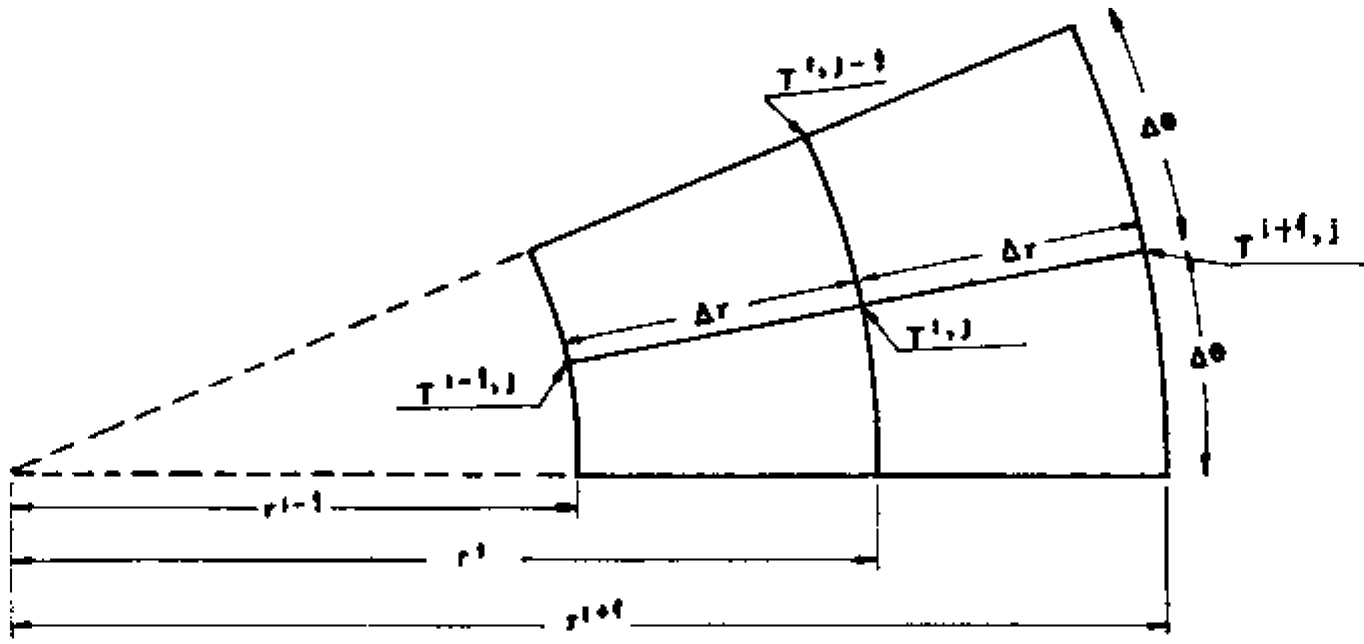

Figure 5 — Regular points.

$$r^{i-1/2} = r^{i} - \frac{\Delta r}{2} \tag{7 2}$$

$$K^{i+1/2\,j} = \frac{K^{i+1\,j} + K^{i\,j}}{2} \tag{7 3}$$

$$K^{i-1/2\,j} = \frac{K^{i-1\,j} + K^{i\,j}}{2} \tag{7-4}$$

$$K^{i\,j+1/2} = \frac{K^{i\,j+1} + K^{i\,j}}{2} \tag{7 5}$$

$$K^{i\,j-1/2} = \frac{K^{i\,j-1} + K^{i\,j}}{2} \tag{7 6}$$

Arranging eq (6) the coefficients of the 5 variables appearing in the finite difference equation at point p(i,j) are obtained as

$$T^{i-1\,j} \qquad \frac{r^{i-1/2} \quad K^{i-1/2\,j}}{\Delta r^2} \tag{8-1}$$

$$T^{i+1\,j} \qquad \frac{r^{i+1/2} \quad K^{i+1/2\,j}}{\Delta r^2} \tag{8-2}$$

$$T^{i\,j-1} \qquad \frac{K^{i\,j-1/2}}{r^{i}\,\Delta\theta^2} \tag{8-3}$$

$$T^{i\,j+1} \qquad \frac{K^{i\,j+1/2}}{r^{i}\,\Delta\theta^2} \tag{8-4}$$

$$T^{i\,j} \qquad - \frac{r^{i+1/2} \quad K^{i+1/2\,j} \; + \; r^{i-1/2} \quad K^{i-1/2\,j}}{\Delta r^2} - \frac{K^{i\,j+1/2} \; + \; K^{i\,j-1/2}}{r^{i}\,\Delta\theta^2} \tag{8-5}$$

Regular points are assigned type 1 (Table I)

b Non regular internal points Those are the points of type 10 11 12 15 and 16 in Table I The finite difference form of the heat conduction equation at point p(i j) where p(i j) is a non regular internal point is obtained by making a heat flow balance on the surface element shown in Figure 6 The heat balance gives

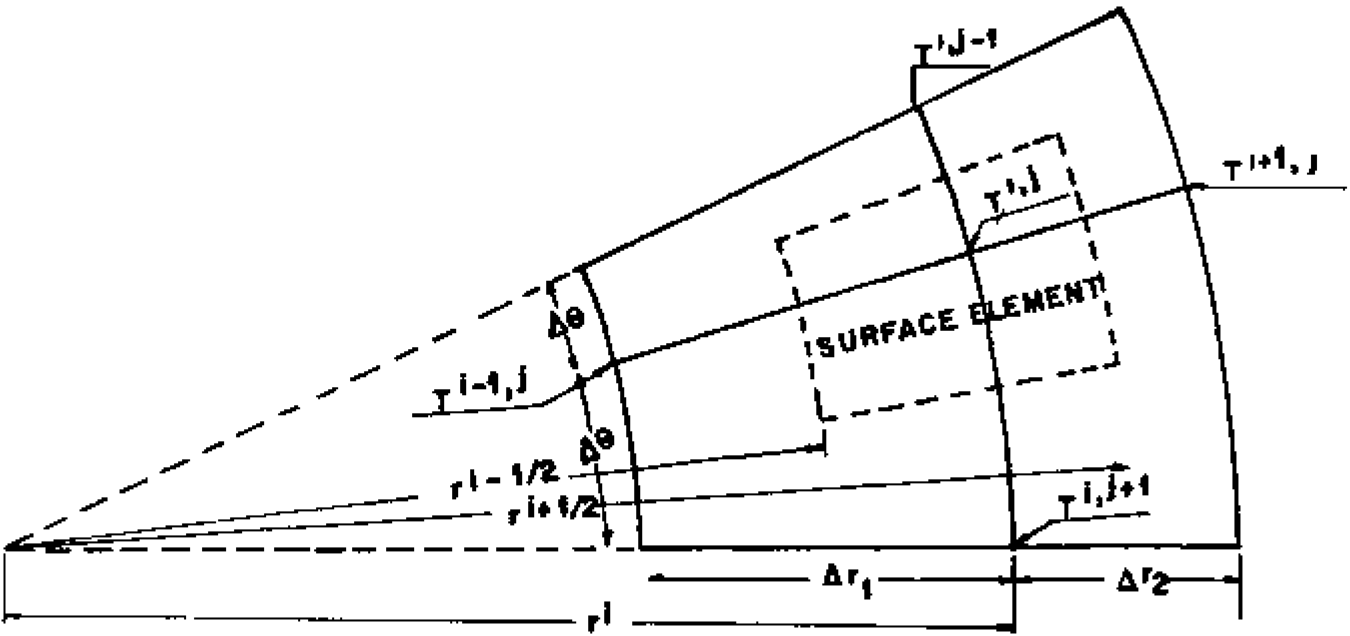

Figure 6 — Non regular internal points.

$$\frac{\Delta\theta_1 + \Delta\theta_2}{2}\left[r^{i+1/2} K^{i+1/2\,j} \left(\frac{\partial T}{\partial r}\right)^{i+1/2\,j} - r^{i-1/2} K^{i-1/2\,j} \left(\frac{\partial T}{\partial r}\right)^{i-1/2\,j} \right]$$

$$+ \frac{\Delta r_1 + \Delta r_2}{2\, r^i}\left[K^{i\,j+1/2} \left(\frac{\partial T}{\partial \theta}\right)^{i\,j+1/2} - K^{i\,j-1/2} \left(\frac{\partial T}{\partial \theta}\right)^{i\,j-1/2} \right] = 0 \qquad (9)$$

Using central difference approximations for the derivatives

$$\left(\frac{\partial T}{\partial r}\right)^{i+1/2\,j} = \frac{T^{i+1\,j} - T^{i\,j}}{\Delta r_2} \qquad (10\text{-}1)$$

$$\left(\frac{\partial T}{\partial r}\right)^{i-1/2\,j} = \frac{T^{i\,j} - T^{i-1\,j}}{\Delta r_1} \qquad (10\text{-}2)$$

$$\left(\frac{\partial T}{\partial \theta}\right)^{i\,j+1/2} = \frac{T^{i\,j+1} - T^{i\,j}}{\Delta\theta_2} \qquad (10\text{-}3)$$

$$\left(\frac{\partial T}{\partial \theta}\right)^{i\,j-1/2} = \frac{T^{i\,j} - T^{i\,j-1}}{\Delta\theta_1} \qquad (10\text{-}4)$$

Combining eqs (9) to (10-4) and rearranging give the coefficients of the 5 variables appearing in the finite difference equation at point p(i j)

$$T^{i-1\,j} \quad \frac{r^{i-1/2}\; K^{i-1/2\,j}}{\Delta r_1\,(\Delta r_1 + \Delta r_2)} \qquad (11\text{-}1)$$

$$T^{i+1\,j} \quad \frac{r^{i+1/2}\; K^{i+1/2\,j}}{\Delta r_2\,(\Delta r_1 + \Delta r_2)} \qquad (11\text{-}2)$$

$$T^{i\,j-1} \quad \frac{K^{i\,j-1}}{\Delta\theta_1\, r^i\,(\Delta\theta_1 + \Delta\theta_2)} \qquad (11\text{-}3)$$

$$T^{i\,j+1} \quad \frac{K^{i\,j+1}}{\Delta\theta_2\, r^i\,(\Delta\theta_1 + \Delta\theta_2)} \qquad (11\text{-}4)$$

$$T^{i\,j} \quad -\left(\frac{r^{i+1/2}\; K^{i+1/2\,j}}{\Delta r_2\,(\Delta r_1 + \Delta r_2)} + \frac{r^{i-1/2}\; K^{i-1/2\,j}}{\Delta r_1\,(\Delta r_1 + \Delta r_2)} \right)$$

$$- \frac{1}{r^i\,(\Delta\theta_1 + \Delta\theta_2)}\left(\frac{K^{i\,j+1/2}}{\Delta\theta_2} + \frac{K^{i\,j-1/2}}{\Delta\theta_1} \right) \qquad (11\text{-}5)$$

Eqs (11-1) to (11-5) are reduced to eqs (8-1) to (8-5) when

$\Delta r_1 = \Delta r_2 = \Delta r$ and $\Delta\theta_1 = \Delta\theta_2 = \Delta\theta$

c **Points on the cold gas hole** In Table I those points are of type 17 when they are obtained by the intersection of a radius with the cold gas hole and of type 18 when they are obtained by the intersection of a circle with the cold gas hole

For non regular points $r^{i+1/2}$ and $r^{i-1/2}$ are defined as

$$r^{i+1/2} = \frac{r^{i+1} + r^i}{2}$$

$$r^{i-1/2} = \frac{r^i + r^{i-1}}{2}$$

In reference to Figure 4 for example point 28 is of type 17 and point 31 is of type 18

The finite difference form of eq (3) is obtained using a forward difference approximation for $(\frac{\partial T}{\partial s})_s$ the temperature gradient at the surface of the cold gas hole In reference to Figures 7-a and 7 b the forward difference approximation for $(\frac{\partial T}{\partial s})_s$ is given by

$$(\frac{\partial T}{\partial s})_s = \frac{Ta - Ts}{\Delta s} \tag{12}$$

where Δs is the distance between points (a) and (s) and Ts and Ta are the temperatures at points (s) and (a) respectively

Point (a) is obtained by the intersection of the cold gas hole radius passing through (s) with a circle or a radius In Figure 7-a the radius passing through (s) first intersects a circle at point (a) and then intersect a radius at (a') Since (s) is closer to (a) than to (a') Δs in eq (12) is taken as the distance of (s) to (a) Using the minimum possible Δr increases the accuracy of forward difference approximation for $(\frac{\partial T}{\partial s})_s$ In Figure 7 b the radius passing through (s) first intersects a radius at point (a), thus Δs is choosen as the distance of (s) to (a)

The temperature Ta in eq (12) is expressed in terms of temperatures T_1 and T_2 (Figures 7-a and 7-b) interpolating linearly between T_1 and T_2 Thus

$$Ta = \Delta\theta_2 \ T_1 + \Delta\theta_1 \ T_2 \tag{13 1}$$

or

$$Ta = \Delta r_2 \ T_1 + \Delta r_1 \ T_2 \tag{13 2}$$

where Δr_1 Δr_2, $\Delta\theta_1$ and $\Delta\theta_2$ are defined in Figures 7 a and 7 b

The finite difference form of eq (3) thus becomes

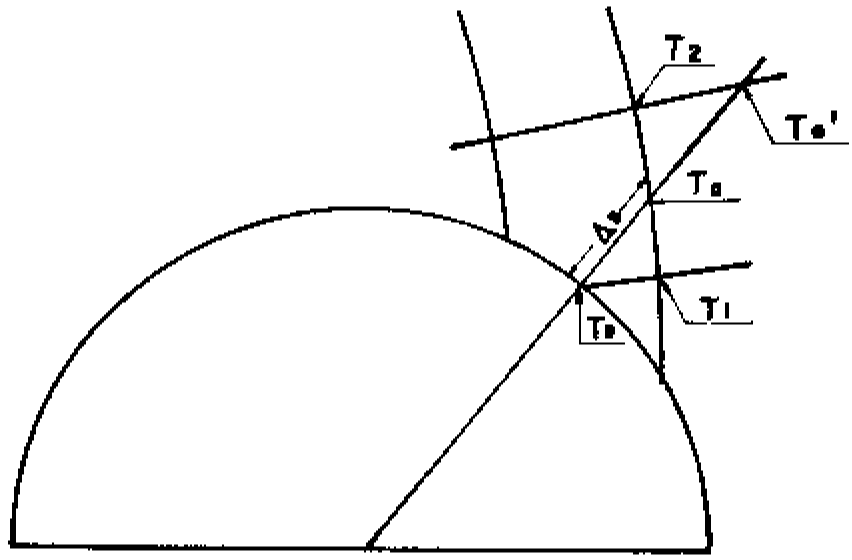

Figure 7 A – Points on the cold gas hole

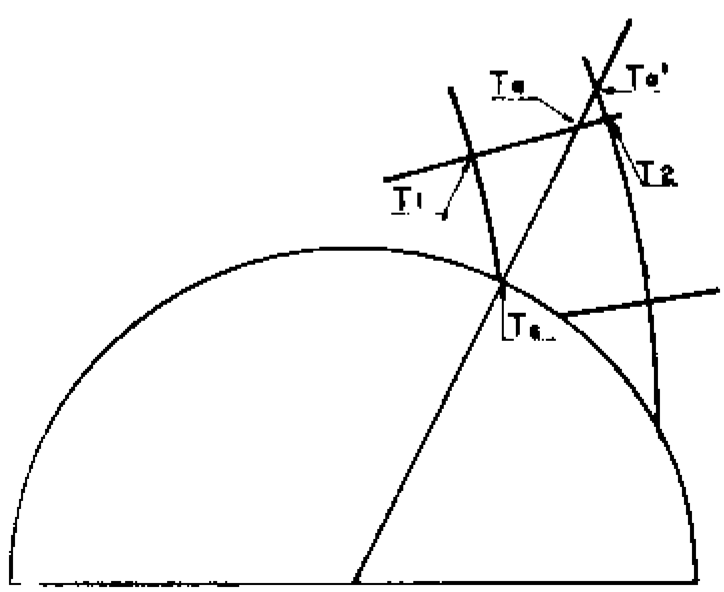

Figure 7 B Points on the cold gas hole

$$\frac{Ks}{\Delta s}\left(\frac{\Delta\theta_2 T_1 + \Delta\theta_1 T_2}{\Delta\theta_1 + \Delta\theta_2} - T_s\right) + h_c\,(T_c - T_s) = 0 \qquad (14\text{-}1)$$

or

$$\frac{Ks}{\Delta s}\left(\frac{\Delta r_2 T_1 + \Delta r_1 T_2}{\Delta r_1 + \Delta r_2} - T_s\right) + h_c\,(T_c - T_s) = 0 \qquad (14\ 2)$$

The coefficientes of the variables in eq (14 1) or (14 2) is than

$$T_1 \quad \frac{K_s\,\Delta\theta_2}{\Delta s\,(\Delta\theta_1 + \Delta\theta_2)} \qquad (15\ 1a)$$

$$T_2 \quad \frac{K_s\,\Delta\theta_1}{\Delta s\,(\Delta\theta_1 + \Delta\theta_2)} \qquad (15\text{-}2a)$$

$$T_s \quad -\left(\frac{Ks}{\Delta s} + h_c\right) \qquad (15\text{-}3a)$$

or

$$T_1 \quad \frac{K_s\,\Delta r_2}{\Delta s\,(\Delta r_1 + \Delta r_2)} \qquad (15\ 1b)$$

$$T_2 \quad \frac{K_s\,\Delta r_1}{\Delta s\,(\Delta r_1 + \Delta r_2)} \qquad (15\ 2b)$$

$$T_s \quad -\left(\frac{K_s}{\Delta s} + h_c\right) \qquad (15\text{-}3)$$

The right hand side B is

$$B = -h_c\,T_c \qquad (15\text{-}4)$$

d **Points on the lower diameter of symmetry** In reference to Figure 4 those are points 105 to 123 and in Table I they can be identified as of type 4

The finite difference form of eq (1) is written at point (i 1) as follows (Figure 8)

$$\frac{1}{\Delta r^2}\left[\, r^{i+1/2}\,K^{i+1/2\ 1}\,(T^{i+1\ 1} - T^{i\ 1}) - r^{i-1/2}\,K^{i-1/2\ 1}\,(T^{i\ 1} - T^{i-1\ 1})\,\right]$$

$$+\frac{1}{r^i\,\Delta\theta^2}\left[\,K^{i\ 3/2}\,(T^{i\ 2} - T^{i\ 1}) - K^{i\ 1/2}\,(T^{i\ 1} - T^{i\ 0})\,\right] = 0 \qquad (16)$$

Eq (16) can be obtained by setting j=1 in the finite difference equation for regular points (eq (6))

The boundary condition equation on the lower diameter of symmetry that is at $\theta = 0$

$$\frac{\partial T}{\partial \theta} = 0 \tag{4}$$

is used to write that at $\theta = 0$

$$0 = \frac{\partial T}{\partial \theta} = \frac{T^{i,2} - T^{i,0}}{2\Delta\theta}$$

which gives

$$T^{i,0} = T^{i,2} \tag{17 1}$$

which could also be deduced directly from symmetry considerations

Eq (17 1) indicates that

$$T^{i,1/2} = T^{i,3/2} \tag{17 2}$$

and since thermal conductivity K is a function of temperature

$$K^{i,1/2} = K^{i,3/2} \tag{17 3}$$

Combining eqs (15 4) (17-1) and (17 3) and then rearranging eq (16) one obtains the coefficients of the temperatures $T^{i-1,1}$ $T^{i+1,1}$ $T^{i,1}$ and $T^{i,2}$ in the finite difference equation written at points on the lower diameter of symmetry

$$T^{i-1,1} \quad \frac{1}{\Delta r^2} \left(r^{i-1/2} \quad K^{i-1/2,1}\right) \tag{18 1}$$

$$T^{i+1,1} \quad \frac{1}{\Delta r^2} \left(r^{i+1/2} \quad K^{i+1/2,1}\right) \tag{18-2}$$

$$T^{i,2} \qquad \frac{2K^{i,3/2}}{r^i \,\Delta\theta^2} \tag{18 3}$$

$$T^{i,1} = -\frac{1}{\Delta r^2} \left(r^{i+1/2} \quad K^{i+1/2,1} \quad + \quad r^{i \quad 1/2} \quad K^{i-1/2,1}\right) - \frac{2K^{i,3/2}}{r^i \,\Delta\theta^2} \tag{18-4}$$

e Points on the upper diameter of symmetry In Figure 4 those are points 2 to 4 and 7 to 9 and in Table I they appear as of Type 5 The finite difference form of eq (1) is written at point (i j) as follows (Figure 8)

$$\frac{1}{\Delta r^2}\left[r^{i+1/2} K^{i+1/2,jj} (T^{i+1,jj} - T^{i,jj}) - r^{i-1/2} K^{i-1/2,jj} (T^{i,jj} - T^{i-1,jj}) \right]$$

$$+ \frac{1}{r^i \Delta\theta^2}\left[K^{i,jj-1/2} (T^{i,jj-1} - T^{i,jj}) - K^{i,jj-1} (T^{i,jj} - T^{i,jj-1}) \right] = 0 \qquad (19)$$

Eq (19) can be obtained from eq (6), setting $j = jj$

The boundary condition on the upper diameter of symmetry, that is, at $\theta = \theta_1$,

$$\left(\frac{\partial T}{\partial \theta} \right) = 0 \qquad (3)$$

is used to write that at $\theta = \theta_1$

$$0 = \frac{\partial T}{\partial \theta} = \frac{T^{i,jj+1} - T^{i,jj-1}}{2\Delta\theta}$$

which gives

$$T^{i,jj+1} = T^{i,jj-1} \qquad (20\text{-}1)$$

which could also be deduced directly from symmetry considerations

Eq (20-1) indicates that

$$T^{i,jj+1/2} = T^{i,jj-1/2} \qquad (20\text{-}2)$$

or

$$K^{i,jj+1/2} = K^{i,jj-1/2} \qquad (20\text{-}3)$$

Combining eqs (19) (20 1) and (20 3) and then rearranging eq (19) one obtains the coefficients of the temperatures $T^{i-1,jj}$ $T^{i+1,jj}$ $T^{i,jj-1}$ and $T^{i,jj}$ in the finite difference equation written at points on the upper diameter of symmetry

$$T^{i-1,jj} \quad \frac{1}{\Delta r^2} (r^{i-1/2} K^{i-1/2,jj}) \qquad (21\ 1)$$

$$T^{i+1,jj} \quad \frac{1}{\Delta r^2} (r^{i+1/2} K^{i+1/2,jj}) \qquad (21\ 2)$$

$$T^{i,jj-1} \quad \frac{2K^{i,jj-1/2}}{r^i \Delta\theta^2} \qquad (21\ 3)$$

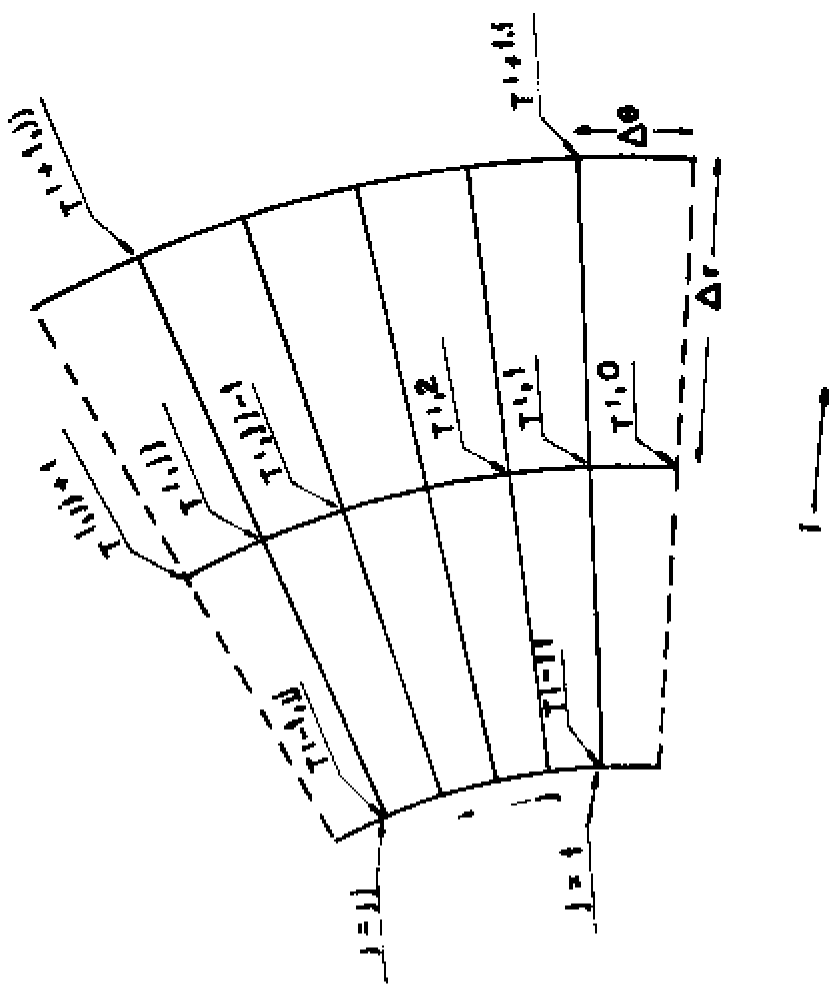

Figure 8 — Points on the diameters of symmetry

$$T^{i,j}: \quad -\frac{1}{\Delta r^2}\left(r^{i+1/2}\ K^{i+1/2,j} + r^{i-1/2}\ K^{i-1/2,j}\right) - \frac{2K^{i,j-1/2}}{r^i\ \Delta\theta^2} \qquad (21\text{-}4)$$

f. **Points on the inside (hot) surface of the duct.** Those are points 1, 11, 23, 37, 54, 83 and 104 in Figure 4 and they are of type 2 in Table I except for point 1 which is of type 6 and point 104 which is of type 7.

The boundary condition given by eq. (2) is written in finite difference form as (Figure 9)

$$h_h\ (T_h - T^{1,j}) + \frac{K^{1,j}}{\Delta r}\ (T^{2,j} - T^{1,j}) = 0 \qquad (22)$$

The coefficients of the temperatures $T^{2,j}$ and $T^{1,j}$ in eq. (22) are then

$$T^{2,j}: \quad \frac{K^{1,j}}{r} \qquad (23.1)$$

$$T^{1,j}: \quad -h_h - \frac{K^{1,j}}{\Delta r} \qquad (23.2)$$

The right hand side of eq. (22), B, is

$$B = -\ h_h\ T_h \qquad (23.3)$$

g. **Points on the outside (cold) surface of the duct.** Those are points 9, 22, 36, 53, 82, 103 and 124 in Figure 4 and they are of type 3 in Table I except for point 36 which is of type 8 and point 124 which is of type 9.

The boundary condition given by eq. (3.a) is written in finite difference form as (Figure 9)

$$h_c\ (T_c - T^{I,j}) + \frac{K^{I,j}}{\Delta r}\ (T^{I-1,j} - T^{I,j}) = 0 \qquad (24)$$

The coefficients of temperatures $T^{I-1,j}$ and $T^{I,j}$ in eq. (24) are

$$T^{I-1,j}: \quad \frac{K^{I,j}}{\Delta r} \qquad (25.1)$$

$$T^{I,j}: \quad -h_c - \frac{K^{I,j}}{\Delta r} \qquad (25.2)$$

The right hand side of eq. (24) is

$$B = -\ h_c\ T_C \qquad (25.3)$$

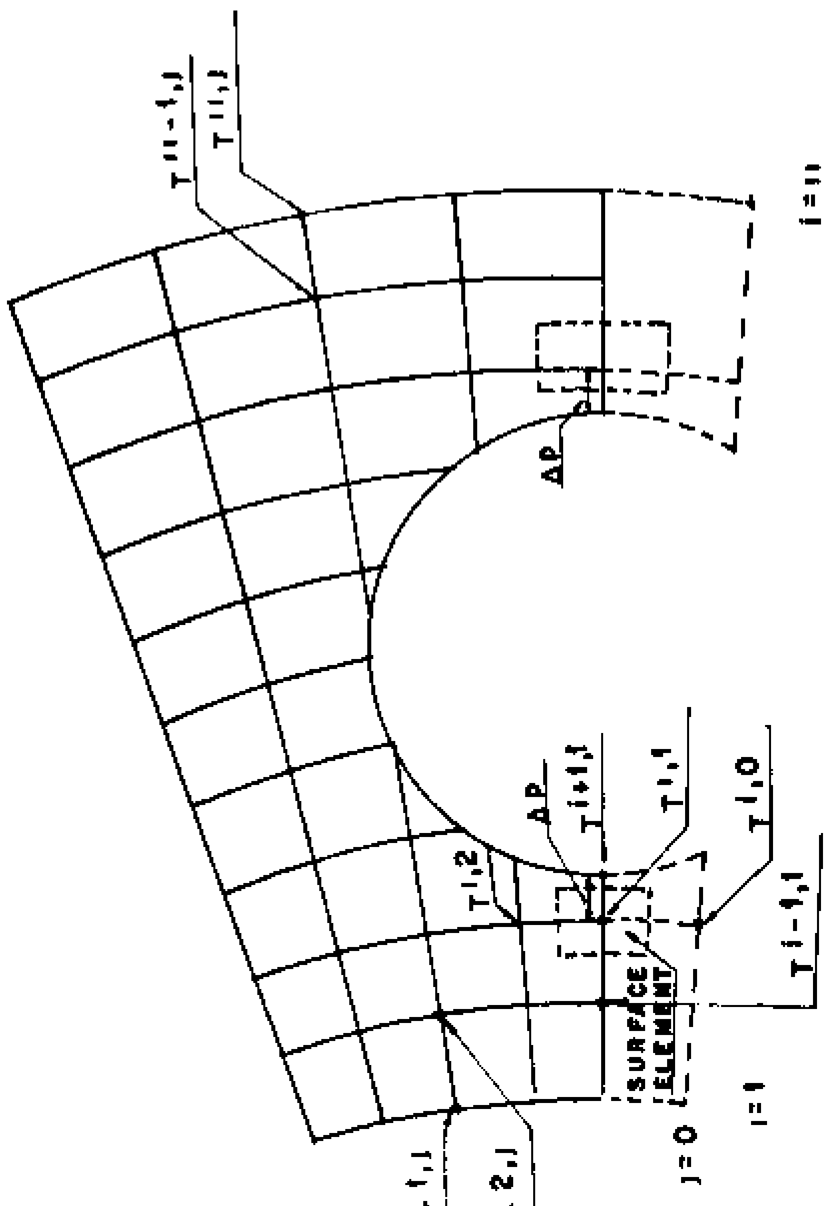

Figure 9 – Points on the inside and outside surfaces of the duct

h. Points on the lower diameter of symmetry next to the cold gas hole

Those are points 4 and 7 in Figure 4 point 4 is assigned type 13 and point 7 type 14 in Table II Note that points of type 13 or 14 do not exist in Figure 4 nor in Table I because the distance of the points 4 and 7 in Figure 4 to the cold gas hole is equal to Δr, therefore both are assigned type 4

The finite difference form of equation (1) at point (i 1) on the left is obtained by considering it as a non regular interior point Then, a heat flow balance on the surface element shown in Figure 9 gives

$$\Delta\theta \left[r^{i+1/2} K^{i+1/2,1} \left(\frac{\partial T}{\partial r} \right)^{i+1/2,1} - r^{i-1/2} K^{i-1/2,1} \left(\frac{\partial T}{\partial r} \right)^{i-1/2,1} \right]$$

$$+ \frac{\Delta r + \Delta p}{2r^i} \left[K^{i,3/2} \left(\frac{\partial T}{\partial \theta} \right)^{i,3/2} - K^{i,1/2} \left(\frac{\partial T}{\partial \theta} \right)^{i,1/2} \right] = 0 \qquad (26)$$

Using central difference approximations for the derivatives one obtains

$$\left(\frac{\partial T}{\partial r} \right)^{i+1/2,1} = \frac{T^{i+1,1} - T^{i,1}}{\Delta p} \qquad (27.1)$$

$$\left(\frac{\partial T}{\partial r} \right)^{i-1/2,1} = \frac{T^{i,1} - T^{i-1,1}}{\Delta r} \qquad (27.2)$$

$$\left(\frac{\partial T}{\partial \theta} \right)^{i,3/2} = \frac{T^{i,2} - T^{i,1}}{\Delta\theta} \qquad (27\text{-}3)$$

$$\left(\frac{\partial T}{\partial \theta} \right)^{i,1/2} = \frac{T^{i,1} - T^{i,0}}{\Delta\theta} \qquad (27\text{-}4)$$

Combining eqs (26) to (27-4) and noting that

$$T^{i,0} = T^{i,1} \qquad (17.1)$$

$$K^{i,1/2} = K^{i,3/2} \qquad (17.3)$$

yields the coefficients of the temperatures $T^{i-1,1}$, $T^{i+1,1}$, $T^{i,2}$ and $T^{i,1}$ in the finite difference equation written at the point on the left of the cold gas hole

$$T^{i-1,1} \quad \frac{r^{i-1/2} K^{i-1/2,1}}{\Delta r (\Delta r + \Delta p)} \qquad (28.1)$$

$$T^{i+1,1} \quad \frac{r^{i+1/2} K^{i+1/2,1}}{\Delta p (\Delta r + \Delta p)} \qquad (28\text{-}1)$$

$$T^{i\,2} \quad \frac{K^{i\,3/2}}{r^{i}\,\Delta\theta^{2}} \tag{28-3}$$

$$T^{i\,1} \quad -\frac{1}{(\Delta r + \Delta p)}\left(\frac{r^{i+1/2}\;K^{i+1/2\,1}}{\Delta p} + \frac{r^{i-1/2}\;K^{i-1/2\,1}}{\Delta r}\right) - \frac{K^{i\,3/2}}{r^{i}\,\Delta\theta^{2}} \tag{28-4}$$

The coefficients of the temperatures in the finite difference equation written at point on the right of the cold gas hole are obtained in a similar way

$$T^{i-1\,1} \quad \frac{r^{i-1/2}\;K^{i-1/2\,1}}{\Delta p\;(\Delta r + \Delta p)} \tag{29-1}$$

$$T^{i+1\,1} \quad \frac{r^{i+1}\;K^{i+1/2\,1}}{\Delta r\;(\Delta r + \Delta p)} \tag{29-2}$$

$$T^{i\,2} \quad \frac{K^{i\,3/2}}{r^{i}\,\Delta\theta^{2}} \tag{29-3}$$

$$T^{i\,1} \quad -\frac{1}{\Delta r + \Delta p}\left(\frac{r^{i+1/2}\;K^{i+1/2\,1}}{\Delta r} + \frac{r^{i-1/2}\;K^{i-1/2\,1}}{\Delta p}\right) - \frac{K^{i\,3/2}}{\Delta r^{i}\Delta\theta^{2}} \tag{29-4}$$

4 — Numerical Solution

The finite difference form of the heat conduction equation — eq (1) and the boundary condition equations lead to a set of n algebraic equations where n is the number of unknown temperatures. The n algebraic equations must be solved simultaneously in order to obtain the unknown temperatures. The system of algebraic equations is linear when the thermal conductivity K is constant, and nonlinear when K is a function of the temperature. The nonlinear system is solved by the successive solutions of the linearized system. Values of $K^{i\,j}$ are evaluated at the arithmetic mean of the hot and cold gases for the first iteration and at the previously computed values of $T^{i\,j}$ for the subsequent iterations. The procedure is continued until all temperatures converged within a given error criterion

Since the set of algebraic equations to be solved is sparse (in no equation appears more than 6 unknowns) subroutine SPAMAT has been used for the solution. SPAMAT solves a set of linear algebraic equations by Gauss elimination using sparse matrix techniques. Only the non zero elements of the coefficient matrix are considered for the storage and the elimination operations. Thus significant savings in computer memory and running time are achieved. SPAMAT is described in an other report[3]. The computer program is listed in Appendix B. It was run on a PDP 11 and took less than 2 minutes to run a problem with 124 grid points

III — RESULTS

The computer program has been run for 12 cases as shown in Table III. The dimensions of the different hot duct geometries used are given in Table IV. Geometry 1 is the one shown in Figure 2. Geometries 2 and 3 are obtained by multiplying the dimensions of geometry 1 by 1 1 and 9 respectively. The finite difference grid for geometries 1 2 and 3 is given in Figure 4 and Table I

Table III

Summary of Runs

$T_h = 950^\circ C$ $T_c = 250^\circ C$ for All Runs

Units K $\frac{W\ m}{m^2\ ^\circ C}$ $v_h\ v_c$ $\frac{m}{s}$ $h_h\ h_c\ h_o$ $\frac{w}{m^2\ ^\circ C}$ T_o $^\circ C$ $\Delta T/m$ $\frac{^\circ C}{m}$

Run	Geometry	K	v_h	v_c	h_h	h_c	h_o	T_o	$\Delta T/m$	Table	Figure
1	G1 6 Loops	5 2	112	53	1333	1646	20000	70	128	A 1	10
2	G1 9 Loops	5 2	75	35	964	1190	20000	70	188	A 2	–
3	G1 12 Loops	5 2	56	26 5	765	945	20000	70	278	A 3	–
4	G1 6 Loops	118	112	53	1333	1646	20000	70	1 40	A-4	11
5	G1 9 Loops	118	75	35	964	1190	20000	70	1 76	A-5	–
6	G1 12 Loops	118	66	26 5	765	945	20000	70	2 04	A-6	–
7	G1 6 Loops	118 05T	112	53	1333	1646	20000	70	1 19	A 7	–
8	G2 9 Loops	5 2	62	28	812	1002	20000	70	167	A-8	–
9	G3 12 Loops	5 2	69	33	925	1142	20000	70	243	A-9	–
10	G1 6 Loops	5 2	112	53	1333	1646	140	25	128	A 10	10
11	G1 6 Loops	5 2	112	53	1333	1646	1	25	128	A 11	12
12	G4 6 Loops	5 2	101	59	1223	1641	140	25	143	A 12	13

Table IV

Duct Dimension

	Geometry 1 (G1)	Geometry 2 (G2)	Geometry 3 (G3)	Geometry 4 (G4)
Number of Cold Gas Holes (N)	10	10	10	12
r_1 (m)	5	55	45	.625
r_2 (m)	1	1 1	90	975
r_3 (m)	15	165	135	13
d (m)	75	825	675	75
A_h (m^2)	785	950	636	.865
A_c (m^2)	707	855	573	637

r_1 r_2 Internal and external radii of the duct respectively

r_3 Radius of the cold gas hole

d Hot gas duct – cold gas hole center to center distance

A_h Area of the hot gas duct $A_h = \Pi r_2^2$

A_c Cold gas hole flow area $A_c = N \Pi r_3^2$

Geometry 4 has a relatively smaller wall tickness than the previous ones Thus it has a smaller cold gas hole diameter and more (12 instead of 10) cold gas holes The finite difference grid for geometry 4 is shown in Figure 4 and Table II

For the thermal conductivity of the ceramic material specified as carbon stone in (1) 3 values have been used The first two are K = 5 2 Wm/(m² °C) and K = 118 wm/(m² °C) corresponding to carbon pipe and graphite pipe at room temperature[4] K for carbon pipe varies very little with temperature[4], but the thermal conductivity of miscellaneous graphite as given in [5] ranges from 20 to 200 wm/(m² °C) in the range of 100 to 1000°C The third expression for K of the duct material has been taken as K = 118 05T (T in °C) to test the computer program when K varies with temperature

In order to have tolerable pressure losses and dimensions in the design a hot gas velocity of about 60-70m/sec and a hot gas duct diameter of 1 1 1 In should not be exceeded [1] According to Figure 8 in reference[1] these data lead to 8 12 loops for a 3000 MW plant The computer program has been run for a plant with 6 9 or 12 loops The 6 loop case leads to highest velocities therefore to highest heat transfer coefficient on the hot gas side resulting in highest duct wall temperatures Although unacceptable high velocities are thus reached the case was studied as an example of severe conditions

The respective hot and cold gas temperatures have been taken as 950°C and 250°C The outside duct temperature T_2 is indicated as 70°C in Figure 7 of reference[1] Except for runs 10 11 and 12 values of T_2 near 70°C have been obtained by using a relatively high value for h_o and taking the surrounding temperature T_o as 70°C In run 10 the surrounding temperature T_o has been taken as 25°C and several values h_o have been tried until computed T_2 was near 70°C As seen in Table A 10 when h_o = 140 w/(m² °C) T_2 varies from 79 0 to 59 9 along the wall When the effective thermal conductivity of the outer insulation is known h_o can be estimated and this estimated value can be used in the computer program as a realistic boundary condition The computed temperature distribution will give the outside duct temperature T_o

The heat transfer coefficients for the hot and cold gases (h_h and h_c) have been calculated from

$$h = 023 \; K/D \; Re^{8} \; Pr^{4} \qquad (30)$$

The helium properties have been taken from[6]

The temperature drop for the hot helium per meter of duct (ΔT) has been calculated from

$$\Delta T = \frac{h_h \; A(950-\overline{T}_w)}{m \; C_p} \qquad (31)$$

A the heat transfer area per meter of duct length is given by $A = 2\pi r_1$ $\overline{T}_w$ is the arithmetic average of the wall temperatures m is the gas mass flow in $\frac{Kg}{s}$ given by m = M/N where M is the total gas mass flow and N is the number of loops C_p is the heat capacity at constant pressure in ws/(Kg°C) Calculated values of ΔT are shown in Table III

The influence on the results of the thermal conductivity number of loops duct dimensions and duct outer insulation is discussed below Figures of isotherms and temperature profiles are given for some runs (Figures 10 to 13) and tables of temperature distribution for all runs are in Appendix A Tables A 1 to A 11 should be used in reference to Figure 4 and Table A 12 in reference to Figure 4

1 **Thermal conductivity K** Comparison of runs 1 2 and 3 with runs 4 5 and 6 show that the temperature gradients are lower when K is higher However the temperature drop per meter increases with higher K reaching about 2 °C/m for run 6 (corresponding to K = 116 wm/(m² °C) and to 12 loops) Run 7 compared with run 4 shows the effect of K varying with temperature In this case 4 iterations were necessary for the temperatures to converge within 1°C (Table A 7)

2 **Number of loops** Higher number of loops for the same duct dimensions leads to lower gas velocities and to lower heat transfer coefficients Thus as indicated by the comparison of runs 1 2 and 3 or of runs 4 5 and 6 lower temperature gradients are obtained with higher number of loops

3 **Duct dimensions** Comparison of run 2 with run 8 and comparison of run 3 with run 9 show that decresing or increasing the duct dimensions by 10% has almost no effect on the temperature distribution Comparison of run 1 with run 12 again indicates that small changes in duct geometry does not effect the temperature distribution significantly Run 12 has been included mainly to give an other example of finite difference grid

4 **Outer insulation of the duct and heat dissipated to the surroundings** Run 11 corresponds to an almost completely insulated duct This has been simulated by using for the outside heat transfer coefficient h_o a very small value (h_o = 1 w/(m² °C)) The surrounding temperature T_o has been taken as T_o = 25°C Comparison of Figure 12 and Table A 11 (run 11) with Figure 10 and Table A 1 (run 1) shows that insulating the duct has no effect on the temperature distribution on the hot half of the duct but leads to higher temperatures (around the cold gas temperature of 250°C) on the cold half on the duct In particular outer insulation does not help to decrease heat losses from the hot gas and temperature drop per meter However heat lost to the surroundings has been calculated to be 30% and 1 5% of the total heat lost by the hot gas for runs 1 and 11 respectively Thus insulation decreases heat losses to the surroundings and causes higher but uniform temperatures on the cold half of the duct

IV – CONCLUSION

The computer program developed allows the steady state computation of temperature distribution in the hot gas duct for different duct and plant configurations The work continues in the following areas

1) Calculation of thermal stresses at steady state conditions

2) Calculation of temperatures and stresses in the transient conditions. This would allow analyses of the duct during normal operational as well as eventual accidental transients.

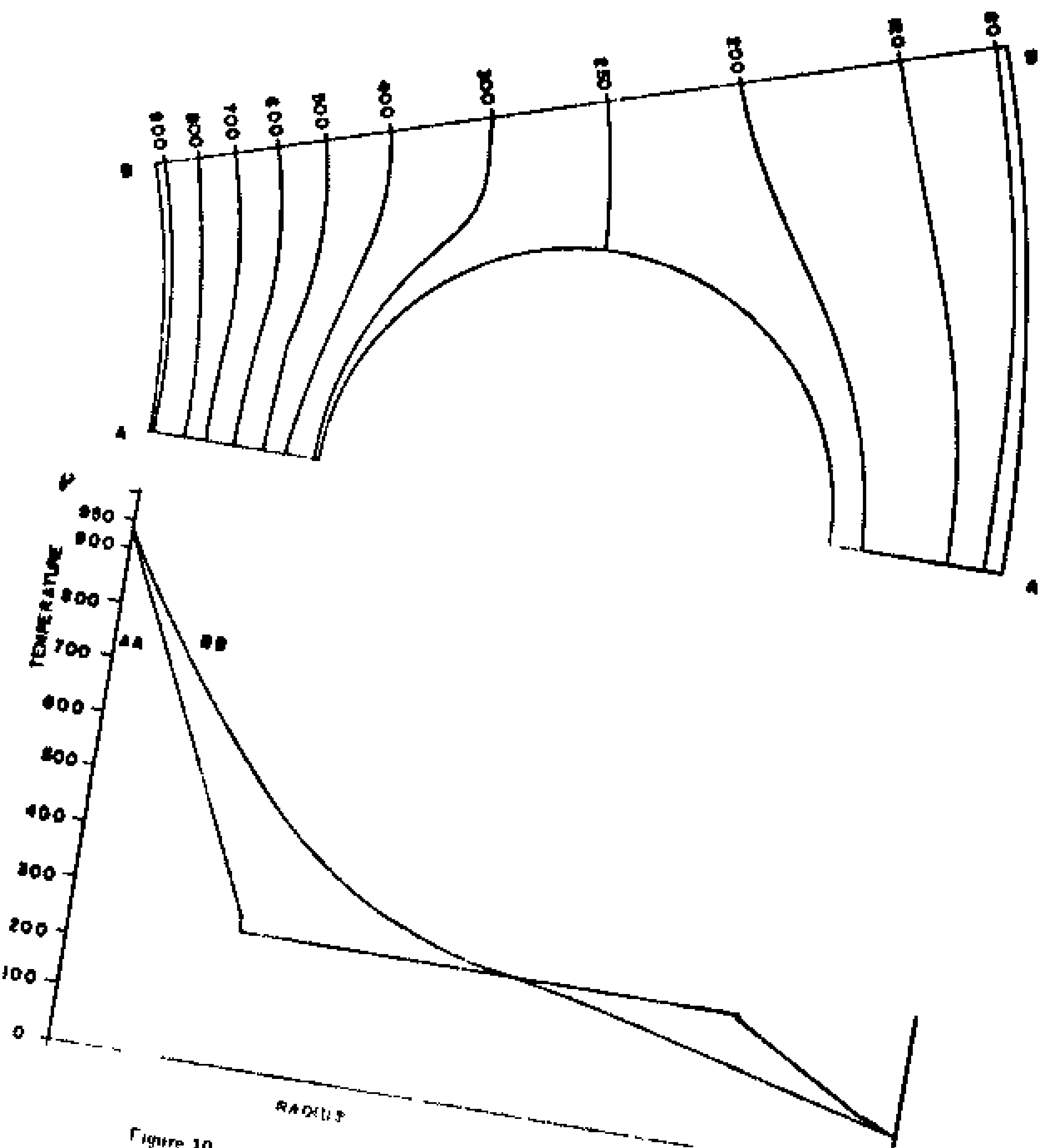

Figure 10 Isotherms and temperature profiles
K 5.2 h_b 1333 h_c = 1646 h_o 20000 T_o = 70
0.1 0 Loop

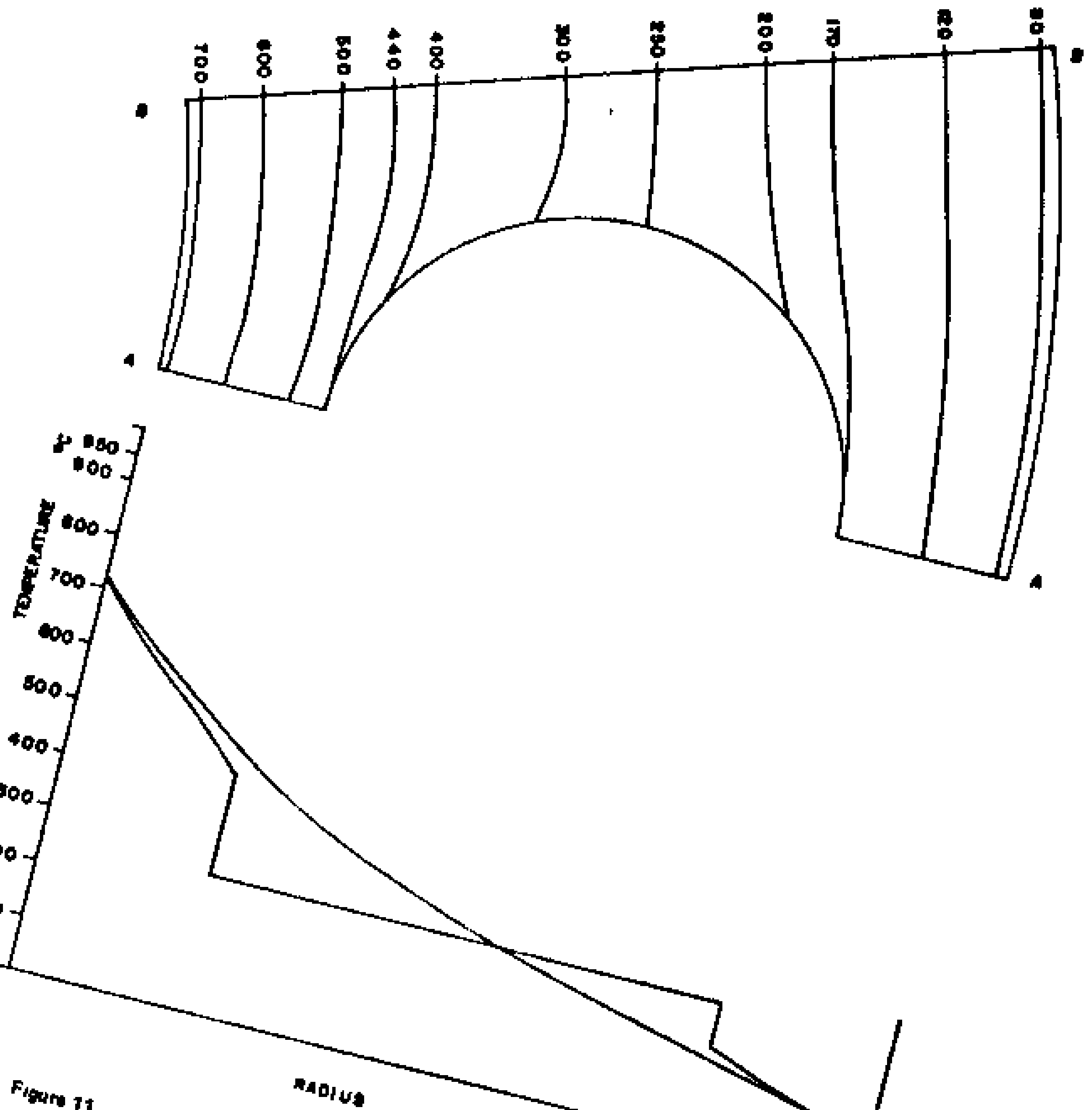

Figure 11 — Isotherms and temperature profiles
$K = 118$ $h_h = 1333$ $h_c = 1646$ $h_o = 20000$ T_c = ...
G1 6 Loops

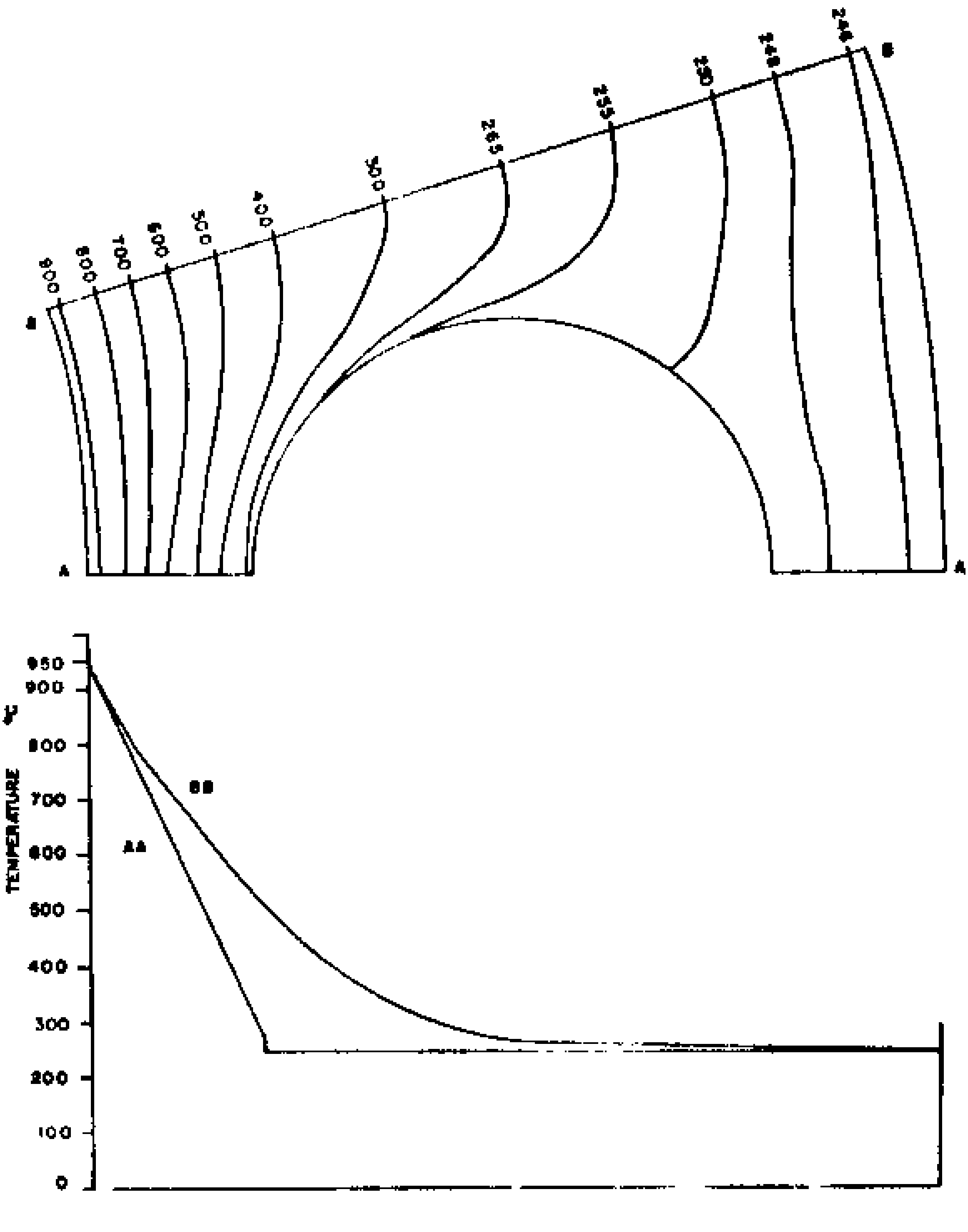

Figure 12 — Isotherms and temperature profiles

$K = 5\ 2 \quad h_o = 1333 \quad h_c = 1646 \quad h_o = 1 \quad T_o = 25$

G1 6 Loops

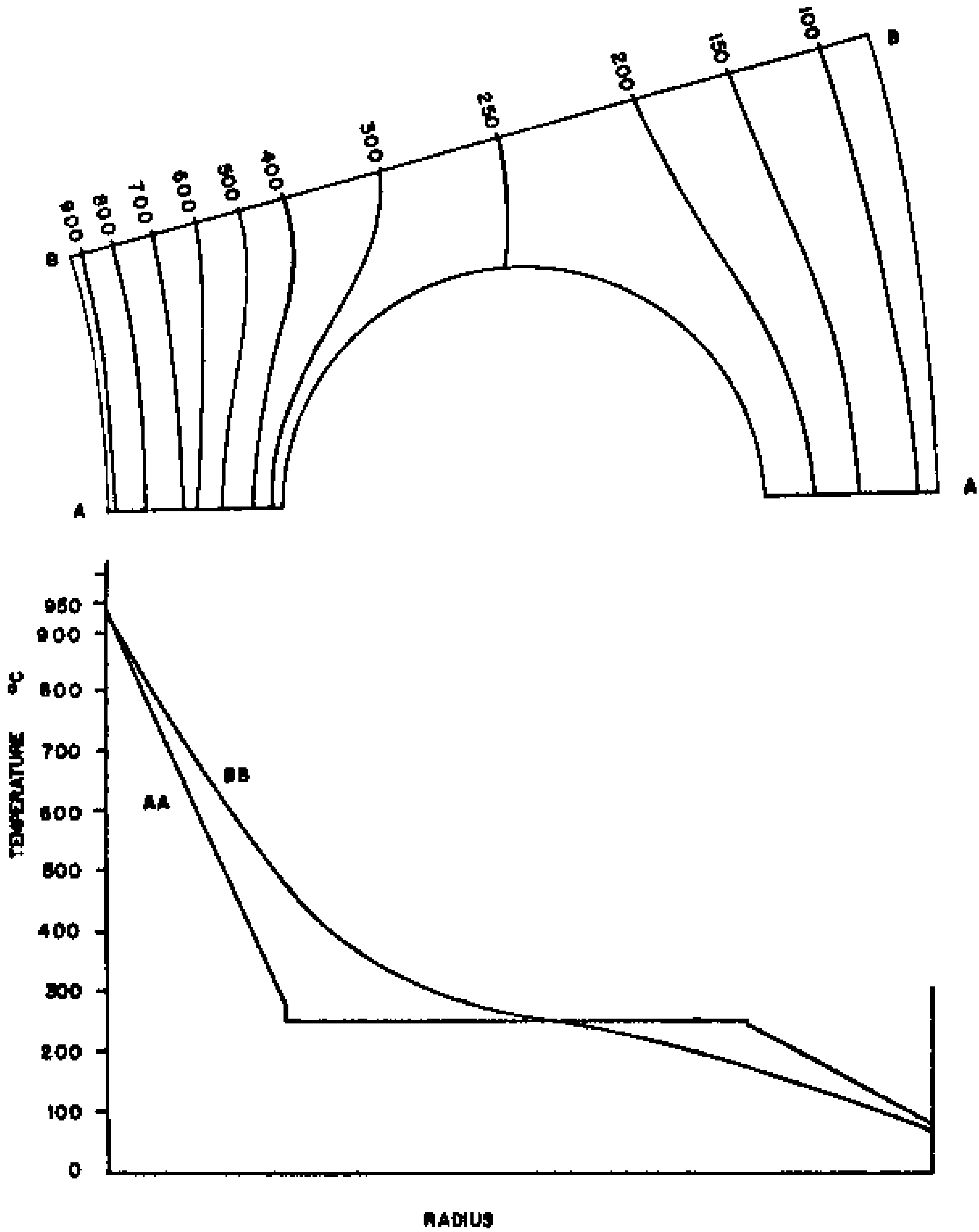

Figure 13 — Isotherms and temperature profiles

$K = 52 \quad h_h = 1223 \quad h_c = 1841 \quad h_a = 140 \quad T_o = 70$

G4 6 Loops

APPENDIX A

Tables of Temperature Distribution

Table A 1

$K = 5.2,\ h_h = 1333\ \ h_c = 1646\ \ h_o = 20000\ \ T_o = 70$

G1 6 Loops

T(1)= [illegible]	T(2)= [illegible]	T(3)= [illegible]	T(4)= [illegible]
T(5)= [illegible]	T(6)= [illegible]	T(7)= [illegible]	T(8)= 150 [illegible]
T(9)= [illegible]	T(10)= [illegible]	T(11)= [illegible]	T(12)= 770 [illegible]
T(13)= [illegible]	T(14)= [illegible]	T(15)= [illegible]	T(16)= 272 [illegible]
T(17)= [illegible]	T(18)= [illegible]	T(19)= [illegible]	T(20)= 146 [illegible]
T(21)= [illegible]	T(22)= [illegible]	T(23)= 926 9	T(24)= 779 [illegible]
T(25)= [illegible]	T(26)= [illegible]	T(27)= [illegible]	T(28)= 267 4
T(29)= [illegible]	T(30)= [illegible]	T(31)= [illegible]	T(32)= 207 [illegible]
T(33)= 171 [illegible]	T(34)= [illegible]	T(35)= [illegible]	T(36)= 70 [illegible]
T(37)= [illegible]	T(38)= [illegible]	T(39)= 653 7	T(40)= 537 [illegible]
T(41)= [illegible]	T(42)= [illegible]	T(43)= [illegible]	T(44)= 260 [illegible]
T(45)= [illegible]	T(46)= [illegible]	T(47)= [illegible]	T(48)= 210 5
T(49)= [illegible]	T(50)= [illegible]	T(51)= [illegible]	T(52)= 39 [illegible]
T(53)= [illegible]	T(54)= [illegible]	T(55)= [illegible]	T(56)= [illegible]
T(57)= [illegible]	T(58)= 471 6	T(59)= [illegible]	T(60)= 323 1
T(61)= [illegible]	T(62)= [illegible]	T(63)= 257 0	T(64)= 265 6
T(65)= 254 [illegible]	T(66)= [illegible]	T(67)= [illegible]	T(68)= 251 3
T(69)= [illegible]	T(70)= [illegible]	T(71)= 249 1	T(72)= [illegible]
T(73)= [illegible]	T(74)= [illegible]	T(75)= 247 4	T(76)= 210 3
T(77)= [illegible]	T(78)= [illegible]	T(79)= [illegible]	T(80)= [illegible]
T(81)= [illegible]	T(82)= [illegible]	T(83)= 330 7	T(84)= [illegible]
T(85)= [illegible]	T(86)= [illegible]	T(87)= 499 3	T(88)= 423 [illegible]
T(89)= [illegible]	T(90)= [illegible]	T(91)= 232 4	T(92)= 272 2
T(93)= [illegible]	T(94)= [illegible]	T(95)= 231 1	T(96)= 216 1
T(97)= [illegible]	T(98)= 173 9	T(99)= 153 1	T(100)= 137 3
T(101)= 114 9	T(102)= [illegible]	T(103)= 70 0	T(104)= 931 0
T(105)= [illegible]	T(106)= [illegible]	T(107)= [illegible]	T(108)= 507 3
T(109)= [illegible]	T(110)= [illegible]	T(111)= 332 6	T(112)= 300 [illegible]
T(113)= [illegible]	T(114)= [illegible]	T(115)= [illegible]	T(116)= 229 1
T(117)= [illegible]	T(118)= [illegible]	T(119)= 176 7	T(120)= 156 4
T(121)= [illegible]	T(122)= 113 5	T(123)= 91 6	T(124)= 70 0

Table A 2

$K = 5\ 2 \quad h_h - 964 \quad h_c = 1190 \quad h_a = 20000 \quad T_a = 70$

G1 9 Loops

TEMPERATURE DISTRIBUTION>

T(1)= 91[illegible]	T([illegible])= 7[illegible]1 8	T([illegible])= [illegible] 4	T(4)= 450 6
T(5)= [illegible]	T([illegible])= [illegible]41 [illegible]	T(7)= 1[illegible] 9	T(8)= 14[illegible] 1
T(9)= 10[illegible] 6	T(10)= 70 0	T(11)= [illegible]17 2	T(12)= 765 3
T(13)= [illegible]1[illegible] 1	T(14)= [illegible]65 [illegible]	T(15)= [illegible]07 6	T(16)= [illegible]7[illegible] 9
T(17)= [illegible]41 [illegible]	T(18)= [illegible] 7	T(19)= 1[illegible]5 7	T(20)= 145 1
T(21)= 10[illegible]	T(22)= 70 0	T(23)= [illegible]1[illegible] 8	T(24)= 774 4
T(25)= [illegible] 0	T(26)= 49[illegible] 2	T(27)= 366 4	T(28)= 273 5
T(29)= [illegible]42 1	T(30)= [illegible]41 4	T(31)= [illegible]42 9	T(32)= 205 5
T(33)= 170 2	T(34)= 1[illegible]	T(35)= 10[illegible] 5	T(36)= 70 0
T(37)= 920 9	T(38)= 7[illegible]5 4	T(39)= 657 3	T(40)= 537 2
T(41)= 427 0	T(42)= [illegible]1 0	T(43)= 270 9	T(44)= 264 2
T(45)= 24[illegible] 0	T(46)= 233 [illegible]	T(47)= 244 6	T(48)= 209 4
T(49)= 1[illegible]2 7	T(50)= 154 6	T(51)= 1[illegible]6 [illegible]	T(52)= 97 9
T(53)= 70 0	T(54)= [illegible]	T(55)= 7[illegible]5 2	T(56)= 676 5
T(57)= 56[illegible] 1	T(58)= 47[illegible] 1	T(59)= [illegible]1 5	T(60)= 330 0
T(61)= 263 8	T(62)= [illegible] 5	T(63)= [illegible]59 6	T(64)= 267 0
T(65)= 255 8	T(66)= 25[illegible] [illegible]	T(67)= [illegible]52 3	T(68)= 251 6
T(69)= 250 5	T(70)= [illegible]46 6	T(71)= [illegible]4[illegible] 8	T(72)= 233 6
T(73)= [illegible]47 4	T(74)= 22[illegible] 3	T(75)= 246 4	T(76)= 209 6
T(77)= 1[illegible] 5	T(78)= 167 1	T(79)= 143 3	T(80)= 118 9
T(81)= 94 3	T(82)= 70 0	T(83)= 923 7	T(84)= 801 8
T(85)= 689 0	T(86)= 587 3	T(87)= 438 5	T(88)= 424 4
T(89)= 3[illegible] 1	T(90)= 3[illegible] 2	T(91)= 233 3	T(92)= 272 8
T(93)= 257 6	T(94)= [illegible]44 4	T(95)= 230 9	T(96)= 215 8
T(97)= 13[illegible] 6	T(98)= 179 4	T(99)= 153 7	T(100)= 137 0
T(101)= 114 7	T(102)= 9[illegible] [illegible]	T(103)= 70 0	T(104)= 924 1
T(105)= 804 1	T(106)= 6[illegible] 3	T(107)= 593 8	T(108)= 507 2
T(109)= 434 8	T(110)= 377 2	T(111)= 333 5	T(112)= 301 5
T(113)= 273 1	T(114)= [illegible]60 0	T(115)= 244 3	T(116)= 229 0
T(117)= 21[illegible] 9	T(118)= 1[illegible]5 4	T(119)= 176 4	T(120)= 156 1
T(121)= 1[illegible] 0	T(122)= 11[illegible]	T(123)= 91 6	T(124)= 70 0

Table A-3

$K = 5.2 \quad h_h = 765 \quad h_c = 945 \quad h_o = 20000 \quad T_a = 70$

G1 12 Loops

TEMPERATURE DISTRIBUTION

T(1)= [illegible]	[illegible]	T(3)= [illegible]	T(4)= 453 4
T(5)= [illegible] 7	T(6)= 2[illegible]9 4	T(7)= 141 3	T(8)= 14 2
T(9)= 1[illegible]	T(10)= 70 0	T(11)= 30[illegible] 6	T(12)= 761 1
T(13)= [illegible]1[illegible] 1	T(14)= 4[illegible]7 5	T(15)= 313 7	T(16)= [illegible] 6
T(17)= [illegible] 5	T(18)= [illegible]7 9	T(19)= 1[illegible]4 4	T(20)= 144 2
T(21)= 1[illegible] 4	T(22)= 70 0	T(23)= 311 5	T(24)= 770 0
T(25)= [illegible] 4	T(26)= 500 [illegible]	T(27)= [illegible]70 [illegible]	T(28)= 273 3
T(29)= [illegible]41 5	T(30)= [illegible] 7	T(31)= 241 [illegible]	T(32)= 204 2
T(33)= 1[illegible] 2	T(34)= 1[illegible] [illegible]	T(35)= 10[illegible]	T(36)= 70 0
T(37)= 91[illegible] 9	T(38)= 7[illegible]	T(39)= [illegible] 1	T(40)= 537 1
T(41)= 4[illegible] 7	T(42)= [illegible]4 0	T(43)= 27[illegible] 7	T(44)= 26[illegible]
T(45)= [illegible]1 0	T(46)= [illegible]	T(47)= [illegible]43 3	T(48)= 203 4
T(49)= 1 1	T(50)= 1[illegible]	T(51)= 1[illegible] 7	T(52)= 97 6
T(53)= 70 0	T(54)= 915 3	T(55)= 730 7	T(56)= 673 9
T(57)= 567 1	T(58)= 4[illegible] 5	T(59)= [illegible] 0	T(60)= 331 7
T(61)= 267 1	T(62)= [illegible]1 2	T(63)= 261 9	T(64)= 263 2
T(65)= 257 2	T(66)= [illegible]7 3	T(67)= 25[illegible] 5	T(68)= 251 8
T(69)= 250 7	T(70)= [illegible]46 4	T(71)= 24[illegible]	T(72)= 23[illegible] 2
T(73)= [illegible]46 [illegible]	T(74)= [illegible]25 8	T(75)= 24 5	T(76)= [illegible] 0
T(77)= 1[illegible]	T(78)= 166 6	T(79)= 142 9	T(80)= 11[illegible] 6
T(81)= 94 [illegible]	T(82)= 70 0	T(83)= 317 [illegible]	T(84)= 737 2
T(85)= [illegible] 1	T(86)= [illegible] 8	T(87)= 49[illegible]	T(88)= 424 9
T(89)= [illegible] 9	T(90)= [illegible]4 2	T(91)= 294 1	T(92)= 273 4
T(93)= [illegible]57 9	T(94)= [illegible]44 [illegible]	T(95)= 230 8	T(96)= 215 5
T(97)= 1[illegible] 2	T(98)= 179 0	T(99)= 158 4	T(100)= 136 7
T(101)= 114 5	T(102)= 9[illegible] 1	T(103)= 70 0	T(104)= 917 8
T(105)= 7[illegible] 5	T(106)= [illegible]30 [illegible]	T(107)= 532 1	T(108)= 506 6
T(109)= [illegible] 0	T(110)= 377 3	T(111)= 334 [illegible]	T(112)= 302 2
T(113)= [illegible] 6	T(114)= [illegible]60 [illegible]	T(115)= 244 4	T(116)= 228 9
T(117)= 1[illegible] 7	T(118)= 1[illegible] 1	T(119)= 176 1	T(120)= 155 8
T(121)= 1[illegible] 7	T(122)= 11[illegible] 1	T(123)= 91 5	T(124)= 70 0

Table A-4

$K = 118 \quad h_h = 1333 \quad h_c = 1646 \quad h_o = 20000 \quad T_o = 70$

G1 6 Loops

TEMPERATURE DISTRIBUTION>

T(1)= 707 7	T(2)= 6[illegible]	T(3)= 57[illegible] 4	T(4)= 506 5
T(5)= 44[illegible]	T(6)= 17[illegible] 1	T(7)= 1[illegible] 3	T(8)= 121 4
T(9)= 97 9	T(10)= 75 3	T(11)= 703 4	T(12)= 640 2
T(13)= [illegible]	T(14)= [illegible]	T(15)= 444 3	T(16)= 433 4
T(17)= 175 4	T(18)= 1[illegible]	T(19)= 143 9	T(20)= 120 1
T(21)= 97 3	T(22)= 7[illegible] 2	T(23)= 710 4	T(24)= 642 8
T(25)= 577 6	T(26)= 514 5	T(27)= 4[illegible]3 1	T(28)= 409 6
T(29)= 186 1	T(30)= 1[illegible]5 0	T(31)= 1[illegible] 4	T(32)= 161 9
T(33)= 1[illegible]9 3	T(34)= 117 3	T(35)= 95 8	T(36)= 74 9
T(37)= 713 0	T(38)= 646 1	T(39)= 532 4	T(40)= 521 7
T(41)= 464 0	T(42)= 4[illegible] 2	T(43)= 397 7	T(44)= 363 5
T(45)= 207 6	T(46)= 195 7	T(47)= 1[illegible]6 7	T(48)= 175 8
T(49)= 1[illegible]5 4	T(50)= 1[illegible]4 8	T(51)= 114 4	T(52)= 94 3
T(53)= 74 6	T(54)= 715 6	T(55)= 649 4	T(56)= 537 0
T(57)= 528 4	T(58)= 473 8	T(59)= 4[illegible]3 6	T(60)= 378 6
T(61)= 359 9	T(62)= 344 5	T(63)= 330 6	T(64)= 308 9
T(65)= 304 2	T(66)= 28[illegible] 2	T(67)= 2[illegible]0 9	T(68)= 262 1
T(69)= 260 6	T(70)= 243 6	T(71)= [illegible]42 6	T(72)= 226 0
T(73)= 226 6	T(74)= 20[illegible] 3	T(75)= 212 5	T(76)= 199 8
T(77)= 170 6	T(78)= 151 2	T(79)= 131 7	T(80)= 112 3
T(81)= 93 2	T(82)= 74 4	T(83)= 717 3	T(84)= 651 6
T(85)= 590 2	T(86)= 533 0	T(87)= 4[illegible]0 2	T(88)= 432 1
T(89)= 389 3	T(90)= 351 9	T(91)= 319 8	T(92)= 292 2
T(93)= 260 2	T(94)= 246 6	T(95)= 226 4	T(96)= 206 9
T(97)= 187 6	T(98)= 16[illegible] 3	T(99)= 149 1	T(100)= 130 0
T(101)= 111 1	T(102)= 92 5	T(103)= 74 3	T(104)= 718 0
T(105)= 652 5	T(106)= 591 3	T(107)= 534 5	T(108)= 482 3
T(109)= 434 9	T(110)= 392 6	T(111)= 355 4	T(112)= 323 1
T(113)= 295 0	T(114)= 270 1	T(115)= 247 7	T(116)= 226 [illegible]
T(117)= 206 7	T(118)= 1[illegible]7 1	T(119)= 167 7	T(120)= 148 5
T(121)= 129 [illegible]	T(122)= 114 [illegible]	T(123)= 92 3	T(124)= 74 3

Table A-5

K = 118 h_h = 964 h_c = 1190 h_o = 20000 T_o = 70

G1 8 Loops

[illegible]

T(1)= [illegible]	T(2)= [illegible]	T(3)= 560 3	T(4)= 507 7
T(5)= 4[illegible] 8	T(6)= 1[illegible] 3	T(7)= 1[illegible] 5	T(8)= 115 0
T(9)= [illegible] 5	T(10)= 71 7	T(11)= [illegible] 6	T(12)= 616 0
T(13)= 5[illegible]1 4	T(14)= [illegible] 5	T(15)= 4[illegible]	T(16)= 44[illegible] 2
T(17)= [illegible] 3	T(18)= 1[illegible] 7	T(19)= 175 0	T(20)= 114 2
T(21)= 94 1	T(22)= 74 [illegible]	T(23)= 673 6	T(24)= 617 1
T(25)= [illegible] 0	T(26)= 51[illegible] 7	T(27)= 4[illegible]0 1	T(28)= 424 4
T(29)= 174 3	T(30)= 17[illegible] 3	T(31)= 173 5	T(32)= 152 6
T(33)= 1[illegible]	T(34)= 112 [illegible]	T(35)= 9[illegible] 2	T(36)= 74 4
T(37)= 674 9	T(38)= [illegible] 7	T(39)= 565 1	T(40)= 513 9
T(41)= 464 9	T(42)= 41[illegible] 7	T(43)= 41[illegible] 4	T(44)= 377 1
T(45)= 19[illegible] 0	T(46)= 1[illegible]7 3	T(47)= 1[illegible] 7	T(48)= 168 3
T(49)= 14[illegible] 0	T(50)= [illegible]	T(51)= 111 0	T(52)= 9[illegible] 4
T(53)= 74 3	T(54)= [illegible]	T(55)= 6[illegible]0 3	T(56)= 567 3
T(57)= 517 [illegible]	T(58)= 4[illegible]	T(59)= 4[illegible]5 3	T(60)= 384 1
T(61)= [illegible]	T(62)= [illegible]47 3	T(63)= 341 0	T(64)= 315 1
T(65)= 311 9	T(66)= [illegible] 7 4	T(67)= 2[illegible] 6	T(68)= 263 [illegible]
T(69)= [illegible]6[illegible] 1	T(70)= [illegible]4[illegible] 4	T(71)= 240 3	T(72)= [illegible]22 7
T(73)= 2[illegible]1 8	T(74)= [illegible]	T(75)= 204 6	T(76)= 1[illegible]4 3
T(77)= 165 9	T(78)= 147 0	T(79)= 12[illegible] 3	T(80)= 109 9
T(81)= 91 8	T(82)= 74 2	T(83)= 677 [illegible]	T(84)= 621 5
T(85)= [illegible] 3	T(86)= 513 5	T(87)= 473 2	T(88)= 430 1
T(89)= [illegible] 5	T(90)= 3[illegible]4 7	T(91)= 322 [illegible]	T(92)= 294 4
T(93)= [illegible] 0	T(94)= [illegible]46 0	T(95)= 224 5	T(96)= 2[illegible] [illegible]
T(97)= 1[illegible] 4	T(98)= 165 1	T(99)= 146 2	T(100)= 127 6
T(101)= 10[illegible] 4	T(102)= [illegible]1 6	T(103)= 74 1	T(104)= 677 5
T(105)= 6[illegible]1 3	T(106)= [illegible] 5	T(107)= 520 3	T(108)= 474 [illegible]
T(109)= [illegible] 7	T(110)= [illegible]92 6	T(111)= 3[illegible]7 1	T(112)= [illegible]25 [illegible]
T(113)= [illegible] 5	T(114)= 270 7	T(115)= [illegible]47 [illegible]	T(116)= [illegible]25 [illegible]
T(117)= [illegible] 4	T(118)= 1[illegible] 4	T(119)= 165 0	T(120)= 14[illegible]
T(121)= [illegible] 4	T(122)= 1[illegible]	T(123)= [illegible]1 [illegible]	T(124)= [illegible]

Table A-6

$K = 118 \quad h_h = 765 \quad h_c = 945 \quad h_o = 20000 \quad T_o = 70$

G1 12 Loops

[illegible]

T(1)= [illegible]	T(2)= [illegible]	T(3)= [illegible]	T(4)= [illegible]
T(5)= [illegible]	T(6)= 144 7	T(7)= [illegible]	T(8)= 110 4
T(9)= [illegible]	T(10)= 74 [illegible]	T(11)= [illegible]	T(12)= 597 7
T(13)= [illegible]	T(14)= [illegible]	T(15)= [illegible]	T(16)= 455 1
T(17)= [illegible]	T(18)= [illegible]	T(19)= [illegible]	T(20)= 110 [illegible]
T(21)= [illegible]	T(22)= 74 [illegible]	T(23)= 647 0	T(24)= [illegible]
T(25)= [illegible]	T(26)= [illegible]	T(27)= [illegible]	T(28)= [illegible]
T(29)= [illegible]	T(30)= [illegible]	T(31)= 165 1	T(32)= 146 0
T(33)= [illegible]	T(34)= [illegible]	T(35)= 91 4	T(36)= 74 1
T(37)= 647 [illegible]	T(38)= [illegible]	T(39)= 551 5	T(40)= 506 6
T(41)= 463 3	T(42)= 421 4	T(43)= [illegible]	T(44)= 334 6
T(45)= 192 6	T(46)= [illegible]	T(47)= 131 5	T(48)= 162 7
T(49)= 144 4	T(50)= [illegible]	T(51)= 108 5	T(52)= 91 1
T(53)= 74 0	T(54)= [illegible]	T(55)= [illegible]	T(56)= 552 1
T(57)= 507 [illegible]	T(58)= 465 [illegible]	T(59)= [illegible]	T(60)= 386 3
T(61)= [illegible]	T(62)= [illegible]	T(63)= [illegible]	T(64)= 318 3
T(65)= 316 0	T(66)= [illegible]	T(67)= [illegible]	T(68)= [illegible]
T(69)= [illegible]	T(70)= [illegible]	T(71)= [illegible]	T(72)= 220 0
T(73)= [illegible]	T(74)= [illegible]	T(75)= 193 7	T(76)= 181 1
T(77)= [illegible]	T(78)= [illegible]	T(79)= 125 3	T(80)= 108 2
T(81)= [illegible]	T(82)= 74 0	T(83)= 648 1	T(84)= 593 2
T(85)= 552 7	T(86)= [illegible]	T(87)= 466 7	T(88)= 427 1
T(89)= [illegible]	T(90)= [illegible]	T(91)= 323 8	T(92)= 235 0
T(93)= [illegible]	T(94)= 244 9	T(95)= 222 7	T(96)= 201 3
T(97)= [illegible]	T(98)= 162 6	T(99)= 143 9	T(100)= 125 8
T(101)= 108 1	T(102)= [illegible]	T(103)= 74 0	T(104)= 648 2
T(105)= [illegible]	T(106)= 552 9	T(107)= 503 9	T(108)= 467 2
T(109)= [illegible]	T(110)= 391 1	T(111)= 356 9	T(112)= 325 5
T(113)= [illegible]	T(114)= [illegible]	T(115)= 246 1	T(116)= 223 6
T(117)= [illegible]	T(118)= [illegible]	T(119)= 162 8	T(120)= 144 0
T(121)= [illegible]	T(122)= [illegible]	T(123)= [illegible]	T(124)= 74 0

Table A 7

(Sheet 1 of 4)

K – 118–05 T h_h · 1333 h_c = 1646 h_o 20000 T_o – 70

G1 6 Loops

TEMPERATURE DISTRIBUTION

T(1)= [illegible]	T [illegible]	T [illegible]	T(4)= 5[illegible]2 4
T(5)= 1 2 0	T(6)= 164 7	T(7)= 154 1	T(8)= 1 [illegible] 1
T(9)= 9[illegible] 7	T(10)= 74 5	T(11)= 740 2	T(12)= [illegible] 9
T(13)= 563 2	T(14)= 50[illegible] 4	T(15)= 124 4	T(16)= 416 3
T(17)= 156 5	T(18)= 174 1	T(19)= 150 9	T(20)= 124 [illegible]
T(21)= 96 9	T(22)= 74 [illegible]	T(23)= 743 0	T(24)= [illegible]
T(25)= 589 0	T(26)= 515 6	T(27)= 413 9	T(28)= 293 1
T(29)= 196 0	T(30)= 1[illegible]4 7	T(31)= 195 3	T(32)= 169 1
T(33)= 144 5	T(34)= 120 4	T(35)= 96 9	T(36)= 74 0
T(37)= 746 6	T(38)= 669 6	T(39)= 596 4	T(40)= 526 9
T(41)= 461 0	T(42)= 394 4	T(43)= 361 5	T(44)= 349 3
T(45)= 214 9	T(46)= 205 5	T(47)= 206 9	T(48)= 191 8
T(49)= 160 1	T(50)= 136 2	T(51)= 116 3	T(52)= 94 8
T(53)= 73 7	T(54)= 750 0	T(55)= 674 3	T(56)= 603 2
T(57)= 536 9	T(58)= 475 7	T(59)= 420 3	T(60)= 372 2
T(61)= 346 1	T(62)= 333 0	T(63)= 319 9	T(64)= 302 3
T(65)= 296 5	T(66)= 276 7	T(67)= 276 1	T(68)= 260 2
T(69)= 258 6	T(70)= 244 1	T(71)= 243 5	T(72)= 226 3
T(73)= 230 2	T(74)= 211 6	T(75)= 218 8	T(76)= 193 3
T(77)= 174 0	T(78)= 153 9	T(79)= 133 6	T(80)= 113 3
T(81)= 93 2	T(82)= 73 5	T(83)= 752 4	T(84)= 677 5
T(85)= 607 9	T(86)= 543 5	T(87)= 484 9	T(88)= 432 5
T(89)= 366 8	T(90)= 346 1	T(91)= 316 0	T(92)= 289 3
T(93)= 766 6	T(94)= 246 4	T(95)= 227 3	T(96)= 206 6
T(97)= 189 6	T(98)= 170 3	T(99)= 150 8	T(100)= 131 2
T(101)= 111 6	T(102)= 92 3	T(103)= 73 3	T(104)= 753 2
T(105)= 678 7	T(106)= 609 5	T(107)= 545 9	T(108)= 488 0
T(109)= 476 4	T(110)= 391 3	T(111)= 352 8	T(112)= 320 2
T(113)= 2[illegible] 6	T(114)= 26[illegible] 7	T(115)= 247 3	T(116)= 227 3
T(117)= 2[illegible] 9	T(118)= 18[illegible] 6	T(119)= 169 [illegible]	T(120)= 149 8
T(1[illegible]1)= [illegible]	T(1[illegible])= 111 1	T([illegible])= [illegible]	T(124)= 73 [illegible]

Table A 7

(Sheet 2 of 4)

TEMPERATURE DISTRIBUTION

T(1)= 740 8	T(2)= 6[illegible]4 7	T(3)= 574 4	T(4)= 498 1
T(5)= 424 2	T(6)= 175 5	T(7)= 147 4	T(8)= 121 7
T(9)= 97 8	T(10)= 75 2	T(11)= 741 7	T(12)= 656 0
T(13)= 576 3	T(14)= 501 2	T(15)= 429 1	T(16)= 417 2
T(17)= 177 5	T(18)= 170 7	T(19)= 144 6	T(20)= 120 2
T(21)= 97 1	T(22)= 75 0	T(23)= 744 2	T(24)= 659 4
T(25)= 581 3	T(26)= 506 6	T(27)= 440 9	T(28)= 394 4
T(29)= 187 8	T(30)= 186 6	T(31)= 187 1	T(32)= 162 5
T(33)= 139 3	T(34)= 117 0	T(35)= 95 5	T(36)= 74 7
T(37)= 747 5	T(38)= 663 8	T(39)= 567 7	T(40)= 518 2
T(41)= 454 7	T(42)= 397 0	T(43)= 363 3	T(44)= 350 8
T(45)= 208 5	T(46)= 196 1	T(47)= 199 8	T(48)= 175 7
T(49)= 154 8	T(50)= 134 0	T(51)= 113 6	T(52)= 93 7
T(53)= 74 4	T(54)= 750 6	T(55)= 666 1	T(56)= 593 7
T(57)= 526 8	T(58)= 466 6	T(59)= 413 7	T(60)= 368 0
T(61)= 347 6	T(62)= 338 6	T(63)= 320 3	T(64)= 300 6
T(65)= 296 1	T(66)= 276 9	T(67)= 274 8	T(68)= 257 6
T(69)= 256 4	T(70)= 240 4	T(71)= 240 1	T(72)= 223 7
T(73)= 225 6	T(74)= 206 4	T(75)= 212 9	T(76)= 188 1
T(77)= 169 0	T(78)= 149 6	T(79)= 130 2	T(80)= 111 1
T(81)= 92 4	T(82)= 74 2	T(83)= 752 8	T(84)= 671 0
T(85)= 597 8	T(86)= 532 5	T(87)= 474 5	T(88)= 423 5
T(89)= 379 6	T(90)= 343 5	T(91)= 311 3	T(92)= 285 0
T(93)= 262 3	T(94)= 241 8	T(95)= 222 3	T(96)= 203 6
T(97)= 184 7	T(98)= 165 6	T(99)= 146 9	T(100)= 128 2
T(101)= 109 7	T(102)= 91 6	T(103)= 74 0	T(104)= 753 6
T(105)= 672 1	T(106)= 599 3	T(107)= 534 5	T(108)= 477 1
T(109)= 426 8	T(110)= 383 3	T(111)= 346 1	T(112)= 311 6
T(113)= 287 5	T(114)= 262 9	T(115)= 242 4	T(116)= 222 4
T(117)= 202 9	T(118)= 183 8	T(119)= 164 9	T(120)= 146 1
T(121)= [illegible] 5	T(122)= 109 2	T(123)= 91 1	T(124)= 74 0

Table A 7

(Sheet 3 of 4)

TEMPERATURE DISTRIBUTION

T(1)= 710 7	T(2)= [illegible]	T(3)= [illegible]	T(4)= 498 2
T(5)= 424 2	T(6)= [illegible]	T(7)= [illegible]	T(8)= [illegible]
T(9)= [illegible]	T(10)= [illegible]	T(11)= 741 7	T(12)= 655 9
T(13)= [illegible]	T(14)= [illegible]	T(15)= [illegible]	T(16)= 417 3
T(17)= [illegible]	T(18)= [illegible]	T(19)= 144 6	T(20)= 120 2
T(21)= [illegible]	T(22)= [illegible]	T(23)= [illegible]	T(24)= 659 3
T(25)= [illegible]	T(26)= 506 9	T(27)= 141 0	T(28)= 394 5
T(29)= [illegible]	T(30)= [illegible]	T(31)= [illegible]	T(32)= 162 5
T(33)= [illegible]	T(34)= [illegible]	T(35)= [illegible]	T(36)= 74 7
T(37)= [illegible]	T(38)= [illegible]	T(39)= [illegible]	T(40)= 518 3
T(41)= 454 [illegible]	T(42)= [illegible]	T(43)= [illegible]	T(44)= 350 9
T(45)= 208 4	T(46)= [illegible]	T(47)= 149 6	T(48)= 175 7
T(49)= 154 8	T(50)= [illegible]	T(51)= [illegible]	T(52)= 93 8
T(53)= 74 4	T(54)= 750 5	T(55)= [illegible]	T(56)= 593 6
T(57)= [illegible]	T(58)= [illegible]	T(59)= [illegible]	T(60)= 368 2
T(61)= 347 7	T(62)= [illegible]	T(63)= [illegible]	T(64)= 300 8
T(65)= 296 2	T(66)= [illegible]	T(67)= 274 9	T(68)= 257 6
T(69)= 256 4	T(70)= 210 4	T(71)= 240 1	T(72)= 223 7
T(73)= 225 6	T(74)= 206	T(75)= 212 9	T(76)= 186 1
T(77)= 169 0	T(78)= 149 7	T(79)= 130 3	T(80)= 111 2
T(81)= 92 4	T(82)= 74 2	T(83)= 752 6	T(84)= 670 7
T(85)= [illegible]	T(86)= [illegible]	T(87)= 474 6	T(88)= [illegible]
T(89)= [illegible]	T(90)= [illegible]	T(91)= 311 5	T(92)= 285 1
T(93)= 262 4	T(94)= 241 9	T(95)= 222 6	T(96)= 203 7
T(97)= 184 6	T(98)= [illegible]	T(99)= 147 0	T(100)= 128 2
T(101)= 109 7	T(102)= 91 6	T(103)= 74 0	T(104)= 753 4
T(105)= 671 6	T(106)= [illegible]	T(107)= 534 4	T(108)= 477 2
T(109)= [illegible]	T(110)= [illegible]	T(111)= [illegible]	T(112)= 314 7
T(113)= [illegible]	T(114)= [illegible]	T(115)= [illegible]	T(116)= 222 4
T(117)= [illegible]	T(118)= [illegible]	T(119)= [illegible]	T(120)= 146 1
T(121)= [illegible]	T(122)= [illegible]	T(123)= 91 4	T(124)= 74 0

Table A 7

(Sheet 4 of 4)

TEMPERATURE DISTRIBUTION

T(1)= 740 8	T(2)= 654 6	T(3)= 574 4	T(4)= 498 [illegible]
T(5)= 424 2	T(6)= 175 4	T(7)= 147 3	T(8)= 121 7
T(9)= 97 9	T(10)= 75 2	T(11)= 741 7	T(12)= 655 9
T(13)= 576 3	T(14)= 501 3	T(15)= 429 3	T(16)= 417 3
T(17)= 177 4	T(18)= 170 6	T(19)= 144 6	T(20)= 120 2
T(21)= 97 1	T(22)= 75 0	T(23)= 744 2	T(24)= 659 3
T(25)= 561 3	T(26)= 506 9	T(27)= 441 1	T(28)= 394 5
T(29)= 187 7	T(30)= 166 5	T(31)= 187 0	T(32)= 162 5
T(33)= 139 3	T(34)= 117 0	T(35)= 95 5	T(36)= 74 7
T(37)= 747 4	T(38)= 663 7	T(39)= 587 7	T(40)= 518 3
T(41)= 454 9	T(42)= 397 2	T(43)= 383 3	T(44)= 350 9
T(45)= 208 4	T(46)= 196 0	T(47)= 199 8	T(48)= 175 7
T(49)= 154 8	T(50)= 134 1	T(51)= 113 7	T(52)= 93 8
T(53)= 74 4	T(54)= 750 5	T(55)= 667 8	T(56)= 593 6
T(57)= 526 6	T(58)= 467 0	T(59)= 413 9	T(60)= 368 2
T(61)= 347 7	T(62)= 330 7	T(63)= 320 4	T(64)= 300 8
T(65)= 296 2	T(66)= 277 0	T(67)= 274 9	T(68)= 257 6
T(69)= 256 4	T(70)= 240 4	T(71)= 240 1	T(72)= 223 7
T(73)= 225 6	T(74)= 206 4	T(75)= 212 9	T(76)= 188 1
T(77)= 169 0	T(78)= 149 7	T(79)= 130 3	T(80)= 111 2
T(81)= 92 4	T(82)= 74 2	T(83)= 752 6	T(84)= 670 0
T(85)= 597 7	T(86)= 532 5	T(87)= 474 6	T(88)= 423 8
T(89)= 379 8	T(90)= 342 7	T(91)= 311 5	T(92)= 285 1
T(93)= 262 4	T(94)= 241 9	T(95)= 222 6	T(96)= 203 7
T(97)= 184 6	T(98)= 165 9	T(99)= 147 0	T(100)= 128 2
T(101)= 109 7	T(102)= 91 6	T(103)= 74 0	T(104)= 753 4
T(105)= 671 8	T(106)= 599 1	T(107)= 534 5	T(108)= 477 2
T(109)= 427 0	T(110)= 383 5	T(111)= 346 3	T(112)= 314 7
T(113)= 287 7	T(114)= 264 0	T(115)= 242 5	T(116)= 222 4
T(117)= 203 0	T(118)= 163 9	T(119)= 164 9	T(120)= 146 1
T(121)= 1[illegible] 6	T(122)= 109 3	T(123)= 91 4	T(124)= 74 0

Table A-8

$K = 5.2\ \ h_h = 812\ \ h_c = 1002\ \ h_b = 20000\ \ T_a = 70$

G2 8 Loops

(TEMPERATURE DISTRIBUTION)

T(1)= 914	T(2)= [illegible]	T(3)= [illegible]	T(4)= 451 5
T(5)= [illegible]	T(6)= [illegible]	T(7)= [illegible]	T(8)= 148 8
T(9)= [illegible]	T(10)= [illegible]	T(11)= 914 9	T(12)= 764 0
T(13)= [illegible]	T(14)= 46[illegible]	T(15)= [illegible]	T(16)= 282 0
T(17)= [illegible]	T(18)= [illegible]	T(19)= [illegible]	T(20)= 144 0
T(21)= [illegible]	T(22)= [illegible]	T(23)= [illegible]	T(24)= 773 0
T(25)= [illegible]	T(26)= [illegible]	T(27)= [illegible]	T(28)= 275 2
T(29)= [illegible]	T(30)= [illegible]	T(31)= [illegible]42 4	T(32)= 205 1
T(33)= 169 9	T(34)= 125 6	T(35)= 102 4	T(36)= 70 0
T(37)= [illegible]	T(38)= [illegible]34 0	T(39)= 656 6	T(40)= 537 2
T(41)= 427 6	T(42)= 3[illegible]2 0	T(43)= [illegible]	T(44)= 265 3
T(45)= 245 7	T(46)= [illegible]	T(47)= [illegible]	T(48)= 209 1
T(49)= [illegible]	T(50)= 154 4	T(51)= 126 0	T(52)= 97 3
T(53)= 70 0	T(54)= [illegible]	T(55)= 7[illegible]3 9	T(56)= 675 7
T(57)= 567 8	T(58)= 47[illegible]	T(59)= [illegible]31 9	T(60)= 330 5
T(61)= 264 6	T(62)= [illegible]	T(63)= [illegible]60 3	T(64)= 267 4
T(65)= 256 2	T(66)= [illegible]56 8	T(67)= 253 0	T(68)= 251 7
T(69)= 250 6	T(70)= [illegible]46 6	T(71)= 240 7	T(72)= 23[illegible] 5
T(73)= 247 3	T(74)= [illegible]26 2	T(75)= 246 1	T(76)= 209 5
T(77)= 139 3	T(78)= 167 0	T(79)= 143 2	T(80)= 118 8
T(81)= 94 3	T(82)= 70 0	T(83)= 921 7	T(84)= 800 4
T(85)= 63[illegible] 1	T(86)= [illegible]	T(87)= 438 4	T(88)= 424 5
T(89)= 366 3	T(90)= 323 5	T(91)= [illegible]	T(92)= 273 0
T(93)= 257 7	T(94)= 244 5	T(95)= 230 9	T(96)= 21[illegible] 7
T(97)= 133 5	T(98)= 179 3	T(99)= 158 6	T(100)= 136 9
T(101)= 114 6	T(102)= 92 2	T(103)= 70 0	T(104)= 922 2
T(105)= [illegible]02 7	T(106)= [illegible]	T(107)= 593 2	T(108)= 507 0
T(109)= 434 3	T(110)= 377 4	T(111)= 333 7	T(112)= 301 7
T(113)= 273 [illegible]	T(114)= 260 1	T(115)= 244 3	T(116)= 229 0
T(117)= 212 9	T(118)= 1[illegible]5 3	T(119)= 176 [illegible]	T(120)= 156 0
T(121)= 1[illegible]4 9	T(122)= 113 3	T(123)= 91 5	T(124)= 70 0

Table A 9

$K = 5\ 2 \quad h_h = 925 \quad h_c = 1142 \quad h_p - 20000 \quad T_o = 70$

G3 12 Loops

TEMPERATURE DISTRIBUTION

T(1)= 911 9	T(2)= 7 9 [illegible]	T(3)= [illegible]	T(4)= 452 3
T(5)= 244 1	T(6)= [illegible]40 2	T(7)= 141 9	T(8)= 148 6
T(9)= 10 4	T(10)= 70 0	T(11)= 31[illegible] 6	T(12)= 762 7
T(13)= 61[illegible] 5	T(14)= 4[illegible]	T(15)= [illegible]11 [illegible]	T(16)= [illegible]84 0
T(17)= 240 2	T(18)= [illegible]	T(19)= 144 9	T(20)= 144 6
T(21)= 10[illegible]	T(22)= 70 0	T(23)= [illegible]14 4	T(24)= 771 7
T(25)= 634 0	T(26)= 44[illegible]	T(27)= 368 8	T(28)= 276 3
T(29)= 242 1	T(30)= 240 4	T(31)= 241 3	T(32)= 204 7
T(33)= 1[illegible]3 6	T(34)= 1[illegible]5 4	T(35)= 1[illegible]2 7	T(36)= 70 0
T(37)= 91[illegible] 6	T(38)= 73[illegible] 7	T(39)= [illegible]56 0	T(40)= 537 2
T(41)= 4[illegible] 1	T(42)= 232 3	T(43)= 273 3	T(44)= 266 3
T(45)= [illegible]45 4	T(46)= 23[illegible] 7	T(47)= 243 3	T(48)= 208 3
T(49)= 1[illegible]2 1	T(50)= 154 2	T(51)= 125 9	T(52)= 97 7
T(53)= 70 0	T(54)= 31[illegible] 5	T(55)= 732 5	T(56)= 674 9
T(57)= 5[illegible]7 5	T(58)= 47[illegible] 1	T(59)= 392 3	T(60)= 331 0
T(61)= 265 8	T(62)= 290 5	T(63)= 261 0	T(64)= 267 7
T(65)= 256 7	T(66)= 257 0	T(67)= 253 2	T(68)= 251 7
T(69)= [illegible]50 6	T(70)= 246 5	T(71)= [illegible]44 6	T(72)= 238 4
T(73)= 247 1	T(74)= 2[illegible]6 0	T(75)= 245 8	T(76)= 209 3
T(77)= 1[illegible]9 2	T(78)= 166 [illegible]	T(79)= 143 1	T(80)= 118 7
T(81)= 94 2	T(82)= 70 0	T(83)= [illegible]13 [illegible]	T(84)= 799 0
T(85)= 687 3	T(86)= 586 4	T(87)= 438 3	T(88)= 424 7
T(89)= 366 6	T(90)= [illegible]	T(91)= 2[illegible]3 [illegible]	T(92)= 273 1
T(93)= 257 8	T(94)= 244 4	T(95)= [illegible]30 8	T(96)= 215 6
T(97)= 193 3	T(98)= 173 2	T(99)= 158 5	T(100)= 136 8
T(101)= 114 5	T(102)= 92 2	T(103)= 70 0	T(104)= 920 3
T(105)= 801 3	T(106)= [illegible]91 5	T(107)= 532 8	T(108)= 506 8
T(109)= 4[illegible]4 9	T(110)= 377 6	T(111)= 3[illegible]3 3	T(112)= 301 9
T(113)= 274 4	T(114)= [illegible]60 1	T(115)= 244 3	T(116)= 229 0
T(117)= 21[illegible]	T(118)= [illegible]	T(119)= 176 [illegible]	T(120)= 155 9
T(121)= 1[illegible]4 [illegible]	T(122)= 11[illegible]	T(123)= 91 5	T(124)= 70 0

Table A 10

$K = 52 \quad h_h = 1333 \quad h_c = 1846 \quad h_o = 140 \quad T_o = 25$

Gt 6 Loops

TEMPERATURE DISTRIBUTIONS

T(1)= [illegible]	T(2)= [illegible]	T(3)= [illegible]	T(4)= 447 4
T(5)= [illegible]	T(6)= [illegible]44 0	T(7)= 1[illegible] 4	T(8)= 154 1
T(9)= 115 [illegible]	T(10)= [illegible]	T(11)= [illegible]	T(12)= [illegible] 1
T(13)= [illegible]	T(14)= 46[illegible] 5	T(15)= [illegible]	T(16)= [illegible] 2
T(17)= 24[illegible]	T(18)= [illegible] 3	T(19)= [illegible] 9	T(20)= 149 1
T(21)= 11[illegible] 1	T(22)= [illegible] 1	T(23)= [illegible]	T(24)= 779 2
T(25)= [illegible] 7	T(26)= [illegible] 9	T(27)= [illegible] 2	T(28)= [illegible]67 4
T(29)= [illegible]4 0	T(30)= [illegible]	T(31)= [illegible]44 8	T(32)= [illegible] 0
T(33)= 1[illegible]1	T(34)= 13[illegible] 5	T(35)= 104 5	T(36)= 72 5
T(37)= [illegible] 5	T(38)= 7[illegible] 4	T(39)= [illegible]59 7	T(40)= 53[illegible] 3
T(41)= 4[illegible]5 1	T(42)= [illegible]	T(43)= 265 4	T(44)= 260 5
T(45)= 24[illegible] 0	T(46)= [illegible]4 1	T(47)= [illegible]46 0	T(48)= 209 6
T(49)= 132 4	T(50)= 1[illegible]3 [illegible]	T(51)= 124 8	T(52)= 96 0
T(53)= [illegible] 4	T(54)= [illegible]	T(55)= [illegible]00 3	T(56)= 679 4
T(57)= 5[illegible] 1	T(58)= 4[illegible]1 6	T(59)= [illegible]90 1	T(60)= 320 0
T(61)= [illegible]0 1	T(62)= [illegible]	T(63)= [illegible]57 0	T(64)= 265 6
T(65)= [illegible]54 [illegible]	T(66)= [illegible] 7	T(67)= [illegible]2 0	T(68)= 251 2
T(69)= 250 2	T(70)= [illegible]4[illegible] 5	T(71)= [illegible]49 1	T(72)= 238 5
T(73)= 24[illegible] 1	T(74)= [illegible] 0	T(75)= [illegible]4[illegible]	T(76)= 20[illegible] 9
T(77)= 1[illegible] 1	T(78)= 16[illegible] 0	T(79)= 140 4	T(80)= 114 9
T(81)= [illegible]9 1	T(82)= [illegible]	T(83)= [illegible]30 7	T(84)= [illegible] 8
T(85)= 692 [illegible]	T(86)= [illegible]	T(87)= 496 9	T(88)= 423 8
T(89)= [illegible]5 0	T(90)= [illegible] 0	T(91)= 292 2	T(92)= 271 9
T(93)= [illegible] 8	T(94)= [illegible]4[illegible] 7	T(95)= [illegible]30 0	T(96)= 214 6
T(97)= 1[illegible]	T(98)= 1[illegible] 9	T(99)= 155 [illegible]	T(100)= 1[illegible]2 5
T(101)= 10[illegible]	T(102)= [illegible]	T(103)= 60 [illegible]	T(104)= 9[illegible]1 0
T(105)= [illegible]0[illegible] 1	T(106)= [illegible]	T(107)= [illegible]35 5	T(108)= 50[illegible] 7
T(109)= [illegible]	T(110)= [illegible] 4	T(111)= [illegible]	T(112)= 300 4
T(113)= [illegible] 1	T(114)= [illegible] 1	T(115)= [illegible]4[illegible]	T(116)= [illegible]27 9
T(117)= [illegible]11 4	T(118)= 1[illegible]	T(119)= 17[illegible]	T(120)= 15[illegible] 3
T(121)= 1[illegible]	T(122)= [illegible]	T(123)= [illegible]	T(124)= 5[illegible] 9

Table A 11

$K = 52 \quad h_h = 1333 \quad h_c = 1848 \quad h_o = 1 \quad T_o = 25$

G1 8 Loops

TEMPERATURE DISTRIBUTION)

T(1)= 925 2	T(2)= 766 5	T(3)= 603 3	T(4)= 447 5
T(5)= 272 2	T(6)= 249 8	T(7)= 248 5	T(8)= 247 3
T(9)= 246 2	T(10)= 245 1	T(11)= 925 7	T(12)= 770 1
T(13)= 617 2	T(14)= 462 6	T(15)= 300 8	T(16)= 272 3
T(17)= 249 9	T(18)= 249 5	T(19)= 248 3	T(20)= 247 2
T(21)= 246 1	T(22)= 245 0	T(23)= 927 0	T(24)= 779 3
T(25)= 636 8	T(26)= 495 0	T(27)= 362 3	T(28)= 267 4
T(29)= 249 9	T(30)= 249 3	T(31)= 249 9	T(32)= 249 0
T(33)= 248 0	T(34)= 247 0	T(35)= 246 0	T(36)= 244 9
T(37)= 923 5	T(38)= 730 5	T(39)= 659 3	T(40)= 537 6
T(41)= 4[illegible]5 5	T(42)= 32[illegible] 0	T(43)= 265 4	T(44)= 260 5
T(45)= 250 1	T(46)= [illegible] 1	T(47)= 2[illegible]0 0	T(48)= 249 7
T(49)= 248 9	T(50)= 24[illegible] 0	T(51)= 247 1	T(52)= 246 0
T(53)= 245 0	T(54)= 923 8	T(55)= 800 5	T(56)= 679 8
T(57)= 563 7	T(58)= 472 4	T(59)= 331 1	T(60)= 323 2
T(61)= 260 2	T(62)= 28[illegible] 3	T(63)= 2[illegible]7 2	T(64)= 267 0
T(65)= 254 6	T(66)= 257 6	T(67)= 252 6	T(68)= 254 5
T(69)= 251 4	T(70)= 253 6	T(71)= 250 7	T(72)= 253 0
T(73)= 250 3	T(74)= 25[illegible] 4	T(75)= 250 1	T(76)= 251 5
T(77)= 250 [illegible]	T(78)= 249 5	T(79)= 248 5	T(80)= 247 4
T(81)= 246 3	T(82)= 245 2	T(83)= 930 7	T(84)= 807 1
T(85)= 692 7	T(86)= 583 7	T(87)= 500 0	T(88)= 425 6
T(89)= 367 4	T(90)= [illegible]5 5	T(91)= 297 5	T(92)= 279 3
T(93)= 263 [illegible]	T(94)= 262 7	T(95)= 25[illegible] 6	T(96)= 255 7
T(97)= 253 5	T(98)= 251 [illegible]	T(99)= 25[illegible]	T(100)= 249 0
T(101)= 247 [illegible]	T(102)= 246 [illegible]	T(103)= 24[illegible]	T(104)= 931 4
T(105)= [illegible]43 4	T(106)= 697 [illegible]	T(107)= [illegible]6 5	T(108)= 509 1
T(109)= [illegible] 5	T(110)= 379 3	T(111)= 336 9	T(112)= 307 1
T(113)= [illegible] 3	T(114)= 274 4	T(115)= [illegible] 4	T(116)= 260 8
T(117)= [illegible]7 1	T(118)= 2[illegible]4 4	T(119)= 25[illegible] 3	T(120)= 250 7
T(121)= 249 2	T(122)= [illegible]47 [illegible]	T(123)= 24[illegible] 6	T(124)= 24[illegible] [illegible]

Table A 12

K = 5 2 h_h = 1223, h_c = 1841 h_o = 140 T_o = 25

G4 6 Loops

TEMPERATURE DISTRIBUTION

T(1)= 9[illegible]1 6	T(2)= 756 [illegible]	T(3)= 5[illegible]1 5	T(4)= 4[illegible]0 4
T(5)= 2[illegible]1 1	T(6)= 244 3	T(7)= 20[illegible] 9	T(8)= 159 2
T(9)= 116 [illegible]	T(10)= 61 0	T(11)= 922 5	T(12)= 760 7
T(13)= 601 5	T(14)= [illegible] 8	T(15)= 269 5	T(16)= 244 4
T(17)= 240 4	T(18)= 24[illegible] 6	T(19)= 194 9	T(20)= 153 5
T(21)= 115 1	T([illegible])= 78 9	T(23)= 9[illegible]4 1	T(24)= 771 5
T(25)= 625 0	T(26)= [illegible]64 0	T(27)= 349 8	T(28)= 264 6
T(29)= 245 7	T(30)= 245 1	T(31)= 245 5	T(32)= 210 5
T(33)= 175 4	T(34)= 140 8	T(35)= 106 9	T(36)= 74 0
T(37)= [illegible]25 8	T(38)= 76[illegible] 3	T(39)= 649 5	T(40)= 526 5
T(41)= [illegible]17 9	T(42)= 329 6	T(43)= 262 6	T(44)= 271 1
T(45)= 259 0	T(46)= 255 7	T(47)= 246 5	T(48)= 247 0
T(49)= 247 3	T(50)= 232 8	T(51)= 246 6	T(52)= 211 7
T(53)= 185 9	T(54)= 157 [illegible]	T(55)= 128 4	T(56)= 98 7
T(57)= 69 0	T(58)= [illegible]27 0	T(59)= 791 7	T(60)= 666 5
T(61)= 554 0	T(62)= 457 4	T(63)= [illegible]80 0	T(64)= 323 9
T(65)= 266 1	T(66)= 25[illegible] 2	T(67)= 267 4	T(68)= 251 9
T(69)= 25[illegible] 7	T(70)= 250 3	T(71)= [illegible]44 0	T(72)= 249 2
T(73)= 231 5	T(74)= [illegible]15 2	T(75)= 195 2	T(76)= 172 1
T(77)= 146 9	T(78)= 120 [illegible]	T(79)= 9[illegible] [illegible]	T(80)= 65 7
T(81)= [illegible]	T(82)= 794 6	T(83)= 672 4	T(84)= 563 3
T(85)= [illegible]70 2	T(86)= 395 [illegible]	T(87)= [illegible] 4	T(88)= 300 9
T(89)= [illegible] 4	T(90)= [illegible]	T(91)= [illegible]	T(92)= 227 7
T(93)= [illegible]	T(94)= 190 [illegible]	T(95)= 1[illegible]	T(96)= 143 4
T(97)= [illegible]	T(98)= 91 [illegible]	T(99)= [illegible]	T

APPENDIX B

Listing of the Computer Program

```
C        CHOCHA FIN
C        PREPARES THE GEOMETRICAL CONFIGURATION OF THE
C        FINITE DIFFERENCE GRID
C
         COMMON  BLOC01 RCE,RCIN RINT ECC TETA,NDH NDV
         COMMON  BLOC02 TA 700,7) F(700 5) D(120),N N1 N2 NANT N1DIF,
      *                 N2DIF ALFA BETA DS DT NDH1 I L2 C1 I IC ID
         COMMON  BLOC03 ILIG R1,R1PAS L2PAS IJ
         COMMON  BLOC04 JLIG R2 R2PAS L PAS JJL NPAS
      *                 N1EFFO N2EFFO
         COMMON  BLOC05 FLIG NDIF N1PAS N2PAS FIM ICH NDV1
         CALL INIT0
         NDV1 NDV+1
         NDH1 NDH+1
         I 1
         IP 0
         FIM 0
         ICH 0
         ILIG 0
         JLIG=0
         FLIG 0
         NANT=0
         N1DIF=0
         N2DIF=0
         DO 100 I=1 NDH1
         DT=TETA FLOAT NDH)
         DT=DT*3 1416/180
         DS=(RCE -RCIN)/FLOAT NDV
         ALFA FLOAT I-1)*DT
         C=CORDA ALFA DIST)
         IF C EQ 0 )GO TO 50
         D1=DIST RCIN
         D2=RCE -DIST-C
         N1=INT(D1/DS)+1
         R1=AMOD D1,DS)
         IF R1 GE 0 01)N1=N1+1
         N2=INT D2/DS)+1
         R2=AMOD D2 DS)
         IF(R2 GE 0 01)N2=N2+1
         N=N1+N2
         IF I GE NDH1)GO TO
         BETA=FLOAT(I)*DT
         C1=CORDA BETA DIST
         IF(C1 EQ 0)GO TO
         D11=DIST-RCIN
         D I-RCE   DIST-C1
         N1  INT D11
         R1 AMOD D11
         IF                    
         N1
         I   1
```

```
      IF(R21 GE 0 01)N2POS=N2POS+1
      NPOS=N1POS+N2POS
      N1DFPO=N1POS-N1
      IF(R1 LT 0 01)N1DFPO=N1DFPO-1
      N2DFPO=N2POS-N2
      IF(R2 LT 0 01)N2DFPO=N2DFPO-1
      GO TO 6
7     NPOS=NDV1
6     CONTINUE
      IF(I LE 1)GO TO 5
      N1DIF=N1-N1PAS
      IF(R1PAS LT 0 01)N1DIF=N1DIF-1
      N2DIF=N2-N2PAS
      IF(R2PAS LT 0 01)N2DIF=N2DIF-1
5     CONTINUE
      IPC=N1DIF+N2DIF
      CALL DO10
      CALL DO20
      GO TO 60
50    ICH=ICH+1
      NDIF=0
      N=NDV1
      IF(ICH NE 1)GO TO 55
      NDIF=NDV1-(N1PAS-1)-(N2PAS-1)
55    CALL DO30
      IPC=NDIF
60    NANT=NANT+N+IPC
      IPC=0
      NPAS=N
      N1PAS=N1
      N2PAS=N2
      L2PAS=L2
      L3PAS=L3
      R1PAS=R1
      R2PAS=R2
100   CONTINUE
      KK=0
      JMAX=J-1
      DO 70 I=1,JMAX
      AUX=0
      IF(IA(I,2) LT 17)GO TO 80
      KK=KK+1
      AUX=D(KK)
80    WRITE(3,11)(IA(I,K),K=1,7),(B(I,L),L=1,5),AUX
11    FORMAT(7I4,6F12 5)
70    CONTINUE
      STOP
      END
```

```
      SUBROUTINE DO18
      COMMON  BLOCO1 ACES RCIN RINT DCC TETA,NDH,NDV
      COMMON  BLOCO2 IA(700 7) E 700 5) D(120) N N1,N2,NANT N1DIF
     *                N2DIF ALFA BETA [S IT NDH1 I L2,R1 J L7 IG
      COMMON  BLOCO3 ILIG R1 RIIHS L2IH  IJ
      L1=NANT+1
      L2=NANT+N1+N1DIF
      L2M1 L2-1
      DO 10 J=L1 L2
      IF ILIG EQ 0)GO TO 14
      ITIPO=18
      ILIG=0
      GO TO 17
14    ITIPO=1
      IF I EQ 1)ITIPO=4
      IF(I EQ NDH1)ITIPO=5
      IF J EQ L1)ITIPO=2
      IF J EQ L1 AND I EQ 1)ITIPO=6
      IF(J EQ L1 AND I EQ NDH1)ITIPO=7
      IF N1DIF GT 0)GO TO 16
      IF R1 LT 0 01)GO TO 15
      IF(J EQ L2M1)ITIPO=10
      IF J EQ L2M1 AND I EQ 1)ITIPO=13
      GO TO 15
16    DO 18 K=1,N1DIF
      L2M1=L2-K+2
      IF J EQ L2M1)ITIPO=1
      IF J EQ L2M1 AND I EQ 1 ITIPO=15
      IF(J EQ L2M1)ILIG 1
18    CONTINUE
15    IF J EQ L2)ITIPO=17
17    IA J 1)=J
      IA(J 2)=ITIPO
      IA(J 3)=J
      IF(ITIPO EQ 17)GO TO  00
      IF(ITIPO EQ 18)GO TO  70
      E(J 5)=RCIN+FLOAT I-1)*DS
      IA J 4)=J+1
      E(J 1)=DS
      IF(J EQ L2-1 AND R1 GE 0 01 E  J 1)=R1
      IF J LE L1)GO TO 10
      IA(J 6)=J-1
      E(J 3)=DS
102   IF I LE 1)GO TO 10
      IF J EQ L2-1 AND R1FAS  I 0 01)GO TO 10E0
      DO 108 IVAFRE-L 900
      IF  IA I/AREL T  NE  I OR IA I)AREAL     LL IT GO TO 108
      IA J    IVAREI
      GO TO 100
108   CONTINUE
10E0  IA J      I 10
```

```
109     E( I 4)=I T
103     IF J LT NCH1)IA(J 5)=J+N+N1DIF+N2DIF
        E T , )-[ T
        IF N1DIF EQ 0)GO TO 10
        DO 110 K=1 N1DIF
        L2M1 L - N1DIF-K+1)*2
        IF K NE L2M1)GO TO 110
        IA J 5)=IA(J 5)-K+1
        IA J 4)=K+2
        IF K EQ N1DIF)B J 1)=R1
        IA J 6)=K-2
        IF(K EQ 1)IA(J 6)=J-1
        IA J 7)=K+1
        AU =FLOAT L2M1-NANT-K)*DS+RCIN
        B(J 3) AUX
        B J 4)=ALFA-ANG(DCC AUX RINT)
110     CONTINUE
        GO TO 10
300     CONTINUE
        IF(I EQ 1)GO TO ___
        AU =ANGALL(1 ALFA DCC RINT)
        VFH=FLDALA(BETA DCC AUX)-RINT
        CUX=FLOAT(L2-L1-N1DIF-1)*DS+RCIN
        BUX=ANGALL(1 AUX DCC CUX)
        VFV=FLDALA(BUX DCC AUX)-RINT
        ID=ID+1
        D(ID)=AMIN1(VFV VFH)
        IVIZ=J-1
        IF(N1DIF GT 0)IVIZ=J-2
        IF(VFV-VFH)307 308 309
307     IA(J 5)=IA(IVIZ 5)
        IA(J 7)=IVIZ
        B J 2)=BETA-BUX
        B(J 4)=DT-B(J 2)
        GO TO 10
309     IA(J 4)=IA(IVIZ 5)+1
        IA(J 6)=IA(IVIZ 5)
        B(J 3)=FLDALA(AUX DCC BETA)-CN
        B(J 1)=DS-B(J 3)
        GO TO 10
308     IA(J 5)=IA(IVIZ 5)
        IA(J 7)=IVIZ
        B(J 4)=DT
        GO TO 10
3_      IA(J 5)=IA(J-1 5)
        IA(J,7)=J-1
        B(J 2)=DT
        ID=ID+1
        D(ID)=R1
        IF(R1 LT 0 01)D ID)=DS
        GO TO 10
350     CONTINUE
        IJK=IJK+1
        CUX=FLOAT((J-1)-L1-(IJK-1))*DS+RCIN
        IF IJK EQ N1DIF)IJK=0
        AUX ANG DCC RINT CUX)
        VFH FLDALA ALFA DCC AUX) RINT
        CUX CU -1 5
        BU =ANGALL 1 AU  DCC CUX )
        VFV FLDALA BU  DCC AU )-RINT
        ID ID+1
        D ID  AMIN1 VFV VFH)
        IVIZ J-1
        IVI 1 IA IVIZ
        IF(       )      _
        IA(
```

```
      IA(J,7)=IA(IVIZ1,7)
      E(J,2)=ALFA-EU
      B(J,4)=DT-E(J,2)
      GO TO 10
159   IA(J,4)=IVIZ
      IA(J,6)=IVIZ1
      B(J,3)=RLDALA(AU) DCC(ALFA)-CU)
      E(J,1)=DS-E(J,3)
      GO TO 10
158   IA(J,5)=IVIZ1
      IA(J,7)=IA(IVIZ1,7)
      B(J,4)=DT
10    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CIRC
      COMMON  BLOC01 ALE   RCIN RINT DEC  TETA NDH NCV
      COMMON  BLOCO  IA  (900 7) B 700 5) E  120) N N1 N2 NANT NIDEP
     *                  N2CIF ALFA BETA C5 CT NCH1 1 L2 L1 J L3 ID
      COMMON  BLOCO4 JLIG F2 F2PAS L FAS IL  NFOS
     *                  N1CFPO N2CFPO
      L  L2+1
      L4 NANT+N+N2CIF+N1CIF
      L M1 L +1
      DO 20 J L  L4
      IF JLIG EQ 0)GO TO 24
      ITIPO=18
      JLIG 0
      GO TO 27
24    ITIPO=1
      IF(I EQ 1)ITIPO=4
      IF I EQ NCH1)ITIPO=5
      IF N2CIF GT 0)GO TO 26
      IF R2 LT 0 01)GO TO 25
      IF J EQ L M1)ITIPO=11
      IF J EQ L3M1 AND I EQ 1)ITIPO=14
      GO TO 2*
26    DO 20 K=1 N2CIF
      IF K EQ 1)L M1=L3+1
      IF K GT 1)L M1=L3+1+(K 1)*2
      IF(J EQ L M1)ITIPO=12
      IF J EQ L3M1 AND I EQ 1)ITIPO=16
      IF J EQ L_M1)JLIG=1
20    CONTINUE
25    IF(J EQ L3)ITIPO=17
      IF(J EQ L4)ITIPO=
      IF(J EQ L4 AND I EQ 1)ITIPO=9
      IF J EQ L4 AND I EQ NCH1)ITIPO=8
27    IA(J 1)=J
      IA J 2)=ITIPO
      IA(J 3)=J
      IF(ITIPO EQ 17)GO TO 400
      IF(ITIPO EQ 18)GO TO 450
      B(J 5)=RCIN+FLOAT(NDV-L4+J)*E
      IA(J 6)=J-1
      B(J 3)=DS
      IF(J EQ L3+1 AND R2 GE 0 01)B(J 3)=R2
      IF(J GE L4)GO TO 202
      IA(J,4)=J+1
      B J,1)=DS
202   IF(I LE 1)GO TO 20
      IF(J EQ L3+1 AND R2FAS LT 0 01)GO TO 2000
      DO 208 IVARRE=1 900
      IF IA(IVARRE 5) NE J OR IA IVARRE 2) GE 17)GO TO 208
      IA J 7)=IVARRE
      GO TO 20
208   CONTINUE
```

```
[illegible]
[illegible]
      IF [illegible] NE 0 GO TO [illegible]
      [illegible]
      GO TO [illegible]
[illegible]
[illegible]
      IF [illegible] GO TO [illegible]
      [illegible]
      [illegible]
      IF [illegible] NE [illegible] GO TO [illegible]
      IA [illegible]
      IA [illegible]
      IA [illegible]
      IF [illegible] NE 1 GO TO [illegible]
      IA [illegible]
      [illegible]
 [illegible] IA [illegible] 7)=[illegible]+1
      [illegible] FLOAT NE [illegible]
      [illegible] ALL
      L [illegible] =[illegible]FA-ANG [illegible] AU [illegible] RINT
 1[illegible] CONTINUE
      IF [illegible]
      GO TO [illegible]
400   CONTINUE
      IF [illegible] 1)GO TO 4[illegible]
      [illegible]=ANGAL [illegible] ALFA [illegible] RINT)
      [illegible] ALDALA BETA DCC AU [illegible] RINT
      [illegible] FLOAT(ND [illegible] (L4-L [illegible] N2DIF 1)[illegible] IN
      [illegible] ANGAL 2 AU DCC [illegible]
      [illegible] ALDALA EU DCC AU [illegible] RINT
      ID=ID+1
      [illegible] ID)=AMIN1(VFV VFH)
      [illegible]=I+1
      IF C1 NE 0)GO TO 401
      IVIZ1=IVIZ+NPOS+(NPOS [illegible] N1 1) [illegible] N2 1))+N2DIF
      GO TO 402
401   IVIZ1=IVIZ+NPOS+N1DFFO+N2DFFO+N2DIF
40[illegible] IF(VFV-VFH)40[illegible] 40[illegible] 409
40[illegible] IA [illegible] 5)=IVIZ1
      IA [illegible] 7) IVIZ
      [illegible] BETA-B[illegible]
      L [illegible] 4)=LT-B(J [illegible]
      GO TO 20
409   IA [illegible] 4)=IVIZ1
      IA(J 6)=IVIZ1-2
      IF N2DFFO LE 0 AND C1 GT 0)IA J 6 =IVIZ1-1
      B J 1)=CUX-RLDALA(AUX DCC BETA)
      B(J 2)=DS-B(J 1)
      GO TO 20
40[illegible] IA(J 5)=IVIZ1
      IA(J 7)=IVIZ
      B(J 4)=DT
      GO TO 20
444   IVIZ=J+1
      IA(J 5)=IVIZ+NPOS+ NPOS-(N1 1)-(N2-1))+N2DIF
      IF(C1 NE 0)IA [illegible] 5)=IVIZ+NPOS+N1DFFO+N2DFFO+N2DIF
      IA(J,7)=J+1
      B J 2)=DT
      ID=ID+1
      D ID)=R2
      IF(R2 LT [illegible] [illegible] ID [illegible]
      GO TO 20
420   CONTINUE
      J[illegible] J[illegible]+1
      [illegible] FLOAT ND [illegible] J-1)-(N DIF-(J[illegible] 1))))*DS+RCIN
```

```
      IF(J.LE.N DIF) [illegible]
      AUX=ANG DE( PINI (I) )
      VFH=RLDALA(ALFA DCC AUX) PINI
      CUY=CUX+DY
      BUX=ANGALL(2 AUX DCC CUY)
      VFV=RLDALA(BUX DCC AUX) PINI
      ID=ID+1
      F(ID)=AMIN1(VFV VFH)
      IVIZ=J 1
      IF(VFV-VFH)457 458 459
457   IA(J 5)=IVIZ+2
      DO 456 IVARRE=1 800
      IF(IA(IVARRE 5) NE IVIZ+2 OR IA(IVARRE 2) GE 17)GO TO 456
      IA(J 7)=IVARRE
      GO TO 455
456   CONTINUE
455   B(J 2)=ALFA-BUX
      B(J 4)=DT-B(J 2)
      GO TO 20
459   IA(J,4)=IVIZ+2
      IA(J 6)=IVIZ
      B(J,1)=CUY-RLDALA(AUX DC( ALFA)
      B(J,3)=DS-B(J 1)
      GO TO 20
458   IA(J,5)=IVIZ+2
      IA(J 7)=IA(IVIZ+2 7)
      B(J 4)=DT
20    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE [illegible]
      COMMON [illegible] RIN FINT DLG TETA NCH N[illegible]
      COMMON [illegible] IA [illegible] N N1 N NAN1 NDIF
     *          N LIF ALFA BETA L5 DI NCH1 [illegible]
      COMMON [illegible] FLOC05 ILIG NDIF N1PAS N2PAS [illegible] ICH N[illegible]
      L5=NAN1+1
      L6=NAN1+ND[illegible]
      IF(ICH EQ 1)L6=L6+NDIF
      DO [illegible]
      IF(ILIG EQ 0)GO TO [illegible]
      ITIPO=16
      ILIG=0
      GO TO 57
 [illegible] ITIPO=1
      IF(I EQ 1)ITIPO=4
      IF(I EQ NCH1)ITIPO=[illegible]
      IF(J EQ L5)ITIPO=[illegible]
      IF(J EQ L5 AND I EQ NCH1)ITIPO=[illegible]
      IF(J EQ L6)ITIPO=[illegible]
      IF(J EQ L6 AND I EQ NCH1)ITIPO=[illegible]
      IF(ICH NE 1)GO TO 57
      DO [illegible] K=1 NDIF
      L7=(L5+N1PAS-1)+K*[illegible]
      IF(J EQ L7)ITIPO=12
      IF(J EQ L7)ILIG=1
 [illegible] CONTINUE
      IA(J 1)=J
      IA(J 2)=ITIPO
      IA(J 3)=J
      IF(ITIPO EQ 16)GO TO 500
      B(J 5)=RIN+FLOAT(J-L5)*DS
      IF(J GE L6)GO TO 15[illegible]
      IA(J 4)=J+1
      B(J 1)=DS
 [illegible] IF(I GE NCH1)GO TO 15[illegible]
      IA(J 5)=J+N
      IF(ICH GT 1)GO TO 151
      IF(J GE L5 AND [illegible] N2PAS[illegible]IA(J [illegible])=J+N+NDIF
151   B(J 2)=DT
15[illegible] IF(J LE L5)GO TO 154
      IA(J,6)=J-1
      B(J 3)=DS
154   DO 508 IVARRE=1 [illegible]
      IF (IA(IVARRE 5) NE J OR [illegible] GE 1)GO TO 508
      IA(J 7)=IVARRE
      GO TO 509
508   CONTINUE
509   B(J 4)=DT
      IF(NDIF EQ 0)GO TO [illegible]
      DO 510 K=1 NDIF
      L[illegible]=(L5+N1PAS-1)+[illegible]
      IF(J NE L7)GO TO [illegible]
      IA(J 4)=J+2
      IA(J [illegible])=IA(J 5)[illegible]
```

```
      IF(F GT E)IA(J 6)=I
      IA(J 7)=J+1
      AU =FLOAT(IZ LS 1+1)*DS+RCIN
      E(J 1)=  -AU
      F(J 1)=ALFA-ANG(DCC AUX RINT)
516   CONTINUE
      IF(J EQ LZ+2)IA(J 6)=J-2
      IF(F GT ( AND I LE LF)) ( 5)=RCIN+FLOAT( I LS NDIF)*DS
      GO TO 20
500   CONTINUE
      KLM=KLM+1
      CUX=FLOAT( J-1)-LS-(KLM-1))*DS+RCIN
      AU =ANG DCC RINT CUX)
      EU =ALDALA AUX DCC ALFA)
      ID=ID+1
      C ID =ALDALA(ALFA DCC AUX) RINT
      IVIZ=J-1
      IF(EU -CU )570 560 590
570   IA(J 4)=IVIZ
      IA(J 6)=IA(IVIZ 6)
      E(J 1)=CUX-EUX
      B(J 2)=DS-E(J 1)
      IF(B(J 2) GE 0 )GO TO 5700
      IA(J 4)=0
      IA(J 6)=0
      E(J 1)=0
      E(J 3)=0
      IVIZ=J-1
      IVIZ1=IA(IVIZ 6)
      IA(J 5)=IVIZ1
      IA(J 7)=IA(IVIZ1 7)
      DUX=CU -DS
      EUX=ANGALL 1 AUX DCC DU )
      C(ID)=ALDALA EUX DCC AUX)-RINT
      B(J 2)=ALFA-EUX
      AU =ANG(DCC RINT DUX)
      EUX=ANGALL(1 AU) DCC DUX)
      E(J 4)=EUY-EUX
      IF(B(J 2)+B(J 4) GE DT+ 001)B(J 4)=DT F ( 2)
5 00  GO TO 30
560   IA(J 4)=IA(IVIZ 4)
      IA(J 6)=IVIZ
      E(J 3)=EUX-CU
      B(J 1)=DS-E(J 3)
      IF(B(J 1) GE 0 )GO TO 5500
      IA(J,4)=0
      IA(J,6)=0
      B(J,1)=0
      B(J 3)=0
      IVIZ=J-1
      IA(J 5)=IVIZ+2
      DO 5456 IVARRE=1 700
      IF(IA(IVARRE 5) NE IVIZ+2 OR IA IVARRE 2) GE 1 )GO TO 5456
      IA(J 7)=IVARRE
      GO TO 5455
5456  CONTINUE
      IA(J 7)=IA J 5)+1
      DUX=CUX+DS
      EUX=ANGALL(2 AU  DCC DU
      D(ID)=ALDALA EUX DCC AU  -RINT
      B(J 2)=ALFA-EU
      AUX=ANG(DCC RINT CU )
      EUX=ANGALL 2 AU  DCC DU )
      E(J 4)=EU -EU
      GO TO 30
5455  EUX=CU +DS
```

```
      CALL ANGALT (2, AU( DCC, DU) )
      ... II  -FLIHLA( EU), DCC, AU) )-AINT
      ... J, 2 )=ALFA-EU)
      F( J, 4 )=DT-E( J, 2 )
 400  GO TO 20
 300  IA( J, 4 )=IVIZ
      IA( J, 6 )=IA( IVIZ, 6 )
      F( J, 3 )=DS
 20   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE ENTRA
      LOGICAL*1 CC(72)
      COMMON  FLOCO1 R(E) RCIN RINT DCC TETA NDH NDV DS DT ALFA
      CALL ERASE
      WRITE(6 1)
1     FORMAT ( 1X  ENTRE OS RAIOS DAS CIRCUNF  CONCENTRICAS   '
     *          1X  E TERNA   INTERNA E DA NAO CONCENT
     *            REE  RCIN RINT)  >   )
      CALL BELL
      READ 6 2)CC
2     FORMAT(72A1)
      P=0
      CALL REALFF(P CC 72 RCE)
      CALL REALFF(P CC 72 RCIN)
      CALL REALFF(P CC 72 RINT)
      WRITE(6 3)
3     FORMAT(  1X  ENTRE A DISTANCIA DO CENTRO DAS CIRC  CONC  AO  /
     *          1X 'CENTRO DA CIRC  NAO CONC  E O ANGULO EM GRAUS
     *           (DCC TETA) >  /)
      CALL BELL
      READ(6 2)CC
      P=0
      CALL REALFF(P CC 72 DCC)
      CALL REALFF(P CC 72 TETA)
      WRITE(6 4)
4     FORMAT ' 1X  ENTRE O NUMERO DE DIVISOES NA HORIZONTAL E ,/
     *          1X  ONUMERO DE DIVISOES NA VERTICAL (NDH NDV)  > ,/)
      CALL BELL
      READ(6 2)CC
      P=0
      CALL INTFF(P CC 72 NDH)
      CALL INTFF P CC 72 NDV)
      RETURN
      END
```

```
C     CHALST FTN
C
      DIMENSION IA(7) B 6)
      DATA DISTMP ERDISTMP/
      WRITE(5 3)
3     FORMAT(20X  GRID CONFIGURATION'    )
      WRITE(5 4)
4     FORMAT(7X  C1  2X  C2  2X  C3  2X  C4  2X  C5  2X
     *  C6 ,3X  C7  5X  C8  5X  C9  5X  C10  4X  C11  4X  C12  /)
      N=1
      GO TO 100
101   N=1
      WRITE(5,5)
5     FORMAT( 1  ///    ' / 7X  C1 ,2X  C2  2X  C3  2X  C4  2X 'C5',
     *  2X  C6  3X  C7  5X  C8  5X  C9  5X  C10  4X  C11' 4X,'C12 ,/)
100   READ(3 1 END=200) IA I) I=1 7) (B J) J=1 6)
  1   FORMAT 7I4 6F1..
```

```
      B(2)=180.*B(2)/3.1416
      B(4)=180.*B(4)/3.1416
      WRITE(5,2)(IA(I),I=1,2),(IA(I),I=4,7),(B(J),J=1,6)
2     FORMAT(5X,6I4,6F7.2)
      IF(N.EQ.45)GO TO 101
      N=N+1
      GO TO 100
200   CALL RESUME(DISTMF)
      CALL EXIT
      END
```

```
      FUNCTION CORDA(ALFA,DIST)
      COMMON [illegible] EIXO,U1,RCEX,RFIN,RINT,CCC,TETA,NCH,NOV
      EO=RCEX*SIN(ALFA)
      IF(EO.GE.RINT)GO TO 10
      CORDA=2*SQRT(RINT**2-EO**2)
      DIST=RCEX*COS(ALFA)-CORDA/2
      GO TO 100
10    CORDA=0
      DIST=RCEX
100   RETURN
      END
```

```
      FUNCTION ANG(X,Y,Z)
      S=(X+Y+Z)
      R=SQRT( [illegible] )
      R=R/(S-Z)
      ANG=ATAN(R)
      RETURN
      END
```

```
      FUNCTION ANGALL(ISOL,ANGULO,A1,A2)
      CK=(A2*(1.+(SIN(ANGULO/2.)/COS(ANGULO/2.))**2))/
     *    (A1+(SIN(ANGULO/2.)/COS(ANGULO/2.)))
      AUX1=(CK+SQRT(CK**2-4.))/2
      AUX2=(CK-SQRT(CK**2-4.))/2
      IF(ISOL.EQ.1)AUX=AMAX1(AUX1,AUX2)
      IF(ISOL.EQ.2)AUX=AMIN1(AUX1,AUX2)
      ANGALL=[illegible] 3.1416-ANG[illegible] *ATAN(AU[illegible]
      [illegible]
      [illegible]
```

```
      [illegible] FUNCTION [illegible] ANG2)
      [illegible] SQRT [illegible] IN([illegible] 3.1416-ANG1-ANG2)
      [illegible]
      [illegible]
```

```
      SUBROUTINE FCALCF(IF,C,LIM,F
      LOGICAL*1 C(LIM
      F=0
      FA=0 1
      I IF
      IS=0
10    I=I+1
      IF(I GT LIM)GO TO 20
      IF(C(I) EQ [illegible]) GO TO [illegible]
      IF(C(I) LT '0' OR C(I) GT [illegible]
 [illegible]   F=10 *F+(C(I)-'0')
      JS=IS+1
      I=I+1
      IF I GT LIM)GO TO [illegible]
      IF(C I) EQ '.')GO TO [illegible]
      IF(C(I) GE [illegible] AND [illegible]
      GO TO 20
[illegible]   I=I+1
      JS=JS+1
      IF(I GT LIM GO TO 20
      IF (C(I) LT [illegible] GT [illegible]) GO TO [illegible]
      F=F+FA*(C I [illegible] 0)
      FA=FA*0 1
      GO TO [illegible]
[illegible]   I[illegible]=I-JS-[illegible]
      IF(JC LE [illegible]
      IF(C(JL) EQ [illegible]
[illegible]   IF=I
      RETURN
      END
```

```
           [illegible] TTFOT
           [illegible] QTU$S ALUN$S [illegible]SE$%

[illegible]    MOV [illegible] R[illegible] R0
           MOV [illegible] R5) R1
           ADD 10 R1
           CLR [illegible]
SKIP       CMP R0 @6 R5)
           BGE DONE
           MOVB [illegible]1) R2
           CMPB R2 #60
           BLT NOTOCT
           CMPB R2 #70
           BLT OCT
NOTOCT     CMPB R0)+ R1)+
           B[illegible] SKIP
NEXT       CMPB R0)+ (R1)+
           CMP R0 @6 R5
           BGE DONE
           MOVB R1) R
           CMPB R2 #60
           BLT DONE
           CMPB R2 #6[illegible]
           BGT DONE
OCT        ASL R2
           ASL R2
           ASL R2
           BIC #177[illegible] 0 R
           BIS R[illegible] R2
           BR NEXT
DONE       MOV R0 @ R[illegible]
           MOV R2 [illegible]
           RTS PC

INTFF      MOV @2(R5) R0
           MOV (R5) R1
           CLR R3
           CLR R4
           ADD R0 R1
           CLRB NEGA
[illegible]  CMP R0 @6 R5)
           BGE F2
           CMPB (R1) #55
           BEQ MENOS
           CMPB R1 #60
           BLT [illegible]1
           CMPB R1) #71
           BLE NUMERO
[illegible]  CMPB (R0)+ R1 +
           BR F[illegible]
[illegible]  INCB NEGA
[illegible]  CMPB (R0)+ (R1)+
           CMP R0 @6 R5)
           BGE F[illegible]IT
           CMPB R1) #60
           [illegible] IT
           [illegible] R[illegible] # [illegible]
```

```
        BGT  EXIT
NUMERO  MOV  R4,R
        CMP  R2 #      ,
        BGE  NXT
        CLC
        ROL  R2
        ROL  R2
        ADD  R4,R2
        ROL  R2
        MOVB (R1) R3
        BIC  #177760,R3
        ADD  R3 R2
        BMI  NXT
        MOV  R2,R4
        BR NXT
EXIT    TSTB NEGA
        BEQ  E2
        NEG  R4
E2      MOV  R0,0(R5)
        MOV  R4,@10(R5)
        RTS  PC
NEGA     BYTE 0
         EVEN
;
BELL    ALUN$S #6,#"TT,#0
        QIO$S #IO ATT,#6
        QIO$S #IO WLE,#6,#2   ,  ,#MSG #1
        WTSE$S #2
        QIO$S #IO DET,#6
        RTS PC
MSG      ASCII <7
         EVEN

BELL E  ALUN$S #C #"TT,#0
        QIO$S #IO ATT,#6
        QIO$S #IO WLE,#6,#2,,,,<#MSG1,#6,>
        WTSE$S #2
        QIO$S #IO DET,#6
        RTS PC
MSG1     ASCII <35 <37><37><37><37><37>

         END
```

```
C         MONTA FTN
C         MOUNTS THE MATRIX OF COEFFICIENTS USING THE OUTPUT OF CHACHA
C
          DIMENSION IA(7) B(6) C 5) IC 5
          COMMON RL(700)
          DATA DISTMF/6HDISTMF/
          READ  2 2'2)RL
  232     FORMAT(4F12 5)
          DO 20 I=1 700
          RL I)=ALAM(I)
  20      CONTINUE
          READ(4 234)HC HH HO TC TH TO
  234     FORMAT(6F12 5)
  900     READ(2 81 END=1000)(IA(I) I=1 7) (B(J) J=1 6)
   81     FORMAT(7I4 6F12 5)
          DO 50 I=1 5
          C(I)=0
          IC(I)=0
   50     VB=0
          GO TO(1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18)IA(2)
    1     IC(1)=IA(7)
          IC(2)=IA(6)
          IC(3)=IA(3)
          IC(4)=IA 4)
          IC(5)=IA(5)
          DS=B(1)
          DT=B(2)
          C(1)=(RL(IA(2))+RL(IA(7)))/(2 *B(5)*DT**2)
          C(2)=(B(5)*2 -DS)*(RL(IA(6))+RL(IA(3)))/(4 *DS**2)
          AUX=((B(5)*2 +DS)*(RL(IA(3))+RL(IA(4)))+
     *         (B(5)*2 -DS)*(RL(IA(6))+RL(IA(?))))/(4 *DS**2)
          BUX=(RL(IA(5))+RL(IA(3))*2 +RL(IA(7)))/(2 *B(5)*DT**2)
          C(3)=-1 *(AUX+BUX)
          C(4)=((B(5)*2 +DS)*(RL(IA(3))+RL(IA(4))))/(4 *DS**2)
          C(5)=(RL(IA(5))+RL(IA(3))) (2 *B(5)*DT**2)
          VB=0
          GO TO 800
  2       CONTINUE
  6       CONTINUE
  7       IC(1)=IA(3)
          IC(2)=IA(4)
          DS=B(1)
          C(1)=-HH RL IA  )  DS
          C(2)=RL(IA(  )) DS
          VB=-HH*TH
          GO TO 600
  3       CONTINUE
  8       CONTINUE
  9       IC 1)=IA 6)
          IC   )=IA   )
```

```
      C( E(2)
      C( 1)=RL(IA(3)) DS
      C(  )=-HO RL(IA( )) DS
      C(  HO+IO
      GO TO 800
4     IC( 1)=IA( 6)
      IC( 2)=IA( 7)
      IC(3)=IA(4)
      IC( 4)=IA(5)
      DS=E( 1)
      DT=B( 2)
      C( 1)=(1 /DS**2)*(B(5)-DS/2 )*((RL(IA(6))+RL(IA(3)))/2 )
      C( 2)= 1 /DS**2)*(B(5)+DS/2 )*((RL(IA(4))+RL(IA(3)))/2 )
      C(4)=(RL(IA(3))+RL(IA(5)))/(E(5)*DT**2)
      AUX=((E(5)+DS/2 )*((RL(IA(4))+RL(IA( )))/2 )+
     1      (B 5)-DS/2 )*((RL(IA(6))+RL(IA 3)))/2 ))*(-1 /DS**2)
      BUX=C(4)
      C(3)=AUX-BUX
      VE=0
      GO TO 800
5     IC( 1)=IA( 7)
      IC(2)=IA(6)
      IC( 3)=IA(3)
      IC( 4)=IA(4)
      DS=E( 1)
      DT=E( 4)
      C( 1)= RL(IA(7))+RL(IA(3)))/(B(5)*DT**2)
      C( 2)= 1 /DS**2)*(B(5)-DS/2 )*((RL(IA(6))+RL(IA(3)))/2 )
      AUX ((B 5)+DS/2 )*((RL(IA(4))+RL(IA(3)))/2 )+
     1      (E(5)-DS/2 )*((RL(IA(6))+RL(IA(3)))/2 ))*(-1 /DS**2)
      BUX=C(1)
      C(3)=AUX-BUX
      C(4)=(1 /DS**2)* (  )+DS/2 )*((RL(IA(4))+RL(IA(3)))/2 )
      VE=0
      GO TO 800
10    CONTINUE
11    CONTINUE
12    CONTINUE
15    CONTINUE
16    IC(1)=IA(7)
      IC(2)=IA(6)
      IC(3)=IA(3)
      IC(4)=IA 4)
      IC 5)=IA 5)
      DS1=B(3)
      DS2=B(1)
      DT1=B(4)
      DT2=B(2)
      C(1)=(1 /(DT1*B(5)*(DT1+DT2)))*((RL IA(3))+RL(IA(7)))/2 )
      C(2)=(1 /((DS1+DS2)*DS1))*(B(5)-DS1 2 )*
     1          ((RL(IA(3))+RL(IA(6)))/2 )
      C(4)=(1 /((DS1+DS2)*DS2))*(B(5)+DS2/2 )*
     1          ((RL(IA(3))+RL(IA 4)))/2 )
      C(5)=(1 /(DT2*B(5)*(DT1+DT2)))*((RL(IA(3))+RL(IA(5)))/2 )
      C(3)=-C(4)-C 2)-C 5)-C(1)
      VB=0
      GO TO 800
1     IC(1)=IA(6)
      IC(2)=IA(3)
      IC 3)=IA 4)
      IC(4)=IA 5)
      DS=E(3)
      DT=E(2)
      DF=E(1)
      C( 1)= 1  ( DS+DF)*DS )* (RL(IA(6))+RL(IA(3)))/2 )*(B(5)-DS 2 )
      C(  )= 1    D +DF  DF )*( RL(IA 4))+RL(IA 3)))/2 )* B(5)+DF 2 )
```

```
         ( )=((RL(IA(3))+RL(IA(5)))/2 )/(B(5)*DT** )
         AU    (RL(IA(3))+RL IA(4)))/2 )*(B(5)+DP 2 )/DP)+
       *       (RL(IA 3))+RL(IA 6)))    )*(B(5)-DS 2 )/DS)
         C(   )
         C    ) -1 /(S+DP))*AU -EU
         VE  0
         GO TO 600
 14      IC 1)-IA 6)
         IC     IA
         IC     IA( )
         IC     IA
         C  -   1)
         C
         C
         C(1 - 1     (S+DP)*DP))*( RL(IA(3))+RL(IA(6)))/2 )*(B(5)-DF
         C       1       +DP)*DS))* (RL(IA(3))+RL(IA(4)))/2 )*(B(5)+DS/
         C          RL  IA  ))+RL  IA 5)))/2 )/(B(5)*DT**2)
         AU      RL  IA    ))+RL(IA(4)))/2  )*(B(5)+DS 2 )/DS)+
       *          RL  IA 3))+RL  IA(6)))/2  )*(B(5)-DP 2 )/DP)
         C(   C  )
         C        -1     DS+DP))*AU   EUX
         VE-0
         GO TO 600
 17      CONTINUE
   16    IF IA 4) EQ 0 AND  IA(6) EQ 0)GO TO 178
         IC(1) MIN0 IA(3) IA 4) IA(6))
         IC(    =MA 0(IA 3) IA(4) IA(6))
         DO   0 K   6
         IF K EQ 5)GO TO 70
         IF IA K) EQ IC(1) OR IA(K) EQ IC(3))GO to 70
         IC(2)=IA(K)
   70    CONTINUE
         DS1=B(3)
         DS2=B(1)
         AUX= DS2*RL(IA(3)))/(B(6)*(D 1+DS2))
         BUX=(DS1*RL(IA(3)))/(B(6)*(DS1+DS2))
         CUX=-1 *(RL(IA(3))/B(6)+HC)
         IF(IC(1) EQ IA(3))C(1)=CUX
         IF(IC(1) EQ IA(6))C(1)=AUX
         IF(IC(2) EQ IA(3))C(2)=CUX
         IF(IC(2) EQ IA(4))C(2)=BUX
         IF(IC(2) EQ IA(6))C(2)=AUX
         IF(IC(3) EQ IA(3))C(3)=CUX
         IF(IC(3) EQ IA(4))C(3)=BU
         GO TO 179
  178    IC(1)=MIN0(IA(3) IA(5) IA(7))
         IC(3)=MAX0(IA(3) IA(5) IA(7))
         DO 60 K=3 7 2
         IF(IA(K) EQ IC(1) OR IA(K) EQ IC(3))GO TO 60
         IC(2)=IA(K)
   60    CONTINUE
         DT1=B(4)
         DT2=B(2)
         AUX=(DT2*RL(IA(3)))/(B(6)*(DT1+DT2))
         BUX=(DT1*RL(IA(3)))/(B(6)*(DT1+DT2))
         CUX=-1 *(RL(IA(3))/B(6)+HC)
         IF(IC(1) EQ IA(3))C(1)=CUX
         IF(IC(1) EQ IA(7))C(1)=AUX
         IF(IC(2) EQ IA(3))C(2)=CUX
         IF(IC(2) EQ IA(5))C(2)=BUX
         IF(IC(2) EQ IA(7))C(2)=AUX
         IF(IC(3) EQ IA 3))C(3) CUX
         IF IC(3) EQ IA(5))C( )=BUX
  179    VE=-HC*TC
  600    ICONT=0
         DO 80 K=1 5
```

```
      IF(IC(I) [illegible]) GO TO [illegible]
      ICONT=ICONT+1
   60 CONTINUE
   90 WRITE(1 [illegible]
   92 FORMAT(F1[illegible]
      GO TO [illegible]
 1000 CALL [illegible]
      [illegible]
      END
```

```
      FUNCTION ALAM(I)
      COMMON [illegible]
C
C  FUNCAO      F(X) ----    A*X + B
C
      A=0.0[illegible]
      B=[illegible]
      ALAM=A*[illegible] +B
      RETURN
      END
```

```
C          FINA FTN
C          CALLS SPAMAT AND PRINTS THE SOLUTION VECTOR
C
           COMMON H(140,5) IC 140,5) INZ(140) B(140),X(140)
           DATA DISTMF EXLISTMP/
           I=1
  10       READ 1 1 END  A) A I J) J 1 5) B I) (IC(I K) K=1 5) INZ(I)
   1       FORMAT (F13 5 I I)
           I-I+1
           GO TO 10
  20       N=I-1
           DO 30 I=1 N
           X(I)=I
  30       CONTINUF
           CALL SPAMAT(N)
           WRITE(2 3)X
   3       FORMAT(4F12 5)
           WRITE(5 4)
   4       FORMAT(20X  TEMPERATURE DISTRIBUTION        /)
           DO 40 I=1,N 4
           K=I+3
           IF(K GT N)K=N
           WRITE(5 2)((L X(L)) L=I K)
   2       FORMAT(     9X 4( I(  I3  )=  F6 1 3X))
  40       CONTINUE
           CALL RESUME DISTMF )
           CALL EXIT
           END
```

```
C         SUBROUTINE
C         SOLVING USING SPARSE MATRIX TECHINIQUES A SYSTEM OF
C         LINEAR EQUATIONS BY GAUSS ELIMINATION METHOD
C
          SUBROUTINE SPAMAT(N)
          COMMON A(140 2  ) IC(140 25) INZ(140) B(140) X(140)
          TOL  E  0
          N M-1
          DO 10 I 1 N 1
          NZ-IN   I)
          AM A  I  I)
          K -1
          DO 15 K1=2 NZ
          IF ABS A(I K1))-ABS(AM))15 15 16
 16       AM=A I K1)
          K2=K1
 15       CONTINUE
          IF IC I K2) EQ I)GO TO 21
          CALL MUDCOL(I N K2)
 21       A1=A I K2)
          IF ABS A1)-TOL)101 101 22
 101      WRITE 5 102)I A1
 102      FORMAT   10X  NA LINHA   I7 5/  VALOR MAX =  E8 4)
 22       CALL TRANS(K2 I)
          B(I)=B I)/A1
          DO 23 J=1 NZ
 23       A I J)=A(I J)/A1
          DO 40 I1=I+1 N
          IF INZ I1) GT NZM)NZM=INZ I1)
          NZ=INZ(I1)
          DO 41 K=1 NZ
          IF(IC(I1 K) EQ I)GO TO 42
 41       CONTINUE
          GO TO 40
 42       A2=A I1 K)
          CALL TRANS(K I1)
          NZ =INZ I)
          NZ1=INZ(I1)
          DO 50 K1=1 NZ1
          DO 60 K=1 NZ
          IF(IC(I1 K1) EQ IC(I K))GO TO 51
 60       CONTINUE
          GO TO 50
 51       A(I1 K1)=A(I1 K1)-A2*A I K)
 50       CONTINUE
          NZ1=INZ(I1)
          DO 70 K=1 NZ
          DO 80 K1=1 NZ1
          IF(IC(I K) EQ 0)GO TO  0
          IF(IC(I1 K1) EQ IC(I K   GO TO  0
 80       CONTINUE
          DO 71 K1=1 NZ1
          IF(IC(I1 K1) EQ 0)GO TO 72
 71       CONTINUE
          INZ I1) INZ(I1)+1
          K1=NZ1+1
          NZ1=NZ1+1
```

```
72      A(I1,K1)=-A2*A(I,K)
        IC(I1,K1)=IC(I,K)
70      CONTINUE
        E(I1)=E(I1)-A2*E(I)
40      CONTINUE
10      CONTINUE
        E(N)=E(N)/A(N,1)
        DO 90 J=1,N-1
        IE=N-J
        IA=N
        NZ=INZ(IE)
        DO 90 M=1,J
        DO 91 K=1,NZ
        IF(IC(IE,K).EQ.IA)GO TO 92
91      CONTINUE
        GO TO 93
92      E(IE)=E(IE)-A(IE,K)*E(IA)
93      IA=IA-1
90      CONTINUE
        DO 94 I=1,N
        L=IFIX(X(I))
        X(I)=E(L)
94      CONTINUE
        RETURN
        END
```

```
      SUBROUTINE MUDCOL(I N K2)
      COMMON A(140 25) IC(140 25) INZ(140) B(140) X(140)
      K=K2
      IC1=IC(I K)
      NZ=INZ(I)
      DO 30 I1=1 NZ
      IF(IC(I I1) EQ I)GO TO 31
30    CONTINUE
      GO TO [illegible]
31    IC(I I1)=IC1
32    IC(I K)=I
      DO 11 K1=1 N
      IF(X(K1) EQ FLOAT(IC1))GO TO [illegible]
      GO TO 1[illegible]
1[illegible]    X(K1)=I
      GO TO 11
1[illegible]    IF(X(K1) EQ FLOAT(I))X(K1)=IC1
11    CONTINUE
      DO 10 I1=1 N
      IF(I1 EQ I)GO TO 10
      NZ=INZ(I1)
      DO 20 K=1 NZ
      IF(IC(I1 K) EQ I)GO TO 21
      IF(IC(I1 K) EQ IC1)IC(I1 K)=I
      GO TO 20
[illegible]1    IC(I1 K)=IC1
[illegible]0    CONTINUE
10    CONTINUE
      RETURN
      END



      SUBROUTINE TRANS(K I)
      COMMON A(140 25) IC(140 25) INZ(140) B(140) X(140)
      NZ=INZ(I)
      K1=K+1
      IF(K1 GT NZ)GO TO [illegible]
      DO 10 K2=K1 NZ
      IC(I K)=IC(I K2)
      A(I K)=A(I K2)
      K=K+1
10    CONTINUE
      IC(I K2)=0
      A(I K2)=0
      GO TO [illegible]0
20    IC(I K)=0
      A(I K)=0
[illegible]0    INZ(I)=INZ(I)[illegible]
      IF(INZ(I) [illegible]) INZ(I)=1
      RETURN
      END
```

```
C        DISTIIF FTN
C        MAIN FROGFIIF WICH CONTFOL   ALL THE OTHER PROGRAMS
C
         LOGICAL*1 C / /
         DIMENSION  D  00)  (125)
         DATA CHACHA E+CHACHA  CHALST/EFCHALST/ RONTA/SRMONTA,
     *       FINA 4AFINA/
         CALL ERASE
         WRITE 6 1)
 1       FORMAT 6    ***  SISTEMA FARA CALCULO DE DISTRIBUICAO
     *          DE TEMPERATURA  ***  / )
 92      WRITE 6 2)
 2       FORMAT(1X   >>>>  FASSO 1  >>>>  //
     *           1    - NESTE FASSO SERA MONTADA UMA TABELA
     *            QUE DEFINE CADA FONTO   / 7X  SEUS VIZINHOS
     *             E A  RESPECTIVAS DISTANCIAS  ESTA TABELA ESTARA
     *            (  EM DISCO SOB O NOME DE FOR002 DAT  /
     *            .    OS DADOS SERAO  A SEGUIR  ENTRADOS PELO TERMINAL
     *                $VOCE ESTA PRONTO PARA BATER OS DADOS ? (S/N) > )
         CALL BELL
         READ(6 3)C
 3       FORMAT(72A1)
         IF C(1) NE  12.)GO TO 92
         CALL REQUES(CHACHA)
 94      WRITE 6 4)
 4       FORMAT //  $QUER LISTAGEM DA TABELA ? (S/N) . )
         CALL BELL
         READ 6 3)C
         IF C(1) EQ  116)GO TO 51
         IF(C(1) NE  123)GO TO 94
         CALL REQUES(CHALST)
         CALL SUSFND
 51      WRITE(6 5)
 5       FORMAT(// 1X  ***  FASSO 1 COMPLETADO !!!   //)
 96      WRITE(6 6)
 6       FORMAT( $BATA  C  PARA CONTINUAR > )
         CALL BELL
         READ(6 3)C
         IF(C(1) NE  103)GO TO 96
         CALL ERASE
         WRITE(6 1)
         WRITE 6 7)
 ..      FORMAT(1X  >> >  PASSO 2  .>
     *           1X  - NESTE PASSO ESTA SENDO CALCULADA UMA SOLUCAO
     *             INICIAL PARA O  / 3X  SISTEMA  ESSA SOLUCAO SERA
     *             DO TIPO   /
     *           12X  X0(I)=(TH+TC)/2     PARA I=1 2     N   /
     *           3X  E ESTARA EM DISCO SOB O NOME DE FOR002 DAT  ///
     *           1X  ENTRE OS VALORES DE HC   HH   HD  E TC  TH  TD
     *              >  .)
         READ(6 3)C
         P=0
         CALL REALFF(P C /2 HC)
         CALL REALFF P C  2 HH
         CALL REALFF(P C 72 HD)
         CALL REALFF P C  2 TC)
         CALL REALFF P C    TH)
         CALL REALFF P C
         WRITE 6 1
 10      FORMAT (1
```

```
      CALL CLOSE(1)
      COLUNI  (MFLT)  2
      DO 10 I=1 ,NA
       X(I)=SOLUNI
10    CONTINUE
      WRITE 2 L  0
8     FORMAT 4F12 5)
      CALL CLOSE 2)
      WRITE 6 5
5     FORMAT    1     ***  FA   O    COMPILTADO ***   //)
99    WRITE  6
      CALL  ELL
      READ  6    L
      IF  L  E  NA   10  GO TO 9
      CALL  ERASE
      WRITE  6  1)
      WRITE  6  11
11    FORMAT  1        )    FA SO        >>)      /
     *        1    - NESTE PASSO SERA MONTADA A MATRIZ DOS
     *         COEFICIENTES E RESOLVIDO   / 3X  O SISTEMA LINEAR
     *         ESSA SOLUCAO SERA COMBINADA COM A SOLUCAO ANTERIOR
     *        / 3X  DO SEGUINTE MODO     / 15X  X0=A*X0+(1-A)X  / 3X
     *         A PARTIR DO NOVO X0 APLICA-SE A FUNCAO LAMBDA E
     *         NOVAMENTE MONTA-SE  / 3X  E RESOLVE-SE O SISTEMA   /
     *        3X  SERA EXECUTADO UM NUMERO ESPECIFICADO DE
     *         ITERACOES  OU ATE HAVER UMA  / 3X  CONVERGENCIA PARA
     *         UM NUMERO EPSILON ESPECIFICADO   ///
     *        1X  ENTRE A CONSTANTE  A   / 1X  O NUMERO DE
     *         ITERACOES DESEJADAS  /  *1  O VALOR DE EPSILON  ) )
      CALL CELL
      READ 6 3)C
      F=0
      CALL REALFF(P C 72 A)
      CALL INTFF(P C 72 ITER)
      CALL REALFF(P C 72 EPS)
      IT=0
100   IT=IT+1
      WRITE(6 12)IT
12    FORMAT(20   ----  EXECUTANDO ITERACAO   I2     -- -  /)
      CALL REQUES MONTA)
      CALL SUSPND
      CALL REQUES(FINA)
      CALL SUSPND
      READ(2 13)X
13    FORMAT(4F12 5)
      CALL CLOSE(2)
      IF(IT GE ITER)GO TO 150
      DO 30 J=1 125
      AUX=ABS((X0(J)-X(J)))
      IF(AUX GE EPS)GO TO 120
30    CONTINUE
      GO TO 150
120   DO 20 J=1 125
      X0(J)=A* X0 J  + 1  A)*X J)
20    CONTINUE
      WRITE 2 8)X0
      CALL CLOSE(2)
      GO TO 100
150   WRITE(6 14)
14    FORMAT  /  1X   ***  PASSO 3 COMPLETADO ***  )
      STOP
      END
```

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