MASTER

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Westinghouse Astronuclear Laboratory

TRACK II

A COMPUTER PROGRAM FOR TRANSIENT THERMAL ANALYSIS OF FLOW SYSTEMS WITH MULTIPLE PARALLEL AND SERIES CHANNELS

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ABSTRACT

TRACK II is a digital computer program for transient and steady-state thermal analysis of heat generating solids of arbitrary geometry which are cooled by fluid flowing through multiple parallel or series channels. The hydraulic and heat convection calculations are coupled with finite element heat conduction calculations to determine coolant conditions and material temperature distributions in a single computation. The primary application is to perform detailed thermal analyses of nuclear reactor components such as the reflector, the control mechanism, and fuel cluster assemblies under various operating conditions. A key feature of the program is the versatility of the flow network. Two independent groups of coolant channels are permitted and the channels may be arranged in series and parallel combinations. Additional features include an option for interface conduction between components which are modeled separately and a method to accommodate the effect of fast neutron fluence on component temperature distributions.

This report presents the formulation for the transient thermal calculations and discusses the calculational models with emphasis on the application of the capability of TRACK II for thermal, hydraulic analysis of complex systems. The thermal analysis of the reflector system for the XE-PRIME NERVA reactor is presented as an example of this capability. Computer users information is presented, including program organization, input and output formats, CDC-6600 deck structure, and a sample problem.

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TABLE OF CONTENTS

<u>Section</u>		<u>Page</u>
	ABSTRACT	iii
	LIST OF ILLUSTRATIONS	vii
	LIST OF TABLES	viii
1.0	INTRODUCTION	1
2.0	ANALYSIS FORMULATION	3
2.1	General Hydrodynamic and Heat Conduction Equations	3
2.2	Coupling of Hydraulic and Conduction Calculations	5
2.3	Convective Heat Transfer Coefficient Correlations	6
2.4	Friction Factor Correlations	9
2.5	Neutron Irradiation Effects on Thermal Conductivity.	10
3.0	CALCULATION MODEL REPRESENTATION	11
3.1	Hydraulic Model	11
3.2	Heat Conduction Model	15
3.3	Multiple Coolant Channel Groups and Multiple Components	24
3.4	Convergence of Hydraulic and Conduction Solutions	24
3.5	Modeling of the XE-PRIME Reflector System	25
4.0	TRACK II DIGITAL COMPUTER PROGRAM	33
4.1	Program Organization	33
4.2	Summary of TRACK II Capability	35
4.3	Input Data Requirements	38

TABLE OF CONTENTS (CONTINUED)

<u>SECTION</u>	<u>PAGE</u>
4.4 Printed Output Data	38
NOMENCLATURE	73
REFERENCES	75
Appendix A. Calculational Procedure (Finite Difference Equations)	77
Appendix B. WANL Materials Thermal Properties Library System	85
Appendix C. Interaction Between Parallel Channel Groups	89
Appendix D. Sample Problem	91

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	Parallel and Series Channel Configurations	12
2	Parallel and Series Channel Combinations	14
3	Typical Series Channel Flow Model	16
4	Typical Parallel Channel Flow System with Three Components	18
5	Typical Conduction Model Cross-Sectional Nodal Pattern	20
6	Typical Series Channel Flow System with One Component	22
7	Conduction Model Cross-Sectional Nodal Pattern	23
8	XE-PRIME Reflector System	26
9	Flow Diagram for the XE-PRIME Reflector System	27
10	Full Power Steady-State Pressure Distributions of the XE-PRIME Reflector System	30
11	Full Power Steady-State Material Temperature Distributions for the XE-PRIME Reflector	31
12	Midplane Isotherms for the XE-PRIME Reflector During Full Power-Steady-State Operation	32
13	TRACK Computer Program Flow Diagram	34
14	Sample Problems: Hydraulic and Conduction Models	92

LIST OF TABLES

<u>Table</u>		<u>Page</u>
I	TRACK II Deck Structure for CDC-6600 Computer	40
II	TRACK II Input Format Conduction Model	42
III	TRACK II Input Data and Formats Hydraulic Model	49
IV	Tape Usage	67
V	TRACK II Output Parameters	70

1.0 INTRODUCTION

In the design and development of a nuclear reactor for rocket propulsion application, the reactor components must fulfill the design requirements in a severe thermal, hydraulic, and nuclear irradiation environment with a high probability of success. Furthermore, the weight of reactor components must be minimized in order to achieve the performance goals. The dual objectives of high performance with high reliability entail precise determination of stresses and, hence, temperature distributions. Increasingly, this has come to mean computerized finite element solutions which provide a practical approach to analyzing components of complex geometry with non-symmetric boundary conditions. This report presents a computer solution to perform detailed transient and steady-state thermal analyses of heat generating solids of arbitrary geometry cooled by fluid flowing through multiple parallel and series channels. The primary application is to perform a detailed thermal analysis of nuclear reactor components such as the reflector, the control mechanisms, and fuel cluster assemblies under various operating conditions. The method of solution may be applied to other heat transfer systems with or without internal heat generation such as heat exchange apparatus.

This method employs one-dimensional, transient (or steady-state) pipe flow analysis coupled with a heat conduction calculation in the solid body. The heat conduction calculation is included to determine the channel wall temperatures required to complete the hydrodynamic calculations and to provide detailed material temperature distributions. Thus, heat conduction effects between coolant channels are evaluated. Various solutions (References 1 to 7) have been developed for one-dimensional, unsteady pipe flow for reactor thermal transients and other applications. Most of these solutions are formulated for their respective specific problems or systems. For example, the Reference 1 solution applies to an "isolated" single plate channel with an incompressible fluid. For the solution presented in this document, the solid body geometry is general and the parallel channels may have different individual flow impedance and be arranged in any non-symmetrical pattern.

The computations are performed by TRACK II, a digital computer program which is an updated version of TRACK (Reference 8). The basic TRACK program was limited to one group of multiple parallel coolant channels. The key features of the new program are that series and parallel combinations of coolant channels are permitted and that a second group of coolant channels has been added to increase the program capacity and flexibility. For example, TRACK II was used in the thermal analysis of the combined reflector-lateral support system for the XE-PRIME reactor, including all the components from the core insulation to the pressure vessel outer diameter. The first group of channels was used to represent parallel flow through the reflector, control mechanism, and graphite barrel coolant channels. The second group was used to simulate series and parallel flow paths in the lateral support seal region with flow direction counter to the reflector flow. Additional innovations include cross flow between the coolant channels and an external flow source, interface conduction between components which are modeled separately, and a method which allows for the variation of material thermal conductivity as a function of temperature and fast neutron fluence.

The TRACK II computer program is written in FORTRAN IV language for the CDC 6600 computer. Material temperature distributions are reserved on tape for direct input to other codes. The printed output includes complete display of coolant conditions throughout the system and nodal temperature distributions for the solid body.

This report presents the formulation for the transient thermal and fluid flow calculations and instructions for model preparation and data input. A sample problem is included. The detailed calculational procedure is described in Appendix A.

2.0 ANALYSIS FORMULATION

The system being considered is a heat generating solid body of arbitrary geometry cooled (or heated) by a fluid flowing through multiple parallel or series channels. The channel cross-sectional areas are constant over the length, but different channels may have different cross-sectional areas and impedances. The fluid is considered compressible in a one-dimensional single phase pipe flow with friction and heat transfer across the channel boundary. The flow may be either laminar or turbulent.

The thermodynamic and transport properties of the fluid are temperature and pressure dependent. Hydrogen is the primary coolant considered, but other fluids can be used by substituting the appropriate fluid property subroutines. The solid body possesses finite and temperature dependent physical properties. The internal heat generation rate in the solid body may vary longitudinally and transversely.

The governing hydrodynamic and heat conduction equations and pertinent correlations of physical phenomena are given in the following subsections. Transformation of the equations into finite difference form is detailed in Appendix A. The symbols used in the equations and elsewhere in this report are explained in the nomenclature section.

2.1 GENERAL HYDRODYNAMIC AND HEAT CONDUCTION EQUATIONS

The hydrodynamic equations in the Eulerian form for the laws of fluid motion are expressed as follows:

$$\text{Continuity: } \frac{\partial \rho}{\partial \theta} + \frac{\partial G}{\partial x} = 0 \quad (1)$$

$$\text{Momentum: } \frac{\partial P}{\partial x} + \frac{1}{g} \frac{\partial G}{\partial \theta} + \frac{1}{g} \frac{\partial (G^2 v)}{\partial x} + F = 0 \quad (2)$$

$$\text{Energy: } \frac{\partial (HG)}{\partial x} + \frac{\partial (H\rho)}{\partial \theta} - \frac{1}{J} \frac{\partial P}{\partial \theta} - QP = 0 \quad (3)$$

The convective heat transfer between the fluid and channel wall in the hydraulic calculations is found from the following equation,

$$q = hA_s (T_w - T_r) \quad (4)$$

For small Mach numbers ($\ll 1.0$) the difference between the recovery temperature (T_r) and the fluid free stream temperature (T_b) is not significant, so that equation (4) may be written as

$$q = hA_s (T_w - T_b) \quad (5)$$

From the above formulation of the fluid flow calculations, it is seen that the flow distribution between channels and the fluid pressure and temperature profiles can be calculated for a given time when the wall temperature distribution is specified. The fluid properties used in the pressure drop and heat transfer calculations within an axial increment are determined by an iteration process.

The temperature distribution in the solid body is calculated by the Fourier heat conduction equation (shown below) utilizing finite element nodal models:

$$\frac{\partial}{\partial x} \left(k \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left(k \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left(k \frac{\partial T}{\partial z} \right) + Q'''(x, y, z, \theta) = \rho c_p \frac{\partial T}{\partial \theta} \quad (6)$$

The channel wall boundary conditions for the conduction calculation are

$$-k \frac{\partial T}{\partial n} \bigg|_{\text{wall}} = h A_s (T_b - T_w) \quad (7)$$

2.2 COUPLING OF HYDRAULIC AND CONDUCTION CALCULATIONS

From the above description of the calculational procedure, it is seen that the fluid flow calculation can be completed for one time step when the channel wall temperature distributions through the flow system are known. In the analysis presented herein, the channel wall temperatures are supplied and checked using a temperature distribution calculation of the solid body. Estimates of the initial wall temperature distribution are specified in the input data. The fluid flow calculation for the first time step can then be completed. The resulting fluid bulk temperatures and channel wall heat transfer coefficients are input to the temperature distribution calculations to compute the temperature change of the solid body during this time step at several transverse cross sections of the system (axial heat conduction is neglected). Linear interpolation is used to complete the axial wall temperature profiles. The channel wall temperatures thus obtained are compared to the wall temperatures used in the fluid flow calculation. If they do not agree within a specified tolerance, the entire procedure is repeated using the new channel wall temperatures. This iteration between the fluid flow calculation and the material temperature distribution calculation is continued until the convergence criterion is satisfied. The iteration process is repeated for each succeeding time step.

It should be noted that the method of coupling the hydraulic and conduction solutions does not provide for conservation of energy except through convergence. For a given channel and axial increment, the heat added to the fluid is calculated from the hydraulic model to be:

$$q_{\text{added to fluid}} = hA_s \left[T_{w_1} - T_b \right] \quad (8)$$

The heat removed from the solid body by the fluid at the corresponding channel and axial position is determined from the conduction calculation to be:

$$q_{\text{removed from solid body}} = hA_s \left[T_{w2} - T_b \right] \quad (9)$$

It is seen that energy is conserved only when the wall temperatures used in the hydraulic calculation (T_{w1}) are identical with those obtained from the conduction calculation (T_{w2}) at all channel and axial positions. Iteration between the hydraulic and conduction calculations for a time interval is concluded when,

$$\left(\left| (T_{w1}) - (T_{w2}) \right| / (T_{w2}) \right) < \epsilon \quad (10)$$

where ϵ is the specified convergence criterion.

2.3 CONVECTIVE HEAT TRANSFER COEFFICIENT CORRELATIONS

The convective heat transfer coefficient, h , used in equations (4) and (5) is determined by the following type of correlation:

$$Nu = f \left(Re^n, Pr^m, \frac{x}{D}, \frac{T_b}{T_w} \right) \quad (11)$$

where Nu , Re , and Pr are the Nusselt, Reynolds, and Prandtl numbers, respectively. At present the analysis is limited to single-phase gaseous flow. For turbulent flow in smooth tubes, three correlations are available. The first is based on the McCarthy-Wolf⁽⁹⁾ investigation of gaseous hydrogen and helium flow through smooth tubes and is suitable for a wide range of T_w/T_b ratios, up to 3.5.

a) McCarthy-Wolf Turbulent Heat Transfer Correlation⁽⁹⁾

$$h = 0.025 \left(\frac{k_b}{D} \right) \left(Re_b \right)^{0.8} \left(Pr_b \right)^{0.4} \left(\frac{T_b}{T_w} \right)^{0.55} \left[1 + 0.3 \left(\frac{X}{D} \right)^{-0.7} \right] \quad (12)$$

where the fluid properties are evaluated at fluid bulk temperature. At $X = 0$, the entrance effect term $(1 + 0.3 (X/D)^{-0.7})$ is replaced by a factor of 1.1.

The second turbulent flow heat transfer correlation is a combination of the Petuhkov⁽¹⁰⁾, McCarthy and Wolf correlation which was developed at WANL.

b) Petuhkov⁽¹⁰⁾-McCarthy - Wolf⁽⁹⁾ Turbulent Heat Transfer Correlation

$$h = 0.0212 \left(\frac{k_b}{D} \right) \left(Re_b \right)^{0.8} \left(Pr_b \right)^{0.4} \left(\frac{T_b}{T_w} \right)^P, \text{ for } \frac{X}{D} < 80 \quad (13)$$

$$h = \left(0.0212 + 0.000211 (X-8) \right) \left(\frac{k_b}{D} \right) \left(Re_b \right)^{0.8} \left(Pr_b \right)^{0.4} \left(\frac{T_b}{T_w} \right)^{0.55} \quad (14)$$

$$\text{for } 80 \leq \frac{X}{D} \leq 260$$

$$h = 0.025 \left(\frac{k_b}{D} \right) \left(Re_b \right)^{0.8} \left(Pr_b \right)^{0.4} \left(\frac{T_b}{T_w} \right)^{0.55}, \text{ for } \frac{X}{D} > 260 \quad (15)$$

In Equation 13, the exponent, P , on the coolant temperature to wall temperature correction is a function of the X/D ratio. This function is tabulated below:

<u>X/D</u>	<u>P</u>
0	.125
10.	.190
20.	.245
30.	.300
40.	.350
50.	.410
60.	.460
70.	.500
80.	.520
90. and up	.530

The third turbulent flow heat transfer correlation was developed by Los Alamos Scientific Laboratory. ⁽¹¹⁾

c) Los Alamos Scientific Laboratory Correlation ⁽¹¹⁾

$$h = 0.023 \left(\frac{k_b}{D} \right) (Re_b)^{0.8} (Pr_b)^{0.4} C_1 \left(\frac{T_w}{T_b} \right)^{-C_2} \quad (16)$$

In Equation (16) the constants C_1 and C_2 are defined as follows:

For $T_w/T_b < 1.8$

$$C_1 = 1.0$$

$$C_2 = 0.765$$

For $T_w/T_b \geq 1.8$

$$C_1 = 0.7$$

$$C_2 = 0.20$$

For laminar flow in the gaseous regime, the following relation ⁽¹²⁾ is used:

$$h = \left\{ 4.36 + \left(\frac{0.036 \frac{D}{x} Re Pr}{1 + 0.001 \frac{D}{x} Re Pr} \right) \right\} \frac{k}{D} \left(\frac{T_w}{T_b} \right)^{0.25} \quad (17)$$

At $X = 0$, the D/X ratio is set equal to 40 in the above equation. The properties are evaluated at the coolant bulk temperature. The change from turbulent to laminar heat transfer correlations is made at $Re = 1200$ to provide a smooth transition.

2.4 FRICTION FACTOR CORRELATIONS

The friction term, F , in Equation 2 is expressed by means of the friction factor, f , as follows,

$$F = \frac{4fG^2}{2g \rho D} \quad (18)$$

The friction factor is obtained from the following correlations by Taylor ⁽¹³⁾ for gaseous flow through a smooth tube:

$$\text{turbulent flow, } f = \left(0.0014 + \frac{0.125}{(Re_w)^{0.32}} \right) \left(\frac{T_b}{T_w} \right)^{0.5} \quad (19)$$

$$\text{laminar flow, } f = \frac{C}{Re_w} \quad (20)$$

where Re_w is a modified surface Reynolds number in which the gas density is evaluated at the fluid bulk temperature, but the viscosity is evaluated at channel wall temperature:

$$Re_w = \left(\frac{GD}{\mu_w} \right) \left(\frac{T_b}{T_w} \right) \quad (21)$$

The constant, C , in Equation 20 depends upon the type of cooling channels used. For example, with cylindrical cooling channels, $C = 16$ and with annular channels $C = 24$.

The transition point between laminar and turbulent friction factor correlations is taken at $Re_w = 1070$ to avoid discontinuities in the pressure drop computations.

2.5 NEUTRON IRRADIATION EFFECT ON THERMAL CONDUCTIVITY

In some materials exposed to high intensity neutron irradiation for long periods of time, as in NERVA reactors, the thermal conductivity has been found to vary. The variation is a function of the neutron fluence which is a measure of the fast neutron intensity integrated over the exposure time.

$$k = f(T, n \text{ v } t)$$

Where experimental correlations of thermal conductivity with temperature and neutron fluence are available for specific materials, thermal conductivity tables may be input as functions of these two independent variables as illustrated in the figure below. Values of fluence are input to individual nodes according to spatial and time-dependent functions, and the thermal conductivity is obtained by double, linear interpolation from the table.

3.0 CALCULATIONAL MODEL REPRESENTATION

The fluid flow analysis and the heat conduction analysis are two separate calculations requiring separate analytical models. These models are discussed in the following subsections, and examples of modeling technique are presented including a brief outline of the model used to represent the XE-PRIME reflector and lateral support system.

3.1 HYDRAULIC MODEL

The hydraulic model consists of constant diameter, parallel, or series flow channels. A channel is divided into a finite number of equal axial increments, and the fluid conditions at the end of each increment are calculated at every time step. The fluid conditions at other axial locations can be obtained by interpolation between calculated values. Channels having the same hydraulic diameter and flow impedances may be lumped into a representative channel. It should be understood, however, that lumping coolant channels influences the solution toward a uniform temperature distribution and should be avoided in regions requiring a high degree of accuracy.

3.1.1 Parallel or Series Channels

Two flow system options are available. The first system consists of multiple parallel coolant channels between common inlet and outlet plena as shown in Sketch (a) of Figure 1. For this "parallel channel" flow system, the wall temperatures vary over the channel length. Sketch (b) illustrates the second kind of flow system referred to herein as "series channels." This system consists of multiple plena in series connected by one or more parallel flow channels. Series channels are considered to be relatively short and the computations are simplified by imposing uniform wall temperatures over the channel length.

3.1.2 Two Groups of Channels

A channel configuration which does not conform to either of the flow system options discussed above is shown in Sketch (c) of Figure 1. To permit hydraulic analysis

(a) PARALLEL CHANNEL FLOW SYSTEM

(b) SERIES CHANNEL FLOW SYSTEM

(c) COMBINATION FLOW SYSTEM (THIS CONFIGURATION REQUIRES TWO GROUPS OF INDEPENDENT CHANNELS)

Figure 1. Parallel and Series Channel Configurations

of this kind of flow configuration, the TRACK computer program was expanded to include two independent groups of channels. The flow direction may be identical or opposite for the two groups. Figure 2 illustrates the possible combinations of flow systems. Fluid inlet conditions to the second group of channels may be externally specified or may be determined from hydraulic calculations for the first group.

3.1.3 Lateral Flow to Series Channels

TRACK II permits intermediate flow input to a series combination of channels. Flow is added or subtracted at specified plena and an enthalpy balance is made between the direct flow and lateral flow streams to determine the mixed mean coolant conditions for downstream calculations. Two input options are available: (1) flow rate and specific enthalpy for the lateral flow stream are specified, or (2) the flow rate and specific enthalpy are calculated for interconnection to an external flow source through a specified impedance. The coolant pressure and temperature distributions for the external source may be specified or, where applicable, they may be obtained from hydraulic calculations for a preceding group of channels. Another source of lateral inflow is porous flow through the material boundaries. Porous flow is determined from a correlation of flow rate versus the parameter $(P \Delta P / \mu RT)$. The porous flow integrated over a prescribed channel length is added to specified plena in conjunction with other forms of lateral inflow. Caution should be exercised in the use of lateral flow from the first group of channels to the second group because the flow subtraction from the first group is not included in the calculations. Coolant channel crossflow between end points is not permitted.

3.1.4 Series Channel Representation

Wall temperature input to series channels differs substantially from that for parallel channels. For the latter, axial wall temperature distributions are obtained from the heat conduction calculation for each coolant channel. For series channels, the channels are classified according to types having similar hydraulic and heat transfer characteristics. Axial

Figure 2. Parallel and Series Channel Combinations

distributions of wall temperature are prepared for each type. The wall temperature for a particular channel is obtained by interpolation of the appropriate wall temperature table at the specified axial location.

A typical series channel flow model is shown in Figure 3. In this example, there are three distinct types of coolant flow paths in repeating patterns. As indicated in Figure 3, Types 2 and 3 constitute a parallel flow system in series with Type 1. Each grouping of parallel channels within the series channels structure is called a section which may comprise one or more channels. Typical crossflow into the system is indicated.

3.1.5 Flow and Pressure Drop Options

Two basic flow balancing options are available: (1) the system overall pressure drop is determined for a specified total flow rate, or (2) the system total flow rate is determined for a specified pressure drop. Flow distribution among parallel coolant channels is determined such that the individual channel pressure drops are within a specified tolerance of either the specified pressure drop or the flow weighted average pressure drop. For series channels, a specified pressure drop pertains to the overall pressure drop of the series flow network. Flow balancing is performed for parallel flow sections within the series channel structure. There is a minor variation to the pressure drop option which applies to the second group of coolant channels in a two-group problem. When the inlet coolant conditions (temperature and pressure) to the second group are to be determined from the first group results and the pressure drop option is selected, the inlet pressure schedule is replaced with a schedule of exit pressure. In this case, the flow rate is adjusted until agreement on exit pressure is attained.

3.2 HEAT CONDUCTION MODEL

The heat conduction model of the solid body consists of two or three-dimensional heat transfer models at selected axial positions. Axial heat conduction between models is neglected. In setting up the heat transfer model, the body is divided into lumped masses (nodal points) and the masses are joined by connectors as required by the TAP-A (Reference 14)

Figure 3. Typical Series Channel Flow Model

conduction code. The coolant temperature and heat transfer coefficient boundary conditions needed for the temperature distribution calculations are obtained from the results of the hydraulic analysis. For a given flow system, there can be more than one independent solid body. The bodies are called components. When there is more than one component in the problem, heat transfer models for each component will be required. Three-dimensional models at the selected axial positions (without axial heat transfer between models) can be used to represent the heat conduction calculational model.

3.2.1 Typical Parallel Channel Flow System with Multiple Components

A typical parallel channel flow system and the associated components are illustrated in Figure 4. The flow system consists of six parallel flow channels (numbered from 1 to 6) between the common inlet and outlet plena, and there are three independent solid bodies (designated A, B, and C). The solid body A is cooled (or heated) internally by the coolant in channel 1 and externally by the coolant in channel 2. The solid body B is cooled (or heated) internally by the coolant in channels 3 and 4 and externally by the coolant in channels 2 and 5. Similarly, the solid body C is cooled (or heated) externally by the coolant in channel 5 and internally by the coolant in channel 6.

The fluid bulk temperature at any axial position of channel 2 is common to solids A and B. However, the local heat transfer coefficient for channel 2 on the side of solid A may be different from that on the side of solid B. They are evaluated separately in the fluid flow calculation and depend on the T_b/T_w correction factor. In each component of this illustration, four heat transfer models at the axial positions X_0 , X_1 , X_2 , and X_3 are specified. Each can be a two- or three-dimensional model. It should be noted that each component must have heat conduction models at the same axial positions.

The procedure for preparing a heat transfer model to compute the temperature distribution in the solid body using the TAP-A code is discussed in Reference 18. However, in order to clarify the procedure in setting up a problem for analysis, the nodal point assignment method used in TAP-A is briefly described as follows:

Figure 4. Typical Parallel Channel Flow System with Three Components

A symmetric section of the solid body (for a three-dimensional model) or a transverse slice of the solid body (for a two-dimensional model) is first divided into a finite number of nodes, called internal nodes. They are numbered starting from 1. A cooling channel wall surface is designated by surface nodes. The surface nodes are numbered starting from 3001. The coolant temperatures which provide convective heat transfer with the surface nodes are designated as boundary nodes. The boundary nodes are numbered starting from 5001. The convective heat transfer coefficient table (as a function of time) which connects a boundary node to a surface node is designated by a FILMCO number which starts from 1. The first step in setting up a problem for analysis is to sketch a cross-sectional view of the components. Figure 5 shows a cross-sectional view of the illustrative flow system in Figure 4. The second step is to number the coolant channels. They must be numbered consecutively starting from 1. In this illustration, the channels are numbered from 1 to 6. Next, a boundary node is assigned to each coolant channel. The most logical numbering system is to assign a boundary node number which equals the channel number plus 5000, i.e., boundary node 5001 is assigned to coolant channel 1. A wall designation is then assigned to each coolant channel wall. Cooling holes have only one wall, whereas annular passages have two. Wall 1 will automatically be assigned a heat transfer coefficient table number (FILMCO number) equal to the boundary node minus 5000, but the FILMCO table for wall 2 is arbitrarily chosen. For example, as shown in Figure 5, coolant channel 1 (a cooling hole) has boundary node 5001, and FILMCO table number 1, channel 2 (an annulus) has boundary node 5002, FILMCO table 2 for wall 1 and FILMCO table 7 (arbitrary) for wall 2. It should be noted that it does not matter which side of an annulus is designated as wall 1 or wall 2.

Once the coolant channel and boundary node system is specified, each component may be treated separately and divided into nodal meshes as described in the TAP-A computer code manual. It is best when making the TAP-A model to number regions sequentially so that the temperatures in these regions can be easily averaged. This applies also to the surface node numbering. It is advisable, but not absolutely necessary, to group the surfaces which make up a coolant channel wall in sequential numbers, so that they may be easily averaged

Figure 5. Typical Conduction Model Cross-Sectional Nodal Pattern

to obtain the channel wall temperature. Figure 5 also shows the internal nodes and the surface nodes of the three components for illustration.

3.2.2 Typical Series Channels With a Single Component

A typical series channel flow system with a single component is shown in Figure 6. The flow system consists of 18 coolant channels (numbered 1 to 18). The solid body, A, is internally cooled (or heated) by the 18 flow channels. There are three hydraulically similar coolant channels types represented by channels 1, 4, 7, 10, 13, and 16 (Type 1), 2, 5, 8, 11, 14, and 17 (Type 2) and 3, 6, 9, 12, 15, and 18 (Type 3). There are three heat conduction models at axial locations X_0 , X_1 , and X_2 .

The procedure for preparing the TAP-A conduction model of the solid body is identical to that previously described in Section 3.2.1. Figure 7 shows the conduction model for this example. The boundary node and FILMCO table designations will be the same at each axial location, but the coolant channels supplying the boundary fluid conditions will change with axial location. The fluid boundary conditions are integrated averages of the fluid conditions over the channel length. Area-weighted average surface node temperatures are paired with the specified axial locations of the conduction model (X_0 , X_1 , X_2 , etc.) to form an axial wall temperature distribution for the corresponding channel type.

3.2.3 Interface Conduction Between Components

The TRACK II computer program includes a technique for simulating interface conduction between adjacent components which are modeled separately. This option permits the subdivision of a composite component into smaller units for more convenient modeling and more efficient use of the nodal capacity of the conduction code. Appropriate boundary temperatures and heat transfer coefficients are applied to the interface surfaces for each of the separate heat conduction calculations. The boundary temperatures are obtained from the most recently calculated temperature distributions in the neighboring component. The

Figure 6. Typical Series Channel Flow System with One Component

Channel Type 2

Channel Type 3

Channel Type I

NOTE: Corresponding Flow System is Shown in Figure 6.

Figure 7. Conduction Model Cross-Sectional Nodal Pattern

corresponding effective heat transfer coefficients are calculated from the thermal conductivity of the adjacent material and the mean conduction path length ($h=k/x$). There is no iteration of conduction solutions for the affected components within the conduction model. However, the interface conduction boundary conditions are updated during each iteration between hydraulic and conduction calculations. Therefore, as the hydraulic and conduction solutions converge, the interface conduction boundary conditions become reasonable estimates of the true boundary conditions. The interface conduction option is properly applied only at low heat flux boundaries such as insulation interfaces.

3.3 MULTIPLE COOLANT CHANNEL GROUPS AND MULTIPLE COMPONENTS

Multiple components should not be confused with multiple coolant channel groups. Separation of the solid body into independent units allows for more efficient use of the capacity of the computer program with adequate nodal representation of each component. Similarly, the use of two groups of coolant channels extends the capability and flexibility of the hydraulic solution. Coolant boundary conditions for one or more solid components may be obtained from one or two groups of coolant channels. Association of coolant channels with conduction model boundary nodes and wall temperatures is completely flexible and arbitrary.

3.4 CONVERGENCE OF HYDRAULIC AND CONDUCTION SOLUTIONS

The coupling and convergence between the hydraulic and conduction calculations are described in Section 2.2. The convergence is made on wall temperatures rather than on power balance. Therefore, equations 8, 9, and 10 should be considered before specifying the convergence criterion, ϵ , for a particular problem. Wall temperatures which agree between hydraulic and conduction models within 1 percent may be well beyond 1 percent of the true distribution. This is particularly true when the final solution is approached from an initially biased condition. Let us consider, for example, a component with a radial temperature variation which results in a thermal stress in the component. We wish to determine the magnitude and distribution of this radial variation. We will most likely begin this calculation with uniform radial wall temperature profiles. In this case, the first fluid boundary temperatures will be rather uniform at a component cross section. The resultant material temperatures will

tend toward the inherent radial variation, but the amplitude will be subdued by the uniformity of fluid boundary temperatures. Subsequent iterations will yield wider variations in coolant boundaries and material temperatures. The relative error between the wall temperatures used in the hydraulic calculations and those obtained from the conduction analysis is the basis for problem convergence but may not relate directly to the error in radial temperature distribution. Engineering judgement must be exercised in the selection of the convergence criterion to insure adequate accuracy of the solution.

3.5 MODELING OF THE XE-PRIME REFLECTOR SYSTEM

The TRACK II digital computer code was used to perform the thermal-hydraulic analysis of the XE-PRIME reflector system. The calculational model included all the major components from the inner diameter of the core insulation to the outer diameter of the pressure vessel, including core insulation, filler strips, inner and outer reflectors, control drums, tie bolts, and pressure vessel. A schematic representation of the system is shown in Figure 8. The system consists of concentric annular regions with a total of 12 control drums. A repeating section representing 1/12 of the total system was chosen for the computational model.

The outer reflector, control drums, tie bolts, and inner reflector have cooling passages extending the entire length of the reflector with flow direction as indicated in Figure 8. Flow through the reflector system originates in the reflector inlet plenum at the nozzle end (aft end) of the reactor and exits into the reflector exit plenum at the forward end. Flow enters the transition region at the forward end and exits into the nozzle chamber. There is crossflow between these streams.

The flow system was modeled for the TRACK II computer code by using two groups of hydraulic channels. The first group of channels represents a parallel flow region comprising the reflector and control drum coolant passages. The second group of channels represents the series flow through the transition region. A schematic diagram of the hydraulic model is shown in Figure 9.

The heat conduction model was composed of three separate finite element models: (1) the outer reflector, pressure vessel, and tie bolts; (2) the control drums; and (3) the inner reflector, transition region. The conduction models were chosen to take advantage of the

Figure 8. XE-PRIME Reflector System

Figure 9. Flow Diagram for the XE-PRIME Reflector System

symmetry of the system. Two-dimensional models with unit depth representing a 30 degree sector of the periphery were made for the outer reflector and control drum. A three-dimensional model was constructed for the inner reflector transition region.

In addition to geometry and materials properties, the external boundary conditions to the heat conduction models consisted of heat generation rates and fuel temperatures at the inner diameter of the transition region, with coolant temperatures and convective heat transfer coefficients for the internal coolant channels to be supplied from the hydraulic solution.

Using the two-group hydraulic model described and the conduction models at seven axial locations, a full-power steady-state analysis was performed. The problem solution begins with a hydraulic-heat convection calculation for the first group of channels representing parallel flow through the reflector system. Total flow was specified and a flow balance was performed such that all channels had the same pressure drop within the input tolerance of 1 percent.

The next step was to compute the coolant conditions in the transition region (Group 2 channels). Calculated coolant temperatures and pressures for Group 1 coolant channels were used as boundary conditions for Group 2 hydraulic calculations. The inlet temperature and pressure were obtained from reflector exit conditions.

Crossflow from the reflector system to the transition region was determined from the coolant pressure and temperature distributions in the reactor annulus, the specified interconnection flow impedance, and the plena pressures. By iteration, the inlet flow rate was determined such that the exit pressure agreed with the input specification (nozzle chamber pressure) within 1 psi.

Upon completion of the hydraulic calculations, boundary conditions for the conduction analysis were prepared from the coolant temperature and convective heat transfer arrays. With the imposed boundary conditions, material temperature distributions were obtained for each component at each of the axial locations. Component surface temperatures were then translated into axial distributions of coolant channel wall temperatures.

The above calculational procedure was repeated until a compatible solution for the hydraulic and conduction models was obtained. The convergence criteria are described in Item 5 of Appendix A. The final temperature distributions were reserved on tape for direct

input to structural analysis codes. The printed output includes complete display of coolant conditions throughout the system and nodal temperature distributions for the solid body.

Typical results for the XE-PRIME full-power, steady-state analysis are presented in Figures 10, 11, and 12 (reflector pressure distributions, reflector material temperature distributions, and reflector isotherms).

Figure 10. Full-Power Steady-State Pressure Distributions of the XE-PRIME Reflector System

Figure 11. Full-Power Steady-State Material Temperature Distributions for the XE-PRIME Reflector

Figure 12. Midplane Isotherms for the XE-PRIME Reflector During Full-Power, Steady-State Operation

4.0 TRACK II DIGITAL COMPUTER PROGRAM

(Transient Analysis with Convection and Conduction)

4.1 PROGRAM ORGANIZATION

The TRACK II computer program was developed primarily for transient analysis, but it can also perform the following two types of calculations: 1) steady-state alone and 2) steady-state followed by a transient calculation. For steady-state problems, the calculations are performed at time $= 0 + \Delta\theta = \Delta\theta$ in which the time increment $\Delta\theta$ is an arbitrary input number. The input boundary conditions are considered as those at time $= \Delta\theta$, but steady-state equations are used in the computations.

The computer program is written in FORTRAN IV language for the CDC-6600 computer. It is divided by overlay structure into three major sections: Input, Hydraulic Calculation, and Heat Conduction. An overall execution flow chart is shown in Figure 13. The overlay structure is shown in the following diagram:

OVERLAY ORGANIZATION (FOR CDC-6600 COMPUTER)

Figure 13. TRACK Computer Program Flow Diagram

4.2 SUMMARY OF TRACK II CAPABILITY

The TRACK II program is currently dimensioned to require a computer memory bank of 330,000 octal locations. The following is a summary of the capability and capacity of the program:

Hydraulic Models

- 1) Transient or steady-state calculations
- 2) Convective heat transfer
- 3) Single-phase, one-dimensional hydrogen, helium, or nitrogen flow
- 4) Turbulent or laminar flow
- 5) Constant area, parallel, or series channels
- 6) Lateral inflow to series channels at specified plena
- 7) Two groups of hydraulic channels
 - (a) 70 channels per group
 - (b) 18 axial increments per channel
 - (c) No cross flow or mixing between channels
 - (d) Inlet conditions for Group 2 may be specified or obtained from Group 1 results
 - (e) Number of time steps in a transient problem (variable time steps) = 220
 - (f) Number of entries of inlet temperature, pressure, and pressure drop or flow rate as functions of time = 50

Conduction Models

- 1) Transient or steady-state calculations
 - 2) Internal heat generation
 - 3) Boundary conditions may be
 - (a) Forced convection
 - (b) Thermal radiation
 - (c) Free convection
 - (d) Adiabatic
- } Convergence difficulties are encountered when these modes of heat transfer constitute the primary heat sources and/or sinks for a component

4) Temperature dependent material properties (c_p and k). Also thermal conductivity, k , as a function of temperature and fast neutron fluence.

5) Multiple independent conduction models (two or three dimensional)

(a) Up to 5 components

(b) Up to 11 axial locations

(c) Maximum dimensions per model:

Internal nodes = 850

Internal connectors = 5

Surface nodes = 500

Surface connectors = 2

Boundary nodes = 500

Boundary temperature tables = 150, entries per table = 10

Film coefficient tables = 150, maximum total entries = 1500

(d) Internal heating rate at any node of a component is computed by the following expression:

$$Q(I, J, M) = \text{Radial factor} * \text{Axial Factor} * \text{General Power Factor} * \text{Individual material power Factor (M, J)} * QQ$$

where

index I = axial position

index J = component number

index M = material table number

QQ = a multiplier for that node input on GEN cards

The radial and axial factors are obtained by interpolation from the input radial and axial tables. There may be up to 10 tables with 25 entries per table. By manipulating the radial factor, axial factor, and the multiplier QQ, one can input the internal heating rate at any one nodal point for all the components in any convenient way suitable for his particular problem.

(e) Power schedule tables as function of time = 15; entries of each table = 50

Material Properties

1.) Material numbers 1 to 200 are reserved for built in materials. Two options are available as discussed below.

2.) Material numbers 201 to 220 are used for temperature dependent input tables. Maximum entries for each table is 10.

3.) Material numbers 221 to 225 are used for temperature and fluence dependent Tables. Up to 250 temperatures and 50 fluences may be used for each table.

4.) Material numbers 226 to 250 are used for constant property materials.

Built-in Thermal Properties (1-200)

Option 1 : For use outside the WANL facility, special subroutines, PROTK and PROCP, may be used to provide temperature dependent thermal conductivity and specific heat values for the eight materials listed below. The corresponding material densities are supplied by the subrouting DENS.

<u>Material</u>	<u>Material No.</u>
Graphite	1
Pyrolytic Graphite	2
Aluminum 6061-T6	3
Beryllium Alloy	4
Stainless Steel 304	5
Copper 99.99 % Pure	6
Titanium Alloy	7
Inconel X-750	8

Option 2: The WANL Material Thermal Properties Library System (MTPLS) provides thermal material properties as a function of temperature, standard deviation, and fluence level for a large number of materials. The system was developed to keep material property information current for WANL use and to standardize the source of material property data. Since a large

bulk of data is available on the standard material library, a pre-processing program was developed to select only those materials specified by the user. A current list of available materials is given in Appendix B. The standard material library is subject to continual updating but the material numbering given in Appendix B is not expected to change. For latest listing, refer to the Thermal Design Computers Code Manual.

4.3 INPUT DATA REQUIREMENTS

The TRACK II input deck structure for the CDC-6600 computer is illustrated in TABLE I. Options are given for execution from the binary program deck (non-WANL users) and for execution from a permanent file record stored on magnetic tape (WANL users). The latter method makes use of the WANL Material Thermal Properties Library System (MTPLS) and requires input to the pre-processing material selector program, SELEC, which selects the materials specified by the user.

The TRACK II input data are separated into two parts: the conduction model and the hydraulic model data. The input formats for these models are described in Tables II and III, including pertinent nomenclature and explanations of the control indicators. Tape usage is described in Table IV.

4.4 PRINTED OUTPUT DATA

The printed output consists of a complete listing of the conduction model input (Table II) and selected hydraulic input parameters and heating rate tables in addition to the results of the hydraulic and conduction calculations at each time step, including non-converged iterations. The hydraulic output data consists of axial distributions of fluid conditions for each channel (coolant temperature, pressure, convective heat transfer coefficients and heat fluxes), and a summary of pressure drop, flow distribution and power distribution. The conduction model output consists of temperatures for internal, surface,

and boundary nodes for each component at the specified axial locations. In addition, selected volume weighted temperature averages and interface temperatures and heat transfer between nodes may be obtained. A description of the TRACK II output parameters and their units are described in Table V. A sample problem is also presented in Appendix D and includes typical examples of the hydraulic and conduction output.

TABLE I
 TRACK II DECK STRUCTURE FOR CDC-6600 COMPUTER
 OPTION I (for non-WANL users)

Control Cards	Job cards (minimum field length =330000 octal)	
	Request Tape 4.	
	Request Tape 10.	
	Request Tape 13.	
	Reserve Tape 4 (X1, a, b, c)	or
	Reserve Tape 10 (X2, a, b, c)	
	Reserve Tape 13 (X3, a, b, c)	
Request Tape 4(X1, a, b, c)		
Request Tape 10 (X2, a, b, c)		
Request Tape 13 (X3, a, b, c)		
Input.		
789		
TRACK II Binary Deck*		
789		
789		
Data	Conduction Data (Table II)	or
	Hydraulic Data (Table III)	
Replace with one blank card when data tape is available (Tape 10)		
6789		

* Includes PROTK, PROCP and DENS subroutines to provide thermal properties for eight materials (see page 37)

TABLE I (continued)
TRACK DECK STRUCTURE FOR CDC-600 COMPUTER
OPTION 2 (for WANL users)

DATA CONTROL CARDS	Job cards (program No. = ASP1004, Field length = 330000)		
	Request Tape 4.		
	Request Tape 10. Request Tape 13. Reserve Tape 4 (X1, a, b, c) Reserve Tape 10 (X2, a, b, c) Reserve Tape 13 (X3, a, b, c)	} or	Request Tape 4 (X1, a, b, c)
			Request Tape 10 (X2, a, b, c)
			Request Tape 13 (X3, a, b, c)
	Request TRACK (ABTR 13, TRACK, OVLAY)		
	Request SELEC (WKMATL)		
	Request LIBR (WKPRO 52, PROTK)		
	SELEC.		
	COPYBR (TRACK, DUMMY, 4I)		
	COPYBF (MATL, DUMMY)		
	DUMMY.		
	789		
	Input data for SELEC *		
789			
Conduction Data (Table II)		} or Replace with one blank card when data tape is available (Tape 10)	
Hydraulic Data (Table III)			
6789			

* Input data for the Selector Program: the material number prefixed by "AMAT" for all materials required, last field = ***** Format 8(A7,3X). For material selection, refer to Thermal Design Computer Code Manual (Current material listing is given in Appendix B)

TABLE II
TRACK II INPUT FORMAT
CONDUCTION MODEL

1 2	A
— STAR1 INDICATES CARD INPUT FOR THE CONDUCTION MODEL	
* * — STAR2 INDICATES CARD INPUT FOR INTERFACE CONDUCTION	

CARDS B—E ARE FOR INTERFACE CONDUCTION

IF STAR2 IS BLANK, GO TO CARD F

INCS ≤ 11	IKK ≤ 5							B
10	20							
XX	X							

TIME(SEC)

TAH(1)	TAH(2)							C
10	20							
XX.X	XX.X							

BOUNDARY TEMPERATURES (°R)

BBT((TIME, STATION), TIME = 1, 2), STATION = 1, INCS)								D
10	20	30	40	50	60	70		
XX.X	XX.X	XX.X	XX.X	XX.X	XX.X	XX.X		

HEAT TRANSFER COEFFICIENTS (BTU/SEC IN² °R)

HHH ((TIME, STATION), TIME = 1, 2), STATION = 1, INCS)								E
10	20	30	40	50	60	70		
XX.X	XX.X	XX.X	XX.X	XX.X	XX.X	XX.X		

INCS NUMBER OF STATIONS IN THE CONDUCTION MODEL

IKK FIRST MODEL WITH INTERFACE CONDUCTION

TAH START AND END OF FIRST TIME STEP

BBT INITIAL BOUNDARY TEMP. APPLIED TO MODEL IKK AT INTERFACE

HHH EFFECTIVE HEAT TRANSFER COEFF. LINKING BOUNDARY TO MODEL IKK
HHH = k/x

TABLE II (Continued)

IF STAR 1 IS BLANK (CARD A), GO TO TABLE III

CARDS F AND G RELATE CONDUCTION MODEL SURFACE NODES TO COOLANT CHANNEL WALLS

REPEAT CARD F FOR EACH GROUP OF CHANNELS (SEE CARD B, TABLE II)

CHLEN (IN)	NCHL	(NMB (I), I = 1, NMOD) NMOD ≤ 5						F
10	25	30	35	40	45	50		
XX.X	XX	XX	XX	XX	XX	XX		

CHLEN Flow channel length, inches

NCHL Total number of channels in the flow system for each group

NMB Number of G cards for each component

REPEAT CARDS G TO Z FOR EACH COMPONENT

REPEAT CARD G NMB(I) TIMES FOR EACH GROUP OF CHANNELS

CH. NO.	WALL NO.	(NDE (I), I = 1, N) N ≤ 10 NDE = SURFACE NODE - 3000										G
5	10	15	20	25	30	35	40	45	50	55	60	
XX	X	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	

Coolant Channel
Walls Related to
Conduction
Surface Nodes

These cards relate the surface nodes to the channel walls of the hydraulic model. Each card begins with the channel number and the wall number (one or two), followed by the integers NDE(I). If the channel number is positive, NDE(1) and NDE(2) denote a sequence of surface nodes and NDE(3) to NDE(10) list individual surfaces. If the channel number is negative, up to five sequences of surface nodes may be specified.
The channel wall temperature is the area weighted average temperature of the specified surfaces.

TABLE II (Continued)

IND		H
5		
X		

IF IND = 0, GO TO CARD K

CARDS I AND J ARE FOR INTERFACE CONDUCTION ONLY.

The average temperature of a portion of the model will be applied through a heat transfer coefficient to an adjacent model.

NBNODE	IFILM	MODEL	NODAV	NODEAV (I), I = 1, NODAV NODAV ≤ 20										I
5	10	15	20	25	30	35	40	45	50	55	60			
XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX	XX		

Use 1215 Format for the continuation of card I

X FILM		J
10		
X.XX		

IND = 0 No interface conduction is being used

IND = 1 Interface conduction is being used

NBNODE The boundary node number of the interface conduction boundary

IFILM The film coefficient table number of the interface conduction boundary

MODEL The component or model number to which this boundary node is to be applied

NODAV The total number of nodes to be averaged to obtain the boundary temperature

NODEAV The list of the node numbers which are to be averaged to obtain the boundary temperature

XFILM The thickness (in) of the internal nodes which are being used to obtain the boundary temperature. This is the heat transfer length to the adjacent component.

TABLE II (Continued)

REPEAT CARDS K THRU Z FOR ALL AXIAL STATIONS

IDENTIFICATION CARD ALL 80 COLUMNS MAY BE USED										K
--	--	--	--	--	--	--	--	--	--	---

Columns

1	2	3	8	13	23	33	43	53	63	73
---	---	---	---	----	----	----	----	----	----	----

INITIAL TEMPERATURES - Internal - Surface and Constant Boundary Nodes ($^{\circ}\text{R}$)

0	1	NODE I	TEMPERATURE						L
			I	I+1	I+2	I+3	I+4	I+5	
X.			XXX.	XXX.	XXX.	XXX.	XXX.	XXX.	

OR IF NODE X THROUGH Z HAVE THE SAME TEMPERATURE

0	1	NODE INDEX	NODE INDEX	TEMP					L
X.		Z.	Y.						

BOUNDARY OR SURFACE TEMPERATURE TABLES (TIME DEPENDENT)

0	2	TABLE NO.	INDEX	TIME	TEMP	TIME	TEMP	TIME	TEMP	M
X.		X.	XX.	XX.	XX.	XX.	XX.	XX.	XX.	

MATERIAL DENSITIES

Material Numbers Range From 201 to 250 (Density, in lb/in^3)

0	3	MATERIAL NO. I	DENSITY						N
			I	I+1	I+2	I+3	I+4	I+5	
X.			XX.	XX.	XX.	XX.	XX.	XX.	

MATERIAL PROPERTIES (TEMPERATURE DEPENDENT)

Material Numbers Range From 201 to 220 (Heat Capacity, C_p in $\text{Btu}/\text{lb } ^{\circ}\text{R}$; Thermal Conductivity, k in $\text{Btu}/\text{sec-in } ^{\circ}\text{R}$; Temp in $^{\circ}\text{R}$)

0	4	MATERIAL NO.	INDEX	C_p	k	TEMP	C_p	k	TEMP	O
XX.		XX.	XX.	XX.	XX.	XX.	XX.	XX.	XX.	

TABLE II (Continued)

Columns										
1	2	3	8	13	23	33	43	53	63	73

MATERIAL PROPERTIES (TEMPERATURE AND FLUENCE DEPENDENT)

Material Numbers Range From 221 to 225 (Use Input Cards 15-17)

MATERIAL PROPERTIES (CONSTANT)

Material Numbers Range From 226 to 250 (Heat Capacity, C_p in Btu/lb $^{\circ}$ R; Thermal Conductivity, k in Btu/sec in $^{\circ}$ R)

	MATERIAL NO.		C_p	k					
0 4	XX.		XX.	XX.					O

INTERNAL NODES (Physical Dimensions in Inches)

	NODE		MATERIAL NO.	LENGTH	WIDTH	DEPTH	*CONN TYPE	**POWER TABLES	P
0 5	XX.		XX.	XX.	XX.	XX.	XX.	XY.	

IF NODES X THROUGH Z HAVE THE SAME INPUT

0 5	X.	Z.	XX.	XX.	XX.	XX.	XX.	XY.	P
-----	----	----	-----	-----	-----	-----	-----	-----	---

INTERNAL CONNECTOR TYPE

	*TYPE		ADDER	LENGTH NODE I	LENGTH ADDER+I	WIDTH	DEPTH		Q
0 6	XX.		XX.	XX.	XX.	XX.	XX.		

INDIVIDUAL INTERNAL CONNECTOR

	NODE I		NODE J	LENGTH NODE I	LENGTH NODE J	WIDTH	DEPTH	***IND	R
0 7	XX.		XX.	XX.	XX.	XX.	XX.		

* A connector type card may be used whenever a group of nodes have identical connectors. Node I (Card P) will be connected to Node I + Adder according to information on Card Q.

** X specifies the time dependent power table (Card ZK, Table III). Y specifies the heat generation table (Card YK, Table III).

*** IND = 1. Calculate interface temperature and heat transfer between nodes I and J
= 0. No interface calculation.

TABLE II (Continued)

Columns

1	2	3	8	13	23	33	43	53	63	73
---	---	---	---	----	----	----	----	----	----	----

SURFACE HEAT TRANSFER (TIME OR ΔT DEPENDENT)

Heat transfer Coefficient, h in Btu/sec - in² - °R

	TABLE NO.	INDEX	TIME	h	TIME	h	TIME	h	S
0 8	X.	X.	XX.	XX.	XX.	XX.	XX.	XX.	

SURFACE TO BOUNDARY CONNECTORS

	SURFACE NODE	SURFACE NODE	BOUND-ARY NODE	TYPE OF CONNEC-TION	B TEMP TABLE	HEAT TRANS. COEFF.		T
0 9	XX.	XX.	XX.	XX.	XX.	XX.		

BASE HEAT GENERATION RATES, Q in Btu/sec in³ (See cards YH - YO, Table III)

	NODE I		$Q(I)$	$Q(I+1)$	$Q(I+2)$	$Q(I+3)$	$Q(I+4)$	$Q(I+5)$	U
12	XX.		XX.	XX.	XX.	XX.	XX.	XX.	

IF NODES X THROUGH Z HAVE THE SAME HEAT GENERATION RATE Y

12	X.	Z.	Y.						U
----	----	----	----	--	--	--	--	--	---

VOLUME WEIGHTED INTERNAL OR AREA WEIGHTED SURFACE TEMPERATURE AVERAGES

	INDEX		FROM	TO	FROM	TO	FROM	TO	V
14	XX.		XX.	XX.	XX.	XX.	XX.	XX.	

TABLE II (Continued)

Columns

1	2	3	8	13	23	33	43	53	63	73
---	---	---	---	----	----	----	----	----	----	----

MATERIAL PROPERTIES (TEMPERATURE AND FLUENCE DEPENDENT) (CARDS W - Y)
Material Numbers Range From 221 to 225

FLUENCE VALUES, FN in N/cm^2 ($E \geq 1.0$ Mev)

	MATERIAL NO.	INDEX J	FN(J)	FN(J+1)	FN(J+2)	FN(J+3)	FN(J+4)	FN(J+5)	W
15	XX.	XX.	XX.	XX.	XX.	XX.	XX.	XX.	

SPECIFIC HEAT (Specific Heat, C_p in Btu/lb $^{\circ}$ R; Temperature in $^{\circ}$ R)

	MATERIAL NO.	INDEX J	TEMP(J)	C_p (J)	TEMP (J+1)	C_p (J+1)	TEMP (J+2)	C_p (J+2)	X
16	XX.	XX.	XX.	XX.	XX.	XX.	XX.	XX.	

THERMAL CONDUCTIVITY (Thermal Conductivity, k in Btu/sec in $^{\circ}$ R)

	MATERIAL	INDEX	k (J)	k (J+1)	k (J+2)	k (J+3)	k (J+4)	k (J+5)	Y
17	XX.	XX.	XX.	XX.	XX.	XX.	XX.	XX.	

LAST CARD FOR EACH AXIAL STATION

*	
---	--

BEGIN HYDRAULIC DATA (Go To Table III)

- * Input for all values of temperature and first fluence value; then repeat for succeeding fluence values.

TABLE III
TRACK II INPUT DATA AND FORMATS
HYDRAULIC MODEL

2 Title Cards are required

TITLE CARD	ALL 80 COLUMNS	A1
------------	----------------	----

TITLE CARD	ALL 80 COLUMNS	A2
------------	----------------	----

ADLOOP ¹⁰ X.XX	TYMLIM ²⁰ X.XX	HYD ³⁰ X.XX	B
------------------------------	------------------------------	---------------------------	---

- ADLOOP = 0 or 1 A single group of hydraulic channels is being input.
- ADLOOP = 2 Two groups of hydraulic channels are being input.
- TYMLIM = XX If the machine CP time exceeds TYMLIM at the start of an iteration, a restart tape is generated and execution is terminated. For TYMLIM = 0, a 20 minute time limit is internally set.
- HYD = 0 Both hydraulic and conduction calculations are desired.
- HYD = 1 Only hydraulic calculations are done.
Omit input cards from card ZJ - YO.

TABLE III (Continued)

REPEAT CARDS C-Z R FOR EACH GROUP OF CHANNELS

CONTROL INDICATORS

10	20	30	40	50	60	70	
RESTART	DUMMY	CHOKE	TRANS	ΔT	CRIT	SST	C
X.XX	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX	

S. S. PF	PFIND	HIND	SEAL	BIG	RECK	BNLET	D
X.XX	X.XX	X.XX	X.XX	X.XX	X.XX	X.XX	

TINVRT		E
X.XX		

RESTART = 0
= T

For initial job
For RESTART job at time = T seconds

CHOKE = X

This parameter is used to check whether the flow is choked at the entrance. If the calculated value of

$(W\sqrt{T_{in}/P_{in}})$ is equal or greater than the input

quantity, X, the pressure after the entrance restriction is set to $0.66 P_{in}$.

TRANS = +1
= -1
= 0

Startup transient with no steady-state base case
Transient following a steady-state base case (for this case SST = 1)
No transient.

ΔT = X

Conduction transient time interval. It must be even multiple of hydraulic time step(sec).

TABLE III (Continued)

CRIT	=	X	X= Conduction heat balance convergence criteria (percent/100) for temperature distribution obtained by Gauss Seidel iteration.
CRIT	=	-1.X	Temperature distribution obtained by Gaussian Elimination. X= Conduction heat balance convergence criteria (percent/100)
SST	=	1	Steady state
SST	=	0	No steady-state case
SST	=	-1	Restart from previous steady-state case
S. S. PF	=	X	Steady-state power factor. For example, 1.0 for full power and 0.5 for 50 % power.
PFIND	=	X	This parameter is used to compare and equate the steady-state power in the hydraulic model to that in the conduction model. The input boundary temperatures to the models are adjusted to account for the power discrepancy in the hydraulic model. Subsequently, the wall temperatures are affected and alignment of the total hydraulic and conduction power levels results. This is intended to reduce the number of iterations required to obtain a steady state solution. For parallel channels X= Power Hyd./Power con. For series channels X= Total power (MW) Do not use for two groups of channels.
HIND			Heat transfer correlation indicator (see Section 2.3)
HIND	=	0 or 1	McCarthy - Wolfe
HIND	=	2	Petuhkov - McCarthy - Wolfe
HIND	=	3	Los Alamos (low temperature)

TABLE III (Continued)

SEAL	=	0	The hydraulic group consists of parallel channels
SEAL	=	1	The hydraulic group consists of series channels
BIG	=	1	Additional input data are printed on first entry to calculation including admittance matrix
BIG	=	0	No additional printout
RECK	=	0	The restart tape number is 13
RECK	=	XX	The new restart tape number is XX. This option is used when a long transient job is generating many restarts and a new restart tape is needed because the initial restart tape is becoming too full.
BNLET	=	0	The hydraulic input for a hydraulic group is being read in by standard tables. (Cards K - N)
BNLET	=	1	Hydraulic input for hydraulic group 2 is being prepared from the previous group.
TINVRT	=	0	The wall temperatures for a hydraulic group are not to be inverted.
TINVRT	=	1	The wall temperatures for hydraulic group 2 are to be inverted because the flow proceeds in the opposite direction of the conduction axial station calculations. (Use for group 2 only)

TABLE III (Continued)

CONVERGENCE ARRAY (WALL TEMPERATURES)

10 CONVERGE X.	20 KI XX	30 KJ XX	40	50	60	70	F
(CHANNEL NOS. I = 1, KI) (INCREMENT NOS. J = 1, KJ)							G
X	X	X	X	X	X	X	

CONVERGENCE
ARRAY

Problem is converged at a time step when

$$\frac{|TW(I, J) \text{ Assumed} - TW(I, J) \text{ computed}|}{TW(I, J) \text{ Computed}} \leq \text{CONVERGE}$$

for each specified channel (I) and increment (J),

(I = 1, KI, and J = 1, KJ)

KI

Channel array

KJ

Axial array

IF GROUP = 2, GO TO CARD J

10 KZ XX	20	30	40	50	60	70	H
----------------	----	----	----	----	----	----	---

IF KZ = 0, GO TO Card J

Times to save restart data on tape.

TAU (I), I = 1, KZ						KZ ≤ 30		I
X.XX	X.XX	X.XX						

KZ = X

Number of times restart data generated

TAU = X

Times in seconds at which the hydraulic data are saved
on tape 13 for subsequent restart runs.

TABLE III (Continued)

HYDRAULIC DATA INDICATORS

NΔT	10	NΔθ	20	NPLEN	30	MAX TIME	40	ΔT	50	DPIND	60		70	J
X.X		X.X		X.X		X.X		X.X		X.X				

HYDRAULIC INPUT SCHEDULES

TIME (Sec) I=1, NΔθ NΔθ≤50													K
X.X		X.X		X.X		X.X		X.X		X.X		X.X	
INLET PRESSURE (psia) I=1, NΔθ													L
X.X		X.X		X.X		X.X		X.X		X.X		X.X	
INLET TEMPERATURE (°R) I=1, NΔθ													M
X.X		X.X		X.X		X.X		X.X		X.X		X.X	
FLOW RATE (lb/sec) or ΔP (psi) I=1, NΔθ													N
X.X		X.X		X.X		X.X		X.X		X.X		X.X	

NΔT	=	0	Use constant hydraulic time step
NΔT	=	X	Specify X number of entries in time step table (Card O)
NΔθ	=	X	Number of entries in hydraulic schedules (Cards K - N)
NPLEN	=	X	Number of axial sections separated by plena. For example, 1. for one section of parallel channels.
MAX TIME	=	X	Problem is terminated when $(T + \Delta T/2) > X$ (Sec)
ΔT	=	X	Constant hydraulic time step (sec); use when NΔT = 0.
DPIND	=	0	Specify total flow
		1	Specify pressure drop (Do not use for seal GT.O.)
		-1	Specify exit pressure with BNLET = 1
		-2	Specify total flow rate with BNLET = 1
		-1	Specify pressure drop for seal GT.O.)

TABLE III (Continued)

OMIT CARD O FOR SECOND GROUP OR IF $N\Delta T = 0$

TIME STEPS (Sec)

(TST(I), I = 1, NΔT) NΔT ≤ 270							O
10	20	30	40	50	60	70	
X.X	X.X	X.X	X.X	X.X	X.X	X.X	

$$\sum_{I=1}^{N\Delta T} \text{TST(I)} \text{ must be greater than MAX TIME (Card J)}$$

PLENA DEFINITION (Repeat Card P for Each Section, I = 1, NPLEN)

LAST CHANNEL	PLENUM VOLUME	BLEED FLOW	BLEED ENTHALPY	P
X.X	X.X	X.X	X.X	

AXIAL SECTION DEFINITION

For each group of parallel channels, called a section, which are arranged in series with other groups, specify the number of the last channel in the section and the inlet plenum volume (in^3). For example, consider a two section model with 20 channels in the first section and 10 channels in the downstream section. The number of the last channel in the section would be 20 for the first section and 30 for the second.

BLEED FLOW

At each plenum a positive (in) or negative (out) bleed flow may be specified (lb/sec).

BLEED ENTHALPY

If the bleed flow is positive an enthalpy must be read for that flow (Btu/lb). If none is specified, or the flow is negative, then the bleed flow enthalpy is assumed equal to that calculated for the plenum.

TABLE III (Continued)

COOLANT CHANNEL DATA (Repeat Card Q for each channel , I = 1, NLAST)

N	10	D	20	L	30	CL in	40	CL out	50	ANN	60	VOID	70	Q
X.X		X.X		X.X		X.X		X.X		X.X		X.X		
LAMINAR FRICTION COEFF. (C(I), I = 1, NLAST) NLAST ≤ 70														R
X.X		X.X		X.X		X.X		X.X		X.X		X.X		
INITIAL FLOW FRACTION (WI(I), I = 1, NLAST) $\sum WI(I) = 1.0$														S
X.X		X.X		X.X		X.X		X.X		X.X		X.X		
FRICTION MULTIPLIER (FMULT(I), I = 1, NLAST)														T
X.X		X.X		X.X		X.X		X.X		X.X		X.X		
INPUT TEMPERATURE TABLE (ITBWL (I), I = 1, NLAST)														U
	XX		XX		XX		XX		XX		XX		XX	

NLAST	Total number of channels for this group of channels (parallel or series)
N	Number of sub-channels. For non-circular channels, $N = \text{flow area} / (\frac{\pi}{4} D^2)$
D	Hydraulic diameter (inches) $D = 4 * \text{flow area} / \text{wetted perimeter}$
L	Channel length (inches)
CL	Inlet and exit loss coefficients where, $\Delta P = CL(G^2 v / 2g)$ $G = \text{Flow} / \text{Area}$
ANN	Annulus ratio = Wall 1 Area / Total Wall Area (1.0 for circular hole)
VOID	Void fraction = Flow Area / Total Area
C	Laminar friction coeff. where $f = C(I) / Re$ For circular channels, $C = 16$; flat plate annulus, $C = 24$.
WI	Initial flow fraction, Flow (I) / Total Flow
FMULT	Turbulent friction factor multiplier (refer to Section 2.4)
FMULT = +X	Multiply smooth tube value by X
FMULT = -X	Multiply smooth tube value by $X(0.73 + 0.000018 Re_f)$
ITBWL	Initial temperature table number specified for each channel

TABLE III (Continued)
INITIAL CONDITIONS (Time = 0)

10	20	30	40	50	60	70	
WIN	PIN	ΔP CONV. SERIES	ΔP ITER	ΔP CONV PARALLEL			V
X.X	X.X	X.X	X.X	X.X			

INITIAL TEMPERATURE TABLES

JMAX	TMAX	FACTOR					W
X.X	X.X	X.X					
Axial Location (X(I), I = 1, JMAX) JMAX $\leq$ 20							X
X.X	X.X	X.X	X.X	X.X	X.X	X.X	
$T_{\text{coolant}}(I)$, I = 1, JMAX							Y
X.X	X.X	X.X	X.X	X.X	X.X	X.X	
$T_{\text{wall } 1}(I)$, I = 1, JMAX							Z
X.X	X.X	X.X	X.X	X.X	X.X	X.X	
$T_{\text{wall } 2}(I)$, I = 1, JMAX							ZA
X.X	X.X	X.X	X.X	X.X	X.X	X.X	

 REPEAT CARDS Y-ZA FOR EACH TABLE, I = 1, TMAX TMAX $\leq$ 70

WIN, PIN	Initial total flow (lb/sec) and inlet pressure (psia)
ΔP CONV SERIES PARALLEL	Pressure drop convergence ratio (percent/100) Overall ΔP for series channels ΔP for parallel channels
ΔP ITER	Maximum number of iterations on ΔP
INITIAL TEMPERATURES	Coolant and wall temperature tables (TMAX tables with JMAX axial values). Computational time is highly dependent on initial wall temperatures.
FACTOR	The input temperatures are adjusted by FACTOR to part power conditions. When omitted, FACTOR is taken as 1.

TABLE III (Continued)

FOR PARALLEL CHANNELS (SEAL = 0), GO TO CARD Z F

NL	10	NI	20		30		40		50		60		70	ZB
	XX		XX											
(XSEAL(I), I = 1, NL) Channel Entrance Location														ZC
X.X		X.X		X.X		X.X		X.X		X.X		X.X		

NL Number of coolant channels in the hydraulic group ≤ 70

NI Number of distinct channel types ≤ 70

XSEAL Axial location of entrance to series channels (inches)

CROSSFLOW INPUT

NLEAK		ZD
	XX	

IF NLEAK = 0, GO TO CARD Z F

((LTBL(I), ATBL(I), DTBL(I), ZTBL(I)), I = 1, NLEAK) NLEAK = 20							
X.X	X.X	X.X	X.X	X.X	X.X	X.X	ZE

NLEAK The number of plena where crossflow between hydraulic groups is to be considered.

LTBL Path length for cross flow (in).

ATBL The cross-sectional flow area (in²) of the cross flow paths between hydraulic groups.

DTBL The hydraulic diameters of the crossflow sections between hydraulic groups.

ZTBL The plenum numbers for which crossflow between hydraulic groups is calculated.

TABLE III(Continued)

RELATION BETWEEN HYDRAULIC AND CONDUCTION MODELS

10 NMOD XX	20 NCHL XX	30 NCS XX	40	50	60	70	ZF
------------------	------------------	-----------------	----	----	----	----	----

AXIAL STATIONS FOR CONDUCTION MODELS

(XXCS(I) = 1, NCS)							ZG
X.X	X.X	X.X	X.X	X.X	X.X	X.X	

- NMOD Number of components. Each component is treated as a separate conduction model so that duplication of node and boundary numbering is allowed between components.
- NCHL Total number of channels ≤ 70
- NCS Number of axial stations ≤ 11
- XXCS Axial stations for conduction models (inches)

FOR PARALLEL CHANNELS (SEAL = 0) GO TO CARD ZJ

(NS(I), I = 1, NI) NI ≤ 70							ZH
XX	XX	XX	XX	XX	XX	XX	
((ITCH(I), XCSSS(I), I = 1, NS(J)), J = 1, NI)							ZI
XX	X.X	(One value of ITCH and XCSSS per card)					

- NS Number of channels in each series channel type, NI from Card ZB
- ITCH The channel numbers for each channel type
- XCSSS The midpoint axial values of the series channels (inches)

Channels must be read in increasing order by channel type. For example, all Type 1 channels would be read first in increasing order, then all Type 2, Type 3, etc.

TABLE III (Continued)

CONDUCTION POWER TABLES

FOR SECOND HYDRAULIC GROUP, GO TO CARD ZL

J1	(J2(I), I = 1, J1 Continuation Format 7110						ZJ
10 XX	20 XX	30 XX	40 XX	50 XX	60 XX	70 XX	
POWER X.X	TIME X.X	POWER X.X	TIME X.X	POWER X.X	TIME X.X		ZK

Repeat card ZK for all values in Table I; then repeat for each Table. Begin each table with a new card.

J1	Number of power tables ≤ 15
J2	Number of values in each table ≤ 50
POWER TABLE	Time dependent power factors for use in the conduction model; there are J1 tables with J2(I) entries in each table. Each node in the conduction model has a power table specified on the NODE card, Card P of Table II. This permits variation of transient power factors, i.e., fueled and unfueled material may have different shutdown power profiles.

COMPONENT DEFINITION

NOCIC XX	LINN XX	LSNN XX		ZL
-------------	------------	------------	--	----

NOCIC	Number of channels in component (number of hydraulic channels associated with the component)
LINN	Maximum internal node used in component ≤ 850
LSNN	Largest surface node used in component ≤ 3400

TABLE III (Continued)

PARALLEL CHANNEL BOUNDARIES (IF SEAL = 1, GO TO CARD ZP)

CH. I	10 IBDY	20 JIBDY	30 HMULT	40		ZM
	XX	XX	XX	X.X		

Repeat Card ZM for each channel in component, $I = 1$, NOCIC

Do Cards ZN-ZQ for each CH. I with a negative prefix (Card ZM)

NAVG(I)												ZN
XX												
(CH(J), AR(J), J = 1, NAVG(I)) NAVG≤5												ZΦ
5	10	15	20	25	30	35	40	45	50	55	60	
XX	X.X	XX	X.X	XX	X.X	XX	X.X	XX	X.X	XX	X.X	

Cards ZN and ZQ are for boundary averaging where,

$$T_I = \sum_{i=1}^{NAVG(I)} T_i AR_i \quad AR_i = \text{Area}_i / \text{Total Area}$$

SERIES CHANNEL BOUNDARIES (OMIT IF SEAL = 0)

LN						ZP
XX						
CH. I	IBDY	JIBDY	JSET	HMULT		ZQ
XX	XX	XX	XX	X.X		

Repeat card ZQ for each channel, CH. I, $I = 1$, LN; then repeat cards ZP-ZQ for each axial station

Repeat Cards ZL-ZQ For Each Component

Repeat Cards C-ZQ For Second Hydraulic Group If ADLOOP = 2

TABLE III (Continued)

Coolant Channel - Conduction Boundary Link

Coolant temperature and convective heat transfer coefficients for specified conduction model boundaries are obtained from corresponding hydraulic channel output. A BTEMP table and a FILM table for wall one are automatically prepared with the table numbers equal to the boundary node number minus 5000. Arbitrary table numbers must be assigned for wall two FILM tables.

Parallel and Series Channels

CH I	Coolant channel number
IBDY	Conduction boundary node corresponding to CH I
JIBDY	Wall two FILM table number
HMULT	This input accounts for variation in coolant channel heat transfer area between the hydraulic and conduction models. $HMULT = \text{Area}_{\text{hyd}} / \text{Area}_{\text{cond}}$

Series Channels Only

LN	Number of channels at each axial station specified for the conduction model. It must be at least one, even though it represents a dummy channel.
JSET	Determines how coolant temperature will be averaged over the channel length
JSET = 10	Average over entire channel length
JSET < 10	Average over first half of channel
JSET > 10	Average over last half of channel

TABLE III (Continued)

INITIAL TEMPERATURES (Conduction Models)

T(I), I = 1, NCS NCS ≤ 11							ZR'
10	20	30	40	50	60	70	
X.X	X.X	X.X	X.X	X.X	X.X	X.X	

TEMPERATURE DIFFERENCES

NDT							ZS
XX							

IF NDT = 0, GO TO CARD YA

(NA(I), NB(I), I = 1, NDT)							ZT
XX	XX	XX	XX	XX	XX	XX	
(NODESA(J), J = 1, NA(I)), (NODESB(J), J = 1, NB(I))							ZU
XX	XX	XX	XX	XX	XX	XX	

Repeat card ZU for I = 1, NDT

NDT Number of differences to be computed ≤ 10

NTA Number of nodes for Point A ≤ 20

NTB Number of nodes for Point B ≤ 20

NODESA List of nodes for Point A

NODESB List of nodes for Point B

Temperature differences may be obtained between various regions within the conduction model with point A representing one region and point B the other. The temperature of each point is the volume weighted average temperature of the nodes associated with that point.

TABLE III (Continued)

Radial Location of Nodes for Irradiation Affected Materials

I	10	J	20	K	30		YA
	XX		XX		XX		

Single Nodes - Repeat YB J Times, Omit YB if J = 0

5	15	20	30	35	45	50	60		YB
NODE	RADIUS	NODE	RADIUS	NODE	RADIUS	NODE	RADIUS		
XX	X.X	XX	X.X	XX	X.X	XX	X.X		

Node Sequences - Repeat YC K Times, Omit YC if K = 0

5	10	20	25	30	40	45	50	60		YC
NODE	NODE	RADIUS	NODE	NODE	RADIUS	NODE	NODE	RADIUS		
FROM	TO		FROM	TO		FROM	TO			
XX	XX	X.X	XX	XX	X.X	XX	XX	X.X		

REPEAT CARDS YA - YC FOR EACH COMPONENT, L = 1, NMOD

- I Neutron fluence indicator. For I = 0, there are no fluence dependent materials in this component
- J Number of cards with single node input (Card YB)
- K Number of cards specifying sequences of nodes (Card YC)
- NODE Conduction model node numbers
- RADIUS Radial position in the neutron flux field described on the following page (inches)

TABLE III (Continued)

NEUTRON FLUX FIELD ($E \geq 1.0$ Mev)

Omit Cards YD-YG if Fluence Indicator, I (Card YA) = 0 for all Components

10 NFZ XX	20 NFR XX	30 NFT XX	40	50	60	70	YD
Axial Variation (XFZ(I), FZ(I), I = 1, NFZ)							YE
X.X	X.X	X.X	X.X	X.X	X.X	X.X	
Radial Variation (XFR(I), FR(I), I = 1, NFR)							YF
X.X	X.X	X.X	X.X	X.X	X.X	X.X	
Time Factor (TIMF(I), TPF(I), I = 1, NFT)							YG
X.X	X.X	X.X	X.X	X.X	X.X	X.X	

The neutron fluence value at each node is found from the product:

$$FL(NODE) = FZ(NODE) * FR(NODE) * PFF(TIME)$$

NFZ	Number of axial values ≤ 10
NFR	Number of radial values ≤ 10
NFT	Number of time values ≤ 10
XFZ	Axial locations (inches)
FZ	Axial fluence factors
XFR	Radial locations (inches)
FR	Radial fluence factors
TIMF	Time values (sec)
TPFF	Time multipliers
FL	Fluence at a given node (nvt)

TABLE III (Continued)

HEAT GENERATION TABLES

TN	Radius of Each Component (R(I), I = 1, NMOD)						
10	20	30	40	50	60	70	YH
X.X	X.X	X.X	X.X	X.X	X.X		
GPF							YI
X.X							
Material Table Power Factors (PF(I), I = 1, TN) TN ≤ 10							YJ
X.X	X.X	X.X	X.X	X.X	X.X	X.X	

Repeat Card YJ for Each Component, I = 1, NMOD

NT	NX	NR	NT is material table number				
XX	XX	XX					YK
Axial Values (X(I), I = 1, NX) NX ≤ 25							YL
X.X	X.X	X.X	X.X	X.X	X.X	X.X	
Axial Heating Factors (QX(I), I = 1, NX)							YM
X.X	X.X	X.X	X.X	X.X	X.X	X.X	
Radial Values (R(I), I = 1, NR) NR ≤ 25							YN
X.X	X.X	X.X	X.X	X.X	X.X	X.X	
Radial Heating Factors (QR(I), I = 1, NR)							YO
X.X	X.X	X.X	X.X	X.X	X.X	X.X	

Repeat Cards YK-YO for Each Material Table, L = 1, TN

The heat generation in conduction node i is:

$$Q_i = Q(\text{Station}, \text{Component}, \text{Material}) * Q_{\text{Node}} * Q_{\theta} \text{ (Btu/sec in}^3\text{)}$$

$$Q(\text{Station}, \text{Component}, \text{Material}) = \text{GPF} * (QX * QR * PF)_{\text{Material}}$$

$$Q_{\text{Node}} = \text{Heating factor for node "i" on Card U, Table II}$$

$$Q_{\theta} = \text{S. S. PF (Card D) for steady-state case or time-dependent power factor (Cards ZJ-ZK') for transient case}$$

TABLE IV
TAPE USAGE

A. PHYSICAL TAPE UNITS

TAPE 4.	Output is stored on this tape for use in stress analysis codes and for plotting with the PLOTRAK code. Only the final converged solutions at each time step are saved. Output includes material temperatures, volumes, and surface areas for all internal and surface nodes in the conduction model, coolant and wall temperatures, coolant pressures, channel flow rates, heat transfer coefficients, and heat input from the hydraulic model.
TAPE 10.	Conduction input data (Table II) is stored on this tape which may be used as input for subsequent runs.
TAPE 13.	Hydraulic and initial temperature data are stored on this tape to restart a job. Several restarts may be stored on one tape, each identified by the problem time. For example, a 40-second shutdown and power scram may have been run in three phases with restarts at 2 seconds (steady-state), 30 seconds (start of power scram), and 40 seconds (end of job). The job may be restarted any of these times. However, a restart at 30 seconds will erase the 40-second restart and a restart at 2 seconds will erase the other two restart records on this tape. Restart records are written at specified problem times and by a normal exit from TRACK.
TAPE 19.	Alternate tape for storage of restart data for use when TAPE 13 approaches capacity. A restart can be made from TAPE 13 data with subsequent restart information saved on TAPE 19.
TAPES 5, 6 & 7.	System card input, printed output, and card output respectively.

TABLE IV (Continued)

The output data stored on TAPE 4 is unformatted and has the following sequence:

CONDUCTION PARAMETERS

CS	=	AXIAL STATION
LI	=	NUMBER OF NODES
NODE (I)	=	INTERNAL NODE NUMBER (1 - 850)
T(I)	=	INTERNAL NODE TEMPERATURE ($^{\circ}\text{R}$)
VOL(I)	=	INTERNAL NODE VOLUME (IN^3)
NSURF	=	SURFACE NODE NUMBER (3001-3400)
TSURF	=	SURFACE NODE TEMPERATURE ($^{\circ}\text{R}$)
AREA	=	SURFACE NODE AREA (IN^2)
TIME	=	PROBLEM TIME (SEC)

TABLE IV (Continued)

HYDRAULIC PARAMETERS

NCHL	= NO. OF CHANNELS
I	= COOLANT CHANNEL
J	= AXIAL INCREMENT
P(I, J)	= COOLANT PRESSURE (PSIA)
T(I, J)	= COOLANT TEMPERATURE ($^{\circ}$ R)
TW1(I, J) TW2(I, J)	= WALL TEMPERATURES USED IN HYDRAULIC CALCULATIONS FOR WALLS 1 AND 2 ($^{\circ}$ R)
TW1 NEW(I, J) TW2 NEW(I, J)	= WALL TEMPERATURES FROM CONDUCTION CALCULATION FOR WALLS 1 AND 2 ($^{\circ}$ R)
$\Delta X(I)$	= CHANNEL INCREMENT LENGTH (IN)
FLOW (I)	= CHANNEL FLOW RATE (LB/SEC)
HEAT (I, J)	= INCREMENTAL CHANNEL WALL HEAT FLUX (BTU/HR FT ²)
H1(I, J) H2(I, J)	= CONVECTIVE HEAT TRANSFER COEFFICIENTS FOR WALLS 1 AND 2 (BTU/HR FT ² $^{\circ}$ R)

B. INTERNAL TAPE USAGE (DISK STORAGE)

Hydraulic Input Data	Tape 12
Computed Hydraulic Data for Current Time Step	Tape 11 (Group 1) Tape 16 (Group 2)
Computed Hydraulic Data for Previous Time Step	Tape 2 (Group 1) Tape 17 (Group 2)
Conduction Model Temperatures	Tapes 8 and 9 which alternate between input and output values
Wall Temperatures from Current Conduction Calculation	Tape 18
Wall Temperatures from Previous Conduction Calculation	Tape 14

TABLE V
TRACK OUTPUT PARAMETERS

(A) Hydraulic Model

THETA	Time, (sec); Initial time is 0.0 sec
X	Channel length, inch
P	Coolant pressure, psia
T	Coolant temperature, °R
TS	Coolant stagnation temperature, °R
TW1(END, START)	Channel wall temperature at Wall 1 at end and at start of the time step, °R
TW2 (END, START)	Channel wall temperature at Wall 2 at end and at start of time step, °R
G	Mass flow rate, lb/sec-ft ²
Q	Channel wall heat flux, BTU/hr-ft ² (for a channel with two walls, Q is the area weighted average heat flux)
H1	Heat transfer coefficient at channel Wall 1, BTU/hr-ft ² - °R
H2	Heat transfer coefficient at channel Wall 2, BTU/hr-ft ² - °R
DELTAP	Channel pressure drop, psi
Mass Flow	Mass flow rate, lb _m /sec
PCT of Total	Distribution of flow between various channel groups, percentage

TABLE V (Continued)

PCT Steady State	Flow in channel "i" compared to input value, fractional
Power/CH	Power pickup in one sub-channel of channel "i", MW
Power	Power pickup in all sub-channels of channel "i", MW
Total Power	Total power pickup in hydraulic model, MW
Exit Temperature	Mixed mean exit temperature, °R
Exit Pressure	Mixed mean exit pressure, psia
Average Propellant Density	Average mass density of the coolant flowing in channel "i", lb_m/ft^3
Section Flow Rate	Total mass flow rate through a section (bounded by common plena), lb_m/sec
(B) Conduction Model	
Time	Time, sec (The output represents conditions at the end of the current problem time step)
Title	The title of the particular conduction model is printed out and should include the component and axial position designations.
Axial Position	Axial position from inlet end relative to coolant channel flow direction, inches
Temperatures	Boundary, internal, and surface node temperatures, °R
Volume	Nodal volumes, in^3
Film Coefficients	Convective heat transfer coefficients, $\text{Btu}/\text{hr-ft}^2$

TABLE V (Continued)

Heat Generation Rate	Total heat generation rate in a conduction model, Btu/sec
Heat Transfer	Total heat transfer rate at boundaries in a conduction model, Btu/sec
Heat Stored	Total heat storage rate in a conduction model, Btu/sec
Ratio Heat Balance	Ratio of heat stored and transferred to heat generated. The convergence parameter (CRIT-CARD C, TABLE III) may be adjusted to revise the accuracy of the conduction solution. A reduction in CRIT will improve the accuracy of the solution at the expense of increased computer time.
Average Heat Generation Rate	Heat generation rate volume averaged for a group of nodes, Btu/sec-in ³
(C) Convergence Check	A wall temperature convergence check is made at the end of each iteration. For an input array of channel numbers and axial increment numbers, the wall temperatures (Wall 1) are compared between the estimate used in the hydraulic calculation (second column) and the conduction computed value (first column).

NOMENCLATURE

A	Channel cross-sectional area, in. ²
A _s	Channel surface area, in. ²
C	Heat capacity, Btu/°R
C _L	Pressure loss coefficient
c _p	Specific heat, Btu/lb _m - °R
D	Hydraulic diameter of flow channel, in.
F	Frictional force term, lb _f /in. ³
f	Friction factor
G	Mass flow rate, lb _m /sec-in. ²
g	Gravitational constant, (in./sec ²) (lb _m /lb _f)
H	Stagnation specific enthalpy, Btu/lb _m
h	Local heat transfer film coefficient, Btu/sec-in. ² -°R
i, j	Indices in finite difference equations, i = space variable; j = time variable
J	Energy conversion factor, lb _f - in./Btu
K	Constant in natural convection and radiation equations
k	Thermal conductivity, Btu/sec-in. ² -°R
l	Conduction node length, in.
Nu	Nusselt number
P	Pressure, psia
Pr	Prandtl number
Q	Heat transfer per unit time per unit mass of fluid, Btu/sec-lb _m
q	Heat flux, Btu/sec-in. ²
q'''	Internal heat generation rate, Btu/sec-in. ³
Re	Reynolds number
T	Fluid bulk or material temperature, °R

NOMENCLATURE (Cont'd)

T_B	Fluid bulk temperature, $^{\circ}\text{R}$
T_r	Fluid recovery temperature, $^{\circ}\text{R}$
T_w	Material wall temperature, $^{\circ}\text{R}$
u	Internal energy, Btu/lb_m
V	Velocity, $\text{in.}/\text{sec}$
Vol	Volume, in.^3
v	Specific volume, $\text{in.}^3/\text{lb}_m$
W	Flow rate, lb_m/sec
x, y, z	Space coordinates
Y	Conduction node admittance, $\text{Btu}/\text{hr} - ^{\circ}\text{R}$
μ	Fluid absolute viscosity, $\text{lb}_m/\text{in.} - \text{sec}$
θ	Time, seconds
α	Stefan-Boltzman radiation constant, $0.1713 \times 10^{-8} \text{ Btu}/\text{ft}^2 \text{ hr} (^{\circ}\text{R})^4$
P	Channel perimeter, in.
ρ	Mass density, $\text{lb}_m/\text{in.}^3$

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APPENDIX A

CALCULATIONAL PROCEDURE

1. Difference Equations Formulation

The governing differential equations, as shown in Equations (1) through (3) of the text, are expressed in the conservative form as pointed out by Lax⁽¹⁵⁾. This philosophy was maintained in the formulation of the finite difference approximation. With the "i" index designating the space variable and the "j" index designating the time variable, backward difference Equation (1) becomes,

$$\frac{e_{i,j} - e_{i,j-1}}{\Delta \theta} + \frac{G_{i,j} - G_{i-1,j}}{\Delta X} = 0, \quad (A1)$$

Solving for $G_{i,j}$, one obtains

$$G_{i,j} = G_{i-1,j} - \frac{\Delta X}{\Delta \theta} (e_{i,j} - e_{i,j-1}) \quad (A2)$$

Similarly, Equation (2) becomes,

$$\frac{P_{i,j} - P_{i-1,j}}{\Delta X} + \frac{1}{g} \left(\frac{G_{i,j} - G_{i,j-1}}{\Delta \theta} \right) + \frac{1}{g} \left(\frac{G_{i,j}^2 v_{i,j} - G_{i-1,j}^2 v_{i-1,j}}{\Delta X} \right) + F_{i,j} = 0 \quad (A3)$$

The frictional term F in Equation (A3) is expressed by means of the friction factor "f" as follows,

$$F = \frac{4fG^2}{2g\rho D} \quad (A4)$$

Using the average values of mass flow rate and the density along an increment, i, the friction term is

$$\begin{aligned}
F_{i,i} &= \frac{2f_{i,i} \bar{G}^2}{g \bar{\rho} D} \\
\bar{G} &= \frac{G_{i,i} + G_{i-1,i}}{2} \\
\bar{\rho} &= \frac{\rho_{i,i} + \rho_{i-1,i}}{2}
\end{aligned} \tag{A5}$$

The friction factor, $f_{i,i}$, is obtained from empirical correlations for gaseous flow in a smooth tube as shown in Equation (14) and Equation (15). A roughness multiplier can be applied to the friction factor for flow passages which are not smooth. This roughness multiplier may be obtained from experimental data. Substituting Equation (A5) into (A3) and solving for $P_{i,i}$ one obtains

$$\begin{aligned}
P_{i,i} = P_{i-1,i} - \frac{1}{g} \left(\frac{\Delta X}{\Delta \theta} (G_{i,i} - G_{i-1,i}) + (G_{i,i}^2 v_{i,i} - G_{i-1,i}^2 v_{i-1,i}) \right) \\
- \frac{2f_{i,i} \bar{G}^2 \Delta X}{g \bar{\rho} D}
\end{aligned} \tag{A6}$$

Similarly, in Equation (3) of Section 2, the last term can be expressed as

$$Q\rho = \frac{qP}{A} \tag{A7}$$

The energy equation then becomes,

$$\begin{aligned}
\frac{H_{i,i} G_{i,i} - H_{i-1,i} G_{i-1,i}}{\Delta X} + \frac{H_{i,i} \rho_{i,i} - H_{i-1,i} \rho_{i-1,i}}{\Delta \theta} \\
- \frac{1}{J} \left(\frac{P_{i,i} - P_{i-1,i}}{\Delta \theta} \right) - \frac{\bar{q} P}{A} = 0
\end{aligned} \tag{A8}$$

Solving for $H_{i,i}$, one obtains

$$H_{i,j} = \frac{1}{\left(G_{i,j} + \rho_{i,j} \frac{\Delta X}{\Delta \theta}\right)} \left\{ G_{i-1,j} H_{i-1,j} + \frac{\Delta X}{\Delta \theta} \left(\rho_{i,j-1} H_{i,j-1} + \frac{1}{J} \right. \right. \\ \left. \left. (P_{i,j} - P_{i,j-1}) + \frac{\bar{q} P}{A} \Delta X \right) \right\} \quad (A9)$$

The heat transfer between the fluid and the channel wall within an axial increment is expressed in terms of the average heat flux based on average conditions across the increment.

$$\bar{q} = h P \Delta x (\bar{T}_w - \bar{T}_b) \quad (A10)$$

where

$$\bar{q} = \frac{q_{i,j} + q_{i-1,j}}{2}$$

$$\bar{h} = \frac{h_{i,j} + h_{i-1,j}}{2}$$

$$\bar{T}_w = \frac{(T_w)_{i,j} + (T_w)_{i-1,j}}{2}$$

$$\bar{T}_b = \frac{(T_b)_{i,j} + (T_b)_{i-1,j}}{2}$$

The heat flux, q , in Equation (A10) is determined by the convective heat transfer relationship as shown by Equation (A6). Equations (A2), (A6), and (A9) are the working finite difference representations for the equations of conservation. These three equations together with the equation of state are sufficient to calculate the fluid conditions: G , ρ , P , and H at any point of the flow system. The calculational procedure is an iteration process as described in the following: For specified values of (1) the channel wall temperature distributions of all channels at time $= \theta_j$, (2) all the fluid conditions and channel wall temperatures at time $= \theta_{j-1}$, and (3) the inlet fluid conditions at time θ_j , the fluid conditions at the end of an increment at time $= \theta_j$ can be calculated. To start the iteration at increment i , the fluid temperature, $T_{i-1,j}$, and pressure, $P_{i-1,j}$, are used as the initial trial values for $T_{i,j}$ and $P_{i,j}$. The iteration continues until successive values of $\rho_{i,j}$, $P_{i,j}$, and $H_{i,j}$ are within a given tolerance.

2. Entrance and Exit Pressure Losses

The pressure losses due to frictional force and momentum change inside a channel are calculated by Equation (A6). The pressure loss at the entrance or exit of the channel is computed from the following expression:

$$\Delta P = C_L \frac{G_v^2}{2g} \quad (A11)$$

The coefficient C_L is the inlet or exit loss coefficient of the channel. It can be determined analytically or by experiment.

3. Flow Rate Adjustment

The total flow of fluid in the system is distributed among the channels in such a way that the overall pressure drop across all channels is the same within a specified tolerance. An estimated flow rate distribution is given as the initial condition.

Following an iteration on flow balance, the flow rate distribution is adjusted according to the following relationship:

$$(G_k)_{\text{new}} = \left[G_k \left(\frac{\Delta P_k}{\Delta \bar{P}} \right)^\beta \right]_{\text{old}} \quad (A12)$$

where

ΔP_k = overall pressure drop in the k^{th} channel

$\Delta \bar{P}$ = flow weighted average pressure drop of all the channels or specified pressure drop of the flow system

G_k = flow rate at the inlet of the k^{th} channel

β = a constant specified as input to the problem, usually 0.5.

The iteration is continued until the flow balance criterion is met on the maximum number of iterations is exceeded.

4. Temperature Distribution in the Solid Body

The TQSS (Transient or Steady-State)⁽⁸⁾ temperature calculation code was modified and integrated into the TRACK program for solution of the heat conduction model. Equation (4), the heat conduction equation, in finite difference form is:

$$\text{Vol}_q \frac{dT_{q,i}}{dt} + \sum_p Y_{pq,i} (T_{p,i} - T_{q,i}) = \frac{C_q}{\Delta \theta} (T_{q,i} - T_{q,i-1}) \quad (\text{A13})$$

where the index "p" denotes all neighboring nodes of the internal node "q" and the index "i" denotes the quantities at time = θ_i . The term $Y_{pq,i}$ is the admittance between adjacent internal nodes or a surface and an internal node, p to q.

For conduction from an internal node to another internal node,

$$Y_{pq,i} = \frac{A_{pq}}{\frac{l_{pq}}{k_{p,i}} + \frac{l_{qp}}{k_{q,i}}} \quad (\text{A14})$$

For conduction from an internal node to a surface node,

$$Y_{pq,i} = \frac{k_{p,i} A_{pq}}{l_{pq}} \quad (\text{A15})$$

The boundary heat transmission is calculated by means of the heat transfer coefficient between the coolant and the channel wall surface node. The surface admittance is determined by the mode of heat transfer between the boundary node, b, and the channel wall surface node, w. The following three modes can be used:

For forced convection,

$$Y_{bw} = h(\theta) A_w \quad (\text{A16})$$

For natural convection,

$$Y_{bw} = A_w K_{bw} \left[T_w - T_b \right]^{E_{bw}} \quad (\text{A17})$$

For radiation,

$$Y_{bw} = A_w K_{bw} \sigma (T_b^2 + T_w^2) (T_b + T_w) \quad (A18)$$

where $h(\theta)$ is the heat transfer coefficient which can be a function of time, and K_{bw} and E_{bw} are input constants.

To solve the system of linear finite difference equations as shown by Equation (A13), a Gauss-Seidel iteration procedure is used. The $(m+1)^{th}$ iteration at time $= \theta_i$ for the temperature at the q^{th} node, $T_{q,i}^{m+1}$, is as follows:

$$T_{q,i}^{m+1} = \frac{\sum_{p=1}^{q-1} Y_{qp} T_{p,i}^{m+1} + \sum_{p=q+1}^n Y_{qp} T_{p,i}^m + q_{q,i}^{''' } Vol_q - C \frac{q_{q,i} - T_{q,i-1}}{\theta}}{-Y_{qq}} \quad (A19)$$

where

$$Y_{qq} = \text{Self admittance} = - \sum_p^n Y_{qp}$$

and

$$T_{q,i-1} = \text{converged temperature for node at time } \theta_{i-1}$$

and "p" ranges over the "n" neighbors of node "q". This iteration continues until all internal node temperatures meet the following criterion:

$$\left| T_q^m - T_q^{m+1} \right| \leq \epsilon \quad (20)$$

where "m" indexes the number of iterations on the internal node array. The convergence parameter, " ϵ ", is an input quantity with units of $^{\circ}\text{R}/\text{iteration}$.

5. Coupling of Hydraulic and Conduction Calculations

From the above description of the calculational procedure, it is seen that the fluid flow calculation can be completed for one time step when the channel wall temperature distributions through the flow system are known. In the analysis presented herein, the channel wall temperatures are supplied and checked using a temperature distribution calculation of the solid body. Estimates of the initial wall temperature distribution are specified in the input

data. The fluid flow calculation for the first time step can then be completed. The resulting fluid bulk temperatures and channel wall heat transfer coefficients are input to the temperature distribution calculations to compute the temperature change of the solid body during this time step at several transverse cross sections of the system (axial heat conduction is neglected). Linear interpolation is used to complete the axial wall temperature profiles. The channel wall temperatures thus obtained are compared to the wall temperatures used in the fluid flow calculation. If they do not agree within a specified tolerance, the entire procedure is repeated using the new channel wall temperatures. This iteration between the fluid flow calculation and the material temperature distribution calculation is continued until the convergence criterion is satisfied. The iteration process is repeated for each succeeding time step. The initial estimates of the wall temperatures at the end of a time step are obtained by linearly extrapolating the wall temperatures from two preceding times. Expressed another way, the channel wall temperatures at θ_i are obtained by extrapolation from the known wall temperatures at θ_{i-1} and at θ_{i-2} .

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APPENDIX B

MATERIAL THERMAL PROPERTIES LIBRARY SYSTEM

- AMAT
1. Grade SX5 Graphite With Grain
 2. Grade SX5 Graphite Across Grain
 3. 6061 Aluminum QQ-A-250/II L & T
 4. S-200 Beryllium VHP Block PDS 30018-1, L & T
 5. Stainless Steel 304 QQ-S-763, Annealed Rod PDS 30066
 6. Copper 99.99% PURE QQ-C-502 HARD
 7. Titanium Alloy, ELI Sheet, Ti-5 Al-2.5 Sn PDS 30028, 29
 8. Inconel X-750 AMS 5698
 9. Pyrolytic Graphite Sleeves, PDS 30014, Across Grain
 10. Bath Shield, Extruded Bar, L & T
 11. Borated Copper (Cu-24% B 10) L & T
 12. TZM Molybdenum Bar, PDS 30012 - L -
 13. PO3 Graphite, Molded Plate, PDS 30086 With Grain
 14. Inconel 718, Aged Bar & Tube, PDS 30038, 43 - L -
 15. Composite PDS 30106-3 With Grain
 16. Pyrolytic Graphite Plate, PDS 30016, Across Grain
 17. ZTA Graphite, PDS 30019, Across Grain
 18. Graphite-G, Extruded Rod, PDS 30020-3, Across Grain
 19. Plain Unbonded Pyrofoil, PDS 30182-2, Across Grain
 20. Embossed Unbonded Pyrofoil, Across Grain
 21. Corrogated Unbonded Pyrofoil, Across Grain
 22. Tungsten-10% Rhenium
 23. Zirconia Stabilized, 95% Density
 24. ZTA Graphite, PDS 30019, With Grain

APPENDIX B (cont'd.)

AMAT	25.	Grade AXM Graphite, PDS 30134, 135, With Grain
	26.	Graphitite-G, PDS 30020-3, With Grain
	27.	
	28.	
	29.	Laminated Pyrofoil, PDS 30097-1, Across Grain
	30.	Plain Unbonded Pyrofoil, PDS 30182-2, With Grain
	31.	Tungsten-2% Thorium, CVD Thin Sheet & Tube Annealed
	32.	Grade H4LM Graphite, PDS 30073-2, With Grain
	33.	Grade AXM Graphite, PDS 30134, 135, Across Grain
	34.	Pyrolytic Graphite Plate, PDS 30016, With Grain
	35.	Composite, PDS 30125, With Grain
	36.	Composite, PDS 30125, Across Grain
	37.	Boral (35B10, 65Al), Plate, L&T
	38.	Composite, PDS 30106-3, Across Grain
	39.	Grade H4LM Graphite, PDS 30073-2, Across Grain
	40.	
	41.	
	42.	Stainless Steel 301 (QQ-S-766) Plate, Sheet, Strip, L&T
	43.	Stainless Steel 316 (QQ-S-766, AMS 5573) Ann. Sheet & Tube - L -
	44.	PO3 Graphite, Molded Plate, PDS 30086, Across Grain
	45.	Uniloy A-286, AMS 5737 Bars, - L -
	46.	2024 Aluminum, QQ-A-225/6 T4-Bars, - L -
	47.	Stainless Steel 304, Plate, Sheet, Tube QQ-S-766, ASTM-A-269
	48.	Titanium Alloy, Bar Forg. PDS 30028-1, 29-1
	49.	Hafnium Dioxide
	50.	Platinum

APPENDIX B (cont'd.)

AMAT	51.	6061-T6 Aluminum Pipe ASTM B-241
	52.	2219-T852 Aluminum Forging PDS 30011
	53.	Boron Nitride
	54.	Uniloy A-286 Sheet, Strip, & Tube, AMS 5524, 5736 - L -
	55.	2219-T851 Aluminum Bar PDS 30037-1
	56.	Beryllium Oxide
	57.	
	58.	
	59.	ATJ Graphite, Across Grain
	60.	Tungsten
	61.	Thorium Oxide
	62.	Rhenium
	63.	Waspaloy Bar, Sheet, Tube AMS 5708, 5709 - L -
	64.	Inconel 625
	65.	
	66.	Thoria (95% Density)
	67.	ZrC Zero Porosity
	68.	Uranium Carbide
	69.	Lead

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APPENDIX C

INTERACTION BETWEEN PARALLEL CHANNEL GROUPS

1. Subroutine C INLET

Coolant temperature and pressure data obtained for Group One channels may be applied as boundary conditions to Group Two hydraulic calculations. The Group Two inlet fluid conditions (temperature and pressure) and a parallel boundary channel (axial temperature and pressure profiles) may be used. At present, these quantities are obtained from the specialized subroutine CINLET which must be rewritten for each specific model. The axial coolant temperature and pressure array and total flow through Group One channels are available to the subroutine as arguments. These values may be manipulated in any desired manner to produce the required output. Shown below is the subroutine logic used for the XE-PRIME reflector calculations.

```
SUBROUTINE CINLET (PSAVE, TSAVE, PSAVE, TSAVE2, P, T, WT)
DIMENSION PSAVE (2), TSAVE (2), P (70, 20, 2), T (70, 20)
DO 1500 J = 1, 19
1500  TSAVE (J) = T (1, 20-J)
      PSAVE2 = (P (15, 17, 2) + P (15, 18, 2) ) / 2. - 3. * WT / 77.
      TSAVE2 = (T (15, 17) + T (15, 18) ) / 2
      WRITE (6, 6520) PSAVE2, TSAVE2
      PSAVE (J) = P (1, 20-J, 2)
6520  FORMAT (2F10.3)
      RETURN
END
```

where,

WT	Group One total flow rate (lb/sec)
T (I,J)	Group One coolant temperatures ($^{\circ}$ R)
P (I,J,K)	Group One coolant pressures (psia)
T SAVE 2	Group Two inlet coolant temperature ($^{\circ}$ R)
P SAVE 2	Group Two inlet pressure (psia)
T SAVE (J)	Axial coolant temperature and pressure
P SAVE (J)	Profiles for boundary channel for Group Two calculations ($^{\circ}$ R, psia)
I	Indicates channels I=70
J	Indicates axial increment J = 20 (J = 1 for inlet, J = 20 for exit, 18 equal increments)
K	Time indicator (K = 1 for previous time, K = 2 for current time)

The subroutine, CINLET, can also be used for external card input of the quantities TSAVE2, PSAVE2, TSAVE(J) and PSAVE(J).

2. Crossflow

Crossflow between a boundary channel and plena between axial sections for series channels may be accomplished through use of the CINLET subroutine which establishes the boundary conditions and the crossflow input described in Table III, Cards ZD-ZE. The connecting path length, cross-sectional flow area, and hydraulic diameter are specified for each connecting link. Flow into the Group Two flow system from the external boundary is calculated for these specified conditions, considering both friction and inlet and exit losses but assuming isothermal fluid in the leakage path. Static loss coefficients of 0.5 and 1.5 are used for the entrance and exit, respectively. Flow rate and enthalpy additions are made to the main fluid stream and the calculations proceed to the next axial section. Flow outward from the main stream is not allowed.

APPENDIX D

SAMPLE PROBLEM

The sample problem is a transient analysis problem in which two independent groups of solid components are analyzed. The components consist of a hollow graphite cylinder and a hollow beryllium cylinder. Each component is cooled by hydrogen gas flowing through its center hole. The hydraulic and heat transfer model input parameters are as follows:

Number of channels	=	2
Channel length	=	40 inches
Channel diameter	=	0.1 inches
Number of sub-channels of channel 1	=	100
Number of sub-channels of channel 2	=	115
Inlet loss coefficient of channel 1	=	30.0
Inlet loss coefficient of channel 2	=	5.0
Inlet loss coefficient of channel 2	=	5.0
Outlet loss coefficients of both channels	=	-0.4
Tolerance in pressure drop calculations	=	0.02
Total problem time	=	2 seconds
Time step	=	1 second
Initial temperature of cylinder	=	540°R
Conduction iteration tolerance	=	0.05
Conduction time step	=	0.1 second

Overall pressure drop across channel is to be calculated. The inlet coolant temperature, pressure, and flow rate as functions of time are shown on the sample output.

In the heat conduction model, the cylinder is divided into 8 segments; each segment is 5 inches long and is represented by a two-dimensional heat transfer conduction model in which the axial heat conduction is neglected. A segment is divided into 3 internal nodes. The internal nodes, surface nodes, and the boundary nodes of the model are shown in Figure 14. The listing of the conduction data and the hydraulic data are shown in the printout pages 88 through 121.

Figure 14. Sample Problems: Hydraulic and Conduction Models

TRACK II ----REVISION 002 DATE OF LAST REVISION 10-24-69

BLOCK-212

BLOCK-212.

TRACK (TRANSIENT THERMAL ANALYSIS WITH CONVECTION AND CONDUCTION) HAS BEEN UPDATED ON OCT. 24, 1969 BY A.Y. LEE AND M.D. WOODS. REASON FOR UPDATE WAS TO CHANGE THE INPUT FORMATS FROM TOSS TO TAP A AND TO INCORPORATE THE LATEST NBS PROPERTIES OBTAINED FROM THE NATIONAL BUREAU OF STANDARDS (NBS REPORT 9288 DATED AUGUST 18, 1967).

REFERENCES

(1) WANL-TME-1736

TRACK INPUT DATA

NOTE

ON THE EXTREME RIGHT IS THE CARD IDENTIFICATION. FOR EXAMPE T2, CD
AND F MEANS THIS IS CARD F DESCRIBED IN TABLE 2, PAGE 42 OF THIS REPORT.

*										T2 CD A
40.		20.		2	2					T2 CD F
	1	1	1	3						T2 CD 1G
	2	1	4	6						T2 CD 2G
										T2 CD H
		CS 2.5	1							T2 CD K
3 214.			.0660							T2 CD 1N
3222.		.078								T2 CD 2N
3 226.		0.234								T2 CD 3N
4 214.	1.	.002001.3889F-04	0.00	.002001.3889F-04	10.00	T2 CD 1O				
4 214.	3.	.002001.2222F-03	50.00	.015002.5116E-03	100.00	T2 CD 2O				
4 214.	5.	.042003.5556F-03	150.00	.060003.6667F-03	175.00	T2 CD 3O				
4 214.	7.	.080003.9722F-03	200.00	.110003.9167F-03	225.00	T2 CD 4O				
4 214.	9.	.130003.8611F-03	250.00	.190003.6944F-03	300.00	T2 CD 5O				
4 214.	11.	.250003.4444F-03	350.00	.315003.2778F-03	400.00	T2 CD 6O				
4 214.	13.	.465002.6389F-03	600.00	.540002.1944F-03	800.00	T2 CD 7O				
4 214.	15.	.750001.2500F-03	2000.00	.750001.0347F-03	2800.00	T2 CD 8O				
4 214.	17.	.750001.0278E-03	3500.00			T2 CD 9O				
4 226.		0.567	0.789			T2 CD 10O				
5 1.	3.	1.	.0393	1.	1.	T2 CD 1P				
5 4.	6.	4.	.0393	1.	1.	T2 CD 2P				
7 1.		2.	.0785	.0785	.05	1.	1.	T2 CD 1R		
7 2.		3.	.0785	.0785	.05	1.		T2 CD 2R		
7 4.		5.	.0785	.0785	.05	1.	1.	T2 CD 3R		
7 5.		6.	.0785	.0785	.05	1.		T2 CD 4R		
7 1.		3001.	.0333		.1046	1.		T2 CD 5R		
7 2.		3002.	.0333		.1046	1.		T2 CD 6R		
7 3.		3003.	.0333		.1046	1.		T2 CD 7R		
7 4.		3004.	.0333		.1046	1.		T2 CD 8R		
7 5.		3005.	.0333		.1046	1.		T2 CD 9R		
7 6.		3006.	.0333		.1046	1.		T2 CD 10R		
93001.3003.5001.		1.		1.		T2 CD 1T				
93004.3006.5002.		2.		2.		T2 CD 2T				
12 1.	6.	1.				T2 CD U				

100.	110.	120.	130.	140.	150.	160.	T3 CD 1L
170.	180.	190.	200.	210.	220.	230.	T3 CD 2L
240.	250.						T3 CD 3L
540.	405.	325.	270.	225.	190.	165.	T3 CD 1M
145.	130.	115.	110.	105.	100.	100.	T3 CD 2M
100.	100.						T3 CD 3M
.05	.09	.125	.15	.18	.20	.22	T3 CD 1N
.24	.26	.28	.30	.32	.34	.36	T3 CD 2N
.38	.40						T3 CD 3N
2.	0.						T3 CD P
100.	.1	40.	30.	-.4	1.	.25	T3 CD 1Q
115.	.1	40.	5.	-.4	1.	.25	T3 CD 2Q
							T3 CD R
.48	.52						T3 CD S
1.	1.						T3 CD T
	1	1					T3 CD U
.05	100.	.02	10.	.02			T3 CD V
3.	1.	1.					T3 CD W
0.	20.	40.					T3 CD X
540.	540.	540.					T3 CD Y
540.	540.	540.					T3 CD Z
540.	540.	540.					T3 CD ZA
	1	2	8				T3 CD ZF
2.5	7.5	12.5	17.5	22.5	27.5	32.5	T3 CD1ZG
37.5							T3 CD2ZG
	1	16					T3 CD ZJ
.5	0.	.51	1.	.52	2.		T3 CD1ZK
.54	3.	.56	4.	.6	5.		T3 CD2ZK
.64	6.	.68	7.	.72	8.		T3 CD3ZK
.74	9.	.8	10.	.84	11.		T3 CD4ZK
.88	12.	.92	13.	.96	14.		T3 CD5ZK
1.	15.						T3 CD6ZK
	2	6	3006				T3 CD ZL
	1	5001	0				T3 CD1ZM
	2	5002	0				T3 CD2ZM
540.	540.	540.	540.	540.	540.	540.	T3 CD1ZR
540.							T3 CD2ZR
	0						T3 CD ZS
	1	1					T3 CD YA
	4	10.	5	10.	6	10.	T3 CD YB
	3	2	2				T3 CD YD
0.0	1.0	20.	1.5	40.	1.0		T3 CD YE
0.0	1.0	40.	0.3				T3 CD YF
0.0	1.0FE18	40.	2.0FE18				T3 CD YG
1.	1.						T3 CD YH

T3 CD YI
T3 CD YJ
T3 CD YK
T3 CD YL
T3 CD YM
T3 CD YN
T3 CD YO

1.			
1.			
	1	3	3
2.	25.	40.	
1.	1.	1.	
2.	25.	40.	
1.	1.	1.	

***** PARA HYDROGEN FLUID PROPERTIES NBS

UPDATED OCT 1969, WANL NSS+FA-022 *****

TRANSIENT RESULTS

THETA= 1.000 SEC.

SECTION 1

CHANNEL 1

X INCHES	P PSIA	T DEG-R	TS DEG-R	TW1(END,START) DEGREES - R		TW2(END,START) DEGREES - R		G LBS SEC-FT**2	Q BTU HR-FT**2	H1 BTU HR-FT**2-R	H2 BTU HR-FT**2-R
0.00	110.00	404.9									
0.00	107.70	404.8	404.9	564.5	539.3	0.0	539.3	6.019	0	366	0
2.22	107.61	460.2	460.3	574.5	539.3	0.0	539.3	6.017	50056	364	0
4.44	107.53	501.6	501.7	584.4	539.3	0.0	539.3	6.016	36247	371	0
6.67	107.45	532.6	532.8	594.4	539.3	0.0	539.3	6.016	27203	379	0
8.89	107.36	556.9	557.1	603.7	539.3	0.0	539.3	6.015	20790	385	0
11.11	107.27	576.0	576.1	612.5	539.3	0.0	539.3	6.015	16212	389	0
13.33	107.18	591.3	591.5	621.1	539.3	0.0	539.3	6.015	13025	392	0
15.56	107.09	604.0	604.2	629.3	539.3	0.0	539.3	6.016	10886	394	0
17.78	106.99	615.1	615.3	637.5	539.3	0.0	539.3	6.016	9467	395	0
20.00	106.90	625.1	625.3	645.4	539.3	0.0	539.3	6.016	9514	396	0
22.22	106.80	634.2	634.5	653.3	539.3	0.0	539.3	6.017	7866	397	0
24.44	106.70	641.6	641.9	654.3	539.3	0.0	539.3	6.018	6359	400	0
26.67	106.60	646.5	646.7	654.3	539.3	0.0	539.3	6.018	4179	401	0
28.89	106.50	648.5	648.7	649.5	539.3	0.0	539.3	6.019	1806	404	0
31.11	106.40	647.2	647.4	641.7	539.3	0.0	539.3	6.020	-1039	406	0
33.33	106.31	643.4	643.6	633.7	539.3	0.0	539.3	6.020	-3138	407	0
35.56	106.21	638.0	638.2	625.7	539.3	0.0	539.3	6.021	-4543	408	0
37.78	106.12	631.5	631.7	617.6	539.3	0.0	539.3	6.022	-5424	408	0
40.00	106.03	624.4	624.6	609.6	539.3	0.0	539.3	6.022	-5959	408	0
40.00	106.08	624.6									

AVERAGE PROPELLANT DENSITY = 3.4322E-02 LBS/FT**3

CHANNEL 2

X INCHES	P PSIA	T DEG-R	TS DEG-R	TW1(END,START) DEGREES - R		TW2(END,START) DEGREES - R		G LBS SEC-FT**2	Q BTU HR-FT**2	H1 BTU HR-FT**2-R	H2 BTU HR-FT**2-R
0.00	110.00	404.9									
0.00	109.12	404.7	404.9	547.3	539.3	0.0	539.3	9.115	0	519	0
2.22	108.96	450.7	450.9	551.6	539.3	0.0	539.3	9.113	62924	513	0
4.44	108.80	484.1	484.3	555.9	539.3	0.0	539.3	9.112	44764	523	0
6.67	108.63	508.6	508.9	560.2	539.3	0.0	539.3	9.111	32580	531	0
8.89	108.47	526.6	526.9	564.1	539.3	0.0	539.3	9.110	23889	539	0
11.11	108.30	540.0	540.4	567.9	539.3	0.0	539.3	9.110	17742	544	0
13.33	108.13	550.5	550.8	571.6	539.3	0.0	539.3	9.109	13439	548	0
15.56	107.96	558.5	558.9	575.1	539.3	0.0	539.3	9.109	10380	550	0
17.78	107.79	565.0	565.4	578.5	539.3	0.0	539.3	9.109	8328	551	0
20.00	107.62	570.4	570.8	581.9	539.3	0.0	539.3	9.109	6958	552	0
22.22	107.44	575.1	575.5	585.3	539.3	0.0	539.3	9.108	6089	553	0
24.44	107.26	578.8	579.2	585.7	539.3	0.0	539.3	9.108	4803	555	0
26.67	107.09	581.3	581.7	585.8	539.3	0.0	539.3	9.108	3204	556	0

28.89	106.91	582.5	582.9	583.7	539.3	0.0	539.3	9.108	1596	558	0
31.11	106.74	582.3	582.7	580.4	539.3	0.0	539.3	9.108	-215	559	0
33.33	106.56	581.0	581.4	577.1	539.3	0.0	539.3	9.108	-1696	560	0
35.56	106.39	578.9	579.3	573.7	539.3	0.0	539.3	9.108	-2642	560	0
37.78	106.22	576.4	576.7	570.4	539.3	0.0	539.3	9.108	-3245	561	0
40.00	106.05	573.5	573.9	567.1	539.3	0.0	539.3	9.108	-3625	561	0
40.00	106.15	573.9									

AVERAGE PROPELLANT DENSITY = 3.7238E-02 LBS/FT**3
SECTION FLOW RATE= .08998 LB/SEC, SECTION POWER = .06401 MW

CHANNEL FLOW DISTRIBUTION SUMMARY							
CHANNEL NO.	DELTAP PSIA	MASS FLOW LBS/SEC	PCT OF TOTAL	PCT STEADY STATE	POWER/CH(MW)	POWER(MW)	
1	3.922	.03285	36.505	1.000	2.72499E-04	2.72499E-02	
2	3.852	.05713	63.495	1.000	3.19629E-04	3.67573E-02	
EXIT TEMP = 592.43 DEG R		EXIT PRESSURE = 106.12 PSIA		TOTAL POWER =		6.400717E-02	MW
0 ITERATIONS ON FLOW BALANCE							

05/04/70 TIME=15.20.15
MTPLS THERMAL PROPERTIES *WANL-DRM-51472G MAR 1970

TRACK OUTPUT FOR AXIAL STATION 2.5 INCHES

T2 CD K

INITIAL TIME 0.0000 FINAL TIME 1.0000 TIME INCREMENT .1000 CONVERGE CRITERIA .0020 PROBLEM TYPE 3.0000 STEPS BEFORE ACCELERATE 20 MAXIMUM NO. ITERATION 500
 MTPLS THERMAL PROPERTIES *WANL-DRM-514728 MAR 1970
 MAT 1 GRADE SX5 GRAPHITE W.G.
 DATA RANGE TK = 131-4991R , CP = 528-4960R
 NO UNCERTAINTY DATA , NO IRRADIATED TK DATA
 MAT 4 BERYLLIUM ALLOY PDS 30010-2
 DATA RANGE TK = 37-1060R , CP = 37-1060R
 UNCERTAINTY AVAILABLE , IRRADIATED TK AVAILABLE

NO. OF ITERATIONS 12, CRIC= .012243 CRIT= .002000 SUM= .001393
 NO. OF ITERATIONS 12, CRIC= .012468 CRIT= .002000 SUM= .001326
 NO. OF ITERATIONS 12, CRIC= .012816 CRIT= .002000 SUM= .001252
 NO. OF ITERATIONS 11, CRIC= .013297 CRIT= .002000 SUM= .001943
 NO. OF ITERATIONS 12, CRIC= .007560 CRIT= .002000 SUM= .001089
 NO. OF ITERATIONS 12, CRIC= .007992 CRIT= .002000 SUM= .001002
 NO. OF ITERATIONS 12, CRIC= .008554 CRIT= .002000 SUM= .000913
 NO. OF ITERATIONS 11, CRIC= .009287 CRIT= .002000 SUM= .001380
 NO. OF ITERATIONS 11, CRIC= .010258 CRIT= .002000 SUM= .001230
 NO. OF ITERATIONS 10, CRIC= .011572 CRIT= .002000 SUM= .001820

INTERNAL TEMPERATURES AT 1.0000 SECONDS
 NODE TEMP NODE TEMP NODE TEMP NODE TEMP NODE TEMP
 1 577.64 2 577.65 3 577.66 4 553.52 5 553.52
 6 553.52

SURFACE TEMPERATURES AT 1.0000 SECONDS
 NODE TEMP NODE TEMP NODE TEMP NODE TEMP NODE TEMP
 3001 576.50 3002 576.51 3003 576.52 3004 552.28 3005 552.28
 3006 552.28 3002 576.51 3003 576.52 3004 552.28 3005 552.28

BOUNDARY TEMPERATURES AT 1.0000 SECONDS

NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE	TEMP
5001	469.09	5002	459.07						

NODE INTERFACE CONDITIONS

INDEX	NODE-I	NODE-J	TEMP-R	QFLO-B/SEC
1	1	2	577.64	-4.5813E-06
2	4	5	553.52	-3.1907E-08

NODE	NODE	TEMPERATURES			AVERAGE HEAT GENERATION RATE	TOTAL VOLUME
		AVE.	MAX.	MIN.		
1	3	577.65	577.66	577.64	5.095E-01	.117900
4	6	553.52	553.52	553.52	5.095E-01	.117900
HEAT GENERATION RATE BTU/SEC	HEAT TRANSFER FROM SURFACES BTU/SEC	HEAT STORED BTU/SEC		RATIO HEAT BALANC		
1.2014E-01	5.0100E-02	6.9824E-02		.001802		

TRACK OUTPUT FOR AXIAL STATION 7.5 INCHES

T2 CD K

INITIAL TIME 0.0000	FINAL TIME 1.0000	TIME INCREMENT .1000	CONVERGE CRITERIA .0020	PROBLEM TYPE -3.0000	STEPS BEFORE ACCELERATE 20	MAXIMUM NO. ITERATION 500
NO. OF ITERATIONS	13, CRIC=	.012234	CRIT= .002000	SUM=	.000851	
NO. OF ITERATIONS	13, CRIC=	.012430	CRIT= .002000	SUM=	.000798	
NO. OF ITERATIONS	12, CRIC=	.012669	CRIT= .002000	SUM=	.001237	
NO. OF ITERATIONS	12, CRIC=	.012951	CRIT= .002000	SUM=	.001162	
NO. OF ITERATIONS	12, CRIC=	.013278	CRIT= .002000	SUM=	.001090	
NO. OF ITERATIONS	12, CRIC=	.013652	CRIT= .002000	SUM=	.001021	
NO. OF ITERATIONS	12, CRIC=	.014078	CRIT= .002000	SUM=	.000955	
NO. OF ITERATIONS	11, CRIC=	.014601	CRIT= .002000	SUM=	.001488	
NO. OF ITERATIONS	11, CRIC=	.015213	CRIT= .002000	SUM=	.001363	
NO. OF ITERATIONS	11, CRIC=	.015897	CRIT= .002000	SUM=	.001248	
INTERNAL TEMPERATURES AT 1.0000 SECONDS						
NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE
1	600.94	2	600.95	3	600.97	4
5	562.93					5
						562.93
SURFACE TEMPERATURES AT 1.0000 SECONDS						
NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE
3001	600.30	3002	600.31	3003	600.32	3004
3006	562.30	3002	600.31	3003	600.32	3004
						562.30
						562.30
BOUNDARY TEMPERATURES AT 1.0000 SECONDS						
NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE
5001	541.61	5002	516.57			

NODE INTERFACE CONDITIONS

INDEX	NODE-I	NODE-J	TEMP-R	QFLO-B/SEC		
1	1	2	600.95	-6.0616E-06		
2	4	5	562.93	-3.7533E-08		
NODE.	NODE	TEMPERATURES			AVERAGE HEAT GENERATION RATE	TOTAL VOLUME
		AVE.	MAX.	MIN.		
1	3	600.95	600.97	600.94	7.642E-01	.117900
4	6	562.93	562.93	562.93	7.642E-01	.117900
HEAT GENERATION RATE BTU/SEC	HEAT TRANSFER FROM SURFACES BTU/SEC	HEAT STORED BTU/SEC	RATIO HEAT BALANC			
1.8021E-01	2.6922E-02	1.5307E-01	.001235			

TRACK OUTPUT FOR AXIAL STATION 12.5 INCHES

T2 CD K

106

INITIAL TIME 0.0000	FINAL TIME 1.0000	TIME INCREMENT .1000	CONVERGE CRITERIA .0020	PROBLEM TYPE -3.0000	STEPS BEFORE ACCELERATE 20	MAXIMUM NO. ITERATION 500
NO. OF ITERATIONS	12, CRIC=	.021608	CRIT= .002000	SUM=	.001394	
NO. OF ITERATIONS	12, CRIC=	.022127	CRIT= .002000	SUM=	.001298	
NO. OF ITERATIONS	12, CRIC=	.022680	CRIT= .002000	SUM=	.001209	
NO. OF ITERATIONS	11, CRIC=	.023266	CRIT= .002000	SUM=	.001880	
NO. OF ITERATIONS	11, CRIC=	.023886	CRIT= .002000	SUM=	.001763	
NO. OF ITERATIONS	11, CRIC=	.024605	CRIT= .002000	SUM=	.001641	
NO. OF ITERATIONS	11, CRIC=	.025535	CRIT= .002000	SUM=	.001495	
NO. OF ITERATIONS	11, CRIC=	.026512	CRIT= .002000	SUM=	.001363	
NO. OF ITERATIONS	11, CRIC=	.023026	CRIT= .002000	SUM=	.001244	
NO. OF ITERATIONS	10, CRIC=	.028613	CRIT= .002000	SUM=	.001982	
INTERNAL TEMPERATURES AT 1.0000 SECONDS						
NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE
1	621.90	2	621.92	3	621.94	4
6	571.50					5
						571.50
SURFACE TEMPERATURES AT 1.0000 SECONDS						
NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE
3001	621.47	3002	621.49	3003	621.51	3004
3006	571.15	3002	621.49	3003	621.51	3004
						571.14
						571.14
						3005
						571.15
						571.15
BOUNDARY TEMPERATURES AT 1.0000 SECONDS						
NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE
5001	583.23	5002	546.20			
						TEMP

NODE INTERFACE CONDITIONS

INDEX	NODE-I	NODE-J	TEMP-H	QFLO-B/SEC		
1	1	2	621.91	-1.0091E-05		
2	4	5	571.50	-8.5266E-08		
NODE	NODE	TEMPERATURES			AVERAGE HEAT GENERATION RATE	TOTAL VOLUME
		AVE.	MAX.	MIN.		
1	3	621.92	621.94	621.90	1.019E+00	.117900
4	6	571.50	571.50	571.50	1.019E+00	.117900
HEAT GENERATION RATE	HEAT TRANSFER FROM SURFACES	HEAT STORED		RATIO		
BTU/SEC	BTU/SEC	BTU/SEC		HEAT BALANC		
2.4028E-01	1.6433E-02	2.2338E-01		.001961		

TRACK OUTPUT FOR AXIAL STATION 17.5 INCHES

T2 CD K

108

INITIAL TIME 0.0000	FINAL TIME 1.0000	TIME INCREMENT .1000	CONVERGE CRITERIA .0020	PROBLEM TYPE -3.0000	STEPS BEFORE ACCELERATE 20	MAXIMUM NO. ITERATION 500			
NO. OF ITERATIONS	12, CRIC=	.028877	CRIT=	.002000	SUM=	.001422			
NO. OF ITERATIONS	12, CRIC=	.022219	CRIT=	.002000	SUM=	.001305			
NO. OF ITERATIONS	12, CRIC=	.022848	CRIT=	.002000	SUM=	.001200			
NO. OF ITERATIONS	12, CRIC=	.023496	CRIT=	.002000	SUM=	.001099			
NO. OF ITERATIONS	12, CRIC=	.024232	CRIT=	.002000	SUM=	.000992			
NO. OF ITERATIONS	11, CRIC=	.025214	CRIT=	.002000	SUM=	.001502			
NO. OF ITERATIONS	11, CRIC=	.026227	CRIT=	.002000	SUM=	.001350			
NO. OF ITERATIONS	11, CRIC=	.027272	CRIT=	.002000	SUM=	.001216			
NO. OF ITERATIONS	11, CRIC=	.028348	CRIT=	.002000	SUM=	.001098			
NO. OF ITERATIONS	10, CRIC=	.029455	CRIT=	.002000	SUM=	.001757			
INTERNAL TEMPERATURES AT 1.0000 SECONDS									
NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE	TEMP
1	641.57	2	641.58	3	641.61	4	579.62	5	579.62
6	579.62								
SURFACE TEMPERATURES AT 1.0000 SECONDS									
NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE	TEMP
3001	641.21	3002	641.22	3003	641.25	3004	579.39	3005	579.39
3006	579.39	3002	641.22	3003	641.25	3004	579.39	3005	579.39
BOUNDARY TEMPERATURES AT 1.0000 SECONDS									
NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE	TEMP
5001	610.01	5002	562.95						

NODE INTERFACE CONDITIONS

INDEX	NODE-I	NODE-J	TEMP-R	QFLO-B/SEC		
1	1	2	641.57	-1.0639E-05		
2	4	5	579.62	-8.6552E-08		
NODE	NODE	TEMPERATURES			AVERAGE HEAT GENERATION RATE	TOTAL VOLUME
		AVE.	MAX.	MIN.		
1	3	641.59	641.61	641.57	1.274E+00	.117900
4	6	579.62	579.62	579.62	1.274E+00	.117900
HEAT GENERATION RATE	HEAT TRANSFER FROM SURFACES	HEAT STORED		RATIO HEAT BALANC		
BTU/SEC	BTU/SEC	BTU/SEC				
3.0035E-01	1.2299E-02	2.8753E-01		.001739		

TRACK OUTPUT FOR AXIAL STATION 22.5 INCHES

T> CD K

INITIAL TIME 0.0000	FINAL TIME 1.0000	TIME INCREMENT .1000	CONVERGE CRITERIA .0020	PROBLEM TYPE -3.0000	STEPS BEFORE ACCELERATE 20	MAXIMUM NO. ITERATION 500
NO. OF ITERATIONS	12, CRIC=	.037174	CRIT= .002000	SUM=	.001435	
NO. OF ITERATIONS	12, CRIC=	.038728	CRIT= .002000	SUM=	.001297	
NO. OF ITERATIONS	11, CRIC=	.040306	CRIT= .002000	SUM=	.001957	
NO. OF ITERATIONS	11, CRIC=	.042020	CRIT= .002000	SUM=	.001758	
NO. OF ITERATIONS	11, CRIC=	.044381	CRIT= .002000	SUM=	.001552	
NO. OF ITERATIONS	11, CRIC=	.035800	CRIT= .002000	SUM=	.001371	
NO. OF ITERATIONS	11, CRIC=	.027105	CRIT= .002000	SUM=	.001214	
NO. OF ITERATIONS	11, CRIC=	.028288	CRIT= .002000	SUM=	.001079	
NO. OF ITERATIONS	11, CRIC=	.029499	CRIT= .002000	SUM=	.000962	
NO. OF ITERATIONS	10, CRIC=	.030736	CRIT= .002000	SUM=	.001545	
INTERNAL TEMPERATURES AT 1.0000 SECONDS						
NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE
1	660.27	2	660.29	3	660.32	4
6	587.50					5
						587.50
SURFACE TEMPERATURES AT 1.0000 SECONDS						
NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE
3001	659.93	3002	659.95	3003	659.98	3004
3006	587.30	3002	659.95	3003	659.98	3004
						587.30
						587.30
BOUNDARY TEMPERATURES AT 1.0000 SECONDS						
NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE
5001	630.38	5002	573.76			

NODE INTERFACE CONDITIONS

INDEX	NODE-I	NODE-J	TEMP-R	QFLO-B/SEC		
1	1	2	660.28	-1.3198E-05		
2	4	5	587.50	-1.1891E-07		
NODE	NODE	TEMPERATURES			AVERAGE HEAT GENERATION RATE	TOTAL VOLUME
		AVE.	MAX.	MIN.		
1	3	660.29	660.32	660.27	1.528E+00	.117900
4	6	587.50	587.50	587.50	1.528E+00	.117900
HEAT GENERATION RATE BTU/SEC	HEAT TRANSFER FROM SURFACES BTU/SEC	HEAT STORED BTU/SEC		RATIO HEAT BALANC		
3.6042E-01	1.1066E-02	3.4880E-01		.001528		

TRACK OUTPUT FOR AXIAL STATION 27.5 INCHES

T? CD K

INITIAL TIME 0.0000	FINAL TIME 1.0000	TIME INCREMENT .1000	CONVERGE CRITERIA .0020	PROBLEM TYPE -3.0000	STEPS BEFORE ACCELERATE 20	MAXIMUM NO. ITERATION 500
NO. OF ITERATIONS	12, CRIC=	.037173	CRIT= .002000	SUM=	.001434	
NO. OF ITERATIONS	12, CRIC=	.038717	CRIT= .002000	SUM=	.001298	
NO. OF ITERATIONS	11, CRIC=	.040272	CRIT= .002000	SUM=	.001959	
NO. OF ITERATIONS	11, CRIC=	.041953	CRIT= .002000	SUM=	.001761	
NO. OF ITERATIONS	11, CRIC=	.044259	CRIT= .002000	SUM=	.001556	
NO. OF ITERATIONS	11, CRIC=	.035532	CRIT= .002000	SUM=	.001375	
NO. OF ITERATIONS	11, CRIC=	.026950	CRIT= .002000	SUM=	.001220	
NO. OF ITERATIONS	11, CRIC=	.028076	CRIT= .002000	SUM=	.001086	
NO. OF ITERATIONS	11, CRIC=	.029219	CRIT= .002000	SUM=	.000969	
NO. OF ITERATIONS	10, CRIC=	.030378	CRIT= .002000	SUM=	.001559	
INTERNAL TEMPERATURES AT 1.0000 SECONDS						
NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE
1	660.83	2	660.85	3	660.88	4
6	587.67					5
						587.67
SURFACE TEMPERATURES AT 1.0000 SECONDS						
NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE
3001	660.61	3002	660.63	3003	660.66	3004
3006	587.55	3002	660.63	3003	660.66	3004
						587.55
						587.55
BOUNDARY TEMPERATURES AT 1.0000 SECONDS						
NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE
5001	641.83	5002	579.62			

NODE INTERFACE CONDITIONS

INDEX	NODE-I	NODE-J	TEMP-R	QFLO-B/SEC		
1	1	2	660.84	-1.3236E-05		
2	4	5	587.67	-1.1917E-07		
NODE	NODE	TEMPERATURES			AVERAGE HEAT GENERATION RATE	TOTAL VOLUME
		AVE.	MAX.	MIN.		
1	3	660.85	660.88	660.83	1.528E+00	.117900
4	6	587.67	587.67	587.67	1.528E+00	.117900
HEAT GENERATION RATE	HEAT TRANSFER FROM SURFACES	HEAT STORED	RATIO	HEAT BALANC		
BTU/SEC	BTU/SEC	BTU/SEC				
3.6042E-01	6.8848E-03	3.5298E-01	.001542			

TRACK OUTPUT FOR AXIAL STATION 32.5 INCHES

T2 CD K

114

INITIAL TIME 0.0000	FINAL TIME 1.0000	TIME INCREMENT .1000	CONVERGE CRITERIA .0020	PROBLEM TYPE -3.0000	STEPS BEFORE ACCELERATE 20	MAXIMUM NO. ITERATION 500
NO. OF ITERATIONS	12, CRIC=	.028876	CRIT=	.002000	SUM=	.001422
NO. OF ITERATIONS	12, CRIC=	.022197	CRIT=	.002000	SUM=	.001305
NO. OF ITERATIONS	12, CRIC=	.022785	CRIT=	.002000	SUM=	.001203
NO. OF ITERATIONS	12, CRIC=	.023367	CRIT=	.002000	SUM=	.001104
NO. OF ITERATIONS	12, CRIC=	.024015	CRIT=	.002000	SUM=	.000999
NO. OF ITERATIONS	11, CRIC=	.024881	CRIT=	.002000	SUM=	.001518
NO. OF ITERATIONS	11, CRIC=	.025750	CRIT=	.002000	SUM=	.001371
NO. OF ITERATIONS	11, CRIC=	.026622	CRIT=	.002000	SUM=	.001241
NO. OF ITERATIONS	11, CRIC=	.027496	CRIT=	.002000	SUM=	.001126
NO. OF ITERATIONS	10, CRIC=	.028369	CRIT=	.002000	SUM=	.001813
INTERNAL TEMPERATURES AT 1.0000 SECONDS						
NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE
1	643.06	2	643.07	3	643.10	4
6	58.11					5
						580.11
SURFACE TEMPERATURES AT 1.0000 SECONDS						
NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE
3001	643.02	3002	643.03	3003	643.06	3004
3006	580.10	3002	643.03	3003	643.06	3004
						580.10
						580.10
BOUNDARY TEMPERATURES AT 1.0000 SECONDS						
NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE
5001	639.55	5002	579.37			
						TEMP

NODE INTERFACE CONDITIONS

INDEX	NODE-I	NODE-J	TEMP-R	QFLO-B/SEC		
1	1	2	643.07	-1.0766E-05		
2	4	5	580.11	-8.7659E-08		
NODE	NODE	TEMPERATURES			AVERAGE HEAT GENERATION RATE	TOTAL VOLUME
		AVE.	MAX.	MIN.		
1	3	643.08	643.10	643.06	1.274E+00	.117900
4	6	580.11	580.11	580.11	1.274E+00	.117900
HEAT GENERATION RATE BTU/SEC	HEAT TRANSFER FROM SURFACES BTU/SEC	HEAT STORED BTU/SEC		RATIO HEAT BALANC		
3.0035E-01	1.0524E-03	2.9876E-01		.001794		

TRACK OUTPUT FOR AXIAL STATION 37.5 INCHES

T2 CD K

INITIAL TIME 0.0000	FINAL TIME 1.0000	TIME INCREMENT .1000	CONVERGE CRITERIA .0020	PROBLEM TYPE -3.0000	STEPS BEFORE ACCELERATE 20	MAXIMUM NO. ITERATION 500
NO. OF ITERATIONS	12, CRIC=	.021605	CRIT= .002000	SUM=	.001394	
NO. OF ITERATIONS	12, CRIC=	.022085	CRIT= .002000	SUM=	.001299	
NO. OF ITERATIONS	12, CRIC=	.022557	CRIT= .002000	SUM=	.001214	
NO. OF ITERATIONS	12, CRIC=	.023019	CRIT= .002000	SUM=	.001137	
NO. OF ITERATIONS	11, CRIC=	.023469	CRIT= .002000	SUM=	.001791	
NO. OF ITERATIONS	11, CRIC=	.023978	CRIT= .002000	SUM=	.001678	
NO. OF ITERATIONS	11, CRIC=	.024639	CRIT= .002000	SUM=	.001541	
NO. OF ITERATIONS	11, CRIC=	.025294	CRIT= .002000	SUM=	.001418	
NO. OF ITERATIONS	11, CRIC=	.025942	CRIT= .002000	SUM=	.001305	
NO. OF ITERATIONS	11, CRIC=	.022770	CRIT= .002000	SUM=	.001202	
INTERNAL TEMPERATURES AT 1.0000 SECONDS						
NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE
1	624.24	2	624.26	3	624.28	4
6	572.35					5
						TEMP
						572.35
SURFACE TEMPERATURES AT 1.0000 SECONDS						
NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE
3001	624.28	3002	624.30	3003	624.32	3004
3006	572.39	3002	624.30	3003	624.32	3004
						TEMP
						572.39
						572.39
BOUNDARY TEMPERATURES AT 1.0000 SECONDS						
NODE	TEMP	NODE	TEMP	NODE	TEMP	NODE
5001	627.67	5002	574.80			
						TEMP

NODE INTERFACE CONDITIONS

INDEX	NODE-I	NODE-J	TEMP-R	QFLO-B/SEC
1	1	2	624.25	-9.3797E-06
2	4	5	572.35	-7.1348E-08

NODE	NODE	TEMPERATURES			AVERAGE HEAT	TOTAL VOLUME
		AVE.	MAX.	MIN.	GENERATION RATE	
1	3	624.26	624.28	624.24	1.019E+00	.117900
4	6	572.35	572.35	572.35	1.019E+00	.117900
HEAT GENERATION RATE		HEAT TRANSFER FROM SURFACES		HEAT STORED	RATIO	HEAT BALANCE
BTU/SEC		BTU/SEC		BTU/SEC		
2.4028E-01		-1.5692E-03		2.4156E-01	.001189	

POWER TRANSFERRED TO FLUID, MW

CHANNEL	WALL 1	WALL 2	TOTAL
1	3.332710E-04	0.	3.332710E-04
2	3.295659E-04	0.	3.295659E-04
SUM			6.628369E-04

05/04/70
RUN# 2

TIME=15.20.58

		TWALL TOSS	TWALL TRACK	ERROR	CONVERGED
1	1	564.62	564.48	.00024	0
1	3	585.77	584.43	.00228	0
1	6	615.60	612.48	.00508	0
1	17	631.59	625.69	.00934	0
2	1	547.28	547.28	.00000	0
2	3	556.18	555.88	.00054	0
2	6	568.69	567.90	.00138	0
2	17	575.39	573.74	.00286	0

THIS GROUP IS CONVERGED

DMPX.

P 032053 A0 000027 B0 000000
 RA 024100 A1 000001 B1 000171
 FL 350000 A2 031673 B2 030012
 EM 070000 A3 030012 B3 000171
 RE 000000 A4 023720 B4 000147
 FE 000000 A5 011416 B5 000001
 MA 000000 A6 000001 B6 000011
 A7 032572 B7 000001

C(A1)= 0102 2400 0000 0000 0000
 C(A2)= 0000 0000 0000 0000 0101
 C(A3)= 2401 2005 3444 0000 0000
 C(A4)= 0000 0000 0000 0000 0000
 C(A5)= 2025 1603 1000 0074 0035
 C(A6)= 0102 2400 0000 0000 0000
 C(A7)= 1116 2025 2400 0000 0000

C(B1)= 5160 0004 4051 5100
 C(B2)= 2401 2005 3444 0000
 C(B3)= 5160 0004 4051 5100
 C(B4)= 0420 0004 3576 6204
 C(B5)= 0102 2400 0000 0000
 C(B6)= 2401 2005 4100 0001
 C(B7)= 0102 2400 0000 0000

x0 7777 7777 7777 7700 0000
 x1 0000 0000 0000 0000 0000
 x2 0000 0000 0000 0000 0101
 x3 2401 2005 3444 0000 0000
 x4 0000 0000 0000 0000 0000
 x5 1523 0700 0000 0000 0000
 x6 0102 2400 0000 0000 0000
 x7 1116 2025 2400 0000 0000

118

00000 00000 00000 00000 00002
 00004 20251 60310 00000 11416
 00010 24012 00540 00000 07352
 00014 24012 00544 00000 16550
 00020 24012 00534 36000 22660
 00024 24012 00534 43000 26770
 00054 51300 00001 03130 00054
 00060 02300 00000 00000 00021
 00064 04251 51531 00000 00000
 00070 00000 00000 00000 00000
 00100 50000 00000 01000 05721

01022 40000 00000 00000
 24012 00535 00000 12440
 24012 00541 00000 10374
 24012 00534 33000 17572
 24012 00534 37000 23702
 24012 00534 44000 30012
 54110 63310 21144 73110
 11162 60114 11045 51726
 00000 00000 00001 66052

11162 02524 00000 07352
 24012 00536 00000 13462
 24012 00542 00000 11416
 24012 00534 34000 20614
 24012 00534 41000 24724
 00000 00000 00000 00000
 03010 00060 66320 56610
 05221 40131 46140 52605
 00335 11710 01041 41052

17252 42025 24000 1037
 24012 00537 00000 1450
 24012 00543 00000 1552
 24012 00534 35000 2163
 24012 00534 42000 2574
 54160 03110 00057 5476
 00000 00000 00000 0000
 00000 00000 60003 4376

31753 66130 01000 32231 46000
 31754 61200 00004 51100 32552
 31760 54777 54117 10711 54777
 31764 10711 71100 32274 20152
 31770 01000 32231 46000 46000
 31774 51200 31705 21236 46000
 32000 51600 32542 36741 54777
 32004 54677 61100 32523 46000
 32010 53217 46000 46000 46000
 32014 53430 74640 51600 32541
 32020 61100 00006 01000 32304
 32024 51100 32541 53210 46000
 32030 11050 20550 03100 32066
 32034 51100 31647 71700 02255
 32040 51260 31662 03020 32047
 32044 51100 32571 36717 46000

10711 74300 01000 32311
 51200 32545 03020 31774
 61100 00006 01000 32304
 51200 31705 43600 46000
 52327 77776 54117 53430
 54117 10711 74130 20152
 01000 32231 46000 46000
 21236 52327 77776 43006
 51100 32561 10711 54117
 54117 36716 54777 76700
 72327 77677 67337 46000
 03250 32066 46000 46000
 20160 20760 71501 52307
 37612 03060 32043 66667
 51700 32571 51100 31660

51600 31647 20630 46000
 51400 31656 01000 32162
 54777 20614 54117 36661
 51600 32545 51100 32540
 74640 51600 32541 10633
 61100 00006 01000 32304
 06300 32027 51100 32540
 20036 11230 20244 46000
 51700 32523 01000 32162
 54777 61100 32523 46000
 07370 32027 03330 32010
 01000 32205 46000 46000
 36671 51600 32571 46000
 04000 32040 46000 46000
 43752 11771 54777 46000

51700 32523 54117 3676
 54117 36741 54777 5411
 54677 61100 32523 4600
 63310 04000 32011 4600
 62347 77677 01000 3216
 54777 20614 54117 3666
 63310 51100 32541 4600
 72227 77770 03120 3202
 36741 54777 74130 2015
 01000 32231 46000 4600
 50500 32331 43022 2002
 01000 32112 46000 4600
 51100 31661 66600 4600
 51100 31657 10711 4600
 75167 20552 36615 4600

32050	56170	03110	32050	56670	71600	10224	20652	46000	56170	03110	32052	56670	00000	00000	46000	4600
32054	11770	13774	03070	31723	04000	31720	46000	46000	10622	51100	32535	46000	51600	32112	63210	4600
32060	71600	00104	71700	00014	01000	33311	46000	46000	51200	32112	26312	63730	01000	33356	46000	4600
32064	76000	61700	00001	46000	04000	32070	46000	46000	51200	32536	20501	74600	03250	32070	01000	3216
32070	20573	63320	21222	63220	21222	63120	51200	32537	74100	53020	21222	63720	03000	31705	52060	3233
32074	51200	31650	51400	32542	03350	32104	51500	32103	72700	00001	36757	46000	50757	77776	51500	3170
32100	21536	52557	77776	46000	52550	00001	10655	53600	00000	00000	00000	00000	46000	46000	04000	0000
32104	71600	32111	51500	32103	72700	00001	36757	20652	71500	00400	50757	77776	36656	20660	53600	4600
32110	04000	32102	46000	46000	61700	00001	04000	32032	04000	32034	00000	00000	46000	46000	46000	4600
32114	61700	00001	71500	00007	66570	56077	46000	46000	54200	54005	03020	32112	63220	56325	20314	4600
32120	03330	32134	43052	53320	15430	03040	32116	46000	71700	00010	01000	33311	66665	06600	32116	4600
32124	51200	33271	71500	00004	12625	53510	71400	00030	11345	37234	54620	46000	03120	32132	52310	0000
32130	52410	00003	13534	46000	03050	32116	46000	46000	01000	34063	46000	46000	04000	32116	46000	4600
32134	56420	20473	03340	32137	01000	32277	46000	46000	04000	32134	46000	46000	43063	22354	71600	0013
32140	71100	00774	11413	13416	03040	32116	76120	11303	36663	54640	71600	31417	20652	12661	46000	4600
32144	56450	03140	32144	56650	01000	32277	46000	46000	04000	32116	46000	46000	71200	32604	71601	5230
32150	56370	03130	32150	20652	03310	32226	15110	46000	03010	32227	36626	56670	53010	46000	46000	4600

15.10.28. KJW7205. ASP1004,KJW7,60,350000.02.
 15.10.28. KJW7205. AS00144.
 15.14.00. KJW7205. 60.
 15.10.28. KJW7205. REQUEST SELEC(WKMATL)
 15.14.04. KJW7205. REQUEST LIBR(WKPRO52,PROTK)
 15.14.05. KJW7205. (62 ASSIGNED)
 15.14.05. KJW7205. REQUEST TRACK (ABTR15,TRACK2,WITH,PLOT)
 15.14.06. KJW7205. (61 ASSIGNED)
 15.17.57. KJW7205. SELEC.
 15.18.05. KJW7205. STOP 7
 15.18.05. KJW7205. COPYBR(TRACK,DUMMY,41)
 15.18.12. KJW7205. COPYBF(MATL,DUMMY)
 15.18.13. KJW7205. DUMMY.
 15.18.18. KJW7205. MAXIMUM FL IF NO COMPILE **** 045700
 15.18.24. KJW7205. MAXIMUM FL IF NO COMPILE **** 153400
 15.18.30. KJW7205. MAXIMUM FL IF NO COMPILE **** 202000
 15.18.36. KJW7205. TRACK8
 15.18.36. KJW7205. TRUNCATED LABELLED COMMON BLOC KEYYEK
 15.18.45. KJW7205. MAXIMUM FL IF NO COMPILE **** 210400
 15.18.48. KJW7205. MAXIMUM FL IF NO COMPILE **** 205400
 15.18.59. KJW7205. MAXIMUM FL IF NO COMPILE **** 331500
 15.19.12. KJW7205. RUN 2.3 PROGRAM... MAIN
 15.24.05. KJW7205. FATAL ERROR 0065 INPUT
 15.24.08. KJW7205. CP 038.545 SEC.
 15.24.08. KJW7205. PP 264.859 SEC.
 18.20.12. 05/04/70 WEC SCOPE 3.2 SYSTEM (6416) 01/31/70