R66SD3017

NASA CR 72141

COMPUTER CODES FOR THERMAL DESIGN OF POTASSIUM BOILERS AND CONDENSERS

Topical Report

BY

D. R. FERGUSON

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CONTRACT NASA 3-2528

SPACE POWER AND PROPULSION SECTION

MISSILE AND SPACE DIVISION

GENERAL ELECTRIC

CINCINNATI, OHIO 45215

Requests for copies of this report should be referred to:

National Aeronautics and Space Administration
Scientific and Technical Information Division
Attention: USS-A
Washington, D.C. 20546

COMPUTER CODES FOR THERMAL DESIGN OF POTASSIUM BOILERS AND CONDENSERS

By

D.R. Ferguson

1966

TOPICAL REPORT

Prepared For

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Contract NAS 3-2528

Technical Management
NASA - Lewis Research Center
Nuclear Power Technology Branch
Ruth N. Weltmann

Approved by: F. E. Tippets, 12/10/66
Program Manager

E. Schnetzer
Manager, Development Engineering

SPACE POWER AND PROPULSION SECTION
MISSILE AND SPACE DIVISION
GENERAL ELECTRIC COMPANY
CINCINNATI, OHIO 45215

FOREWORD

The work described in this report is part of an alkali metal boiling and condensing heat transfer program conducted by the General Electric Company for the National Aeronautics and Space Administration under Contract NAS 3-2528.

The author wishes to acknowledge the contribution to this work by Mrs. Mary E. McCarthy, who wrote the subroutines THERMA, DUBIN and CURV used in the computer programs.

The conscientious efforts in the preparation of this report by Mrs. Mary Helen Jones, editorial assistant, and Mrs. J.C. Henderson who typed the report, are gratefully acknowledged.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

Simple Latin Letter Symbols

Symbol	Quantity	Units
A	Area	ft^2
D	Diameter	ft, inch
E	Error	dimensionless
f	Darcy-Weisbach friction factor	dimensionless
G	Mass velocity (flow rate per unit flow area)	$lb_m/sec\text{-}ft^2$
h	Heat transfer coefficient	$Btu/ft^2\text{-}hr\text{-}^\circ F$
K	Slip ratio $(K = \frac{\text{vapor velocity}}{\text{liquid velocity}})$	dimensionless
k	Thermal conductivity	$Btu\text{-}ft/ft^2\text{-}hr\text{-}^\circ F$
L	Length	ft
M	Molecular weight	$lb_m/lb\text{-}mole$
p	Pitch	ft, inch
P	Pressure	lb_f/ft^2, psi
q	Rate of heat flow	Btu/sec, Btu/hr
R	Universal gas constant	$\frac{1545\ ft\text{-}lb_f}{lb\ mole\ ^\circ R}$
T	Temperature	$^\circ F$
U	Overall heat transfer coefficient	$Btu/ft^2\text{-}hr\text{-}^\circ F$
w	Mass flow rate	lb_m/sec
x	Flowing quality $x = w_g/w_{tot}$	dimensionless

Composite Latin Letter Symbols

Symbol	Quantity	Units
A_s	Shell flow area	ft^2
C_p	Constant pressure specific heat	$Btu/lb_m\text{-}^\circ F$
E_i	Individual error	dimensionless
G_S	Shell mass velocity	$lb_m/ft^2\text{-}sec$
g_c	Conversion factor	$ft\text{-}lb_m/lb_f\text{-}sec^2$
$\bar{h}_B$	Average boiling heat transfer coefficient	$Btu/ft^2\text{-}hr\text{-}^\circ F$
h_c	Condensing heat transfer coefficient	$Btu/ft^2\text{-}hr\text{-}^\circ F$

NOMENCLATURE (CONT'D)

Composite Latin Letter Symbols

Symbol	Quantity	Units
h_f	Liquid film heat transfer coefficient	Btu/ft^2-hr-°F
h_{fg}	Latent heat of vaporization	Btu/lb
h_v	Vapor phase heat transfer coefficient	Btu/ft^2-hr-°F
k_f	Thermal conductivity of liquid film	$Btu-ft/ft^2$-hr-°F
N_o	Number of tubes in outer row of tube bundle	dimensionless
N_t	Number of tubes	dimensionless
N_{Nu}	Nusselt Number, hD/k	dimensionless
N_{Nuc}	Nusselt condensing ratio, $\frac{h}{k}\left[\frac{\nu^2}{g_c}\right]^{1/3}$	dimensionless
N_{Pe}	Peclet Number, GDC_p/k	dimensionless
N_{Pr}	Prandtl Number, $\mu C_p/k$	dimensionless
N_{Re}	Reynolds Number, DG/μ	dimensionless
N_{ReL}	Liquid film Reynolds Number, $4w(1-x)/\pi D\mu$	dimensionless
p_s	Tube spacing	ft, inch
p/D	Insert twist ratio	dimensionless
p_s/D_{ot}	Tube spacing to diameter ratio	dimensionless
WP	Wetted perimeter	ft
W_i	Weighting factor for integration error	dimensionless
y_i^P	Dummy variable, predicted value	dimensionless
y_i^C	Dummy variable, corrected value	dimensionless

Simple Greek Letter Symbols

Symbol	Quantity	Units
α, β, γ	Coefficients in Dwyer's equations	dimensionless
δ	Film thickness	ft
ϵ_m	Eddy diffusivity	ft^2/sec
μ	Dynamic viscosity	lb_m/ft-sec
ν	Kinematic viscosity	ft^2/sec
ψ	Ratio of eddy diffusivity for heat transfer to eddy diffusivity for momentum	dimensionless
ϕ	Two-phase pressure drop multiplier	dimensionless
ρ	Mass density	lb_m/ft^3

NOMENCLATURE (CONT'D)

Composite Greek Letter Symbols

Symbol	Quantity	Units
σ_c	Condensation coefficient	dimensionless
τ^*_v	Dimensionless shear stress	dimensionless
ϕ_{0-1}	Integrated two-phase friction multiplier (x = 0 to 1)	dimensionless
ϕ_{1-0}	Integrated two-phase friction multiplier (x = 1 to 0)	dimensionless

Subscripts

B	Boiling section
c	Cross flow
C	Condensing
eq	Equivalent
f	Saturated liquid
fr	Friction
g	Saturated vapor
H	Helical
h	Equivalent diameter of tube
i	Inside
in, I	Inlet
it	Inside diameter
K	Potassium
L	Liquid region
m	Momentum
max	Maximum
min	Minimum
NaK	Sodium-potassium alloy
O	Outlet
ot	Tube outside
P	Primary

Subscripts (Cont'd)

Sh	Shell
s	Secondary
sub	Subcooled section
sup	Superheat section
tot	Total
w	Wall

SUMMARY

Calculation procedures and computer codes for the thermal design of multiple-tube potassium condensers and boilers are presented.

The condenser code provides for using either sodium, lithium or NaK as the shell-side cooling fluid. The main output from the condenser code is the condenser tube length required to satisfy specified design-point conditions. Additional output includes the local values of vapor quality, potassium temperature and pressure, and thermal parameters such as the local heat flux and heat transfer coefficients along the condenser tubes.

The boiler code uses either liquid sodium or lithium as the shell-side heating fluid. The main output from the boiler code is the boiler tube length required to satisfy specified design-point conditions. The boiler code is based on using overall average values for the potassium boiling heat transfer coefficient from 0% to 100% quality.

Both the condenser code and the boiler code are programmed in FORTRAN IV, and the source languages are compatible with either the IBM-7094 or the G.E. - 625/635 machines.

I INTRODUCTION

Calculation procedures and digital computer codes, developed for preliminary thermal design studies of multiple-tube condensers and once-through boilers applicable to Rankine cycle space power systems using potassium as the working fluid, are presented in this report. This work was done under NASA Contract NAS 3-2528 as a supporting effort to the potassium multiple-tube test condenser design study described in Reference 1.

The condenser computer code calculates the condenser tube length required to satisfy specified design-point conditions. In addition, local values of the thermal parameters, such as potassium temperature and pressure, local heat flux and heat transfer coefficients are computed as functions of distance along the condenser tubes. The local potassium condensing heat transfer coefficient results reported in Reference 5 are used as the basis for the condenser code.

The boiler computer code employs average boiling potassium heat transfer coefficients, averaged over the entire boiling region from 0% quality to 100% quality, to calculate the boiler tube length required to satisfy specified design-point conditions. The average potassium boiling heat transfer coefficient results reported in Reference 11 are used as the basis for the boiler code.

The basic thermal and fluid dynamic equations used in the codes, the formats of the code inputs and outputs, and illustrative test cases are given in following Sections of this report. Listings of the computer codes from which duplicate program cards can be made are given in the Appendices.

II POTASSIUM CONDENSER THERMAL DESIGN PROGRAM

The condenser thermal design code is applicable to potassium condensers using uniform tubes without inserts in either counterflow or cocurrent flow with saturated potassium vapor at the inlet and subcooled liquid potassium at the outlet. The code is based on the single-tube condensing potassium heat transfer results reported in Reference 5.

Design Relations

The system considered is a counterflow or cocurrent flow condenser with saturated potassium vapor at the inlet and subcooled liquid potassium at the outlet. Distance L is measured in the direction of potassium flow and heat transferred from the potassium is taken as positive. Since vapor quality decreases in the direction of potassium flow, the differential rate of heat transfer is obtained as follows, where changes in vapor kinetic energy and liquid sensible heat are ignored.

Expressing an energy balance between the potassium condensing fluid (secondary fluid) and the condenser cooling fluid (primary fluid) for a length-increment dL gives after re-arrangement.

$$\frac{dL}{dx} = \frac{-C_1}{T_s - T_P} \qquad (1a)$$

where

$$C_1 = \frac{w_s\ h_{fg}}{\pi\ D_i\ N_t\ U_i} \qquad (1b)$$

Distance along the tubes is positive in the direction of potassium flow and heat transfer from the potassium is taken as positive.

Differentiating Equation (1a) results in the following equation involving the temperature derivatives dT/dx, which will be used in the subsequent analysis,

$$\frac{d^2L}{dx^2} = \frac{C_1}{(T_s - T_P)^2} \left[\frac{dT_s}{dx} - \frac{dT_P}{dx} \right] \qquad (1c)$$

It remains to determine expressions for the $\frac{dT}{dx}$ terms in Equation (1c).

The shell-side coolant temperature gradient can be written as:

$$\frac{dT_P}{dx} = \pm \frac{w_s \; h_{fg}}{w_P \; Cp_P} \qquad (2)$$

where the + sign pertains to counterflow, and the - sign indicates parallel flow.

The secondary temperature gradient may be written as:

$$\frac{dT_s}{dx} = \frac{dT_s}{dP_s} \; \frac{dP_s}{dL} \; \frac{dL}{dx} \qquad (3)$$

where:

$\frac{dT_s}{dP_s}$ = Slope of saturated vapor temperature - pressure curve

$\frac{dP_s}{dL}$ = Total two-phase pressure gradient

Ignoring elevation effects, the total two-phase pressure gradient is composed of the frictional and momentum contributions and can be expressed as

$$\frac{dP_s}{dL} = - \frac{f \; G^2 \; \phi}{2 \; \rho_f \; g_c \; D_{eq}} - \frac{G^2}{g_c} \; \frac{d}{dx} \left(\frac{1}{\hat{\rho}}\right) \frac{dx}{dL} \qquad (4)$$

where:

$$\frac{d}{dx} \left(\frac{1}{\hat{\rho}}\right) = \frac{1}{\rho_g} \left\{ \left[1 + x \; (K-1)\right] \left[\frac{1}{K} - \frac{\rho_g}{\rho_f}\right] + \left[(1-x) \frac{\rho_g}{\rho_f} + \frac{x}{K}\right] \; (K-1) \right\} \qquad (4a)$$

In Equation (4), the first term on the right hand side is the friction pressure gradient and the second term is the momentum or acceleration pressure gradient. Note that the friction pressure gradient term is negative whereas the momentum pressure gradient is positive (since dx/dL is negative). The net effect is that the pressure gradient may be either positive or negative depending on the relative magnitude of these terms.

Substituting Equation (4) into Equation (3),

$$\frac{dT_s}{dx} = - \frac{f\, G^2\, \phi}{2\, \rho_f\, g_c\, D_{eq}} \; \frac{dT_s}{dP_s} \; \frac{dL}{dx} - \frac{G^2}{g_c} \; \frac{d}{dx} \left(\frac{1}{\hat{\rho}}\right) \; \frac{dT_s}{dP_s} \qquad (5)$$

Then, substituting Equations (2) and (5) into Equation (1c) gives

$$\frac{d^2L}{dx^2} = \frac{C_1}{(T_s - T_P)^2} \left\{ \frac{-\, f\, G^2\, \phi}{2\, \rho_f\, g_c\, D_{eq}} \; \frac{dT_s}{dP_s} \; \frac{dL}{dx} - \frac{G^2}{g_c} \; \frac{d}{dx} \left(\frac{1}{\hat{\rho}}\right) \frac{dT_s}{dP_s} \pm C_2 \right\} \qquad (6)$$

where:

$$C_2 = \frac{w_s\, h_{fg}}{w_P\, Cp_P}$$

(+) = Parallel flow

(-) = Counterflow

Equation (6) is the differential equation for the condensing length as a function of gravity. The additional equations to be solved along with Equation (6) are Equation (5), and the following differential equation:

$$\frac{dq}{dx} = - w_s\, h_{fg} \qquad (7)$$

These latter two relations yield the local secondary saturation temperature and rate of heat transfer as functions of local quality.

Equations (5) to (7) may be considered a set of linear differential equations with non-constant coefficients. Due to the complexity of the system, numerical methods are employed for the integrations. In order to reduce the system to a set of equations more amenable to computer solution, it is appropriate to make the variable transformation $J = \frac{dL}{dx}$. The system is then reduced to first order in the dependent variables L, J, T_s and q, and becomes

$$\frac{dL}{dx} = J \tag{8a}$$

$$\frac{dJ}{dx} = A(x)\ J + B(x) \tag{8b}$$

$$\frac{dT_s}{dx} = \frac{-\ f\ G^2\ \phi}{2\ \rho_f\ g_c\ D_{eq}}\ \frac{dT_s}{dP_s}\ J - \frac{G^2}{g_c}\ \frac{d}{dx}\left(\frac{1}{\hat{\rho}}\right)\frac{dT_s}{dP_s} \tag{8c}$$

$$\frac{dq}{dx} = -\ w_s\ h_{fg} \tag{8d}$$

where:

$$A(x) = \frac{C_1}{(T_s - T_p)^2}\left[-\frac{f\ G^2\ \phi}{2\ \rho_f\ g_c\ D_{eq}}\ \frac{dT_s}{dP_s}\right] \tag{8e}$$

$$B(x) = \frac{C_1}{(T_s - T_p)^2}\left[-\frac{G^2}{g_c}\ \frac{d}{dx}\left(\frac{1}{\hat{\rho}}\right)\frac{dT_s}{dP_s} \pm C_2\right] \tag{8f}$$

The initial conditions at $x = x_{in}$ are:

$$J = \frac{-C_1}{(T_{s_{in}} - T_p)} \tag{9a}$$

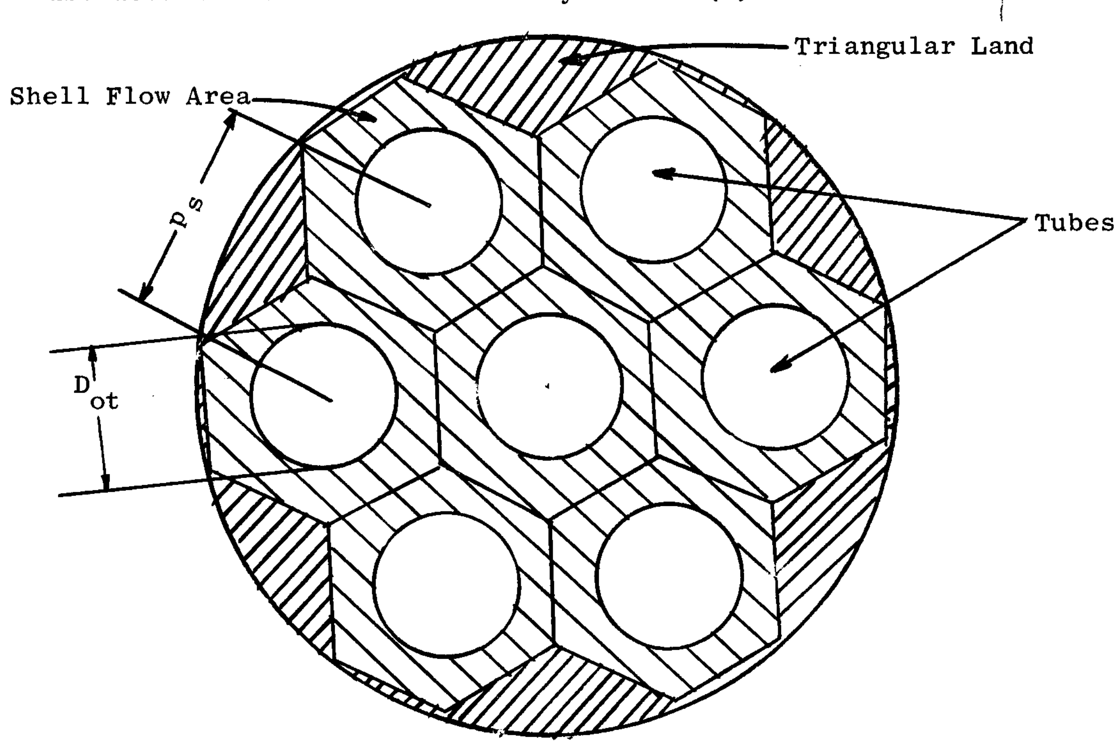
$$L = 0 \tag{9b}$$

$$T_s = T_{s_{in}} \tag{9c}$$

$$q = 0 \tag{9d}$$

Equations 8 are integrated numerically in the condenser code using the 5-point Lanczos scheme (Reference 2). This technique was chosen for its inherent stability and capacity for yielding minimum round-off error. The first four steps are taken using the Runge-Kutta-Gill method (Reference 3)to generate 5 points for the more accurate and faster Lanczos equations. Step size changes (halving and doubling) are made on the basis of pre-set error criteria.

The assumed shell-side geometry consists of a tube bundle enclosed by a cylindrical shell. The tubes are assumed to be arranged in a triangular array. The inner periphery of the shell consists of a cylindrical geometry with triangular lands positioned in the spaces between the tubes in the outer row. With this arrangement, the net flow area of the shell may be divided into hexagonal channels surrounding each tube in the array. This geometry is illustrated for a seven-tube case by sketch (a).



Typical Shell-Side Flow Geometry

Sketch-a

For a geometry of this type, the following equation yields the shell-side (primary) fluid flow area (A_{Sh}).

$$A_{Sh} = \frac{\pi D_{ot}^2}{4} N_t \left[\frac{2\sqrt{3}}{\pi} \left(\frac{p_s}{D_{ot}}\right)^2 - 1 \right] \quad (10)$$

The equivalent diameter to be utilized in the shell-side Reynolds number may be evaluated as

$$D_{eq} = \frac{2 A_{Sh}}{\text{Wetted Perimeter}} = \frac{4 A_{Sh}}{WP} \quad (11a)$$

The total wetted perimeter WP includes wetted surfaces due to the tubes, the triangular lands, and the shell circumference not occupied by lands, as given by Equation (11b),

$$WP = \pi N_t D_{ot} \sqrt{3} N_o p_s \quad (11b)$$

The shell-side heat transfer coefficient is calculated by the method of Dwyer and Tu (Reference 4). The equation recommended in Reference 4 for parallel flow through rod bundles is

$$N_{Nu} = \alpha + \beta (\bar{\Psi} N_{Pe})^{\gamma} \quad (12)$$

where

$$\alpha = 0.93 + 10.81 \left(\frac{p_s}{D_{ot}}\right) - 2.01 \left(\frac{p_s}{D_{ot}}\right)^2 \quad (12a)$$

$$\beta = 0.0252 \left(\frac{p_s}{D_{ot}}\right) \quad (12b)$$

$$\gamma = 0.8 \quad (12c)$$

The quantity $\bar{\Psi}$ represents the ratio of the eddy diffusivity for heat transfer to the eddy diffusivity for momentum transfer. From Reference 13,

$$\bar{\Psi} = 1 - \frac{1.82}{N_{Pr} (\epsilon_m/\nu)_{max}^{\frac{1}{4}}} \quad (13)$$

where:

$$\left(\frac{\epsilon m}{\nu}\right)_{max} = f\ (N_{Re}) \qquad (14)$$

The condensing heat transfer relations are based on the forced convection potassium condensing coefficient data reported in Reference 5. The local condensing heat transfer resistance may be represented as the sum of a vapor phase and a liquid film resistance as follows:

$$\frac{1}{h_c} = \frac{1}{h_v} + \frac{1}{h_f} \qquad (15)$$

where:

$$h_f = k_f/\delta \qquad (15a)$$

δ = liquid film thickness

The vapor phase heat transfer coefficient is given as:

$$h_v = \sigma_c\ h_{fg}\ \left(\frac{M\ g_c}{2\pi RT}\right)^{\frac{1}{2}} \left[\frac{dP}{dT} - \frac{P}{2T}\right] \qquad (16)$$

where T is in °R

It is shown in Reference 5 that the condensation coefficient σ_c for potassium vapor is approximately 0.2 over the temperature range from 1100°F to 1400°F.

The local film thickness δ for use in Equation (15a) is estimated using the Dukler model (Reference 6). In the condenser program, the liquid film coefficient is implicitly represented in Nusselt's condensing ratio, which is a function of the local film Reynolds number and the local shear exerted by the vapor on the liquid film interface. The relevant defining equations are:

$$N_{Nu_C} = N_{Nu_C} (N_{Re_L}, \tau_v^*) = \frac{h_f}{k_f} \left(\frac{\nu^2}{g_c}\right)^{1/3} \tag{17}$$

where:

$$N_{Re_L} = \frac{4(1-x)w}{\pi D \mu}$$

The dimensionless vapor shear, τ_v^*, is estimated from the local two-phase frictional pressure gradient as:

$$\tau_v^* = \left\{ \frac{\rho_g \left(\frac{g}{g_c}\right) + \frac{\phi}{2} \frac{f}{\rho_f} \frac{G^2}{g_c D_{eq}}}{\rho_f \left(\frac{g}{g_c}\right)} \right\} \left(\frac{D_{it}}{4}\right) \left(\frac{g}{\nu^2}\right)^{1/3} \tag{18}$$

Overall heat transfer coefficients are utilized in both the condensing region and the subcooling region. The overall heat transfer coefficient based on the inside heat transfer area is defined as:

$$U_i = \frac{1}{\left(\frac{1}{h_s} + \frac{1}{h_w} + \frac{D_i}{D_{ot} h_P}\right)} \tag{19}$$

where:

$$\frac{1}{h_w} = \frac{D_{it}}{2k_w} \ln \frac{D_{ot}}{D_{it}} \tag{20}$$

The wall thermal conductivity is assumed to be a linear function of temperature, for which the mean wall conductivity is given as:

$$\bar{k}_w = \frac{1}{T_{wo} - T_{wi}} \int_{T_{wi}}^{T_{wo}} (a + bT)\, dT$$

or

$$\bar{k}_w = a + \frac{b}{2} (T_{wo} + T_{wi}) \tag{21}$$

where: T_{wo} = Outer wall temperature, °F

T_{wi} = Inner wall temperature, °F

The overall heat transfer coefficient is applied on a local basis in the condensing region.

In the subcooled region, the liquid potassium heat transfer coefficient is calculated using:

$$N_{Nu} = 3.66 + .0055\, N_{Pe} \tag{22}$$

Equation (22) is based on liquid heat transfer coefficient data reported in Reference 5. The tube length in the subcooled region is calculated from:

$$L_{sub} = \frac{q_{sub}}{\pi\, D_{it}\, N_t\, U_{iL}\, \Delta T_{Lm\ sub}} \tag{23}$$

where: $\Delta T_{Lm\ sub}$ = Logarithmic mean temperature difference in the subcooled region

The shell-side fluid pressure drop is composed of the friction losses, the radial cross-flow losses, and the entrance and exit expansion-contraction losses. Only the friction and radial pressure drops are accounted for in the condenser design program. It is assumed that the expansion-contraction losses will be calculated separately after the inlet-exit geometry is established.

The frictional pressure losses are given as:

$$\Delta P_{fr\text{-}shell} = \frac{f\, L_{tot}\, G_s^2}{2\, \rho_f\, g_c\, D_{eq}} \tag{24}$$

where

$$f = 0.316/\left(\frac{D_{eq}\, G_s}{\mu}\right)^{0.25} \tag{24a}$$

The analysis of Reference 7 is utilized to compute the radial pressure losses in the crossflow regions at the primary fluid inlet and exit. The resulting expressions for the radial pressure loss in the shell are:

$$\Delta P_{radial} = \frac{4}{2\,\rho_f\,g_c}\left[0.25 + \frac{0.118}{\left(\frac{p}{D_o} - 1\right)^{1.08}}\right]\left(\frac{D_{ot}}{\mu}\right)^{-.16}\sum_{i=1}^{n}\left(G_{max\ i}\right)^{1.84} \qquad (25)$$

The maximum mass velocity in any tube row is given as a function of the total flow rate and the shell geometry.

$$G_{max\ i} = \frac{\left[\frac{3(i-1)^2}{(3n^2 - 3n + 1)}\right] w_P}{6(i-1)\ (p-D_{ot})L_c} \qquad i = 1,n \qquad (26)$$

where: n = the total number of tube rows

i = the summation index on the tube rows

L_c = the length along the tubes over which crossflow occurs

The homogeneous model K = 1 is used to calculate the two-phase friction pressure drop multiplier. The equation for the local two-phase friction multiplier is (Reference 8):

$$\phi = \frac{1 + x\left[(\rho_f/\rho_g) - 1\right]}{\left\{1 + x\left[(\mu_f/\mu_g) - 1\right]\right\}^{\frac{1}{4}}} \qquad (27)$$

Thermodynamic properties of the saturated potassium liquid and vapor are taken from Reference 9. Transport properties of the potassium liquid and vapor are taken from Reference 10, and are compiled directly into the program as tabular functions of temperature.

The shell-side cooling fluid may be NaK, sodium or lithium. The properties of these fluids are taken from Reference 10 and are programmed directly into the code as tabular functions of temperature.

Computer Code

The condenser design code is programmed in FORTRAN-IV. The source programs are compatible with both the IBM-7094 and the GE-625/635 machines. The subsequent discussion, however, is limited to programs run on the IBM-7094.

The code is composed of a main program and a sèries of shorter subprograms. Common data storage is utilized to facilitate data transmission between the main program and the subroutines. The majority of the numerical calculations are performed in the subroutines. The main program is primarily utilized to call the calculation routines, read the input, and transmit the output data to the peripheral I/O media. The individual programs and their respective primary functions are summarized in Table I. A detailed listing of the main code and the subroutines is given in Appendix A.

Data are read into the program by means of the standard "namelist" routine. The input consists primarily of the shell and tube geometry, the total power, the primary flow rate and inlet temperature, the secondary inlet temperature and quality, and the level of subcooling at the condenser exit. Additional input includes the starting increment in quality, the flow direction of the primary and secondary fluids, and the parameters pertinent to the per step error of the integration routine.

The output produced by the program consists of the total tube length and the shell and tube parameters which provide a measure of the design point performance. The printout of local conditions along the condenser is optional. If desired, the local values of quality, length, static pressure, primary and secondary temperatures, heat transfer coefficients, secondary film Reynolds number, heat flux and cumulative heat transferred are printed. In this case, the interval between local print-points may be specified as 1, 2, 4 or 5. The first page of output contains the tube length and the relevant design point performance information. The local conditions are printed consecutively on the subsequent format pages.

In the numerical integration of a system of ordinary differential equations by a conventional predictor-corrector technique, the truncation error in the i-th dependent variables refers to the per-step difference between the predicted and corrected values of the particular variable being integrated. For the Lanczos scheme, which is a pseudo predictor-corrector method (Reference 2), this type of error is given as:

$$E_i = 0.11 \left| y_i^c - y_i^P \right| \tag{28}$$

where the superscripts c and P designate corrected and predicted values, respectively, of the y_i - variable being calculated. These errors may be treated independently by requiring the individual errors to be less than a set of corresponding maximum tolerable error limits. However, in the condenser design program, it has been found to be more convenient to use a weighted error for the entire system of differential equations as recommended in Reference 3.

$$E_{tot} = 0.11 \sum_i W_i \left| \frac{y_i^c - y_i^P}{y_i^c} \right| \quad i = 1, 4 \tag{29}$$

The weighting factors (W_i) and an allowable maximum error limit (E_{max}) are read into the program at object time. Within the program, an additional minimum error bound is established as:

$$E_{min} = E_{max}/40 \tag{30}$$

For a given incremental step in quality, E_{tot} is tested against E_{max}. If $E_{tot} > E_{max}$, the step size is halved and the step is repeated. If E_{tot} is still greater than E_{max}, the step size is again halved, and the integration is restarted at this location. Five such restarts are allowed for each case being calculated. If $E_{tot} < E_{max}$ it is then tested against E_{min}. Then, if $E_{tot} > E_{min}$, the integration is continued with the current step size. If, on the other hand, $E_{tot} < E_{min}$, the current step size is doubled, and the next step is taken with $\Delta x_{new} = 2\ \Delta x_{old}$. Doubling is restricted to every fourth step to prevent too rapid a growth of the step size in regions of small truncation error.

In addition to truncation errors, round-off errors can accumulate as the solution proceeds along the length of the condenser. Both the Runge-Kutta Gill starting routine and the Lanczos technique are formulated to minimize the round-off errors.

When differential equations are approximated by a difference expression, as in the present case, extraneous solutions are normally carried along with the desired solution. This situation occurs because the approximating difference equations are of higher order than the original differential equation. An integration procedure may become unstable when errors cause these unwanted solutions to grow exponentially. The ultimate result is that the true solution is swamped by the extraneous solutions and is completely lost. The stability criterion that must be satisfied for the Lanczos method is:

$$\frac{\Delta x \left(\frac{dy_i}{dx}\right)}{y_i} \leqslant -0.3, \qquad i = 1, 4 \tag{31}$$

In the condenser design program, a stability check is made after each quality step. If the conditions of Equation (31) are not satisfied, the step size in quality is halved and the step is repeated. If the system is still unstable, the step size is again halved, and the integration is restarted using the current values of the dependent variables. As in the case of the truncation errors, five restarts are allowed for each case.

Data are put into the program by means of the standard FORTRAN-IV "namelist" routine. Input data are loaded into the machine on punched cards. The card input format is given below.

CARD INPUT FORM

Column 2

$INPUT ① TITLE = 48H (48 Hollerith Characters) ________,

NT = ____, ITP = ____, NCF = ____, NQ = ____ MINC = ____, ITWMAX = ___, JHP ___,

DT = _____, XW = _____, DCB = _____, PODT = _____ WP = _____, GS = _____,

POWER = _____, TSATIN = _____, TPIN = _____, TSUBO = _____, HP = _____,

HCON = _____, PF = _____, AK = _____, BK = _____, RADPL = ______,

SLIPEX = _____, DELTAY = _____, PRINT = _____, TOLP = _____, TOLW = _____,

ERLIMT = _____, XIN = _____, SIGMAC = _____, WGHT = ____, ____, ____, ____$

The input variables and relevant units are defined in Table II. Variables beginning with the characters I, J, N, M must be entered as integer variables; viz, (NT = 50). The remainder of the input consists of real variables. These data may be entered using either an F or an E type format; viz, (POWER = 300), or (POWER = 3. E + 2). Change cases may be run by simply entering new values for the variables being changed. These new input values are stacked behind the initial case input cards.

Some special instructions are necessary for some of the variables in the input list, as given in the following table. Where pertinent, values found to be satisfactory for the cases run to date are indicated.

Symbol	Instruction
ITP	Satisfactory value = 20
NCF	1) Enter NCF = 0 if counterflow
	2) Enter NCF = 1 if parallel flow
NQ	Satisfactory value = 20
ITWMAX	Satisfactory value = 30

Symbol	Instruction
JHP	1) Enter JHP = 0 if primary heat transfer coefficient is to be calculated by program
	2) Enter JHP = 1 if primary heat transfer coefficient is input
DCB	Enter DCB = 0 for tube with no centerbody
GS	Enter GS = 0 if number of tubes is specified. This value must be entered for every case.
HP	Enter HP = 0 if primary heat transfer coefficient is computed by the program
HCON	Enter HCON = 0 if condensing heat transfer coefficient is computed by program
PRINT	1) Enter PRINT = 0 if local condition printout is not desired
	2) Enter PRINT = 1 if local condition printout is desired
TOLP	Satisfactory value = .02 (2 percent accuracy)
DELTAY	Satisfactory value = - .001
ERLIMT	Satisfactory value = .0005 (.05 percent accuracy) for DELTAY = - .001
WGHT	Satisfactory values are WGHT = .2, .5, .1, .2 for DELTAY = - .001

The complete input deck for an IBM-7094 calculation consists of the requisite IBSYS monitor control cards, the binary decks (main and subprograms), and the input data. The following deck set-up pertains specifically to the IBM-7094 computer installed at General Electric Company in Evendale.

DECK SET-UP (IBM-7094)

Yellow Sequence Card

Pink ID Card

Col. 1	Col. 7	Col. 16
ISTOP	IBSYS	
13L	IBSYS	
$JOB		
$REWIND		SYSPP1
$EXECUTE	IBJOB	
$IBJOB		GO, MAP, DLOGIC
(Binary Programs)		
$DATA		
(Input Data Cards)		
7 8 ← (Punch in Col. 1)		
$IBSYS		
$ENDFILE		SYSPP1
$ENDFILE		SYSPP1
$ENDFILE		SYSPP1
$STOP		

Certain types of program errors will cause the execution of a particular case to be aborted. If these situations occur, appropriate error comments will be printed before the case is terminated. In most instances, these comments will be accompanied by the program results up to the point where the error was encountered. Error printouts will occur for the following situations:

(1) If the exit temperature from the condensing region is less than the specified subcooled outlet temperature, the outlet temperature is lowered, and the case is re-run with the adjusted subcooled outlet temperature. If the same condition prevails at the end of this pass, an error comment is printed and the case is terminated.

(2) The primary temperature profile is established by nodal iteration of the coolant heat balance relation. If any of the iterations fail to converge, an appropriate error comment is printed. The node at which non-convergence occurred is included in the printout.

(3) If the mean wall temperature iteration fails to converge, the case will be terminated. The error comment in this situation includes the local quality at which the iteration failed to converge.

(4) Under certain conditions the condensing fluid temperature may become lower than the primary coolant temperature. This temperature cross indicates a physically impossible situation in the condenser. If a cross occurs, an error comment to this effect is printed, along with the computed values of local quality, length and temperatures.

(5) The program will be terminated if the total number of restarts exceeds 5. In this instance, the final variable errors and the local values of quality, length, and temperatures will be printed before an exit is made from the program.

Sample Case

Results of some sample calculations are given to illustrate the use of the program and to show typical output produced by the program. The specified design conditions for these sample calculations are:

Tube material	Stainless steel-316
Number of tubes	19
Tube OD, inches	0.6875
Wall thickness, inches	0.035
Tube, p/D_{ot}	1.3
Power, KW	225
Secondary Fluid	Potassium
Potassium inlet temperature, °F	1300
Potassium inlet quality	1.0
Potassium exit temperature, °F	1191
Primary coolant	NaK (counterflow)
NaK inlet temperature, °F	1190
NaK flow rate, lb_m/sec	10.2
Initial quality increment Δx	-.001
Maximum allowable error	.0005 (or .05%)
Average wall temperature tolerance	.0005
Length of shell-side radial pressure drop region	0
Condensation coefficient	0.2

The printed output for this sample calculation is shown in Figures 1 and 2.

The programs used in the condenser code are listed in Table I, the nomenclature for the condenser code input is given in Table II and the nomenclature for the printed output is given in Table III (Appendix A).

CONDENSER DESIGN (GENERAL PARAMETERS)

TITLE= POWER-225KW, TSAT-1300, 10 APPROACH

GEOMETRY

NT	= 19	COND LENGTH	= 2.6834 FEET
TUBE ID	= 0.6175 INCHES	SUBC LENGTH	= 0.0079 FEET
TUBE OD	= 0.6875 INCHES	TOTL LENGTH	= 2.6914 FEET
WALL XW	= 0.0350 INCHES	TUBE P/D	= 1.30
TUBE FLOW AREA	= 0.03951 SQ FT	SHELL ID	= 4.091 INCHES
CENTER BODY OD	= 0. INCHES	SHELL FLOW AREA	= 0.0423 SQ FT

THERMAL PARAMETERS

POWER KW	QTOT,BTU/SEC	QCOND,BTU/SEC	QSUB,BTU/SEC
225.00	213.25	207.93	5.32

PRIMARY			SECONDARY		
TPIN	= 1190.00	DEG F	TSIN	= 1300.00	DEG F
TPOUT	= 1290.0C	DEG F	TSATCE	= 1304.33	DEG F
WP	= 10.1360	LBM/SEC	TSOUT	= 1191.00	DEG F
GP	= 239.653	LBM/FT2SEC	WS	= 0.24386	LBM/SEC
VP	= 5.403	FT/SEC	GS	= 6.172	LBM/FT2SEC
REP	= 83635.6		VMAX	= 319.283	FT/SEC
			HSL	= 1332.85	B/FT2HRDEG
			REL	= 3299.8	
DPFRIC	= 0.191	PSIA	PEL	= 11.42	
DPRAD	= 0.	PSIA	UIL	= 842.69	B/FT2HRDEG
			DELTAP	= -0.221	PSIA
DPTOT	= 0.191	PSIA	DPFRIC	= 0.203	PSIA
			DPMOM	= -0.425	PSIA

Figure 1. Typical Computer Printout of Overall Data From The Condenser Thermal Design Code

CONDENSER DESIGN (LOCAL CONDITIONS) 1

. TITLE= POWER-225KW, TSAT-1300, 10 APPROACH

X	Z FT.	TSC DEG F	PLOCAL PSIA	TPC DEG F	HSC HR UNITS	HP HR UNITS	UI HR UNITS	Q B/SEC	UOA B/FT2 HR	REZ
1.00000	0.	1300.00	8.822	1290.00	28903.3	5476.4	2331.8	0.	23326.8	0.
0.99900	0.0104	1299.99	8.821	1289.90	32173.3	5476.4	2351.1	0.21	23718.0	3.4
0.99800	0.0207	1299.97	8.821	1289.80	32170.9	5476.5	2351.1	0.42	23916.7	6.8
0.99700	0.0310	1299.96	8.820	1289.70	32168.6	5476.5	2351.1	0.62	24115.8	10.2
0.99600	0.0411	1299.95	8.819	1289.61	32166.3	5476.5	2351.1	0.83	24315.3	13.6
0.99500	0.0512	1299.94	8.819	1289.51	32164.0	5476.5	2351.1	1.04	24515.3	17.0
0.99400	0.0612	1299.93	8.818	1289.41	32161.7	5476.5	2351.1	1.25	24715.8	20.4
0.99300	0.0711	1299.91	8.817	1289.32	32159.4	5476.6	2351.1	1.46	24916.6	23.8
0.99200	0.0809	1299.90	8.817	1289.22	32157.2	5476.6	2351.1	1.66	25117.8	27.2
0.99100	0.0907	1299.89	8.816	1289.12	32154.9	5476.6	2351.1	1.87	25319.4	30.6
0.99000	0.1004	1299.88	8.816	1289.02	32152.7	5476.6	2351.0	2.08	25521.5	34.0
0.98800	0.1195	1299.86	8.815	1288.83	32148.4	5476.7	2351.0	2.50	25926.8	40.8
0.98600	0.1384	1299.84	8.813	1288.63	32144.1	5476.7	2351.0	2.91	26333.6	47.6
0.98400	0.1570	1299.81	8.812	1288.44	32139.8	5476.8	2351.0	3.33	26741.8	54.4
0.98200	0.1753	1299.79	8.811	1288.24	32135.7	5476.8	2351.0	3.74	27151.5	61.2
0.98000	0.1933	1299.77	8.810	1288.05	32131.6	5476.8	2351.0	4.16	27562.6	68.0
0.97600	0.2286	1299.74	8.809	1287.66	32123.6	5476.9	2350.9	4.99	28389.0	81.6
0.97200	0.2629	1299.70	8.807	1287.27	32115.8	5477.0	2350.9	5.82	29220.4	95.3
0.96800	0.2963	1299.67	8.805	1286.88	32004.7	5477.1	2350.3	6.66	30049.6	108.9
0.96400	0.3287	1299.64	8.803	1286.49	31847.0	5477.2	2349.5	7.49	30879.8	122.5
0.96000	0.3604	1299.61	8.802	1286.10	31698.8	5477.3	2348.7	8.32	31714.5	136.1
0.95200	0.4212	1299.55	8.799	1285.33	31425.0	5477.5	2347.2	9.98	33396.2	163.3
0.94400	0.4791	1299.51	8.797	1284.55	31175.4	5477.6	2345.8	11.65	35093.0	190.5
0.93600	0.5343	1299.47	8.795	1283.77	30930.3	5477.8	2344.5	13.31	36802.2	217.7
0.92800	0.5871	1299.43	8.793	1282.99	30693.1	5478.0	2343.1	14.97	38522.8	244.9
0.92000	0.6376	1299.40	8.792	1282.21	30469.2	5478.2	2341.8	16.64	40254.2	272.1
0.90400	0.7324	1299.35	8.789	1280.65	30038.3	5478.5	2339.3	19.97	43744.4	326.5
0.88800	0.8201	1299.32	8.788	1279.10	29626.2	5478.9	2336.8	23.29	47266.1	380.9
0.87200	0.9016	1299.31	8.787	1277.54	29241.9	5479.2	2334.5	26.62	50814.9	435.4
0.85600	0.9776	1299.30	8.787	1275.98	28880.1	5479.5	2332.2	29.95	54387.4	489.8
0.84000	1.0490	1299.31	8.787	1274.42	28537.1	5479.9	2330.0	33.28	57979.1	544.2
0.82400	1.1162	1299.32	8.788	1272.86	28209.9	5480.2	2327.8	36.61	61588.1	598.6
0.80800	1.1796	1299.35	8.789	1271.31	27877.5	5480.6	2325.6	39.93	65207.4	653.0
0.79200	1.2397	1299.38	8.790	1269.75	27557.2	5480.9	2323.4	43.26	68838.3	707.5
0.77600	1.2968	1299.41	8.792	1268.19	27248.0	5481.3	2321.3	46.59	72479.6	761.9
0.74400	1.4031	1299.51	8.797	1265.07	26645.7	5482.0	2316.9	53.25	79781.4	870.8
0.71200	1.5001	1299.62	8.803	1261.96	26067.4	5482.7	2312.6	59.90	87105.1	979.7
0.68000	1.5898	1299.75	8.809	1258.84	25491.7	5483.4	2308.0	66.56	94432.6	1088.7
0.64800	1.6725	1299.90	8.817	1255.72	24931.8	5484.1	2303.5	73.21	101764.0	1197.6
0.61600	1.7500	1300.06	8.825	1252.60	24388.4	5484.8	2298.8	79.87	109092.1	1305.6
0.58400	1.8225	1300.23	8.833	1249.48	23858.3	5485.5	2294.2	86.52	116412.1	1415.7
0.55200	1.8906	1300.40	8.842	1246.36	23338.5	5486.2	2289.4	93.18	123719.1	1524.7
0.52000	1.9550	1300.59	8.852	1243.24	22826.0	5486.9	2284.4	99.83	131007.0	1633.8
0.48800	2.0159	1300.79	8.862	1240.12	22320.3	5487.6	2279.4	106.49	138271.8	1742.9
0.45600	2.0739	1300.99	8.872	1237.00	21818.3	5488.3	2274.1	113.14	145508.4	1852.0
0.42400	2.1290	1301.19	8.883	1233.88	21316.7	5489.0	2268.7	119.79	152709.7	1961.2
0.39200	2.1817	1301.41	8.893	1230.76	20812.4	5489.7	2263.0	126.45	159868.7	2070.3
0.36000	2.2321	1301.63	8.904	1227.64	20299.6	5490.4	2256.9	133.10	166974.9	2179.6
0.29600	2.3268	1302.07	8.927	1221.40	19228.9	5491.8	2243.2	146.41	180976.8	2398.1
0.23200	2.4143	1302.54	8.951	1215.15	18053.2	5493.2	2226.5	159.71	194569.0	2616.8
0.16800	2.4958	1303.02	8.976	1208.90	16751.2	5494.6	2205.5	173.02	207571.8	2835.5
0.10400	2.5718	1303.51	9.001	1202.66	16277.4	5496.0	2197.3	186.32	221605.5	3054.5
0.04000	2.6433	1304.01	9.027	1196.41	15767.6	5497.4	2188.0	199.62	235433.9	3273.5
0.	2.6834	1304.33	9.043	1192.50	15113.9	5498.3	2175.1	207.93	243233.8	3410.5
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

Figure . Typical Computer Printout of Local Data From The Condenser Thermal Design Code

III POTASSIUM BOILER THERMAL DESIGN PROGRAM

The boiler thermal design code is applicable to once-through potassium boilers using uniform tubes with or without helical inserts in counterflow with subcooled liquid potassium at the inlet and saturated or superheated potassium vapor at the outlet. The code is based on the single-tube boiling potassium heat transfer and pressure drop results reported in Reference 11.

Design Relations

Determination of the required boiler tube length for a fixed tube geometry, power level, and fluid conditions involves a simultaneous solution of the applicable heat transfer and pressure drop relationships.

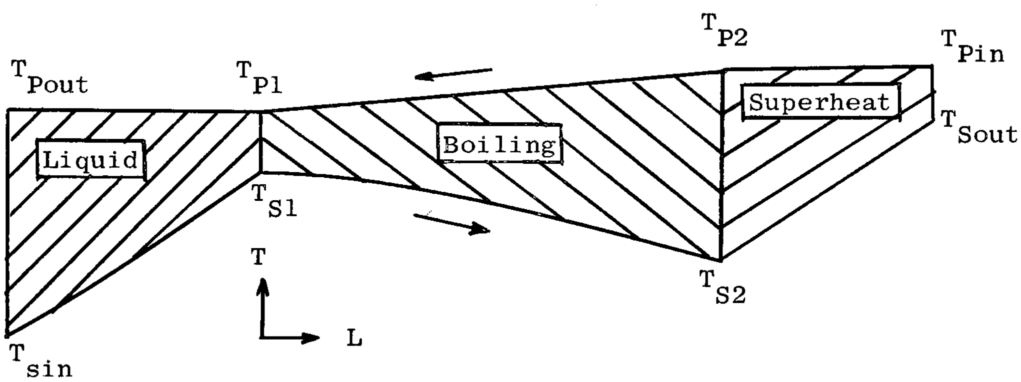
The total boiler length may be divided into a liquid region, a boiling region, and a superheat region. Distance L along the tubes is positive in the direction of potassium flow,and heat transfer to the potassium is taken as positive. The respective channel lengths may be related to the total heat transfer rate, the regional overall heat transfer coefficients, and the logarithmic temperature difference in each region as follows:

$$L_{sub} = \frac{q_{sub}}{U_{sub}\, N_t\, \pi D_i \left[\dfrac{(T_{P1} - T_{S1}) - (T_{Pout} - T_{Sin})}{\ln \dfrac{(T_{P1} - T_{S1})}{T_{Pout} - T_{Sin}}} \right]} \tag{32}$$

$$L_B = \frac{q_B}{U_B\, N_t\, \pi D_i \left[\dfrac{(T_{P2} - T_{S2}) - (T_{P1} - T_{S1})}{\ln \dfrac{(T_{P2} - T_{S2})}{(T_{P1} - T_{S1})}} \right]} \tag{33}$$

$$L_{sup} = \frac{q_{sup}}{U_{sup} \; N_t \; \pi D_i \left[\dfrac{(T_{Pin} - T_{Sout}) - (T_{P2} - T_{S2})}{\ell n \; \dfrac{(T_{Pin} - T_{Sout})}{(T_{P2} - T_{S2})}} \right]} \qquad (34)$$

where the subscripts on the temperatures are keyed to the following sketch.



Fluid Temperature Distributions
<u>Sketch-b</u>

The remaining heat transfer relations are supplied by the following heat balance relations:

$$q_{sub} = w_s \; \bar{C}_{Ps} \; (T_{s1} - T_{Sin}) = \bar{C}p_P \; (T_{Pl} - T_{Pout}) \qquad (35)$$

$$q_B = w_s \; h_{fg} = w_P \; \bar{C}p_P \; (T_{P2} - T_{Pl}) \qquad (36)$$

$$q_{sup} = w_s \bar{C}p_s (T_{Sout} - T_{s2}) = w_P \bar{C}p_P (T_{Pin} - T_{P2}) \tag{37}$$

$$q_{total} = q_{sub} + q_B + q_{sup} \tag{38}$$

The various heat capacities in the above equations are evaluated at the average fluid temperatures in the respective regions.

There are seven equations and nine unknowns; viz: L_{sub}, L_B, L_{sup}, q_B, q_{sup}, T_{P2}, T_{P1}, T_{s2}, and T_{s1}. The remaining two equations are the pressure drop relations for the boiling and the superheat regions.

The pressure drop in both the boiling and the superheat regions are composed of frictional and momentum contributions.

$$\Delta P_B = \Delta P_{fr_B} + \Delta P_{m_B}$$

$$\Delta P_{sup} = \Delta P_{fr_{sup}} + \Delta P_{m_{sup}}$$

or

$$\Delta P_B = P_{s1} - P_{s2} = \frac{f_H L_{BH} G_H^2}{2\bar{\rho}_f g_c D_{eq}} \phi_{O-1} + \frac{G_H^2}{g_c} \left(\frac{1}{\rho_{g2}} - \frac{1}{\rho_{f1}}\right) \tag{39}$$

$$\Delta P_{sup} = P_{s2} - P_{sout} = \frac{f_H L_{supH} G_H^2}{2 \bar{\rho}_g g_c D_{eq}} + \frac{G_H^2}{g_c} \left(\frac{1}{\rho_{gout}} - \frac{1}{\rho_{g2}}\right) \tag{40}$$

The pressures P_{s1} and P_{s2} are related to the corresponding temperatures T_{s1} and T_{s2} by the saturation properties of the boiling fluid.

$$q_{sup} = w_s \bar{C}p_s \; (T_{Sout} - T_{s2}) = w_P \bar{C}p_P \; (T_{Pin} - T_{P2}) \tag{37}$$

$$q_{total} = q_{sub} + q_B + q_{sup} \tag{38}$$

The various heat capacities in the above equations are evaluated at the average fluid temperatures in the respective regions.

There are seven equations and nine unknowns; viz: L_{sub}, L_B, L_{sup}, q_B, q_{sup}, T_{P2}, T_{P1}, T_{s2}, and T_{s1}. The remaining two equations are the pressure drop relations for the boiling and the superheat regions.

The pressure drop in both the boiling and the superheat regions are composed of frictional and momentum contributions.

$$\Delta P_B = \Delta P_{fr_B} + \Delta P_{m_B}$$

$$\Delta P_{sup} = \Delta P_{fr_{sup}} + \Delta P_{m_{sup}}$$

or

$$\Delta P_B = P_{s1} - P_{s2} = \frac{f_H \, L_{BH} \, G_H^2}{2\bar{\rho}_f \; g_c \; D_{eq}} \; \phi_{O-1} + \frac{G_H^2}{g_c} \left(\frac{1}{\rho_{g2}} - \frac{1}{\rho_{f1}}\right) \tag{39}$$

$$\Delta P_{sup} = P_{s2} - P_{sout} = \frac{f_H \, L_{supH} \, G_H^2}{2 \, \bar{\rho}_g \, g_c \, D_{eq}} + \frac{G_H^2}{g_c} \left(\frac{1}{\rho_{gout}} - \frac{1}{\rho_{g2}}\right) \tag{40}$$

The pressures P_{s1} and P_{s2} are related to the corresponding temperatures T_{s1} and T_{s2} by the saturation properties of the boiling fluid.

may be either lithium or sodium. The secondary boiling fluid is potassium.

The thermodynamic and transport properties of lithium and sodium are taken from Reference 10 and are programmed directly into the code as tabular functions of temperature. The thermodynamic properties of potassium are taken from Reference 9 and are included as a subroutine in the code.

The average potassium heat transfer coefficients used in the code for the boiling region are supplied as an input. Experimental boiling potassium heat transfer coefficients obtained from Reference 11 are used.

For tubes without inserts, the superheated vapor heat transfer coefficient is calculated from the conventional Colburn relation (Reference 12):

$$N_{Nu} = 0.023 \, (N_{Re})^{0.8} \, (N_{Pr})^{1/3} \qquad (43)$$

In the case of tubes with helical inserts, the coefficient is calculated from the empirical relation developed in Reference 11:

$$N_{Nu} = 0.39 \, (N_{Re})^{0.56} \, (N_{Pr})^{1/3} \qquad (44)$$

The length mass velocity and equivalent diameter employed in Equation (44) are the helical values as given by Equations (41) and (42).

The local two-phase pressure drop multiplier is based on the homogeneous model (K = 1) as follows (Reference 8):

$$\phi = \frac{1 + x \left[(\rho_f/\rho_g) - 1\right]}{\left\{1 + x \left[(\mu_f/\mu_g) - 1\right]\right\}^n} \qquad (45)$$

Where n = 0.25 (Reference 8).

For a uniform axial heat flux distribution in the boiler, quality is linear with length, which approximates the actual distribution. Equation (45) can be integrated from x = 0 to x = 1, assuming linear variation in quality, to yield an average integrated two-phase multiplier for the boiling region:

$$\phi_{0\rightarrow 1} = \frac{(1+b)^{1-n}}{\eta\,(1-n)} - \frac{1}{\eta\,(1-n)} + \frac{\xi}{\eta^2}\left[\frac{1}{(n-1)(1+\eta)^{n-1}} - \frac{1}{(n-2)(1-\eta)^{n-2}} + \frac{1}{(n-2)} - \frac{1}{n-1}\right] \quad (46)$$

where

$$\xi = \left(\frac{\rho_f}{\rho_g} - 1\right) \quad \text{and} \quad \eta = \left(\frac{\mu_f}{\mu_g} - 1\right)$$

Computer Code

The boiler design code is programmed in FORTRAN-IV. The source programs are compatible with both the IBM-7094 and GE-625/635 machines. The following discussion, however, is limited to programs run on the IBM-7094.

The code consists of a main program and several smaller subprograms. The majority of the numerical calculations are performed in the main program, along with the relevant input and output operations. The subroutines are utilized primarily to perform repetitive calculations. The main program and the subroutines utilized are listed in the following table:

Program	Primary Function
PBDES (Main Program)	
RDP	Computes radial pressure drop
FRIC	Computes helical flow friction factors
DICHOA	Iteration routine
LININT	Linear interpolation
THERMA	NRL Thermodynamic Properties
(1) DUBIN	
(2) CURV	

A complete listing of these programs is given in Appendix B.

The requisite input to the program consists of the shell and tube geometry, the total power level, the primary flow rate and inlet temperature, and the secondary inlet and exit temperatures. The secondary exit temperature is fixed by specifying the exit pressure and the degree of superheat above the saturation temperature corresponding to this pressure.

The output produced by the program consists primarily of the required tube length to transfer the specified power at the given temperature levels of the primary and secondary fluids. Additional output includes the design point performance as indicated by the tube and shell-side pressure drops, the potassium temperature at boiling initiation and the radial acceleration produced by the helical insert.

Data are put into the program by means of the standard FORTRAN-IV "namelist" routine. Input data are loaded into the machine on punched cards. The card input format is given below.

CARD INPUT FORM

Column 2

```
$INPUT      TITLE = 48H ________(48 Hollerith Characters)________
NT = _____, ITP = _____, ITS = _____, ITSUP = _____, JHP = ______,
POWER = _____, TRINS = _____, TSIN = _____, DTSUP = ______,
PSOUT = _____, DT = _____, XW = _____, PODT = _____, PODI = _____, DCB = _____,
HB = ____, HSUP = ____, HP = ______, HPMARG = ______, GS = _______,
WP = _____, XINST = _____, RADPL = _____, TOLP = ____, TOLS = _____,
TOLSUP = ____, PF = _____, CSLOPE = ____, CS = _____, XN = _____,
TW = ______, ______, -------- up to 20 values in Table ------,
XKW = ______, ______, --------up to 20 values in Table ------.$
```

The input variables and relevant units are identified in Table IV. Variables beginning with the characters I, J, N must be entered as integer variables; viz, (NT = 50). The remainder of the input consists of real variables. These data may be entered using either an F or an E type format. Change cases may be run by entering new values for the variables being changed.

Some special instructions are necessary for some of the variables in the input list. These instructions are given in the following table. Where pertinent, values found to be satisfactory for the cases run to date are indicated.

Symbol	Instruction
ITP	Satisfactory value = 20
ITS	Satisfactory value = 50
ITSUP	Satisfactory value = 50
JHP	1) Enter JHP = 0 if primary heat transfer coefficient is to be calculated by program 2) Enter JHP = 1 if primary heat transfer coefficient is input
DCB	Enter DCB = 0 for tubes with no insert
HSUP	Enter HSUP = 0 if superheated vapor heat transfer coefficient is calculated by program
HP	Enter HP = 0 if primary heat transfer coefficient is calculated by program
HPMARG	Set HPMARG = 1 for most cases
GS	Enter GS = 0 if number of tubes is specified. This value must be entered for every case.
TOLP	Satisfactory value = .25°F
TOLS	Satisfactory value = .005
TOLSUP	Satisfactory value = .003
CSLOPE	Set CSLOPE = 1
CS	Set CS = 1

The deck set-up is the same as for the condenser thermal design code (Section II).

Execution of the program will be terminated if any of the following types of errors occur:

(1) The primary exit temperature is established by iteration of the primary fluid heat balance. If this iteration fails to converge, an error comment is printed and the program calls EXIT.

(2) If the number of iterations for either the boiling length or the superheat length are exceeded, subroutine DICHOA will call DUMP. The difference between the iterated variables will be printed. Execution of following cases will be suppressed.

Sample Case

Results of some sample calculations are given to illustrate the use of the program and to show typical output produced by the program. The specified design conditions for these sample calculations are:

Tube material	Haynes-25 alloy
Number of tubes	7
Tube OD, inches	0.75
Tube p_s/D_{ot}	1.3
Helical insert p/D	2, 4 and 6
Power, KW	300
Primary heating fluid	Sodium
Secondary fluid	Potassium
Potassium inlet temperature, °F	1200
Net superheat of potassium outlet, °F	50
Potassium exit pressure, psia	56.7 (1700°F sat.)
Sodium inlet temperature, °F	1850
Sodium flow rate, lb_m/sec	9.03
Potassium boiling heat transfer coefficient, Btu/ft^2-hr-°F	4000
Helical insert vane thickness, inches	0.0625
Length of shell-side radial pressure drop region	0

The potassium boiling heat transfer coefficient of 4,000 Btu/hr-ft^2-°F, average for the entire boiling region from 0% to 100% quality, is typical of the average boiling potassium heat transfer coefficient data reported in Reference 11 for tubes with helical inserts. Further discussion of the use of the Reference 11 data for boiler thermal design is given in Reference 1.

The printed outputs for these sample calculations are shown in Figures 3a, 3b and 3c.

The nomenclature for the boiler code input is given in Table IV and the nomenclature for the printed output is given in Table V (Appendix B).

POWER BOILER THERMAL/HYDRAULIC DESIGN

TITLE= 7-TUBE BOILER. CASE 1-B

GEOMETRY

NT =	7	TUBE P/D =	1.30000
TUBE ID =	0.6900 INCHES	TUBE FLOW AREA =	0.018177 FT 2
TUBE OD =	0.7500 INCHES	INSERT P/D =	4.00
WALL XW =	0.0300 INCHES	SHELL ID =	2.709 INCHES
TUBE LTOT=	7.0434 FEET	SHELL FLOW AREA=	0.0185 FT 2
TUBE LB =	4.6559 FEET		
TUBE LSC =	0.6078 FEET		

THERMAL PARAMETERS

POWER KW	QTOT BTU/SEC	QB BTU/SEC	QSC BTU/SEC	Q/A BOILING BTU/FT2 HR
300.	284.34	250.10	30.56	152933.29

PRIMARY			SECONDARY		
TPIN =	1850.00	DEG F	TSIN =	1200.00	DEG F
TPOUT =	1750.18	DEG F	TSAT =	1717.10	DEG F
WP =	9.080	LBM/SEC	TSOUT =	1705.10	DEG F
GP =	489.645	LBM/FT2SEC	WS =	0.315	LBM/SEC
VP =	10.845	FT/SEC	GMAX =	25.500	LBM/FT2 SEC
REP =	180115.0		VMAX =	143.26	FT/SEC
PEP =	614.10		ACCL =	713808.62	FT/SEC2
HP =	13483.46	B/FT2HRDEG	ACCL/G =	22167.97	GEES
HWALL =	6819.52	B/FT2HRDEG	HSL =	849.10	B/FT2HR DEG
DELTAP =	1.791	PSIA	HB =	4000.00	B/FT2HR DEG
DPRIN =	0.	PSIA	REL =	12797.3	
DPROUT =	0.	PSIA	PEL =	51.93	
			UIL =	715.25	B/FT2HR DEG
			UIB =	2151.14	B/FT2HR DEG
			DELTAP =	2.643	PSIA
			DPFRIC =	1.371	PSIA
			DPMOM =	1.272	PSIA

SUPERHEAT REGION

QSUP BTU/SEC	HSUPS HR UNITS	TSUPS DEG F	TUBE LSUP FT	DPSUP PSI	DPSFRIC PSI	DPSMOM PSI
3.68	57.37	1750.00	1.7798	1.098	1.027	0.0709

Figure 3a. Typical Computer Printout of Overall Data From The Boiler Thermal Design Code (Case 1-B, Insert p/D = 4)

POWER BOILER THERMAL/HYDRAULIC DESIGN

TITLE= 7-TUBE BOILER. CASE 1-C

GEOMETRY

NT	= 7		TUBE P/D	=	1.30000
TUBE ID	= 0.6900	INCHES	TUBE FLOW AREA	=	0.018177 FT 2
TUBE OD	= 0.7500	INCHES	INSERT P/D	=	6.00
WALL XW	= 0.0300	INCHES	SHELL ID	=	2.709 INCHES
TUBE LTOT	= 7.0105	FEET	SHELL FLOW AREA	=	0.0185 FT 2
TUBE LB	= 4.4770	FEET			
TUBE LSC	= 0.5858	FEET			

THERMAL PARAMETERS

POWER KW	QTOT BTU/SEC	QB BTU/SEC	QSC BTU/SEC	Q/A BOILING BTU/FT2 HR
300.	284.34	250.26	30.30	159146.26

PRIMARY / SECONDARY

PRIMARY			SECONDARY		
TPIN	= 1850.00	DEG F	TSIN	= 1200.00	DEG F
TPOUT	= 1750.18	DEG F	TSAT	= 1712.86	DEG F
WP	= 9.030	LBM/SEC	TSOUT	= 1703.95	DEG F
GP	= 489.645	LBM/FT2SEC	WS	= 0.315	LBM/SEC
VP	= 10.845	FT/SEC	GMAX	= 22.637	LBM/FT2 SEC
REP	= 180115.0		VMAX	= 95.88	FT/SEC
PEP	= 614.10		ACCL	=319781.24	FT/SEC2
HP	= 13483.46	B/FT2HRDEG	ACCL/G	= 9931.09	GEES
HWALL	= 6816.14	B/FT2HRDEG	HSL	= 849.40	B/FT2HR DEG
DELTAP	= 1.783	PSIA	HB	= 4000.00	B/FT2HR DEG
DPRIN	= 0.	PSIA	REL	= 12785.0	
DPROUT	= 0.	PSIA	PEL	= 51.80	
			UIL	= 715.50	B/FT2HR DEG
			UIB	= 2150.80	B/FT2HR DEG
			DELTAP	= 1.947	PSIA
			DPFRIC	= 0.940	PSIA
			DPMOM	= 1.006	PSIA

SUPERHEAT REGION

QSUP BTU/SEC	HSUPS HR UNITS	TSUPS DEG F	TUBE LSUP FT	DPSUP PSI	DPSFRIC PSI	DPSMOM PSI
3.77	53.66	1750.00	1.9478	0.850	0.798	0.0519

Figure 3b. Typical Computer Printout of Overall Data From The Boiler Thermal Design Code (Case 1-C, Insert p/D = 6)

POWER BOILER THERMAL/HYDRAULIC DESIGN

TITLE= 7-TUBE BOILER. CASE 1-F

GEOMETRY

NT	= 7		TUBE P/D	=	1.30000
TUBE ID	= 0.6900	INCHES	TUBE FLOW AREA	=	0.018177 FT 2
TUBE OD	= 0.7500	INCHES	INSERT P/D	=	2.00
WALL XW	= 0.0300	INCHES	SHELL ID	=	2.709 INCHES
TUBE LTOT	= 9.6543	FEET	SHELL FLOW AREA	=	0.0185 FT 2
TUBE LB	= 7.4808	FEET			
TUBE LSC	= 0.9115	FEET			

THERMAL PARAMETERS

POWER KW	QTOT BTU/SEC	QB BTU/SEC	QSC BTU/SEC	Q/A BOILING BTU/FT2 HR
300.	284.34	248.67	32.46	94638.28

PRIMARY

TPIN	= 1850.00	DEG F
TPOUT	= 1750.18	DEG F
WP	= 9.080	LBM/SEC
GP	= 489.645	LBM/FT2SEC
VP	= 10.845	FT/SEC
REP	= 180115.0	
PEP	= 614.10	
HP	= 13483.46	B/FT2HRDEG
HWALL	= 6937.90	B/FT2HRDEG
DELTAP	= 2.455	PSIA
DPRIN	= 0.	PSIA
DPROUT	= 0.	PSIA

SECONDARY

TSIN	= 1200.00	DEG F
TSAT	= 1749.08	DEG F
TSOUT	= 1710.89	DEG F
WS	= 0.315	LBM/SEC
GMAX	= 37.343	LBM/FT2 SEC
VMAX	= 280.84	FT/SEC
ACCL	=743367.47	FT/SEC2
ACCL/G	= 85197.75	GEES
HSL	= 847.59	B/FT2HR DEG
HB	= 4000.00	B/FT2HR DEG
REL	= 12884.2	
PEL	= 52.85	
UIL	= 713.64	B/FT2HR DEG
UIB	= 2152.97	B/FT2HR DEG
DELTAP	= 8.866	PSIA
DPFRIC	= 6.192	PSIA
DPMOM	= 2.673	PSIA

SUPERHEAT REGION

QSUP BTU/SEC	HSUPS HR UNITS	TSUPS DEG F	TUBE LSUP FT	DPSUP PSI	DPSFRIC PSI	DPSMOM PSI
3.21	71.08	1750.00	1.2619	2.362	2.155	0.2062

Figure 3c. Typical Computer Printout of Overall Data From The Boiler Thermal Design Code (Case 1-F, Insert p/D = 2)

IV CONCLUDING REMARKS

The analytical procedures and digital computer codes presented in this report are useful for thermal design studies of multiple-tube condensers and boilers applicable to Rankine cycle space power systems using potassium as the working fluid. The relatively short machine times of 3 to 7 seconds for each code enable rapid computation of several design-point cases to be done with a minimum of cost and effort for parametric studies.

Currently available experimental heat transfer results for condensing potassium (Reference 5) and once-through boiling of potassium in tubes with and without helical inserts (Reference 11) are the bases for the computer codes and associated analytical procedures. When more experimental data and improved analytical methods become available, the computer codes given in this report can be used as a guide for the preparation of more extensive programs.

REFERENCES

1. Tippets, F.E., Peterson, J.R. and Sawochka, S.G., "Potassium Multiple-Tube Test Condenser Design Study", Topical Report, Contract NAS 3-2528, General Electric Company - SPPS, NASA-CR-72137.

2. Harker, W.H., Harriman, J.M., Walter, J.N., "Glance - A FORTRAN Subroutine for Numerical Integration of Ordinary Differential Equations by the Lanczos Method", Report GEAP 3448, General Electric Company - APED.

3. Ralston, A., Wilf, H.S., "Mathematical Methods for Digital Computers", Section 8, John Wiley and Sons, Inc., 1960.

4. Dwyer, O.E. and Tu, P.S., "Analytical Study of Heat Transfer Rates for Parallel Flow of Liquid Metals Through Tube Bundles I", Chemical Engineering Progress Symposium Series, No. 30, Vol. 56, 1960.

5. Sawochka, S.G., "Thermal And Fluid Dynamic Performance of Potassium During Condensation In Single-Tube", Topical Report, Contract NAS 3-2528, General Electric Company - SPPS, 1966.

6. Dukler, A.E., "Fluid Mechanics and Heat Transfer in Vertical Falling-Film Systems", Chemical Engineering Progress Symposium Series, No. 30, Vol. 56, 1960.

7. Hess, H.L., Kunz, H.R. and Wyde, S.S., "Analytical Study of Liquid Metal Condensers", Report PWA-2320, Vol. 1, Contract NAS 3-2355, Pratt and Whitney Aircraft, July 15, 1965.

8. Tippets, F.E., "Alkali Metal Boiling and Condensing Investigations", Quarterly Progress Report No. 8, Contract NAS 3-2528, General Electric Company - SPPS, October 20, 1964, NASA-CR-54138.

9. Stone, J.P., Ewing, C.T., Spann, J.R., Stienkuller, E.W., Williams, D.D. and Miller, R.R., "High Temperature Properties of Sodium, Potassium, and Cesium", NRL Report 6128, August 1964.

10. Weatherford, W.D., Jr., Tyler, J.C. and Ku, P.M., "Properties of Inorganic Energy Conversion and Heat Transfer Fluids for Space Applications", WADD Technical Report 61-96, November, 1961.

11. Peterson, J.R., "High-Performance Once-Through Boiling of Potassium In Single-Tubes At Vapor Temperatures From 1500°F To 1750°F", Topical Report, Contract NAS 3-2528, General Electric Company - SPPS, 1966.

12. McAdams, W.H., "Heat Transmission", 3rd-edition, McGraw Hill, 1964.

13. Dwyer, O.E., "Analytical Study of Heat Transfer To Liquid Metals Flowing In-Line Through Closely Packed Rod Bundles", paper submitted to Nuclear Science and Engineering for publication, January 26, 1965.

APPENDIX A

POTASSIUM CONDENSER THERMAL DESIGN CODE

TABLE I

PROGRAMS USED IN THE CONDENSER DESIGN CODE

Program		Primary Function
1)	MAIN (CONDES)	Input and Output
2)	CONSEC	Calls derivative and integration subroutines. Stores computed data
3)	DERIV	Computes derivatives of dependent variables
4)	TPRIMC	Determines primary coolant temperature profile
5)	CONDH	Computes the local condensing heat transfer coefficient
6)	SHELL	Computes primary coolant heat transfer coefficient and shell side pressure drops
7)	PMULT	Computes two-phase pressure drop multiplier
8)	GLANCE	Integration routine (RKG + Lanczos)
9)	INTERP	Performs double linear interpolation
10)	LININT	Performs linear interpolation
11)	THERMA	NRL Thermodynamic properties
	a) DUBIN	
	b) CURV	

TABLE II

NOMENCLATURE FOR CONDENSER DESIGN CODE INPUT*

Symbol	Quantity	Units
TITLE	Identification block, 48 characters	-
NT	Number of tubes	dimensionless
ITP	Number of nodal iterations for primary coolant temperature profile	-
NCF	Flow direction indicator 0 = counterflow 1 = parallel flow	-
NQ	Number of nodes for primary coolant temperature profile	-
MINC	Print interval indicator. May be 1, 2, 4 or 5	-
ITWMAX	Maximum number of iterations for average wall temperature	-
JHP	Indicator for primary fluid heat transfer coefficient 0 = calculated by program 1 = input	-
DT	Tube outside diameter	inches
XW	Tube wall thickness	inches
DCB	Center body diameter	inches
PODT	Tube pitch to diameter ratio	dimensionless
WP	Primary coolant flow rate	lb_m/sec
GS	Secondary fluid mass velocity	lb_m/ft^2-sec
POWER	Total power	KW
TSATIN	Secondary inlet temperature	°F
TPIN	Primary inlet	°F
TSUBO	Secondary subcooled outlet temperature	°F
HP	Primary fluid heat transfer coefficient	Btu/ft^2-hr-°F
HCON	Secondary (condensing) heat transfer coefficient	Btu/ft^2-hr-°F

*Symbols are given in literal order of appearance on input cards

TABLE II (Cont'd)

Symbol	Quantity	Units
PF	Primary fluid indicator -1 = NaK 0 = Lithium 1 = Sodium	-
AK	Intercept of linear equation for wall thermal conductivity = f(T)	Btu-ft/ft^2-hr-°F
BK	½ Slope of linear equation for wall thermal conductivity = f(T)	Btu-ft/ft^2-hr-°F
RADPL	Length of radial pressure drop region	inches
SLIPEX	Reciprocal of slip ratio exponent; viz, $2. = \left(\frac{\rho_f}{\rho_g}\right)^{\frac{1}{2}}$	dimensionless
DELTAY	Starting increment in quality	dimensionless
PRINT	Print indicator for local properties 0 = Do not print 1 = Print	-
TOLP	Tolerance on primary temperature iterations	°F
TOLW	Tolerance on average wall temperature	$\frac{\text{Percent}}{100}$
ERLIMT	Maximum allowable per-step itegration error limit	$\frac{\text{Percent}}{100}$
XIN	Secondary inlet vapor quality	dimensionless
SIGMAC	Condensation coefficient $0 \; \sigma_c - 1$	dimensionless
WGHT	Weighting factors for integration errors, $\sum_{i=1}^{4} W_i = 1$	dimensionless

TABLE III

NOMENCLATURE FOR CONDENSER DESIGN CODE PRINTOUT

Symbol	Quantity	Units
DELTAP	Net condensing pressure drop	psia
DPFRIC	Primary frictional pressure drop or condensing friction pressure drop	psia
DPMOM	Condensing momentum pressure drop	psia
GP	Primary mass velocity	lb_m/ft^2-sec
GS	Secondary mass velocity	lb_m/ft^2-sec
HP	Local primary heat transfer coefficient	Btu/ft^2-hr-°F
HSC	Local condensing heat transfer coefficient	Btu/ft^2-hr-°F
HSL	Secondary heat transfer coefficient in liquid region	Btu/ft^2-hr-°F
NT	Number of tubes	
PEL	Secondary Peclet number in liquid region	dimensionless
POWER	Total power	KW
PLOCAL	Local secondary static pressure	psia
Q	Cumulative heat transfer rate	Btu/sec
QCOND	Heat transfer rate in condensing region	Btu/sec
QSUB	Heat transfer rate in subcooled region	Btu/sec
QTOT	Total heat transfer rate	Btu/sec
QOA	Local heat flux	Btu/ft^2-hr
REL	Secondary Reynolds number in liquid region	dimensionless
REP	Primary Reynolds number	dimensionless
REZ	Local secondary film Reynolds number	dimensionless
TPC	Local primary fluid temperature	°F
TPIN	Primary fluid inlet temperature	°F
TPOUT	Primary fluid exit temperature	°F
TSC	Local secondary fluid saturation temperature	°F
TSIN	Secondary fluid inlet temperature	°F

TABLE III (Cont'd)

Symbol	Quantity	Units
TSOUT	Secondary fluid subcooled exit temperature	°F
UI	Local overall heat transfer coefficient	Btu/ft^2-hr-°F
UIL	Overall heat transfer coefficient in liquid region	Btu/ft^2-hr-°F
VMAX	Inlet secondary vapor velocity	fps
VP	Primary fluid velocity	fps
WP	Primary flow rate	lb_m/sec
WS	Secondary flow rate	lb_m/sec
X	Local secondary	dimensionless
XW	Wall thickness	in.
Z	Length	ft.

CONDENSER CODE LISTING

```
$IBFTC CONDES  FULIST,SDD
C
       DIMENSION TITLE(8)
C
       DIMENSION VISL(20),VISG(20),TT(20),TCKL(20)
       DIMENSION WGHT(4),TPQ(100),QPRIM(100),X(1000),
      1TSC(1000),Q(1000),HSC(1000),TPC(1000),UI(1000),QOA(1000),
      2Z(1000)
       DIMENSION HP(1000),PLOCAL(1000),REZ(1000)
       COMMON SHFA,SHID,GP,VP,REP,DELPP,DPRAD,DPCEX,DPTOTP
       COMMON NT,ITP,ITWMAX,NCF,NQ,DT,XW,DIT,DLM,PODT,
      1WP,WS,GS,TSATIN,TPIN,POWER,QTOT,HP,HCON,TOLP,TOLW,
      2PF,XIN,AK,BK,EXN,TPQ,QPRIM,X,TSC,HSC,TPC,UI,QOA,JL,
      3WGHT,ERLIMT,DELTAX,Q,Z
       COMMON SLIPEX
       COMMON PLOCAL,REZ,DEQV
       COMMON DCB,ZTOT
       COMMON SIGMAC
       COMMON JHP
C
C      PROGRAM IS APPLICABLE TO A COUNTERFLOW OR
C      CO-FLOW CONDENSER WITH ENTERING QUALITY
C      XIN. SECONDARY FLUID EXITS SATURATED OR
C      SUBCOOLED.
C
       NAMELIST/INPUT/TITLE,NT,ITP,NCF,NQ,MINC,
      1ITWMAX,DT,XW,RADPL,DCB,PODT,WP,GS,POWER,
      2TSATIN,TPIN,TSUBO,HP,HCON,PF,XIN,TOLP,TOLW,
      3EXN,AK,BK,ERLIMT,WGHT,PRINT,DELTAY,SLIPEX,SIGMAC,JHP
     1 READ(5,INPUT)
       BITS=0.
       DELTAX=DELTAY
       RDP=RADPL
       ISUB=0
     2 QTOT=.9478*POWER
       DIT=DT-2.*XW
       DLM=2.*XW/ALOG(DT/DIT)
C
C      COMPUTE WS FROM AN ENTHALPY BALANCE. THEN
C      COMPUTE GS OR NT FROM TOTAL POWER
C      AND SECONDARY FLOWRATE
C
     3 TSATIR=TSATIN+459.69
       TSUBRO=TSUBO+459.69
       CALL THERMA(PU,TSATIR,PSIN,HLIN,HGIN,SL7,SV7,
      1VL7,VGIN,CPG7,CPL7,EX,AV,-1.,0.,HS7,SS7,VS7,CPSH7,EXS7,
      2AVS7)
       CALL THERMA(PU,TSUBRO,PSO,HLOUT,HGOUT,SL7,SV7,VL7,
      1VG7,CPG7,CPL7,EX,AV,-1.,0.,HS7,SS7,VS7,CPSH7,EXS7,AVS7)
       WS=QTOT/(XIN*HGIN+(1.-XIN)*HLIN-HLOUT)
       IF(GS)4,4,5
     4 AS=3.1416*(DIT**2-DCB**2)/4.*FLOAT(NT)/144.
       GS=WS/AS
       GO TO 6
     5 ATUBE=3.1416*(DIT**2-DCB**2)/4./144.
       XNT=WS/GS/ATUBE
       NT=IFIX(XNT)
     6 CONTINUE
       WET=3.1416*(DCB+DIT)/12.*FLOAT(NT)
       DEQV=4.*AS/WET*12.
C
```

```
C      COMPUTE THE PRIMARY TEMPERATURE PROFILE.
C
       CALL SLITET(2,JSEN)
       CALL TPRIMC
       CALL SLITET(2,JSEN2)
       IF(JSEN2-1)1,1,666
  666  CONTINUE
C
       IF(JHP)7,7,8
    8  SHFA=BITS
       PODT=BITS
       SHID=BITS
       GP=BITS
       VP=BITS
       REP=BITS
       DPRAD=BITS
       DELPP=BITS
    9  CONTINUE
    7  CONTINUE
C
C      ENTER SUBROUTINE CONSEC TO INTEGRATE THE
C      DEQS IN THE CONDENSING REGION.
C
       SAVEX=DELTAX
       CALL SLITET(1,JSEN)
       CALL CONSEC(JL)
       CALL SLITET(1,JSEN1)
       IF(JSEN1-1)1,1,11
   11  CONTINUE
C
C      TEST TO SEE IF THE EXIT SATURATION
C      TEMPERATURE IS LOWER THAN THE SUBCOOLED
C      EXIT TEMPERATURE.
C
       TSATCE=TSC(JL)
       DTSUBC=TSATCE TSUBO
   10  IF(DTSUBC)15,16,16
   15  IF(ISUB)17,17,18
   18  WRITE (6,500) (TITLE(K),K=1,8)
       GO TO 1
   17  ISUB=1
       DELTAX=SAVEX
       GS=0.
       TSUBO=TSUBO+DTSUBC-10.
       GO TO 2
   16  CONTINUE
C
C
C      COMPUTE QSUB AND THE LENGTH IN THE
C      SUBCOOLED REGION.DETERMINE THE MEAN WALL
C      TEMPERATURE BY SUCCESSIVE APPROXIMATION.
C
       TCWM1=0.
       ITW=1
       IF(NCF)20,20,21
   20  TPP=TPIN
       TPOUT=TPQ(1)
       GO TO 22
   21  NZQ=NQ+1
       TPP=TPQ(NZQ)
       TPOUT=TPP
```

```
   22 CONTINUE
      TWO=(TPP+TPC(JL))/2.
      TWI=(TSC(JL)+TSUBO)/2.
      TW2=TWI+459.69
      CALL THERMA(PU,TW2,PS7,HL7,HG7,SL7,SV7,VL7,
     1VG7,CPG7,CPLS,EX,AV,-1.,0.,HS7,SS7,VS7,CPSH7,EXS7,AVS7)
      CALL LININT(TT,VISL,TWI,VISLS,OUT,20)
      CALL LININT(TT,TCKL,TWI,TCKLS,OUT,20)
      PRL=CPLS*VISLS/TCKLS
      REL=DEQV/12.*GS*3600./VISLS
      PECL=PRL*REL
      ZNUSC=3.66+.0055*PECL
      HTSC=ZNUSC*12.*TCKLS/DEQV
      QSC=QTOT-Q(JL)
      IF(JHP)31,31,32
   31 CALL SHELL(0,TWO,TWO,RDP,HPSC,1)
      GO TO 33
   32 HPSC=HP(1)
   33 CONTINUE
      T1=TWI
      T2=TWO
   23 TCWM2=AK+BK*(TWO+TWI)
      DELTA=(TCWM2-TCWM1)/TCWM2
      IF(ABS(DELTA) TOLW)100,100,24
   24 RESW=XW*DIT/12./TCWM2/DLM
      UIL=1./(1./HTSC+RESW+DIT/HPSC/DT)
      DT1=TSC(JL)-TPC(JL)
      DT2=TSUBO-TPP
      DTLMSC=(DT1-DT2)/ALOG(DT1/DT2)
      ASC=QSC/UIL/DTLMSC*3600.
      DTIF=QSC*3600./HTSC/ASC
      DTOF=QSC*3600./HPSC/ASC*DT/DIT
      TWI=T1-DTIF
      TWO=T2+DTOF
      TCWM1=TCWM2
      IF(ITW-ITWMAX)25,25,26
   26 WRITE (6,1000)
      CALL EXIT
   25 ITW=ITW+1
      GO TO 23
C
C
  100 CONTINUE
      ZSC=ASC/3.1416*12./DIT/FLOAT(NT)
      ZCON=Z(JL)
      ZTOT=ZSC+ZCON
C
C     COMPUTE TOTAL CONDENSING PRESSURE DROP
C
      T69=TSATCE+459.69
      CALL THERMA(PU,T69,PSOUT,HL7,HG7,SL7,SV7,VLOUT,
     1VG7,CPG7,CPL7,EX,AV,-1.,0.,HS7,SS7,VS7,CPSH7,EXS7,AVS7)
      DELP=(PSIN-PSOUT)
      PMOM=GS**2/32.2/144.*(VLOUT-VGIN)
      PFRIC=DELP-PMOM
      VMAX=GS*VGIN
      QCOND=Q(JL)
      DO 156 K=1,JL
      TSCRAN=TSC(K) 459.69
  156 CALL THERMA(PU,TSCRAN,PLOCAL(K),HL8,HG8,SL8,SV8,VL8,
     1VG8,CPG8,CPL8,EX,AV,-1.,0.,HS8,SS8,VS8,CPSH8,EXS8,AVS8)
```

```
C
C
C     SET UP THE OUTPUT.
C
      TPIN1=TPIN
      IF(PODT)109,109,111
  111 CALL SHELL(1,TPIN1,TPOUT,RDP,HP1,1)
      DPTOTP=DELPP+DPRAD
      GO TO 131
  109 DPTOTP=BITS
  131 CONTINUE
C
C     WRITE THE FIRST PAGE OF OUTPUT
      WRITE (6,5999) (TITLE(K),K=1,8),NT,ZCON,DIT,
     1ZSC,DT,ZTOT,XW,PODT,AS,SHID,DCB,SHFA,POWER,QTOT,
     2QCOND,QSC,TPIN,TSATIN,TPOUT,TSATCE,WP,TSUBO
      WRITE (6,6001) GP,WS,VP,GS,REP,VMAX,HTSC,REL,DELPP,
     1PECL,DPRAD,UIL,DELP,DPTOTP,PFRIC,PMOM
C
      IF(PRINT)700,700,601
  601 K=JL+1
      DO 602 J=K,1000
      X(J)=BITS
      TSC(J)=BITS
      Q(J)=BITS
      TPC(J)=BITS
      UI(J)=BITS
      HSC(J)=BITS
      HP(J)=BITS
      PLOCAL(J)=BITS
      REZ(J)=BITS
      QOA(J)=BITS
  602 Z(J)=BITS
  600 CONTINUE
C
C     MINC=INTERVAL BETWEEN PRINT POINTS.
C          =1,2,4,5
      MSTART=1
      NPAGES=20/MINC
      IPAGE=0
      MFINAL=0
      DO 610 L=1,NPAGES
      IPAGE=IPAGE+1
      MFINAL=MFINAL MINC*50
C
      WRITE (6,6000) IPAGE,(TITLE(K),K=1,8),(X(K),Z(K),
     1TSC(K),PLOCAL(K),TPC(K),HSC(K),HP(K),UI(K),Q(K),
     2QOA(K),REZ(K),K=MSTART,MFINAL,MINC)
      MSTART=MSTART 50*MINC
      IF(X(MSTART)-BITS)610,700,610
  610 CONTINUE
C
  700 CONTINUE
      DATA TT/600.,700.,800.,900.,1000.,1050.,1100.,1150.,
     11200.,1250.,1300.,1350.,1400.,1450.,1500.,1550.,1600.,
     21650.,1700.,1800./
      DATA VISL/.58,.54,.496,.449,.408,.393,.380,.368,.356,
     1.346,.336,.327,.319,.312,.305,.298,.292,.287,.281,.271/
      DATA TCKL/25.3,24.2,23.1,22.1,21.0,20.5,20.0,19.5,18.9,
     118.4,17.9,17.3,16.8,16.3,15.8,15.2,14.7,14.1,13.6,12.6/
 5777 GO TO 1
```

```
 500 FORMAT GENERATOR
     RESTORE
     TITLE=-X                                                     -A
     SPACE 2
     SUBCOOLED TOUT SPECIFIED TOO HIGH.
     END OF FORMAT
1000 FORMAT GENERATOR
     RESTORE
     WALL TEMPERATURE IN SUBCOOLED REGION
     NON CONVERGENT.
     END OF FORMAT
5999 FORMAT GENERATOR
     RESTORE
               CONDENSER DESIGN (GENERAL PARAMETERS)
     SPACE
     TITLE=-X                                                   -A
     SPACE
                              GEOMETRY
     SPACE
         NT          =       -I            COND LENGTH     =       -F4 FEET
     SPACE
    TUBE ID          =     -F4 INCHES      SUBC LENGTH     =       -F4 FEET
     SPACE
    TUBE OD          =     -F4 INCHES      TOTL LENGTH     =       -F4 FEET
     SPACE
    WALL XW          =     -F4 INCHES      TUBE P/D        =       -F2
     SPACE
    TUBE FLOW AREA=        -F5 SQ FT       SHELL ID        =       -F3 INCHES
     SPACE
    CENTER BODY OD=        -F4 INCHES      SHELL FLOW AREA=        -F4 SQ FT
     SPACE 2
                          THERMAL PARAMETERS
     SPACE
    POWER KW          QTOT,BTU/SEC      QCOND,BTU/SEC       QSUB,BTU/SEC
       -F2                 -F2               -F2                 -F2
     SPACE
            PRIMARY                               SECONDARY
     SPACE
      TPIN      =     -F2   DEG F           TSIN      =      -F2   DEG F
     SPACE
      TPOUT     =     -F2   DEG F           TSATCE    =      -F2   DEG F
     SPACE
      WP        =     -F4   LBM/SEC         TSOUT     =      -F2   DEG F
     END OF FORMAT
6001 FORMAT GENERATOR
     SPACE
      GP        =     -F3   LBM/FT2SEC      WS        =      -F5   LBM/SEC
     SPACE
      VP        =     -F3   FT/SEC          GS        =      -F3   LBM/FT2SEC
     SPACE
      REP       =     -F1                   VMAX      =      -F3   FT/SEC
     SPACE
                                            HSL       =      -F2   B/FT2HRDEG
     SPACE
                                            REL       =      -F1
     SPACE
      DPFRIC    =     -F3   PSIA            PEL       =      -F2
     SPACE
      DPRAD     =     -F3   PSIA            UIL       =      -F2   B/FT2HRDEG
      SPACE
                                            DELTAP    =      -F3   PSIA
```

```
      SPACE
       DPTOT     =      -F3   PSIA                DPFRIC    =        -F3   PSIA
      SPACE
                                                  DPMOM     =        -F3   PSIA
      END OF FORMAT
 6000 FORMAT GENERATOR
      RESTORE
      SPACE
                CONDENSER DESIGN (LOCAL CONDITIONS)                        -I
      SPACE
      TITLE=-X                                                        -A
      SPACE
    X         Z        TSC      PLOCAL     TPC       HSC       HP        UI
X   Q        QOA       REZ
             FT.      DEG F      PSIA     DEG F   HR UNITS HR UNITS HR UNITS
X B/SEC  B/FT2-HR
     -F5       -F4      -F2       -F3       -F2       -F1       -F1       -F1
X    -F2        -F1     -F1
      REPEAT 1
      END OF FORMAT
      END
```

```
$IBFTC CONSEC   FULIST,SDD
      SUBROUTINE CONSEC(JK)
C     SUBROUTINE INTEGRATES THE CONDENSER DEQ FOR
C     A SPECIFIED INLET VAPOR SATURATION TEMPERATURE.
C     THE FIRST 4 STEPS ARE RKG TO GENERATE 5
C     POINTS FOR THE LANCZOS SCHEME.
      DIMENSION VISL(20),VISG(20),TT(20),TCKL(20)
      DIMENSION BITS(1)
      DIMENSION WGHT(4),TPQ(100),QPRIM(100),X(1000),
     1TSC(1000),Q(1000),HSC(1000),TPC(1000),UI(1000),QOA(1000),
     2Z(1000)
      DIMENSION HP(1000),PLOCAL(1000),REZ(1000)
      COMMON SHFA,SHID,GP,VP,REP,DELPP,DPRAD,DPCEX,DPTOTP
      COMMON NT,ITP,ITWMAX,NCF,NQ,DT,XW,DIT,DLM,PODT,
     1WP,WS,GS,TSATIN,TPIN,POWER,QTOT,HP,HCON,TOLP,TOLW,
     2PF,XIN,AK,BK,EXN,TPQ,QPRIM,X,TSC,HSC,TPC,UI,QOA,JL,
     3WGHT,ERLIMT,DELTAX,Q,Z
      COMMON SLIPEX
      COMMON PLOCAL,REZ,DEQV
      COMMON DCB,ZTOT
      COMMON SIGMAC
      COMMON JHP
      DIMENSION ZZ(3),TSCC(3),QCC(3),XX(3)
      DIMENSION VAL(4),DVAL(4),REFER(4),ERR(4)
      DIMENSION DSTB(4)
      ERRMIN=ERLIMT/40.
      START=0.
 6000 MODE=4
      SAVE=DELTAX
      J=1
      X(J)=XIN
      TSC(J)=TSATIN
      Q(J)=0.
      Z(J)=0.
    1 K=0
      TSC1=TSC(J)
      X1=X(J)
      Q1=Q(J)
    5 CALL DERIV(X1,Q1,TSC1,VARJ,TPC1,DVAL,HSC1,UI1,FLUXI,HP1,REZ1)
C
C     STARTING VALUES OF THE DERIVATIVES ARE NOW
C     AVAILABLE FOR USE.
C
      IF(MODE-4)801,7,801
    7 VAL(1)=0.
      VAL(2)=DVAL(1)
      VAL(3)=TSC1
      VAL(4)=Q1
  801 IF(K)80,80,2
   80 HSC(J)=HSC1
      TPC(J)=TPC1
      UI(J)=UI1
      QOA(J)=FLUXI
      HP(J)=HP1
      REZ(J)=REZ1
      K=1
    2 CALL GLANCE(MODE,X1,DELTAX,DVAL,VAL,REFER)
      IF(MODF)3,4,3
    3 MODE=-4
      VARJ=VAL(2)
      TSC1=VAL(3)
```

```
      Q1=VAL(4)
      GO TO 5
C
    4 J=J 1
      Z(J)=VAL(1)
      VARJ=VAL(2)
      TSC(J)=VAL(3)
      Q(J)=VAL(4)
      X(J)=X1
      IF(J-5)6,777,777
    6 MODE=-4
      GO TO 1
C
  777 IXA=4
   10 TSC1=TSC(J)
      X1=X(J)
      Q1=Q(J)
      CALL DERIV(X1,Q1,TSC1,VARJ,TPC1,DVAL,HSC1,UI1,FLUXI,HP1,REZ1)
      HSC(J)=HSC1
      TPC(J)=TPC1
      UI(J)=UI1
      HP(J)=HP1
      REZ(J)=REZ1
      QOA(J)=FLUXI
      IF(TSC1-TPC1)609,609,21
   21 CONTINUE
    8 CALL GLANCE(MODE,X1,DELTAX,DVAL,VAL,REFER)
      IF(X1)340,340,222
C
C     CHECK THE STABILITY OF THE SYSTEM
C
  222 XSTAB=X1
      QSTAB=VAL(4)
      TSTAB=VAL(3)
      VSTAB=VAL(2)
      CALL DERIV(XSTAB,QSTAB,TSTAB,VSTAB,TPSTAB,DSTB,
     1HSTAB,UISTAB,FLXTAB,HPSTAB,REZTB)
      DO 273 K1=1,4
      IF(DELTAX*DSTB(K1)/VAL(K1)+.3)30,273,273
  273 CONTINUE
C
C     COMPUTE THE ERROR AND DOUBLE OR HALVE
C     THE QUALITY INTERVAL ACCORDINGLY.
C
   11 DO 20 K=1,4
   20 ERR(K)=.11*ABS((VAL(K)-REFER(K))/VAL(K))
      ERTOT=WGHT(1)*ERR(1)+WGHT(2)*ERR(2)+WGHT(3)*ERR(3)
     1+WGHT(4)*ERR(4)
      IF(ERTOT-ERLIMT)41,30,30
   41 IF(ERTOT-ERRMIN)40,40,50
C
C     STEP SIZE IS HALVED IF ALLOWABLE.
C
   30 IF(MODE+1)32,197,33
   33 MODE=-1
      GO TO 8
C
   32 MODE=0
      IXA=IXA+1
      GO TO 50
C
```

```
C       STEP SIZE IS DOUBLED IF ALLOWABLE
C
   40 IF(IXA-4)51,49,51
   49 MODE=-2
      IXA=0
      GO TO 50
   51 MODE=0
      IXA=IXA+1
   50 J=J 1
      Z(J)=VAL(1)
      VARJ=VAL(2)
      TSC(J)=VAL(3)
      Q(J)=VAL(4)
      X(J)=X1
      GO TO 10
C
C
  340 JK=J+1
      Z(JK)=VAL(1)
      VARJ=VAL(2)
      TSC(JK)=VAL(3)
      Q(JK)=VAL(4)
      X(JK)=X1
C
C       TEST TO SEE IF THE FINAL QUALITY IS
C       ZERO OR NEGATIVE. IF 0,CONTINUE. IF
C       NEGATIVE,THE VALUES AT X=0,J=JL= ARE
C       DETERMINED BY INITIATING A RKG
C       INTEGRATION USING VALUES AT JL-1 WITH
C       A DELTAX OF X(JK-1).
C
      IF(X(JK))105,106,106
  105 J=JK-1
      DELTAX=-X(J)
      MODE=4
  555 TSC1=TSC(J)
      X1=X(J)
      Q1=Q(J)
  556 CALL DERIV(X1,Q1,TSC1,VARJ,TPC1,DVAL,HSC1,UI1,FLUXI,HP1,REZ1)
      IF(MODE-4)557,558,557
  558 HSC(J)=HSC1
      TPC(J)=TPC1
      UI(J)=UI1
      HP(J)=HP1
      REZ(J)=REZ1
      QOA(J)=FLUXI
      VAL(1)=Z(J)
      VAL(2)=DVAL(1)
      VAL(3)=TSC1
      VAL(4)=Q1
  557 CALL GLANCE(MODE,X1,DELTAX,DVAL,VAL,REFER)
      IF(MODE)560,561,560
  560 MODE=-4
      VARJ=VAL(2)
      TSC1=VAL(3)
      Q1=VAL(4)
      GO TO 556
C
  561 JK=J+1
      Z(JK)=VAL(1)
      VARJ=VAL(2)
```

```
      TSC(JK)=VAL(3)
      Q(JK)=VAL(4)
      X(JK)=0.
  106 CALL DERIV(X(JK),Q(JK),TSC(JK),VARJ,TPC(JK),DVAL,HSC(JK),
     1UI(JK),QOA(JK),HP(JK),REZ(JK))
  111 RETURN
C
C
C     RESTART INTEGRATION. ALLOWABLE NUMBER OF
C     RESTARTS=5.
C
  197 IF(START-5.)198,198,199
  198 START=START+1.
      DELTAX=DELTAX/2.
      MODE=4
      K=0
      TSC1=TSC(J)
      X1=X(J)
      Q1=Q(J)
      CALL DERIV(X1,Q1,TSC1,VARJ,TPC1,DVAL,HSC1,UI1,FLUXI,HP1,REZ1)
      VAL(1)=Z(J)
      VAL(2)=DVAL(1)
      VAL(3)=TSC1
      VAL(4)=Q1
      GO TO 801
C
C
  199 WRITE (6,1002) ERLIMT,ERTOT,(ERR(K),K=1,4),
     1(X(K),Z(K),TSC(K),TPC(K),K=1,J)
      CALL SLITE(1)
      GO TO 111
  609 WRITE (6,1001) J,(X(K),Z(K),TSC(K),TPC(K),K=1,J)
      CALL SLITE(1)
      GO TO 111
C
C
 1001 FORMAT GENERATOR
      RESTORE
      J=           -I
      SPACE
      TEMPERATURE CROSS HAS OCCURRED.
      SPACE
         X                      Z                  TSC                 TPC
                               FT.               DEG F               DEG F
        -F5                    -F5                 -F2                 -F2
      REPEAT 1
      END OF FORMAT
 1002 FORMAT GENERATOR
      RESTORE
      NUMBER OF RESTARTS EXCEEDED
      CHECK ERROR LIMITS.
      SPACE
      ERLIMT=   -F5 ERTOT=    -F5 ERR=      -F5      -F5      -F5      -F5
      SPACE
         X                      Z                  TSC                 TPC
                               FT.               DEG F               DEG F
        -F5                    -F5                 -F2                 -F2
      REPEAT 1
      END OF FORMAT
      END
```

```
$IBFTC DERIV    FULIST,$DD
      SUBROUTINE DERIV(X1,QX,TSC1,VARJ,TPC1,DVAR,HSC1,UI1,
     1FLUXI,HP1,REZ1)
C
C     SUBROUTINE RETURNS VALUES OF THE DERIVATIVES AND
C     THE LOCAL CONDITIONS TO SUBROUTINE SECOND.
C
      DIMENSION VISL(20),VISG(20),TT(20),TCKL(20)
      DIMENSION BITS(1)
      DIMENSION WGHT(4),TPQ(100),QPRIM(100),X(1000),
     1TSC(1000),Q(1000),HSC(1000),TPC(1000),UI(1000),QOA(1000),
     2Z(1000)
      DIMENSION HP(1000),PLOCAL(1000),REZ(1000)
      COMMON SHFA,SHID,GP,VP,REP,DELPP,DPRAD,DPCEX,DPTOTP
      COMMON NT,ITP,ITWMAX,NCF,NQ,DT,XW,DIT,DLM,PODT,
     1WP,WS,GS,TSATIN,TPIN,POWER,QTOT,HP,HCON,TOLP,TOLW,
     2PF,XIN,AK,BK,EXN,TPQ,QPRIM,X,TSC,HSC,TPC,UI,QOA,JL,
     3WGHT,ERLIMT,DELTAX,Q,Z
      COMMON SLIPEX
      COMMON PLOCAL,REZ,DEQV
      COMMON DCB,ZTOT
      COMMON SIGMAC
      COMMON JHP
      DIMENSION TEMP(20),CPLI(20),CPNA(20),CPNAK(20)
      DIMENSION DVAR(4)
      NTQ=NQ+1
      CALL LININT(QPRIM,TPQ,QX,TPC1,OUT,NTQ)
      TP=TPC1
C
C     COMPUTE DERIVATIVES
      SIG=SIGMAC
      WSS=WS
      TEM=TSC1+459.69
      CALL THERMA(PU,TEM,PVAP1,HL1,HG1,SL1,SV1,VL1,VG1,
     1CPG1,CPL1,EX,ALPHA,-1.,0.,HS,SS,VSH,CPSH,EXS,AVS)
      HFG1=HG1-HL1
      RHOL1=1./VL1
   16 IF(PF)22,23,24
   22 CALL LININT(TEMP,CPNAK,TP,CPAV,OUT,20)
      GO TO 25
   23 CALL LININT(TEMP,CPLI,TP,CPAV,OUT,20)
      GO TO 25
   24 CALL LININT(TEMP,CPNA,TP,CPAV,OUT,20)
   25 RHOG1=1./VG1
      CALL LININT(TT,VISL,TSC1,VISL1,OUT,20)
      CALL LININT(TT,VISG,TSC1,VISG1,OUT,20)
      PHI1=PMULT(X1,RHOL1,RHOG1,VISL1,VISG1,EXN)
      PVAP1=PVAP1/14.696
      DPDT=1./(PVAP1*14.696*144.*(18717.22/TEM**2-.53299/TEM))
   26 DTDP1=DPDT
      RELOC=DEQV*GS*300./VISL1
      FRIC=.316/RELOC**.25
      GROUP=-12.*PHI1*FRIC*GS**2/2./RHOL1/32.2/DEQV
      IF(HCON)2,2,3
    2 CALL CONDH(TSC1,WSS,X1,SIG,HSC1,REVV,GROUP)
      REZ1=REVV
      GO TO 53
    3 CONTINUE
      HSC1=HCON
   53 CONTINUE
C
```

```
      IF(JHP)51,51,52
   51 CONTINUE
      KC=0
      RDP=0.
      CALL SHELL(0,TPC1,TPC1,RDP,HPP,KC)
      HP1=HPP
      GO TO 57
   52 HP1=HP(1)
   57 CONTINUE
C
C     DETERMINE LOCAL Q/A AND LOCAL UI BY SUCCESSIVE
C     APPROXIMATION
C
      TCWM1=0.
      ITW=1
      TWO=TPC1
      TWI=TSC1
    4 TCWM2=AK+BK*(TWO+TWI)
      DELTA=(TCWM2-TCWM1)/TCWM2
      IF(ABS(DELTA) TOLW)10,10,5
    5 RESW=XW*DIT/12./TCWM2/DLM
      UI1=1./(1./HSC1+RESW+DIT/HP1/DT)
      FLUXI=UI1*(TSC1-TPC1)
      FLUXO=FLUXI*(DIT/DT)
      TCWM1=TCWM2
      TWI=TSC1-FLUXI/HSC1
      TWO=TPC1+FLUXO/HP1
      IF(ITW-ITWMAX)6,6,7
    7 WRITE (6,1000) X1
      CALL EXIT
    6 ITW=ITW+1
      GO TO 4
   10 CONTINUE
      C1=WS*HFG1/3.1416/DIT*12./UI1/FLOAT(NT)*3600.
      IF(SLIPEX)61,61,62
   61 SLIP=1.
      GO TO 63
   62 CONTINUE
      SLIP=(RHOL1/RHOG1)**(1./SLIPEX)
   63 CONTINUE
   27 DVHAT=((1.+X1*(SLIP-1.))*(1./SLIP-RHOG1/RHOL1)+
     1((1.-X1)*RHOG1/RHOL1+X1/SLIP)*(SLIP-1.))/RHOG1
      C2=WS*HFG1/WP/CPAV
C
C     TEST TO SEE IF CONDENSER IS COUNTERFLOW OR
C     COFLOW.
C
      IF(NCF)29,29,28
   29 C2= C2
      GO TO 30
   28 CONTINUE
C
   30 AOFX=C1*GROUP*DTDP1/(TSC1-TPC1)**2
      GROUP2=C1/(TSC1-TPC1)**2
      BOFX=GROUP2*( DVHAT*DTDP1+C2)
      IF(X1-XIN)40,41,40
   41 DLDX=-C1/(TSC1-TPC1)
      GO TO 42
   40 DLDX=VARJ
   42 DDLDX=AOFX*DLDX+BOFX
      DTSDX=GROUP*DTDP1*DLDX-GS**2/32.2*DVHAT*DTDP1
```

```
      DQDX=-WS*HFG1
      DVAR(1)=DLDX
      DVAR(2)=DDLDX
      DVAR(3)=DTSDX
      DVAR(4)=DQDX
2000  RETURN
      DATA TT/600.,700.,800.,900.,1000.,1050.,1100.,1150.,
     11200.,1250.,1300.,1350.,1400.,1450.,1500.,1550.,1600.,
     21650.,1700.,1800./
      DATA VISL/.58,.54,.496,.449,.408,.393,.380,.368,.356,
     1.346,.336,.327,.319,.312,.305,.298,.292,.287,.281,.271/
      DATA VISG/.0349,.0365,.0379,.0395,.0411,.0419,.0427,
     1.0435,.0442,.0449,.0457,.0464,.0471,.0478,.0485,.0493,
     2.0499,.0506,.0512,.0524/
      DATA TCKL/25.3,24.2,23.1,22.1,21.0,20.5,20.0,19.5,18.9,
     118.4,17.9,17.3,16.8,16.3,15.8,15.2,14.7,14.1,13.6,12.6/
      DATA TEMP/400.,500.,550.,600.,650.,700.,
     1750.,800.,850.,900.,950.,1000.,1050.,1100.,1150.,1200.,
     21300.,1400.,1500.,1600./
      DATA CPNAK/.2166,.2138,.2127,.2118,.2110,.2103,
     1.2097,.2093,.2090,.2088,.2088,.2089,.2090,.2093,.2096,
     2.210,.211,.2122,.2139,.2159/
      DATA CPNA/.320,.316,.314,.312,.310,.308,
     1.306,.304,.3032,.3022,.3014,.3008,.3004,.3,.3,
     2.3,.3006,.3018,.3038,.3064/
      DATA CPLI/.992,.992,.992,.992,.992,.992,.992,
     1.992,.992,.992,.992,.992,.992,.992,.992,.992,.992,
     2.992,.992,.992/
1000  FORMAT GENERATOR
      RESTORE
      WALL TEMPERATURE NON CONVERGENT.
      X=           -F5
      END OF FORMAT
      END
```

```
$IBFTC CONDH    FULIST,SDD
      SUBROUTINE CONDH(TLOC,WS,X1,SIGMAC,HCON,RES,GROUP)
C
C     SUBROUTINE RETURNS LOCAL CONDENSING HEAT
C     TRANSFER COEFFICIENT BASED ON THE SUM
C     OF A VAPOR PHASE AND A LIQUID FILM
C     RESISTANCE
      DIMENSION VISL(20),VISG(20),TT(20),TCKL(20)
      DIMENSION BITS(1)
      DIMENSION WGHT(4),TPQ(100),QPRIM(100),X(1000),
     1TSC(1000),Q(1000),HSC(1000),TPC(1000),UI(1000),QOA(1000),
     2Z(1000)
      DIMENSION HP(1000),PLOCAL(1000),REZ(1000)
      COMMON SHFA,SHID,GP,VP,REP,DELPP,DPRAD,DPCEX,DPTOTP
      COMMON NT,ITP,ITWMAX,NCF,NQ,DT,XW,DIT,DLM,PODT,
     1WP,WS,GS,TSATIN,TPIN,POWER,QTOT,HP,HCON,TOLP,TOLW,
     2PF,XIN,AK,BK,EXN,TPQ,QPRIM,X,TSC,HSC,TPC,UI,QOA,JL,
     3WGHT,ERLIMT,DELTAX,Q,Z
      COMMON SLIPEX
      COMMON PLOCAL,REZ,DEQV
      COMMON DCB,ZTOT
      COMMON SIGMAC
      COMMON JHP
C
      DIMENSION REF(10),TAU(6),CONRL(10,6)
      DIMENSION T(20),THCONK(20),VISK(20)
    1 TRANK=TLOC+459.69
      CALL THERMA(PU,TRANK,PVAP1,HL1,HG1,SL1,SV1,VL1,VG1,
     1CPG1,CPL1,EX,ALPHA,-1.,0.,HS,SS,VSH,CPSH,EXS,AVS)
    2 HFG1=HG1-HL1
      RHOL1=1./VL1
      RHOG1=1./VG1
      CALL LININT(T,THCONK,TLOC,THCON1,OUT,20)
      CALL LININT(T,VISK,TLOC,VISK1,OUT,20)
    3 PRESS=144.*PVAP1
    4 DPDT=PRESS*(18717.22/TRANK**2-.53299/TRANK)
    5 GROVP=39.1*32.2/2./3.1416/1545./TRANK
      GROUP1=SQRT(GROVP)
      HV=3600.*SIGMAC*HFG1*GROUP1*(DPDT-PRESS/2./TRANK)
C
C     COMPUTE LIQUID FILM RESISTANCE FROM THE
C     DUKLER FILM THICKNESS
C
      IF(X1-XIN)6,7,6
    7 RES=100.
      REST=0.
      TVSTAR=500.
      RATIO=32.2*3600.**2*RHOL1**2/VISK1**2
      GO TO 801
    6 DPDL=GROUP
      FTERM=(RHOG1-DPDL)/RHOL1
      RAD=DIT/24.
      RATIO=32.2*3600.**2*RHOL1**2/VISK1**2
      TVSTAR=FTERM*RAD/2.*RATIO**(1./3.)
      IF(TVSTAR-500.)20,20,30
   30 TVSTAR=500.
   20 CONTINUE
      TVSL=ALOG10(TVSTAR)
C
      GAMMA=WS*(1.-X1)*43200./3.1416/DIT/FLOAT(NT)
    8 RES=4.*GAMMA/VISK1
```

```
      REST=RES
      IF(RES-100.)35,21,21
   35 RES=100.
   21 CONTINUE
  801 CONTINUE
      REZ1=ALOG10(RES)
      CALL INTERP(REF,TAU,CONRL,REZ1,TVSL,CONRU,10,6,ERR)
      CONRL1=EXP(2.303*CONRU)
      HL=THCON1*RATIO**(1./3.)*CONRL1
      HCON=1./(1./HV+1./HL)
      RES=REST
  500 RETURN
C
      DATA BITS/O-377777777777/
      DATA T/600.,700.,800.,900.,1000.,1050.,1100.,1150.,
     11200.,1250.,1300.,1350.,1400.,1450.,1500.,1550.,1600.,
     21650.,1700.,1800./
      DATA VISK/.58,.54,.496,.449,.408,.393,.380,.368,.356,
     1.346,.336,.327,.319,.312,.305,.298,.292,.287,.281,.271/
      DATA THCONK/25.3,24.2,23.1,22.1,21.0,20.5,20.0,19.5,18.9,
     118.4,17.9,17.3,16.8,16.3,15.8,15.2,14.7,14.1,13.6,12.6/
      DATA REF/2.,2.30103,2.47712,2.77815,2.90309,3.0,3.30103,
     13.47712,3.8451,4.0/
      DATA TAU/-10.,1.30103,1.69897,2.00,2.30103,2.69897/
      DATA CONRL/-.69037,-.72816,-.88273,-.91722,-.96257,
     1-1.00044,-1.13077,-1.20761,-1.38722,-1.47496,-.20066,
     2-.33724,-.42597,-.59346,-.67162,-.73283,-.92082,-1.03621,
     3-1.28819,-1.39794,.00432,-.14267,-.24033,-.42022,-.49757,
     4-.56067,-.76700,-.88606,-1.15490,-1.27572,.14922,-.00437,
     5-.10237,-.28400,-.36653,-.43180,-.64782,-.76955,-1.05061,
     6-1.16749,.25285,.13033,.04532,-.13077,-.20761,-.27165,
     7-.48812,-.55284,-.92082,-1.05061,.53148,.38202,.28330,
     8.09691,.01284,-.05552,-.27984,-.41454,-.71670,-.84771/
C
      END
```

```
$IBFTC SHELL    FULIST,SDD
      SUBROUTINE SHELL(JK,TEMP1,TEMP2,RADPL,HP1,KC)
C
C     IF(JK)=0 COMPUTES HP1
C     IF(JK=1 COMPUTES FRICTION AND RADIAL
C     PRESSURE DROP
      DIMENSION REG(5),EPSMAX(5)
      DIMENSION TEMP(20),CPNAK(20),CPLI(20),CPNA(20),
     1RHONAK(20),RHOLI(20),RHONA(20),VISNAK(20),VISLI(20),
     2VISNA(20),TCNAK(20),TCLI(20),TCNA(20)
      DIMENSION VISL(20),VISG(20),TT(20),TCKL(20)
      DIMENSION BITS(1)
      DIMENSION WGHT(4),TPQ(100),QPRIM(100),X(1000),
     1TSC(1000),Q(1000),HSC(1000),TPC(1000),UI(1000),QOA(1000),
     2Z(1000)
      DIMENSION HP(1000),PLOCAL(1000),REZ(1000)
      COMMON SHFA,SHID,GP,VP,REP,DELPP,DPRAD,DPCEX,DPTOTP
      COMMON NT,ITP,ITWMAX,NCF,NQ,DT,XW,DIT,DLM,PODT,
     1WP,WS,GS,TSATIN,TPIN,POWER,QTOT,HP,HCON,TOLP,TOLW,
     2PF,XIN,AK,BK,EXN,TPQ,QPRIM,X,TSC,HSC,TPC,UI,QOA,JL,
     3WGHT,ERLIMT,DELTAX,Q,Z
      COMMON SLIPEX
      COMMON PLOCAL,REZ,DEQV
      COMMON DCB,ZTOT
      COMMON SIGMAC
      COMMON JHP
C
C     INITIALLY COMPUTE PROPERTIES
C
    1 IF(PF)2,3,4
    2 CALL LININT(TEMP,CPNAK,TEMP1,CP1,OUT,20)
      CALL LININT(TEMP,CPNAK,TEMP2,CP2,OUT,20)
      CALL LININT(TEMP,RHONAK,TEMP1,RHO1,OUT,20)
      CALL LININT(TEMP,RHONAK,TEMP2,RHO2,OUT,20)
      CALL LININT(TEMP,VISNAK,TEMP1,VIS1,OUT,20)
      CALL LININT(TEMP,VISNAK,TEMP2,VIS2,OUT,20)
      CALL LININT(TEMP,TCNAK,TEMP1,TC1,OUT,20)
      CALL LININT(TEMP,TCNAK,TEMP2,TC2,OUT,20)
      GO TO 5
    3 CALL LININT(TEMP,CPLI,TEMP1,CP1,OUT,20)
      CALL LININT(TEMP,CPLI,TEMP2,CP2,OUT,20)
      CALL LININT(TEMP,RHOLI,TEMP1,RHO1,OUT,20)
      CALL LININT(TEMP,RHOLI,TEMP2,RHO2,OUT,20)
      CALL LININT(TEMP,VISLI,TEMP1,VIS1,OUT,20)
      CALL LININT(TEMP,VISLI,TEMP2,VIS2,OUT,20)
      CALL LININT(TEMP,TCLI,TEMP1,TC1,OUT,20)
      CALL LININT(TEMP,TCLI,TEMP2,TC2,OUT,20)
      GO TO 5
    4 CALL LININT(TEMP,CPNA,TEMP1,VIS1,OUT,20)
      CALL LININT(TEMP,CPNA,TEMP2,VIS2,OUT,20)
      CALL LININT(TEMP,RHONA,TEMP1,RHO1,OUT,20)
      CALL LININT(TEMP,RHONA,TEMP2,RHO2,OUT,20)
      CALL LININT(TEMP,VISNA,TEMP1,VIS1,OUT,20)
      CALL LININT(TEMP,VISNA,TEMP2,VIS2,OUT,20)
      CALL LININT(TEMP,TCNA,TEMP1,TC1,OUT,20)
      CALL LININT(TEMP,TCNA,TEMP2,TC2,OUT,20)
C
    5 CONTINUE
      IF(KC)6,6,7
    6 SHID=DT*PODT*SQRT(2.*SQRT(3.)/3.1416*FLOAT(NT))
      SHFA=FLOAT(NT)*3.1416*DT**2/4.*(2.*SQRT(3.)/
```

```
     13.1416*PODT**2-1.)/144.
      NT1=1
      I=1
 4111 NT1=NT1+6*(I-1)
      IF(NT1-NT)4112,4113,4114
 4112 I=I 1
      GO TO 4111
 4114 I=I 1
 4113 CONTINUE
      PITCH=PODT*DT
      RATIO=PITCH/SQRT(SHID**2-PITCH**2)
      ANG=ATAN(RATIO)
      NOUTR=6*(I-1)
      XNROWS=FLOAT(NOUTR)
      XNT1=FLOAT(NT)
      WETPER=3.1416*(SHID+XNT1*DT)+XNROWS*(2.*
     1PITCH/SQRT(3.)-SHID*ANG)
      DEQSH=4.*SHFA*12./WETPER
      GP=WP/SHFA
      KC=1
C
    7 IF(JK)8,8,80
C
C     COMPUTE LOCAL PRIMARY HEAT TRANSFER
C     COEFFICIENT.
C
    8 RE1=DEQSH*3600.*GP/VIS1
      PR1=CP1*VIS1/TC1
      PEC1=RE1*PR1
      REPL=ALOG10(RE1)
      CALL LININT(REG,EPSMAX,REPL,EPS,OUT,5)
      EPSP=EXP(2.303*EPS)
      PSIBAR=1.-1.82/PR1/EPSP**1.4
      ALPHA=.93+10.81*PODT-2.01*PODT**2
      BETA=.0252*PODT**.273
      GAMMA=.8
      IF(PSIBAR)666,666,667
  666 ZNUP=ALPHA
      GO TO 668
  667 CONTINUE
      ZNUP=ALPHA+BETA*(PSIBAR*PEC1)**GAMMA
  668 CONTINUE
      HP1=ZNUP*TC1/DEQSH
    9 RETURN
C
C     COMPUTE FRICTION PRESSURE DROP BASED
C     ON AVERAGE SHELL TEMPERATURE.
C
   80 TPAV=(TEMP1+TEMP2)/2.
      IF(PF)81,82,83
   81 CALL LININT(TEMP,RHONAK,TPAV,RHOAV,OUT,20)
      CALL LININT(TEMP,VISNAK,TPAV,VISAV,OUT,20)
      GO TO 85
   82 CALL LININT(TEMP,RHOLI,TPAV,RHOAV,OUT,20)
      CALL LININT(TEMP,VISLI,TPAV,VISAV,OUT,20)
      GO TO 85
   83 CALL LININT(TEMP,RHONA,TPAV,RHOAV,OUT,20)
      CALL LININT(TEMP,VISNA,TPAV,VISAV,OUT,20)
   85 CONTINUE
      REP=DEQSH*3600.*GP/VISAV
      VP=GP/RHOAV
```

```
      FRIC=.316/REP**.25
      DELPP=FRIC*ZTOT*GP**2/2./RHOAV/32.2/DEQSH
     1/144.
      IF(RADPL)500,500,501
C
C     COMPUTE RADIAL PRESSURE DROP
C
  501 F=0.
      XNT=FLOAT(NT)
      DO 502 J=2,I
      NROW=J-1
      F1=FLOAT(NROW)/XNT
      F=F F1**1.84
  502 CONTINUE
      TERM1=.25/(PODT-1.)**1.84
      TERM2=.118/(PODT-1.)**2.92
      GAM=(TERM1+TERM2)*F
      TERMI=(VIS1*RADPL/12./WP/3600.)**.16
      TERMO=(VIS2*RADPL/12./WP/3600.)**.16
      TERM3=(WP/RADPL*144./DT)**2
C
      DPRAD=(TERMI/RHO1+TERMO/RHO2)*.562/32.2/144.
     1*GAM*TERM3
      GO TO 510
  500 DPRAD=0.
  510 CONTINUE
      DPTOTP=DELPP+DPRAD
 1067 RETURN
C
      DATA REG/3.,4.,5.,6.,7./
      DATA EPSMAX/.477,1.2455,2.072,2.9775,3.929/
      DATA TEMP/400.,500.,550.,600.,650.,700.,750.,800.,
     1850.,900.,950.,1000.,1050.,1100.,1150.,1200.,1300.,
     21400.,1500.,1600./
C
      DATA CPNAK/.2166,.2138,.2126,.2118,.2110,.2103,.20975,
     1.2093,.2090,.2088,.2088,.2089,.2090,.20925,.2096,.2100,
     2.2109,.2122,.2138,.2158/
C
      DATA CPLI/1.0115,1.0099,1.0091,1.0083,1.0075,1.0067,1.0059,
     11.0051,1.0043,1.0035,1.0027,1.0019,1.0011,1.0003,0.9995,
     20.9987,0.9971,0.9955,0.9939,0.9923/
C
      DATA CPNA/.3252,.3175,.3142,.3114,.3090,.3070,.3055,
     1.3042,.3032,.3022,.3015,.3008,.3004,.3000,.2999,.3000,
     2.3006,.3018,.3038,.3064/
C
      DATA RHONAK/51.42,50.58,50.16,49.74,49.32,48.90,
     148.48,48.06,47.64,47.22,46.80,46.38,45.96,45.54,45.12,
     244.70,43.84,43.00,42.16,41.32/
C
      DATA RHOLI/31.27,30.98,30.85,30.70,30.56,30.42,30.28,
     130.15,30.01,29.87,29.74,29.60,29.48,29.35,29.23,
     229.10,28.85,28.60,28.36,28.12/
C
      DATA RHONA/56.48,55.50,55.01,54.54,54.07,53.60,53.14,
     152.65,52.21,51.78,51.35,50.92,50.50,50.11,49.71,49.33,
     248.59,47.86,47.17,46.47/
C
      DATA VISNAK/.895,.780,.730,.688,.648,.612,.580,.551,
     1.523,.500,.476,.454,.435,.418,.402,.388,.362,.342,
```

```
      2.323,.308/
C
       DATA VISLI/1.37,1.22,1.16,1.10,1.055,1.01,.973,.935,
      1.900,.866,.840,.812,.786,.765,.744,.725,.686,.652,
      2.620,.592/
C
       DATA VISNA/.860,.805,.777,.751,.725,.699,.674,.648,
      1.624,.600,.576,.556,.533,.513,.493,.476,.444,.416,
      2.392,.372/
C
       DATA TCNAK/14.34,14.82,14.93,15.01,15.067,15.115,15.146,
      115.167,15.173,15.160,15.135,15.096,15.040,14.985,14.925,
      214.86,14.732,14.587,14.432,14.266/
C
       DATA TCLI/26.62,26.775,26.855,26.928,27.005,27.08,
      127.16,27.24,27.32,27.395,27.47,27.55,27.63,27.705,
      227.78,27.86,28.01,28.16,28.32,28.48/
C
       DATA TCNA/48.90,46.25,45.04,43.97,42.95,42.02,41.20,
      140.42,39.63,38.95,38.25,37.63,37.06,36.53,36.01,35.53,
      234.60,33.72,32.94,32.23/
       END
```

```
$IBFTC TPRIMC  FULIST,SDD
      SUBROUTINE TPRIMC
C
C     SUBROUTINE EVALUATES PRIMARY TEMPERATURE
C     PROFILE AS A FUNCTION OF Q TRANSFERRED.
C
      DIMENSION VISL(20),VISG(20),TT(20),TCKL(20)
      DIMENSION BITS(1)
      DIMENSION WGHT(4),TPQ(100),QPRIM(100),X(1000),
     1TSC(1000),Q(1000),HSC(1000),TPC(1000),UI(1000),QOA(1000),
     2Z(1000)
      DIMENSION HP(1000),PLOCAL(1000),REZ(1000)
      COMMON SHFA,SHID,GP,VP,REP,DELPP,DPRAD,DPCEX,DPTOTP
      COMMON NT,ITP,ITWMAX,NCF,NQ,DT,XW,DIT,DLM,PODT,
     1WP,WS,GS,TSATIN,TPIN,POWER,QTOT,HP,HCON,TOLP,TOLW,
     2PF,XIN,AK,BK,EXN,TPQ,QPRIM,X,TSC,HSC,TPC,UI,QOA,JL,
     3WGHT,ERLIMT,DELTAX,Q,Z
      COMMON SLIPEX
      COMMON PLOCAL,REZ,DEQV
      COMMON DCB,ZTOT
      COMMON SIGMAC
      COMMON JHP
      DIMENSION TEMP(20),CPLI(20),CPNA(20),CPNAK(20)
      DELTAQ=QTOT/FLOAT(NQ)
C
C     TEST TO SEE IF PARALLEL OR COUNTERFLOW.
C
      IF(NCF)100,100,200
  100 K5=NQ+1
      TPQ(K5)=TPIN
      QPRIM(K5)=QTOT
   50 TP=TPQ(K5)
      IT1=1
    6 IF(PF)2,3,4
    2 CALL LININT(TEMP,CPNAK,TP,CPAV,OUT,20)
      GO TO 5
    3 CALL LININT(TEMP,CPLI,TP,CPAV,OUT,20)
      GO TO 5
    4 CALL LININT(TEMP,CPNA,TP,CPAV,OUT,20)
    5 TP1=TPQ(K5)+DELTAQ/WP/CPAV
      TZ=(TP1+TPQ(K5))/2.
      IF(ABS(TZ-TP) TOLP)7,7,8
    8 IF(IT1-ITP)10,11,11
   11 WRITE (6,1000) K5
      CALL SLITE(2)
      GO TO 500
   10 IT1=IT1+1
      TP=TZ
      GO TO 6
    7 K5=K5-1
      TPQ(K5)=TP1
      QPRIM(K5)=QPRIM(K5+1)-DELTAQ
      IF(K5-1)51,51,50
   51 QPRIM(1)=0.
      GO TO 500
C
C     PARALLEL FLOW
C
  200 K6=NQ+1
      K5=1
      TPQ(K5)=TPIN
```

```
      QPRIM(K5)=0.
   60 TP=TPQ(K)
      IT1=1
   16 IF(PF)22,23,24
   22 CALL LININT(TEMP,CPNAK,TP,CPAV,OUT,20)
      GO TO 25
   23 CALL LININT(TEMP,CPLI,TP,CPAV,OUT,20)
      GO TO 25
   24 CALL LININT(TEMP,CPNA,TP,CPAV,OUT,20)
   25 TP1=TPQ(K5)+DELTAQ/WP/CPAV
      TZ=(TP1+TPQ(K5))/2.
      IF(ABS(TZ-TP) TOLP)27,27,28
   28 IF(IT1-ITP)30,31,31
   31 WRITE (6,1000) K5
      CALL SLITE(2)
      GO TO 500
   30 IT1=IT1+1
      TP=TZ
      GO TO 16
   27 K5=K5+1
      TPQ(K5)=TP1
      QPRIM(K5)=QPRIM(K5-1)+DELTAQ
      IF(K5-K6)60,61,61
   61 QPRIM(K6)=QTOT
      GO TO 500
C
C
C
C
      DATA TEMP/400.,500.,550.,600.,650.,700.,
     1750.,800.,850.,900.,950.,1000.,1050.,1100.,1150.,1200.,
     21300.,1400.,1500.,1600./
      DATA CPNAK/.2166,.2138,.2127,.2118,.2110,.2103,
     1.2097,.2093,.2090,.2088,.2088,.2089,.2090,.2093,.2096,
     2.210,.211,.2122,.2139,.2159/
C
      DATA CPNA/.320,.316,.314,.312,.310,.308,
     1.306,.304,.3032,.3022,.3014,.3008,.3004,.3,.3,
     2.3,.3006,.3018,.3038,.3064/
C
C
      DATA CPLI/.992,.992,.992,.992,.992,.992,.992,
     1.992,.992,.992,.992,.992,.992,.992,.992,.992,.992,
     2.992,.992,.992/
  500 RETURN
 1000 FORMAT GENERATOR
      RESTORE
      PRIMARY TEMPERATURE NON CONVERGENT
      SPACE 5
      K5=-I
      END OF FORMAT
      END
```

```
$IBFTC PMULT    FULIST,SDD
C       FUNCTION RETURNS 2-PHASE MULTIPLIER
C
        FUNCTION PMULT(X,RHOL,RHOG,VISL,VISG,EX)
      1 A=VISL/VISG-1.
        B=RHOL/RHOG-1.
        C=1./(1.+X*A)
        D=1.+X*B
C
        PMULT=C**EX*D
     50 RETURN
        END
```

```
$IBFTC GLANCE  FULIST,SDD
      SUBROUTINE GLANCE(MG,TF,HG,DG,YG,ZG)
C
C     MG= MODE INDICATOR
C     TF= INDEPENDENT VARIABLE
C     HG= STEP SIZE
C     DG(I)= DERIVATIVE OF YG EVALUATED AT TF.
C     YG(I)= DEPENDENT VARIABLE. INTEGRATED VALUE OF DG(I) AT T.
C     ZG(I)=REF. VALUE OF YG(I) FOR ESTIMATE OF TRUNCATION ERROR
C           I=1,2,.....,IMAX LESS THAN OR EQUAL TO 30.
C
C     INSTRUCTIONS TO GLANCE ARE MADE AS FOLLOWS
C      M= N   START INTEGRATION WITH N DEPENDENT VARIABLES
C      M=0    CONTINUE,NO CHANGE
C      M= 1   HALVE HG REPEAT LAST STEP
C      M= 2   DOUBLE H,TAKE NEXT STEP
C      M= 4   CONTINUE USING RUNGE KUTTA GILL METHOD
C
C     GLANCE INDICATES THE ACTION TAKEN AS FOLLOWS
C      M=0    STEP WAS COMPLETED WITHOUT CHANGE
C      M= 1   STEP WAS REPEATED WITH HG HALVED
C      M= 2   STEP WAS TAKEN WITH HG DOUBLED
C      M= 3   STEP WAS PARTIALLY COMPLETED R-K-G.
C      M= 5   ERROR,M WAS NOT POSITIVE ON FIRST CALL
C
      DIMENSION YG(30),ZG(30),DG(30),Y(9,30),D(9,30)
      DIMENSION A(4),B(4),C(4),J(7),B2(5),B4(5),DY(30),DYG(30),Q(30)
      M=MG
      T=TF
      H=HG
      IF(M)10,10,5
    5 IXA=0
   10 I=IXA+1
   90 GO TO (100,200,450),I
  100 IF(M)110,110,130
  110 M=-5
      GO TO 760
  130 HALFE=0.5*H
      B2(1)=.0234375
      B2(2)=-.15625
      B2(3)=.703125
      B2(4)=.46875
      B2(5)=-.0390625
      B4(1)=-.0390625
      B4(2)=.21875
      B(4)=-.546875
      B4(4)=1.09375
      B4(5)=.2734375
      A(1)=0.5
      A(2)=0.29289322
      A(3)=1.7071068
      A(4)=0.1666667
      B(1)=1.0
      B(2)=A(2)
      B(3)=A(3)
      B(4)=0.33333333
      C(1)=A(1)
      C(2)=A(2)
      C(3)=A(3)
      C(4)=A(1)
      J(1)=0
```

```
      J(2)=1
      J(3)=-1
      J(4)=0
      J(5)=-1
      J(6)=-1
      J(7)=0
  150 IMAX=M
      M=-3
      DO 151 I=1,IMAX
      Y(1,I)=YG(I)
      D(1,I)=DG(I)
  151 Q(I)=0.0
      T=T HALFE
      N=2
      NL=1
      L=1
      IXA=1
  160 LL=N-NL
      DO 161 I=1,IMAX
      DY(I)=D(LL,I)*H
      R=A(L)*DY(I)-B(L)*Q(I)
      Y(N,I)=Y(LL,I)+R
      Q(I)=Q(I)+3.*R-C(L)*DY(I)
  161 CONTINUE
  170 IF(M)750,180,750
  180 DO 181 I=1,IMAX
  181 ZG(I)=Y(N,I)
      GO TO 750
  200 DO 201 I=1,IMAX
  201 D(N,I)=DG(I)
  205 IF(L-3)210,240,260
  210 IF(L-2)230,220,230
  220 T=T HALFE
  230 M=-3
      NL=0
      GO TO 250
  240 M=0
  250 L=L 1
      GO TO 160
  260 IF(M)270,270,150
  270 IF(N-5)280,290,280
  280 N=N 1
      GO TO 320
  290 IF(M+4)350,300,350
  300 DO 310 I=1,IMAX
      DO 310 M=1,4
      Y(M,I)=Y(M+1,I)
      D(M,I)=D(M+1,I)
  310 CONTINUE
  320 M=-3
      T=T HALFE
      NL=1
      L=1
      GO TO 160
  350 M=0
      IXA=2
      T=T H
      ASSIGN 430 TO IXC
      GO TO 360
  400 DO 410 I=1,IMAX
      Y(N,I)=.20*(Y(N-1,I)+Y(N-2,I)+Y(N-3,I)+Y(N-4,I)+Y(N-5,I)+V1*D(N-1,
```

```
   1I)+V2*D(N-2,I)+V3*D(N-3,I)+V4*D(N-4,I)+V5*D(N-5,I))
410 CONTINUE
    GO TO IXC,(430,750)
430 DO 440 I=1,IMAX
    ZG(I)=Y(6,I)
440 CONTINUE
    ASSIGN 750 TO IXC
    GO TO 750
450 DO 451 I=1,IMAX
451 D(N,I)=DG(I)
    KAY=K+4
455 IF(M)460,550,150
460 IF(M+2)550,470,490
470 IF(K)480,650,480
480 IF(J(KAY))550,550,650
490 IF(K)500,700,500
500 IF(J(KAY))700,550,550
550 IF(K)560,580,570
560 K=K 1
    GO TO 580
570 K=K 1
580 M=0
    T=T H
585 IF(N-9)590,600,600
590 N=N 1
    GO TO 620
600 DO 610 I=1,IMAX
    DO 610 L=1,8
    Y(L,I)=Y(L+1,I)
    D(L,I)=D(L+1,I)
610 CONTINUE
620 DO 621 I=1,IMAX
621 ZG(I)=.20*(Y(N-2,I)+Y(N 3,I)+Y(N-4,I)+Y(N-5,I)+Y(N-6,I)+W1*D(N-2
   1,I) W2*D(N-3,I)+W3*D(N-4,I)+W4*D(N-5,I)+W5*D(N-6,I))
    GO TO IXD,(400,660)
650 H=H H
    T=T H
    N=11
    ASSIGN 660 TO IXD
    GO TO 620
660 DO 670 I=1,IMAX
    Y(2,I)=Y(3,I)
    D(2,I)=D(3,I)
    Y(3,I)=Y(5,I)
    D(3,I)=D(5,I)
    Y(4,I)=Y(7,I)
    D(4,I)=D(7,I)
    Y(5,I)=Y(9,I)
    D(5,I)=D(9,I)
670 CONTINUE
360 N=6
    K=3
    ASSIGN 400 TO IXB
    ASSIGN 400 TO IXD
370 V1=14.520833*H
    V2= 14.291667*H
    V3=19.50*H
    V4= 6.7083333*H
    V5=1.9791667*H
    W1=61.263889*H
    W2= 128.13889*H
```

```
      W3=142.66667*H
      W4= 70.972222*H
      W5=15.180555*H
      GO TO IXB,(400,620)
  700 H=.5*H
      T=T H
      K=-3
      DO 720 I=1,IMAX
      W1=0.0
      W2=0.0
      W3=0.0
      V1=0.0
      V2=0.0
      V3=0.0
      DO 710 L=1,5
      KK=6-L
      M=N KK
      V1=V1+B2(L)*D(M,I)
      W1=W1+B2(L)*Y(M,I)
      V2=V2+B4(L)*D(M,I)
      W2=W2+B4(L)*Y(M,I)
      VO=V3+B2(KK)*D(M,I)
      W3=W3+B2(KK)*Y(M,I)
  710 CONTINUE
      G2=Y(N-4,I)
      G4=Y(N-3,I)
      G6=Y(N-2,I)
      Y(8,I)=Y(N-1,I)
      Y(6,I)=G6
      Y(4,I)=G4
      Y(2,I)=G2
      G2=D(N-4,I)
      G4=D(N-3,I)
      G6=D(N-2,I)
      D(8,I)=D(N-1,I)
      D(6,I)=G6
      D(4,I)=G4
      D(2,I)=G2
      Y(3,I)=W3
      D(3,I)=V3
      Y(5,I)=W1
      D(5,I)=V1
      Y(7,I)=W2
      D(7,I)=V2
  720 CONTINUE
      M=-1
      N=9
      ASSIGN 620 TO IXB
      GO TO 370
  750 DO 751 I=1,IMAX
  751 YG(I)=Y(N,I)
      TF=T
      HG=H
  760 MG=M
  770 RETURN
      END
```

```
      SUBROUTINE INTERP(TABX,TABY,TABZ,X,Y,Z,NX,NY,ER)
C
C     TABX=(X-TABLE(NX))
C     TABY=(Y-TABLE(NY))
C     TABZ(X-ROW,Y-COLUMN)=2-DIM.ARRAY
C     X=X VALUE
C     Y=Y VALUE
C     Z=INTERPOLATED VALUE
C
      DIMENSION TABX(NX),TABY(NY),TABZ(NX,NY)
      DO 1 J=1,NY
      IF(TABY(J)-Y)1,3,2
    1 CONTINUE
      GO TO 100
    2 XX=1.
      CALL LININT(TABX(1),TABZ(1,J-1),X,ZZ1,OUT,NX)
      IF(OUT)8,100,8
    8 IF(OUT-100.)4,100,4
    3 XX=0.
    4 CALL LININT(TABX(1),TABZ(1,J),X,ZZ2,OUT,NX)
      IF(OUT)9,100,9
    9 IF(OUT-100.)5,100,5
    5 IF(XX)6,99,6
    6 Z=ZZ1-(TABY(J 1)-Y)*(ZZ1-ZZ2)/(TABY(J-1)-TABY(J))
      ER=0.
      GO TO 101
  100 ER=1.
      GO TO 101
   99 ER=0.
      Z=ZZ2
  101 RETURN
      END
```

```
$IBFTC LININT   FULIST,SDD
       SUBROUTINE LININT(Z,Y,ARGZ,ARGY,AL,N)
C      SUBROUTINE FOR LINEAR INTERPOLATION
C
       DIMENSION Z(100),Y(100)
     6 NN=N
     7 M=N 1
     5 DO 11I=1,M
     8 LL=I+1
     9 L=I
    10 A=(Z(I)-ARGZ)*(Z(I+1)-ARGZ)
    12 IF(A)14,14,15
    15 AL=0.0
    11 CONTINUE
    20 IF(ARGZ-Z(1))25,14,26
    25 IF(Z(1)-Z(2))27,14,28
    26 IF(Z(1)-Z(2))28,14,27
    27 ARGY=Y(2)-((Z(2)-ARGZ)/(Z(2)-Z(1)))*(Y(2)-Y(1))
       GO TO 22
    28 ARGY=((ARGZ-Z(M))/(Z(NN)-Z(M)))*(Y(NN)-Y(M))+Y(M)
       AL=100.0
       GO TO 22
    14 RAT=(ARGZ-Z(L))/(Z(LL)-Z(L))
    23 ARGY=Y(L)+RAT*(Y(LL)-Y(L))
    24 AL=L
    22 M=N 1
       RETURN
       END
```

```
$IBFTC THERMA  FULIST,SDD
      SUBROUTINE THERMA(PR,T,VPSIA,HLL,HEN,SL,SEN,VOLLL,VENN,CPV,CPL,
     1POLLYV,AV,CHOICE,SUPER,HGG,SG,VV,CPP,POLLY,A)
C     SUBROUTINE RETURNS THERMODYNAMIC PROPERTIES
C     OF SATURATED AND/OR SUPERHEATED POTASSTUM.
C     (NRL PROPERTIES).
C     SUPER=-1., SP. VOL,ENTHALPY,AND ENTROPY ONLY.
C     SUPER=0., SATURATED PROPERTIES ONLY.
C     SUPER=1., SUPERHEATED PROPERTIES.
C
C     CHOICE=1., PRESSURE INPUT(SATURATED)
C     CHOICE=-1., TEMPERATURE INPUT(SATURATED)
C     CHOICE=ABS GREATER THAN 6736.0, SP VOL
C     ITERATIONS PRINTED.
C     CHOICE=ABS GREATER THAN 1362.0, VIRIAL COEF.
C     AND THEIR DERIVATIVES PRINTED.
C
      DIMENSION PLUSH(18),TUSH(12),VUME(300),FF(100)
      DATA PLUSH/10.,2.,1.,.3333,.2,.166667,.125,.1,
     10.083333333,0.07142857,0.0625,0.055555556,0.05,0.038461538,
     20.33333,0.025,0.016667,0.0125/
      DATA TUSH/8.33333E-4,7.66923077E-4,7.142857E-4,6.666667E-4,
     16.25E-4,5.8823529E-4,5.5555555E-4,5.263157E-4,5.0E-4,
     14.761904E-4,4.5454E-4,4.3478E-4/
      DATA(VUME(I),I=1,208)/3254.8,618.1,285.2,266.,247.,228.,209.,90.,
     1171.0,152.0,133.0,114.0,95.0,76.0,57.0,38.0,19.0,1.0,3545.5,
     2691.4,333.6,91.16,38.94,24.71,5.18,20.0,18.0,16.0,14.0,12.0,10.0,
     48.0,6.0,4.0,2.0,10.0,3828.1,755.13,370.62,112.84,59.89,46.22,
     428.48,17.142,9.005,2.696,2.,1.8,1.6,1.4,1.2,1.,.8,.6,
     54106.9,814.8,403.1,128.0,72.37,58.28,40.40,29.37,21.77,16.13,12.,
     68.100,5.10,3.10,1.60,1.30,1.00,.7,4383.9,872.4,433.3,140.4,
     781.47,66.64,48.02,36.7,29.03,23.45,19.18,15.78,12.99,6.86,
     83.908,2.0,1.0,0.5,4659.9,928.9,462.5,151.4,89.02,73.38,53.76,
     941.92,33.96,28.23,23.88,20.46,17.68,11.75,8.99,4.18,2.0,1.0,
     94935.2,984.8,491.0,161.7,97.76,79.25,58.57,46.12,37.79,
     131.8,27.29,23.76,20.91,14.91,12.17,7.53,2.39,1.0,5210.3,1040.4,
     2519.16,171.61,102.05,84.65,62.87,49.78,41.03,34.76,30.04,26.36,
     323.41,17.21,14.41,9.75,4.49,19.99,5485.1,1095.8,547.09,181.28,
     4108.09,89.78,66.88,53.22,43.94,37.37,32.43,28.58,25.49,19.026,
     516.152,11.383,6.419,1.977,5759.7,1151.0,574.9,190.8,114.0,
     694.74,70.71,56.28,46.65,39.77,34.6,30.57,27.34,20.605,17.611,
     712.68,7.62,4.96,6034.3,1206.1,602.6,200.2,119.7,99.58,74.42,
     859.31,49.24,42.03,36.63,32.42,29.05,22.02,18.9,13.78,8.54,5.88,
     96308.8,1261.1,630.2,209.5,125.4,104.4,78.05,62.27,51.74,44.22/
      DATA(VUME(I),I=209,216)/38.57,34.17,30.66,23.33,20.08,14.76,9.35,
     16.61/
  200 PNRL=PR/14.69594
  230 IF (PNRL-0.007)231,232,232
  231 PNRL=0.007
  232 IF (PNRL-21.0)233,233,234
  234 PNRL=21.0
  233 AJ=778.26
      E=67.0
      F=68.0
      G=69.0
      DECKA=0
      DECKB=0
      DECKC=0
      VALA=0
      VALB=0
      VALC=0
```

```
      CHECK=CHOICE
      J=3
      JJ=10
      PRENT=ABS(CHECK)
  300 TNRL=T
  330 IF (TNRL-1250.0)331,332,332
  331 TNRL=1250.0
  332 IF (TNRL-2700.0)350,350,333
  333 TNRL=2700.0
  350 KAM=0
  500 TLAG=(ALOG(TNRL))*.4342945
  600 IF(CHOICE)800,800,820
  820 PSATAT=PNRL
      GO TO 1000
  800 PVLAG=(6.12758-8128.77/TNRL-0.53299*TLAG)*2.302585
  900 PSATAT=EXP(PVLAG)
 1000 PSAT=PSATAT*14.69594
 1100 PSATSF=PSATAT*2116.2
 1200 BANLUG=(4544.3/TNRL-3.7641+TLAG)*2.302585
 1300 BAN=EXP(BANLUG)
 1400 B=BAN*(-1.0)
 1500 CLUG=(0.6988+5725.0/TNRL)*2.302585
 1600 C=EXP(CLUG)
 1700 DANLUG=(1.9274+5671.4/TNRL)*2.302585
 1800 DAN=EXP(DANLUG)
 1900 D=DAN*(-1.0)
 2000 DBDT=(B/TNRL)*(1.0-10463.637/TNRL)
 2100 TSQ=TNRL*TNRL
 2200 DCDT=13182.2*C*(-1.0)/TSQ
 2300 DDDT=13058.8*D*(-1.0)/TSQ
 2400 TCUBE=TSQ*TNRL
 2500 ELLA=39375.0/TNRL
 2600 ELLEN=EXP(ELLA)
 2700 HZERA=998.95+.127*TNRL+24836.0/ELLEN
 2800 SARAH=31126.0/TNRL
 2900 SALLY=EXP(SARAH)
 3000 SZERA=0.18075 0.127*TLAG*2.302585+0.7617/SALLY
 3100 RR=1545.43
 3200 WAYT=39.10
 3300 RRM=39.52506
 3400 PARLUG=(4080.0/TNRL-1.803)*2.302585
 3500 PAR=EXP(PARLUG)
 3600 VAL1=(RRM*TNRL/PSATSF-PAR)*39.1
      MARK=1
 8200 TFAR=TNRL-459.69
 8300 TFAR2=TFAR*TFAR
 8400 TFAR3=TFAR*TFAR2
 8500 DUNSL=52.7274 7.3539E-3*TFAR-0.56013E-6*TFAR2+0.03158
     1E-9*TFAR3
 8600 VLAQ=1.0/DUNSL
 8700 VOLLL=VLAQ
 9500 T4=TSQ*TSQ
 9700 D2B=1.094877E8*B/T4
 9800 D2C=26364.4*C/TCUBE-13182.2*DCDT/TSQ
 9900 D2D=26117.6*D/TCUBE-13058.8*DDDT/TSQ
  601 EMMA=28070.0/TNRL
  701 EMMY=EXP(EMMA)
  801 CZERA=0.127+2.888/EMMY
      CPLAQ=0.22712 0.64848E-4*TNRL+0.23178E-7*TSQ
      CPL=CPLAQ
      IF(PRENT-1362.0)3700,102,102
```

```
 102 WRITE (6,101) B,C,D,DBDT,DCDT,DDDT,D2B,
    1D2C,D2D,PSAT,TNRL
3700 VAL12=VAL1*VAL1
3800 VAL13=VAL1*VAL12
3900 SLEFT=PSATSF*VAL1/(1545.43*TNRL)
4000 RIGHT=1.0+B/VAL1+C/VAL12+D/VAL13
4100 TALLY=0.001*SLEFT
     IF(PRENT-6736.0)4200,103,103
 103 WRITE (6,104) VAL1,SLEFT,RIGHT,DECKA,DECKB,
    1DECKC,VALA,VALB,VALC,CZERA,HZERA,SZERA,PSAT,TNRL
4200 DECK=SLEFT-RIGHT
4250 ADECK=ABS(DECK)
4300 IF(TALLY-ADECK)4400,4500,4500
4400 IF(MARK-10)4600,4700,4700
4700 VAL1=(RRM*TNRL/PSATSF-PAR)*39.1
     GO TO 4500
4600 IF(MARK-2)4800,5200,5500
4800 VALA=VAL1
4900 DECKA=DECK
5000 VAL1=VALA*1.03
5100 MARK=MARK+1
     GO TO 3700
5200 VALB=VAL1
5300 DECKB=DECK
5400 VAL1=VALA*0.97
     MARK=MARK+1
5450 GO TO 3700
5500 VALC=VAL1
5600 DECKC=DECK
5700 DECKA2=DECKA*DECKA
5800 DECKB2=DECKB*DECKB
5900 DECKC2=DECKC*DECKC
6000 Z1Z3=DECKA-DECKC
6100 Z1Z2=DECKA-DECKB
6200 W1W3=DECKA2-DECKC2
6300 W1W2=DECKA2-DECKB2
6400 Y1Y3=VALA-VALC
6500 Y1Y2=VALA-VALB
6600 ANUM=Z1Z3*Y1Y2-Z1Z2*Y1Y3
6700 ADEN=W1W2*Z1Z3-W1W3*Z1Z2
6800 AAA=ANUM/ADEN
6900 BBB=(Y1Y2-AAA*W1W2)/Z1Z2
7000 VAL1=VALA-AAA*DECKA2-BBB*DECKA
7100 MARK=MARK+1
7400 DECKA=DECKB
7500 DECKB=DECKC
7600 VALA=VALB
7700 VALB=VALC
     GO TO 3700
4500 VENNA=VAL1/39.1
7800 VAL2=VAL1*VAL1
7900 VAL3=VAL1*VAL2
7950 VAL4=VAL2*VAL2
7951 VAL5=VAL2*VAL3
8000 HG1=HZERA+(RRM*TNRL/AJ)*((B-TNRL*DBDT)/VAL1+(C-TNRL
    1*DCDT/2.0)/VAL2+(D-TNRL*DDDT/3.0)/VAL3)
8100 HENNA=HG1
8150 HGSAT=HENNA
9200 VRT=VAL1/(RR*TNRL)
     VRTAB=ABS(VRT)
     VRT=VRTAB
```

```
9300 VRTLUG=ALOG(VRT)
9400 SGSAT=SZERA-(RRM/AJ)*((B+TNRL*DBDT)/VAL1-VRTLUG
    1+(C TNRL*DCDT)/(2.0*VAL2)+(D+TNRL*DDDT)/(3.0*VAL3)-7.65738)
9600 SENNA=SGSAT
     VALSAT=VENNA
8800 HATTY=(PSATSF/AJ)*(18717.2/TNRL-0.53299)*(VALSAT-VLAQ)
8900 HLNRL=HGSAT-HATTY
     SATTY=HATTY/TNRL
     SLNRL=SENNA-SATTY
     IF(SUPER)2001,201,201
 201 BRAKET=1.0+(B TNRL*DBDT)/VAL1+(C+TNRL*DCDT)/VAL2
    1+(D TNRL*DDDT)/VAL3
 301 CGNUM=BRAKET*BRAKET
 401 CGDEN=1.0+2.0*B/VAL1+3.0*C/VAL2+4.0*D/VAL3
 501 PAR2=TNRL*D2B 2.0*DBDT+0.5*(TNRL*D2C+2.0*DCDT)/VAL1
    1+(TNRL*D2D+2.0*DDDT)/(3.0*VAL2)
 901 CPG=CZERA+(RRM/AJ)*(CGNUM/CGDEN-1.0-(TNRL/VAL1)
    1*PAR2)
1050 BRUCK=1.0/VAL2+2.0*B/VAL3+3.0*C/VAL4+4.0*D/VAL5
1101 DRHDT=RR*TNRL*(-1.0)*BRUCK
1201 DVDP=1.0/(DRHDT*WAYT)
1301 DVDT=(PSATSF/(RR*TSQ)+DBDT/VAL2+DCDT/VAL3+DDDT/VAL4)
    1/(BRUCK*WAYT)
1401 PALE=1.0/((PSATSF/VENNA)*(DVDP+(TNRL/(AJ*CPG))*DVDT*DVDT))
1501 PALM=PALE*(-1.0)
1601 ALF=PALM*32.174*RRM*TNRL
1701 ABALF=ABS(ALF)
1801 ALE=SQRT(ABALF)
1901 IF(KAM)2101,2001,2101
2001 VENN=VENNA
2201 HEN=HENNA
2301 SEN=SENNA
     SL=SLNRL
9000 HLL=HLNRL
9100 VPSIA=PSAT
2351 IF(SUPER)2352,2401,2401
2352 CPV=0.0
2353 POLLYV=0.0
2354 AV=0.0
     GO TO 2801
2401 CPV=CPG
2501 POLLYV=PALM
2601 AV=ALE
2701 IF(SUPER)2801,2801,3401
2801 HGG=0
2901 SG=0
3001 VV=0
3101 CPP=0
3201 POLLY=0
3301 A=0
3351 GO TO 4601
3401 KAM=1
3501 MARK=1
3601 PSATAT=PNRL
3701 PSAT=PSATAT*14.69594
3801 PSATSF=PSATAT*2116.2
     MM=18
     NN=12
     RPSAT=1.0/PSAT
     RTNRL=1.0/TNRL
3903 CALL DUBIN(RPSAT,RTNRL,VELD,PLUSH,TUSH,VUME,MM,NN,JAN,JAQ)
```

```
      MARK=1
 4001 VAL1=VELD*39.1
      GO TO 3700
 2101 HGG=HENNA
 4101 SG=SENNA
      CPP=CPG
 4201 VV=VAL1/39.1
 4301 CPP=CPG
 4401 POLLY=PALM
 4501 A=ALE
 4601 HARRY=6.0
C
      RETURN
  101 FORMAT GENERATOR
      B         C            D          DBDT          DCDT         DDDT
      -1PE3         -E5          -E5          -E5          -E5          -E5
      SPACE
                    D2B          D2C          D2D         PRESS         TEMP
                -E5          -E5          -E5          -E5          -E5
      SPACE
      END OF FORMAT
  104 FORMAT GENERATOR
      SPACE
             VAL1        LEFT         RIGHT        DEC1         DEC2
                  -E5          -E5          -E5          -E5          -E5
      SPACE
             DEC3        VOL1         VOL2         VOL3         CO
                  -E5          -E5          -E5          -E5          -E5
      SPACE
             HO          SO           PRESS        TEMP
                  -E5          -E5          -E5          -E5
      SPACE
      END OF FORMAT
      END
```

```
$IBFTC DUBIN    FULIST,SDD
      SUBROUTINE DUBIN(P,T,V,PLUSH,TUSH,VUME,MM,NN,JA,JB)
C
C     SUBROUTINE FOR DOUBLE LINEAR INTERPOLATION
C
      DIMENSION PLUSH(40),TUSH(40),VUME(1600)
  100 PP=P
  200 TT=T
  600 M=MM
  700 N=NN
  800 DO 1100 I=1,M
  850 L=I
  900 C=(PLUSH(I)-P)*(PLUSH(I 1)-P)
 1000 IF(C)2700,2700,1200
 1200 JAM=3
 1100 CONTINUE
 1400 TEST=(PLUSH(1)-P)*(PLUSH(2)-PLUSH(1))
 1500 IF(TEST)1700,2100,2500
 1700 JAB=100
 1750 MN=M-1
 1800 RAP=(P-PLUSH(MN))/(PLUSH(M)-PLUSH(MN))
      LL=MN
 1950 GO TO 2800
 2100 RAP=0.0
 2200 LL=1
      JAB=200
      GO TO 2800
 2500 RAP=(P-PLUSH(1))/(PLUSH(2)-PLUSH(1))
 2550 JAB=0
 2600 LL=1
 2250 GO TO 2800
 2700 LL=L
      LLL=LL+1
 2950 JAB=LL
 2900 RAP=(P-PLUSH(LL))/(PLUSH(LLL)-PLUSH(LL))
 2800 LLL=LL+1
 3000 DO 3500 I=1,N
 3100 K=I
 3200 C=(TUSH(I)-T)*(TUSH(I+1)-T)
 3300 IF(C)4500,4500,3400
 3400 JAM=10
 3500 CONTINUE
 3600 TEST=(TUSH(1) T)*(TUSH(2)-TUSH(1))
 3700 IF(TEST)3800,4100,4300
 3800 NJ=N-1
 3900 RAT=(T-TUSH(NJ))/(TUSH(N)-TUSH(NJ))
      KK=NJ
 3850 JBB=100
 4050 GO TO 4600
 4100 RAT=0.0
 4200 KK=1
      JBB=200
      GO TO 4600
 4300 RAT=(T-TUSH(1))/(TUSH(2)-TUSH(1))
 4350 JBB=0
 4400 KK=1
 4250 GO TO 4600
 4500 KK=K
      KKK=KK+1
 4675 JBB=KK
 4650 RAT=(T-TUSH(KK))/(TUSH(KKK)-TUSH(KK))
```

```
4600 KKK=K+1
4700 KV1=M*KK+LL-M
4800 KV2=KV1+1
4900 V1=VUME(KV1)+RAP*(VUME(KV2)-VUME(KV1))
     KV1=M*KKK+LL-M
5100 KV2=KV1+1
5200 V2=VUME(KV1)+RAP*(VUME(KV2)-VUME(KV1))
5300 VV=V1+RAT*(V2 V1)
5400 V=VV
5500 JA=JAB
5600 JB=JBB
     RETURN
     END
```

```
$IBFTC CURV     FULIST,SDD
      FUNCTION CURV(P)
   17 PYP=P/14.69594
   18 PUN=(ALOG(PYP))/2.3025851
   19 PEEP=(PUN+0.10705539)/2.1805446
   20 PUP=PEEP*PEEP
   21 PUPPY=PUP*PEEP
   22 PURP=PUP*PUP
   23 PURPLE=PUP*PUPPY
   24 PURSE=PUPPY*PUPPY
   25 PERK=PURP*PUPPY
   26 PERKY=PURP*PURP
   27 PLUP=1.3190232*PEEP-.13299096+.69237968*PUP+.37008034
     1*PUPPY+.19876127*PURP+.10754778*PURPLE+.066299672
     2*PURSE+.041265195*PERK+.013472973*PERKY
   28 CURV=1900.0+700.0*PLUP
      RETURN
      END
```

APPENDIX B

POTASSIUM BOILER THERMAL DESIGN CODE

TABLE IV

NOMENCLATURE FOR BOILER DESIGN CODE INPUT*

Symbol	Quantity	Units
TITLE	Identification block	-
NT	Number of tubes	-
ITP	Number of iterations for primary exit temperature	-
ITS	Number of iterations for tube length in boiling region	-
ITSUP	Number of iterations for tube length in superheat region	-
JHP	Enter JHP = 0 if primary heat transfer coefficient is calculated by program	-
	Enter JHP = 1 if primary heat transfer coefficient is input	
POWER	Total power	KW
TPINS	Primary fluid inlet temperature	°F
TSIN	Secondary fluid inlet temperature	°F
DTSUP	Degree of superheat	°F
PSOUT	Secondary outlet pressure	psi
DT	Outside tube diameter	inches
XW	Tube wall thickness	inches
PODT	Pitch to diameter ratio of tube bundle	dimensionless
PODI	Pitch to diameter ratio of insert	dimensionless
DCB	Center body diameter	inches
HB	Average boiling heat transfer coefficient	Btu/ft^2-hr-°F
HSUP	Average superheated vapor heat transfer coefficient	Btu/ft^2-hr-°F
HP	Average primary fluid heat transfer coefficient	Btu/ft^2-hr-°F
HPMARG	Margin factor for tube bundles with tight pitch	dimensionless

*Input variables are given in order of literal appearance on input cards

TABLE IV (Cont'd)

Symbol	Quantity	Units
GS	Boiling fluid mass velocity (secondary)	lb_m/ft^2-sec
WP	Primary fluid mass flow rate	lb_m/sec
XINST	Insert vane thickness	inches
RADPL	Length of radial pressure drop region	inches
TOLP	Tolerance on primary exit temperature iterations	°F
TOLS	Tolerance on iteration for tube length in boiling region	$\frac{\text{Percent}}{100}$
TOLSUP	Tolerance on iteration for tube length in superheat region	$\frac{\text{Percent}}{100}$
PF	Primary fluid indicator 0 = Lithium 1 = Sodium	-
CSLOPE	Sign of iteration line slope. Use 1	-
CS	Sign of iteration line slope. Use 1	-
XN	Exponent on friction factor model; smooth tube = 0.25	dimensionless

TABLE V

NOMENCLATURE FOR BOILER DESIGN CODE PRINTOUT

Symbol	Quantity	Units
ACCL	Radial acceleration	ft/sec^2
ACCL/G	Ratio of radial acceleration to the local gravitational acceleration	g's
DELTAP	Primary friction pressure drop or Secondary total pressure drop in boiling region	psia
DPFRIC	Secondary friction pressure drop in boiling region	psia
DPMOM	Secondary momentum pressure drop in boiling region	psia
DPRIN	Primary radial pressure drop at inlet	psia
DPROUT	Primary radial pressure drop at exit	psia
DPSUP	Secondary total pressure drop in superheat region	psia
DPSFRIC	Secondary friction pressure drop in superheat region	psia
DPSMOM	Secondary momentum pressure drop in superheat region	psia
GMAX	Secondary maximum helical mass	lb_m/ft^2-sec
GP	Primary mass velocity	lb_m/ft^2-sec
HB	Boiling heat transfer coefficient	Btu/ft^2-hr-°F
HP	Primary heat transfer coefficient	Btu/ft^2-hr-°F
HSL	Secondary heat transfer coefficient in liquid region	Btu/ft^2-hr-°F
HSUPS	Secondary heat transfer coefficient in superheat region	Btu/ft^2-hr-°F
HWALL	Effective wall heat transfer coefficient	Btu/ft^2-hr-°F
LTOT	Total tube length	ft
LB	Tube length in boiling region	ft
LSC	Tube length in subcooled region	ft
LSUP	Tube length in superheat region	ft
NT	Number of tubes	dimensionless

TABLE V (Cont'd)

Symbol	Quantity	Units
PEL	Secondary fluid Peclet number	dimensionless
PEP	Primary fluid Peclet number	dimensionless
POWER	Total power	KW
P/D	Pitch to diameter ratio	dimensionless
QB	Heat transfer rate in boiling region	Btu/sec
QSC	Heat transfer rate in subcooled region	Btu/sec
QSUP	Heat Transfer rate in superheat region	Btu/sec
QTOT	Total heat transfer rate	Btu/sec
Q/A BOILING	Heat flux in boiling region	Btu/ft^2-sec
REP	Primary fluid Reynolds number	dimensionless
REL	Secondary fluid Reynolds number	dimensionless
TPIN	Primary inlet temperature	°F
TPOUT	Primary exit temperature	°F
TSIN	Secondary inlet temperature	°F
TSAT	Secondary temperature at inlet to boiling region	°F
TSOUT	Secondary exit superheated vapor temperature	°F
UIB	Overall heat transfer coefficient in boiling region	Btu/ft^2-hr-°F
UIL	Overall heat transfer coefficient liquid region	Btu/ft^2-hr-°F
VMAX	Maximum secondary helical velocity	fps
VP	Primary fluid axial velocity	fps
WP	Primary fluid flow rate	lb_m/sec
WS	Secondary fluid flow rate	lb_m/sec
XW	Wall thickness	inches

BOILER CODE LISTING

```
$IBFTC PBDES    FULIST,SDD
*PBDES
C
      DIMENSION TCLI(20),RHOLI(20),CPLI(20),VISLI(20),
     1TCNA(20),RHONA(20),CPNA(20),VISNA(20),VISK(20),VISKG(20),
     2TCK(20),TEMP(20),XKW(20),TW(20)
C
      DIMENSION TITLE(8),BITS(1),DUMMY(50),REG(5)
      DIMENSION FOFO(4,4),POD(4),RES(4),EPSMAX(5)
      DIMENSION TCKG(20)
C
      NAMELIST/INPUT/TITLE,NEX,NT,ITP,ITS,ITSUP,POWER,
     1TPINS,TSIN,DTSUP,DT,XW,XKW,PODT,PODI,HB,HBTB,
     2HSUP,TOLP,TOLS,TOLSUP,HP,HPMARG,PF,TW,CSLOPE,
     3CS,XN,FOFO,GS,DCB,WP,PSOUT,XINST,RADPL,JHP
    1 READ (5,INPUT)
C
C     PROGRAM IS APPLICABLE TO A COUNTERFLOW
C     BOILER WITH SUBCOOLED FEED AT INLET
C     AND 100 PERCENT QUALITY VAPOR AT EXIT.
C
    2 QTOT=.9478*POWER
      DIT=DT-2.*XW
      DLM=2.*XW/ALOG(DT/DIT)
C
C     COMPUTE GS OR NT FROM TOTAL POWER
C     AND SECONDARY FLOW RATE
  400 TSINR=TSIN+459.69
      CALL THERMA(PU,TSINR,PSINR,HLIN,HG7,SL7,SV7,VL7,
     1VG7,CPG7,CPL7,EX,AV,-1.,0.,HS7,SS7,VS7,CPSH7,EXS7,AVS7)
C     COMPUTE EQUIVALENT SAT. TEMP. AT PSOUT.
C
  300 TKSATO=CURV(PSOUT)
      TKSATO=TKSATO-459.69
 2971 CONTINUE
      TKSUPO=TKSATO+DTSUP
      T99=TKSUPO+459.69
      CALL THERMA(PSOUT,T99,PV7,HL7,HG7,SL7,SV7,VL7,VG7,
     1CPG7,CPL7,EX,AV,0.,1.,HSUOUT,SS7,VSUPO,CPSH7,EXS7,AVS7)
      WS=QTOT/(HSUOUT-HLIN)
      IF(GS)401,401,402
  401 AS=3.1416*DIT**2/4.*FLOAT(NT)/144.
      GS=WS/AS
      GO TO 403
  402 ATUBE=3.1416*DIT**2/4./144.
      XNT=WS/GS/ATUBE
      NT=IFIX(XNT)
  403 CONTINUE
C
C     DETERMINE PRIMARY EXIT TEMPERATURE AND
```

```
C     PROPERTIES AT AVERAGE PRIMARY TEMPERATURE.
C
      RAD1=DIT/2.-DCB/2.
      ABLOCK=RAD1*XINST*FLOAT(NT)/144.
      AFAX=3.1416*(DIT**2-DCB**2)/4./144.*FLOAT(NT)-ABLOCK
      GAX=GS*AS/AFAX
      BETA=SQRT(1.+(3.1416/PODI)**2)
      GMAX=BETA*GAX
      DCOD=DCB/DIT
      IF(DCB)6111,6111,6112
 6112 CONTINUE
      DENOD=(1.-DCOD**2)/(1.+DCOD+(1.-DCOD)/3.1416)
      DEN=DIT*DENOD
      GO TO 6113
 6111 DEN=DIT
 6113 CONTINUE
      IT1=1
      TP=TPINS
    6 IF(PF)3,3,4
    3 CALL LININT(TEMP,CPLI,TP,CPAV,OUT,20)
      GO TO 5
    4 CALL LININT(TEMP,CPNA,TP,CPAV,OUT,20)
    5 TP1=TPINS-QTOT/WP/CPAV
      TZ=(TP1+TPINS)/2.
      IF(ABS(TZ-TP)-TOLP)7,7,8
    8 IF(IT1-ITP)10,11,11
   11 CALL EXIT
   10 IT1=IT1+1
      TP=TZ
      GO TO 6
    7 TPA=TZ
      TPOUT=TPINS-QTOT/WP/CPAV
      IF(PF)15,15,16
   15 CALL LININT(TEMP,TCLI,TPA,TCP,OUT,20)
      CALL LININT(TEMP,RHOLI,TPA,RHOP,OUT,20)
      CALL LININT(TEMP,VISLI,TPA,VISP,OUT,20)
      CALL LININT(TEMP,RHOLI,TPINS,RHOIN,OUT,20)
      CALL LININT(TEMP,RHOLI,TPOUT,RHOUT,OUT,20)
      CALL LININT(TEMP,VISLI,TPINS,VISIN,OUT,20)
      CALL LININT(TEMP,VISLI,TPOUT,VISOUT,OUT,20)
      CPP=CPAV
   16 CALL LININT(TEMP,TCNA,TPA,TCP,OUT,20)
      CALL LININT(TEMP,RHONA,TPA,RHOP,OUT,20)
      CALL LININT(TEMP,VISNA,TPA,VISP,OUT,20)
      CALL LININT(TEMP,RHONA,TPINS,RHOIN,OUT,20)
      CALL LININT(TEMP,RHONA,TPOUT,RHOUT,OUT,20)
      CALL LININT(TEMP,VISNA,TPINS,VISIN,OUT,20)
      CALL LININT(TEMP,VISNA,TPOUT,VISOUT,OUT,20)
      CPP=CPAV
C
```

```
C
C     COMPUTE SHELL SIZE AND PRIMARY PARAMETERS.
C
      IF(PODT)2322,2322,2321
 2322 SHID=BITS
      SHFA=BITS
      GP=BITS
      VP=BITS
      REP=BITS
      GO TO 2323
 2321 SHID=DT*PODT*SQRT(2.*SQRT(3.)/3.1416*FLOAT(NT))
      SHFA=FLOAT(NT)*3.1416*DT**2/4.*(2.*SQRT(3.)/
     13.1416*PODT**2-1.)/144.
      NT1=1
      I=1
 4111 NT1=NT1+6*(I-1)
      IF(NT1-NT)4112,4113,4114
 4112 I=I+1
      GO TO 4111
 4114 I=I-1
 4113 CONTINUE
      PITCH=PODT*DT
      RATIO=PITCH/SQRT(SHID**2-PITCH**2)
      ANG=ATAN(RATIO)
      NOUTR=6*(I-1)
      XNROWS=FLOAT(NOUTR)
      XNT1=FLOAT(NT)
      WETPER=3.1416*(SHID+XNT1*DT)+XNROWS*(2.*
     1PITCH/SQRT(3.)-SHID*ANG)
      DEQSH=4.*SHFA*12./WETPER
      GP=WP/SHFA
      VP=GP/RHOP
      REP=DEQSH*3600.*GP/VISP
      PRP=CPP*VISP/TCP
      PECP=REP*PRP
C
C     CALCULATE HP USING DWYER TU RELATION.
C     HMARG=FUDGE FACTOR FOR CONSERVATISM.
C
 2323 IF(JHP)17,17,18
   17 CONTINUE
      REPL=ALOG10(REP)
      CALL LININT(REG,EPSMAX,REPL,EPS,OUT,5)
      EPSP=EXP(2.303*EPS)
      PSIBAR=1.-1.82/PRP/EPSP**1.4
      IF(PSIBAR)5555,5555,5556
 5555 PNU=.93+10.81*PODT-2.01*PODT**2
      GO TO 5557
 5556 CONTINUE
      PNU=.93+10.81*PODT-2.01*PODT**2+.0252*PODT**.273
```

```
     1*(PSIBAR*PECP)**.8
 5557 CONTINUE
      HP=PNU*TCP/DEQSH*HPMARG
   18 CONTINUE
C
      IF(PF)280,280,281
  280 CALL LININT(TEMP,CPLI,TPINS,CPRIMS,OUT,20)
      GO TO 282
  281 CALL LININT(TEMP,CPNA,TPINS,CPRIMS,OUT,20)
  282 CONTINUE
      IF(DTSUP)3712,3712,2972
 3712 TPIN=TPINS
      TSOUT=TKSATO
      QSUP=0.
      HLSUP=0.
      DELPSU=0.
      DPFSUP=0.
      DPSMOM=0.
      GO TO 377
C
C     ENTER ITERATION LOOP FOR DETERMINATION OF
C     LENGTH OF TUBES IN SUPERHEAT REGION.
 2972 CONTINUE
      TKMAX=TKSUPO
      TKMIN=TKSATO
      BALP=0.
  301 CALL DICHOA(VAR,TKMAX,TKMIN,BALP,TOLSUP,CS,ICON,
     1TSOUT,ITSUP)
 2973 IF(ICON)302,302,377
C     COMPUTE THE SUPERHEATED VAPOR PROPERTIES AT
C     TSUPAV AND PSUPAV.
C
  302 TSUPAV=(TSOUT+TKSUPO)/2.
      T77=TSUPAV+459.69
      T88=TSOUT+459.69
      CALL THERMA(PU,T88,PVOUT,HL7,HG7,SL7,SV7,VL7,VGOUT,
     1CPG7,CPL7,EX,AV,-1.,0.,HS7,SS7,VS7,CPSH7,EXS7,AVS7)
      PSUPAV=(PSOUT+PVOUT)/2.
      CALL THERMA(PSUPAV,T77,PV7,HL7,HG7,SL7,SV7,VL7,VG7,
     1CPG7,CPL7,EX,AV,0.,1.,HSUPAV,SSUPAV,VSUPAV,CPSUAV,EXSAV,AVSAV)
      CALL LININT(TEMP,VISKG,TSUPAV,VISUPA,OUT,20)
      CALL LININT(TEMP,TCKG,TSUPAV,TCKSUP,OUT,20)
C
C     SET TEST3=0. TWLA3=SUM OF DELTAT S.
C
      QSUP=WS*CPSUAV*(TKSUPO-TSOUT)
      TPIN=TPINS-QSUP/WS/CPRIMS
      TWLA3=(TPIN+TPINS+TSOUT+TKSUPO)/4.
      TEST3=0.
  304 CALL LININT(TW,XKW,TWLA3,XKW3,OUT,20)
```

```
      RESW3=XW*DIT/12./XKW3/DLM
      HSUPS=HSUP
      IF(HSUP)309,310,309
  310 PRG=CPSUAV*VISUPA/TCKSUP
      REGSU=DEN*GMAX*300./VISUPA
      IF(DCB)6211,6211,6212
 6212 CONTINUE
      ZNSUP=.39*REGSU**.56*PRG**(1./3.)
      GO TO 6213
 6211 ZNSUP=.023*REGSU**.8*PRG**(1./3.)
 6213 CONTINUE
      HSUPS=ZNSUP*TCKSUP*12./DEN
  309 USUP=1./(1./HSUPS+RESW3+DIT/HP/DT)
      T51=TPINS-TKSUPO
      T52=TPIN-TSOUT
      TLMSUP=(T51-T52)/ALOG(T51/T52)
      ASUP=3600.*QSUP/USUP/TLMSUP
      IF(TEST3)305,305,320
  305 DTSOFM=QSUP*3600./ASUP/HP*DT/DIT
      DTSIFM=QSUP*3600./HSUPS/ASUP
      TWOS=(TPIN+TPINS)/2.-DTSOFM
      TWIS=(TSOUT+TKSUPO)/2.+DTSIFM
      TWLA3=(TWOS+TWIS)/2.
      TEST3=1.
      GO TO 304
  320 CONTINUE
      HLSUP=ASUP*12./3.1416/DIT/FLOAT(NT)
C
C     COMPUTE SUPERHEAT LENGTH BASED ON THE
C     PRESSURE DROP RELATIONSHIP.
C
      REGSU=DEN*GMAX*300./VISUPA
  321 CALL FRIC(PODI,DCB,DIT,GS,VISUPA,FR)
      DELPSU=PVOUT-PSOUT
      DPSMOM=GMAX**2/32.2/144.*(VSUPO-VGOUT)
      RHOSAV=1./VSUPAV
      PPS=DELPSU-DPSMOM
      GROUPS=GAX**2*BETA**3/64.4/RHOSAV*12./DEN
      PLSUP=144.*PPS/GROUPS/FR
      DPFSUP=DELPSU-DPSMOM
C
C
C     COMPUTE VAR AND TO 301
C
      VAR=(HLSUP-PLSUP)/HLSUP
      GO TO 301
C
  377 CONTINUE
C
C     SET UP ITERATION LOOP FOR DETERMINATION
```

```
C     OF TUBE LENGTH.
C
      JK=0
      TSLAV=(TSIN+TSOUT)/2.
      GO TO 41
   57 TSMAX=TPSAT-2.
      TSMIN=TSOUT
      BAL=0.
   30 CALL DICHOA(V,TSMAX,TSMIN,BAL,TOLS,CSLOPE,KCON,TSAT,ITS)
      IF(KCON)31,31,100
C
C     COMPUTE RELEVANT PROPERTIES AT TSAT,TSAV,TSOUT.
C
   31 TSAV=(TSAT+TSOUT)/2.
      TK1=TSAT+459.69
      TK2=TSAV+459.69
      TK3=TSOUT+459.69
      CALL THERMA(PU,TK1,PV1,HL1,HG1,SL1,SV1,VL1,VG1,CPG1,CPL1,
     1EX,ALPHA,-1.,0.,HS,SS,VSH,CPSH,EXS,AVS)
      RHOL1=1./VL1
      CALL THERMA(PU,TK2,PV2,HL2,HG2,SL2,SV2,VL2,VG2,CPG2,CPL2,
     1EX,ALPHA,-1.,0.,HS,SS,VSH,CPSH,EXS,AVS)
      RHOL2=1./VL2
      RHOG2=1./VG2
      CALL LININT(TEMP,VISK,TSAV,VISAV,OUT,20)
      CALL LININT(TEMP,TCK,TSAV,TCAV,OUT,20)
      CALL THERMA(PU,TK3,PV3,HL3,HG3,SL3,SV3,VL3,VG3,CPG3,CPL3,
     1EX,ALPHA,-1.,0.,HS,SS,VSH,CPSH,EXS,AVS)
      RHOL3=1./VL3
   40 RHOG3=1./VG3
C
C     COMPUTATION OF SUBCOOLED REGION
C
   41 TK4=TSLAV+459.69
      TK4=TSLAV+459.69
      CALL THERMA(PU,TK4,PV4,HL4,HG4,SL4,SV4,VL4,VG4,CPG4,CPL4,
     1EX,ALPHA,-1.,0.,HS,SS,VSH,CPSH,EXS,AVS)
      QSC=WS*CPL4*(TSAT-TSIN)
      TPSAT=TPOUT+QSC/WP/CPP
      IF(JK)55,55,56
   55 JK=1
      GO TO 57
   56 CONTINUE
C
C     SET TEST1=0. TWLA1=SUM OF DELTAT S
      TWLA1=(TPOUT+TPSAT+TSIN+TSAT)/4.
      TEST1=0.
   42 CALL LININT(TW,XKW,TWLA1,XKW1,OUT,20)
      CALL LININT(TEMP,VISK,TSLAV,VISKL,OUT,20)
      REAL=DIT*300.*GS/VISKL
```

```
      CALL LININT(TEMP,TCK,TSLAV,TCKL,OUT,20)
      PREAL=CPL4*VISKL/TCKL
      PEEAL=REAL*PREAL
      IF(PEEAL-100.)45,45,46
   45 ZNUL=3.
      GO TO 47
   46 ZNUL=7.+.025*(PEEAL)**.8
   47 HSL=ZNUL*12.*TCKL/DIT
      RESW=XW*DIT/12./XKW1/DLM
      UIL=1./(1./HSL+RESW+DIT/HP/DT)
      DTLMSC=(TPOUT-TSIN-TPSAT+TSAT)/ALOG((TPOUT-
     1TSIN)/(TPSAT-TSAT))
      ASC=QSC/UIL/DTLMSC*3600.
      IF(TEST1)43,43,44
   43 DTOF=QSC*3600./HP/ASC*DT/DIT
      DTIF=QSC*3600./HSL/ASC
      TWO=(TPOUT+TPSAT)/2.-DTOF
      TWI=(TSIN+TSAT)/2.+DTIF
      TWLA1=(TWO+TWI)/2.
      TEST1=1.
      GO TO 42
C
C     COMPUTE BOILING LENGTH BASED ON HEAT TRANSFER.
C     SET TEST2=0.
   44 TWBA=(TPSAT+TSAT+TPIN+TSOUT)/4.
      TEST2=0.
   62 CALL LININT(TW,XKW,TWBA,XKW2,OUT,20)
      RESWB=XW*DIT/12./XKW2/DLM
      UIB=1./(1./HB+RESWB+DIT/HP/DT)
      DTLMB=(TPSAT-TSAT-TPIN+TSOUT)/ALOG((TPSAT-
     1TSAT)/(TPIN-TSOUT))
      QB=QTOT-QSUP-QSC
      AB=QB*3600./UIB/DTLMB
      IF(TEST2)63,63,64
   63 DTOF=QB*3600./HP/AB*DT/DIT
      DTIF=QB*3600./HB/AB
      TWOB=(TPSAT+TPIN)/2.-DTOF
      TWIB=(TSAT+TSOUT)/2.+DTIF
      TWBA=(TWOB+TWIB)/2.
      TEST2=1.
      GO TO 62
C
   64 HLEN=AB*12./3.1416/DIT/FLOAT (NT)
C
C     COMPUTE PRESSURE DROPS AND LENGTH BASED
C     ON THE PRESSURE DROP
C
      PRBAV=CPL2*VISAV/TCAV
      RE=DIT*GS*3600./12./VISAV
      PECAV=RE*PRBAV
```

```
      CALL FRIC(PODI,DCB,DT,GS,VISAV,FR)
C     CALCULATE TWO PHASE MULTIPLIER FROM
C     HOMOGENEOUS MODEL USING CONSTANT Q/A
C
      CALL LININT(TEMP,VISKG,TSAV,VISG,OUT,20)
      AA=RHOL2/RHOG2-1.
      BB=VISAV/VISG-1.
      R3=AA/BB**2
      R4=(1.+BB)**(1.-XN)/BB/(1.-XN)
      R5=1./BB/(1.-XN)
      R6=1./(XN-1.)/(1.+BB)**(XN-1.)
      R7=1./(XN-2.)/ (1.+BB)**(XN-2.)
      R8=1./(XN-2.)
      R9=1./(XN-1.)
      PHI=R4-R5+R3*(R6-R7+R8-R9)
C
      DELPT=PV1-PV3
      DPMOM=GMAX**2/32.2/144.*(VG3-VL1)
      PP=DELPT-DPMOM
      GROUP=GAX**2*BETA**3/64.4/RHOL2*12./DEN*PHI
      PLEN=144.*PP/GROUP/FR
C
C     COMPUTE V AND RETURN TO 30
C
      V=(HLEN-PLEN)/HLEN
      GO TO 30
C
C
  100 IF(PODT)2391,2391,2392
 2391 DELPP=BITS
      DPRAD1=BITS
      DPRAD2=BITS
      GO TO 2393
 2392 FP=.316/(REP)**.25
      DELPP=FP*HLEN*GP**2/64.4/DEQSH/RHOP/144.
 2393 IF(RADPL)2395,2395,2394
 2394 RDDP=RADPL
      DB=DT
      WB=WP
      PODB=PODT
      NB=NT
      CALL RDP(DB,RDDP,WB,RHOIN,VISIN,PODB,NB,DPRAD1)
      CALL RDP(DB,RDDP,WB,RHOUT,VISOUT,PODB,NB,DPRAD2)
 2395 CONTINUE
      DPFRIC=PP
      THETA=ATAN(PODI/3.1416)
      VVTMAX=GMAX/RHOG3*COS(THETA)
      RAD=DIT/24.
      ACCMAX=(VVTMAX)**2/RAD
      AOG=ACCMAX/32.2
```

```
      HLSC=ASC/3.1416*12./DIT/FLOAT(NT)
      HLETOT=HLSC+HLEN+HLSUP
      DELPP=FP*HLETOT*GP**2/64.4/DEQSH/RHOP/144.
      HWALL=1./RESWB
      HFLUXB=QB*3600./AB
C
C
      WRITE (6,2000) (TITLE(K),K=1,8),NT,PODT,DIT,
     1AS,DT,PODI,XW,SHID,HLETOT,SHFA,HLEN,HLSC,
     2POWER,QTOT,QB,QSC,HFLUXB,TPINS,TSIN,TPOUT,
     3TSAT,WP,TSOUT,GP,WS
      WRITE (6,7000) VP,GMAX,REP,VVTMAX,PECP,ACCMAX,HP,AOG,HWALL,
     1HSL,DELPP,HB,DPRAD1,RE,DPRAD2,PECAV,UIL,UIB,DELPT,DPFRIC,
     2DPMOM,QSUP,HSUPS,TKSUPO,HLSUP,DELPSU,DPFSUP,DPSMOM
C
      DATA BITS/0./
      DATA TEMP/1000.,1100.,1200.,1300.,1350.,1400.,1450.,1500.,
     11550.,1600.,1650.,1700.,1750.,1800.,1850.,1900.,1950.,2000.,2100.,
     22200./
      DATA VISLI/.81,.77,.725,.69,.67,.65,.64,.62,.605,
     1.59,.585,.56,.55,.53,.51,.49,.47,.45,.41,.39/
      DATA TCLI/27.55,27.70,27.86,28.00,28.10,28.17,28.25,
     128.32,28.40,28.48,28.56,28.63,28.71,28.79,28.87,28.95,29.03,
     229.11,29.27,29.43/
      DATA RHOLI/29.60,29.35,29.10,28.85,28.72,28.60,28.48,
     128.36,28.25,28.12,28.00,27.88,27.78,27.66,27.54,27.42,
     227.30,27.18,26.94,26.72/
      DATA CPLI/1.0019,1.0003,.9987,.9971,.9963,.9955,
     1.9947,.9939,.9930,.9923,.9915,.9907,.9898,.989,.9882,
     2.9874,.9867,.9859,.9843,.9828/
      DATA VISNA/.556,.512,.476,.444,.430,.416,
     1.403,.392,.382,.372,.362,.354,.346,.338,.330,.323,
     2.316,.309,.296,.284/
      DATA TCNA/37.60,36.50,35.50,34.60,34.15,33.70,
     133.30,32.95,32.60,32.25,31.95,31.65,31.35,31.10,30.80,
     230.55,30.35,30.05,29.50,28.90/
      DATA RHONA/50.95,50.1,49.3,48.6,48.25,47.85,47.50,
     147.15,46.80,46.45,46.15,45.80,45.50,45.15,44.85,44.50,
     244.20,43.90,43.30,42.70/
      DATA CPNA/.3008,.300,.300,.3006,.3012,.3018,
     1.3028,.3038,.3051,.3064,.3079,.3097,.3116,.3137,.3160,
     2.3184,.3210,.3237,.3300,.3366/
      DATA VISKG/.0412,.0427,.0442,.0456,.0464,.0471,
     1.0478,.0485,.0492,.0499,.0505,.0512,.0518,.0524,
     2.0529,.0535,.0540,.0545,.0555,.0562/
      DATA VISK/.414,.379,.354,.336,.327,.319,.312,
     1.305,.298,.292,.287,.281,.276,.271,.266,.261,.257,.253,
     2.245,.238/
      DATA TCK/21.1,20.1,18.9,17.9,17.3,16.8,16.3,
     115.8,15.2,14.7,14.15,13.60,13.10,12.50,12.05,11.50,
```

```
    211.00,10.45,9.40,8.30/
     DATA REG/3.,4.,5.,6.,7./
     DATA EPSMAX/.477,1.2455,2.072,2.9775,3.929/
     DATA TCKG/.00713,.0074,.00765,.007925,.008025,.00815,.008275,
    1.0084,.008525,.00863,.00875,.00881,.00897,.00908,.009175,.009275,
    2.00935,.00945,.00960,.00971/
5000 GO TO 1
2000 FORMAT GENERATOR
     RESTORE
                POWER BOILER THERMAL/HYDRAULIC DESIGN
     SPACE
     TITLE=-X                                                -A
     SPACE 2
                            GEOMETRY
     SPACE
         NT    =      -I                 TUBE P/D        =       -F5
    TUBE ID    =      -F4 INCHES         TUBE FLOW AREA  =       -F6 FT 2
    TUBE OD    =      -F4 INCHES         INSERT P/D      =       -F2
    WALL XW    =      -F4 INCHES         SHELL ID        =       -F3 INCHES
    TUBE LTOT=        -F4 FEET           SHELL FLOW AREA=        -F4 FT 2
    TUBE LB    =      -F4 FEET
    TUBE LSC   =      -F4 FEET
     SPACE 2
                        THERMAL PARAMETERS
     SPACE
     POWER         QTOT            QB            QSC         Q/A BOILING
       KW        BTU/SEC         BTU/SEC       BTU/SEC       BTU/FT2 HR
      -F0            -F2             -F2           -F2              -F2
     SPACE 2
             PRIMARY                               SECONDARY
     SPACE
      TPIN     =      -F2   DEG F          TSIN     =      -F2 DEG F
      TPOUT    =      -F2   DEG F          TSAT     =      -F2 DEG F
      WP       =      -F3   LBM/SEC        TSOUT    =      -F2 DEG F
      GP       =      -F3   LBM/FT2SEC     WS       =      -F3 LBM/SEC
     END OF FORMAT
7000 FORMAT GENERATOR
      VP       =      -F3   FT/SEC         GMAX     =      -F3 LBM/FT2 SEC
      REP      =      -F1                  VMAX     =      -F2 FT/SEC
      PEP      =      -F2                  ACCL     =      -F2 FT/SEC2
      HP       =      -F2   B/FT2HRDEG     ACCL/G   =      -F2 GEES
      HWALL    =      -F2   B/FT2HRDEG     HSL      =      -F2 B/FT2HR DEG
      DELTAP   =      -F3   PSIA           HB       =      -F2 B/FT2HR DEG
      DPRIN    =      -F3   PSIA           REL      =      -F1
      DPROUT   =      -F3   PSIA           PEL      =      -F2
                                           UIL      =      -F2 B/FT2HR DEG
                                           UIB      =      -F2 B/FT2HR DEG
                                           DELTAP   =      -F3 PSIA
                                           DPFRIC   =      -F3 PSIA
                                           DPMOM    =      -F3 PSIA
```

```
    SPACE
                                   SUPERHEAT REGION
    SPACE
  QSUP       HSUPS       TSUPS      TUBE LSUP   DPSUP      DPSFRIC      DPSMOM
 BTU/SEC   HR UNITS      DEG F         FT        PSI         PSI          PSI
    -F2       -F2         -F2          -F4        -F3         -F3          -F4
    END OF FORMAT
    END
```

```
$IBFTC FRIC     FULIST,SDD
      SUBROUTINE FRIC(POD,DCB,DT,G,VIS,FR1)
    1 BETA=SQRT(1.+3.1416/POD**2)
    2 GMAX=G*BETA
    3 A=DCB/DT
    4 B=A**2
    5 DENOD=(1.-B)/(1.+A+(1.-A)/3.1416)
    6 DEN=DT*DENOD
    7 REQ=DEN*300.*GMAX/VIS
    8 FR1=.316/REQ**.25
      RETURN
      END
```

```
$IBFTC RDP      FULIST,SDD
      SUBROUTINE RDP(DT,RDPL,WP,RHO,VIS,PODT,NT,DPR)
C
C     SUBROUTINE COMPUTES RADIAL PRESSURE DROP.
C
  501 F=0.
      XNT=FLOAT(NT)
      NT1=1
      I=1
 4111 NT1=NT1+6*(I-1)
      IF(NT1-NT)4112,4113,4114
 4112 I=I 1
      GO TO 4111
 4114 I=I 1
 4113 CONTINUE
C
      DO 502 J=2,I
      NROW=J-1
      F1=FLOAT(NROW)/XNT
      F=F F1**1.84
  502 CONTINUE
      TERM1=.25/(PODT-1.)**1.84
      TERM2=.118/(PODT-1.)**2.92
      GAM=(TERM1+TERM2)*F
      TERM=(VIS*RDPL/12./WP/3600.)**.16
      TERM3=(WP/RDPL*144./DT)**2
      DPR=TERM/RHO*.562/32.2/144.*GAM*TERM3
 1067 RETURN
      END
```

```
$IBFTC DICHOA  FULIST,SDD
      SUBROUTINE DICHOA(XVAL,ULIMIT,XLIMIT,BALPT,TOL,SLOPE,K,ANSWER,NIT)
C
C
C     XVAL=VARIABLE TO BE ITERATED OR COMPARED
C     ULIMIT=UPPER LIMIT ON ABCISSA
C     XLIMIT=LOWER LIMIT ON ABCISSA
C     BALPT=BALANCE POINT
C     TOL=TOLERANCE
C     SLOPE=SLOPE OF CURVE
C         FOR NEGATIVE SLOPE=1.
C         FOR POSITIVE SLOPE=0.
C     K=CONVERGENCE INDICATOR=1 FOR CONVERGENCE.
C     ANSWER=ANSWER(ABCISSA)
C
      IF(I-71)54,2,54
    2 IF(AFORK)10,4,10
    4 AFORK=1.0
      PEMAX=ULIMIT
      PEMIN=XLIMIT
    6 XMAXI=PEMAX
      XMINI=PEMIN
    8 TDIFF=(XMAXI+XMINI)/2.0
      ANSWER=TDIFF
      K=0
      RETURN
C
C     TEST THE DIFFERENCE.
C
   10 TDIFF=XVAL-BALPT
      IF(ABS(TDIFF) TOL)12,12,20
C
C     PASS DIFFERENCE EQUAL OR LESS THAN TOL.
C
   12 AFORK=0.
      ITCTR=0
      I=0
      K=1
      RETURN
C
   20 IF(SLOPE)26,22,26
   22 IF(TDIFF)24,23,23
C
C     Y GREATER THAN BALPT
C
   23 XMAXI=ANSWER
      GO TO 32
C
C     Y LESS THAN BALPT
C
   24 XMINI=ANSWER
      GO TO 32
   26 IF(TDIFF)30,28,28
   28 XMINI=ANSWER
      GO TO 32
   30 XMAXI=ANSWER
   32 ITCTR=ITCTR+1
      IF(ITCTR-NIT)8,42,8
   42 CFORK=0.
      BFORK=0.
      AFORK=0.
```

```
      ITCTR=0
      I=0
      CALL DUMP(TDIFF,2)
   54 I=71
      AFORK=0.
      BFORK=0.
      CFORK=0.
      GO TO 2
      END
```

```
$IBFTC LININT  FULIST,SDD
      SUBROUTINE LININT(Z,Y,ARGZ,ARGY,AL,N)
C     SUBROUTINE FOR LINEAR INTERPOLATION
C
      DIMENSION Z(100),Y(100)
    6 NN=N
    7 M=N 1
    5 DO 11I=1,M
    8 LL=I+1
    9 L=I
   10 A=(Z(I)-ARGZ)*(Z(I+1)-ARGZ)
   12 IF(A)14,14,15
   15 AL=0.0
   11 CONTINUE
   20 IF(ARGZ-Z(1))25,14,26
   25 IF(Z(1)-Z(2))27,14,28
   26 IF(Z(1)-Z(2))28,14,27
   27 ARGY=Y(2)-((Z(2)-ARGZ)/(Z(2)-Z(1)))*(Y(2)-Y(1))
      GO TO 22
   28 ARGY=((ARGZ-Z(M))/(Z(NN)-Z(M)))*(Y(NN)-Y(M))+Y(M)
      AL=100.0
      GO TO 22
   14 RAT=(ARGZ-Z(L))/(Z(LL)-Z(L))
   23 ARGY=Y(L)+RAT*(Y(LL)-Y(L))
   24 AL=L
   22 M=N 1
      RETURN
      END
```

```
$IBFTC DUBIN    FULIST,SDD
      SUBROUTINE DUBIN(P,T,V,PLUSH,TUSH,VUME,MM,NN,JA,JB)
C
C     SUBROUTINE FOR DOUBLE LINEAR INTERPOLATION
C
      DIMENSION PLUSH(40),TUSH(40),VUME(1600)
  100 PP=P
  200 TT=T
  600 M=MM
  700 N=NN
  800 DO 1100 I=1,M
  850 L=I
  900 C=(PLUSH(I)-P)*(PLUSH(I 1)-P)
 1000 IF(C)2700,2700,1200
 1200 JAM=3
 1100 CONTINUE
 1400 TEST=(PLUSH(1)-P)*(PLUSH(2)-PLUSH(1))
 1500 IF(TEST)1700,2100,2500
 1700 JAB=100
 1750 MN=M-1
 1800 RAP=(P-PLUSH(MN))/(PLUSH(M)-PLUSH(MN))
      LL=MN
 1950 GO TO 2800
 2100 RAP=0.0
 2200 LL=1
      JAB=200
      GO TO 2800
 2500 RAP=(P-PLUSH(1))/(PLUSH(2)-PLUSH(1))
 2550 JAB=0
 2600 LL=1
 2250 GO TO 2800
 2700 LL=L
      LLL=LL+1
 2950 JAB=LL
 2900 RAP=(P-PLUSH(LL))/(PLUSH(LLL)-PLUSH(LL))
 2800 LLL=LL+1
 3000 DO 3500 I=1,N
 3100 K=I
 3200 C=(TUSH(I)-T)*(TUSH(I+1)-T)
 3300 IF(C)4500,4500,3400
 3400 JAM=10
 3500 CONTINUE
 3600 TEST=(TUSH(1) T)*(TUSH(2)-TUSH(1))
 3700 IF(TEST)3800,4100,4300
 3800 NJ=N-1
 3900 RAT=(T-TUSH(NJ))/(TUSH(N)-TUSH(NJ))
      KK=NJ
 3850 JBB=100
 4050 GO TO 4600
 4100 RAT=0.0
 4200 KK=1
      JBB=200
      GO TO 4600
 4300 RAT=(T-TUSH(1))/(TUSH(2)-TUSH(1))
 4350 JBB=0
 4400 KK=1
 4250 GO TO 4600
 4500 KK=K
      KKK=KK+1
 4675 JBB=KK
 4650 RAT=(T-TUSH(KK))/(TUSH(KKK)-TUSH(KK))
```

```
4600-KKK=K+1
4700 KV1=M*KK+LL-M
4800 KV2=KV1+1
4900 V1=VUME(KV1)+RAP*(VUME(KV2)-VUME(KV1))
     KV1=M*KKK+LL-M
5100 KV2=KV1+1
5200 V2=VUME(KV1)+RAP*(VUME(KV2)-VUME(KV1))
5300 VV=V1+RAT*(V2 V1)
5400 V=VV
5500 JA=JAB
5600 JB=JBB
     RETURN
     END
```

```
$IBFTC CURV     FULIST,$DD
      FUNCTION CURV(P)
   17 PYP=P/14.69594
   18 PUN=(ALOG(PYP))/2.3025851
   19 PEEP=(PUN+0.10705539)/2.1805446
   20 PUP=PEEP*PEEP
   21 PUPPY=PUP*PEEP
   22 PURP=PUP*PUP
   23 PURPLE=PUP*PUPPY
   24 PURSE=PUPPY*PUPPY
   25 PERK=PURP*PUPPY
   26 PERKY=PURP*PURP
   27 PLUP=1.3190232*PEEP-.13299096+.69237968*PUP+.37008034
     1*PUPPY+.19876127*PURP+.10754778*PURPLE+.066299672
     2*PURSE+.041265195*PERK+.013472973*PERKY
   28 CURV=1900.0+700.0*PLUP
      RETURN
      END
```

```
$IBFTC THERMA  FULIST,SDD
      SUBROUTINE THERMA(PR,T,VPSIA,HLL,HEN,SL,SEN,VOLLL,VENN,CPV,CPL,
     1POLLYV,AV,CHOICE,SUPER,HGG,SG,VV,CPP,POLLY,A)
C     SUBROUTINE RETURNS THERMODYNAMIC PROPERTIES
C     OF SATURATED AND/OR SUPERHEATED POTASSTUM.
C     (NRL PROPERTIES).
C     SUPER=-1., SP. VOL,ENTHALPY,AND ENTROPY ONLY.
C     SUPER=0., SATURATED PROPERTIES ONLY.
C     SUPER=1., SUPERHEATED PROPERTIES.
C
C     CHOICE=1., PRESSURE INPUT(SATURATED)
C     CHOICE=-1., TEMPERATURE INPUT(SATURATED)
C     CHOICE=ABS GREATER THAN 6736.0, SP VOL
C     ITERATIONS PRINTED.
C     CHOICE=ABS GREATER THAN 1362.0, VIRIAL COEF.
C     AND THEIR DERIVATIVES PRINTED.
C
      DIMENSION PLUSH(18),TUSH(12),VUME(300),FF(100)
      DATA PLUSH/10.,2.,1.,.3333,.2,.166667,.125,.1,
     10.083333333,0.07142857,0.0625,0.055555556,0.05,0.038461538,
     20.33333,0.025,0.016667,0.0125/
      DATA TUSH/8.33333E-4,7.66923077E-4,7.142857E-4,6.666667E-4,
     16.25E-4,5.8823529E-4,5.5555555E-4,5.263157E-4,5.0E-4,
     14.761904E-4,4.5454E-4,4.3478E-4/
      DATA(VUME(I),I=1,208)/3254.8,618.1,285.2,266.,247.,228.,209.,90.,
     1171.0,152.0,133.0,114.0,95.0,76.0,57.0,38.0,19.0,1.0,3545.5,
     2691.4,333.6,91.16,38.94,24.71,5.18,20.0,18.0,16.0,14.0,12.0,10.0,
     48.0,6.0,4.0,2.0,10.0,3828.1,755.13,370.62,112.84,59.89,46.22,
     428.48,17.142,9.005,2.696,2.,1.8,1.6,1.4,1.2,1.,.8,.6,
     54106.9,814.8,403.1,128.0,72.37,58.28,40.40,29.37,21.77,16.13,12.,
     68.100,5.10,3.10,1.60,1.30,1.00,.7,4383.9,872.4,433.3,140.4,
     781.47,66.64,48.02,36.7,29.03,23.45,19.18,15.78,12.99,6.86,
     83.908,2.0,1.0,0.5,4659.9,928.9,462.5,151.4,89.02,73.38,53.76,
     941.92,33.96,28.23,23.88,20.46,17.68,11.75,8.99,4.18,2.0,1.0,
     94935.2,984.8,491.0,161.7,97.76,79.25,58.57,46.12,37.79,
     131.8,27.29,23.76,20.91,14.91,12.17,7.53,2.39,1.0,5210.3,1040.4,
     2519.16,171.61,102.05,84.65,62.87,49.78,41.03,34.76,30.04,26.36,
     323.41,17.21,14.41,9.75,4.49,19.99,5485.1,1095.8,547.09,181.28,
     4108.09,89.78,66.88,53.22,43.94,37.37,32.43,28.58,25.49,19.026,
     516.152,11.383,6.419,1.977,5759.7,1151.0,574.9,190.8,114.0,
     694.74,70.71,56.28,46.65,39.77,34.6,30.57,27.34,20.605,17.611,
     712.68,7.62,4.96,6034.3,1206.1,602.6,200.2,119.7,99.58,74.42,
     859.31,49.24,42.03,36.63,32.42,29.05,22.02,18.9,13.78,8.54,5.88,
     96308.8,1261.1,630.2,209.5,125.4,104.4,78.05,62.27,51.74,44.22/
      DATA(VUME(I),I=209,216)/38.57,34.17,30.66,23.33,20.08,14.76,9.35,
     16.61/
  200 PNRL=PR/14.69594
  230 IF (PNRL-0.007)231,232,232
  231 PNRL=0.007
  232 IF (PNRL-21.0)233,233,234
  234 PNRL=21.0
  233 AJ=778.26
      E=67.0
      F=68.0
      G=69.0
      DECKA=0
      DECKB=0
      DECKC=0
      VALA=0
      VALB=0
      VALC=0
```

```
      CHECK=CHOICE
      J=3
      JJ=10
      PRENT=ABS(CHECK)
  300 TNRL=T
  330 IF (TNRL-1250.0)331,332,332
  331 TNRL=1250.0
  332 IF (TNRL-2700.0)350,350,333
  333 TNRL=2700.0
  350 KAM=0
  500 TLAG=(ALOG(TNRL))*.4342945
  600 IF(CHOICE)800,800,820
  820 PSATAT=PNRL
      GO TO 1000
  800 PVLAG=(6.12758-8128.77/TNRL-0.53299*TLAG)*2.302585
  900 PSATAT=EXP(PVLAG)
 1000 PSAT=PSATAT*14.69594
 1100 PSATSF=PSATAT*2116.2
 1200 BANLUG=(4544.3/TNRL-3.7641+TLAG)*2.302585
 1300 BAN=EXP(BANLUG)
 1400 B=BAN*(-1.0)
 1500 CLUG=(0.6988+5725.0/TNRL)*2.302585
 1600 C=EXP(CLUG)
 1700 DANLUG=(1.9274+5671.4/TNRL)*2.302585
 1800 DAN=EXP(DANLUG)
 1900 D=DAN*(-1.0)
 2000 DBDT=(B/TNRL)*(1.0-10463.637/TNRL)
 2100 TSQ=TNRL*TNRL
 2200 DCDT=13182.2*C*(-1.0)/TSQ
 2300 DDDT=13058.8*D*(-1.0)/TSQ
 2400 TCUBE=TSQ*TNRL
 2500 ELLA=39375.0/TNRL
 2600 ELLEN=EXP(ELLA)
 2700 HZERA=998.95+.127*TNRL+24836.0/ELLEN
 2800 SARAH=31126.0/TNRL
 2900 SALLY=EXP(SARAH)
 3000 SZERA=0.18075 0.127*TLAG*2.302585+0.7617/SALLY
 3100 RR=1545.43
 3200 WAYT=39.10
 3300 RRM=39.52506
 3400 PARLUG=(4080.0/TNRL-1.803)*2.302585
 3500 PAR=EXP(PARLUG)
 3600 VAL1=(RRM*TNRL/PSATSF-PAR)*39.1
      MARK=1
 8200 TFAR=TNRL-459.69
 8300 TFAR2=TFAR*TFAR
 8400 TFAR3=TFAR*TFAR2
 8500 DUNSL=52.7274 7.3539E-3*TFAR-0.56013E-6*TFAR2+0.03158
     1E-9*TFAR3
 8600 VLAQ=1.0/DUNSL
 8700 VOLLL=VLAQ
 9500 T4=TSQ*TSQ
 9700 D2B=1.094877E8*B/T4
 9800 D2C=26364.4*C/TCUBE-13182.2*DCDT/TSQ
 9900 D2D=26117.6*D/TCUBE-13058.8*DDDT/TSQ
  601 EMMA=28070.0/TNRL
  701 EMMY=EXP(EMMA)
  801 CZERA=0.127+2.888/EMMY
      CPLAQ=0.22712 0.64848E-4*TNRL+0.23178E-7*TSQ
      CPL=CPLAQ
      IF(PRENT-1362.0)3700,102,102
```

```
 102 WRITE (6,101) B,C,D,DBDT,DCDT,DDDT,D2B,
    1D2C,D2D,PSAT,TNRL
3700 VAL12=VAL1*VAL1
3800 VAL13=VAL1*VAL12
3900 SLEFT=PSATSF*VAL1/(1545.43*TNRL)
4000 RIGHT=1.0+B/VAL1+C/VAL12+D/VAL13
4100 TALLY=0.001*SLEFT
     IF(PRENT-6736.0)4200,103,103
 103 WRITE (6,104) VAL1,SLEFT,RIGHT,DECKA,DECKB,
    1DECKC,VALA,VALB,VALC,CZERA,HZERA,SZERA,PSAT,TNRL
4200 DECK=SLEFT-RIGHT
4250 ADECK=ABS(DECK)
4300 IF(TALLY-ADECK)4400,4500,4500
4400 IF(MARK-10)4600,4700,4700
4700 VAL1=(RRM*TNRL/PSATSF-PAR)*39.1
     GO TO 4500
4600 IF(MARK-2)4800,5200,5500
4800 VALA=VAL1
4900 DECKA=DECK
5000 VAL1=VALA*1.03
5100 MARK=MARK+1
     GO TO 3700
5200 VALB=VAL1
5300 DECKB=DECK
5400 VAL1=VALA*0.97
     MARK=MARK+1
5450 GO TO 3700
5500 VALC=VAL1
5600 DECKC=DECK
5700 DECKA2=DECKA*DECKA
5800 DECKB2=DECKB*DECKB
5900 DECKC2=DECKC*DECKC
6000 Z1Z3=DECKA-DECKC
6100 Z1Z2=DECKA-DECKB
6200 W1W3=DECKA2-DECKC2
6300 W1W2=DECKA2-DECKB2
6400 Y1Y3=VALA-VALC
6500 Y1Y2=VALA-VALB
6600 ANUM=Z1Z3*Y1Y2-Z1Z2*Y1Y3
6700 ADEN=W1W2*Z1Z3-W1W3*Z1Z2
6800 AAA=ANUM/ADEN
6900 BBB=(Y1Y2-AAA*W1W2)/Z1Z2
7000 VAL1=VALA-AAA*DECKA2-BBB*DECKA
7100 MARK=MARK+1
7400 DECKA=DECKB
7500 DECKB=DECKC
7600 VALA=VALB
7700 VALB=VALC
     GO TO 3700
4500 VENNA=VAL1/39.1
7800 VAL2=VAL1*VAL1
7900 VAL3=VAL1*VAL2
7950 VAL4=VAL2*VAL2
7951 VAL5=VAL2*VAL3
8000 HG1=HZERA+(RRM*TNRL/AJ)*((B-TNRL*DBDT)/VAL1+(C-TNRL
    1*DCDT/2.0)/VAL2+(D-TNRL*DDDT/3.0)/VAL3)
8100 HENNA=HG1
8150 HGSAT=HENNA
9200 VRT=VAL1/(RR*TNRL)
     VRTAB=ABS(VRT)
     VRT=VRTAB
```

```
9300 VRTLUG=ALOG(VRT)
9400 SGSAT=SZERA-(RRM/AJ)*((B+TNRL*DBDT)/VAL1-VRTLUG
    1+(C TNRL*DCDT)/(2.0*VAL2)+(D+TNRL*DDDT)/(3.0*VAL3)-7.65738)
9600 SENNA=SGSAT
     VALSAT=VENNA
8800 HATTY=(PSATSF/AJ)*(18717.2/TNRL-0.53299)*(VALSAT-VLAQ)
8900 HLNRL=HGSAT-HATTY
     SATTY=HATTY/TNRL
     SLNRL=SENNA-SATTY
     IF(SUPER)2001,201,201
 201 BRAKET=1.0+(B TNRL*DBDT)/VAL1+(C+TNRL*DCDT)/VAL2
    1+(D TNRL*DDDT)/VAL3
 301 CGNUM=BRAKET*BRAKET
 401 CGDEN=1.0+2.0*B/VAL1+3.0*C/VAL2+4.0*D/VAL3
 501 PAR2=TNRL*D2B 2.0*DBDT+0.5*(TNRL*D2C+2.0*DCDT)/VAL1
    1+(TNRL*D2D+2.0*DDDT)/(3.0*VAL2)
 901 CPG=CZERA+(RRM/AJ)*(CGNUM/CGDEN-1.0-(TNRL/VAL1)
    1*PAR2)
1050 BRUCK=1.0/VAL2+2.0*B/VAL3+3.0*C/VAL4+4.0*D/VAL5
1101 DRHDT=RR*TNRL*(-1.0)*BRUCK
1201 DVDP=1.0/(DRHDT*WAYT)
1301 DVDT=(PSATSF/(RR*TSQ)+DBDT/VAL2+DCDT/VAL3+DDDT/VAL4)
    1/(BRUCK*WAYT)
1401 PALE=1.0/((PSATSF/VENNA)*(DVDP+(TNRL/(AJ*CPG))*DVDT*DVDT))
1501 PALM=PALE*(-1.0)
1601 ALF=PALM*32.174*RRM*TNRL
1701 ABALF=ABS(ALF)
1801 ALE=SQRT(ABALF)
1901 IF(KAM)2101,2001,2101
2001 VENN=VENNA
2201 HEN=HENNA
2301 SEN=SENNA
     SL=SLNRL
9000 HLL=HLNRL
9100 VPSIA=PSAT
2351 IF(SUPER)2352,2401,2401
2352 CPV=0.0
2353 POLLYV=0.0
2354 AV=0.0
     GO TO 2801
2401 CPV=CPG
2501 POLLYV=PALM
2601 AV=ALE
2701 IF(SUPER)2801,2801,3401
2801 HGG=0
2901 SG=0
3001 VV=0
3101 CPP=0
3201 POLLY=0
3301 A=0
3351 GO TO 4601
3401 KAM=1
3501 MARK=1
3601 PSATAT=PNRL
3701 PSAT=PSATAT*14.69594
3801 PSATSF=PSATAT*2116.2
     MM=18
     NN=12
     RPSAT=1.0/PSAT
     RTNRL=1.0/TNRL
3903 CALL DUBIN(RPSAT,RTNRL,VELD,PLUSH,TUSH,VUME,MM,NN,JAN,JAQ)
```

```
      MARK=1
 4001 VAL1=VELD*39.1
      GO TO 3700
 2101 HGG=HENNA
 4101 SG=SENNA
      CPP=CPG
 4201 VV=VAL1/39.1
 4301 CPP=CPG
 4401 POLLY=PALM
 4501 A=ALE
 4601 HARRY=6.0
C
      RETURN
  101 FORMAT GENERATOR
      B            C            D            DBDT         DCDT         DDDT
      -1PE3        -E5          -E5          -E5          -E5          -E5
      SPACE
                   D2B          D2C          D2D          PRESS        TEMP
             -E5          -E5          -E5          -E5          -E5
      SPACE
      END OF FORMAT
  104 FORMAT GENERATOR
      SPACE
              VAL1         LEFT         RIGHT        DEC1         DEC2
                   -E5          -E5          -E5          -E5          -E5
      SPACE
              DEC3         VOL1         VOL2         VOL3         CO
                   -E5          -E5          -E5          -E5          -E5
      SPACE
              HO           SO           PRESS        TEMP
                   -E5          -E5          -E5          -E5
      SPACE
      END OF FORMAT
      END
```

ABSTRACT

Calculation procedures and digital computer codes for thermal design of multiple-tube potassium condensers and boilers are presented. The computer programs are given, together with typical input and output formats as illustrated by representative test cases. The computer codes are useful for preliminary thermal design studies of condensers and boilers applicable to Rankine cycle space power systems using potassium as the working fluid.