MISSILES AND SPACE DIVISION

LTV AEROSPACE CORPORATION

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TECHNICAL REPORT
NASA CONTRACT NAS9-2772

THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER - HOUSTON, TEXAS

COMPUTER PROGRAM FOR APOLLO FUEL CELL RADIATOR-CONDENSER COOLING SYSTEM ANALYSIS

Report No. 00.704
Revision A

17 December 1968

Original Report - 30 October 1965

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FOREWORD

This report describes the analytical methods and user's instructions for a generalized heat transfer and fluid flow computer program which is especially suited to performance predictions of the Apollo fuel cell radiator and condenser cooling system. The computer program was developed under NASA-MSC Crew Systems Division Contract NAS9-2772. Mr. D. W. Morris is the contract technical monitor. Mr. J. A. Raymer of the NASA-MSC Propulsion and Power Division provided the fuel cell cooling loop analysis requirements.

Revision A includes modifications which were added to the LVVM20 routine under Contract NAS9-6807, Task 3.4. The most significant addition was the fuel cell option which permits the analysis of an Apollo type fuel cell described in Section 3.6. Sections 4.10, 4.11, and 4.12 were also added. A revised data preparation manual is also included in Section 5.2.

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A	matrix of simultaneous equation coefficients, coefficient of flow rate
A_c	inside area of tube (cross-section)
A_e	tube lump external radiation area
A_{ec}	effective conduction area between fin and structure lumps
A_f, A_{HT}	area for fluid convective heat transfer to tube
A_{gr}	conduction area for fin base gradient
A_{LC}	tube lump longitudinal conduction area
A_n	eigenfunction coefficients
A_s	area for fin lump external radiation
A_t	tube lump external radiating area
a,b,c	quadratic equation solution terms
c	specific heat
c_p	constant pressure specific heat
c_s	specific heat of fin structure lump
c_t	specific heat of tube lump
D_h	hydraulic diameter
D	inside tube diameter
$\mathcal{D}$	diffusion coefficient
E	proportionality constant
F_1,F_2,F_3	factors
f	friction factor
Gr	Grashof Number
H	enthalpy
h_f	fluid heat transfer coefficient
$\mathcal{K}$	pressure loss factor

LIST OF SYMBOLS (Continued)

K	thermal conductivity and $\Delta P/\dot{w}$
K_m	mass transfer coefficient
K_f	fluid conductivity
K_j	thermal conductivity of adjacent lump j
K_t	thermal conductivity of tube lump t
L	radiator length;fin half width
ℓ	tube lump length
ℓ'	fluid lump length
N_b	base surface temperature parameter, $4\,K\,t\,L/\dot{w}\,c_p\,h_f$
N_c	fin conductance parameter, $\epsilon\sigma T_b^3\,L^2/K\delta$
N_{c_1}	fin conductance parameter based on fluid inlet temperature
WP	wetted perimeter of tube
P	gas pressure
p	gas component partial pressure
$\mathcal{P}$	pumping power
Pr	Prandtl Number
Q	fluid heat rejection
Q_E	heat absorbed from surrounding environment
Q_i	incident heat flux
Q_R	radiated heat flux
Q_S	heat stored in fin element
Q_t	incident heat flux on tube lumps
R	gas constant
Rev	special Reynolds Number $\frac{4\,\dot{w}_g}{(WP)\,\mu_L}\left[\frac{\rho_L}{\rho_g}\right]^{1/2}$

LIST OF SYMBOLS (Continued)

Re	Reynolds Number
St	Stanton Number
Sc	Schmidt Number
T	absolute temperature
T'	temperature at time $\tau + \Delta\tau$
T_b	fin base temperature
T_e	equivalent temperature of surrounding space
T_f	temperature of fluid at time τ
$T_{f_{in}}$	temperature of fluid at radiator inlet
$T_{f_{out}}$	temperature of fluid at radiator outlet
$T_{f'}$	temperature of fluid at time $\tau+\Delta\tau$
T_{fu}	upstream fluid temperature
T_s	temperature of fin or structure lump at time τ
T_s'	temperature of fin or structure lump at time $\tau+\Delta\tau$
T_t	temperature of tube lump at time τ
T_t'	temperature of tube lump at time $\tau+\Delta\tau$
U	liquid film conductance
U_{sj}	heat transfer conductance between fin or structure lump, s, and adjacent fin or structure lumps, j
U_{tj}	heat transfer conductance between tube lump, t, and adjacent fin and structure lumps, j
$\Delta \dot{w}_L$	condensation rate
w	mass of finite difference lumps
$\dot{w}$	fluid mass flow rate
w_s	fin or structure lump weight
w_t	tube lump weight
$\dot{w}'$	intermediate flow rate for balancing of pressure drop

LIST OF SYMBOLS (Continued)

$\dot{w}''$	flow rate for next iteration during balancing of pressure drop
χ	fraction of flow bypassed
x	distance from fin base, distance downstream of condensation origin
Δx	fluid lump length
X	dimensionless distance x/L, distance from tube entrance
Y_j	is the portion of the conductance path between lump s and j which lies in lump j
Y_t	that portion of the conduction path length between lump t and s which lies in lump t
α	tube to liquid cross-sectional area ratio
α_s	absorptivity of fin or structure lump for incident heat flux
α_t	absorptivity of tube lump for incident heat flux
β	matrix
δ	fin thickness
γ	fraction of fluid lump
$\Delta\tau$	time increment for next calculation
ΔP	pressure loss between inlet and outlet of radiator
$(\Delta P)_{avg}$	average pressure loss
ϵ_s	emissivity of fin or structure lump
ϵ_t	emissivity of tube lump
θ	T/T_b
θ	convergence factor
ϕ	pressure drop factor
χ_T	correlating parameters for turbulent two-phase flow
χ_L	correlating parameters for laminar two-phase flow
γ	fraction of length advanced by liquid in one increment
ψ	humidity ratio

LIST OF SYMBOLS (Continued)

λ_n	eigenvalue
λ	latent heat
θ_e	T_e/T_b
θ_r	$\frac{T \text{ at } X = 2L}{T \text{ at } X = 0}$
μ_b	viscosity evaluated at fluid bulk temperature
μ_w	viscosity evaluated at tube wall temperature
ρ	density
$(\rho_f)_{avg}$	average density
σ	Stefan-Boltzmann constant
τ	time variable

Subscripts

L,S	indicates liquid surface
g	indicates gas mixture
o	indicates non-condensible component
1, v	indicates vapor or condensible component

1.0 SUMMARY

This report presents analytical methods, user's instructions, and a sample problem for a generalized computer routine developed for the analysis of Apollo type fuel cell cooling loops. The routine methods are particularly suited to analysis of the fuel cell radiator, primary to secondary loop condenser, and associated flow loops and controls. The routine can be used for simultaneous performance predictions of the entire secondary cooling loop and the condenser portion of the primary loop. Although the routine version presented herein was developed for the Apollo fuel cell cooling system, the generalized data input allows application to a wide range of space radiator and flow system problems.

The generalized computer routine utilizes an explicit finite difference method to obtain steady state or transient heat transfer solutions. Thermal properties and dimensions are input directly without computing thermal capacitances or resistances. Multi-dimensional conduction heat transfer is easily accommodated by the generalized data input. Temperature dependent fluid and material properties are specified separately for each problem and any number of these properties can be used in any one problem. The external heat flux environment can also be specified separately for each subdivision of the thermal model.

The routine contains a flow system analysis capability which permits solution of any combination of parallel and series flow circuits, including manifolding, for incompressible laminar or turbulent fluid flow or for two-phase condensing flow with laminar liquid flow and laminar or turbulent gas. Various flow control options allow the system flow to (1) be balanced in parallel flow paths, (2) be independently specified in each flow path, or (3) be a function of the pump flow rate/pressure drop characteristics. Valve control options provide for use of rate and/or temperature dependent bypass, on-off, or proportional flow control valves in the fluid systems. The fluid systems may consist of an open or closed loop flow network. Fluid may also be stagnant or frozen in portions of the flow system. Three commonly applied methods are provided for specifying cooling loop heat exchanger heat transfer characteristics.

Two methods are provided for obtaining steady state thermal balances on space radiators. A simplified method provides for rapid analysis of radiators with simple rectangular radiating fins. A second method provides for steady state or transient solutions of radiators with more complex geometry. A special routine option provides for determination of equilibrium radiator inlet and outlet temperatures when only the radiator flow rate, heat load, and environment are specified.

The routine provides for interruption and restart of a problem to check answers during the initial phases of a long transient computation or to continue a problem taken off of the computer in a previous run. A detailed checkout print of all the thermal and flow terms is also provided as an option to examine details of the input.

This report describing the routine and its use is organized into four major sections. These include (1) Analytical Methods, (2) Special Routine Options, (3) Description and Use of the Computer Routine, and (4) Sample Problem. The report is written so that the program user may read through a narrative discussion of analytical procedures and options without numerous cross references to specifics in the data preparation. In the data preparation section, however, each input quantity carries a cross reference to the applicable analytical methods description. The analytical methods common to this and previous versions of the routine are described. The sample problem is a very simplified model of an Apollo fuel cell cooling loop for which the routine will initially be utilized.

2.0 INTRODUCTION

During the past two years LTV Astronautics has developed a generalized space radiator analysis computer routine for the Crew Systems Division of NASA-MSC. The original program capabilities and computing options have been broadened to provide a capability for analysis of complex space radiator configurations and entire fluid cooling loops. Several versions of the routine have been created to provide added capability for specific problems. Such special capabilities would make the routine too complex if included in all versions of the computer program.

This report describes a special version developed from requirements provided by the NASA-MSC Propulsion and Power Division for analysis of the Apollo fuel cell heat rejection system. The program includes two phase-two component flow analysis and multiple loop capabilities. The generalized nature of the program makes it suitable for much wider application than the Apollo fuel cell cooling system to which it will be applied initially.

3.0 ANALYTICAL METHODS

This section presents the methods employed in the computer routine for (1) thermal analysis, (2) convergence and accuracy of the analysis, (3) fluid heat transfer, (4) fluid flow analysis, and (5) two phase flow analysis. Each of these will be described fully in the paragraphs which follow.

3.1 Thermal Analysis

Two separate methods of thermal analysis were programmed as options of a single computer routine for predicting the performance of space radiators. The methods are referred to herein as the nodal and the gradient method of analyses. The nodal method provides for accurate transient or steady-state analyses of radiators with any geometrical configuration, and the gradient method provides for rapid steady-state analyses of radiators with simple rectangular fin elements. Both methods were developed for the analyses of prescribed radiator configurations.

The capabilities and underlying assumptions for both the nodal and the gradient method are outlined and the equations used for the thermal analysis of the radiator structure with each method are developed. Finally, a fluid element heat balance common to both methods is described.

3.1.1 Nodal Method - With this very accurate method of steady-state or transient thermal analysis, the differential equations which describe convective, conductive, and radiative heat transfer throughout the radiator are solved by a commonly used explicit finite difference approximation (reference 1). The radiator is divided into many individual lumps for the finite difference solution, and a capability is provided to analyze the following significant conditions which may occur in space radiators:

1. Different incident heat quantities for every tube and fin lump.
2. Three dimensional conduction in radiator fins, tubes, and supporting structure.
3. Dissimilar materials and surface coatings.
4. Temperature dependent material properties including surface emissivity and absorptivity.
5. Temperature dependent fluid thermodynamic properties.

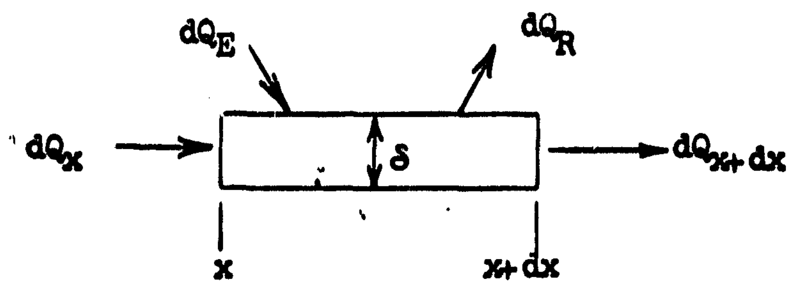
The following simplifying assumptions have been made for the nodal method of analysis:

1. The fluid thermodynamic properties are considered constant within each finite fluid element, but may vary between elements.
2. Cylindrical radiator surfaces are approximated by small rectangular segments.
3. Radiant interchange is not considered.

These assumptions are judged to have too small an effect in most environmental control system radiators to justify the added complexity of the analytical description required to include them.

The development of the equations used with the nodal method of analysis will first be illustrated by a one-dimensional heat balance on a typical radiating fin element. The resulting finite difference equation is easily extended to include two or three-dimensional conduction into the radiating fin element. A typical radiator tube element heat balance will also be shown, and will later be used to illustrate the differences between the nodal and gradient methods.

The heat balance of the radiating fin element of differential length and unit width shown below can be written as:



$$dQ_s = dQ_x + dQ_E - dQ_R - dQ_{x+dx} \tag{1}$$

where:

Q_s = heat stored in the fin element

Q_R = radiated heat flux

Q_E = heat absorbed from surrounding environment

δ = fin thickness

By use of the Fourier heat conduction law,

$$dQ_x - dQ_{x+dx} = \frac{\partial}{\partial x}\left(K \frac{\partial T}{\partial x}\right) \delta \, dx$$

where:

K = fin material thermal conductivity

Since K is a function of T only, $\frac{\partial K}{\partial x} = \frac{\partial K}{\partial T}\frac{\partial T}{\partial x} = \frac{dK}{dT} \cdot \frac{\partial T}{\partial x}$, thus

$$dQ_x - dQ_{x+dx} = K \delta \frac{\partial^2 T}{\partial x^2} \, dx + \delta \left(\frac{\partial T}{\partial x}\right)^2 \frac{dK}{dT} \, dx \tag{3}$$

Combining (3) and (1),

$$\rho c \delta \, dx \, \frac{\partial T}{\partial \tau} = \delta K \frac{\partial^2 T}{\partial x^2} \, dx + \delta \left(\frac{\partial T}{\partial x}\right)^2 \frac{dK}{dT} \, dx + \alpha Q_1 dx - \epsilon \sigma T^4 dx \tag{4}$$

where: ρ = fin material density

c = fin material specific heat

τ = time

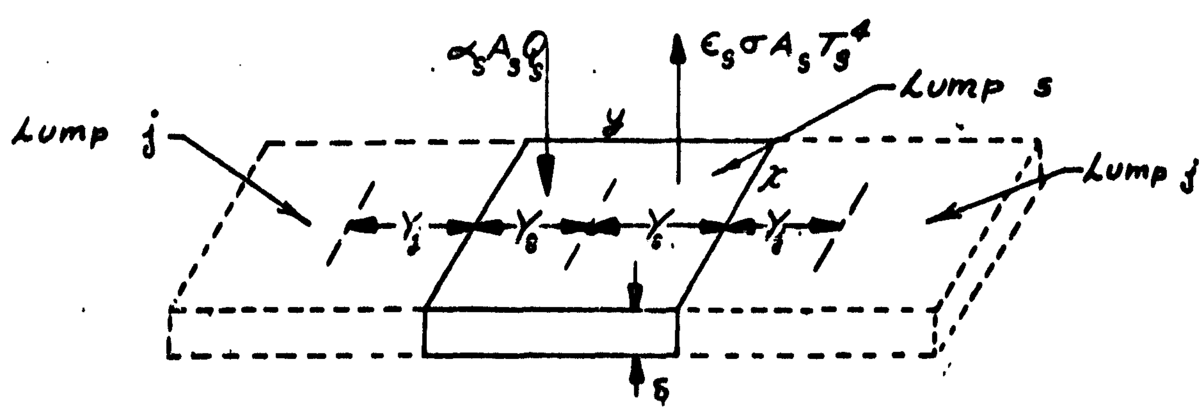
α = surface absorptivity for incident heat flux

Q_i = incident heat flux

ϵ = surface emissivity

σ = Stefan-Boltzmann constant

Since closed form solutions of equation (4) with the appropriate boundary conditions have not been obtained, numerical solutions using finite difference approximations are generally employed. The radiator structure is divided into lumps which are considered to be isothermal for heat capacitance effects, and which are considered to have temperatures located at their geometric centers (nodes) for conduction effects. The one-dimensional heat balance for a typical radiator fin lump, s, shown below, may be written in finite difference form as:



$$w_s\, c_s\, \frac{T_s' - T_s}{\Delta \tau} = \sum_j U_{sj}\,(T_j - T_s) + \alpha_s A_s Q_s - \epsilon_s \sigma A_s T_s^4 \quad (5)$$

Rearranging:

$$T_s' = T_s + \frac{\Delta \tau}{w_s\, c_s} \left[\sum_j U_{sj}(T_j - T_s) + \alpha_s A_s Q_s - \epsilon_s \sigma A_s T_s^4 \right] \quad (6)$$

where:

w_s = $x \cdot y \cdot \delta \cdot \rho$ = weight of fin lump (ρ is the density of the fin lump material)

c_s = specific heat of fin lump s

T_s = temperature of fin lump s at time τ

T_s' = temperature of fin lump s at time $\tau + \Delta\tau$

$\Delta\tau$ = time increment for next step in calculation as determined by convergence criteria (Appendix A)

U_{sj} = the conductance between fin or structure lump s and adjacent fin or structure lumps, j

$$U_{sj} = A_{ec}\left[\frac{1}{\frac{Y_s}{K_s} + \frac{Y_j}{K_j}}\right]$$

where:

Y_s is that portion of the conduction path length between lump s and j which lies in lump s

Y_j is that portion of the conduction path length between lump s and j which lies in lump j

A_{ec} is the effective conduction area between lumps s and j (i.e., $x \cdot \delta$ in figure above)

K_s is the thermal conductivity of lump s

K_j is the thermal conductivity of lump j

T_j = temperature of adjacent fin lumps at time τ

Q_s = incident heat flux on fin lump s

A_s = area of fin lump s (i.e., $x \cdot y$ in figure above)

α_s = absorptivity of fin lump s for incident heat flux

ϵ_s = emissivity of fin lump s

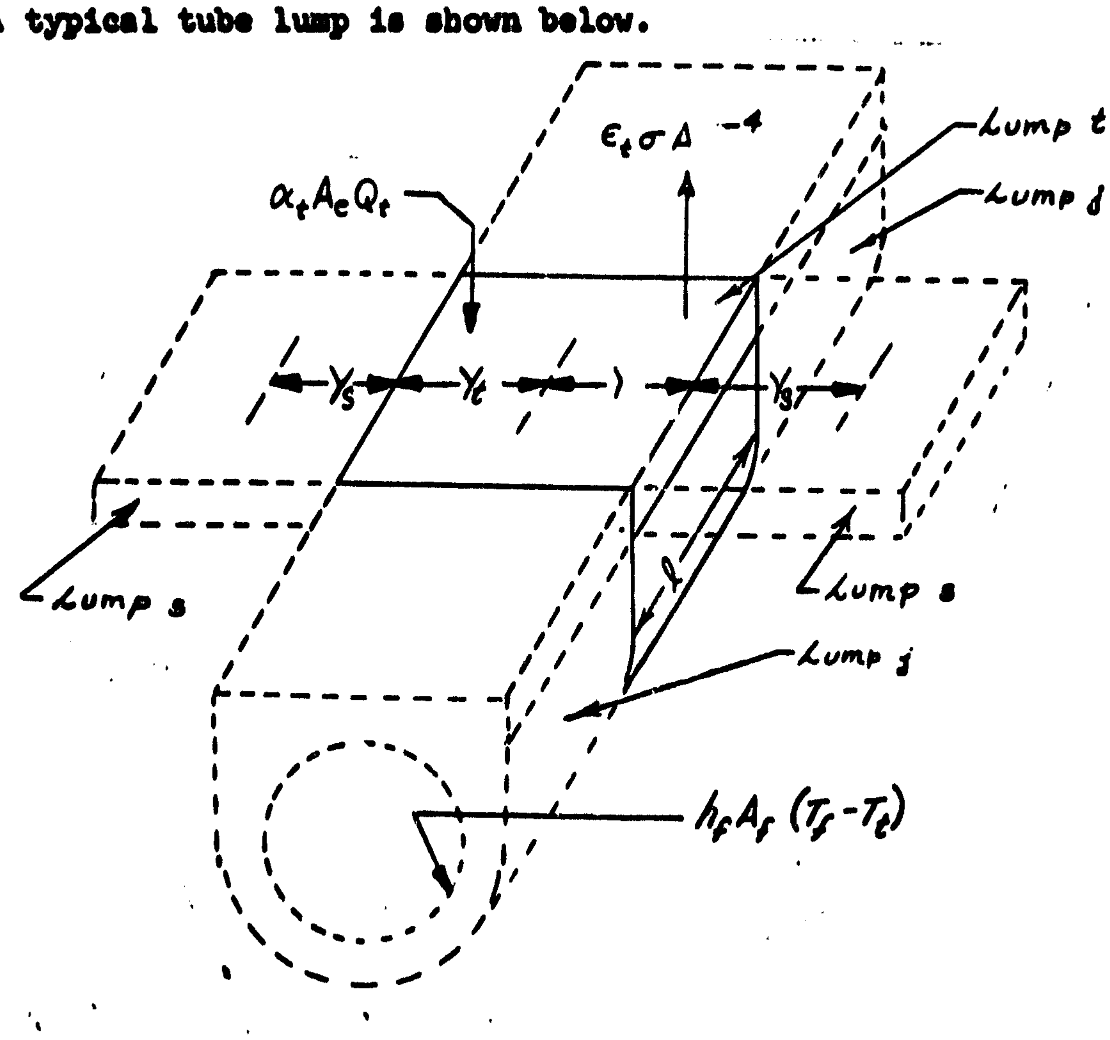
The finite difference heat balance of equation (5) is basically a "forward difference" heat balance (reference 1) chosen because it yields an explicit solution for the future temperature of fin lumps. The form of the thermal conductance, U_{sj}, with separate conduction distances and conductivities for adjacent lumps, serves a multiple purpose. First, since the conduction distances are separate, the size of adjacent lumps may be varied. Secondly, for comprehensive radiator thermal analyses which may include low conductivity supporting structure, the conduction paths in the different materials of adjacent lumps can be accurately described. Finally, the evaluation of conductivities at the different temperatures of adjacent lumps approximates the effect of the term $\delta\left(\frac{\partial T}{\partial x}\right)^2 \frac{dK}{dT}$ in equation (4). This approximate method of accounting for variable conductivity is judged to be as good as other methods where a single conductivity based on the average temperature of adjacent lumps is employed (reference 1).

The inclusion of variable material properties is not intended to remove large errors from steady-state space radiator analyses. A previous investigation (reference 2) can be used to show that the error in heat rejection incurred by use of constant material properties is less than 2% for the steady-state analysis of typical environmental control system radiating fin elements.

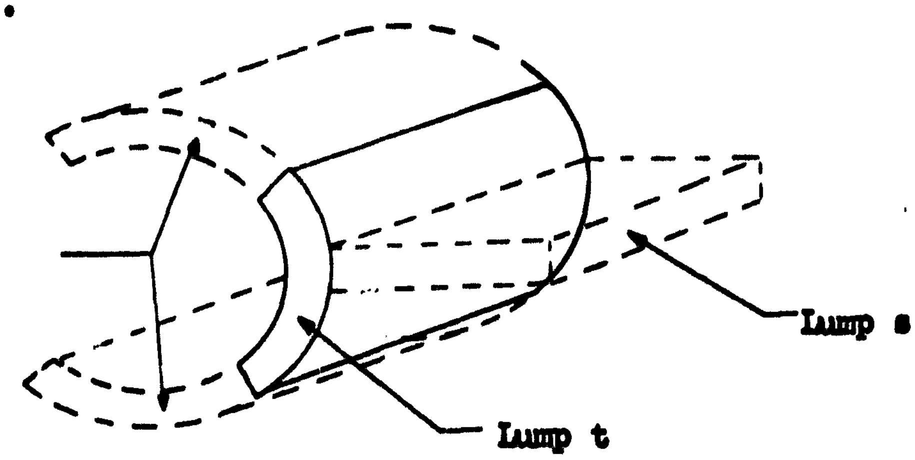
A somewhat larger error may be removed, however, by use of variable properties for transient radiator operating conditions.

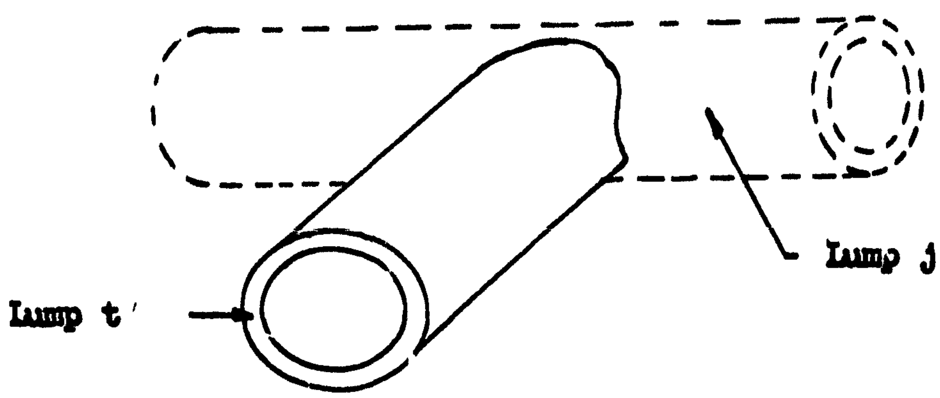
Although the heat balance of equation (5) is only for one-dimensional heat transfer, one, two, and even three-dimensional heat balances may be used in the radiator routine. To do this, the numbers of adjacent fin lumps and appropriate conduction distances (Y_s and Y_j) must be specified. Fin lump type numbers are used to describe each fin lump. Lumps having the same dimensions, conduction data, external radiation area and of the same material may be designated as a single "type". This format reduces the required data input for many problems. Radiator structural supports may be included in a thermal analysis by adding another type of fin lump or by specifying a constant temperature for those lumps representing boundary condition supports.

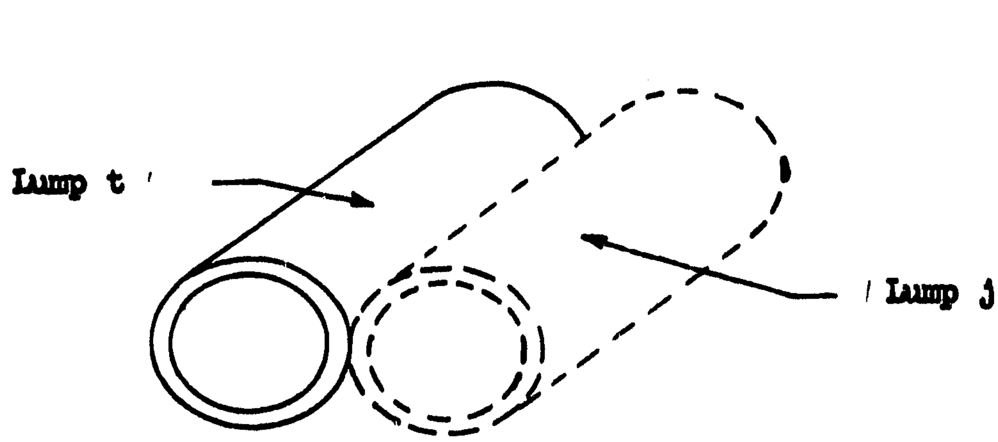
A typical tube lump is shown below.



Other types of tube lumps, in addition to isothermal lumps which completely enclose fluid lumps or lumps which only conduct longitudinally, can be accommodated in the computer routine. The three sketches below illustrate tube lumps used in peripheral subdivisions, tube junctions, and juxtapositioned tubes.







The finite difference heat balance for these lumps is:

$$w_t \, c_t \, \frac{T_{t'} - T_t}{\Delta \tau} = \sum_j U_{tj}(T_j - T_t) + \sum_s U_{ts}(T_s - T_t) + \alpha_t \, A_e \, Q_t - \epsilon_t \, \sigma A_e \, T_t^4 + h_f \, A_f \, (T_f - T_t) \qquad (7)$$

Rearranging:

$$T_t' = T_t + \frac{\Delta\tau}{w_t c_t} \left[\sum_j U_{tj}(T_j - T_t) + \sum_s U_{ts}(T_s - T_t) + \alpha_t \ A_e \ Q_t - \epsilon_t \sigma A_e T_t^4 + h_f' A_f (T_f - T_t) \right] \quad (8)$$

where:

$w_t = A_{LC} \cdot \ell \cdot \rho$ = tube lump weight, where:

A_{LC} = tube lump longitudinal conduction area (i.e., tube lump cross-sectional area)

ℓ = tube lump length

ρ = density of tube lump material

c_t = tube lump specific heat

T_t = temperature of tube lump at time

T_t' = temperature of tube lump at time $\tau + \Delta\tau$

$\Delta\tau$ = time increment for next step in calculation as determine by convergence criteria (Paragraph 3.2)

U_{tj} = the conductance between tube lump t and adjacent tube lumps j

$$= A_{ec} \left[\frac{1}{\frac{Y_t}{K_t} + \frac{Y_j}{K_j}} \right]$$

A_{ec} is the effective conduction area between tube lumps t and j
Y_t is that portion of the conduction path length between lump t and j which lies in lump t
Y_j is that portion of the conduction path length between lump t and j which lies in lump j
K_t is the thermal conductivity of tube lump t
K_j is the thermal conductivity of tube lump j

U_{ts} = the conductance between tube lump t, and adjacent fin or structure lumps, s

$$U_{ts} = A_{ec} \left[\frac{1}{\frac{Y_t}{K_t} + \frac{Y_s}{K_s}} \right]$$, where:

Y_t is that portion of the conduction path length between lump t and s which lies in lump t

Y_s is that portion of the conduction path length between lump t and s which lies in lump s

T_s = temperature of adjacent fin or structure lump s at time τ

Q_t = incident heat on tube lump, t

A_e = tube lump external area

α_t = absorptivity of lump t for incident heat flux

ϵ_t = emissivity of tube lump, t

h_f = fluid convective heat transfer coefficient

A_f = area for fluid convective heat transfer

T_f = fluid lump temperature at time τ

For the case where tube lump-to-tube lump conduction involves only upstream and downstream tube lumps, the term $\sum U_{tj}(T_j-T_t)$ in equation (7) was further expanded in terms of upstream and downstream tube lump values for use in the computer routine. The subscript tu refers to the upstream tube lump and td refers to the downstream tube lump.

$$\sum U_{tj}\,(T_j-T_t) = A_{LC}\left[\frac{1}{\frac{\ell/2}{K_{tu}}+\frac{\ell/2}{K_t}}\right](T_{tu}-T_t) + A_{LC}\left[\frac{1}{\frac{\ell/2}{K_{td}}+\frac{\ell/2}{K_t}}\right](T_{td}-T_t)$$

$$= \frac{2A_{LC}}{\ell}\left[\frac{(T_{tu}-T_t)\,K_{tu}\,K_t}{K_{tu}+K_t} - \frac{(T_t-T_{td})\,K_{td}\,K_t}{K_{td}+K_t}\right]$$

$$= \frac{2\,A_{LC}\,K_t}{\ell}\left[\frac{T_{tu}\,K_{tu}}{K_{tu}+K_t} + \frac{T_{td}\,K_{td}}{K_{td}+K_t} - T_t\left(\frac{K_{tu}}{K_{tu}+K_t} + \frac{K_{td}}{K_{td}+K_t}\right)\right] \tag{9}$$

The inclusion or omission of tube lump to tube lump longitudinal conduction was left as a program input option.

The tube lump characterization is completely general as a result of specifying a tube type number for each lump. Different lumps, having the same dimensions, conduction data, external radiation areas, and of the same material may be classed as a single "type" which is specified separately from the lump number.

A discussion of the convergence and accuracy criteria which determine the size of the time step that can be used for transient calculations and the size of the lumps into which the radiator must be divided is presented in Paragraph 3.2.

3.1.2 Gradient Method - This steady-state method of analysis was developed for rapid performance predictions of radiators with simple rectangular fin geometries. The computation and problem setup time required for this method are considerably less than for the nodal method because only the tubes and fluid are divided into isothermal lumps. The heat transferred from the tube lumps to the fins is determined from precalculated tabulations of fin base thermal gradients. These gradients differ from those used with common fin effectiveness radiator analyses because they apply for both adiabatic and non-adiabatic fin midpoints. The removal of the adiabatic midpoint requirement extends the usefulness of the gradient method to conditions where adjacent radiator tubes are at different temperatures as a result of being shut-off, being in different flow circuits, or because they are arranged in a counterflow pattern across the radiator skin. Severe variations of environmental heat influx which may also yield unequal fin base temperatures can be approximated in a step-wise fashion across the radiator.

The assumptions underlying the gradient method differ from those of the nodal method in the following respects:

1. Incident heat is assumed to be constant for an entire strip of fin between adjoining radiator tubes. As with the nodal method, a different incident heat may be used for each tube lump.

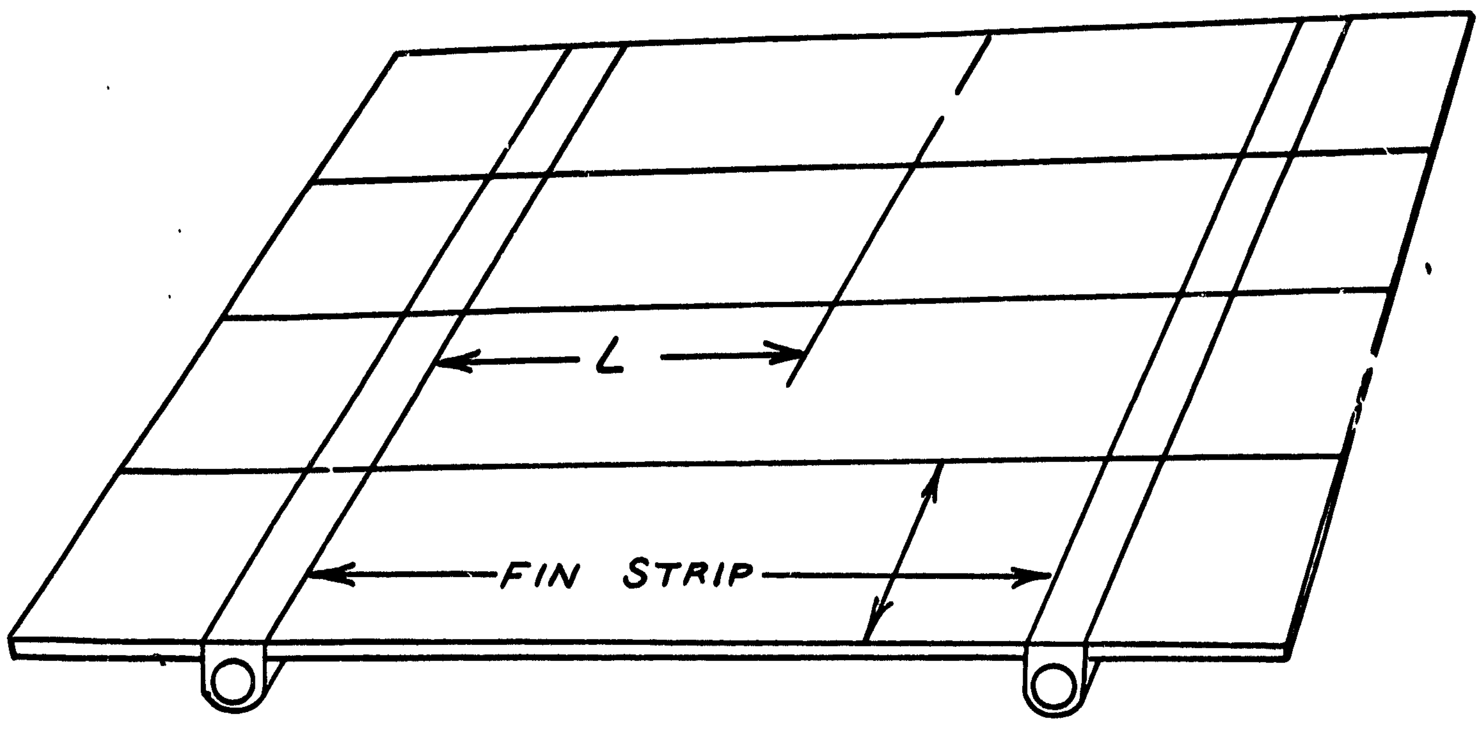
2. Fin heat conduction is assumed to be one dimensional, therefore longitudinal conduction in the fins is neglected. The conduction in the tubes is retained from the nodal method.

3. The material properties are assumed to be constant within each fin strip. However, for each fin strip, temperature dependent properties are a function of the fin base temperature or of the base temperature multiplied by a factor which the program user specifies.

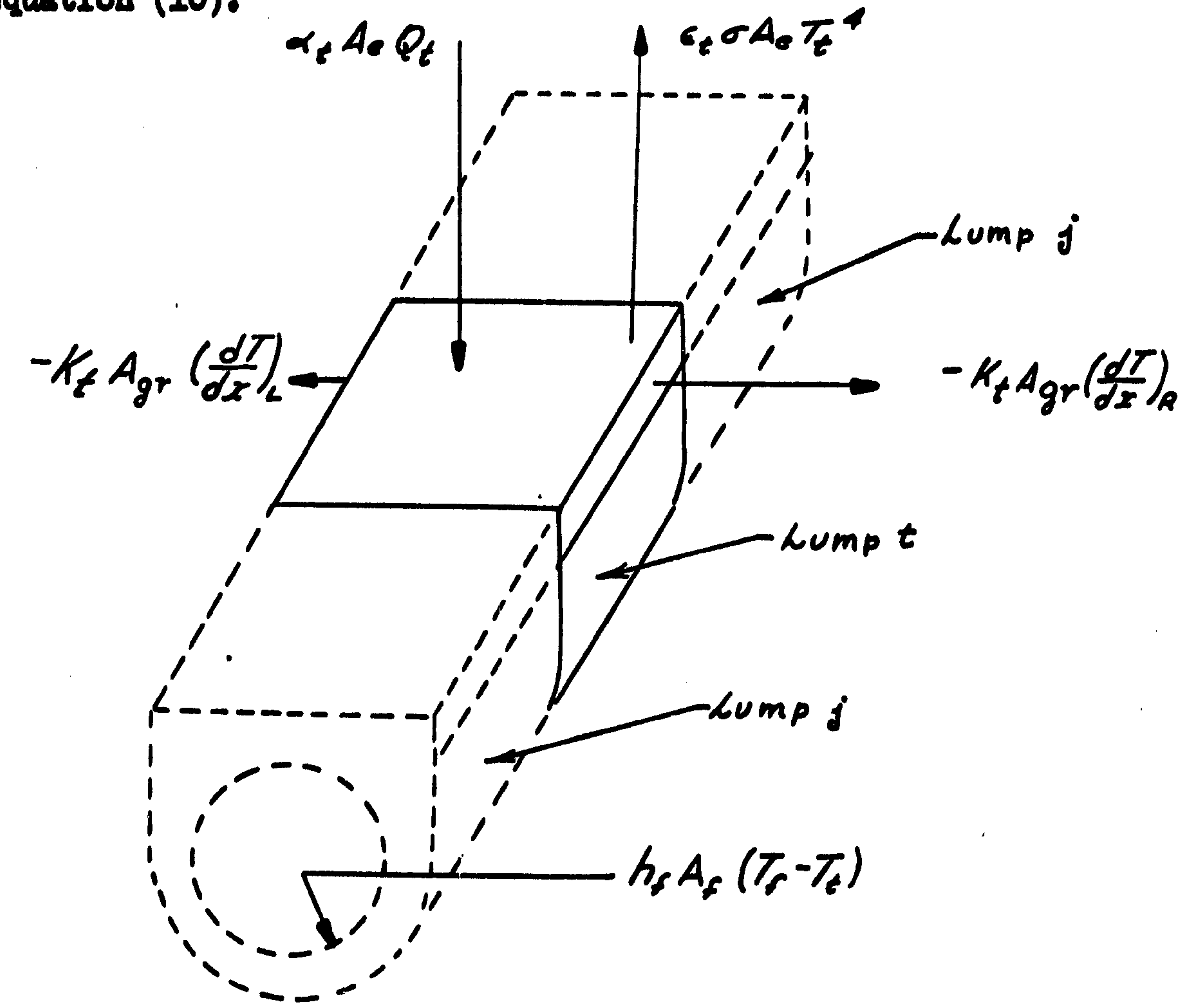
4. Temperature dependent fluid thermodynamic properties are used, and as with the nodal method, they are considered constant within each fluid element but variable between elements.

5. The radiator fins are assumed to be rectangular and of constant cross-section.

A typical radiator subdivision used with the gradient method is shown below. The radiator fins are divided into large non-isothermal strips, but the tubes and fluid are again divided into small isothermal lumps.



The finite difference heat balance of a typical tube lump shown below is given by equation (10).



$$T_t' = T_t + \frac{\Delta \tau}{w_t c_t} \left[\sum_j U_{tj}(T_j - T_t) + K_t A_{gr} \left(\frac{dT}{dx}_R + \frac{dT}{dx}_L \right) + \alpha_t A_e Q_t - \epsilon_t \sigma A_e T_t^4 + h_f A_f (T_f - T_t) \right] \quad (10)$$

where:

$\frac{dT}{dx}$ R & L = the fin base thermal gradients on the right and left side of the tube lump

A_{gr} = the cross-section area to be used with the fin base thermal gradients

As with the nodal method of solution, each tube lump may have different characteristics specified by the tube lump type number. Those lumps with the same dimensions and identical dimensions in adjoining fin structure may be classed as a single lump type.

Equation (10) differs from equation (8) only in that the conduction to the adjoining fins is now described by fin base thermal gradients to the left and right of the tube. These gradients are determined separately from parametric solutions of a fin heat transfer equation, and are not necessarily equal in magnitude.

Since heat conduction in the y coordinate direction between fin strips is assumed to be zero, the strips may be analyzed as separate rectangular radiating fins with different base temperatures and environmental influx values. For example, a different influx value for each of the 4 fin strips shown above may be used, if required, to approximate an actual variation of incident heat on the radiator surface.

The differential equation defining one-dimensional heat transfer in a simple rectangular radiating fin with constant influx has been established in the literature (references 3 and 4). The equation and nomenclature used herein are shown below.

$$\frac{d^2\theta}{dX^2} = N_c (\theta^4 - \theta_e^4) \quad (11)$$

$\theta = \frac{T}{T_b}$ where T is fin temperature, T_b is fin base temperature (i.e., T @ X = 0)

$\theta_e = \frac{T_e}{T_b}$ where T_e is the equivalent temperature of surrounding space

$X = \frac{x}{L}$ where x is distance from fin base, L is fin half width

$N_c = \frac{\sigma \epsilon T_b^3 L^2}{K \delta}$ where K is fin conductivity, δ is fin thickness

This equation has previously been solved for an adiabatic boundary condition at the fin midpoint. The resulting fin base thermal gradients were then non-dimensionalized on the basis of ideal heat rejection (i.e., heat rejection with the whole fin at the base temperature) to yield commonly used fin effectiveness values. For the gradient method of analysis, the fin base thermal gradients were calculated by numerical integration of equation (11) subject to boundary conditions of:

$$\theta = 1 \;@\; X = 0$$

$$\theta = \theta_r \;@\; X = 2$$

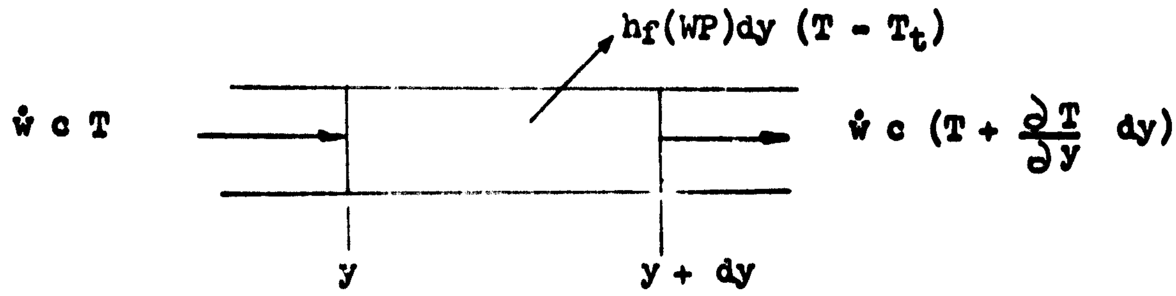
A Runge-Kutta numerical integration routine was used to determine $d\theta/dX$ at $X = 0$ for a range of θ_e, θ_r, and N_c values. The gradients were determined by assuming a value for $d\theta/dX$ at $X = 0$, integrating to $X = 2$, and comparing θ at $X = 2$ with the desired value of θ_r. The value of $d\theta/dX$ at $X = 0$ which matched θ_r was obtained by successive iteration. The iterated solution to the equation yields gradients at both ends of the fin, but only the gradient at $X = 0$ was retained. The integration interval used between $X = 0$ and $X = 2$ was .025.

The fin effectiveness gradients result for $\theta_r = 1.0$. The other θ_r values, in addition to $\theta_r = 1.0$, yield a more general set of solutions which apply for both adiabatic and non-adiabatic fin midpoint conditions. Figures A1 through A3 of Appendix A show the variation of the non-dimensional fin base gradient with N_c, θ_r, and θ_e. For very low N_c values and high temperatures at $X = 2$ (for example $N_c = .10$, $\theta_r = 1.50$), heat will flow into the tube to which the fin is attached rather than from the tube to the fin as is normally the case. For a typical $N_c = .50$ and a severe θ_r of .60 or 1.50, the fin base gradient varies about 30 percent from the adiabatic midpoint value. Thus the use of the more general gradients can remove considerable inaccuracy by accounting for heat flow across the fin midpoint.

Table A1 of Appendix A lists the gradient values which have been generated to date. These values are used as curve data since it is not necessary to generate them specifically for each problem. Gradient values outside of the parameter range of Table A1 may be generated with a numerical integration subroutine which is part of the program source deck. Since a large number of gradient values have already been determined, it is recommended that only new values be computed on a program run, and that these values be added to the existing set as expanded curve data for a separate radiator problem run.

3.1.3 Fluid Heat Balance

The energy balance on the fluid which flows through a tube lump is common to both methods of solution. The energy balance is given by equation (12) for the differential fluid element shown below.



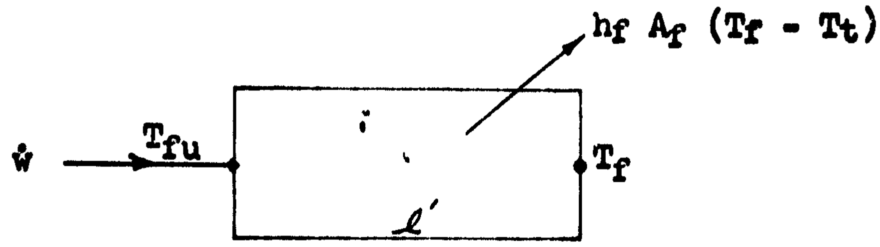
$$\rho c\ A_c\ dy \frac{\partial T}{\partial \tau} = \dot{w}\ c\ T - \dot{w}\ c\ (T + \frac{\partial T}{\partial y}\ dy) - h_f(WP)\ dy\ (T - T_t) \qquad (12)$$

where:

ρ = fluid density
A_c = fluid cross-section area
τ = time
$\dot{w}$ = mass flow rate
c = fluid specific heat
h_f = fluid convective heat transfer coefficient
WP = tube wetted perimeter
T_t = tube temperature

The fluid temperature is taken as the mixed mean temperature, the fluid specific heat and density are assumed to be constant, and the fluid conduction in the y direction is neglected in equation (12).

The finite difference fluid energy balance is given in equation (13).



$$w_f c_f \frac{T_f' - T_f}{\Delta \tau} = \dot{w}\ c_f\ (T_{fu} - T_f) - h_f\ A_f\ (T_f - T_t) \qquad (13)$$

thus

$$T_f' = T_f + \frac{\Delta \tau}{w_f c_f} \left[\dot{w}\ c_f\ (T_{fu} - T_f) - h_f\ A_f\ (T_f - T_t) \right] \qquad (14)$$

where

W_f = weight of fluid in lump f = A_c (ℓ') (ρ) where ρ is the fluid density and ℓ' is the fluid lump length
c_f = specific heat of fluid in lump f
T_f = temperature of fluid at time τ
T_f' = temperature of fluid at time $\tau + \Delta\tau$
$\Delta\tau$ = time increment for next calculation step as determined from convergence criteria (paragraph 3.2)
$\dot{w}$ = fluid flow rate
T_{fu} = upstream fluid lump temperature
h_f = fluid convective heat transfer coefficient
A_f = area for convective heat transfer
T_t = temperature of tube lump which encloses fluid lump

Equation (13) is a frequently used approximate equation (Reference 1) which yields an explicit solution for T_f'. It involves the approximation that the fluid capacitance effect is based on the outlet fluid temperature of the tube length ℓ'. In writing equation (13), an isothermal tube wall is also assumed so the temperature T_t is not located at a node at a finite depth in the tube lump.

The fluid temperature, T_f, in the term $h_f A_f (T_f - T_t)$ of equations (7) and (13) can be more accurately represented by $(T_{fu} + T_f)/2$. However, use of this latter form in equation (13) also imposes an additional convergence criteria (see paragraph 3.2) which restricts A_f of the fluid lump. Since this size limitation is not a practical requirement for all radiator analyses, because A_f will have to be very small for low flow rates, the use of either $(T_{fu} + T_f)/2$ of T_f was left as a routine option.

The variation of the fluid properties with temperature is approximated by using properties in equation (13) which correspond to the temperatures of the different fluid lumps.

3.1.4 Calculation of Heat Rejection

The total radiator heat rejection is determined by summing up fluid heat losses in each tube. The individual tube heat losses are computed from:

$$Q = \dot{w} (H_{in} - H_{out}) \qquad (15)$$

where:

Q = fluid heat rejection
H_{in} = enthalpy of fluid at radiator tube inlet
H_{out} = enthalpy of fluid at radiator tube outlet

The program user supplies a curve of fluid specific heat versus temperature. This data is integrated by a trapezoidal integration method within the routine to provide an enthalpy versus temperature curve.

3.2 CONVERGENCE AND ACCURACY CRITERIA

The heat transfer equations used in the computer routine described herein are based on an explicit method of finite difference solution. With this method, the future temperatures of any radiator fluid, tube, or structural lump are evaluated from the present temperature of surrounding lumps and the thermal environment. The validity of this type of solution depends on satisfying criteria for stability, oscillation, and truncation error minimization. A discussion of these criteria and a review of the literature are presented by Clark (Reference 5). Chu (Reference 6) also discusses convergence criteria in the report on the basic routine from which the radiator analysis routine was derived. The pertinent points from both references are outlined below.

3.2.1 Stability

The term stability usually refers to errors in equation solution that progressively increase or accumulate as the calculations proceed. After a review of the literature, Clark concludes any explicit forward difference equation will yield stable results for the future temperAtures of any lump if the coefficients of the present lump temperature are at least zero or have the same sign as the other coefficients of known temperatures. Chu (Reference 6) also bases his convergence proof on the condition that the coefficient of the present lump temperature be of the same sign as other coefficients of other known temperatures. This stability criterion defines the size of the time step to be used with the basic equations. The equations used in the space radiator routine for both techniques are rearranged below to show the development of the stability requirement.

<u>Nodal Technique - Equation (5) for Fin or Structure Lumps</u>

$$w_s c_s \frac{(T_s' - T_s)}{\Delta\tau} = \sum_j U_{sj}(T_j - T_s) + \alpha_s A_s Q_s - \epsilon_s \sigma T_s^4 A_s$$

Rearranging,

$$T_s' = \frac{\Delta\tau}{w_s c_s}\left[\sum_j U_{sj} T_j + \alpha_s A_s Q_s\right] + T_s\left[1 - \frac{\Delta\tau}{w_s c_s}\left(\sum_j U_{sj} + \epsilon_s \sigma T_s^3 A_s\right)\right]$$

For the coefficient of T_s to be positive,

$$\Delta\tau = \frac{\theta\, w_s c_s}{\sum_j U_{sj} + \epsilon_s \sigma T_s^3 A_s} \quad \text{where } \theta = \text{convergence factor} \le 1.0 \qquad (16)$$

Nodal Technique - Equation (7) for Tube Lumps

$$w_t c_t \frac{(T_t' - T_t)}{\Delta\tau} = \sum_j U_{tj}(T_j - T_t) + \sum_s U_{ts}(T_s - T_t) + \alpha_t A_e Q_t - \epsilon_t \sigma A_e T_t^4 + h_f A_f(T_f - T_t)$$

Rearranging,

$$T_t' = \frac{\Delta\tau}{w_t c_t}\left[\sum_j U_{tj} T_j + \sum_s U_{ts} T_s + \alpha_t A_e Q_t + h_f A_f T_f\right] + T_t \left[1 - \frac{\Delta\tau}{w_t c_t}\left(\sum_j U_{tj} + \sum_s U_{ts} + \epsilon_t \sigma A_e T_t^3 + h_f A_f\right)\right]$$

For the coefficient of T_t to be positive,

$$\Delta\tau = \frac{\theta\, w_t c_t}{\sum_j U_{tj} + \sum_s U_{ts} + \epsilon_t \sigma A_e T_t^3 + h_f A_f} \quad \text{where } \theta < 1.0 \qquad (17)$$

From the development above, it is evident that the use of $(T_{fu} + T_f)/2$ instead of T_f in the convective heat transfer term will not affect the convergence expression for $\Delta\tau$ because the coefficient of T_t is unchanged. Similarly, the $\Delta\tau$ convergence expression is the same for equation (10) of the gradient technique because it only involves substitution of the term $K_t A_{gr}\left[\frac{dT}{dx_R} + \frac{dT}{dx_L}\right]$ for the term $\sum U_{ts}(T_s - T_t)$ in equation (7).

Fluid Lump - Nodal and Gradient Techniques - Equation (13)

$$w_f c_f \frac{(T_f' - T_f)}{\Delta\tau} = \dot{w} c_f (T_{fu} - T_f) - h_f A_f (T_f - T_t)$$

Rearranging,

$$T_f' = \frac{\Delta\tau}{w_f c_f}\left[\dot{w} c_f T_{fu} + h_f A_f T_t\right] + T_f\left[1 - \frac{\Delta\tau}{w_f \cdot c_f}(\dot{w} c_f + h_f A_f)\right]$$

For the coefficient of the T_f to be positive,

$$\Delta\tau = \frac{\theta\, w_f c_f}{\dot{w} c_f + h_f A_f} \quad \text{where } \theta < 1.0 \qquad (18)$$

If T_f is replaced by $(T_{fu} + T_f)/2$ in the convective heat transfer term for greater solution accuracy, the convergence criteria for $\Delta\tau$ changes, and another limitation on the size of the fluid lump is required, as shown below.

$$w_f c_f \frac{(T_f' - T_f)}{\Delta\tau} = \dot{w} c_f (T_{fu} - T_f) - h_f A_f \left(\frac{T_{fu} + T_f}{2} - T_t\right)$$

Rearranging,

$$T_f' = \frac{\Delta\tau T_t}{w_f c_f}(h_f A_f) + T_{fu} \frac{\Delta\tau}{w_f c_f} \left(\dot{w} c_f - \frac{h_f A_f}{2}\right) +$$

$$T_f \left[1 - \frac{\Delta\tau}{w_f c_f} \left(\dot{w} c_f + \frac{h_f A_f}{2}\right)\right]$$

For the coefficient of T_f to be positive,

$$\Delta\tau = \frac{\theta w_f c_f}{\dot{w} c_f + \frac{h_f A_f}{2}} \quad \text{where } \theta < 1.0 \tag{19}$$

Furthermore, for the coefficient of T_{fu} to be positive,

$$\frac{h_f A_f}{2} \leq \dot{w} c_f$$

or

$$A_f \leq \frac{2 \dot{w} c_f}{h_f} \tag{20}$$

This places a restriction on the size of the fluid lump to be used in the radiator routine. Since it may not be practical to meet this restriction for all radiator problems, the use of averaged fluid temperatures is left as a program option.

During nodal problem solution, time increments for fin lumps, tube lumps, and fluid lumps are computed with the equations given above and the smallest of the three time increments is used for all T' calculations. In a gradient problem solution, the smaller of the time increments for the fluid and tube lumps is used. The routine uses a θ of 0.90 unless otherwise specified.

3.2.2 Oscillation

Even though a solution is stable, it may oscillate around a correct mean value. To eliminate this undesirable oscillation, Clark (reference 5) recommends that the calculation time increment based on the stability criterion be further reduced by a factor of 1.5. It should be noted that this reduction may not suffice for all cases since the oscillation depends strongly on the size of space increment and the problem boundary conditions. In setting up the basic routine from which this space radiator routine was derived, Chu used a factor 1.11. The space radiator routine will also employ this factor unless otherwise specified by the program user.

3.2.3 Truncation Error

The truncation error in the routine solution results from replacing derivatives with finite differences. In order to provide a measure of the accumulated truncation error, results for smaller time and space increments (subject to stability and oscillation criteria) should be compared. Chu recommends halving the space increment and quartering the time increment to obtain an estimate of the error in a numerical result. In general, an investigation of truncation error must be made by changing lump sizes for each type of problem to determine the maximum size of isothermal lumps that can be used for a valid solution.

The truncation error has been shown to be of the form A + B, (Reference 5) where A is proportional to the time increment and B is proportional to the square of the lump linear dimension. LTV experience indicates that time truncation error (A) is relatively small ($\approx$3 percent) if the time increment satisfies the stability criteria. The spatial truncation error (B) can be evaluated at steady state. For typical radiators and segments of radiators, changing the number of lumps along the length of the tube from 20 to 10 causes less than 0.2 percent difference in heat rejection (Reference 7). Further reduction to 5 lumps along the tube in the analysis of large radiators also appears to have only a slight effect, but no direct comparison is available. A comparison of two and four fin lumps between tubes in the analysis of large radiators with high fin effectiveness shows about a 2 percent difference in heat rejection, even though the fin temperatures are considerably different. These results are subject to variation due to radiator design differences.

3.2.4 Steady State Shutdown and Jump Ahead

Since the computer routine uses a transient approach to steady state conditions, a shutdown criteria indicating that steady state has been reached must be specified to terminate a run. Experience gained during the program showed that most problem solutions have reached steady state when the temperature change of every lump between successive calculations for T' was less than .0001 to .001 percent of the lump absolute temperature. However, since the temperature change between successive calculations is a function of the minimum time step for convergence, which is in turn a function of lump size, it was decided to allow the program user to specify the steady state shutdown as part of the routine data input.

When transient problems are being considered, equilibrium conditions may also be achieved at intermittant points (such as on the dark side of the moon in a lunar orbit analysis). To conserve transient analysis computer time the criteria for steady state conditions is considered at every iteration. When every temperature satisfies the input criteria a transient problem will be considered at steady state. In such an event the iteration process is terminated and problem time is jumped ahead to the next point at which any time-dependent curve change occurs whereupon iterations are continued. This option permits exclusion of long periods of calculation in mission analysis where the system is at steady state, thus shortening calculation time. The option can also be utilized to analyze several successive steady state conditions in one submission of transient data since the problem will jump ahead after reaching equilibrium at each intermittant condition.

3.3 FLUID HEAT TRANSFER COEFFICIENT

Commonly used equations for determining both laminar and turbulent flow heat transfer coefficients were programmed in the computer routine. An investigation of the basis for laminar flow heat transfer coefficient equations was undertaken since a majority of space radiator flow conditions are in the laminar regime. It was found that both experimental correlations and theoretical equations for laminar flow heat transfer coefficients can only be applied with considerable approximation to the flow conditions in space radiators. It was decided therefore to let the program user specify a factor in the data input which modifies the heat transfer coefficients determined by the equations within the routine. This provision not only permits studies of the effect of heat transfer coefficient variations, but also provides a method for specifying non-circular duct coefficients. The performance of space radiators is not directly proportional to changes of fluid heat transfer coefficient. In general, if the path between a radiator fluid temperature and an equivalent temperature of space is characterized by the resistance of an internal heat transfer coefficient and the resistance of a radiating fin, the former will be found to be quite small compared to the latter. Thus, appreciable changes in fluid heat transfer coefficient may affect the net radiator heat rejection by only a small degree. This fact, however, does not permit gross errors in heat transfer coefficients if accurate radiator performance predictions are expected.

3.3.1 Laminar Flow

Both the thermal entry length and the fully developed flow regimes must be considered to properly evaluate a laminar flow heat transfer coefficient. The thermal entry length region is usually considered to include those values of $(1/\mathrm{Re\ Pr})(x/D_h)$ below .050. The portion of total radiator length in the thermal entry region may vary from the entire radiator length for higher fluid flow rates and higher fluid temperatures to only a small percentage of the total length for radiators with low flow rates and low fluid temperatures.

The theoretical solutions which have been obtained for thermal entry lengths are frequently based on boundary conditions of either constant tube wall surface temperature or constant heat rate per unit of tube length. These solutions are also formulated under the assumptions of constant fluid properties and symmetrical heat transfer around the tube periphery. In addition, many of the solutions only apply rigorously if a hydrodynamic starting length is provided because the flow is considered to be isothermal with a fully established velocity profile at the tube entrance. Results are shown in Figure 1 for both local and mean Nusselt Numbers obtained by the Graetz solution for circular tubes with uniform surface temperature under the assumptions outlined above (Reference 8).

The solutions exhibit an asymptotic approach to a fully developed flow Nusselt Number of 3.66. The local Nusselt Number has reached the fully developed flow value for $(\mathrm{Re\ Pr})\ (D_h/X) < 20$. The local Nusselt Number is employed to arrive at local heat transfer coefficients for the tube lump heat balances in the computer routine, whereas mean Nusselt Numbers are commonly used for overall heat exchanger calculations.

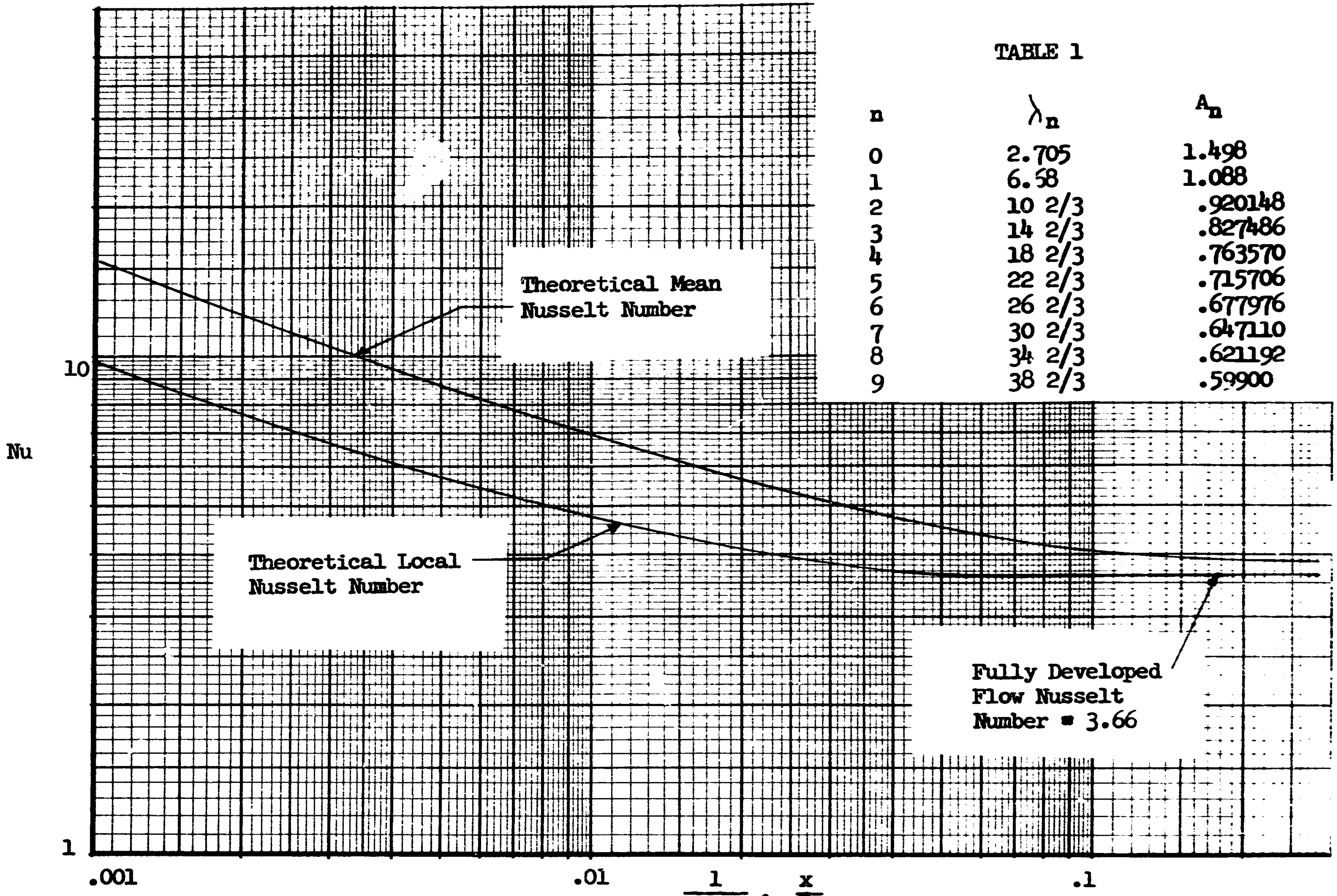


TABLE 1

n	λ_n	A_n
0	2.705	1.498
1	6.58	1.088
2	10 2/3	.920148
3	14 2/3	.827486
4	18 2/3	.763570
5	22 2/3	.715706
6	26 2/3	.677976
7	30 2/3	.647110
8	34 2/3	.621192
9	38 2/3	.59900

$\frac{1}{Re\ Pr} \cdot \frac{x}{D_h}$

FIGURE 1

COMPARISON OF CIRCULAR TUBE LAMINAR FLOW NUSSELT NUMBERS
FOR CONSTANT WALL TEMPERATURE

The use of theoretical solutions based on the assumptions of constant fluid properties can introduce errors for fluids where viscosity is a strong function of temperature. Yang (Reference 8a) and Deissler (Reference 9), among others, have considered the effects of variable properties on fully developed and thermal entry length solutions. The Nusselt Numbers, in general, fall below the constant property solutions for cooling and above the constant property solutions for heating. The effects of variable viscosity reported by Yang for uniform wall temperature can be approximated by multiplying the constant property Nusselt Number by $(\mu_b/\mu_w)^{0.11}$ (where μ_b is fluid viscosity evaluated at fluid bulk temperature and μ_w is fluid viscosity evaluated at tube wall temperature) for both heating and cooling conditions. Deissler (Reference 9) recommends use of the empirical correction of $(\mu_b/\mu_w)^{.14}$ for fully developed constant heat rate solutions.

The analyses of References 8 and 9, like most other theoretical solutions, were derived for conditions of symmetrical heating or cooling (i.e., the derivative of temperature with respect to tube radius is zero at the tube centerline). Reynolds (Reference 10) has shown the type of variations in Nusselt Number which can be encountered for non-uniform peripheral heat flux. For thin-walled tubes attached to the backside of radiating surfaces, theoretical equations derived for symmetrical heating must be regarded as approximate for predicting heat transfer coefficients.

The analytical solution of Graetz which was extended in Reference (8) is programmed to determine heat transfer coefficients in the laminar entry length region. The coefficient approaches the appropriate steady state value as large lengths ($\ell >$ Re Pr $D_h/20$) are attained, thus the equation is also used for fully developed heat transfer. The equation is:

$$h_f = \frac{K_f}{2D_h} \frac{\sum A_n \, e^{\frac{-2\lambda_n^2 X}{Re\,Pr\,D_h}}}{\sum \left[\frac{A_n}{\lambda_n^2}\right] e^{\frac{-2\lambda_n^2 X}{Re\,Pr\,D_h}}} \left[\frac{\mu_b}{\mu_w}\right]^{.14} (F_1) \qquad (16)$$

where:

h_f	=	convective heat transfer coefficient	
K_f	=	fluid conductivity	
D_h	=	tube hydraulic diameter	
A_n	=	coefficients eigenfunctions	(Table 1)
λ_n	=	eigenvalues	(Table 1)
X	=	distance from tube entrance	
Re	=	Reynolds Number	
Pr	=	Prandtl Number	
μ_b	=	fluid viscosity evaluated at fluid bulk temperature	
μ_w	=	fluid viscosity evaluated at tube wall temperature	
F_1	=	data input factor	

In selecting the heat transfer coefficient factor (F_1) it should be remembered that a Nusselt Number of 3.66 applies for

1. Constant wall temperature boundary condition.
2. Circular ducts.

The constant wall temperature value is pessimistic since the actual radiator Nusselt Number will probably lie between the constant wall temperature solution of 3.66 and the constant heat rate value of 4.36. The circular duct value of 3.66 should be appropriately modified by (F_1) for non-circular tube configurations.

The entry length heat transfer coefficients are considered at the entrance of each tube in complex flow systems such as those which will be discussed in paragraph 3.4.3.

3.3.2 Turbulent Flow

A commonly used equation for turbulent heat transfer coefficients was programmed directly without a detailed investigation of the underlying assumptions. The correlation of equation (17), recommended in Reference 11, is used to determine heat transfer coefficients at Reynolds Numbers greater than 2000.

$$h_f = .023 \frac{K_f}{D_h} \left[\frac{\mu_b}{\mu_w}\right]^{.14} (Re)^{.8} (Pr)^{1/3} \qquad (17)$$

where:

h_f = convective heat transfer coefficient
K_f = fluid conductivity
D_h = tube diameter
μ_b = fluid viscosity evaluated at fluid bulk temperature
μ_w = fluid viscosity evaluated at tube wall temperature
Re = Reynolds Number
Pr = Prandtl Number

In turbulent flow the undeveloped region of heat transfer is short ($\approx$ 4 diameters) such that for most cases it will constitute only a small portion of the total internal heat transfer region.

3.4 FLOW SYSTEM ANALYSIS

This section includes a description of the methods used for (1) computing incompressible fluid pressure losses, (2) analyzing simple flow systems with tubes in parallel, (3) analyzing complex parallel/series systems with manifolding, (4) analyzing flow rate as a function of pressure loss, and (5) computing pumping power. The description of pressure loss calculations for two-phase flow is given in paragraph 3.5.1. For all systems involving parallel flow paths, the flow rates which give balanced system pressures are determined after each temperature iteration and these flow rate values are used in the thermal calculations for the next temperature iteration.

3.4.1 Fluid Pressure Loss

The flow system pressure loss for those portions of the system involving single phase incompressible fluids is calculated by the usual Fanning equation with a dynamic head loss factor ($\mathcal{K}$) added. The pressure loss for each fluid lump is calculated by:

$$\Delta P = 4 f \frac{\ell'}{D_h} \frac{\rho V^2}{2} + \mathcal{K} \frac{\rho V^2}{2} = \frac{\dot{w}^2}{2 \rho A_c^2} \left[\frac{f (WP) \ell'}{A_c} + \mathcal{K} \right] \quad (18)$$

where

f = friction factor = 16/Re for Reynolds Numbers less that 2000 and is read from input data for Reynolds Numbers greater than 2000

ℓ' = fluid lump length

$\mathcal{K}$ = number of fluid dynamic head losses

$\dot{w}$ = tube fluid flow rate

WP = wetted perimeter

A_c = fluid cross-section area

D_h = tube hydraulic diameter = 4 A_c/WP

ρ = fluid density

V = fluid velocity

Two additional terms F_2 and $(\mu_b/\mu_w)^{-.14}$ were added to equation (18) to account for non-circular ducts and non-isothermal flow:

$$\Delta P = \frac{\dot{w}^2}{2 A_c^2 \rho} \left[\frac{f (WP) \ell' F_2 (\mu_b/\mu_w)^{-.14}}{A_c} + \mathcal{K} \right] \quad (19)$$

where:

F_2 = pressure loss factor for non-circular ducts, is 1.0 for circular ducts

μ_b = fluid viscosity evaluated at fluid bulk temperature

μ_w = fluid viscosity evaluated at tube wall temperature

The fluid lump type cards provide for inputs of ($\mathcal{K}$) which can be different for each fluid lump type. The term is used to account for pressure losses in tube entrance regions, bends, contractions, and expansions. Entrance pressure losses for varying duct geometries (Reference 12) may also be specified by ($\mathcal{K}$).

3.4.2 Parallel Flow

The term parallel flow is used herein to refer to systems with simple sets of tubes arranged in parallel as shown in Figure 2. The tubes do not have to be the same diameter or length. The tube manifolds are not included in the analysis; the system inlet temperature and pressure are supplied to the entrance of each parallel flow tube. The flow rates which give equal pressure losses do not involve any fluid outlet manifolding. A mixed fluid outlet temperature is computed by using flow rates and enthalpies of each parallel fluid stream.

The pressure balancing subroutine is called after initial flow rates are read from the data input before the first temperature iteration is made and after each successive temperature iteration. The individual tube pressure losses are calculated and compared. If the pressure losses differ by more than 0.1 percent, the individual tube fluid flows are adjusted by the equations shown below, and the comparison is repeated. No advance in time is made until a pressure balance is obtained.

$$\dot{w}_1' = \frac{\Delta P_{avg}}{\Delta P_1} (\dot{w}_1) ,$$

$$\dot{w}_2' = \frac{\Delta P_{avg}}{\Delta P_2} (\dot{w}_2) \quad \text{etc. to}$$

$$\dot{w}_n' = \frac{\Delta P_{avg}}{\Delta P_n} (\dot{w}_n) \qquad n = \text{number of radiator tube}$$

$$\dot{w}_t = \sum_1^n \dot{w} \; ; \; \dot{w}_t' = \sum_1^n \dot{w}'$$

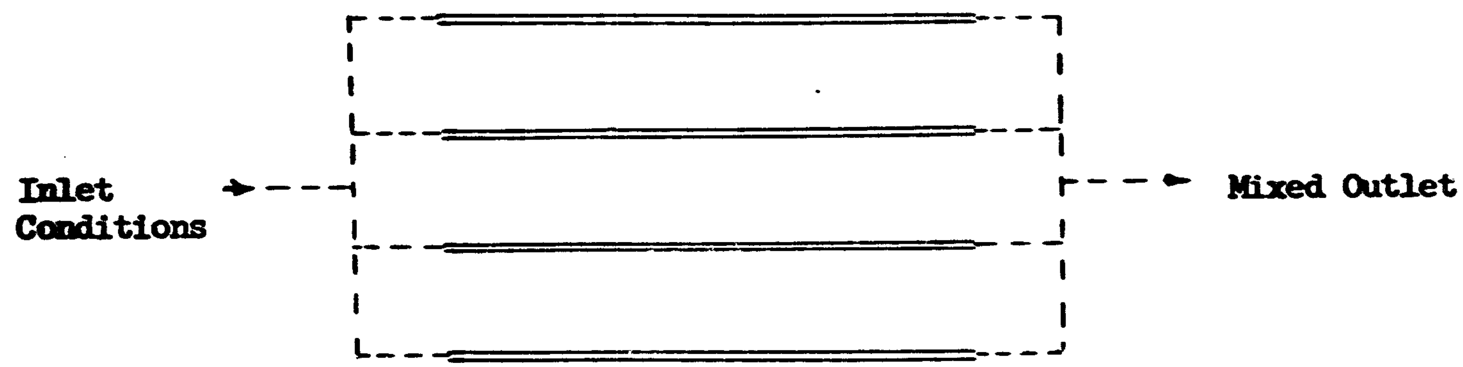


FIGURE 2

PARALLEL FLOW SYSTEM

$$\dot{w}_1'' = \frac{\dot{w}_t}{\dot{w}_t'}(\dot{w}_1') \quad , \quad \dot{w}_2'' = \frac{\dot{w}_t}{\dot{w}_t'}(\dot{w}_2') \text{ , etc. to}$$

$$\dot{w}_n'' = \frac{\dot{w}_t}{\dot{w}_t'}(\dot{w}_n') \qquad n = \text{number of radiator tube}$$

where:

$\dot{w}$ = individual tube fluid flow rates. Prime values are intermediate calculation numbers and double prime values are the assigned flow rates for the next pressure drop calculation.

ΔP_{avg} = the arithmetic average of all individual tube pressure drops.

subscripts 1 through n denote parallel flow tube numbers for flow rate and pressure drop.

3.4.3 Banks and Headers Flow

The banks and headers option permits analysis of combinations of parallel and series flow in general networks. The name is derived from "banks" of parallel flow paths and "headers" or manifold arrangements. To aid in discussing the use of the option certain terms require definition. First a "feeder" (referring to Figure 3) is the single inlet or exhaust tube of a manifold. A "bank" of pipes is the portion of flow network between the inlet and outlet manifold. A "manifold" is the system of tubes separating or joining the flow from or into a feeder. For analysis, manifolds are subdivided into tubes. A "tube" or "segment" is the largest subdivision in a network in which the flow is the same; hence, is the portion of a flow path between two tube junctures. The tubes are subdivided into lumps to provide for thermal considerations of fluid flow. When the banks and headers option is used, there must be two tubes per bank minimum and at least four tubes per system. Two portions of a flow line cannot be called two tubes in series due to the definition of a tube.

The present routine does not permit tubes of a bank to connect into the manifold of another bank which is arranged in series with the first bank. Each tube in a bank must rejoin the feeder connecting two series banks. Figure 3 shows schematically the arrangement which is thus not permitted.

The flow rates in a general network must be determined so as to (1) preserve flow continuity and (2) balance pressure drop in the various parallel sections of the network. The flow rates which satisfy these requirements are determined by solving a set of simultaneous equations. The pressure drop is linearized to be proportional to the flow rate of the previous iteration,or problem input flow rates,and the equations are set up and solved for new flow rates. Using this set of flow rates the pressure

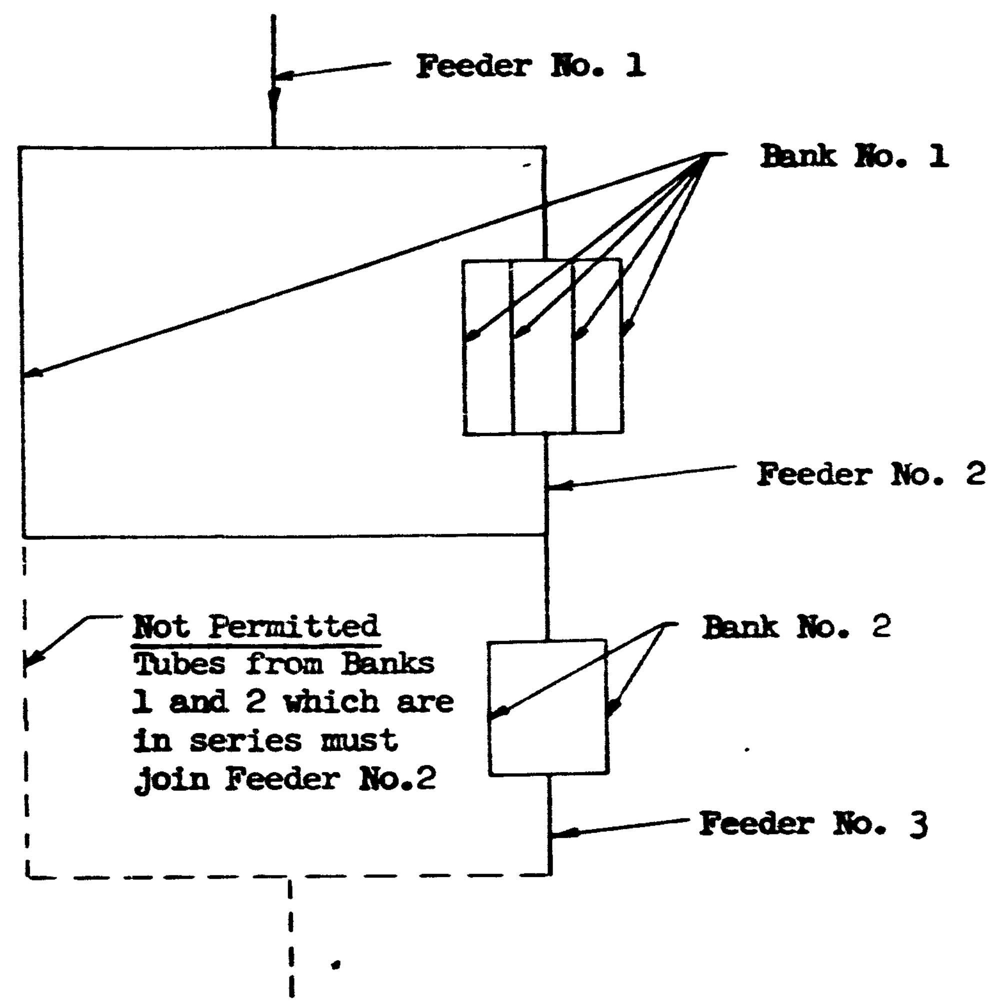


FIGURE 3

HEADERS AND BANKS FLOW SYSTEM

balance is checked. If the pressures are not balanced a new pressure drop per flow rate is used to resolve the simultaneous equations until a pressure balance is achieved.

For problems with laminar flow and no ($\mathcal{K}$) losses, only one solution of the simultaneous equation at each iteration is required. If the flow is turbulent, or if $\mathcal{K}$ losses are high, successive solutions of the equations will be required. The new flows are adjusted to the average of two successive equation solutions to provide for rapid convergence. Any problem will be terminated by the routine if a pressure balance is not obtained after solving the simultaneous equations twenty times at any one iteration.

The pressure drop per tube is computed from the sum of the pressure drops of the lumps in the tube. The equations for flow rates are set up as shown below for the flow system in Figure 4 . Only three tubes may join at any one point. When several tubes are manifolded together, "dummy" short tubes must be inserted. There are seven flow rates for the system in Figure 4 requiring seven equations. These are:

(1) $\dot{w}_1$ = known value

$$\dot{w}_1 = \dot{w}_2 + \dot{w}_3$$

$$\dot{w}_3 = \dot{w}_4 + \dot{w}_5$$

$$\dot{w}_6 = \dot{w}_2 + \dot{w}_5$$

(2) $\dot{w}_7 = \dot{w}_4 + \dot{w}_6$

$$\Delta P_2 = \Delta P_3 + \Delta P_5$$

$$\Delta P_4 = \Delta P_5 + \Delta P_6$$

The last two equations are linearized by dividing the ΔP of the tube by the flow rate to give the coefficient of flow rate, A.

$$A_2 \dot{w}_2 = A_3 \dot{w}_3 + A_5 \dot{w}_5$$

$$A_4 \dot{w}_4 = A_5 \dot{w}_5 + A_6 \dot{w}_6$$

The first equation of the set (1) and the equation for the flow continuity into the last tube (2) are not considered in the solution because they are known. The others are written in the form:

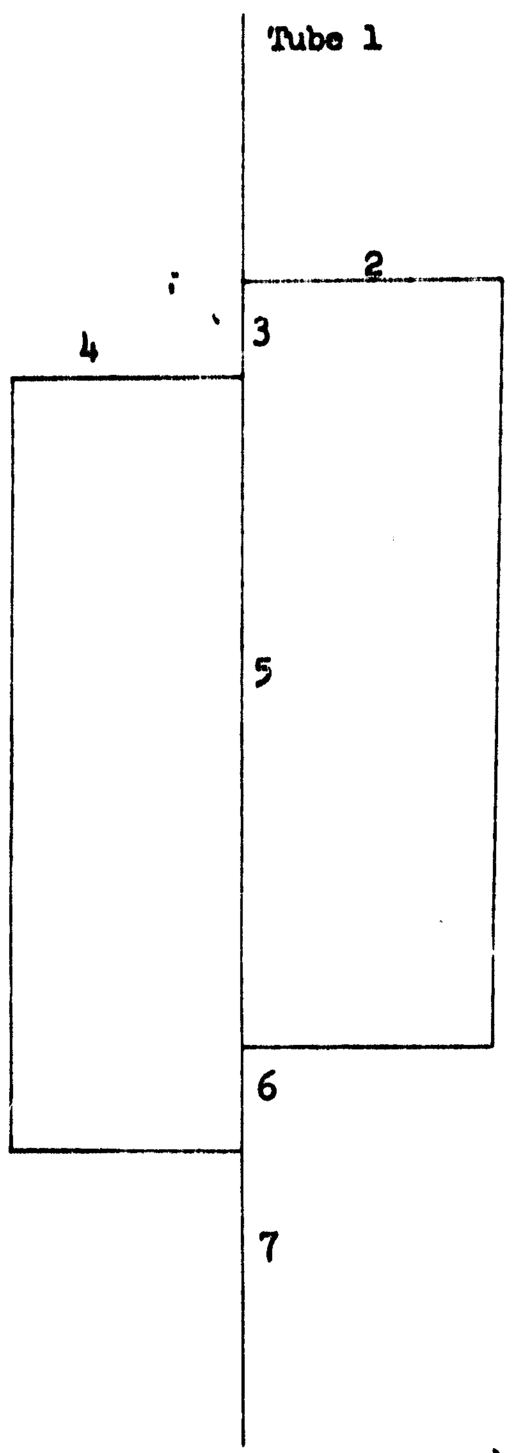


FIGURE 4

HEADERS AND BANK FLOW SYSTEM

$$
\begin{array}{lllllll}
\dot{w}_2 & + \dot{w}_3 & & & & = & \dot{w}_1 \\
 & \dot{w}_3 & - \dot{w}_4 & - \dot{w}_5 & & = & 0 \\
- \dot{w}_2 & & & - \dot{w}_5 & + \dot{w}_6 & = & 0 \\
A_2\dot{w}_2 & - A_3\dot{w}_3 & & - A_5\dot{w}_5 & & = & 0 \\
 & & A_4\dot{w}_4 & - A_5\dot{w}_5 & - A_6\dot{w}_6 & = & 0
\end{array}
$$

The matrix of coefficients β is written from these equations as:

$$
\beta = \begin{bmatrix}
1 & 1 & 0 & 0 & 0 \\
0 & 1 & -1 & -1 & 0 \\
-1 & 0 & 0 & -1 & 1 \\
A_2 & -A_3 & 0 & -A_5 & 0 \\
0 & 0 & A_4 & -A_5 & -A_6
\end{bmatrix}
$$

The equation $\beta \dot{w} = C$ is solved by determining A^{-1} and results in:

$$
\dot{w} = \beta^{-1} C
$$

3.4.4 Flow Rate Versus Pressure Loss

For many flow systems pump characteristics determine system flow rate as a function of pressure loss. The routine provides for data input of pump ΔP versus $\dot{w}$ characteristics. If this option is used, after each solution for pressure balance a flow rate for the total system pressure loss is determined from the pump characteristic curve. If the flow rate is within 0.1 percent of the flow rate used for the pressure balance the next temperature iteration is made. If the flow rate is out of tolerance, the average flow between iterations is used for successive iterations until a match point is achieved.

3.4.5 Pumping Power

For radiators with a series flow arrangement, the total fluid pressure loss will be the summation of fluid lump ΔP's for a single tube. For parallel flow arrangements, a flow balancing procedure shown in paragraph 3.2.2 is employed to insure equal pressure drops in all radiator tubes.

The fluid pumping power requirement is based on the frictional and dynamic head pressure loss of the fluid. The pumping power is calculated for each tube separately and totaled for parallel flow radiators. The following equation is used to calculate pumping power.

$$\mathcal{P} = \frac{\dot{w}}{(\rho_f)_{avg}} \Delta P \quad , \quad (\rho_f)_{avg} = \frac{\sum_j \rho_j}{\text{Number of fluid lumps per radiator tube}}$$

$\mathcal{P}$ = pumping power

$\dot{w}$ = fluid flow rate

$(\rho_f)_{avg}$ = average fluid density

ΔP = pressure loss between inlet and outlet of radiator tube

3.5 TWO-PHASE FLOW ANALYSIS

Prediction of two-phase condensing flow in a space radiator and heat exchanger requires a suitable analytical model. An analytical model describing the phenomena of condensing heat transfer in the presence of a non-condensible gas is described in the paragraphs which follow. The description includes (1) a flow model, (2) the heat and mass transfer rate equations and (3) the energy equation and method of solution.

3.5.1 Flow Model

Two-phase isothermal flow in a pipe presents the problem of determining (1) the pressure drop and (2) the amount of liquid contained in a portion of the pipe. A correlation was developed in Reference 13 in which the pressure drop of each phase was considered equal; and correlating parameters were derived from relations governing the pressure drop of each of the phases as if it were flowing alone. The choice of correlating parameter is dependent on whether the gas and liquid flow is turbulent or laminar in nature. The liquid flow in radiators and heat exchangers is expected to be laminar so only laminar liquid with laminar gas and laminar liquid with turbulent gas is considered. The correlating factors are denoted χ_T and χ_L and are defined as:

$$\chi_T = (Re_g)^{-0.8} \left[\frac{16}{.046}\right] \cdot \frac{\rho_g}{\rho_L} \cdot \frac{\mu_L}{\mu_g} \cdot \frac{\dot{w}_L}{\dot{w}_g} \quad \text{(turbulent gas)}$$

$$\chi_L = \frac{\mu_L}{\mu_g} \; \frac{\rho_g}{\rho_L} \; \frac{\dot{w}_L}{\dot{w}_g} \quad \text{(laminar gas)}$$

where

Re_g = superficial gas Reynolds Number, $\frac{4 \dot{w}_g}{WP \mu_g}$

ρ_g = gas density

ρ_L = liquid density

μ_L = liquid viscosity

μ_g = gas viscosity

$\dot{w}_L$ = liquid flow rate

$\dot{w}_g$ = gas flow rate

The amount of liquid in the [illegible] is defined by the relation

$$\alpha = \frac{4 A_{c_L}}{\pi (D_{h_L})^2}$$

where

α = area ratio

A_{C_L} = liquid cross-sectional area

D_{h_L} = liquid hydraulic diameter

If the wetted perimeter of the liquid is the tube perimeter

$$D_{h_L} = \frac{4 A_{L_C}}{WP}$$

where

WP = wetted perimeter

and

$$\alpha = \frac{(WP)^2}{4 \pi A_{C_L}} = \frac{A_{C_T}}{A_{C_L}}$$

where

A_{C_T} = cross-sectional area of tube for flow

This relation shows that as long as the liquid film wets the entire perimeter that α uniquely determines the liquid cross-sectional area, regardless of the flow type (i.e., slug, annular, or wavey annular).

The pressure drop is related intimately to the values of α and the parameter χ. In the analysis of Reference 13, the pressure drop in two-phase flow is greater than that of the gas phase flowing alone by a factor of ϕ^2. The value of ϕ^2 from that analysis is determined from the equation

$$\phi = 1 + \sqrt{\alpha \chi_T} \qquad Re_g > 2000$$

$$\phi = \alpha \sqrt{\chi_L} \qquad Re_g < 2000$$

The value of ϕ being determined from only α and χ implies that a unique relation between α and χ will also determine the pressure drop. The turbulent flow correlation of α versus χ_T of Reference 13 is programmed into the routine and is shown in Figure 5.

With both laminar gas and liquid, a simple analysis may be performed to determine α and ϕ. The Navier-Stokes equations may be solved in two regions, (1) a core and (2) an annulus, with the following assumptions and

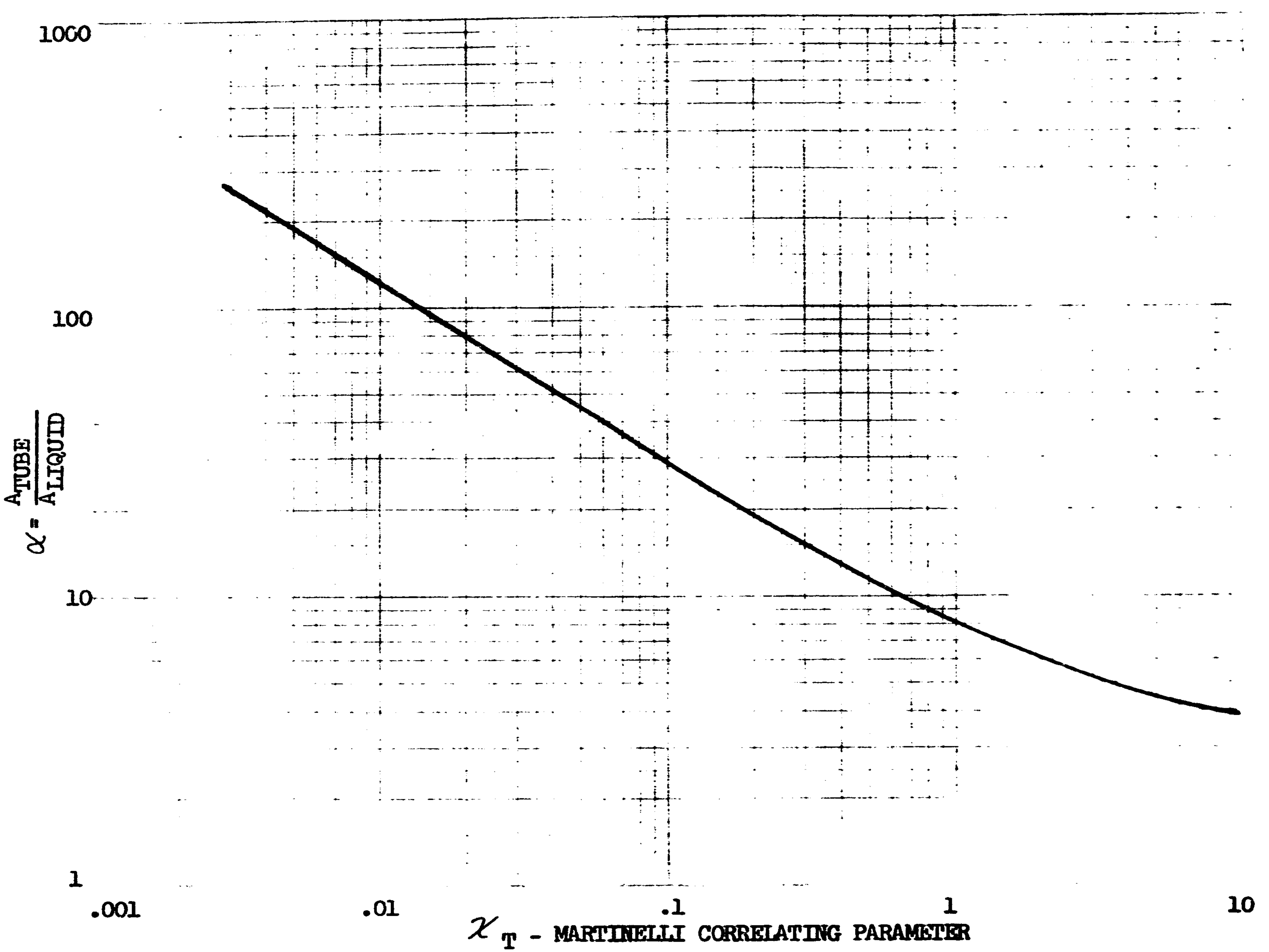


FIGURE 5

CURVE RELATING α AND χ_T

boundary conditions.

Assumptions:

(1) Both regions have equivalent pressure drop
(2) Steady state, developed flow profiles are assumed
(3) Both phases are laminar

Boundary Conditions:

(1) Zero velocity at tube radius
(2) Symmetrical flow
(3) Velocities at region interface are equal
(4) Shear at region interface is equal

This problem results in a solution for α in terms of χ_L with the component viscosity ratio as a parameter. The equation is:

$$\phi^2 = \alpha^2 \chi_L \text{ and } \alpha^2 = \frac{1}{\chi_L} + 1 - 2\left(1 - \frac{\mu_g}{\mu_L}\right)\left(\frac{\mu_g}{\mu_L} - \sqrt{\left(\frac{\mu_g}{\mu_L}\right)^2 + \frac{1}{\chi_L}}\right)$$

Due to the characteristically high gas velocities, the flow continuity for the gas is determined by assuming that transient changes in the gas flow rate are propagated through the length of the tube in one time increment rather than one lump per time increment. At each node, the gas mixture flow rate is depleted on the basis of the most recently determined condensation rate at that node. Denoting the lump position by an integer subscript and the time by an integer superscript, this is:

$$\dot{w}_{gj}^{i+1} = \dot{w}_{gj-1}^{i+1} - \Delta \dot{w}_{Lj}^{i+1}$$

where

$\Delta \dot{w}_L$ = condensation rate

The condensation rate, $\Delta \dot{w}_L$ may be written as:

$$\Delta \dot{w}_L = K_m A_{HT} (P_b - P_s)$$

Thus $\dot{w}_{gj}^{i+1} = \dot{w}_{gj-1}^{i+1} + K_m A_{HT} P_s - K_m A_{HT} P_b$

where

K_m = mass transfer coefficient
A_{HT} = area for heat transfer
P_s = vapor partial pressure at the condensing surface
P_b = bulk vapor partial pressure

P_b may be written as:

$$P_b = \frac{\psi \, P_G}{\psi + MWR} = \frac{(\dot{w}_g - \dot{w}_o)\, P_b}{\dot{w}_g - \dot{w}_o - (MWR)\, \dot{w}_o}$$

where

ψ = specific humidity of gas

$= \frac{\dot{w}_g - \dot{w}_o}{\dot{w}_o}$

$\dot{w}_g$ = total gas flow rate
$\dot{w}_o$ = non-condensible gas flow rate
P_g = total gas pressure
MWR = ratio of condensible molecular weight to non-condensible molecular weight

The above relation for P_b is substitited into the equation for $\Delta \dot{w}_L$ and an expression for $\dot{w}_g$ results:

$$\dot{w}_g = Q_B + \sqrt{Q_B^2 + RA}$$

where

$$Q_B = 1/2\left[(MWR-1)\dot{w}_o - \dot{w}_{g\,j-1} - K_m A_{HT} \quad P_s + K_m A_{HT}^{-} P_g\right] \dot{w}_g$$

$$RA = \dot{w}_{g_{j-1}}(MWR-1)\dot{w}_o + K_m A_{HT}\, P_s\, (MWR-1)\dot{w}_o + K_m A_{HT}\, P_s\, \dot{w}_o$$

The above relation will give good results for values of P_s near P_b. However, there are some conditions where it gives unrealistic results. To prevent this from occurring, a limiting condition was placed on $\dot{w}_g$. This limit prevents $\dot{w}_g$ from being larger than that required for the gas to be saturated under evaporating conditions, and smaller than that required for the gas to be saturated under condensing conditions. The limiting $\dot{w}_g$, $\dot{w}_{g_{sat}}$) is given by:

$$\dot{w}_{g_{sat}} = \dot{w}_o\left[1 + \frac{MWR\; P_s\; T_g}{P_g\; T_s - P_s\; T_g}\right]$$

An attempt to simulate a precise transient liquid continuity equation during the development of the routine was not successful. The transient liquid continuity equation is:

$$\frac{\partial \dot{w}_L}{\partial x} + \frac{\Delta \dot{w}_L}{L} + \rho_L \frac{d\, A_C}{d\tau} = 0 = \frac{\partial \dot{w}_L}{\partial x} + \frac{\Delta \dot{w}_L}{L} - \rho_L\, A_{C_T} \frac{1}{\alpha^2} \frac{\partial \alpha}{\partial \tau}$$

In difference form, this equation is, with position denoted by subscript and time by superscript,

$$\frac{\dot{w}_{L\,j-1}^{\,i+1} - \dot{w}_{L,j}^{\,i+1}}{\Delta x} + \frac{\Delta \dot{w}_L}{\Delta x} - \rho_L \frac{A_{C_T}}{(\alpha_j^i)^2} \frac{\alpha_j^{i-1} - \alpha_j^{i}}{\Delta \tau} = 0$$

With α determined using the correlation of α versus χ, the right hand term causes an instability, especially when the time increment is shortened. Because of this difficulty an approximate form of the continuity equation was adopted. Symbolically, this is written

$$\dot{w}_{Lj}^{i+1} = \gamma \dot{w}_{Lj-1}^{i} + (1 - \gamma) \dot{w}_{Lj}^{i} + \gamma \Delta \dot{w}_{Lj}^{i}$$

$$\gamma = \text{velocity} \left(\frac{\Delta \tau}{\ell'} \right) = \frac{\alpha \dot{w}_L^{i} \Delta \tau}{\rho A_c \ell'}$$

The value of γ is the fraction of lump length the fluid advances during the time interval. This equation seems to be satisfactory and not susceptible to instability.

3.5.2 Heat and Mass Transfer Rates

The heat transfer coefficient equations of paragraphs 3.3.1 and 3.3.2 were used for laminar and turbulent gas heat transfer coefficients in the two-phase flow characterization.

Mass transfer rates are based on an analogy of heat, mass, and momentum transfer proposed by Colburn (Reference 14). This analogy has been subjected to a number of verification tests, which in general, show its validity. Two of these tests, for the case of condensation within a tube, may be found in References 15 and 16. The results of these tests bear out the analogy for both turbulent and laminar flow. The equations used to determine the local coefficient of mass transfer, K_m, are:

$$K_m = \frac{\frac{1}{2} \mathcal{D} P_g}{D_h R_v T_g P_m} \; \frac{\sum A_n \exp\left[\dfrac{-2 \lambda_n^2 x}{D \, Re_g \, Sc}\right]}{\sum \dfrac{A_n}{\lambda_n^2} \exp\left[\dfrac{-2 \lambda_n^2 x}{D \, Re_g \, Sc}\right]} \qquad \text{(laminar)}$$

$$K_m = .023 \frac{\mathcal{D} P_g}{D_h R_v T_g P_m} Re_g^{.8} \, Sc^{1/3} \qquad \text{(turbulent)}$$

where

$\mathcal{D}$ = diffusion coefficient
D = tube diameter
R_v = vapor gas constant
T_g = gas temperature
P_g = gas pressure
P_b = bulk vapor partial pressure

p_s = vapor partial pressure at condensing surface

p_m = $\dfrac{p_b - p_s}{\log \dfrac{p_g - p_s}{p_g - p_b}}$ log mean pressure of non-condensible gas

x = distance downstream of condensation origin

Sc = Schmidt number of gas

The film coefficient relating heat transfer through the liquid film adjacent to the wall is not directly measurable when condensation occurs in the presence of non-condensibles. The thickness of liquid film is a dynamic problem depending on the properties, etc., as is the pressure drop determination. The dynamic forces on the film should be independent of whether the gas is a pure vapor or mixture. Due to this dynamic similarity with condensation of a pure vapor, it is postulated that the film coefficient should be the same for both cases. Many correlations have been derived from experimental data of condensation in tubes. From the correlations available, the one judged most appropriate is that of Reference 17. In spite of the relatively wide range of experimentation for which the correlation pertains, the thick films encountered in low velocity flow may fall outside of the range of applicability of the correlation. To check this condition, the routine computes the film thickness in order to print a statement that the prediction is out of the range of correlation. The equation used for the film coefficient U is:

$$U = \frac{K_L}{D_h}\, 13.8\, (Pr_L)^{1/3} \left[\frac{\lambda}{Cp_L(T_g - T_w)}\right]^{1/6} Re_v^{\,1/5} \quad \text{for } Re_v < 20{,}000$$

$$U = \frac{K_L}{D_h}\, (.1)(Pr_L)^{1/3} \left[\frac{\lambda}{Cp_L(T_g - T_w)}\right]^{1/6} Re_v^{\,2/3} \quad \text{for } Re_v > 20{,}000$$

$$Re_v = \frac{4\dot{w}_g}{(WP)\,\mu_L} \left[\frac{\rho_L}{\rho_g}\right]^{1/2} \quad 1000 < Re_v < 100{,}000$$

where

K_L = liquid thermal conductivity

Pr_L = liquid Prandtl Number

λ = latent heat

Cp_L = liquid specific heat

The heat transfer, mass transfer, and film coefficients determined above are used in the following equations:

The heat transfer rate from gas to liquid (or tube if condensation has not begun) is

$$Q = h_f A_{HT} (T_g - T_s)$$

where

T_s = surface temperature
A_{H_T} = (WP) (ℓ') when liquid is present
A_{H_T} = data input from tube when liquid is absent

The heat transfer by condensation is

$$Q_{L(latent)} = K_m A_{HT} \lambda (p_b - p_s)$$

where

$$A_{HT} = (WP)(\ell')$$

The heat transfer through the liquid film is

$$Q = U A_{HT} (T_s - T_w)$$

where

A_{HT} = data input from tube data

3.5.3 Energy Equations and Their Solution

The general form of the energy conservation equations are written for the gas and liquid lumps as

energy storage rate = convective net influx + heat transferred into lump + latent heat added.

The gas lumps have only one heat transfer source, the surface of tube or liquid, whichever is applicable. The term "latent heat added", is zero and the equation is similar to equation (13) of paragraph 3.1.3.

$$w_g C_{p_g} \frac{\Delta T}{\Delta \tau} = \dot{w}_g C_{p_g} (T_{upstream} - T_{lump}) + h_f A_{HT} (T_s - T_g)$$

Denoting the lump position by an integer subscript and the time by an integer superscript, the explicit difference equation may be written

$$T_j^{i+1} = T_j^{i} + \frac{\Delta\tau}{w_g C_p}\left[\dot{w}_g C_p \left(T_{j-1}^{i} - T_j^{i}\right) + h_f A_{HT}\left(T_{s_j}^{i} - T_j^{i}\right)\right]$$

The liquid lumps have heat transfer sources as the gas the tube wall, and the "heat added" is the latent heat rate. The explicit equation is, assuming energy to be stored at the lump surface temperature,

$$T_j^{i+1} = T_j^{i} + \frac{\Delta\tau}{w_L C_p}\left[\dot{w}_L C_p \left(T_{s_{j-1}}^{i} - T_{s_j}^{i}\right) + h_f A_{HT}\left(T_{g_j}^{i} - T_{s_j}^{i}\right) + U A_{HT}\left(T_{w_j}^{i} - T_{s_j}^{i}\right) + Q_L\right]$$

It is known that the time increment ($\Delta\tau$) must be limited for the successive iterations of the above equations to remain stable (paragraph 3.2.1). The commonly applied criterion is to have the coefficient of T_j^i constrained to be positive. When using this approach to determine the maximum allowable time increment, $\Delta\tau$, a problem is encountered. The latent heat transfer exerts a large influence on the stability which is not contained in the expression for temperature calculation.

To express the effect of latent heat on the stability requirement the following is considered. During one time increment the net heat addition cannot be so great that the temperatures achieved in one iteration would cause a reversal in the direction of net heat flow. For condensation, this implies that the latent heat addition should never be sufficient to cause the liquid surface temperature to exceed the gas dew point temperature. The latent heat rate can be expressed as if it were sensible heat transferred from the gas dew point temperature as follows.

$$Q_L = \frac{Q_L}{T_{DP} - T_s}\left[T_{DP} - T_s\right]$$

$$= K_m A_{HT} \lambda \left[\frac{p_b - p_s}{T_{DP} - T_s}\right]\left(T_{DP} - T_s\right)$$

T_{DP} = dew point temperature of bulk gas

The points (p_b, T_{DP}) and (p_s, T_s) both lie on the vapor pressure versus temperature saturation line. On this line the slope of the line may be expressed using the Clausius-Clapeyron equation (Reference 18).

$$\frac{\partial p}{\partial T} = \frac{\lambda}{T\left[\frac{1}{\rho_v} - \frac{1}{\rho_L}\right]}$$

If the liquid volume is neglected compared to the gas volume, and the gas volume is calculated using an ideal gas relation (error < 5% for T < 250°F for H_2O)

$$\frac{\Delta p}{\Delta T} \approx \frac{\partial p}{\partial T} \approx \frac{\lambda\, p_b}{R_v\, T^2}$$

Substitution into the equation for Q_L results in

$$Q_L = K_m A_{HT} \frac{\lambda^2 p_b}{R_v\, T^2} (T_{DP} - T_s)$$

If the coefficient of $T_{s_j}^{i}$, namely

$$K_m A_{HT} \frac{\lambda^2 p_b}{T^2 R_v}$$

is added to the other coefficients for the determination of $\Delta \Upsilon$ for liquid lumps, the resulting $\Delta \Upsilon$ is

$$\Delta \Upsilon = \frac{\Theta\, w_L C_{p_L}}{\dot{w}_L C_{p_L} + h_f A_{HT} + U A_{H_T} + K_m \frac{A_{H_T} \lambda^2 p_b}{R_v\, T_g^2}}$$

where

Θ = convergence factor < 1.0 (See Paragraph ...)

This constrains the surface temperature to greater or less than the dew point temperature, not both on one iteration.

During condensation, in any one increment vapor is extracted from the gas. The entering vapor rate may not be great enough to replenish this for long fluid lumps, resulting in a vapor pressure reduced below the pressure to which mass transfer had occurred the previous iteration. Hence, the lump lengths must be limited. An equation was developed which, a priori, would allow the user to select a value of length less than that value which would produce the above mentioned situation. The derivative $\partial p_b / \partial (\Delta \dot{w}_L)$ can be evaluated from purely thermodynamic considerations. The $\Delta \dot{w}_L$ is simply Q_L/λ in a lump and is proportional to $(p_b - p_s)$, the driving potential. When $\partial p_b / \partial (\Delta \dot{w}_L)$ exceeds $(p_b - p_s)/\Delta \dot{w}_L = 1/K_m A_{H_T}$ the aforementioned difficulty will occur. Thus, the area for mass transfer must be limited to that value for which

$$\frac{1}{K_m A_{H_T}} \geq \frac{\partial p_b}{\partial(\Delta \dot{w}_L)}$$

The resulting equation is

$$\frac{K_m A_{H_T} p_b^2}{\dot{w}_o P_g \psi^2} \cdot \frac{M_1}{M_o} \leq 1.0$$

If the A_{H_T} (proportional to length) is too large a diagnostic will be printed indicating the margin by which it is too large. For several example systems this restriction has amounted to lengths which are about 5-15 diameters (hydraulic diameters). This length restriction need only be applied for lumps where condensation occurs, not all lumps in a condensing system.

3.5.4 Transport Properties

Calculation of transport properties in gaseous mixtures involves the integration of collision integrals for the molecular force potentials into kinetic theory assuming a set of combination rules which will enable the calculation of the properties. The calculation of thermal conductivity is further complicated by molecular internal energy, in addition to translatory energy. There are several models of combination rules which for non-polar gases give very reasonable predictions using the Leonard-Jones 6:12 potential, Reference 19. However, with the molecular dipole moments of polar gases, the 6:12 potential fails to predict transport properties. A recent work (Reference 20) sets forth a calculation model for polar gas mixtures that appears to be quite successful. However, it is not complete, i.e., thermal conductivity is not included, and its procedures would require considerable manipulations to enable reasonable calculations. The calculation technique used in the computer routine is either a simple mole or mass average of the individual properties. This method produces fairly representative variations for each transport property and predicts the Prandtl number versus gas composition dip observed with gas mixtures. Binary diffusion coefficients require an input value at 14.7 psia and 60°F and will be calculated under the assumption that the coefficient varies in proportion to $\sqrt{T^3}/P$.

3.5.5 Calculation Procedure

The order in which the calculations of paragraphs 3.5.1 and 3.5.2 are performed is stated in this paragraph. Those calculations required to establish the pressure and flow rate are performed first for each lump. Following this determination, the heat transfer coefficients, mass transfer coefficients and latent heat transfer rates are determined. Then the time increments are determined and compared to select the problem time increment. An examination is made to insure that the calculated condensation rates will not cause the physically impossible condition of negative vapor flow rates or negative liquid flow rates. Finally, the temperature solution is performed for temperatures at the next time increment.

Due to the order of calculation, instances such as an initial discontinuity will produce condensation rates in some downstream lumps much greater than would be expected under equilibrium conditions. This occurs because successive temperatures will, on one iteration, drop below dew point temperature at which time condensation will be calculated in each lump. For example if the initial temperatures of five series tube lumps are 70°F initially, and the gas dew point is initially 150°F at each position, the same condensation rate will be calculated at each lump. If, for example, 10 pounds of vapor were flowing and the calculated condensation rate were 5 pounds per lump, the last three of the five lumps would not be permitted any condensation, since the first two lumps exhausted the vapor flow. The steady solution results in a decreasing dew point temperature rather than having a constant value, hence some lumps in general may evaporate some liquid for several iterations until the dew point temperature profile is established. It is felt that the time lag error produced by this characteristic will be small in any practical transient problem.

3.6 FUEL CELL CHARACTERIZATION

3.6.1 Thermal and Mass Balance

The capability to perform thermal analysis on fuel cells simular to those on Apollo was programmed into the routine. When the fuel cell option is used, the routine will perform a heat and mass balance on the fuel cell and include the effect of the fuel cell on the heat rejection system.

In characterizing the fuel cell the following assumptions were made:

(1) The fuel cell stack is represented by a single isothermal lump.
(2) The gas leaving the fuel cell stack is at the stack temperature.
(3) The fuel cell exit vapor pressure is the same as the vapor pressure inside the fuel cell stack.
(4) Each fuel cell module operates independent of the others

The heat balance on the fuel cell stack is given by the following relation:

$$wc \frac{dT_s}{d\tau} = Q_{net}$$

In finite difference form:

$$T_s^{i+1} = T_s^{i} + \frac{\Delta\tau}{wc} (Q_{net})$$

where

T_s^{i+1} = stack temperature at time $\tau + \Delta\tau$
T_s^{i} = stack temperature at time τ
$\Delta\tau$ = finite difference time increment
wc = the thermal capacitance
Q_{net} = the net energy being transferred to the fuel cell stack

The net energy being transferred to the stack, Q_{net}, is given by:

$$Q_{net} = Q_r - Q_e - Q_g - Q_c - Q_p$$

where

Q_r = chemical energy due to the hydrogen-oxygen reaction
Q_g = energy removed from the stack by recirculating gas
Q_e = energy carried out by vapor evaporated from the cell electrolyte solution
Q_c = heat removed by conduction or radiation
Q_p = energy removed by electrical power usage

When the water is formed within the fuel cell stack by the chemical reaction of hydrogen (H_2) and oxygen (O_2) the water is formed as a liquid in the water-potassium hydroxide (KOH) solution present within the stack. Thus, the higher heating value would be used in determining Q_r. Q_r, then, is given by:

$$Q_r = \dot{w}_{O_R}\left[H_{OH} + h_{O_R} - h_{O77} + \frac{M_{O2}}{M_O}(h_{O_{2R}} - h_{O_{277}}) - \frac{M_v}{M_O}(h_{\ell s} - h_{\ell 77})\right]$$

where

$\dot{w}_{O_R}$ = flow rate of reactant hydrogen

$= C_1 \frac{\mathbb{P}}{E}$

C_1 = constant for the reaction

$\mathbb{P}$ = fuel cell power

E = fuel cell voltage

H_{O_H} = higher heating value for hydrogen

h_{O_R} = enthalpy of hydrogen at the reactant temperature

$h_{O_{77}}$ = enthalpy of hydrogen at 77°F

M_{O_2} = atomic weight of oxygen

M_O = molecular weight of hydrogen

M_v = molecular weight of water vapor

$h_{O_{2R}}$ = enthalpy of oxygen at reactant oxygen temperature

$h_{O_{2_{77}}}$ = enthalpy of oxygen at 77°F

h_{ℓ_s} = enthalpy of liquid water at stack temperature

$h_{\ell_{77}}$ = enthalpy of liquid water at 77°F

If it is desired to use the lower heating value, the following conversion can be made:

$$H_{O_H} = H_{O_L} + \frac{w_o}{w_{H_2}}(h_{f_{g77}})$$

$$= H_{O_L} + \frac{M_v}{M_O}(h_{f_{g77}})$$

Then, Q_r may be written

$$Q_r = C_1 \frac{\mathbb{P}}{E}\left[H_{O_L} + h_{O_R} - h_{O_{77}} + \frac{M_{O2}}{M_O}(h_{O_{2R}} - h_{O_{277}}) - \frac{M_v}{M_O}(h_{\ell s} - h_{\ell 77} - h_{f_{g77}})\right]$$

but the quantity ($h_{f_s} - h_{f_{77}} - h_{fg_{77}}$) may be written ($h_{v_s} - h_{v_{77}} - h_{fg_s}$). Thus, for the lower heating value,

$$Q_r = \frac{C_1 \mathbb{P}}{E}\left[H_{O_L} + h_{O_R} - h_{O_{77}} + \frac{M_{O_2}}{M_O}\left(h_{O_{2R}} - h_{O_{2_{77}}}\right) - \frac{M_v}{M_O}\left(h_{v_s} - h_{v_{77}} - h_{fg_s}\right)\right]$$

where

h_{v_s} = enthalpy of water vapor at stack temperature

$h_{v_{77}}$ = enthalpy of water vapor at 77°F

h_{fg_s} = latent heat of vaporization for water at the stack temperature

The energy carried out by evaporated vapor, Q_e, is given by:

$$Q_e = h_{fg_s}\,(RE)$$

where

RE = rate of evaporation

$= \dot{w}_O\,(\gamma_{out} - \gamma_{w_s})$

The energy removed by recirculating gas is given by:

$$Q_g = \dot{w}_O\left[h_{O_s} - h_{O_{in}} + \gamma_{w_s}\,(h_{v_s} - h_{v_{in}})\right]$$

where

$\dot{w}_O$ = recirculated hydrogen flow rate

h_{O_s} = enthalpy of hydrogen at stack temperature

$h_{O_{in}}$ = enthalpy of hydrogen at temperature of recirculating gas entering the fuel cell stack

γ_{w_s} = specific humidity at the water separator

$h_{v_{in}}$ = enthalpy of the water vapor at the temperature of recirculating gas entering the fuel cell stack

γ_{out} = specific humidity of gas leaving the fuel cell stack

The energy removed by electrical power, Q_p, is given by:

$$Q_p = 3.413\,\mathbb{P}$$

The net heat transferred into the fuel cell stack is then

$$Q_{net} = \frac{C_1 \mathbb{P}}{E} \Big[H_{O_R} + h_{O_R} - H_{O_{77}} + \frac{M_{O_2}}{M_O} (h_{O_{2R}} - h_{O_{2_{77}}})$$

$$- \frac{M_V}{M_O} (h_{v_s} - h_{v_{77}} - h_{f_{g_s}}) \Big] - h_{f_{g_s}} (RE)$$

$$- \dot{w}_O \Big[h_{O_s} - h_{O_{in}} + \gamma_{w_s} (h_{v_s} - h_{v_{in}}) \Big]$$

$$- Q_c - 3.413 \mathbb{P}$$

and the finite difference temperature equation for the fuel cell stack is:

$$T_s^{i+1} = T_s^{i} + \frac{\Delta \tau}{wc} \Big\{ \frac{C_1 \mathbb{P}}{E} \Big[H_{O_R} + h_{O_R} - h_{O_{77}} + \frac{M_{O_2}}{M_O} (h_{O_{2R}} - h_{O_{2_{77}}})$$

$$- \frac{M_V}{M_O} (h_{v_s} - h_{v_{77}} - h_{f_{g_s}}) \Big] - h_{f_{g_s}} (RE)$$

$$- \dot{w}_O \Big[h_{O_s} - h_{O_{in}} + \gamma_{w_s} (h_{v_s} - h_{v_{in}}) \Big]$$

$$- Q_c - 3.413 \mathbb{P} \Big\}$$

A mass balance on the fuel cell stack gives the following relation for a new value of electrolyte concentration at the end of time $\tau + \Delta\tau$

$$P_{KOH}^{i+1} = \frac{1}{\frac{1}{P_{KOH}^{i}} + \frac{\Delta \tau}{M_{KOH}} (RP - RE)}$$

where

P_{KOH}^{i+1} = electrolyte concentration at time $\tau + \Delta\tau$

P_{KOH}^{i} = electrolyte concentration @ τ

M_{KOH} = mass of electrolyte in the fuel cell stack

RP = rate of production of water by the reaction

$$= \frac{M_V}{M_O} \frac{C_1 \mathbb{P}}{E}$$

RE = rate of evaporation of water

$$= \dot{w}_O (\gamma_{out} - \gamma_{w_s})$$

γ_{w_s} = specific humidity at the water separator

$$= \frac{\dot{w}_{gw_s} - \dot{w}_O}{\dot{w}_O}$$

$\dot{w}_{g_{ws}}$ = total gas flow rate at the water separator

$\dot{w}_o$ = recirculated hydrogen

γ_{out} = specific humidity of gas leaving the fuel cell stack

$$= \frac{M_v}{M_o}\left[\frac{P_v}{P - P_v}\right]$$

M_v = molecular weight of water

M_o = molecular weight of hydrogen

P_v = vapor pressure in fuel cell

P = total system pressure

The recirculated hydrogen which enters the heat rejection system is calculated each iteration by the following relation:

$$\dot{w}_o = \frac{(V)\,\rho_{ws}}{1 + \gamma_{ws}}$$

where

ρ_{ws} = gas density at the water separator

V = volumetric flow rate read from pump curve

The total gas entering the heat rejection system (leaving the fuel cell stack) is given by:

$$\dot{w}g_1 = \dot{w}c\,(1 + \gamma_{out})$$

$\dot{w}g_1$, T_g^{i+1} (as entering gas temperature) and $\dot{w}_o$ are input to the heat rejection system to determine its performance on each iteration.

3.6.2 Transient Fuel Cell Characterization

In the early versions of the MSD-T routine which were used for analysis of the Apollo Electrical Power Systems the fuel cell performance was characterized by a series of steady state curves which represented one given volumetric pump flow and condenser exit temperature. These curves specified the module voltage versus temperature and power output. In the actual operation, the fuel cell module voltage is also a function of electrolyte concentration. The use of the steady state performance curves for fuel cell transient conditions and for steady state conditions (at other than the specified condenser exit temperature and volumetric flow) caused inaccuracies in the predictions of the fuel cell module voltage. Since the voltage is used in the calculation of the rate of water production, the inaccuracy of the voltage calculation was compounded in the repetitive finite difference calculations of heat and mass balance.

To overcome these computational inaccuracies, a curve fit of module voltage as a function of temperature, power and electrolyte concentration was implemented. The best form of the curve fit was found to be that given in Reference 21.

$$V = (aT + b)\frac{P}{V} + (cT_S + d) + e\,(f - PKOH)$$

where

V	=	module voltage
P	=	module power
T_S	=	stack temperature
PKOH	=	percent electrolyte concentration
a,b,c,d,e,&f	=	curve fit constants

The constants were determined in Reference 16 to be:

a = 7.960×10^{-4}
b = -.8470
c = .02600
d = 11.05
e = -0.2473
f = .73

(b, and d have been adjusted to account for the fact that stack temperature is in °R instead of °F as given in Reference 16).

3.6.3 Load Sharing

The early version of the MSD-T computer routine being used for fuel cell analysis assumed that each of the three fuel cell modules would operate independently of the others. However, the Apollo EPS system actually has the three fuel cell modules connected electrically in parallel with the total electrical load being divided between the three in accordance with their particular performance levels. Changes were made to reflect the parallel connections of the three fuel cells in the present routine version.

Since the performance of each of the three cells is determined explicitly as a function of the variables which affect it, the portion of the total load which each module produces could be established. Since the three fuel cells are connected in parallel in the actual system, they were assumed to have equal voltages. Temperature and electrolyte concentration were assumed to be fixed and an iterative technique was used to find the voltage that would produce the total load desired. The Newton-Raphson technique was applied to improve convergence.

The performance equations used for each fuel cell was of the form:

$$P_i = \frac{V}{a_i T_i + b_i} \left[V - c_i T_i - d_i - e_i \; (.73 - PKOH) \right]$$

where

P_i = power of module i
V = voltage of each module
T_i = temperature of each module
PKOH = fraction of electrolyte in solution

and

$$P_T = \sum_{i=1}^{n} P_i$$

where

P_T = total power required from Apollo EPS
n = number of fuel cell modules

or

$$P_T = \sum_{i=1}^{n} \frac{V}{a_i T_i + b_i} \left[V - c_i T_i - d - e_i \; (.73 - PKOH_i) \right]$$

Substituting into the Newton-Raphson technique, the voltage is determined as follows:

$$V_{j+1} = V_j + \frac{P_T - \sum_{j=1}^{n} \frac{V_j}{a_i T_i + b_i} \left[V_i - c_i T_i - d_i - e_i \; (.73 - PKOH) \right]}{\sum_{i=1}^{n} \left[2 \; V_j - c_i T_i - d_i - e_i \; (.73 - PKOH_i) \right] \frac{1}{a_i \; T_i + b_i}}$$

where

V_{j+1} = voltage at j+1 passes through load sharing loop

V_j = voltage at j passes through load sharing loop

When $\left| P_T - \sum_{i=1}^{n} P_i \right|$ is less than a specified tolerance, the voltage has been found which gives the required power.

4.0 SPECIAL ROUTINE OPTIONS

4.1 Flow Control Valves

A generalized capability is provided for analyzing systems with four types of control valves. Each of the valves, rate-limited bypass, polynomial bypass, proportioning, and shut-off is described in this section. Figures 6 and 7 show a typical deployment of the valves described together with the data input nomenclature for "from" and "to" tubes. In each case the valves are set in position at the end of a time increment by the sensor lump temperatures at that time.

For both the bypass and shut-off valves the equations (Section 3.4.3) generated for the determination of flow rate are changed by deleting the pressure drop equation and adding in its place the flow proportion caused by the valve. As an example consider a bypass valve in the system schematic of Figure 6. The equations which normally determine flow rate would contain the equation

$$\Delta P_3 = \Delta P_2 + \Delta P_6 + \Delta P_7$$

With the valve in operation this equation would be replaced simply by $\dot{w}_3 = \chi \dot{w}_1$, and the pressure drop would not necessarily be balanced.

A pressure balance is maintained across the proportioning valves as described below in paragraph 4.1.4.

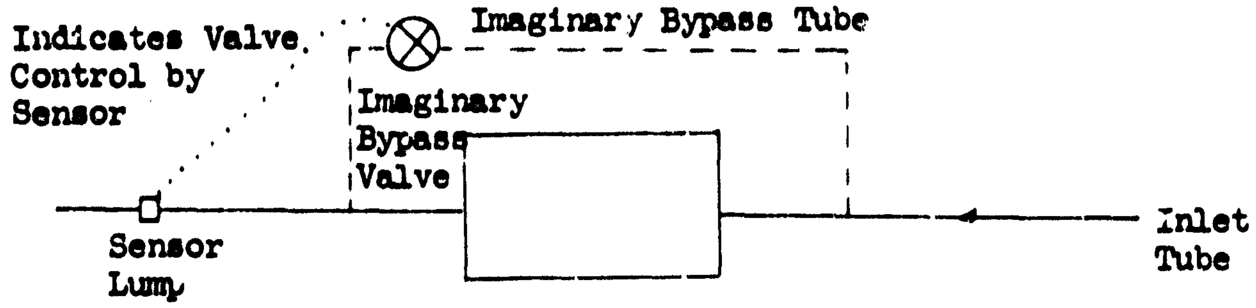
Any of these valves may be unused for a particular problem or part of a problem as determined by the program user. This feature enables the assessment of the system performance characteristics with and without the valves for a minimum of data input.

4.1.1 Rate-Limited Bypass Valve

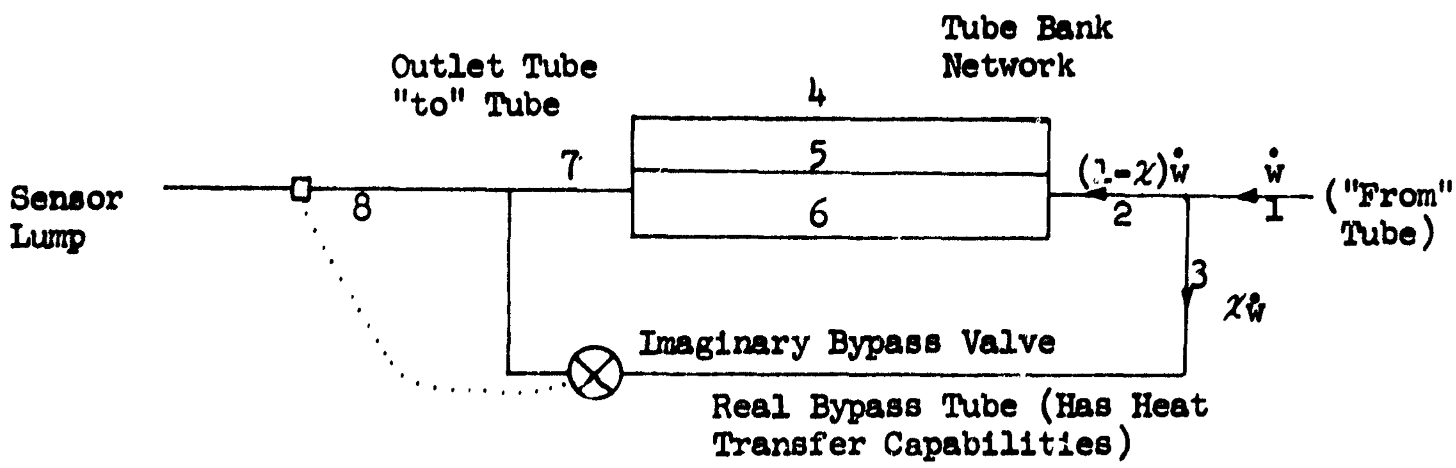
This valve is designed to proportion the flow branching from a single tube in such a way that the temperature at a designated sensor tube lump is constrained to a specified temperature if obtaining the temperature at the end of each time increment is within the valve response capability. The valve's position (fraction bypassed) is determined by integration of its velocity. The velocity is determined according to the difference between the sensor lump temperature after each iteration and the desired temperature of the sensor lump. The model for this velocity dependance is shown in Figure 8. This model was designed to represent an electromechanical bypass valve used during past radiator test programs. Since the valve is rate sensitive, a value for the time increment must be used for steady state solution even though it is physically meaningless.

4.1.2 Polynomial Bypass Valve

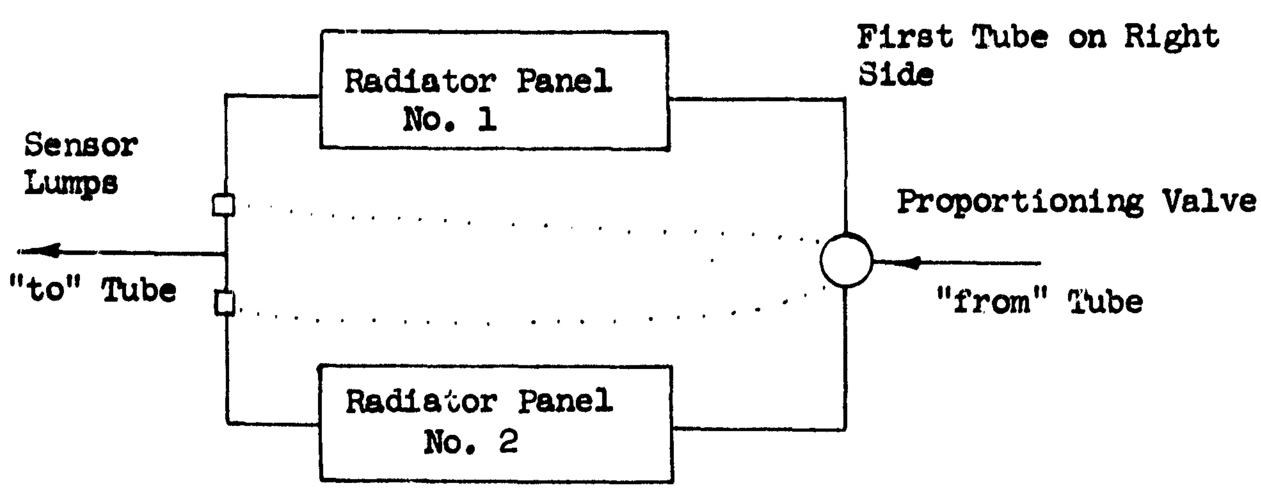
The polynomial bypass valve distributes the flow at a branch dependent on a specified temperature in the problem. The fraction bypassed



IMAGINARY BYPASS VALVE



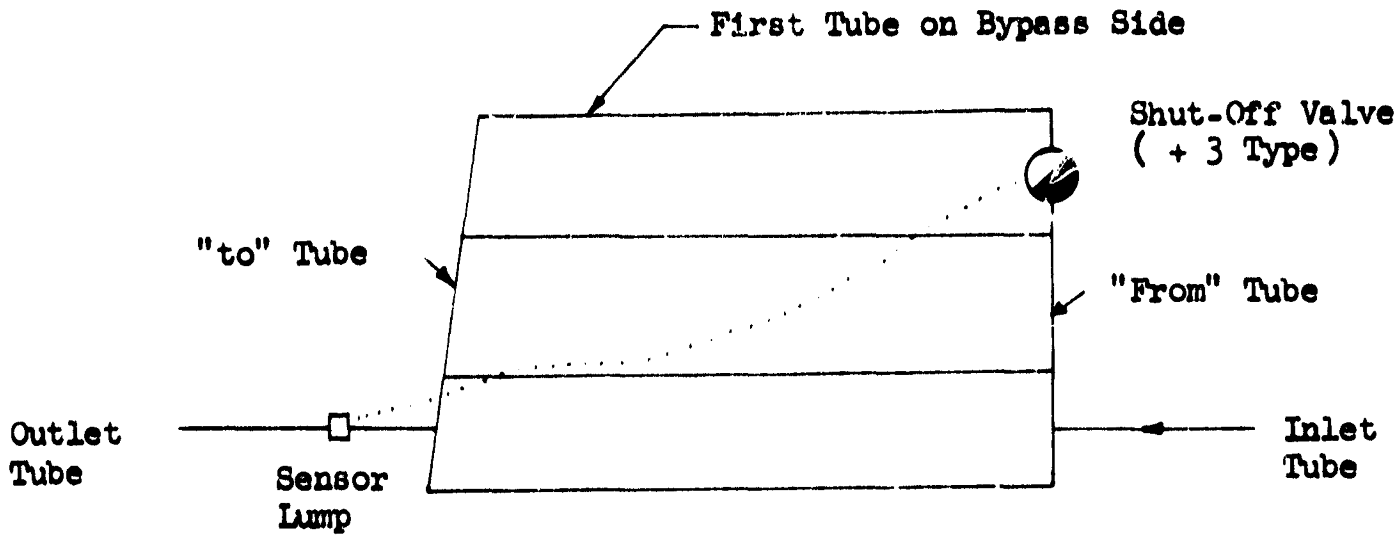
IMAGINARY BYPASS VALVE WITH REAL TUBE



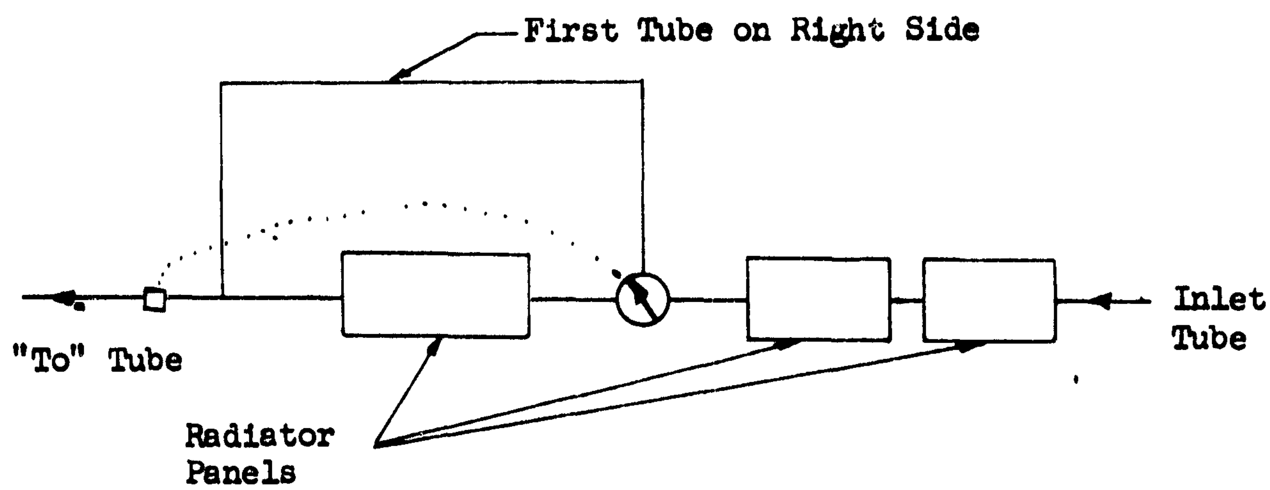
TYPICAL PROPORTIONING VALVE DEPLOYMENT

FIGURE 6

SCHEMATICS SHOWING TYPICAL VALVE DEPLOYMENT



TYPICAL SHUT-OFF VALVE DEPLOYMENT



TYPICAL SWITCHING VALVE DEPLOYMENT

FIGURE 7

SCHEMATICS SHOWING TYPICAL VALVE DEPLOYMENT

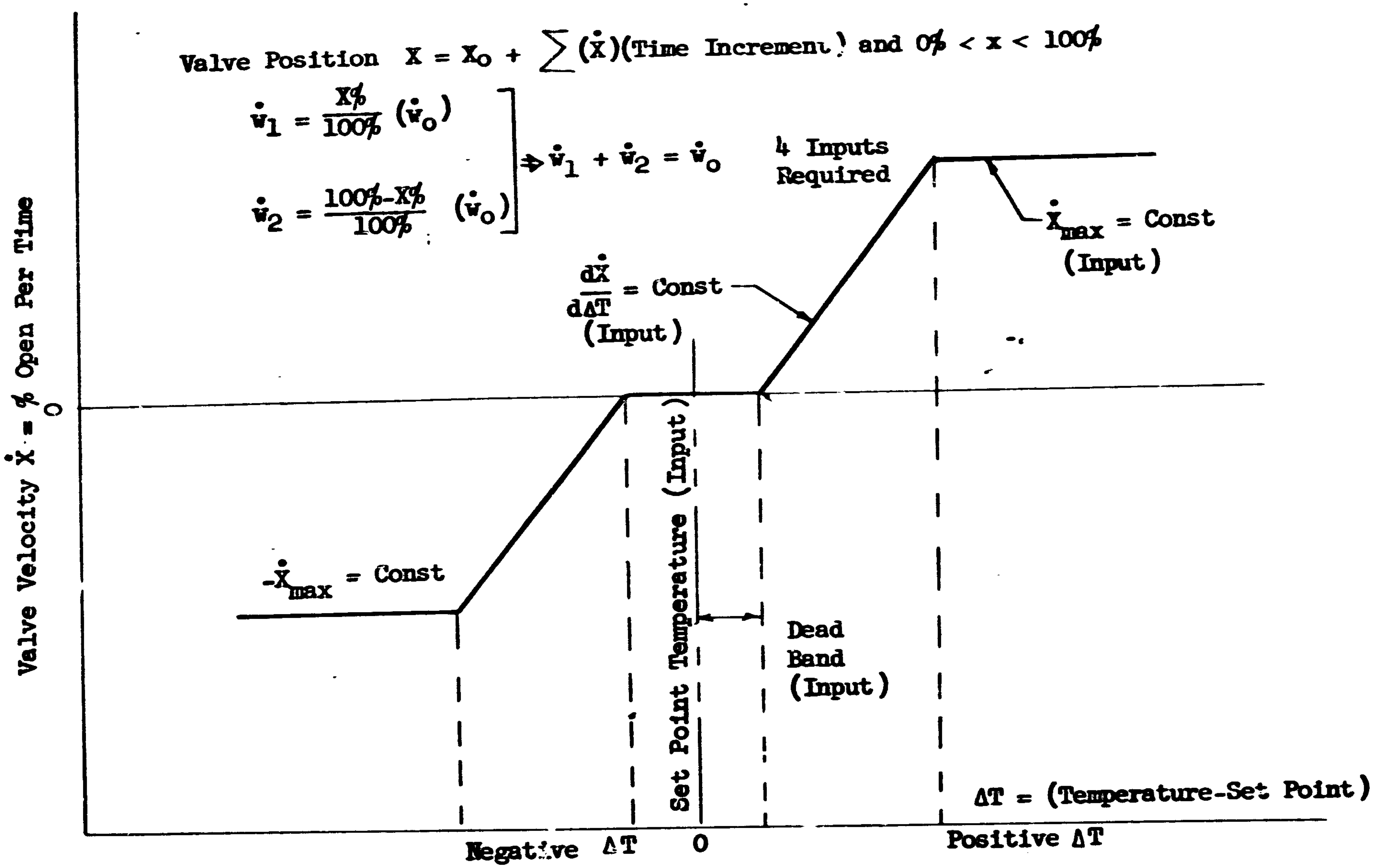


FIGURE 8

BYPASS VALVE OPERATION

is determined by a fourth order polynomial (x versus temperature) for which the coefficients are data inputs.

4.1.3 Shut-Off Valves

Three types of shut-off valves are available for use. The first and second merely are open or shut depending on a temperature in the system. The first closes when the selected temperature drops below a pre-arranged value and re-opens when that temperature exceeds a separate higher value. The second opens as the temperature falls below a first value and closes when a second value is exceeded. The third valve combines the first and second valve such that it switches the flow between two branches as a function of the two temperatures chosen.

4.1.4 Proportioning Valve

The proportioning valve is designed to respond in the direction of causing the flow in two parallel paths to exhaust at the same temperature. This arrangement is utilized to provide maximum heat rejection when two sides of a radiator system operate in a significantly different incident heat environment. The valve operates in a manner designed to reproduce characteristics of an actual valve used during radiator tests. The equation describing the operation of the valve is:

$$\chi = \chi_{previous} + \Delta\tau\,(\chi_i - \chi_{previous}) + \text{Valve gain}\,(T_{RT} - T_{LT})$$

where:

Valve gain is allowed as an input constant in the data.

$\Delta\tau$ = time increment

χ_i = initial valve position

χ = present valve position

T_{RT}, T_{LT} = temperature of sensors in right and left hand tubes

After the position χ is determined, it is used to define the pressure drops in each side of the valve through the relation:

$$\Delta P_{RT} = E\left[\frac{w_{RT}}{\chi_2}\right]^2$$

$$\Delta P_{LT} = E\left[\frac{w_{LT}}{\chi_1}\right]^2$$

E = proportionality factor ($= \frac{PPARA}{2\ GFACT}$ see Parameter Card 22 of data preparation)

$\dot{w}_{RT}, \dot{w}_{LT}$ = right and left flow rates

χ_1 = valve position from left

χ_2 = valve position from right

The valve pressure drops are considered together with the pressure drops in the remainder of the right and left hand flow paths to determine flow rates which give a pressure balance for both sides of the system. Considering the pressure drop of the radiator to be a linear function of flow rate, such that $\Delta P = K\dot{w}$, the pressure balance in the radiator and valve can be written as:

$$K_{RT}\,\dot{w}_{RT} + E\left[\frac{\dot{w}_{RT}}{\chi_2}\right]^2 = K_{LT}\,\dot{w}_{LT} + E\left[\frac{\dot{w}_{LT}}{\chi_1}\right]^2$$

where:

K_{RT} = ΔP of radiator right branch/right side flow rate

K_{LT} = ΔP of radiator left branch/left side flow rate

$\dot{w}_{RT}, \dot{w}_{LT}$ = right and left flow rates

The pressure drop equation may be solved for the left side flow rate by substituting $\dot{w}_{RT} = \dot{w}_{TOT} - \dot{w}_{LT}$.

$$E\left[\frac{1}{\chi_1^2} - \frac{1}{\chi_2^2}\right](\dot{w}_{LT})^2 + \left[K_{LT} + K_{RT} + \frac{2E\,\dot{w}_{TOT}}{\chi_2^2}\right]\dot{w}_{LT} = K_{RT}\dot{w}_{TOT} + \frac{E(\dot{w}_{TOT})^2}{\chi_2^2}$$

Denoting the coefficient of $\dot{w}_{LT}^2$ by (a), of $\dot{w}_{LT}$ by (b), and the constant term by (c), the $\dot{w}_{LT}$ may be put into the standard quadratic form.

$$\dot{w}_{LT} = \frac{-b + \sqrt{b^2 - 4ac}}{2a}$$

When χ_1 and χ_2 are different by less than a specified tolerance (VLVTOL, Card 22, Columns 31-40), the value of (a) will be small and the approximation $\dot{w}_{LT} = c/b$ is used.

4.2 HEAT EXCHANGERS

A heat exchanger option is provided in the program which will allow transient analysis of systems containing a heat exchanger. The heat transfer process is calculated in the following manner. First the data input designates certain lumps to be heat exchanger lumps and indicates whether they are on the cold side of the exchanger and if so, the numbers of the adjacent hot side lumps. For lumps in the heat exchanger, the heat transfer calculations are performed as if the hot side tube lump exchanges heat with both hot and cold side fluid lumps. The cold side tube lump does not participate in the thermal exchange except to provide necessary information, such as heat transfer area to cold side fluid lump. Given the following information, the heat transfer rates may be calculated.

Denoting the position by subscript and time by superscript, the energy balance equation for the hot side tube lump is

$$w_{Tj} c_{Tj} \frac{T_j^{i+1} - T_j^{i}}{\Delta \tau} = (h_f A_{HT})_{cold} (T_{f_{cold}\,j}^{i} - T_j^{i}) + (h_f A_{HT})_{hot} (T_{f_{hot}\,j}^{i} - T_j^{i})$$

$$+ U_+ (T_{j+1}^{i} - T_j^{i}) + U_- (T_{j-1}^{i} - T_j^{i}) + \sum_K U_{jK} (T_K^{i} - T_j^{i})$$

h_{cold}	- cold side heat transfer coefficient
h_{hot}	- hot side heat transfer coefficient
$A_{HT\ cold}$	- cold side area for heat transfer
$A_{HT\ hot}$	- hot side area for heat transfer
$w_t\ c_t$	- weight of hot side tube lump x specific heat
U_+	- conductance of hot side tube lump to downstream lump
U_-	- conductance of hot side tube lump to upstream lump
U_{jK}	- conductance to any other tube or structure lumps

This equation is used to solve for T_j^{i+1}. The cold tube temperature merely follows the cold fluid temperature and has no meaning. Each of the fluid temperatures, hot and cold, is determined in the same manner as for other lumps except that the cold fluid lump transfer is from the hot tube temperature rather than the cold tube temperature.

The solution thus determined is quite general in application potential, allowing either counterflow or parallel flow and unmixed cross flow. However, certain precautions should be observed. (1) The mass and longitudinal conduction area of the entire exchanger should be input for the hot side tube lump alone. The mass of cold side tube lump does not enter the problem. (2) The area for heat transfer to the enclosed fluid lump must be entered properly for the cold tube lump. (3) No conduction data for conduction between hot and cold tube lumps should be used. Essentially the cold tube lumps do not participate in the heat exchange, since the heat exchanger characterization is one in which one tube lump transfers heat with two fluid lumps. The second tube lump (cold side, by convention) is retained to enable independent specification of parameters determining pressure drop in and heat transfer from the cold fluid lump.

Three options are available to the user to determine the heat transfer coefficient in heat exchanger lumps, (1) the coefficient may be determined as per the normal flow-in-tube equations used for all other lumps, (2) a curve of heat transfer coefficient versus flow rate may be input as curve data, (3) a curve of Stanton number x (Prandtl number)$^{2/3}$ versus Reynold's number may be input from which the heat transfer coefficient may be determined. These data options permit a maximum of variety for the user's convenience.

A sufficient number of lumps should be used in any heat exchanger to prevent a lower than desired heat exchanger effectiveness. A limitation on effectiveness results because of the finite difference method of calculation for tube and fluid lumps. As an example of the limitation which could occur for a counter flow heat exchanger, the maximum effectiveness for the finite difference characterization is given by:

$$\epsilon_{max} = \frac{\left(2 - \frac{M_1C_1}{M_2C_2}\right)^n - 1}{\left(2 - \frac{M_1C_1}{M_2C_2}\right)^n - \frac{M_1C_1}{M_2C_2}}$$

or if $M_1C_1 = M_2C_2$

$$\epsilon_{max} = \frac{n}{n+1}$$

where

n = number of lumps in heat exchanger in the flow direction
M_1C_1 = mass flow rate times specific heat for side 1
M_2C_2 = mass flow rate times specific heat for side 2

For a counter flow heat exchanger, n becomes large as ϵ_{max} approaches 1.0.

4.3 KNOWN HEAT LOAD

An option was provided for calculation of steady state radiator fluid inlet and outlet temperatures for a fixed geometry radiator rejecting a specified heat load. The computer routine data input includes the known heat load value, the radiator surface emissivity and area, and an initial value of fin effectiveness and fluid specific heat. Using this data an average radiator temperature is calculated by

$$T_{avg} = \left[\frac{Q}{\eta \epsilon \sigma A}\right]^{1/4}$$

The radiator inlet temperature is then calculated by $T_{in} = T_{avg} - Q/\dot{w}\, c_p$. The difference between the known heat load and the load calculated with the first value of inlet temperature is tested for sign. If the calculated Q value is less than the known heat load, the radiator inlet temperature is raised by 10°F (or by the overriding value specified in the input data). On subsequent calculations, if the calculated heat rejection exceeds the known heat load, the inlet temperature is decreased by 1/2 of 10° (or the data input value). When subsequent calculated heat rejection values fall below the known heat load, the temperature is raised by 1/2 of the past step changes, thus providing a rapid convergence to the inlet and outlet temperatures which match the given heat load. The program user may input a tolerance for matching the iterated load to the given heat load to terminate the computations. The user can also specify the maximum number of iterations which will be permitted for a solution.

4.4 RESTART

Provisions for problems requiring extended computer time have been made in that a dump tape is written from which the run may be continued if all conditions of the problem are not satisfied (i.e., transient time not achieved). The problem may also be dumped by the user even if specified conditions are satisfied, and then restarted from the dump tape at a later date. This latter option is particularly useful for examining the output of a long problem after a short initial period to determine whether the data has been input properly. The detail instructions on the use of the restart option are given in paragraph 5.3 of the data preparation.

4.5 TIME INCREMENT SELECTION

Several options were programmed into the routine to provide alternate methods for computing the problem time increment. These options can increase the speed of the problem solution without loss of accuracy when properly used. The use of the time increment in the finite difference equations is shown and the various computing options are described.

The basic finite difference equations (paragraph 3.1) may be written in a general form as:

$$T_j^{i+1} = T_j^{\,i} + \frac{\Delta\tau}{w_j c_j}\left[\sum_K U_{jK}(T_K^{\,i} - T_j^{\,i}) + Q - B_j(T_j^{\,i})^4\right].$$

The subscript denotes lump number, the superscript time.

- $\Delta\tau$ = time increment
- w_j = weight of lump j
- c_j = specific heat of lump j
- U_{jK} = coefficient of energy transfer between j and K
- Q = heat added to lump
- B_j = radiation coefficient

Further, in Section 3.2 it was demonstrated that the maximum time increment for which iterations of the equation above would remain stable is:

$$\Delta\tau = \frac{\Theta\, w\, c}{\sum_K U_{jK} + B_j(T_j^{\,i})^3} \qquad \Theta \text{ (convergence factor)} \le 1.0$$

If $T_j^{\,i}$ is set to $T_j^{\,i+1}$, the temperature of lump j may be solved for its steady state value. The finite difference equation may be written:

$$\sum_K U_{jK}\,(T_K^{\,i} - T_j^{\,i+1}) + Q - B_j\,(T_j^{\,i+1})^4 = 0$$

$$T_j^{i+1} = \frac{\sum_K U_{jK}\, T_K^{\,i} + Q}{\sum_K U_{jK} + B_j\left[T_j^{\,i+1}\right]^3}$$

Substitution of the $\Delta\tau$ from the convergence criterion into the finite difference equation yields:

$$T_J^{i+1} = T_J^i + \frac{\theta}{\sum_K U_{JK} + B_J(T_J^i)^3}\left[\sum_K U_{JK}(T_K^i - T_J^i) + Q - B_J(T_J^i)^4\right]$$

$$T_J^{i+1} = T_J^i\,(1 - \theta) + \theta\;\frac{\sum_K U_{JK}\,T_K^i + Q}{\sum_K U_{JK} + B_J(T_J^i)^3}$$

The term on the right is by inspection exactly θ times the steady state value of temperature except that T_J^i instead of T_J^{i+1} is in the denominator. For most cases, these two are not greatly different, such that T_J^{i+1} will be approximately $(1 - \theta)$ of the previous temperature and θ of the steady state value at time i. For cases, such as fluid lumps, where radiation is non-existent, this relation is exact.

For lumps in a problem with very short time increments the time increment may be substituted into the respective difference equation and that particular lump will assume steady state with respect to its surroundings at each iteration. The value of θ is retained in the calculation to insure that the non-linearity will not cause instability. The "floating" or steady state lump may be employed in several manners in the routine:

(1) No lump's time increment will be overridden, such that the shortest of all the time increments will be used for each node.
(2) All lumps whose time increments are shorter than a specified minimum time increment will be "floating" and will assume steady state as described above at every time increment. Lumps with longer time increments will use the minimum time increment in the finite difference equation.
(3) All fluid and tube lumps will be considered "floating" using the steady state approximation, and all structure lumps will be surveyed to determine the smallest time increment, which is then used in all structure lump finite difference equations. This option is attractive only when the mass of fluid and tube lumps is very small as is the case in many radiator problems.
(4) All lumps will use the "floating" steady state approximation and the equations will be iterated without regard to time. In this iterative option the solution is only steady state but a time increment must be input to control the operation of the rate sensitive bypass valve.

4.6 CHECKOUT PRINT

The routine user may select the checkout print option which will give a detailed print at each iteration. The checkout print provides a direct, relatively simple check of the data input consistency, and indicates the time increments calculated for each lump. The check of data consistency may be performed by examining values of weight, conductance, and other quantities which are known o have recognizable symmetries and variations in the problem. One may survey the time increments and pick the value of a minimum time increment which will accurately characterize the transient and only override those lumps which realistically can be considered at steady state compared to their neighbors. An explanation of the terms of the check out print is included in paragraph 6.3.

4.7 FLUID FREEZING

An option is provided to analyze stagnant or frozen fluid lumps. The option operates in the following manner. The flow in each radiator tube is tested against a minimum flow rate which is specified in the data input. If the flow drops below this minimum flow rate, the fluid is considered to be stagnant in the tubes. Conduction data which was previously input is then used to compute fluid lump to fluid lump conduction and fluid to tube conduction. The change of phase of a fluid is accounted for in an input curve of specific heat versus fluid temperature.

In order to judge when a tube should be considered flowing after the fluid begins to thaw, a flow rate is computed at every iteration based on the fluid lump temperatures in each tube. If the calculated flow is higher than the specified minimum flow, the tube is considered to be flowing again.

4.8 CLOSED LOOP OPTION

A closed loop option is available to use when the fluid loop is continuous. The fluid temperature leaving the last lump in the last tube in the system is merely input to the system inlet, thus closing the loop.

4.9 FLOW BALANCE OPTIONS

Several methods of specifying the fluid flow have been found to be of use. Normally one will specify the total flow of a system and require that the flow will be such that a pressure balance is maintained in all parallel flow paths. This option is designated NFD = 0 (page 70) and is suitable for any flow network (i.e., banks and headers and parallel flow, steady state or transient).

In certain instances it may be desirable to use predetermined flow rates in parallel flow systems and not balance pressure drops. This can be useful when attempting to establish thermal verification of test results. Two such options are available. With NFD = 1, the flow rates of each tube are input as functions of time and with NFD = 2, the flow rates of each tube are specified independently as constant percentages. The total of the flows remains the total flow with NFD = 2, but flow is allowed to bypass the radiator, thus reducing proportionately the flow in each tube.

In many systems, the total system flow is not independent of the thermal solution but is dependent on the operation characteristics of a pump. This option (described in paragraph 3.4.4) is available for the user's choice as NFD = 3 (page 70). If multi-system problems are run each system will require its own pump curve. Except for the selection of total flow rate, NFD = 0 and NFD = 3 operate identically.

4.10 LIQUID SEPARATOR

An option is provided whereby the user may designate a fluid lump as a liquid separator lump. The liquid separator lump reduces the total flow rate by an amount equal to the liquid flow rate into it; thus $\dot{w}_L = 0$. out of liquid separator lump.

4.11 INLINE HEATER

The capability to simulate an inline heater for any fuel cell system has been provided in the routine. The heater control is assumed to be an on-off control with a constant deadband. The inline heater is simulated by allowing the specified tube lump to receive the heat produced by the heater element when the sensor fluid lump is below the minimum sensor temperature. The routine logic permits the heater to perform as follows:

(1) When the heater is off it will remain off until the sensor lump temperature drops below the minimum sensor lump temperature.

(2) When the heater is off but the sensor lump temperature drops below the minimum, the rate of heat produced by the heating element (input) is added to the inline heater tube node. The heater power is also added to the input fuel cell total power and this sum is used for determining fuel cell performance.

(3) When the heater is on it will remain on until the sensor lump temperature rises above the heater off temperature. When this occurs, the heater will go off and the heater power will no longer be added to the fuel cell total power.

The required input for the inline heater are the following:

(1) Heater power

(2) Heater tube lump

(3) Sensor fluid lump

(4) Heater on temperature

(5) Heater off temperature

4.12 EDIT

The large number of data cards required for problems run on this routine presents three problems: (1) increased probability of operator and/or card reader error, (2) increased probability of a card reader jam, and (3) significant extra time required to read in data from the card reader when problem (2) occurs. For these reasons a routine was developed for reading input data from tape with the capability for modifying the data on read-in.

The EDIT routine is called by parameter INDATA input in columns 61 and 62 on parameter card 2. Possible inputs are:

(1) INDATA = 0, All data is supplied on cards.

(2) INDATA = 1, All data is supplied on cards and the card images are written on tape on unit B. (Should be specified as an output tape on job card)

(3) INDATA = 2, Use data input on tape on unit C with desired changes on cards to write a new data tape on unit B. (C is input tape and B is output tape)

(4) INDATA = 3, Use the data read in from unit B without change. Parameter cards 1 and 2 are read in from cards. (B is input tape)

When INDATA = 2, the deck set-up consists of parameter cards 1 and 2, the EDIT control cards (described below), and the new data cards (with the same format as the cards being replaced).

The EDIT control cards, used only when INDATA has a value of 2 are:

Col	Format	Name	Description
1-5	I5	K3	Card number K3 will be either removed or pushed down depending upon the contents of the next two fields (K4 and K5). If K3 is greater than the number of cards on the tape plus 10000, no edit will be performed.
6-10	I5	K4	K4 must be equal to or greater than K3 or must be left blank. If K4 > K3, cards numbered K3 to K4 inclusive will not be transferred to the new data tape on unit B. If left blank no cards will be deleted.
11-15	I5	K5	If not blank or zero, K5 cards, which must immediately follow this edit control card will be inserted ahead of card K3 or in place of cards K3 through K4.

Giving K3 the value of 99999 will cause the continuing transfer of card images from Unit C to Unit B until a card image containing bbbl3b(b = blank) in columns 1-6 is found. The unit C tape is not altered in any way should there be errors in the edit deck which cause fatal errors in the LTV program. It is the responsibility of the user to maintain extra copies of the data tape and/or an up-to-date card deck.

5.0 DESCRIPTION AND USE OF COMPUTER ROUTINE

5.1 DESCRIPTION

This computer routine was written in Fortran IV for the Univac 1108 computer having a core storage capacity of 65,536 words and a minimum of eight magnetic tape units. To use certain options of the routine requires as many as three additional tape units. The program makes use of the chain feature of Fortran IV in order to minimize the amount of core storage required and still provide a large data block. The first four chain links read, process, and store the data in a packed data block, and the fifth chain executes the main program. The operations performed by each chain and its corresponding subroutines are outlined briefly in the following paragraphs.

5.1.1 Chain 1

1. Reads the first two data cards and stores all of the first card for a heading to be printed at the top of every page of output. Stores the parameters on the second card and begins writing description of the problem.

2. Tests the re-start code. If it is zero, the data processing will be continued by Chain 1 as described in the following paragraphs. If it is not zero, this indicates that all data is from the dump of a previous problem. Chain 1 reads tape NDPT. NVLVRS is tested and Parameter Cards 20 and 22 are read as needed. Chain 5 is called to begin calculations.

3. Calls Subroutine EDIT which makes required changes to the data input tape. Data cannot be changed by EDIT when the problem is restarted from a dump tape.

4. Reads the third card, stores the parameters, and continues writing the description of the problem, listing the options indicated on this card.

5. If fluid flow is indicated, reads the fourth card and stores and writes the heat transfer coefficient factor.

6. If the tubes are arranged in parallel and if more than one system is to be analyzed, reads the fifth card and as many additional cards as needed to supply the number of tubes in each system.

7. If the tubes are arranged in banks and headers form, reads the sixth card and as many additional cards as necessary to furnish the number of flow paths in each system. Reads and writes the seventh card and as many additional cards as needed to supply a list of the flow paths.

8. Reads the eighth card and as many additional cards as necessary and stores the molecular weight ratio, the two-phase flow option, and the curve numbers of entering flow rate of gas curve, entering flow rate of liquid curve, and entering pressure of gas for each system.

9. Reads the ninth card and as many additional cards as needed to supply a closed loop code for each system.

10. If a steady state solution involving parallel fluid flow is indicated, reads the tenth card and as many other cards as necessary to supply an inlet temperature for every tube in every system.

If a steady state solution involving banks and headers fluid flow is indicated, reads the eleventh card and as many other cards as needed to furnish an inlet temperature for the first tube in each system.

If a transient solution involving parallel fluid flow is indicated, reads the twelfth card and as many additional cards as needed to supply table numbers for the inlet temperature of each tube in each system.

If a transient solution involving banks and headers fluid flow is indicated, reads the thirteenth card and as many additional cards as necessary to furnish a table number for the inlet temperature of the first tube in each system.

11. Reads the fourteenth, fifteenth, sixteenth, or seventeenth card according to the flow control option indicated.

12. Reads the eighteenth card if the flow control option indicates it is needed.

13. If a gradient solution is indicated, reads the ninteenth card supplying curve numbers, temperature factor, and density needed for the structure.

14. Reads the twentieth, twenty-first and twenty-second cards according to the valve options if valves are used. These cards supply valve parameters.

15. Calls subroutine SUBP to write the page heading, count lines, skip pages, and increment the page count.

16. Calls subroutine RESET, CLOCK, and WCLCL to read the computer clock and accumulate the time usage in the chain link. RESET and CLOCK are called to determine the initial time entered and the present time; then WCLCK is called to determine elapsed time. Dummy subroutines may be used if desired.

17. Chain 1 calls Chain 2 if fluid flow is indicated and Chain 3 if fluid flow is not indicated.

5.1.2 Chain 2

1. Calls subroutine SUBA to read, write, and store all of the fluid lump data.

2. Calls subroutine SUBB to read, write, and store all of the tube lump data.

3. Calls subroutine SUBP to write the page heading, count lines, skip pages, and increment the page count.

4. Calls subroutine RESET, CLOCK, and WCLCK to read the computer clock and accumulate the time usage in the chain link.

5. Writes the amount of data space used by the parameter data and the fluid data.

6. Writes the amount of data space used by the parameter data, fluid data, and tube data combined.

7. If a nodal solution is indicated, calls Chain 3.

8. If a gradient solution is indicated, calls Chain 4.

5.1.3 Chain 3

1. Reads, stores, and writes the structure lump data.

2. Calls subroutine SUBP to write the page heading, count lines, skip pages, and increment the page count.

3. Calls subroutines RESET, CLOCK, and WCLCK to read the computer clock and accumulate the time usage in the chain link.

4. Writes the amount of data space used including the structure lump data.

5. Calls Chain 4.

5.1.4 Chain 4

1. Reads, writes, and stores all the curve data.

2. Checks to see that all required curves are given.

3. Calls subroutine SUBI which reads the input required, computes, stores, and writes the gradient table provided that

(a) a gradient solution is indicated,
(b) the parameter data indicates that a gradient table should be computed by the routine, and
(c) another gradient table was not included in the data.

4. Calls subroutine SUBP to write the page heading, count lines, skip pages, and increment the page count.

5. Calls subroutines RESET, CLOCK, and WCLCK to read the computer clock and accumulate the time usage in the chain link.

6. Writes the amount of data space used including the curve data.

7. Calls Chain 5.

5.1.5 Chain 5

1. Evaluates the heat balance equations for the various types of lumps.

2. If a known heat load problem is indicated, inputs the known heat load data.

3. Calls the following subroutines as needed:

(a) Subroutine SUBP to write the page heading, count lines, skip pages, and increment the page count.
(b) Subroutines RESET, CLOCK, and WCLCK to read the computer clock and accumulate the time usage in the chain link.
(c) Subroutine START which calls Chain 1 and a new problem if the data exceeds the allowable data space.
(d) Subroutine POL which does table look-up and straight line interpolation.
(e) Subroutine TRPOL which does table look-up and straight line interpolation for the three dimensional tables.
(f) Subroutine SUBWT which converts a block of temperatures from absolute Rankine to Fahrenheit and back to absolute Rankine.
(g) Subroutine SUBEND which writes the flow rates and pressure drops and computes and writes the power requirement, total heat rejected, and the radiator structure and fluid weight.
(h) Subroutines CHECK and SURVEY find and search all time-dependent tables so in a transient problem time can be updated to minimum point at which any table value changes.
(i) Subroutine SUBDP which initializes flow rates and inlet temperature for certain flow control options. SUBDP computes the pressure drop for each tube, the flow control code and adjusts the flow rate as required. SUBDP analyzes the valves and adjusts flow rates accordingly, recalculating pressure drop. SUBDP adjusts total flow in each system according to the pump curve, if present, and recalculates pressure drop. SUBDP tests for freezing and recomputes pressure drop and flow rate when freezing occurs.
(j) Subroutine REVPOL which does a reverse table look-up and straight line interpolation.
(k) Subroutine FLARAN which arranges the fluid lumps into a physical order rather than a numeric order.
(l) Subroutine SUBFC to perform a heat and mass balance on the fuel cell.

4. Tests the temperature change for every lump. If a steady state solution is indicated and the change for all lumps is less than the value of SSTEST multiplied by the lump absolute temperature, the steady state condition has been reached and the solution is ended. If a transient solution is indicated, the time is tested and the solution is ended when the total time for transient is reached.

5. Tests the computer time usage and ends the solution if the requested time is exceeded.

6. If the solution is ended before completion or if the dump option is used, writes the entire data block and the variable block on tape IDPT so that the problem can be restarted.

5.2 DATA PREPARATION

An explanation of the input data is presented in this section of the report. Where applicable, the inputs are referenced to page numbers in the analytical methods portion of the report.

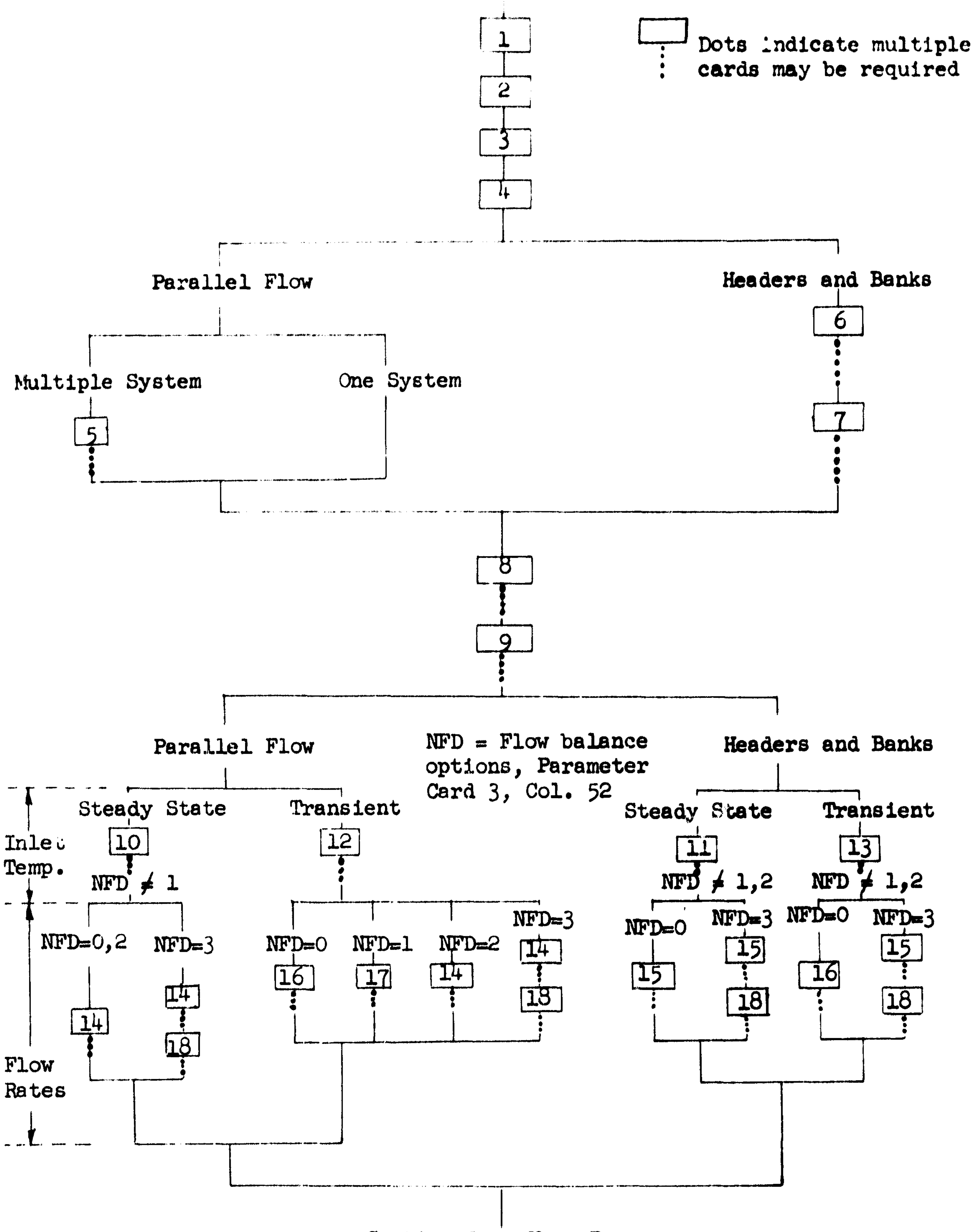
The data input is described in terms of seven sets of cards (1) Parameter Cards, (2) Fluid Data Cards, (3) Tube Data Cards, (4) Structure Data Cards, (5) Fuel Cell and Inline Heater Cards, (6) Curve Data Cards, (7) Gradient Table Computation Cards, and (8) Known Heat Load Cards. The preparation of these cards is described in paragraphs 5.2.1 through 5.2.8, respectively.

Although the twenty-seven parameter cards determine almost all of the computing options, many are not required for any one particular problem. A flow chart in Figure 9 shows which parameter cards are required for the basic routine options and is intended to supplement paragraph 5.2.1.

The thermal conduction data which is read in as part of the fluid, tube and structure cards is explained on pages 83 through 84 which have been inserted between the parameter card description and the fluid, tube, and structure card description.

A five column field is used for all data unless otherwise specified. Integers should be right adjusted within the field. The option codes are one digit, usually "0" or "1". An "0" need not be punched as blanks are read as zero. The integer format is designated simply as "I".

Unless otherwise stated, the fixed point format specification is F5.2. That is, if the decimal point is not written, it is assumed to be between the third and fourth columns of the five column field. A decimal point may be written in any column of the field and its position will override the indicated position in the format specification. The fixed point format is designated simply as "FP".



Continued on Next Page

FIGURE 9

PARAMETER CARD REQUIREMENTS

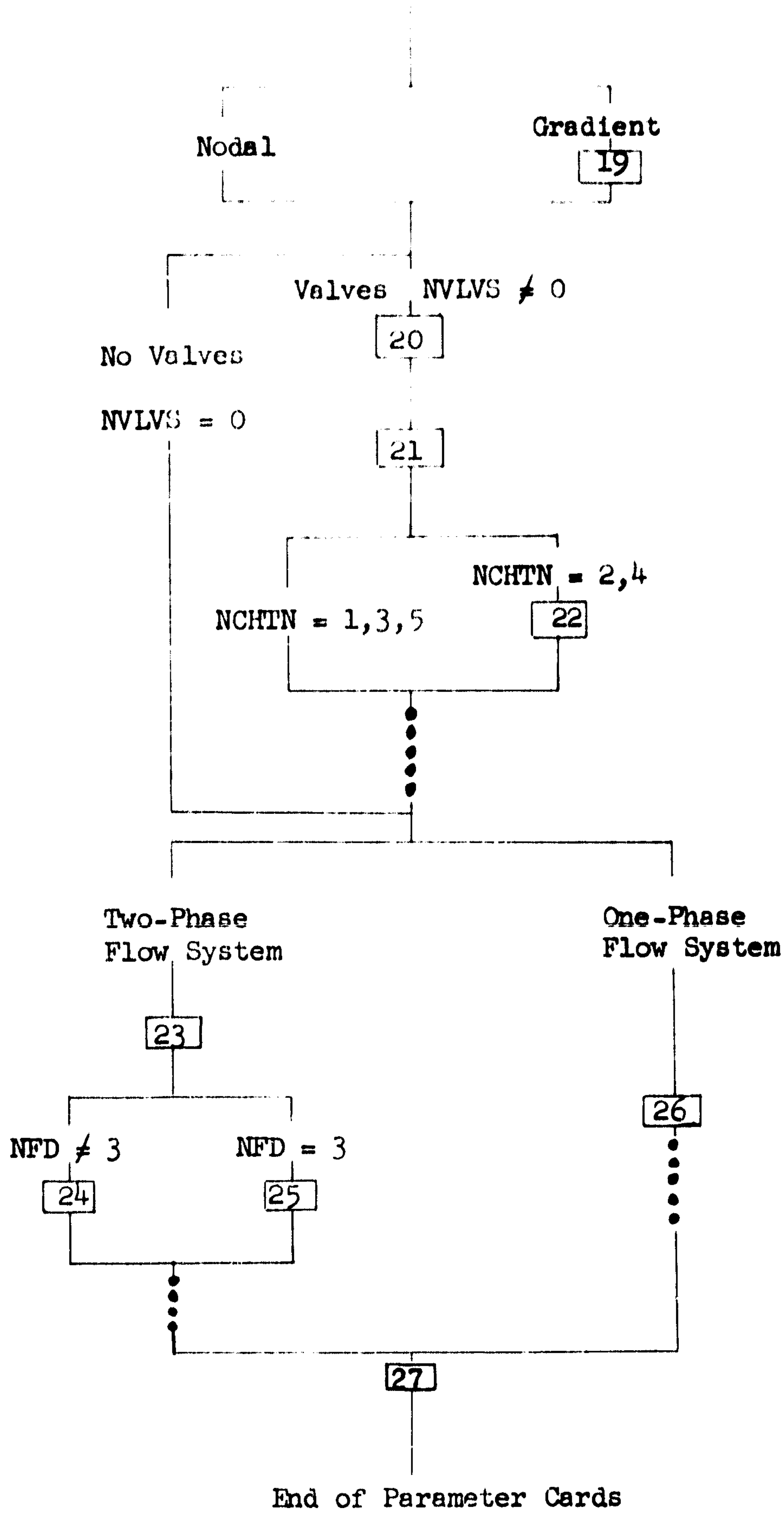


FIGURE 9 (Continued)

PARAMETER CARD REQUIREMENTS

5.2.1 Parameter Cards

Card 1

Any 72 alphanumeric characters which are desired can be printed at the top of every page of output. Columns 1 through 72 will be read and printed. Any part or all of the card may be blank.

Card 2

Columns	Fortran Nomenclature	Form	Description	Analysis Page Reference
1	INDATA	I1	= 0 All data supplied on cards = 1 Write card images on Unit B = 2 Use Cards with C to update B = 3 Use B without edit	
2-6	BLANK			
7-20	TINCMN	FP	Minimum time increment if NCC = 1 (Col. 37). Time increment for valve operation if NCC = 3.	55
21-23	NVLVRS	I	Valve restart code: If I_{start} = 0 (Col. 38), NVLVRS = 0 If I_{start} ≠ 0, the number of valves having parameters to be changed.	46 and 54
24-25	KHEAT	I	= 0, not a known-heat load problem. > 0, number of known heat load variations to be run with this set of data.	54
26-30	ISET	I	Data set number. May be any number except for the first set which must be 00001 (or 1 in column 30).	
31-35	RTIME	FP	Requested computer time for this set of data. The problem will be written on a dump tape for re-starting if this time is exceeded (minutes).	
36	Blank			
37	NCC	I	= 0, Survey all lumps to determine the smallest time increment which will then be used as the transient time step for all lumps. = 1, Minimum time increment supplied (Col. 20). Lumps with time increments smaller than minimum time increment will be considered steady state. All other lumps use the minimum time increment.	55

Columns	Fortran Nomenclature	Form	Description	Analysis Page Reference
37 (cont'd)	NCC	I	= 2, each fluid and tube lump will be considered steady state. The smallest structure lump time increment will be used for the transient time interval.	55
			= 3, each fluid, tube, and structure lump will be considered steady state. Equations are iterated to determine steady state answer. Do not use for a transient problem.	
38	ISTART	I	0, This problem has not been run before. New data follows. 1, The data for this problem is to be read from the dump tape. 2, Skip over this problem on the dump tape. It is not to be re-started.	54
39	NFLXCD	I	= 0, Incident heat flux on cards ≠ 0, Incident heat flux applied on input tape	
40	IDUMP	I	0, Do not dump this problem for re-starting. 1, Dump this problem for re-starting at a later time if conditions such as TAU (Col. 45) or SSTEST (Col. 70) are satisfied.	54
41-45	TAU	FP	= 0, A steady state solution is desired. ≠ 0, The total time for a transient solution (hours),	
46-50	DELTAU	FP	= 0, Print only at end of every hour if problem time is greater than one hour. ≠ 0, Print interval (hours).	
51-55	MAXI	I	Maximum number of iterations for a steady state solution. Routine sets to 10,000 if left blank.	
56-60	THETA	FP	Convergence factor. Routine sets to .9 if left blank. Use 0.5 if NCC = 3 (Col. 37).	55

Columns	Fortran Nomencla- ture	Form	Description	Analysis Page Reference
61-70	SSTEST	FP F10.9	Steady state testing factor. Routine sets to .000001 if left blank.	26
71	NCKOUT	I	0, Print under control of print interval. 1, Provide checkout printing during every iteration and regular print at end of each time interval.	57
72	NREG	I	= 0, Not heat exchanger problem ≠ 0, Heat exchanger problem.	52
73-75	IPLOT	I	= 0, A Plot tape will not be written ≠ 0, Number of iterations between each plot interval	
	Card 3			
1-5	NTUBE	I	Total number of tubes in all systems.	
6-10	NTFL	I	Total number of all fluid lumps.	
11-15	NTML	I	Total number of all tube lumps.	
16-20	NSL	I	= 0, A gradient solution ≠ 0, The number of fin lumps for a nodal solution.	11
21-25	NSYS	I	Number of systems. Routine sets to one if left blank.	
26-30	MAXTB	I	Number of tubes in system that has greatest number of tubes of any system. Maximum value is 102.	
31-35	TIME	FP	Time in hours. Usually will be left blank but may be input for beginning a transient problem at some particular point on the time dependent tables. Do not set greater than TAU (Card 2, Col. 41).	
36-40	NVLV	I	Number of valves.	46
41-42	NAVTC	I	= 0, Use $(T_{fu}+T_f)/2$ for equation (14) page 15. Check stability criteria for A_f, page 19 before using this option. Two-phase flow will not average fluid lump temperatures. = 1, Use T_f in equation (14) page 15.	15

Columns	Fortran Nomencla-ture	Form	Description	Analysis Page Reference
43-44	KODFC	I	= 0 No fuel cells will be considered ≠ 0 Fuel cells will be considered	
45-46	MGTC	I	For gradient problems only. = 0, Gradient curve in data. = 1, Compute gradient curve. = 2, Read gradient table from binary tape.	Appendix A
47-48	NPFC	I	= 0, Parallel flow. ≠ 0, Banks and headers flow.	27 29
49-50	NFC	I	= 0, Do not consider freezing. ≠ 0, Consider a tube to be frozen if the flow rate is less than FMIN (Col. 70).	57
51-52	NFD	I	= 0, The flow rates are adjusted in subroutine SUBDP to maintain equal pressure drops in parallel flow paths. If a transient problem, the total flow is read in as a function of time (Card 16). At each time interval, the total flow is found from the $\dot{w}$ versus time curve. If a steady state problem, parallel flow, the flow rate of each tube is input (Card 14) and summed for total flow. If a steady state problem, banks and headers flow, the total flow in each system is input (Card 15). = 1, Use only for transient parallel flow. The flow rate of each tube is a function of time (Card 17). The pressure drops in the tubes are computed for the print-out but the flow rates are not adjusted. Use of bypass valve not allowed. = 2, The flow rates of each tube are read in (Card 14) and remain proportional. The pressure drops will be computed for print-out. Each flow rate is bypassed proportionately when a bypass valve is used.	53

Columns	Fortran Nomencla-ture	Form	Description	Analysis Page Reference
51-52 (cont'd)	NFD	I	= 3, Pressure drop is computed and the total flow as a function of pressure drop is found from the $\dot{w}$ versus ΔP curve (Card 18). For either steady state or transient problems. If parallel flow, the initial flow rate of each tube is read in (Card 14) and summed for total initial flow. If banks and headers flow, the flow in each system (Card 15) is read as total initial flow.	58
53-55	Blank			
56-60	HUMID		Initial Humidity estimate	
61-70	FMIN	FP F10.9	Minimum flow, lb/hr, of a tube before freezing. If NFC ≠ 0 (Col. 50) any tube will be considered frozen if the flow rate drops below FMIN.	57

Card 4 (Heat transfer coefficients for fluid flow)

Columns	Fortran Nomenclature	Form	Description	Analysis Page Reference
1-5	HI1	FP F5.4	Heat transfer coefficient factor.	24

Card 5 (For parallel flow, if NSYS > 1)

Columns	Fortran Nomenclature	Form	Description
1-5	N35+1	I	Number of tubes in system 1.
6-10	N35+2	I	Number of tubes in system 2.

Etc. through Column 70.

Repeat this card as many times as needed to supply NTB for every system. If NSYS = 1, omit this card and NTB1 will be set to NTUBE.

Card 6 (For banks and headers)

Columns	Fortran Nomenclature	Form	Description
1-5	N33+1	I	Number of flow paths in system 1.
6-10	N33+2	I	Number of flow paths in system 2.

Etc, through Column 70.

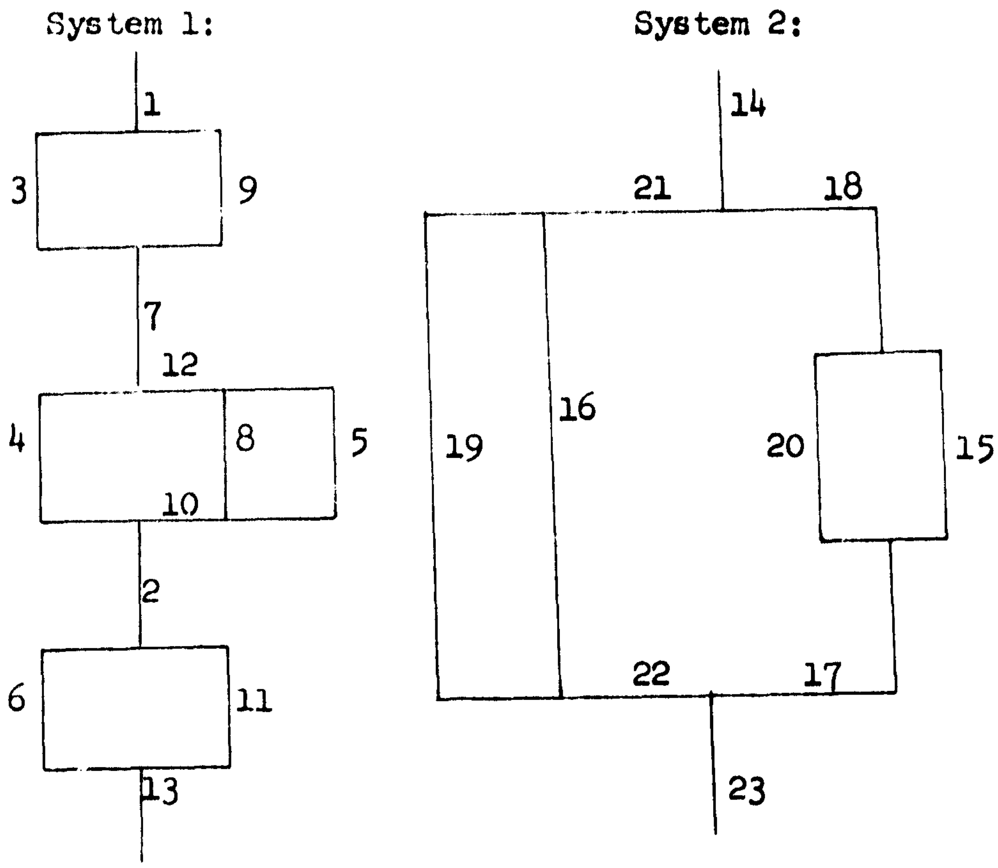
Repeat this card as many times as needed to supply NFLO for each system.

Columns	Fortran Nomenclature	Form	Description	Analysis Page Reference
	Card 7 (For banks and headers)			
1-5	M37+1	I	Number of first tube in first flow path (see example on next page for definition of a flow path) in first system.	29
6-10	M37+2	I	Number of second tube in first flow path in first system.	
11-15	M37+3	I	Number of third tube in first flow path in first system.	
Etc.				
	M37+n	I	Number of last tube in first flow path in first system.	
	Blank		Leave 5 columns blank to indicate the end of a flow path.	
	M37+n+1	I	Number of first tube in second flow path in first system.	
	M37+n+2	I	Number of second tube in second flow path in first system.	
	M37+n+2	I	Number of third tube in second flow path in first system.	
Etc.				
	M37+n+w1	I	Number of last tube in second flow path in first system.	
	Blank		Leave 5 columns blank to indicate the end of a flow path.	

Etc. through Column 70.

Repeat this card as many times as needed until all flow paths in all systems have been listed. No blank is required after the last tube in the last flow path in the last system.

For example:



Flow path 1 consists of tubes 1, 3, 7
Flow path 2 consists of tubes 1, 9, 7
Flow path 3 consists of tubes 7, 4, 2
Flow path 4 consists of tubes 7, 12, 8, 10, 2
Flow path 5 consists of tubes 7, 12, 5, 10, 2
Flow path 5 consists of tubes 2, 6, 13
Flow path 7 consists of tubes 2, 11, 13
Flow path 8 consists of tubes 14, 21, 19, 22, 23
Flow path 9 consists of tubes 14, 21, 16, 22, 23
Flow path 10 consists of tubes 14, 18, 20, 17, 23
Flow path 11 consists of tubes 14, 18, 15, 17, 23

Restrictions:

(a) Two and only two tubes must branch from or flow into another tube.
(b) Tubes must be numbered one through NTUBE.
(c) The first tube in a system must have the smallest number of any tube in that system, the first tube in system 1 being numbered 1.
(d) Each system must have at least four tubes.
(e) One tube cannot connect into two banks, see paragraph 3.4.3 (Figure 3).
(f) The last tube in a system must have the largest number of any tube in that system, the last tube in the last system being numbered NTUBE.
(g) If one fluid lump in a tube is to be considered for two-phase flow calculations, then all fluid lumps in that tube and in the system which contains that tube must also be considered for two-phase flow calculations.

Columns	Fortran Nomenclature	Form	Description	Analysis Page Reference
	Card 8			
1-5	MM16+1	I	Two-phase flow option for system 1: = 0, Two-phase flow not considered in system. = 1, Two-phase flow is considered in system.	35
6-10	MM16+2	I	Two-phase flow option for system 2.	

Etc. through Column 70.

Repeat this card as needed to supply two-phase flow options for all systems.

	Card 9 (Closed loop code card)			
1-5	N37+1	I	Close loop code for system 1: = 0, open. = 1, closed, TIN ($\tau+\Delta\tau$) = T_{out} (τ)	57
6-10	N37+2	I	Close loop code for system 2.	

Etc. through Column 70.

Repeat this card as needed to supply close loop codes for all systems.

	Card 10 (For steady state solution involving parallel fluid flow)			
1-5	N000+1	FP	Inlet temperature for tube 1, ^oF	
6-10	N000+2	FP	Inlet temperature for tube 2, ^oF	

Etc. through Column 70.

Repeat this card as many times as necessary to supply an inlet temperature for every tube in each system.

	Card 11 (For steady state solution involving banks and headers fluid flow)			
1-5	N32+1	FP	Inlet temperature for first tube in first system, ^oF.	
6-10	N32+2	FP	Inlet temperature for first tube in second system, ^oF.	

Etc. through Column 70.

Repeat this card as many times as needed to supply an inlet temperature table number for every tube in every system.

Columns	Fortran Nomenclature	Form	Description	Analysis Page Reference
	Card 12 (For transient solution involving parallel fluid flow)			
1-5	N32+1	I	Curve number of table for inlet temperature of tube 1.	
6-10	N32+2	I	Curve number of table for inlet temperature of tube 2.	

Etc. through Column 70.

Repeat this card as many times as needed to supply an inlet temperature table number for every tube in every system.

Columns	Fortran Nomenclature	Form	Description	Analysis Page Reference
	Card 13 (For transient solution involving banks and headers fluid flow)			
1-5	N32+1	I	Curve number of table for inlet temperature of first tube in system 1.	
6-10	N32+2	I	Curve number of table for inlet temperature of first tube in system 2.	

Etc. through Column 70.

Repeat this card as many times as needed to supply an inlet temperature table number for the inlet tube in each system.

Columns	Fortran Nomenclature	Form	Description	Analysis Page Reference
	Card 14 (For steady state solution involving parallel fluid flow; for transient solution involving parallel fluid flow if NFD = 2 or 3)			
1-5	M35+1	FP	Flow rate of tube 1, lb/hr.	
6-10	M35+2	FP	Flow rate of tube, lb/hr.	

Etc. through Column 70.

Repeat this card as many times as needed to supply a flow rate for every tube in every system.

Columns	Fortran Nomenclature	Form	Description	Analysis Page Reference
	Card 15 (For steady state solution involving banks and headers fluid flow; for transient solution involving banks and headers fluid flow if NFD = 3, see paragraph 4.9)			
1-5	N34+1	FP	Total flow rate in system 1, lb/hr.	
6-10	N34+2	FP	Total flow rate in system 2, lb/hr.	

Etc. through Column 70.

Repeat this card as many times as needed to supply a total flow rate in each system.

Columns	Fortran Nomenclature	Form	Description	Analysis Page Reference
	Card 16 (For transient solution involving parallel fluid flow or banks and headers fluid flow if NFD = 0)			
1-5	M35+1	I	Curve number of table for total flow rate in system 1.	
6-10	M35+2	I	Curve number of table for total flow rate in system 2.	

Etc. through Column 70.

Repeat this card as many times as needed to supply a total flow rate curve number for each non-two-phase system, and bland end for each two-phase-system.

Columns	Fortran Nomenclature	Form	Description	Analysis Page Reference
	Card 17 (For transient solution involving parallel fluid flow if NFD = 1)			
1-5	M35+1	I	Curve number of table for flow rate of tube 1.	
6-10	M35+2	I	Curve number of table for flow rate of tube 2.	

Etc. through Column 70.

Repeat this card as many times as needed to supply a flow rate curve number for every tube in every system.

Columns	Fortran Nomenclature	Form	Description	Analysis Page Reference
	Card 18 (If NFD = 3)			
1-5	M35+1	I	Curve number for total flow in system 1 as function of pressure drop.	
6-10	M35+2	I	Curve number for total flow in system 2 as a function of pressure drop.	

Columns	Fortran Nomenclature	Form	Description	Analysis Page Reference

Card 18 (Continued)

Etc. through Column 70.

Repeat this card as many times as needed to supply a curve number for each system.

Card 19 (Required for gradient only)

1-5	NCONC (1)	I	Conductivity curve number for fin.	
6-10	NCONC (2)	I	Emissivity curve number for fin.	
11-15	NCONC (3)	I	Absorptivity curve number for fin.	
16-20	FF	FP	Factor for estimating fin temperature to be used for NCONC, NEMC, and NABC curve lookup, $T_{fin} = FF \cdot T_i$ where T_i is temperature of associated tube lump. If not given, FF = 1.	
21-25	FDEN	FP	Density of fin material, lb_m/ft^3.	

Parameter Cards 20 and 21 and sometimes 22 are necessary for each valve in non-restart data. Cards 20 and 22 can be included following Parameter Card 2 in restart data. Valves should be numbered 1 through NVLV. Cards 20 and 21 (and 22) for one valve should be together but valve numbers need not be in numerical order. The value of NCHTN (Card 21, Col. 5) influences the format of the cards.

Card 20 (For valves)

Columns	If NCHTN = (Card 21, Column 5)	Nomenclature	Form	Description	Analysis Page Reference
1-3	1,2,3,4,5	N41 + 1	I	Valve number.	
4-5	1,2,3,4,5	N41 + 2	I	Operating Mode. = 0, valve is operating. ≠ 0, valve is not operating. A valve can essentially be added on restart.	
6-10	1,2,3,5	N41 + 3	I	Sensor lump number. If the bypass tube is imaginary and encompasses whole system, NSLMP = 0.	

Columns	If NCHTN = (Card 21, Column 5)	Nomencla-ture	Form	Description	Analysis Page Reference
	4	Blank			
11-20	1,2,3,5	N41 + 4	FP F10.5	Minimum fraction of flow required through non-bypass tube(s).	
	4	N41 + 4	FP F10.5	Minimum allowable proportioning valve position measured from left, milli-inches	
21-30	1,2,3,5	N41 + 5	FP F10.5	Maximum fraction of flow allowed through non-bypass tube(s).	
	4	N41 + 5	FP F10.5	Maximum allowable proportioning valve position measured from left. Milli-inches.	
31-40	1	N41 + 6	FP F10.5	Set point temperature °F.	49
	2	Blank			
	3,5	N41 + 6	FP	Sensor lump temperature-°F. If sensor lump temperature < T1, + 3 valve closes, - 3 valve opens (see Column 5, Card 21).	50
	4	N41 + 6	FP F10.5	Maximum possible proportioning valve position measured from left. Milli - inches.	
41-50	1	N41 + 7	FP F10.5	Bypass valve dead band °F	49
	2,4	Blank			
	3,5	N41 + 7	FP F10.5	Sensor lump temperature-°F. If sensor lump temperature > T2, + 3 valve opens - 3 valve closes (see Column 5, Card 21).	50
51-60	1	N41 + 8	FP F10.5	Rate factor. Bypass valve. Units are fraction bypass per hour per degree °F.	49

Columns	If NCHTN = (Card 21, Column 5)	Nomenclature	Form	Description	Analysis Page Reference
	2,3,4,5	Blank			
61-70	1	N41 + 9	FP F10.5	Bypass valve. Rate limit. Usual value .033. Units are fraction bypass per hour.	49
	2,3,4,5	Blank			
	Card 21 (For valves)				
1-3	1,2,3,4,5	N41 + 10	I	Number of system containing valve.	
4-5	1,2,3,4,5	N41 + 11	I	Characterization code - 1, rate limit bypass 2, polynomial bypass +3, on/off, -3 off/on 4, proportioning 5, switching	50
6-10	1,2,3	N41 + 12	I	Number of first tube on bypass side.	47
	4,5	N41 + 12	I	Number of first tube on right side. Right side of switching valve closes when T < T_1 (Col. 31-40, Card 20).	48
11-15	1,2,3,4,5	N41 + 13	I	Number of "from" tube.	48
16-20	1,2,3,4,5	N41 + 14	I	Number of "to" tube.	
21-30	1	N41 + 15	FP F10.5	Initial fraction of flow assigned to non-bypass tube(s).	
	2,3	Blank			
	4	N41 + 15	FP F10.5	Initial proportioning valve position measured from left.	
	5	N41 + 15	FP F10.5	Initial fraction of flow assigned to tube(s) on left. Must be 0 or 1.	

Card 22 (Necessary only if NCHTN = 2 or 4)

Columns	Nomenclature	Form	Description	Analysis Page Reference
If NCHTN = 2,				
1-10	A_0(N41+16)	FP	Coefficients in fraction bypass =	46
11-20	A_1(N41+17)	F10.5	$A_0 + A_1 T + A_2 T^2 + A_3 T^3 + A_4 T^4$	
21-30	A_2(N41+18)		where T = temperature sensor	
31-40	A_3(N41+19)		lump (°F).	
41-50	A_4(N41+20)			
If NCHTN = 4,				
1-10	N41 + 16	FP F10.5	Proportioning valve gain. Usual value 1.155. Units are Milli-inches per °F.	50
11-20	N41 + 17	FP F10.5	Panel parameter. Usual value 2.	
21-30	N41 + 18	FP F10.5	Geometry factor. Usual value .03. Units are milli-inches^2. GFACT = $(2.92)(10^{-6})(D^2)$ where D is valve orifice diameter in milli-inches.	50
31-40	N41 + 19	FP F10.5	Proportioning valve null position tolerance. Usual value .001. Milli-inches.	51

Card 23 (For each system in which two-phase flow is being considered)

Columns	Nomenclature	Form	Description
1-5	NSYS	I	System Number.
6-10	MM53 + 1	I	Curve number of entering gas pressure.
11-15	MM31 + 1	I	Curve number of viscosity of non-condensible component.
16-20	MM32 + 1	I	Curve number of viscosity of condensible component.
21-25	MM33 + 1	I	Curve number of viscosity of liquid.
26-30	MM34 + 1	I	Curve number of specific heat of non-condensible component.
31-35	MM35 + 1	I	Curve number of specific heat of condensible component.

Columns	Nomenclature	Form	Description	Analysis Page Reference
36-40	MM36 + 1	I	Curve number of specific heat of liquid.	
41-45	MM37 + 1	I	Curve number of conductivity of non-condensible component.	
46-50	MM38 + 1	I	Curve number of conductivity of condensible component.	
51-55	MM39 + 1	I	Curve number of conductivity of liquid.	
56-60	MM40 + 1	I	Curve number of latent heat of vaporization.	
61-65	MM41 + 1	I	Curve number of Prandtl number of liquid.	
66-70	MM42 + 1	I	Curve number of liquid density.	

Follow card 23 by the appropriate card , 24 or 25.

Card 24 (NFD $\neq$ 3)

Columns	Nomenclature	Form	Description	Analysis Page Reference
1-5	MM55 + 1	I	Curve number of entering gas flow rate.	
6-10	MM48 + 1	I	Curve number of entering liquid flow rate.	
11-15	MM45 + 1	I	Curve number of entering Non-condensible component flow rate.	
16-20	MM44 + 1	I	Curve number of partial pressure of vaporization.	
21-30	MM52 + 1	F10.5	Value of diffusion coefficient at 60°F, 14.7 psia, ft^2/hr.	45
31-40	MM54 + 1	F10.5	Gas constant for condensible component, $ft\text{-}lb_f/lb_m\text{-}^{\circ}R$.	
41-50	MM27 + 1	F10.5	Gas constant for non-condensible component, $ft\text{-}lb_f/lb_m\text{-}^{\circ}R$.	
51-60	MM23 + 1	F10.5	Molecular weight ratio (weight of condensible component to non-condensible component).	

Columns	Nomenclature	Form	Description	Analysis Page Reference
	Card 25 (NFD = 3)			
1-5	MM55 + 1	I	Curve number of ratio of gas flow to total flow rate in system (humidity versus WG).	
6-10	MM48 + 1	I	Curve number of ratio of liquid flow rate to total flow rate in system (humidity versus WL).	
11-15	MM45 + 1	I	Curve number of ratio of non-condensible flow rate to total flow rate in system (humidity versus WO).	
16-70			Same as Card 24 above.	

Repeat Card 23 followed by Card 24 or 25 for each system in which two-phase flow is being considered.

Columns	Nomenclature	Form	Description
	Card 26 (For each system in which two-phase flow is not being considered)		
1-5	NSYS	I	System number.
6-10	M1 + 1	I	Curve number of density.
11-15	M2 + 1	I	Curve number of conductivity.
16-20	M3 + 1	I	Curve number of specific heat.
21-25	M4 + 1	I	Curve number of viscosity.
26-30	M5 + 1	I	Curve number of friction factor.

Repeat Card 26 for each system in which two-phase flow is not being considered.

Columns	Nomenclature	Form	Description
	Card 27		
1-5	MM63 + 1	I	Liquid separator lump for system 1 (blank for non-two-phase flow system, zero for two-phase flow system without separator).
6-10	MM63 + 2	I	Liquid separator lump for system 2.

etc. through Column 70

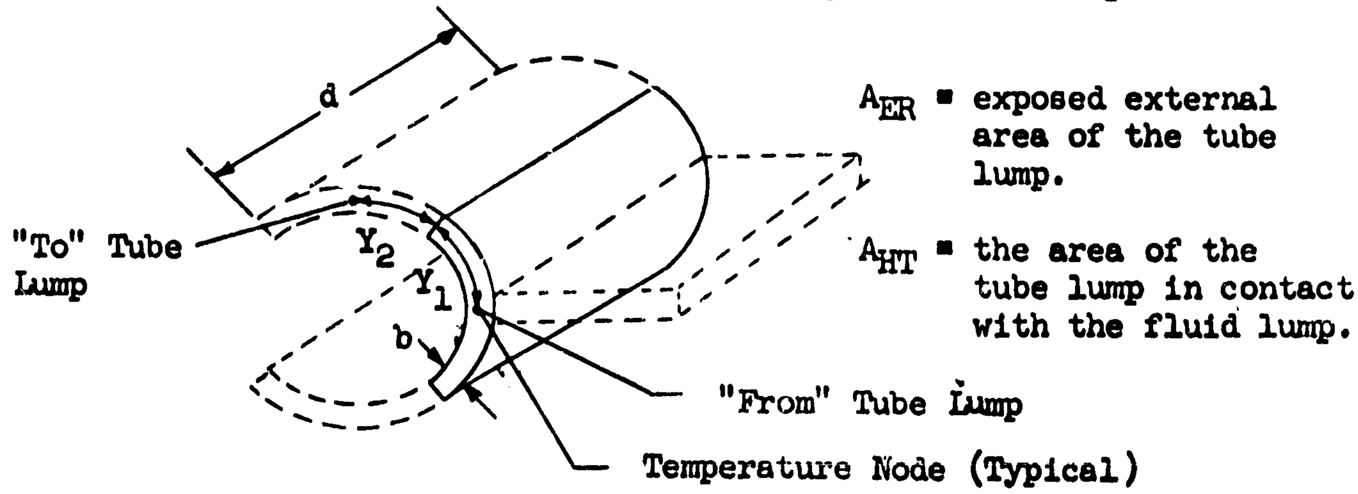
Repeat this card as many times as needed to supply liquid separator option for each system.

Thermal Conduction Data

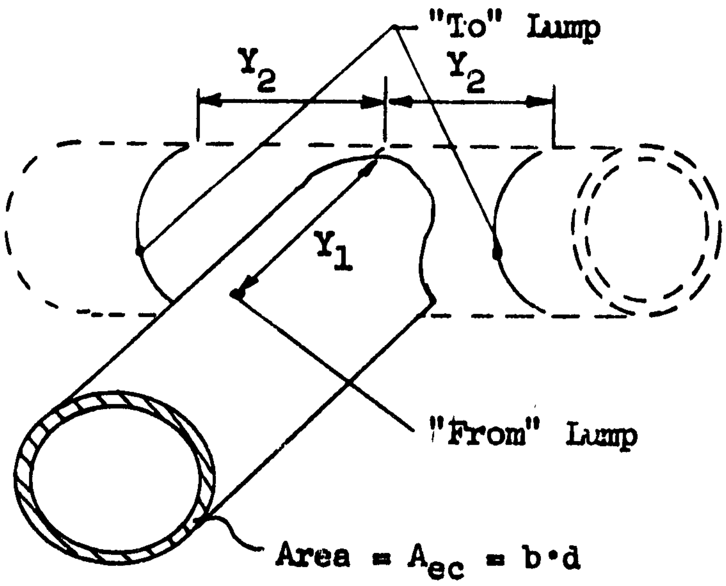
All conduction data for fluid, tube and structure lumps is input in terms of "from" and "to" data such as conduction "from" lump 1 "to" lump 2. Only unique conduction relationships should be specified so that if lump 1 conducts "to" lump 2 then conduction "from" lump 2 "to" lump 1 must not be entered. Lumps can conduct to any number of numerically higher or lower neighboring lumps.

The examples which follow show typical conduction data to illustrate the method.

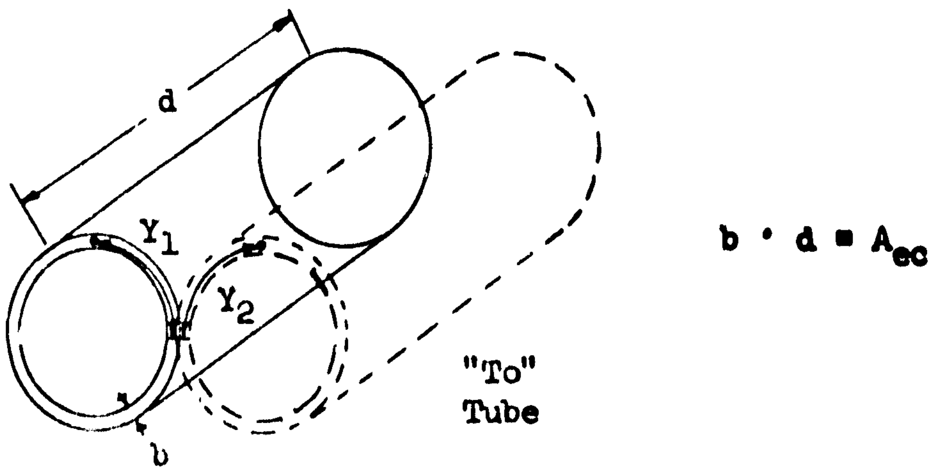
When tube-to-tube heat conduction is other than longitudinal conduction in a tube (for peripheral breakdowns, junctions, and parallel juxtapositioned tubes), conduction information should be input as shown in the following examples for conduction from tube lump 1 to tube lump 2.



Schematic showing conduction breakdown of tube to account for peripheral gradients.

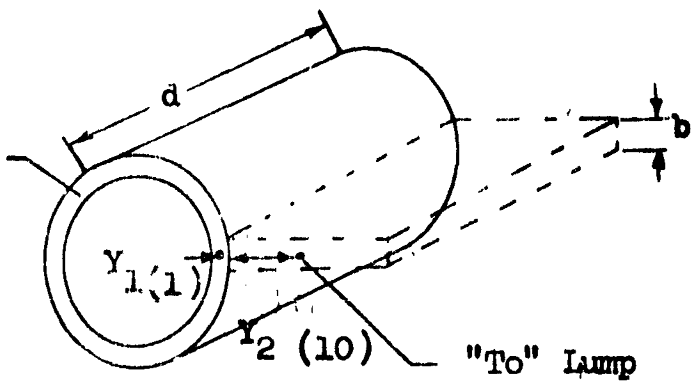


Schematic showing conduction input for conduction between tubes at a junction.

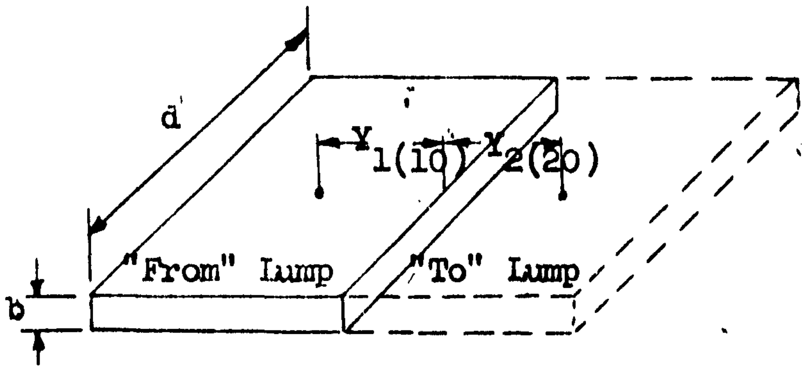


Schematic showing conduction for juxtapositioned tubes.

The tube to structure and structure to structure lump data is input similarly.



Conduction from tube lump 1 to structure lump 10



Conduction from structure lump 10 to structure lump 20

5.2.2 Fluid Data Cards

Columns	Nomenclature	Form	Description
	Card 1		
1-5	NFLT	I	Number of types of fluid lumps.
	Card 2 (Type Data Card)		
1-10	M6+1	F10.5	Fluid lump length, inches.
11-20	M7+1	F10.5	Cross-sectional area of fluid lumps, sq. inches.
21-30	M8+1	F10.5	Wetted perimeter, inches.
31-35	M50+1	I	Number of fluid lumps conducted "to". (See page 83 for example of conduction data). Leave blank for two-phase flow types. Used only if stagnant or frozen fluid is being considered.
36-40	M51+1	I	Number of tube lumps conducted "to". (See page 83 for example of conduction data). Leave blank for two-phase flow types. Used only if stagnant or frozen fluid is being considered.
41-45	N36+1	F5.4	Factor for computing friction factor as a function of Reynold's number. Routine sets to 1 if left blank. Leave blank for two-phase flow types.
46-50	N38+1	I	= 0, if this type of lump is not in the heat exchanger. = 1, if this type of lump is in the heat exchanger on the hot side. = 2, if this type of lump is in the heat exchanger on the cold side.
51-55	N51+1	I	= 0, use regular equation for heat transfer coefficient (HHH). = 1, heat transfer coefficient (HHH) is a function of $\dot{w}$. = 2, heat transfer coefficient (HHH) is a function of $S_t\,Pr^{2/3}$.

Columns	Nomencla-ture	Form	Description
56-60	N52+1	I	If NHHH = 1, curve number of HHH = f(θ). If NHHH = 2, curve number of $S_t Pr^{2/3}$ = f(Re). If NHHH = 0, leave blank.
61-65	M40+1	I	Number of K curve for pressure drop, leave blank for two-phase flow types. (May be left blank).
66-70	MM56+1	I	Two-phase flow option for lump type = 0, not two-phase flow type. = 1, is two-phase flow type.

If NFCT + NICT > 0, enter Card 3.

Card 3 (For non-two-phase flow, fluid conduction only considered when freezing occurs, see page 59)

Columns	Nomenclature	Form	Description
1-10	FAC	F10.5	Factor for dividing conduction distances and dimensions. Set equal to 1 if not given. Used when conduction distances do not fit five column field.
11-15	M53+1	F5.5	Conduction distance x FAC of this type of "from" lump to first "to" lump.
16-20	M53+2	F5.5	Conduction distance x FAC of first "to" lump listed for this type "from" lump.
21-25	M53+3	F5.5	Dimensions x FAC for computing effective conduction area for this type "from" lump and first "to" lump.
26-30	M53+4	F5.5	
31-35 36-40 41-45 46-50			As above for second "to" lump.
51-55 56-60 61-65 66-70			As above for third "to" lump.

Repeat Card 3 as needed. FAC should be omitted on all cards which are a repeat of card 4.

Repeat Card 2 (followed by Card 5, if needed) for every fluid lump type.

NOTE: Any variation in lump size, curve number, number of lumps conducted "to" conduction distance or area, whether or not the lump is in the heat exchanger, or whether or not the lump is two-phase flow can be indicated only by changing the type number.

Columns	Nomenclature	Form	Description	Analysis Page Reference
	Card 4 (Fluid lumps cards. One for each fluid lump. The lumps must be numbered 1 through NTFL and must be in numerical order)			
1-5		I	Lump number.	
6-10	N4+1	I	Lump upstream. If banks and headers problem, NLU = 0 for first lump in every tube.	
11-15	N5+1	I	Tube number.	
16-20	M9+1	I	Type number.	
21-30	N3+1	F10.5	Initial temperature (of gas, for two-phase flow lump; of fluid, for non-two-phase flow lump, °F.	
31-40	MM14+1	F10.5	Pressure of gas. PSIA (Leave blank on non-two-phase flow lump.)	
41-50	MM21+1	F10.5	Initial temperature of liquid for two-phase flow lumps °F. (Leave blank on non-two-phase flow lump.)	
	Card 5 (Follow Card 4 by Card 5 for each fluid lump which is a non-two-phase flow lump)			
1-5	M10+1	I	First lump conducted "to".	
6-10	M10+2	I	Second lump conducted "to".	
11-15	M10+3	I	Etc.	
16-20	M10+4	I	The order in which the lumps conducted "to" are listed will depend upon the order in which the conduction data was given on the type cards. The fluid lumps conducted "to" (if any) must be listed before the tube lumps conducted "to" (if any).	
.	.	.		
.	.	.		
.	.	.		
.	.	.		
66-70	M10+14	I		

If the number of lumps conducted "to" is greater than 14, repeat Card 5 as needed.

Columns	Nomenclature	Form	Description
	Card 6 (For lumps on cold side of heat exchanger only)		
1-5	N50+1	I	Number of adjacent lump on hot side of regenerator.

Repeat Card 4 (followed by Cards 5 and 6, if required) for every lump. The lumps must be submitted in increasing numerical order.

5.2.3 Tube Data Cards

Columns	Nomenclature	Form	Description
	Card 1		
1-5	NMET	I	Number of types of tube lumps.
	Card 2 (Type Data Cards)		
1-5	M11+1	F5.2	Density of tube material for type 1, lb/ft^3.
6-10	M12+1	I	Curve number for conductivity.
11-15	M13+1	I	Curve number for specific heat.
16-20	M14+1	I	Curve number for absorptivity.
21-25	M15+1	I	Curve number for emissivity.
26-30	M55+1	I	Number of tube lumps conducted "to".
31-35	M56+1	I	Number of fin lumps conducted "to".
36-40	M41+1	I	= 0, lumps of this type have longitudinal conduction. = 1, do not compute longitudinal conduction for lumps of this type.
41-50	X1	F10.5	Dimensions, inches. X1·X2·X3 = Volume
51-60	X2	F10.5	X1/2 = Longitudinal Conduction Distance.
61-70	X3	F10.5	X2·X3 = Area for longitudinal conduction.
	Card 3 (For gradient)		
1-10	M18+1	F10.5	Area for heat transfer to enclosed fluid lump, sq. in.
11-20	M19+1	F10.5	Area of surface for external radiation, sq. in.
21-30	ACR	F10.5	Area of surface for gradient effect, sq. in.
31-40	FTHR	F10.5 *	Fin thickness for fin to right of tube, inches.
41-50	FHWR	F10.5 *	Fin half width to right of tube, inches.

* See next page

Columns	Nomencla-ture	Form	Description
51-60	FTHL	F10.5 *	Fin thickness for fin to left of tube, inches.
61-70	FHWL	F10.5 *	Fin half width to left of tube, inches.

*NOTE: Use typical values of this input for tubes with no fins or gradient table will be exceeded. Then for no heat to fin, set AGR = 0 (see page 13 and Appendix A).

Card 4 (For gradient if NTCT > 0. NFCT must be 0 for gradient)

Columns	Nomencla-ture	Form	Description
1-10	FAC	F10.5	Factor for dividing conduction distances and dimensions. Routine will set to 1 if left blank, Used when number is too small for five column field.
11-15	Y1	F5.5	Conduction distance. FAC of this type of "from" lump to first "to" lump.
16-20	Y2	F5.5	Conduction distance. FAC of first "to" lump listed for this type "from" lump.
21-25	B	F5.5	Dimensions. FAC for computing effective conduction area for this type "from" lump
26-30	D	F5.5	and first "to" lump.
31-35	Y1		
36-40	Y2		As above for second "to" lump.
41-45	B		
46-50	D		
51-55	Y1		
56-60	Y2		As above for third "to" lump.
61-65	B		
66-70	D		

Repeat Card 4 as needed. FAC should be omitted on all cards which are a repeat of Card 4.

Repeat Cards 2 and 3 (followed by Card 4 if needed) for every tube lump type.

Card 3 (For nodal)

Columns	Nomencla-ture	Form	Description
1-20			See Card 3 for gradient.

Columns	Nomencla-ture	Form	Description
21-30	FAC	F10.5	Factor for dividing conduction distances and dimensions.
31-35	M58+1	F5.5	Conduction data for first "to" lump given for this type "from" lump.
36-40	M58+2	F5.5	
41-45	M58+3	F5.5	
46-50	M58+4	F5.5	
51-55	M58+5	F5.5	Conduction data for second "to" lump.
56-60	M58+6	F5.5	
61-65	M58+7	F5.5	
66-70	M58+8	F5.5	

If NTCT + NFCT > 2, follow with Card 4.

Card 4 (For nodal, if needed for conduction)

1-10	Blank		
11-15	M58+9	F5.5	Conduction data for third "to" lump.
16-20	M58+10	F5.5	
21-25	M58+11	F5.5	
26-30	M58+12	F5.5	
31-35	M58+13		Conduction data for fourth "to" lump.
36-40	M58+14		
41-45	M58+15		
46-50	M58+16		
51-55	M58+17		Conduction data for fifth "to" lump.
56-60	M58+18		
61-65	M58+19		
66-70	M58+20		

Repeat Card 4 if NTCT + NFCT > 5. If NTCT > 0, the data for tube lump "to" tube lump must be given before the data for tube lump "to" fin lump.

Repeat Cards 2 and 3 (followed by Card 4 if needed) for every tube lump type.

Card 5 (Tube Lump Cards) (One for each tube lump. The lumps must be numbered 1 through NTML and must be entered in numerical order.)

1-5		I	Lump number.
6-10	N10+1	I	Lump number of tube lump downstream.

Columns	Nomenclature	Form	Description
11-15	N9+1	I	Lump number of enclosed fluid lump.
16-20	M22+1	I	Type number of lump.
21-30	N8+1	F10.5	Initial temperature, °F.
31-35	Q1 or NQIC	F5.2 or I	Incident heat value for steady state. Incident heat curve number for transient.
36-40	TW or NTWC	F5.2 or I	Constant temperature, °F, for steady state. Constant temperature curve number for transient (may be left blank).
For gradient solution:			
41-45	LR	I	Lump number of tube lump to the right.
46-50	QR	FP	Incident heat for the fin to the right of the tube lump, BTU/hr-ft^2.
51-55	LL	I	Lump number of tube lump to the left.
56-60	QL	FP	Incident heat for the fin to the left of the tube lump, BTU/hr-ft^2.
61-65	NTL1	I	First lump conducted "to".
66-70	NTL2	I	Second lump conducted "to".
For a nodal solution:			
41-45	M23+1	I	First lump conducted "to".
46-50	M23+2	I	Second lump conducted "to".
51-55	M23+3	I	Etc.
56-60	M23+4	I	The order in which the lumps conducted "to" are listed will depend upon the order in which the conduction data was given on the type cards. The tube lumps conducted "to" (if any) must be listed before the fin lumps conducted "to" (if any).
61-65	M23+5	I	
66-70	M23+6	I	

Columns	Nomencla-ture	Form	Description
	Card 6 (Continuation of list of lumps conducted "to". If the number of lumps conducted "to" is greater than 6(for nodal or 2 (for gradient), follow Card 5 with Card 6.)		
1-5	M23+7	I	Next lump conducted "to".
6-10	M23+8		Next lump conducted "to".
Etc. to			
66-70	M23+20		

Repeat Card 6 as needed to list all lumps.

Repeat Card 5 followed by Card 6 (if required) for every lump. The lumps must be given in increasing numerical order.

5.2.4 Structure Data Cards for Nodal Solution

Columns	Nomenclature	Form	Description
	Card 1		
1-5	NT	I	Number of types of structure lumps.
	Card 2 (Structure Lump Type Cards)		
1-5	N18+1	F5.2	Density of fin material. lb/ft3
6-10	N19+1	I	Conductivity curve number.
11-15	N20+1	I	Specific heat curve number.
16-20	N21+1	I	Absorptivity curve number.
21-25	N22+1	I	Emissivity curve number.
26-30	M59+1	I	Number of fin lumps conducted "to" by lumps of this type.
31-40	X1	F10.5	Dimensions of lump, inches.
41-50	X2	F10.5	X1·X2·X3 = Volume.
51-60	X3	F10.5	X1·X2 = External radiation area.

If NFCT > 0, enter Card 3.

Columns	Nomenclature	Form	Description
	Card 3		
1-10	FAC	F10.5	Factor for dividing conduction distances and dimensions. Routine sets to 1. if not given. Use when numbers are too small to fit five column field.
11-15	M61+1	F5.5	Data for conduction to first lump conducted "to" by this type lump.
16-20	M61+2	F5.5	
21-25	M61+3	F5.5	
26-30	M61+4	F5.5	
31-35	M61+5		Data for second lump conducted "to" by this type lump.
36-40	M61+6		
41-45	M61+7		
46-50	M61+8		
51-55	M61+9		Data for third lump conducted "to" by this type lump.
56-60	M61+10		
61-65	M61+11		
66-70	M61+12		

Columns	Nomenclature	Form	Description

If NFCT > 3, repeat Card 3 as needed. FAC should be omitted on all cards which are a repeat of Card 3.

Repeat Card 2 (followed by Card 3 if needed) for every fin lump type.

Card 4 (Structure Lump Cards) (One for each structure lump. The lumps must be numbered 1 through NSL and must be entered in numerical order.)

1-5	LN	I	Lump number.
6-10	N24+1	I	Type number of lump.
11-20	N25+1	F10.5	Initial temperature of lump, °F.
21-25	N26+1	F5.2 or I	Incident heat for steady state or Incident heat curve number, transient.
26-30	N27+1	F5.2 or I	Constant temperature, steady state or Constant temperature curve number, transient (may be left blank).
31-35	N30+1	I	First lump conducted "to".
36-40	N30+2	I	Second lump conducted "to"
41-45	N30+3	I	Etc.
46-50	N30+4	I	The order in which the lumps conducted "to" are listed will depend upon the order in which the conduction data was given on the type cards.
51-55	N30+5	I	
56-60	N30+6	I	
61-65	N30+7	I	
66-70	N30+8	I	

Card 5 (Continuation of list of lumps conducted "to". If the number of lumps conducted "to" is greater than 8, follow Card 4 with Card 5.)

1-5	N30+9	I	Ninth lump conducted "to"
6-10			
11-15			

Etc. to

Columns	Nomenclature	Form	Description
66-70	N30+22		Twenty-second lump conducted "to".

Repeat Card 5 if number of lumps conducted "to" is greater than 22.

Repeat Card 4 followed by Card 5 (if required) for every lump. The lumps must be entered in increasing numerical order.

5.2.5 Fuel Cell and Inline Heater Data

It is assumed that every system that has a fuel cell has an inline heater and vice versa and, in addition, that no system may contain more than one of each.

Immediately following the last structure lump card:

Card FCCRV-1

Columns	Nomenclature	Form	Description
1-5	MM87+1	I	No. of oxygen enthalpy vs. temperature curve.
6-10	MM88+1	I	No. of total power vs. time curve.

Card FCCD-1

Columns	Nomenclature	Form	Description
1	MM80+1	I	Fuel cell and inline heater code for System 1 = 0, the system does not contain a fuel cell and inline heater. = 1, the system does contain a fuel cell and inline heater, and the fuel cell is operating. >1, the system does contain a fuel cell and inline heater, but the fuel cell is turned off.
2	MM80+2	I	Fuel cell and inline heater code for System 2.

etc. through Column 70.

Repeat this card as many times as necessary to supply a fuel cell/inline heater code for each system.

Card FC-1

Columns	Nomenclature	Form	Description
1-5	MM81+1	I	Fuel cell (structure) lump for first system that contains a fuel cell.
6-10	MM89+1	I	No. of vapor pressure vs. temperature vs. percent KOH vs. dummy variable curve.
11-20	MM82+1	FP F10.5	Hydrogen reactant temperature for first system that contains a fuel cell, degrees Fahrenheit.
21-30	MM83+1	FP F10.5	Oxygen reactant temperature for first system that contains a fuel cell, degrees Fahrenheit.
31-40	MM84+1	FP F10.5	Initial percent potassium hydroxise concentration in the first system that contains a fuel cell.

Columns	Nomenclature	Form	Description
41-50	MM85+1	FP F1015	Fuel cell thermal capacity of the first system that contains a fuel cell, BTU per degree Fahrenheit.
51-60	MM86+1	FP F10.5	Mass of potassium hydroxide in the first system that contains a fuel cell, LB_m

Repeat FC card until Fuel Cell parameters have been supplied (only) for each system containing a fuel cell/inline heater.

Card LS-1 (Supplies coefficients for the fuel cell performance equation written in the form $V - (a_i T_{stack_i} + b_i) I_i + c_i\, T_{stack_i} + d_i + e_i\, (.73 - PKOH)$)

Columns	Nomenclature	Form	Description
1-10	ICOEFA+1	FP E10.3	a_1.
11-20	ICOEFB+1	FP E10.3	b_1, adjusted for T_{stack} in degrees Rankine.
21-30	ICOEFC+1	FP E10.3	c_1.
31-40	ICOEFD+1	FP E10.3	d_1, adjusted for T_{stack} in degrees Rankine.
41-50	ICOEFE+1	FP E10.3	e_1.

Repeat LS card until performance coefficients have been supplied (only) for each system containing a fuel cell/inline heater.

Card IH-1

Columns	Nomenclature	Form	Description
1-5	IHLUMP+1	I	Inline heater (tube) lump for first system that contains an inline heater.
6-10	IHSENS+1	I	Inline heater sensor (fluid) lump for first system that contains an inline heater.
11-20	IHPWRW+1	FP F10.5	Inline heater power for first system that contains an inline heater, watts.
21-30	IHTON+1	FP F10.5	"On" temperature for first system that contains an inline heater, degrees Fahrenheit.
31-40	IHTOFF+1	FP F10.5	"Off" temperature for first system that contains an inline heater, degrees Fahrenheit.

Repeat IH card until inline heater parameters have been supplied (only) for each system containing a fuel cell/inline heater.

5.2.6 Curve Data Cards

Card 1 is followed by Card 2 through 2NP/7 for each curve. Curves may be entered in any order.

Columns	Nomenclature	Form	Description
	Card 1 (Curve Header Card)		
4-5	KCRV	I	Kind of curve code.
		0	$\mathcal{K}$ curve for pressure drop, dimensionless = f(Re).
		1	Density of fluid or liquid, lb_m/ft^3 = f(°F)
		2	Viscosity of fluid, liquid, condensible or non-condensible component, (lb_m/ft-sec) (x 10^3) = f(°F).
		3	Friction factor for fluid, F x 10^3 = f(Re x 10^{-3}). (Used when Re > 2000).
		4	Conductivity, BTU/hr-ft °F = f(°F).
		5	Specific heat, BTU/lb_m °F = f(°F).
		6	Absorptivity, Dimensionless = f(°F).
		7	Emissivity, Dimensionless = f(°F).
		8	Gradient (used for gradient solution). $-\frac{d\theta}{dX} = f(\theta_e, \theta_r, N_c)$
		9	Incident heat, BTU/hr-ft^2 = f(hours) (used for transient).
		10	Constant temperature, °F = f(hours)(used for transient).
		11	Flow rate curve (total flow rate). If transient and NFD = 0, total flow rate = f(time), lb_m/hr = f(hours). If transient and NFD = 1, flow rate for each tube = f(time). If NFD = 3, for either steady state or transient, total flow rate = f(pressure drop). lb_m/hr = f(1000 x lb_f/sq. in.).
		12	Fluid inlet temperature, °F = f(hours). (Used for transient).

Columns	Nomenclature	Form	Description
		14	Latent heat of vaporization, BTU/lb_m = f(°F).
		15	Prandtl Number of liquid, Dimensionless = f(°F).
		16	Partial pressure of vapor, psia = f(°F).
		17	Entering flow rates of liquid, gas or non-condensible, lb_m/hr = f(hours).
		18	Entering gas pressure, psia = f(hours).
		24	St $Pr^{2/3}$ = f(Re).
		25	Heat transfer coefficient (HHH) = f($\dot{w}$) curve.
		44	Incident heat curve identical to curve type 9 except that it will not be part of a flux tape should one be called for, BTU/hr-ft^2 = f (time).
		45	Oxygen enthalpy, BTU = f (°F).
		46	Total power output required from all operating fuel cells, watts = f (time)
		47	Fuel cell vapor pressure, psig = f (°F, $\%_{KOH}$, dummy variable).
		48	Fuel cell voltage curve Volts = f (°F, P, % KOH)
		13	This card signals the END OF CURVE DATA.
6-10	NC	I	Curve number.
11-15	NP NX1	I	Number of points on curve (NP). For gradient curve, number of X1 values (NX1).
16-20	Blank except for tri-variant curve.		
	NX2	I	Number of X2 values.
21-25	Blank except for tri-variant curve.		
	NX3	I	Number of X3 values.
26-72			May be used for curve title.

Cards 2 through 2NP/7 (Curve Data Cards, except for tri-variant curve)

Columns	Nomenclature	Form	Description
1-10	X1	FP F10.5	Independent variable.

Columns	Nomencla-ture	Form	Description
11-20	X2		
21-30	X3		
Etc.			
	Y1	FP F10.5	Dependent variable.
	Y2		
	Y3		
Etc.			

Start Y1 in the first field after X_{NP}.

Do not write beyond Column 70.

If the number of points given is 1, the value in Columns 11-20 will be used for the dependent variable.

Cards 2 through (NX1 + NX2 + NX3 + NX1 · NX2 · NX3)/7
For tri-varient curve.

1-5	XI_1	FP	Values for the independent variable X1.
6-10	XI_2		
11-15	XI_3		
Etc.	XI_{NX1}		

Start TR1 in first field after XI_{NX1}.

	$X2_1$	FP F5.4	Values for the independent variable X2.
	$X2_2$		
Etc.	$X2_{NX2}$		

Start $X3_1$ in the first field after $X2_{NX2}$.

	$X3_1$	FP F5.4	Values for the independent variable X3.
	$X3_2$		
Etc.	$X3_{NX3}$		

Columns	Nomenclature	Form	Description

Start the values for the dependent variable in the first field after $X3_{NX3}$ Fixed point, (F10.4). Enter values of Y.

	Y1,1,1		
	Y1,1.2		
	Y1,1,3		
Etc.			
	Y1,1,NX3		
	Y1,2.1		
	Y1,2,2		
	Y1,2,3		
Etc.			
	Y1,2,NX3		
Etc.			
	Y1, NX2, NX3		
Etc.			
	YNX_1, NX_2, NX_3		

Where Y1,1,1 is the dependent variable corresponding to $X1_1$, $X2_1$, and $X3_1$,

YNX_1, NX_2, NX_3 is the dependent variable corresponding to $X1_{NX1}$, $X2_{NX2}$, $X3_{NX3}$.

NX_1 = number of X1 independent variable points.
NX_2 = number of X2 independent variable points.
NX_3 = number of X3 independent variable points.

5.2.7 Gradient Table Computation Cards

If a gradient solution is indicated, the option MGTC = 1, (Parameter Card 3) is used and a gradient curve is not included in the data, the following card must follow the Curve Type Card 13.

Columns	Nomenclature	Form	Description
	Card 1		
1-5	Not used		
6-10	Not used		
11-15	NTE	I	Number of Theta E values.
16-20	NTR	I	Number of Theta R values.
21-25	NNC	I	Number of N_c values.
26-67	Any alphanumeric information.		
	Card 2 through K where $K = \frac{NTE + NTR + NNC}{14} + 1$		
1-5	THETA E_1	FP	
6-10	THETA E_2	FP	
11-15	Etc.		
	THETA E_{NTE}		
	THETA R_1 follows in next field after last THETA E		
	THETA R_2		
	Etc.		
	THETA R_{NTR}		
	FNC_1		
	FNC_2		
	Etc.		
	FNC_{NNC}		

Columns	Nomenclature	Form	Description
	LAST CARD		
1-5	TDA	FP	Assumed value of first derivative $(d\theta/dx)$ $(\theta_{e1}, \theta_{r1}, N_{c1})$
6-10	TI	FP	Theta at X = XI
11-15	XI	FP	Lower limit of integration interval.
16-20	DX	FP	Integration increment.
21-25	XL	FP	Upper limit of integration interval.
26-30	DXP	FP	Not used in SUBI but must be greater than DX for numerical integration.

5.2.8 Known Heat Load Cards

If KHEAT ≠ 0 (on the second parameter card), omit the inlet temperature data (for steady state solution only) and input a total of KHEAT cards of this type (see page 54 of Analysis Section).

Columns	Nomenclature	Form	Description
1-5	QLOAD	FP	Total heat rejected, BTU/hr. which is known heat load.
6-10	EMIS	FP	Emissivity of radiator surface.
11-15	AREA	FP	Total area of radiator surface. sq. ft.
16-20	CP	FP	Specific heat of radiator fluid (BTU/lb).
21-25	CZERO	FP	Increment (°F) for adjusting inlet temperature for iteration. Routine sets to 10. if blank.
26-30	ENU	FP	Fin effectiveness. Routine sets to .7 if not given.
31-35	TOL	FP	Tolerance factor for comparing QLOAD with computed value in routine. Routine sets to .01 if left blank.
36-40	MTRY	I	Number of iterations to be allowed.

5.3 Interruption and Re-start Procedure

The following conditions during execution will cause a problem to be discontinued by writing the data and variable blocks of core storage on a binary tape:

1. Using the IDUMP = 1 option

2. Exceeding the maximum number of iterations desired for a steady-state solution.

3. Exceeding the computer request time which is input on the second parameter card.

4. Setting down Sense Switch 5 to interrupt a run and cause an exit to the next job.

5.3.1 Tape Requirements

The binary tape used for writing is loaded on logical unit 11 (A6 at LTV and at NASA). If a dump is expected, a request to ring and mount a blank tape on A6 should be made on the computer request card. All sets of data which are loaded together will dump on the same tape.

The binary dump tape is loaded on logical unit 12 (A7 at LTV, B6 at NASA) for a re-start. If a data set is dumped again, it will be written on a blank tape on A6. Thus, for certain runs, two tape units are required.

5.3.2 Data Cards for Re-starting

The first set of data which dumps on the binary tape will be identified as Data Set No. 1 and all following sets which dump will be identified as the set number given on the parameter card and on the listing. These set numbers need not be in consecutive order but must be greater than 1 (one).

Input the first two parameter cards, in order, for every set of data which was dumped on the same tape. A "1" in column 38 of the second card indicates that the problem should be re-started and a "2" in column 38 indicates that the problem should not be re-started. This is needed to by-pass a set of data on the dump tape and position the tape to read the next set. Parameter cards 20 and 22 can be included if NVLRS ≠ 0. Any items can be changed on these except NVLVN.

The alphanumeric characters for the page heading and any of the parameters on Card 2 may be changed for the re-start.

If a steady-state solution was completed and dumped by using the IDUMP option, SSTEST must be decreased for a re-start.

If a steady-state solution was dumped because of excessive iteration, the value for MAXI must be increased for re-starting.

If a transient problem was completed and dumped with the IDUMP option, the value of TAU must be increased for re-starting.

If a problem was dumped because of excessive computer time or if a run was interrupted using Sense Switch 5, the problem may be re-started without changing any of the parameters.

There will be a printing of regular output at the time of re-start which should be identical to the printing at the time of interruption.

5.4 Assembly of Binary Object Deck and Data

The order of assembly for the routine deck and data is given below. The order of subroutines within a chain is optional. If clock reading subroutines (RESET and CLOCK) are available on the FORTRAN MONITOR library tape, the subroutines RESET, CLOCK, and WCLCK can be removed from each chain. If the simultaneous equation subroutine (XSIMEQF) is available on the FORTRAN MONITOR library tape, the subroutine XSIMEQF can be removed from Chain 5. Refer to the Fortran II Manual for information on Monitor Control Cards. Numbers in parentheses following subroutine names are number of cards in binary deck.

5.4.1 Chain 1

1. Monitor Control Cards

    a. ID Card
    b. XEQ
    c. CHAIN (1,4)

2. Binary Decks

    a. Chain link 1 routine (167)
    b. SUBP (4)
    c. RESET (3)
    d. CLOCK (3)
    e. WCLCK (4)

5.4.2 Chain 2

1. Monitor Control Cards

    a. CHAIN (2, 4)

2. Binary Decks

    a. Chain link 2 routine (7)
    b. SUBA (101)
    c. SUBB (99)
    d. SUBP (4)
    e. RESET (3)
    f. CLOCK (3)
    g. WCLCK (4)

5.4.3 Chain 3

1. Monitor Control Cards

    a. CHAIN (3,4)

2. Binary Decks

a. Chain link 3 routine (53)
b. SUBP (4)
c. RESET (3)
d. CLOCK (3)
e. WCLCK (4)

5.4.4 Chain 4

1. Monitor Control Cards

a. CHAIN (4,4)

2. Binary Decks

a. Chain link 4 routine (139)
b. SUBI (38)
and all associated subroutines including LVD205 which is the package of subroutines for numerical integration:
ERROR (3)
PRINT (3)
IAVBLK (17)
c. SUBP (4)
d. RESET (3)
e. CLOCK (3)
f. WCLCK (4)

5.4.5 Chain 5

1. Monitor Control Cards

a. CHAIN (5,4)

2. Binary Decks

a. Chain link 5 routine (351)
b. SUBDP (339)
c. SUBEND (39)
d. SUBWT (8)
e. START (5)
f. CHECK (10)
g. SURVEY (9)
h. POL (10)
i. TRPOL (23)
j. XSIMEQF (23)
k. SUBP (4)
l. FLARAN (9)
m. REVPOL (11)
n. TABLE (14)

o. RESET (10)
p. CLOCK (3)
q. WCLCK (4)

5.4.6 Data

1. Monitor Control Cards

   a. DATA

2. The data following the DATA control card in the order in which it appears in the instructions for preparation.

   a. Parameter cards.
   b. Fluid lump data.
   c. Tube lump data.
   d. Fin lump data (for nodal only).
   f. Curve data.

      1) The curves may be in any order.
      2) The last card of the curve data must be the end of the curve data card (Type 13).

   g. If the gradient curve is not given and the option MGTC = 1 is chosen, the input for SUBI will follow the end of curve data card.
   h. Known heat load data (for KHEAT ≠ 0).

3. Other sets of data may follow if more than one problem is to be executed. However, there is no carry over of data between problems. Every data set must be complete.

For certain types of problems, nodal, for example, dummy subroutines can be used to save space in the machine and allow for a larger data array.

5.0 CORE STORAGE SPACE REQUIREMENTS

Almost all of the input to this routine is stored in a block of core called DATA. Basically, the size of this block is determined by the size of 7090 core (32768 locations) and the size of the Chain 5 link. The size of the DATA block is fixed by subroutine START such that the sum of locations used in all subroutines plus the DATA block will not exceed the core. Increases or decreases in subroutine locations used require reassembly of subroutine START to change the allowable data block size.

5.5.1 Breakdown of Core Space

The following values are based on the Fortran II Monitor system.

	Item	Number Core Locations Used
1.	System	100
2.	Chain 5 Main Routine	7246
3.	SUBDP	7157
4.	SUBEND	621
5.	SUBWT	142
6.	START	71
7.	CHECK	184
8.	SURVEY	152
9.	POL	186
10.	TRPOL (448 locations but dummy for nodal =	49)
11.	FLARAN	177
12.	TABLE	301
13.	REVPOL	203
14.	SUBP	50
15.	RESET	177
16.	CLOCK	28
17.	WCLCK	71
18.	Library Subroutines (including XS1MEQF)	2805
19.	I/O Buffers	205
20.	Some Data Space not in Data	407
		20332
21.	DATA	12400
		32732

5.5.2 Breakdown of DATA Block Size

A. Basic formula for determining amount of core space in DATA block that a radiator setup will require:

31 NSYS + 15 NTUBE + 18 NFLT + 26 NTFL + 14 NMLT + 9 NTML

+ 3 (NTTOT + NTTOS) + NLCTBT + CURSP

B. In Addition:

1. If this is a banks and headers problem (NPFC ≠ 0), add the following to basic formula:

NSYS + 2 NFLOWP + MAXTB + (MAXTB - 2)^2 + FPSP

2. If some flow can possibly bypass the radiator (NBYP ≠ 0), add the following to basic formula:

   8NSYS

3. If the problem includes a Regenerator setup (NREG ≠ 0), add the following to basic formula:

   3NSYS + 1NFLT

4. If freezing is to be considered (NFC ≠ 0), add the following to the basic formula:

   1NTUBE + 3(NFTOF + NFTOT) + NLCTBF

5. For a nodal problem (NSL > 0), add the following to the basic formula:

   8NT + 6NSL + 3NSTOS + NLCTBS

6. For a gradient problem (NSL = 0), add the following to the basic formula:

   5NMLT + 4NTML + GCURSP

C. Identification of symbols used in above formulas.

1. CURSP - Curve space for all curves except gradient curve.

   CURSP = NCR + 2NP

   where NCR - Number of curves other than gradient.
   NP - Number of points on all curves other than gradient.

2. FPSP - Flow path space. Number of 5 column fields on Parameter Card 7 containing segment numbers (do not count blank fields).

3. GCURSP - Gradient curve space.

   GCURSP = NTE + NTR + NNC + (NTE)(NTR)(NNC) + 3

   where NTE - Number of θ_e values in gradient table.
   NTR - Number of θ_r values in gradient table.
   NNC - Number of N_c values in gradient table.

4. MAXTB - Number of tubes in system having greatest number of tubes.

5. NFLOWP - Total number of flow paths in all systems.

6. NFLT - Number of types of fluid lumps.

7. (NFTOF + NFTOT) - Number of sets of conduction data given on the fluid type cards.

NFTOF - Total of number of fluid lumps conducted "to" as listed in columns 31-35 on Fluid Data Card 2.

NFTOT - Total of number of tube lumps conducted "to" as listed in columns 36-40 on Fluid Data Card 2.

8. NLCTBF - Number of lumps conducted "to" by fluid lumps. This is a count of all lumps listed as being conducted "to" on Structure Data Cards 4 and 5.

9. NLCTBS - Number of lumps conducted "to" by structure lumps. A count of all lumps listed as being conducted "to" on Structure Data Cards 4 and 5.

10. NLCTBT - Number of lumps conducted "to" by tube lumps. A count of all lumps listed as being conducted "to" on Tube Data Cards 5 and 6.

11. NMLT - Number of types of tube lumps.

12. NSL - Number of structure lumps.

13. NSTOS - Number of sets of conduction data given on the structure type cards. It is also the total number of structure lumps conducted "to" as listed in columns 26-30 on Structure Data Card 2.

14. NSYS - Number of systems.

15. NT - Number of types of structure lumps.

16. NTFL - Number of fluid lumps.

17. NTML - Number of tube lumps.

18. (NTTOT + NTTOS) - Number of sets of conduction data given on the tube type cards.

NTTOT - Total of number of tube lumps conducted "to" as listed in columns 26-30 on Tube Data Card 2.

NTTOS - Total of number of structure lumps conducted "to" as listed in columns 31-35 on Tube Data Card 2.

19. NTUBE - Total number of tubes in all systems.

5.6 ERROR MESSAGES

A resume of errors detected in reading the data will be printed throughout the data listing. If errors are found, the statement "Run discontinued because of error in data" will be printed at the end of the data listing. Some errors prevent the continuance of data reading and an immediate stop occurs.

All error messages in Chain 5 are self-explanatory with the exception of the one in SUBDP. To save core space but still facilitate error tracking, instead of explaining the error in detail, the value of an error code KON7 was varied. For better understanding of the error message "Error in SUBDP KON7 = X", a table showing correlation between all possible values of KON7 and probable errors follows.

KON7	Explanation
0	In using the interpolation subroutine POL on the inlet temperature curves, a variable was found to be out of the range of the table.
1	In using the interpolation subroutine POL on the flow rate curves = f(time), a variable was found to be out of the range of the table.
2	The last tube in some system does not have the largest number of any tube in that system, the first tube in some system does not have the smallest number of any tube in that system, or a number has been skipped in numbering the tubes. Check Parameter Card 7.
3,4	In using the interpolation subroutine POL on the flow rate curves = f(time), a variable was found to be out of the range of the table.
5	In using the interpolation subroutine POL on the pressure loss curves, friction factor curves, specific heat curves, viscosity curves, or density curves, a variable was found to be out of the range of a table.
6	Check Parameter Card 7.
7	The first tube in some system does not have the smallest number of any tube in that system. Check Parameter Card 7.
8	Check Parameter Card 7. Possibly two flow paths begin with the same tube but end with two different tubes.

KONT	Explanation
9	Check Parameter Card 7.
10	The last tube in some system does not have the largest number of any tube in that system. Check Parameter Card 7.
11,12	In using the interpolation subroutine POL on the enthalpy curves, a variable was found to be out of the range of a table.
13,14	Check Parameter Card 7.
15	The first tube in a system is frozen.
16	The last tube in a system in frozen.
17,18	Check Parameter Card 7.
19	In using interpolation subroutine POL on inlet temperature curves, a variable was found to be out of the range of a table.
20,21	In using the interpolation subroutine POL on the enthalpy curves, a variable was found to be out of the range of the table.
22	Branch of computer routine entered illegally.
23,24,26,27	Check Parameter Cards 15 and 7 to see that the flow paths are correct or that the valve is in the correct system.
25	A proportioning valve has been included in a parallel flow system.
28	In using the interpolation subroutine POL on the NFPC curves, a variable was found to be out of the range of the table.
29	In using the interpolation subroutine POL on the density of the liquid curve, a variable was found to be out of the range of the table.
30	In using the interpolation subroutine POL on the entering flow rate of the liquid, a variable was found to be out of the range of the table.
31	In using the interpolation subroutine POL on the two-phase flow viscosity curves, a variable was found to be out of the range of the table.

KON7	Explanation
32	In using the interpolation subroutine POL on the two-phase flow specific heat curves, a variable was found to be out of the range of a table.
33	In using the interpolation subroutine POL on the two-phase flow internal curve of area ratio versus χ_T, a variable was found to be out of the range of the table.

All of the above errors will cause the problem to be terminated.

6.0 SAMPLE PROBLEM

6.1 THERMAL AND FLOW SYSTEM MODEL

A simple problem designed to represent the type of system used for Apollo fuel cell heat rejection was prepared to check out the routine. A schematic of the system, Figure 10, shows the lump and tube numbering scheme. The data input is not representative of the actual Apollo fuel cell cooling system and should not be compared with known test data in any attempt to verify the computer routine or data input. The condenser input was modified to satisfy the length requirement for condensing lumps (page 44) but the data was not changed so that the length of the condenser would be accurate. Also, the area for heat transfer was not changed to be equivalent to (length) x (wetted perimeter) of the fluid lump. Despite the discrepancies which exist, the run illustrates a sample data input and output.

6.2 INPUT DATA LISTING

The input data for the system shown in Figure 10 are shown in the input format required for Data Cards in Table 2 .

6.3 CHECKOUT PRINT

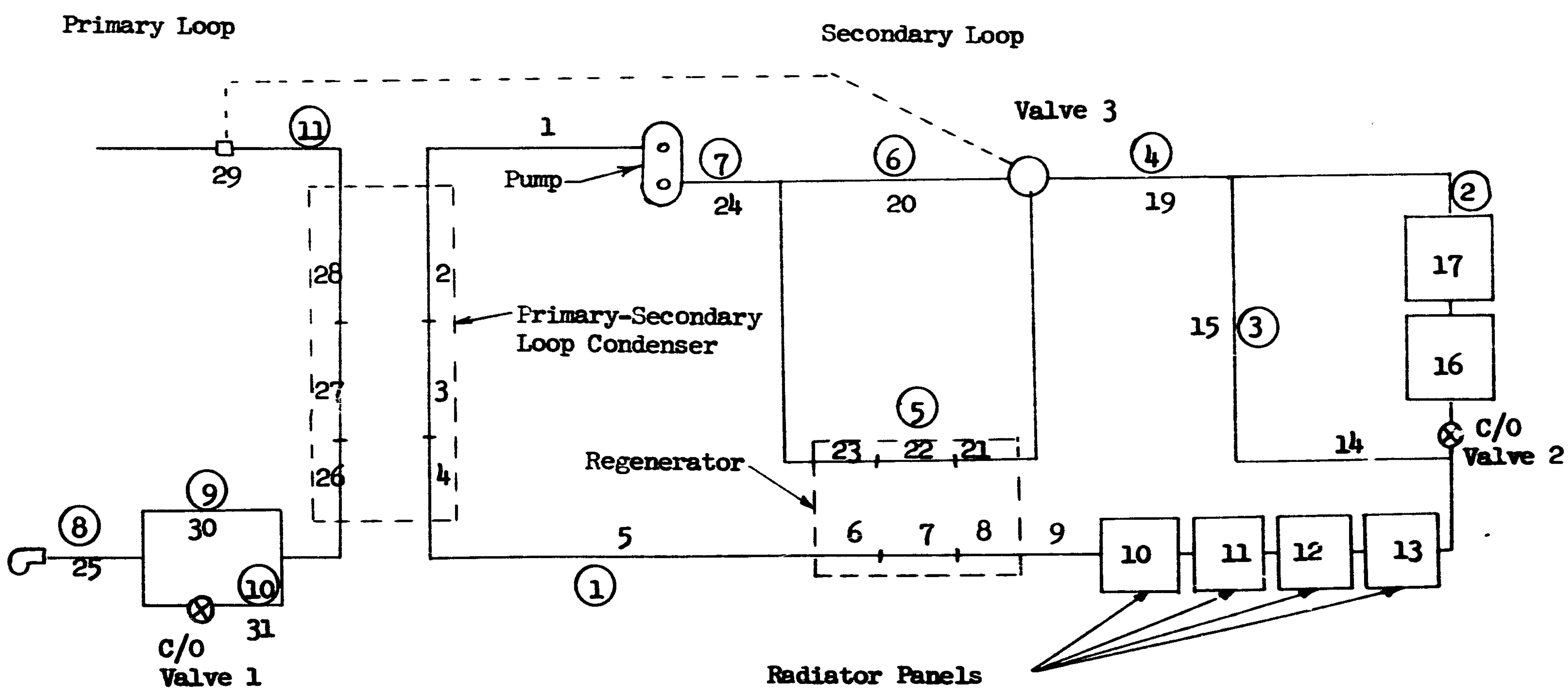
The data was run for checkout printing which is shown in Table 3 . An explanation of the terms in the order of appearance is given below.

SUBDP Checkout Printing for Non Two-Phase Flow Lumps

I	Lump Number
NPT	Type Lump
NTB	Tube Containing I
FREZ	0 is not frozen, 1 if frozen
DEN	Lump density
UI	Lump viscosity
FLL	Lump length
CSA	Cross-section area
WP	Wetted perimeter
RE	Reynolds Number
F	Friction factor
FR	Flow rate
FR	Lump pressure drop from viscous loss
DELP	Lump pressure drop from "K" loss
SH	Lump specific heat
DPTB	Accumulated tube pressure drop
DPRAD	Radiator pressure drop

SUBDP Checkout Printing for Two-Phase Flow Lumps

I	Lump number
NTUBE	Tube number
FLL	Length
WDOTG	Gas flow rate



◯ Circled numbers indicate tube numbers.
Non-circled numbers indicate fluid and tube lump numbers.

FIGURE 10

SYSTEM SCHEMATIC FOR CHECKOUT PROBLEM INPUT

```
PPD SECONDARY LOOP MOCK UP FOR PARTIAL CHECK OUT          2-PHASE             PC1
           .0001                    1  20.   1   1.0005  0.1                11PC2
   11      31      31       6       2       7          3 1     1     3      1.          PC3
1.0
    4       2                                                                         PC6
    1       2       4               1       3       4         4       5      7       4     6  PC7
    7               8       9      11               8    10  11                            PC7
    0       1                                                                         PC8
    1       0                                                                         PC9
    1       1                                                                         PC13
 100.    16.4                                                                         PC15
    1       2                                                                         PC18
  1 0      29     0.0              1.0             500.        700.                   PC20
  2 3      10       8      11                                                         PC21
  2 0      29     0.0              1.0             130.        170.                   PC20
  1 3       2       1       4                                                         PC21
  3 0      29     0.0              1.0                                                PC20
  1 2       6       4       7                                                         PC21
-3012.150056.252219 -.3501702 .00072669 6 0.0                                          PC22
    2      13      14      15      16      17      18      19      20      21      22      23      24      25  PC23
    1       2       3      26            3.22            85.7           772.            9.          PC25
    1       5       6       7       8       9                                             PC26
                                                                                     PC27
    8                                                                                 FDC1
  12.              .196            1.57             0       0                       1     FDC2
  60.              .196            1.57                                             1     FDC2
  1.66             7.0             189.                            1                1     FDC2
12000.             .196            1.57                                             1     FDC2
  12.              .196            1.57                                             1     FDC2
  1.66             7.0             139.                            2                1     FDC2
   .53             7.0             189.                                                   1  FDC2
   .53             7.0             189.                            1                      1  FDC2
    1       0       1       1    160.
    2       1       1       6    160.
   28
    3       2       1       6    160.
   27
    4       3       1       6    160.
   26
    5       4       1       1    160.
    6       5       1       3    160.
    7       6       1       3    160.
    8       7       1       3    160.
    9       8       1       1    160.
   10       9       1       2    160.
   11      10       1       2    160.
   12      11       1       2    160.
   13      12       1       2    160.
   14       0       3       1    160.
   15      14       3       4    160.
   16       0       2       2    160.
   17      16       2       2    160.
   18      17       2       5    160.
```

19	0	4	1	160.								
20	0	6	1	160.								
21	0	5	6	160.								
8												
22	21	5	6	160.								
7												
23	22	5	6	160.								
6												
24	0	7	1	160.								
25	0	8	7	160.		59.0						
26	0	11	8	160.		59.0						
27	26	11	8	160.		59.0						
28	27	11	8	160.		59.0						
29	28	11	7	160.		59.0						
30	0	10	7	160.		59.0						
31	0	9	7	160.		59.0						
4												TDC1
169.	1	2	3	4					12.0	1.0	.077	TDC2
94.		0.										TDC3
169.	1	2	3	4		1			60.0	1.0	.077	TDC2
470.		0.			0.		1.5	.050	60.			TDC3
169.	1	2	3	4					1.66	1.0	1.0	TDC2
1600.		0.										TDC3
169.	27	28	29	30					1.0	1.0	1.0	TDC2
100.		0.										TDC3
1	2	1	1	160.		1						
2	3	2	3	160.		1						
3	4	3	3	160.		1						
4	5	4	3	160.		1						
5	6	5	1	160.		1						
6	7	6	3	160.		1						
7	8	7	3	160.		1						
8	9	8	3	160.		1						
9	10	9	1	160.		1						
10	11	10	2	160.		1			1			
11	12	11	2	160.		1			2			
12	13	12	2	160.		1			3			
13	0	13	2	160.		1			4			
14	15	14	1	160.		1						
15	0	15	1	160.		1						
16	17	16	2	160.		1			5			
17	18	17	2	160.		1			6			
18	0	18	1	160.		1						
19	0	19	1	160.		1						
20	0	20	1	160.		1						
21	22	21	3	160.		1						
22	23	22	3	160.		1						
23	0	23	3	160.		1						
24	0	24	1	160.		1						
25	0	25	4	160.		1						
26	27	26	4	160.		1						
27	28	27	4	160.		1						
28	29	28	4	160.		1						
29	0	29	4	160.		1						
30	0	30	4	160.		1						

31	0	31	4	160.	1	
1						SDC1
169.	1	2	3	4	60. 6. .050	SDC2
1	1	160.		1		
2	1	160.		1		
3	1	160.		1		
4	1	160.		1		
5	1	160.		1		
6	1	160.		1		
12	1	1			INLET TEMP SYSTEM 1	
	0.	229.				
11	1	3			SYSTEM 1 PUMP CURVE	
0.0		30000.		100000.	70. 4. 0.	
11	2	1			SYSTEM 2 PUMP CURVE	
	0.	16.4				
1	5	1			FLUID DENSITY	
	0.	70.				
4	6	1			FLUID CONDUCTIVITY	
	0.	0.3				
5	7	1			FLUID CP	
	0.	0.75				
2	8	1			FLUID VISCOSITY	
	0.	6.0				
3	9	1			FRICTION FACTOR	
	0.	3.0				
0	1	1			K CURVE PRESSURE	
	0.	2.0				
4	1	1			ALUMINUM CONDUCTIVITY	
	0.	96.				
5	2	1			ALUMINUM CP	
	0.	0.2				
6	3	1			FIN ABSORPTANCE	
	0.	0.2				
7	4	1			FIN EMITTANCE	
	0.	0.92				
9	1	1			ZERO INCIDENT HEAT	
		0.0				
18	13	1			ENTER PG	
		59.				
2	14	1			VISC NON-CONDEN	
		.022				
2	15	1			VISC CONDEN	
		.025				
2	16	1			VISC LIQUID	
		2.0				
5	17	1			CP NON-CONDEN	
		3.5				
5	18	1			CP CONDEN	
		.42				
5	19	1			CP LIQUID	
		1.0				
4	20	1			COND NON-CONDEN	
		0.11				
4	21	1			CONDUCT CONDEN	

```
             0.035
   4    22       1                     CONDUCT LIQUID
             0.32
  14    23       1                     LATENT HEAT OF VAPOR
             1000.
  15    24       1                     PRANDTL LIQUID
             62.5
   1    25       1                     DENSITY LIQUID
             62.4
  16    26      35                     PARTIAL PRES
  30.        30.5       30.6      30.7      30.72      30.73      30.74
 100.       140.       150.      160.      164.       168.       172.
 176.       180.       184.      188.      192.       196.       200.
 204.       208.       212.      216.      220.       225.       230.
 235.       240.       245.      250.      255.       260.       270.
   0.       .00001     .00002    .00003    .000031    .000032    .00004
 0.95       2.88       3.76      4.73      5.2        5.72       6.272
 6.869      7.51       8.201     8.944     9.744      10.605     11.525
12.51      13.57      14.696    15.991    17.188      18.915     20.78
22.8       24.97      27.31     29.82     32.53      35.43      41.85
   4    27       1                     SYSTEM 2 TUBE COND
             100.
   5    28       1                     SYSTEM 2 TUBE SH
             .02
   6    29       1                     SYSTEM 2 TUBE ABS
             1.0
   7    30       1                     SYSTEM 2 TUBE EMIS
             1.0
  26     1       1                          GAS FLOW/TOTAL FLOW
                      1.
  26     2       1                          LIQ. FLOW/TOTAL FLOW
                      0.
  26     3       1                          NON-COND. FLOW/TOTAL FLOW
                    .305
  13
- EOF
```

WDOTL	Liquid flow rate
RE(L)	Superficial liquid Reynold's Number
PG	Gas pressure
PDR	ϕ^2 (see page 36)
DELP	Pressure drop

Fluid Lump Checkout Printing for Non Two-Phase Flow Lumps

I	Lump number
TI	Present temperature
WL	Surrounding tube lump number
T_{wall}	Constant temperature value
NLU	Number of upstream lump
TU	Upstream lump temperature
G	Heat transfer coefficient • area for heat transfer
H	(NAVTC = 0, Parameter Card 2) G/2 x TU
HI	Heat transfer coefficient = HTC $(\mu_b/\mu_w)^{.14}$ (HTC is item below)
ACON	Sum of hA and $\dot{w}$ cp,
ATEM	Sum of hAT_t and $\dot{w}$ cp TU
DTAU	Calculated maximum time increment
TYPE	Lump type
RE	Reynolds Number
PR	Prandtl number
COND	Fluid conductivity
DEN	Fluid density
SP HT	Fluid specific heat
V_{BULK}	μ at TI (bulk viscosity)
V_{WALL}	μ at T_t (tube wall viscosity)
WEIGH	Lump weight
HEAT TRAN COEFF	Isothermal heat transfer coefficient (HTC above)

Fluid Lump Checkout Printing for Two-Phase Flow Lumps

I, NTY, NLU	Same as above
NLD	Number of downstream lump
WP, CSA	Same as above
WDOTG	Gas flow rate
WDOTL	Liquid flow rate
WDOTO	Non-condensible flow rate
HUMID	Humidity ratio ($lb_{vapor}/lb_{non-condensible}$)
VISO	Viscosity of non-condensible (x 10^3)
VISI	Viscosity of condensible (x 10^3)
VISL	Viscosity of liquid (x 10^3)
CPO	Specific heat of non-condensible
CPI	Specific heat of condensible
CPL	Liquid specific heat
LAMDA	Latent heat of vaporization
Ko	Conductivity of non-condensible
K_1	Conductivity of condensible
KL	Liquid conductivity

PRL	Liquid Prandtl Number
DENL	Liquid density
VISI	Gas mixture viscosity
CPG	Gas mixture specific heat
KG	Conductivity of gas mixture
PR(G)	Mixture Prandtl Number
DENG	Gas density
TWALL	Tube temperature
RE(G)	Gas superficial Reynolds Number
AREAR	α (see page 36)
CHI	χ (see page 35)
PG	Gas pressure
BULK	Vapor partial pressure
DIF	Diffusion coefficient value
SC	Schmidt Number
PSURF	Vapor pressure at condensing surface
PM	Log mean pressure of non-condensible
KM	Mass transfer coefficient
Q_L	Latent heat rate
H	Heat transfer coefficient
TS	Condensing surface temperature
TG	Gas temperature
REV	Special Reynolds Number (page 40)
ACON	Sum of (coefficient x area) relating heat transfer to tube
ATEM	Sum of (coefficient x area x temperature) + Q relating to tube
U	Film conductance
DTAUG	Gas maximum time increment
DTAUL	Liquid maximum time increment

Tube Lump Checkout Printing

The tube lump print explanation is as follows

I	Lump number
NDL	Lump number downstream
TI	Present temperature
TD	Present temperature of tube downstream
CONI	Conductivity of I
COND	Conductivity of lump downstream
U	Conductance to last lump conducted "to"
EM	Emissivity of lump
AB	Absorptivity of fin (gradient problems only)
Q	Incident heat value
ACON(NDL)	ACON for downstream lump
ATEM(NDL)	ATEM for downstream lump
ACON(I)	Sum of all UA products plus Q RA
ATEM(I)	Sum of all UAT products, T associated with proper U
DTAU	Stability required time increment
USUM	Sum of all conductances from tube lump

UTSUM	Sum of conductance x temperature for lump I ($U_{jI}T_I$, $j > I$ not included)
QA	(Q)(AREA)(ABsorptivity)
QRA	(EM)(AREA)(σ)(T^3)

Structure Lump Checkout Printing

I	Structure lump number
Q	Incident heat
CONI	Conductivity of I
WEIGHT	Weight of lump
SP HEAT	Specified heat
USUM	Sum of all conductances from tube lump and "to" other fin (structure) lumps
UTSUM	Sum of product of the conductances with respective temperatures
QA	Incident heat addition rate
QR	(Emissivity)(Area)(σ) T^3
ACON	Sum of conductance-area products plus QR
ATEM	Sum of UAT products plus QA
DTAU	Time increment required for stability

6.4 RESULTS AND OUTPUT FORMAT

The problem as set up was found to be slightly unstable with $\theta = 0.9$. To insure a solution in this situation, θ was set to 0.5 and the problem was run 3000 iterations (.3 hours), with no instability noticed. The printout at 0.3 hours is shown in Table 4 . Thermally the problem was very close to steady state; but the liquid flow rates were still dropping from their initial rise. The slow decay time results because the velocity of the liquid in the condenser is such that the condenser is traversed by a fluid particle in about 300 iterations.

```
PPD SECONDARY LOOP MOCK UP FOR PARTIAL CHECK OUT          2-PHASE
                    DATA SET    1

     CONVERGENCE FACTOR                 .9000

     PRINT TEMPERATURE DISTRIBUTION EVERY   .100 HR.

     TRANSIENT, TOTAL TIME IS     .0005 HR.

     NUMBER OF SYSTEMS                     2

     NUMBER OF TUBES                      11

     NUMBER OF FLUID LUMPS                31

     NUMBER OF TUBE LUMPS                 31

     NUMBER OF FIN LUMPS                   6

     HEAT TRANSFER COEFFICIENT        1.0000

     INITIAL HUMIDITY GLESS            1.00000

     OUTLET TEMPERATURE WILL BE USED FOR FLUID FLOW

     SYSTEM      1 CONTAINS THE FOLLOWING FLOWPATHS

          FLOWPATH      1 CONSISTS OF TUBES NUMBERED
                 1.  2.  4.

          FLOWPATH      2 CONSISTS OF TUBES NUMBERED
                 1.  3.  4.

          FLOWPATH      3 CONSISTS OF TUBES NUMBERED
                 4.  5.  7.

          FLOWPATH      4 CONSISTS OF TUBES NUMBERED
                 4.  6.  7.

     SYSTEM      2 CONTAINS THE FOLLOWING FLOWPATHS

          FLOWPATH      1 CONSISTS OF TUBES NUMBERED
                 8.  9. 11.

          FLOWPATH      2 CONSISTS OF TUBES NUMBERED
                 8. 10. 11.
```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```
PPD SECONDARY LOOP MOCK UP FOR PARTIAL CHECK OUT          2-PHASE
                     DATA SET    1

TWO PHASE FLOW OPTIONS (=0,NOT 2PH.FL./ =1,IS 2PH.FL.) FOR EACH SYSTEM
     SYSTEM     1     OPTION     0
     SYSTEM     2     OPTION     1

INLET TEMPERATURE CURVE NUMBER FOR INLET TUBE IN SYSTEM   1          1

INLET TEMPERATURE CURVE NUMBER FOR INLET TUBE IN SYSTEM   2          1

TOTAL FLOW RATE (LBS./HR.) IN SYSTEM    1      100.0000

TOTAL FLOW RATE (LBS./HR.) IN SYSTEM    2       16.4000

CURVE NUMBER FOR TOTAL FLOW=F(PRESSURE DROP) IN SYSTEM    1          1

CURVE NUMBER FOR TOTAL FLOW=F(PRESSURE DROP) IN SYSTEM    2          2

NODAL SOLUTION

MINIMUM TIME INCREMENT =     .00010000

    PARAMETERS FOR VALVE   1   (ON/OFF TYPE)
SENSOR LMP NO. =     29   SYSTEM NO.  =     2              OPERATING MODE = YES
FROM TUBE NO.  =      8   TO TUBE NO. =    11   FIRST TUBE ON BYPASS SIDE =    10
MIN RAD FRCT =      .00000  MAX RAD FRCT =    1.00000
    T1 =  500.00000                 T2 =  700.00000

    PARAMETERS FOR VALVE   2   (ON/OFF TYPE)
SENSOR LMP NO. =     29   SYSTEM NO.  =     1              OPERATING MODE = YES
FROM TUBE NO.  =      1   TO TUBE NO. =     4   FIRST TUBE ON BYPASS SIDE =     2
MIN RAD FRCT =      .00000  MAX RAD FRCT =    1.00000
    T1 =  130.00000                 T2 =  169.99999
```


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PPD SECONDARY LOOP MOCK UP FOR PARTIAL CHECK OUT 2-PHASE
DATA SET 1

```
          PARAMETERS FOR VALVE   3   (POLY   TYPE)
SENSOR LMP NO. =    29   SYSTEM NO.  =     1            OPERATING MODE = YES
FROM TUBE NO.  =     4   TO TUBE NO. =     7   FIRST TUBE ON BYPASS SIDE =      6
MIN RAD FRCT =     .00000  MAX RAD FRCT =    1.00000  INITIAL RAD FRCT =    -.00000
     A0 =   -3.0121499+03        A1 =    5.6252216+01            A2 =   -3.5017020-01
     A3 =    7.2669599-04        A4 =    0.0000000
```


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PPD SECONDARY LOOP MOCK UP FOR PARTIAL CHECK OUT 2-PHASE
DATA SET 1

PARAMETERS FOR SYSTEM = 2

CURVE NO.OF ENTERING GAS PRESSURE IS 13
CURVE NO.OF VISCOSITY OF NONCONDENSIBLE IS 14
CURVE NO.OF VISCOSITY OF CONDENSIBLE IS 15
CURVE NO.OF VISCOSITY OF LIQUID IS 16
CURVE NO.OF SPECIFIC HEAT OF NONCONDENSIBLE IS 17
CURVE NO.OF SPECIFIC HEAT OF CONDENSIBLE IS 18
CURVE NO.OF SPECIFIC HEAT OF LIQUID IS 19
CURVE NO.OF CONDUCTIVITY OF NONCONDENSIBLE IS 20
CURVE NO.OF CONDUCTIVITY OF CONDENSIBLE IS 21
CURVE NO.OF CONDUCTIVITY OF LIQUID IS 22
CURVE NO.OF LATENT HEAT OF VAPORIZATION IS 23
CURVE NO.OF PRANDTL NUMBER OF LIQUID IS 24
CURVE NO.OF LIQUID DENSITY IS 25
CURVE NO. FOR PORTION OF TOTAL FLOW IN SYSTEM THAT IS GAS FLOW IS 1
CURVE NO. FOR PORTION OF TOTAL FLOW IN SYSTEM THAT IS LIQUID FLOW IS 2
CURVE NO. FOR PORTION OF TOTAL FLOW IN SYSTEM THAT IS NONCONDENSIBLE FLOW IS 3
CURVE NO.OF PARTIAL PRESSURE OF VAPORIZATION IS 26
BINARY DIFFUSION CONSTANT IS 3.22000
GAS CONSTANT FOR CONDENSIBLE COMPONENT IS 85.76000
GAS CONSTANT FOR NONCONDENSIBLE COMPONENT IS 772.00000
MOLECULAR WEIGHT RATIO IS 9.00000

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PPD SECONDARY LOOP MOCK UP FOR PARTIAL CHECK OUT 2-PHASE
DATA SET 1

PARAMETERS FOR SYSTEM - 1

CURVE NO.OF DENSITY IS 5
CURVE NO.OF CONDUCTIVITY IS 6
CURVE NO.OF SPECIFIC HEAT IS 7
CURVE NO.OF VISCOSITY IS 6
CURVE NO.OF FRICTION FACTOR IS 9

```
PPD SECONDARY LOOP MOCK UP FOR PARTIAL CHECK OUT          2-PHASE
                    DATA SET     1

FLUID LUMP DATA

NUMBER OF TYPES OF LUMPS     8

TYPE -     1

  FLUID LUMP LENGTH      12.00000000 INCHES
  CROSS SECTIONAL AREA     .19599999 SQ.IN.
  WETTED PERIMETER       1.56999999 INCHES
  NO.OF FLUID LUMPS CONDUCTED TO     0
  NO.OF TUBE LUMPS CONDUCTED TO     0
  FRICTION FACTOR    -.000000
  HEAT EXCHANGER CODE    -0
  CALCULATION OF HHH OPTION    -0
  CURVE  NO.OF FLOW RATE VS HHH (OR) ST*PR**2/3 VS REYNOLDS NO     -0
  K CURVE FOR PRESSURE DROP IS     1
  TWO PHASE OPTION -    -0
TYPE -     2

  FLUID LUMP LENGTH      59.99999900 INCHES
  CROSS SECTIONAL AREA     .19599999 SQ.IN.
  WETTED PERIMETER       1.56999999 INCHES
  NO.OF FLUID LUMPS CONDUCTED TO    -0
  NO.OF TUBE LUMPS CONDUCTED TO    -0
  FRICTION FACTOR    -.000000
  HEAT EXCHANGER CODE    -0
  CALCULATION OF HHH OPTION    -0
  CURVE  NO.OF FLOW RATE VS HHH (OR) ST*PR**2/3 VS REYNOLDS NO     -0
  K CURVE FOR PRESSURE DROP IS     1
  TWO PHASE OPTION -    -0
TYPE -     3

  FLUID LUMP LENGTH       1.66000000 INCHES
  CROSS SECTIONAL AREA    7.00000000 SQ.IN.
  WETTED PERIMETER      169.00000000 INCHES
  NO.OF FLUID LUMPS CONDUCTED TO    -0
  NO.OF TUBE LUMPS CONDUCTED TO    -0
  FRICTION FACTOR    -.000000
  HEAT EXCHANGER CODE     1
  CALCULATION OF HHH OPTION    -0
  CURVE  NO.OF FLOW RATE VS HHH (OR) ST*PR**2/3 VS REYNOLDS NO     -0
  K CURVE FOR PRESSURE DROP IS     1
  TWO PHASE OPTION -    -0
```

```
PPD SECONDARY LOOP MOCK UP FOR PARTIAL CHECK OUT        2-PHASE
                    DATA SET    1

TYPE -    4

   FLUID LUMP LENGTH  11999.99990000 INCHES
   CROSS SECTIONAL AREA    .19599999 SQ.IN.
   WETTED PERIMETER      1.56999999 INCHES
   NO.OF FLUID LUMPS CONDUCTED TO   -0
   NO.OF TUBE LUMPS CONDUCTED TO   -0
   FRICTION FACTOR   -.000000
   HEAT EXCHANGER CODE   -0
   CALCULATION OF HHH OPTION   -0
   CURVE  NO.OF FLOW RATE VS HHH (OR) ST*PR**2/3 VS REYNOLDS NO    -0
   K CURVE FOR PRESSURE DROP IS    1
   TWO PHASE OPTION -   -0
TYPE -    5

   FLUID LUMP LENGTH      12.00000000 INCHES
   CROSS SECTIONAL AREA    .19599999 SQ.IN.
   WETTED PERIMETER      1.56999999 INCHES
   NO.OF FLUID LUMPS CONDUCTED TO   -0
   NO.OF TUBE LUMPS CONDUCTED TO   -0
   FRICTION FACTOR   -.000000
   HEAT EXCHANGER CODE   -0
   CALCULATION OF HHH OPTION   -0
   CURVE  NO.OF FLOW RATE VS HHH (OR) ST*PR**2/3 VS REYNOLDS NO    -0
   K CURVE FOR PRESSURE DROP IS    1
   TWO PHASE OPTION -   -0
TYPE -    6

   FLUID LUMP LENGTH      1.66000000 INCHES
   CROSS SECTIONAL AREA  7.00000000 SQ.IN.
   WETTED PERIMETER    189.00000000 INCHES
   NO.OF FLUID LUMPS CONDUCTED TO   -0
   NO.OF TUBE LUMPS CONDUCTED TO   -0
   FRICTION FACTOR   -.000000
   HEAT EXCHANGER CODE    2
   CALCULATION OF HHH OPTION   -0
   CURVE  NO.OF FLOW RATE VS HHH (OR) ST*PR**2/3 VS REYNOLDS NO    -0
   K CURVE FOR PRESSURE DROP IS    1
   TWO PHASE OPTION -   -0
TYPE -    7

   FLUID LUMP LENGTH       .52999999 INCHES
   CROSS SECTIONAL AREA  7.00000000 SQ.IN.
   WETTED PERIMETER    189.00000000 INCHES
   NO.OF FLUID LUMPS CONDUCTED TO   -0
   NO.OF TUBE LUMPS CONDUCTED TO   -0
   FRICTION FACTOR   -.000000
   HEAT EXCHANGER CODE   -0
   CALCULATION OF HHH OPTION   -0
   CURVE  NO.OF FLOW RATE VS HHH (OR) ST*PR**2/3 VS REYNOLDS NO    -0
   K CURVE FOR PRESSURE DROP IS   -0
   TWO PHASE OPTION -    1
```

PPD SECONDARY LOOP MOCK UP FOR PARTIAL CHECK OUT 2-PHASE

DATA SET 1

TYPE - 8

FLUID LUMP LENGTH .52999999 INCHES
CROSS SECTIONAL AREA 7.00000000 SQ.IN.
WETTED PERIMETER 189.00000000 INCHES
NO.OF FLUID LUMPS CONDUCTED TO -0
NO.OF TUBE LUMPS CONDUCTED TO -0
FRICTION FACTOR -.000000
HEAT EXCHANGER CODE 1
CALCULATION OF HHP OPTION -0
CURVE NO.OF FLOW RATE VS HHH (OR) ST*PR**2/3 VS REYNOLDS NO -0
K CURVE FOR PRESSURE DROP IS -0
TWO PHASE OPTION - 1

FLUID LUMP DATA

LUMP	UP	TUBE	TYPE	TEMPER(GAS)	PRESSURE	TEMPER(LIQ)
1	0	1	1	160.000000		
2	1	1	6	160.000000		
					ADJACENT LUMP IS	28
3	2	1	6	160.000000		
					ADJACENT LUMP IS	27
4	3	1	6	160.000000		
					ADJACENT LUMP IS	26
5	4	1	1	160.000000		
6	5	1	3	160.000000		
7	6	1	3	160.000000		
8	7	1	3	160.000000		
9	8	1	1	160.000000		
10	9	1	2	160.000000		
11	10	1	2	160.000000		
12	11	1	2	160.000000		
13	12	1	2	160.000000		
14	0	3	1	160.000000		
15	14	3	4	160.000000		
16	0	2	2	160.000000		
17	16	2	2	160.000000		
18	17	2	5	160.000000		
19	0	4	1	160.000000		
20	0	6	1	160.000000		
21	0	5	6	160.000000		
					ADJACENT LUMP IS	8
22	21	5	6	160.000000		
					ADJACENT LUMP IS	7
23	22	5	6	160.000000		
					ADJACENT LUMP IS	6
24	0	7	1	160.000000		
25	0	8	7	160.000000	59.0000	-.000000
26	0	11	6	160.000000	59.0000	-.000000
27	26	11	6	160.000000	59.0000	-.000000

28	27	11	8	160,000000	59,0000	-,000000
29	28	11	7	160,000000	59,0000	-,000000
30	0	10	7	160,000000	59,0000	-,000000
31	0	9	7	160,000000	59,0000	-,000000

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PPD SECONDARY LOOP MOCK UP FOR PARTIAL CHECK OUT 2-PHASE

DATA SET 1

SUM OF FLUID LUMP LENGTHS IN EACH TUBE (INCHES)

285.9600	132.0000	17011.9996	12.0000	4.9800
12.0000	12.0000	.5300	.5300	.5300
2.1200				

DATA SPACE USED 1302

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```
PPD SECONDARY LOOP MOCK UP FOR PARTIAL CHECK OUT        2-PHASE
                  DATA SET    1

TUBE LUMP DATA

NUMBER OF TYPES OF LUMPS    4

TYPE NUMBER    1
  DENSITY          169.0000 LBS./CU.FT.
  CONDUCTIVITY CURVE NUMBER          1
  SPECIFIC HEAT CURVE NUMBER         2
  ABSORPTIVITY CURVE NUMBER          3
  EMISSIVITY CURVE NUMBER            4
  VOLUME (X1.X2.X3)                          .924000 CU.INS.
  AREA FOR LONG. CONDUCTION (X2.X3)          .077000 SQ.INS.
  COND. DIST. FOR LONG. COND. (X1/2.)       6.000000 INCHES
  WILL LONG. CONDUCTION BE COMPUTED            YES
  NO. OF TUBE LUMPS CONDUCTED TO              -0
  NO. OF STRUCTURE LUMPS CONDUCTED TO         -0
  AREA FOR HEAT TRANSFER                   94.000000 SQ.INS.
  AREA FOR EXTERNAL RADIATION                .000000 SQ.INS.

TYPE NUMBER    2
  DENSITY          169.0000 LBS./CU.FT.
  CONDUCTIVITY CURVE NUMBER          1
  SPECIFIC HEAT CURVE NUMBER         2
  ABSORPTIVITY CURVE NUMBER          3
  EMISSIVITY CURVE NUMBER            4
  VOLUME (X1.X2.X3)                         4.520000 CU.INS.
  AREA FOR LONG. CONDUCTION (X2.X3)          .377000 SQ.INS.
  COND. DIST. FOR LONG. COND. (X1/2.)      30.000000 INCHES
  WILL LONG. CONDUCTION BE COMPUTED            YES
  NO. OF TUBE LUMPS CONDUCTED TO              -0
  NO. OF STRUCTURE LUMPS CONDUCTED TO          1
  AREA FOR HEAT TRANSFER                  470.000000 SQ.INS.
  AREA FOR EXTERNAL RADIATION                .000000 SQ.INS.
  CONDUCTION DATA
        .000000000 INS.     1.500000000 INS.     3.000000000 SQ.INS.
```

PPD SECONDARY LOOP MOCK UP FOR PARTIAL CHECK OUT 2-PHASE
DATA SET 1

```
TYPE NUMBER     3
  DENSITY            165.0000 LBS./CU.FT.
  CONDUCTIVITY CURVE NUMBER               1
  SPECIFIC HEAT CURVE NUMBER              2
  ABSORPTIVITY CURVE NUMBER               3
  EMISSIVITY CURVE NUMBER                 4
  VOLUME (X1,X2,X3)                          1.660000 CU.INS.
  AREA FOR LONG. CONDUCTION (X2,X3)          1.000000 SQ.INS.
  COND. DIST. FOR LONG. COND. (X1/2.)         .830000 INCHES
  WILL LONG. CONDUCTION BE COMPUTED            YES
  NO. OF TUBE LUMPS CONDUCTED TO              -0
  NO. OF STRUCTURE LUMPS CONDUCTED TO         -0
  AREA FOR HEAT TRANSFER                  1600.000000 SQ.INS.
  AREA FOR EXTERNAL RADIATION                 .000000 SQ.INS.

TYPE NUMBER     4
  DENSITY            165.0000 LBS./CU.FT.
  CONDUCTIVITY CURVE NUMBER              27
  SPECIFIC HEAT CURVE NUMBER             28
  ABSORPTIVITY CURVE NUMBER              29
  EMISSIVITY CURVE NUMBER                30
  VOLUME (X1,X2,X3)                          1.000000 CU.INS.
  AREA FOR LONG. CONDUCTION (X2,X3)          1.000000 SQ.INS.
  COND. DIST. FOR LONG. COND. (X1/2.)         .500000 INCHES
  WILL LONG. CONDUCTION BE COMPUTED            YES
  NO. OF TUBE LUMPS CONDUCTED TO              -0
  NO. OF STRUCTURE LUMPS CONDUCTED TO         -0
  AREA FOR HEAT TRANSFER                   100.000000 SQ.INS.
  AREA FOR EXTERNAL RADIATION                 .000000 SQ.INS.
```

TUBE LUMPS

LUMP	NDL	NFL	TYPE	TEMPERATURE	G	ALL	LUMPS CONDUCTED TO	
1	2	1	1	160.000000	1	-0		
2	3	2	3	160.000000	1	-0		
3	4	3	3	160.000000	1	-0		
4	5	4	3	160.000000	1	-0		
5	6	5	1	160.000000	1	-0		
6	7	6	3	160.000000	1	-0		
7	8	7	3	160.000000	1	-0		
8	9	8	3	160.000000	1	-0		
9	10	9	1	160.000000	1	-0		
10	11	10	2	160.000000	1	-0	FIN	1
11	12	11	2	160.000000	1	-0	FIN	2
12	13	12	2	160.000000	1	-0	FIN	3

PPD SECONDARY LOOP MOCK UP FOR PARTIAL CHECK OUT 2-PHASE

DATA SET 1

13	0	13	2	160.000000	1	-0	FIN	4
14	15	14	1	160.000000	1	-0		
15	0	15	1	160.000000	1	-0		
16	17	16	2	160.000000	1	-0	FIN	5
17	16	17	2	160.000000	1	-0	FIN	6
18	0	18	1	160.000000	1	-0		
19	0	19	1	160.000000	1	-0		
20	0	20	1	160.000000	1	-0		
21	22	21	3	160.000000	1	-0		
22	23	22	3	160.000000	1	-0		
23	0	23	3	160.000000	1	-0		
24	0	24	1	160.000000	1	-0		
25	0	25	4	160.000000	1	-0		
26	27	26	4	160.000000	1	-0		
27	28	27	4	160.000000	1	-0		
28	29	28	4	160.000000	1	-0		
29	0	29	4	160.000000	1	-0		
30	0	30	4	160.000000	1	-0		
31	0	31	4	160.000000	1	-0		

SUM OF TUBE LUMP LENGTHS IN EACH TUBE (INCHES)

285.9600	132.0000	24.0000	12.0000	4.9800
12.0000	12.0000	1.0000	1.0000	1.0000
4.0000				

TOTAL AREA FOR EXTERNAL RADIATION FOR TUBE LUMPS = .00000 SQ. IN.

DATA SPACE USED 1646

PPD SECONDARY LOOP MOCK UP FOR PARTIAL CHECK OUT   2-PHASE
DATA SET 1

FIN LUMP DATA

NUMBER OF TYPES OF LUMPS 1

TYPE	1
DENSITY	169.00000 LBS./CU.FT.
WEIGHT	1.76042 LBS.
EXTERNAL RADIATION AREA	2.50000 SQ.FT.
CONDUCTIVITY CURVE NUMBER	1
SPECIFIC HEAT CURVE NUMBER	2
ABSORPTIVITY CURVE NUMBER	3
EMISSIVITY CURVE NUMBER	4
NO. OF LUMPS CONDUCTED TO	-0

LUMP	TYPE	TEMPERATURE	INC.HEAT	WALL TEMP.	LUMPS CONDUCTED TO
1	1	160.000000	1	-0	
2	1	160.000000	1	-0	
3	1	160.000000	1	-0	
4	1	160.000000	1	-0	
5	1	160.000000	1	-0	
6	1	160.000000	1	-0	

TOTAL SURFACE AREA FOR FIN LUMPS =2159.99990 SQ. IN.

DATA SPACE USED 1690

007

```
PPD SECONDARY LOOP MOCK UP FOR PARTIAL CHECK OUT        2-PHASE
                    DATA SET    1

CURVE DATA

 12    1     1   -0    -0     INLET TEMP SYSTEM 1
     .0000000        226.9999900

 11    1     3   -0    -0     SYSTEM 1 PUMP CURVE
     .0000000     30000.0000000    100000.0000000        70.0000000
    4.0000000          .0000000

 11    2     1   -0    -0     SYSTEM 2 PUMP CURVE
     .0000000         16.4000000

  1    5     1   -0    -0     FLUID DENSITY
     .0000000         70.0000000

  4    6     1   -0    -0     FLUID CONDUCTIVITY
     .0000000           .3000000

  5    7     1   -0    -0     FLUID CP
     .0000000           .7500000

  5    7     2   -0    -0ENTHALPY CURVE - GENERATED FROM ABOVE.
 -459.6900000        540.3100000          .0000000       750.0000000

  2    8     1   -0    -0     FLUID VISCOSITY
     .0000000          6.0000000

  3    9     1   -0    -0     FRICTION FACTOR
     .0000000          3.0000000

  0    1     1   -0    -0     K CURVE PRESSURE
     .0000000          2.0000000

  4    1     1   -0    -0     ALUMINUM CONDUCTIVITY
     .0000000         96.0000000

  5    2     1   -0    -0     ALUMINUM CP
     .0000000           .2000000

  6    3     1   -0    -0     FIN ABSORPTANCE
     .0000000           .2000000

  7    4     1   -0    -0     FIN EMITTANCE
```


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```
PPD SECONDARY LOOP MOCK UP FOR PARTIAL CHECK OUT        2-PHASE
                         DATA SET    1

       .0000000          .9200000

    9    1    1   -0    -0    ZERO INCIDENT HEAT
     -.0000000           .0000000

   18   13    1   -0    -0    ENTER PC
     -.0000000         59.0000000

    2   14    1   -0    -0    VISC NON-CONDEN
     -.0000000           .0220000

    2   15    1   -0    -0    VISC CONDEN
     -.0000000           .0250000

    2   16    1   -0    -0    VISC LIQUID
     -.0000000          2.0000000

    5   17    1   -0    -0    CP NON-CONDEN
     -.0000000          3.5000000

    5   17    2   -0    -0ENTHALPY CURVE - GENERATED FROM ABOVE.
  -459.6900000        540.3100000        .0000000     3499.9999000

    5   18    1   -0    -0    CP CONDEN
     -.0000000           .4200000

    5   19    1   -0    -0    CP LIQUID
     -.0000000          1.0000000

    5   19    2   -0    -0ENTHALPY CURVE - GENERATED FROM ABOVE.
  -459.6900000        540.3100000        .0000000     1000.0000000

    4   20    1   -0    -0    COND NON-CONDEN
     -.0000000           .1100000

    4   21    1   -0    -0    CONDUCT CONDEN
     -.0000000           .0350000

    4   22    1   -0    -0    CONDUCT LIQUID
     -.0000000           .3200000

   14   23    1   -0    -0    LATENT HEAT OF VAPOR
     -.0000000       1000.0000000

   15   24    1   -0    -0    PRANDTL LIQUID
     -.0000000         62.5000000

    1   25    1   -0    -0    DENSITY LIQUID
```

```
PPD SECONDARY LOOP MOCK UP FOR PARTIAL CHECK OUT        2-PHASE
                   DATA SET    1

     -.0000000       62.3999990

 16   26   35   -0   -0      PARTIAL PRES
    30.0000000      30.5000000      30.5999990      30.7000000
    30.7199990      30.7299993      30.7400000     100.0000000
   139.9999900     150.0000000     160.0000000     164.0000000
   168.0000000     172.0000000     176.0000000     180.0000000
   184.0000000     187.9999900     191.9999900     195.9999900
   200.0000000     204.0000000     208.0000000     212.0000000
   216.0000000     220.0000000     224.9999900     230.0000000
   235.0000000     239.9999900     245.0000000     250.0000000
   255.0000000     260.0000000     270.0000000        .0000000
      .0000100        .0000200        .0000300        .0000310
      .0000320        .0000400        .9500000       2.8800000
     3.7599999       4.7300000       5.2000000       5.7200000
     6.2719999       6.8690000       7.5100000       8.2010000
     8.9439999       9.7440000      10.6049998      11.5250000
    12.5100000      13.5699999      14.6959999      15.9909999
    17.1880000      18.9150000      20.7799990      22.7999990
    24.9699990      27.3100000      29.8200000      32.5299990
    35.4299990      41.8500000

  4   27    1   -0   -0      SYSTEM 2 TUBE CONC
     -.0000000      170.0000000

  5   28    1   -0   -0      SYSTEM 2 TUBE SH
     -.0000000        .2000000

  6   29    1   -0   -0      SYSTEM 2 TUBE ABS
     -.0000000       1.0000000

  7   30    1   -0   -0      SYSTEM 2 TUBE EMIS
     -.0000000       1.0000000

 26    1    1   -0   -0         GAS FLOW/TOTAL FLOW
     -.0000000       1.0000000

 26    2    1   -0   -0         LIQ. FLOW/TOTAL FLOW
     -.0000000        .0000000

 26    3    1   -0   -0         NON-COND. FLOW/TOTAL FLOW
     -.0000000        .3050000

 13   -0   -0   -0   -0
```

```
PPD SECONDARY LOOP MOCK UP FOR PARTIAL CHECK OUT          2-PHASE
                    DATA SET    1

  CONDENSIBLE COMPONENT ENTHALPY CURVE FOR SYSTEM     2
        -.0000000      1000.0000000      1459.6900000      1879.6899000

DATA SPACE USED       1887

 IF NECESSARY TO STOP, THE FOLLOWING PROCEDURE WILL WRITE A DUMP TAPE WHICH CAN BE USED TO RE-START
 (1) IF A BLANK TAPE WAS NOT MOUNTED ON A6 DURING SET-UP, RING AND MOUNT ONE.
 (2) SET DOWN SENSE SWITCH 5.
 (3) WAIT FOR MESSAGE TO  RESET SENSE SWITCH.


 CHECK OUT PRINTING FOR PRESSURE DROP SUBROUTINE


 I    =        1 NPT  =        1 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI   =    6.00000
 FLL  =  1.00000 CSA  =   .00136 WP   =   .13083 RE   = 141.54281 F    =    .11304 FR   =  100.00000
 FR   =  6.97701 DELF =  1.28423 SH   =   .75000 DPTB =   8.26124

 I    =        2 NPT  =        6 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI   =    6.00000
 FLL  =   .13833 CSA  =   .04661 WP   = 15.75000 RE   =   1.17578 F    =  13.60800 FR   =  100.00000
 FR   =   .30704 DELF =   .00101 SH   =   .75000 DPTB =   8.56928

 I    =        3 NPT  =        6 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI   =    6.00000
 FLL  =   .13833 CSA  =   .04661 WP   = 15.75000 RE   =   1.17578 F    =  13.60800 FR   =  100.00000
 FR   =   .30704 DELF =   .00101 SH   =   .75000 DPTB =   8.87733

 I    =        4 NPT  =        6 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI   =    6.00000
 FLL  =   .13833 CSA  =   .04661 WP   = 15.75000 RE   =   1.17578 F    =  13.60800 FR   =  100.00000
 FR   =   .30704 DELF =   .00101 SH   =   .75000 DPTB =   9.18538

 I    =        5 NPT  =        1 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI   =    6.00000
 FLL  =  1.00000 CSA  =   .00136 WP   =   .13083 RE   = 141.54281 F    =    .11304 FR   =  100.00000
 FR   =  6.97701 DELF =  1.28423 SH   =   .75000 DPTB =  17.44661

 I    =        6 NPT  =        3 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI   =    6.00000
 FLL  =   .13833 CSA  =   .04661 WP   = 15.75000 RE   =   1.17578 F    =  13.60800 FR   =  100.00000
 FR   =   .30704 DELF =   .00101 SH   =   .75000 DPTB =  17.75466

 I    =        7 NPT  =        3 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI   =    6.00000
 FLL  =   .13833 CSA  =   .04661 WP   = 15.75000 RE   =   1.17578 F    =  13.60800 FR   =  100.00000
 FR   =   .30704 DELF =   .00101 SH   =   .75000 DPTB =  18.06271
```

```
I    =        8 NPT  =       3 NTB  =        1 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =   .13833 CSA  =  .04361 WP   = 15.75000 RE   =   1.17578 F    =  13.60800 FR  = 100.00000
FR   =   .30704 DELP =  .00101 SH   =   .75000 DPTB =  18.37075

I    =        9 NPT  =       1 NTB  =        1 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =  1.00000 CSA  =  .00136 WP   =   .13083 RE   = 141.54281 F    =    .11304 FR  = 100.00000
FR   =  6.97701 DELP = 1.28423 SH   =   .75000 DPTB =  26.63199

I    =       10 NPT  =       2 NTB  =        1 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =  5.00000 CSA  =  .00136 WP   =   .13083 RE   = 141.54281 F    =    .11304 FR  = 100.00000
FR   = 34.88504 DELP = 1.28423 SH   =   .75000 DPTB =  62.80126

I    =       11 NPT  =       2 NTB  =        1 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =  5.00000 CSA  =  .00136 WP   =   .13083 RE   = 141.54281 F    =    .11304 FR  = 100.00000
FR   = 34.88504 DELP = 1.28423 SH   =   .75000 DPTB =  98.97053

I    =       12 NPT  =       2 NTB  =        1 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =  5.00000 CSA  =  .00136 WP   =   .13083 RE   = 141.54281 F    =    .11304 FR  = 100.00000
FR   = 34.88504 DELP = 1.28423 SH   =   .75000 DPTB = 135.13980

I    =       13 NPT  =       2 NTB  =        1 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =  5.00000 CSA  =  .00136 WP   =   .13083 RE   = 141.54281 F    =    .11304 FR  = 100.00000
FR   = 34.88504 DELP = 1.28423 SH   =   .75000 DPTB = 171.30908

I    =       16 NPT  =       2 NTB  =        2 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =  5.00000 CSA  =  .00136 WP   =   .13083 RE   =  70.77141 F    =    .22606 FR  =  50.00000
FR   = 17.44252 DELP =  .32106 SH   =   .75000 DPTB =  17.76358

I    =       17 NPT  =       2 NTB  =        2 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =  5.00000 CSA  =  .00136 WP   =   .13083 RE   =  70.77141 F    =    .22608 FR  =  50.00000
FR   = 17.44252 DELP =  .32106 SH   =   .75000 DPTB =  35.52716

I    =       18 NPT  =       5 NTB  =        2 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =  1.00000 CSA  =  .00136 WP   =   .13083 RE   =  70.77141 F    =    .22608 FR  =  50.00000
FR   =  3.46850 DELP =  .32106 SH   =   .75000 DPTB =  39.33672

I    =       14 NPT  =       1 NTB  =        3 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =  1.00000 CSA  =  .00136 WP   =   .13083 RE   =  70.77141 F    =    .22608 FR  =  50.00000
FR   =  3.46850 DELP =  .32106 SH   =   .75000 DPTB =   3.66956

I    =       15 NPT  =       4 NTB  =        3 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  = 999.99999 CSA =  .00136 WP   =   .13083 RE   =  70.77141 F    =    .22608 FR  =  50.00000
FR   =3468.50440 DELP = .32106 SH   =   .75000 DPTB =3492.63500

I    =       19 NPT  =       1 NTB  =        4 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =  1.00000 CSA  =  .00136 WP   =   .13083 RE   = 141.54281 F    =    .11304 FR  = 100.00000
FR   =  6.97701 DELP = 1.28423 SH   =   .75000 DPTB =   6.26124

I    =       21 NPT  =       6 NTB  =        5 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =   .13833 CSA  =  .04061 WP   = 15.75000 RE   =    .58789 F    =  27.21600 FR  =  50.00000
FR   =   .15352 DELP =  .00025 SH   =   .75000 DPTB =    .15377

I    =       22 NPT  =       6 NTB  =        5 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =   .13833 CSA  =  .04061 WP   = 15.75000 RE   =    .58759 F    =  27.21600 FR  =  50.00000
FR   =   .15352 DELP =  .00025 SH   =   .75000 DPTB =    .30754

I    =       23 NPT  =       6 NTB  =        5 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
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FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =    .58789 F    =  27.21600 FR   =  50.00000
FR   =    .15352 DELP =    .00025 SH   =    .75000 DPTB =    .46131

I    =        20 NPT  =         1 NTB  =         6 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =    .13083 RE   =  70.77141 F    =    .22608 FR   =  50.00000
FR   =   3.48850 DELP =    .32106 SH   =    .75000 DPTB =   3.60956

I    =        24 NPT  =         1 NTB  =         7 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =    .13083 RE   = 141.54281 F    =    .11304 FR   = 100.00000
FR   =   6.97701 DELP =   1.28423 SH   =    .75000 DPTB =   8.26124

VALVES

OUTPUT FOR VALVE    2 AFTER ITERATION    0
RFRCTN =      .50000
TOUT =  160.00000     TMIX =  160.00000

OUTPUT FOR VALVE    3 AFTER ITERATION    0
RFRCTN =      .69519
TOUT =  160.00000     TMIX =  160.00000

I    =         1 NPT  =         1 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =    .13083 RE   = 141.54281 F    =    .11304 FR   = 100.00000
FR   =   6.97701 DELP =   1.28423 SH   =    .75000 DPTB =   8.26124

I    =         2 NPT  =         6 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =   1.17578 F    =  13.60800 FR   = 100.00000
FR   =    .30704 DELP =    .00101 SH   =    .75000 DPTB =   8.56928

I    =         3 NPT  =         6 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =   1.17578 F    =  13.60800 FR   = 100.00000
FR   =    .30704 DELP =    .00101 SH   =    .75000 DPTB =   8.87733

I    =         4 NPT  =         6 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =   1.17578 F    =  13.60800 FR   = 100.00000
FR   =    .30704 DELP =    .00101 SH   =    .75000 DPTB =   9.18538

I    =         5 NPT  =         1 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =    .13083 RE   = 141.54281 F    =    .11304 FR   = 100.00000
FR   =   6.97701 DELP =   1.28423 SH   =    .75000 DPTB =  17.44661

I    =         6 NPT  =         3 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =   1.17578 F    =  13.60800 FR   = 100.00000
FR   =    .30704 DELP =    .00101 SH   =    .75000 DPTB =  17.75466

I    =         7 NPT  =         3 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =   1.17578 F    =  13.60800 FR   = 100.00000
FR   =    .30704 DELP =    .00101 SH   =    .75000 DPTB =  18.06271

I    =         8 NPT  =         3 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =   1.17578 F    =  13.60800 FR   = 100.00000
FR   =    .30704 DELP =    .00101 SH   =    .75000 DPTB =  18.37075

I    =         9 NPT  =         1 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =    .13083 RE   = 141.54281 F    =    .11304 FR   = 100.00000
FR   =   6.97701 DELP =   1.28423 SH   =    .75000 DPTB =  26.63199

I    =        10 NPT  =         2 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
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```
FLL  =    5.00000 CSA  =     .00136 WP   =       .13083 RE   = 141.54281 F    =     .11304 FR   = 100.00000
FR   =   34.88504 DELP =    1.28423 SH   =       .75000 DPTB =  62.60126

I    =         11 NPT  =          2 NTB  =            1 FREZ =         0 DEN  = 70.000000 UI   =    6.00000
FLL  =    5.00000 CSA  =     .00136 WP   =       .13083 RE   = 141.54281 F    =     .11304 FR   = 100.00000
FR   =   34.88504 DELP =    1.28423 SH   =       .75000 DPTB =  96.97053

I    =         12 NPT  =          2 NTB  =            1 FREZ =         0 DEN  = 70.000000 UI   =    6.00000
FLL  =    5.00000 CSA  =     .00136 WP   =       .13083 RE   = 141.54281 F    =     .11304 FR   = 100.00000
FR   =   34.88504 DELP =    1.28423 SH   =       .75000 DPTB = 135.13980

I    =         13 NPT  =          2 NTB  =            1 FREZ =         0 DEN  = 70.000000 UI   =    6.00000
FLL  =    5.00000 CSA  =     .00136 WP   =       .13083 RE   = 141.54281 F    =     .11304 FR   = 100.00000
FR   =   34.88504 DELP =    1.28423 SH   =       .75000 DPTB = 171.30958

I    =         16 NPT  =          2 NTB  =            2 FREZ =         0 DEN  = 70.000000 UI   =    6.00000
FLL  =    5.00000 CSA  =     .00136 WP   =       .13083 RE   = 139.96641 F    =     .11431 FR   =  98.88627
FR   =   34.49652 DELP =    1.25578 SH   =       .75000 DPTB =  35.75230

I    =         17 NPT  =          2 NTB  =            2 FREZ =         0 DEN  = 70.000000 UI   =    6.00000
FLL  =    5.00000 CSA  =     .00136 WP   =       .13083 RE   = 139.96641 F    =     .11431 FR   =  98.88627
FR   =   34.49652 DELP =    1.25578 SH   =       .75000 DPTB =  71.50460

I    =         18 NPT  =          5 NTB  =            2 FREZ =         0 DEN  = 70.000000 UI   =    6.00000
FLL  =    1.00000 CSA  =     .00136 WP   =       .13083 RE   = 139.96641 F    =     .11431 FR   =  98.88627
FR   =    6.49930 DELP =    1.25578 SH   =       .75000 DPTB =  79.65968

I    =         14 NPT  =          1 NTB  =            3 FREZ =         0 DEN  = 70.000000 UI   =    6.00000
FLL  =    1.00000 CSA  =     .00136 WP   =       .13083 RE   =   1.57641 F    =  10.14965 FR   =    1.11373
FR   =     .07771 DELP =     .00016 SH   =       .75000 DPTB =    .07786

I    =         15 NPT  =          4 NTB  =            3 FREZ =         0 DEN  = 70.000000 UI   =    6.00000
FLL  =  999.99999 CSA  =     .00136 WP   =       .13083 RE   =   1.57641 F    =  10.14965 FR   =    1.11373
FR   =   77.70522 DELP =     .00016 SH   =       .75000 DPTB =  77.78324

I    =         19 NPT  =          1 NTB  =            4 FREZ =         0 DEN  = 70.000000 UI   =    6.00000
FLL  =    1.00000 CSA  =     .00136 WP   =       .13083 RE   = 141.54281 F    =     .11304 FR   = 100.00000
FR   =    6.97701 DELP =    1.28423 SH   =       .75000 DPTB =   8.26124

I    =         21 NPT  =          6 NTB  =            5 FREZ =         0 DEN  = 70.000000 UI   =    6.00000
FLL  =     .13833 CSA  =     .04861 WP   =     15.75000 RE   =    .71157 F    =  22.48535 FR   =  60.51941
FR   =     .18582 DELP =     .00037 SH   =       .75000 DPTB =    .18619

I    =         22 NPT  =          6 NTB  =            5 FREZ =         0 DEN  = 70.000000 UI   =    6.00000
FLL  =     .13833 CSA  =     .04861 WP   =     15.75000 RE   =    .71157 F    =  22.48535 FR   =  60.51941
FR   =     .18582 DELP =     .00037 SH   =       .75000 DPTB =    .37237

I    =         23 NPT  =          6 NTB  =            5 FREZ =         0 DEN  = 70.000000 UI   =    6.00000
FLL  =     .13833 CSA  =     .04861 WP   =     15.75000 RE   =    .71157 F    =  22.48535 FR   =  60.51941
FR   =     .18582 DELP =     .00037 SH   =       .75000 DPTB =    .55856

I    =         20 NPT  =          1 NTB  =            6 FREZ =         0 DEN  = 70.000000 UI   =    6.00000
FLL  =    1.00000 CSA  =     .00136 WP   =       .13083 RE   =  55.88194 F    =     .28632 FR   =  39.48059
FR   =    2.75456 DELP =     .20017 SH   =       .75000 DPTB =   2.95474

I    =         24 NPT  =          1 NTB  =            7 FREZ =         0 DEN  = 70.000000 UI   =    6.00000
FLL  =    1.00000 CSA  =     .00136 WP   =       .13083 RE   = 141.54281 F    =     .11304 FR   = 100.00000
FR   =    6.97701 DELP =    1.28423 SH   =       .75000 DPTB =   8.26124
```

```
I   =        1 NPT  =       1 NTB  =        1 FREZ =          0 DEN  = 70.000000 UI  =  6.00000
FLL =  1.00000 CSA  =  .00136 WP   =   .13083 RE   = 119.63646 F    =    .13374 FR  = 84.52316
FR  =  5.89719 DELF =  .91747 SH   =   .75000 DPTB =   6.81466

I   =        2 NPT  =       6 NTB  =        1 FREZ =          0 DEN  = 70.000000 UI  =  6.00000
FLL =   .13833 CSA  =  .04661 WP   = 15.75000 RE   =    .99381 F    =  16.09973 FR  = 84.52316
FR  =   .25952 DELF =  .00072 SH   =   .75000 DPTB =   7.07490

I   =        3 NPT  =       6 NTB  =        1 FREZ =          0 DEN  = 70.000000 UI  =  6.00000
FLL =   .13833 CSA  =  .04661 WP   = 15.75000 RE   =    .99381 F    =  16.09973 FR  = 84.52316
FR  =   .25952 DELF =  .00072 SH   =   .75000 DPTB =   7.33514

I   =        4 NPT  =       6 NTB  =        1 FREZ =          0 DEN  = 70.000000 UI  =  6.00000
FLL =   .13833 CSA  =  .04661 WP   = 15.75000 RE   =    .99381 F    =  16.09973 FR  = 84.52316
FR  =   .25952 DELF =  .00072 SH   =   .75000 DPTB =   7.59538

I   =        5 NPT  =       1 NTB  =        1 FREZ =          0 DEN  = 70.000000 UI  =  6.00000
FLL =  1.00000 CSA  =  .00136 WP   =   .13083 RE   = 119.63646 F    =    .13374 FR  = 84.52316
FR  =  5.89719 DELF =  .91747 SH   =   .75000 DPTB =  14.41004

I   =        6 NPT  =       3 NTB  =        1 FREZ =          0 DEN  = 70.000000 UI  =  6.00000
FLL =   .13833 CSA  =  .04661 WP   = 15.75000 RE   =    .99381 F    =  16.09973 FR  = 84.52316
FR  =   .25952 DELF =  .00072 SH   =   .75000 DPTB =  14.67028

I   =        7 NPT  =       3 NTB  =        1 FREZ =          0 DEN  = 70.000000 UI  =  6.00000
FLL =   .13833 CSA  =  .04661 WP   = 15.75000 RE   =    .99381 F    =  16.09973 FR  = 84.52316
FR  =   .25952 DELF =  .00072 SH   =   .75000 DPTB =  14.93052

I   =        8 NPT  =       3 NTB  =        1 FREZ =          0 DEN  = 70.000000 UI  =  6.00000
FLL =   .13833 CSA  =  .04661 WP   = 15.75000 RE   =    .99381 F    =  16.09973 FR  = 84.52316
FR  =   .25952 DELF =  .00072 SH   =   .75000 DPTB =  15.19076

I   =        9 NPT  =       1 NTB  =        1 FREZ =          0 DEN  = 70.000000 UI  =  6.00000
FLL =  1.00000 CSA  =  .00136 WP   =   .13083 RE   = 119.63646 F    =    .13374 FR  = 84.52316
FR  =  5.89719 DELF =  .91747 SH   =   .75000 DPTB =  22.00542

I   =       10 NPT  =       2 NTB  =        1 FREZ =          0 DEN  = 70.000000 UI  =  6.00000
FLL =  5.00000 CSA  =  .00136 WP   =   .13083 RE   = 119.63646 F    =    .13374 FR  = 84.52316
FR  = 29.48594 DELF =  .91747 SH   =   .75000 DPTB =  52.40883

I   =       11 NPT  =       2 NTB  =        1 FREZ =          0 DEN  = 70.000000 UI  =  6.00000
FLL =  5.00000 CSA  =  .00136 WP   =   .13083 RE   = 119.63646 F    =    .13374 FR  = 84.52316
FR  = 29.48594 DELF =  .91747 SH   =   .75000 DPTB =  82.81225

I   =       12 NPT  =       2 NTB  =        1 FREZ =          0 DEN  = 70.000000 UI  =  6.00000
FLL =  5.00000 CSA  =  .00136 WP   =   .13083 RE   = 119.63646 F    =    .13374 FR  = 84.52316
FR  = 29.48594 DELF =  .91747 SH   =   .75000 DPTB = 113.21566

I   =       13 NPT  =       2 NTB  =        1 FREZ =          0 DEN  = 70.000000 UI  =  6.00000
FLL =  5.00000 CSA  =  .00136 WP   =   .13083 RE   = 119.63646 F    =    .13374 FR  = 84.52316
FR  = 29.48594 DELF =  .91747 SH   =   .75000 DPTB = 143.61907

I   =       16 NPT  =       2 NTB  =        2 FREZ =          0 DEN  = 70.000000 UI  =  6.00000
FLL =  5.00000 CSA  =  .00136 WP   =   .13083 RE   = 118.30403 F    =    .13524 FR  = 83.58170
FR  = 29.15754 DELF =  .89715 SH   =   .75000 DPTB =  30.05470

I   =       17 NPT  =       2 NTB  =        2 FREZ =          0 DEN  = 70.000000 UI  =  6.00000
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```
FLL  =   5.00000 CSA  =  .00136 WP  =   .13083 RE   = 116.30403 F   =   .13524 FR  =  83.56179
FR   =  29.15754 DELF =  .69715 SH  =   .75000 DPTB =  60.10939

I    =        18 NPT  =       5 NTB =        2 FREZ =         0 DEN = 70.000000 UI  =   6.00000
FLL  =   1.00000 CSA  =  .00136 WP  =   .13083 RE   = 116.30403 F   =    .13524 FR  =  83.56179
FR   =   5.83151 DELF =  .69715 SH  =   .75000 DPTB =  66.83605

I    =        14 NPT  =       1 NTB =        3 FREZ =         0 DEN = 70.000000 UI  =   6.00000
FLL  =   1.00000 CSA  =  .00136 WP  =   .13083 RE   =   1.33243 F   =  12.00813 FR  =    .94136
FR   =    .06568 DELF =  .00011 SH  =   .75000 DPTB =    .06579

I    =        15 NPT  =       4 NTB =        3 FREZ =         0 DEN = 70.000000 UI  =   6.00000
FLL  = 999.99999 CSA  =  .00136 WP  =   .13083 RE   =   1.33243 F   =  12.00813 FR  =    .94136
FR   =  65.67890 DELF =  .00011 SH  =   .75000 DPTB =  65.74491

I    =        19 NPT  =       1 NTB =        4 FREZ =         0 DEN = 70.000000 UI  =   6.00000
FLL  =   1.00000 CSA  =  .00136 WP  =   .13083 RE   = 119.63646 F   =    .13374 FR  =  84.52316
FR   =   5.89719 DELF =  .91747 SH  =   .75000 DPTB =   6.81466

I    =        21 NPT  =       6 NTB =        5 FREZ =         0 DEN = 70.000000 UI  =   6.00000
FLL  =    .13833 CSA  =  .04861 WP  = 15.75000 RE   =    .60145 F   =  26.60259 FR  =  51.15291
FR   =    .15706 DELF =  .00026 SH  =   .75000 DPTB =    .15732

I    =        22 NPT  =       6 NTB =        5 FREZ =         0 DEN = 70.000000 UI  =   6.00000
FLL  =    .13833 CSA  =  .04861 WP  = 15.75000 RE   =    .60145 F   =  26.60259 FR  =  51.15291
FR   =    .15706 DELF =  .00026 SH  =   .75000 DPTB =    .31465

I    =        23 NPT  =       6 NTB =        5 FREZ =         0 DEN = 70.000000 UI  =   6.00000
FLL  =    .13833 CSA  =  .04861 WP  = 15.75000 RE   =    .60145 F   =  26.60259 FR  =  51.15291
FR   =    .15706 DELF =  .00026 SH  =   .75000 DPTB =    .47197

I    =        20 NPT  =       1 NTB =        6 FREZ =         0 DEN = 70.000000 UI  =   6.00000
FLL  =   1.00000 CSA  =  .00136 WP  =   .13083 RE   =  47.23318 F   =    .33874 FR  =  33.37024
FR   =   2.32824 DELF =  .14301 SH  =   .75000 DPTB =   2.47125

I    =        24 NPT  =       1 NTB =        7 FREZ =         0 DEN = 70.000000 UI  =   6.00000
FLL  =   1.00000 CSA  =  .00136 WP  =   .13083 RE   = 119.63646 F   =    .13374 FR  =  84.52316
FR   =   5.89719 DELF =  .91747 SH  =   .75000 DPTB =   6.81466

I    =         1 NPT  =       1 NTB =        1 FREZ =         0 DEN = 70.000000 UI  =   6.00000
FLL  =   1.00000 CSA  =  .00136 WP  =   .13083 RE   = 108.79247 F   =    .14707 FR  =  76.86186
FR   =   5.36266 DELF =  .75669 SH  =   .75000 DPTB =   6.12135

I    =         2 NPT  =       6 NTB =        1 FREZ =         0 DEN = 70.000000 UI  =   6.00000
FLL  =    .13833 CSA  =  .04861 WP  = 15.75000 RE   =    .90373 F   =  17.70448 FR  =  76.86186
FR   =    .23600 DELF =  .00059 SH  =   .75000 DPTB =   6.35794

I    =         3 NPT  =       6 NTB =        1 FREZ =         0 DEN = 70.000000 UI  =   6.00000
FLL  =    .13833 CSA  =  .04861 WP  = 15.75000 RE   =    .90373 F   =  17.70448 FR  =  76.86186
FR   =    .23600 DELF =  .00059 SH  =   .75000 DPTB =   6.59453

I    =         4 NPT  =       6 NTB =        1 FREZ =         0 DEN = 70.000000 UI  =   6.00000
FLL  =    .13833 CSA  =  .04861 WP  = 15.75000 RE   =    .90373 F   =  17.70448 FR  =  76.86183
FR   =    .23600 DELF =  .00059 SH  =   .75000 DPTB =   6.83112

I    =         5 NPT  =       1 NTB =        1 FREZ =         0 DEN = 70.000000 UI  =   6.00000
FLL  =   1.00000 CSA  =  .00136 WP  =   .13083 RE   = 108.79247 F   =    .14707 FR  =  76.86186
FR   =   5.36266 DELF =  .75669 SH  =   .75000 DPTB =  12.95247
```

```
I    =        6 NPT  =        3 NTB  =        1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   .13833 CSA  =   .04861 WP   = 15.75000 RE   =    .90373 F    =  17.70448 FR   =  76.86184
FR   =   .23600 DELP =   .00059 SH   =   .75000 DPTB =  13.18976

I    =        7 NPT  =        3 NTB  =        1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   .13833 CSA  =   .04861 WP   = 15.75000 RE   =    .90373 F    =  17.70448 FR   =  76.86184
FR   =   .23600 DELP =   .00059 SH   =   .75000 DPTB =  13.42566

I    =        8 NPT  =        3 NTB  =        1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   .13833 CSA  =   .04861 WP   = 15.75000 RE   =    .90373 F    =  17.70448 FR   =  76.86184
FR   =   .23600 DELP =   .00059 SH   =   .75000 DPTB =  13.66225

I    =        9 NPT  =        1 NTB  =        1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =  1.00000 CSA  =   .00136 WP   =   .13083 RE   = 108.79247 F    =    .14707 FR   =  76.86184
FR   =  5.36266 DELP =   .75869 SH   =   .75000 DPTB =  19.78360

I    =       10 NPT  =        2 NTB  =        1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =  5.00000 CSA  =   .00136 WP   =   .13083 RE   = 108.79247 F    =    .14707 FR   =  76.86184
FR   = 26.81330 DELP =   .75869 SH   =   .75000 DPTB =  47.35559

I    =       11 NPT  =        2 NTB  =        1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =  5.00000 CSA  =   .00136 WP   =   .13083 RE   = 108.79247 F    =    .14707 FR   =  76.86184
FR   = 26.81330 DELP =   .75869 SH   =   .75000 DPTB =  74.92758

I    =       12 NPT  =        2 NTB  =        1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =  5.00000 CSA  =   .00136 WP   =   .13083 RE   = 108.79247 F    =    .14707 FR   =  76.86184
FR   = 26.81330 DELP =   .75869 SH   =   .75000 DPTB = 102.49956

I    =       13 NPT  =        2 NTB  =        1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =  5.00000 CSA  =   .00136 WP   =   .13083 RE   = 108.79247 F    =    .14707 FR   =  76.86184
FR   = 26.81330 DELP =   .75869 SH   =   .75000 DPTB = 130.07155

I    =       16 NPT  =        2 NTB  =        2 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =  5.00000 CSA  =   .00136 WP   =   .13083 RE   = 107.58081 F    =    .14873 FR   =  76.00584
FR   = 26.51467 DELP =   .74188 SH   =   .75000 DPTB =  27.25656

I    =       17 NPT  =        2 NTB  =        2 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =  5.00000 CSA  =   .00136 WP   =   .13083 RE   = 107.58081 F    =    .14873 FR   =  76.00584
FR   = 26.51467 DELP =   .74188 SH   =   .75000 DPTB =  54.51311

I    =       18 NPT  =        5 NTB  =        2 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =  1.00000 CSA  =   .00136 WP   =   .13083 RE   = 107.58081 F    =    .14873 FR   =  76.00584
FR   =  5.30293 DELP =   .74188 SH   =   .75000 DPTB =  60.55793

I    =       14 NPT  =        1 NTB  =        3 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =  1.00000 CSA  =   .00136 WP   =   .13083 RE   =   1.21166 F    =  13.20506 FR   =    .85604
FR   =   .05973 DELP =   .00009 SH   =   .75000 DPTB =    .05962

I    =       15 NPT  =        4 NTB  =        3 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  = 999.99999 CSA =   .00136 WP   =   .13083 RE   =   1.21166 F    =  13.20506 FR   =    .85604
FR   = 59.72569 DELP =   .00009 SH   =   .75000 DPTB =  59.78560

I    =       19 NPT  =        1 NTB  =        4 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =  1.00000 CSA  =   .00136 WP   =   .13083 RE   = 108.79247 F    =    .14707 FR   =  76.86184
FR   =  5.36266 DELP =   .75869 SH   =   .75000 DPTB =   6.12135

I    =       21 NPT  =        6 NTB  =        5 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
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FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =     .54693 F    =  29.25423 FR   =  46.51635
FR   =    .14282 DELP =    .00022 SH   =    .75000 DPTB =     .14334

I    =        22 NPT  =         6 NTB  =         5 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =     .54693 F    =  29.25423 FR   =  46.51635
FR   =    .14282 DELP =    .00022 SH   =    .75000 DPTB =     .24656

I    =        23 NPT  =         6 NTB  =         5 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =     .54693 F    =  29.25423 FR   =  46.51635
FR   =    .14282 DELP =    .00022 SH   =    .75000 DPTB =     .42912

I    =        25 NPT  =         1 NTB  =         6 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =    .13083 RE   =   42.95191 F    =    .37251 FR   =  30.34552
FR   =   2.11721 DELP =    .11626 SH   =    .75000 DPTB =    2.23547

I    =        24 NPT  =         1 NTB  =         7 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =    .13083 RE   =  108.79247 F    =    .14707 FR   =  75.66185
FR   =   5.36266 DELP =    .75869 SH   =    .75000 DPTB =    6.12135

I    =         1 NPT  =         1 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =    .13083 RE   =  103.42388 F    =    .15470 FR   =  73.06897
FR   =   5.09803 DELP =    .68566 SH   =    .75000 DPTB =    5.78369

I    =         2 NPT  =         6 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =     .85913 F    =  18.62350 FR   =  73.06897
FR   =    .22435 DELP =    .00054 SH   =    .75000 DPTB =    6.00858

I    =         3 NPT  =         6 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =     .85913 F    =  18.62350 FR   =  73.06897
FR   =    .22435 DELP =    .00054 SH   =    .75000 DPTB =    6.23346

I    =         4 NPT  =         6 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =     .85913 F    =  18.62350 FR   =  73.06897
FR   =    .22435 DELP =    .00054 SH   =    .75000 DPTB =    6.45835

I    =         5 NPT  =         1 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =    .13083 RE   =  103.42388 F    =    .15470 FR   =  73.06897
FR   =   5.09803 DELP =    .68566 SH   =    .75000 DPTB =   12.24204

I    =         6 NPT  =         3 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =     .85913 F    =  18.62350 FR   =  73.06897
FR   =    .22435 DELP =    .00054 SH   =    .75000 DPTB =   12.46693

I    =         7 NPT  =         3 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =     .85913 F    =  18.62350 FR   =  73.06897
FR   =    .22435 DELP =    .00054 SH   =    .75000 DPTB =   12.69182

I    =         8 NPT  =         3 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =     .85913 F    =  18.62350 FR   =  73.06897
FR   =    .22435 DELP =    .00054 SH   =    .75000 DPTB =   12.91671

I    =         9 NPT  =         1 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =    .13083 RE   =  103.42388 F    =    .15470 FR   =  73.06897
FR   =   5.09803 DELP =    .68566 SH   =    .75000 DPTB =   18.70039

I    =        10 NPT  =         2 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =   5.00000 CSA  =    .00136 WP   =    .13083 RE   =  103.42388 F    =    .15470 FR   =  73.06897
FR   =  25.49014 DELP =    .68566 SH   =    .75000 DPTB =   44.87619
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I   =        11 NPT  =        2 NTB  =        1 FREZ =          0 DEN  = 70.000000 UI  =   6.00000
FLL =   5.00000 CSA  =   .00136 WP   =   .13083 RE   = 103.42388 F    =    .15470 FR  =  73.06897
FR  =  25.49014 DELP =   .68566 SH   =   .75000 DPTB =  71.05200

I   =        12 NPT  =        2 NTB  =        1 FREZ =          0 DEN  = 70.000000 UI  =   6.00000
FLL =   5.00000 CSA  =   .00136 WP   =   .13083 RE   = 103.42388 F    =    .15470 FR  =  73.06897
FR  =  25.49014 DELP =   .68566 SH   =   .75000 DPTB =  97.22780

I   =        13 NPT  =        2 NTB  =        1 FREZ =          0 DEN  = 70.000000 UI  =   6.00000
FLL =   5.00000 CSA  =   .00136 WP   =   .13083 RE   = 103.42388 F    =    .15470 FR  =  73.06897
FR  =  25.49014 DELP =   .68566 SH   =   .75000 DPTB = 123.40360

I   =        16 NPT  =        2 NTB  =        2 FREZ =          0 DEN  = 70.000000 UI  =   6.00000
FLL =   5.00000 CSA  =   .00136 WP   =   .13083 RE   = 102.27272 F    =    .15645 FR  =  72.25519
FR  =  25.23625 DELP =   .67047 SH   =   .75000 DPTB =  25.67672

I   =        17 NPT  =        2 NTB  =        2 FREZ =          0 DEN  = 70.000000 UI  =   6.00000
FLL =   5.00000 CSA  =   .00136 WP   =   .13083 RE   = 102.27272 F    =    .15645 FR  =  72.25519
FR  =  25.23625 DELP =   .67047 SH   =   .75000 DPTB =  51.75344

I   =        18 NPT  =        2 NTB  =        2 FREZ =          0 DEN  = 70.000000 UI  =   6.00000
FLL =   1.00000 CSA  =   .00136 WP   =   .13083 RE   = 102.27272 F    =    .15645 FR  =  72.25519
FR  =   5.04125 DELP =   .67047 SH   =   .75000 DPTB =  57.46517

I   =        14 NPT  =        1 NTB  =        3 FREZ =          0 DEN  = 70.000000 UI  =   6.00000
FLL =   1.00000 CSA  =   .00136 WP   =   .13083 RE   =   1.15167 F    =  13.89051 FR  =    .01379
FR  =    .05678 DELP =   .00009 SH   =   .75000 DPTB =    .05686

I   =        15 NPT  =        4 NTB  =        3 FREZ =          0 DEN  = 70.000000 UI  =   6.00000
FLL = 999.99999 CSA  =   .00136 WP   =   .13083 RE   =   1.15167 F    =  13.89051 FR  =    .01379
FR  =  56.77841 DELP =   .00009 SH   =   .75000 DPTB =  56.83535

I   =        19 NPT  =        1 NTB  =        4 FREZ =          0 DEN  = 70.000000 UI  =   6.00000
FLL =   1.00000 CSA  =   .00136 WP   =   .13083 RE   = 103.42388 F    =    .15470 FR  =  73.06897
FR  =   5.09803 DELP =   .68566 SH   =   .75000 DPTB =   5.78369

I   =        21 NPT  =        6 NTB  =        5 FREZ =          0 DEN  = 70.000000 UI  =   6.00000
FLL =    .13833 CSA  =   .04861 WP   = 15.75000 RE   =    .51994 F    =  30.77277 FR  =  44.22091
FR  =    .13578 DELP =   .00020 SH   =   .75000 DPTB =    .13597

I   =        22 NPT  =        6 NTB  =        5 FREZ =          0 DEN  = 70.000000 UI  =   6.00000
FLL =    .13833 CSA  =   .04861 WP   = 15.75000 RE   =    .51994 F    =  30.77277 FR  =  44.22091
FR  =    .13578 DELP =   .00020 SH   =   .75000 DPTB =    .27195

I   =        23 NPT  =        6 NTB  =        5 FREZ =          0 DEN  = 70.000000 UI  =   6.00000
FLL =    .13833 CSA  =   .04861 WP   = 15.75000 RE   =    .51994 F    =  30.77277 FR  =  44.22091
FR  =    .13578 DELP =   .00020 SH   =   .75000 DPTB =    .40792

I   =        20 NPT  =        1 NTB  =        6 FREZ =          0 DEN  = 70.000000 UI  =   6.00000
FLL =   1.00000 CSA  =   .00136 WP   =   .13083 RE   =  40.83236 F    =    .39185 FR  =  28.84806
FR  =   2.01273 DELP =   .10687 SH   =   .75000 DPTB =   2.11961

I   =        24 NPT  =        1 NTB  =        7 FREZ =          0 DEN  = 70.000000 UI  =   6.00000
FLL =   1.00000 CSA  =   .00136 WP   =   .13083 RE   = 103.42388 F    =    .15470 FR  =  73.06897
FR  =   5.09803 DELP =   .68566 SH   =   .75000 DPTB =   5.78369

I   =         1 NPT  =        1 NTB  =        1 FREZ =          0 DEN  = 70.000000 UI  =   6.00000
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```
FLL  =   1.00000 CSA  =   .00136 WP   =     .13083 RE   = 100.76588 F    =    .15878 FR   =  71.19109
FR   =   4.96701 DELP =   .65087 SH   =     .75000 DPTB =   5.61788

I    =         2 NPT  =        6 NTB  =          1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =   .04861 WP   =   15.75000 RE   =    .83705 F    =  19.11475 FR   =  71.19109
FR   =    .21858 DELP =   .00051 SH   =     .75000 DPTB =   5.83697

I    =         3 NPT  =        6 NTB  =          1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =   .04861 WP   =   15.75000 RE   =    .83705 F    =  19.11475 FR   =  71.19109
FR   =    .21858 DELP =   .00051 SH   =     .75000 DPTB =   6.05607

I    =         4 NPT  =        6 NTB  =          1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =   .04861 WP   =   15.75000 RE   =    .83705 F    =  19.11475 FR   =  71.19109
FR   =    .21858 DELP =   .00051 SH   =     .75000 DPTB =   6.27516

I    =         5 NPT  =        1 NTB  =          1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =   .00136 WP   =     .13083 RE   = 100.76588 F    =    .15878 FR   =  71.19109
FR   =   4.96701 DELP =   .65087 SH   =     .75000 DPTB =  11.89304

I    =         6 NPT  =        3 NTB  =          1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =   .04861 WP   =   15.75000 RE   =    .83705 F    =  19.11475 FR   =  71.19109
FR   =    .21858 DELP =   .00051 SH   =     .75000 DPTB =  12.11214

I    =         7 NPT  =        3 NTB  =          1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =   .04861 WP   =   15.75000 RE   =    .83705 F    =  19.11475 FR   =  71.19109
FR   =    .21858 DELP =   .00051 SH   =     .75000 DPTB =  12.33123

I    =         8 NPT  =        3 NTB  =          1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =   .04861 WP   =   15.75000 RE   =    .83705 F    =  19.11475 FR   =  71.19109
FR   =    .21858 DELP =   .00051 SH   =     .75000 DPTB =  12.55033

I    =         9 NPT  =        1 NTB  =          1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =   .00136 WP   =     .13083 RE   = 100.76588 F    =    .15878 FR   =  71.19109
FR   =   4.96701 DELP =   .65087 SH   =     .75000 DPTB =  18.16820

I    =        10 NPT  =        2 NTB  =          1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   5.00000 CSA  =   .00136 WP   =     .13083 RE   = 100.76588 F    =    .15878 FR   =  71.19109
FR   =  24.83504 DELP =   .65087 SH   =     .75000 DPTB =  43.65412

I    =        11 NPT  =        2 NTB  =          1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   5.00000 CSA  =   .00136 WP   =     .13083 RE   = 100.76588 F    =    .15878 FR   =  71.19109
FR   =  24.83504 DELP =   .65087 SH   =     .75000 DPTB =  69.14003

I    =        12 NPT  =        2 NTB  =          1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   5.00000 CSA  =   .00136 WP   =     .13083 RE   = 100.76588 F    =    .15878 FR   =  71.19109
FR   =  24.83504 DELP =   .65087 SH   =     .75000 DPTB =  94.62594

I    =        13 NPT  =        2 NTB  =          1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   5.00000 CSA  =   .00136 WP   =     .13083 RE   = 100.76588 F    =    .15878 FR   =  71.19109
FR   =  24.83504 DELP =   .65087 SH   =     .75000 DPTB = 120.11185

I    =        16 NPT  =        2 NTB  =          2 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   5.00000 CSA  =   .00136 WP   =     .13083 RE   =  99.64361 F    =    .16057 FR   =  70.39822
FR   =  24.55845 DELP =   .63645 SH   =     .75000 DPTB =  25.19490

I    =        17 NPT  =        2 NTB  =          2 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   5.00000 CSA  =   .00136 WP   =     .13083 RE   =  99.64361 F    =    .16057 FR   =  70.39822
FR   =  24.55845 DELP =   .63645 SH   =     .75000 DPTB =  50.38980
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I   =       18 NPT   =      5 NTB   =       2 FREZ =         0 DEN   = 70.000000 UI  =  6.00000
FLL =  1.00000 CSA   = .00136 WP    =  .13083 RE   =  99.64361 F     =    .16057 FR  = 70.39822
FR  =  4.91169 DELP  = .63645 SH    =  .75000 DPTB =  55.93794

I   =       14 NPT   =      1 NTB   =       3 FREZ =         0 DEN   = 70.000000 UI  =  6.00000
FLL =  1.00000 CSA   = .00136 WP    =  .13083 RE   =   1.12226 F     =  14.25692 FR  =   .792[illegible]
FR  =   .05532 DELP  = .00008 SH    =  .75000 DPTB =    .05540

I   =       15 NPT   =      4 NTB   =       3 FREZ =         0 DEN   = 70.000000 UI  =  6.00000
FLL = 999.99999 CSA  = .00136 WP    =  .13083 RE   =   1.12226 F     =  14.25692 FR  =   .792[illegible]
FR  = 55.31920 DELP  = .00008 SH    =  .75000 DPTB =  55.37468

I   =       19 NPT   =      1 NTB   =       4 FREZ =         0 DEN   = 70.000000 UI  =  6.00000
FLL =  1.00000 CSA   = .00136 WP    =  .13083 RE   = 100.76588 F     =    .15878 FR  = 71.19109
FR  =  4.96701 DELP  = .55087 SH    =  .75000 DPTB =   5.61788

I   =       21 NPT   =      6 NTB   =       5 FREZ =         0 DEN   = 70.000000 UI  =  6.00000
FLL =   .13833 CSA   = .04861 WP    = 15.75000 RE  =    .50658 F     =  31.58450 FR  = 43.08443
FR  =   .13229 DELP  = .00019 SH    =  .75000 DPTB =    .13247

I   =       22 NPT   =      6 NTB   =       5 FREZ =         0 DEN   = 70.000000 UI  =  6.00000
FLL =   .13833 CSA   = .04861 WP    = 15.75000 RE  =    .50658 F     =  31.58450 FR  = 43.08443
FR  =   .13229 DELP  = .00019 SH    =  .75000 DPTB =    .26495

I   =       23 NPT   =      6 NTB   =       5 FREZ =         0 DEN   = 70.000000 UI  =  6.00000
FLL =   .13833 CSA   = .04861 WP    = 15.75000 RE  =    .50658 F     =  31.58450 FR  = 43.58443
FR  =   .13229 DELP  = .00019 SH    =  .75000 DPTB =    .39742

I   =       20 NPT   =      1 NTB   =       6 FREZ =         0 DEN   = 70.000000 UI  =  6.00000
FLL =  1.00000 CSA   = .00136 WP    =  .13083 RE   =  39.78296 F     =    .40216 FR  = 28.19666
FR  =  1.96100 DELP  = .10145 SH    =  .75000 DPTB =   2.06246

I   =       24 NPT   =      1 NTB   =       7 FREZ =         0 DEN   = 70.000000 UI  =  6.00000
FLL =  1.00000 CSA   = .00136 WP    =  .13083 RE   = 100.76588 F     =    .15678 FR  = 71.19109
FR  =  4.96701 DELP  = .65087 SH    =  .75000 DPTB =   5.61788

I   =        1 NPT   =      1 NTB   =       1 FREZ =         0 DEN   = 70.000050 UI  =  6.00000
FLL =  1.00000 CSA   = .00136 WP    =  .13083 RE   =  99.44985 F     =    .16089 FR  = 70.26132
FR  =  4.90214 DELP  = .63398 SH    =  .75000 DPTB =   5.53612

I   =        2 NPT   =      6 NTB   =       1 FREZ =         0 DEN   = 70.000000 UI  =  6.00000
FLL =   .13833 CSA   = .04861 WP    = 15.75000 RE  =    .82612 F     =  19.36770 FR  = 70.26132
FR  =   .21573 DELP  = .00050 SH    =  .75000 DPTB =   5.75234

I   =        3 NPT   =      6 NTB   =       1 FREZ =         0 DEN   = 70.000000 UI  =  6.00000
FLL =   .13833 CSA   = .04861 WP    = 15.75000 RE  =    .82612 F     =  19.36770 FR  = 70.26132
FR  =   .21573 DELP  = .00050 SH    =  .75000 DPTB =   5.96857

I   =        4 NPT   =      6 NTB   =       1 FREZ =         0 DEN   = 70.000000 UI  =  6.00000
FLL =   .13833 CSA   = .04861 WP    = 15.75000 RE  =    .82612 F     =  19.36770 FR  = 70.26132
FR  =   .21573 DELP  = .00050 SH    =  .75000 DPTB =   6.18480

I   =        5 NPT   =      1 NTB   =       1 FREZ =         0 DEN   = 70.000000 UI  =  6.00000
FLL =  1.00000 CSA   = .00136 WP    =  .13083 RE   =  99.44985 F     =    .16089 FR  = 70.26132
FR  =  4.90214 DELP  = .63398 SH    =  .75000 DPTB =  11.72092

I   =        6 NPT   =      3 NTB   =       1 FREZ =         0 DEN   = 70.000000 UI  =  6.00000
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```
FLL  =     .13833 CSA  =    .04861 WP   =  15.75000 RE   =     .82612 F    =  19.36770 FR    =   70.26132
FR   =     .21573 DELP =    .00050 SH   =    .75000 DPTB =   11.93714

I    =          7 NPT  =         3 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI    =    6.00000
FLL  =     .13833 CSA  =    .04861 WP   =  15.75000 RE   =     .82612 F    =  19.36770 FR    =   70.26132
FR   =     .21573 DELP =    .00050 SH   =    .75000 DPTB =   12.15337

I    =          8 NPT  =         3 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI    =    6.00000
FLL  =     .13833 CSA  =    .04861 WP   =  15.75000 RE   =     .82612 F    =  19.36770 FR    =   70.26132
FR   =     .21573 DELP =    .00050 SH   =    .75000 DPTB =   12.36960

I    =          9 NPT  =         1 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI    =    6.00000
FLL  =    1.00000 CSA  =    .00136 WP   =    .13083 RE   =   99.44985 F    =    .16089 FR    =   70.26132
FR   =    4.90214 DELP =    .63398 SH   =    .75000 DPTB =   17.90571

I    =         10 NPT  =         2 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI    =    6.00000
FLL  =    5.00000 CSA  =    .00136 WP   =    .13083 RE   =   99.44985 F    =    .16089 FR    =   70.26132
FR   =   24.51069 DELP =    .63398 SH   =    .75000 DPTB =   43.05038

I    =         11 NPT  =         2 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI    =    6.00000
FLL  =    5.00000 CSA  =    .00136 WP   =    .13083 RE   =   99.44985 F    =    .16089 FR    =   70.26132
FR   =   24.51069 DELP =    .63398 SH   =    .75000 DPTB =   68.19505

I    =         12 NPT  =         2 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI    =    6.00000
FLL  =    5.00000 CSA  =    .00136 WP   =    .13083 RE   =   99.44985 F    =    .16089 FR    =   70.26132
FR   =   24.51069 DELP =    .63398 SH   =    .75000 DPTB =   93.33972

I    =         13 NPT  =         2 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI    =    6.00000
FLL  =    5.00000 CSA  =    .00136 WP   =    .13083 RE   =   99.44985 F    =    .16089 FR    =   70.26132
FR   =   24.51069 DELP =    .63398 SH   =    .75000 DPTB =  118.48440

I    =         16 NPT  =         2 NTB  =         2 FREZ =          0 DEN  = 70.000000 UI    =    6.00000
FLL  =    5.00000 CSA  =    .00136 WP   =    .13083 RE   =   98.34224 F    =    .16270 FR    =   69.47879
FR   =   24.23771 DELP =    .61994 SH   =    .75000 DPTB =   24.85764

I    =         17 NPT  =         2 NTB  =         2 FREZ =          0 DEN  = 70.000000 UI    =    6.00000
FLL  =    5.00000 CSA  =    .00136 WP   =    .13083 RE   =   98.34224 F    =    .16270 FR    =   69.47879
FR   =   24.23771 DELP =    .61994 SH   =    .75000 DPTB =   49.71529

I    =         18 NPT  =         5 NTB  =         2 FREZ =          0 DEN  = 70.000000 UI    =    6.00000
FLL  =    1.00000 CSA  =    .00136 WP   =    .13083 RE   =   98.34224 F    =    .16270 FR    =   69.47879
FR   =    4.84754 DELP =    .61994 SH   =    .75000 DPTB =   55.18277

I    =         14 NPT  =         1 NTB  =         3 FREZ =          0 DEN  = 70.000000 UI    =    6.00000
FLL  =    1.00000 CSA  =    .00136 WP   =    .13083 RE   =    1.10761 F    =  14.44558 FR    =     .78252
FR   =     .05460 DELP =    .00008 SH   =    .75000 DPTB =     .05468

I    =         15 NPT  =         4 NTB  =         3 FREZ =          0 DEN  = 70.000000 UI    =    6.00000
FLL  =  999.99999 CSA  =    .00136 WP   =    .13083 RE   =    1.10761 F    =  14.44558 FR    =     .78252
FR   =   54.59671 DELP =    .00008 SH   =    .75000 DPTB =   54.65147

I    =         19 NPT  =         1 NTB  =         4 FREZ =          0 DEN  = 70.000000 UI    =    6.00000
FLL  =    1.00000 CSA  =    .00136 WP   =    .13083 RE   =   99.44985 F    =    .16089 FR    =   70.26132
FR   =    4.90214 DELP =    .63398 SH   =    .75000 DPTB =    5.53612

I    =         21 NPT  =         6 NTB  =         5 FREZ =          0 DEN  = 70.000000 UI    =    6.00000
FLL  =     .13833 CSA  =    .04861 WP   =  15.75000 RE   =     .49996 F    =  32.00246 FR    =   42.52174
FR   =     .13056 DELP =    .00018 SH   =    .75000 DPTB =     .13074
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I   =       22 NPT  =      6 NTB  =        5 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =   .13833 CSA  = .04661 WP   = 15.75000 RE   =   .49996 F    =  32.00244 FR  = 42.52174
FR  =   .13056 DELP = .00016 SH   =   .75000 DPTB =   .26148

I   =       23 NPT  =      6 NTB  =        5 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =   .13833 CSA  = .04661 WP   = 15.75000 RE   =   .49996 F    =  32.00244 FR  = 42.52174
FR  =   .13056 DELP = .00016 SH   =   .75000 DPTB =   .39272

I   =       20 NPT  =      1 NTB  =        6 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =  1.00000 CSA  = .00136 WP   =   .13083 RE   = 39.26339 F    =    .40750 FR  = 27.73950
FR  =  1.93539 DELP = .09882 SH   =   .75000 DPTB =  2.03421

I   =       24 NPT  =      1 NTB  =        7 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =  1.00000 CSA  = .00136 WP   =   .13083 RE   = 99.44985 F    =    .16049 FR  = 70.26132
FR  =  4.90214 DELP = .63396 SH   =   .75000 DPTB =  5.53612

I   =        1 NPT  =      1 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =  1.00000 CSA  = .00136 WP   =   .13083 RE   = 98.79825 F    =    .16195 FR  = 69.80096
FR  =  4.87002 DELP = .62570 SH   =   .75000 DPTB =  5.49572

I   =        2 NPT  =      6 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =   .13833 CSA  = .04661 WP   = 15.75000 RE   =   .82071 F    =  19.49543 FR  = 69.80096
FR  =   .21432 DELP = .00049 SH   =   .75000 DPTB =  5.71052

I   =        3 NPT  =      6 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =   .13833 CSA  = .04661 WP   = 15.75000 RE   =   .82071 F    =  19.49543 FR  = 69.80096
FR  =   .21432 DELP = .00049 SH   =   .75000 DPTB =  5.92533

I   =        4 NPT  =      6 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =   .13833 CSA  = .04661 WP   = 15.75000 RE   =   .82071 F    =  19.49543 FR  = 69.80096
FR  =   .21432 DELP = .00049 SH   =   .75000 DPTB =  6.14014

I   =        5 NPT  =      1 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =  1.00000 CSA  = .00136 WP   =   .13083 RE   = 98.79825 F    =    .16195 FR  = 69.80096
FR  =  4.87002 DELP = .62570 SH   =   .75000 DPTB = 11.63586

I   =        6 NPT  =      3 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =   .13833 CSA  = .04661 WP   = 15.75000 RE   =   .82071 F    =  19.49543 FR  = 69.80096
FR  =   .21432 DELP = .00049 SH   =   .75000 DPTB = 11.85066

I   =        7 NPT  =      3 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =   .13833 CSA  = .04661 WP   = 15.75000 RE   =   .82071 F    =  19.49543 FR  = 69.80096
FR  =   .21432 DELP = .00049 SH   =   .75000 DPTB = 12.06547

I   =        8 NPT  =      3 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =   .13833 CSA  = .04661 WP   = 15.75000 RE   =   .82071 F    =  19.49543 FR  = 69.80096
FR  =   .21432 DELP = .00049 SH   =   .75000 DPTB = 12.28028

I   =        9 NPT  =      1 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =  1.00000 CSA  = .00136 WP   =   .13083 RE   = 98.79825 F    =    .16195 FR  = 69.80096
FR  =  4.87002 DELP = .62570 SH   =   .75000 DPTB = 17.77600

I   =       10 NPT  =      2 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =  5.00000 CSA  = .00136 WP   =   .13083 RE   = 98.79825 F    =    .16195 FR  = 69.80096
FR  = 24.35010 DELP = .62570 SH   =   .75000 DPTB = 42.75179

I   =       11 NPT  =      2 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
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FLL  =   5.00000 CSA  =    .00136 WP  =     .13083 RE   =  98.79825 F    =     .16195 FR   =  69.80096
FR   =  24.35010 DELP =    .62570 SP  =     .75000 DPTB =  67.72753

I    =        12 NPT  =         2 NTB =          1 FREZ =         0 DEN  =  70.000000 UI   =   6.00000
FLL  =   5.00000 CSA  =    .00136 WP  =     .13083 RE   =  96.79825 F    =     .16195 FR   =  69.80096
FR   =  24.35010 DELP =    .62570 SP  =     .75000 DPTB =  92.70338

I    =        13 NPT  =         2 NTB =          1 FREZ =         0 DEN  =  70.000000 UI   =   6.00000
FLL  =   5.00000 CSA  =    .00136 WP  =     .13083 RE   =  96.79825 F    =     .16195 FR   =  69.80096
FR   =  24.35010 DELP =    .62570 SP  =     .75000 DPTB = 117.67917

I    =        16 NPT  =         2 NTB =          2 FREZ =         0 DEN  =  70.000000 UI   =   6.00000
FLL  =   5.00000 CSA  =    .00136 WP  =     .13083 RE   =  97.69790 F    =     .16377 FR   =  69.02357
FR   =  24.07890 DELP =    .61184 SP  =     .75000 DPTB =  24.69074

I    =        17 NPT  =         2 NTB =          2 FREZ =         0 DEN  =  70.000000 UI   =   6.00000
FLL  =   5.00000 CSA  =    .00136 WP  =     .13083 RE   =  97.69790 F    =     .16377 FR   =  69.02357
FR   =  24.07890 DELP =    .61184 SP  =     .75000 DPTB =  49.38148

I    =        18 NPT  =         5 NTB =          2 FREZ =         0 DEN  =  70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP  =     .13083 RE   =  97.69790 F    =     .16377 FR   =  69.02357
FR   =   4.81578 DELP =    .61184 SP  =     .75000 DPTB =  54.00910

I    =        14 NPT  =         1 NTB =          3 FREZ =         0 DEN  =  70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP  =     .13083 RE   =   1.10035 F    =   14.54085 FR   =    .77740
FR   =    .05424 DELP =    .00006 SP  =     .75000 DPTB =    .05432

I    =        15 NPT  =         4 NTB =          3 FREZ =         0 DEN  =  70.000000 UI   =   6.00000
FLL  = 999.99999 CSA  =    .00136 WP  =     .13083 RE   =   1.10035 F    =   14.54065 FR   =    .77741
FR   =  54.23899 DELP =    .00006 SP  =     .75000 DPTB =  54.29339

I    =        19 NPT  =         1 NTB =          4 FREZ =         0 DEN  =  70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP  =     .13083 RE   =  96.79825 F    =     .16195 FR   =  69.80096
FR   =   4.87002 DELP =    .62570 SP  =     .75000 DPTB =   5.49572

I    =        21 NPT  =         6 NTB =          5 FREZ =         0 DEN  =  70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP  =   15.75000 RE   =    .49669 F    =   32.21352 FR   =  42.24313
FR   =    .12970 DELP =    .00018 SP  =     .75000 DPTB =    .12988

I    =        22 NPT  =         6 NTB =          5 FREZ =         0 DEN  =  70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP  =   15.75000 RE   =    .49669 F    =   32.21352 FR   =  42.24313
FR   =    .12970 DELP =    .00018 SP  =     .75000 DPTB =    .25977

I    =        23 NPT  =         6 NTB =          5 FREZ =         0 DEN  =  70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP  =   15.75000 RE   =    .49669 F    =   32.21352 FR   =  42.24313
FR   =    .12970 DELP =    .00018 SP  =     .75000 DPTB =    .38965

I    =        20 NPT  =         1 NTB =          6 FREZ =         0 DEN  =  70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP  =     .13083 RE   =  39.00613 F    =     .41019 FR   =  27.55783
FR   =   1.92271 DELP =    .09753 SP  =     .75000 DPTB =   2.02024

I    =        24 NPT  =         1 NTB =          7 FREZ =         0 DEN  =  70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP  =     .13083 RE   =  98.79825 F    =     .16195 FR   =  69.80096
FR   =   4.87002 DELP =    .62570 SP  =     .75000 DPTB =   5.49572

I    =         1 NPT  =         1 NTB =          1 FREZ =         0 DEN  =  70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP  =     .13083 RE   =  98.47562 F    =     .16248 FR   =  69.57303
FR   =   4.85412 DELP =    .62162 SP  =     .75000 DPTB =   5.47573
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I   =        2 NPT  =       6 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =   .13833 CSA  =  .04861 WP   = 15.75000 RE   =   .81803 F    =  19.55930 FR  = 69.57303
FR  =   .21362 DELP =  .00049 SH   =   .75000 DPTB =  5.68984

I   =        3 NPT  =       6 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =   .13833 CSA  =  .04861 WP   = 15.75000 RE   =   .81803 F    =  19.55930 FR  = 69.57303
FR  =   .21362 DELP =  .00049 SH   =   .75000 DPTB =  5.90394

I   =        4 NPT  =       6 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =   .13833 CSA  =  .04861 WP   = 15.75000 RE   =   .81803 F    =  19.55930 FR  = 69.57303
FR  =   .21362 DELP =  .00049 SH   =   .75000 DPTB =  6.11805

I   =        5 NPT  =       1 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =  1.00000 CSA  =  .00136 WP   =   .13083 RE   = 98.47562 F    =    .16248 FR  = 69.57303
FR  =  4.85412 DELP =  .62162 SH   =   .75000 DPTB = 11.59378

I   =        6 NPT  =       3 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =   .13833 CSA  =  .04861 WP   = 15.75000 RE   =   .81803 F    =  19.55930 FR  = 69.57303
FR  =   .21362 DELP =  .00049 SH   =   .75000 DPTB = 11.80789

I   =        7 NPT  =       3 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =   .13833 CSA  =  .04861 WP   = 15.75000 RE   =   .81803 F    =  19.55930 FR  = 69.57303
FR  =   .21362 DELP =  .00049 SH   =   .75000 DPTB = 12.02199

I   =        8 NPT  =       3 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =   .13833 CSA  =  .04861 WP   = 15.75000 RE   =   .81803 F    =  19.55930 FR  = 69.57303
FR  =   .21362 DELP =  .00049 SH   =   .75000 DPTB = 12.23609

I   =        9 NPT  =       1 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =  1.00000 CSA  =  .00136 WP   =   .13083 RE   = 98.47562 F    =    .16248 FR  = 69.57303
FR  =  4.85412 DELP =  .62162 SH   =   .75000 DPTB = 17.71183

I   =       10 NPT  =       2 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =  5.00000 CSA  =  .00136 WP   =   .13083 RE   = 98.47562 F    =    .16248 FR  = 69.57303
FR  = 24.27058 DELP =  .62162 SH   =   .75000 DPTB = 42.60403

I   =       11 NPT  =       2 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =  5.00000 CSA  =  .00136 WP   =   .13083 RE   = 98.47562 F    =    .16248 FR  = 69.57303
FR  = 24.27058 DELP =  .62162 SH   =   .75000 DPTB = 67.49623

I   =       12 NPT  =       2 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =  5.00000 CSA  =  .00136 WP   =   .13083 RE   = 98.47562 F    =    .16248 FR  = 69.57303
FR  = 24.27058 DELP =  .62162 SH   =   .75000 DPTB = 92.38842

I   =       13 NPT  =       2 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =  5.00000 CSA  =  .00136 WP   =   .13083 RE   = 98.47562 F    =    .16248 FR  = 69.57303
FR  = 24.27058 DELP =  .62162 SH   =   .75000 DPTB = 117.28062

I   =       16 NPT  =       2 NTB  =        2 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =  5.00000 CSA  =  .00136 WP   =   .13083 RE   = 97.37886 F    =    .16431 FR  = 68.79817
FR  = 24.00027 DELP =  .60785 SH   =   .75000 DPTB = 24.60812

I   =       17 NPT  =       2 NTB  =        2 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
FLL =  5.00000 CSA  =  .00136 WP   =   .13083 RE   = 97.37886 F    =    .16431 FR  = 68.79817
FR  = 24.00027 DELP =  .60785 SH   =   .75000 DPTB = 49.21624

I   =       18 NPT  =       5 NTB  =        2 FREZ =        0 DEN  = 70.000000 UI  =  6.00000
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FLL  =   1.00000 CSA  =    .00136 WP   =     .13083 RE   =  97.37886 F    =      .16431 FR   =  68.79817
FR   =   4.80005 DELP =    .09775 SH   =     .75000 DPTB =  54.62414

I    =        14 NPT  =         1 NTB  =          3 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =     .13083 RE   =   1.09676 F    =  14.58849 FR   =    .77486
FR   =    .05406 DELP =    .00006 SH   =     .75000 DPTB =    .05414

I    =        15 NPT  =         4 NTB  =          3 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  = 999.99999 CSA  =    .00136 WP   =     .13083 RE   =   1.09676 F    =  14.58849 FR   =    .77486
FR   =  54.06167 DELP =    .00006 SH   =     .75000 DPTB =  54.11609

I    =        19 NPT  =         1 NTB  =          4 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =     .13083 RE   =  98.47562 F    =      .16248 FR   =  69.57303
FR   =   4.85412 DELP =    .62162 SH   =     .75000 DPTB =   5.47573

I    =        21 NPT  =         6 NTB  =          5 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =   15.75000 RE   =    .49506 F    =  32.31906 FR   =  42.10519
FR   =    .12928 DELP =    .00018 SH   =     .75000 DPTB =    .12946

I    =        22 NPT  =         6 NTB  =          5 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =   15.75000 RE   =    .49506 F    =  32.31906 FR   =  42.10519
FR   =    .12928 DELP =    .00018 SH   =     .75000 DPTB =    .25892

I    =        23 NPT  =         6 NTB  =          5 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =   15.75000 RE   =    .49506 F    =  32.31906 FR   =  42.10519
FR   =    .12928 DELP =    .00018 SH   =     .75000 DPTB =    .38837

I    =        20 NPT  =         1 NTB  =          6 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =     .13083 RE   =  38.87876 F    =      .41154 FR   =  27.46734
FR   =   1.91643 DELP =    .09689 SH   =     .75000 DPTB =   2.01333

I    =        24 NPT  =         1 NTB  =          7 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =     .13083 RE   =  98.47562 F    =      .16248 FR   =  69.57303
FR   =   4.85412 DELP =    .62162 SH   =     .75000 DPTB =   5.47573

I    =         1 NPT  =         1 NTB  =          1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =     .13083 RE   =  98.31588 F    =      .16274 FR   =  69.46017
FR   =   4.84624 DELP =    .61960 SH   =     .75000 DPTB =   5.46585

I    =         2 NPT  =         6 NTB  =          1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =   15.75000 RE   =    .81670 F    =  19.59108 FR   =  69.46017
FR   =    .21327 DELP =    .00049 SH   =     .75000 DPTB =   5.67960

I    =         3 NPT  =         6 NTB  =          1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =   15.75000 RE   =    .81670 F    =  19.59108 FR   =  69.46017
FR   =    .21327 DELP =    .00049 SH   =     .75000 DPTB =   5.69336

I    =         4 NPT  =         6 NTB  =          1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =   15.75000 RE   =    .81670 F    =  19.59108 FR   =  69.46017
FR   =    .21327 DELP =    .00049 SH   =     .75000 DPTB =   6.10711

I    =         5 NPT  =         1 NTB  =          1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =     .13083 RE   =  98.31588 F    =      .16274 FR   =  69.46017
FR   =   4.84624 DELP =    .61960 SH   =     .75000 DPTB =  11.57296

I    =         6 NPT  =         3 NTB  =          1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =   15.75000 RE   =    .81670 F    =  19.59108 FR   =  69.46017
FR   =    .21327 DELP =    .00049 SH   =     .75000 DPTB =  11.78672
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I   =        7 NPT  =        3 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI  =    6.00000
FLL =   .13833 CSA  =   .04861 WP   =  15.75000 RE   =    .81670 F    =  19.59108 FR  =   69.46017
FR  =   .21327 DELP =   .00049 SH   =    .75000 DPTB =  12.00047

I   =        8 NPT  =        3 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI  =    6.00000
FLL =   .13833 CSA  =   .04861 WP   =  15.75000 RE   =    .81670 F    =  19.59108 FR  =   69.46017
FR  =   .21327 DELP =   .00049 SH   =    .75000 DPTB =  12.21423

I   =        9 NPT  =        1 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI  =    6.00000
FLL =  1.00000 CSA  =   .00136 WP   =    .13083 RE   =  98.31588 F    =    .16274 FR  =   69.46017
FR  =  4.84624 DELP =   .61960 SH   =    .75000 DPTB =  17.68007

I   =       10 NPT  =        2 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI  =    6.00000
FLL =  5.00000 CSA  =   .00136 WP   =    .13083 RE   =  98.31588 F    =    .16274 FR  =   69.46017
FR  = 24.23121 DELP =   .61960 SH   =    .75000 DPTB =  42.53089

I   =       11 NPT  =        2 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI  =    6.00000
FLL =  5.00000 CSA  =   .00136 WP   =    .13083 RE   =  98.31588 F    =    .16274 FR  =   69.46017
FR  = 24.23121 DELP =   .61960 SH   =    .75000 DPTB =  67.38170

I   =       12 NPT  =        2 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI  =    6.00000
FLL =  5.00000 CSA  =   .00136 WP   =    .13083 RE   =  98.31588 F    =    .16274 FR  =   69.46017
FR  = 24.23121 DELP =   .61960 SH   =    .75000 DPTB =  92.23251

I   =       13 NPT  =        2 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI  =    6.00000
FLL =  5.00000 CSA  =   .00136 WP   =    .13083 RE   =  98.31588 F    =    .16274 FR  =   69.46017
FR  = 24.23121 DELP =   .61960 SH   =    .75000 DPTB = 117.08332

I   =       16 NPT  =        2 NTB  =         2 FREZ =         0 DEN  = 70.000000 UI  =    6.00000
FLL =  5.00000 CSA  =   .00136 WP   =    .13083 RE   =  97.22090 F    =    .16457 FR  =   68.68657
FR  = 23.96134 DELP =   .60588 SH   =    .75000 DPTB =  24.56722

I   =       17 NPT  =        2 NTB  =         2 FREZ =         0 DEN  = 70.000000 UI  =    6.00000
FLL =  5.00000 CSA  =   .00136 WP   =    .13083 RE   =  97.22090 F    =    .16457 FR  =   68.68657
FR  = 23.96134 DELP =   .60588 SH   =    .75000 DPTB =  49.13444

I   =       18 NPT  =        5 NTB  =         2 FREZ =         0 DEN  = 70.000000 UI  =    6.00000
FLL =  1.00000 CSA  =   .00136 WP   =    .13083 RE   =  97.22090 F    =    .16457 FR  =   68.68657
FR  =  4.79227 DELP =   .60588 SH   =    .75000 DPTB =  54.53258

I   =       14 NPT  =        1 NTB  =         3 FREZ =         0 DEN  = 70.000000 UI  =    6.00000
FLL =  1.00000 CSA  =   .00136 WP   =    .13083 RE   =   1.09498 F    =  14.61219 FR  =     .77360
FR  =   .05397 DELP =   .00008 SH   =    .75000 DPTB =    .05405

I   =       15 NPT  =        4 NTB  =         3 FREZ =         0 DEN  = 70.000000 UI  =    6.00000
FLL = 999.99999 CSA =   .00136 WP   =    .13083 RE   =   1.09498 F    =  14.61219 FR  =     .77360
FR  = 53.97418 DELP =   .00008 SH   =    .75000 DPTB =  54.02830

I   =       19 NPT  =        1 NTB  =         4 FREZ =         0 DEN  = 70.000000 UI  =    6.00000
FLL =  1.00000 CSA  =   .00136 WP   =    .13083 RE   =  98.31588 F    =    .16274 FR  =   69.46017
FR  =  4.84624 DELP =   .61960 SH   =    .75000 DPTB =   5.46585

I   =       21 NPT  =        6 NTB  =         5 FREZ =         0 DEN  = 70.000000 UI  =    6.00000
FLL =   .13833 CSA  =   .04861 WP   =  15.75000 RE   =    .49426 F    =  32.37157 FR  =   42.03688
FR  =   .12907 DELP =   .00018 SH   =    .75000 DPTB =    .12925

I   =       22 NPT  =        6 NTB  =         5 FREZ =         0 DEN  = 70.000000 UI  =    6.00000
```

```
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =    .49426 F    =  32.37157 FR   =  42.03688
FR   =    .12917 DELP =    .00018 SH   =    .75000 DPTB =    .25850

I    =        23 NPT  =         6 NTB  =         5 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =    .49426 F    =  32.37157 FR   =  42.03688
FR   =    .12917 DELP =    .00013 SH   =    .75000 DPTB =    .38774

I    =        20 NPT  =         1 NTB  =         4 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =    .13083 RE   =  38.01569 F    =    .41227 FR   =  27.42329
FR   =   1.91333 DELP =    .09658 SH   =    .75000 DPTB =   2.00991

I    =        24 NPT  =         1 NTB  =         7 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =    .13083 RE   =  98.31588 F    =    .16274 FR   =  69.46017
FR   =   4.84624 DELP =    .61960 SH   =    .75000 DPTB =   5.46585

I    =         1 NPT  =         1 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =    .13083 RE   =  98.23678 F    =    .16287 FR   =  69.40429
FR   =   4.84234 DELP =    .61861 SH   =    .75000 DPTB =   5.46095

I    =         2 NPT  =         6 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =    .81604 F    =  19.60686 FR   =  69.40429
FR   =    .21310 DELP =    .00046 SH   =    .75000 DPTB =   5.67453

I    =         3 NPT  =         6 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =    .81604 F    =  19.60686 FR   =  69.40429
FR   =    .21310 DELP =    .00043 SH   =    .75000 DPTB =   5.88812

I    =         4 NPT  =         5 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =    .81604 F    =  19.60686 FR   =  69.40429
FR   =    .21310 DELP =    .00046 SH   =    .75000 DPTB =   6.10170

I    =         5 NPT  =         1 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =    .13083 RE   =  98.23675 F    =    .16287 FR   =  69.40429
FR   =   4.84234 DELP =    .61861 SH   =    .75000 DPTB =  11.56265

I    =         6 NPT  =         3 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =    .81604 F    =  19.60686 FR   =  69.40429
FR   =    .21310 DELP =    .00048 SH   =    .75000 DPTB =  11.77623

I    =         7 NPT  =         3 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =    .81604 F    =  19.60686 FR   =  69.40429
FR   =    .21310 DELP =    .00048 SH   =    .75000 DPTB =  11.98982

I    =         8 NPT  =         3 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =    .81604 F    =  19.60686 FR   =  69.40429
FR   =    .21310 DELP =    .00045 SH   =    .75000 DPTB =  12.20340

I    =         9 NPT  =         1 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =    .13083 RE   =  98.23678 F    =    .16287 FR   =  69.40429
FR   =   4.84234 DELP =    .61861 SH   =    .75000 DPTB =  17.66435

I    =        10 NPT  =         2 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   5.00000 CSA  =    .00136 WP   =    .13083 RE   =  98.23678 F    =    .16287 FR   =  69.40429
FR   =  24.21172 DELP =    .61861 SH   =    .75000 DPTB =  42.49468

I    =        11 NPT  =         2 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   5.00000 CSA  =    .00136 WP   =    .13083 RE   =  98.23678 F    =    .16287 FR   =  69.40429
FR   =  24.21172 DELP =    .61861 SH   =    .75000 DPTB =  67.32500
```

```
I    =        12 NPT  =        2 NTB  =        1 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =   5.00000 CSA  =   .00136 WP   =   .13083 RE   =  98.23678 F    =    .16287 FR  =  69.40429
FR   =  24.21172 DELF =   .61861 SH   =   .75000 DPTB =  92.15532

I    =        13 NPT  =        2 NTB  =        1 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =   5.00000 CSA  =   .00136 WP   =   .13083 RE   =  98.23678 F    =    .16287 FR  =  69.40429
FR   =  24.21172 DELF =   .61861 SH   =   .75000 DPTB = 116.98564

I    =        16 NPT  =        2 NTB  =        2 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =   5.00000 CSA  =   .00136 WP   =   .13083 RE   =  97.14269 F    =    .16471 FR  =  68.63131
FR   =  23.94206 DELF =   .60490 SH   =   .75000 DPTB =  24.54697

I    =        17 NPT  =        2 NTB  =        2 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =   5.00000 CSA  =   .00136 WP   =   .13083 RE   =  97.14269 F    =    .16471 FR  =  68.63131
FR   =  23.94206 DELF =   .60490 SH   =   .75000 DPTB =  49.09393

I    =        18 NPT  =        5 NTB  =        2 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =   1.00000 CSA  =   .00136 WP   =   .13083 RE   =  97.14269 F    =    .16471 FR  =  68.63131
FR   =   4.78841 DELF =   .60490 SH   =   .75000 DPTB =  54.48725

I    =        14 NPT  =        1 NTB  =        3 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =   1.00000 CSA  =   .00136 WP   =   .13083 RE   =   1.09410 F    =  14.62396 FR  =    .77296
FR   =    .05393 DELF =   .00008 SH   =   .75000 DPTB =    .05401

I    =        15 NPT  =        4 NTB  =        3 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  = 999.99999 CSA  =   .00136 WP   =   .13083 RE   =   1.09410 F    =  14.62396 FR  =    .77296
FR   =  53.93075 DELF =   .00008 SH   =   .75000 DPTB =  53.98484

I    =        19 NPT  =        1 NTB  =        4 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =   1.00000 CSA  =   .00136 WP   =   .13083 RE   =  98.23678 F    =    .16287 FR  =  69.40429
FR   =   4.84234 DELF =   .61861 SH   =   .75000 DPTB =   5.46095

I    =        21 NPT  =        6 NTB  =        5 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =    .13833 CSA  =   .04861 WP   = 15.75000 RE   =    .49386 F    =  32.39763 FR  =  42.00307
FR   =    .12897 DELF =   .00018 SH   =   .75000 DPTB =    .12914

I    =        22 NPT  =        6 NTB  =        5 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =    .13833 CSA  =   .04861 WP   = 15.75000 RE   =    .49386 F    =  32.39763 FR  =  42.00307
FR   =    .12897 DELF =   .00018 SH   =   .75000 DPTB =    .25329

I    =        23 NPT  =        6 NTB  =        5 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =    .13833 CSA  =   .04861 WP   = 15.75000 RE   =    .49386 F    =  32.39763 FR  =  42.00307
FR   =    .12897 DELF =   .00018 SH   =   .75000 DPTB =    .38743

I    =        20 NPT  =        1 NTB  =        6 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =   1.00000 CSA  =   .00136 WP   =   .13083 RE   =  38.78446 F    =    .41254 FR  =  27.40122
FR   =   1.91179 DELF =   .09642 SH   =   .75000 DPTB =   2.00821

I    =        24 NPT  =        1 NTB  =        7 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =   1.00000 CSA  =   .00136 WP   =   .13083 RE   =  98.23678 F    =    .16287 FR  =  69.40429
FR   =   4.84234 DELF =   .61861 SH   =   .75000 DPTB =   5.46095

I    =         1 NPT  =        1 NTB  =        1 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =   1.00000 CSA  =   .00136 WP   =   .13083 RE   =  98.15646 F    =    .16300 FR  =  69.34895
FR   =   4.83848 DELF =   .61762 SH   =   .75000 DPTB =   5.45610

I    =         2 NPT  =        6 NTB  =        1 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
```

```
FLL  =    .13833 CSA  =   .04861 WP   =  15.75000 RE   =     .81539 F    =  19.62250 FR   =  69.34895
FR   =    .21293 DELP =   .00048 SH   =    .75000 DPTB =    5.66952

I    =         3 NPT  =        6 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =   .04861 WP   =  15.75000 RE   =     .81539 F    =  19.62250 FR   =  69.34895
FR   =    .21293 DELP =   .00048 SH   =    .75000 DPTB =    5.68293

I    =         4 NPT  =        6 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =   .04861 WP   =  15.75000 RE   =     .81539 F    =  19.62250 FR   =  69.34895
FR   =    .21293 DELP =   .00048 SH   =    .75000 DPTB =    6.09634

I    =         5 NPT  =        1 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =   .00136 WP   =    .13083 RE   =   98.15846 F    =    .16300 FR   =  69.34895
FR   =   4.83848 DELP =   .61762 SH   =    .75000 DPTB =   11.55245

I    =         6 NPT  =        3 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =   .04861 WP   =  15.75000 RE   =     .81539 F    =  19.62250 FR   =  69.34895
FR   =    .21293 DELP =   .00048 SH   =    .75000 DPTB =   11.76586

I    =         7 NPT  =        3 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =   .04861 WP   =  15.75000 RE   =     .81539 F    =  19.62250 FR   =  69.34895
FR   =    .21293 DELP =   .00048 SH   =    .75000 DPTB =   11.97927

I    =         8 NPT  =        3 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA  =   .04861 WP   =  15.75000 RE   =     .81539 F    =  19.62250 FR   =  69.34895
FR   =    .21293 DELP =   .00048 SH   =    .75000 DPTB =   12.19268

I    =         9 NPT  =        1 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =   .00136 WP   =    .13083 RE   =   98.15846 F    =    .16300 FR   =  69.34895
FR   =   4.83848 DELP =   .61762 SH   =    .75000 DPTB =   17.64879

I    =        10 NPT  =        2 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =   5.00000 CSA  =   .00136 WP   =    .13083 RE   =   98.15846 F    =    .16300 FR   =  69.34895
FR   =  24.19241 DELP =   .61762 SH   =    .75000 DPTB =   42.45802

I    =        11 NPT  =        2 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =   5.00000 CSA  =   .00136 WP   =    .13083 RE   =   98.15846 F    =    .16300 FR   =  69.34895
FR   =  24.19241 DELP =   .61762 SH   =    .75000 DPTB =   67.26805

I    =        12 NPT  =        2 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =   5.00000 CSA  =   .00136 WP   =    .13083 RE   =   98.15846 F    =    .16300 FR   =  69.34895
FR   =  24.19241 DELP =   .61762 SH   =    .75000 DPTB =   92.07809

I    =        13 NPT  =        2 NTB  =         1 FREZ =          0 DEN  = 70.000000 UI   =   5.00000
FLL  =   5.00000 CSA  =   .00136 WP   =    .13083 RE   =   98.15846 F    =    .16300 FR   =  69.34895
FR   =  24.19241 DELP =   .61762 SH   =    .75000 DPTB =  116.88892

I    =        16 NPT  =        2 NTB  =         2 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =   5.00000 CSA  =   .00136 WP   =    .13083 RE   =   97.06524 F    =    .16484 FR   =  68.57659
FR   =  23.92297 DELP =   .60394 SH   =    .75000 DPTB =   24.52691

I    =        17 NPT  =        2 NTB  =         2 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =   5.00000 CSA  =   .00136 WP   =    .13083 RE   =   97.06524 F    =    .16484 FR   =  68.57659
FR   =  23.92297 DELP =   .60394 SH   =    .75000 DPTB =   49.05383

I    =        18 NPT  =        5 NTB  =         2 FREZ =          0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA  =   .00136 WP   =    .13083 RE   =   97.06524 F    =    .16484 FR   =  68.57659
FR   =   4.78459 DELP =   .60394 SH   =    .75000 DPTB =   54.44236
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```
I    =        14 NPT   =        1 NTB   =        3 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA   =   .00136 WP    =   .13083 RE   =   1.09322 F    = 14.63563 FR   =    .77236
FR   =    .05389 DELP  =   .00008 SH    =   .75000 DPTB =    .05396

I    =        15 NPT   =        4 NTB   =        3 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  = 999.99999 CSA   =   .00136 WP    =   .13083 RE   =   1.09322 F    = 14.63563 FR   =    .77236
FR   =  53.84776 DELP  =   .00008 SH    =   .75000 DPTB =  53.94180

I    =        19 NPT   =        1 NTB   =        4 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA   =   .00136 WP    =   .13083 RE   =  98.15846 F    =   .16300 FR   =  69.34895
FR   =   4.83848 DELP  =   .61762 SH    =   .75000 DPTB =   5.45610

I    =        21 NPT   =        6 NTB   =        5 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA   =   .04861 WP    = 15.75000 RE   =    .49347 F    = 32.42349 FR   =  41.96958
FR   =    .12886 DELP  =   .00018 SH    =   .75000 DPTB =    .12904

I    =        22 NPT   =        6 NTB   =        5 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA   =   .04861 WP    = 15.75000 RE   =    .49347 F    = 32.42349 FR   =  41.96958
FR   =    .12886 DELP  =   .00018 SH    =   .75000 DPTB =    .25808

I    =        23 NPT   =        6 NTB   =        5 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =    .13833 CSA   =   .04861 WP    = 15.75000 RE   =    .49347 F    = 32.42349 FR   =  41.96958
FR   =    .12886 DELP  =   .00018 SH    =   .75000 DPTB =    .36712

I    =        20 NPT   =        1 NTB   =        6 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA   =   .00136 WP    =   .13083 RE   =  38.75354 F    =   .41287 FR   =  27.37934
FR   =   1.91026 DELP  =   .09627 SH    =   .75000 DPTB =   2.00653

I    =        24 NPT   =        1 NTB   =        7 FREZ =         0 DEN  = 70.000000 UI   =   6.00000
FLL  =   1.00000 CSA   =   .00136 WP    =   .13083 RE   =  96.15846 F    =   .16300 FR   =  69.34895
FR   =   4.83848 DELP  =   .61762 SH    =   .75000 DPTB =   5.45610

    DPRAD =        295.68283

I    =        25 NTUBE=        8 FLL   =   .04417 WDCTG= 16.400000 WDOTL=    .00000
RE(L)=    .00000 PG    = 59.00000 PDF   =  1.00000 DELP =    .00009

I    =        31 NTUBE=        9 FLL   =   .04417 WDCTG=  8.200000 WDOTL=    .00000
RE(L)=    .00000 PG    = 58.99991 PDF   =  1.00000 DELP =    .00005

I    =        30 NTUBE=       10 FLL   =   .04417 WDCTG=  8.200000 WDOTL=    .00000
RE(L)=    .00000 PG    = 58.99991 PDF   =  1.00000 DELP =    .00005

I    =        26 NTUBE=       11 FLL   =   .04417 WDCTG= 16.400000 WDOTL=    .00000
RE(L)=    .00000 PG    = 58.99986 PDF   =  1.00000 DELP =    .00009

I    =        27 NTUBE=       11 FLL   =   .04417 WDCTG= 16.400000 WDOTL=    .00000
RE(L)=    .00000 PG    = 58.99986 PDF   =  1.00000 DELP =    .00009

I    =        28 NTUBE=       11 FLL   =   .04417 WDCTG= 16.400000 WDOTL=    .00000
RE(L)=    .00000 PG    = 58.99977 PDF   =  1.00000 DELP =    .00009

I    =        29 NTUBE=       11 FLL   =   .04417 WDCTG= 16.400000 WDOTL=    .00000
RE(L)=    .00000 PG    = 58.99968 PDF   =  1.00000 DELP =    .00009

    VALVES
```


* U. S. GOVERNMENT PRINTING OFFICE: 1969-781-460

```
OUTPUT FOR VALVE    1 AFTER ITERATION    0
REFCTN =    1.00000
TOUT =  160.00000      TMIX =  160.00000

I     =         25 NTUBE=          8 FLL   =     .04417 WDCTG= 16.399999 WDOTL=     .00000
RE(L)=     .00000 PG    =  59.00000 PDF   =    1.00000 DELP  =    .00009

I     =         31 NTUBE=          9 FLL   =     .04417 WDCTG= 16.399999 WDOTL=     .00000
RE(L)=     .00000 PG    =  58.99991 PDF   =    1.00000 DELP  =    .00009

I     =         30 NTUBE=         10 FLL   =     .04417 WDCTG=   .000000 WDOTL=    -.00000
RE(L)=     .00000 PG    =    .00000 PDF   =    1.00000 DELP  =    .00000

I     =         26 NTUBE=         11 FLL   =     .04417 WDCTG= 16.399999 WDOTL=     .00000
RE(L)=     .00000 PG    =  58.99982 PDF   =    1.00000 DELP  =    .00009

I     =         27 NTUBE=         11 FLL   =     .04417 WDCTG= 16.399999 WDOTL=     .00000
RE(L)=     .00000 PG    =  58.99982 PDF   =    1.00000 DELP  =    .00009

I     =         28 NTUBE=         11 FLL   =     .04417 WDCTG= 16.399999 WDOTL=     .00000
RE(L)=     .00000 PG    =  58.99973 PDF   =    1.00000 DELP  =    .00009

I     =         29 NTUBE=         11 FLL   =     .04417 WDCTG= 16.399999 WDOTL=     .00000
RE(L)=     .00000 PG    =  58.99964 PDF   =    1.00000 DELP  =    .00009

UPRAD =          .54741
```


★ U. S. GOVERNMENT PRINTING OFFICE: 1965-781-486

PPD SECONDARY LOOP MOCK UP FOR PARTIAL CHECK OUT 2-PHASE
DATA SET 1

COMPUTER TIME= .010

INITIAL CONDITIONS

```
FLOW RATES (LBS./HR.) IN SYSTEM    1
        69.34695100   68.57659000    .77236188   69.34695100   41.96957700
        27.37937600   69.34695100

FLOW RATES (LBS./HR.) IN SYSTEM    2
        16.39999900   16.39999900   -.00000000   16.39999900

PRESSURE DROPS (X1000.) (LBS./SQ. IN.) IN SYSTEM    1
       116.88891800   54.44256000   53.94179703    5.45610350    .38712160
         2.00653110    5.45610350

PRESSURE DROPS (X1000.) (LBS./SQ. IN.) IN SYSTEM    2
          .09123531     .09123545     .00000000     .36494278
```

POWER REQUIREMENT (X 1000.) 53968.422000 FT.LB./HR.

TOTAL HEAT REJECTED .000000 BTU/HR. IN SYSTEM 1

TOTAL HEAT REJECTED 1539.296900 BTU/HR. IN SYSTEM 2

WEIGHT 16.232605 LBS.

PPD SECONDARY LOOP MOCK UP FOR PARTIAL CHECK OUT 2-PHASE
DATA SET 1

LUMP NUMBER	GAS PRESSURE	GAS TEMPERATURE	LIQUID TEMPERATURE	LIQUID FLOW RATE
25	59.000000	160.000	160.000	.000000
26	58.999818	160.000	160.000	.000000
27	58.999726	160.000	160.000	.000000
28	58.999635	160.000	160.000	.000000
29	58.999544	160.000	160.000	.000000
30	58.999909	160.000	160.000	-.000000
31	58.999909	160.000	160.000	.000000

FLUID LUMP CHECK OUT PRINTING

```
I      =          1 TI     = 619.68999 WL     =          1 TWALL= 619.68999 NLU    =          0 TU     = 619.68999
G      =   29.13212 H      =    .00000 HI     =   44.62792 ACON  =   81.14383 ATEM   *********** DTAU   =   .0007926

TYPE   =          1 RE     =  98.15846 PR     =   54.00000 COND.=     .30000 DEN.   =   70.00000
SP.HT=       .75000 V.BLK=     6.00000 VWALL=      6.00000 WEIGH=     .09528 HEAT TRAN.COEF=  44.62792

I      =          2 TI     = 619.68999 WL     =          2 TWALL= 619.68999 NLU    =          1 TU     = 619.68999
G      =  987.93352 H      =    .00000 HI     =   88.91402 ACON  = 1039.94520 ATEM   *********** DTAU   =   .0003055

TYPE   =          6 RE     =    .81539 PR     =   54.00000 COND.=     .30000 DEN.   =   70.00000
SP.HT=       .75000 V.BLK=     6.00000 VWALL=      6.00000 WEIGH=     .47072 HEAT TRAN.COEF=  88.91402

I      =          3 TI     = 619.68999 WL     =          3 TWALL= 619.68999 NLU    =          2 TU     = 619.68999
G      =  987.93354 H      =    .00000 HI     =   88.91402 ACON  = 1039.94520 ATEM   *********** DTAU   =   .0003055

TYPE   =          6 RE     =    .81539 PR     =   54.00000 COND.=     .30000 DEN.   =   70.00000
SP.HT=       .75000 V.BLK=     6.00000 VWALL=      6.00000 WEIGH=     .47072 HEAT TRAN.COEF=  88.91402

I      =          4 TI     = 619.68999 WL     =          4 TWALL= 619.68999 NLU    =          3 TU     = 619.68999
G      =  987.93353 H      =    .00000 HI     =   88.91402 ACON  = 1039.94520 ATEM   *********** DTAU   =   .0003055

TYPE   =          6 RE     =    .81539 PR     =   54.00000 COND.=     .30000 DEN.   =   70.00000
SP.HT=       .75000 V.BLK=     6.00000 VWALL=      6.00000 WEIGH=     .47072 HEAT TRAN.COEF=  88.91402

I      =          5 TI     = 619.68999 WL     =          5 TWALL= 619.68999 NLU    =          4 TU     = 619.68999
G      =   22.63765 H      =    .00000 HI     =   34.67896 ACON  =   74.64937 ATEM   *********** DTAU   =   .0008635

TYPE   =          1 RE     =  98.15846 PR     =   54.00000 COND.=     .30000 DEN.   =   70.00000
SP.HT=       .75000 V.BLK=     6.00000 VWALL=      6.00000 WEIGH=     .09528 HEAT TRAN.COEF=  34.67896
```

```
I     =          6 TI    = 619.68999 WL    =         6 TWALL= 619.68999 NLU   =          5 TU    = 619.68999
G     =  988.19997 H     =    .00000 HI    =  88.93800 ACCN =1040.21160 ATEM *********** DTAU  =  .0003055

TYPE  =          3 RE    =    .81539 PR    =  54.00000 COND.=    .30000 DEN. =  70.00000
SP.HT=      .75000 V.BLK=    6.00000 VWALL=    6.00000 WEIGH=    .47072 HEAT TRAN.COEF=  88.93800

I     =          7 TI    = 619.68999 WL    =         7 TWALL= 619.68999 NLU   =          6 TU    = 619.68999
G     =  988.19997 H     =    .00000 HI    =  88.93800 ACCN =1040.21160 ATEM *********** DTAU  =  .0003055

TYPE  =          3 RE    =    .81539 PR    =  54.00000 COND.=    .30000 DEN. =  70.00000
SP.HT=      .75000 V.BLK=    6.00000 VWALL=    6.00000 WEIGH=    .47072 HEAT TRAN.COEF=  88.93800

I     =          8 TI    = 619.68999 WL    =         8 TWALL= 619.68999 NLU   =          7 TU    = 619.68999
G     =  988.19997 H     =    .00000 HI    =  88.93800 ACCN =1040.21160 ATEM *********** DTAU  =  .0003055

TYPE  =          3 RE    =    .81539 PR    =  54.00000 COND.=    .30000 DEN. =  70.00000
SP.HT=      .75000 V.BLK=    6.00000 VWALL=    6.00000 WEIGH=    .47072 HEAT TRAN.COEF=  88.93800

I     =          9 TI    = 619.68999 WL    =         9 TWALL= 619.68999 NLU   =          8 TU    = 619.68999
G     =   29.26925 H     =    .00000 HI    =  31.05076 ACCN =  72.28096 ATEM *********** DTAU  =  .0008894

TYPE  =          1 RE    =  98.15846 PR    =  54.00000 COND.=    .30000 DEN. =  70.00000
SP.HT=      .75000 V.BLK=    6.00000 VWALL=    6.00000 WEIGH=    .09528 HEAT TRAN.COEF=  31.05076

I     =         10 TI    = 619.68999 WL    =        10 TWALL= 619.68999 NLU   =          9 TU    = 619.68999
G     =   88.88513 H     =    .00000 HI    =  27.20833 ACCN = 140.81684 ATEM *********** DTAU  =  .0022536

TYPE  =          2 RE    =  98.15846 PR    =  54.00000 COND.=    .30000 DEN. =  70.00000
SP.HT=      .75000 V.BLK=    6.00000 VWALL=    6.00000 WEIGH=    .47639 HEAT TRAN.COEF=  27.20830

I     =         11 TI    = 619.68999 WL    =        11 TWALL= 619.68999 NLU   =         10 TU    = 619.68999
G     =   86.60473 H     =    .00000 HI    =  26.53422 ACCN = 138.61644 ATEM *********** DTAU  =  .0023196

TYPE  =          2 RE    =  98.15846 PR    =  54.00000 COND.=    .30000 DEN. =  70.00000
SP.HT=      .75000 V.BLK=    6.00000 VWALL=    6.00000 WEIGH=    .47639 HEAT TRAN.COEF=  26.53422

I     =         12 TI    = 619.68999 WL    =        12 TWALL= 619.68999 NLU   =         11 TU    = 619.68999
G     =   86.19179 H     =    .00000 HI    =  26.40770 ACCN = 138.20349 ATEM *********** DTAU  =  .0023267

TYPE  =          2 RE    =  98.15846 PR    =  54.00000 COND.=    .30000 DEN. =  70.00000
SP.HT=      .75000 V.BLK=    6.00000 VWALL=    6.00000 WEIGH=    .47639 HEAT TRAN.COEF=  26.40770

I     =         13 TI    = 619.68999 WL    =        13 TWALL= 619.68999 NLU   =         12 TU    = 619.68999
G     =   86.11435 H     =    .00000 HI    =  26.38397 ACCN = 136.12605 ATEM *********** DTAU  =  .0023280

TYPE  =          2 RE    =  98.15846 PR    =  54.00000 COND.=    .30000 DEN. =  70.00000
SP.HT=      .75000 V.BLK=    6.00000 VWALL=    6.00000 WEIGH=    .47639 HEAT TRAN.COEF=  26.38397

I     =         16 TI    = 619.68999 WL    =        16 TWALL= 619.68999 NLU   =          0 TU    = 619.68999
G     =   95.67504 H     =    .00000 HI    =  29.37448 ACCN = 147.30748 ATEM *********** DTAU  =  .0021829

TYPE  =          2 RE    =  97.06524 PR    =  54.00000 COND.=    .30000 DEN. =  70.00000
SP.HT=      .75000 V.BLK=    6.00000 VWALL=    6.00000 WEIGH=    .47639 HEAT TRAN.COEF=  29.37440

I     =         17 TI    = 619.68999 WL    =        17 TWALL= 619.68999 NLU   =         16 TU    = 619.68999
G     =   87.85936 H     =    .00000 HI    =  26.91861 ACCN = 139.29180 ATEM *********** DTAU  =  .0023086

TYPE  =          2 RE    =  97.06524 PR    =  54.00000 COND.=    .30000 DEN. =  70.00000
```


★ U. S. GOVERNMENT PRINTING OFFICE: 1965-781-458

```
SP.HT=    .75000 V.BLK=    6.00000 VWALL=    6.00000 WEIGH=    .47639 HEAT TRAN.COEF=  26.91861

I    =        18 TI    = 619.68999 WL    =          18 TWALL= 619.68999 NLU   =          17 TU    = 619.68999
G    =  17.47067 H     =    .00000 HI    =    26.76358 ACCN  =   66.90311 ATEM  *********** DTAU  =   .0009334

TYPE =         6 RE    =  97.06524 PR    =    54.00000 COND.=     .30000 DEN.  =  70.00000
SP.HT=    .75000 V.BLK=    6.00000 VWALL=     6.00000 WEIGH=     .09528 HEAT TRAN.COEF=  26.76358

I    =        14 TI    = 619.68999 WL    =          14 TWALL= 619.68999 NLU   =           0 TU    = 619.68999
G    =  17.21938 H     =    .00000 HI    =    26.37850 ACCN  =   17.79857 ATEM  *********** DTAU  =   .0036134

TYPE =         1 RE    =   1.09322 PR    =    54.00000 COND.=     .30000 DEN.  =  70.00000
SP.HT=    .75000 V.BLK=    6.00000 VWALL=     6.00000 WEIGH=     .09528 HEAT TRAN.COEF=  26.37850

I    =        15 TI    = 619.68999 WL    =          15 TWALL= 619.68999 NLU   =          14 TU    = 619.68999
G    =  17.22394 H     =    .00000 HI    =    26.38561 ACCN  =   17.80321 ATEM  *********** DTAU  =  3.6124097

TYPE =         4 RE    =   1.09322 PR    =    54.00000 COND.=     .30000 DEN.  =  70.00000
SP.HT=    .75000 V.BLK=    6.00000 VWALL=     6.00000 WEIGH=   95.27777 HEAT TRAN.COEF=  26.38561

I    =        19 TI    = 619.68999 WL    =          19 TWALL= 619.68999 NLU   =           0 TU    = 619.68997
G    =  29.13212 H     =    .00000 HI    =    44.62792 ACCN  =   81.14383 ATEM  *********** DTAU  =   .0007926

TYPE =         1 RE    =  98.15846 PR    =    54.00000 COND.=     .30000 DEN.  =  70.00000
SP.HT=    .75000 V.BLK=    6.00000 VWALL=     6.00000 WEIGH=     .09528 HEAT TRAN.COEF=  44.62792

I    =        21 TI    = 619.68999 WL    =          21 TWALL= 619.68999 NLU   =           0 TU    = 619.68999
G    = 987.93354 H     =    .00000 HI    =    68.91402 ACCN  =1019.41071 ATEM  *********** DTAU  =   .0003117

TYPE =         6 RE    =    .49347 PR    =    54.00000 COND.=     .30000 DEN.  =  70.00000
SP.HT=    .75000 V.BLK=    6.00000 VWALL=     6.00000 WEIGH=     .47072 HEAT TRAN.COEF=  68.91402

I    =        22 TI    = 619.68999 WL    =          22 TWALL= 619.68999 NLU   =          21 TU    = 619.68999
G    = 987.93353 H     =    .00000 HI    =    68.91402 ACCN  =1019.41071 ATEM  *********** DTAU  =   .0003117

TYPE =         6 RE    =    .49347 PR    =    54.00000 COND.=     .30000 DEN.  =  70.00000
SP.HT=    .75000 V.BLK=    6.00000 VWALL=     6.00000 WEIGH=     .47072 HEAT TRAN.COEF=  68.91402

I    =        23 TI    = 619.68999 WL    =          23 TWALL= 619.68999 NLU   =          22 TU    = 619.68999
G    = 987.93352 H     =    .00000 HI    =    68.91402 ACCN  =1019.41070 ATEM  *********** DTAU  =   .0003117

TYPE =         6 RE    =    .49347 PR    =    54.00000 COND.=     .30000 DEN.  =  70.00000
SP.HT=    .75000 V.BLK=    6.00000 VWALL=     6.00000 WEIGH=     .47072 HEAT TRAN.COEF=  68.91402

I    =        20 TI    = 619.68999 WL    =          20 TWALL= 619.68999 NLU   =           0 TU    = 619.68999
G    =  22.36116 H     =    .00000 HI    =    34.25540 ACCN  =   42.89570 ATEM  *********** DTAU  =   .0014993

TYPE =         1 RE    =  38.75354 PR    =    54.00000 COND.=     .30000 DEN.  =  70.00000
SP.HT=    .75000 V.BLK=    6.00000 VWALL=     6.00000 WEIGH=     .09528 HEAT TRAN.COEF=  34.25540

I    =        24 TI    = 619.68999 WL    =          24 TWALL= 619.68999 NLU   =           0 TU    = 619.68997
G    =  29.13212 H     =    .00000 HI    =    44.62792 ACCN  =   81.14383 ATEM  *********** DTAU  =   .0007926

TYPE =         1 RE    =  98.15846 PR    =    54.00000 COND.=     .30000 DEN.  =  70.00000
SP.HT=    .75000 V.BLK=    6.00000 VWALL=     6.00000 WEIGH=     .09528 HEAT TRAN.COEF=  44.62792

      I                 ACCN                 ATEM                 DTAU
```

1	81.1436300	50284.0200000	.0007926
2	1039.9452000	644443.6500000	.0003055
3	1039.9452000	644443.6600000	.0003055
4	1039.9452000	644443.6600000	.0003055
5	74.6493660	46259.4660000	.0008615
6	1040.2116000	644608.7700000	.0003055
7	1040.2116000	644608.7700000	.0003055
8	1040.2116000	644608.7700000	.0003055
9	72.2809620	44791.7690000	.0008898
10	140.8168400	67262.7880000	.0022836
11	138.6164400	65899.2250000	.0023198
12	138.2034900	65643.3260000	.0023267
13	138.1260500	65595.3370000	.0023280
14	17.7985660	11029.5945000	.0036134
15	17.8032120	11032.4726000	3.6124097
16	147.3074800	91284.9740000	.0021829
17	139.2918000	66317.7390000	.0023086
18	68.9031090	42698.5670000	.0009334
19	81.1438300	50284.0180000	.0007926
20	42.8956960	26582.0330000	.0014993
21	1019.4107100	631718.6200000	.0003117
22	1019.4107100	631718.6200000	.0003117
23	1019.4107000	631718.6100000	.0003117
24	81.1438300	50284.0180000	.0007926

```
I      =        25 NTY   =         7 NLU   =         0 NLD   =         0 WP   =15.7499999
CSA    =   .048511 WDOTG=  13.29131 WDOTL=    .00000 WDOTO=   5.00200 HUMID=  1.657199
VISO   =   .022000 VIS1  =   .025000 VISL  =  2.000000 CP   = 3.5000000 CP1   =  .4200000
CPL    = 1.0000000 LAMDA= 1000.0000 KO    =   .110000 K1    =   .035000 KL    =   .320000
PRL    = 62.500000 DENL  =  62.40000 VISI  =   .022606 CPG   = 1.359400 KG    =   .094847
PR(G)=   1.166407 DENG  =   .046463 TWALL=  619.6900 RE(G)=    51.179 AREAR=   .000
CHI    =      .000 PG    = 55.000000 BULK  = 9.1745248 DIF   =  1.043705 SC    = 1.6781994
PSURF=   4.730000 PM    = 50.589645 KM    =  1.005488 QL    =3108.69020 H     =   28.31
```


089

```
TS    = 619.68999 TG    = 619.68999 REV   =     17.179 ACCN  =    19.6628 ATEM  = 15293.545
U     =1419.32170 DTALG=    .323-05 DTAUL=      .000

I     =        31 NTY   =          7 NLU   =          0 NLC   =          0 WP    =15.7499999
CSA   =   .044611 WDOTG=   13.29131 WDOTL=     .00000 WDOTC=    5.00200 HUMID=   1.657200
VISO  =   .022000 VIS1  =    .025000 VISL  =   2.000000 CPO   =  3.5000000 CP1   =   .4200000
CPL   = 1.0000000 LAMDA= 1000.0000 KO    =    .110000 K1    =    .035000 KL    =    .320000
PRL   = 62.500000 DENL  =   62.40000 VISI  =    .022606 CPG   =   1.359400 KG    =    .094847
PR(G)=  1.166407 DENG  =    .046463 TWALL=   619.6900 RE(G)=     51.179 AREAR=      .000
CHI   =      .000 PG    =  58.999909 BULK  =  9.1745134 DIF   =   1.043707 SC    =  1.6781994
PSURF=  4.730000 PM    =  50.569760 KM    =  1.005490 QL    =3106.66730 H     =     28.314
TS    = 619.68999 TG    = 619.68999 REV   =     17.180 ACCN  =    19.6628 ATEM  = 15293.545
U     =1419.32170 DTALG=    .323-05 DTAUL=      .000

I     =        30 NTY   =          7 NLU   =          0 NLC   =          0 WP    =15.7499999
CSA   =   .044611 WDOTG=     .00000 WDOTL=    -.00000 WDOTC=     .00000 HUMID=    .000000
VISO  =   .022000 VIS1  =    .025000 VISL  =   2.000000 CPO   =  3.5000000 CP1   =   .4200000
CPL   = 1.0000000 LAMDA= 1000.0000 KO    =    .110000 K1    =    .035000 KL    =    .320000
PRL   = 62.500000 DENL  =   62.40000 VISI  =    .022000 CPG   =  3.500000 KG    =    .110000
PR(G)=  2.520000 DENG  =    .000000 TWALL=   619.6900 RE(G)=       .000 AREAR=      .000
CHI   =      .000 PG    =  58.999909 BULK  =   .0000000 DIF   =   1.043707 SC    =   .0000000
PSURF=    .000000 PM    =    .000000 KM    =    .000000 QL    =     .00000 H     =    147.975
TS    = 619.68999 TG    = 619.68999 REV   =       .000 ACCN  =   102.7634 ATEM  = 63691.438
U     =    .00000 DTALG=       .000 DTAUL=      .000

I     =        26 NTY   =          6 NLU   =          0 NLC   =         27 WP    =15.7499999
CSA   =   .044611 WDOTG=   13.29131 WDOTL=     .00000 WDOTC=    5.00200 HUMID=   1.657200
VISO  =   .022000 VIS1  =    .025000 VISL  =   2.000000 CPO   =  3.5000000 CP1   =   .4200000
CPL   = 1.0000000 LAMDA= 1000.0000 KO    =    .110000 K1    =    .135000 KL    =    .320000
PRL   = 62.500000 DENL  =   62.40000 VISI  =    .022606 CPG   =   1.359400 KG    =    .094847
PR(G)=  1.166407 DENG  =    .046463 TWALL=   619.6900 RE(G)=     51.179 AREAR=      .000
CHI   =      .000 PG    =  58.999619 BULK  =  9.1745019 DIF   =   1.043709 SC    =  1.6781994
PSURF=  4.730000 PM    =  50.569681 KM    =  1.005491 QL    =3106.68419 H     =     28.314
TS    = 619.68999 TG    = 619.68999 REV   =     17.180 ACCN  =  1007.5964 ATEM  =627506.050
U     =1419.32170 DTALG=    .323-05 DTAUL=      .000

I     =        27 NTY   =          8 NLU   =         26 NLC   =         28 WP    =15.7499999
CSA   =   .044611 WDOTG=   11.46645 WDOTL=     .00000 WDOTC=    5.00200 HUMID=   1.292374
VISO  =   .022000 VIS1  =    .025000 VISL  =   2.000000 CPO   =  3.5000000 CP1   =   .4200000
CPL   = 1.0000000 LAMDA= 1000.0000 KO    =    .110000 K1    =    .035000 KL    =    .320000
PRL   = 62.500000 DENL  =   62.40000 VISI  =    .022606 CPG   =   1.359400 KG    =    .094847
PR(G)=  1.166407 DENG  =    .046463 TWALL=   619.6900 RE(G)=     51.179 AREAR=      .000
CHI   =      .000 PG    =  58.999726 BULK  =  7.4083681 DIF   =   1.043710 SC    =  1.6781968
PSURF=  4.730000 PM    =  50.569604 KM    =    .979454 QL    =1824.86060 H     =     28.111
TS    = 619.68999 TG    = 619.68999 REV   =     14.821 ACCN  =  1007.4567 ATEM  =626135.670
U     =1419.32170 DTALG=    .347-05 DTAUL=      .000

I     =        28 NTY   =          8 NLU   =         27 NLC   =         29 WP    =15.7499999
CSA   =   .044611 WDOTG=   10.39209 WDOTL=     .00000 WDOTC=    5.00200 HUMID=   1.077586
VISO  =   .022000 VIS1  =    .025000 VISL  =   2.000000 CPO   =  3.5000000 CP1   =   .4200000
CPL   = 1.0000000 LAMDA= 1000.0000 KO    =    .110000 K1    =    .035000 KL    =    .320000
PRL   = 62.500000 DENL  =   62.40000 VISI  =    .022606 CPG   =   1.359400 KG    =    .094847
PR(G)=  1.166407 DENG  =    .046463 TWALL=   619.6900 RE(G)=     51.179 AREAR=      .000
CHI   =      .000 PG    =  58.999635 BULK  =  6.3087813 DIF   =   1.043712 SC    =  1.6781968
PSURF=  4.730000 PM    =  50.569515 KM    =    .978253 QL    =1074.35670 H     =     28.111
TS    = 619.68999 TG    = 619.68999 REV   =     13.432 ACCN  =  1007.4550 ATEM  =625384.120
U     =1419.32170 DTALG=    .362-05 DTAUL=      .000
```


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```
I     =        29 NTY  =          7 NLL  =        28 NLD  =          0 WP  =15.7499999
CSA   =   .046611 XDOTG=    9.76758 WDOTL=      .00000 WDCTO=    5.00200 HUMID=    .952735
VISO  =   .022000 VIS1 =    .025000 VISL =   2.000000 CPP  =  3.5000000 CP1  =    .4200000
CPL   = 1.0000000 LAMDA= 1000.0000 KO    =    .110000 K1   =    .035000 KL   =    .320000
PRL   = 62.500000 DENL =   62.40000 VISI =    .022606 CPS  =   1.359400 KG   =    .094847
PR(G) =  1.166407 DENG =    .046463 TWALL=  619.69000 RE(G)=     51.179 AREAR=      .000
CHI   =      .000 PG   =  58.999544 BULK = 5.6477850 DIF  =   1.043713 SC   =  1.6781966
PSURF =  4.730000 PM   =  50.569435 KM   =    .978199 GL   = 624.51598 H    =     28.111
TS    = 619.68999 TG   =  619.68999 REV  =     12.625 ACON =    19.5214 ATEM = 12721.757
U     =1419.32170 DTALG=   .372-05 DTAUL=       .000
```

TUBE LUMP CHECK OUT PRINTING

I	NDL	TI AB USUM	TD G UTSUM	CONI ACON(NDL) GA	COND ATEM(NDL) GRA	U ACON(I)	F ATEM(I)	DTAU
1	2	619.68999000 .00000000 29.22230700	619.68999000 .00000000 18108.77100000	96.00000000 988.02371000 .00000000	96.00000000 612268.40000000 .00000000	.09019034 29.22230700	.91999999 18108.77100000	.00055644
2	3	619.68999000 .00000000 992.84298000	619.68999000 .00000000 615254.86000000	96.00000000 992.75281000 .00000000	96.00000000 615198.98000000 .00000000	4.81927710 992.84298000	.91999999 615254.86000000	.00002943
3	4	619.68999000 .00000000 997.57209000	619.68999000 .00000000 618185.43000000	96.00000000 992.75281000 .00000000	96.00000000 615198.98000000 .00000000	4.81927710 997.57209000	.91999999 618185.43000000	.00002929
4	5	619.68999000 .00000000 993.92411000	619.68999000 .00000000 615924.82000000	96.00000000 23.80895600 .00000000	96.00000000 14754.17210000 .00000000	1.17130308 993.92411000	.91999999 615924.82000000	.00002940
5	6	619.68999000 .00000000 23.89914600	619.68999000 .00000000 14810.06210000	96.00000000 1976.22370000 .00000000	96.00000000 1224646.00000000 .00000000	.09019034 23.89914600	.91999999 14810.06210000	.00068062
6	7	619.68999000 .00000000 1981.04290000	619.68999000 .00000000 1227632.50000000	96.00000000 1980.95280000 .00000000	96.00000000 1227576.60000000 .00000000	4.81927710 1981.04290000	.91999999 1227632.50000000	.00001475
7	8	619.68999000 .00000000 1985.77200000	619.68999000 .00000000 1230563.00000000	96.00000000 1980.95280000 .00000000	96.00000000 1227576.60000000 .00000000	4.81927710 1985.77200000	.91999999 1230563.00000000	.00001472

8	9	619.68999000 .00000000 1982.12410000	619.68999000 .00000000 1228302.40000000	96.00000000 21.44055100 .00000000	96.00000000 13266.49540000 .00000000	1.17130304 1982.12410000	.91999999 1228302.40000000	.00001474
9	10	619.68999000 .00000000 21.45766200	619.68999000 .00000000 13297.09890000	96.00000000 88.82224000 .00000000	96.00000000 55042.25400000 .00000000	.01711111 21.45766200	.91999999 13297.09890000	.00075896
10	11	619.68999000 .00000000 104.83250600	619.68999000 .00000000 64963.65500000	96.00000000 86.61499900 .00000000	96.00000000 53674.44800000 .00000000	15.99999980 104.83250600	.91999999 64963.65500000	.00077582
11	12	619.68999000 .00000000 102.62526400	619.68999000 .00000000 63595.85000000	96.00000000 86.20235400 .00000000	96.00000000 53418.55100000 .00000000	15.99999980 102.62526400	.91999999 63595.85000000	.00079251
12	13	619.68999000 .00000000 102.21231900	619.68999000 .00000000 63339.95200000	96.00000000 86.12461200 .00000000	96.00000000 53370.56000000 .00000000	15.99999980 102.21231900	.91999999 63339.95200000	.00079571
13	0	619.68999000 .00000000 102.12461100	619.68999000 .00000000 63285.60000000	96.00000000 102.12461100 .00000000	96.00000000 63285.60000000 .00000000	15.99999980 102.12461100	.91999999 63285.60000000	.00079639
14	15	619.68999000 .00000000 17.27063000	619.68999000 .00000000 10702.43660000	96.00000000 17.27527400 .00000000	96.00000000 10705.31460000 .00000000	.05133333 17.27063000	.91999999 10702.43660000	.00094164
15	0	619.68999000 .00000000 17.27527400	619.68999000 .00000000 10705.31460000	96.00000000 17.27527400 .00000000	96.00000000 10705.31460000 .00000000	.05133333 17.27527400	.91999999 10705.31460000	.00094159
16	17	619.68999000 .00000000 111.88531600	619.68999000 .00000000 69334.20500000	96.00000000 87.86963100 .00000000	96.00000000 54451.93100000 .00000000	15.99999980 111.88531600	.91999999 69334.20500000	.00072692
17	18	619.68999000 .00000000 103.86674000	619.68999000 .00000000 64377.57400000	96.00000000 17.48777900 .00000000	96.00000000 10837.00140000 .00000000	15.99999980 103.86674000	.91999999 64377.57400000	.00078268
18	0	619.68999000 .00000000 17.48777900	619.68999000 .00000000 10837.00140000	96.00000000 17.48777900 .00000000	96.00000000 10837.00140000 .00000000	15.99999980 17.48777900	.91999999 10837.00140000	.00093015
19	0	619.68999000	619.68999000	96.00000000	96.00000000	15.99999980	.91999999	

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		.00000000 29.13211700	.00000000 18052.86100000	17.48777900 .00000000	10837.00140000 .00000000	29.13211700	18052.88100000	.00055836
20	0	619.68999000 .00000000 22.36116300	619.68999000 .00000000 13856.96900000	96.00000000 17.48777900 .00000000	96.00000000 10837.00140000 .00000000	15.99999980 22.36116300	.91999999 13856.96900000	.00072743
21	22	619.68999000 .00000000 992.75281000	619.68999000 .00000000 615198.98000000	96.00000000 992.75281000 .00000000	96.00000000 615198.98000000 .00000000	4.81927710 992.75281000	.91999999 615198.98000000	.00012944
22	23	619.68999000 .00000000 997.57208000	619.68999000 .00000000 618185.43000000	96.00000000 992.75279000 .00000000	96.00000000 615198.97000000 .00000000	4.81927710 997.57208000	.91999999 618185.43000000	.00012929
23	0	619.68999000 .00000000 992.75279000	619.68999000 .00000000 615198.97000000	96.00000000 992.75279000 .00000000	96.00000000 615198.97000000 .00000000	4.81927710 992.75279000	.91999999 615198.97000000	.00012944
24	0	619.68999000 .00000000 29.13211700	619.68999000 .00000000 18052.88100000	96.00000000 992.75279000 .00000000	96.00000000 615198.97000000 .00000000	4.81927710 29.13211700	.91999999 18052.88100000	.00055836
25	0	619.68999000 .00000000 19.66282700	619.68999000 .00000000 15293.54750000	100.00000000 992.75279000 .00000000	96.00000000 615198.97000000 .00000000	4.81927710 19.66282700	1.00000000 15293.54750000	.00012888
26	27	619.68999000 .00000000 1015.92968000	619.68999000 .00000000 632670.13000000	100.00000000 1015.76999000 .00000000	100.00000000 631299.75000000 .00000000	8.33333340 1015.92968000	1.00000000 632670.13000000	.00001588
27	28	619.68999000 .00000000 1024.12330000	619.68999000 .00000000 636463.82000000	100.00000000 1015.76830000 .00000000	100.00000000 630548.20000000 .00000000	8.33333340 1024.12330000	1.00000000 636463.82000000	.00001549
28	29	619.68999000 .00000000 1024.12160000	619.68999000 .00000000 635712.27000000	100.00000000 27.85477300 .00000000	100.00000000 17885.84000000 .00000000	8.33333340 1024.12160000	1.00000000 635712.27000000	.00001564
29	0	619.68999000 .00000000 27.85477300	619.68999000 .00000000 17885.84000000	100.00000000 27.85477300 .00000000	100.00000000 17885.84000000 .00000000	8.33333340 27.85477300	1.00000000 17885.84000000	.00014849
30	0	619.68999000 .00000000 102.76337900	619.68999000 .00000000 63681.43800000	100.00000000 27.85477300 .00000000	100.00000000 17885.84000000 .00000000	8.33333340 102.76337900	1.00000000 63681.43800000	.00017131

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31	C	619.68999000	619.6899900	100.0000000	100.0000000	8.3333334	1.0000000	
		.00330000	.0000000	27.654773	17685.8400000	19.6628779	15293.5440000	.0010288
		19.66282700	15293.5440000	.0000000	.00000000			

I	ACCN	ATEM	DTAU
1	29.7223070	10108.7710000	.0005566
2	992.8429800	615254.0600000	.0000294
3	997.5720500	616165.4300000	.0000293
4	993.9241100	615924.8200000	.0000294
5	23.8991460	14619.6621000	.0006606
6	1981.0429000	1227632.5000000	.0000148
7	1985.7720000	1230563.0000000	.0000147
8	1982.1241000	1228302.4000000	.0000147
9	21.4576670	13297.0949000	.0007569
10	104.8325060	64963.6550000	.0007758
11	102.6252640	63595.6560000	.0007925
12	102.2123190	63339.9520000	.0007957
13	102.1246110	63265.6600000	.0007964
14	17.2706300	10702.4366000	.0009416
15	17.2752740	10705.3146000	.0009416
	111.8853650	69334.2050000	.0007269
17	103.8867400	64377.5740000	.0007829
18	17.4877790	10837.0014000	.0009301
19	29.1321170	18052.6610000	.0005564
20	22.3611630	13856.9890000	.0007274
21	992.7528100	615198.9800000	.0000294
22	997.5720800	618185.4300000	.0000293
23	992.7527900	615198.9700000	.0000294
24	29.1321170	18052.6610000	.0005584

25	19.6628270	15293.5475000	.0001029
26	1015.9296800	632670.1300000	.0000151
27	1024.1233000	636463.9200000	.0000154
28	1024.1216000	635712.2700000	.0000156
29	27.8547730	17685.8400000	.0001485
30	102.7633790	63681.4380000	.0001713
31	19.6628270	15293.5446000	.0001029

STRUCTURE LUMP CHECK OUT PRINTING

I	Q CA	CONI GR	WEIGHT ACON	SP. HEAT ATEM	USUM DTAU	UTSUM
1	.0000000 .0000000	96.0000000 .9468853	1.7604166 16.9468840	.2000000 9915.0397000	15.9999998 .0186981	9915.0397000
2	.0000000 .0000000	96.0000000 .9468853	1.7604166 16.9468840	.2000000 9915.0397000	15.9999998 .0186981	9915.0397000
3	.0000000 .0000000	96.0000000 .9468853	1.7604166 16.9468840	.2000000 9915.0397000	15.9999998 .0186981	9915.0397000
4	.0000000 .0000000	96.0000000 .9468853	1.7604166 16.9468840	.2000000 9915.0397000	15.9999998 .0186981	9915.0397000
5	.0000000 .0000000	96.0000000 .9468853	1.7604166 16.9468840	.2000000 9915.0397000	15.9999998 .0186981	9915.0397000
6	.0000000 .0000000	96.0000000 .9468853	1.7604166 16.9468840	.2000000 9915.0397000	15.9999998 .0186981	9915.0397000

I	ACON	ATEM	DTAU
1	16.9468840	9915.0397000	.0186981
2	16.9468840	9915.0397000	.0186981
3	16.9468840	9915.0397000	.0186981
4	16.9468840	9915.0397000	.0186981
5	16.9468840	9915.0397000	.0186981

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6        16.9468840        9915.0397000        .0186981


CHECK OUT PRINTING FOR PRESSURE DROP SUBROUTINE


I   =        1 NPT  =        1 NTB  =        1 FREZ =        0 DEN  = 70.000000 LI  =   6.00000
FLL =  1.00000 CSA  =   .00136 WP   =   .13083 RE   = 98.15846 F    =    .16300 FR  =  69.34895
FR  =  4.83848 DELF =   .61762 SH   =   .75000 DPTB =  5.45610

I   =        2 NPT  =        6 NTB  =        1 FREZ =        0 DEN  = 70.000000 LI  =   6.00000
FLL =   .13833 CSA  =   .04861 WP   = 15.75000 RE   =   .81539 F    =  19.62250 FR  =  69.34895
FR  =   .21293 DELF =   .00048 SH   =   .75000 DPTB =  5.66952

I   =        3 NPT  =        6 NTB  =        1 FREZ =        0 DEN  = 70.000000 LI  =   6.00000
FLL =   .13833 CSA  =   .04861 WP   = 15.75000 RE   =   .81539 F    =  19.62250 FR  =  69.34895
FR  =   .21293 DELF =   .00048 SH   =   .75000 DPTB =  5.88293

I   =        4 NPT  =        6 NTB  =        1 FREZ =        0 DEN  = 70.000000 LI  =   6.00000
FLL =   .13833 CSA  =   .04861 WP   = 15.75000 RE   =   .81539 F    =  19.62250 FR  =  69.34895
FR  =   .21293 DELF =   .00048 SH   =   .75000 DPTB =  6.09634

I   =        5 NPT  =        1 NTB  =        1 FREZ =        0 DEN  = 70.000000 LI  =   6.00000
FLL =  1.00000 CSA  =   .00136 WP   =   .13083 RE   = 98.15846 F    =    .16300 FR  =  69.34895
FR  =  4.83848 DELF =   .61762 SH   =   .75000 DPTB = 11.55245

I   =        6 NPT  =        3 NTB  =        1 FREZ =        0 DEN  = 70.000000 LI  =   6.00000
FLL =   .13833 CSA  =   .04861 WP   = 15.75000 RE   =   .81539 F    =  19.62250 FR  =  69.34895
FR  =   .21293 DELF =   .00048 SH   =   .75000 DPTB = 11.76586

I   =        7 NPT  =        3 NTB  =        1 FREZ =        0 DEN  = 70.000000 LI  =   6.00000
FLL =   .13833 CSA  =   .04861 WP   = 15.75000 RE   =   .81539 F    =  19.62250 FR  =  69.34895
FR  =   .21293 DELF =   .00048 SH   =   .75000 DPTB = 11.97927

I   =        8 NPT  =        3 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =   6.00000
FLL =   .13833 CSA  =   .04861 WP   = 15.75000 RE   =   .81539 F    =  19.62250 FR  =  69.34895
FR  =   .21293 DELF =   .00048 SH   =   .75000 DPTB = 12.19268

I   =        9 NPT  =        1 NTB  =        1 FREZ =        0 DEN  = 70.000000 UI  =   6.00000
FLL =  1.00000 CSA  =   .00136 WP   =   .13083 RE   = 98.15846 F    =    .16300 FR  =  69.34895
FR  =  4.83848 DELF =   .61762 SH   =   .75000 DPTB = 17.64879

I   =       10 NPT  =        2 NTB  =        1 FREZ =        0 DEN  = 70.000000 LI  =   6.00000
FLL =  5.00000 CSA  =   .00136 WP   =   .13083 RE   = 98.15846 F    =    .16300 FR  =  69.34895
FR  = 24.19241 DELF =   .61762 SH   =   .75000 DPTB = 42.45862

I   =       11 NPT  =        2 NTB  =        1 FREZ =        0 DEN  = 70.000000 LI  =   6.00000
FLL =  5.00000 CSA  =   .00136 WP   =   .13083 RE   = 98.15846 F    =    .16300 FR  =  69.34895
FR  = 24.19241 DELF =   .61762 SH   =   .75000 DPTB = 67.26885
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```
I   =       12 NPT  =        2 NTB  =        1 FREZ =         0 DEN  = 70.000000 UI  =  6.00000
FLL =  5.00000 CSA  =   .00136 WP   =   .13083 RE   =  98.15846 F    =    .16300 FR  = 69.34895
FR  = 24.19241 DELP =   .61762 SH   =   .75000 DPTB =  92.07889

I   =       13 NPT  =        2 NTB  =        1 FREZ =         0 DEN  = 70.000000 UI  =  6.00000
FLL =  5.00000 CSA  =   .00136 WP   =   .13083 RE   =  98.15846 F    =    .16300 FR  = 69.34895
FR  = 24.19241 DELP =   .61762 SH   =   .75000 DPTB = 116.88892

I   =       16 NPT  =        2 NTB  =        2 FREZ =         0 DEN  = 70.000000 UI  =  6.00000
FLL =  5.00000 CSA  =   .00136 WP   =   .13083 RE   =  97.06524 F    =    .16484 FR  = 68.57659
FR  = 23.92297 DELP =   .60394 SH   =   .75000 DPTB =  24.52691

I   =       17 NPT  =        2 NTB  =        2 FREZ =         0 DEN  = 70.000000 UI  =  6.00000
FLL =  5.00000 CSA  =   .00136 WP   =   .13083 RE   =  97.06524 F    =    .16484 FR  = 68.57659
FR  = 23.92297 DELP =   .60394 SH   =   .75000 DPTB =  49.05383

I   =       18 NPT  =        5 NTB  =        2 FREZ =         0 DEN  = 70.000000 UI  =  6.00000
FLL =  1.00000 CSA  =   .00136 WP   =   .13083 RE   =  97.06524 F    =    .16484 FR  = 68.57659
FR  =  4.78459 DELP =   .60394 SH   =   .75000 DPTB =  54.44236

I   =       14 NPT  =        1 NTB  =        3 FREZ =         0 DEN  = 70.000000 UI  =  6.00000
FLL =  1.00000 CSA  =   .00136 WP   =   .13083 RE   =   1.09322 F    =  14.63563 FR  =   .77236
FR  =   .05389 DELP =   .00008 SH   =   .75000 DPTB =    .05396

I   =       15 NPT  =        4 NTB  =        3 FREZ =         0 DEN  = 70.000000 UI  =  6.00000
FLL =999.99999 CSA  =   .00136 WP   =   .13083 RE   =   1.09322 F    =  14.63563 FR  =   .77236
FR  = 53.88776 DELP =   .00008 SH   =   .75000 DPTB =  53.94160

I   =       19 NPT  =        1 NTB  =        4 FREZ =         0 DEN  = 70.000000 UI  =  6.00000
FLL =  1.00000 CSA  =   .00136 WP   =   .13083 RE   =  98.15846 F    =    .16300 FR  = 69.34895
FR  =  4.83848 DELP =   .61762 SH   =   .75000 DPTB =   5.45610

I   =       21 NPT  =        6 NTB  =        5 FREZ =         0 DEN  = 70.000000 UI  =  6.00000
FLL =   .13833 CSA  =   .04861 WP   = 15.75000 RE   =    .49347 F    =  32.42349 FR  = 41.96958
FR  =   .12886 DELP =   .00016 SH   =   .75000 DPTB =    .12904

I   =       22 NPT  =        6 NTB  =        5 FREZ =         0 DEN  = 70.000000 UI  =  6.00000
FLL =   .13833 CSA  =   .04861 WP   = 15.75000 RE   =    .49347 F    =  32.42349 FR  = 41.96958
FR  =   .12886 DELP =   .00016 SH   =   .75000 DPTB =    .25808

I   =       23 NPT  =        6 NTB  =        5 FREZ =         0 DEN  = 70.000000 UI  =  6.00000
FLL =   .13833 CSA  =   .04861 WP   = 15.75000 RE   =    .49347 F    =  32.42349 FR  = 41.96958
FR  =   .12886 DELP =   .00018 SH   =   .75000 DPTB =    .38712

I   =       20 NPT  =        1 NTB  =        6 FREZ =         0 DEN  = 70.000000 UI  =  6.00000
FLL =  1.00000 CSA  =   .00136 WP   =   .13083 RE   =  36.75354 F    =    .41237 FR  = 27.37930
FR  =  1.91026 DELP =   .09627 SH   =   .75000 DPTB =   2.00653

I   =       24 NPT  =        1 NTB  =        7 FREZ =         0 DEN  = 70.000000 UI  =  6.00000
FLL =  1.00000 CSA  =   .00136 WP   =   .13083 RE   =  98.15846 F    =    .16300 FR  = 69.34895
FR  =  4.83848 DELP =   .61762 SH   =   .75000 DPTB =   5.45610

    VALVES

    OUTPUT FOR VALVE    2 AFTER ITERATION    1
    WFRCT =       .01114
    TOUT =  160.00000     TMIX =  160.00000
```


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```
OUTPUT FOR VALVE    3 AFTER ITERATION    1
RFRCTN =       .60519
TOUT =  160.00000     TMIX =  160.00000

I    =         1 NPT  =         1 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =    .13083 RE   =  98.15922 F    =    .16300 FR  =  69.34949
FR   =   4.83852 DELP =    .61763 SH   =    .75000 DPTB =   5.45615

I    =         2 NPT  =         6 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =    .81540 F    =  19.62235 FR  =  69.34949
FR   =    .21293 DELP =    .00048 SH   =    .75000 DPTB =   5.66957

I    =         3 NPT  =         6 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =    .81540 F    =  19.62235 FR  =  69.34949
FR   =    .21293 DELP =    .00048 SH   =    .75000 DPTB =   5.86298

I    =         4 NPT  =         6 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =    .81540 F    =  19.62235 FR  =  69.34949
FR   =    .21293 DELP =    .00048 SH   =    .75000 DPTB =   6.09639

I    =         5 NPT  =         1 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =    .13083 RE   =  98.15922 F    =    .16300 FR  =  69.34949
FR   =   4.83852 DELP =    .61763 SH   =    .75000 DPTB =  11.55254

I    =         6 NPT  =         3 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =    .81540 F    =  19.62235 FR  =  69.34949
FR   =    .21293 DELP =    .00048 SH   =    .75000 DPTB =  11.76596

I    =         7 NPT  =         3 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =    .81540 F    =  19.62235 FR  =  69.34949
FR   =    .21293 DELP =    .00048 SH   =    .75000 DPTB =  11.97937

I    =         8 NPT  =         3 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =    .13833 CSA  =    .04861 WP   =  15.75000 RE   =    .81540 F    =  19.62235 FR  =  69.34949
FR   =    .21293 DELP =    .00048 SH   =    .75000 DPTB =  12.19279

I    =         9 NPT  =         1 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =   1.00000 CSA  =    .00136 WP   =    .13083 RE   =  98.15922 F    =    .16300 FR  =  69.34949
FR   =   4.83852 DELP =    .61763 SH   =    .75000 DPTB =  17.64694

I    =        10 NPT  =         2 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =   5.00000 CSA  =    .00136 WP   =    .13083 RE   =  98.15922 F    =    .16300 FR  =  69.34949
FR   =  24.19260 DELP =    .61763 SH   =    .75000 DPTB =  42.45917

I    =        11 NPT  =         2 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =   5.00000 CSA  =    .00136 WP   =    .13083 RE   =  98.15922 F    =    .16300 FR  =  69.34949
FR   =  24.19260 DELP =    .61763 SH   =    .75000 DPTB =  67.26940

I    =        12 NPT  =         2 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =   5.00000 CSA  =    .00136 WP   =    .13083 RE   =  98.15922 F    =    .16300 FR  =  69.34949
FR   =  24.19260 DELP =    .61763 SH   =    .75000 DPTB =  92.07963

I    =        13 NPT  =         2 NTB  =         1 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =   5.00000 CSA  =    .00136 WP   =    .13083 RE   =  98.15922 F    =    .16300 FR  =  69.34949
FR   =  24.19260 DELP =    .61763 SH   =    .75000 DPTB = 116.88986

I    =        16 NPT  =         2 NTB  =         2 FREZ =         0 DEN  = 70.000000 UI  =   6.00000
FLL  =   5.00000 CSA  =    .00136 WP   =    .13083 RE   =  97.06599 F    =    .16484 FR  =  68.57712
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FR   =  23.92316 DELP =     .60395 SH   =      .75000 DPTB =  24.52711

I    =        17 NPT  =          2 NTB  =           2 FREZ =           0 DEN  = 70.000000 UI   =    6.00000
FLL  =   5.00000 CSA  =     .00136 WP   =      .13083 RE   =    97.06599 F    =    .16484 FR   =   68.57712
FR   =  23.92316 DELP =     .60395 SH   =      .75000 DPTB =    49.05422

I    =        18 NPT  =          5 NTB  =           2 FREZ =           0 DEN  = 70.000000 UI   =    6.00000
FLL  =   1.00000 CSA  =     .00136 WP   =      .13083 RE   =    97.06599 F    =    .16484 FR   =   68.57712
FR   =   4.78463 DELP =     .60395 SH   =      .75000 DPTB =    54.44280

I    =        14 NPT  =          1 NTB  =           3 FREZ =           0 DEN  = 70.000000 UI   =    6.00000
FLL  =   1.00000 CSA  =     .00136 WP   =      .13083 RE   =     1.09323 F    =  14.63551 FR   =     .77237
FR   =    .05389 DELP =     .00006 SH   =      .75000 DPTB =      .05396

I    =        15 NPT  =          4 NTB  =           3 FREZ =           0 DEN  = 70.000000 UI   =    6.00000
FLL  = 999.99999 CSA  =     .00136 WP   =      .13083 RE   =     1.09323 F    =  14.63551 FR   =     .77237
FR   =  53.83817 DELP =     .00006 SH   =      .75000 DPTB =    53.94221

I    =        19 NPT  =          1 NTB  =           4 FREZ =           0 DEN  = 70.000000 UI   =    6.00000
FLL  =   1.00000 CSA  =     .00136 WP   =      .13083 RE   =    98.15922 F    =    .16300 FR   =   69.34949
FR   =   4.83852 DELP =     .01763 SH   =      .75000 DPTB =     5.45615

I    =        21 NPT  =          6 NTB  =           5 FREZ =           0 DEN  = 70.000000 UI   =    6.00000
FLL  =    .13833 CSA  =     .04861 WP   =    15.75000 RE   =      .49347 F    =  32.42323 FR   =   41.96990
FR   =    .12866 DELP =     .00016 SH   =      .75000 DPTB =      .12904

I    =        22 NPT  =          6 NTB  =           5 FREZ =           0 DEN  = 70.000000 UI   =    6.00000
FLL  =    .13833 CSA  =     .04861 WP   =    15.75000 RE   =      .49347 F    =  32.42323 FR   =   41.96995
FR   =    .12886 DELP =     .00018 SH   =      .75000 DPTB =      .25806

I    =        23 NPT  =          6 NTB  =           5 FREZ =           0 DEN  = 70.000000 UI   =    6.00000
FLL  =    .13833 CSA  =     .04861 WP   =    15.75000 RE   =      .49347 F    =  32.42323 FR   =   41.9699[illegible]
FR   =    .12886 DELP =     .00016 SH   =      .75000 DPTB =      .38712

I    =        20 NPT  =          1 NTB  =           6 FREZ =           0 DEN  = 70.000000 UI   =    6.00000
FLL  =   1.00000 CSA  =     .00136 WP   =      .13083 RE   =    38.75394 F    =    .41286 FR   =   27.37359
FR   =   1.91028 DELP =     .09627 SH   =      .75000 DPTB =     2.00655

I    =        24 NPT  =          1 NTB  =           7 FREZ =           0 DEN  = 70.000000 UI   =    6.00000
FLL  =   1.00000 CSA  =     .00136 WP   =      .13083 RE   =    98.15922 F    =    .16300 FR   =   69.34949
FR   =   4.83852 DELP =     .01763 SH   =      .75000 DPTB =     5.45615

        DPRAD =        295.66520

I    =        25 NTUBE=          8 FLL  =      .04417 WDOTG= 13.291309 WDOTL=     .06217
RE(L)=    .00219 PG   =   59.00000 PUF  =     1.03175 DELP =      .00009

I    =        31 NTUBE=          9 FLL  =      .04417 WDOTG= 13.291312 WDOTL=     .06217
RE(L)=    .00219 PG   =   58.99991 PUF  =     1.03291 DELP =      .00009

I    =        30 NTUBE=         10 FLL  =      .04417 WDOTG=   .000000 WDOTL=     .00000
RE(L)=    .00000 PG   =     .00000 PUF  =     1.00000 DELP =      .00000

I    =        26 NTUBE=         11 FLL  =      .04417 WDOTG= 13.291315 WDOTL=     .06217
RE(L)=    .00219 PG   =   58.99982 PUF  =     1.03291 DELP =      .00009

I    =        27 NTUBE=         11 FLL  =      .04417 WDOTG= 11.466455 WDOTL=     .05450
RE(L)=    .00129 PG   =   58.99982 PUF  =     1.02535 DELP =      .00008
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I     =        25 NTUBE=         11 FLL   =    .04417 *DCTG= 10.392098 *DOTL=    .02149
RE(L)=     .00074 PG    =  56.99973 PUF   =   1.01966 DELP =      .00008

I     =        29 NTUBE=         11 FLL   =    .04417 *DCTG=  9.767582 *DOTL=    .01249
RE(L)=     .00044 PG    =  56.99965 PUF   =   1.01508 DELP =      .00008

      VALVES

      OUTPUT FOR VALVE     1 AFTER ITERATION     1
      RFRCTY  =     1.00000
      TOUT  =  160.00000      TMIX  =   160.00000

I     =        25 NTUBE=          6 FLL   =    .04417 *DCTG= 13.291309 *DOTL=    .06217
RE(L)=     .00219 PG    =  59.00000 PUF   =   1.03175 DELP =      .00009

I     =        31 NTUBE=          9 FLL   =    .04417 *DCTG= 13.291312 *DOTL=    .06217
RE(L)=     .00219 PG    =  56.99991 PUF   =   1.03005 DELP =      .00010

I     =        30 NTUBE=         10 FLL   =    .04417 *DCTG=    .00000 *DOTL=    .00000
RE(L)=     .00000 PG    =    .00000 PUF   =   1.00000 DELP =      .00000

I     =        26 NTUBE=         11 FLL   =    .04417 *DCTG= 13.291315 *DOTL=    .06217
RE(L)=     .00219 PG    =  56.99983 PUF   =   1.03005 DELP =      .00010

I     =        27 NTUBE=         11 FLL   =    .04417 *DCTG= 11.466454 *DOTL=    .03659
RE(L)=     .00129 PG    =  56.99983 PUF   =   1.02337 DELP =      .00010

I     =        28 NTUBE=         11 FLL   =    .04417 *DCTG= 10.392096 *DOTL=    .02149
RE(L)=     .00074 PG    =  56.99970 PUF   =   1.01809 DELP =      .00010

I     =        29 NTUBE=         11 FLL   =    .04417 *DCTG=  9.767582 *DOTL=    .01249
RE(L)=     .[illegible]44 PG    =  56.99960 PUF   =   1.[illegible]306 DELP =      .00010

      OPRAD =          .58996
```


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```
PPD SECONDARY LOOP MOCK UP FOR PARTIAL CHECK OUT          2-PHASE
                    DATA SET    1

TIME=   .00010 HOURS   TIME INC.= .0001000   ****** LUMP    0
COMPUTER TIME=     .010 MINUTES   ROUTINE ITERATIONS=    1

FLOW RATES (LBS./HR.) IN SYSTEM     1
     69.34948800   66.57712100    .77236786   69.34948800   41.96990200
     27.37958900   69.34948800

FLOW RATES (LBS./HR.) IN SYSTEM     2
     16.39999800   16.39999800   -.00000000   16.39999800

PRESSURE DROPS (X1000.) (LBS./SQ. IN.) IN SYSTEM    1
    116.88985500   54.44279800   53.94221400    5.45615050    .38712479
      2.00654750    5.45615050

PRESSURE DROPS (X1000.) (LBS./SQ. IN.) IN SYSTEM    2
       .00263409     .10316443     .00000000     .39416210

POWER REQUIREMENT (X 1000.)   70582.984000 FT.LB./HR.

TOTAL HEAT REJECTED              .000000 BTU/HR. IN SYSTEM    1

TOTAL HEAT REJECTED          6863.629100 BTU/HR. IN SYSTEM    2

WEIGHT                        119.367389 LBS.
```


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PPU SECONDARY LOOP MOCK UP FOR PARTIAL CHECK OUT 2-PHASE
DATA SET 1

LUMP NUMBER	GAS PRESSURE	GAS TEMPERATURE	LIQUID TEMPERATURE	LIQUID FLOW RATE
25	59.000000	189.711	160.000	.062174
26	58.999804	160.000	160.000	.062174
27	58.999701	160.000	160.000	.036497
28	58.999602	160.000	160.000	.021487
29	58.999506	160.000	160.000	.012490
30	58.999909	160.000	160.000	.000000
31	58.999907	160.000	160.000	.062174

FLUID LUMP TEMPERATURES (DEGREES F.)

160.00000	160.00000	160.00000	160.00000	160.00000
160.00000	160.00000	160.00000	160.00000	160.00000
160.00000	160.00000	160.00000	160.00000	160.00000
160.00000	160.00000	160.00000	160.00000	160.00000
160.00000	160.00000	160.00000	160.00000	169.71141
159.99999	160.00000	160.00000	160.00000	160.00000
160.00000				

TUBE LUMP TEMPERATURES (DEGREES F.)

160.00000	160.00000	160.00000	160.00000	160.00000
160.00000	160.00000	160.00000	160.00000	160.00000
160.00000	160.00000	160.00000	160.00000	160.00000
160.00000	160.00000	160.00000	160.00000	160.00000
160.00000	160.00000	160.00000	160.00000	175.89294
162.39666	161.43657	160.85914	163.19279	160.00000
175.89293				

STRUCTURES LUMP TEMPERATURES (DEGREES F.)

159.83334	159.83334	159.83334	159.83334	159.83334
159.83334				

```
PPD SECONDARY LOOP PCCK-UP FOR PARTIAL CHECKOUT
                    DATA SET    1

TIME=   .51059 HOURS   TIME INC.= .0001000   ****** LUMP    0
COMPUTER TIME=   13.920 MINUTES   ROUTINE ITERATIONS=  5106

FLOW RATES (LBS./HR.) IN SYSTEM    1
     69.34195100   68.56258700    .77936479   69.34195100     .00000000
     69.34195100   69.34195100

FLOW RATES (LBS./HR.) IN SYSTEM    2
     16.39999700   16.39999700    .00000000   16.39999700

PRESSURE DROPS (X1000.) (LBS./SQ. IN.) IN SYSTEM    1
    116.87668100   54.43087400   54.43088200    5.45549040     .00000000
      5.45549040    5.45549040

PRESSURE DROPS (X1000.) (LBS./SQ. IN.) IN SYSTEM    2
       .10139398     .10139415    .00000000      .42870714

POWER REQUIREMENT (X 1000.)   62897.675000 FT.LB./HR.

TOTAL HEAT REJECTED              3.046463 BTU/HR. IN SYSTEM    1

TOTAL HEAT REJECTED           2681.117600 BTU/HR. IN SYSTEM    2

WEIGHT                       119.367389 LBS.
```

PPD SECONDARY LOOP MOCK-UP FOR PARTIAL CHECKOUT
DATA SET 1

LUMP NUMBER	GAS PRESSURE	GAS TEMPERATURE	LIQUID TEMPERATURE	LIQUID FLOW RATE
25	59.000000	229.000	229.000	.000000
26	58.999798	215.865	201.027	.067154
27	58.999696	206.420	195.863	.655771
28	58.999569	195.456	183.723	2.062805
29	58.999480	194.230	192.922	2.147138
30	56.999969	160.000	160.000	.000000
31	58.999898	229.000	229.000	.000000

FLUID LUMP TEMPERATURES (DEGREES F.)

144.35713	180.15617	194.30790	[illegible].34366	200.34265
200.33163	200.31627	200.29625	20[illegible].28988	189.75253
179.75570	170.25306	161.20680	159.53583	159.99365
152.45924	144.13498	144.13017	144.30521	144.30193
200.29537	200.31558	200.33112	144.29855	228.99992
215.86536	206.41993	195.45595	194.23013	160.00000
228.99985				

TUBE LUMP TEMPERATURES (DEGREES F.)

144.46656	180.21534	194.26879	200.31418	200.34104
200.33116	200.31565	200.29546	200.27622	183.56511
173.75672	164.52419	15[illegible].74916	159.52545	159.99217
147.77316	139.27030	144.12345	144.30404	144.30[illegible]74
200.29531	200.31553	200.33106	144.29733	228.99985
200.66147	195.05336	182.03472	192.83051	160.00000
228.99978				

STRUCTURES LUMP TEMPERATURES (DEGREES F.)

149.34792	141.29114	133.66943	126.37746	119.76882
112.55742				

TRANSIENT PROBLEM HAS REACHED STEADY STATE

STEADY STATE REACHED, IN TRANSIENT STEP-AHEAD CHECK, NO FUTURE
HANGE NOTED IN ANY TIME DEPENDENT TABLE SO PROBLEM WILL BE TERMINATED.

TRANSIENT PROBLEM COMPLETED.

TYPE = 1 RE = 98.14855 PR = 54.00000 COND.= .30000 DEN. = 70.00000
SP.HT= .75000 V.BLK= 6.00000 V-ALL= 6.00000 WEIGHT= .9520 HEAT TRAN.COEF= 44.62654

TYPE = 6 RE = .61531 PR = 54.00000 COND.= .30000 DEN. = 70.00000
SP.HT= .75000 V.BLK= 6.00000 V-ALL= 6.00000 WEIGHT= .47072 HEAT TRAN.COEF= 44.91482

```
TYPE =         6 RE    =     .81531 PR    =  54.00000 COND.=     .30000 DEN. =  70.00000
SP.HT=    .75000 V.BLK=     6.00000 VWALL=    6.00000 WEIGH=     .47072 HEAT TRAN.COEF=  86.91492

TYPE =         6 RE    =     .81531 PR    =  54.00000 COND.=     .30000 DEN. =  70.00000
SP.HT=    .75000 V.BLK=     6.00000 VWALL=    6.00000 WEIGH=     .47072 HEAT TRAN.COEF=  86.91482

TYPE =         1 RE    =   58.14855 PR    =  54.00000 COND.=     .30000 DEN. =  70.00000
SP.HT=    .75000 V.BLK=     6.00000 VWALL=    6.00000 WEIGH=     .09528 HEAT TRAN.COEF=  34.67805

TYPE =         3 RE    =     .81531 PR    =  54.00000 COND.=     .30000 DEN. =  70.00000
SP.HT=    .75000 V.BLK=     6.00000 VWALL=    6.00000 WEIGH=     .47072 HEAT TRAN.COEF=  86.93800

TYPE =         3 RE    =     .81531 PR    =  54.00000 COND.=     .30000 DEN. =  70.00000
SP.HT=    .75000 V.BLK=     6.00000 VWALL=    6.00000 WEIGH=     .47072 HEAT TRAN.COEF=  86.93800

TYPE =         3 RE    =     .81531 PR    =  54.00000 COND.=     .30000 DEN. =  70.00000
SP.HT=    .75000 V.BLK=     6.00000 VWALL=    6.00000 WEIGH=     .47072 HEAT TRAN.COEF=  86.93800

TYPE =         1 RE    =   58.14655 PR    =  54.00000 COND.=     .30000 DEN. =  70.00000
SP.HT=    .75000 V.BLK=     6.00000 VWALL=    6.00000 WEIGH=     .09528 HEAT TRAN.COEF=  [illegible]

TYPE =         2 RE    =   58.14655 PR    =  54.00000 COND.=     .30000 DEN. =  70.00000
SP.HT=    .75000 V.BLK=     6.00000 VWALL=    6.00000 WEIGH=     .47639 HEAT TRAN.COEF=  27.20813

TYPE =         2 RE    =   58.14655 PR    =  54.00000 COND.=     .30000 DEN. =  70.00000
SP.HT=    .75000 V.BLK=     6.00000 VWALL=    6.00000 WEIGH=     .47639 HEAT TRAN.COEF=  26.53414

TYPE =         2 RE    =   58.14655 PR    =  54.00000 COND.=     .30000 DEN. =  70.00000
SP.HT=    .75000 V.BLK=     6.00000 VWALL=    6.00000 WEIGH=     .47639 HEAT TRAN.COEF=  26.40768

TYPE =         2 RE    =   58.14655 PR    =  54.00000 COND.=     .30000 DEN. =  70.00000
SP.HT=    .75000 V.BLK=     6.00000 VWALL=    6.00000 WEIGH=     .47639 HEAT TRAN.COEF=  26.35350

TYPE =         2 RE    =   57.04541 PR    =  54.00000 COND.=     .30000 DEN. =  70.00000
SP.HT=    .75000 V.BLK=     6.00000 VWALL=    6.00000 WEIGH=     .47639 HEAT TRAN.COEF=  26.37339

TYPE =         2 RE    =   57.04541 PR    =  54.00000 COND.=     .30000 DEN. =  70.00000
SP.HT=    .75000 V.BLK=     6.00000 VWALL=    6.00000 WEIGH=     .47639 HEAT TRAN.COEF=  26.51624

TYPE =         5 RE    =   57.04541 PR    =  54.00000 COND.=     .30000 DEN. =  70.00000
SP.HT=    .75000 V.BLK=     6.00000 VWALL=    6.00000 WEIGH=     .09528 HEAT TRAN.COEF=  26.76320

TYPE =         1 RE    =    1.10313 PR    =  54.00000 COND.=     .30000 DEN. =  70.00000
SP.HT=    .75000 V.BLK=     6.00000 VWALL=    6.00000 WEIGH=     .09526 HEAT TRAN.COEF=  26.37850

TYPE =         4 RE    =    1.10313 PR    =  54.00000 COND.=     .30000 DEN. =  70.00000
SP.HT=    .75000 V.BLK=     6.00000 VWALL=    6.00000 WEIGH=   95.27777 HEAT TRAN.COEF=  26.35561

TYPE =         1 RE    =   58.14856 PR    =  54.00000 COND.=     .30000 DEN. =  70.00000
SP.HT=    .75000 V.BLK=     6.00000 VWALL=    6.00000 WEIGH=     .09528 HEAT TRAN.COEF=  44.62654

TYPE =         6 RE    =     .00000 PR    =  54.00000 COND.=     .30000 DEN. =  70.00000
SP.HT=    .75000 V.BLK=     6.00000 VWALL=    6.00000 WEIGH=     .47072 HEAT TRAN.COEF= 403.57982

TYPE =         6 RE    =     .00000 PR    =  54.00000 COND.=     .30000 DEN. =  70.00000
SP.HT=    .75000 V.BLK=     6.00000 VWALL=    6.00000 WEIGH=     .47072 HEAT TRAN.COEF= 403.57982

TYPE =         6 RE    =     .00000 PR    =  54.00000 COND.=     .30000 DEN. =  70.00000
```

```
SP.HT=    .75000 V.BLK=    6.00000 VWALL=    6.00000 WEIGH=     .47072 HEAT TRAN.COEF= 403.57982

TYPE =          1 RE     =  58.14855 PR     =  54.00000 COND.=     .30000 DEN.  =  70.00000
SP.HT=    .75000 V.BLK=    6.00000 VWALL=    6.00000 WEIGH=     .09528 HEAT TRAN.COEF=  44.62654

TYPE =          1 RE     =  58.14855 PR     =  54.00000 COND.=     .30000 DEN.  =  70.00000
SP.HT=    .75000 V.BLK=    6.00000 VWALL=    6.00000 WEIGH=     .09528 HEAT TRAN.COEF=  44.62654

 DATA FOR RESTARTING THIS PROBLEM IS WRITTEN ON THE DUMP TAPE AS DATA SET NO.     1
```

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1. Dusinberre, G. M., "Heat Transfer Calculations by Finite Differences," International Textbook Company, Scranton, Pennsylvania, 1961.

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4. Lieblein, S., "Analysis of Temperature Distribution and Radiant Heat Transfer Along a Rectangular Fin," NASA TND-196, 1959.

5. Clark, T. B., "Finite Difference Methods for Heat Conduction Problems," M.S. Thesis, Southern Methodist University.

6. Chu, W H., "Transient Heat Transfer with Radiation and Convection," Memorandum enclosure to "Development of Generalized Computer Program for Radiant Heat Transfer" by D. R. Falconer and G. E. Nevill, Jr., Southwest Research Institute, San Antonio, Texas, December 1962.

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8. Sellers, J. R., Tribus, Myron, Klein, S. J., "Heat Transfer to Laminar Flow in a Round Tube or Flat Conduit - The Graetz Problem Extended," Trans, ASME, Vol. 78, 1956, pp. 441-448.

8a. Yang, K. T., "Laminar Forced Convection of Liquids in Tubes with Variable Viscosity," J. Heat Transfer, ASME Trans., Vol. 84, pp. 353-362, November 1962.

9. Deissler, Robert G., "Analytical Investigation of Fully Developed Laminar Flow in Tubes with Heat Transfer with Fluid Properties Variable Along the Radius," NASA TN 2410, July 1951.

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APPENDIX A

FIN BASE THERMAL GRADIENTS

The non-dimensional fin base thermal gradients are determined by numerical integration of the differential equation defining one dimensional heat transfer in a radiating fin, as explained in paragraph 3.1.2. This operation is preformed by subroutine SUBI (if required). The subroutine uses a Runge-Kutta-Gill standard integration procedure. For a given N_c and θ_r, initial values of $d\theta/dX$ @ $X = 0$ are automatically assumed and the equation is integrated to $X = 2$. If the value of θ_r @ $X = 2$ does not match the given θ_r, an iteration procedure is employed until the θ_r's match. In order to obtain an initial assumption for $d\theta/dX$ which will not give a divergent solution, an array of slopes, $\Delta\dot{\theta}/\Delta N_c$ are written into SUBI for each θ_e. Thus, calculations can automatically be made for $.10 \leq N_c \leq 10.0$. The slope values written into SUBI are tabulated below.

	$0.10 \leq N_c < 1.0$	$1.0 \leq N_c < 2.0$	$2.0 \leq N_c < 5.0$	$5.0 \leq N_c \leq 10.0$
$0 \leq \theta_e < .5$	.494	.285	.185	.124
$.5 < \theta_e < .6$	.464	.240	.1635	.116
$.6 < \theta_e < .7$	.427	.190	.140	.112
$.7 < \theta_e < .8$	.362	.146	.125	.093
$.8 < \theta_e < .85$	.276	.124	.0984	.064
$.85 < \theta_e < .90$	.221	.116	.0677	.048
$.90 < \theta_e < .95$	.155	.090	.0533	.032
$\theta_e > .95$	.0815	.050	.0300	.020

These values have been used successfully for all calculations made to date (see Table A1). However, because of the sensitivity of θ_r for initial values of $d\theta/dX$, divergence could occur at some intermediate values of θ_e. In this event, a finer array of slopes must be used or the desired points can be calculated separately.

The values of $d\theta/dX$ which have been used as table input for sample problems are shown in Table A1. Plots for θ_e of 0, 0.70, and 0.90 are shown in Figures A1, A2, and A3. The $d\theta/dX$ values below zero correspond to conditions where the adjacent tube temperature is so high that heat flows into the reference radiator tube.

TABLE A1

NON-DIMENSIONAL FIN BASE THERMAL GRADIENTS $(-d\theta/dX)$

N_c \ θ_r	.60	.70	.80	.90	1.00	1.10	1.20	1.30	1.40	1.50
					$\theta_e = 0$					
.10	.2566	.2133	.1708	.1293	.0890	.0499	.0120	-.0247	-.0597	-.0939
.25	.3314	.2948	.2598	.2265	.1949	.1649	.1336	.1100	.0849	.0613
.50	.4369	.4079	.3804	.3552	.3317	.3099	.2898	.2713	.2542	.2385
.75	.5275	.5032	.4806	.4599	.4411	.4239	.4083	.3940	.3810	.3692
1.0	.6074	.5863	.5671	.5497	.5340	.5198	.5070	.4954	.4849	.4755
1.5	.7458	.7292	.7143	.7011	.6893	.6788	.6694	.6610	.6535	.6468
2.0	.8650	.8513	.8392	.8285	.8191	.8109	.8034	.7969	.7911	.7860
2.5	.9709	.9593	.9491	.9402	.9324	.9255	.9195	.9142	.9095	.9054
3.0	1.0672	1.0571	1.0483	1.0406	1.0340	1.0282	1.0231	1.0187	1.0147	1.0113
3.5	1.156	1.1470	1.1393	1.1326	1.1268	1.1218	1.1175	1.1137	1.1103	1.1073
4.0	1.2388	1.2308	1.2238	1.2179	1.2128	1.2084	1.2046	1.2012	1.1983	1.1958
					$\theta_e = .50$					
.10	.2508	.2075	.1651	.1237	.0834	.0443	.0065	-.0301	-.0651	-.0992
.25	.3180	.2817	.2467	.2139	.1824	.1527	.1246	.0981	.0732	.0498
.50	.4135	.3846	.3578	.3330	.3099	.2885	.2687	.2506	.2338	.2184
.75	.4950	.4712	.4495	.4295	.4112	.3946	.3793	.3656	.3530	.3416
1.0	.5670	.5469	.5285	.5120	.4970	.4834	.4712	.4601	.4501	.4411
1.5	.6916	.6763	.6626	.6504	.6395	.6298	.6210	.6133	.6064	.6001
2.0	.7990	.7868	.7759	.7664	.7580	.7505	.7439	.7381	.7328	.7282
2.5	.8941	.8842	.8754	.8677	.8609	.8550	.8498	.8452	.8411	.8374
3.0	.9807	.9723	.9649	.9586	.9531	.9482	.9439	.9402	.9369	.9339
3.5	1.0603	1.0532	1.0470	1.0416	1.0370	1.0329	1.0294	1.0263	1.0235	1.0211
4.0	1.1346	1.1264	1.1231	1.1185	1.1146	1.1111	1.1081	1.1055	1.1032	1.1011

TABLE A1 (Cont'd)

NON-DIMENSIONAL FIN BASE THERMAL GRADIENTS $(-d\theta/dX)$

N_c \ θ_r	.60	.70	.80	.90	1.00	1.10	1.20	1.30	1.40	1.50
					θ_e = .60					
.10	.2447	.2013	.1589	.1176	.0774	.0384	.0006	-.0359	-.0709	-.1049
.25	.3038	.2678	.2332	.2003	.1691	.1396	.1117	.0854	.0607	.0375
.50	.3882	.3598	.3337	.3092	.2864	.2657	.2463	.2285	.2121	.1970
.75	.4605	.4375	.4166	.3972	.3795	.3635	.3488	.3355	.3232	.3122
1.0	.5244	.5053	.4879	.4721	.4578	.4449	.4333	.4227	.4133	.4046
1.5	.6352	.6212	.6806	.5973	.5873	.5784	.5703	.5632	.5567	.5509
2.0	.7308	.7199	.7104	.7019	.6944	.6878	.6819	.6766	.6720	.6678
2.5	.8157	.8072	.7996	.7931	.7873	.7821	.7776	.7736	.7700	.7669
3.0	.8928	.8860	.8800	.8747	.8701	.8660	.8625	.8593	.8565	.8540
3.5	.9640	.9584	.9535	.9492	.9455	.9422	.9393	.9368	.9345	.9326
4.0	1.0304	1.0257	1.0216	1.0181	1.0150	1.0123	1.0100	1.0079	1.0061	1.0045
					θ_e = .70					
.10	.2343	.1912	.1489	.1076	.0675	.0286	-.0090	-.0454	-.0804	-.1142
.25	.2803	.2448	.2106	.1781	.1473	.1181	.0905	.0646	.0402	.0175
.50	.3471	.3197	.2943	.2706	.2485	.2284	.2096	.1925	.1765	.1619
.75	.4047	.3830	.3632	.3449	.3283	.3130	.2992	.2866	.2751	.2645
1.0	.4561	.4384	.4224	.4079	.3948	.3829	.3721	.3624	.3536	.3455
1.5	.5458	.5337	.5227	.5128	.5041	.4963	.4892	.4830	.4772	.4721
2.0	.6240	.6151	.6072	.6002	.5940	.5884	.5836	.5791	.5752	.5717
2.5	.6938	.6872	.6814	.6762	.6716	.6676	.6640	.6608	.6579	.6554
3.0	.7577	.7526	.7482	.7443	.7408	.7378	.7350	.7327	.7305	.7286
3.5	.8168	.8128	.8094	.8063	.8037	.8013	.7993	.7974	.7958	.7943
4.0	.8720	.8689	.8662	.8638	.8617	.8599	.8583	.8568	.8556	.8544

TABLE A1 (Cont'd)

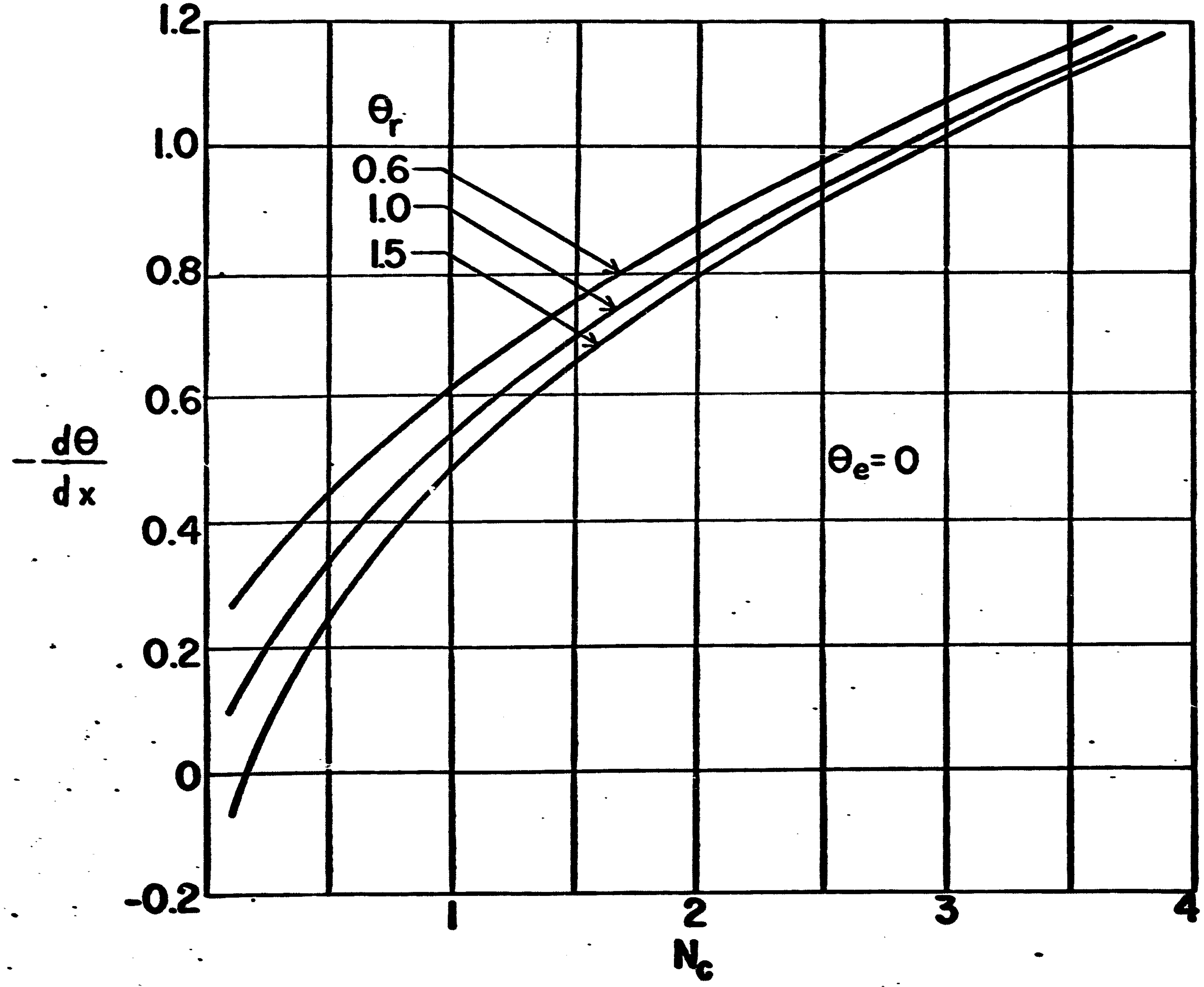
NON-DIMENSIONAL FIN BASE THERMAL GRADIENTS $(-d\theta/dX)$

N_c \ θ_r	.60	.70	.80	.90	1.00	1.10	1.20	1.30	1.40	1.50
					θ_e = .80					
.10	.2186	.1756	.1335	.0924	.0524	.0175	-.0238	-.0588	-.0950	-.1285
.25	.2450	.2100	.1762	.1442	.1139	.0853	.0583	.0329	.0091	-.0133
.50	.2852	.2590	.2346	.2121	.1913	.1721	.1543	.1380	.1228	.1089
.75	.3215	.3016	.2835	.2667	.2514	.2375	.2248	.2131	.2026	.1929
1.0	.3552	.3397	.3256	.3128	.3011	.2907	.2812	.2724	.2647	.2575
1.5	.4164	.4064	.3974	.3895	.3823	.3758	.3700	.3648	.3600	.3558
2.0	.4713	.4646	.4586	.4533	.4486	.4444	.4406	.4371	.4341	.4313
2.5	.5214	.5167	.5126	.5090	.5057	.5028	.5003	.4979	.4958	.4940
3.0	.5677	.5644	.5615	.5589	.5566	.5546	.5528	.5511	.5497	.5484
3.5	.6110	.6086	.6065	.6046	.6030	.6015	.6002	.5990	.5979	.5970
4.0	.6517	.6499	.6484	.6470	.6458	.6447	.6437	.6428	.6421	.6414
					θ_e = .85					
.10	.2083	.1653	.1232	.0882	.0424	.0038	-.0336	-.0697	-.1047	-.1379
.25	.2213	.1867	.1535	.1219	.0920	.0637	.0370	.0118	-.0117	-.0336
.50	.2446	.2194	.1960	.1742	.1540	.1353	.1182	.1024	.0877	.0743
.75	.2703	.2491	.2319	.2161	.2017	.1886	.1765	.1655	.1555	.1464
1.0	.2908	.2765	.2635	.2517	.2410	.2314	.2225	.2145	.2072	.2007
1.5	.3348	.3262	.3183	.3112	.3049	.2992	.2941	.2894	.2852	.2814
2.0	.3760	.3705	.3655	.3610	.3570	.3534	.3502	.3473	.3447	.3423
2.5	.4145	.4108	.4075	.4045	.4019	.3996	.3974	.3955	.3938	.3923
3.0	.4505	.4480	.4457	.4437	.4419	.4403	.4389	.4376	.4365	.4354
3.5	.4844	.4826	.4811	.4797	.4784	.4773	.4763	.4754	.4746	.4739
4.0	.5164	.5151	.5140	.5130	.5121	.5113	.5106	.5099	.5094	.5089

TABLE A1 (Cont'd)

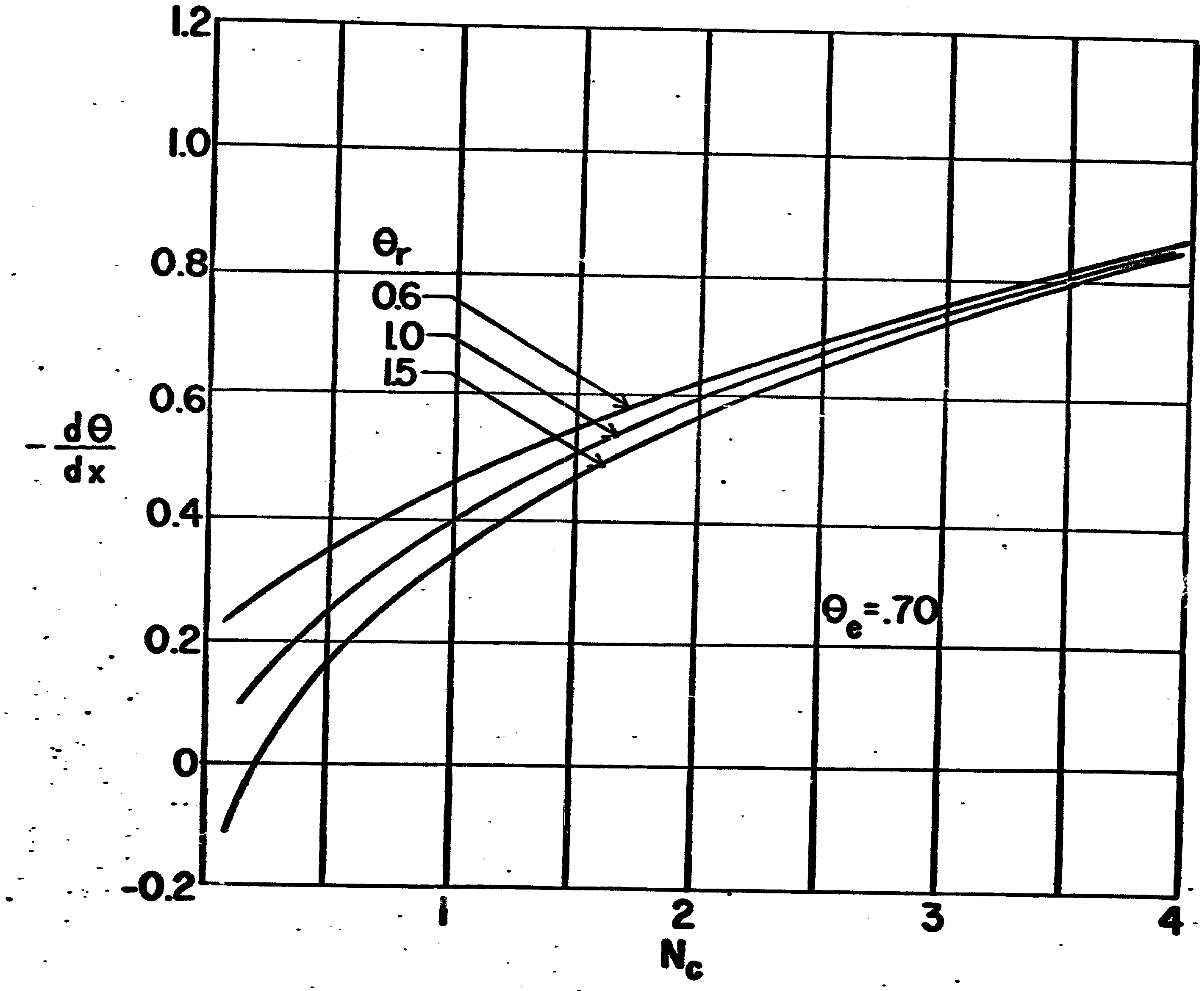
NON-DIMENSIONAL FIN BASE THERMAL GRADIENTS ($-d\theta/dX$)

N_c \ θ_r	.60	.70	.80	.90	1.00	1.10	1.20	1.30	1.40	1.50
					θ_e = .90					
.10	.1959	.1530	.1111	.0702	.0305	.0081	-.0453	-.0812	-.1159	-.1492
.25	.1938	.1594	.1266	.0955	.0660	.0381	.0119	-.0129	-.0362	-.0577
.50	.1971	.1730	.1503	.1293	.1100	.0921	.0756	.0604	.0463	.0334
.75	.2054	.1878	.1717	.1571	.1435	.1312	.1200	.1098	.1003	.0918
1.0	.2163	.2034	.1916	.1808	.1711	.1623	.1543	.1469	.1403	.1342
1.5	.2414	.2340	.2273	.2212	.2157	.2108	.2063	.2023	.1986	.1953
2.0	.2676	.2631	.2590	.2553	.2520	.2491	.2464	.2440	.2418	.2398
2.5	.2932	.2903	.2877	.2854	.2834	.2815	.2798	.2783	.2769	.2757
3.0	.3178	.3159	.3142	.3126	.3113	.3101	.3090	.3080	.3071	.3063
3.5	.3412	.3399	.3387	.3377	.3368	.3360	.3352	.3346	.3340	.3334
4.0	.3634	.3625	.3617	.3610	.3604	.3598	.3593	.3589	.3585	.3581
					θ_e = .95					
.10	.1813	.1385	.0967	.0560	.0164	-.0219	-.0590	-.0948	-.1293	-.1625
.25	.1612	.1273	.0923	.0644	.0354	.0082	-.0178	-.0420	-.0646	-.0860
.50	.1419	.1187	.0973	.0773	.0588	.0418	.0260	.0115	-.0019	-.0143
.75	.1336	.1174	.1025	.0890	.0765	.0651	.0547	.0452	.0365	.0285
1.0	.1314	.1198	.1092	.0996	.0909	.0830	.0758	.0692	.0632	.0578
1.5	.1359	.1296	.1239	.1188	.1142	.1100	.1062	.1028	.0997	.0968
2.0	.1456	.1420	.1387	.1358	.1332	.1308	.1286	.1267	.1249	.1233
2.5	.1571	.1549	.1529	.1511	.1495	.1481	.1468	.1456	.1446	.1436
3.0	.1689	.1675	.1663	.1652	.1642	.1633	.1625	.1617	.1611	.1605
3.5	.1806	.1797	.1789	.1782	.1775	.1770	.1764	.1760	.1755	.1751
4.0	.1919	.1914	.1908	.1902	.1899	.1895	.1892	.1889	.1886	.1883



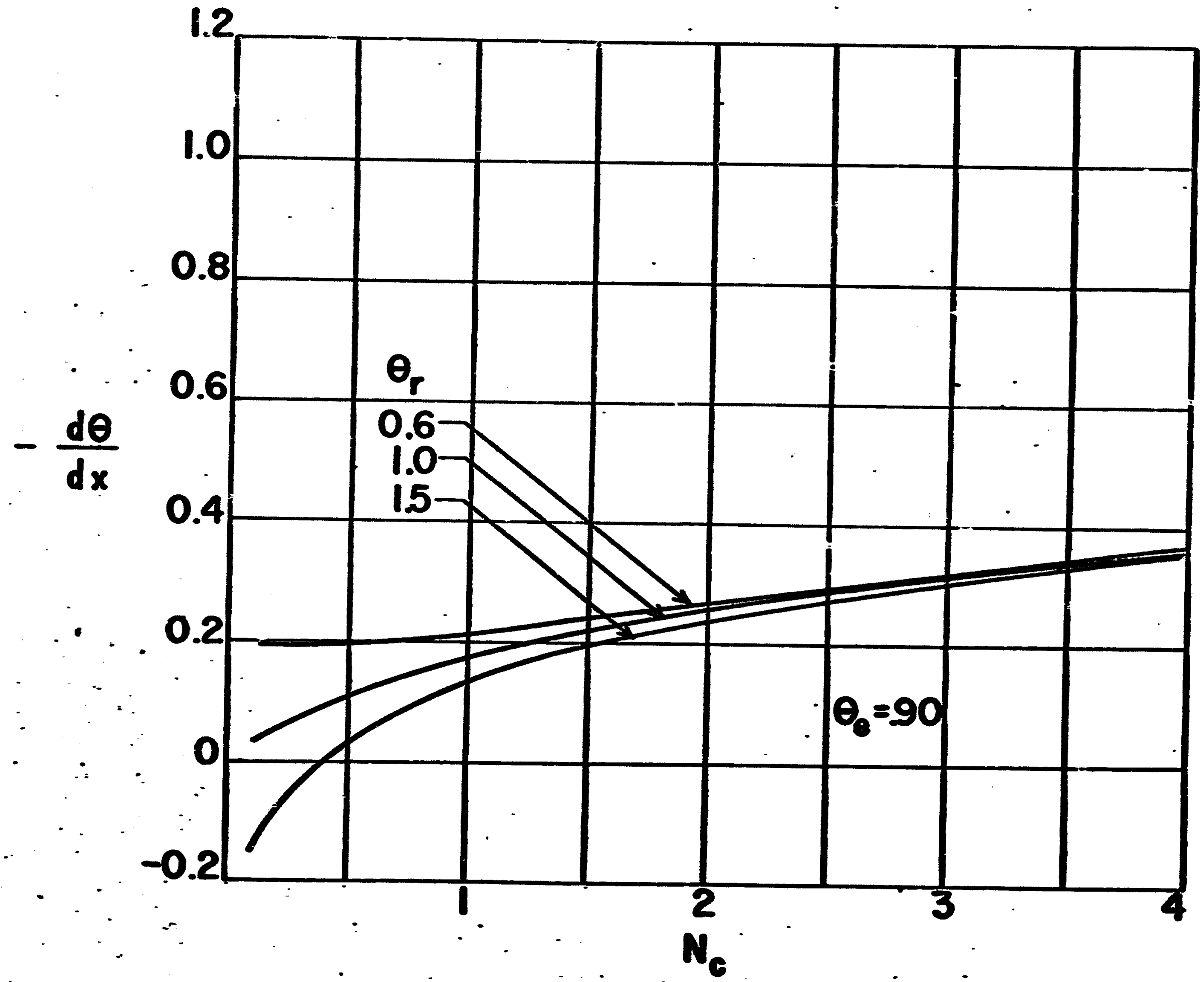
NON-DIMENSIONAL FIN BASE THERMAL GRADIENTS

FIGURE A1



NON-DIMENSIONAL FIN BASE THERMAL GRADIENTS

FIGURE A 2



NON-DIMENSIONAL FIN BASE THERMAL GRADIENTS

FIGURE A3