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CODE FOR COMPUTING TEMPERATURE DISTRIBUTION IN GEOLOGIC FORMATION AROUND HIGH-LEVEL WASTE REPOSITORY, "HOT"

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When solidified high-level wastes from reprocessing are deposited in a geologic formation, the heat released from these wastes will result in temperature increase throughout the geologic formation. To estimate the temperature distribution in the peripheral geologic formation, the computer code, "HOT" has been developed. "HOT" is designed to compute the temperature distribution in complex formation as a problem of steady-state and/or transient heat transfer in three-dimensional Cartesian coordinates using the finite difference method.

The area of the calculation by this code is such a rectangular prism as 1000 m x 1000 m x 5000 m, which consists of several kinds of materials. The characteristics of HOT-code are as follows; It is possible that the near site calculation is carried out using the result of the far site calculation which has already been run as a boundary condition.

This code is written in FORTRAN-IV, and can be used by FACOM-M200 computer.

Keywords; High-Level Wastes, Geologic Formation, Computer Code, Complex Formation, Finite Difference Method, Boundary Condition, Numerical Method, Repository, Near Site, Far Site.

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高レベル廃棄物地層処分における地層内温度分布計算コード（HOT）

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高レベル放射性廃棄物を地層処分した時，この廃棄物の崩壊熱による発熱で周辺地層の温度上昇がおこる。この周辺地層の温度分布を評価するために，計算コード“HOT”を開発した。“HOT”は定常または非定常の熱伝達の問題として，複雑な地層内の温度分布を計算するために作られたもので，三次元有限差分法を採用している。

本コードによる計算の対象領域は，幾つかの岩石層から成る直方体（例えば，1000 m×1000 m×5000 m）であり，計算に先立って岩石層を定めることができる，HOTコードの特徴は，あらかじめ大きな領域で計算を行い，その結果を境界条件として，小さな領域で計算できることにある。

本コードはFORTRAN－Ⅳで書いており，使用計算機はFACOM－M 200である。

+ 安全解析部

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1. Introduction

Code for computing temperature distribution in geologic formation around high-level waste repository,"HOT" has been developed for the assessment of a geological barrier for a repository.

As the disposal of solidified high-level wastes, the geological isolation is one of the most promissive options. Therefore, in the world the research on geological isolation has been carried out under the conditions of each country. In Japan, since several years ago, the guide-line for the disposal of high-level waste products has been shown[1].

Several trials were reported on the estimation of temperature distribution as assessment of a geological barrier[2][3][4][5], however, it was difficult to evaluate the thermal impact from the wastes both to the near site and far site with complex formation. HOT-code has been developed to estimate the temperature distribution of near site and far site with complex formation. In this report, this specific computer code "HOT" is described.

2. Equations for HOT-code

HOT-code has been delived by the following procedures.

2.1 Fundamental equation

Heat flow in an isotropic solid is governed by the following differential equation on heat flow expressed in rectangular Cartesian coordinates[12] :

$$\rho C_p\frac{\partial T}{\partial t} = \frac{\partial}{\partial x}(k\frac{\partial T}{\partial x})+\frac{\partial}{\partial y}(k\frac{\partial T}{\partial y})+\frac{\partial}{\partial z}(k\frac{\partial T}{\partial z})+ q \qquad \ldots(2\text{-}1)$$

$$\text{in } \Omega \quad (\Omega:[a_x,b_x]\times[a_y,b_y]\times[a_z,b_z])$$

where symbols are as follows: T; the temperature, t; the time, ρ; the density, C_p; the specific heat at constant pressure, k; the thermal conductivity, q; the heat generation per unit time and unit volume, a,b; the coordinates of initial and final points, x,y,z; the distances along the axes of the coordinate system.

Boundary conditions

a) Prescribed surface temperature

The temperature on the boundary surface is given as a function of time, or position, or both. That is,

$$T = T_b(x,y,z,t) \qquad \text{on } \partial\Omega \qquad \cdots (2\text{-}2)$$

Where $\partial\Omega$ means the boundary surface of Ω.

b) No flux across the boundary surface

Adiabatic condition is given on the boundary surface. That is,

$$\frac{\partial T}{\partial n} = 0 \qquad \text{on } \partial\Omega \qquad \cdots (2\text{-}3)$$

where $\partial/\partial n$ represents the partial derivative of T with respect to the direction normal to the boundary surface.

Initial conditions

a) The temperature throughout the region is prescribed as a function of position, that is,

$$T = T_i(x,y,z) \qquad \dots (2\text{-}4)$$

where the subscript i means initial values.

b) The steady solution is used as the initial temperature.

2.2 Numerical method

The numerical method for the solution of the problem are derived from eq's (2-1) - (2-4) on the following assumption.

Assumption

a) The finit difference method is used in three dimensional rectangular Cartesian coordinates.

b) The thermal properties of solid, ρ, C_p and k, vary with temperature.

c) The heat generation, q, varies with time.

d) The surface temperature given as a boundary condition varies with time and position.

(1) Steady state calculation

Assuming point "N" in relative to M adjacent points (N1 - N6 in Fig.1) from the heat balance, the rate of thermal conduction from point "N" must be equal to the rate of heat generation at the same point in steady-state heat conduction. That is,

$$\sum_{i=1}^{M} {}_N K_i (T_i - T_N) + Q_N = 0 \qquad \text{(for all N)} \qquad \dots (2\text{-}5)$$

where T_i is the temperature at point "i", ${}_N K_i$ is the quantity of heat between point "i" and point "N",

$$_{N}K_{i} = \frac{kA_c}{\Delta x}$$

k is the thermal conductivity between N and i, A_c is the heat conduction area, Δx is the distance between N and i, Q_N is the heat generation at point "N",

$$Q_N = q_N \cdot V_N$$

q_N is the heat generation rates per unit volume, V_N is the volume of node N, T_N(for all N) satisfying eq.(2-5) can be obtained by the repetitive method, that is, the following two equations must be satisfied in regard to T_N.

$$\sum_{i=1}^{M} {}_{N}K_{i}(T_i - T_N^n) + Q_N = \varepsilon \qquad \text{...(2-6)}$$

$$(\varepsilon \leqq 10^{-5})$$

$$\sum_{i=1}^{M} {}_{N}K_{i}(T_N^{n+1} - T_N^n) = \varepsilon \qquad \text{...(2-7)}$$

Where T_N^n corresponds to the temperature at point "N" for the n-th iteration. From eq's(2-6), (2-7), eq.(2-8) is obtained.

$$(T_N^{n+1} - T_N^n)\sum_{i=1}^{M} {}_{N}K_{i} = \sum_{i=1}^{M} {}_{N}K_{i}(T_i - T_N^n) + Q_N \qquad \text{...(2-8)}$$

The over-relaxation factor,β is introduced to accelerating the convergence, eq.(2-8) becomes the following equation.

$$T_N^{n+1} = T_N^n(1-\beta) + \frac{\beta(\sum_{i=1}^{M} {}_{N}K_{i}T_i + Q_N)}{\sum_{i=1}^{M} {}_{N}K_{i}} \qquad \text{...(2-9)}$$

$$(1 \leqq \beta < 2)$$

In eq.(2-9) β must be used the optimum value at each point, however, it is imposible to obtain β analytically. Therefore we have empiricaly used 1.9 as β-value[6]. In eq.(2-9), $T_i = T_i^n$ if i>N and $T_i = T_i^{n+1}$ if i<N. We reiterate eq.(2-9) until the following equation (2-10) is satisfied.

$$\frac{T_N^n - T_N^{n+1}}{T_N^{n+1}} \leqq \varepsilon \qquad \ldots(2\text{-}10)$$

Where ε is 10^{-5}.

If the thermal conductivity is dependent on temperature, the appropriate value for the specified temperature is determined by linear interpolation between two points, N and i.

(2) Transient calculation

In the same manner of steady state calculation, the following equation is formed for an arbitrary point "N".

$$\sum_{i=1}^{M} {}_NK_i [T_i(t) - T_N(t)] + Q_N(t) = C_N \frac{\Delta T_N}{\Delta t} \qquad \ldots(2\text{-}11)$$

Where $Q_N(t)$ is the heat generation at point "N", C_N is the heat capacity at point "N" ($C_N = \rho C_p V_N$), Δt is the time step and $\Delta T_N = T_N(t+\Delta t) - T_N(t)$.

Then from eq.(2-11) and the above equation for ΔT_N, eq.(2-12) is obtained.

$$T_N(t+\Delta t) = T_N(t) + \frac{\Delta t}{C_N}[\sum_{i=1}^{M} {}_NK_i \{T_i(t) - T_N(t)\} + Q_N(t)] \qquad \ldots(2\text{-}12)$$

Where Δt has to satisfy the following equation (2-13) for maintaining stability. That is,

$$\Delta t \leqq \frac{C_N}{\sum_{i=1}^{M} {}_NK_i} \qquad \ldots(2\text{-}13)$$

Finally the problem of transient calculation is solved by use of eq's (2-12) and (2-13).

But this method require a large amount of computer time according to the calculation. Hence, for transient calculations, a modified explicit method[6][7] is incorporated into the program as an option which allows the use of an arbitrary time increment while maintaining stability. Its solution is stated briefly. Now eq.(2-12) is rewritten as follows:

$$T_N(t+\Delta t) = T_N(t) + \frac{1}{1+Z_N}\left[\frac{\Delta t}{C_N}\left\{\sum_{i=1}^{M} {}_N K_i (T_i(t) - T_N(t)) + Q(t)\right\} + Z_N\{T_N(t) - T_N(t-\Delta t)\}\right] \quad \ldots(2\text{-}14)$$

where Z_N = a factor for point N which will insure a stable solution for any time step Δt,

$T_N(t)$ = current temperature at point N,

$T_N(t+\Delta t)$ = temperature at point N one time step later,

$T_N(t-\Delta t)$ = temperature at point N one time step earlier.

If from eq.(2-13), $(\Delta t_{max.})_N$ is the maximum time step allowed at point N for a stable solution in the regular explicit method, then the factor Z_N in eq.(2-14) is given as eq.(2-15) and eq.(2-16) for each condition.

$$Z_N = 0, \quad \text{if } \frac{\Delta t}{(\Delta t_{max.})_N} < 1 \quad \ldots(2\text{-}15)$$

$$Z_N = \frac{1}{2}\left[\frac{\Delta t}{(\Delta t_{max.})_N} - 1\right], \quad \text{if } \frac{\Delta t}{(\Delta t_{max.})_N} > 1 \quad \ldots(2\text{-}16)$$

(3) Interpolation method of initial conditions and the boundary conditions

When a near site calculation is done, the temperature distribution which has been obtained by far site calculation is used as the boundary conditions. These boundary temperatures are decided by using two dimensional interpolation in x-y plane and one dimensional interpolation in z direction. This is illustrated in Fig.2. The origin is taken at the center of rectangular prism and the rectangular coordinate axis (ξ,η,ζ) is considered. Assuming the temperature and position of each vertex of the rectangular prism as shown in Fig.2, the temperature, T at arbitrary point (ξ,η,ζ) in the rectangular prism is calculated as follows.

Now let the temperatures at the feet of the perpendiculars from T to the plane $T_AT_BT_CT_D$ and the plane $T_ET_FT_GT_H$ be T_1, T_2, respectively. Then T_1 and T_2 are

$$T_1=\frac{1}{4}[(1-\xi)(1-\eta)T_A+(1+\xi)(1-\eta)T_B+(1+\xi)(1+\eta)T_C+(1-\xi)(1+\eta)T_D] \quad \ldots(2\text{-}17)$$

and

$$T_2=\frac{1}{4}[(1-\xi)(1-\eta)T_E+(1+\xi)(1-\eta)T_F+(1+\xi)(1+\eta)T_G+(1-\xi)(1+\eta)T_H \quad \ldots(2\text{-}18)$$

Hence, finally we get

$$\begin{aligned}T &=\frac{1}{2}[(1-\zeta)T_1+(1+\zeta)T_2]\\ &=\frac{1}{8}[(1-\zeta)\{(1-\xi)(1-\eta)T_A+(1+\xi)(1-\eta)T_B+(1+\xi)(1+\eta)T_C\\ &\quad+(1-\xi)(1+\eta)T_D\}+(1+\zeta)\{(1-\xi)(1-\eta)T_E+(1+\xi)(1-\eta)T_F\\ &\quad+(1+\xi)(1+\eta)T_G+(1-\xi)(1+\eta)T_H\}] \quad \ldots(2\text{-}19)\end{aligned}$$

3. Computer code

3.1 Formation of HOT-code

The flow sheet of HOT-code is shown in Fig.3. This code is formed from a main program (FTMAIN) as the control code for HOT and twentynine subroutines. The formation of this code and the functions of these subroutines are shown in Fig.4.

HOT-code has been stored on a disk at the Computing Center at JAERI and is now avilable to users by FACOM-M200 computer in JAERI. A name of the file is as follows.

```
//EXEC LMGO,LM='J2993.HOTEA'
```

3.2 Drawing up isotherms and time dependent graphs

GPCP-I[8], which is a provided program for drawing up a contour line, is used for drawing up isotherms at a designated plane and time.

VOLTES-5, which is a program for expressing some time dependent values in a graph, is used for drawing up time dependent graphs at the designated points. This program has been stored on a disk at the Computing Center at JAERI and is now available to users. The file name of this program is as follows.

```
//EXEC LMGO,LM='J2993.VOLTES'
```

3.3 Files for HOT-code

In this code, five files, F_{01}, F_{02}, F_{10}, F_{20}, F_{30} are used as follows.

F_{01} : File for output of the fimal computing temperatures.

F_{02} : File for input of the initial temperatures.

F_{20} : File for drawing the isotherms.

F_{30} : File for drawing the time dependent graphs.

F_{10} : File for drawing the time dependent graphs. (This is a scrach file.)

Fig.5 illustrates the relation of these files used in HOT-code.

4. Input and output

4.1 Input formats

The summary of input data of this code is described in this section. First the geometrical appearance of the formation is represented with a lattice of points. The physical properties of materials are input as functions of time or temperature. Initial and boundary conditions are decided. Finaly, the output option of the final temperature distribution is set. Summary and formats of these input data are shown in Table 1-1 - Table 1-6.

4.2 Output formats

First, HOT-code prints out the input data, that is, the geometrical appearance of formation, the kinds and the physical properties of materials, and so on. Then, the final temperature distribution is printed for steady-state condition, and the temperatures are presented as a function of time for transient calculations. If the plotter option is desired, the isotherms or the graphs of time dependent temperature can be drawn up.

5. Sample calculations

As sample calculations using HOT-code, the procedure and the results of the computing temperature distributions in geologic formation around high-level waste repository are described in this chapter. Sample calculation 1 is a far site calculation in a large area and sample calculation 2 is a near site calculation in a small area contained within the area of sample calculation 1. In these sample calculations, the arrangement of vitrified products ($30\ cm^{\phi}$ x $300\ cm^{L}$) shown in Fig.6 is used. Assuming 4 canisters are put into one pit, total of canisters become 148.

[Sample calculation 1]

The transient temperature distribution is calculated in an area of rectangular prism, 900 m x 900 m x 1050 m as in Fig.7. The conditions of the calculation are as follows:

Region I consists of material No.1 (surface soil); region II consists of material No.2 (shale); and regions III to VIII consist of material No.3 (granite). The physical properties of these materials are given in Table 2 [2][3][9][10].

There is a uniform heat generation in region V as in the shadowed portion at the rate of $1.0963 \times 10^{-5} \times q(t)\ W/m^3$ ($\frac{148}{4} \times \frac{1}{150^3} \times q(t)$), where q(t) is time dependent heat generation per one vitrified product given in Table 3 [2][3][11]. The initial temperature as in Fig.7 is determined considering geothermal effect 3 °C each 100 meters. The boundary conditions on each of the faces are shown in Fig.7, and they are numbered in square frames. Boundary condition A is no heat flux across the boundary surface. Boundary condition B is a temperature on the boundary surface given as a function of position by input data.

Initial and final time of this calculation are 0 and 970,000 hours ($\approx$110 years), respectively. And the time increment is 1,000 hours.

Output of the transient temperature is required at three points((1,1,5),(1,1,6),(1,2,5)) and four planes (X-Y,Z=1, X-Z, Y=2, Y-Z,X=3, X-Y,Z=4).

The input data for this calculation are given in Table 4. Table 5-1 to 5-4 give a part of the printed output for this calculation. Table 6 gives the control cards used by FACOM-M 200 computer, in JAERI.

[Sample calculation 2]

The transient temperature distribution is calculated in an area as in Fig.8. The condition of the calculation are as follows:

Region all over consists of material No.1 (granite). The physical properties of the granite are given in Table 2 [2][3][9][10], which is used in sample calculation 1.
There is the uniform heat generation in each of regions II to VII. If the change of the heat generation at various time per one vitrified product is represented by q(t), the heat generations

in each of regions, $Q_{\text{region No.}}$, become

$$Q_{II,IV} = 1.0 \times 4 \times q(t) \times \frac{1}{20 \times 12 \times 10\sqrt{3}} = 9.6225 \times 10^{-4} \times q(t)$$

$$Q_{III} = 0.5 \times 4 \times q(t) \times \frac{1}{20 \times 12 \times 10\sqrt{3}} = 4.8113 \times 10^{-4} \times q(t)$$

$$Q_{V} = 0.75 \times 4 \times q(t) \times \frac{1}{20 \times 12 \times 10\sqrt{3}} = 7.2169 \times 10^{-4} \times q(t)$$

$$Q_{VI,VII} = 0.25 \times 4 \times q(t) \times \frac{1}{20 \times 12 \times 10\sqrt{3}} = 2.4056 \times 10^{-4} \times q(t)$$

where q(t) is given in Table 3 [2][3][11].

As the initial temperatures for this calculation, the results of sample calculation 1 are used. The boundary conditions on all of the faces are shown in Fig.8, and they are numbered in square frames. Boundary condition No.1 is no heat flux across the boundary surface. Boundary condition No.2 is a temperature in the boundary surface used the result of sample calculation 1.

Initial and final time in this case are 0 and 870,000 hours (100 years), respectively. And the time increment is 876 hours.

Output of the transient temperature is required at eight points((1,1,3),(1,1,7),(1,1,6),(5,1,5),(1,5,6),(5,5,6),(9,9,6),(4,4,6)) and seven planes (X-Y,Z=6, X-Y,Z=8, X-Z,Y=1, X-Z,Y=3, X-Z,Y=7, Y-Z,X=1, Y-Z,X=3).

The input data for this calculation are given in Table 7. Table 8-1 to 8-7 give a part of the printed output for this calculation. Table 9 gives the control cards for computing this calculation by FACOM-M200 computer, in JAERI.

The isotherms and the graphs of relation between temperature and time, which are drawn up from the results of this calculation by using GPCP-I program and VOLTES-5 program, are shown in Fig.9 - Fig.14 and Fig.15 - Fig.22, respectively. Table 10 and Table 11 give the control cards for using these calculations.

6. Concluding remarks

"HOT" is a computer code for the heat transfer analyses of the high-level radioactive waste repository. To estimate the temperature distribution of near site and far site with complex formation, HOT-code has been developed. The steady-state and/or transient calculation can be calculated by the code.

HOT uses the finite difference method in three dimensional Cartesian coordinates. The area of the calculation by this code is such a rectangular prism as 1000 m x 1000 m x 5000 m, which consists of several kinds of materials.

The characteristics of HOT-code are as follows; It is possible that the near site calculation is carried out using the result of the far site calculation which has already been run as a boundary condition.

This code is written in FORTRAN-IV, and can be used by FACOM-M200 computer, in JAERI.

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Table 1-1 Summary and format of input

Name of card	Name of variable	Description
TITLE		FORMAT:(18A4)
	JOBDES	Job description
IP1		FORMAT:(8I9)
	IGT	≧2 Total number of lattice points in X direction.
	JGT	≧2 Total number of lattice points in Y direction.
	KGT	≧2 Total number of lattice points in Z direction.
	MATLT	≧1 Total number of materials.
	NGENFN	≧0 Total number of heat generation functions.
	NTDFN	≧0 Total number of time dependent functions.
	NBDTPT	≧0 Total number of boundaries.
	NSUBN	≧0 Number of sub-node blocks.
IP2		FORMAT:(4I9)
	JIN	Option for input of initial temperature. Input unit number for restart
	JOUT	Option for output of final temperature distribution. Output unit number for restart.
	JPLT1	Option for output of plotter. Output unit number for time dependent temperature at arbitrary point.
	JPLT2	Option for output of plotter. Output unit number for isotherms on arbitrary plane.
IP3		FORMAT:(6I9)
	NTYPE	Type of calculations. 1. S-S(Steady state) only. -1. Trans. only. 2. S-S, Trans.(Transient) -2. Trans.,S-S. 3. S-S, Trans.,S-S. -3. Trans.,S-S,Trans. ⋮ ⋮ n. S-S, Trans., ... -n. Trans.,S-S, ···
	NOITX	Maximum number of steady state iterations.
	NPRNT1	Total number of points printed out.
	NDATA1	Number of time steps between printed outputs for point.

Table 1-2 (Con't)

Name of card	Name of variable	Description
	NPRNT2	Total number of plane printed out.
	NDATA2	Number of time steps between printed outputs for plane.
IP4		FORMAT:(3F9.0, I9, 2F9.0)
	EPI	Steady state convergence criterion.
	BETA	Steady state over-relaxation factor $1.0 \leqq \beta < 2.0$. If blank or zero, BETA is 1.9 .
	DELTAT	Time increment for transient problem.
	KTMFCT	Option for modified explicit method. If KTMFCT is blank or < 2, this method is not used. Leave blank, if steady state only.
	TIM	Initial time for transient problem.
	TIME	Final time for transient problem. (TIM ≦ TIME)
SYS		FORMAT:(I9, 6F9.0)
	NCONFG	≧1 Number of node characteristics(number of regions).
	XXLB	Coordinates of X-left boundary.
	XXRB	Coordinates of X-right boundary.(0.≦XXLB<XXRB)
	YYLB	Coordinates of Y-left boundary.
	YYRB	Coordinates of Y-right boundary.(0.≦YYLB<YYRB)
	ZZBM	Coordinates of Z-bottom boundary.
	ZZTP	Coordinates of Z-top boundary.(0.≦ZZBM<ZZTP)
NC1		FORMAT:(8I9)
	IILB	Lattice point number on X-left boundary of node characteristic.
	IIRB	Lattice point number on X-right boundary of node characteristic.(0<IILB<IIRB)
	JJLB	Lattice point number on Y-left boundary of node characteristic.
	JJRB	Lattice point number on Y-right boundary of node characteristic.(0<JJLB<JJRB)
	KKBM	Lattice point number on Z-bottom boundary of node characteristic.
	KKTP	Lattice point number on Z-top boundary of node characteristic.(0<KKBM<KKTP)

Table 1-3 (Con't)

Name of card	Name of variable	Description
	MATEL	$\geq$1 Material number.
	NHTGEN	Heat generation function number. If NHTGEN is zero or blank, there is no heat generation. If NHTGEN is negative, heat generation is calculated from time dependent function(table).
NC2		FORMAT:(6I9, F9.0)
	ILBCD	Boundary number of smaller coordinates of X.
	IRBCD	Boundary number of larger coordinates of X.
	JLBCD	Boundary number of smaller coordinates of Y.
	JRBCD	Boundary number of larger coordinates of Y.
	KBBCD	Boundary number of smaller coordinates of Z.
	KTBCD	Boundary number of larger coordinates of Z.
	TINI	Initial temperature of this node.
		Input NCONFG sets of NC1 card and NC2 card.
SN1		FORMAT:(6I9)
	ISLB	Lattice point number on X-left boundary of sub-node.
	ISRB	Lattice point number on X-right boundary of sub-node. (0<ISLB<ISRB)
	JSLB	Lattice point number on Y-left boundary of sub-node.
	JSRB	Lattice point number on Y-right boundary of sub-node. (0<JSLB<JSRB)
	KSBM	Lattice point number on Z-bottom boundary of sub-node.
	KSTP	Lattice point number on Z-top boundary of sub-node. (0<KSBM<KSTP)
		If NSUBN is zero or blank, omit SN1 card.
MAT		FORMAT:(I9,b,A8, 3F9.0, 3I9)
	MAT	$\leq$100 Material number.
	MATNUM	Material name.
	CONDTY	Conductivity if constant; if temperature dependent, leave blank.

Table 1-4 (Con't)

Name of card	Name of variable	Description
	DENSTY	Density if constant; if temperature dependent or steady state only, leave blank.
	SPHEAT	Specific heat if constant; if temperature dependent or steady state only, leave blank.
	NCON	≦25 Number of pairs in CON cards. Leave blank and omit CON cards if constant.
	NDEN	≦25 Number of pairs in DEN cards. Leave blank and omit DEN cards if constant or steady state.
	NSHT	≦25 Number of pairs in SPE cards. Leave blank and omit SPE cards if constant or steady state.
CON		FORMAT:(nF9.0) n=2×NCON
	T(1)	Temperature.
	V(1)	Conductivity.
		If CONDTY is zero or blank, input NCON pairs.
		If NCON is zero or blank, omit this card.
DEN		FORMAT:(nF9.0) n=2×NDEN
	T(1)	Temperature.
	V(1)	Density.
		If DENSTY is zero or blank, input NDEN pairs.
		If steady state only, omit this card.
SPE		FORMAT:(nF9.0) n=2×NSHT
	T(1)	Temperature.
	V(1)	Specific heat.
		If SPHEAT is zero or blank, input NSHT pairs.
		If steady state only, omit this card.
GEN		FORMAT:(I9, 5F9.0)
	NGN	Heat generation function number.
	GCOEF1	Coefficient value:A_1 The heat generation will be $Q(t)=A_1+A_2t+A_3t^2+A_4\exp(A_5t)$, where Q(t) is time dependent function.
	GCOEF2	Coefficient value: A_2
	GCOEF3	Coefficient value: A_3
	GCOEF4	Coefficient value: A_4

Table 1-5 (Con't)

Name of card	Name of variable	Description
	GCOEF4	Coefficient value: A_5 Omit GEN cards, if NGENFN is zero or blank.
BOUND		FORMAT:(2I9, F9.0, I9)
	NBDTP	Boundary number.
	NBYTYP	Boundary type. 0 or blank: Adiabatic condition. 1: Specification of boundary temperature.(BYTEMP is a boundary temperature.) 2: Specification of boundary temperature.(This temperature is input from JIN unit.)
	BYTEMP	Boundary temperature. If NBYTYP=1 and boundary temperature is constant, input the value.
	NBYTFN	Time dependent function number of boundary temperature. If NBYTYP=1 and boundary temperature is dependent on time, input the function number.
TIMDF		FORMAT:(2I9, 6F9.0)
	NTM	Time dependent function number.($\leqq$ NTDFN)
	NTIMFP	$\leqq$50 Number of pairs in table.
	TIMFN(1)	Time.
	TIMFN(2)	Time dependent value. If NTDFN is zero or blank, omit TIMDF card. If TIMFN(1) is negative, TIMFN(2) is multiplied the following time dependent values.
POINT		FORMAT:(n(b, I2, b, I2, b, I2, b)) n=NPRNT1
	IO1(1)	Lattice point number in X direction.
	JO1(1)	Lattice point number in Y direction.
	KO1(1)	Lattice point number in Z direction. This card specifies points printed out. If NPRNT1 $\leqq$ 0, omit POINT card.
PLANE		FORMAT:(n(b, I3, b, I4, b)) n=NPRNT2

Table 1-6 (Con't)

Name of card	Name of variable	Description
	IPLANE(1)	Specification of plane IPLANE Plane 1 X - Y 2 X - Z 3 Y - Z
	IOUT2(1)	Lattice point number in residual direction. This card specifies planes printed out. If NPRNT2 $\leqq 0$, omit PLANE card.

Table 2 Thermal properties of the geologic formation

Material	Density (kg/m3)	Thermal conductivity (W/m°C)	Specific heat (Wh/kg°C)
Surface soil	2.4×10^3	2.75	0.232458
Shale	2.4×10^3	1.65	0.232458
Granite	2.62×10^3	2.22	0.22442

Table 3 Transient thermal power per one vitrified product

Time (years)*	Thermal power (W/product)
0	1875.0
3	1730.0
5	1653.2
7	1580.0
10	1463.2
15	1300.0
20	1146.6
24	1005.0
28	950.0
30	900.0
34	830.0
40	715.0
45	632.7
50	565.0
60	440.0
70	352.7
90	220.0
110	138.0
130	91.0
150	56.0
170	50.1
200	32.5

*) Time is counted from the disposal time that is 30 years after the reprocessing.

Table 4 Input data of sample calculation 1

```
          **********  I N P U T   D A T A   D U M P  **********

1.......10........20........30........40........50........60........70........80
HOT3 CODE SAMPLE DATA-2 (TRANSIENT CALCULATION)    530327
         7         7         8         3                   1         8         1
                   1         1         1
        -1                   3        10         4        10
                      1000.              0.         970000.
         8 0.        900.       0.        900.     0.         1050.
         1         7         1         7         7         8         1
                   2                   2                   1 20.
         1         7         1         7         6         7         2
                   3                   3                      24.5
         1         7         1         7         5         6         3
                   4                   4                     29.
         1         7         1         7         4         5         3
                   5                   5                      33.5
         1         2         1         2         4         5         3        -1
                                                              33.5
         1         7         1         7         3         4         3
                   6                   6                      38.
         1         7         1         7         2         3         3
                   7                   7                      42.5
         1         7         1         7         1         2         3
                   8                   8         8            47.
         1         2         1         2         4         5
         1 SOIL      2.75        2.4 +3 .232458
         2 SHALE     1.65        2.4 +3 .232458
         3 GRANITE   2.22        2.62+3 .22442
         1         1 20.
         2         1 24.5
         3         1 29.
         4         1 33.5
         5         1 38.
         6         1 42.5
         7         1 47.
         8         1 51.5
         1        23 -1.      1.0963-5  0.        1875.     26280.    1730.
43800.    1653.2    61320.    1580.     87600.    1463.2    131400.   1300.
175200.   1146.6    210240.   1005.     245280.   950.      262800.   900.
297840.    830.     350400.   715.      394200.   632.7     438000.   565.
525600.    440.     613200.   352.7     788400.   220.      963600.   138.
1138800.  91.       1314000.  56.       1489200.  50.12     1752000.  32.5
  1  1   5   1  1  6   1  2  5
    1    1    2    2    3    3    1    4
```

Table 5-1 Output data of sample calculation 1

X – Y PLANE LATTICE POINT TEMPERATURE Z = 1
ELAPSED TIME = 0.10000D+05 TIME STEPS = 10

	X = 1	X = 2	X = 3	X = 4	X = 5	X = 6	X = 7
Y = 7	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02
Y = 6	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02
Y = 5	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02
Y = 4	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02
Y = 3	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02
Y = 2	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02
Y = 1	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02

Table 5-2 (Con't)

X – Z PLANE LATTICE POINT TEMPERATURE Y = 2
ELAPSED TIME = 0.10000D+05 TIME STEPS = 10

	X = 1	X = 2	X = 3	X = 4	X = 5	X = 6	X = 7
Z = 8	0.20000D+02	0.20000D+02	0.20000D+02	0.20000D+02	0.20000D+02	0.20000D+02	0.20000D+02
Z = 7	0.24496D+02	0.24496D+02	0.24496D+02	0.24496D+02	0.24496D+02	0.24496D+02	0.24500D+02
Z = 6	0.29002D+02	0.29002D+02	0.29002D+02	0.29002D+02	0.29002D+02	0.29002D+02	0.29000D+02
Z = 5	0.33582D+02	0.33541D+02	0.33500D+02	0.33500D+02	0.33500D+02	0.33500D+02	0.33500D+02
Z = 4	0.38082D+02	0.38041D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02
Z = 3	0.42500D+02	0.42500D+02	0.42500D+02	0.42500D+02	0.42500D+02	0.42500D+02	0.42500D+02
Z = 2	0.46999D+02	0.46999D+02	0.46999D+02	0.46999D+02	0.46999D+02	0.46999D+02	0.47000D+02
Z = 1	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02

Table 5-3 (Con't)

Y - Z PLANE LATTICE POINT TEMPERATURE X = 3
ELAPSED TIME = 0.10000D+05 TIME STEPS = 10

	Y = 1	Y = 2	Y = 3	Y = 4	Y = 5	Y = 6	Y = 7
Z = 8	0.20000D+02	0.20000D+02	0.20000D+02	0.20000D+02	0.20000D+02	0.20000D+02	0.20000D+02
Z = 7	0.24496D+02	0.24496D+02	0.24496D+02	0.24496D+02	0.24496D+02	0.24496D+02	0.24500D+02
Z = 6	0.29002D+02	0.29002D+02	0.29002D+02	0.29002D+02	0.29002D+02	0.29002D+02	0.29000D+02
Z = 5	0.33500D+02	0.33500D+02	0.33500D+02	0.33500D+02	0.33500D+02	0.33500D+02	0.33500D+02
Z = 4	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02
Z = 3	0.42500D+02	0.42500D+02	0.42500D+02	0.42500D+02	0.42500D+02	0.42500D+02	0.42500D+02
Z = 2	0.46999D+02	0.46999D+02	0.46999D+02	0.46999D+02	0.46999D+02	0.46999D+02	0.47000D+02
Z = 1	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02	0.51500D+02

Table 5-4 (Con't)

X - Y PLANE LATTICE POINT TEMPERATURE Z = 4
ELAPSED TIME = 0.10000D+05 TIME STEPS = 10

	X = 1	X = 2	X = 3	X = 4	X = 5	X = 6	X = 7
Y = 7	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02
Y = 6	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02
Y = 5	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02
Y = 4	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02
Y = 3	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02
Y = 2	0.38082D+02	0.38041D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02
Y = 1	0.38163D+02	0.38082D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02	0.38000D+02

Table 6 Control cards for sample calculation 1

```
//JCLG JOB
// EXEC JCLG
//SYSIN DATA,DLM='++'
// JUSER......
  C.2
  W.3
  T.5
// EXEC    LMGO,LM='J2993.HOTEA'
// EXPAND  DISKTN,DDN=FT01F001,DSN='J2993.D2'
// EXPAND  DISKTN,DDN=FT20F001,DSN='J2993.F202'
// EXPAND  DISKTN,DSN=FT30F001,DSN='J2993.F302'
// EXPAND  DISK,DDN=FT10F001
// SYSIN   DD    *
 ( input data )
++
//
```

Table 7 Input data of sample calculation 2

```
          **********  I N P U T   D A T A   D U M P  **********

1.......10........20........30........40........50........60........70........80
HOT3 SAMPLE DATA-2 (FINE MESH , TRANSIENT CALC.)    53- 4-12              TITLE
        10        10        10         1         0         4         1         0  IP1
         1         0         1         1
        -1                   8        10         7        20
                  876.                0.        870000.
         7 0.     180.      0.        155.88    452.      560.                  SYS
         1        10         1        10         1        10         1            NC1-1
                   1                   1         1         1                      NC2-1
         1         3         1         4         5         6         1        -1  NC1-2
                                                                                  NC2-2
         1         3         4         5         5         6         1        -3  NC1-3
                                                                                  NC2-3
         3         4         1         2         5         6         1        -1  NC1-4
                                                                                  NC2-4
         3         4         2         3         5         6         1        -2  NC1-5
                                                                                  NC2-5
         3         4         3         4         5         6         1        -4  NC1-6
                                                                                  NC2-6
         4         5         1         2         5         6         1        -4  NC1
                                                                                  NC2-7
         1 GRANITE  2.22      2.62+3 .22442
                                                                                  BOUND
         1         2
         1        23 -1.      9.6225-4 0.       1875.     26280.    1730.
 43800.   1653.2    61320.    1580.    87600.   1463.2    131400.   1300.
 175200.  1146.6    210240.   1005.    245260.  950.      262800.   900.
 297840.   830.     350400.   715.     394200.  632.7     438000.   565.
 525600.   440.     613200.   352.7    788400.  220.      963600.   138.
 1138800.  91.      1314000.  56.      1489200. 50.12     1752000.  32.5
         2        23 -1.      7.2169-4 0.       1875.     26280.    1730.
 43800.   1653.2    61320.    1580.    87600.   1463.2    131400.   1300.
 175200.  1146.6    210240.   1005.    245260.  950.      262800.   900.
 297840.   830.     350400.   715.     394200.  632.7     438000.   565.
 525600.   440.     613200.   352.7    788400.  220.      963600.   138.
 1138800.  91.      1314000.  56.      1489200. 50.12     1752000.  32.5
         3        23 -1.      4.6113-4 0.       1875.     26280.    1730.
 43800.   1653.2    61320.    1580.    87600.   1463.2    131400.   1300.
 175200.  1146.6    210240.   1005.    245260.  950.      262800.   900.
 297840.   830.     350400.   715.     394200.  632.7     438000.   565.
 525600.   440.     613200.   352.7    788400.  220.      963600.   138.
 1138800.  91.      1314000.  56.      1489200. 50.12     1752000.  32.5
         4        23 -1.      2.4056-4 0.       1875.     26280.    1730.
 43800.   1653.2    61320.    1580.    87600.   1463.2    131400.   1300.
 175200.  1146.6    210240.   1005.    245280.  950.      262800.   900.
 297840.   830.     350400.   715.     394200.  632.7     438000.   565.
 525600.   440.     613200.   352.7    788400.  220.      963600.   138.
 1138800.  91.      1314000.  56.      1489200. 50.12     1752000.  32.5
  1  1  3  1  1  7  1  1  6  5  1  5  1  5  6  5  5  6  9  9  6              POINT
  4  4  6
    1    6    1    8    2    1    2    3    2    7    3    1    3    3        PLANE
```

Table 8-1 Output data of sample calculation 2

X - Y PLANE LATTICE POINT TEMPERATURE Z = 6
ELAPSED TIME = 0.87600D+05 TIME STEPS = 100

	X = 1	X = 2	X = 3	X = 4	X = 5	X = 6	X = 7
Y = 10	0.36768D+02	0.36727D+02	0.36685D+02	0.36643D+02	0.36602D+02	0.36560D+02	0.36519D+02
Y = 9	0.36400D+02	0.36365D+02	0.36357D+02	0.36326D+02	0.36303D+02	0.36286D+02	0.36273D+02
Y = 8	0.36469D+02	0.36451D+02	0.36374D+02	0.36269D+02	0.36214D+02	0.36194D+02	0.36188D+02
Y = 7	0.37562D+02	0.37445D+02	0.37029D+02	0.36512D+02	0.36262D+02	0.36185D+02	0.36168D+02
Y = 6	0.42141D+02	0.41699D+02	0.39913D+02	0.37593D+02	0.36551D+02	0.36242D+02	0.36175D+02
Y = 5	0.58421D+02	0.57145D+02	0.50401D+02	0.41061D+02	0.37446D+02	0.36429D+02	0.36207D+02
Y = 4	0.86643D+02	0.84376D+02	0.73228D+02	0.49409D+02	0.39498D+02	0.36856D+02	0.36283D+02
Y = 3	0.95862D+02	0.94511D+02	0.87341D+02	0.62559D+02	0.42876D+02	0.37580D+02	0.36414D+02
Y = 2	0.98422D+02	0.97575D+02	0.92955D+02	0.75633D+02	0.47479D+02	0.38504D+02	0.36576D+02
Y = 1	0.98948D+02	0.98309D+02	0.94644D+02	0.82549D+02	0.50236D+02	0.39011D+02	0.36661D+02

	X = 8	X = 9	X = 10
Y = 10	0.36477D+02	0.36435D+02	0.36394D+02
Y = 9	0.36267D+02	0.36291D+02	0.36424D+02
Y = 8	0.36195D+02	0.36250D+02	0.36454D+02
Y = 7	0.36178D+02	0.36246D+02	0.36484D+02
Y = 6	0.36178D+02	0.36252D+02	0.36514D+02
Y = 5	0.36185D+02	0.36261D+02	0.36544D+02
Y = 4	0.36198D+02	0.36271D+02	0.36574D+02
Y = 3	0.36220D+02	0.36282D+02	0.36604D+02
Y = 2	0.36247D+02	0.36294D+02	0.36634D+02
Y = 1	0.36261D+02	0.36301D+02	0.36664D+02

Table 8-2 (Con't)

X - Y PLANE LATTICE POINT TEMPERATURE Z = 8
ELAPSED TIME = 0.87600D+05 TIME STEPS = 100

	X = 1	X = 2	X = 3	X = 4	X = 5	X = 6	X = 7
Y = 10	0.36048D+02	0.36007D+02	0.35965D+02	0.35923D+02	0.35882D+02	0.35840D+02	0.35799D+02
Y = 9	0.35724D+02	0.35709D+02	0.35684D+02	0.35659D+02	0.35636D+02	0.35615D+02	0.35597D+02
Y = 8	0.35710D+02	0.35693D+02	0.35649D+02	0.35599D+02	0.35567D+02	0.35546D+02	0.35536D+02
Y = 7	0.36082D+02	0.36033D+02	0.35879D+02	0.35689D+02	0.35585D+02	0.35543D+02	0.35527D+02
Y = 6	0.37451D+02	0.37297D+02	0.36766D+02	0.36072D+02	0.35701D+02	0.35573D+02	0.35536D+02
Y = 5	0.40909D+02	0.40538D+02	0.39132D+02	0.37119D+02	0.36024D+02	0.35653D+02	0.35557D+02
Y = 4	0.45796D+02	0.45250D+02	0.43013D+02	0.39107D+02	0.36678D+02	0.35817D+02	0.35595D+02
Y = 3	0.48305D+02	0.47860D+02	0.45919D+02	0.41534D+02	0.37623D+02	0.36069D+02	0.35652D+02
Y = 2	0.49189D+02	0.48881D+02	0.47451D+02	0.43661D+02	0.38627D+02	0.36354D+02	0.35716D+02
Y = 1	0.49391D+02	0.49145D+02	0.47967D+02	0.44623D+02	0.39125D+02	0.36497D+02	0.35750D+02

	X = 8	X = 9	X = 10
Y = 10	0.35757D+02	0.35715D+02	0.35674D+02
Y = 9	0.35584D+02	0.35597D+02	0.35704D+02
Y = 8	0.35533D+02	0.35569D+02	0.35734D+02
Y = 7	0.35527D+02	0.35571D+02	0.35764D+02
Y = 6	0.35533D+02	0.35582D+02	0.35794D+02
Y = 5	0.35543D+02	0.35595D+02	0.35824D+02
Y = 4	0.35556D+02	0.35608D+02	0.35854D+02
Y = 3	0.35573D+02	0.35622D+02	0.35884D+02
Y = 2	0.35590D+02	0.35636D+02	0.35914D+02
Y = 1	0.35600D+02	0.35645D+02	0.35944D+02

Table 8-3 (Con't)

X - Z PLANE LATTICE POINT TEMPERATURE Y = 1
ELAPSED TIME = 0.87600D+05 TIME STEPS = 100

	X = 1	X = 2	X = 3	X = 4	X = 5	X = 6	X = 7
Z = 10	0.35998D+02	0.35912D+02	0.35826D+02	0.35740D+02	0.35654D+02	0.35568D+02	0.35482D+02
Z = 9	0.40431D+02	0.40308D+02	0.39830D+02	0.38603D+02	0.36757D+02	0.35802D+02	0.35491D+02
Z = 8	0.49391D+02	0.49145D+02	0.47967D+02	0.44623D+02	0.39125D+02	0.36497D+02	0.35750D+02
Z = 7	0.67470D+02	0.67021D+02	0.64716D+02	0.57490D+02	0.43594D+02	0.37676D+02	0.36181D+02
Z = 6	0.98948D+02	0.98309D+02	0.94844D+02	0.82549D+02	0.50236D+02	0.39011D+02	0.36661D+02
Z = 5	0.99308D+02	0.98669D+02	0.95204D+02	0.82909D+02	0.50596D+02	0.39371D+02	0.37021D+02
Z = 4	0.68550D+02	0.68101D+02	0.65796D+02	0.58570D+02	0.44674D+02	0.38758D+02	0.37261D+02
Z = 3	0.51191D+02	0.50945D+02	0.49767D+02	0.46423D+02	0.40925D+02	0.38297D+02	0.37550D+02
Z = 2	0.42951D+02	0.42828D+02	0.42350D+02	0.41123D+02	0.39277D+02	0.38322D+02	0.38011D+02
Z = 1	0.39237D+02	0.39152D+02	0.39066D+02	0.38980D+02	0.38894D+02	0.38808D+02	0.38722D+02

	X = 8	X = 9	X = 10
Z = 10	0.35397D+02	0.35310D+02	0.35224D+02
Z = 9	0.35403D+02	0.35407D+02	0.35584D+02
Z = 8	0.35600D+02	0.35645D+02	0.35944D+02
Z = 7	0.35907D+02	0.35956D+02	0.36304D+02
Z = 6	0.36261D+02	0.36301D+02	0.36664D+02
Z = 5	0.36621D+02	0.36661D+02	0.37024D+02
Z = 4	0.36987D+02	0.37036D+02	0.37384D+02
Z = 3	0.37400D+02	0.37445D+02	0.37744D+02
Z = 2	0.37923D+02	0.37927D+02	0.38104D+02
Z = 1	0.38636D+02	0.38550D+02	0.38464D+02

Table 8-4 (Con't)

X - Z PLANE LATTICE POINT TEMPERATURE Y = 3
ELAPSED TIME = 0.87600D+05 TIME STEPS = 100

	X = 1	X = 2	X = 3	X = 4	X = 5	X = 6	X = 7
Z = 10	0.35849D+02	0.35773D+02	0.35697D+02	0.35621D+02	0.35545D+02	0.35469D+02	0.35393D+02
Z = 9	0.39967D+02	0.39176D+02	0.39055D+02	0.37567D+02	0.36209D+02	0.35612D+02	0.35423D+02
Z = 8	0.48305D+02	0.47860D+02	0.45919D+02	0.41534D+02	0.37623D+02	0.36069D+02	0.35652D+02
Z = 7	0.65385D+02	0.64504D+02	0.60307D+02	0.49388D+02	0.40041D+02	0.36801D+02	0.36011D+02
Z = 6	0.95862D+02	0.94511D+02	0.87341D+02	0.62559D+02	0.42876D+02	0.37580D+02	0.36414D+02
Z = 5	0.96222D+02	0.94871D+02	0.87701D+02	0.62919D+02	0.43236D+02	0.37940D+02	0.36774D+02
Z = 4	0.66465D+02	0.65584D+02	0.61387D+02	0.50468D+02	0.41121D+02	0.37881D+02	0.37091D+02
Z = 3	0.50105D+02	0.49660D+02	0.47719D+02	0.43334D+02	0.39423D+02	0.37869D+02	0.37452D+02
Z = 2	0.42487D+02	0.42296D+02	0.41575D+02	0.40087D+02	0.38729D+02	0.38132D+02	0.37943D+02
Z = 1	0.39089D+02	0.39013D+02	0.38937D+02	0.38861D+02	0.38785D+02	0.38709D+02	0.38633D+02

	X = 8	X = 9	X = 10
Z = 10	0.35317D+02	0.35240D+02	0.35164D+02
Z = 9	0.35365D+02	0.35372D+02	0.35524D+02
Z = 8	0.35573D+02	0.35622D+02	0.35884D+02
Z = 7	0.35875D+02	0.35937D+02	0.36244D+02
Z = 6	0.36220D+02	0.36282D+02	0.36604D+02
Z = 5	0.36580D+02	0.36642D+02	0.36964D+02
Z = 4	0.36955D+02	0.37017D+02	0.37324D+02
Z = 3	0.37373D+02	0.37422D+02	0.37684D+02
Z = 2	0.37885D+02	0.37892D+02	0.38044D+02
Z = 1	0.38557D+02	0.38480D+02	0.38404D+02

Table 8-5 (Con't)

X - Z PLANE LATTICE POINT TEMPERATURE Y = 7
ELAPSED TIME = 0.87600D+05 TIME STEPS = 100

	X = 1	X = 2	X = 3	X = 4	X = 5	X = 6	X = 7
Z = 10	0.35551D+02	0.35495D+02	0.35439D+02	0.35382D+02	0.35326D+02	0.35270D+02	0.35213D+02
Z = 9	0.35647D+02	0.35610D+02	0.35530D+02	0.35435D+02	0.35371D+02	0.35333D+02	0.35304D+02
Z = 8	0.36082D+02	0.36033D+02	0.35879D+02	0.35689D+02	0.35585D+02	0.35543D+02	0.35527D+02
Z = 7	0.36799D+02	0.36716D+02	0.36433D+02	0.36081D+02	0.35902D+02	0.35843D+02	0.35828D+02
Z = 6	0.37562D+02	0.37445D+02	0.37029D+02	0.36512D+02	0.36262D+02	0.36165D+02	0.36168D+02
Z = 5	0.37922D+02	0.37805D+02	0.37389D+02	0.36872D+02	0.36622D+02	0.36545D+02	0.36528D+02
Z = 4	0.37879D+02	0.37796D+02	0.37513D+02	0.37161D+02	0.36982D+02	0.36923D+02	0.36908D+02
Z = 3	0.37882D+02	0.37833D+02	0.37679D+02	0.37489D+02	0.37385D+02	0.37343D+02	0.37327D+02
Z = 2	0.38167D+02	0.38130D+02	0.38050D+02	0.37955D+02	0.37891D+02	0.37853D+02	0.37824D+02
Z = 1	0.38791D+02	0.38735D+02	0.38679D+02	0.38622D+02	0.38566D+02	0.38510D+02	0.38453D+02

	X = 8	X = 9	X = 10
Z = 10	0.35157D+02	0.35101D+02	0.35044D+02
Z = 9	0.35284D+02	0.35292D+02	0.35404D+02
Z = 8	0.35527D+02	0.35571D+02	0.35764D+02
Z = 7	0.35836D+02	0.35897D+02	0.36124D+02
Z = 6	0.36178D+02	0.36246D+02	0.36484D+02
Z = 5	0.36538D+02	0.36606D+02	0.36844D+02
Z = 4	0.36916D+02	0.36977D+02	0.37204D+02
Z = 3	0.37327D+02	0.37371D+02	0.37564D+02
Z = 2	0.37804D+02	0.37812D+02	0.37924D+02
Z = 1	0.38397D+02	0.38340D+02	0.38284D+02

Table 8-6 (Con't)

Y - Z PLANE LATTICE POINT TEMPERATURE X = 1
ELAPSED TIME = 0.87600D+05 TIME STEPS = 100

	Y = 1	Y = 2	Y = 3	Y = 4	Y = 5	Y = 6	Y = 7
Z = 10	0.35998D+02	0.35923D+02	0.35849D+02	0.35774D+02	0.35700D+02	0.35626D+02	0.35551D+02
Z = 9	0.40431D+02	0.40330D+02	0.39967D+02	0.39036D+02	0.37394D+02	0.36177D+02	0.35647D+02
Z = 8	0.49391D+02	0.49189D+02	0.48305D+02	0.45796D+02	0.40909D+02	0.37451D+02	0.36082D+02
Z = 7	0.67470D+02	0.67191D+02	0.65385D+02	0.60018D+02	0.47710D+02	0.39632D+02	0.36799D+02
Z = 6	0.98948D+02	0.98422D+02	0.95862D+02	0.86843D+02	0.58421D+02	0.42141D+02	0.37562D+02
Z = 5	0.99308D+02	0.98762D+02	0.96222D+02	0.87203D+02	0.58761D+02	0.42501D+02	0.37922D+02
Z = 4	0.68550D+02	0.68161D+02	0.66465D+02	0.61098D+02	0.48790D+02	0.40712D+02	0.37879D+02
Z = 3	0.51191D+02	0.50989D+02	0.50105D+02	0.47596D+02	0.42709D+02	0.39251D+02	0.37882D+02
Z = 2	0.42951D+02	0.42850D+02	0.42487D+02	0.41556D+02	0.39914D+02	0.38697D+02	0.38167D+02
Z = 1	0.39237D+02	0.39163D+02	0.39089D+02	0.39014D+02	0.38940D+02	0.38866D+02	0.38791D+02

	Y = 8	Y = 9	Y = 10
Z = 10	0.35477D+02	0.35403D+02	0.35328D+02
Z = 9	0.35482D+02	0.35486D+02	0.35666D+02
Z = 8	0.35710D+02	0.35724D+02	0.36046D+02
Z = 7	0.36073D+02	0.36045D+02	0.36408D+02
Z = 6	0.36489D+02	0.36400D+02	0.36766D+02
Z = 5	0.36849D+02	0.36760D+02	0.37128D+02
Z = 4	0.37158D+02	0.37125D+02	0.37488D+02
Z = 3	0.37510D+02	0.37524D+02	0.37648D+02
Z = 2	0.38002D+02	0.38005D+02	0.38208D+02
Z = 1	0.38717D+02	0.38643D+02	0.38568D+02

Table 8-7 (Con't)

Y - Z PLANE LATTICE POINT TEMPERATURE X = 3
ELAPSED TIME = 0.87600D+05 TIME STEPS = 100

	Y = 1	Y = 2	Y = 3	Y = 4	Y = 5	Y = 6	Y = 7
Z = 10	0.35826D+02	0.35761D+02	0.35697D+02	0.35632D+02	0.35568D+02	0.35503D+02	0.35439D+02
Z = 9	0.39830D+02	0.39627D+02	0.39055D+02	0.38034D+02	0.36729D+02	0.35882D+02	0.35530D+02
Z = 8	0.47967D+02	0.47451D+02	0.45919D+02	0.43013D+02	0.39132D+02	0.36766D+02	0.35879D+02
Z = 7	0.64716D+02	0.63509D+02	0.60307D+02	0.53459D+02	0.43656D+02	0.38244D+02	0.36433D+02
Z = 6	0.94844D+02	0.92955D+02	0.87341D+02	0.73228D+02	0.50401D+02	0.39913D+02	0.37029D+02
Z = 5	0.95204D+02	0.93315D+02	0.87701D+02	0.73588D+02	0.50761D+02	0.40273D+02	0.37389D+02
Z = 4	0.65796D+02	0.64689D+02	0.61387D+02	0.54539D+02	0.44736D+02	0.39324D+02	0.37513D+02
Z = 3	0.49767D+02	0.49251D+02	0.47719D+02	0.44813D+02	0.40932D+02	0.38566D+02	0.37679D+02
Z = 2	0.42350D+02	0.42147D+02	0.41575D+02	0.40554D+02	0.39249D+02	0.38402D+02	0.38050D+02
Z = 1	0.39066D+02	0.39001D+02	0.38937D+02	0.38872D+02	0.38808D+02	0.38743D+02	0.38679D+02

	Y = 8	Y = 9	Y = 10
Z = 10	0.35374D+02	0.35310D+02	0.35245D+02
Z = 9	0.35421D+02	0.35433D+02	0.35605D+02
Z = 8	0.35649D+02	0.35684D+02	0.35965D+02
Z = 7	0.35991D+02	0.36006D+02	0.36325D+02
Z = 6	0.36374D+02	0.36357D+02	0.36685D+02
Z = 5	0.36734D+02	0.36717D+02	0.37045D+02
Z = 4	0.37071D+02	0.37086D+02	0.37405D+02
Z = 3	0.37449D+02	0.37484D+02	0.37765D+02
Z = 2	0.37941D+02	0.37953D+02	0.38125D+02
Z = 1	0.38614D+02	0.38550D+02	0.38485D+02

Table 9 Control cards for sample calculation 2

```
//JCLG JOB
// EXEC JCLG
//SYSIN DATA,DLM='++'
// JUSER.........
  C.2
  W.3
  T.6
// EXEC     LMGO,LM='J2993.HOTEA'
// EXPAND   DISKTO,DDN=FT02F001,DSN='J2993.D2'
// EXPAND   DISKTN,DDN=FT20F001,DSN='J2993.F204'
// EXPAND   DISKTN,DDN=FT30F001,DSN='J2993.F304'
// EXPAND   DISK,DDN=FT10F001
// SYSIN    DD     *
  ( input data )
++
//
```

Table 10 Control cards for GPCP-I program

```
//JCLG  JOB
// EXEC JCLG
//SYSIN DD DATA,DLM='++'
// JUSER 53482993,TU.BANBA,0964.100,HOT                    0331
   T.1                                                     CPU10SEC
   C.1                                                     ME 512KB
   W.3                                                     6K(160)
   I.3                                                     I/O 4000
   C35                                                     COM35
// EXEC   LMGO,LM='J1622.GPCPCOM'
// EXPAND DISK,DDN=FT01F001
// EXPAND DISK,DDN=FT04F001
//SYSIN   DD DSN=J2993.F204.DATA,DISP=OLD
// EXPAND GCOM35
++
//
```

Table 11 Control cards for VOLTES-5 program

```
//JCLG  JOB
// EXEC JCLG
//SYSIN DD DATA,DLM='++'
// JUSER 53482993,TU.BANBA,0964.100,HOT                         0331
   T.1                                                          CPU10SEC
   C.1                                                          ME 512KB
   W.3                                                          6K(160)
   I.3                                                          I/O 4000
   C35                                                          COM35
//EXEC     LMGO,LM='J2993.VOLTES'
//EXPAND   DISKTO,DDN=FT20F001,DSN='J2993.F204'
//EXPAND   DISKTO,DDN=FT30F001,DSN='J2993.F304'
//EXPAND   GCOM35
++
//
```

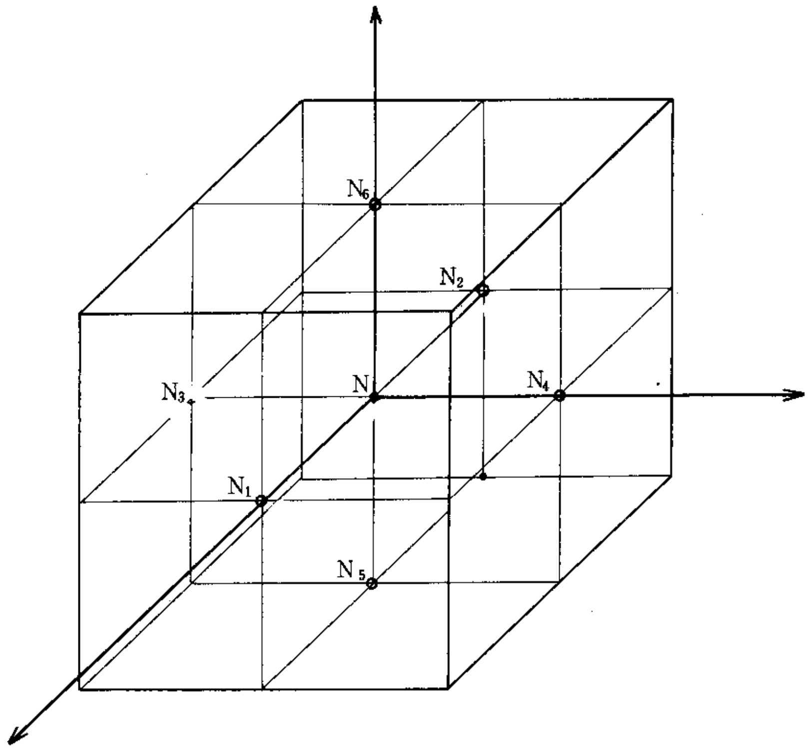


Fig.1 Geometry used for numerical method (N, N_1-N_6; points)

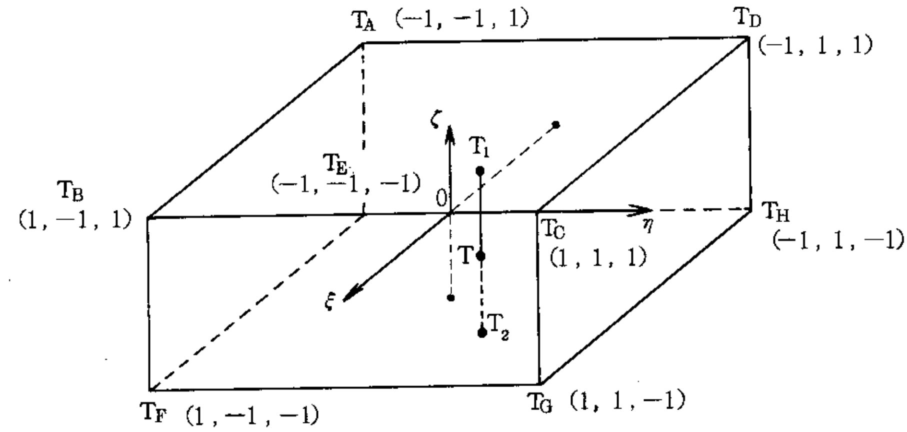


Fig.2 Interpolation of initial condition and boundary condition

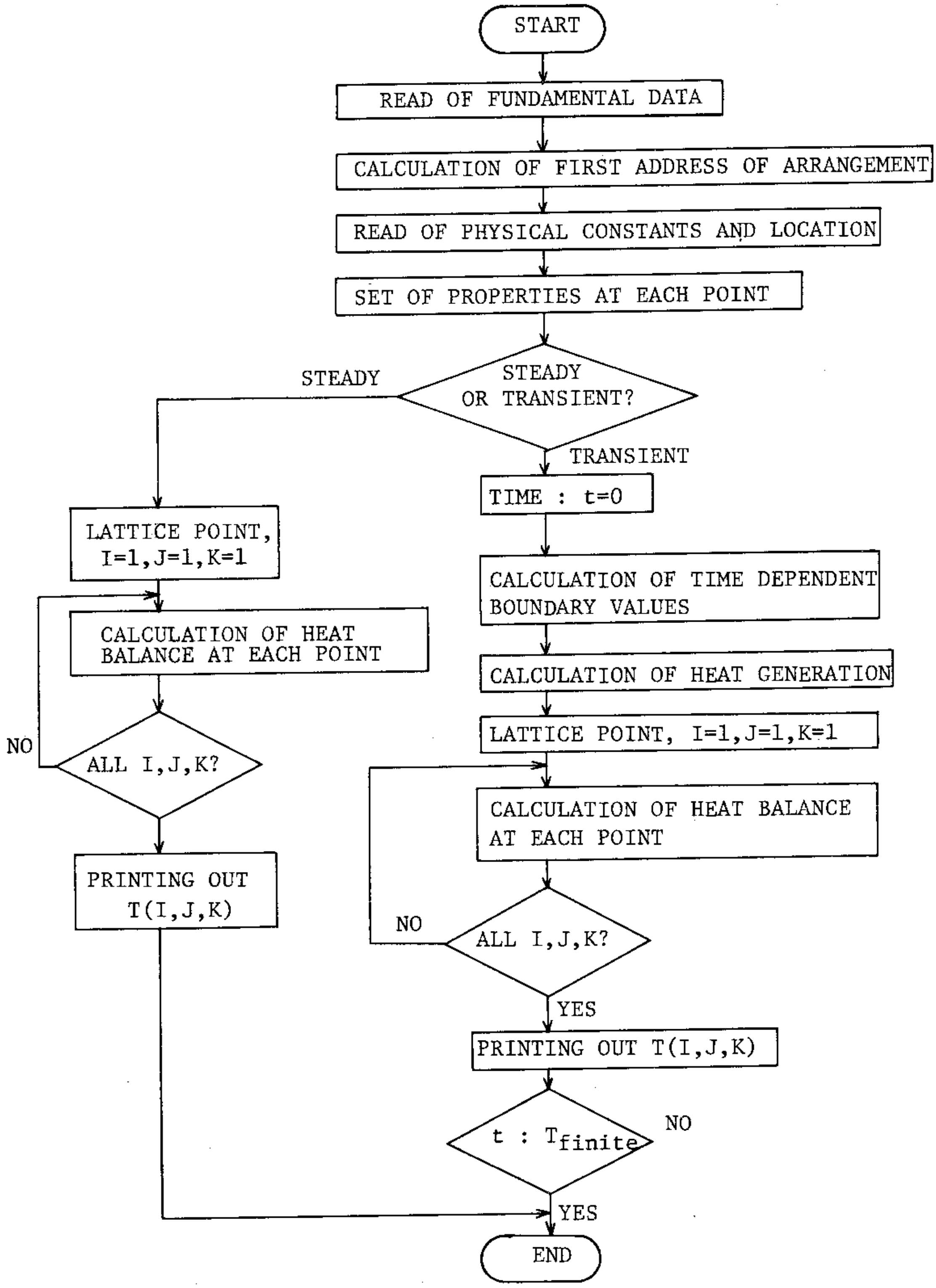


Fig. 3 Flow sheet of code for computing temperature distributions in geologic formation around high-level waste repository

- FTMAIN — HOT control routine
  - INPUTP — Read of fundamental data
  - SETARY — Calculation of first address of arrangement
  - INPUT — Read of physical constants and location
    - RCOND — Read of conductivity as temperature dependent function
    - RDEN — Read of density as temperature dependent function
    - RHTCP — Read of specific heat as temperature dependent function
  - POINTS — Set of properties at each point
  - THRMPR(THRM1) — Calculation of heat balance at each point
    - TIMEDF — Calculation of time dependent boundary values
    - GENFN — Calculation of heat generation
    - PREADC — Calculation of restart and fine mesh
      - TABLES — Calculation for interpolation
      - TEMRD — Read of temperature
      - INT3DI — Interpolation of initial values
    - DUMP1 — Sweep of data for plotter
    - BDCOND — Calculation of boundary heat transfer coefficient
    - COND — Calculation of conductivity
    - CSUBP — Calculation of specific heat
    - RHO — Calculation of density
  - CALQLT — Control routine of steady and transient calculation
    - TIMEDF — Calculation of time dependent boundary values
    - TEMRD — Read of temperature
    - INT3DB — Interpolation of boundary values
    - GENFN — Calculation of heat generation
    - THRM1 — Heat balance at each point
    - DUMP2 — Sweep of data for plotter
    - PLOTR — Sweep of data for plotter
    - PRINTR — Print out
  - PLTEDT — Compilation of data for plotter

Fig. 4 Formation of HOT-code and function of subroutines

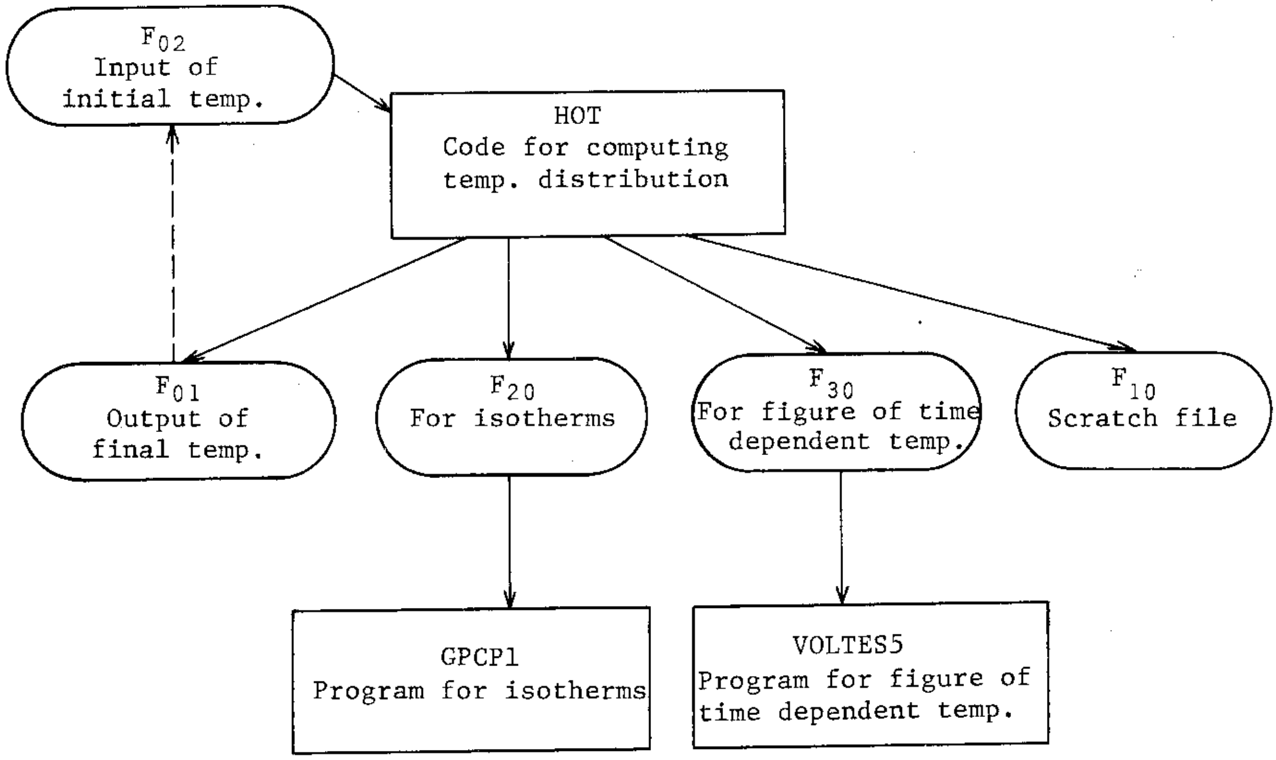


Fig. 5 Files used for HOT-code

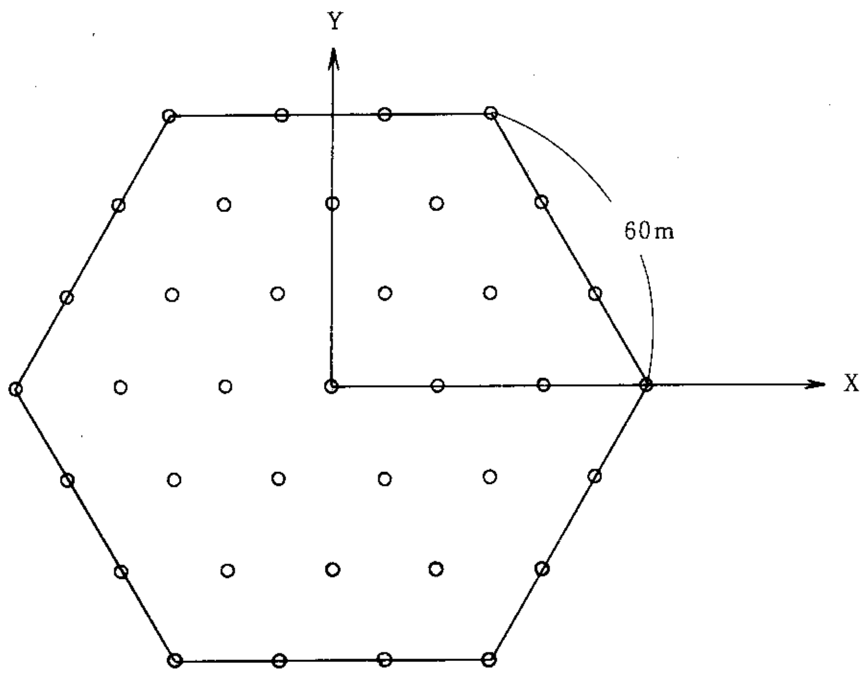
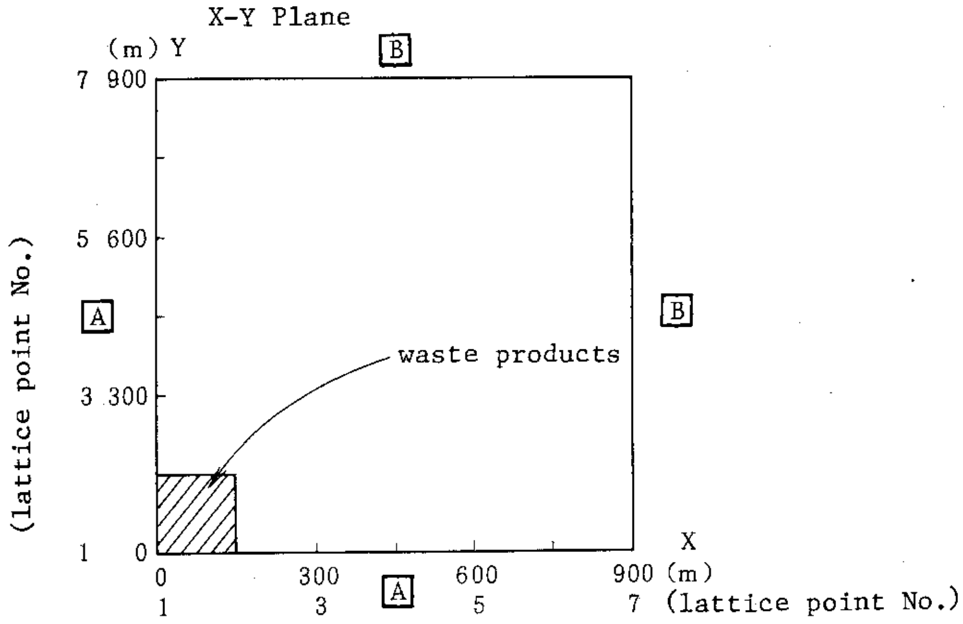


Fig.6 Arrangement of high-level waste products



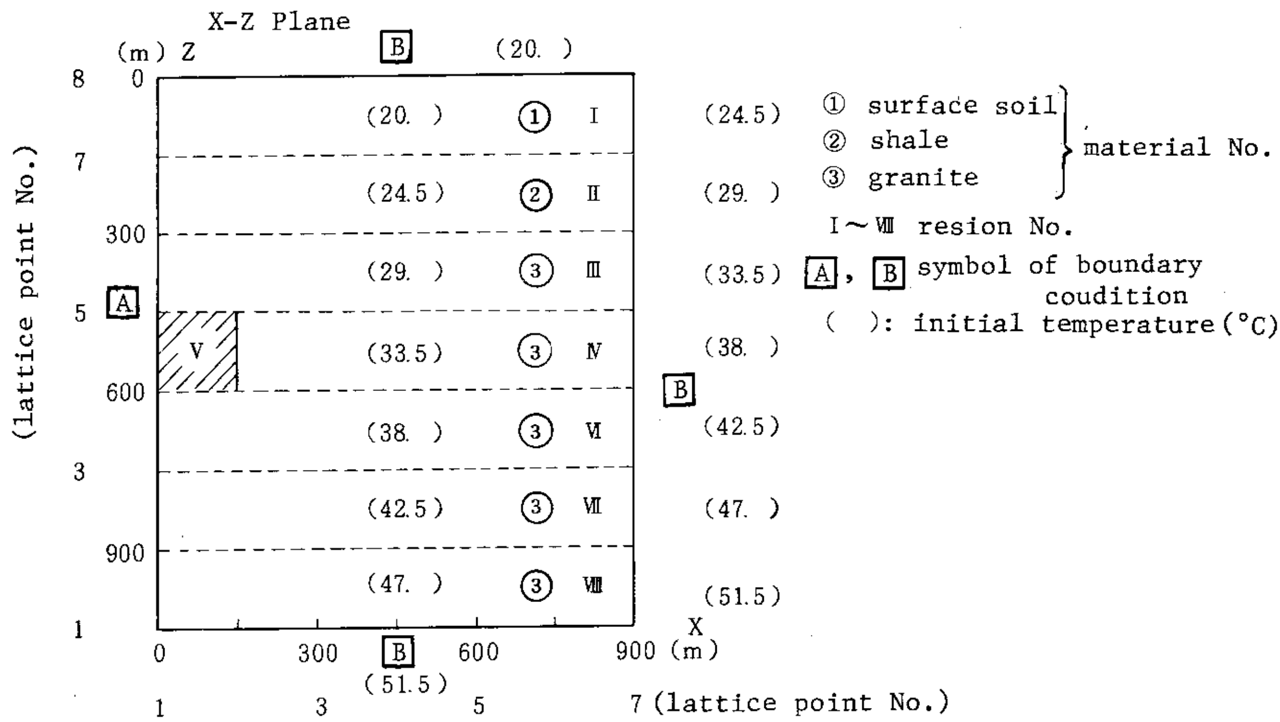
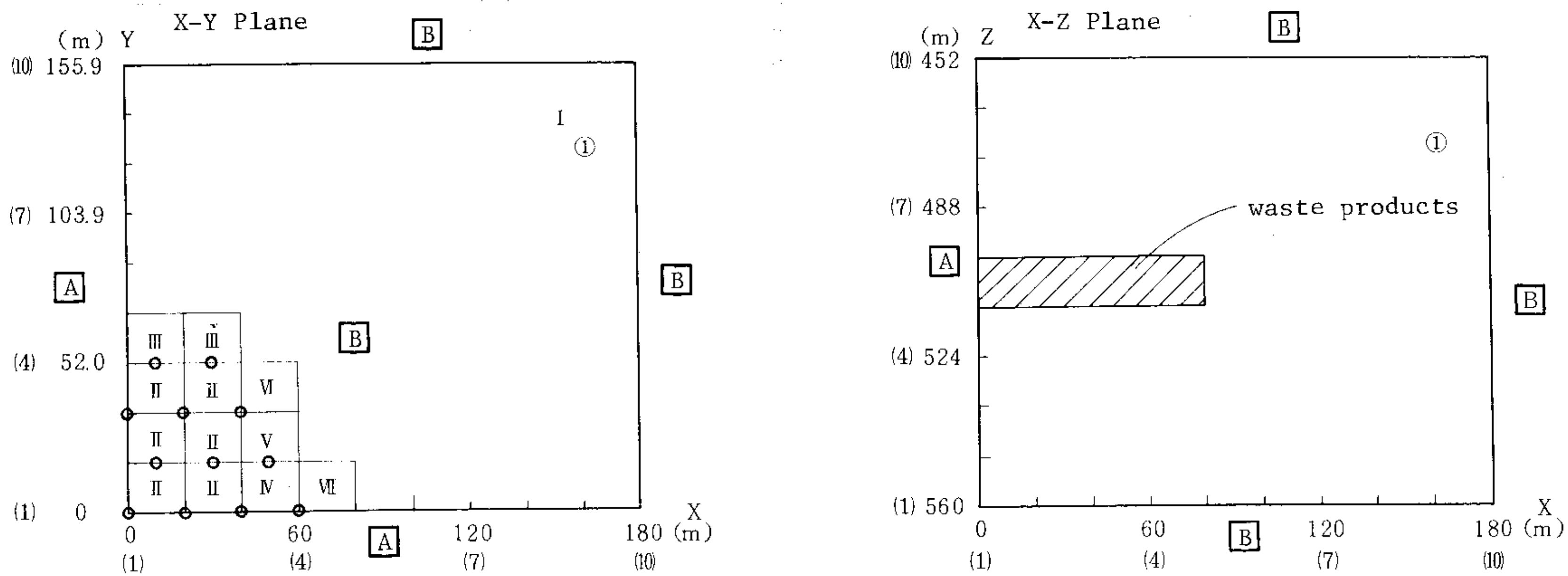


Fig. 7　Calculation system of sample calculation 1



I ~ VII: resion No.
① : material No. (granite)
( ) : lattice point No.
○ : waste products
A, B : symbol of boundary coudition

Fig. 8 Calculation system of sample calculation 2

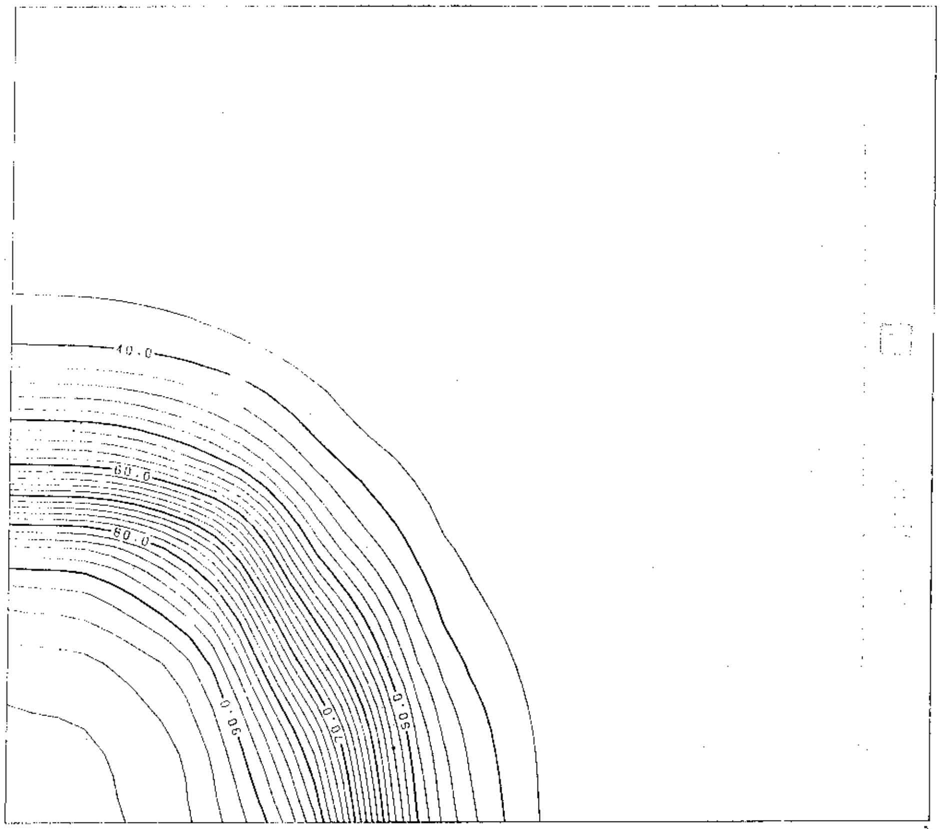


Fig. 9 Output data of sample calculation 2 (Isotherms on X-Y plane, Z=6)

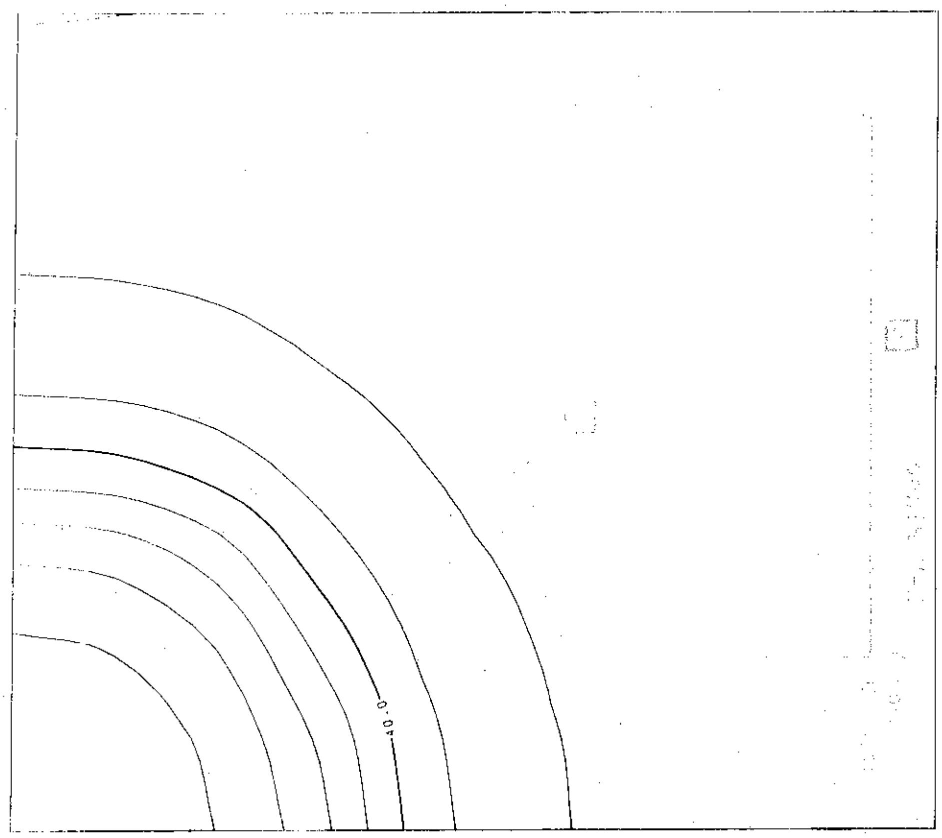


Fig. 10 Output data of sample calculation 2 (Isotherms on X-Y plane, Z=8)

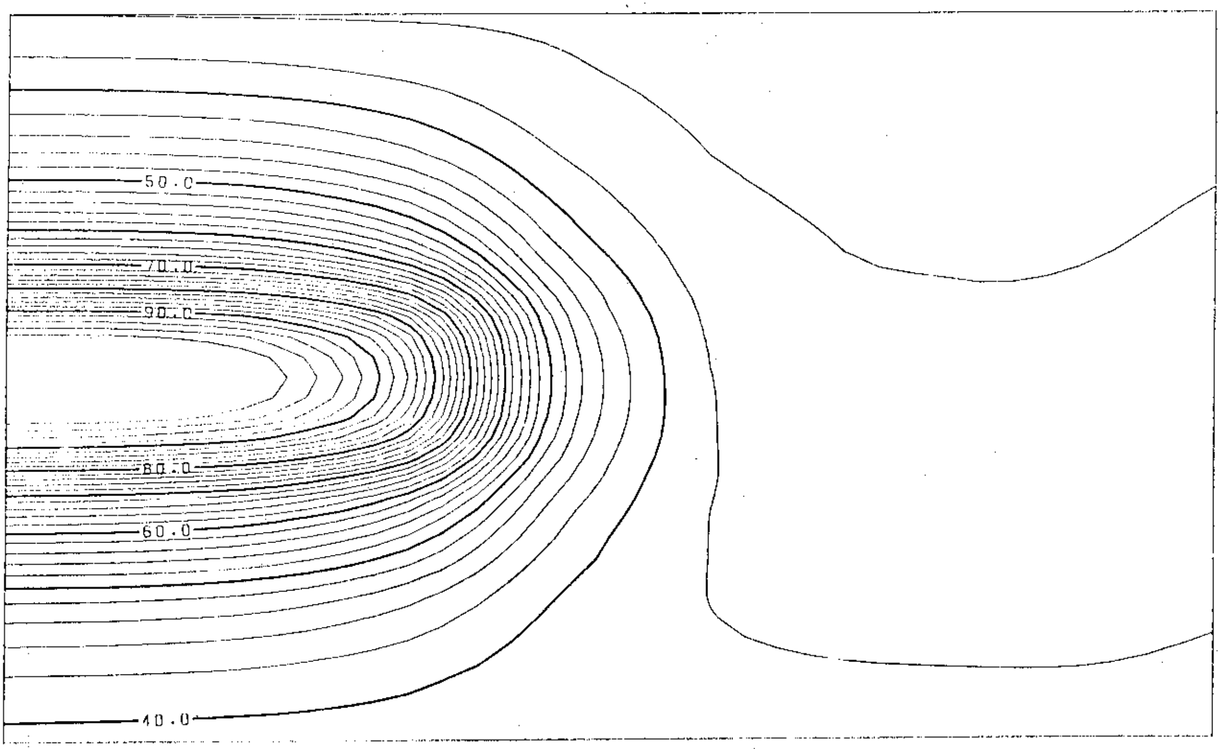


Fig. 11 Output data of sample calculation 2 (Isotherms on X-Z plane, Y=1)

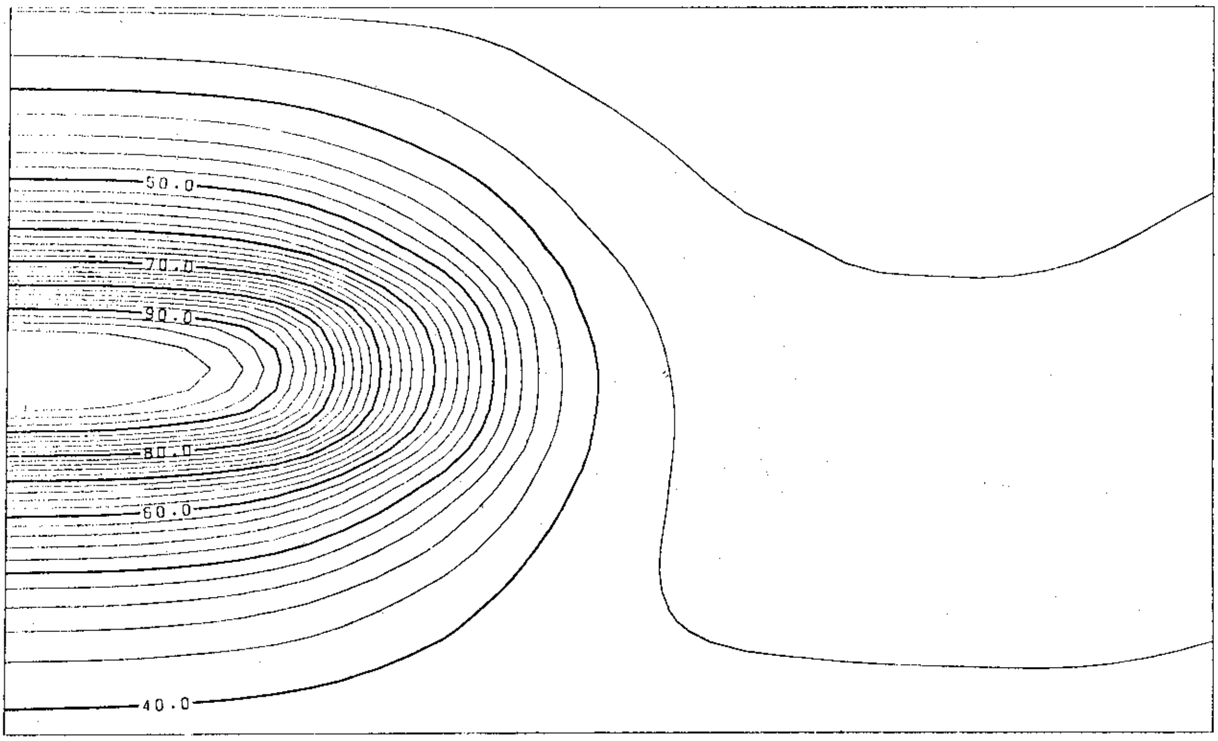


Fig. 12 Output data of sample calculation 2 (Isotherms on X-Z plane, Y=3)

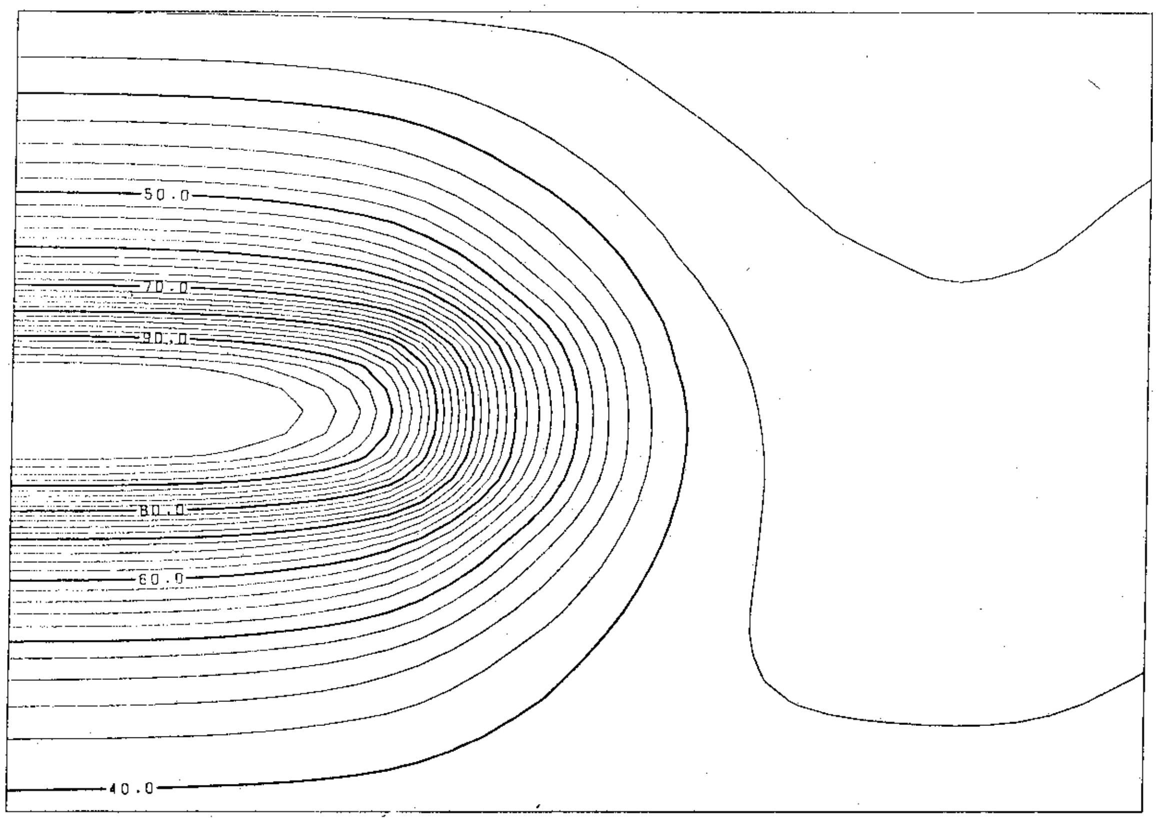


Fig. 13 Output data of sample calculation 2 (Isotherms on Y-Z plane, X=1)

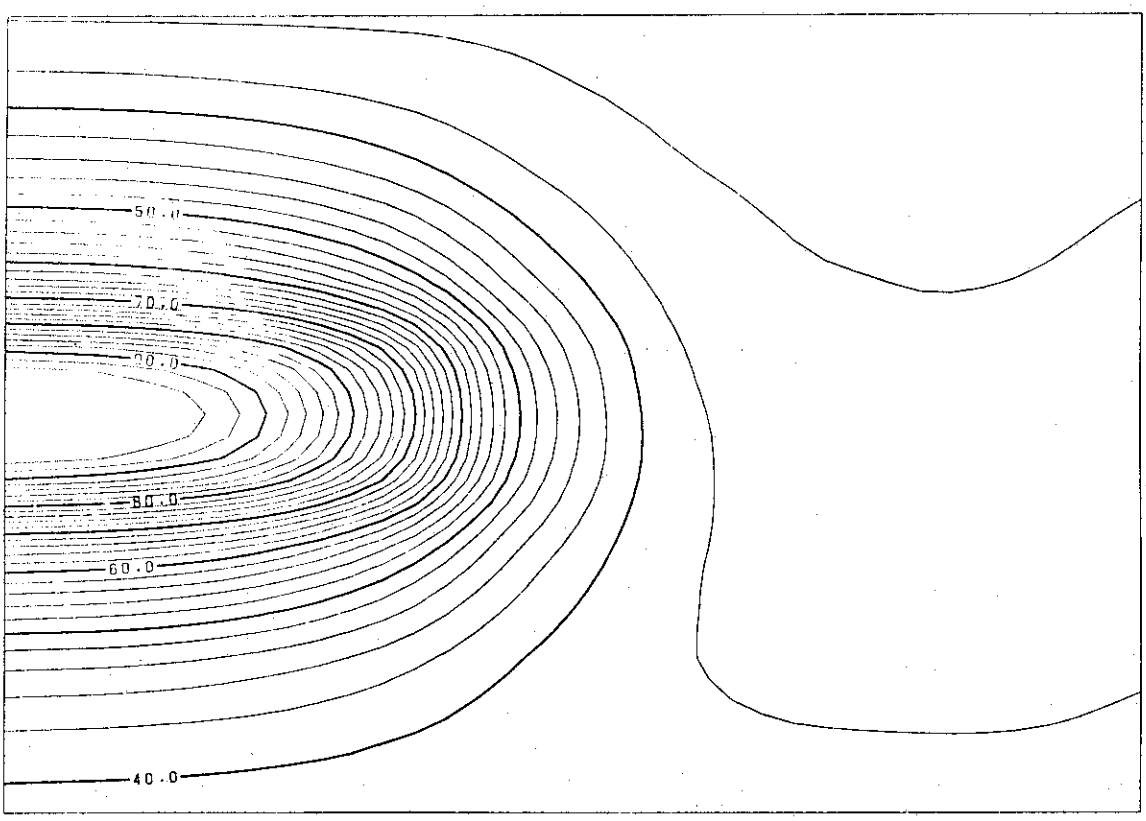


Fig. 14 Output data of sample calculation 2 (Isotherms on Y-Z plane, X=3)

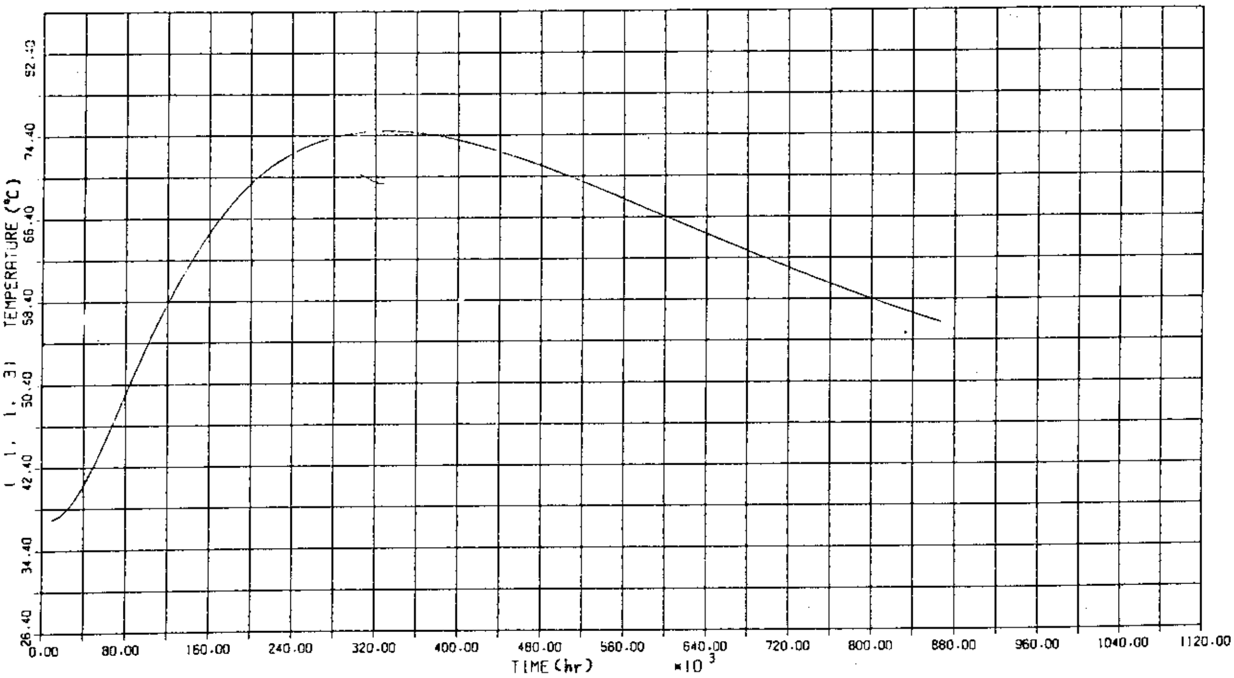


Fig.15 Output data of sample calculation 2
(Graph of time dependent temperature at point(1,1,3))

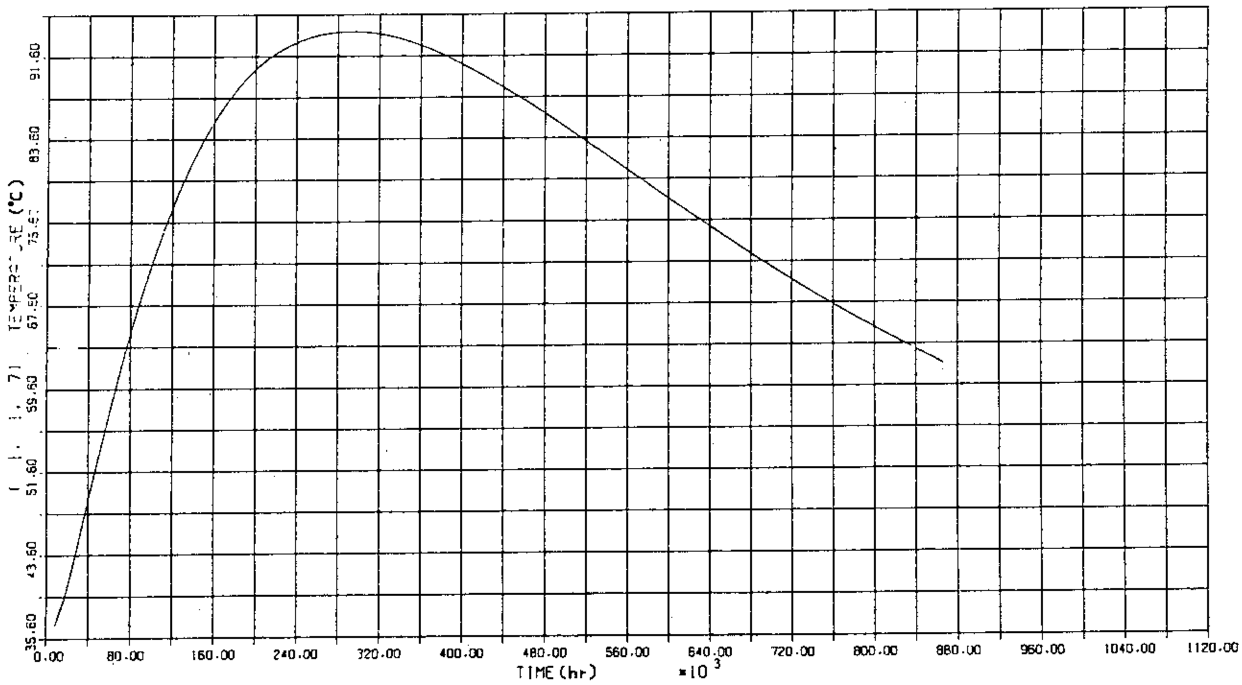


Fig.16 Output data of dample calculation 2
(Graph of time dependent temperature at point(1,1,7))

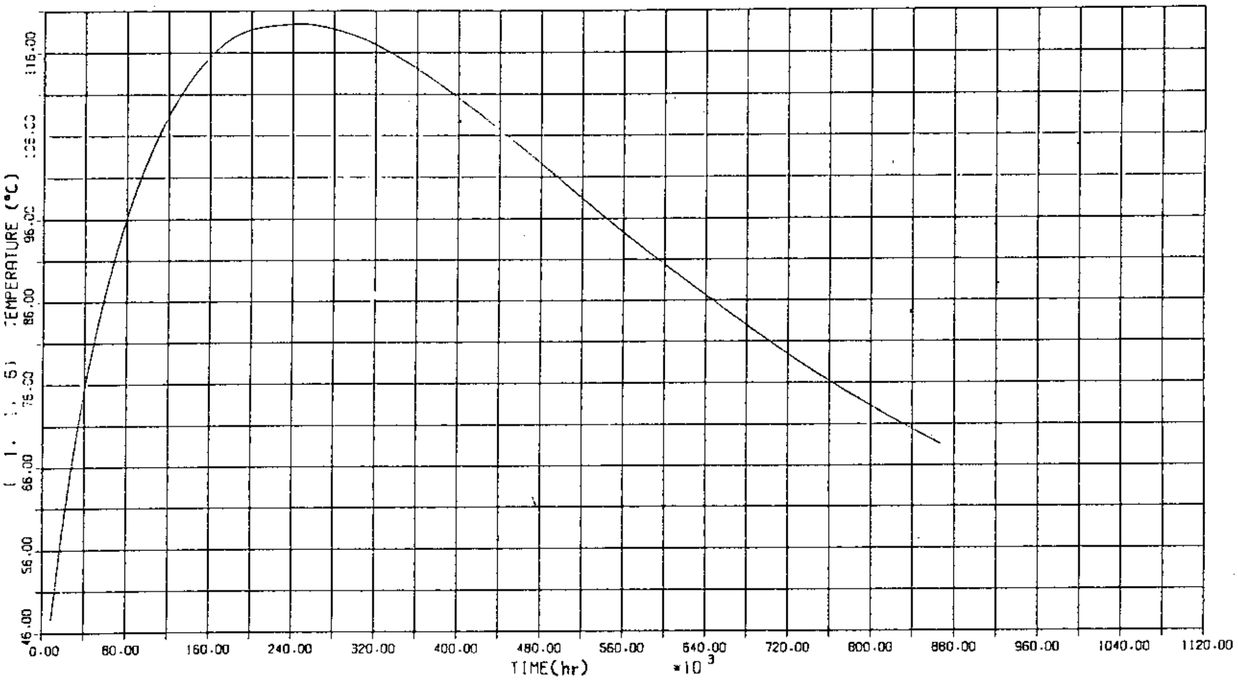


Fig.17 Output data of sample calculation 2
(Graph of time dependent temperature at point(1,1,6))

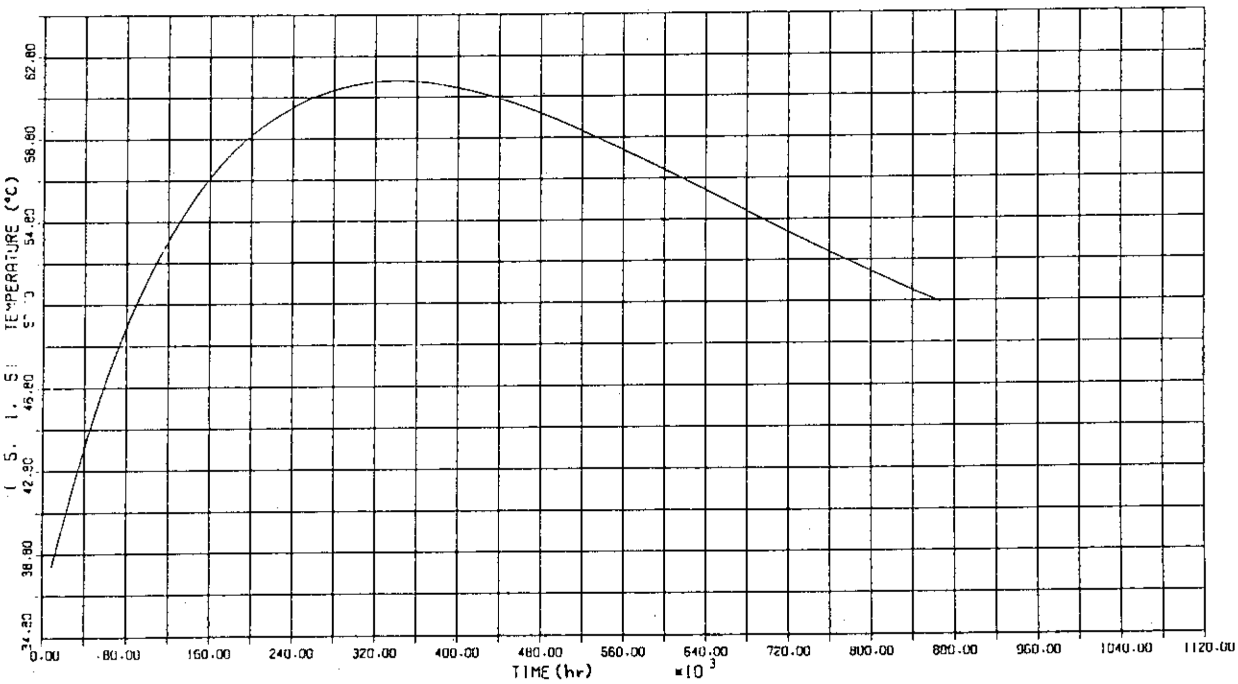


Fig.18 Output data of sample calculation 2
(Graph of time dependent temperature at point(5,1,5))

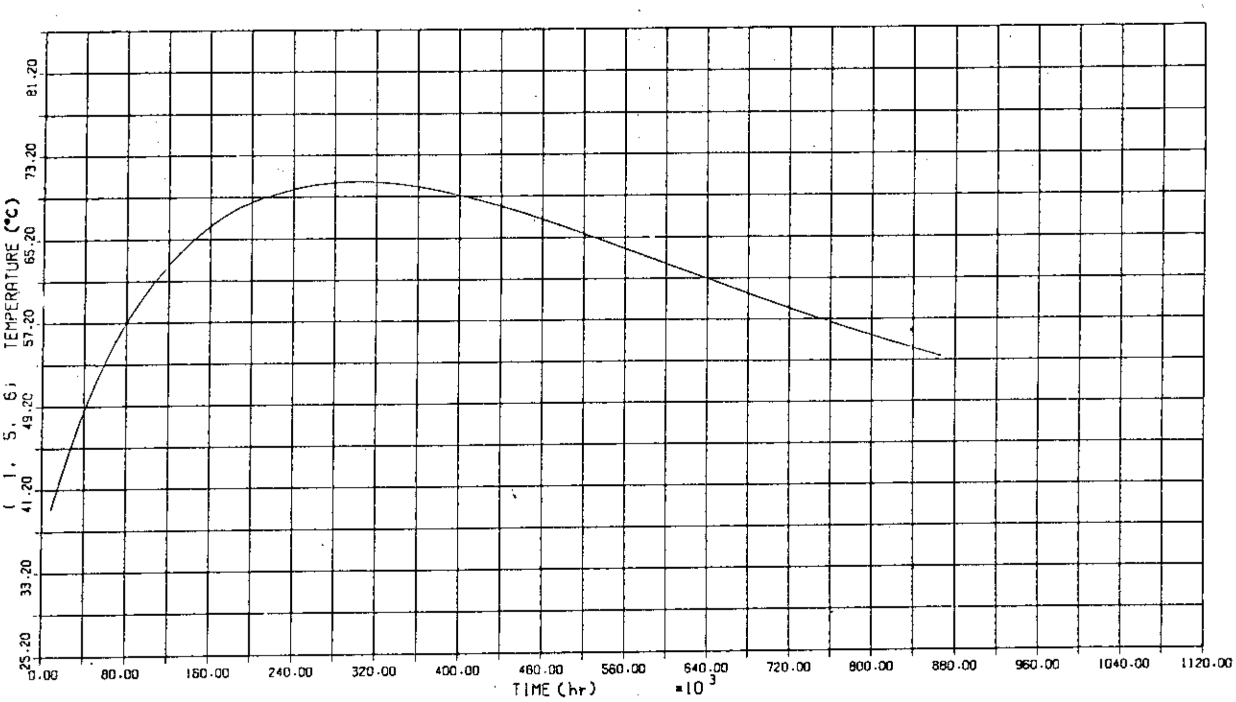


Fig.19 Output data of sample calculation 2
(Graph of time dependent temperature at point(1,5,6))

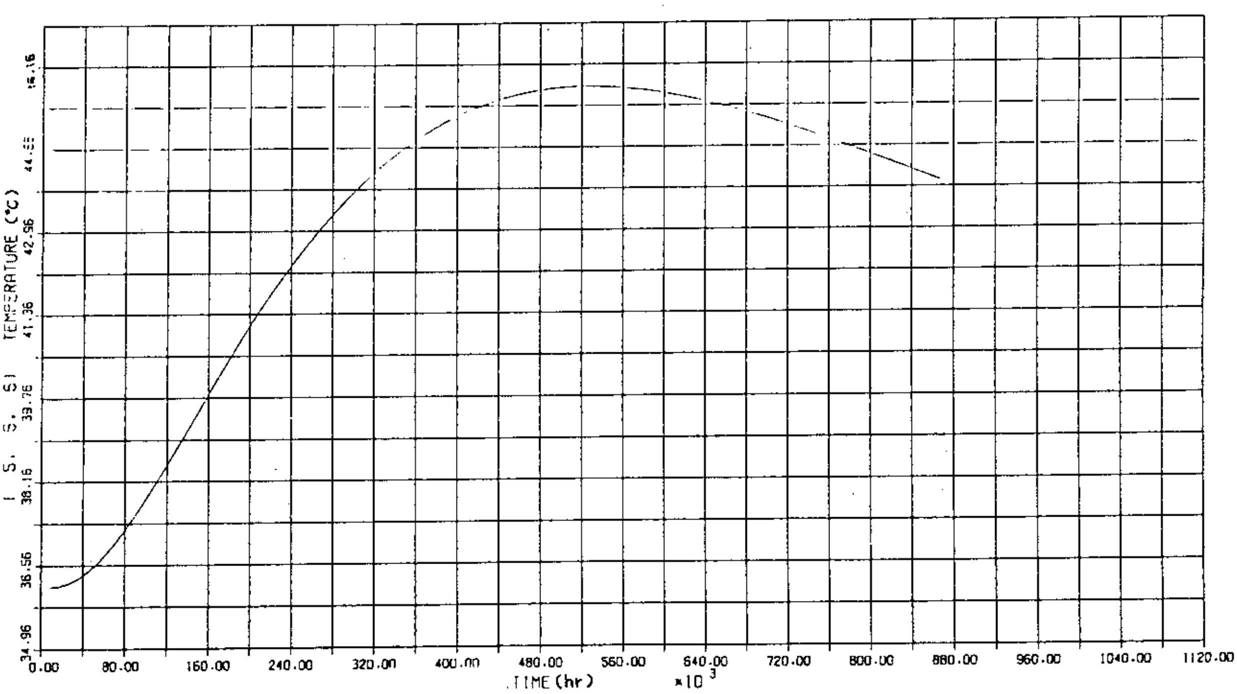


Fig.20 Output data of sample calculation 2
(Graph of time dependent temperature at point(5,5,6))

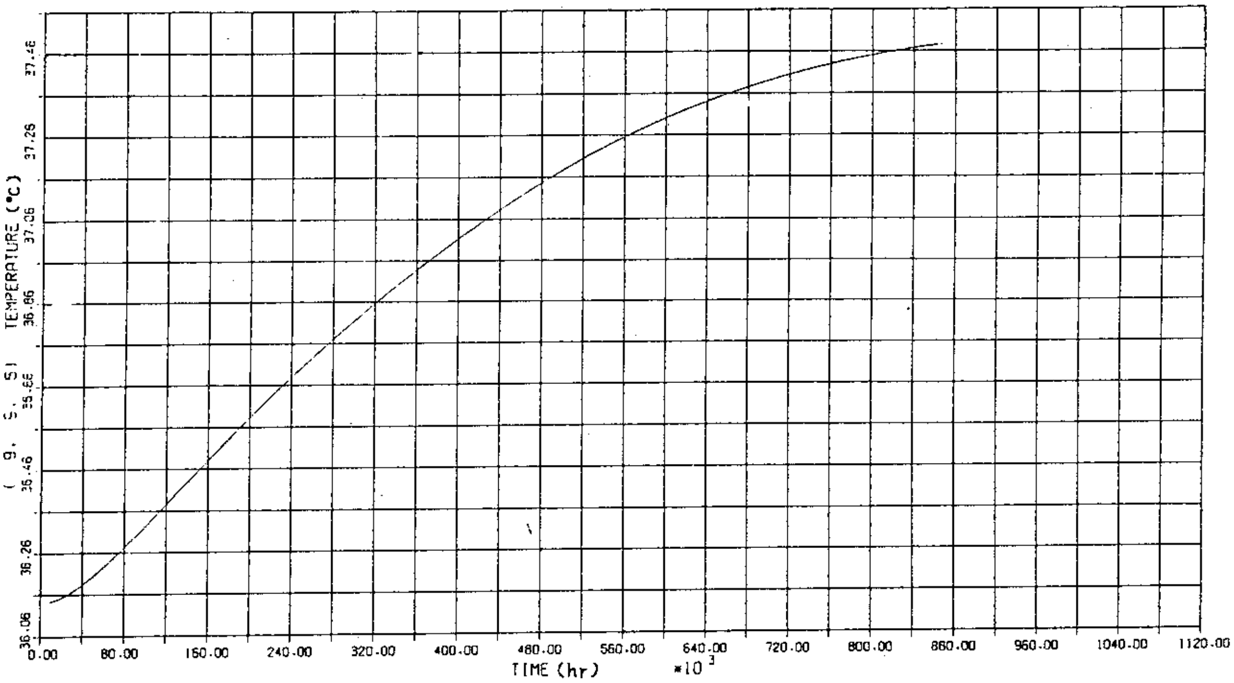


Fig.21 Output data of sample calculation 2
(Graph of time dependent temperature at point(9,9,6))

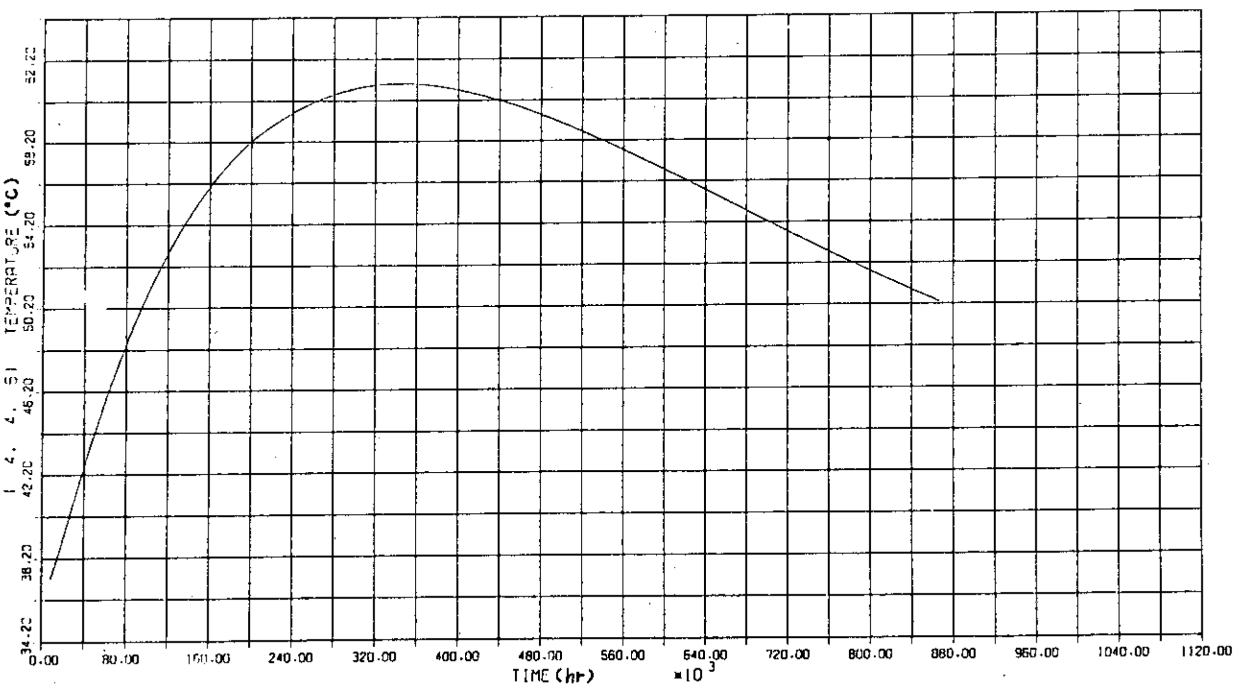


Fig.22 Output data of sample calculation 2
(Graph of time dependent temperature at point(4,4,6))