HEATUP—A Computer Program Thermal Analysis of a LOF in an HTGR

I. I. Siman-Tov
W. D. Turner

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COMPUTER SCIENCES DIVISION

HEATUP - A COMPUTER PROGRAM FOR THE
THERMAL ANALYSIS OF A LOFC ACCIDENT IN AN HTGR

I. I. Siman-Tov
W. D. Turner

Performed for the U.S. Nuclear Regulatory Commission,
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TABLE OF CONTENTS

ABSTRACT	1
1. INTRODUCTION	1
2. THE COMPUTATIONAL MODEL	2
2.1 The Basic Problem	2
2.2 Results from Parametric Studies	10
2.2.1 Thermal Properties of Core Materials	12
2.2.2 Boundary Conditions on the Outer Boundaries of the Model	20
2.2.3 Initial Conditions	22
2.3 The Three-Dimensional Model	25
2.3.1 Basic Assumptions	30
2.3.2 Geometry	31
2.3.3 Materials	34
2.3.4 Boundary Conditions	34
2.3.5 Initial Conditions	38
2.4 The Two-Dimensional Model	38
3. CODE MODIFICATIONS	40
3.1 Effective Axial Thermal Conductivity in the Active Core	41
3.2 Anisotropic Thermal Conductivities in R and Z Directions	42
3.3 Fuel Condition as a Function of Lifetime in the Active Core	43
4. INPUT PREPARATION	45
4.1 Card Description	47
4.2 JCL Information for the ORNL Computing Center	50
4.3 Varying Core Required by HEATUP	55
5. SAMPLE PROBLEM - THREE-DIMENSIONAL FULTON GENERATING STATION MODEL	55
5.1 Region Description	55
5.2 Material Thermal Properties	56
5.3 Heat Generation Description in the Active Core	56
5.4 Initial Conditions - Temperature Distribution	71
5.5 Boundary Conditions	71
REFERENCES	75

APPENDIX A	- Listing of Input Data for HEATUP Sample Problem	77
APPENDIX B	- Listing of Computer Output for HEATUP Sample Problem	85
APPENDIX C	- List of Reports Describing Code and Model Development Leading to the HEATUP Code	137

LIST OF FIGURES

Figure No.		Page
2.1.1	General View of Reactor, Fulton Generating Station, Units 1 and 2 (Fig. 4.1.3-1, Ref. 3, Change 0)	4
2.1.2	Typical Regular Refueling Region in Active Core of HTGR, Fulton Generating Station	5
2.1.3	Partial View of Components within PCRV Liner, Fulton Generating Station, Units 1 and 2 (Fig. 4.1.1-1, Ref. 3, Change 4)	6
2.1.4	Bottom Reflector and Core Support Details, Fulton Generating Station, Units 1 and 2 (Fig. 4.2.1-4, Ref. 3, Change 21)	7
2.1.5	Flow Control Valve and Plenum Arrangement, Fulton Generating Station, Units 1 and 2 (Fig. 4.2.1-5, Ref. 3, Change 3)	8
2.1.6	Arrangement of Components in Radial Direction from Permanent Side Reflector to Cooling Tubes, Fulton Generating Station (Detail E of Fig. 4.2.2-2, Ref. 3, Change 3)	9
2.2.1	One-Dimensional, Radial Model of the HTGR Core during LOFC, Fort St. Vrain Nuclear Generating Station	11
2.2.2	Temperature Development in One-Dimensional, Radial Model after LOFC + Scram, Fort St. Vrain Nuclear Generating Station	14
2.2.3	Two-Dimensional Model of Unit Cell in HTGR Active Core during Normal Operation and Reduced Coolant Flow, Fort St. Vrain Nuclear Generating Station	15
2.2.4	Temperature Development at Horizontal Mid-planes in Two-Dimensional Model of Unit Cell after LOFC + Scram, Fort St. Vrain Nuclear Generating Station	16
2.2.5	Axial Temperature Profiles at the Fuel Center Line and the Graphite-Coolant Interface in Two-Dimensional Model of Unit Cell at 30 Seconds After LOFC + Scram, Summit Power Station	17

LIST OF FIGURES (contd)

Figure No.		Page
2.2.6	Unit Cell Used in the Evaluation of Effective Radial Thermal Conductivity in HTGR Core, Fort St. Vrain Nuclear Generating Station	18
2.2.7	Temperature Development at Selected Radii in One-Dimensional, Radial Model for Various Conductivities, Fort St. Vrain Nuclear Generating Station	21
2.2.8	Maximum Temperatures in One-Dimensional, Radial Model for Various Boundary Conditions, Fort St. Vrain Nuclear Generating Station	23
2.2.9	Axial Temperature Profiles in Fuel Bed in Various Refueling Regions, Fulton Generating Station	24
2.3.1	Radial Power Factor Map of Core Showing Portion for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station, Units 1 and 2 (modified from Fig. C.4-1, Ref. 3, Change 8)	32
2.3.2	RZ Cross-Section at $\theta=45^\circ$ for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station	35
2.3.3	R θ Cross-Section at Horizontal Midplane for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station	36
2.3.4	R θ Cross-Section through Bottom Reflector for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station	37
2.4.1	Radial Homogeneous Rings for 2D Model, LOFC Accident, Fulton Generating Station (Fig. C.3-1, Ref. 3, Change 8)	39
3.3.1	Flow Chart of Coding which Calculates Percentage by Volume of a Particular Age Group which Exceeds the Temperature Criteria	44

LIST OF FIGURES (contd)

Figure No.		Page
4.1	Format of JCL to Run HEATUP at ORNL When Overriding Maximum Number of Nodes Allowed, Create Plot Data Set, Save Final Temperature Distribution	52
4.2	Basic Format of JCL to Run HEATUP at ORNL	54
5.1	Region and Boundary Condition Description in RZ Cross-Section at $\theta=45^\circ$ for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station	57
5.2	Region and Boundary Condition Description With Age-Group Identification Numbers in R θ Cross-Section at Horizontal Midplane for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station	58
5.3	Region and Boundary Condition Description in R θ Cross-Section Through Bottom (top) Plenum for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station	59
5.4	Region and Boundary Condition Description in R θ Cross-Section through Core Support Blocks for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station	60
5.5	Region and Boundary Condition Description in R θ Cross-Section Through Bottom (top) Reflector for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station	61
5.6	Region and Boundary Condition Description in R θ Cross-Section Through Bottom (top) Insulation for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station	62

LIST OF TABLES

Table No.		Page
2.2.1	Axial Power Distribution, Fulton Generating Station	26
2.2.2	Initial Temperature Distribution in RZ Cross-Section at $\theta = 0^\circ$ for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station	27
2.2.3	Initial Temperature in RZ Cross-Section at $\theta = 50^\circ$ for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station	28
2.2.4	Initial Temperature Distribution in RZ Cross-Section at $\theta = 90^\circ$ for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station	29
4.1	Input Description for the HEATUP Code	46
5.1.1	Description of Regions for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station	63
5.2.1	Temperature-Dependent Properties of Composite Core Material, 3-D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station	64
5.2.2	Thermal Conductivities of Materials Used to Compute Effective Axial Thermal Conductivity of Active Core	65
5.2.3	Temperature Dependent Properties of the Side Reflector	66
5.2.4	Temperature Dependent Properties of Helium	67
5.2.5	Temperature Dependent Properties of the Support Blocks, Bottom Reflector and Top Reflectors	68
5.2.6	Temperature Dependent Properties of the Insulation Materials	69
5.3.1	Axial Power Factors for Two-Dimensional and Three-Dimensional Models, LOFC Accident, Fulton Generating Station	71

LIST OF TABLES (Contd.)

Table No.		Page
5.4.1	Initial Temperature Distribution for 3-D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station	72
5.5.1	Boundary Conditions for 3-D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station	73

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HEATUP - A COMPUTER PROGRAM FOR THE THERMAL ANALYSIS OF A LOFC ACCIDENT IN AN HTGR

I. I. Siman-Tov
W. D. Turner

ABSTRACT

The HEATUP code, a modification of the general, time-dependent, one-, two- and three-dimensional program HEATING5, was designed for the thermal analysis of a Loss of Forced Circulation accident in a High Temperature Gas-Cooled Reactor. This report contains a description of the computational model which includes: a description of the basic problem; a short review of preliminary results related to the choice of thermal properties, boundary conditions and initial conditions; a full description of a typical three-dimensional R6Z model and a limited one of a two-dimensional RZ model. HEATUP's additional computations are presented together with the method of input preparation. The three-dimensional model of the Fulton Generating Station Loss of Forced Circulation accident is used as a sample problem. A complete presentation of the input data is made. Also, the computer printout of the sample problem input data and results are given.

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1. INTRODUCTION

This work was the result of an effort to develop a model (or models) for the thermal analysis of a Loss of Forced Circulation (LOFC) accident in a High Temperature Gas-Cooled Reactor (HTGR). This is part of the general project dealing with the Safety Studies on the HTGR carried out for the Division of Systems Safety of the Nuclear Regulatory Commission.

The LOFC accident was recognized as one that would lead to a Maximum Hypothetical Fission Product Release (MHFPR). The sequence of events and a thermal analysis of such an accident are described in detail in the Final Safety Analysis Report (FSAR) for the Fort St. Vrain (FSV) Nuclear

Generating Station (Ref. 1). The design and primary analysis of this reactor were performed by the General Atomic Company (GAC); the Oak Ridge National Laboratory (ORNL) code and model development were based on the existing core design for the particular reactor in review. The basic objective of the thermal analysis was to describe the transient temperature distribution in the core in order to evaluate the applicants' claims as to the thermal response of such a LOFC accident. A second objective of this analysis was to establish how much of the fuel exceeded given temperature criteria as a function of time. This information was used to evaluate the MHFPR under LOFC conditions, which was of prime concern in such an event. Because of the basic similarities in the design of HTGR cores, it was found feasible to develop general two-dimensional and three-dimensional models for a HTGR LOFC accident thermal analysis. This effort led to the development of a modified version of the HEATING5 code (Ref. 2) named HEATUP. HEATUP allows for special input describing some geometric parameters and anisotropic thermal conductivities as well as temperature criteria indicating the condition of the fuel as a result of the temperature development in the active core. Appendix C contains a list of reports describing this model development in detail with underlying assumptions, conclusions and qualifications.

2. THE COMPUTATIONAL MODEL

2.1 THE BASIC PROBLEM

A LOFC accident in an HTGR involves a sequence of events whose main features are: the immediate scram of the reactor followed by the depressurization of the Prestressed Concrete Reactor Vessel (PCRV) as soon as

it becomes evident that cooling cannot be restored. A more detailed description of this sequence of events is given in the FSV Generating Station FSAR - Appendix D (Ref. 1).

The general physical structure of an HTGR core is shown in Fig. 2.1.1. Figs. 2.1.1 and 2.1.3 through 2.1.6 were taken from Ref. 3 with permission from GAC. The main components of this structure are discussed below.

- (i) The active core consists of a given number of refueling regions; the refueling regions contain six regular fuel element stacks and a central control element stack (Fig. 2.1.2). The refueling regions on the periphery are incomplete.
- (ii) The active core is surrounded by reflector elements (bottom, side and top reflectors) (Fig. 2.1.3).
- (iii) The core support blocks appear below the bottom reflector (Fig. 2.1.4).
- (iv) The coolant entrance plenum with the orificing system and other penetration guides is above the top reflector (Fig. 2.1.5).
- (v) Insulation cover sheets and top insulation protect the PCRV cooling system (Fig. 2.1.3).
- (vi) The side reflector is constrained by the core barrel and a gas gap exists to allow for the expansion of the core (Fig. 2.1.6).
- (vii) The exit plenum for the coolant which contains the support posts is under the core support blocks (Fig. 2.1.3).
- (viii) Insulation protecting the bottom part of the PCRV is below the coolant exit plenum (Fig. 2.1.3).

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Fig. 2.1.1. General View of Reactor, Fulton Generating Station, Units 1 and 2 (Fig. 4.1.3-1, Ref. 3, Change 0).

Fig. 2.1.2. Typical Regular Refueling Region in Active Core of HTGR, Fulton Generating Station.

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Fig. 2.1.3. Partial View of Components within PCRV Liner, Fulton Generating Station, Units 1 and 2 (Fig. 4.1.1-1, Ref. 3, Change 4).

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Fig. 2.1.4. Bottom Reflector and Core Support Details, Fulton Generating Station, Units 1 and 2 (Fig. 4.2.1-4, Ref. 3, Change 21).

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Fig. 2.1.5. Flow Control Valve and Plenum Arrangements, Fulton Generating Station, Units 1 and 2 (Fig. 4.2.1-5, Ref. 3, Change 3).

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Fig. 2.1.6. Arrangement of Components in Radial Direction from Permanent Side Reflector to Cooling Tubes, Fulton Generating Station (Detail E of Fig. 4.2.2-2, Ref. 3, Change 3).

The complexity of the physical structure rules out the possibility of an analysis where each component is represented in full detail. The computational model is therefore a simplified simulation of the existing conditions, and the results indicate the general temperature development expected with upper limiting values on the critical information.

In the general computational model of the active core, the material is treated as a single composite material with equivalent thermal properties (Ref. 4). Since the volume of all metal components within the PCRV is small compared to the total volume of the reactor and since the thermal conductivity of these components is high, these metal components can be omitted without any loss of generality. Thus, a lot of detail can be omitted which results in fewer nodes. The gaps between fuel elements, the natural convection in the active core and the forced convection by the water cooling the PCRV liner are also neglected (Ref. 4).

The initial temperature distribution and power level are those prevailing approximately 30 seconds after scram of the reactor. At this time all the gradients across the fuel beds and moderator have flattened out (Ref. 4).

2.2 RESULTS FROM PARAMETRIC STUDIES

Sensitivity studies were used to investigate the effects of changing the equivalent conductivity in the active core and the effects of imposing different boundary conditions representing the water-cooled PCRV liner. A summary of the results from these analyses (Ref. 4,5) which underlie some of the modeling considerations is given below.

Fig. 2.2.1. One-Dimensional, Radial Model of the HTGR Core during LOFC, Fort St. Vrain Nuclear Generating Station.

2.2.1 Thermal Properties of Core Materials

A one-dimensional radial model (Fig. 2.2.1) based on the Fort St. Vrain HTGR was used to develop a model of the active core (Ref. 4). The model represented the composite active core regions, gaps between elements, side reflectors, core barrel, gas space separation between the barrel and liner insulation, insulation and a heat sink at the outer boundary. The four zones depicted describe the radial power distribution (Figs. D.1 - 10 of Ref. 1). This model was used with a fuel bed and surrounding graphite at the center of the model followed by the homogeneous regions modeling the composite active core as shown in Fig. 2.2.1. The results obtained (Fig. 2.2.2) indicated that, within two minutes after scram, the temperature gradients between the fuel and the moderator become negligible.

A two-dimensional RZ model (Fig. 2.2.3) was used in other types of analyses. This model consisted of a single fuel bed, surrounding graphite and a coolant channel (Ref. 5). The model was generally used when flow was present so that it presented a typical symmetrical element in the active core. The transient temperature response at the horizontal mid-plane is shown in Fig. 2.2.4 for the center of fuel and for the fuel-graphite and graphite-coolant interfaces for the Fort St. Vrain HTGR. The results reinforce the conclusion that the gradients that existed during normal operating conditions become negligible within two minutes after scram of the reactor. Fig. 2.2.5 shows the temperature profiles of the fuel centerline and the moderator-coolant interface at 30 seconds after LOFC plus scram for the Summit Power Station as calculated by a two-dimensional RZ model similar to the one shown in Fig. 2.2.3.

A parametric study was made to determine the best choice of effective thermal conductivities for this analysis (Ref. 4). Several cases were run using the one-dimensional, radial model depicted in Fig. 2.2.1 to determine the effects of various effective, radial thermal conductivities on the transient temperature distribution. Four of the cases used in this study are described below:

Case I: An analytical form for a radial effective conductivity was obtained (Ref. 6) based on the model shown in Fig. 2.2.6:

$$K_r = \frac{1}{W} \sum_{i=1}^7 W_i K_i \quad (2.1)$$

where

K_r is the effective radial thermal conductivity,

W_i is the width of the i th heat flow path,

K_i is the effective thermal conductivity of the i th heat flow path,

$$W = \sum_{i=1}^7 W_i ,$$

$$K_i = \frac{L}{\frac{L_i}{\frac{k_i}{k_r} + \frac{k_g}{k_r}} + \frac{L-L_i}{k_g}} , \quad i = 1 \text{ to } 3,$$

$$K_i = \frac{L}{\frac{L_i}{\frac{k_i}{k_f} + \frac{k_g}{k_f}} + \frac{L-L_i}{k_g}} , \quad i = 4 \text{ to } 6,$$

$$K_7 = k_g ,$$

Fig. 2.2.2. Temperature Development in One-Dimensional, Radial Model after LOFC + Scram, Fort St. Vrain Nuclear Generating Station.

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Fig. 2.2.3. Two-Dimensional Model of Unit Cell in HTGR Active Core during Normal Operation and Reduced Coolant Flow, Fort St. Vrain Nuclear Generating Station.

Fig. 2.2.4. Temperature Development at Horizontal Midplanes in Two-Dimensional Model of Unit Cell after LOFC + Scram, Fort St. Vrain Nuclear Generating Station.

Fig. 2.2.5. Axial Temperature Profiles at the Fuel Center Line and the Graphite-Coolant Interface in Two-Dimensional Model of Unit Cell at 30 Seconds after LOFC + Scram, Summit Power Station.

Fig. 2.2.6. Unit Cell Used in the Evaluation of Effective Radial Thermal Conductivity in HTGR Core, Fort St. Vrain Nuclear Generating Station.

L is the total length of each of the seven heat flow paths.

L_i is the length of the heat flow path in either the coolant or fuel.

k_f and k_g are the thermal conductivities of the fuel and graphite, respectively, and

k_r is the effective thermal conductivity across the coolant due to radiation.

Case II: A temperature-dependent conductivity was obtained from GAC (Ref. 1) as given by

$$\bar{k}_r = C_1 k_g \frac{1 + C_2 \frac{\tau^3}{k_g} \left[\left(C_4 + \frac{k_g}{k_f} \right) / \left(C_6 + \frac{k_g}{k_f} \right) \right]}{1 + C_3 \frac{\tau^3}{k_f} \left[\left(C_5 + \frac{k_g}{k_f} \right) / \left(C_6 + \frac{k_g}{k_f} \right) \right]}, \quad (2.2)$$

where the C_i are geometrical constants dependent upon the graphite-fuel-void configuration. The values of the C_i were determined in the equivalent conductance calculation to be:

$$\begin{array}{ll} C_1 = .36 & C_4 = 4.1 \\ C_2 = 5.23 & C_5 = 1.2 \\ C_3 = 2.5 & C_6 = 8.7 \end{array}$$

The variable τ in the $\bar{k}_r$ equation is $T(^{\circ}R)/1000$, which has been combined from equation

$$k_r = \frac{16}{3} \sigma T^3$$

into the effective conductivity geometrical constants C_i .

Case III: A constant conductivity of 10^{-7} Btu/hr·in·°F was used to check the effect on the maximum temperature in the core.

Case IV: The effect of modeling the gaps between fuel elements was also examined with this model. Cases I through III include gaps between fuel elements, while Case IV is similar to Case I with no gaps modeled.

A comparison of temperature development at the center line, at the radial location where the maximum temperature occurred and at the edge of the active core for the four cases is presented in Fig. 2.2.7.

The results given by GAC data was found to agree closely with the results obtained from ORNL's effective radial conductivity analysis, and it was decided to use the GAC data for the thermal properties of the materials in the active core and reflectors. In the axial directions, however, it was not clear how the effective conductivity was obtained by GAC. Therefore, an effective conductivity based on a parallel network consisting of fuel, coolant (conduction only) and moderator paths was included in the computation. This method neglects any radiative and natural convective effects and will transfer less heat out of the high-powered regions.

2.2.2 Boundary Conditions on the Outer Boundaries of the Model

An analysis based on a model similar to the three-dimensional model presented in Sec. 2.3 showed that the PCRV is well insulated for the first few hours after the LOFC accident takes place. Cases with different boundary conditions were studied; the results are shown in Fig. 2.2.8 for the following cases:

- Case I: A no-flux outer boundary was imposed; i.e., all the heat had to be stored in the model.
- Case II: A forced convective heat transfer coefficient of $0.208 \text{ Btu/hr}\cdot\text{in}^2\cdot^\circ\text{F}$ was used based on GAC data (Ref. 7). The related boundary temperature was 150°F .
- Case III: A fixed surface temperature of 150°F was imposed representing the maximum allowed temperature for the water-cooled tubes protecting the PCRV of the Summit Power Station (Ref. 8).

Fig. 2.2.7. Temperature Development at Selected Radii in One-Dimensional, Radial Model for Various Conductivities, Fort St. Vrain Nuclear Generating Station.

2.2.3 Initial Conditions

The initial conditions of this three-dimensional model reflect conditions at about 30 seconds after LOFC which was assumed to be simultaneous with reactor scram. The choice of this time was based on results previously obtained showing that the temperature gradients between the fuel sticks and moderator equilibrated very quickly, and the fuel-moderator matrix could then be viewed as a homogeneous material.

The results used for determining the initial temperature distribution in the active core were taken from the studies made on the two-dimensional model shown in Fig. 2.2.3. Cases were studied for different radial power peaking factors, and the axial temperature distribution in the active core was based on a radial power peaking factor of 1.0. The axial distribution for this case was fitted with a fifth degree polynomial in Z as follows:

$$f(z) = T_0 \times (-4.248 + 0.0789z - 0.000431z^2 + 1.036 \times 10^{-6} z^3 - 9.366 \times 10^{-10} z^4 + 6.195 \times 10^{-16} z^5) \quad (2.3)$$

where

z is the distance from the bottom of the model (in), and

T_0 is the normalizing factor that can be modified as a function of the power level in the refueling region in question.

The following factors were used:

$T_0 = 1500^\circ\text{F}$ was used in regions with a radial power peaking factor of 1.0.

$T_0 = 1550^\circ\text{F}$ was used in the relatively high-powered regions.

$T_0 = 1450^\circ\text{F}$ was used in the relatively low-powered regions.

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Fig. 2.2.8. Maximum Temperatures in One-Dimensional, Radial Model for Various Boundary Conditions, Fort St. Vrain Nuclear Generating Station.

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Fig. 2.2.9. Axial Temperature Profiles in Fuel Bed in Various Refueling Regions, Fulton Generating Station.

Fig. 2.2.9 shows the results of the axial temperature distribution in the fuel for the following three cases at 30 seconds after LOFC plus reactor scram:

Case I: Refueling region with a radial power peaking factor of 1.0.

Case II: Refueling region with a radial power peaking factor of 1.6.

Case III: Refueling region with a radial power peaking factor of 0.6701.

The axial power distribution for these cases was identical and is shown in Table 2.2.1. An example of the initial temperature distribution in the three RZ planes for the Fulton Generating Station is shown in Tables 2.2.2, 2.2.3 and 2.2.4.

2.3 THE THREE-DIMENSIONAL MODEL

The assumptions made in the development of the three-dimensional model were chosen mainly to ensure that the calculations yielded upper limits on the maximum temperatures developed in the core as a function of time. The second objective of this analysis was to obtain fractions of the active core describing given fuel conditions. These fractions may be underestimated by using the same assumptions since conditions that tend to maximize the active core temperature prevent heat flow from the high-powered to the low-powered regions. However, the low-powered regions represent the older fuel which deteriorates at lower temperatures.

Table 2.2.1. Axial Power Distribution, Fulton Generation Station

Zone (from bottom)	Lower Z (inch)	Upper Z (inch)	Factor (dimensionless)
1	167.23	198.0	0.515
2	198.0	229.0	0.587
3	229.0	260.0	0.815
4	260.0	292.0	0.903
5	292.0	323.0	1.173
6	323.0	354.0	1.456
7	354.0	385.0	1.335
8	385.0	417.0	1.216

Table 2.2.2. Initial Temperature Distribution (°F) in RZ Cross-Section at $\theta=0^\circ$ for 3-D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station

Axial Distance (in) \ Radial Distance (in)	9.84	19.68	52.06	85.77	119.69	153.69	165.14	170.14
0.0	179.99	179.99	179.99	179.99	179.99	179.99	179.99	179.99
9.00	1391.99	1391.99	1391.99	1391.99	1391.99	1391.99	1391.99	1391.99
85.50	1392.01	1392.01	1392.01	1392.01	1392.01	1392.01	1392.01	1392.01
103.00	1415.14	1415.14	1415.14	1415.14	1415.14	1415.14	1415.14	1415.14
120.50	1438.24	1438.24	1438.24	1438.24	1438.24	1438.24	1419.19	1376.63
141.42	1465.85	1465.85	1465.85	1465.85	1465.85	1465.85	1409.94	1285.08
162.33	1493.45	1493.45	1493.45	1493.45	1493.45	1493.45	1416.64	1245.10
167.33	1511.20	1543.38	1526.93	1532.27	1508.45	1483.15	1425.95	1235.54
182.94	1589.75	1634.35	1611.54	1618.94	1585.93	1550.88	1470.98	1205.69
198.55	1627.73	1673.38	1650.03	1657.61	1623.81	1587.92	1487.97	1175.85
214.16	1639.69	1685.68	1662.16	1669.80	1635.75	1599.60	1487.01	1146.00
229.77	1634.66	1680.51	1657.06	1664.67	1630.73	1594.68	1474.30	1116.16
245.38	1619.62	1665.04	1641.81	1649.35	1615.72	1580.01	1454.68	1086.31
276.60	1577.53	1621.78	1599.15	1606.50	1573.74	1538.96	1407.15	1026.63
307.82	1529.45	1572.35	1550.41	1557.53	1525.77	1492.05	1355.48	966.94
339.64	1457.53	1498.41	1477.50	1484.29	1454.03	1421.89	1286.99	906.10
370.26	1319.26	1356.26	1337.34	1343.48	1316.09	1287.00	1173.37	847.56
401.48	1029.15	1058.02	1043.25	1048.05	1026.68	1003.98	954.53	787.87
417.09	789.10	805.97	797.35	800.15	787.56	774.40	779.49	758.02
422.09	762.71	762.71	762.71	762.71	762.71	762.71	758.30	748.46
450.75	700.83	700.83	700.83	700.83	700.83	700.83	698.62	693.67
479.41	638.99	638.99	638.99	638.99	638.99	638.99	638.98	638.97
564.91	638.96	638.96	638.96	638.96	638.96	638.96	638.96	638.96
567.91	178.68	178.68	178.68	178.68	178.68	178.68	178.68	178.68

Table 2.2.3. Initial Temperature Distribution (°F) in RZ Cross-Section at $\theta=50^\circ$ for 3-D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station

Axial Distance (in)	Radial Distance (in)							
	9.84	19.68	52.06	85.77	119.69	153.69	165.14	170.14
0.0	179.99	179.99	179.99	179.99	179.99	179.99	179.99	179.99
9.00	1391.99	1391.99	1391.99	1391.99	1391.99	1391.99	1391.99	1391.99
85.50	1392.01	1392.01	1392.01	1392.01	1392.01	1392.01	1392.01	1392.01
103.00	1415.14	1415.14	1415.14	1415.14	1415.14	1415.14	1415.14	1415.14
120.50	1438.24	1438.24	1438.24	1438.24	1438.24	1438.24	1419.19	1376.63
141.42	1465.85	1465.85	1465.85	1465.85	1465.85	1465.85	1409.94	1285.08
162.33	1493.45	1493.45	1493.45	1493.45	1493.45	1493.45	1416.64	1245.10
167.33	1511.20	1511.20	1511.20	1515.88	1494.65	1483.15	1425.95	1235.54
182.94	1589.75	1589.75	1589.75	1596.24	1566.81	1550.88	1470.98	1205.69
198.55	1627.73	1627.73	1627.73	1634.37	1604.24	1567.92	1487.97	1175.85
214.16	1639.69	1639.69	1639.69	1646.38	1616.03	1599.60	1487.01	1146.00
229.77	1634.66	1634.66	1634.66	1641.33	1611.07	1594.68	1474.30	1116.16
245.38	1619.62	1619.62	1619.62	1626.23	1596.24	1580.01	1454.68	1086.31
276.60	1577.53	1577.53	1577.53	1583.97	1554.77	1538.96	1407.15	1026.63
307.82	1529.45	1529.45	1529.45	1535.69	1507.38	1492.05	1355.48	966.94
339.64	1457.53	1457.53	1457.53	1463.48	1436.49	1421.89	1286.99	906.10
370.26	1319.26	1319.26	1319.26	1324.64	1300.22	1287.00	1173.37	847.56
401.48	1029.15	1029.15	1029.15	1033.35	1014.30	1003.98	954.53	787.87
417.09	789.10	789.10	789.10	791.56	780.42	774.40	799.49	758.02
422.09	762.71	762.71	762.71	762.71	762.71	762.71	758.30	748.46
450.75	700.83	700.83	700.83	700.83	700.83	700.83	698.62	693.67
479.41	638.99	638.99	638.99	638.99	638.99	638.99	638.98	638.97
564.91	638.96	638.96	638.96	638.96	638.96	638.96	638.96	638.96
567.91	178.68	178.68	178.68	178.68	178.68	178.68	178.68	178.68

Table 2.2.4. Initial Temperature Distribution (°F) RZ Cross-Section at $\theta=90^\circ$ for 3-D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station

Axial Distance (in)	Radial Distance (in)							
	9.84	19.68	52.06	85.77	119.69	153.69	165.14	170.14
0.0	179.99	179.99	179.99	179.99	179.99	179.99	179.99	179.99
9.00	1391.99	1391.99	1391.99	1391.99	1391.99	1391.99	1391.99	1391.99
85.50	1392.01	1392.01	1392.01	1392.01	1392.01	1392.01	1392.01	1392.01
103.00	1415.14	1415.14	1415.14	1415.14	1415.14	1415.14	1415.14	1415.14
120.50	1438.24	1438.24	1438.24	1438.24	1438.24	1438.24	1419.19	1376.63
141.42	1465.85	1465.85	1465.85	1465.85	1465.85	1465.85	1409.94	1285.08
162.33	1493.45	1493.45	1493.45	1493.45	1493.15	1493.45	1416.64	1245.10
167.33	1511.20	1511.20	1533.72	1528.38	1511.20	1511.20	1425.95	1235.54
182.94	1589.75	1589.75	1620.96	1613.56	1589.75	1589.75	1470.98	1205.69
198.55	1627.73	1627.73	1659.68	1652.10	1627.73	1627.73	1487.97	1175.85
214.16	1639.69	1639.69	1671.88	1664.24	1639.69	1639.69	1487.01	1146.00
229.77	1634.66	1634.66	1666.74	1659.13	1634.66	1634.66	1474.30	1116.16
245.38	1619.62	1619.62	1651.41	1643.87	1619.62	1619.62	1454.68	1086.31
276.60	1577.53	1577.53	1608.50	1601.16	1577.53	1577.53	1407.15	1026.63
307.82	1529.45	1529.45	1559.47	1552.35	1529.45	1529.45	1355.48	966.94
339.64	1457.53	1457.53	1486.14	1479.35	1457.53	1457.53	1286.99	906.10
370.26	1319.26	1319.26	1345.15	1339.01	1319.26	1319.26	1173.37	847.56
401.48	1029.15	1029.15	1049.35	1044.56	1029.15	1029.15	954.53	787.87
417.09	789.10	789.10	800.91	798.11	789.10	789.10	779.49	758.02
422.09	762.71	762.71	762.71	762.71	762.71	762.71	758.30	748.46
450.75	700.83	700.83	700.83	700.83	700.83	700.83	698.62	693.67
479.41	638.99	638.99	638.99	638.99	638.99	638.99	638.98	638.97
564.91	638.96	638.96	638.96	638.96	638.96	638.96	638.96	638.96
567.91	178.68	178.68	178.68	178.68	178.68	178.68	178.68	178.68

2.3.1 Basic Assumptions

- (i) The choice of the power distribution to be used for this analysis must be made with special care since slight differences in the subsequent temperature development may make a considerable change in the estimate of the fraction of volumes exceeding the specified temperature criteria. The power distribution is based on a particular choice of time in the life of the reactor for which a radial and axial power distribution is given.
- (ii) The calculational technique assumes that the heat sources are directly related to the power distribution preceding the reactor trip. This results in conservative estimates for the maximum temperatures since the gamma sources actually tend to be deposited over a large volume leading to a more uniform power distribution.
- (iii) Since the redistribution of heat sources due to migration of fission products is not included in this analysis, conservative estimates for the maximum temperatures result.
- (iv) The relative position of each refueling region is preserved in the models since the homogenizing process combined only regions of similar power levels. Conservative estimates on maximum temperatures result as well as a realistic model of the heat flow in the active core.
- (v) Natural convection is not considered in the active core. If natural convection were included, it would have the effect

of redistributing the heat by moving it from the hotter regions to the cooler regions.

- (vi) All the details in the entrance and exit plenums are neglected (such as the orificing system, support posts, etc., thus allowing for less heat transfer across the plenums and out to the liner).
- (vii) All metal parts in the core were neglected in order to simplify the model and the numerical technique. This has very little effect on the temperatures in the core since the thermal properties of these metals are relatively insignificant with respect to the other materials in the core and, therefore, have a negligible effect on the general temperature development in the core.
- (viii) A zone representing the helium bypass has been included as an added resistance to heat leaving the core in the radial direction. The heat flow across this region is by radiation and conduction only.

2.3.2 Geometry

The three-dimensional model represents a quarter of the core with zero heat flux surfaces at the planes $\theta = 0$ and $\theta = 90^\circ$ (Fig. 2.3.1). The "Symmetry" in the choice of the particular quarter of core to be used in the model has to be examined. The power generated in this model should not be under a quarter of the total power generated in the active core. The age-groups should be as closely divided among the four possible age-groups as permitted; and, if this is not possible, weighting toward

		ASSUMED IRRADIATION LIFE (YR)	POSTULATED TIME OF EVENT	NOTE: INTEGERS ARE REFUELING REGION NUMBERS; REAL NUMBERS ARE RADIAL POWER DENSITIES; LETTERS DESIGNATE RELOAD TYPE.
A	RELOAD 1	2		
B	RELOAD 2	1		
C	RELOAD 3	4		
D	RELOAD 4	3		

Fig. 2.3.1. Radial Power Factor Map of Core Showing Portion for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station, Units 1 and 2 (modified from Fig. C.4-1, Ref. 3, Change 8).

the older fuel is recommended. Although the quarter of core model is not a symmetrical segment of the core, it is nevertheless a typical segment whose pattern is closely repeated in the other three segments of the core.

(i) Fig. 2.3.2 represents the RZ cross section of the three-dimensional model through the θ -plane of $\pi/4$ radians. In the radial direction the regions in the midplane are:

1. The composite active core represented by a number of radial regions based on the arrangement depicted in Fig. 2.3.1.
2. The "side reflector" representing the side reflectors, the permanent reflector blocks and the boronated shields.
3. The coolant bypass.
4. The side (Class A) insulation protecting the PCRVR cooling system.

(ii) The regions in the axial direction are:

1. The floor (Class C) insulation protecting the PCRVR cooling system.
2. The coolant exit (bottom) plenum.
3. The core support blocks.
4. The bottom reflector.
5. The composite active core.
6. The top reflector.
7. The coolant entrance (top) plenum.
8. The top (Class A) insulation protecting the PCRVR cooling system.

(iii) Fig. 2.3.3 and 2.3.4 show R θ cross-sections through different Z planes in the model. Fig. 2.3.3 describes the midplane cross-section through the active core.

1. The active core regions represent the different refueling regions in as much detail as is possible (the constraint being the number of nodes used to describe the model). The number in each zone of the active core represents the radial power peaking factor.
2. The "side reflector" which is adjacent to the active core.
3. The coolant bypass.
4. The side (Class A) insulation.

(iv) Fig. 2.5.4 describes an R θ cross-section through the bottom (or top) reflector:

1. The bottom (or top) reflector which is located under (above) the active core.
2. The "side reflector" adjacent to the bottom (top) reflector.
3. The coolant bypass.
4. The side (Class A) insulation.

2.3.3 Materials

The thermal properties of the materials used in the model were obtained in different ways. The materials that could not be shown in detail have equivalent thermal properties, most of which were taken from GAC data (i.e., the composite core material, reflectors, and support blocks) (Ref. 1). Thermal properties of materials found commercially are available from independent sources (i.e., helium, graphite, and the insulation materials).

2.3.4 Boundary Conditions

Based on analysis mentioned previously (Ref. 4), the use of a fixed temperature boundary condition on the boundary representing the liner cooling system was found to be adequate. This temperature represents the maximum allowable temperature in the coolant.

Fig. 2.3.2. RZ Cross-Section at $\theta=45^\circ$ for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station.

ORNL-DWG 75-7604

Fig. 2.3.3. Rθ Cross-Section at Horizontal Midplane for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station.

ORNL-DWG 75-7606R

Fig. 2.3.4. Rθ Cross-Section through Bottom Reflector for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station.

2.3.5 Initial Conditions

The initial temperature distribution in the active core is based on the results given in Section 2.2.3. The initial temperature distribution in the rest of the model is based on data given by the design characteristics and operating conditions of the HTGR in question (Refs. 1, 3, 8).

The power level in the active core following scram of the reactor is described according to the normalized time-dependent decay function as (Ref. 9):

$$f(t) = 0.128(t + 0.0003796)^{-0.261} , \quad (2.4)$$

where t is the time in seconds after scram and the heat generated at a particular point is described by

$$q = q_0 P_{R\theta} P_Z f(t) , \quad (2.5)$$

where

q is the total heat generated,

q_0 is the normal operating average heat generation rate,

$P_{R\theta}$ is the power peaking factor as a function of R and θ , and

P_Z is the power peaking factor as a function of Z .

Thus, the initial power level at a point in the active core is determined by evaluating Eq. (2.5) at $t=0$.

2.4 THE TWO-DIMENSIONAL MODEL

A two-dimensional model was developed as a tool for parametric studies. The three-dimensional model is a very costly model, and thus, its use in either sensitivity studies or program modification test cases is discouraged. An RZ geometry was chosen for the two-dimensional model since heat can leave the core only in the radial and axial directions;

ORNL DWG 76 10932

3-RS-72224 A
4/74

Fig. 2.4.1. Radial Homogeneous Rings for 2D Model, LOFC Accident, Fulton Generating Station (Fig. C.3-1, Ref. 3, Change 8)

therefore, heat flow in the angular direction is of less consequence during the time of interest.

The two-dimensional model describes the power and age-group distribution in less detail. The power distribution in the radial direction is represented by a volumetrically weighted average in each ring of refueling regions as shown in Fig. 2.4.1. Since all fuel elements are of the same dimensions, the computation is as follows:

$$P_i = \frac{\sum_j n_j P_{rj}}{N_i} \quad (2.6)$$

where

- i describes the radial active core region (homogeneous ring) in the model,
- j describes the refueling regions in the homogeneous ring,
- n_j is the number of fuel elements (including the control element) in refueling region "j",
- P_{rj} is the radial power peaking factor in refueling region "j", and
- N_i is the total number of fuel elements in the homogeneous ring.

In the assignment of age-group to a radial active core region, more care must be taken since up to four age-groups may be included in one such region. Judgment must be made whether the equivalence should be expressed by using some mean temperatures to describe the fuel condition or whether the mean age must be weighted in a conservative manner.

3. CODE MODIFICATIONS

The HEATING5 code (Ref. 2) provided a basic tool for the thermal analysis of the HTGR. As a result of the different requirements regarding the LOFC accident, a version of the HEATING5 code was modified to handle the special input parameters and special calculations needed in the

thermal analysis of these accident conditions. This version was named HEATUP.

3.1 EFFECTIVE AXIAL THERMAL CONDUCTIVITY IN THE ACTIVE CORE

Geometric parameters describing the active core configuration are used for the calculation of an effective axial conductivity in the active core. The calculation of the effective conductivity in the axial direction based on the three parallel paths created by the fuel beds, coolant channels and moderator is given by:

$$k_z = \frac{A_f}{A} k_f + \frac{A_c}{A} k_c + \frac{A_m}{A} k_m, \quad (3.1)$$

where

k_z is the axial thermal conductivity of the composite core material,

k_f, k_c, k_m are the axial thermal conductivities of the fuel, coolant and moderator, respectively,

A is the total R0 cross-sectional area of the active core, and

A_f, A_c, A_m are the R0 cross-sectional areas of the fuel, coolant and moderator, respectively.

All the thermal conductivities can be temperature dependent.

To perform this calculation, the user must provide some parameters describing the active core horizontal cross section. These parameters are as follows:

N_s is the total number of fuel element stacks.

N_b is the total number of fuel beds in the R0 cross section of the active core.

- N_c is the total number of coolant channels in the R0 cross section of the active core.
- R_f is the radius of a fuel bed,
- R_c is the radius of a coolant hole,
- S is the length of a side of a hexagonal fuel element.

The computation of the area is as follows:

Area of one fuel element stack:

$$A_s = 3 \times S^2 \times \cos(30^\circ), \quad (3.2)$$

total cross-section area

$$A = A_s \times N_s, \quad (3.3)$$

total cross-sectional area of fuel beds

$$A_f = N_b \times (\pi \times R_f^2), \quad (3.4)$$

total cross-sectional area of coolant holes:

$$A_c = N_c \times (\pi \times R_c^2), \quad (3.5)$$

total cross-sectional area of the moderator

$$A_m = A - A_f - A_c. \quad (3.6)$$

For output purposes, the fractional area of the different components are converted to percent of the total horizontal cross-sectional area of the active core.

3.2 ANISOTROPIC THERMAL CONDUCTIVITIES IN R AND Z DIRECTIONS

The code was modified to calculate different thermal conductivities as a function of R and Z for up to twenty materials. The regular entry in the input is considered for the R direction and a special tabular entry is made for the Z direction. No analytical function is allowed in the Z direction when this option is used.

3.3 FUEL CONDITION AS A FUNCTION OF LIFETIME IN THE ACTIVE CORE

Each age-group must be described by a different material number. "Age-group" is defined here as all of the refueling regions that were loaded into the active core at the same time and therefore has spent the same length of time in the active core. The material number for which such an age-group can be defined cannot exceed four. For each material that is specified as describing a unique age-group, a set of three temperature criteria must be supplied. These temperature criteria are then used to compute the percentage by volume of a particular age-group that exceeded each of the three criteria. The loop shown in Fig. 3.3.1 describes the following sets of computations:

- (i) The fraction of age-group ($j = 1, \dots, \text{number of age-groups}$) exceeding temperature criteria T_{1j} , T_{2j} , and T_{3j} :

$$\frac{\sum_m v_m}{V_j} ; \frac{\sum_n v_n}{V_j} ; \frac{\sum_l v_l}{V_j} , \quad (3.7)$$

where

- m is a node in age-group j whose temperature exceeds criterion T_{1j} ,
- n is a node in age-group j whose temperature exceeds criterion T_{2j} ,
- l is a node in age-group j whose temperature exceeds criterion T_{3j} ,
- v_m, v_n, v_l are the volumes associated with nodes m, n, l , respectively,
- v_j is the total volume associated with age-group " j ", and
- T_{1j}, T_{2j}, T_{3j} are the three temperature criteria associated with age-group " j ".

Fig. 3.3.1. Flow Chart of Coding which Calculates Percentage by Volume of a Particular Age-Group which Exceeds the Temperature Criteria.

- (ii) The fraction of the active core exceeding the temperature criteria T_{1j} , T_{2j} , and T_{3j} :

$$\frac{\sum_j V_{1j}}{V} ; \frac{\sum_j V_{2j}}{V} ; \frac{\sum_j V_{3j}}{V} \quad j = 1, 2, \dots \text{ numbers of age-groups represented in the model,} \quad (3.8)$$

V_{1j} is the volume of age-group "j" exceeding T_{1j} ,

V_{2j} is the volume of age-group "j" exceeding T_{2j} ,

V_{3j} is the volume of age-group "j" exceeding T_{3j} , and

V is the total volume of the active core.

The results of Eq. (3.8), however, have meaning only when the respective temperature criteria for each age-group represent the same condition of the fuel; i.e., T_{11} , T_{12} , T_{13} , and T_{14} represent the same fuel condition in all these age-groups.

For purposes of output, all these fractional values are converted to percentages.

4. INPUT PREPARATION

In addition to the input data required by HEATING5, the HEATUP code requires a number of additional data cards as described in this section. An outline of the format of the input data is presented in Table 4.1. In addition to the description presented in this section, a detailed description of the remaining input data is presented in Ref. 2. A sample problem based on the three-dimensional model for the Fulton Generating Station is used for a detailed description of input data preparation. This sample problem is presented in Section 5. Table A.1 represents the actual form of the input data for the sample problem.

[illegible]

Heat transfer	Dist. $h_0 = P_0$	Live coefficient, h_0	Dist. positive if	no additional
Heat transfer			Dist. positive if	no additional

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9
1	2	3	4	5	6	7	8	9
10	11	12	13	14	15	16	17	18
19	20	21	22	23	24	25	26	27
28	29	30	31	32	33	34	35	36
37	38	39	40	41	42	43	44	45
46	47	48	49	50	51	52	53	54
55	56	57	58	59	60	61	62	63
64	65	66	67	68	69	70	71	72
73	74	75	76	77	78	79	80	81
82	83	84	85	86	87	88	89	90
91	92	93	94	95	96	97	98	99
100	101	102	103	104	105	106	107	108
109	110	111	112	113	114	115	116	117
118	119	120	121	122	123	124	125	126
127	128	129	130	131	132	133	134	135
136	137	138	139	140	141	142	143	144
145	146	147	148	149	150	151	152	153
154	155	156	157	158	159	160	161	162
163	164	165	166	167	168	169	170	171
172	173	174	175	176	177	178	179	180
181	182	183	184	185	186	187	188	189
190	191	192	193	194	195	196	197	198
199	200	201	202	203	204	205	206	207
208	209	210	211	212	213	214	215	216
217	218	219	220	221	222	223	224	225
226	227	228	229	230	231	232	233	234
235	236	237	238	239	240	241	242	243
244	245	246	247	248	249	250	251	252
253	254	255	256	257	258	259	260	261
262	263	264	265	266	267	268	269	270
271	272	273	274	275	276	277	278	279
280	281	282	283	284	285	286	287	288
289	290	291	292	293	294	295	296	297
298	299	300	301	302	303	304	305	306
307	308	309	310	311	312	313	314	315
316	317	318	319	320	321	322	323	324
325	326	327	328	329	330	331	332	333
334	335	336	337	338	339	340	341	342
343	344	345	346	347	348	349	350	351
352	353	354	355	356	357	358	359	360
361	362	363	364	365	366	367	368	369
370	371	372	373	374	375	376	377	378
379	380	381	382	383	384	385	386	387
388	389	390	391	392	393	394	395	396
397	398	399	400	401	402	403	404	405
406	407	408	409	410	411	412	413	414
415	416	417	418	419	420	421	422	423
424	425	426	427	428	429	430	431	432
433	434	435	436	437	438	439	440	441
442	443	444	445	446	447	448	449	450
451	452	453	454	455	456	457	458	459
460	461	462	463	464	465	466	467	468
469	470	471	472	473	474	475	476	477
478	479	480	481	482	483	484	485	486
487	488	489	490	491	492	493	494	495
496	497	498	499	500	501	502	503	504
505	506	507	508	509	510	511	512	513
514	515	516	517	518	519	520	521	522
523	524	525	526	527	528	529	530	531
532	533	534	535	536	537	538	539	540
541	542	543	544	545	546	547	548	549
550	551	552	553	554	555	556	557	558
559	560	561	562	563	564	565	566	567
568	569	570	571	572	573	574	575	576
577	578	579	580	581	582	583	584	585
586	587	588	589	590	591	592	593	594
595	596	597	598	599	600	601	602	603
604	605	606	607	608	609	610	611	612
613	614	615	616	617	618	619	620	621
622	623	624	625	626	627	628	629	630
631	632	633	634	635	636	637	638	639
640	641	642	643	644	645	646	647	648
649	650	651	652	653	654	655	656	657
658	659	660	661	662	663	664	665	666
667	668	669	670	671	672	673	674	675
676	677	678	679	680	681	682	683	684
685	686	687	688	689	690	691	692	693
694	695	696	697	698	699	700	701	702
703	704	705	706	707	708	709	710	711
712	713	714	715	716	717	718	719	720
721	722	723	724	725	726	727	728	729
730	731	732	733	734	735	736	737	738
739	740	741	742	743	744	745	746	747
748	749	750	751	752	753	754	755	756
757	758	759	760	761	762	763	764	765
766	767	768	769	770	771	772	773	774
775	776	777	778	779	780	781	782	783
784	785	786	787	788	789	790	791	792
793	794	795	796	797	798	799	800	801
802	803	804	805	806	807	808	809	810
811	812	813	814	815	816	817	818	819
820	821	822	823	824	825	826	827	828
829	830	831	832	833	834	835	836	837
838	839	840	841	842	843	844	845	846
847	848	849	850	851	852	853	854	855
856	857	858	859	860	861	862	863	864
865	866	867	868	869	870	871	872	873
874	875	876	877	878	879	880	881	882
883	884	885	886	887	888	889	890	891
892	893	894	895	896	897	898	899	900
901	902	903	904	905	906	907	908	909
910	911	912	913	914	915	916	917	918
919	920	921	922	923	924	925	926	927
928	929	930	931	932	933	934	935	936
937	938	939	940	941	942	943	944	945
946	947	948	949	950	951	952	953	954
955	956	957	958	959	960	961	962	963
964	965	966	967	968	969	970	971	972
973	974	975	976	977	978	979	980	981
982	983	984	985	986	987	988	989	990
991	992	993	994	995	996	997	998	999
1000	1001	1002	1003	1004	1005	1006	1007	1008
1009	1010	1011	1012	1013	1014	1015	1016	1017
1018	1019	1020	1021	1022	1023	1024	1025	1026
1027	1028	1029	1030	1031	1032	1033	1034	1035
1036	1037	1038	1039	1040	1041	1042	1043	1044
1045	1046	1047	1048	1049	1050	1051	1052	1053
1054	1055	1056	1057	1058	1059	1060	1061	1062
1063	1064	1065	1066	1067	1068	1069	1070	1071
1072	1073	1074	1075	1076	1077	1078	1079	1080
1081	1082	1083	1084	1085	1086	1087	1088	1089
1090	1091	1092	1093	1094	1095	1096	1097	1098
1099	1100	1101	1102	1103	1104	1105	1106	1107
1108	1109	1110	1111	1112	1113	1114	1115	1116
1117	1118	1119	1120	1121	1122	1123	1124	1125
1126	1127	1128	1129	1130	1131	1132	1133	1134
1135	1136	1137	1138	1139	1140	1141	1142	1143
1144	1145	1146	1147	1148	1149	1150	1151	1152
1153	1154	1155	1156	1157	1158	1159	1160	1161
1162	1163	1164	1165	1166	1167	1168	1169	1170
1171	1172	1173	1174	1175	1176	1177	1178	1179
1180	1181	1182	1183	1184	1185	1186	1187	1188
1189	1190	1191	1192	1193	1194	1195	1196	1197
1198	1199	1200	1201	1202	1203	1204	1205	1206
1207	1208	1209	1210	1211	1212	1213	1214	1215
1216	1217	1218	1219	1220	1221	1222	1223	1224
1225	1226	1227	1228	1229	1230	1231	1232	1233
1234	1235	1236	1237	1238	1239	1240	1241	1242
1243	1244	1245	1246	1247	1248	1249	1250	1251
1252	1253	1254	1255	1256	1257	1258	1259	1260
1261	1262	1263	1264	1265	1266	1267	1268	1269
1270	1271	1272	1273	1274	1275	1276	1277	1278
1279	1280	1281	1282	1283	1284	1285	1286	1287
1288	1289	1290	1291	1292	1293	1294	1295	1296
1297	1298	1299	1300	1301	1302	1303	1304	1305
1306	1307	1308	1309	1310	1311	1312	1313	1314
1315	1316	1317	1318	1319	1320	1321	1322	1323
1324	1325	1326	1327	1328	1329	1330	1331	1332
1333	1334	1335	1336	1337	1338	1339	1340	1341
1342	1343	1344	1345	1346	1347	1348	1349	1350
1351	1352	1353	1354	1355	1356	1357	1358	1359
1360	1361	1362	1363	1364	1365	1366	1367	1368
1369	1370	1371	1372	1373	1374	1375	1376	1377
1378	1379	1380	1381	1382	1383	1384	1385	1386
1387	1388	1389	1390	1391	1392	1393	1394	1395
1396	1397	1398	1399	1400	1401	1402	1403	1404
1405	1406	1407	1408	1409	1410	1411	1412	1413
1414	1415	1416	1417	1418	1419	1420	1	

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[illegible]

Table 8.1 is the computer printout of a run executed by HEATUP and contains a tabulation of the input data, the temperature distribution maps and a table showing the percentage by volume of active core that exceeds specified temperatures.

HEATUP is not designed to solve a problem involving change of phase calculations. As with HEATING5, units for input data may be in any system so long as they are consistent. Temperature units must be in either degrees Fahrenheit or Celsius.

4.1 CARD DESCRIPTION

To fully describe the LOFC problem in a given reactor, the following additional cards must be supplied:

a. General Parameter Card (Card 1a)

This card comes after the TITLE card (Card 1).

- (i) Columns 1 - 9: inactive
- (ii) Columns 10 - 18: total number of materials that have additional information associated with them; up to 20 materials are allowed to have other information than the regular entries accepted by the HEATING5 code. This entry is an integer.

b. Anisotropic (or Effective) Axial Conductivity Card (Card M2)

All the entries on this card are integers. There must be as many materials with this card added as specified in the first parameter card (e.g., if the second entry in Card 1a is 7, then the first seven materials must have Card M2 as well). The M2 card follows the M card.

- (i) The first entry specifies whether the material has the axial conductivity tabulated separately or whether an effective conductivity must be computed for a composite material as described in Section 3.1. The latter option is allowed for the first four materials only.

-1 indicates the axial conductivity of the composite active core must be input in tabular form.

1 indicates a code-generated effective axial conductivity using input data.

- (ii) For the case in which the first entry is "-1", the second entry contains the table number for the axial, temperature-dependent conductivity of the material. For the case in which the first entry is "1", the second entry contains the table number of the axial, temperature-dependent conductivity of the fuel.

NOTE: The table number may be the same as that for the thermal conductivity for the radial direction.

- (iii) The third entry is active only when an effective conductivity is to be calculated and contains the table number of the axial, temperature-dependent conductivity of the coolant.

- (iv) The fourth entry is active only when an effective conductivity is to be calculated and contains the table number of the axial, temperature-dependent conductivity of the moderator.

NOTE: All table numbers in these entries must follow the general convention of the HEATING5 code; they, therefore, appear as negative integers. There can be up to a maximum of 20 materials with axial conductivities and up to a maximum of four materials with effective axial conductivities calculated, based on the parallel paths described in Section 3.1. Since these tables are dimensioned by the material identification number, the material numbers cannot exceed 20 or 4 as the case may be.

- (v) The fifth entry is read only for the first four materials and specifies whether this material describes an age-group of fuel in the active core.

1 - an age-group is described and temperature criteria will be supplied,

blank - no age-group associated with this material.

Entries (vi, vii, and viii) of this card are inactive.

c. Core Geometric Description Card (Card M3)

All entries in this card are floating point numbers. Card M3 appears after the M2 card.

NOTE: This card appears only after the first time the first entry of the previous card is "1"; i.e., the first time it is indicated that an effective conductivity in the active core is to be calculated.

- (i) This entry contains the total number of fuel element stacks in the active core including the control element stacks and the fuel element stacks in incomplete refueling regions.
- (ii) This entry contains the total number of fuel beds (fuel holes) in the R0 cross section of the active core, computed as follows:

$$N_{fb} = n_c \times N_{ce} + n_r \times N_{re} , \quad (4.1)$$

where

- N_{fb} is the total number of fuel beds in the R0 cross section of the active core,
  - n_c is the number of fuel beds in one control element,
  - n_r is the number of fuel beds in one regular fuel element,
  - N_{ce} is the total number of control element stacks in the active core, and
  - N_{re} is the total number of regular fuel element stacks in the active core.
- (iii) This entry contains the total number of coolant channels in the R0 cross section of the active core. This is computed similarly to the previous entry:

$$N_{cc} = n_c \times N_{ce} + n_r \times N_{re} , \quad (4.2)$$

where

N_{CC} is the total number of coolant channels in the R_0 cross section of the active core,

n_C is the number of coolant channels in one control element, and

n_r is the number of coolant channels in one regular fuel element.

(iv) This entry contains the radius of a single fuel bed.

(v) This entry contains the radius of a single coolant channel.

(vi) This entry contains the dimension of one side of the hexagonal fuel element.

Entries (vii) and (viii) are inactive.

d. Temperature Criteria Card (Card M4)

The temperature criteria card is supplied only if it was indicated in Card M2 that an age-group is represented by this material. All entries in this card are floating point numbers. Three temperature criteria are expected for each material, and they must be supplied in ascending order. Card M4 follows Card M2 or Card M3 when it is present.

(i) This entry contains the lowest temperature criterion to be considered for this material.

(ii) This entry contains an intermediate value of the temperature criterion to be considered.

(iii) This entry contains the highest value of the temperature criterion to be considered.

4.2 JCL INFORMATION FOR THE ORNL COMPUTING CENTER

The set of JCL card images in Fig. 4.1 describes the problem as it would be run on the 360/91 machine at ORNL.

This particular set of JCL also contains a FORTRAN deck of the main routine which is used for a problem that involves more than 1075 nodes (the maximum number allowed without overriding the dimensions for the program stored on the disk). It also has JCL cards specifying unit 8 as a 9-track tape. This unit was specified in the input as the unit number where the output needed for plots is to be stored. These cards can be omitted if it is not desired to save this information. The JCL specifying unit 7 describes the unit where the last temperature distribution is to be stored for the purpose of continuing the problem in another run. In this set, it is the standard punch unit but it may be specified as any other unit (i.e., the PDP-10, a scratch disk, etc). The JCL for unit 15 has to be supplied since this is the unit number where the table of "percentage by volume of the active core..." is to be written. This unit can also be specified to be other than a printer.

NOTE:

- 1) The order of linking the stored object module is important since "ANISGT" overrides subroutines in "HTN4HTGR".
- 2) User-supplied subroutines have to appear first in the LKED step if they are in object module form; otherwise they appear in the FORT step.

```

//ABC JOB 12345,'IDENTIFICATION ',
/*CLASS REGION=1350K,CPU=20M,LINES=15,SPECIAL=TAPE
/*ROUTE XEQ CPU1
//HEATUP EXEC FORTHCLG,REGION.GO=1350K,TIME.GO=20.
// PARM.GO='EU'-1'
//FORT.SYSPRINT DD DUMMY
//FORT.SYSIN DD *
C The following FORTRAN statements are designed to override the dimensions
C specified on the disk version which allows up to 1075 nodes in the
C problem.
C N - the total number of nodes
C CORE(34 x N) is the dimension
      INTEGER N/3800/
      REAL*8 CORE(129200)
      INTEGER*2 ICORE(1)
      EQUIVALENCE (CORE(1), ICORE(1))
      CALL HEATN4(CORE,ICORE,N)
      STOP
      END
/*
//LKED.FT32F001 DD DISP=SHR,
// DSN=ONLINEA.ISTHD845.ANISOT
//LKED.FT33F001 DD DISP=SHR,
//DSN=ONLINEA.WDT13845.HTN4HTGR
//LKED.SYSIN DD *
      INCLUDE FT32F001
      INCLUDE FT33F001
/*

```

Fig. 4.1. Format of JCL to Run HEATUP at ORNL When Overriding Maximum Number of Nodes Allowed, Create Plot Data Set, Save Final Temperature Distribution.

```
//GO.FT15F001 DD SYSOUT=A,DCB=(RECFM=FBA,LRECL=133,BLKSIZE=3458)
//GO.FT08F001 DD UNIT=TAPE9,DISP=OLD,VOLUME=SER=08,LABEL=(,NL),
// DCB=(RECFM=VBS,LRECL=3620,BLKSIZE=3624)
//GO.FT07F001 DD SYSOUT=B
//GO.FT06F001 DD SYSOUT=A
//GO.FT05F001 DD *
      data
/*
//
```

Fig. 4.1. (contd.)

```

//ABC JOB 12345,'IDENTIFICATION  ',
/*CLASS REGION=540K,CPU=5M,LINES=15
/*ROUTE XEQ CPU1
//HEATUP EXEC FORTHLG,PARM.GO='EU=-1'
//LKED.FT33F001 DD DISP=SHR,
// DSN=ONLINEA.ISTHD845.ANISOT
//LKED.FT34F001 DD DISP=SHR,
// DSN=ONLINEA.WDT13845.HTN4HTGR
//LKED.SYSIN DD *
  INCLUDE FT33F001
  INCLUDE FT34F001
/*
//GO.FT15F001 DD SYSOUT=A,DCB=(RECFM=LRECL=133,BLKSIZE=3458)
//GO.FT06F001 DD SYSOUT=A
//GO.FT05F001 DD *
      data
/*
//

```

Fig. 4.2. Basic Format of JCL to Run HEATUP at ORNL.

4.3 VARYING CORE REQUIRED BY HEATUP

The main routine in the HEATUP code is designed to allocate the amount of core required to solve a problem as a function of the maximum number of nodes allowed. If a version of the code stored on a direct access device is used, the user can tailor the amount of core required by a model by overriding the main routine in the manner as presented in Fig. 4.1.

The set of JCL cards depicted in Fig. 4.2 is designed to run a problem on the 360/91 using the disk version only.

This JCL will not store output for plotting or the last temperature distribution for continuation of the problem. If the input data contains assigned units for either option, an error message will result.

5. SAMPLE PROBLEM - THREE-DIMENSIONAL FULTON GENERATING STATION MODEL

The Fulton Generation Station LOFC accident was used as a sample problem. A description of the model and the related data used to solve the problem is presented in this section. A listing of the input data required to solve the problem on HEATUP is presented in Appendix A.

The problem was solved in an R3Z geometry. Figures 5.1 through 5.6 show the definitions of the regions and the boundary conditions. The units are Btu, °F, lbm, in, and hrs.

5.1 REGION DESCRIPTION

The geometric definition of the regions and the materials of which they consist are listed in Table 5.1.1.

5.2 MATERIAL THERMAL PROPERTIES

The properties of the materials listed in Table 5.1.1 are presented in Tables 5.2.1 through 5.2.6.

5.3 HEAT GENERATION DESCRIPTION IN THE ACTIVE CORE

The Fulton Generating Station generates a power of 3000 Mw(th). For the thermal analysis of this accident, power was assumed to be at 105%. This power was divided by the entire active core volume so that an average volumetric heat generation rate of $502.22 \text{ Btu}/(\text{hr-in}^3)$ was computed.

The time-dependent power decay function is given by Eq. (2.5).

The R_0 distribution of the power-peaking factors is shown in Fig. 2.3.1, and the axial distribution is given in Table 5.3.1.

Fig. 5.1. Region and Boundary Condition Description in RZ Cross-Section at $\theta=45^\circ$ for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station.

ORNL-DWG 75-7605R

Fig. 5.2. Region and Boundary Condition Description With Age Group Identification Numbers in R₀ Cross-Section at Horizontal Midplane for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station.

ORNL-DWG 75-7610R

Fig. 5.3. Region and Boundary Condition Description in Rθ Cross-Section Through Bottom (top) Plenum for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station.

ORNL-DWG 75-7608

Fig. 5.4. Region and Boundary Condition Description in Rθ Cross-Section Through Core Support Blocks for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station.

ORNL-DWG 75-7607R

Fig. 5.5. Region and Boundary Condition Description in R θ Cross-Section Through Bottom (top) Reflector for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station.

ORNL-DWG 75-7609R

Fig. 5.6. Region and Boundary Condition Description in Rθ Cross-Section Through Bottom (top) Insulation for 3D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station.

Table 5.1.1. Description of Regions for 3-D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station

Region Number	Material Name	Inner-R (inch)	Outer-R (inch)	Left θ (radian)	Right θ (radian)	Bottom-Z (inch)	Top-Z (inch)
1	Composite	0.0	19.68	0.0	1.5715	167.33	417.09
2	Composite	19.68	52.06	0.0	0.5238	167.33	417.09
3	Composite	19.68	52.06	0.5238	1.5715	167.33	417.09
4	Composite	52.06	85.77	0.0	0.2619	167.33	417.09
5	Composite	52.06	85.77	0.2619	0.7857	167.33	417.09
6	Composite	52.06	85.77	0.7857	1.3095	167.33	417.09
7	Composite	52.06	85.77	1.3095	1.5715	167.33	417.09
8	Composite	85.77	119.69	0.0	0.1746	167.33	417.09
9	Composite	85.77	119.69	0.1746	0.5238	167.33	417.09
10	Composite	85.77	119.69	0.5238	0.8730	167.33	417.09
11	Composite	85.77	119.69	0.8730	1.5715	167.33	417.09
12	Composite	119.69	153.69	0.0	0.3929	167.33	417.09
13	Composite	119.69	153.69	0.3929	0.6548	167.33	417.09
14	Composite	119.69	153.69	0.6548	1.1785	167.33	417.09
15	Composite	119.69	153.69	1.1785	1.4405	167.33	417.09
16	Composite	119.69	153.69	1.4405	1.5715	167.33	417.09
17	Composite	153.69	165.14	0.0	1.5715	167.33	417.09
18	Side reflector	165.14	216.89	0.0	1.5715	120.50	479.41
19	Helium	216.89	228.89	0.0	1.5715	85.50	479.41
20	Helium	19.68	228.89	0.0	1.5715	9.00	85.50
21	Helium	19.68	228.89	0.0	1.5715	479.41	564.91
22	Support block	0.0	216.89	0.0	1.5715	85.50	120.50
23	Bottom reflector	0.0	165.14	0.0	1.5715	120.50	167.33
24	Top reflector	0.0	165.14	0.0	1.5715	417.09	479.41
25	Class C insulation	19.68	228.89	0.0	1.5715	0.0	9.0
26	Kaowool	228.89	228.89	0.0	1.5715	85.50	479.41
27	Kaowool	19.68	228.89	0.0	1.5715	564.91	567.91
28	Helium*	0.0	19.68	0.0	1.5715	9.0	85.50
29	Helium*	0.0	19.68	0.0	1.5715	479.41	564.91
30	Class C insulation*	0.0	19.68	0.0	1.5715	0.0	9.0
31	Kaowool*	0.0	19.68	0.0	1.5715	564.91	567.91

* Helium, Class C insulation, and Kaowool with specific heat multiplied by a factor of 10.

Table 5.2.1. Temperature-Dependent Properties of Composite Core Material,
3-D, Quarter-of-Core Model, LOFC Accident, Fulton Generating
Station

Temperature °F	RO Conductivity (Btu./hr-in.-°F)	Density (lbm/in)	Specific Heat (Btu/lbm-°F)
500	0.3275	0.0527	0.255
1000	0.4235		0.34
1500	0.4878		0.39
2000	0.5692		0.41
2500	0.6694		
3000	0.7523		0.44
3500	0.8106		
4000	0.8746		0.45
4500	0.9389		
5000	0.9775		
5500	0.9701		
6000	0.8774		
6500	0.7140		
7000	0.3281		

Table 5.2.2. Thermal Conductivities of Materials Used to Compute Effective Axial Thermal Conductivity of Active Core

Material	Temperature (°F)	Conductivity (Btu/hr-in-°F)
Graphite	500.0	1.3333
	1000.0	1.8750
	1500.0	2.1250
	2000.0	2.2917
	2500.0	2.3750
	3000.0	2.3750
	3500.0	2.2500
	4000.0	2.0830
	4500.0	1.8750
	5000.0	1.6670
	5500.0	1.3750
	6000.0	1.0420
Helium	1472.0	0.01833
	1562.0	0.01893
	1652.0	0.01952
	1742.0	0.02011
	1832.0	0.02069
	1922.0	0.02125
	2012.0	0.02183
	2102.0	0.02239
	2192.0	0.02295
	2282.0	0.02350
	2372.0	0.02404
	2462.0	0.02458
	2552.0	0.02512
	2642.0	0.02565
	2732.0	0.02618
Fuel	Any Temperature	0.2500

Table 5.2.3 Temperature Dependent Properties of the Side Reflector

Temperature (°F)	Rθ Conductivity (Btu/hr-in-°F)	Z Conductivity (Btu/hr-in-°F)	Density (lbm/in ³)	Specific Heat (Btu/lbm-°F)
500	0.327487		0.06192	0.295
1000	0.423523	1.5104		0.39
1500	0.487776	1.7708		0.435
2000	0.569188	1.8750		0.465
2500	0.669443	2.0625		
3000	0.752273	2.2708		0.5
3500	0.810588	2.3125		
4000	0.874567	2.4323		0.515
4500	0.938860	2.5729		
5000	0.977472	2.75		
5500	0.970125	2.9167		
6000	0.877358	3.1563		
6500	0.713995	3.3854		
7000	0.328090	3.8854		

Table 5.2.4. Temperature Dependent Properties of Helium

Temperature (°F)	Thermal Conductivity (Btu/hr-in-°F)	Density (lbm/in ³)	Specific Heat (Btu/lbm-°F)
572.0	0.01174	3.0386E-6	1.2425
662.0	0.01246	2.7950E-6	
752.0	0.01316	2.5873E-6	
842.0	0.01385	2.4086E-6	
932.0	0.01452	2.2526E-6	
1022.0	0.01518	2.1158E-6	
1112.0	0.01583	1.9950E-6	
1202.0	0.01647	1.8868E-6	
1292.0	0.01710	1.7898E-6	
1382.0	0.01772	1.7026E-6	
1472.0	0.01833	1.6230E-6	
1562.0	0.01893	1.5509E-6	
1652.0	0.01952	1.4847E-6	
1742.0	0.02011	1.4239E-6	
1832.0	0.02069	1.3682E-6	
1922.0	0.02126	1.3165E-6	
2012.0	0.02183	1.2687E-6	
2102.0	0.02239	1.2238E-6	
2192.0	0.02295	1.1826E-6	
2282.0	0.02350	1.1435E-6	
2372.0	0.02404	1.1073E-6	
2462.0	0.02458	1.0733E-6	
2552.0	0.02512	1.0411E-6	
2642.0	0.02565	1.0110E-6	
2732.0	0.02618	0.9825E-6	

**Table 5.2.5 Temperature Dependent Properties of the Support Blocks,
Bottom Reflector and Top Reflectors**

Bottom and Top Reflectors				
Temperature (°F)	Rθ Conductivity (Btu/hr-in-°F)	Z Conductivity (Btu/hr-in-°F)	Density (lbm/in³)	Specific Heat (Btu/lbm-°F)
1000	0.6042	1.5104	0.04919	0.34
1500	0.8542	1.7708		0.39
2000	1.1250	1.8750		0.41
2500	1.4375	2.0625		
3000	1.7083	2.2708		0.44
3500	1.8646	2.3125		
4000	1.8438	2.4323		0.45
4500	1.7292	2.5729		
Support Blocks				
Temperature (°F)	Rθ Conductivity (Btu/hr-in-°F)	Z Conductivity (Btu/hr-in-°F)	Density (lbm/in³)	Specific Heat (Btu/lbm-°F)
0	1.025		0.05382	0.115
500				0.255
1000		1.5104		0.34
1500		1.7708		0.39
2000		1.8750		0.41
2500		2.0625		
3000		2.2708		0.44
3500		2.3125		
4000		2.4323		0.45

Table 5.2.6. Temperature Dependent Properties of the Insulation Materials

Class C

Temperature (°F)	R0 Conductivity (Btu/hr-in-°F)	Density (lbm/in)	Specific Heat (Btu/lbm-°F)
500	0.0182	0.06944	0.24
1000	0.0300		
1500	0.0396		
2000	0.0517		
2500	0.0625		
3000	0.0733		

Kaowool

Temperature (°F)	R0 Conductivity (Btu/hr-in-°F)	Density (lbm/in)	Specific Heat (Btu/lbm-°F)
0	0.008	0.00694	0.26
500	0.012		
1000	0.016		
1500	0.026		
2000	0.042		
2500	0.066		
3000	0.096		

Table 5.3.1. Axial Power Factors for Two-Dimensional and Three-Dimensional Models, LOFC Accident, Fulton Generating Station

Lower Z (in.)	Upper Z (in.)	Axial Power Factor
385.87	417.09	1.03
354.65	385.87	1.08
323.43	354.65	1.14
292.21	323.43	1.17
260.99	292.21	1.01
229.77	260.99	0.97
198.55	229.77	0.90
167.33	198.55	0.67

5.4 INITIAL TEMPERATURE DISTRIBUTION

The initial conditions were assumed to be those present at 30 seconds after the onset of the LOFC plus scram. The temperature distribution assumed to exist at that time is given in Table 5.4.1.

5.5 BOUNDARY CONDITIONS

The boundary conditions indicated in Figs. 5.1 and 5.6 are defined in Table 5.5.1.

Table 5.4.1. Initial Temperature Distribution for 3-D, Quarter-of-Core Model, LOFC Accident, Fulton Generation Station

Regions	T_o (°F)	$f(R)$	$F(Z)$
1, 3, 4, 5, 6 9, 11, 13, 16, 17	1500		Equation (2.3)
2, 7, 8, 10, 15	1550		Equation (2.3)
12, 14	1450		Equation (2.3)
18, 19	639		$2.4342 - 0.002992Z$
20, 28	1392		
21, 29	639		
22, 23	1500		$0.8528 + 0.0008799Z$
24	639		$2.6198 - 0.003379Z$
25, 30	1392		$0.1293 + 0.09674Z$
26	1015	$62.94356 - 0.27422R$	
27, 31	639		$136.26 - 0.23944Z$

Table 5.5.1. Boundary Conditions for 3-D, Quarter-of-Core Model, LOFC Accident, Fulton Generating Station

Number	Boundary Condition Description	Expression (Btu/hr-in ² -°R ⁴)
1	Fixed surface temperature of 180°F represents the water-cooled liner	
2	Surface-to-surface radiation between parallel disks of diameter d separated by distance x (Ref. 10). $d/x = 5.354$, $F_{1-2} = 0.68$, $h_r = \sigma F_{1-2}$	$h_r = 8.094 \times 10^{-12}$
3	Surface-to-surface radiation between 2 infinitely long axisymmetrical cylinders having radii r_1 and r_2 . $h_r = \frac{\sigma}{\frac{1}{\epsilon_1} + \frac{r_1}{r_2} (\frac{1}{\epsilon_2} - 1)}$ $\epsilon_1 = 0.7$ $r_1 = 216.89$ $r_2 = 225.89$	$h_r = 6.469 \times 10^{-12}$
4	Surface-to-surface radiation between parallel disks of diameter d separated by distance x (Ref. 10). $d/x = 5.984$, $F_{1-2} = 0.71$, $h_r = \sigma F_{1-2}$	$h_r = 8.451 \times 10^{-12}$

REFERENCES

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8. Summit Power Station, Preliminary Safety Analysis Report, Delmarva Power and Light Company.
9. R. W. Schleicher, et al., An Analysis of HTGR Core Cooling Capability, Gulf-GA-A12504 (GA-LTR-1), March, 1973.
10. J. P. Holman, Heat Transfer, 3rd ed., p. 249, 262, McGraw-Hill, New York, 1972.

APPENDIX A

Listing of Input Data for HEATUP Sample Problem

FTER LOFC ACCIDENT - FULTON POWER STATION(3000MW(T)) 3D.MOEL

600	7	31	13		17	25	
11	12	19	25	19		1	
	30	8	1			7	
-1				0.001	40		3.0
1	2	0.0	19.68	0.0	1.5715	167.33	417.09
1	1						
2	1	19.68	52.06	0.0	0.5238	167.33	417.09
2	2						
3	4	19.68	52.06	0.5238	1.5715	167.33	417.09
3	3						
4	2	52.06	85.77	0.0	0.2619	167.33	417.09
4	4						
5	3	52.06	85.77	0.2619	0.7857	167.33	417.09
5	5						
6	2	52.06	85.77	0.7857	1.3095	167.33	417.09
6	6						
7	1	52.06	85.77	1.3095	1.5715	167.33	417.09
7	7						
8	1	85.77	119.69	0.0	0.1746	167.33	417.09
8	8						
9	4	85.77	119.69	0.1746	0.5238	167.33	417.09
9	9						
10	1	85.77	119.69	0.5238	0.8730	167.33	417.09
10	10						
11	4	85.77	119.69	0.8730	1.5715	167.33	417.09
11	11						
12	3	119.69	153.69	0.0	0.3929	167.33	417.09
12	12						
13	2	119.69	153.69	0.3929	0.6548	167.33	417.09
13	13						
14	3	119.69	153.69	0.6548	1.1785	167.33	417.09
14	14						
15	1	119.69	153.69	1.1785	1.4405	167.33	417.09
15	15						
16	2	119.69	153.69	1.4405	1.5715	167.33	417.09
16	16						
17	4	153.69	165.14	0.0	1.5715	167.33	417.09
17	17						
18	5	165.14	216.89	0.0	1.5715	120.50	479.41
18							
19	8	216.89	225.89	0.0	1.5715	85.5	479.41
18	3		3				
20	8	19.68	228.89	0.0	1.5715	9.0	85.5
19						4	4
21	8	19.68	228.89	0.0	1.5715	479.41	564.91
20						2	2
22	6	0.0	216.89	0.0	1.5715	85.5	120.5
21							

23	7	0.0	165.14	0.0	1.5715	120.5	167.33
21							
24	7	0.0	165.14	0.0	1.5715	417.09	479.41
22							
25	9	19.68	228.89	0.0	1.5715	0.0	9.0
23							
26	10	225.89	228.89	0.0	1.5715	85.5	479.41
24							
27	10	19.68	228.89	0.0	1.5715	564.91	567.91
25							
28	11	0.0	19.68	0.0	1.5715	9.0	85.5
19							
29	11	0.0	19.68	0.0	1.5715	479.41	564.91
20							
30	12	0.0	19.68	0.0	1.5715	0.0	9.0
23							
31	13	0.0	19.68	0.0	1.5715	564.91	567.91
25							
1	ONE		5.266E-2		-6		-7
1	-18	-10	-1	1			
493.	60988.	33379.	0.3075	0.413	8.182		
2318.0	2561.0	2804.0					
2	TWO		5.266E-2		-6		-7
1	-18	-10	-1	1			
2084.0	2368.0	2651.0					
3	THREE		5.266E-2		-6		-7
1	-18	-10	-1	1			
1976.0	2255.0	2534.0					
4	FOUR		5.266E-2		-6		-7
1	-18	-10	-1	1			
1904.0	2192.0	2480.0					
5	SREFLECT		6.192E-2		-8		-9
-1	-19						
6	SBLOCKS		0.05382		-12		-13
-1	-19						
7	SBREFLECT		0.04919		-14		-15
-1	-19						
8	HELIUM			1.2425	-10	-11	
9	CLASSC		0.06944	0.24	-16		
10	KADWOL		6.94E-3	0.26	-17		
11	HELIUM1	2.183E-21	5.509E-6	12.42			
12	CLASSC1	3.96E-20	0.0694399	2.4			
13	KADWOL1	0.26E-1	6.94E-3	2.6			
1	502.22	24		1		-5	
2	502.22	24		2		-5	
3	502.22	24		3		-5	
4	502.22	24		4		-5	
5	502.22	24		5		-5	
6	502.22	24		6		-5	
7	502.22	24		7		-5	

8	502.22	24	8	-5				
9	502.22	24	9	-5				
10	502.22	24	10	-5				
11	502.22	24	11	-5				
12	502.22	24	12	-5				
13	502.22	24	13	-5				
14	502.22	24	14	-5				
15	502.22	24	15	-5				
16	502.22	24	16	-5				
17	502.22	24	17	-5				
1	1500.0		25					
2	1550.0		25					
3	1500.0		25					
4	1500.0		25					
5	1500.0		25					
6	1500.0		25					
7	1550.0		25					
8	1550.0		25					
9	1500.0		25					
10	1550.0		25					
11	1500.0		25					
12	1450.0		25					
13	1500.0		25					
14	1450.0		25					
15	1550.0		25					
16	1500.0		25					
17	1500.0		25					
18	639.0		18					
19	1392.0							
20	639.0		19					
21	1500.0		20					
22	639.0		21					
23	1392.0							
24	1015.0	22						
25	639.0		23					
1	2	180.0						
2	3							
3	8.094E-12							
4	3							
5	6.469E-12							
6	3							
7	8.451E-12							
8	0.0	19.68	52.06	85.77	119.69	153.69	165.14	170.14
9	216.89	225.89	228.89					
10	2	1	1	1	1	1	1	3
11	1	1						
12	0.0	0.1746	0.2619	0.3929	0.5238	0.6548	0.7857	0.8730
13	1.1785	1.3095	1.4405	1.5715				
14	1	1	1	1	1	1	1	1

1	0.0	9.0	85.5	120.5	162.33	167.33	182.94	214.16
245.38	276.60	307.82	339.64	370.26	401.48	417.09	422.09	
479.41	564.91	567.91						
1	1	2	2	1	1	2	2	
1	1	1	1	1	1	1	2	
1	1							
1	1.0079							
2	1							
1	1.5207							
3	1							
1	0.8965							
4	1							
1	1.2351							
5	1							
1	0.9315							
6	1							
1	1.2360							
7	1							
1	1.6227							
8	1							
1	1.5092							
9	1							
1	0.8499							
10	1							
1	1.5869							
11	1							
1	0.8327							
12	1							
1	0.7297							
13	1							
1	0.9558							
14	1							
1	0.7404							
15	1							
1	1.4175							
16	1							
1	1.0302							
17	1							
1	0.8834							
18	2							
1	2.4342	2-0.002992						
19	2							
1	0.8528	20.0008769						
20	2							
1	2.6198	2-3.3789-3						
21	2							
1	0.1293	2 0.09674						
22	2							

1	62.94356		2-0.27422				
23	2						
1	136.260		2 -0.23944				
24							
25							
1	12						
500.0	1.3333	1000.0	1.875	1500.0	2.125	2000.0	2.2917
2500.0	2.375	3000.0	2.375	3500.0	2.25	4000.0	2.083
4500.0	1.875	5000.0	1.467	5500.0	1.375	6000.0	1.042
2	25						
572.0	0.01174	662.0	0.01246	752.0	0.01316	842.0	0.01385
932.0	0.01452	1022.0	0.01518	1112.0	0.01583	1202.0	0.01647
1292.0	0.01710	1382.0	0.01772	1472.0	0.01833	1562.0	0.01893
1652.0	0.01952	1742.0	0.02011	1832.0	0.02049	1922.0	0.02126
2012.0	0.02183	2102.0	0.02239	2192.0	0.02295	2282.0	0.02350
2372.0	0.02404	2462.0	0.02458	2552.0	0.02512	2642.0	0.02565
2732.0	0.02618						
3	3						
500.0	0.25	2000.0	0.25	5000.0	0.25		
4	13						
1000.0	1.5104	1500.0	1.7708	2000.0	1.8750	2500.0	2.0425
3000.0	2.2708	3500.0	2.3125	4000.0	2.4323	4500.0	2.5729
5000.0	2.75	5500.0	2.9167	6000.0	3.1563	6500.0	3.3854
7000.0	3.8854						
5	10						
167.33	0.67	182.94	0.67	214.16	0.9	245.38	0.97
276.60	1.01	307.82	1.17	339.04	1.14	370.26	1.08
401.48	1.03	418.00	1.03				
6	14						
500.0	0.327487	1000.0	0.423523	1500.0	0.487776	2000.0	0.569188
2500.0	0.669443	3000.0	0.752273	3500.0	0.810588	4000.0	0.874567
4500.0	0.938860	5000.0	0.977472	5500.0	0.970125	6000.0	0.877358
6500.0	0.713995	7000.0	0.328090				
7	7						
0.0	0.115	500.0	0.255	1000.0	0.34	1500.0	0.39
2000.0	0.41	3000.0	0.44	4000.0	0.45		
8	14						
500.0	0.327487	1000.0	0.423523	1500.0	0.487776	2000.0	0.569188
2500.0	0.669443	3000.0	0.752273	3500.0	0.810588	4000.0	0.874567
4500.0	0.938860	5000.0	0.977472	5500.0	0.970125	6000.0	0.877358
6500.0	0.713995	7000.0	0.328090				
9	7						
0.0	0.115	500.0	0.295	1000.0	0.39	1500.0	0.435
2000.0	0.465	3000.0	0.5	4000.0	0.515		
10	25						
572.0	0.01174	662.0	0.01246	752.0	0.01316	842.0	0.01385
932.0	0.01452	1022.0	0.01518	1112.0	0.01583	1202.0	0.01647
1292.0	0.01710	1382.0	0.01772	1472.0	0.01833	1562.0	0.01893
1652.0	0.01952	1742.0	0.02011	1832.0	0.02049	1922.0	0.02126
2012.0	0.02183	2102.0	0.02239	2192.0	0.02295	2282.0	0.02350

2372.0	0.02404	2462.0	0.02458	2552.0	0.02512	2642.0	0.02565
2732.0	0.02618						
11	25						
572.03.0306E-6		662.02.7950E-6		752.02.5873E-6		842.02.4086E-6	
932.02.2526E-6		1022.02.1150E-6		1112.01.9950E-6		1202.01.8860E-6	
1292.01.7890E-6		1382.01.7026E-6		1472.01.6230E-6		1562.01.5509E-6	
1652.01.4847E-6		1742.01.4239E-6		1832.01.3682E-6		1922.01.3165E-6	
2012.01.2687E-6		2102.01.2230E-6		2192.01.1826E-6		2282.01.1435E-6	
2372.01.1073E-6		2462.01.0733E-6		2552.01.0411E-6		2642.01.0110E-6	
2732.00.9825E-6							
12	3						
500.0	1.025	2500.0	1.025	6000.0	1.025		
13	7						
0.0	0.115	500.0	0.255	1000.0	0.34	1500.0	0.39
2000.0	0.41	3000.0	0.44	4000.0	0.45		
14	13						
1000.0	0.6062	1500.0	0.8542	2000.0	1.125	2500.0	1.4375
3000.0	1.7083	3500.0	1.8446	4000.0	1.8438	4500.0	1.7292
5000.0	1.5625	5500.0	1.1563	6000.0	0.7292	6500.0	0.4063
7000.0	0.1354						
15	7						
0.0	0.115	500.0	0.255	1000.0	0.34	1500.0	0.39
2000.0	0.41	3000.0	0.44	4000.0	0.45		
16	6						
500.0	0.0182	1000.0	0.03	1500.0	0.0396	2000.0	0.0517
2500.0	0.0625	3000.0	0.0733				
17	7						
0.0	0.008	500.0	0.012	1000.0	0.016	1500.0	0.026
2000.0	0.042	2500.0	0.046	3000.0	0.096		
18	3						
500.0	0.25	1000.0	0.25	2000.0	0.25		
19	13						
1000.0	1.5104	1500.0	1.7708	2000.0	1.8750	2500.0	2.0625
3000.0	2.2708	3500.0	2.3125	4000.0	2.4323	4500.0	2.5729
5000.0	2.75	5500.0	2.9167	6000.0	3.1563	6500.0	3.3854
7000.0	3.8854						
C.008333	0.016667	0.033333	0.5	0.066667	0.083333	0.106667	0.25
C.266667	0.283333	0.316667	0.333333	0.366667	0.4	0.433333	0.5
C.680400	0.75	0.833333	0.916667	1.0	1.166667	1.333333	1.5
1.66667	1.83333	2.0	2.25	2.5	3.0		

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APPENDIX B

Listing of Computer Output for HEATUP Sample Problem

८

THIS VERSION OF HEATING CAN HANDLE A MAXIMUM OF 3000 LATTICE POINTS.

DATE 06-23-76
FILE 06-23-23

[illegible]

Since this problem involves radiation, eqs. (9) will be applied to the temperatures to convert them to absolute temperatures. Number of transient points specified is 20. The final temperature distribution will be written on unit

THE PINK, INTERNATIONAL DISTRIBUTION WILL BE BETWEEN 2001
AND 1998. THE NUMBER 1

ALL INFORMATION CONTAINED HEREIN IS UNCLASSIFIED
DATE 08-08-2001 BY 60322 UCBAW

CONFIDENTIAL - CIVILIAN 1-0000

443714

1. 00000000-0

TIME: 11:00 AM
DATE: 11/11/11
BY: [illegible]
[illegible]

LEWIS' EMPLOYMENT ENDED DUE TO UNDO WITH A TIME WARP ON 10/11/44. APPROX 1944 THAT WAS IN THE BIRMINGHAM (ALABAMA) TELEPHONE

1947 JUL 21 1947

PAGE TWO

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NUMBER OF AGE GROUPS IN THE ACTIVE LUMP = 0
TOTAL NUMBER OF FUEL ELEMENT STACKS = 0.000000 01
TOTAL NUMBER OF FUEL NODES IN LUMP = 0.000000 00
TOTAL NUMBER OF CIRCULAR NODULES IN LUMP = 3.125000 00
RADIUS OF A FUEL NODULE = 3.000000-01
RADIUS OF A CIRCULAR NODULE = 0.100000-01
LENGTH OF THE HORIZONTAL FUEL ELEMENT STACK = 0.000000 00
TOTAL CROSS SECTIONAL AREA OF THE ACTIVE LUMP = 0.000000 00
TOTAL CROSS SECTIONAL AREA OF THE CIRCULAR NODULES = 0.000000 00
PERCENTAGE OF CIRCULAR NODULE AREA = 0.000000 01
PERCENTAGE OF STACKED AREA = 0.000000 01

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***** SUMMARY OF MATERIAL DATA *****

MATERIAL NUMBER	MATERIAL NAME	CONDUCTIVITY 0.0	TEMPERATURE-DEPENDENT CONDUCTIVITY	INTERNAL PARAMETER FUNCTION NUMBER	ANISOTROPIC FUNCTION NUMBER
1	ONE	0.0	0.000000-02	0.0	-1
2	TWO	0.0	0.000000-02	0.0	-1
3	THREE	0.0	0.000000-02	0.0	-1
4	FOUR	0.0	0.000000-02	0.0	-1
5	FIVE	0.0	0.000000-02	0.0	-1
6	SIX	0.0	0.000000-02	0.0	-1
7	SEVEN	0.0	0.000000-02	0.0	-1
8	EIGHT	0.0	0.000000-02	0.0	-1
9	NINE	0.0	0.000000-02	0.0	-1
10	TEN	0.0	0.000000-02	0.0	-1
11	ELEVEN	0.0	0.000000-02	0.0	-1
12	TWELVE	0.0	0.000000-02	0.0	-1
13	THIRTEEN	0.0	0.000000-02	0.0	-1

***** SUMMARY OF ISOTROPIC AND EFFECTIVE CONDUCTIVITIES *****

NUMBER	NAME	EFFECTIVE UN ANISOTROPIC CONDUCTIVITY	FUNCTION NUMBER
1	ONE	0.0	-1
2	TWO	0.0	-1
3	THREE	0.0	-1
4	FOUR	0.0	-1
5	FIVE	0.0	-1
6	SIX	0.0	-1
7	SEVEN	0.0	-1

***** SUMMARY OF INITIAL TEMPERATURE DATA *****

NUMBER	INITIAL TEMPERATURE	POSITION-DEPENDENT FUNCTION NUMBER
1	1.000000 03	25
2	1.000000 03	25
3	1.000000 03	25
4	1.000000 03	25
5	1.000000 03	25
6	1.000000 03	25
7	1.000000 03	25
8	1.000000 03	25
9	1.000000 03	25
10	1.000000 03	25
11	1.000000 03	25
12	1.000000 03	25
13	1.000000 03	25

NUMBER	SUMMARY OF HEAT GENERATION DATA		TIME AND POSITION		ULP	MULTI	NUMBERS
	POWER	DENSITY	TIME	POSITION			
1	1.000000	0.000000	12	1	0	0	1
2	1.000000	0.000000	12	2	0	0	1
3	1.000000	0.000000	12	3	0	0	1
4	1.000000	0.000000	12	4	0	0	1
5	1.000000	0.000000	12	5	0	0	1
6	1.000000	0.000000	12	6	0	0	1
7	1.000000	0.000000	12	7	0	0	1
8	1.000000	0.000000	12	8	0	0	1
9	1.000000	0.000000	12	9	0	0	1
10	1.000000	0.000000	12	10	0	0	1
11	1.000000	0.000000	12	11	0	0	1
12	1.000000	0.000000	12	12	0	0	1
13	1.000000	0.000000	12	13	0	0	1
14	1.000000	0.000000	12	14	0	0	1
15	1.000000	0.000000	12	15	0	0	1
16	1.000000	0.000000	12	16	0	0	1
17	1.000000	0.000000	12	17	0	0	1
18	1.000000	0.000000	12	18	0	0	1
19	1.000000	0.000000	12	19	0	0	1
20	1.000000	0.000000	12	20	0	0	1
21	1.000000	0.000000	12	21	0	0	1
22	1.000000	0.000000	12	22	0	0	1
23	1.000000	0.000000	12	23	0	0	1
24	1.000000	0.000000	12	24	0	0	1
25	1.000000	0.000000	12	25	0	0	1

*****SUMMARY OF BOUNDARY DATA*****

GENERAL			TEMPERATURE INFORMATION		HEAT TRANSFER COEFFICIENTS RELATIVE FUNCTION NUMBERS						
NO.	TYPE	PCT FLAG	TEMPERATURE	TIME PCT	ASSOC. PCTS	FORCED CONV.	RADIATION	NATURAL CONV.	EMISSIV	FLUX	
1	2	0	1.000000	02	0	0.0	0.0	0.0	0.0	0.0	
2	3	0	0.0	0	0	0.0	0.000000-12	0.0	0.0	0.0	
3	3	0	0.0	0	0	0.0	0.000000-12	0.0	0.0	0.0	
4	3	0	0.0	0	0	0.0	0.000000-12	0.0	0.0	0.0	

GROSS LATTICE AND NUMBERS OF INCREMENTS

R OR X											
0.0	19.000000	0.0	32.000000	05.773000	114.070000	153.000000	170.140000	170.140000	170.140000	170.140000	170.140000
210.000000	225.000000	225.000000	225.000000	1	1	1	1	1	1	1	1
THETA OR Y											
0.0	0.174000	0.0	0.201000	0.304000	0.423000	0.534000	0.634000	0.726000	0.811000	0.871000	0.910000
1.174000	1.329000	1.329000	1.440000	1.571000	1	1	1	1	1	1	1
Z											
0.0	0.000000	0.0	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
255.000000	270.000000	270.000000	270.000000	270.000000	270.000000	270.000000	270.000000	270.000000	270.000000	270.000000	270.000000
470.000000	504.000000	504.000000	504.000000	504.000000	504.000000	504.000000	504.000000	504.000000	504.000000	504.000000	504.000000
1	1	1	1	1	1	1	1	1	1	1	1

LISTING OF ANALYTIC FUNCTIONS

F(1) = A(1) + A(2)X + A(3)X^2 + A(4)COS(A(5)X) + A(6)EXP(A(7)X) + A(8)LINEAR(X) + A(9)LOG(X) + A(10)X^3

NO.	A(1)	A(2)	A(3)	A(4)	A(5)	A(6)	A(7)	A(8)	A(9)	A(10)	A(11)
1	1.0000 00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1.5812 00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.9650-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	1.2350 00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	0.3150-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	1.2370 00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	1.6230 00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	1.5090 00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	0.4000-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	1.5870 00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.3270-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12	7.2970-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13	0.3000-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	7.4000-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	1.4100 00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	1.0300 00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.8340-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	2.4340 00	-2.9920-03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.5200-01	0.7900-04	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	2.0200 00	-1.3700-03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	1.2030-01	0.8700-02	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.2040 01	-2.7420-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	1.3130 02	-2.3040-01	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

ANALYTIC FUNCTION NO. 24 IS USED SUPPLIED

ANALYTIC FUNCTION NO. 25 IS USED SUPPLIED

2

44

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TABLE NUMBER	5	NUMBER OF PAIRS	10
ARGUMENT		VALUE	
1.0713300000 02		0.7000000000-01	
1.4299400000 02		0.7000000000-01	
2.1411000000 02		0.7000000000-01	
2.4533800000 02		0.7000000000-01	
2.7660000000 02		1.0100000000 00	
3.0782000000 02		1.1700000000 00	
3.3904000000 02		1.1400000000 00	
3.7026000000 02		1.0800000000 00	
4.0148000000 02		1.0300000000 00	
4.3270000000 02		1.0300000000 00	
TABLE NUMBER	6	NUMBER OF PAIRS	14
ARGUMENT		VALUE	
5.0000000000 02		3.2768700000-01	
5.0000000000 03		4.2352300000-01	
1.5000000000 03		4.8777400000-01	
2.0000000000 03		5.6918800000-01	
2.5000000000 03		6.4944300000-01	
3.0000000000 03		7.3227300000-01	
3.5000000000 03		8.1883900000-01	
4.0000000000 03		9.0988700000-01	
4.5000000000 03		9.7747200000-01	
5.0000000000 03		9.7014300000-01	
5.5000000000 03		9.7735800000-01	
6.0000000000 03		7.1399800000-01	
6.5000000000 03		5.2809000000-01	
7.0000000000 03		5.2809000000-01	
TABLE NUMBER	7	NUMBER OF PAIRS	7
ARGUMENT		VALUE	
0.0000000000 02		1.1200000000-01	
1.0000000000 02		1.2500000000-01	
2.0000000000 02		2.5000000000-01	
3.0000000000 02		3.4000000000-01	
4.0000000000 02		4.1000000000-01	
5.0000000000 02		4.4000000000-01	
6.0000000000 02		4.5000000000-01	
TABLE NUMBER	8	NUMBER OF PAIRS	14
ARGUMENT		VALUE	
5.0000000000 02		3.2768700000-01	
5.0000000000 03		4.2352300000-01	
1.0000000000 03		4.8777400000-01	
2.0000000000 03		5.6918800000-01	
3.0000000000 03		6.4944300000-01	
4.0000000000 03		7.3227300000-01	
5.0000000000 03		8.1883900000-01	
6.0000000000 03		9.0988700000-01	
7.0000000000 03		9.7747200000-01	
8.0000000000 03		9.7014300000-01	
9.0000000000 03		9.7735800000-01	
0.0000000000 03		7.1399800000-01	
1.0000000000 03		5.2809000000-01	
TABLE NUMBER	9	NUMBER OF PAIRS	7
ARGUMENT		VALUE	
0.0000000000 02		1.1200000000-01	
1.0000000000 02		1.2500000000-01	
2.0000000000 02		2.5000000000-01	
3.0000000000 02		3.4000000000-01	
4.0000000000 02		4.1000000000-01	
5.0000000000 02		4.4000000000-01	
6.0000000000 02		4.5000000000-01	
7.0000000000 02		4.5000000000-01	

TABLE NUMBER 10 NUMBER UP PAID

ARGUMENT	VALUE
5.72000000 02	1.17400000 00
5.62000000 02	1.12400000 00
7.32000000 02	1.11600000 00
6.62000000 02	1.10500000 00
9.12000000 02	1.05200000 00
1.02200000 03	1.01800000 00
1.11200000 03	1.04300000 00
1.12000000 03	1.04700000 00
1.19200000 03	1.07000000 00
1.13200000 03	1.07700000 00
1.17200000 03	1.08300000 00
1.20200000 03	1.09200000 00
1.22000000 03	2.01100000 00
1.23000000 03	2.04900000 00
1.02200000 03	2.11400000 00
2.10200000 03	2.18100000 00
2.19200000 03	2.23900000 00
2.19200000 03	2.29500000 00
2.24200000 03	2.35000000 00
2.27200000 03	2.40400000 00
2.46200000 03	2.45400000 00
2.52200000 03	2.51200000 00
2.54200000 03	2.56500000 00
2.73200000 03	2.61800000 00

TABLE NUMBER 11 NUMBER UP PAID

ARGUMENT	VALUE
5.72000000 02	1.01860000 00
5.62000000 02	2.79200000 00
7.32000000 02	2.58700000 00
6.62000000 02	2.40800000 00
9.12000000 02	2.25200000 00
1.02200000 03	2.11580000 00
1.11200000 03	1.99500000 00
1.12000000 03	1.88800000 00
1.19200000 03	1.78700000 00
1.13200000 03	1.62400000 00
1.17200000 03	1.52000000 00
1.20200000 03	1.46200000 00
1.22000000 03	1.42300000 00
1.23000000 03	1.36800000 00
1.02200000 03	1.31800000 00
2.10200000 03	1.26870000 00
2.19200000 03	1.22380000 00
2.19200000 03	1.18260000 00
2.24200000 03	1.14350000 00
2.27200000 03	1.10730000 00
2.46200000 03	1.04310000 00
2.52200000 03	1.01100000 00
2.54200000 03	0.98230000 00
2.73200000 03	0.92530000 00

TABLE NUMBER 12 NUMBER UP PAID

ARGUMENT	VALUE
5.72000000 02	1.02500000 00
5.62000000 02	1.02600000 00
6.62000000 02	1.02600000 00
9.12000000 02	1.15000000 00
1.02200000 03	2.35000000 00
1.11200000 03	1.40000000 00
1.12000000 03	3.40000000 00
1.19200000 03	4.10000000 00
1.13200000 03	4.40000000 00
1.17200000 03	4.50000000 00
1.20200000 03	4.50000000 00

TABLE NUMBER 14

ARGUMENT 03
1.00000000 03
2.00000000 03
3.00000000 03
4.00000000 03
5.00000000 03
6.00000000 03
7.00000000 03

NUMBER OF PAIRS - 13

VALUE
0.74200000-01
1.14200000 00
1.41200000 00
1.70400000 00
1.94400000 00
1.72920000 00
1.56250000 00
1.36300000 00
1.29200000-01
1.06100000-01
1.35400000-01

TABLE NUMBER 15

ARGUMENT 02
5.00000000 02
1.00000000 03
1.30000000 03
2.00000000 03
3.00000000 03
4.00000000 03

NUMBER OF PAIRS - 7

VALUE
1.15000000-01
2.55000000-01
3.40000000-01
3.90000000-01
4.10000000-01
4.00000000-01
4.50000000-01

TABLE NUMBER 16

ARGUMENT 02
5.00000000 02
1.00000000 03
1.50000000 03
2.00000000 03
2.50000000 03
3.00000000 03

NUMBER OF PAIRS - 6

VALUE
1.62000000-02
3.00000000-02
3.46000000-02
5.17000000-02
6.25000000-02
7.33000000-02

TABLE NUMBER 17

ARGUMENT 02
5.00000000 02
1.00000000 03
1.50000000 03
2.00000000 03
2.50000000 03
3.00000000 03

NUMBER OF PAIRS - 7

VALUE
1.00000000-03
1.30000000-02
1.60000000-02
2.60000000-02
4.20000000-02
6.40000000-02
9.00000000-02

TABLE NUMBER 18

ARGUMENT 02
5.00000000 02
1.00000000 03
2.00000000 03

NUMBER OF PAIRS - 3

VALUE
2.50000000-01
2.80000000-01
2.50000000-01

TABLE NUMBER 19

ARGUMENT 03
1.00000000 03
1.30000000 03
2.00000000 03
2.50000000 03
3.00000000 03
4.00000000 03
5.00000000 03
6.00000000 03
7.00000000 03

NUMBER OF PAIRS - 13

VALUE
1.51040000 00
1.77080000 00
1.87530000 00
2.04250000 00
2.21250000 00
2.47250000 00
2.75000000 00
2.91670000 00
3.15610000 00
3.38540000 00
3.60540000 00

TABLE OF OUTPUT TIMES

OUTPUT NO.	OUTPUT TIME	OUTPUT NO.	OUTPUT TIME	OUTPUT NO.	OUTPUT TIME
1	0.333000-03	27	1.833130 00	11	119.990007
2	1.666700-02	28	2.000000 00	12	201.398667
3	3.333300-02	29	2.450000 00		
4	5.000000-01	30	2.500000 00		
5	6.666700-02		3.500000 00		
6	8.333300-02				
7	1.666670-01				
8	2.500000-01				
9	2.666670-01				
10	3.333300-01				
11	3.333300-01				
12	3.333300-01				
13	3.666670-01				
14	4.000000-01				
15	4.333300-01				
16	5.000000-01				
17	6.804000-01				
18	7.500000-01				
19	8.333300-01				
20	9.166700-01				
21	1.000000-00				
22	1.333300 00				
23	1.500000 00				
24	1.666670 00				
25	1.666670 00				

FINE LATTICE. X OR R, Y OR THETA, AND Z

2	0.840000	3	15.640000	13	85.770000	19	119.990007
7	15.640000	8	165.140000	14	185.725000	20	201.398667
12	215.890000	13	225.890000				
1	0.0	2	0.174000	9	2.494000	16	0.123400
6	0.654000	7	0.765000	10	1.170000	17	1.109000
11	1.445000	12	1.571500				
1	0.0	2	9.300000	9	103.000000	16	120.600000
4	191.415000	7	192.330000	10	182.340000	17	198.600000
11	215.160000	12	229.770000	13	278.600000	18	307.120000
16	339.640000	17	370.260000	19	417.090000	20	422.640000
21	450.750000	22	476.410000	23	507.910000		

THIS PROBLEM CONTAINS 3744 NODES.

[illegible][illegible]

NODAL TEMPERATURES AFTER 0 TIME ST-MS, TIME = 0.0
FOR THE PLANE THETA = 1.740000-01

GROSS GRID		1	2	3	4	5	6	7	8	9	10	11	12	13
FINE GRID		1	2	3	4	5	6	7	8	9	10	11	12	13
DISTANCE		0.0	9.84	19.68	29.52	39.36	49.20	59.04	68.88	78.72	88.56	98.40	108.24	118.08
1	1	0.0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
2	2	9.84	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
3	3	19.68	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
4	4	29.52	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
5	5	39.36	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
6	6	49.20	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
7	7	59.04	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
8	8	68.88	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
9	9	78.72	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
10	10	88.56	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
11	11	98.40	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
12	12	108.24	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
13	13	118.08	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
14	14	127.92	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
15	15	137.76	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
16	16	147.60	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
17	17	157.44	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
18	18	167.28	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
19	19	177.12	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

GROSS GRID		11
FINE GRID		14
DISTANCE		228.89
1	1	0.0
2	2	9.84
3	3	19.68
4	4	29.52
5	5	39.36
6	6	49.20
7	7	59.04
8	8	68.88
9	9	78.72
10	10	88.56
11	11	98.40
12	12	108.24
13	13	118.08
14	14	127.92
15	15	137.76
16	16	147.60
17	17	157.44
18	18	167.28
19	19	177.12

			NODAL TEMPERATURES AFTER 0 TIME STEPS, TIME = 0.0 FOR THE PLANE THETA = 2.619000-01									
GROSS GRID			1	2	3	4	5	6	7	8	9	10
FINE GRID			1	2	3	4	5	6	7	8	9	10
DISTANCE			1	2	3	4	5	6	7	8	9	10
1	1	0.0	-9.84	9.84	19.68	32.06	45.77	119.69	153.69	165.14	170.14	185.74
2	2	9.00	010	010	010	010	010	010	010	010	010	010
3	3	85.50	010	010	010	010	010	010	010	010	010	010
4	4	103.00	010	010	010	010	010	010	010	010	010	010
5	5	120.50	010	010	010	010	010	010	010	010	010	010
6	6	141.42	010	010	010	010	010	010	010	010	010	010
7	7	162.33	010	010	010	010	010	010	010	010	010	010
8	8	187.33	010	010	010	010	010	010	010	010	010	010
9	9	182.94	010	010	010	010	010	010	010	010	010	010
10	10	198.55	010	010	010	010	010	010	010	010	010	010
11	11	216.16	010	010	010	010	010	010	010	010	010	010
12	12	229.77	010	010	010	010	010	010	010	010	010	010
13	13	243.38	010	010	010	010	010	010	010	010	010	010
14	14	276.60	010	010	010	010	010	010	010	010	010	010
15	15	307.82	010	010	010	010	010	010	010	010	010	010
16	16	339.64	010	010	010	010	010	010	010	010	010	010
17	17	370.26	010	010	010	010	010	010	010	010	010	010
18	18	401.48	010	010	010	010	010	010	010	010	010	010
19	19	417.09	010	010	010	010	010	010	010	010	010	010
20	20	422.09	010	010	010	010	010	010	010	010	010	010
21	21	430.75	010	010	010	010	010	010	010	010	010	010
22	22	479.41	010	010	010	010	010	010	010	010	010	010
23	23	544.91	010	010	010	010	010	010	010	010	010	010
24	24	567.91	010	010	010	010	010	010	010	010	010	010

GROSS GRID			11
FINE GRID			14
DISTANCE			228.99
1	1	0.0	100100
2	2	9.00	100100
3	3	85.50	100100
4	4	103.00	100100
5	5	120.50	100100
6	6	141.42	100100
7	7	162.33	100100
8	8	187.33	100100
9	9	182.94	100100
10	10	198.55	100100
11	11	216.16	100100
12	12	229.77	100100
13	13	243.38	100100
14	14	276.60	100100
15	15	307.82	100100
16	16	339.64	100100
17	17	370.26	100100
18	18	401.48	100100
19	19	417.09	100100
20	20	422.09	100100
21	21	430.75	100100
22	22	479.41	100100
23	23	544.91	100100
24	24	567.91	100100

CROSS GRID		INITIAL TEMPERATURES AFTER 0 TIME STEPS, TIME = 0.0 FOR THE PLANE THETA = 0.730000-01												
FINE GRID		1	2	3	4	5	6	7	8	9	10	11	12	13
DISTANCE		1	2	3	4	5	6	7	8	9	10	11	12	13
1	1	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

CROSS GRID		11
FINE GRID		11
DISTANCE		11
1	1	0.0
2	2	0.00
3	3	0.00
4	4	0.00
5	5	0.00
6	6	0.00
7	7	0.00
8	8	0.00
9	9	0.00
10	10	0.00
11	11	0.00
12	12	0.00
13	13	0.00
14	14	0.00
15	15	0.00
16	16	0.00
17	17	0.00
18	18	0.00
19	19	0.00
20	20	0.00
21	21	0.00
22	22	0.00
23	23	0.00
24	24	0.00

CROSS GRID		NUCLEAR TEMPERATURES AFTER 0 TIME STEPS, TIME = 0.0 FOR THE PLANE THETA = 1.178500 UU									
FINE GRID		1	2	3	4	5	6	7	8	9	10
DISTANCE		1	2	3	4	5	6	7	8	9	10
1	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

CROSS GRID		11
FINE GRID		14
DISTANCE		220.00
1	1	0.0
2	2	0.00
3	3	0.00
4	4	0.00
5	5	0.00
6	6	0.00
7	7	0.00
8	8	0.00
9	9	0.00
10	10	0.00
11	11	0.00
12	12	0.00
13	13	0.00
14	14	0.00
15	15	0.00
16	16	0.00
17	17	0.00
18	18	0.00
19	19	0.00

NUDOL TEMPERATURES AFTER 0 TIME STOPS TIME = 0.0
FOR THE PLANE THEA = 1.440000 00

CROSS GRID	1	2	3	4	5	6	7	8	9	10	11	12	13
FINE GRID	1	2	3	4	5	6	7	8	9	10	11	12	13
DISTANCE	1	2	3	4	5	6	7	8	9	10	11	12	13
1 1 0.0	-9.84	9.84	19.68	29.52	39.36	49.20	59.04	68.88	78.72	88.56	98.40	108.24	118.08
2 2 9.00	010	010	010	010	010	010	010	010	010	010	010	010	010
3 3 85.50	040	040	040	040	040	040	040	040	040	040	040	040	040
4 4 103.00	080	080	080	080	080	080	080	080	080	080	080	080	080
5 5 120.50	080	080	080	080	080	080	080	080	080	080	080	080	080
6 6 141.42	080	080	080	080	080	080	080	080	080	080	080	080	080
7 7 162.33	080	080	080	080	080	080	080	080	080	080	080	080	080
8 8 167.33	080	080	080	080	080	080	080	080	080	080	080	080	080
9 9 182.94	080	080	080	080	080	080	080	080	080	080	080	080	080
10 10 198.55	080	080	080	080	080	080	080	080	080	080	080	080	080
11 11 214.16	080	080	080	080	080	080	080	080	080	080	080	080	080
12 12 229.77	080	080	080	080	080	080	080	080	080	080	080	080	080
13 13 245.38	080	080	080	080	080	080	080	080	080	080	080	080	080
14 14 276.60	080	080	080	080	080	080	080	080	080	080	080	080	080
15 15 307.82	080	080	080	080	080	080	080	080	080	080	080	080	080
16 16 339.64	080	080	080	080	080	080	080	080	080	080	080	080	080
17 17 370.26	080	080	080	080	080	080	080	080	080	080	080	080	080
18 18 401.48	080	080	080	080	080	080	080	080	080	080	080	080	080
19 19 417.09	080	080	080	080	080	080	080	080	080	080	080	080	080
20 20 422.09	080	080	080	080	080	080	080	080	080	080	080	080	080
21 21 450.75	080	080	080	080	080	080	080	080	080	080	080	080	080
22 22 479.41	080	080	080	080	080	080	080	080	080	080	080	080	080
23 23 504.91	080	080	080	080	080	080	080	080	080	080	080	080	080
24 24 567.91	080	080	080	080	080	080	080	080	080	080	080	080	080

CROSS GRID	11
FINE GRID	14
DISTANCE	228.89
1 1 0.0	--479194
2 2 9.00	--479194
3 3 85.50	--479194
4 4 103.00	180100
5 5 120.50	180100
6 6 141.42	180100
7 7 162.33	180100
8 8 167.33	180100
9 9 182.94	180100
10 10 198.55	180100
11 11 214.16	180100
12 12 229.77	180100
13 13 245.38	180100
14 14 276.60	180100
15 15 307.82	180100
16 16 339.64	180100
17 17 370.26	180100
18 18 401.48	180100
19 19 417.09	180100
20 20 422.09	180100
21 21 450.75	180100
22 22 479.41	--479177
23 23 504.91	--479194
24 24 567.91	--479194

CROSS GRID 11
 FINE GRID 14
 DISTANCE 228.89
 1 1 0.0 --170199
 2 2 9.00 --170199
 3 3 83.50 --1700136
 4 4 103.00 180100
 5 5 120.50 180100
 6 6 141.42 180100
 7 7 162.33 180100
 8 8 187.33 180100
 9 9 198.94 180100
 10 10 198.53 180100
 11 11 214.16 180100
 12 12 229.77 180100
 13 13 245.38 180100
 14 14 276.60 180100
 15 15 307.82 180100
 16 16 339.64 180100
 17 17 370.26 180100
 18 18 401.48 180100
 19 19 417.09 180100
 20 20 422.09 180100
 21 21 450.75 180100
 22 22 479.41 --623177
 23 23 564.91 --623196
 24 24 567.91 --170168

TEMPERATURES ON NUMBERED BOUNDARIES

BOUNDARY NUMBER	TEMPERATURE
1	180.000000
2	0.0
3	0.0
4	0.0

THE CURRENT TIME STEP (DELTAT) = 1.000000000-03

ELAPSED CPU TIME IS 237.76 SECONDS

THE MAXIMUM TEMPERATURE IS - 1.68508D 03 (+-0.1)
 MAX. TEMP. APPEARS AT NODES - 1562 1575 1588 1601
 THE MINIMUM TEMPERATURE IS - 1.78683D 02 (+-0.1)
 MIN. TEMP. APPEARS AT NODES -

3589	3590	3591	3592	3593
3594	3595	3596	3597	3598
3599	3600	3601	3602	3603
3604	3605	3606	3607	3608
3609	3610	3611	3612	3613
3614	3615	3616	3617	3618
3619	3620	3621	3622	3623
3624	3625	3626	3627	3628
3629	3630	3631	3632	3633
3634	3635	3636	3637	3638

NODAL TEMPERATURES AFTER 52 TIME STEPS, TIME = 9.530870-31
FOR THE PLANE THETA = 0.0

CROSS GRID	1	2	3	4	5	6	7	8	9	10
FINE GRID	1	2	3	4	5	6	7	8	9	10
DISTANCE	0.0	9.00	85.50	103.00	120.50	141.42	162.33	187.33	214.60	245.38
1	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	9.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	85.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	103.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	120.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	141.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	162.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	187.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	214.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	245.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	276.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	307.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	339.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	370.26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	401.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	432.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	462.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	493.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	524.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	554.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	585.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	616.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	646.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	677.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

CROSS GRID	11	12	13	14
FINE GRID	1	2	3	4
DISTANCE	0.0	9.00	85.50	103.00
1	0.0	0.00	0.00	0.00
2	9.00	0.00	0.00	0.00
3	85.50	0.00	0.00	0.00
4	103.00	0.00	0.00	0.00
5	120.50	0.00	0.00	0.00
6	141.42	0.00	0.00	0.00
7	162.33	0.00	0.00	0.00
8	187.33	0.00	0.00	0.00
9	214.60	0.00	0.00	0.00
10	245.38	0.00	0.00	0.00
11	276.60	0.00	0.00	0.00
12	307.92	0.00	0.00	0.00
13	339.64	0.00	0.00	0.00
14	370.26	0.00	0.00	0.00
15	401.48	0.00	0.00	0.00
16	432.09	0.00	0.00	0.00
17	462.71	0.00	0.00	0.00
18	493.41	0.00	0.00	0.00
19	524.11	0.00	0.00	0.00
20	554.81	0.00	0.00	0.00
21	585.51	0.00	0.00	0.00
22	616.21	0.00	0.00	0.00
23	646.91	0.00	0.00	0.00
24	677.61	0.00	0.00	0.00

NOOD TEMPERATURES AFTER 52 TIME STEPS. TIME = 9.500870-01
FOR THE PLANE THETA = 1.740000-01

CFSS GRID		1	2	3	4	5	6	7	8	9	10
FINE GRID		1	1	1	1	1	1	1	1	1	1
DISTANCE		1	2	3	4	5	6	7	8	9	10
1	1	0.0	9.84	19.68	29.52	39.36	49.20	59.04	68.88	78.72	88.56
2	2	9.00	18.00	27.00	36.00	45.00	54.00	63.00	72.00	81.00	90.00
3	3	85.50	171.00	256.50	342.00	427.50	513.00	598.50	684.00	769.50	855.00
4	4	103.00	206.00	312.00	418.00	524.00	630.00	736.00	842.00	948.00	1054.00
5	5	120.50	241.00	361.50	482.00	602.50	723.00	843.50	964.00	1084.50	1205.00
6	6	141.42	282.84	424.26	565.68	707.10	848.52	989.94	1131.36	1272.78	1414.20
7	7	162.33	324.66	487.00	649.33	811.66	974.00	1136.33	1298.66	1461.00	1623.33
8	8	182.94	365.88	531.72	697.56	863.40	1029.24	1195.08	1360.92	1526.76	1692.60
9	9	198.55	397.10	575.65	754.20	932.75	1111.30	1289.85	1468.40	1646.95	1825.50
10	10	214.16	428.32	617.88	807.44	997.00	1186.56	1376.12	1565.68	1755.24	1944.80
11	11	229.77	459.54	659.31	859.08	1058.85	1258.62	1458.39	1658.16	1857.93	2057.70
12	12	245.38	490.76	690.53	890.30	1090.07	1289.84	1489.61	1689.38	1889.15	2088.92
13	13	260.99	521.98	721.75	921.52	1121.29	1321.06	1520.83	1720.60	1920.37	2120.14
14	14	276.60	553.20	752.97	952.74	1152.51	1352.28	1552.05	1751.82	1951.59	2151.36
15	15	292.21	584.42	784.19	983.96	1183.73	1383.50	1583.27	1783.04	1982.81	2182.58
16	16	307.82	615.64	815.41	1015.18	1214.95	1414.72	1614.49	1814.26	2014.03	2213.80
17	17	323.43	646.86	846.63	1046.40	1246.17	1445.94	1645.71	1845.48	2045.25	2245.02
18	18	339.04	678.08	877.85	1077.62	1277.39	1477.16	1676.93	1876.70	2076.47	2260.64
19	19	354.65	709.30	909.07	1108.84	1308.61	1508.38	1708.15	1907.92	2107.69	2300.26
20	20	370.26	740.52	940.29	1140.06	1340.03	1539.80	1739.57	1939.34	2139.11	2335.88
21	21	385.87	771.74	971.51	1170.28	1370.05	1569.82	1769.59	1969.36	2169.13	2361.50
22	22	401.48	802.96	1002.73	1202.50	1402.27	1602.04	1801.81	2001.58	2201.35	2401.12
23	23	417.09	834.18	1033.95	1233.72	1433.49	1633.26	1833.03	2032.80	2232.57	2422.34
24	24	432.70	865.40	1065.17	1264.94	1464.71	1664.48	1864.25	2064.02	2263.79	2447.96

CFSS GRID		11
FINE GRID		1
DISTANCE		1
1	1	0.0
2	2	9.00
3	3	85.50
4	4	103.00
5	5	120.50
6	6	141.42
7	7	162.33
8	8	182.94
9	9	198.55
10	10	214.16
11	11	229.77
12	12	245.38
13	13	260.99
14	14	276.60
15	15	292.21
16	16	307.82
17	17	323.43
18	18	339.04
19	19	354.65
20	20	370.26
21	21	385.87
22	22	401.48
23	23	417.09
24	24	432.70

[illegible][illegible]

Figure 1 is a schematic diagram of a 10x10 grid representing a 1000-acre area. The grid is divided into four quadrants by a vertical line labeled "FINE SCALE" and a horizontal line labeled "COARSE GRID". The top-left quadrant is labeled "11" and contains a dense pattern of small circles. The top-right quadrant is labeled "1" and contains a sparse pattern of small circles. The bottom-left quadrant is labeled "2" and contains a pattern of small circles. The bottom-right quadrant is labeled "3" and contains a pattern of small circles. The grid is labeled "1000 ACRES" at the bottom.

[illegible]

[illegible]

[illegible]

MINI-MAX TEMPERATURES AFTER 24 HRS. OF TIME OF PLANE TIME = 1.00000000

TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
CROSS GND	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
PLANE DISTANCE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100

MINI-MAX TEMPERATURES AFTER 24 HRS. OF TIME OF PLANE TIME = 1.00000000

TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
CROSS GND	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
PLANE DISTANCE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100

NUAL TEMPERATURES AFTER 59 TIME STEPS. FIML = J.034000 90

TIME PLANE TIME = 0.0

LESS GRID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
TIME	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
GRID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
TEMP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100

LESS GRID

TIME

GRID

TEMP

NODAL TEMPERATURES AFTER 54 TIME STEPS, TIME = 3.034030 00
FOR THE PLANE THETA = 2.619000-01

CROSS GRID	1	2	3	4	5	6	7	8	9	10	11	12	13
FINE GRID	1	2	3	4	5	6	7	8	9	10	11	12	13
DISTANCE	0.0	85.50	103.00	120.50	141.42	162.33	182.94	198.55	214.16	229.77	245.38	276.60	307.82
1 1	9.24	9.24	19.28	32.06	45.77	119.09	123.17	165.14	170.14	185.72	201.31	212.89	228.86
2 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3 3	85.50	85.50	103.00	120.50	141.42	162.33	182.94	198.55	214.16	229.77	245.38	276.60	307.82
4 4	103.00	103.00	120.50	141.42	162.33	182.94	198.55	214.16	229.77	245.38	276.60	307.82	339.04
5 5	120.50	120.50	141.42	162.33	182.94	198.55	214.16	229.77	245.38	276.60	307.82	339.04	370.26
6 6	141.42	141.42	162.33	182.94	198.55	214.16	229.77	245.38	276.60	307.82	339.04	370.26	401.48
7 7	162.33	162.33	182.94	198.55	214.16	229.77	245.38	276.60	307.82	339.04	370.26	401.48	432.70
8 8	182.94	182.94	198.55	214.16	229.77	245.38	276.60	307.82	339.04	370.26	401.48	432.70	463.92
9 9	198.55	198.55	214.16	229.77	245.38	276.60	307.82	339.04	370.26	401.48	432.70	463.92	495.14
10 10	214.16	214.16	229.77	245.38	276.60	307.82	339.04	370.26	401.48	432.70	463.92	495.14	526.36
11 11	229.77	229.77	245.38	276.60	307.82	339.04	370.26	401.48	432.70	463.92	495.14	526.36	557.58
12 12	245.38	245.38	276.60	307.82	339.04	370.26	401.48	432.70	463.92	495.14	526.36	557.58	588.80
13 13	276.60	276.60	307.82	339.04	370.26	401.48	432.70	463.92	495.14	526.36	557.58	588.80	620.02
14 14	307.82	307.82	339.04	370.26	401.48	432.70	463.92	495.14	526.36	557.58	588.80	620.02	651.24
15 15	339.04	339.04	370.26	401.48	432.70	463.92	495.14	526.36	557.58	588.80	620.02	651.24	682.46
16 16	370.26	370.26	401.48	432.70	463.92	495.14	526.36	557.58	588.80	620.02	651.24	682.46	713.68
17 17	401.48	401.48	432.70	463.92	495.14	526.36	557.58	588.80	620.02	651.24	682.46	713.68	744.90
18 18	432.70	432.70	463.92	495.14	526.36	557.58	588.80	620.02	651.24	682.46	713.68	744.90	776.12
19 19	463.92	463.92	495.14	526.36	557.58	588.80	620.02	651.24	682.46	713.68	744.90	776.12	807.34

CROSS GRID	11	14
FINE GRID	11	14
DISTANCE	0.0	228.89
1 1	0.00	228.89
2 2	85.50	228.89
3 3	103.00	228.89
4 4	120.50	228.89
5 5	141.42	228.89
6 6	162.33	228.89
7 7	182.94	228.89
8 8	198.55	228.89
9 9	214.16	228.89
10 10	229.77	228.89
11 11	245.38	228.89
12 12	276.60	228.89
13 13	307.82	228.89
14 14	339.04	228.89
15 15	370.26	228.89
16 16	401.48	228.89
17 17	432.70	228.89
18 18	463.92	228.89
19 19	495.14	228.89
20 20	526.36	228.89
21 21	557.58	228.89
22 22	588.80	228.89
23 23	620.02	228.89
24 24	651.24	228.89

NUDAL TEMPERATURES AFTER 54 TIME STEPS, TIME = JJJJ90JD 00
FOR THE PLANE THETA = JJJJJJ0J-01

CROSS GRID		1	2	3	4	5	6	7	8	9	10	11	12	13
FINE GRID		1	2	3	4	5	6	7	8	9	10	11	12	13
DISTANCE		0.0	9.84	19.68	29.52	39.36	49.20	59.04	68.88	78.72	88.56	98.40	108.24	118.08
1	1	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	2	9.84	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	3	19.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	4	29.52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	5	39.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	6	49.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	7	59.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	8	68.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	9	78.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	10	88.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	11	98.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	12	108.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	13	118.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	14	127.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	15	137.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	16	147.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	17	157.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	18	167.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	19	177.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	20	186.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	21	196.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	22	206.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	23	216.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	24	226.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

CROSS GRID		1
FINE GRID		1
DISTANCE		228.89
1	1	0.0
2	2	9.84
3	3	19.68
4	4	29.52
5	5	39.36
6	6	49.20
7	7	59.04
8	8	68.88
9	9	78.72
10	10	88.56
11	11	98.40
12	12	108.24
13	13	118.08
14	14	127.92
15	15	137.76
16	16	147.60
17	17	157.44
18	18	167.28
19	19	177.12
20	20	186.96
21	21	196.80
22	22	206.64
23	23	216.48
24	24	226.32

[illegible]

[illegible]

NOON TEMPERATURES AFTER 50 FINE SLIMS LINE A 1-119030 00

REF ID: A640

FINE GOLD

1	1	0.0
2	2	9.00
3	3	45.50
4	4	103.50
	5	123.50
5	6	141.42
6	7	162.33
	8	167.33
	9	182.94
7	10	198.55
	11	214.16
	12	229.77
8	13	245.38
10	14	276.60
11	15	307.82
12	16	339.04
13	17	370.26
14	18	401.48
15	19	417.09
16	20	422.53
	21	427.97
17	22	477.81
18	23	564.91
19	24	597.91

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85															

LESS GOOD

FINE print

1	1	0.00	--	2281.00
2	2	5.00	--	1801.00
3	3	85.30	--	1801.00
	4	103.00	--	1801.00
5	5	120.50	--	1801.00
	6	141.42	--	1801.00
	7	164.33	--	1801.00
8	8	187.33	--	1801.00
	9	182.94	--	1801.00
10	10	198.55	--	1801.00
	11	218.66	--	1801.00
	12	249.77	--	1801.00
13	13	285.38	--	1801.00
14	14	270.67	--	1801.00
15	15	307.82	--	1801.00
16	16	333.64	--	1801.00
17	17	370.26	--	1801.00
18	18	401.48	--	1801.00
19	19	417.09	--	1801.00
20	20	432.99	--	1801.00
21	21	450.75	--	1801.00
22	22	479.41	--	1801.00
23	23	504.91	--	1801.00
24	24	567.91	--	1801.00

GROSS GRID		NODAL TEMPERATURES AFTER 50 TIME STEPS, TIME = 0.030000 00 FOR THE PLANE THETA = 0.170000 00														
FINE GRID		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
DISTANCE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	2	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
3	3	85.50	85.50	85.50	85.50	85.50	85.50	85.50	85.50	85.50	85.50	85.50	85.50	85.50	85.50	85.50
4	4	103.00	103.00	103.00	103.00	103.00	103.00	103.00	103.00	103.00	103.00	103.00	103.00	103.00	103.00	103.00
5	5	120.50	120.50	120.50	120.50	120.50	120.50	120.50	120.50	120.50	120.50	120.50	120.50	120.50	120.50	120.50
6	6	141.42	141.42	141.42	141.42	141.42	141.42	141.42	141.42	141.42	141.42	141.42	141.42	141.42	141.42	141.42
7	7	162.33	162.33	162.33	162.33	162.33	162.33	162.33	162.33	162.33	162.33	162.33	162.33	162.33	162.33	162.33
8	8	182.33	182.33	182.33	182.33	182.33	182.33	182.33	182.33	182.33	182.33	182.33	182.33	182.33	182.33	182.33
9	9	194.55	194.55	194.55	194.55	194.55	194.55	194.55	194.55	194.55	194.55	194.55	194.55	194.55	194.55	194.55
10	10	214.16	214.16	214.16	214.16	214.16	214.16	214.16	214.16	214.16	214.16	214.16	214.16	214.16	214.16	214.16
11	11	229.77	229.77	229.77	229.77	229.77	229.77	229.77	229.77	229.77	229.77	229.77	229.77	229.77	229.77	229.77
12	12	245.38	245.38	245.38	245.38	245.38	245.38	245.38	245.38	245.38	245.38	245.38	245.38	245.38	245.38	245.38
13	13	276.60	276.60	276.60	276.60	276.60	276.60	276.60	276.60	276.60	276.60	276.60	276.60	276.60	276.60	276.60
14	14	307.82	307.82	307.82	307.82	307.82	307.82	307.82	307.82	307.82	307.82	307.82	307.82	307.82	307.82	307.82
15	15	339.64	339.64	339.64	339.64	339.64	339.64	339.64	339.64	339.64	339.64	339.64	339.64	339.64	339.64	339.64
16	16	370.26	370.26	370.26	370.26	370.26	370.26	370.26	370.26	370.26	370.26	370.26	370.26	370.26	370.26	370.26
17	17	401.48	401.48	401.48	401.48	401.48	401.48	401.48	401.48	401.48	401.48	401.48	401.48	401.48	401.48	401.48
18	18	417.09	417.09	417.09	417.09	417.09	417.09	417.09	417.09	417.09	417.09	417.09	417.09	417.09	417.09	417.09
19	19	422.09	422.09	422.09	422.09	422.09	422.09	422.09	422.09	422.09	422.09	422.09	422.09	422.09	422.09	422.09
20	20	450.75	450.75	450.75	450.75	450.75	450.75	450.75	450.75	450.75	450.75	450.75	450.75	450.75	450.75	450.75
21	21	479.41	479.41	479.41	479.41	479.41	479.41	479.41	479.41	479.41	479.41	479.41	479.41	479.41	479.41	479.41
22	22	504.91	504.91	504.91	504.91	504.91	504.91	504.91	504.91	504.91	504.91	504.91	504.91	504.91	504.91	504.91
23	23	567.91	567.91	567.91	567.91	567.91	567.91	567.91	567.91	567.91	567.91	567.91	567.91	567.91	567.91	567.91
24	24	567.91	567.91	567.91	567.91	567.91	567.91	567.91	567.91	567.91	567.91	567.91	567.91	567.91	567.91	567.91

GROSS GRID		11
FINE GRID		14
DISTANCE		229.84
1	1	0.0
2	2	9.00
3	3	85.50
4	4	103.00
5	5	120.50
6	6	141.42
7	7	162.33
8	8	182.33
9	9	194.55
10	10	214.16
11	11	229.77
12	12	245.38
13	13	276.60
14	14	307.82
15	15	339.64
16	16	370.26
17	17	401.48
18	18	417.09
19	19	422.09
20	20	450.75
21	21	479.41
22	22	504.91
23	23	567.91
24	24	567.91

EXPRESS GRID	FINE GRID	FINE DISTANCE	11
1	1	0.00	101000
1	2	0.00	101000
1	3	0.00	101000
1	4	0.50	101000
1	5	1.00	101000
1	6	1.25	101000
1	7	1.41	101000
1	8	1.57	101000
1	9	1.73	101000
1	10	1.88	101000
1	11	2.04	101000
1	12	2.20	101000
1	13	2.36	101000
1	14	2.52	101000
1	15	2.68	101000
1	16	2.84	101000
1	17	3.00	101000
1	18	3.16	101000
1	19	3.32	101000
1	20	3.48	101000
1	21	3.64	101000
1	22	3.80	101000
1	23	3.96	101000
1	24	4.12	101000
1	25	4.28	101000
1	26	4.44	101000
1	27	4.60	101000
1	28	4.76	101000
1	29	4.92	101000
1	30	5.08	101000
1	31	5.24	101000
1	32	5.40	101000
1	33	5.56	101000
1	34	5.72	101000
1	35	5.88	101000
1	36	6.04	101000
1	37	6.20	101000
1	38	6.36	101000
1	39	6.52	101000
1	40	6.68	101000
1	41	6.84	101000
1	42	7.00	101000
1	43	7.16	101000
1	44	7.32	101000
1	45	7.48	101000
1	46	7.64	101000
1	47	7.80	101000
1	48	7.96	101000
1	49	8.12	101000
1	50	8.28	101000
1	51	8.44	101000
1	52	8.60	101000
1	53	8.76	101000
1	54	8.92	101000
1	55	9.08	101000
1	56	9.24	101000
1	57	9.40	101000
1	58	9.56	101000
1	59	9.72	101000
1	60	9.88	101000
1	61	10.04	101000
1	62	10.20	101000
1	63	10.36	101000
1	64	10.52	101000
1	65	10.68	101000
1	66	10.84	101000
1	67	11.00	101000
1	68	11.16	101000
1	69	11.32	101000
1	70	11.48	101000
1	71	11.64	101000
1	72	11.80	101000
1	73	11.96	101000
1	74	12.12	101000
1	75	12.28	101000
1	76	12.44	101000
1	77	12.60	101000
1	78	12.76	101000
1	79	12.92	101000
1	80	13.08	101000
1	81	13.24	101000
1	82	13.40	101000
1	83	13.56	101000
1	84	13.72	101000
1	85	13.88	101000
1	86	14.04	101000
1	87	14.20	101000
1	88	14.36	101000
1	89	14.52	101000
1	90	14.68	101000
1	91	14.84	101000
1	92	15.00	101000
1	93	15.16	101000
1	94	15.32	101000
1	95	15.48	101000
1	96	15.64	101000
1	97	15.80	101000
1	98	15.96	101000
1	99	16.12	101000
1	100	16.28	101000
1	101	16.44	101000
1	102	16.60	101000
1	103	16.76	101000
1	104	16.92	101000
1	105	17.08	101000
1	106	17.24	101000
1	107	17.40	101000
1	108	17.56	101000
1	109	17.72	101000
1	110	17.88	101000
1	111	18.04	101000
1	112	18.20	101000
1	113	18.36	101000
1	114	18.52	101000
1	115	18.68	101000
1	116	18.84	101000
1	117	19.00	101000
1	118	19.16	101000
1	119	19.32	101000
1	120	19.48	101000
1	121	19.64	101000
1	122	19.80	101000
1	123	19.96	101000
1	124	20.12	101000
1	125	20.28	101000
1	126	20.44	101000
1	127	20.60	101000
1	128	20.76	101000
1	129	20.92	101000
1	130	21.08	101000
1	131	21.24	101000
1	132	21.40	101000
1	133	21.56	101000
1	134	21.72	101000
1	135	21.88	101000
1	136	22.04	101000
1	137	22.20	101000
1	138	22.36	101000
1	139	22.52	101000
1	140	22.68	101000
1	141	22.84	101000
1	142	23.00	101000
1	143	23.16	101000
1	144	23.32	101000
1	145	23.48	101000
1	146	23.64	101000
1	147	23.80	101000
1	148	23.96	101000
1	149	24.12	101000
1	150	24.28	101000
1	151	24.44	101000
1	152	24.60	101000
1	153	24.76	101000
1	154	24.92	101000
1	155	25.08	101000
1	156	25.24	101000
1	157	25.40	101000
1	158	25.56	101000
1	159	25.72	101000
1	160	25.88	101000
1	161	26.04	101000
1	162	26.20	101000
1	163	26.36	101000
1	164	26.52	101000
1	165	26.68	101000
1	166	26.84	101000
1	167	27.00	101000
1	168	27.16	101000
1	169	27.32	101000
1	170	27.48	101000
1	171	27.64	101000
1	172	27.80	101000
1	173	27.96	101000
1	174	28.12	101000
1	175	28.28	101000
1	176	28.44	101000
1	177	28.60	101000
1	178	28.76	101000
1	179	28.92	101000
1	180	29.08	101000
1	181	29.24	101000
1	182	29.40	101000
1	183	29.56	101000
1	184	29.72	101000
1	185	29.88	101000
1	186	30.04	101000
1	187	30.20	101000
1	188	30.36	101000
1	189	30.52	101000
1	190	30.68	101000
1	191	30.84	101000
1	192	31.00	101000
1	193	31.16	101000
1	194	31.32	101000
1	195	31.48	101000
1	196	31.64	101000
1	197	31.80	101000
1	198	31.96	101000
1	199	32.12	101000
1	200	32.28	101000
1	201	32.44	101000
1	202	32.60	101000
1	203	32.76	101000
1	204	32.92	101000
1	205	33.08	101000
1	206	33.24	101000
1	207	33.40	101000
1	208	33.56	101000
1	209	33.72	101000
1	210	33.88	101000
1	211	34.04	101000
1	212	34.20	101000
1	213	34.36	101000
1	214	34.52	101000
1	215	34.68	101000
1	216	34.84	101000
1	217	35.00	101000
1	218	35.16	101000
1	219	35.32	101000
1	220	35.48	101000
1	221	35.64	101000
1	222	35.80	101000
1	223	35.96	101000
1	224	36.12	101000
1	225	36.28	101000
1	226	36.44	101000
1	227	36.60	101000
1	228	36.76	101000
1	229	36.92	101000
1	230	37.08	101000
1	231	37.24	101000
1	232	37.40	101000
1	233	37.56	101000
1	234	37.72	101000
1	235	37.88	101000
1	236	38.04	101000
1	237	38.20	101000
1	238	38.36	101000
1	239	38.52	101000
1	240	38.68	101000
1	241	38.84	101000
1	242	39.00	101000
1	243	39.16	101000
1	244	39.32	101000
1	245	39.48	101000
1	246	39.64	101000
1	247	39.80	101000
1	248	39.96	101000
1	249	40.12	101000
1	250	40.28	101000
1	251	40.44	101000
1	252	40.60	101000
1	253	40.76	101000
1	254	40.92	101000
1	255	41.08	101000
1	256	41.24	101000
1	257	41.40	101000
1	258	41.56	101000
1	259	41.72	101000
1	260	41.88	101000
1	261	42.04	101000
1	262	42.20	101000
1	263	42.36	101000
1	264	42.52	101000
1	265	42.68	101000
1	266	42.84	101000
1	267	43.00	101000
1	268	43.16	101000
1	269	43.32	101000
1	270	43.48	101000
1	271	43.64	101000
1	272	43.80	101000
1	273	43.96	101000
1	274	44.12	101000
1	275	44.28	101000
1	276	44.44	101000
1	277	44.60	101000
1	278	44.76	101000
1	279	44.92	101000
1	280	45.08	101000
1	281	45.24	101000
1	282	45.40	101000
1	283	45.56	101000
1	284	45.72	101000
1	285	45.88	101000
1	286	46.04	101000
1	287	46.20	101000
1	288	46.36	101000
1	289	46.52	101000
1	290	46.68	101000
1	291	46.84	101000
1	292	47.00	101000
1	293	47.16	101000
1	294	47.32	101000
1	295	47.48	101000
1	296	47.64	101000
1	297	47.80	101000
1	298	47.96	101000
1	299	48.12	101000
1	300	48.28	101000
1	301	48.44	101000
1	302	48.60	101000
1	303	48.76	101000
1	304	48.92	101000
1	305	49.08	101000
1	306	49.24	101000
1	307	49.40	101000
1	308	49.56	101000
1	309	49.72	101000
1	310	49.88	101000
1	311	50.04	101000
1	312	50.20	101000
1	313	50.36	101000
1	314	50.52	101000
1	315	50.68	101000
1	316	50.84	101000
1	317	51.00	101000
1	318	51.16	101000
1	319	51.32	101000
1	320	51.48	101000
1	321	51.64	101000

MODAL TEMPERATURES AFTER 64 TIME STEPS TIME = 3.039000 00
FOR THE PLANE T=1.1 = 1.000000 00

CESS GRID		1	2	3	4	5	6	7	8	9	10	11	12	13
FINE GRID		1	2	3	4	5	6	7	8	9	10	11	12	13
DISTANCE		0.0	9.00	18.00	27.00	36.00	45.00	54.00	63.00	72.00	81.00	90.00	99.00	108.00
1	1	0.0	9.00	18.00	27.00	36.00	45.00	54.00	63.00	72.00	81.00	90.00	99.00	108.00
2	2	9.00	18.00	27.00	36.00	45.00	54.00	63.00	72.00	81.00	90.00	99.00	108.00	117.00
3	3	18.00	27.00	36.00	45.00	54.00	63.00	72.00	81.00	90.00	99.00	108.00	117.00	126.00
4	4	27.00	36.00	45.00	54.00	63.00	72.00	81.00	90.00	99.00	108.00	117.00	126.00	135.00
5	5	36.00	45.00	54.00	63.00	72.00	81.00	90.00	99.00	108.00	117.00	126.00	135.00	144.00
6	6	45.00	54.00	63.00	72.00	81.00	90.00	99.00	108.00	117.00	126.00	135.00	144.00	153.00
7	7	54.00	63.00	72.00	81.00	90.00	99.00	108.00	117.00	126.00	135.00	144.00	153.00	162.00
8	8	63.00	72.00	81.00	90.00	99.00	108.00	117.00	126.00	135.00	144.00	153.00	162.00	171.00
9	9	72.00	81.00	90.00	99.00	108.00	117.00	126.00	135.00	144.00	153.00	162.00	171.00	180.00
10	10	81.00	90.00	99.00	108.00	117.00	126.00	135.00	144.00	153.00	162.00	171.00	180.00	189.00
11	11	90.00	99.00	108.00	117.00	126.00	135.00	144.00	153.00	162.00	171.00	180.00	189.00	198.00
12	12	99.00	108.00	117.00	126.00	135.00	144.00	153.00	162.00	171.00	180.00	189.00	198.00	207.00
13	13	108.00	117.00	126.00	135.00	144.00	153.00	162.00	171.00	180.00	189.00	198.00	207.00	216.00
14	14	117.00	126.00	135.00	144.00	153.00	162.00	171.00	180.00	189.00	198.00	207.00	216.00	225.00
15	15	126.00	135.00	144.00	153.00	162.00	171.00	180.00	189.00	198.00	207.00	216.00	225.00	234.00
16	16	135.00	144.00	153.00	162.00	171.00	180.00	189.00	198.00	207.00	216.00	225.00	234.00	243.00
17	17	144.00	153.00	162.00	171.00	180.00	189.00	198.00	207.00	216.00	225.00	234.00	243.00	252.00
18	18	153.00	162.00	171.00	180.00	189.00	198.00	207.00	216.00	225.00	234.00	243.00	252.00	261.00
19	19	162.00	171.00	180.00	189.00	198.00	207.00	216.00	225.00	234.00	243.00	252.00	261.00	270.00

CESS GRID		11	12
FINE GRID		11	12
DISTANCE		216.00	225.00
1	1	0.0	9.00
2	2	9.00	18.00
3	3	18.00	27.00
4	4	27.00	36.00
5	5	36.00	45.00
6	6	45.00	54.00
7	7	54.00	63.00
8	8	63.00	72.00
9	9	72.00	81.00
10	10	81.00	90.00
11	11	90.00	99.00
12	12	99.00	108.00
13	13	108.00	117.00
14	14	117.00	126.00
15	15	126.00	135.00
16	16	135.00	144.00
17	17	144.00	153.00
18	18	153.00	162.00
19	19	162.00	171.00


```

CROSS GRID      11
FINE GRID      14
DISTANCE      228.89
1 1 0.0 --100100
2 2 0.0 --100100
3 3 85.50 --100100
4 4 103.00 180100
5 5 120.50 180100
6 6 141.42 180100
7 7 162.33 180100
8 8 167.33 180100
9 9 162.94 180100
10 10 198.55 180100
11 11 216.16 180100
12 12 229.77 180100
13 13 255.38 180100
14 14 276.60 180100
15 15 307.62 180100
16 16 339.64 180100
17 17 370.26 180100
18 18 401.48 180100
19 19 417.09 180100
20 20 422.09 180100
21 21 450.75 180100
22 22 472.41 --100100
23 23 564.91 --100100
24 24 567.91 --100100

```

TEMPERATURES ON NUMBERED BOUNDARIES

BOUNDARY NUMBER	TEMPERATURE
1	180.000000
2	0.0
3	0.0
4	0.0

THE CURRENT TIME STEP (DELTAT) = 2.79874060-01

ELAPSED CPU TIME IS 1942.40 SECONDS

THE MAXIMUM TEMPERATURE IS - 3.363260 03 (+-0.1)

MAX. TEMP. APPEARS AT NODES - 2185

THE MINIMUM TEMPERATURE IS - 1.800000 02 (+-0.1)

MIN. TEMP. APPEARS AT NODES -

1	2	3	8	9
6	7	8	9	10
11	12	13	14	15
16	17	18	19	20
21	22	23	24	25
26	27	28	29	30
31	32	33	34	35
36	37	38	39	40
41	42	43	44	45
46	47	48	49	50

HYDR LUPC ACCIDENT - FULTON POWER STATION(JOJO0MBT1) 30.MJUL

HIGH TEMPERATURE GAS COOLED REACTOR ANALYSIS

WATERIA- ID NAME	VOLUME (CU.IN.)	TEMPERATURE CRITERIA (DEG.F)		
		LOW	MEDIUM	HIGH
JNE	1063554.07	4318.000	4501.000	2000.000
TWO	987947.59	2088.000	4500.000	4001.000
THREE	1367864.22	1970.000	4400.000	4500.000
FOUR	1932181.21	1908.000	2100.000	4000.000
TOTAL	5351507.39			

PERCENTAGE OF ACTIVE CORE VOLUME EXCEEDING TEMPERATURE CRITERIA

TIME	TEMPERATURE CRITERIA	RELATIVE TO AGE OF FULL POWER				TOTAL
		ONE	TWO	THREE	FOUR	
C.0	LOW	0.0	0.0	0.0	0.0	0.0
	MEDIUM	0.0	0.0	0.0	0.0	0.0
	HIGH	0.0	0.0	0.0	0.0	0.0
C.007200	LOW	0.0	0.0	0.0	0.0	0.0
	MEDIUM	0.0	0.0	0.0	0.0	0.0
	HIGH	0.0	0.0	0.0	0.0	0.0
C.014400	LOW	0.0	0.0	0.0	0.0	0.0
	MEDIUM	0.0	0.0	0.0	0.0	0.0
	HIGH	0.0	0.0	0.0	0.0	0.0
C.031200	LOW	0.0	0.0	0.0	0.0	0.0
	MEDIUM	0.0	0.0	0.0	0.0	0.0
	HIGH	0.0	0.0	0.0	0.0	0.0
C.057112	LOW	0.0	0.0	0.0	0.0	0.0
	MEDIUM	0.0	0.0	0.0	0.0	0.0
	HIGH	0.0	0.0	0.0	0.0	0.0
C.057099	LOW	0.0	0.0	0.0	0.0	0.0
	MEDIUM	0.0	0.0	0.0	0.0	0.0
	HIGH	0.0	0.0	0.0	0.0	0.0
C.053087	LOW	1.691	94.942	42.182	30.025	40.853
	MEDIUM	0.0	0.0	0.0	0.0	0.0
	HIGH	0.0	0.0	0.0	0.0	0.0

1-251076	LO4 MEDIUM HIGH	29.004 0.436 0.0	94.749 11.09 0.0	94.825 43.890 0.070	57.577 13.921 0.027
1-254002	LO4 MEDIUM HIGH	36.005 7.341 0.0	70.071 22.942 0.744	67.408 41.122 2.231	69.601 17.270 1.128
1-2547344	LO4 MEDIUM HIGH	62.144 2.141 0.551	39.071 37.525 0.220	20.744 20.625 11.550	71.612 41.047 7.826
1-2549316	LO4 MEDIUM HIGH	74.596 42.280 5.883	61.986 50.903 14.910	72.047 57.977 13.743	70.248 51.927 16.566
1-2549324	LO4 MEDIUM HIGH	70.507 50.287 15.857	66.977 67.767 28.137	73.210 69.251 33.016	80.018 60.869 28.408
1-2549331	LO4 MEDIUM HIGH	61.594 66.122 49.691	67.923 72.731 42.694	73.609 65.097 44.722	62.336 69.333 37.520
1-2549344	LO4 MEDIUM HIGH	64.307 71.489 41.461	69.986 77.205 51.584	76.043 74.923 37.948	64.157 72.047 43.752

APPENDIX C

**List of Reports Describing Code and
Model Development Leading to the HEATUP Code**

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List of Reports Describing Code and Model Development
Leading to the HEATUP Code

1. J. P. Sanders, HTGR Safety Studies Progress Report for the Period Ending January 31, 1973, ORNL/TM-4752, October 1974.
2. J. P. Sanders, HTGR Safety Studies Progress Report for the Period Ending March 31, 1973, ORNL/TM-4753, October 1974.
3. J. P. Sanders, HTGR Safety Studies Progress Report for the Period Ending June 30, 1973, ORNL/TM-4741, October 1974.
4. J. P. Sanders, HTGR Safety Studies Progress Report for the Period Ending September 30, 1973, ORNL/TM-4739, October 1974.
5. I. I. Siman-Tov and J. P. Sanders, Development of Models for the Evaluation of Temperatures in a HTGR Core Following a Loss of Forced Circulation and Simultaneous Reactor Trip, ORNL/TM-4740, October 1974.
6. P. R. Kasten, J. H. Coobs, A. L. Lotts, Gas-Cooled Reactor Programs Annual Progress Report for Period Ending December 31, 1973, ORNL-4975, April 1976.
7. J. P. Sanders, HTGR Safety Studies Progress Report for the Period Ending June 30, 1974, ORNL/TM-4737, October 1974.
8. J. P. Sanders, HTGR Safety Studies Progress Report for the Period Ending September 30, 1974, ORNL/TM-4806, September 1975.
9. J. P. Sanders, HTGR Safety Studies Progress Report for the Period Ending March 31, 1975, ORNL/TM-5075, November 1975.