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**REPP: A THERMAL HYDRAULIC
DESIGN CODE FOR WATER-COOLED REACTORS**

MARCH 1969

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REPP: A THERMAL HYDRAULIC
DESIGN CODE FOR WATER-COOLED REACTORS

By

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ABSTRACT

REPP, a digital computer method for designing pressure water and boiling water reactor cores within specified heat transfer and fuel centerline temperature limits is presented. The method incorporates the Westinghouse W-2 and W-3 empirical correlations and a theoretical hot channel model to predict burnout conditions in a rod bundle. Two geometries are considered; rods in a triangular array and rods in a square lattice. The heat transfer problem solved is a one-dimensional analysis. Pressure drop is considered for four types of fuel-pin spacers. Variable heat generation rate through the fuel-pin and sintering in low density fuels are also included.

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1.0 INTRODUCTION

This report describes a digital computer code, REPP, a one-dimensional heat transfer code written for the primary purpose of sizing and designing boiling water and pressurized water reactor cores. The design limits are total reactor power, burnout heat flux and fuel centerline temperature. The design is based on hot channel analysis.

The code is particularly useful in conjunction with a nuclear burnup code for fuel element and lattice design. In essence, REPP can be used to determine a range of rod sizes and lattice spacings that optimizes heat removal within the core. Nuclear analysis can then be made over this range of potential cores to minimize fuel cycle cost. Thus the code serves the important function of assuring useful reactor core designs on which nuclear and economic studies may be made.

The remainder of this report includes a description of the code, detailed operating instructions and a Fortran listing. A detailed discussion of the various approximations incorporated in the code is included where appropriate.

2.0 SUMMARY

REPP, a digital computer program written in FORTRAN IV provides the capability for designing boiling water and pressure water reactors within specified fuel centerline temperatures and burnout heat flux limits. The code is programmed for solving steady-state, one-dimensional, heat transfer problems. Provision is made for two core geometries:

- (1) The first consists of square subassemblies which contain fueled rods in a square lattice.
- (2) The second consists of hexagonal subassemblies with fueled rods in a triangular array.

The principal features of REPP are as follows:

- Calculation of the pressure drop and coolant properties for both two-phase flow and single-phase flow at a minimum of 10 and a maximum of 100 nodal locations along a coolant channel. These calculations are made for nominal* and hot channel conditions.
- Determines thermal and hydraulic conditions for a core designed to burnout heat flux limits.

* Nominal conditons are defined to be those conditions calculated by standard practices and procedures without assessing the influence of core uncertainties commensurate with hot channel considerations.

- The capability of designing to specified maximum fuel centerline temperature limits.
- Includes either solid or annular fuel pin geometry.
- Includes the option for calculating the void formation at the center of the fuel pin caused from sintering* of low density fuels. Thus the effect of sintering on fuel temperature can be assessed.
- Accommodates radial heat generation variance in the fuel pin. Only the relative heat generation profile need be specified. The magnitude is determined to correspond to the nodal heat fluxes.
- Allows the use of variable fuel thermal conductivities and variable axial power in the fuel pin.
- Includes the option for calculating the pressure drop across several types of fuel pin spacers.
- Use of a cross flow factor to modify hot channel coolant temperatures and burnout heat flux predictions. The factor is used, if the user so desires, to compensate for the cross flows which may exist in a subassembly.
- Use of a flow redistribution factor to compensate for orificing effects or non symmetric geometry effects.

* Grain growth develops in low-density fuels at certain temperatures. The porosity of the fuel decreases and consequently the density of the fuel increases to 95% or 98% TD (theoretical density). The pores move toward the center of the pin in the direction of increased temperature gradient.

3.0 CODE DESCRIPTION

REPP is a one-dimensional heat transfer code developed to calculate heat removal from circular rods with a nuclear heat source. Two constraints, burnout heat flux and fuel centerline temperature, are used to determine reactor core size and fuel pin diameters. The pressure drop, the coolant temperatures, surface heat fluxes, and fuel centerline temperature are predicted from the input data and a thermal energy balance at various mesh points along the core. For a design problem, the analysis is divided into two main divisions. The first division develops a mathematical model. The second division predicts the thermal and hydraulic conditions through the core. An iterative process between the two subdivisions is used to design within specified fuel centerline temperatures, and heat flux limits for a given reactor power level.

3.1 CORE GEOMETRY

Two types of fuel geometries can be evaluated using REPP. They are identified by the configuration of the sub-assemblies and the fuel arrangement.

The first geometry, Figure I, is composed of a number of closely fitted square shaped subassemblies which contain fueled pins in a square lattice. Space is provided between the subassemblies to accommodate thermal expansion and, if applicable, positioning of control rods.

The second geometry, Figure II, consists of a number of closely fitted hexagonal shaped subassemblies which contain fuel pins in an equilateral

Square Lattice Core

FIGURE I

A Square Lattice Core Model Used in REPP

TRIANGULAR LATTICE CORE

FIGURE II

A Triangular Lattice Core Model Used in REPP

triangular array. Control rod spacing, if applicable, and thermal expansion spacing is provided between the subassemblies.

3.2 THE THERMAL HYDRAULIC MODEL

A modification of the actual core geometry is made internally in the code to simplify the investigation of thermal and hydraulic conditions in the core. This model eliminates components in the core which are not pertinent, or generally may be considered negligible, to heat transport considerations. Components eliminated are the subassembly sheath cladding and the space provided for both thermal expansion between subassemblies and control rod assemblies. This model, the thermal and hydraulic model shown in Figures III and IV, is thus defined to be a right circular cylinder containing fuel pins in either a square lattice or an equilateral triangular array and which assumes uniform fuel pin spacing throughout the core.

Since the coolant flow area associated with each peripheral pin in the subassembly may be greater than flow areas associated with central pins, due to oversized subassemblies, and since no special consideration is given to restricted coolant flow areas in the corners of each subassembly, some error may be introduced into the thermal and hydraulic predictions due to the assumption of uniform pin spacing. Additionally, the cold wall effect on burnout is not analyzed. Also, no attempt was

FIGURE III
A Mathematical Heat Transfer Model of Fuel-Pins in a Square
Lattice Which is Used in REPP Calculations

FIGURE IV
A Mathematical Heat Transfer Model of Fuel-Pins in a Triangular Lattice Which is Used in RELPP Calculations

made to evaluate the effect on heat transport from coolant leakage* through the core. However, since the sizing routine limits heat flux and fuel centerline temperatures according to a theoretical hot channel, the above conditions do not seriously restrict the utility of the code in preliminary design studies. Once design parameters have been delineated, a more rigorous evaluation of hot spot hot channel behavior may be ascertained from more detailed thermal hydraulic codes such as COBRA.⁽¹⁾ Since all coolant channel surfaces are not represented in the thermal and hydraulic model, head loss due to these frictional surfaces is not included in the coolant pumping power considerations. However the error is negligible when such surfaces are small compared to the total heat transfer surface area of the core. Mathematical development of the model is given in Appendix B.

3.3 REPP ROUTINES AND FLOW CHART

There are thirteen routines used in REPP as follows:

REPP The main program which reads in the data and acts as a calling routine.

INPUTR A base case input generator.

BIG A subroutine which correlates the data from all the other routines and recycles the iteration process.

GEOM Designs the geometry of the reactor

* Coolant which is channeled through the core and not directly associated with heated surfaces is defined as leakage. This includes coolant flowing between subassemblies or through control rod assemblies, etc.

PRESS 2 Used to calculate the pressure drop and coolant properties at the mesh points.

LAGRIN A third order central difference lagrangian interpolation routine.

SIMPIN A numerical integration routine using Simpson's rule. This routine can be adjusted to any order desired.

STMTBL The Keenan and Keyes steam tables with linear interpolation between values.

PROPS A water properties table which supplements STMTBL with values of thermal conductivity and viscosity.

GRIDS A subroutine which calculates pressure drop across various spacer types.

FLOT An on-line plotting routine capable of plotting up to five variables.

HOLE Used to calculate the size of the annulus developed in a fuel pin for low-density sintered fuels.

SLIP 4 Tabular values of the gravitational slip factor used in two phase flow calculations.

Table I illustrates the flow of information as it is processed in REPP.

TABLE I
REPP Flow Chart

4.0 HEAT TRANSFER

The heat transfer package in REPP consists of three major steps or subdivisions. After each step is completed, the user has the option of transferring control to a center which writes the output and calls for a subsequent case when appropriate, or he may continue the design process. The three steps are:

- (1) Calculate from input data an initial core geometry and predict the thermal and hydraulic conditions through the core.
- (2) Calculate the size of the core required to perform within specified heat transfer limitations at a given reactor power level and a specified power distribution.
- (3) Calculate the size of the core required to perform within specified heat flux limits and fuel centerline temperature limits at a specified reactor power level.

The spatial heat production may vary within a fuel-pin in the radial direction. However, it is postulated that the relative heat generation profile across a fuel pin is the same throughout the core. Only the magnitude of the integrand is allowed to vary by a constant. Thus the heat fluxes at each location parallel to a fuel rod may be nonuniform.

The initial core geometry is determined from the input data. After the geometry has been delineated, the thermal and hydraulic conditions through the core are calculated. A minimum of ten and a maximum of one

hundred nodes are defined parallel to a coolant channel. Both nominal and hot channel conditions are predicted at each nodal location based on an energy and momentum balance and nominal conditions. The modes of heat movement considered are: one-dimensional conduction and forced convection including local boiling (mass media). The relative power profile (local/ave), the relative fuel-pin heat generation rate (local/ave), and a thermal conductivity profile are input parameters which are integrated in a numerical integration routine. A minimum of four and a maximum of twenty data points* may be used to specify each of the profiles. The input data are then processed through a Lagrangian⁽²⁾ interpolation subroutine. A third order polynomial is used in the interpolation process to generate an equivalent number of data points commensurate with a given set of mesh points. The resulting data are numerically integrated in a subroutine using Simpson's rule⁽²⁾ for the integration procedure. In this manner the integrals,** $\int Kdt$, $\int Qdx$, and $\int q^rdr$ are solved and stored in arrays along with corresponding temperatures, lengths, and fuel-pin radial distances respectively. The local heat flux at each of the nodes and the energy increase of the coolant is calculated using the integrated

* A maximum of sixteen for the radial fuel-pin heat generation profile is allowed.

** Where:

K represents the fuel thermal conductivity (Btu/hr-ft-°F)
 Q represents the thermal energy per unit length (Btu/hr-ft)
 q^r represents the fuel-pin heat generation rate (Btu/hr-ft³)
 t represents temperature
 x represents distance through the core parallel to the coolant channel
 r represents radial distance across a fuel-pin.

power profile data. Using the Keenan and Keyes steam tables⁽³⁾ and an energy and momentum balance, the temperature of the coolant is determined. The local fuel surface temperatures are calculated for each node based on the local heat flux, the coolant temperature, a local forced convective film coefficient⁽⁴⁾ and a heat transfer coefficient which defines the heat movement at the fuel-clad interface. The temperature profile through the fuel-pin perpendicular to the coolant channel is determined from the integrated thermal conductivity data and the integrated radial heat generation data. The temperature differential across the fuel-clad is not calculated. This method should introduce only negligible error since the cladding is generally a better conductor of heat than most fissile fuels. However, if better accuracy is desired, the effect of the clad can be included in the fuel-clad interface heat transfer coefficient.

The numerical integration scheme becomes an especially useful tool capable of handling irregular shaped profiles and discontinuous functions. It is limited to single valued functions, however. For example, a sintering⁽⁵⁾ process can be simulated in pins fueled with low density fuels and containing a variable radial heat generation rate. The effect of the sintering process on fuel centerline temperatures at various rod power levels can be assessed. To facilitate the grain growth in the sintering fuels, the code iterates on the size of the void formed at the rod center. The temperature at which sintering begins is an input parameter. An initial void can be assumed at the beginning of the process when desired.

From these initial conditions and using the numerically integrated heat generation data and the integrated fuel thermal conductivity data a temperature profile through the fuel-pin is calculated. The temperatures are then sampled stepwise in increments of ($\Delta R/R = .05$) inward from the outer surface of the fuel until the sintering temperature is reached. A linear interpolation is made when the sintering temperature does not coincide with the radial mesh. The remaining fuel is assumed to sinter to 95% density forming a hole or void in the fuel-pin center. Each time the void calculated changes from its previous value, the heat generation profile is numerically integrated again with the new annular fuel arrangement and a new temperature profile is calculated. The process is repeated until a negligible change occurs. In each case only that part of the heat generation profile is integrated which corresponds to the radial limits of the integral, which changes as the fuel develops an annular geometry. In all instances, the integrand is adjusted to agree with the surface heat flux which was predicted from the axial power distribution. Thus the process results in a steady state process* which predicts a void and fuel center-line temperatures which are compatible with a predicted local surface heat flux.

The development of the equations used for heat transfer is shown in Appendix A. The Colburn equation⁽⁴⁾ is used to predict the forced convective

* Microstructural changes are dependent on the time, temperature gradient, and initial density of the fuel.

film coefficient in subcooled regions and a constant value, required as input, is used when subcooled incipient nucleate boiling or bulk boiling occurs. The Jens' and Lottes' equation⁽⁶⁾ is used to locate the point where incipient nucleate boiling begins. A description of the process used for calculating the pressure drop is given later.

The user may at this point transfer control to the output section concluding the run or cause the code to iterate on a heat flux limited core. The design requirement of a heat transfer limited core is to determine the proper core heat transfer surface area which will maintain the structural integrity of the core for a given reactor performance level. In this process, a burnout heat flux is calculated for each node using semi-empirical correlations.^(7,8,9,10) The position of MDNBR* (minimum departure from nucleate boiling ratio) is located and the core is sized based on conditions at this location. The value for the MDNBR is established from the input data. When the heat transfer surface area does not satisfy the MDNBR requirement, control is transferred to a sizing routine where the equivalent core radius, the core length, the number of fuel-pins, and other parameters are adjusted to satisfy the heat flux requirements. After the core parameters have been modified, control is transferred to the beginning of the program and the process is repeated until the design heat flux requirements are met at the point of MDNBR. The reactor power level is left unchanged in the process. It

* The DNB ratio is equal to the local burnout heat flux divided by the local heat flux.

usually requires from six to ten passes through the code to settle on the correct core size. At the completion of the core sizing routine, control may be transferred to the output section concluding the run. An alternative method is to continue the process and design to a fuel-pin centerline temperature limitation. This constraint is used to determine a fuel-pin diameter which will perform within desired temperature requirements when subjected to hot channel conditions.

A fuel centerline temperature limited case requires more computer time than the previous cases since additional passes through the code are necessary. Each time a modification is made to the fuel-pin diameter and consequently the fuel-pin pitch (as mitigated by the temperature requirement), control is transferred to the beginning of the program where a new heat transfer limited core is generated based on the new rod size. This considerably adds to the number of passes required depending on how close the initial parameters were to the final calculated values. This occurs since the calculated fuel temperatures are always one step behind the core sizing routine. An average of sixty passes is reasonable, however one hundred passes may be required. Anything over one hundred generally means the code cannot converge to a solution. The running time is generally increased when a fuel sintering process is included with a fuel centerline temperature limit option. A problem of this type may require as much as one minute of the UNIVAC 1108 computer for a single case. It is generally good practice to begin a preliminary design study using the first or second option. This

provides an opportunity to insure the input data is practical and thus conserve computer time. It also provides the user with additional insight into the influence of the various parameters on a design problem. The code is capable of sizing several cores within thirty-five to sixty seconds. A single pass can be made in less than 5 seconds.

Two other options which may add to the running time are:

- (1) Maintaining a constant L/D (length/core diameter) ratio.

The code is faster when the length is held constant.

- (2) Maintaining a constant mass velocity (lb/hr-ft^2) and

letting the mass flow rate (lb/hr) vary. The code is faster when the mass flow rate is held constant.

4.1 BOILING CRISIS

To effectively delineate reactor core designs within desired performance levels, it is necessary to define heat transfer rates which will preserve the structural integrity of the core. These limits are generally established from maximum fuel and cladding temperatures, or, the point at which a severe deterioration of the heat transfer mechanism occurs which may result in excessive fuel and cladding temperatures. This phenomena is sometimes referred to as departure from nucleate boiling or boiling crisis.

Boiling crisis is a combined phenomenon of hydrodynamics and heat transfer. The exact mechanism of boiling crisis is not yet known. With the advent of reactor technology, experimental data and hypotheses have

appeared in rapidly increasing numbers.⁽¹¹⁾ It is known that the heat flux in nucleate boiling cannot be increased indefinitely, for a constant energy system, without causing damage to the heating surface. It appears that the population of bubbles forming on a heat surface becomes so high that at some point they obstruct the path of the incoming liquid and thus cause a vapor blanket to form over the heated surface. This film of insulation then causes a rapid temperature excursion of the heated surface which may result in structural damage. This condition, referred to as "boiling burnout" or "departure from nucleate boiling" (DNB) is defined to be that point in boiling heat transfer where a severe deterioration of the heat transfer mechanism occurs accompanied by a large increase in the surface temperature. Since damage to the heated surface is generally to be avoided, it thus becomes imperative to predict and prevent the occurrence of the crisis in boiling equipment. One is forced to turn to empirical correlations since the fundamental description of boiling heat transfer in its present state of development fails to provide useful predictions of DNB conditions. Commensurate with the various modes of thermal energy transmission the empirical equations are twofold in application:

- those which apply to subcooled regions
- those which apply to bulk boiling regions

4.2 BOILING CRISIS IN A SUBCOOLED REGION

During local flow fluctuations due to nucleation, the boundary layer may be retarded periodically by the changing bulk flow velocity. The heated surface under this temporarily stagnant layer may become overheated and thus cause a premature boiling crisis. Also in subcooled flow, surface boiling often results in a bubble layer moving parallel to the heated surface. This layer is so close to the wall that it shields the surface from incoming cold liquid. The increased bubble population produced locally in this way may destroy the liquid film and hence result in a boiling crisis.

Subcooled boiling crisis occurs only at relatively high heat flux. The magnitude of the critical flux is a function of the "surface proximity parameters" much more strongly than it depends on the subcooling of the bulk stream.⁽¹¹⁾ The correlations used in REPP to establish the local heat flux are the Westinghouse W-2 and W-3 correlations.^(9,10) The W-2 correlation is used for coolant qualities less than (-15 w/o) and the W-3 correlation is used for qualities greater than (-15 w/o). They were selected since they include the most recent experimental work and technology available for designing pressured water reactors. The W-2 and W-3 correlations were developed by Westinghouse when investigation of existing correlations and models demonstrated them too inaccurate for reactor design problems. The equations for the two correlations are as follows:

W-2

$$q_{\text{DNB}} = (0.23 \times 10^6 + 0.094G) \times (3.0 + 0.01 (T_f - T_{\text{Local}})) \times (0.435 + 1.23e^{-0.0093 L/De}) \times (1.7 - 1.4e^{-a})$$

Where

$$a = 0.532 \times (H_f - H_{\text{in}})/(H_G - H_f)^{3/4} \times (\rho_g/\rho_f)^{-1/3}$$

$$H_f = \text{Enthalpy of saturation liquid (Btu/lb)}$$

$$H_G = \text{Enthalpy of saturated steam (Btu/lb)}$$

$$T_f = \text{Saturated liquid temperature (°F)}$$

$$T_{\text{Local}} = \text{Local coolant temperature (°F)}$$

$$L = \text{Length to point of analysis (Ft.)}$$

$$De = \text{Hydraulic diameter based on the heated surface (Ft.)}$$

$$G = \text{The mass velocity (lb/hr-ft}^2\text{)}$$

W-3

$$q''_{\text{DNB,EU}} = ABCD$$

$$q''_{\text{DNB,N}} = q''_{\text{DNB,EU}}/F$$

Where:

$$q'' = \text{Heat flux}$$

$$q''_{\text{DNB,EU}} = \text{Equivalent uniform departure from nucleate boiling heat flux}$$

$$q''_{\text{DNB,N}} = \text{Non-uniform departure from nucleate boiling heat flux}$$

$$A = [(2.022 - 0.0004302P) + (0.1722 - 0.0000984P) \text{ EXP } (18.177 - 0.004129P)X]$$

$$B = [(0.1484 - 1.596_X + 0.1729X \times G/10^6 + 1.037] [1.157 - 0.869X]$$

$$C = [0.2664 + 0.8357 \text{ EXP}^{-3.151} D_h]$$

$$D = [0.8258 + 0.000794 (H_{\text{SAT}} - H_{\text{IN}})]$$

$$E = 0.44 \frac{(1-X_{\text{DNB}})^{7.9}}{(G/10^6)^{1.72}} \text{ in}^{-1}$$

$$F = \frac{E}{q''_{\text{local}} (1 - \text{EXP}^{-E L_{\text{DNB}, \text{EU}}})} \int_0^{L_{\text{DNB}, \text{N}}} q''(z) \text{EXP}^{-E(L_{\text{DNB}, \text{N}} - z)} dz$$

P = Pressure (psia)

G = Mass velocity (lb-hr-ft²)

D_h = Hydraulic diameter (in)

X = Quality of the coolant (percent)

X_{DNB} = Quality of the coolant at the departure from nucleate boiling location (percent)

H_{IN} = Coolant inlet enthalpy (Btu/lb)

H_{SAT} = Coolant saturation enthalpy (Btu/lb)

L_{DNB} = Length from inception of local boiling to departure-of-nucleate-boiling location

Z = Distance from the inception of local boiling measured in the direction of flow

The W-2 correlation correlates the existing uniform heat flux DNB data within 20% at a probability level of 95%. Because the data were obtained from uniform heat flux test sections, it was not clear whether the q_{DNB} predicted was a local DNB flux or an average heat flux up to the point of DNB. However it was found that a smooth transition existed between the W-2 and W-3 DNB predictions at a (-20 w/o) quality, when the length was twelve feet, the pressure equal to 2250 psia, the inlet enthalpy was 542 Btu/lb, the equivalent diameter was .535 inches, and a mass velocity equal to 1.525×10^6 lb/hr-ft². The W-2 correlation was adjusted to nonuniform burnout heat flux conditions by using a similar method outlined for the W-3 correlation.

4.3 BOILING CRISIS IN BULK BOILING REGIONS

This type of boiling crisis occurs at lower heat fluxes than that previously described. Because of the good heat transfer coefficient of a fast moving vapor core, however, the transient wall temperature may be slow to rise after boiling crisis occurs especially in the high quality region. It may even be possible to obtain steady state at these high wall temperatures and physical damage to the equipment may not occur. The equation implemented to predict a boiling crisis for bulk boiling conditions is the Westinghouse correlation: (7, 8)

$$\Delta H_{\text{DNB}} = 0.529(H_f - H_{\text{in}}) + (0.825 - 2.36e^{-17D_h}) \times \\ H_{fg}e^{-1.5G/10^6} - 0.41H_{fg}e^{-0.0048L/D_h} - 1.12H_{fg} \times \\ (\rho_g/\rho_f) + 0.548H_{fg}$$

Where:

$$\begin{aligned} \Delta H_{\text{DNB}} &= H_{\text{crit}} - H_{\text{in}} \\ H_f &= \text{saturation enthalpy (Btu/lb)} \\ H_{\text{in}} &= \text{inlet enthalpy (Btu/lb)} \\ D_h &= \text{hydraulic diameter (Ft)} \\ H_{fg} &= H - H_f \\ H_g &= \text{saturated vapor enthalpy (Btu/lb)} \\ L &= \text{length of the heated channel (Ft)} \\ \rho_g &= \text{density of saturated vapor (lb/ft}^3\text{)} \\ \rho_f &= \text{density of saturated liquid (lb/ft}^3\text{)} \end{aligned}$$

The bulk boiling DNB equation is the result of correlating approximately 3,000 published DNB data points into one equation. The accuracy of the equation is within 25% of the data used for its derivation with a probability level of 95%. Thus a design factor is needed to compensate for correlation uncertainty. Experimental data demonstrates it to be equally compatible for uniform and non-uniform heat flux.

The correlation was chosen since it includes more recent experimental data and was developed after an investigation demonstrated that existing correlations were too inaccurate for design purposes. General Electric Company has recently developed a new burnout heat flux correlation for reactor design work but at present it is considered proprietary and therefore is not available. The Westinghouse correlation was used to design a typical 1000 MW_t reactor core which compared favorably with the G.E. data illustrated in Table VII page 47.

The foregoing discussion postulates the DNB correlations to be applicable over a wide range of thermal and hydraulic parameters. However, additional uncertainty exists in the accuracy of the predictions when applying the equations outside the range used in generating the DNB functions. Increasing the minimum departure from nucleate boiling ratio (MDNBR) to compensate for this degree of uncertainty may be desirable. Table II shows the ranges for the parameters used in developing the PWR and Table III lists the ranges for the BWR correlations.

5.0 PRESSURE DROP

Prediction of pressure drop through the core is a twofold problem dependent upon the properties of the coolant fluid and the forces acting on the coolant. Head loss for single phase flow is calculated using conventional methods. However, an empirical equation is used to predict head loss for two phase flow. In both cases the Darcy-Weisbach friction factor⁽¹²⁾ is used as determined from the equation

$$f = a R_e^b + c$$

TABLE II

RANGE OF THE CORRELATED EXPERIMENTAL DATA USED IN DEVELOPINGTHE WESTINGHOUSE APD SUBCOOLED DNB CORRELATIONW-3

Geometries	Circular tube, rectangular channel
Mass Velocity	1.0×10^6 to 5.0×10^6 (lb/hr-ft ²)
Pressure	1000 to 2300 (psia)
Length	10 to 144 (in)
Inlet enthalpy	≥ 400 (Btu/lb)
Quality	± 0.15 to ± 0.15
Equivalent diameter	0.2 to 0.7 (in)
Heated-to wetted perimeter ratio	0.88 to 1.0
Axial heat flux distribution uniform (modified by a memory factor to non-uniform)	

W-2

Geometries	Circular tube, rectangular channel
Axial heat flux	Uniform
Mass velocity	0.2×10^6 to 8.0×10^6 (lb/hr-ft ²)
Pressure	800 to 2750 (psia)
L/De	21 to 365
Inlet subcooling	$(H_f - H_{in}) = 0$ to 700 (Btu/lb)
Quality	Less than (-.15 w/o)
Subcooling at DNB (T_{SC})	0 - 228 °F
Local heat flux	0.4×10^6 to 4.0×10^6 (Btu/hr-ft ²)
Equivalent diameter	0.1 to 0.54 (in)
Heated to wetted perimeter ratio	0.88 to 1.0

TABLE III

THE RANGE OF THE CORRELATED EXPERIMENTAL DATA USED IN DEVELOPING
THE WESTINGHOUSE APD CRITICAL ENTHALPY CORRELATION (BULK BOILING CRISIS)

Geometries	Circular tube rectangular channel and rod bundle
Mass velocity	0.4×10^6 to 2.5×10^6 lb/hr-ft ²
Pressure	800 to 2750 psia
Length	9 to 76 in
Inlet enthalpy	$\leq H_{sat}$ and ≥ 400 Btu/lb
Equivalent diameter	0.1 to 0.54 in
Local heat flux	0.1×10^6 to 1.8×10^6 Btu/hr-ft ²
Heated-to-wetted perimeter	0.88 to 1.0
Axial heat flux distribution	Uniform and nonuniform
Exit quality	0 to 90% by weight

where a , b and c are input constants and R_e is the local Reynolds number. The pressure drop is calculated for one mesh length and the resultant pressure is used to determine coolant properties for the succeeding mesh length. Thus local conditions can best be predicted as the mesh length approaches zero. It has been found that incremental lengths less than ($\Delta x/L = .02$) add little accuracy to the results. However, ($\Delta x/L = .01$) is compatible with the code and may be used when additional accuracy is desirable with respect to computer time consumption.

5.1 PRESSURE DROP FOR SINGLE PHASE FLOW

When a fluid is flowing along a heated surface, the heat transfer, and flow behavior varies with the heat flux and condition of the fluid. Thus a preliminary investigation of the local coolant properties is necessary before the incremental pressure drop through the core can be determined. These properties are functions of the initial conditions and the spatial power distribution. To evaluate the coolant properties, linear interpolation between tabular values is provided in REPP. The tabular values consist of the Keenan and Keys saturated steam tables⁽³⁾ supplemented by pertinent values necessary for heat transfer considerations.

Once the local coolant properties have been determined, the incremental pressure drop across each channel mesh length can be determined.

It is postulated that the flow is fully developed and the pressure is uniform over the cross section of the coolant channel.* The resulting pressure drop is calculated as a threefold problem.

- the pressure drop resulting from an increase in momentum of the coolant as it acquires thermal energy from the heated surface.
- the pressure drop due to frictional forces acting parallel to the flow
- the pressure drop due to an increase in the gravitational energy potential as the coolant rises in the channel.

In equation form the above criteria results in the expression:

$$\begin{aligned}\Delta P_{inc} &= \Delta P_{acl} + \Delta P_{grav} + \Delta P_{fric} \\ &= \frac{1}{g_c} (V_2 - V_1)G^2 + \frac{fL}{4 g_c D_h} (V_1 + V_2)G^2 + \frac{g}{g_c} \frac{2L}{(V_2 + V_1)}\end{aligned}$$

Where:

- ΔP_{inc} = the incremental pressure drop across one mesh length (lb/ft²)
- ΔP_{acl} = the incremental pressure drop due to local changes in momentum (lb/ft²)
- ΔP_{grav} = the incremental pressure drop due to changes in the gravitational potential (lb/ft²)
- ΔP_{fric} = the incremental viscous head loss (lb/ft²)
- f = friction factor

* Inter-channel mixing is permitted only through the introduction of a cross flow factor as part of the input.

g_c = acceleration of gravity constant (ft/hr²)

V_x = specific volume at position x (ft³/lb)

G = mass velocity (lb/hr-ft²)

L = the length of the mesh element (ft)

g = local acceleration of gravity (ft/hr²)

Head loss due to entrance and exit effects is calculated using drag coefficients.⁽¹³⁾ The effect of fuel pin spacers on head loss is discussed in section 5.3.

5.2 PRESSURE DROP FOR TWO-PHASE FLOW

Two-phase fluid flow with heat addition is a coupled thermohydrodynamic problem. Heat transfer causes a phase change and hence a change in the phase distribution and flow pattern. A change in the hydrodynamics results from a change in pressure along the flow path which affects the heat transfer mechanism and changes the state of the fluid. Thus a single component two-phase flow can never become fully developed and the phase distribution and flow pattern are highly dependent on previous history of the flow process. Additional complexities are introduced by the hydrodynamic instabilities and the occasional fluctuations from thermodynamic equilibrium between the phases. This suggests that a stepwise integration technique may lead to greater accuracy in predicting the pressure drop and heat transfer characteristics for two phase fluid flow. However, a description of the local flow patterns inherent to such an analysis is not available as yet although

visualization studies have led to some insight to the problems.⁽¹¹⁾ Since analytical methods are lacking, present technology must depend on empirical correlations⁽¹⁴⁾ for predicting pressure drop for two-phase flow until such time that more sophisticated methods may be established.

REPP uses a simplified scheme⁽¹⁵⁾ to determine the pressure drop for a two-phase mixture of boiling water and steam. The method follows that proposed by Martinelli and Nelson⁽¹⁶⁾ which has been extended to include the gravitational term in vertical coolant channels. The correlation⁽¹⁷⁾ postulates that annular flow conditions exist and a slip model is used to determine the pressure drop with the steam moving at a higher velocity than the liquid. Commensurate with the greater frictional losses in two-phase flow regions, a slip factor (or correction factor) was developed so that homogeneous flow theory can be used to calculate these frictional losses. In like manner the pressure loss due to momentum exchange and the change in the gravitational energy potential is calculated. The evaluation of these slip factors was determined by experimental effort,⁽¹⁸⁾ and the results showed good agreement with the Martinelli and Nelson data. However void fractions less than 3% showed data scattering. The correlation was selected since it:

- is applicable over a wide range of operating pressures,
15-3000 psia.
- is not restricted to a limited range of steam quality,
from 3-100%.
- presents an easy method of solution
- is applicable to vertical channels

The slip factors are presented in equation form when a good fit was possible. However the gravitation slip factor is in the form of a table and a subroutine was written to linearly interpolate to appropriate values. The two-phase flow pressure drop correlation used is:

$$\Delta P_{TPf} = \frac{1}{g_c} V_f G^2 \gamma_2 + \frac{fL}{2 g_c D_h} V_f G^2 \gamma_3 + \frac{g}{g_c} \frac{L}{V_f} \gamma_4$$

Where:

- ΔP_{TPf} = pressure drop for two-phase flow
- g_c = acceleration of gravity constant ft/hr²
- V_f = specific volume of saturated liquid (ft³/lb)
- G = mass velocity (lb/hr-ft²)
- f = friction factor for single phase flow
- D_h = the hydraulic diameter (ft)
- L = length of increment (ft)
- γ_2 = acceleration slip factor
- γ_3 = frictional slip factor
- γ_4 = gravitational slip factor

Table IV, V, and VI give tabular values of the slip factors corresponding to pressure and exit quality. The values were obtained directly from reference 15.

TABLE IV

VALUES OF THE ACCELERATION MULTIPLIER (γ_2) USED
IN CALCULATING PRESSURE DROP FOR TWO PHASE FLOW

Outlet quality by mass	<u>Pressure (psia)</u>				
	250	600	1250	2100	3000
0.01	0.4125	0.2007	0.0955	0.0431	0.0132
0.015	0.6201	0.3034	0.1441	0.0649	0.0195
0.02	0.8325	0.4055	0.1930	0.0865	0.0261
0.03	1.268	0.6132	0.2903	0.1297	0.0392
0.04	1.710	0.8242	0.3886	0.1739	0.0562
0.05	2.169	1.040	0.4892	0.2182	0.0657
0.06	2.635	1.258	0.5893	0.2582	0.0787
0.07	3.116	1.479	0.6903	0.3076	0.0924
0.08	3.605	1.704	0.7940	0.3521	0.1055
0.09	4.110	1.734	0.8969	0.3975	0.1188
0.10	4.620	2.165	1.001	0.4431	0.1319
0.15	7.365	3.379	1.538	0.6751	0.1996
0.20	10.39	4.678	2.100	0.9139	0.2676
0.30	17.30	7.539	3.292	1.412	0.4067
0.40	25.37	10.75	4.584	1.937	0.5495
0.50	34.58	14.30	5.968	2.490	0.6957
0.60	44.93	18.21	7.448	3.070	0.8455
0.70	56.44	22.46	9.030	3.678	0.9988
0.80	69.09	27.06	10.79	4.312	1.156
0.90	82.90	32.01	12.48	5.067	1.316
1.0	98.10	37.30	14.34	5.664	1.480

TABLE V
VALUES OF FRICTION MULTIPLIER (γ_3) USED IN
CALCULATING PRESSURE DROP FOR TWO PHASE FLOW

Outlet quality by mass	<u>Pressure (psia)</u>				
	250	600	1250	2100	3000
0.01	1.49	1.111	1.03		
0.015	1.76	1.25	1.05		
0.02	2.05	1.38	1.08	1.02	
0.03	2.63	1.62	1.15	1.05	
0.04	3.19	1.86	1.23	1.07	
0.05	3.71	2.09	1.31	1.10	
0.06	4.21	2.30	1.40	1.12	
0.07	4.72	2.50	1.48	1.14	
0.08	5.25	2.70	1.56	1.16	1.04
0.09	5.78	2.90	1.64	1.19	1.05
0.10	6.30	3.11	1.71	1.21	1.06
0.15	9.00	4.11	2.10	1.33	1.09
0.20	11.4	5.08	2.47	1.46	1.12
0.30	16.2	7.00	3.20	1.72	1.18
0.40	21.0	8.80	3.89	2.01	1.26
0.50	25.9	10.6	4.55	2.32	1.33
0.60	30.5	12.4	5.25	2.62	1.41
0.70	35.2	14.2	6.00	2.93	1.50
0.80	40.1	16.0	6.75	3.23	1.58
0.90	45.0	17.8	7.50	3.53	1.66
1.00	49.93	19.65	8.165	3.832	1.740

TABLE VI

VALUES OF THE GRAVITATIONAL MULTIPLIER (γ_L) USED
IN CALCULATING PRESSURE DROP FOR TWO PHASE FLOW

Outlet quality by mass	<u>Pressures (psia)</u>				
	250	600	1250	2100	3000
0.01	0.842	0.915	0.956	0.991	0.994
0.015	0.784	0.877	0.937	0.966	0.992
0.02	0.736	0.845	0.918	0.960	0.990
0.03	0.658	0.787	0.882	0.947	0.979
0.04	0.597	0.738	0.850	0.923	0.974
0.05	0.549	0.696	0.823	0.910	0.970
0.06	0.508	0.660	0.795	0.892	0.963
0.07	0.475	0.627	0.771	0.879	0.957
0.08	0.446	0.599	0.746	0.860	0.952
0.09	0.421	0.573	0.724	0.848	0.948
0.10	0.399	0.549	0.705	0.836	0.941
0.15	0.319	0.460	0.624	0.774	0.916
0.20	0.268	0.399	0.558	0.718	0.889
0.30	0.206	0.317	0.468	0.637	0.843
0.40	0.167	0.269	0.406	0.575	0.803
0.50	0.142	0.228	0.357	0.525	0.767
0.60	0.123	0.201	0.321	0.482	0.733
0.70	0.109	0.180	0.291	0.444	0.702
0.80	0.098	0.163	0.267	0.413	0.675
0.90	0.089	0.149	0.248	0.389	0.651
1.00	0.081	0.136	0.229	0.364	0.626

5.3 PRESSURE DROP DUE TO FUEL PIN SPACERS

Rod spacers which limit vibration and maintain coolant space dimensions varies from core to core and the type used are usually determined from design conditions. They may be divided into two main categories.

- spiral wires wrapped about each pin
- transverse spacer grids of various types

The method used in REPP to handle the pressure drop is the summation of three components

- pressure drop due to inlet and exit effects of each coolant channel including orificing
- pressure drop across each mesh increment through the reactor
- pressure drop due to spacers for each applicable mesh increment

An empirical correlation was developed by A. N. deStordeur⁽¹⁹⁾ for wire wrapped fuel pin spacers and three types of transverse spacers which include honeycomb, lenticular wire, and spiral wire devices. The transverse spacers were always arranged perpendicular to the fluid flow and are illustrated in Figure V. The data points obtained and correlated by deStordeur were from models containing fuel pins in a square lattice geometry. From these data drag coefficients were developed to adjust the pressure drop to compensate for the grid spacer. The accuracy of the results should be within $\pm 25\%$ for the transverse grids and $\pm 40\%$ for the spiral wire devices. The assumption was made that the drag coefficients derived in this manner were also applicable

FIGURE V

Transverse Grid Type Spacer Systems Applicable for Use in REPP

to triangular spaced pins and two phase flow. Figure VI shows a comparison of the two arrangements for a honeycomb and circular wire-type spacer systems.

The number and type of grids and their location in the core are input items and the pressure drop contributed by them is assigned to that particular mesh point which is in closer proximity to the grid location. This presents a more practical model on which the limiting thermal and hydraulic criteria may operate in the core sizing routine. In the case of the wire wrapped pins, sampling locations for determining the pressure drop is optional. However a maximum of twenty samplings is permissible for both types of spacers.

6.0 SUBCHANNEL ANALYSIS

One of the purposes of REPP is to serve the important function of establishing a base core on which nuclear and economic investigations may be made. This is especially useful since core size and reactor operating power levels are usually determined from thermal and hydraulic considerations. Thus only cores purporting maximum heat removal capacity need be assessed in a time consuming neutronic and economic study. An iterative process between the three disciplines can lead to optimal core designs for specific applications.

According to Tong⁽²⁰⁾ a subchannel analysis is essential to accurately predict and evaluate DNB behavior for design purposes. Heizer⁽²¹⁾ et al. states that cross mixing behavior and flow disparity should be accounted for in a subchannel analysis to properly predict coolant conditions at the

Honeycomb or Egg Crate System

Circular Wire System

FIGURE VI

A Comparison of Two Spacer Arrangements for Fuel-Pins
In a Square and Triangular Lattice

point of DNB. Jansen and Levy⁽²²⁾ determined a set of burnout curves based on a single channel analysis which included the cold wall effect on burnout conditions. Thus, in addition to the local heat flux conditions, burnout depends largely upon the coolant properties in the subchannel at the burnout location. The past history of the coolant behavior may cause the local flow conditions in various subchannels to differ widely from the core average. Therefore, some means of evaluating the effect of these parameters on DNB is required. REPP uses the following method to give the user some control over these phenomena.

First, in the absence of better data, the power distribution can initially be represented by a modified cosine profile. It is always a safe practice to reassess the results from REPP after the power distribution is better known from a nuclear analysis. Also the changes in local power conditions during burnup will require continual re-evaluation of the design data to insure the structural integrity of the core is maintained. The numerical technique used in REPP allows more latitude in defining power shapes and hence improves local power representations.

Second, a cross flow factor is used to account for the flow oscillations, turbulence and pressure disparity across the core which cause interchannel mixing of the coolant fluid. The "outflow" from a hot channel may be compensated with an equivalent "inflow" from adjacent channels. It is postulated that the inflow of coolant at one node passes through the control volume and exits at the succeeding node removing a portion of the

thermal energy from the hot channel. This is especially so when mixing promoters are used for fuel rod spacers. Since the properties of the coolant in the channels surrounding the hot channel are usually not well known in a one-channel analysis, the temperature of the incoming fluid is assumed to be that of the hot channel. Hence, an additional cooling effect in the hot channel may result. However, the opposite effect may exist. That is the hot channel may tend towards drying out when cross flow is not stimulated and only an "outflow" occurs which decreases the net flow through the hot channel. For example, a cross flow factor of -3% would cause the code to evaluate DNB conditions in the hot channel for a flow rate of 3% less than the subassembly average. Thus it is apparent that the cross flow factor represents a net effect. The cross flow factor does not directly affect the pressure drop nor the end result of the exiting coolant bulk temperature.

Third, a flow redistribution factor is used to evaluate the flow disparity across the core resulting from orificing or non symmetric geometry effects. The pressure drop and hot-channel fuel centerline temperature are directly determined from this adjusted flow rate. The output coolant temperature is the core average and is not affected by this factor.

Although some engineering skill is required to use the flow re-distribution and cross flow factors, a conservative estimate can usually be obtained by assigning them a zero and a negative value respectively. The computer code Cobra⁽¹⁾ may be used to obtain more practical value of the cross flow factor under specific conditions.

6.1 DNB AND HOT CHANNEL UNCERTAINTIES

Calculation of local heat flux and coolant enthalpy are made for a minimum of 10 and a maximum of 100 mesh points along the coolant channel. The calculations are made assuming nominal conditions exist through the reactor. Commensurate with present reactor technology a theoretical hot channel model is generated and thermal hydraulic conditions are predicted for this model to compensate for radial peaking and the various uncertainties which may exist in the core. The uncertainties due to fabrication tolerances are usually lumped together under the heading of engineering factors. Nuclear factors include uncertainties in local power predictions. The implication of a theoretical hot channel due to uncertainties arises mainly from the following conditions:

Engineering Factors

- structural tolerances necessary due to existing fabrication techniques.
- variation in fuel density

- limited accuracy of thermal and hydraulic equations, correlations and data
- coolant channel dimension inconsistencies
- meat thickness variation
- fuel to clad bonding problems
- cold wall effect existing in the peripheral pins
- coolant flow distribution

Nuclear

- maximum to average radial peaking factor
- maximum to average axial peaking factor

The product of the nominal heat flux at each mesh location and a modified over all peaking factor generates hot channel conditions through the core which satisfy the various modes of heat transfer. The over all peaking factor is referred as the hot channel factor for the purpose of this report and is defined as the product of the engineering and nuclear factors. It is applicable to a local hot spot and therefore must be modified to apply to a channel analysis. The modified value includes the radial and a local engineering peaking factor. Thus fuel temperatures and cladding temperatures corresponding to hot channel conditions are simulated. Coupled with the hot channel concept, a design factor is defined to compensate for possible error in fixing critical thermal and hydraulic limits as calculated for each mesh point using the burnout correlations. This factor called "departure from nucleate boiling ratio" (DNBR) is a

measure of the consequence of equipment failure. It is defined as the ratio of the local hot channel heat flux to the predicted DNB heat flux (or critical heat flux). At some position in the core the DNBR takes on a minimum value. This minimum value is required input and thus the resultant core design is assured a margin of safety.

7.0 DESIGN COMPARISONS

A search of the literature⁽²⁰⁻²⁸⁾ illustrates that thermal and hydraulic design codes are not generally available. Companies which design water-cooled reactors for commercial purposes undoubtedly have developed such codes but they are proprietary and are not available for general usage.

A number of existing reactor designs were used to assess REPP output. It was difficult to gather sufficient input information for any one reactor design and establish a good check on REPP predictions. Four important pieces of information usually missing were:

- The size of the fuel pin spacers and their location in the core
- The pressure drop across the core
- The flow distribution through the core
- A good value for the cross flow factor

The designing technique used in REPP is quite sensitive to all four parameters and therefore a good engineering design approach was not attempted. Rather, an attempt was made to generate the G.E. 1000 MW_e BWR and the Westinghouse 1000 MW_e PWR by judiciously selecting values for parameters which were not available from the literature.

Table VII illustrates a comparison of the results of that effort. Since the PWR was constructed with an open channel* between subassemblies it was believed that the flow redistribution was best represented with a very small value for the redistribution factor. The cross flow factor was assigned a zero value for the same reason. However the BWR was composed of subassemblies characteristic of an independant flow channel (no flow between subassemblies). It was assumed that coolant flow through the hot assembly was 29% greater than the core average. A value of (-7%) was assumed for the cross flow in the hot channel. With these values excellent results were obtained for the two cores.** Complete listings of the input are given in example problems illustrated in Section 8.4.

8.0 USER'S GUIDE

The input data requires a knowledge of the fuel properties, coolant inlet properties, reactor operating power level, spatial power distribution, and a set of initially assumed geometric parameters. A minimum of twelve Fortran data cards (including one blank card) are required to enter a base case into the program.*** Each card may contain from 1 to 5 variables.

* There was no sheath cladding and hence coolant could flow from sub-assembly to subassembly.

** A small variation is shown in the coolant to fuel ratio for the PWR but further investigation showed this to result from a difference in definition. The ratio represented in REPP is the total coolant volume to theoretical fuel density volume. That illustrated for the PWR is a local coolant volume to the volume of 93% density fuel.

*** An input generator subroutine was added which generates the two base cores illustrated in the example problems. Section 8.4 change cards may be used to modify the cases as desired.

TABLE VII

COMPARISON OF A BOILING WATER 1000 MW_e AND A 1000 MW_e

PRESSURE WATER REACTOR DESIGNS WITH PREDICTIONS

MADE USING REPP

	BWR		PWR	
	General Electric 1000 MW _e	REPP Output Input*	Westinghouse 1000 MW _e	REPP Output Input*
Total heat output (MW _t)	3293	3293	3083	3083
Avg. heat generation rate (Btu/hr-ft ³)	2.0737 x 10 ⁷	2.06 x 10 ⁷	2.96238 x 10 ⁷	3.25 x 10 ⁷
Coolant mass flow rate (lb/hr)	9.96 x 10 ⁷	9.96 x 10 ⁷	121.8 x 10 ⁶	118.6 x 10 ⁶
Number of fuel pins	37,436	37,585	39,372	39,368
Fuel-pin O.D. (inches)	0.562	0.562	.422	.422
Core Volume (ft ³) active	2.29 x 10 ³	2.30 x 10 ³	1.169 x 10 ³	1.17 x 10 ³
ΔT Coolant (°F)	?	17.6	65	65
Exit Coolant Temp (°F)	546.4	543.5	610	610
Average Coolant Velocity(ft/sec)	?	18.3	?	15.5
Avg. heat flux (Btu/hr-ft ²)	1.632 x 10 ⁵	1.6226 x 10 ⁵	1.96 x 10 ⁵	1.964 x 10 ⁵
Maximum heat flux (Btu/hr-ft ²)	4.25 x 10 ⁵	4.22 x 10 ⁵	5.535 x 10 ⁵	5.537 x 10 ⁵
Hot channel peaking factor (F _q)	2.6	2.6	2.82	2.82
Departure from nucleate boiling ratio	1.74	1.74	1.86	1.86
Maximum fuel temp. (°F)	4,380	4,387	4,100	4,104
Total heat transfer area (ft ²)	6.6096 x 10 ⁴	6.649 x 10 ⁴	5.22 x 10 ⁴	5.219 x 10 ⁴
Total pressure drop across the core (psi)	?	58	50	50

* Complete sets of input are shown in the example problems illustrated in Section 8.4

TABLE VII (continued)

	BWR			PWR		
	General Electric 1000 MW _e	REPP Output	REPP Input*	Westinghouse 1000 MW _e	REPP Output	REPP Input*
Core length (ft)	13.33	13.35	14.16**	12.333	12.333	14.69**
Equivalent core diameter (ft)	15.59	15.62	16.667**	11.14166	11.142	13.333**
Fuel-pin wall thickness (inches)	0.032		0.032**	0.0243		0.0243**
Coolant to fuel ratio	2.41	2.45		1.66	1.872	
Fuel-pin pitch (inches)	0.738	0.738		.563	.56314	
(1 - fuel fraction)	.76315		.76315	.724258		.724258
Apparent fuel density ratio	.93		.93	.93		0.93
Grid type	egg crate		honeycomb	?		honeycomb
Number grids	7		7	9		9
Diametric gap (inches)	.005		0.005	.00325		.00325
Mesh (hx/L)	N/A		0.02	N/A		0.02
Cross flow factor	?		-.07	?		0.0
Flow redistribution factor	?		1.29	?		1.011
Fraction of power generated in fuel	.96		.96	.974		.974
Fuel-pin spacer (inches)	?	.0968	.55***		0.0776	.55***

* Complete sets of input are shown in the example problems illustrated in Section 8.4

** Initial guess (core length to core diameter is held constant, also the clad thickness to fuel diameter is held constant).

*** The ratio is equal to the wire diameter/(fuel-pin pitch minus the fuel pin diameter).

Sequential cases may be generated by using one of the following two systems:

1. change cards
2. uniform variation of (1-fuel fraction)

The change card system may be used to change 1 to 5 variables per card which may be in any order. Indeed the input data deck for a single case may even be shuffled and still read properly into the program.* Thus, subsequent cases may be generated from a base case with a minimal effort since only a new value and the variable address need appear on a card.

The second system that may be used to generate successive cases is based on small increments of the variable (1-fuel fraction). This method accommodates a study of the effect of this parameter on design problems. This is especially useful since the volumetric fuel fraction is a measure of the critical mass in the core. The step size and the number of steps are input numbers. The step size may be either a positive or a negative number depending on which end of the series the initial values are defined. For example, if the initial value of (1-fuel fraction) is 0.80, 3 steps of (-0.05) would run 3 cases. The final case would illustrate (1-fuel fraction) equal to 0.70. However if the initial value was 0.70, 3 steps of (+0.05) leads to a final case value of 0.80. At the

* The only exception is that a blank card must always appear as the last card in each case.

conclusion of this type of case generator, all parameters are initialized and a change card could be used to run another series. The eventual selection of a "best" value for (1-fuel fraction) may be obtained using this approach.

An end-of-file card serves to call exit and terminates the run.

8.1 OVER-SPECIFIED PROBLEMS

There are many options available to REPP users which may result in over-specifying conditions or, inputting data which are not geometrically possible. When such occurs, control is transferred to a message center where instructions outlining the possible errors are written, and a subsequent case is called. However, when practical, over-specified problems are corrected by selection of important base parameters and recalculating those leading to inconsistencies. All input data for each case are printed out and are thus preserved for inspection at the conclusion of the run. This greatly aids in the diagnosis of bad input which may lead to erroneous conclusions, or cause the code to fail.

8.2 GENERAL INSTRUCTIONS

The input data are divided into three subdivisions as follows:

1. Alpha-numeric data (title) Format (11, 5X, 9A6)
2. Integer Data Format (11, 4X, 5I5, 5I10)
3. Fixed point and floating point data Format
(11, 4X, 5I5, 5E10.0)

The alpha-numeric field is restricted to 54 characters beginning in column 7 and extending through 60. All other data are in fields of 5 and 10 spaces. Each card may define from 1 to 5 variables in any order so long as the data is consistent. This means that mixed modes are not allowed. The first column on each card is used as a data designator and flags the type of data to be entered from the card. The number (1) flags an alpha-numeric sequence, the number (2) flags integer data, and the number (3) flags fixed and floating point data. Columns 2, 3, 4 and 5 are left blank. Columns 6 through 30 consist of 5 fields of 5 spaces each and are used for the addresses (or identification numbers) of the variables to be entered from the card. Columns 31 through 80 consist of 5 fields of 10 spaces each and are used for the input variables. The address numbers are integers and must be right adjusted in each field for all cases. The address field consisting of columns 6 through 10 corresponds to the data field consisting of columns 31 through 40. The correspondence of address and data continue in a consecutive order across the card with the final address field consisting of columns 26 through 30 corresponding with the final data field consisting of columns 71 through 80. Figure VII illustrates the division of a typical input data card.

An input generator routine has been added which generates the data used in the examples illustrated in Section 8.4. A (1) or (5) in column 1 causes transfer of control to the input generator generating a PWR or

FIGURE VII

A Typical Input Data Card Used for Inputting
Fixed and Floating Point Data or Integer Data

* Data Type:

- (1) Alpha-numeric (Title) begins in column 7
- (2) Integer
- (3) Fixed or floating point or both
- (4) Call an input generator which generates the Westinghouse PWR input illustrated in Section 8.4. Change cards may be used to alter this base core.
- (5) Call an input generator which generates the GE BWR input illustrated in Section 8.4. Change cards may be used to alter this base core.

BWR respectively. Change cards may be used to modify these base cases as desired.

8.3 INPUT DESCRIPTION

The input data can be read into the program in any order. However, to accommodate the unfamiliar user, the following order is suggested:

- The title
- Fixed and floating point data
- Integer data

8.3.a THE TITLE

The title card is identified in the program by a number (1) appearing in column 1 of the card. Any descriptive title may be written in columns 7 through 60. The remainder of the card should be left blank.

8.3.b FIXED AND FLOATING POINT DATA

The number (3) must be punched in column number 1 of each input data card for the following series of data.

FORMAT (I1, 4X, 5I5, 5E10.0)

<u>Address</u>	<u>Variable Name</u>	<u>Description</u>
1	RADP	An assumed equivalent core radius in (inches). This parameter is subject to change when iterating on a heat transfer limited core. If no value is assigned, the code assigns an initial value of 60 inches.

<u>Address</u>	<u>Variable Name</u>	<u>Description</u>
2	XLX	An assumed active core length in (inches). This parameter may be allowed to change or may be held constant at the option of the user. If no value is assigned the code assigns a value of 120 inches.
3	ENTL	Entrance (preheat) length in (inches). This value is held constant during the iterative process.
4	EXITL	Exit (postheat) length in (inches). This value is held constant during the iterative process.
5	DP	The fuel pellet diameter in (inches). This value should be left out if the hydraulic diameter is specified.
6	DH	The hydraulic diameter in (inches). This value should be left out when the fuel pellet diameter is specified.
7	XW	Fuel-pin clad thickness in (inches).
8	STAG	The diametric gap (space width) at the fuel clad interface in (inches).
9	THETA	Leave out for solid fuel pins. The ratio of (inside diameter/fuel diameter) for fuel pins with holes through the center.
10	CORE	Leave out for fuel pins in a square lattice. Greater than zero for fuel pins in a triangular lattice.
11	WRAP	Leave out for transverse grids. Pitch in (inches/turn) for spiral wire spacers.

<u>Address</u>	<u>Variable Name</u>	<u>Description</u>
12	ALPHAP	The value for (1-fuel fraction) where the fuel-fraction is based on (theoretical dense fuel/core volume).
13	ALPHAS	The volumetric fraction of the core provided for thermal expansion between subassemblies (space/core volume). Leave out for zero value.
14	ALPHOT	The volumetric fraction of the core which contains the sheath cladding of a subassembly (clad/core volume). The control rods should be included in this fraction. Leave out for zero values.
15	Q11	The total reactor operating power in (MW_t).
16	XQUAL	The fraction of heat generated in the fuel and cladding. This parameter is used to predict heat flux only. The code assumes all the heat is received by the coolant.
17	TO1	The coolant inlet temperature ($^{\circ}F$).
18	POO	The coolant inlet pressure (psia).
19	G	The coolant mass velocity ($lb/hr-ft^2$). Leave out if the coolant flow rate is specified.
20	WDOT	The coolant flow rate (lb/hr). Leave out if the coolant mass velocity is specified.
21	XMIX	A coolant cross flow factor. A value of ($\pm .03$ to $\pm .10$) may be practical. Refer to Section 6.0 for more details. Assign a negative value for conservative calculations.
22	XPFACT	MDNBR (minimum departure from nucleate boiling ratio). Values of 1.86 for large PWR and 1.8 for large BWR may be practical.

<u>Address</u>	<u>Variable Name</u>	<u>Description</u>
23	HCFAC	Hot channel peaking factor consists of the product of all the peaking and uncertainty factors. Values of 2.82 for PWR and 2.6 for BWR may be practical for 1000 MW _e reactors.
24	XLPFAC	A local peaking factor (included in HCFAC) resulting from core uncertainties. Leave out for conservative calculations but include it in (HCFAC Address 23). Approximate values of 1.04 to 1.10 may be practical.
25	HCTEMP	The maximum fuel centerline temperature design limit (°F). Leave out when designing to heat flux limits only or for a first attempt at running REPP.
26	FUDENS	The ratio of the apparent fuel density to the theoretical fuel density (ρ_a/ρ_t).
27	RHOF	The density of the fuel in (lb/ft ³). Leave out if the core weight is not a desired output.
28	RHOC	The coolant density (lb/ft ³). Leave out if the core weight is not a desired output.
29	RHOT	Structural material density (lb/ft ³). Leave out if the core weight is not a desired output.
30	VK01	An entrance head loss coefficient. The code assigns a value of 1.0 if this parameter is left out.
31	VKL23	An exit head loss coefficient. A value of (1.5) is assigned by the code if this parameter is left out.
32	FCON1	The value of (A) in the friction equation

$$F = A Re^B + C$$

where F = Darcy-Weibach friction factor

Re = The local Reynolds number

<u>Address</u>	<u>Variable Name</u>	<u>Description</u>
33	FCON2	The value of (B) in the above friction equation.
34	FCON3	The value of (C) in the above friction equation.
35	E	A heat transfer film coefficient in (Btu/hr-ft ² -°F) used to determine the temperature change at the fuel clad interface. A value of 1500 may be appropriate where poor bonding exists between the two surfaces. Leave out for good fuel-clad bonding if a very small temperature difference is expected. The code will automatically set the value to 30,000. Values of 500 to 1500 may be appropriate when a diametric gap filled with He exists at the fuel-clad interface. The value is dependent on the gap size, surface roughness and properties of the fluid in the gap.
36	HFILM	A boiling heat transfer film coefficient in (Btu/hr-ft ² -°F). This value is also used for subcooled nucleate boiling. The code automatically sets the value to 20,000. If this value is acceptable, leave out.
37	GRID	The temperature (°F) at which sintering begins in low density fuels. Leave out if sintering effects is not desired. Refer to Section 3.0 for more detailed information.
38	XINCR	The dimensionless mesh length ($\Delta X/L$). Recommended value of (.02) has given good results. The range permitted is: $.01 \leq (\Delta X/L) \leq .1$ <p>When computer time is of no consequence (.01) adds a little accuracy. Leave out if (.02) is acceptable.</p>

<u>Address</u>	<u>Variable Name</u>	<u>Description</u>
39	DELEPS	Acts as a case generator. It is the step function for incrementing the parameter (1-fuel fraction). Refer to Section 9.0 for greater detail. Leave out when subsequent cases are to be defined using change cards.
40	DUMDUM(1)	The ratio (spacer diameter/fuel-pin pitch minus fuel-pin diameter). The parameter is used to determine the size of the fuel pin spacer and hence - pressure drop due to the spacer. Leave out when the spacer is wire-wrap.
41	DUMDUM(2)	A flow redistribution factor which adjusts flow and accounts for orificing or nonuniform coolant flow patterns.

DIMENSIONED ARRAYS

49 thru 68	GX(I)	The dimensionless fuel-pin spacer locations (X/L), or the location at which pressure drop due to wire wrap spacers are to be calculated. The beginning address is 49. Leave out for no spacers.
70 thru 89	GBX(I)	The dimensionless locations (X/L) at which the axial power profile (local flux/AVE flux) is to be identified. A minimum of 4 data points are required beginning with address 70. Cluster the points around locations of greatest slope change.
92 thru 111	QBF(I)	The relative axial power profile (local/average) corresponding to GBX(I). A minimum of 4 data points are required beginning with address 92.
114 thru 133	TKK(I)	The temperatures ($^{\circ}$ F) at which the fuel thermal conductivity curve is to be identified. The temperatures should be in ascending order. A minimum of 4 temperatures are required beginning with address 114. Cluster the points around locations of greatest slope change.

<u>Address</u>	<u>Variable Name</u>	<u>Description</u>
136 thru 155	QKK(I)	The fuel thermal conductivity in (Btu/hr-ft -°F) corresponding to TKK(I). A minimum of 4 values are required beginning with address 136.
158 thru 173	RG(I)	The dimensionless fuel radius ($\cdot/R_0$) at which the relative heat generation profile (local/AVE) is to be defined. The values should be in ascending order. A minimum of 4 values are required beginning with address 158. Cluster the values at points of most rapid change in slope. Leave out if the heat generation rate is constant.
175 thru 190	QDOT(I)	The relative heat generation profile through the fuel-pin (local/AVE) corresponding to RG(I). A minimum of 4 values are required beginning in address 175. Leave out if QDOT(I) = constant.

8.3.c INTEGER DATA

A (2) must always appear in column 1 of each data card for the following data.

FORMAT (T1, 4X, 5I5, 5I10)

<u>Address</u>	<u>Variable Name</u>	<u>Description</u>
1	NU	<u>Less than (0)</u> causes the code to print out all available data. <u>greater than (0)</u> causes the code to calculate the geometry of a given core only and prints this information out. (No thermal hydraulic data). <u>Equal to (0)</u> causes the code to calculate and print out all available data except it supresses the burnout heat flux on-line plotter routine. (NU = 0 is usually used).

<u>Address</u>	<u>Variable Name</u>	<u>Description</u>
2	II	<u>Equal (0)</u> for lenticular type fuel-pin spacers <u>Equal (1)</u> for circular wire transverse spacers <u>Equal (2)</u> for honeycomb type spacers <u>Equal (3)</u> for spiral wire spacers
3	LOPT	<u>Greater than (0)</u> if the length of the core is to be held constant. <u>Equal to (0)</u> if the ratio (core length/core diameter) is to be held constant.
4	LL	<u>Greater than (0)</u> eliminates the designing technique. A thermal and hydraulic assessment of a given core is made without attempting to design within heat flux or fuel centerline temperature limits. <u>Equal to (0)</u> the designing technique is implemented.
5	IFLOW	<u>Greater than (0)</u> the coolant flow rate in (lb/hr) is held constant. <u>Equal to (0)</u> the coolant mass velocity in (lb/hr-ft ²) is held constant.
6	ITMAX	Limits the number of iterations. ITMAX equal to (N) gives (N) total iterations per case. A value of 100 should be sufficient in most cases.
7	NOPS	The number of fuel-pin transverse spacers in the core. In the case of wire-wrapped fuel-pins, this number represents the total number of locations at which the pressure drop due to the spacer is to be determined. NOPS can never be greater than 20. NOPS must agree with the total number of GX(I) shown in address 49 through 68 Section 8.3.b.
8	NPOW	The number of axial power points to be read into the program. (20 max) must agree with QBF(I) shown in address 92 through 111 Section 8.3.b.

<u>Address</u>	<u>Variable Name</u>	<u>Description</u>
9	KNUM	The number of fuel thermal conductivity points to be read into the program (20 max) must agree with QKK(I) shown in address 136 through 155 Section 8.3.b.
10	NQ	The number of radial fuel-pin heat generation points to be read into the program (16 max). Leave blank for constant heat generation rate. Must agree with QDOT(I) shown in address 175 through 190 Section 8.3.b.
11	ITH	Serves the purpose of change cards when the only input parameter to be changed for a subsequent case is (1-fuel fraction). ITH = (N) gives (N) cases with (1-fuel fraction) incremented in each case by the step function in address 39 of Section 8.3.b. Leave out if this option is not desired.

8.4 SAMPLE PROBLEMS

The Westinghouse 1000 MW_e PWR and the General Electric 1000 MW_e BWR input data are illustrated on the following 80-80 Fortran coding forms. The code output for these two cases is also illustrated below.

COPIES	Y1	Y2	Y3
1	1.00+00	4.01+00	1.00+00
2	1.71+00	5.00+03	3.15+00

INPUT DATA AS RECEIVED BY PROGRAM - UNITS IN INCHES, POUNDS, BTU, DEGREES F, AND PSI

CASE NUMBER 1 SAMPLE PROBLEM TO ILLUSTRATE PRESSURE-WATER INPUT DATA

FILM COEFFICIENTS
 FUEL DENSITY 9300 FUEL-TUBE COOLANT-TUBE ENTRANCE HEAD EXIT HEAD FUEL DENSITY COOLANT DENSITY STRUCTURAL MAT DENSITY POWER INPUT-MW
 RATIO 1930.0 20000.0 500 1.000 1.000 .00 .00 .00 .00 3083.00

WRAP CORE CORE LENGTH EXIT EQUIVALENT FUEL PIN SPACER NO. GRID HEAT TRANSFER TYPE
 FL/TURN LATTICE ENT ACTIVE EXIT CORE RADIUS OR GRID-TYPE LOCATIONS LIMITED-CORE YES OF RUN
 900000 SQUARE 2.000 172.33 2.000 80.000 HONEYCOMB 9 COMPLETE

GRID LOCATIONS
 .1000 .2000 .3000 .4000 .5000 .6000 .7000 .8000 .9000

INLET TEMP INLET PRES DIAM OF FUEL HYDRATIC DIAM WALL THICKNESS FUEL PIN GEOMETRY MAX-FUEL
 OF COOLANT OF COOLANT IN FUEL PIN OF COOLANT CHAN OF FUEL PIN RI/PO GAS-GAP TEMP-F
 545.00 2250.0 .366900 .000000 2.43000E-02 .0000 .003250 .0

1-FUEL ASSEMBLY SPACING SUPPORT CLAD MASS VELOCITY FLOW-RATE MESH DNR HOT CHANNEL LOCAL PEAK-
 FRACTION FRACTION FRACTION OF COOLANT OF COOLANT NUMBER RATIO PEAK-FACTOR ING-FACTOR
 .724258 .019101 .091561 0.00000 1.18619E+08 .020 1.86000 2.820 1.0800

NUMBER OF NO. OF THERMAL FRACTION HEAT TEMP. AT WHICH FLOW RATE L/D RATIO
 POWER POINTS CONDUCTIVITY POINTS GEN. IN FUEL AGAIN GROWTH REGINS OF COOLANT OF CORE
 11 12 .9740 9000.0 HELD-CONSTANT HELD-CONSTANT

CROSS-FLOW FLOW REDISTRIBUTION SPACER TO FRICTION = .1840 * RE**(-.2000) + .0000
 COEFFICIENT COEFFICIENT SPACE RATIO
 .0000 1.0110 .5500

PRESSURE WATER REACTOR FLUID FLOW AND HEAT TRANSFER

CASE NUMBER 1		SAMPLE PROBLEM TO ILLUSTRATE PRESSURE-WATER INPUT DATA										THIS CASE REQUIRED 14.3 SEC.			
INLET TEMP-F	2250.00	POWER MW	3083.00	HEAT GEN RATE-B/H-CUF	3.2419+07	CORE LENGTH-FT	12.333	EQUIVALENT CORE RADIUS-IN FEET	0.000	HOLE H2O	0.000	NOM PEAKING FACTOR	1.7162	AVG-COOLANT TEMP DEG F	572.73
WALL THICK INCHES	0.024300000	COOLANT FLOW RATE LB/HR	1.186+08	COOLANT MASS VEL-LR/HR-SQF	2.448+06	NO. COOLANT CHANNELS	39367.62	PIN ON INCHES	0.422000	AVG HEAT FLUX	1.9636+05	MAX HEAT FLUX	5.5374+05	HOT CHANNEL	
SPACER COOLANT-TO FUEL RATIO	1.87200	PITCH INCHES	0.56314	CORE VOLUME-CUF	1.17+03	WEIGHT-LR	0.00	REYNOLDS NUMBER	5.00+05	CRITICAL HEAT FLUX	9.85+05	LIMITING HEAT FLUX	9.85+05		
HOT CHANNEL VOID DIAMETER-RATIO (RI/RO) = .00000 POINT OF MIN. DNR = .74000 MC EXIT QUAL. = -.04271															
MATERIAL VOLUME FRACTIONS															
FUEL COOLANT	.49711	FUEL CLAD	.08514	CELL CLAD	.09155	CELL SPACE	.01910	PIN ANNULUS	.00000	FUEL VOID	.03135	1-FUEL FRACTION	.72426	QUALITY	.0000000
LENGTH X/L	= .00000	.10000	.20000	.30000	.40000	.50000	.60000	.70000	.80000	.98649	1.00000				
COOLANT TEMP	= 545.0	545.3	547.0	551.3	552.5	558.1	579.1	590.3	600.3	610.0	610.0				
WALL TEMP	= 545.0	548.3	559.8	577.5	598.6	619.4	635.6	646.9	646.6	613.9	610.0				
LIMITING HEAT FLUX	= 0.000	0.000	0.000	0.000	0.000	1.606+05	1.368+06	1.081+06	9.322+05	7.865+05	0.000				
NOMINAL HEAT FLUX	= 0.000	1.739+04	7.308+04	1.500+05	2.305+05	2.968+05	3.302+05	3.331+05	2.741+05	2.299+04	0.000				
NOM FUEL CL TEMP	= .0	628.6	924.6	1416.2	2056.5	2633.9	2906.4	2936.1	2496.5	724.2	.0				
VOID DIAM RATIO	= .00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000				
INLET VELOCITY	16.417	IN CHANNEL PRESSURE	2240.461	IN CHANNEL STATIC PRESS	2248.360	EXIT CHANNEL STATIC PRESS	2199.548	EXIT CHANNEL PRESSURE	2200.779	PRESSURE DROP	50.425				
SATURATION POINT-X/L	NONE	POSITION OF MAX FLUX-X/L		AVG FUEL TEMP-F	4103.8	MAX FUEL TEMP-F	448.2	MAX WALL TEMP	648.2	HEAT TRANSFER AREA-SQF	5.21887+04				

6 ITERATIONS. (MORE THAN 100 ITERATIONS MEANS NO CONVERGENCE--CHECK INPUT DATA, ESPECIALLY FLOW DATA.)

[illegible]

INPUT DATA AS RECEIVED BY PROGRAM - UNITS IN INCHES, POUNDS, RTU, DEGREES F, AND PSI

CASE NUMBER 2 EXAMPLE PROBLEM TO ILLUSTRATE BOILING-WATER INPUT DATA

FILM COEFFICIENTS									
POW-RATIO	FUEL-TUBE	COOLANT-TUBE	ENTRANCE-HEAD	EXIT-HEAD	FUEL	COOLANT	STRUCTURAL	POWER	
.9300	INTERFACE	INTERFACE	LOSS COEFF	LOSS COEFF	DENSITY	DENSITY	MAT DENSITY	INPUT-MW	
	800.0	20000.0	1.000	1.500	637.40	62.40	637.00	3293.00	

WEAP	CORE	CORE LENGTH	EQUIVALENT	FUEL PIN SPACER	NO. GRID	HEAT TRANSFER	TYPE
FLUTURN	LATTICE	ENT-ACTIVE	EXIT	OR-GRID-TYPE	LOCATIONS	LIMITED CORE	OF RUN
.00000	SQUARE	.000	153.92	16.000	100.000	7	COMPLETE
				HONEYCOMB		YES	

GRID LOCATIONS			
.1250	.2500	.3750	.5000
		.6250	.7500
		.8750	

INLET TEMP	INLET PRES	DIAM OF FUEL	HYDRAULIC DIAM	WALL THICKNESS	FUEL PIN GEOMETRY	MAX FUEL
OF COOLANT	OF COOLANT	IN FUEL PIN	OF COOLANT CHAN	OF FUEL PIN	R/P/O	TEMP-F
526.00	1050.0	.488000	.000000	3.200000-02	.0000	.005000

1-FUEL	ASSEMBLY SPACING	SUPPORT CLAD	MASS VELOCITY	FLOW-RATE	MESH	DNR	HOT CHANNEL	LOCAL PEAK-
FRACTION	FRACTION	FRACTION	OF COOLANT	OF COOLANT	NUMBER	RATIO	PEAK-FACTOR	ING-FACTOR
.763155	.178200	.000306	0.00000	9.96000+07	.020	1.74000	2.600	1.2400

NUMBER OF	NO. OF THERMAL	FRACTION HEAT	TEMP. AT WHICH	FLOW RATE	L/D RATIO
POWER POINTS	CONDUCTIVITY POINTS	GEN. IN FUEL	GRAIN GROWTH BEGINS	OF COOLANT	OF CORE
5	15	.9600	9000.0	HELD CONSTANT	HELD CONSTANT

CROSS-FLOW	FLOW REDISTRIBUTION	SPACER TO	FRICTION	=	.1840 * RE**(-.20000) +	.0000
COEFFICIENT	COEFFICIENT	SPACE RATIO				
-.0700	1.2900	.5500				

BOILING WATER REACTOR FLUID FLOW AND HEAT TRANSFER

CASE NUMBER 2 EXAMPLE PROBLEM TO ILLUSTRATE BOILING-WATER INPUT DATA THIS CASE REQUIRED 8.1 SEC.

INLET TEMP-F	524.0	INLET PRESS-PSI	1050.00	POWER VW	3293.00	HEAT GEN RATE-B/H-CUF	2.0587+07	CORE LENGTH-FT	13.357	EQUIVALENT CORE RADIUS IN	FFET	NOM PEAKING FACTOR	1.4917	AVG COOLANT TEMP DEG F	543.80
HYD DIAM INCHES	.671657	WALL THICK INCHES	.032000000	COOLANT RATE	9.960+07	COOLANT MASS VEL-LB/HR-SQF	1.287+06	NO. COOLANT CHANNELS	37585.96	OF PTNS	562000	AVG HEAT FLUX	1.6226+05	MAX HEAT FLUX	4.2188+05
SPACER DIA-IN.	.09076	COOLANT TO FUEL RATIO	2.45700	PITCH INCHES	.73792	CORE VOLUME-CUF	2.30+03	CORE WEIGHT-LB	6.30+05	REYNOLDS NUMBER	3.03+05	CRITICAL HEAT FLUX	0.00	LIMITING HEAT FLUX	0.00
HOT CHANNEL VOID DIAMETER RATIO (RI/RO) = .00000 POINT OF MIN. DIA = .74000 HC EXIT QUAL. = .16946															

MATERIAL VOLUME FRACTIONS															
FUEL	.23685	COOLANT	.40367	FUEL CLAD	.07255	CELL CLAD	.08031	CELL SPACE	.17826	PIN ANNULUS	.00000	FUEL VOID	.02937	1-FUEL FRACTION	.1396716
LENGTH-X/L	=	.00000	.16000	.20000	.30000	.40000	.50000	.60000	.70000	.80000	.90017	1.00000			
COOLANT TEMP	=	526.0	530.0	539.7	549.8	549.4	549.3	548.5	547.2	545.6	543.7	543.6			
WALL TEMP	=	526.0	535.4	549.0	561.1	561.4	561.4	560.1	555.1	548.6	544.8	543.6			
LIMITING ENTHALPY	=	0.000	7.244+02	7.502+02	7.731+02	7.934+02	8.118+02	8.279+02	8.429+02	8.565+02	8.690+02	8.690+02			
NOMINAL ENTHALPY	=	5.162+02	5.241+02	5.363+02	5.527+02	5.710+02	5.897+02	6.080+02	6.224+02	6.304+02	6.321+02	6.321+02			
SAFETY MARGIN ENTHE	=	1.600+05	1.908+02	1.793+02	1.524+02	1.172+02	7.896+01	3.935+01	9.397+00	1.316+01	7.546+00	7.546+00			
NOMINAL HEAT FLUX	=	0.000	1.080+05	1.852+05	2.264+05	2.412+05	2.420+05	2.323+05	1.568+05	6.014+04	3.784+03	0.000			
NOM FUEL CL TEMP	=	.0	1147.5	1762.2	2163.2	2312.2	2320.5	2219.6	1534.8	864.0	562.9	.0			
VOID DIAM RATIO	=	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000			

IN	EXIT	IN CHANNEL	IN CHANNEL	EXIT CHANNEL	EXIT CHANNEL	PRESSURE	PRESSURE
VELOCITY	VELOCITY	PRESSURE	STATIC PRESS	STATIC PRESS	PRESSURE	PROP	PROP
7.536	29.091	1046.709	1049.226	991.665	993.531	58.151	58.151
SATURATION	POSITION OF	CRITICAL	LIMITING	AVG FUEL	MAX FUEL	MAX WALL TEMP	HEAT TRANSFER
POINT-X/L	MAX FLUX-X/L	ENTHALPY-B/LR	ENTHALPY-B/LR	TFMP-F	TFMP-F	HOT CHANNEL	AREA-SQF
.26613	.50000	856.4	856.5	1751.9	4387.0	570.4	6.64900+04

7 ITERATIONS. (MORE THAN 100 ITERATIONS MEANS NO CONVERGENCE--CHECK INPUT DATA, ESPECIALLY FLOW DATA.)

CASE NO. 2 PLOT 1 IS LIMITING ENTHALPY VS DISTANCE THRU CORE *** PLOT 2 IS HOT CHANNEL ENTHALPY VS DISTANCE.									
1	2	3	4	5	6	7	8	9	10
1	1	1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4	4	4
5	5	5	5	5	5	5	5	5	5
6	6	6	6	6	6	6	6	6	6
7	7	7	7	7	7	7	7	7	7
8	8	8	8	8	8	8	8	8	8
9	9	9	9	9	9	9	9	9	9
10	10	10	10	10	10	10	10	10	10
11	11	11	11	11	11	11	11	11	11
12	12	12	12	12	12	12	12	12	12
13	13	13	13	13	13	13	13	13	13
14	14	14	14	14	14	14	14	14	14
15	15	15	15	15	15	15	15	15	15
16	16	16	16	16	16	16	16	16	16
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20	20	20	20	20	20	20	20	20	20
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97	97	97	97	97	97	97	97	97	97
98	98	98	98	98	98	98	98	98	98
99	99	99	99	99	99	99	99	99	99
100	100	100	100	100	100	100	100	100	100

COEFFICIENTS - X1 = 1.00+00 Y1 = 8.69+02 X2 = 1.00+00 Y2 = 8.69+02

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NOMENCLATURE

AFL	The cross sectional core area containing coolant (Ft^2).
AFU	The cross sectional core area containing theoretical dense fuel (Ft^2).
AHEAT	The total heat transfer surface area in the core (Ft^2).
AI(N)	The integrated axial power profile value at node (N). Btu/hr
ALPHA	The volumetric fraction of the <u>heat transfer core model</u> which does not contain theoretical dense fuel. $(1-\text{ALPHA})$ is the volumetric fraction of the heat transfer core model which contains theoretical dense fuel.
ALPHAC	The volumetric fraction of the core containing coolant. This fraction pertains to flow over the fuel-pins.
ALPHAF	The volumetric fraction of the core containing theoretical dense fuel $(1-\text{ALPHAP})$.
ALPHAP	The volumetric fraction of the core which does not contain theoretical dense fuel.
ALPHAT	The volumetric fraction of the core containing fuel cladding material.
ALPHAS	The volumetric fraction of the core containing space between the subassemblies for thermal expansion purposes.
ALPHAW	The volumetric fraction of the core containing center space for annular fuel-pins.
ALPHFV	The volumetric fraction of the core containing fuel porosity space.
ALPHOT	The volumetric fraction of the core containing sheath cladding for the subassemblies. The control rod volume may be lumped into this parameter.

APHI	One of three parts of the burnout heat flux equation. $\text{PHI}_{\text{BO}} = \text{APHI} \times \text{BPHI} \times \text{DPHI}$
BPHI	One of three parts of the burnout heat flux equation. $\text{PHI}_{\text{BO}} = \text{APHI} \times \text{BPHI} \times \text{DPHI}$
CORE	A parameter which designates the type of core model used as the basis for REPP calculations. (Refer to input description)
CPHI	A constant used in the upstream - memory equation used in the burnout heat flux equation. An empirical equation is used in calculating its value. (inches)
CVOL	The core volume in Ft^3 .
CWT	The core weight in pounds.
DELEPS	The step increment for consecutive changes in ALPHAP used as a case generator.
DH	The hydraulic diameter in feet.
DHI	The hydraulic diameter in inches.
DHM	The minimum possible value of the hydraulic diameter for a given geometry (ft).
DIST	An adjusted length (x/l) or active length which excludes preheat and postheat regions. (dimensionless).
DIVR	A dummy mesh length increment used in calculating the memory constant (FPHI) dimensionless.
DP	The fuel diameter adjusted to coincide with inner fuel pin diameters in (ft).
DPHI	One of the three parts of the burnout equation $\text{PHI}_{\text{BO}} = \text{APHI} \times \text{BPHI} \times \text{DPHI}$
DPO	The outside diameter of the fuel-pin in ft.
DPOI	The outside diameter of the fuel-pin in inches.

DP1	The previous value of the fuel diameter in the fuel temperature iterative process (ft).
DP2	The second previous value of the fuel diameter in the fuel temperature iterative process (ft).
DS	The diameter of the feul-pin spacer wire (inches).
DUMMY(1-105)	The simulated hot channel coolant temperature at node (N) N = 1-105.
DUMMY(106-210)	The hot channel coolant quality at node (N) N = 106-210.
DUMMY(211-221)	The hot channel coolant quality on a coarse mesh scale at node (I) I = 211-221
DUMMY(222)	The hot channel coolant temperature at the location of the maximum heat flux.
DUMMY(223-233)	The fuel-pin surface wall temperature (°F) in the hot channel on a coarse mesh scale and at node (I) I = 223-233.
DUMMY(296)	Is equivalenced to RPFACF which is the core radial peaking fact.
DUMMY(297)	Is equivalenced to EDHEAT which is the post heated length of the fuel-pin (ft).
DUMMY(298)	Is equivalenced to STHEAT which is the pre-heated length of the fuel-pin (ft).
DUMMY(299)	A control parameter which, if assigned a value of (20), transfers control to a message center. A statement is written advising the user to correct input data.
DUMMY(300)	A control parameter which, if assigned a value of (50), transfers control to a message center which advises the user that the code ran into trouble in the subroutine press 2.
DVOP(I)	The size of the void at the center of the fuel pin located at node (I) I = 1-13.
E	The film coefficient at the fuel clad interface in (Btu/hr-ft ² -°F).

EDHEAT	The location of the end of the fuel in the fuel pin in ft.
EN	The number of coolant channels in the core.
ENTL	The entrance length (preheat length) of the fuel-pin in ft.
EXITL	The exit length (post heat length) of the fuel-pin in ft.
FCON1	A constant in the friction factor equation.
FCON2	A constant in the friction factor equation.
FCON3	A constant in the friction factor equation.
FPHI(N)	The upstream memory constant used in the burnout heat flux equation and applied at node (N). $N = 1-105$.
FRIC	The Darcy Weisbach friction factor used in calculating pressure drop.
FUDENS	The apparent fuel density to the theoretical fuel density ratio.
G	The coolant mass velocity in (lb/hr-ft^2) .
GAMMA	The slip factor used for calculating two phase flow pressure drop.
GAMMA 2	The acceleration slip factor used for calculating two-phase flow pressure drop.
GAMMA 3	The friction slip factor used for calculating two-phase flow pressure drop.
GAMMA 4	The gravitational slip factor used for calculating two-phase flow pressure drop.
GRID	The temperature ($^{\circ}\text{F}$) at which grain growth begins in low density fuel.
GX(I)	The dimensionless location (x/l) at which fuel-pin spacers are positioned in the core.

HC	The heat transfer film coefficient in subcooled regions and calculated from the Colburn equation.
HCFAC	The hot channel factor composed of the product of the power peaking factors and the uncertainty factors.
HCTEMP	A maximum fuel centerline temperature design limit ($^{\circ}\text{F}$) (refer to input description).
HCRIT	The critical enthalpy or the coolant enthalpy at the location of DNB. (Btu/lb)
HF	The saturated liquid enthalpy (Btu/lb).
HFG	The latent heat of vaporization (Btu/lb).
HFHC	The saturated liquid enthalpy of the hot channel (Btu/lb).
HFICM	The heat transfer film coefficient for local boiling in (Btu/hr-ft ² - $^{\circ}\text{F}$).
HFRAT	The difference ratio (HFL-HR)/HF.
HG	The saturation enthalpy for steam (Btu/lb).
HLIM	The coolant enthalpy (limiting enthalpy) at which burnout would occur (Btu/lb).
H(1)	The coolant enthalpy at the saturation point in the core (should saturation exist) (Btu/lb).
H(2)	The coolant exit enthalpy (Btu/lb).
HL	The coolant inlet enthalpy (Btu/lb).
HFL	The local coolant enthalpy (Btu/lb).
IFLOW	The coolant flow option control (refer to input description).
II	The fuel-pin spacer control option (refer to input description).
INCR	The last mesh point generating heat.

ITH	The number of cases to be run with variation in ALPHAP (refer to input description).
ITMAX	The maximum number of iterations allowed per case (refer to input description).
ITN	A counter for the number of iterations completed in the heat flux design process.
JJ	An integer which controls the design margin.
KNUM	The number of thermal conductivity points input to the code (refer to input description).
LDNB	The mesh point at which incipient nucleate boiling begins.
LL	A control for a single pass through the thermal-hydraulic process (refer to input description).
LLDNB	The mesh point at which incipient nucleate boiling ends.
LOPT	The coolant flow option (refer to input description).
LSAT	The mesh point at which bulk boiling begins.
MM	A variable that directs control to the boiling water or pressure water sizing routine.
NDNB	The node where the minimum departure from nucleate boiling occurs.
NN	A control which identifies boiling water cases. It is used only after a boiling water core has been determined and prevents the iterative process on temperature from reconsidering pressure water conditions.
NOPS	The number of grids in the core (refer to input description).
NOT	The number of iterations the code steps through (refer to input description).
NOUT	The total number of nodes through the core.

NPOW	The number of power points input to the code (refer to input description).
NQ	The number of heat generation points input to the code (refer to input descriptions).
NTERP	The number of points considered in the Lagrangian interpolation routine. It is presently set equal to 4 and a third order polynomial is used as the interpolation polynomial.
NU	A control when REPP is run to generate a geometry only (refer to input description).
P(N)	The local pressure at node (N) in psia, N = 1-150.
PC(N)	The local pressure at node (N) in psia for a coarse mesh for write out purposes, N = 1-12.
PD	The fuel-pin pitch (ft).
PDI	The fuel-pin pitch (inches).
PF(N)	A local pressure used in iterating to a saturation pressure should one exist in the core, N = 1-5.
PFACT	The axial power peaking factor calculated in REPP.
PH(N)	The local nominal heat flux at node (N), N = 1-202.
PHCRIT	The critical heat flux on the local heat flux at the node of minimum DNB ratio.
PHI(N)	The local heat flux for a coarse mesh used for print out purposes, N = 1-12.
PHI(13)	The critical heat flux or the heat flux at MDNBR in the hot channel.
PHI(14)	The average heat flux in the core.
PHILIM	The burnout or limiting heat flux at the point of minimum DNB ratio.

PHIMAX	The maximum heat flux in the core.
PI	The constant 3.1459.
PHLIM(N)	The burnout or limiting heat flux at the point of minimum DNB ratio for a course mesh used for print out, $N = 1-12$.
PINS	The number of fuel-pins in the core.
PR	The Prandtl number (dimensionless).
POO	The stagnation inlet pressure (zero velocity) (psia).
PO1	The static pressure after entrance into the coolant channel (psia).
PO2	The static pressure before exiting from the coolant channel (psia).
PO3	The stagnation pressure after exiting from the coolant channel (psia).
PO3POO	The total pressure drop through the core (psia).
Q	The total reactor power in Btu/hr calculated internally.
QB	The average heat generation rate in the fuel (Btu/hr-ft ³).
QBF(N)	The relative power profile at node (N), $N = 1-22$.
QBX(N)	The axial dimensionless distance to node (N) corresponding to QBF(N), $N = 1-22$.
QDOT(N)	The relative radial heat generation rate in a fuel-pin at radial node (N), $N = 1-17$.
QF(N)	The interpolated values of QBF to coincide with a set number of (N) mesh points, $N = 1-101$.
QFG	The total heat generation at various distances through the core (Btu/hr).
QFX	A dummy quality calculated consecutively for the various nodes through the core.

QK(N)	The integrated value of Kdt which corresponds to the temperature mesh TEMK(N), N = 1-201.
QKDUMM	The integrated value of Kdt which corresponds to a course mesh nodal temperature. Linear extrapolation is used to evaluate the term between mesh temperature values.
QKHCTP	The integrated value of Kdt at the maximum fuel centerline temperature design limit.
QKK(N)	The fuel thermal conductivity at temperature (N), N = 1-22. (refer to input description).
QKTMAX	The integrated value of Kdt at the local fuel centerline temperature.
QUAL	The local coolant quality. The final value is the exit quality.
Q1	The total reactor power in MW_t as calculated in REPP.
Q11	The total reactor power in MW_e input to the code (refer to input description).
RAD	The equivalent core radius of the heat transfer model (ft).
RADP	The equivalent core radius (ft) (refer to input description).
RG(N)	The radial mesh dimensionless distance which corresponds to the fuel-pin heat generation ((QDOT(N)) at radial node (N), N = 1-17. (refer to input description).
RGI(N)	The interpolated radial dimensionless distance (RG) in increments of .05, N = 1-17.
RHFG	The hot channel coolant enthalpy at various nodes along the core (Btu/lb).
RHO(N)	The coolant density at node (N) (lb/ft^3), N = 1-150.

RHOC	The coolant density (lb/ft^3) at room temperature.
RHOF	The fuel density (lb/ft^3) at room temperature.
RHOT	The equivalent density of the core hardware (lb/ft^3) at room temperature.
RPFAC	Radial peaking factor.
STAG	The diametric gap at the fuel-clad interface in ft.
SFACT	A dummy peaking factor used to calculate hot channel conditions.
STHEAT	The dimensionless length of the preheat section.
T(N)	The coolant temperature ($^{\circ}\text{F}$) at node (N), $N = 1-202$.
TA	An average coolant temperature between nodes ($^{\circ}\text{F}$).
TC(N)	The coolant temperature ($^{\circ}\text{F}$) for a coarse mesh used in print-out, $N = 1-12$.
TCAVE	The average coolant temperature ($^{\circ}\text{F}$) in the core.
TEMPK(N)	The temperature mesh points ($^{\circ}\text{F}$) for the iterated values of the fuel thermal conductivity input data, $N = 1-201$.
TF	Saturation coolant temperature ($^{\circ}\text{F}$).
TFG	The film temperature at the fuel-clad interface ($^{\circ}\text{F}$).
TFO(13)	The fuel surface temperature ($^{\circ}\text{F}$) in the hot channel at the position of maximum heat flux.
TFO(14)	The average fuel surface temperature ($^{\circ}\text{F}$).
THETA	(Inner radius/outer radius) for annular fuel-pins. (refer to input descriptions).
THQUAL(N)	A dummy coolant quality for an equivalent uniform heat flux at node (N), $N = 1-101$.

TITLE	A descriptive title given to a particular case. (refer to input description).
TKK(1-22)	The temperature mesh ($^{\circ}\text{F}$) corresponding to the thermal conductivity input (refer to input description).
TMAX(N)	The fuel centerline temperature ($^{\circ}\text{F}$) at node (N), N = 1-12.
TMAX(13)	The maximum fuel centerline temperature ($^{\circ}\text{F}$) in the hot channel.
TMAX(14)	The average fuel centerline temperature ($^{\circ}\text{F}$) in the core.
TSAT	The saturation temperature for a local pressure and used in determining incipient nucleate boiling conditions.
TW(N)	The fuel-clad wall temperature ($^{\circ}\text{F}$) for a course mesh and at node (N), N = 1-12.
TW(13)	The fuel-clad wall temperature ($^{\circ}\text{F}$) in the hot channel at the location of maximum heat flux.
TW(14)	The average fuel-clad wall temperature ($^{\circ}\text{F}$).
TO1	The coolant inlet temperature ($^{\circ}\text{F}$).
TEM 1, 2	The temperature difference (design fuel centerline temperature - maximum fuel centerline temperature) for 2 previous histories in the iterative process.
TRDEL 1, 2	The heat flux difference ratio (burnout heat flux - critical heat flux/burnout heat flux) for 2 previous histories in the iterative process.
TRIAL 1, 2	The equivalent core radius in (ft) for 2 previous histories corresponding to TRDEL.
UDEL(N)	The heat flux difference ratio (burnout-critical/burnout) for each node (N), N = 1-101.
UFP(N)	The value of the integral for mesh node (N) in the upstream memory equation, N = 1-1000.

UFPI(N)	The value of the integrand for mesh node (N) in the upstream memory equation, $N = 1-1000$.
UPH(N)	The interpolated values of (PH) for a fine mesh and used in the upstream memory equation, $N = 1-1000$.
UX(N)	The length mesh in inches corresponding to UFP and UFPI, $N = 1-1000$.
V(N)	The specific volume of the coolant (liquid phase) (ft^3/lb) at node (N), $N = 1-202$.
VF(N)	The specific volume of the coolant (boiling phase) (ft^3/lb) at node (N), $N = 1-101$.
VEL1	The coolant inlet velocity (ft/sec).
VEL2	The coolant exit velocity (ft/sec).
VKL01	The inlet pressure drop coefficient.
VKL23	The exit pressure drop coefficient.
WDOT	The coolant flow rate (lb/hr).
WRAP	Ft per turn for wire wrapped spacers (refer to input description).
X(1-150)	The axial nodal mesh (x/l) dimensionless.
XCRIT	The dimensionless location of minimum DNB ratio.
XH(N)	The enthalpy of the coolant at node (N) for a course mesh, $N = 1-12$.
XHCRIT	The dimensionless length where the burnout enthalpy occurs.
XHLIM(N)	The burnout enthalpy at node (N) for a course mesh, $N = 1-12$.
XI	The volumetric (water/fuel) ratio.
XINCR	The dimensionless distance between each node ($\Delta x/l$)

XL	The length of the core in feet.
XLDRAT	The core length to the core diameter ratio.
XLF	The dimensionless distance to the coolant saturation point.
XLPFAC	The local power peaking factor.
XL RAT	The difference ratio $(XLF - XCN)/XLF$ which serves to transfer control from single-phase pressure calculations to two-phase pressure calculation.
XLX	The active (fueled) length of the core in feet.
XMAX	The dimensionless location of the maximum heat flux.
XMIX	A flow redistribution factor (refer to input description).
XMU	The coolant fluid viscosity.
XNRE	The local Reynolds number.
XPFACT	The minimum DNB ratio (refer to input description).
XQUAL	The percent of the core power generated in the fuel.
XW	The thickness of the fuel clad (ft).
XWI	The thickness of the fuel clad (inches).
XWRAT	The ratio (XW/DP) .
XXINCR	A fine mesh in inches used in the upstream memory equation for predicting burnout heat flux conditions.
XXK	The thermal conductivity of the coolant fluid.
ZETA(1-12)	The dimensionless length (x/l) for a course mesh used in the printout.

APPENDIX A

DEVELOPMENT OF THE HEAT TRANSFER EQUATIONS

APPENDIX A

Development of the Heat Transfer Equations

The heat transfer process used in REPP is a one-dimensional analysis which incorporates a numerical technique in its solution. In general, nondimensional parameters normalized to 1 are used to describe the heat generation characteristics of the fuel in the axial and radial direction of the fuel pin and thus constants for each node must be developed which is used to determine the magnitude of the integrand properly. This is not a difficult problem for the axial direction since the value of the integrand over the core represents the total core power which is an input quantity and one constant is applicable to every node. However the radial heat generation must correspond to local heat fluxes and thus must be calculated separately for each node. The equations for the removal of heat were developed as follows:

The differential equation for the heat conduction in a cylinder

is:

$$\begin{aligned} \frac{\partial T}{\partial t} = & \frac{\partial}{\partial r} \left(\frac{K}{\rho C_p} \frac{\partial T}{\partial r} \right) + \frac{K}{\rho C_p r} \frac{\partial T}{\partial r} + \frac{1}{r^2} \frac{\partial}{\partial \theta} \left(\frac{K}{\rho C_p} \frac{\partial T}{\partial \theta} \right) + \\ & \frac{\partial}{\partial z} \left(\frac{K}{\rho C_p} \frac{\partial T}{\partial z} \right) + \frac{q'}{\rho C_p} \end{aligned} \quad (1)$$

Where

T = temperature

t = time

r = radius of cylinder

K = thermal conductivity of the fuel

ρ = density of the fuel

C_p = specific heat of the fuel

θ = angular dimension

z = axial dimension

q' = heat generation rate (Btu/hr-ft³)

The following assumptions are made

$$\frac{\partial T}{\partial t} = 0 \quad (\text{steady state heat transfer problem}) \quad (2)$$

$$\frac{\partial T}{\partial \theta} = 0 \quad (\text{no heat movement in } \theta \text{ direction}) \quad (3)$$

$$\frac{\partial T}{\partial z} = 0 \quad (\text{no heat movement in } z \text{ direction}) \quad (4)$$

Thus the equation reduces to

$$\frac{\partial}{\partial r} \left(\frac{K}{\rho C_p} \frac{\partial T}{\partial r} \right) + \frac{K}{\rho C_p r} \frac{\partial T}{\partial r} = - \frac{q'}{\rho C_p}$$

Multiplication through by r gives:

$$r \frac{\partial}{\partial r} \left(\frac{K}{\rho C_p} \frac{\partial T}{\partial r} \right) + \frac{K}{\rho C_p} \frac{\partial T}{\partial r} = - \frac{q' r}{\rho C_p} \quad (5)$$

Note that the following expression is valid.

$$\frac{\partial}{\partial r} \left(r \frac{K}{\rho C_p} \frac{\partial T}{\partial r} \right) = r \frac{\partial}{\partial r} \left(\frac{K}{\rho C_p} \frac{\partial T}{\partial r} \right) + \frac{K}{\rho C_p} \frac{\partial T}{\partial r} \quad (6)$$

where $\frac{K}{\rho C_p} = f(T)$

substitution of equation 6 into equation 5 gives:

$$\frac{\partial}{\partial r} \left(r \frac{K}{\rho C_p} \frac{\partial T}{\partial r} \right) = - \frac{q' r}{\rho C_p} \quad (7)$$

Integration yields

$$r \frac{K}{\rho C_p} \frac{\partial T}{\partial r} = - \frac{1}{\rho C_p} \int_{r_i}^r q' r dr$$

where $q' = f(r)$

multiplying through by ρC_p and dividing by r gives:

$$K \frac{\partial T}{\partial r} = - \frac{1}{r} \int_{r_i}^{r_o} q' r' \partial r'$$

separation of variables and writing in total differential form gives:

$$K dT = - \left[\frac{1}{r} \int_{r_i}^{r_o} q' r' \partial r' \right] dr \quad (8)$$

integration yields:

$$- \int_{T_i}^{T_o} K dt = \left[\int_{r_i}^{r_o} \frac{1}{r} \int_{r_i}^r q' r' \partial r' \right] dr \quad (9)$$

Equation 9 is solved by numerical methods. The data points vary from 16 to 1000 points. The thermal conductivity data are integrated between the limits $0 \leq T \leq 5000$ degrees fahrenheit. Thus for fuel surface temperatures equal to $(0 \leq T_s)$ the $\int K dt$ may be evaluated if the magnitude of the right side of equation 9 can be determined. Since the heat generation profile is to be applicable at each mesh point in the core and since the value of the integrand must correspond to local heat fluxes at the various points, a relative profile (local/average) is used for q' in equation 9 and the magnitude is determined as follows.

Define:

Q = the total heat generation per unit volume

ϕ = the local heat flux

L = length

D = fuel-pin outside diameter

then

$$Q = 2\pi L \int_{r_i}^{r_o} q' r dr$$

also $Q = \phi \pi DL$

Equating the two expressions gives:

$$2\pi L \int_{r_i}^{r_o} q' r dr = \phi \pi DL$$

$$\text{or } \int_{r_i}^{r_o} q' r dr = \frac{\phi \pi DL}{2\pi L}$$

$$\int_{r_i}^{r_o} q' r dr = \frac{\phi D}{2} \quad \text{a constant at any mesh node.} \quad (10)$$

Thus the magnitude of the integral $\int q' r' dr'$ in equation 9 when integrated between the limits of the inner radius to the outer radius of the fuel must be equal to the local heat flux times the fuel-pin outside diameter divided

by 2. The fuel diameter and the heat flux is known at each node and consequently the magnitude of equation 9 can be determined by substitution of equation 10 into equation 9.

$$-\int_{T_i}^{T_o} K dt = \frac{OD}{2} \int_{r_i}^{r_o} \frac{1}{r} dr$$

APPENDIX B

The Mathematical Models

APPENDIX B

The Mathematical Models

The objective of the mathematical development of the two models was to delineate the core geometry with a minimal input and offer some latitude in the selection of input parameters. For example, either the hydraulic diameter or the fuel diameter can be specified. Additionally there is a choice between the coolant mass flow rate (lb/hr) and the coolant mass velocity (lb/hr-ft²). Since the code was programmed for use in core design problems in conjunction with nuclear and economic studies, the parameter (1-fuel fraction) was selected for the basis of the calculations and allows communication between the disciplines. Further, each of the core components are represented in volumetric fraction form to add additional compatibility between the two models and the neutronics and economic investigations. The equations to be developed were therefore functions primarily of (1-fuel fraction) designated (α_p) for crevity in the physical model or (α'_h) for the heat transfer model. The mathematical relationship of α'_h to α_p is:

$$\alpha'_h = 1 - \frac{1 - \alpha_p}{1 - \alpha_s - \alpha_{ot}}$$

α_s and α_{ot} are defined in the list below:

A Area

A_c Cross sectional core area occupied by coolant per coolant
channel (see figure below)

Act	The total active coolant area in the core
Af	Cross sectional core area occupied by theoretical dense fuel
AHEAT	The total heat transfer area in the core
At	The fuel-pin clad area per coolant channel
C	Wetted perimeter of a coolant channel
Dp	The inner diameter of the fuel-pin cladding
Dpi	The inner diameter of the fuel
Dpo	The outer diameter of the fuel-pin cladding
Dh	The hydraulic diameter
G	The mass velocity (lb/hr-ft ²)
lp	The fuel-pin pitch
Nc	The total number of subassemblies
Np	The total number of fuel-pins in the core
req	The equivalent core radius
r ['] eq	The equivalent core radius of the heat transfer model
Tc	The thickness of the fuel-pin clad
XI	Coolant to fuel ratio
W	The mass flow rate (lb/hr)
ρ	The apparent fuel density (lb/ft ³)
ρ _t	The theoretical fuel density (lb/ft ³)
α _h	The volumetric fraction of the heat transfer core model which does not contain theoretical dense fuel

θ	The ratio (D_{pi}/D_p)
α_c	The volumetric coolant fraction (coolant/core)
α_f	The volumetric fuel porosity fraction (fuel pores/core)
α_p	(1-fuel fraction) in the physical model
α_T	The volumetric clad fraction (fuel-clad/core)
α_w	The volumetric space fraction (space at the fuel-pin center/ core) for annular fuel pins.

The mathematical development of the two models is divided into two sections. The square lattice model is presented first.

Consider the heat transfer model to be as follows where the sheath clad and thermal space area (α_s and α_{ot}) are eliminated. The heat transfer model is identified below.

Then the core fraction not occupied by 100% theoretical dense fuel is:

$$\alpha'_h = \frac{\ell_p^2 - \frac{\rho}{\rho_t} \left(\frac{\pi D_p^2 - \pi \theta^2 D_p^2}{4} \right)}{\ell_p^2}$$

$$\alpha'_h = \frac{\ell_p^2 - \frac{\rho}{\rho + 4} \pi D_p^2 (1 - \theta^2)}{\ell_p^2}$$

$$\alpha'_h \ell_p^2 = \ell_p^2 - \frac{\rho}{\rho_t} \frac{\pi D_p^2}{4} (1-\theta^2)$$

solving for D_p^2 gives:

$$D_p^2 = \frac{4\ell_p^2 (1-\alpha'_h)}{\pi(\rho/\rho_t)(1-\theta^2)} \quad \left[\begin{array}{l} \text{Note that as } \theta \text{ goes to } 0 \\ \text{the equation is valid for a} \\ \text{solid pin.} \end{array} \right] \quad \text{S-1*}$$

Also

$$D_h = \frac{4A}{C} \quad \text{and } C = \pi D_{po}$$

$$A = \frac{\pi D_h D_{po}}{4}$$

and the total area of the rectangle becomes:

$$\frac{\pi D_{po}^2}{4} + \frac{\pi D_h D_{po}}{4} = \ell_p^2$$

$$\ell_p^2 = \frac{\pi D_{po}}{4} (D_h + D_{po}) \quad \text{S-2}$$

Substitution into equation 1

$$D_p^2 = \frac{4(1-\alpha'_h) \frac{\pi D_{po}}{4} (D_h + D_{po})}{\pi(\rho/\rho_t)(1-\theta^2)}$$

$$D_p^2 = \frac{(1-\alpha'_h)(D_{po}D_h + D_{po}^2)}{(\rho/\rho_t)(1-\theta^2)} \quad \text{S-3}$$

But $D_{po} = D_p + 2T_c$

$$D_{po}^2 = D_p^2 + 4D_pT_c + 4T_c^2 \quad \text{S-4}$$

*S signifies equations derived for a fuel-pin lattice in a square arrangement

Then equation 3 becomes

$$Dp^2 = \frac{(1-\alpha'_h)[DpDh+2DhTc + Dp^2+4DpTc + 4Tc^2]}{(\rho/\rho_t)(1-\theta^2)}$$

collecting terms:

$$\left[1 - \frac{(\rho/\rho_t)(1-\theta^2)}{(1-\alpha'_h)} \right] Dp^2 + (Dh+4Tc) Dp + 2DhTc + 4Tc^2 = 0$$

$$\left[\frac{(1-\alpha'_h) - (\rho/\rho_t)(1-\theta^2)}{(1-\alpha'_h)} \right] Dp^2 + (Dh+4Tc) Dp + 2(DhTc+2Tc^2) = 0$$

$$Dp^2 + \left[\frac{(1-\alpha'_h)(Dh+4Tc)}{(1-\alpha'_h) - (\rho/\rho_t)(1-\theta^2)} \right] Dp + \frac{2(1-\alpha'_h)(DhTc+2Tc^2)}{(1-\alpha'_h) - (\rho/\rho_t)(1-\theta^2)} = 0$$

or by multiplication by $\frac{-1}{-1}$

$$Dp^2 - \left[\frac{(1-\alpha'_h)(Dh+4Tc)}{(\rho/\rho_t)(1-\theta^2) - (1-\alpha'_h)} \right] Dp - \frac{2(1-\alpha'_h)(DhTc+2Tc^2)}{(\rho/\rho_t)(1-\theta^2) - (1-\alpha'_h)} = 0$$

$$Dp = \frac{(1-\alpha'_h)(Dh+4Tc)}{2[(\rho/\rho_t)(1-\theta^2) + \alpha'_h - 1]} + \sqrt{\left[\frac{(1-\alpha'_h)(Dh+4Tc)}{2[(\rho/\rho_t)(1-\theta^2) + \alpha'_h - 1]} \right]^2 + \frac{2(1-\alpha'_h)(DhTc+2Tc^2)}{[(\rho/\rho_t)(1-\theta^2) + \alpha'_h - 1]}}$$

From equation 3 the solution for Dh is:

$$D_p^2 = \frac{(1-\alpha_h)(D_p D_h + D_p^2)}{(\rho/\rho_t)(1-\theta^2)}$$

$$\frac{D_p^2 (\rho/\rho_t)(1-\theta^2)}{1-\alpha_h} - D_p^2 = D_p D_h$$

$$D_h = \frac{(\rho/\rho_t)(1-\theta^2)}{(1-\alpha_h) D_p} D_p^2 - D_p$$

S-6

Equations 5 and 6 are used in the code depending on the input data. Either Dh or Dp must be specified along with the clad thickness, (ρ/ρ_t) , and θ .

Define Nc to be the total number of assemblies then

$$N_c \ell_p^2 = \pi r_{eq}^2$$

substitution for ℓ_p^2

$$\frac{N_c \pi D_p}{4} (D_h + D_p) = \pi r_{eq}^2$$

$$N_c = \frac{4 \pi r_{eq}^2}{\pi D_p (D_h + D_p)}$$

$$N_c = \frac{4 r_{eq}^2}{D_p (D_h + D_p)}$$

S-7

Define the total number of pins to be (Np)

$$(1-\alpha_h) \pi r_{eq}^2 = N_p \pi \frac{(D_p^2 - \theta^2 D_p^2)}{4} (\rho/\rho_t)$$

$$N_p = \frac{4(1-\alpha_h) \pi r_{eq}^2}{\pi D_p^2 (1-\theta^2) (\rho/\rho_t)}$$

$$N_p = \frac{4(1-\alpha'_h) r_{eq}^2}{D_p^2 (1-\theta^2) (\rho/\rho_t)}$$

S-8

The coolant fraction becomes:

$$\alpha_c \pi r_{eq}^2 = N_c A \quad \text{where} \quad = \frac{\pi D_h D_{po}}{4}$$

$$\alpha_c = \frac{4 r_{eq}^2}{D_{po}(D_h + D_{po})} \quad \frac{\pi D_h D_{po}}{\pi 4 r_{eq}^2}$$

$$\alpha_c = \frac{\pi r_{eq}^2 D_h D_{po}}{D_{po}(D_h + D_{po}) \pi r_{eq}^2}$$

$$\alpha_c = \frac{D_h (1-\alpha_p)}{(D_h + D_{po})(1-\alpha'_h)}$$

S-9

$$G = \frac{\dot{W}}{\alpha_c \pi r_{eq}^2} \quad \text{or} \quad \dot{W} = G \alpha_c \pi r_{eq}^2$$

$$\dot{W} = \frac{G D_h (1-\alpha_p) \pi r_{eq}^2}{(D_h + D_{po})(1-\alpha'_h)}$$

$$\text{but} \quad \frac{1-\alpha_p}{1-\alpha'_h} = \frac{r_{eq}^2}{r_{eq}^2}$$

$$\dot{W} = \frac{G D_h r_{eq}^2 \pi r_{eq}^2}{r_{eq}^2 (D_h + D_{po})}$$

$$\dot{W} = \frac{G D_h \pi r_{eq}^2}{(D_h + D_{po})}$$

S-10

Let PD = center to center pin spacing

$$PD^2 = \frac{\pi D_{po}^2}{4} + \frac{\pi D_h D_{po}}{4} \quad PD^2 = \text{outside pin area} + \text{coolant area}$$

$$PD = \sqrt{\frac{\pi D_{po}(D_{po} + D_h)}{4}} \quad S-11$$

The minimum value of PD occurs when

$$PD = D_{po}$$

thus

$$D_{po}^2 = \frac{\pi D_{po}}{4} (D_{po} + D_h)$$

$$D_h = \frac{4 D_{po}^2}{\pi D_{po}} - D_{po}$$

$$D_{h \text{ minimum}} = \frac{4 D_{po}}{\pi} - D_{po}$$

$$D_{h \text{ min}} = \left(\frac{4 - \pi}{\pi} \right) D_{po} \quad S-12$$

This equation is used to assure useful and practical cores that are generated in the code. Thus calculated values of fuel pin pitch which would cause over lapping of the fuel-pins is avoided.

The total coolant area in the core becomes:

$$A_{ct} = N_c A = \frac{\pi D_{po} D_h}{4} \frac{4 r_{eq}^2}{D_{po}(D_h + D_{po})}$$

$$A_{ct} = \frac{\pi D_h r_{eq}^2}{D_h + D_{po}}$$

or

$$A_{ct} = \alpha_c \pi r_{eq}^2$$

$$A_{ct} = \frac{D_h(1-\alpha_p)\pi r_{eq}^2}{(D_h+D_{po})(1-\alpha_h)} = \frac{D_h r_{eq}^2 \pi r_{eq}^2}{(D_h+D_{po}) r_{eq}^2}$$

$$A_{ct} = \frac{\pi D_h r_{eq}^2}{(D_h+D_{po})}$$

The coolant per fuel ratio can now be calculated

$$A_f = \pi r_{eq}^2 (1-\alpha_h)$$

$$A_c = \pi r_{eq}^2 \alpha_c$$

$$\frac{A_c}{A_f} = \frac{\pi r_{eq}^2 \alpha_c}{\pi r_{eq}^2 (1-\alpha_h)} = \frac{(1-\alpha_h) \alpha_c}{(1-\alpha_p)(1-\alpha_h)}$$

$$\frac{A_c}{A_f} = \frac{\alpha_c}{(1-\alpha_p)} = \frac{D_h(1-\alpha_p)}{(D_h+D_{po})(1-\alpha_h)}$$

$$\frac{A_c}{A_f} = \frac{D_h}{(D_h+D_{po})(1-\alpha_h)}$$

S-13

The core fraction occupied by tube clad is now calculated

$$\alpha_T = \frac{\left(\frac{\pi D_{po}^2}{4} - \frac{\pi D_p^2}{4} \right) N_c}{\pi r_{eq}^2}$$

$$D_p^2 = (D_{po} - 2T_c)^2 = D_{po}^2 - 4D_{po}T_c + 4T_c^2$$

$$\alpha_t = \left[\frac{\frac{\pi D_{po}^2}{4} - \frac{\pi}{4} (D_{po}^2 - 4D_{po}T_c + 4T_c^2)}{\pi r_{eq}^2} \right] \frac{4r_{eq}^2}{D_{po}(D_h + D_{po})}$$

$$\alpha_t = \frac{(D_{po}^2 - D_{po}^2 + 4D_{po}T_c - 4T_c^2) r_{eq}^2}{D_{po} r_{eq}^2 (D_h + D_{po})}$$

$$\alpha_t = \frac{4T_c (D_{po} - T_c) (1 - \alpha_p)}{D_{po} (D_h + D_{po}) (1 - \alpha_h)}$$

S-14

The total heat transfer area is:

$$A_{HEAT} = N_p \pi D_{po} X_L$$

$$A_{HEAT} = \frac{4 r_{eq}^2 D_{po} X_L \pi}{D_{po} (D_h + D_{po})}$$

S-15

$$A_{HEAT} = \frac{4\pi r_{eq}^2 X_L}{(D_h + D_{po})}$$

$$(\rho/\rho_t) (\alpha_f \pi r_{eq}^2 + \alpha_f \pi r_{eq}^2) = \alpha_f \pi r_{eq}^2$$

$$\alpha_F + \alpha_f = \frac{\alpha_F}{(\rho/\rho_t)}$$

$$\alpha_f = \left(\frac{1}{\rho/\rho_t} - 1 \right) \alpha_F$$

$$\alpha_f = \left(\frac{1}{(\rho/\rho_t)} - 1 \right) (1 - \alpha_p)$$

S-16

$$\alpha_w \pi \text{req}^2 = \frac{\pi \theta^2 D_p^2}{4} N_p$$

$$\alpha_w \text{req}^2 = \frac{\theta^2 D_p^2}{4} \frac{4(1-\alpha_p) \text{req}^2}{D_p^2(1-\theta^2)(\rho/\rho_t)}$$

$$\alpha_w = \frac{\pi \theta^2 D_p^2 (1-\alpha_p) \text{req}^2}{D_p^2(1-\theta^2)(\rho/\rho_t) \pi \text{req}^2}$$

$$\alpha_w = \frac{\theta^2 (1-\alpha_p)}{(1-\theta^2)(\rho/\rho_t)}$$

S-17

Also

$$\begin{aligned} \alpha_w \pi \text{req}^2 &= \frac{\pi \theta^2 D_p^2}{4} N_c \\ &= \frac{\pi \theta^2 D_p^2}{4} \frac{4 r' \text{eq}^2}{D_{po}(D_h + D_{po})} \end{aligned}$$

$$\alpha_w = \frac{\pi \theta^2 D_p^2 r' \text{eq}^2}{\pi D_{po}(D_h + D_{po}) \text{req}^2}$$

$$\alpha_w = \frac{\theta^2 D_p^2 (1-\alpha_p)}{D_{po}(D_h + D_{po})(1-\alpha_h')}$$

$$\alpha_w = \frac{\theta^2 (1-\alpha_p)}{(1-\alpha_h')} \left[\frac{D_p^2}{D_{po}(D_h + D_{po})} \right]$$

thus

$$\frac{1}{(1-\theta^2)(\rho/\rho_t)} = \frac{D_p^2}{(1-\alpha_h')(D_{po}D_h + D_{po}^2)}$$

$$(1-\alpha_h)(D_p D_h + D_p o^2) = D_p^2 (1-\theta^2)(\rho/\rho_t)$$

$$\frac{D_p o (D_h + D_p o)}{D_p^2} = \frac{(1-\theta^2)(\rho/\rho_t)}{(1-\alpha_h)}$$

The triangular pin-array with annular geometry considerations may be calculated as follows. From the geometry below we have:

$$A = \frac{1}{2} l_p l_p \cos 30 - \frac{\pi D_p o^2}{8}$$

$$A = \frac{1}{2} l_p^2 \cos 30 - \frac{\pi}{8} D_p o^2$$

T-1*

* T signifies equations derived for a fuel-pin lattice in a triangular arrangement.

The tube clad area becomes:

$$A_t = \frac{1}{2} \frac{\pi D_{po}^2}{4} - \frac{1}{2} \frac{\pi D_p^2}{4}$$

$$A_t = \frac{\pi}{8} (D_{po}^2 - D_p^2)$$

T-2

The total area is:

$$A_t = \frac{1}{2} \ell_p^2 \cos 30$$

$$A_f = \frac{1}{2} \left[\frac{\pi D_p^2}{4} - \frac{1}{2} \frac{\pi \theta^2 D_p^2}{4} \right] (\rho/\rho_t)$$

$$A_f = \frac{\pi D_p^2}{8} (1 - \theta^2) (\rho/\rho_t)$$

T-3

Now define

$$(1 - \alpha_h) \frac{1}{2} \ell_p^2 \cos 30 = \frac{\pi D_p^2}{8} (1 - \theta^2) (\rho/\rho_t)$$

T-4

Also:

$$D_h C = 4A \quad \text{where} \quad C = \frac{1}{2} \pi D_{po}$$

$$A = \frac{D_h \pi D_{po}}{8}$$

Substitution into equation 1 gives

$$\ell_p^2 = \frac{\pi (D_h D_{po} + D_{po}^2)}{4 \cos 30}$$

T-5

Thus A becomes

$$A = \frac{\pi (D_h D_{po} + D_{po}^2)}{8 \cos 30} \cos 30 - \frac{\pi}{8} D_{po}^2$$

$$A = \frac{\pi}{8} (D_h D_{po} + D_{po}^2 - D_{po}^2)$$

$$A = \frac{\pi D_h D_{po}}{8}$$

T-6

Also equation 4 becomes

$$(1-\alpha'_h) \frac{\pi}{2} \frac{(D_h D_{po} + D_{po}^2)}{4 \cos 30} \cos 30 = \frac{\pi D_p^2}{8} (1-\theta^2) (\rho/\rho_t)$$

$$(1-\alpha'_h) \frac{\pi}{8} (D_h D_{po} + D_{po}^2) - \frac{\pi D_p^2}{8} (1-\theta^2) (\rho/\rho_t) = 0$$

solving for D_h we have:

$$D_h = \frac{D_p^2 (1-\theta^2) (\rho/\rho_t)}{(1-\alpha'_h) D_{po}} - D_{po}$$

T-7

But $D_{po} = D_p + 2T_c$

$$D_{po}^2 = D_p^2 + 4D_p T_c + 4T_c^2$$

$$D_h = \frac{D_p^2 (1-\theta^2) (\rho/\rho_t)}{(1-\alpha'_h)(D_p + 2T_c)} - (D_p + 2T_c)$$

Solving the same expression for D_p gives:

$$(1-\alpha'_h) [D_h(D_p + 2T_c) + D_p^2 + 4D_p T_c + 4T_c^2] - D_p^2 (1-\theta^2) (\rho/\rho_t) = 0$$

$$[(1-\alpha'_h) - (1-\theta^2)(\rho/\rho_t)] D_p^2 + [(1-\alpha'_h)(D_h + 4T_c)] D_p + (1-\alpha'_h)(2D_h T_c + 4T_c^2) = 0$$

$$D_p^2 + \left[\frac{(1-\alpha'_h)(D_h + 4T_c)}{(1-\alpha'_h) - (1-\theta^2)(\rho/\rho_t)} \right] D_p + \frac{2(1-\alpha'_h)(D_h T_c + 2T_c^2)}{(1-\alpha'_h) - (\rho/\rho_t)(1-\theta^2)} = 0$$

T-8

The total number of pins become:

$$(1-\alpha_h) \pi r_{eq}^2 = N_p \frac{\pi D_p^2}{4} (1-\theta^2) (\rho/\rho_t)$$

$$N_p = \frac{4(1-\alpha_h) r_{eq}^2}{(\rho/\rho_t)(1-\theta^2) D_p^2}$$

T-9

and the number of coolant passages from

$$A_t = \frac{1}{2} l_p^2 \cos 30$$

$$A_t = \frac{\pi}{2} \frac{(D_h D_{po} + D_{po}^2)}{4 \cos 30} \cos 30$$

$$A_t = \frac{\pi}{8} (D_h D_{po} + D_{po}^2)$$

$$\pi r_{eq}^2 = N_c A_t$$

$$\pi r_{eq}^2 = \frac{\pi N_c}{8} (D_h D_{po} + D_{po}^2)$$

$$N_c = \frac{8 r_{eq}^2}{(D_h D_{po} + D_{po}^2)} \quad \text{Twice the number in square pin array} \quad T-10$$

$$\dot{W} = N_c A G$$

$$\dot{W} = \frac{8 r_{eq}^2}{(D_h D_{po} + D_{po}^2)} \left(\frac{\pi D_h D_{po}}{8} \right) G$$

$$\dot{W} = \frac{\pi r_{eq}^2 D_h G}{(D_h + D_{po})} \quad T-11$$

$$PD = \ell_p = \sqrt{\frac{\pi(DhDpo + Dpo^2)}{4 \cos 30}}$$

The minimum Dh occurs when

$$\sqrt{\frac{\pi(DhDpo + Dpo^2)}{4 \cos 30}} = Dpo$$

$$\frac{\pi(DhDpo + Dpo^2)}{4 \cos 30} = Dpo^2$$

$$Dh Dpo = \frac{4 \cos 30 Dpo^2}{\pi} - Dpo$$

$$Dh = \left(\frac{4 \cos 30 - \pi}{\pi} \right) Dpo^2 \quad T-12$$

The total coolant flow area is:

$$G \text{ Act} = \dot{W}$$

$$\text{Act} = \frac{\dot{W}}{G} = \frac{\pi r_{eq}^2 Dh}{(Dh + Dpo)} \quad \text{from equation 10} \quad T-13$$

The total theoretical dense fuel cross sectional area becomes:

$$Af = \pi r_{eq}^2 (1 - \alpha_h)$$

The coolant to fuel ratio in the core is:

$$XI = \frac{\text{Act}}{Af} = \frac{\pi r_{eq}^2 Dh}{(Dh + Dpo) \pi r_{eq}^2 (1 - \alpha_h)}$$

$$XI = \frac{Dh}{(Dh + Dpo)(1 - \alpha_h)}$$

The total heat transfer area becomes:

$$A_{HEAT} = N_p \pi D_{po} L$$

$$A_{HEAT} = \frac{4(1-\alpha_h) r_{eq}^2 \pi D_{po} L}{(\rho/\rho_t) (1-\theta^2) D_p^2}$$

But from equation 7 we obtain

$$\frac{D_{po}}{D_p^2} = \frac{(\rho/\rho_t) (1-\theta^2)}{(D_h + D_{po})(1-\alpha_h)}$$

Substitution into the above equation gives

$$A_{HEAT} = \frac{4(1-\alpha_h) r_{eq}^2 \pi L}{(\rho/\rho_t)(1-\theta^2)} \cdot \frac{(\rho/\rho_t) (1-\theta^2)}{(D_h + D_{po})(1-\alpha_h)}$$

$$A_{HEAT} = \frac{4\pi r_{eq}^2 L}{(D_h + D_{po})}$$

T-14

The coolant fraction becomes

$$\alpha_c \pi r_{eq}^2 = N_c A$$

$$\alpha_c = \frac{8 r_{eq}^2}{(D_h D_{po} + D_{po}^2)} \cdot \frac{\pi D_{po} D_h}{\pi 8 r_{eq}^2}$$

$$\alpha_c = \frac{(1-\alpha_p) D_h}{(1-\alpha_h)(D_h + D_{po})}$$

T-15

$$\alpha_t = \frac{N_p \frac{\pi}{4} (D_{po}^2 - D_p^2)}{\pi r_{eq}^2}$$

$$\alpha_t = \frac{4(1-\alpha_h) r_{eq}^2 (D_{po}^2 - D_p^2)}{4(\rho/\rho_t)(1-\theta^2) D_p^2 r_{eq}^2}$$

$$\alpha_t = \frac{(1-\alpha_h) (D_{po}^2 - D_p^2) r_{eq}^2}{(\rho/\rho_t)(1-\theta^2) D_p^2 r_{eq}^2}$$

but $D_p^2 = (D_{po} - 2Tc)^2 = D_{po}^2 - 4D_{po}Tc + 4Tc^2$

$$\alpha_t = \frac{(1-\alpha_h)(D_{po}^2 - D_{po}^2 + 4D_{po}Tc - 4Tc^2) r_{eq}^2}{(\rho/\rho_t)(1-\theta^2) D_p^2 r_{eq}^2}$$

$$\alpha_t = \frac{4Tc(D_{po} - Tc)(1-\alpha_h)(1-\alpha_p)}{(\rho/\rho_t)(1-\theta^2) D_p^2 (1-\alpha_h)} \quad \text{where} \quad \frac{1-\alpha_p}{1-\alpha_h} = \frac{r_{eq}^2}{r_{eq}^2}$$

$$\alpha_t = \frac{4Tc (D_{po}-Tc) (1-\alpha_p)}{(\rho/\rho_t)(1-\theta^2) D_p^2}$$

But from equation 7 $D_p^2 = \frac{(D_h+D_{po}) D_{po} (1-\alpha_h)}{(\rho/\rho_t)(1-\theta^2)}$

Substitution

$$\alpha_t = \frac{4Tc(D_{po}-Tc)(1-\alpha_p)}{(\rho/\rho_t)(1-\theta^2) (D_h+D_{po})D_{po}(1-\alpha_h)} \cdot \frac{(\rho/\rho_t)(1-\theta^2)}{(\rho/\rho_t)(1-\theta^2)}$$

$$\alpha_t = \frac{4Tc(D_{po}-Tc)(1-\alpha_p)}{D_{po}(D_h+D_{po})(1-\alpha_h)}$$

BNWL-1013

APPENDIX C

REPP Output

```

C REPP - A THERMAL HYDRAULIC REACTOR CORE DESIGN CODE.
C
C REQUIRES SUBROUTINES BIG, PRESS2, GEOM, GRIDS, HOLF, LAGRIN, SIMPIN,
C FLOT, STMTL, PROPS, INPUT, AND SLIP4, PLUS THE INCLUDE PROCEDURE INPURE
C
COMMON IINPUT(16), ICOM(4), RINPUT(200), RCOM(1342)
DIMENSION ICATCH(1), IDATA(40), RCATCH(1), RDATA(200)
CALL SETIO (3,2)
CALL SETIO (2,1)
CALL SETEOF($2020)
ICATCH(1) = 0
RCATCH(1) = 0.
IINPUT(16) = 0
ITIMES = 0
DO 10 I=1,40
  10 IDATA(I) = 0
DO 20 I=1,200
  20 RDATA(I) = 0.
IX = -4
1 READ(2,1000) IFORMT
IF (IFORMT.EQ.0) GO TO 100
GO TO (30,40,50,60,90), IFORMT
30 READ(IX,1001)(RDATA(I),I=192,200)
GO TO 1
40 READ(IX,1002) J1,J2,J3,J4,J5, IDATA(J1), IDATA(J2), IDATA(J3),
  1 IDATA(J4), IDATA(J5)
GO TO 1
50 READ(IX,1003) J1,J2,J3,J4,J5, RDATA(J1), RDATA(J2), RDATA(J3),
  1 RDATA(J4), RDATA(J5)
IF (J1.EQ.5.OR.J2.EQ.5.OR.J3.EQ.5.OR.J4.EQ.5.OR.J5.EQ.5) GO TO 51
49 IF (J1.EQ.20.OR.J2.EQ.20.OR.J3.EQ.20.OR.J4.EQ.20.OR.J5.EQ.20) GO TO 52
GO TO 1
51 IF (RDATA(5).GT.0.) RDATA(6) = 0.
GO TO 49
52 IF (RDATA(20).GT.0.) RDATA(19) = 0.
GO TO 1
100 DO 60 I=1,15
  60 IINPUT(I) = IDATA(I)
DO 70 I=1,200
  70 RINPUT(I) = RDATA(I)
GO TO 80
90 CALL INPUTR(IFORMT)
DO 92 I=1,15
  92 IDATA(I) = IINPUT(I)

```

```
DO 94 I=1,200
94 READ(I) = RINPUT(I)
GO TO 1
80 CALL BIG
CONTINUE
GO TO 1
2020 PRINT 2022
1000 FORMAT(11)
1001 FORMAT(6X,9A4)
1002 FORMAT(5X,5I5,5I10)
1003 FORMAT(5X,5I5,5E10.0)
2022 FORMAT(15H END OF PROGRAM)
2024 STOP
END
```

REPIN* FCOPY

COMMON NU	IT	LOPT	LI
COMMON IFLOW	ITMAX	NOPS	NPOW
COMMON KNUM	NO	ITH	IDUMMY(5)
COMMON NEND	NOUT	TNCR	LSAT
COMMON RADP	XLX	ENTL	EXITL
COMMON OP	DH	XW	STAG
COMMON THETA	CORE	WRAP	ALPHAP
COMMON ALPHAS	ALPHOT	Q11	XQUAT
COMMON T01	P00	G	WDOT
COMMON XMIX	XPFAC	HCFAC	XLPFAC
COMMON HCTEMP	FUDENS	RHOF	RHOC
COMMON RHOT	VKL01	VKL23	FCON1
COMMON FCON2	FCON3	F	HFILM
COMMON GRID	XTNCR	DELEPS	DUMDUM(9)
COMMON GX(21)	GRX(22)	GRF(22)	TKK(22)
COMMON GK(22)	RG(17)	QDOT(17)	TITLE(9)
COMMON DUMMY(300)	QR	ALPHA	Q
COMMON ALPHAC	PH(202)	VEL1	VFL2
COMMON P01	P02	P03	P03P00
COMMON P(150)	X(150)	DPO	XI
COMMON EN	ALPHAF	ALPHAW	ALPHAT
COMMON ALPHFV	H1	AFL	T(202)
COMMON AI(150)	PI	PINS	POI
COMMON QUAL	RHO(150)	XWI	PO
COMMON AHEAT	DS	DPOI	RAD
COMMON DH1	XNRE	YLF	H(2)
COMMON XI	STHEAT	FDHEAT	RPFAC
END			

PROCEDURE NAME TABLE

```

SUBROUTINE INPUTR(KKK)
COMMON IINPUT(16),ICOM(4),RINPUT(200),RCOM(1342)
DIMENSION IP(16),IR(16),RP(200),RB(200)
DATA (IP(I),I=1,16) / -1,2,0,0,1,100,9,11,12,5,6*0 /
DATA (RP(I),I=1,191)/80.,172.326,2.,2.,3669,0.,.0243,.00425,3*0.,
1.724258,.019101,.091551,3083.,.974,545.,2250.,0.,1.186198,0.,
21.86,2.82,1.08,0.,.93,3*0.,.51.,.184,-2,0.,1930.,2000,0.,0.,.02,
30.,.550,1.011,7*0.,1.,2,3,4,5,6,7,8,9,13*0.,.55,.60,.65,
4,7,75,8.,.85,9.,.95,1.,12*0.,1.552,1.6,1.625,1.6,1.52,1.3,1.182,
5,8779.,4863,13*0.,500.,1000.,10*0.,3,0,2,25,1.75,1.40,1.22,1.20,1.50,1.85,
64500.,7000.,10000.,10*0.,3,0,2,25,1.75,1.40,1.22,1.20,1.50,1.85,
72.42,3.12,6.00,4,0,10*0.,2,4,6,8,1.,12*0.,5*3,12*0. /
DATA (RP(I),I=192,200)/54HSAMPLE PROBLEM TO ILLUSTRATE PRESSURE-WA
1TER INPUT DATA /
DATA (IR(I),I=1,16) / -1,2,0,0,1,100,7,5,15,5,6*0 /
DATA (RB(I),I=1,191)/100.,153.92,0.,16.,.488,0.,.032,.005,3*0.,
1.763155.,178260.,080306,3293.,.96,526.,1050.,0.,9.96E7,-.070,1.74,
22.60,1.24,0.,.93,637,4,62,4,637,1.,1.5.,184,-2,0.,800.,0,20000.,
30.,.02,0.,.550,1.29,7*0.,.125.,250.,375.,500.,625.,750.,875,15*0.,
4,3333333,5.,6666667,1.,18*0.,.950,1.00,950,18*0.,392.,752.,
5112.,1472.,1832.,2192.,2552.,2912.,3272.,3632.,3992.,4352.,4712.,
65072.,8500.,7*0.,3,687,2,908,2,339,1.973,1.714,1.532,1.402,1.324,
71,272,1.246,1.258,1.298,1.376,1.454,1.400,7*0.,.2,.4,.6,.8,1.,
812*0.,5*3,12*0. /
DATA (RB(I),I=192,200)/54HEXAMPLE PROBLEM TO ILLUSTRATE BOILING-WA
1TER INPUT DATA /
L = KKK-3
GO TO (10,40),L
10 DO 20 I=1,15
20 IINPUT(I) = IP(I)
DO 30 I=1,200
30 RINPUT(I) = RP(I)
WFSATINGHOUSE PWR (1000 MWt) RASF CASE
RETURN
40 DO 50 I=1,15
50 IINPUT(I) = IR(I)
DO 60 I=1,200
60 RINPUT(I) = RB(I)
BROWNS FERRY STATION -- GENERAL ELECTRIC BWR
RETURN
END

```

```

SUBROUTINE RIG
C THIS ROUTINE CALCULATES COOLANT, TUBEWALL, AND FUEL TEMPERATURES
C ALSO CHECKS FOR HEAT TRANSFER LIMITATION.
  DIMENSION ZETA(12), PHI(14), TW(14), STV(10), PV(7), TWAX(14), TC(12),
  2 PC(12), TFO(14), XH(12), OFLXH(12), XHLM(12), DFLPH(12), PHLIM(12)
  DIMENSION CRJ(22), CBK(10)
  DIMENSION DVDP(13), UDEL(110), UPHLM(110),
  1 UEP(1000), UX(1000), UPH(1000), UEFI(1000)
  DIMENSION DQ(5,101), CL(5), XMAXI(5), GQA(5,101), GF(101)
  DIMENSION TEMPK(201), QK(201), QLK(201), RGI(23), QDOI(23), QDOITK(23)
  DIMENSION TEMDUM(14), XI XNUM(14)
  INCLUDE REPIN.LIST
  EQUIVALENCE (ITIMES, IDUMMY(4))
  EQUIVALENCE (ICASE, IDUMMY(5))
  EQUIVALENCE (PHI(1), DUMMY(234)), (PHCRIT, DUMMY(248)), (TMAX(1),
  1 DUMMY(249)), (TW(1), DUMMY(263)), (PERMIX, DUMMY(277))
  DATA (CRJ(1), I=1, 22) / 132H SQUARE TRIANGULAR HONEYCOMB
  1 CIRCULAR WIRE LENTICULAR WIRE SPIRAL WIRE YES NO
  2 GEOM ONLY COMPLETE / GQH FLOW RATE MASS VELOCITY I F
  DATA (CRK(1), I=1, 10) / GQH FLOW RATE MASS VELOCITY I F
  LGTH L/D RATIO /
  DATA CRITPH / 64H/A /
  CALL ETIME
  DIVR = 0.1
  XLX = XLX / 12.
  ENIL = ENIL / 12.
  EXITL = EXITL / 12.
  RAPP = RAPP / 12.
  NOPS = NOPS+1
  GX(NOPS) = 1.5
  NPOW = NPOW
  NPGWX = NPGWX
  KNUMX = KNUM
  IF(NQ.GI.0) GO TO 198
  NQ = 6
  GQGT(1) = 1.0
  DO 710 I=2,NQ
  RG(I) = RG(I-1)+.2
  710 QDOT(I) = QDOT(I-1)
  198 IF(HFILM.LT.1.) HFILM = 20000.
  IF(E.LT.1.) E = 30000.
  IF(XINCR.LT..01.OR.XINCR.GT..1) XINCR = .02
  IF(VKL01.LT..0001) VKL01 = 1.0
  IF(VKL23.LT..0001) VKL23 = 1.5

```



```

IF (GRID.LT.100.) GRID = 9999.
IF (XLX.LT.1) XLX = 10.0
IF (DUMDUM(2).LT.0.0001) DUMDUM(2) = 1.0
ALPHPX = ALPHAP
LPVAX = 0
RANPX = RANP
PI = 3.14159
XL = XLX+ENTL+EXITL
C CALCULATE DIMENSIONLESS SCALE ADJUSTMENT FROM ACTIVE TO TOTAL
C LENGTH
C
IF (RG(1)) 42,43,40
40 DO 41 I=1,NG
   RG(NG-I+2) = RG(NG-I+1)
41 QDOT(NG-I+2) = QDOT(NG-I+1)
   NG = NG+1
42 RG(1) = 0.
   QDOT(1) = QDOT(2)
43 IQ = 21
   RGI(1) = 0.
   DO 44 I=2,IQ
44 RGI(I) = RGI(I-1)+.05
   NTERP = 4
   CALL LAGRIN(RG,QDOT,NG,RGI,QDOT,I,IQ,NTERP)
   IF (TKK(1)) 511,512,511
511 KNUM = KNUM+1
   DO 513 I=2,KNUM
   TKK(KNUM+2-I) = TKK(KNUM+1-I)
513 GKK(KNUM+2-I) = GKK(KNUM+1-I)
   TKK(1) = 0.
   GKK(1) = GKK(2)-(GKK(3)-GKK(2))/(TKK(3)-TKK(2))*TKK(2)
512 IF (TKK(KNUM)-10000.) 514,515,516
514 KNUM = KNUM+1
   TKK(KNUM) = 10000.
   GKK(KNUM) = 1.
   GO TO 515
516 TKK(KNUM) = 10000.
515 CONTINUE
   IF (ENTL) 900,900,998
998 DO 999 I=1,NPOW
   GRX(NPOW-I+2) = (GRX(NPOW-I+1)*XLX+ENTL)/XL
999 GRF(NPOW-I+2) = GRF(NPOW-I+1)
   GRX(1) = ENTL/XL-XINCR
   IF (GRX(1).LT.0.) GRX(1) = 0.0
   GRF(1) = 0.0
   NPOW = NPOW+1
900 IF (EXITL) 905,905,901
901 IF (ENTL) 902,902,904

```

```

902 DO 903 I=1,NPOW
903 GRX(I) = (GRX(I)*XLX+ENTL)/XL
904 NPOW= NPOW+1
    GRX(NPOW)=(XLX+ENTL)/XI +YINCR
    GRF(NPOW) = 0.0
    IF(GRX(NPOW).GT.1.0)GRX(NPOW)=1.0
905 NOUT = 1.0/XINCR+1.001
    X(1) = 0.0
    DO 907 I=2,NOUT
907 X(I) = X(I-1)+XINCR
    IF(ENTL.LT..000001.AND.GRX(I).GT.0.0) GO TO 908
910 IF(ENTL.LT..000001.AND.GRX(NPOW).LT.1.0) GO TO 420
906 CALL LAGRIN(GRX,GRF,NPOW,X,GRF,NOUT,NITERP)
    GO TO 98
908 DO 1000 I=1,NPOW
    GRX(NPOW-I+2) = GRX(NPOW-I+1)
1000 GRF(NPOW-I+2) = GRF(NPOW-I+1)
    NPOW = NPOW+1
    GRX(1) = 0.0
    GRF(1) = 0.0
    GO TO 910
420 NPOW = NPOW+1
    GRX(NPOW) = 1.0
    GRF(NPOW) = 0.0
    GO TO 906
98 CONTINUE
    NOUT = 2.0/XINCR+1.001
    TEMPK(1) = 0.
    RMOUT = MOUT-1
    DO 510 I=2,MOUT
510 TEMPK(I) = TEMPK(I-1)+10000./RMOUT
    CALL LAGRIN(TKK,QKK,KNUM,TEMPK,QLK,MOUT,NITERP)
    CALL SIMPIN(MOUT,TEMPK,QKK,QK)
    FUREN = FURENS
135 CONTINUE
    KCASE = ICASF+1
    WRITE(3,5001)KCASE
    XMAXI(1) = 1.0
    XMAXI(2) = 5000.0
    XMAXI(3) = 1.0
    RATZ = .01/XINCR
    DO 87 I=1,101
    J = RATZ*I+.91
    K = .2*I+.81
    QGG(1,I) = X(J)
    QGG(2,I) = QGG(1,I)*XMAXI(2)
    QGG(3,I) = RGI(K)
    DG(1,I) = GF(J)
    DG(2,I) = QLK(J)

```

```

DQ(3,I) = QDOTI(K)
A7 CONTINUE
  CLU(1) = DQ(1,1)
  CLU(2) = DQ(2,1)
  CLU(3) = DQ(3,1)
  DO 88 I=2,101
    CLU(1) = AMAX1(CLU(1),DQ(I,1))
    CLU(3) = AMAX1(CLU(3),DQ(3,I))
  A8 CLU(2) = AMAX1(CLU(2),DQ(2,I))
    CLU(1) = 1.05*CLU(1)
    CLU(2) = 1.05*CLU(2)
    CLU(3) = 1.05*CLU(3)
    CALL FPL0T(3,101,5,QQQ,NO,XMAXI,CLU,25,26)
  DO 45 I=1,10
    45 QDOTI(I) = QDOTI(I)*RGY(I)
    JCASE = 1
    IF(XLPFAC.LT..000001) XLPFAC = 1.0
    IF(XQUAL.LT..05) XQUAL = 1.0
    DP = DP /12.
    DH = DH /12.
    XW = XW /12.
    STAG = STAG /12.
  504 DHX = DH
    FUNENS = FUNFN
    RADP1 = 0.
    WNOT1 = 0.
    XL = XLX+ENTL+EXITL
    IF (DP) 125,125,127
  125 ALPHA = 1.0 - (1.0 - ALPHAP)/(1.0 - ALPHAS - ALPHOT)
    IF (ALPHA.GT.0.0) GO TO 126
    ALPHAP = ALPHAP + 0.01
    GO TO 125
  126 DP = (1.-ALPHA)*(DH+4.*XW)/(2.*(FUNENS*(1.-THETA**2)+ALPHA-1.))+
    1SQRT(((1.-ALPHA)*(DH+4.*XW)/(2.*(FUNENS*(1.-THETA**2)+ALPHA-1.)))+
    2**2+2.*(1.-ALPHA)*(DH*XW+2.*XW**2)/(FUNENS*(1.-THETA**2)
    3+ALPHA-1.))
  127 CONTINUE
    FUNENS = FUNFN*DP**2/(DP+2.*STAG)**2
    DPX = DP
    DP = DP + 2.*STAG
    XWRAT = XW/DP
    PERMIX = XMIX
    XMIX = PERMIX+1.0
    IF(CORF)1,1,2
  1 CORT1 = CBJ(1)
    CORT2 = CBJ(2)
    GO TO 401
  2 CORT1 = CBJ(3)
    CORT2 = CBJ(4)

```

```

A01 IF(II=2)4,3,5
  3 FPGT1 = CRJ(5)
  FPGT2 = CRJ(6)
  FPGT3 = CRJ(7)
  GO TO A02
  5 FPGT1 = CRJ(14)
  FPGT2 = CRJ(15)
  FPGT3 = CRJ(16)
  GO TO A02
  4 IF(II)6,6,7
  6 FPGT1 = CRJ(11)
  FPGT2 = CRJ(12)
  FPGT3 = CRJ(13)
  GO TO A02
  7 FPGT1 = CRJ(8)
  FPGT2 = CRJ(9)
  FPGT3 = CRJ(10)
A02 IF(LL)8,8,9
  8 HTLCI = CRJ(17)
  GO TO A03
  9 HTLCI = CRJ(18)
A03 IF(NU)10,10,11
  10 TORUN1 = CRJ(21)
  TORUN2 = CRJ(22)
  GO TO A04
  11 TORUN1 = CRJ(19)
  TORUN2 = CRJ(20)
A04 IF(IFLOW)951,951,952
  951 FLOW1 = CBK(4)
  FLOW2 = CBK(5)
  FLOW3 = CBK(6)
  GO TO A05
  952 FLOW1 = CBK(1)
  FLOW2 = CBK(2)
  FLOW3 = CBK(3)
A05 IF(LOPT)953,953,954
  953 RLOPT1 = CRK(9)
  RLOPT2 = CRK(10)
  GO TO A06
  954 RLOPT1 = CRK(7)
  RLOPT2 = CRK(8)
A06 CONTINUE
  132 CONTINUE
  ICASE = ICASE+1
  ENTL = 12.* ENTI
  XLX = 12.* XLX
  FXITL = 12.* FXITL
  RAPP = 12.* RAPP

```

```

DPX = 12.* DPX
DH = 12.* DH
XW = 12.* XW
STAG = 12.* STAG
WRITE(3,3999)
WRITE(3,1710) ICAGF
WRITE(3,1800) (ITL(I), I=1,9)
WRITE(3,1810)
WRITE(3,4000)
WRITE(3,4001)
WRITE(3,4002) FUMFN,E,HFILM,V/Ln1,VKL,2,PHOF,PHOC,RHOT,Q1,
WRITE(3,4003)
WRITE(3,4004)
NOPS = NOPS-1
WRITE(3,4005) WRAP,CORT1,CORT2,ENTL,XLX,FXITL,RADP,FPSGT1,FPSGT2,
IFPSGT3,NOPS,HILCT,TORUN1,TORUN2
WRITE(3,4006)
WRITE(3,4007) (GX(I), I=1,NOPS)
NOPS = NOPS+1
WRITE(3,4020)
WRITE(3,4008)
WRITE(3,4009)
WRITE(3,4010) T01,P00,DPX,DH,XW,THETA,STAG,HCTEMP
WRITE(3,4011)
WRITE(3,4012)
WRITE(3,4013) ALPHAP,ALPHAS,ALPHOT,G,WDOT,XINCR,XPEACT,HCFACF,
1XLPFAC
WRITE(3,4014) FLOW1,FLOW2,FLOW3,RLOPT1,RLOPT2
WRITE(3,4015)
WRITE(3,4016) NPOWX,KNUMX,XGUA1,GRID
WRITE(3,4017) FCON1,FCON2,FCON3
WRITE(3,4018)
WRITE(3,4019) PERMIX,DJUMDUM(2),DUMDUM(1)
ENTL = ENTL /12.
XLX = XLX /12.
EXITL = EXITL /12.
RADP = RADP /12.
DPX = DPX /12.
DH = DH /12.
XW = XW /12.
STAG = STAG /12.
IF(NU.GT.0) GO TO 138
NOT = 0
ITN = 0
KCHECK = 0
LCHECK = 0
ITCHK = ITMAX/7
IF(ITCHK.GT.6) ITCHK = 7
ITX = 1

```

```

      DUMMY(299) = 0.
138  CONTINUE
      ALPHFV = (1./FUDENS-1.)*(1.-ALPHAP)
      PT = 3.14159
      NN = 0
      IRADP = 0
      JJ = JIMAX/10
142  CONTINUE
      HCRIT = 0.
      HLTM = 0.
      PHCRIT = 0.
      PHILIM = 0.
      IF(RADP.LT.0.0001) RADP=5.0
      IF(WOOT.LT.1.0.AND.G.LT.1.0) G = 3.0F+4
      IF(LOPT.GT.0) XLORAT = XLX/(2.*RADP)
      XLX = XLORAT*2.*RADP
      XL = XLX+ENTL+EXITL
      DUMMY(300) = 0.
      QUAL = 0.
      RAN = SORT(1.-ALPHAS-ALPHOT)*RADP
      ALPHA = 1.-(1.-ALPHAP)/(1.-ALPHAS-ALPHOT)
      IF(ALPHA.GT.0) GO TO 137
      ALPHAP = ALPHA + .01
      ALPHFV = (1./FUDENS-1.)*(1.-ALPHAP)
      GO TO 142
137  CONTINUE
C     SET INDECS TO ZERO
      I=0
      J=0
      K=0
      L=0
      INCR = 0
      LSAT=0
C     CALCULATE AUXILIARY EQUATIONS
      IF(NOT.EQ.0.AND.JCASE.EQ.1) GO TO 407
      NOUT = 1.0/XINCR+1.0001
      DO 406 I=2,NOUT
      406 X(I) = X(I-1)+XINCR
      CALL LAGRIN(QFX,QBF,NPOW,X,QF,NOUT,NTERP)
      407 INCR = (ENTL+XLX)/(XL*YINCR)+1.001
      IF(LPMAX.GT.0) GO TO 207
      PMAX = 0.
      DO 206 N=1,INCR
      PMAX = AMAX1(PMAX,QF(N))
      IF(QF(N)+.00001 -PMAX)206,204,204
      204 LPMAX = N
      206 CONTINUE
      207 CALL SIMPIA(INCR,X,QF,AT)
C     CALCULATE THE BEGINNING AND END LOCATIONS FOR HEAT ADDITION

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```

SIHEAT = ENT1/XL
EDHEAT = (XLX+ENT1)/XL
IF(X(INCR)+.0001.GT.EDHEAT)GO TO 409
INCR = INCR+1
IF(LPMAX.EQ.INCR-1)LPMAX = INCR
XDIFF = (EDHEAT-X(INCR-1))/(X(INCR)-X(INCR-1))
AI(INCR) = AI(INCR-1)+XDIFF*(AI(INCR-1)-AI(INCR-2))
IN = NOUT-INCR+1
DO 408 I=1,IN
408 X(NOUT-I+2) = X(NOUT-I+1)
X(NOUT) = EDHEAT
NOUT = NOUT+1
409 IF(INCR.EQ.NOUT)GO TO 411
IN = INCR+1
DO 410 I = IN,NOUT
410 AI(I) = 0.0
411 CONTINUE
POW = Q11/AI(INCR)
VAR = 3412750.
405 DO 89 I=1,NOUT
89 AI(I) = POW*AI(I)*VAR
Q = AI(INCR)
Q1 = Q/3412750.
IF(ABS(Q1-Q1)/Q1.LT..00001) GO TO 129
POW = Q11/Q1
VAR = 1.0
GO TO 405
129 CALL GEOM
DS = (PD-DPO)*DUMDUM(1)
IF(DUMVY(299).GT.0.)GO TO 180
IF(DU.GT.0)GO TO 149
RPFAC = HCFAC*XL*(Y(IPMAX)-X(LPMAX-1))/(X(X*(AI(IPMAX)-AI(IPMA
1 X-1))*XLPFAC)
CALL PRESS2
CONTINUE
INCR = INCR
LSAT = LSAT
IT = IT
IF(NOT.GT.ITMAX+1) LL = 2
IF(LL.EQ.2) GO TO 15
NOT = NOT+1
IF(DUMVY(300).GT.20.) GO TO 340
C CALCULATE THE COOLANT TEMPERATURE AND PRESSURE AT 11 LOCATIONS
C FIND THE POINT WHERE THE MAXIMUM HEAT FLUX OCCURS
C CALCULATE THE LOCAL HEAT FLUX AT 11 LOCATIONS
15 ZFTA(1) = -.1
PHI(1) = -50.
XH(1) = HI
PHIMAX = 0.0

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```

DO 476 I=1,INCR
  PHIMAX = AMAX1(PHIMAX,PH(I))
  IF(PHIMAX - PH(I))475,475,476
475 XMAX = X(I)
  ENERGY = AI(I)*HCFACI*Q/(PHIMAX*AHFAT*VMIX*WDOI)+H1
  IP = I
  CALL SIMIBL(1,P(I),SIV)
  IF(ENERGY-STV(5)) 473,474,474
473 CALL SIMIBL(5,ENERGY,SIV)
C
C      *** ASSIGNMENT OF VARIABLE DUMMY ***
C
C  DUMMY(1-105) = HOT CHANNEL COOLANT TEMP.
C  DUMMY(106-210) = HOT CHANNEL QUALITY ON FINE MESH SCALE
C  DUMMY(211-221) = HOT CHANNEL QUALITY ON 11 LOCATION SCALE
C  DUMMY(222) = HOT CHANNEL TEMP. AT MAXIMUM HEAT FLUX
C  DUMMY(223-233) = WALL TEMP. IN HOT CHANNEL
C  DUMMY(234-247) = PHI(T)
C  DUMMY(248) = PHCRIT
C  DUMMY(249-262) = TMAX(I)
C  DUMMY(263-276) = TW(I)
C  DUMMY(277) = PERMTX
C  DUMMY(296) = RPFACI
C  DUMMY(297) = EDHEAT
C  DUMMY(298) = SIHEAT
C  DUMMY(299) = 20 MEANS GEOMTRY IS IMPOSSIBLE
C  DUMMY(300) = 50 MEANS CODE RAN INTO TROUBLE IN PRESS2
C
474 DUMMY(222) = STV(2)
476 CONTINUE
  PHI(14) = Q/AHEAT*XQUAL
  PHIMAX = PHIMAX*XQUAL
  RFACT = PHIMAX/PHI(14)
  SFACI = HCFACI/RFACT*XDRFACT
  JNN = 0
  DO 32 I=2,12
    ZETA(I) = ZETA(I-1) + .1
    IF(JNN-2)470,470,469
469 JNN = 2
    ZFTA(I) = ZFTA(I-2)+XFIX
    IF(ZETA(I).GT.1.) ZETA(I) = 1.0
470 CONTINUE
  C  FIND X(N) CORRESPONDING TO ZETA(I)
  NOUT = NOUT
  DO 28 N=1,NOUT
    IF(N.EQ.INCR)GO TO 27
    19 XDIFF = ABS((ZETA(I)-X(N))/(ZFTA(I)+.01))
    IF(XDIFF-.0001)14,14,22
    14 TC(I) = I(N)

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```

DUMMY(I+209) = DUMMY(N)
PHI(I) = PH(N)*XGUAL
XH(I) = H1+AI(N)/WDOT
IF ( XH(I).LT.XH(T-1)) XH(I) = XH(I-1)
IF(JNN.EQ.1) JNN=3
18 PC(I) = P(N)
   RHO(I) = RHO(N)
IF(ZETA(I).LT.STHEAT+.001)THEAT = I + 1
GO TO 32
22 IF(ZETA(I)-X(N).AT.0001) GO TO 28
   XDIFF = (ZETA(I)-X(N-1))/IX(N)-X(N-1)
   TC(I) = T(N-1)+XDIFF*(T(N)-T(N-1))
   DUMMY(I+209) = DUMMY(N-1)+XDIFF*(DUMMY(N)-DUMMY(N-1))
   PHI(I) = PH(N-1)+XDIFF*(PH(N)-PH(N-1))
   PC(I) = P(N-1)+XDIFF*(P(N)-P(N-1))
   RHO(I) = RHO(N-1)+XDIFF*(RHO(N)-RHO(N-1))
   XH(I) = H1+AI(N-1)/WDOT+XDIFF*(AI(N)-AI(N-1))/WDOT
   IF ( XH(I).LT.XH(T-1)) XH(I) = XH(I-1)
IF(ZETA(I).LT.STHEAT+.001)THEAT = I + 1
IF(JNN.EQ.1) JNN=3
GO TO 32
27 IF(JNN.EQ.2) GO TO 19
   IF(I.EQ.12.AND.X(N).LT.99999) GO TO 26
   NHEAT = I
   IF(ZETA(I) - X(N)) 29,14,29
29 ZETA(I) = X(N)
   XFIX = .2
   JNN = JNN+1
GO TO 14
26 ZETA(I-1) = X(N)
   TC(I-1) = T(N)
   DUMMY(I+209) = DUMMY(N)
   PHI(I-1) = PH(N)*XGUAL
   XH(I-1) = H1+AI(N)/WDOT
   PC(I-1) = P(N)
   RHO(I-1) = RHO(N)
   NHEAT = I-1
   XFIX = .3
   JNN = JNN+1
GO TO 19
28 CONTINUE
32 CONTINUE
C  CALCULATE LOCAL HEAT TRANSFER COEFFICIENT AND WALL TEMPERATURE
C  AT 11 LOCATIONS
34 HC = 7000.
   LNNR = 0
   LLNNR = 0
DO 12A I=2,12

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CALL SIMTBL(1,PC(I),STV)
TSAT = STV(2)
100 TW(I) = PHI(I)/HC + TC(I)
NUMMY(I+221) = PHI(I)*RPFAC*VLPFAC/HC+NUMMY(I+209)
TF0(I) = PHI(I)/F+TW(I)
TFG = (TW(I)+TC(I))/2.
IF (TFG.GT.700.0) TFG = 700.0
CALL PROPS(TFG,PV)
PR=P/PCV(6)
XW(I) = PV(3)
XXK = PV(5)
HNF = .023*XXK*(G*DH/XW(I))**.6*PR**.3/nH
DEL=ABS(HNEW-HC)/HNEW
IF(DEL.LT..0001)GO TO 120
HC=HNEW
GO TO 100
C CHECK FOR NUCLEATE BOILING
120 DELT = TW(I)-TSAT
NCH = ZETA(I)/XINCR+1.001
ROIL = PHI(I)*RPFAC*XLPFAC/HC+NUMMY(NCH)
DELT = ROIL-TSAT
DELTH = 60.*(PHI(I)*RPFAC/(1.E6))**.25/EXP(PC(I)/900.)
IF(DELTH.LT.DELENH=.0001) GO TO 121
IF(LDNR.EQ.0) LDNR = ZETA(I)/XINCR+1.001
LLDNB = ZETA(I)/XINCR+1.001
NUMMY(I+221) = PHI(I)*RPFAC*XLPFAC/HFILM+NUMMY(I+209)
121 DELN = 60.*(PHI(I)/(1.E6))**.25/EXP(PC(I)/900.)
J=1
IF(DELTH.LT.DELENH)GO TO 128
C CALCULATE WALL TEMPERATURE FOR INCIPIENT NUCLEATE BOILING SECTION
TW(I) = PHI(I)/HEILM+TC(I)
TF0(I) = PHI(I)/F+TW(I)
128 CONTINUE
IF(LDNR.EQ.0)LDNR = ZETA(NHEAT)/XINCR+1.001
IF(LLDNB.EQ.0) LLDNB = LDNR
C COMPARE PHI WITH PHILIM AT EACH LOCATION TO DETERMINE WHEN
C THE CRITICAL HEAT FLUX OCCURS
209 NOT = 1
LUFP = 1
PC 230 N=1,NOUT
UPHILIM(N) = 0.
URFL(N) = 0.
NUFP = X(N)/.1+2.001
IF(NUFP-LUFP)230,230,216
216 LUFP = NUFP
PHIIM(LUFP) = 0.
PHIPL(LUFP) = 0.
230 CONTINUE
CALL SIMTBL(1,P(1),STV)

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HSAT = STV(5)
CONW2 = .532*(HSAT-H1)/(STV(6)-HSAT)**.75*(STV(4)/STV(3))**(1./3.)
205 LUFP = 1
DO 226 NLONR, INCR
208 CALL STMTBL(1,P(N),STV)
HF = STV(5)
IF (HSAT.LT..1) HSAT = HF
HG = STV(6)
HFG = HG - HF
DIST = 1.
APHI = (2.022-0.0004302*P(N))+(0.1722-0.0000984*P(N))*EXP((
1 1R.177-0.004129*P(N))*DUMMY(N+105))
RPHI = ((0.1484-1.596*DUMMY(N+105)+0.1729*DUMMY(N+105))*ARS(DUMMY
1 (N+105)))*G*DUMDUM(2)*XVIX/1.E6+1.037)*((1.157-0.869*DUMMY(N+105))
DPHI = (0.2664+0.8357*EXP(-3.151*DH1))*(0.8258+0.000794*(HSAT-H1))
WPHLIM = APHI*RPPI*DPHI*1.F6
VPHLIM = (0.23E6+0.094*XVIX*G*DUMDUM(2))*(3.0+.01*(STV(2)-
IDUMY(N)))*(.435+1.23*EXP(-.0093*DIST*XLX/DH1))*(1.7-1.4*EXP(
2 -CONW2))
UPHLIM(N) = AMIN1(WPHLIM,VPHLIM)
IF (WPHLIM.LT.0.) GO TO 22A
UNFL(N) = UPHLIM(N)-PH(N)*SFACT*YQUAL
NUFP = X(N)/.1+2.001
IF (N.EG.INCR) GO TO 212
IF (NUFP-LUFP) 226,226,212
212 LUFP = NUFP
PHLIM(LUFP) = UPHLIM(N)
DELPH(LUFP) = UDFL(N)
226 CONTINUE
COFLPH = 5.F7
DO 21A JOELONR, IACR
1 = LONR+INCR-JOF
IF (ITN.GT.3) GO TO 221
COFLPH = AMIN1(COFLPH,NUFP(I))
IF (COFLPH-UDFL(I)) 218,219,219
219 NDNB = 1
221 PHLIM = UPHLIM(NDNB)
PHCRIT = PH(NDNB)*SFACT*YQUAL
XCRIT = X(NDNB)
218 CONTINUE
IF (LONR.LT.2) LONR = 2
193 IUD = 12.*X(I LONR)*XL/NIVR+2.001-((.06/VINCR+.001)
IF (IUD.LT.2) IUD = 2
IF (IUD.GT.1000) GO TO 192
DO 197 I=1,IUD
UFP(I) = 0.0
197 UFP(I) = 0.0
NUF = 12.*XL/NIVR+2.001
IF (NUF-1000) 191,191,192

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192 DIVR = XL/AB3.
GO TO 193
191 FAKE = NUF-1
IF (DIVR.GT..1.AND.NUF.LT.998) GO TO 192
XXINCR = 12.*XL/FAKE
UX(1) = 0.0
DO 203 I=2,NUE
203 UX(I) = UX(I-1)+XXINCR
199 DO 194 I=1,NOUT
194 X(I) = X(I)*12.*XL
CALL LAGRIN(X,PH,NOUT,I,X,UPH,NUF,INTERP)
DO 195 I=1,NOUT
195 X(I) = X(I)/(12.*XL)
210 XNCR = XCRIT*12.*XL
CPHI = 0.44*(1.-PLUMY(NONR+105))*7.9/(DUMDUM(2)*6/1.F6)**1.72
NF = XNCR/DIVR+2.001
UX(NF) = XNCR
UPH(NF) = PH(NONR)
DO 202 I=IULD,NF
202 UFP(I) = UPH(I)*FYP(-CPHI*(XNCR-UX(I)))
NRANGE = NF-IULD+1
CALL STMPIN(NRANGE,UX(TIUN),UFP(IULD),IUP(TIUN))
CPHI = CPHI*(UFP(NF)-UFP(IULD))/(PH(NONR)*(1.-FYP(-CPHI*(UX(NF)
1 -UX(TIUN))))
IF (FPHI.LT.1.) FPHI = 1.0
PHILIM = PHILIM/FPHI
UPHILIM(NONR) = PHILIM
RANP1 = RANP
RANP2=0.
RANP = PINS*PHCRIT*DP**2*(1.-THETA**2)*FUDENS/(4.*(1.-ALPHAP))*
1PHILIM
IF (DUMVY(INCR+105).LT.0.) GO TO 308
FIND THE POINT WHERE THE MAXIMUM ENTHALPY OCCURS
228 CONTINUE
MOT = 1
HCRIT = 0.
COFLH = 5000.
DEIXH(1) = 100000.
X(1) = H1
DO 306 I=2,12
306 IF (ZETA(I).LT.STEAT.OB.ZETA(I).GT.EDHEAT) GO TO 309
CALL STIMBL(1,PC(I),STV)
IF (I.GT.2) GO TO 231
HF=STV(5)
231 VF = STV(3)
HG = STV(6)
VG=STV(4)
HFG = HG-HF
DIST = XL/XLY*ZETA(1)-FNTI/XLY

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235 IF(DIST)309,309,235
CONTINUE
XRURP = 1.5*XMIX*G*DUMDUM(2)/(1.E6)
IF(XRURP.GT.99.) GO TO 509
XHLIM(I)=H1+(-.529*(HF-H1)+(-.825+2.36/FYP(17.*DH))*HFG/FYP(1.5*
1*XMIX*G*DUMDUM(2)/
2(1.E6))-.41*HFG/FYP(.004*DIST*XLX/DH)-1.12*HFG*VF/VG+.54*HFG)
DELXH(I) = XHLIM(I)-H1-(XH(I)-H1)*SFAC
GO TO 306
309 CONTINUE
XHLIM(I) = XHLIM(I-1)
DELXH(I) = DELXH(I-1)
306 CONTINUE
DO 301 I=HEAT,NHEAT
CDELH = AMIN1(CDELH,DELXH(I))
IF(CDELH+.00001 - DELXH(I))301,300,300
300 HCRIT = XH(I)
XHLIM = XHLIM(I)
HCRIT = ZETA(I)
301 CONTINUE
RANP2 = RANP
IF(LL.GT.0) GO TO 326
RANP = WDOT*SFAC*(HCRIT-H1)/(XHLIM-H1)*(1.-ALPHA)*(DH+DPO)/(G*
1(1.-ALPHA)*PI*DH)
106 IF(RADPF-RADPE) 308,308,312
308 CONTINUE
DELPHI = ARS((PHYLIM-PHCRIT)/PHYLIM)
IF(NOT.GT.ITMAX) LL=2
RANP2 = 0.
IF(LL.GT.0.OR.NN.EQ.2) GO TO 326
IF(DELPHI.LT..0001) GO TO 326
IF(ITN.GT.0) GO TO 311
TRIAL1 = RANP
TRDEL1 = PHYLIM-PHCRIT
316 CONTINUE
RANP = SORT(PINS*PHCRIT*DP**2*(1.-THETA**2)*FIDENS / (4.*
2 (1.-ALPHA)*PHYLIM))
RANP = (RANP**2*X/(2.*VIRAT))**(1./3.)
IF(ARS((RANP-RADP1)/RANP).LT..02) ITN = 1
305 IF(DELPHI.LT..05) ITN=1
IF(IFLOW.GT.0) GO TO 310
WDOT = G*PI*RANP**2*ALPHAC
310 WDOT1 = WDOT
IF(IFLOW.GT.0) G = 0.0
IF(ARS(RADP1-RADP)/RADP.LT..0003.AND.NOT.GT.JJ) GO TO 110
IF((RADP1-RADP)/RADP1.GT..1) RANP = .99*RANP1
IF((RANP-RADP1)/RADP1.GT..1) RANP = 1.1*RANP1
GO TO 142
311 IF(ITN.EQ.6) GO TO 326

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11N = IIN+1
TRIAL2 = TRIAL1
TRIAL1 = RADP
TRDEL2 = TRDEL1
TRDEL1 = PHILIM-PHCRIT
319 CONTINUE
RADP = TRIAL2-TRDEL2*(TRIAL2-TRIAL1)/(TRDEL2-TRDEL1)
IF(RADP) 316,316,305
312 DELHL = ABS((HLIM-H1)-(HCRIT-H1)*SFAC1)/(HLIM-H1))
RADP1 = 0.
IF(DELHL.LT..001) GO TO 326
IF(DELHL.LT..001) LL = 2
IF(DELHL.LT..001) LL = 2
IF (IFLOW.GT.0) GO TO 317
314 WDOT = WDOT*SFAC1*(HCRIT-H1)/(H1IM-H1)
IF(WDOT) 598,598,318
318 RADP = SQRT(WDOT*(1.-ALPHA)*(NH+DPO)/(C*(1.-ALPHA)*PT*NH))
RADP = (RADP**2*XLX/(2.*XLDRAT))**(1./3.)
IF(IFLOW.GT.0) G = 0.0
IF(ARS(RADP2-RADP)/RADP.LT..0003.AND.NOT.GT..0) GO TO 111
IF((RADP2-RADP)/RADP2.GT..1) RADP = .99*RADP2
IF((RADP-RADP2)/RADP2.GT..1) RADP = 1.1*RADP2
GO TO 142
317 G = (HLIM-H1)/(HCRIT-H1)*SFAC1)*G
GO TO 318
110 RADP = RADP1
GO TO 326
111 RADP = RADP2
326 CALCULATE FUEL TEMPERATURE AT 11 PLACES
326 CONTINUE
327 PHI(13) = PHI(14)*HCFAC1
329 CONTINUE
HC = 7000.
CALL SIMBI(1,P(TP),STV)
TSAT = STV(2)
IF(TSAT-DUMMY(22))341,341,337
337 TW(13) = PHI(13)/HC+DUMMY(22)
TEO(13) = PHI(13)/E+TW(13)
TFG = (TW(13)+DUMMY(22))/2.0
IF(TFG.GT.700.160 TO 341
CALL PROPS(TFG,PV)
PR = PV(6)
XVI = PV(3)
XXK = PV(5)
HNFW = .023*XXK*(TUMDUM(2)*G*H/XMU)**.8*PR**3/PH
DEL = ABS(HNEW-HC)/HNEW
IF(DEL.LT..00011) GO TO 339
HC = HNEW
GO TO 337
339 DELT = TW(13)-TSAT

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DELN = 60.*(PHI(13)/(1.E6))**.25/EXP(P(IP)/900.)
IF(DELN.GT.NFIN) GO TO 340
341 HC = HFILN
TW(13) = PHI(13)/HC+DUMMY(221)
TFO(13) = PHI(13)/E+TW(13)
330 TW(14) = .1*(TW(2)+TW(12))/2.+TW(3)+TW(4)+TW(5)+TW(6)+TW(7)+TW(8)
2+TW(9)+TW(10)+TW(11)
TW(13) = 0.
DO 350 I=2,12
350 TW(13) = AMAX1(TW(13),DUMMY(I+221))
DO 517 I=1,MOUT
L = I
517 IF(TEMPK(I).GT.GRID) GO TO 518
518 TCIC = GK(L-1)+(GRID-TEMPK(L-1))/(TEMPK(L)-TEMPK(L-1))*GK(I)
1-GK(L-1)
DO 519 I=2,MOUT
L = I
519 IF(TEMPK(I).GT.HCTEMP) GO TO 520
520 QKHCTP = GK(L-1)+(HCTEMP-TEMPK(L-1))/(TEMPK(L)-TEMPK(L-1))*GK(I)
1-GK(L-1)
GTHETA = THETA
DO 370 N=2,13
DO 521 I=2,MOUT
L = I
521 IF(TEMPK(I).GT.TEC(N)) GO TO 522
522 TFOK = GK(L-1)+(TFO(N)-TEMPK(L-1))/(TEMPK(L)-TEMPK(L-1))*GK(I)
1-GK(L-1)
ICLK = 0
55 DVDP(N) = THETA
58 IQ = 21
PHIX = PHI(N)*DPO/2.
IF(PHI(N)) 572,572,56
57 IF(ICLK.LI.5) GO TO 55
CORREC = DVDP(N)
DVDP(N) = THETA
THETA = (CORREC +THETA)/2.0
IF(ICLK.GT.7) GO TO 505
GO TO 58
56 CALL HOLEITOLK,TECK,PHIX,RGI,QDOTI,FUDENS,QK,THETA,QDOTK,IQ,
1QTHETA)
IF(THETA.LT.QTHETA) THETA = QTHETA
ICLK = ICLK+1
IF(ARS(DVDP(N)-THETA)/.001.GT.1.) GO TO 57
505 DVDP(N) = THETA
THETA = QTHETA
QKTMAX = TFOK+QDOTK(IQ)
333 DO 525 I=2,MOUT
L = I
525 IF(QK(I).GT.QKTMAX) GO TO 526

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526 TMAX(N) = TEMPK(L-1) + (OKTMAX-OK(L-1)) / (OK(L)-OK(L-1)) * (TEMPK(L)-
1TEMPK(L-1))
IF (LL.GT.0) GO TO 370
IF (TMAX(N).LT.0.) GO TO 383
IF (HCTEMP) 370,370,369
369 IF (N.LT.13.OR.N.GT.13) GO TO 470
C COMPARE MAXIMUM FUEL TEMPERATURE IN HOT CHANNEL
DELTA = (TMAX(N)-HCTEMP)/HCTEMP
IF (ABS(DELTA).LT..0001) GO TO 370
IF (ITX.GT.ITCHK) GO TO 370
IF (LCHECK.EQ.3) GO TO 591
363 DO 523 I=2,MOUT
L = I
523 IF (TEMPK(I).GT.DUMMY(N)) GO TO 524
524 OKDUM=OK(L-1)+(DUMMY(N)-TEMPK(L-1)) / (TEMPK(L)-TEMPK(L-1)) * (OK(L)
1-OK(L-1))
DPOPH1 = OKTMAX-OKDUM
DPOPH2 = OKHCTP-OKDUM
TEMP2 = TEM1
TFM1 = HCTEMP-TMAX(13)
DP2 = DP1
DP1 = DP
TFWDUM(ITX) = ABS(TEM1)
XLXDUU(ITX) = DP
362 DP = DP*DPOPH2/DPOPH1
IF (ITX.EQ.1) GO TO 592
IF (TEM1.LT.0.,AND.TEM2.GT.0.,OR.TEM1.GT.0.,AND.TEM2.LT.0.) GO TO 592
IF (ABS(TEM1).GT.ABS(TEM2)) KCHECK = 1
IF (KCHECK.EQ.1) DP = DP1*DPOPH1/DPOPH2
IF (ABS((DP2-DP1)/DP1).LT..05) LCHECK = 3
592 DH = 0.
ITN = 0
XW = XWRAT*DP
ITX = ITX+1
IF (IFLOW.GT.0) G = 0.0
IF (RADP2.LT.RADP1.AND.OP.GT.0.) GO TO 138
IF (DP) 383,383,142
591 TFM2 = TEM1
TFM1 = HCTEMP-TMAX(13)
DP2 = DP1
DP1 = DP
TFWDUM(ITX) = ABS(TEM1)
XLXDUU(ITX) = DP
IF (ITX.EQ.ITCHK) GO TO 600
DP = DP2-TFM2*(DP2-DP1)/(TFM2-TFM1)
IF (DP) 363,363,592
572 TMAX(N) = 0.0
DUMP(N) = 0.0
GO TO 370

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600 TFDUMM = 6000.
   DO 601 I=1,ITCHK
      TFDUMM = AMINI(TFDUMM(I),TFDUMM)
      IF(TFDUMM(I)-TFDUMM) 602,602,601
602 DP = XLXDUM(I)
601 CONTINUE
370 CONTINUE
   IF(DP-DP1) 592,370,592
      HCRIT = (HCRIT-H1)*SFACT+H1
      CVOL = PI*RADP**2*XLX
      CWT = CVOL*(ALPHAF*RHOE+(ALPHAT+ALPHAT1*RHOT+ALPHAC*RHOC)
      MKL = 0
      DO 378 I = 2,12
         IF(TMAX(I)) 378,378,377
377 KLM = I
         IF(MKL.EQ.0)MKL=I
378 CONTINUE
         TINCR = KLM-MKL
         TMAX(14) = 1./TINCR*(TMAX(MKL)+TMAX(KLM))/2.
         KLM = KLM-1
         MKL = MKL+1
         DO 384 I=MKL,KLM
            TMAX(14) = TMAX(14)+1./TINCR*TMAX(I)
384 TCAVE = .1*((TC(9)+TC(12))/2.+TC(3)+TC(4)+TC(5)+TC(6)+TC(7)+TC(8)
              1 +TC(9)+TC(10)+TC(11))
            DS = DS*12.
C      OUTPUT ROUTINE NEXT
154 CONTINUE
      XI = (ALPHAC+ALPHAS)/ALPHAF
      IF(RADP1-RADP2) 150,150,151
151 IF(DUMMY(NDNR+105)) 105,105,102
102 RADP2 = RADP1
      RADP1 = 0.
      WRITE(3,1704)
      GO TO 152
105 WRITE(3,1700)
      GO TO 152
150 WRITE(3,1701)
      IRADP = 1
      GO TO 152
149 WRITE(3,1702)
152 WRITE
           (3,1710),ICASE
      CALL ETIMEF(TIME)
      WRITE(3,1805) TIME
      WRITE(3,1810)
160 WRITE(3,1100)
      WRITE(3,1102)
      WRITE(3,1105) T01,P00,Q1,OR,XL,RADP,RADP1,RADP2,PEACT,TCAVE

```

```

164 WRITE(3,1110)
   WRITE(3,1112)
   WRITE(3,1115) DHI,XWL,WDOT,G,ENPINS,DPOI,PHI(14),PHI(13)
165 WRITE(3,3020)
   WRITE(3,3021)
   K = IRADP+1
   GO TO (103,104), K
104 WRITE(3,3023) DS,XI,PD1,CVOL,CWT,XNRE,CRITPH,CRITPH
   GO TO 107
103 WRITE(3,3022) DS,XI,PD1,CVOL,CWT,XNRE,PHCRIT,PHILIM
107 IF(NU,GI,0) GO TO 371
   WRITE(3,3005) DVDP(13),XCRT,DUMMY(INCP+105)
371 WRITE(3,1150)
   WRITE(3,1155)
   WRITE(3,1160) ALPHAF,ALPHAC,ALPHA1,ALPHA2,ALPHAS,ALPHAV,
1ALPHAP,QUAL
   IF(NU,GI,0) GO TO 382
   WRITE(3,1720) (ZETA(I),I=2,12)
   WRITE(3,3050) (TC(I),I=2,12)
   WRITE(3,1728) (TW(I),I=2,12)
   IF(IRADP,GI,0) GO TO 373
372 WRITE(3,3010) (PHIM(I),I=2,12)
   WRITE(3,1729) (PHI(I),I=2,12)
   WRITE(3,1730) (TMAX(I),I=2,12)
   WRITE(3,1732) (DVDP(I),I=2,12)
   GO TO 374
373 WRITE(3,3016) (XHLIM(I),I=2,12)
   WRITE(3,3014) (XH(I),I=2,12)
   WRITE(3,3012) (DELX(I),I=2,12)
   WRITE(3,1729) (PHI(I),I=2,12)
   WRITE(3,1730) (TMAX(I),I=2,12)
   WRITE(3,1732) (DVDP(I),I=2,12)
374 WRITE(3,1748)
   WRITE(3,1749)
   WRITE(3,1750) VEL1,VEL2,P01,P(1),P(NOUT),P02,P03P00
   IF(IRADP,EG,0) GO TO 376
375 WRITE(3,3030)
   WRITE(3,3031)
   WRITE(3,3040) XLF,YMAX,HCRIT,HIM,TMAX(14),TMAX(13),TW(13),AHEAT,
1NOT,ITMAX
   IF(NU,GE,0) GO TO 380
   WRITE(3,5002) ICASE
   CLU(1) = AMAX1(XHLIM(2),XHLIM(3),XHLIM(4),XHLIM(5),XHLIM(6),
1XHLIM(7),XHLIM(8),XHLIM(9),XHLIM(10),XHLIM(11),XHLIM(12))
   CLU(2) = CLU(1)
   XMAXI(1) = 1.0
   XMAXI(2) = 1.0
   DO 500 I=1,101
   J = (I-1)/10+2

```

```

      QQQ(1,I) = .1*ELQAT(J-1)-.1
      QQQ(2,I) = QQQ(1,I)
      DO(1,I) = XHLIM(J)
      IF(DO(1,I).LT.0.001) DO(1,I) = -50.
      500 DO(2,I) = (XH(J)-H1)*SFAC*H1
      CALL FPLDT(2,101,5,QQQ,DO,XMAXI,CLU,25,26)
      GO TO 380
376 WRITE(3,3035)
   WRITE(3,3036)
   IF(QUAL.GT.0.) GO TO 444
   WRITE(3,3039) XMAX,TMAX(14),TMAX(13),TW(13),AHFAT,NOT,ITMAX
      GO TO 445
444 WRITE(3,3041)XLF,XMAX,TMAX(14),TMAX(13),TW(13),AHFAT,NOT,ITMAX
445 IF(NU.GE.0) GO TO 380
   WRITE(3,5003)ICASE
   CLU(1) = 0.
   DO 501 I=1,101
      J = RATZ*I+.91
      DO(1,I) = IPHLIM(J)
      IF(DO(1,I).LT.0.001) DO(1,I) = -50.
      DO(2,I) = PH(J)*SFAC*XQUAL
      501 CLU(1) = AMAX1(CLU(1),DO(1,I),DO(2,I))
      CLU(2) = CLU(1)
      XMAXI(1) = 1.0
      XMAXI(2) = 1.0
      QQQ(2,I) = QQQ(1,I)
      CALL FPLDT(2,101,5,QQQ,DO,XMAXI,CLU,25,26)
      380 DS = 0.
      382 CONTINUE
      IF(JCASE.LT.ITH) GO TO 379
      GO TO 2000
379 ALPHAP = ALPHAP+RELEPS
   JCASF = JCASF+1
   RADP1 = 0.
   WROT1 = 0.
   LI = 0
   DH = 0.0
   IF (YFLOW.GT.N) G = 0.0
   CALL ETIME
      GO TO 132
383 WRITE(3,5000)
      GO TO 380
599 WRITE(3,5004)
      GO TO 380
598 WRITE(3,5005)
      GO TO 380
2000 RETURN
1002 FORMAT(10I5,3F10.0)
1100 FORMAT(119H INJET TALEY POWER HFAAT GFN CORF

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1	EQUIVALENT CORE RADIUS IN FEET	NOM PEAKING	AVG COOLANT
1102	FORMAT(119H, TEMP-F, PRESS-PSI, MW, RATF-R/H-CUF, LENGTH-FT)		
1	CRITICAL PRES H2O, BOIL H2O, FACTOR, TEMP, DEG F		
1105	FORMAT(1H, F1, F11, 2, F9, 2, 1PF13, 4, 0P2F12, 3, 2F11, 3, F13, 4, F15, 2/)		
1110	FORMAT(120H, HYD DIAM, WALL THICK, COOLANT FLOW, COOLANT MASS VEL)		
1-	NO. COOLANT, NUMBER, PIN ON, AVG HEAT, MAX HEAT FLUX		
1112	FORMAT(119H, INCHES, INCHES, RATE, LB/HR, OCITY, LB/HR-SQ)		
IF	CHANNELS OF PTNG, INCHES, FLUX, HOT CHANNEL		
1115	FORMAT(1H, F10, 6, F12, 9, 1PF12, 3, F17, 3, 0PF15, 2, F14, 2, F11, 6, 1P2E12, 4)		
1150	FORMAT(29H, MATERIAL VOLUME FRACTIONS)		
1155	FORMAT(120H, FUEL, COOLANT, FUEL CLAD, CELL CLAD)		
1	CELL SPACE, PIN ANNUUS, FUEL VOID, 1-FUEL FRACTION, QUALITY		
1160	FORMAT(1H, F13, 5, F15, 7/)		
1600	FORMAT(8E10, 0)		
1610	FORMAT(4I5, 6F10, 0)		
1700	FORMAT(100H, PRESSURE, WATER, REACTOR, FLUID, FLOW, AND HEAT TRANSFER)		
1			
1701	FORMAT(100H, 1, BOILING, WATER, REACTOR, FLUID, FLOW, AND HEAT TRANSFER)		
1	WESTINGHOUSE W-2 CORRELATION		
1702	FORMAT(50H, 1, CORE, GEOMETRY)		
1704	FORMAT(100H, 1, BOILING, WATER, REACTOR, FLUID, FLOW, AND HEAT TRANSFER)		
1	WESTINGHOUSE W-3 CORRELATION		
1710	FORMAT(17H, CASE NUMBER, I2)		
1720	FORMAT(21H, LENGTH X/L, =, 11F9, 5)		
1728	FORMAT(21H, WALL TEMP, =, 11F9, 1)		
1729	FORMAT(21H, NOMINAL HEAT FLUX, =, 1P11E9, 3)		
1730	FORMAT(21H, NOM FUEL CL TEMP, =, 11F9, 1)		
1732	FORMAT(21H, VOID DIAM RATIO, =, 11F9, 5/)		
1748	FORMAT(120H, IN, EXIT, IN CHANNEL, EXIT CHANNEL, FYIT CHANNEL, PRESSURE, S)		
1	IN CHANNEL, EXIT CHANNEL, VELOCITY, PRESSURE, DROP		
1749	FORMAT(119H, VELOCITY, PRESSURE, DROP)		
1	STATIC PRESS, STATIC PRESS, PRESSURE, DROP		
1750	FORMAT(1H, F9, 3, F16, 3, 4F19, 3, F16, 3/)		
1800	FORMAT(1H, 25X, 9A6)		
1805	FORMAT(1H, 87X, 1A, THIS CASE REQUIRED, F6, 1, 5H SEC.)		
1810	FORMAT(1H, 0)		
3002	FORMAT(22H, 600F, 1P, HAS, OCCURRED)		
3005	FORMAT(44H, HOT CHANNEL VOID DIAMETER RATIO (RI/RO) = F8, 5, 10X, 19)		
1	IMPINT OF MIN, DNP = F8, 5, 9X, 15HHC, EXIT QUAL, =, F8, 5 /		
3010	FORMAT(21H, LIMITING HEAT FLUX, 1P11E9, 3)		
3012	FORMAT(21H, SAFETY MARGIN ENTH, 1P11E9, 3)		
3014	FORMAT(21H, NOMINAL ENTHALPY, =, 1P11E9, 3)		
3016	FORMAT(21H, LIMITING ENTHALPY, =, 1P11E9, 3)		
3020	FORMAT(119H, SPACER, COOLANT TO, PITCH, CRITICAL, LIMITING, VOLUME-CU, HEAT FLUX)		
1	CORE, REYNOLDS, FUEL RATIO, INCHES, HEAT FLUX, HEAT FLUX		
3021	FORMAT(120H, CORE, DIAM-IN, FUEL RATIO, INCHES, HEAT FLUX, HEAT FLUX)		
1	WEIGHT-LB, NUMBER, HEAT FLUX, HEAT FLUX		
3022	FORMAT(1H, F9, 5, F15, 5, F14, 5, 1P2F16, 2, F14, 2, F17, 2, F16, 2/)		
3023	FORMAT(1H, F9, 5, F15, 5, F14, 5, 1P2F16, 2, F14, 2, 12X, A6, 10X, A6 /)		

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3030 FORMAT(120H SATURATION POSITION OF CRITICAL LIMIT
1TNG AVG FUEL MAX FUEL MAX WALL TEMP HEAT TRANSFER)
3031 FORMAT(120H POINT-X/1 MAX FLUX-X/L ENTHALPY-R/LR ENTHAL
1PY-R/LR TEMP-F HOT CHANNEL ARFA-SQF )
3035 FORMAT(119H SATURATION POSITION OF AVG FUEL
1 MAX FUEL MAX WALL TEMP HEAT TRANSFER )
3036 FORMAT(119H POINT-X/1 MAX FLUX-X/L TEMP-F
1 TEMP-F HOT CHANNEL ARFA-SQF )
3039 FORMAT(6X,5H NONE ,F20.5,F21.1,1PE23.5 /// 15, 24H ITE
1RATIONS. (MORE THAN,14, 80H ITERATIONS MEANS NO CONVERGENCE--CHFC
2K INPUT DATA, ESPECIALLY FLOW DATA.)
3040 FORMAT(F11.5,F15.5,2F16.1,F14.1,F12.1,F14.1,1PE21.5 /// 15,24H ITE
1RATIONS. (MORE THAN,14, 80H ITERATIONS MEANS NO CONVERGENCE--CHFC
2K INPUT DATA, ESPECIALLY FLOW DATA.)
3041 FORMAT(1H ,F10.5 ,F20.5,F21.1,1PE23.5 /// 15, 24H ITE
1RATIONS. (MORE THAN,14, 80H ITERATIONS MEANS NO CONVERGENCE--CHFC
2K INPUT DATA, ESPECIALLY FLOW DATA.)
3050 FORMAT(21H COOLANT TEMP = ,11F9.1)
3099 FORMAT(1H,1100H INPUT DATA AS RECEIVED BY PROGRAM - UNITS IN I
1NCHES, POUNDS, BTU, DEGREES F, AND PSI ///)
4000 FORMAT(150H FILM COEFFICIENTS /
1 120H FUEL DENSITY FUEL-TUBE COOLANT-TUBE ENTRANCE HEA
20 EXIT HEAD FUEL COOLANT STRUCTURAL POWER )
4001 FORMAT(120H RATIO INTERFACE INTERFACE LOSS COEFF
1 LOSS COEFF DENSITY MAT DENSITY INPUT-MW)
4002 FORMAT(1H ,F10.4,F15.1,F12.1,2F14.3,F13.2,F11.2,F13.5,F15.2 ///)
4003 FORMAT(120H WRAP CORE CORE LENGTH EQUIVA
1LENT FUEL PIN SPACER NO. GRID HEAT TRANSFER TYPE )
4004 FORMAT(120H FT/TURN LATTICE ENT ACTIVE EXIT CORE R
1ADIUS OR GRID TYPE LOCATIONS LIMITED CORE OF RUN )
4005 FORMAT(1H ,F9.6,2X,2A6,F7.3,F8.2,F8.3,F11.3,5X,3A6,17,10X,A6,4X,
12A6///)
4006 FORMAT(19H GRID LOCATIONS )
4007 FORMAT(11F10.4)
4008 FORMAT(120H IN FT TEMP TALFT PRES DIAM OF FUEL HYDRAULI
1C DIAM WALL THICKNESS FUEL PIN GEOMETRY MAX FUEL )
4009 FORMAT(120H OF COOLANT OF COOLANT IN FUEL PIN OF COOLA
1NT CHAN OF FUEL PIN RI/RO GAS-GAP TEMP-F )
4010 FORMAT(1H ,F10.2,F14.1,F15.6,F18.6,1PF22.5,0PF15.4,F10.6,F13.1 ///)
4011 FORMAT(120H 1-FUEL ASSEMBLY SPACING SUPPORT CLAD MASS VEL
1OCITY FLOW-RATE MESH DNR HOT CHANNEL LOCAL PEAK- )
4012 FORMAT(120H FRACTION FRACTION FRACTION OF COO
1LANT OF COOLANT NUMBER RATIO PEAK FACTOR ING FACTOR )
4013 FORMAT(1H ,F9.6,F14.6,F17.6,1PE18.5,F15.5,0PFA.3,F10.5,F10.3,F14.4
1///)
4014 FORMAT( 80H NUMBER OF NO. OF THERMAL FRACTION HE
1AT TEMP. AT WHICH 7X,5A6 )
4015 FORMAT(120H POWER POINTS CONDUCTIVITY POINTS GEN. IN FUEL
1L GRAIN GROWTH BEGINS OF COOLANT OF CORE )

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4016 FORMAT(1H ,I8,I22,F22.4,F21.1,I3X,35HHELD CONSTANT      HELD CONST
1ANT )
4017 FORMAT(//85H      CROSS-FLOW      FLOW REDISTRIBUTION
1SPACER TO      FRICTION =,F8.4,8H * RE**(,F7.4,3H) +,F8.4 )
4018 FORMAT(65H      COEFFICIENT      COEFFICIENT      CPA
1CE RATIO )
4019 FORMAT(1H ,F10.4,F26.4,F24.4 )
4020 FORMAT(1H0)
5000 FORMAT(1H1,/////////120H      THE TEMPERATURE EXCEEDS THAT SHOWN F
1OR THE MAXIMUM THERMAL CONDUCTIVITY PROFILE (NEGATIVE THERMAL COND
2UCTIVITY //100H RESULTS). INCREASE THE LAST TEMPERATURE IN
3 THE EQUATION. NEXT CASE HAS BEEN CALLED. //)
5001 FORMAT(10H1 CASE NO.,I3,107H PLOT 1 IS POWER VS DIST. ** PLOT 2
1IS FUEL CONDUCTIVITY VS TEMP. ** PLOT 2 IS HEAT GEN. RATE VS RADIU
2S. )
5002 FORMAT(10H1 CASE NO.,I3,103H PLOT 1 IS LIMITING ENTHALPY VS DIST
1ANCE THRU CORE ** PLOT 2 IS HOT CHANNEL ENTHALPY VS DISTANCE. )
5003 FORMAT(10H1 CASE NO.,I3,103H PLOT 1 IS LIMITING HEAT FLUX VS DIS
1TANCE THRU CORE ** PLOT 2 IS MAXIMUM HEAT FLUX VS DISTANCE. )
5004 FORMAT( 70H MASS VELOCITY OF COOLANT IS TOO HIGH. NEXT CASE HAS
1 BEEN CALLED. )
5005 FORMAT(120H LIMITING ENTHALPY IS LESS THAN INLET ENTHALPY. CAUSI
1NG A NEGATIVE FLOW-RATE TO BE CALCULATED. TRY INCREASING THE
2// 58H VALUE OF '1-FUEL FRACTION'. NEXT CASE HAS BEEN CALLED. )
END

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SUBROUTINE GEOM
  INCLUDE REPIN,LIST
  THIS ROUTINE CALCULATES GEOMETRY RELATIONSHIPS FOR A SQUARE PIN
  C      ARRAY
  QH = Q/((XLX*PI*RAD**2)*(1.-ALPHA))
  204 CONTINUE
  IF(DH.GT..0)GO TO 205
  DH = FUDENS*(1.-THETA**2)*DP**2/((1.-ALPHA)*(np+2.*XW))-(np+2.*XW)
  GO TO 206
  205 DP=(1.-ALPHA)*(DH+4.*XW)/(2.*(FUDENS*(1.-THETA**2)+ALPHA-1.))
  2 *SQRT((1.-ALPHA)*(DH+4.*XW)/(2.*(FUDENS*(1.-THETA**2)+ALPHA-1.))
  3 )**2 +2.*(1.-ALPHA)*(DH*XW+2.*XW**2)/(FUDENS*(1.-THETA**2))+
  4 ALPHA-1.))
  206 DPO=DP+2.*XW
  PINS = 4.*(1.-ALPHA)*RAD**2/(DP**2*(1.-THETA**2)*FUDENS)
  IF(G)212,212,214
  212 G = WDOT*(DH+DPO)/(PI*DH*RAD**2)
  GO TO 216
  214 WDOT = G*PI*DH*RAD**2/(DH+DPO)
  216 CONTINUE
  IF(ICORE)207,207,208
  207 EN = 4.*RAD**2/(NPO*DH +npO**2)
  PN=SQRT(PI*NPO*(DH+DPO)/4.)
  DHW = (4.-PI)/PI *DPO
  GO TO 210
  208 EN=8.*RAD**2/(DH*NPO+DPO**2)
  PN=SQRT(PI*NPO*(DH+DPO)/(4.*.866))
  DHW=(4.*.866-PI)/PI*DPO
  210 IF(DH -DHW)235,238,238
  235 WRITE(3,1000)
  DUMMY(299) = 20.
  238 CONTINUE
  AFL = PI*DH*RAD**2/(DH*NPO)
  AFU= PI *RAD**2*(1.-ALPHA)
  XI = DH/((DH+DPO)*(1.-ALPHA))
  ALPHA F=1.-ALPHA P
  AHEAT = 4.*PI*RN**2/(DH+DPO)*XLX
  DPOI = DPO*12.
  POI = PO*12.
  DHI = DH*12.
  XWI = XW*12.
  ALPHAC = DH*(1.-ALPHA)/(DH+DPO)*(1.-ALPHA))
  ALPHAT = 4.*XW*(NPO-XW)*(1.-ALPHA)/(DPO*(DH+NPO)*(1.-ALPHA))
  ALPHAW = THETA**2*(1.-ALPHA)/(FUDENS*(1.-THETA**2))

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SUBROUTINE PRFSS2
C   THIS ROUTINE CALCULATES PRESSURE DROP FOR PWR AND PWR
  DIMENSION STV(10),PF(12),PV(7),VF(10),V(202)
  INCLUDE REPIN.LIST
  EQUIVALENCE (P1,PF(1))
C   SOLVE FOR SPECIFIC VOLUMES AND SATURATION PROPERTIES AT INLET
C   CONDITIONS
  NOUT = NOUT
  INCR = INCR
  LSAT = LSAT
  MFND = MFND
  IT = IT
  T1 = T01
  10 CALL STMTBL(2,T1,STV)
  V1 = STV(3)
  RH0(1) = 1.0/V1
  H1 = STV(5)
  CON1 = 32.2*(60.)*4 * 144.
  CONV = 64.4*144.
  VEL1 = G/3600.*V1
  P01 = P00-VKLD1*VEL1**2/(V1*CONV)
  P1 = P01-(G*RUMDUM(2))**2*V1/(2.*CON1)
  QFX = 0.
  CONTINUE
  DO 120 J=2,5
  NXLF = -2
  PF(J) = PF(J-1)
  IF (PF(J).LT.,2) GO TO 102
  CALL STMTBL(1,PF(J),STV)
  VF1 = STV(3)
  HF = STV(5)
  TF = STV(2)
  HG = STV(6)
C   CHECK FOR SATURATION OR QUALITY AT INLET CONDITIONS
  QF = (HF-H1)*WDOT*RUMDUM(2)
  IF (J-2) 30,30,32
  30 1SAT = 1
  P(1SAT) = P1
  XLFE = 0.
  HF1 = H1
  GDFLP = 0.
  HFG = H1
  GFX = (H1+Q*PFFACT/(WDOT*RUMDUM(2))-HF)/(HG-HF)
  IF (QF) 121,121,32

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C CHECK TO SEE IF SUBCOOLING EXISTS THRU DISTANCE XI
32 IF(Q*RPFACT-QF) 34,34,16
34 XLF = 1.0
   GO TO 58
C FIND POINT (XLF) ALONG XI WHERE SATURATION OCCURS
36 CONTINUE
DO 54 I=1,NOUT
  IF(QF-AI(I)*RPFACT) 42,44,46
  42 XLF = (QF-AI(I-1)*RPFACT)/(AI(I)-AI(I-1)*RPFACT)*XINCR+Y(I-1)
  NXLF = I
  IN = NOUT-I+1
DO 43 JN=1,IN
  AI(NOUT-JN+2) = AI(NOUT-JN+1)
  43 X (NOUT-JN+2) = Y (NOUT-JN+1)
  AI(I) = QF/RPFACT
  X(I) = XLF
  NOUT = NOUT+1
  INCR = INCR+1
GO TO 58
44 XLF = X(I)
GO TO 58
46 XLF = 1.0
54 CONTINUE
C CALCULATE SATURATION PROPERTIES AT DISTANCE XLF
58 P(1) = P1
  VF(1) = VF1
  T(1) = T1
  TEMP1 = T1
  VHC1 = V1
  RUMNY(1) = T1
  V(1) = V1
  PH(1) = 0.
  GDELP = 0.
  XLRAT = 1.0
  HF1 = H1
  HFHC = H1
DO 100 N = 2, 120
  XLRAT = (XLF-X(N))/XLF
  IF(X(N)-STEAT) 62,62,64
  62 AI(N) = 0.0
  GO TO 440
  64 IF(N.GT.INCR) GO TO 440
  PH(N) = (AI(N)-AI(N-1))/(X(N)-X(N-1))*XL*PI*PP0*PTNS)
  HF1 = H1+AI(N)/WDCI
  HF2 = H1+AI(N)*RPFACT/(WDCI*RUMDUM(2))
  HFHC = H1+RPFACT*(AI(N-1)+XLPFAC*(AI(N)-AI(N-1)))/(XMIY*WDCI*
    RUMDUM(2))
  IF(HF1.GT.902.) GO TO 304
GO TO 442

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440 PH(N) = 0.
442 CALL STMTBL(5,HF1,STV)
T(N)=STV(2)
V(N) = STV(3)
CALL STMTBL(5,HF2,STV)
TEMP2 = STV(2)
VHC2 = STV(3)
IF(PF(J).LT..2) GO TO 402
CALL STMTBL(1,PF(J),STV)
IF(STV(5).LT.HFHC) GO TO 407
CALL STMTBL(5,HFHC,STV)
407 DUMMY(N) = STV(2)
IF(T(N).GT.STV(2)) T(N) = STV(2)
IF(TEMP2.GT.STV(2)) TEMP2 = T(N)
TA = (TEMP1+TEMP2)/2.
TEMP1 = TEMP2
VHC1 = VHC2
CALL PROPS(TA,PV)
VTSC = PV(3)
FRIC = FCON1*(DUMDUM(2)*G*DH/VTSC)**FCON2+FCON3
DELFC = (VHC2-VHC1) /CON1*(DUMDUM(2)*G)**2+(VHC2+VHC1)/(4.*CON1
1*PH)*FRIC*(X(N)-Y(N-1))*XL*(DUMDUM(2)*G)**2+2.*(X(N)-Y(N-1))*XL/
2*((VHC2+VHC1)*144.)
P(N)=P(N-1) - DELFC
IF(N.GT.2)GO TO 70
IT1 = 1
XGRID = GX(IT1)
70 DELFC = (XGRID-X(N))/XGRIN
72 IF(DELFC.GT.0.) GO TO 9A
DELFC2 = (XGRID - X(N-1))/XGRIN
Y = X(N)*XL
Z = V(N)
IF(IT1.FQ.3) Z = (V1+VHC2)/2.
CALL GRIDS(Z,DELFC,PD,DS,EN,G,VTSC,WRAP,PO,CORF,IT,Y,GDELFC)
CONTINUE
P(N) = P(N)-GDELFC
IT1 = IT1 + 1
XGRID = GX(IT1)
IF(ARS(DELFC)-ARS(DELFC2)) 9A,9A,74
74 P(N-1) = P(N-1)-GDELFC
9A CONTINUE
PF(J)=P(N)
IF(PF(J).LT..2) GO TO 402
CALL STMTBL(1,PF(J),STV)
TF = STV(2)
VF(N)=STV(3)
RHO(N) = 1.0/V(N)
PF = STV(5)
VF1= VF(N)

```

```

MEAD = N
DUMMY(N+105) = ( HFHC-HF)/(STV(4)-HF)
LSAT = N
CHECK FOR SATURATION DISTANCE CORRESPONDENCE
H(1) = HF1
H(2) = HF1
IF(HF+.05,LT,HE2) GO TO 102
IF(N=NOUT) 101,103,103
101 IF(ABS(XLRAT),LT,.00001) GO TO 102
100 CONTINUE
103 X(N) = 1.0
GO TO 280
102 HERAT = (HE2-HF)/HF
CALCULATE SATURATION BALANCE AND CHECK FOR ERROR
IF(.0005-ABS(HERAT))45,122,122
445 IF(NXLF,LT,.0 OR. J.EQ.5) GO TO 120
INCR = INCR+1
NOUT = NOUT+1
DO 446 I=NXLF,NOUT
X(I) = X(I+1)
446 AI(I) = AI(I+1)
120 CONTINUE
HERAT = HERAT+100.
IF(HF,LT,HE2) WRITE(3,5000) HERAT,HF,HE2,XIF
121 CONTINUE
122 J = LSAT+1
I = LSAT + 120
GNFL = 0.
IF(GFX)128,128,129
IF(P(LSAT),LT,.2) GO TO 102
128 CALL STMTB1(1,P(LSAT),STV)
GFX = (H1+(0-AI(LSAT))*RPFAC/(WDOT*NDUM(2))-STV(5))/(STV(6)
1-STV(5))
129 GF = GFX
DO 238 NE,J,I
IF(X(N)-STHFAT)125,125,127
125 AI(N) = 0.0
GO TO 480
127 IF(N.GI,INCR)GO TO 480
PH(N) = (AI(N)-AI(N-1))/(Y(N)-Y(N-1))*XL*PI*DDO*PINS)
HEG = H1+AI(N)/WDCI
RHFG = H1+RPFAC*(AI(N-1)+XLPEAC*(AI(N)-AI(N-1)))/(XMTX*WDOT*
1NDUM(2))
IF(P(N-1)) 302,302,123
480 PH(N) = 0.
123 CALL STMTB1(1,P(N-1),STV)
IF = STV(2)
VG = STV(4)
HF = STV(5)

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```

HG = STV(6)
QUAL = (HFG - HF) / (HG - HF)
DUMMY(N+105) = (P1FG-HF)/(HG-HF)
IF(QUAL)124,124,126
124 QUAL = .00001
126 CONTINUE
IF(QUAL.GT.1.0)GO TO 244
VFG = STV(3)+QUAL*(VG-STV(3))
CALL PROPS(TF,PV)
IF(N.GT.J)GO TO 140
VISC1 = PV(3)
GAMMA = 38.563*EXP(-.0030575*P(I SAT))+2.178F-7*P(I SAT)**2-.004173*
1P(LSAT)+11.4416+2907.0/P(I SAT)
ALPHA1= VG/VF1
141 CONTINUE
GAMMA2=(1.+ QF*(GAMMA-1.)) * (1.+ QF * (ALPHA1-GAMMA)/GAMMA)-1.
GAMMA3 = (26400./P(LSAT)-6.8)*QF/2.+1.
CALL SIIP4 (QF,GAMMA,GAMMA4)
140 VISC = (VISC1+PV(3))/2.
FRIC = FCON*(DUMDUM(2)*G*DH/VISC)**FCON2+FCON3
250 DELP = VF1*(DUMDUM(2)*G)**2*GAMMA2/CON+VF1/(2.*CON1*DH)*FRIC*
1(X(N)-XLF)*XL*(DUMDUM(2)*G)**2*GAMMA3+(X(N)-XLF)*YI/(VF1*144.)*
1GAMMA4
254 P(N) = P(LSAT) - DELP - GDEL
IF(N.GT.3)GO TO 256
III = 1
XGRID = GX(III)
256 DELG = (XGRID-X(N))/XGRID
257 IF(DELG.GT.0) GO TO 260
DELG2 = (XGRID - X(N-1))/XGRID
Y = X(N)*XL
Z = VFG
IF(II.FG.3)7 = (VF1+VFG)/2.
CALL GRIDS(7,AFL,PD,DS,EN,G,VISC,WRAP,NPO,CORF,IT,Y,GDEL,P)
CONTINUE
GDEL = GDEL+GDEL
P(N) = P(N) - GDEL
III = III + 1
XGRID = GX(III)
IF(ABS(DELG)-ABS(DELG2)) 260,260,258
258 P(N-1) = P(N-1)-GDEL
260 CONTINUE
IF(P(N).LT..2) GO TO 302
CALL STMTBI(1,P(N),STV)
T(N) = STV(2)
DUMMY(N) = STV(2)
RHO(N)=1.0/(STV(3)+(HFG-STV(5))/(STV(4)-STV(3)))
NEND = N
CHECK TO SEE TF Y = XL

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```

IF(N=NQUIT) 238,262,262
238 CONTINUE
262 CONTINUE
X(N) = 1.0
H(2) = HFG
V(MEND) = VFG
280 VEL2 = G/3600.*V(MEND)
TA = (T1+T(MEND))/2.
CALL PROPS(TA,PV)
XMU = PV(3)
XNBE = (VEL1+VEL2)*3600.*DH/(XMU*(V(MEND)+V1))
P02 = P(MEND)+(6*NUMDUM(2))**2*V(MEND)/(2.*CON1)
P03 = P02-VKL23*VEL2**2/(V(MEND)*CONV)
P03P00 = P00-P03
240 RETURN
244 PRINT 1000
300 DUMMY(300) = 50.
303 RETURN
302 WRITE(3,5002)
DUMMY(300) = 50.
RETURN
304 DUMMY(300) = 50.
WRITE(3,5001)
RETURN
1000 FORMAT(60H QUALITY EXCEEDED 100 PERCENT. NEXT CASE HAS BEEN CAL-
LED. )
5000 FORMAT(//125H PRESSURE DROP IS EXCESSIVE, CORRELATION RFTW
1EEN SATURATION ENTHALPY AND ACTUAL ENTHALPY AT SATURATION POINT IS
2 NOT // 22H EXACT, BUT DIFFERS BY,F6.4,11H PERCENT. SATURATED
3 ENTHALPY =,F9.4,27H, AND CALCULATED ENTHALPY =,F9.4,12H AT LOCATIO
4N,F6.4,2H. )
5001 FORMAT(70H NOMINAL ENTHALPY EXCEEDS 900 BTU/LR. NEXT CASE HAS RE
1EN CALLED. )
5002 FORMAT(90H CALCULATED LOCAL PRESSURE IS LFSS THAN ZERO. NEXT CAS
1E HAS BEEN CALLED. )
END

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SUBROUTINE LAGRIN(X,Y,N,XOUT,YOUT,NOUT,INTERP)
  DIMENSION X(1000),Y(1000),XOUT(1000),YOUT(1000),P(50)

  C X AND Y ARE THE INPUT VALUES FOR THE INTERPOLATION
  C XOUT IS THE MESH THAT IS TO BE RE-CONSTITUTED.
  C YOUT IS THE RE-CONSTITUTED FUNCTION.
  C N IS THE LENGTH OF THE X AND Y ARRAYS.
  C NOUT IS THE LENGTH OF THE XOUT AND YOUT ARRAYS.
  C INTERP IS THE ORDER OF INTERPOLATION--LESS THAN 50.
  C ***** *****
  C IF (INTERP.GE.51) NTERP=50
  C TEST TO SEE IF THE ORDER OF INTERPOLATION IS GREATER THAN 50.
  C IF (INTERP.GE.N) NTERP=N
  C TEST TO SEE IF THE INTERPOLATION ORDER IS GREATER THAN THE LIST.
  C INDEX=INTERP/2
  C DO 100 JN=1,NOUT
  C IF (XOUT(JN)-X(1)) 301,302,305
  C 301 YOUT(JN)=0.
  C GO TO 100
  C 302 YOUT(JN)=Y(1)
  C GO TO 100
  C 305 IF (XOUT(JN)-X(N)) 308,307,306
  C 306 YOUT(JN)=0.0
  C GO TO 100
  C 307 YOUT(JN)=Y(N)
  C GO TO 100
  C 308 CONTINUE
  C IF (XOUT(JN)-X(INDEX)) 1,1,2
  C 1 ISTART=0
  C GO TO 10
  C THE XOUT VALUE IS LOCATED BETWEEN X(1) AND X(INTERP).
  C 2 IF (XOUT(JN)-X(N-INDEX)) 4,3,3
  C 3 ISTART=N-INTERP-1
  C IF (2*(INTERP/2).EQ.NTERP) ISTART = N-INTERP
  C GO TO 10
  C THE XOUT VALUE IS LOCATED ABOVE X(N-INTERP).
  C 4 DO 7 L=INDEX,N
  C IF (XOUT(JN)-X(L)) 5,6,7
  C 5 ISTART=L-INDEX-1
  C GO TO 10
  C 6 YOUT(JN)=Y(L)
  C GO TO 100
  C POINT VALUES OF X AND YOUT ARE EQUAL.

```

```

7 CONTINUE
  ISTART=N/2-1
10 DO 20 J=1,INTERP
  P(J)=1.
  DO 20 I=1,INTERP
    IF(I=J) 15,20,15
    15 P(J)=P(J)*(XOUT(JN)-X(ISTART+I))/(X(ISTART+J)-X(ISTART+I))
  20 CONTINUE
  C      THIS LOOP CALCULATES THE COEFFICIENTS OF THE EXPANSION.
    YOUT(JN)=0
    DO 30 I=1,INTERP
      30 YOUT(JN)=YOUT(JN)+P(I)*Y(ISTART+I)
  C      THIS LOOP COMPUTES THE POLYNOMIAL EXPANSION OF THE FUNCTION.
    100 CONTINUE
      RETURN
    END

```

SIMPIN,1,680610, 43718

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C-----SIMPSON RULE WEIGHT GENERATOR
C      JWT = NUMBER OF POINTS
C      WTA = X VALUES
C      FIN = Y VALUES
C      F = INTEGRAL VALUES
C-----SURROUTINE SIMPIN(JWT,WTA,FIN,F)
C-----DIMENSION WTA(1000),WATES(1000),FIN(1000),F(1000)
C-----JWT = JWT
C-----DO 300 NWT=1,JWT
C-----WTA = NWT
C-----IF(NWT-2) 19,39,39
C-----19 WATES(1) = 0.0
C-----39 WDEL = ABS((WTA(1)-WTA(NWT))/(WTA-1.))
C-----IF(NWT-2) 259,1190,139
C-----1190 WATES(1) = WDEL*.5
C-----WATES(2) = WATES(1)
C-----GO TO 259
C-----139 NWT=(WTA/2.+1)
C-----NWT=(WTA/2.-1)
C-----NWT=(WTA/4.+1)
C-----NWT=(WTA/4.-1)
C-----WDEL=WDEL/3.
C-----WATES(1)=WATES(1)
C-----WATES(NWT) = WATES(1)
C-----DO 159 I=1,NWTB
C-----WATES(I+1)=WDEL+WTC
C-----WATES(NWT-I)=WDEL+WTC
C-----159 WTC=WTC
C-----WTD=1./24.
C-----IF(NWTC.GT.NWTD) WTD=WTC
C-----IF(NWTA-NWTR) 259,259,179
C-----179 WATES(NWTR)=WATES(NWTR)-WTD*WTDFL
C-----WATES(NWTR+1)=WATES(NWTR+1)+5.*WTD*WTDFT
C-----WATES(NWTR+3)=WATES(NWTR)
C-----WATES(NWTR+2)=WATES(NWTR+1)
C-----259 F(NWT)=0.0
C-----DO 260 I=1,NWT
C-----260 F(NWT)=F(NWT)+WATES(I)*FIN(I)
C-----300 CONTINUE
C-----RETURN
C-----END

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SUBROUTINE STMTRI (M,V,STVM)
  DIMENSION STVD(10),X(295,10)
  C SUBROUTINE PROGRAM,STEAM TABLES,SAT,INTERPOLATION
  C FOLLOWING STATEMENTS TO APPEAR IN MAIN PROGRAM.
  C DIMENSION STV(10) WHERE STV IS ANY IFGAI FORTRAN VARIABLE
  C DEFINITIONS
  C THE CALL STATEMENT IS CALL STMTRI (N,P,STV)
  C WHERE N=INPUT COLUMN INTEGER,P=ASSIGNED VALUE OF THE COLUMN
  C AND STV=INTERPOLATED VALUES FOR P RANGING FROM 1 TO 10.
  C THUS STV(J)=TABLE VALUE CORRESPONDING TO P IN COLUMN J.
  C N=STEAM TABLE ROW ENTRY UPON WHICH INTERPOLATION IS TO BE MADE (N=1,10)
  C THIS SHOULD NOT BE CONFUSED WITH THE CALL STATEMENT
  C VALUE OF PROPERTY AT WHICH CORRESPONDING VALUES ARE TO BE DETERMINED
  C IF SCANNING ON UG OR HG, SINCE THESE VALUES REACH MAX. VALUES AT ABOUT
  C 450PSIG, THIS PROGRAM WILL FIND VALUES ON ASCENDING SIDE ONLY. IF
  C DESCENDING VALUES ARE REQUIRED,USE 10*M
  C
  C STV(1) = PRESSURE (PSIA)
  C STV(2) = TEMPERATURE (DEGREES F)
  C STV(3) = SPECIFIC VOLUME (SATURATED LIQUID)
  C STV(4) = SPECIFIC VOLUME (SATURATED VAPOR)
  C STV(5) = ENTHALPY (SATURATED LIQUID)
  C STV(6) = ENTHALPY (SATURATED VAPOR)
  C STV(7) = ENTROPY (SATURATED LIQUID)
  C STV(8) = ENTROPY (SATURATED VAPOR)
  C STV(9) = INTERNAL ENERGY (SATURATED LIQUID)
  C STV(10) = INTERNAL ENERGY (SATURATED VAPOR)
  C
  DATA ( X(1,1),1=1,272) /20.,25.,30.,35.,40.,45.,50.,55.,60.,65.,70.,75.,80.,85.,90.,95.,100.,105.,110.,115.,120.,125.,130.,135.,140.,145.,150.,155.,160.,165.,170.,175.,180.,185.,190.,195.,200.,205.,210.,215.,220.,225.,230.,235.,240.,245.,250.,255.,260.,265.,270.,275.,280.,285.,290.,295.,300.,
  11.0,12.1,13.4,14.6,15.8,17.0,18.2,19.4,20.6,21.8,23.0,24.2,25.4,26.6,27.8,29.0,30.3,31.5,32.7,34.0,35.2,36.4,37.7,38.9,40.1,41.4,42.7,43.9,45.2,46.4,47.7,48.9,50.1,51.4,52.6,53.8,55.1,56.3,57.5,58.8,59.9,61.1,62.3,63.5,64.6,65.8,67.0,68.2,69.4,70.6,71.8,73.0,74.2,75.4,76.6,77.8,79.0,80.1,81.3,82.5,83.7,84.9,86.1,87.3,88.5,89.7,90.9,92.1,93.3,94.5,95.7,96.9,98.1,99.3,100.5,101.7,102.9,104.1,105.3,106.5,107.7,108.9,110.1,111.3,112.5,113.7,114.9,116.1,117.3,118.5,119.7,120.9,122.1,123.3,124.5,125.7,126.9,128.1,129.3,130.5,131.7,132.9,134.1,135.3,136.5,137.7,138.9,140.1,141.3,142.5,143.7,144.9,146.1,147.3,148.5,149.7,150.9,152.1,153.3,154.5,155.7,156.9,158.1,159.3,160.5,161.7,162.9,164.1,165.3,166.5,167.7,168.9,170.1,171.3,172.5,173.7,174.9,176.1,177.3,178.5,179.7,180.9,182.1,183.3,184.5,185.7,186.9,188.1,189.3,190.5,191.7,192.9,194.1,195.3,196.5,197.7,198.9,199.1,200.3,201.5,202.7,203.9,205.1,206.3,207.5,208.7,209.9,211.1,212.3,213.5,214.7,215.9,217.1,218.3,219.5,220.7,221.9,223.1,224.3,225.5,226.7,227.9,229.1,230.3,231.5,232.7,233.9,235.1,236.3,237.5,238.7,239.9,241.1,242.3,243.5,244.7,245.9,247.1,248.3,249.5,250.7,251.9,253.1,254.3,255.5,256.7,257.9,259.1,260.3,261.5,262.7,263.9,265.1,266.3,267.5,268.7,269.9,271.1,272.3,273.5,274.7,275.9,277.1,278.3,279.5,280.7,281.9,283.1,284.3,285.5,286.7,287.9,289.1,290.3,291.5,292.7,293.9,295.1,296.3,297.5,298.7,299.9,301.1,302.3,303.5,304.7,305.9,307.1,308.3,309.5,310.7,311.9,313.1,314.3,315.5,316.7,317.9,319.1,320.3,321.5,322.7,323.9,325.1,326.3,327.5,328.7,329.9,331.1,332.3,333.5,334.7,335.9,337.1,338.3,339.5,340.7,341.9,343.1,344.3,345.5,346.7,347.9,349.1,350.3,351.5,352.7,353.9,355.1,356.3,357.5,358.7,359.9,361.1,362.3,363.5,364.7,365.9,367.1,368.3,369.5,370.7,371.9,373.1,374.3,375.5,376.7,377.9,379.1,380.3,381.5,382.7,383.9,385.1,386.3,387.5,388.7,389.9,391.1,392.3,393.5,394.7,395.9,397.1,398.3,399.5,400.7,401.9,403.1,404.3,405.5,406.7,407.9,409.1,410.3,411.5,412.7,413.9,415.1,416.3,417.5,418.7,419.9,421.1,422.3,423.5,424.7,425.9,427.1,428.3,429.5,430.7,431.9,433.1,434.3,435.5,436.7,437.9,439.1,440.3,441.5,442.7,443.9,445.1,446.3,447.5,448.7,449.9,451.1,452.3,453.5,454.7,455.9,457.1,458.3,459.5,460.7,461.9,463.1,464.3,465.5,466.7,467.9,469.1,470.3,471.5,472.7,473.9,475.1,476.3,477.5,478.7,479.9,481.1,482.3,483.5,484.7,485.9,487.1,488.3,489.5,490.7,491.9,493.1,494.3,495.5,496.7,497.9,499.1,500.3,501.5,502.7,503.9,505.1,506.3,507.5,508.7,509.9,511.1,512.3,513.5,514.7,515.9,517.1,518.3,519.5,520.7,521.9,523.1,524.3,525.5,526.7,527.9,529.1,530.3,531.5,532.7,533.9,535.1,536.3,537.5,538.7,539.9,541.1,542.3,543.5,544.7,545.9,547.1,548.3,549.5,550.7,551.9,553.1,554.3,555.5,556.7,557.9,559.1,560.3,561.5,562.7,563.9,565.1,566.3,567.5,568.7,569.9,571.1,572.3,573.5,574.7,575.9,577.1,578.3,579.5,580.7,581.9,583.1,584.3,585.5,586.7,587.9,589.1,590.3,591.5,592.7,593.9,595.1,596.3,597.5,598.7,599.9,601.1,602.3,603.5,604.7,605.9,607.1,608.3,609.5,610.7,611.9,613.1,614.3,615.5,616.7,617.9,619.1,620.3,621.5,622.7,623.9,625.1,626.3,627.5,628.7,629.9,631.1,632.3,633.5,634.7,635.9,637.1,638.3,639.5,640.7,641.9,643.1,644.3,645.5,646.7,647.9,649.1,650.3,651.5,652.7,653.9,655.1,656.3,657.5,658.7,659.9,661.1,662.3,663.5,664.7,665.9,667.1,668.3,669.5,670.7,671.9,673.1,674.3,675.5,676.7,677.9,679.1,680.3,681.5,682.7,683.9,685.1,686.3,687.5,688.7,689.9,691.1,692.3,693.5,694.7,695.9,697.1,698.3,699.5,700.7,701.9,703.1,704.3,705.5,706.7,707.9,709.1,710.3,711.5,712.7,713.9,715.1,716.3,717.5,718.7,719.9,721.1,722.3,723.5,724.7,725.9,727.1,728.3,729.5,730.7,731.9,733.1,734.3,735.5,736.7,737.9,739.1,740.3,741.5,742.7,743.9,745.1,746.3,747.5,748.7,749.9,751.1,752.3,753.5,754.7,755.9,757.1,758.3,759.5,760.7,761.9,763.1,764.3,765.5,766.7,767.9,769.1,770.3,771.5,772.7,773.9,775.1,776.3,777.5,778.7,779.9,781.1,782.3,783.5,784.7,785.9,787.1,788.3,789.5,790.7,791.9,793.1,794.3,795.5,796.7,797.9,799.1,800.3,801.5,802.7,803.9,805.1,806.3,807.5,808.7,809.9,811.1,812.3,813.5,814.7,815.9,817.1,818.3,819.5,820.7,821.9,823.1,824.3,825.5,826.7,827.9,829.1,830.3,831.5,832.7,833.9,835.1,836.3,837.5,838.7,839.9,841.1,842.3,843.5,844.7,845.9,847.1,848.3,849.5,850.7,851.9,853.1,854.3,855.5,856.7,857.9,859.1,860.3,861.5,862.7,863.9,865.1,866.3,867.5,868.7,869.9,871.1,872.3,873.5,874.7,875.9,877.1,878.3,879.5,880.7,881.9,883.1,884.3,885.5,886.7,887.9,889.1,890.3,891.5,892.7,893.9,895.1,896.3,897.5,898.7,899.9,901.1,902.3,903.5,904.7,905.9,907.1,908.3,909.5,910.7,911.9,913.1,914.3,915.5,916.7,917.9,919.1,920.3,921.5,922.7,923.9,925.1,926.3,927.5,928.7,929.9,931.1,932.3,933.5,934.7,935.9,937.1,938.3,939.5,940.7,941.9,943.1,944.3,945.5,946.7,947.9,949.1,950.3,951.5,952.7,953.9,955.1,956.3,957.5,958.7,959.9,961.1,962.3,963.5,964.7,965.9,967.1,968.3,969.5,970.7,971.9,973.1,974.3,975.5,976.7,977.9,979.1,980.3,981.5,982.7,983.9,985.1,986.3,987.5,988.7,989.9,991.1,992.3,993.5,994.7,995.9,997.1,998.3,999.5,1000.7,1001.9,1003.1,1004.3,1005.5,1006.7,1007.9,1009.1,1010.3,1011.5,1012.7,1013.9,1015.1,1016.3,1017.5,1018.7,1019.9,1021.1,1022.3,1023.5,1024.7,1025.9,1027.1,1028.3,1029.5,1030.7,1031.9,1033.1,1034.3,1035.5,1036.7,1037.9,1039.1,1040.3,1041.5,1042.7,1043.9,1045.1,1046.3,1047.5,1048.7,1049.9,1051.1,1052.3,1053.5,1054.7,1055.9,1057.1,1058.3,1059.5,1060.7,1061.9,1063.1,1064.3,1065.5,1066.7,1067.9,1069.1,1070.3,1071.5,1072.7,1073.9,1075.1,1076.3,1077.5,1078.7,1079.9,1081.1,1082.3,1083.5,1084.7,1085.9,1087.1,1088.3,1089.5,1090.7,1091.9,1093.1,1094.3,1095.5,1096.7,1097.9,1099.1,1100.3,1101.5,1102.7,1103.9,1105.1,1106.3,1107.5,1108.7,1109.9,1111.1,1112.3,1113.5,1114.7,1115.9,1117.1,1118.3,1119.5,1120.7,1121.9,1123.1,1124.3,1125.5,1126.7,1127.9,1129.1,1130.3,1131.5,1132.7,1133.9,1135.1,1136.3,1137.5,1138.7,1139.9,1141.1,1142.3,1143.5,1144.7,1145.9,1147.1,1148.3,1149.5,1150.7,1151.9,1153.1,1154.3,1155.5,1156.7,1157.9,1159.1,1160.3,1161.5,1162.7,1163.9,1165.1,1166.3,1167.5,1168.7,1169.9,1171.1,1172.3,1173.5,1174.7,1175.9,1177.1,1178.3,1179.5,1180.7,1181.9,1183.1,1184.3,1185.5,1186.7,1187.9,1189.1,1190.3,1191.5,1192.7,1193.9,1195.1,1196.3,1197.5,1198.7,1199.9,1201.1,1202.3,1203.5,1204.7,1205.9,1207.1,1208.3,1209.5,1210.7,1211.9,1213.1,1214.3,1215.5,1216.7,1217.9,1219.1,1220.3,1221.5,1222.7,1223.9,1225.1,1226.3,1227.5,1228.7,1229.9,1231.1,1232.3,1233.5,1234.7,1235.9,1237.1,1238.3,1239.5,1240.7,1241.9,1243.1,1244.3,1245.5,1246.7,1247.9,1249.1,1250.3,1251.5,1252.7,1253.9,1255.1,1256.3,1257.5,1258.7,1259.9,1261.1,1262.3,1263.5,1264.7,1265.9,1267.1,1268.3,1269.5,1270.7,1271.9,1273.1,1274.3,1275.5,1276.7,1277.9,1279.1,1280.3,1281.5,1282.7,1283.9,1285.1,1286.3,1287.5,1288.7,1289.9,1291.1,1292.3,1293.5,1294.7,1295.9,1297.1,1298.3,1299.5,1300.7,1301.9,1303.1,1304.3,1305.5,1306.7,1307.9,1309.1,1310.3,1311.5,1312.7,1313.9,1315.1,1316.3,1317.5,1318.7,1319.9,1321.1,1322.3,1323.5,1324.7,1325.9,1327.1,1328.3,1329.5,1330.7,1331.9,1333.1,1334.3,1335.5,1336.7,1337.9,1339.1,1340.3,1341.5,1342.7,1343.9,1345.1,1346.3,1347.5,1348.7,1349.9,1351.1,1352.3,1353.5,1354.7,1355.9,1357.1,1358.3,1359.5,1360.7,1361.9,1363.1,1364.3,1365.5,1366.7,1367.9,1369.1,1370.3,1371.5,1372.7,1373.9,1375.1,1376.3,1377.5,1378.7,1379.9,1381.1,1382.3,1383.5,1384.7,1385.9,1387.1,1388.3,1389.5,1390.7,1391.9,1393.1,1394.3,1395.5,1396.7,1397.9,1399.1,1400.3,1401.5,1402.7,1403.9,1405.1,1406.3,1407.5,1408.7,1409.9,1411.1,1412.3,1413.5,1414.7,1415.9,1417.1,1418.3,1419.5,1420.7,1421.9,1423.1,1424.3,1425.5,1426.7,1427.9,1429.1,1430.3,1431.5,1432.7,1433.9,1435.1,1436.3,1437.5,1438.7,1439.9,1441.1,1442.3,1443.5,1444.7,1445.9,1447.1,1448.3,1449.5,1450.7,1451.9,1453.1,1454.3,1455.5,1456.7,1457.9,1459.1,1460.3,1461.5,1462.7,1463.9,1465.1,1466.3,1467.5,1468.7,1469.9,1471.1,1472.3,1473.5,1474.7,1475.9,1477.1,1478.3,1479.5,1480.7,1481.9,1483.1,1484.3,1485.5,1486.7,1487.9,1489.1,1490.3,1491.5,1492.7,1493.9,1495.1,1496.3,1497.5,1498.7,1499.9,1501.1,1502.3,1503.5,1504.7,1505.9,1507.1,1508.3,1509.5,1510.7,1511.9,1513.1,1514.3,1515.5,1516.7,1517.9,1519.1,1520.3,1521.5,1522.7,1523.9,1525.1,1526.3,1527.5,1528.7,1529.9,1531.1,1532.3,1533.5,1534.7,1535.9,1537.1,1538.3,1539.5,1540.7,1541.9,1543.1,1544.3,1545.5,1546.7,1547.9,1549.1,1550.3,1551.5,1552.7,1553.9,1555.1,1556.3,1557.5,1558.7,1559.9,1561.1,1562.3,1563.5,1564.7,1565.9,1567.1,1568.3,1569.5,1570.7,1571.9,1573.1,1574.3,1575.5,1576.7,1577.9,1579.1,1580.3,1581.5,1582.7,1583.9,1585.1,1586.3,1587.5,1588.7,1589.9,1591.1,1592.3,1593.5,1594.7,1595.9,1597.1,1598.3,1599.5,1600.7,1601.9,1603.1,1604.3,1605.5,1606.7,1607.9,1609.1,1610.3,1611.5,1612.7,1613.9,1615.1,1616.3,1617.5,1618.7,1619.9,1621.1,1622.3,1623.5,1624.7,1625.9,1627.1,1628.3,1629.5,1630.7,1631.9,1633.1,1634.3,1635.5,1636.7,1637.9,1639.1,1640.3,1641.5,1642.7,1643.9,1645.1,1646.3,1647.5,1648.7,1649.9,1651.1,1652.3,1653.5,1654.7,1655.9,1657.1,1658.3,1659.5,1660.7,1661.9,1663.1,1664.3,1665.5,1666.7,1667.9,1669.1,1670.3,1671.5,1672.7,1673.9,1675.1,1676.3,1677.5,1678.7,1679.9,1681.1,1682.3,1683.5,1684.7,1685.9,1687.1,1688.3,1689.5,1690.7,1691.9,1693.1,1694.3,1695.5,1696.7,1697.9,1699.1,1700.3,1701.5,1702.7,1703.9,1705.1,1706.3,1707.5,1708.7,1709.9,1711.1,1712.3,1713.5,1714.7,1715.9,1717.1,1718.3,1719.5,1720.7,1721.9,1723.1,1724.3,1725.5,1726.7,1727.9,1729.1,1730.3,1731.5,1732.7,1733.9,1735.1,1736.3,1737.5,1738.7,1739.9,1741.1,1742.3,1743.5,1744.7,1745.9,1747.1,1748.3,1749.5,1750.7,1751.9,1753.1,1754.3,1755.5,1756.7,1757.9,1759.1,1760.3,1761.5,1762.7,1763.9,1765.1,1766.3,1767.5,1768.7,1769.9,1771.1,1772.3,1773.5,1774.7,1775.9,1777.1,1778.3,1779.5,1780.7,1781.9,1783.1,1784.3,1785.5,1786.7,1787.9,1789.1,1790.3,1791.5,1792.7,1793.9,1795.1,1796.3,1797.5,1798.7,1799.9,1801.1,1802.3,1803.5,1804.7,1805.9,1807.1,1808.3,1809.5,1810.7,1811.9,1813.1,1814.3,1815.5,1816.7,1817.9,1819.1,1820.3,1821.5,1822.7,1823.9,1825.1,1826.3,1827.5,1828.7,1829.9,1831.1,1832.3,1833.5,1834.7,1835.9,1837.1,1838.3,1839.5,1840.7,1841.9,1843.1,1844.3,1845.5,1846.7,1847.9,1849.1,1850.3,1851.5,1852.7,1853.9,1855.1,1856.3,1857.5,1858.7,1859.9,1861.1,1862.3,1863.5,1864.7,1865.9,1867.1,1868.3,1869.5,1870.7,1871.9,1873.1,1874.3,1875.5,1876.7,1877.9,1879.1,1880.3,1881.5,1882.7,1883.9,1885.1,1886.3,1887.5,1888.7,1889.9,1891.1,1892.3,1893.5,1894.7,1895.9,1897.1,1898.3,1899.5,1900.7,1901.9,1903.1,1904.3,1905.5,1906.7,1907.9,1909.1,1910.3,1911.5,1912.7,1913.9,1915.1,1916.3,1917.5,1918.7,1919.9,1921.1,1922.3,1923.5,1924.7,1925.9,1927.1,1928.3,1929.5,1930.7,1931.9,1933.1,1934.3,1935.5,1936.7,1937.9,1939.1,1940.3,1941.5,1942.7,1943.9,1945.1,1946.3,1947.5,1948.7,1949.9,1951.1,1952.3,1953.5,1954.7,1955.9,1957.1,1958.3,1959.5,1960.7,1961.9,1963.1,1964.3,1965.5,1966.7,1967.9,1969.1,1970.3,1971.5,1972.7,1973.9,1975.1,1976.3,1977.5,1978.7,1979.9,1981.1,1982.3,1983.5,1984.7,1985.9,1987.1,1988.3,1989.5,1990.7,1991.9,1993.1,1994.3,1995.5,1996.7,1997.9,1999.1,2000.3,2001.5,2002.7,2003.9,2005.1,2006.3,2007.5,2008.7,2009.9,2011.1,2012.3,2013.5,2014.7,2015.9,2017.1,2018.3,2019.5,2020.7,2021.9,2023.1,2024.3,2025.5,2026.7,2027.9,2029.1,2030.3,2031.5,2032.7,2033.9,2035.1,2036.3,2037.5,2038.7,2039.9,2041.1,2042.3,2043.5,2044.7,2045.9,2047.1,2048.3,2049.5,2050.7,2051.9,2053.1,2054.3,2055.5,2056.7,2057.9,2059.1,2060.3,2061.5,2062.7,2063.9,2065.1,2066.3,2067.5,2068.7,2069.9,2071.1,2072.3,2073.5,2074.7,2075.9,2077.1,2078.3,2079.5,2080.7,2081.9,2083.1,2084.3,2085.5,2086.7,2087.9,2089.1,2090.3,2091.5,2092.7,2093.9,2095.1,2096.3,2097.5,2098.7,2099.9,2101.1,2102.3,2103.5,2104.7,2105.9,2107.1,2108.3,2109.5,2110.7,2111.9,2113.1,2114.3,2115.5,2116.7,2117.9,2119.1,2120.3,2121.5,2122.7,2123.9,2125.1,2126.3,2127.5,2128.7,2129.9,2131.1,2132.3,2133.5,2134.7,2135.9,2137.1,2138.3,2139.5,2140.7,2141.9,2143.1,2144.
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6310.,320.,330.,340.,350.,360.,370.,380.,390.,400.,410.,420.,430.,
 7440.,450.,460.,470.,480.,490.,500.,520.,540.,560.,580.,600.,620.,
 8640.,660.,680.,700.,720.,740.,760.,780.,800.,820.,840.,860.,880.,
 9900.,920.,940.,960.,980.,1000.,1050.,1100.,1150.,1200.,1250.,
 DATA (X(1,1),1=273,295)/1300.,1350.,1400.,1450.,1500.,1600.,
 11700.,1800.,1900.,2000.,2100.,2200.,2300.,2400.,2500.,2600.,
 22700.,2800.,2900.,3000.,3100.,3200.,3206.2
 DATA (X(1,2),1=1,176 1753,14,59,30,64,72,86,93,72,86,76,38,79,58,
 185,21,90,08,94,38,98,24,101,74,107,92,113,26,117,99,122,23,126,08,
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 DATA (X(1,2),1=177,295)/358,42,359,46,360,49,361,52,362,53,363,53,
 1364,53,365,51,366,48,367,45,368,41,369,36,370,29,371,22,372,14,
 2373,06,373,96,374,86,375,75,376,64,377,51,378,38,379,24,380,10,
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 6434,40,437,03,439,60,442,12,444,59,447,01,449,39,451,73,454,02,
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 X 537,16,539,68,542,17,544,61,550,57,556,31,
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 2613,15,621,03,628,58,635,82,642,77,649,46,655,91,662,12,668,13,
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 DATA (X(1,3),1=1,174 1753,14,59,30,64,72,86,93,72,86,76,38,79,58,
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 2,01621.,01623.,01624.,01626.,01627.,01629.,01630.,01633.,01636,
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C      ..01739..01740..01741..01742..01743..01744,
1.01745..01746..01747..01748..01749..01750..01751..01752..01753,
2.01754..01755..01756..01757..01758..01759..01760..01761,
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4.01769..01770..01771..01772..01773..01774..01775..01776,
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6.01783..01784..01785..01786..01787..01788..01789,
7.01790..01791..01792..01793..01794..01795,
8.01796..01797..01798..01799..01800..01801..01802,
9.01802..01803..01804..01805..01806..01807 /
DATA (X(1,3),I=175,295)/,01808..01809..01810..01812..01813,
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3.01835..01836..01838..01839..01842..01844..01847..01850..01852,
4.01854..01857..01860..01863..01865..01868..01870..01873..01875,
5.01878..01880..01883..01885..01887..01890..01894..01899..01904,
6.01908..01913..01917..01921..01925..01930..0193..0194..0194,0194,
7.0195..0196..0196,0197,0197,0197,0197,0198,0199,0200,0201,
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9.0209,0210,0211,0212,0213,0214,0214,0215,0216,0218,
X      ..0220..0221..0223..0225..0227..0229..0231,
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2.0287,0295,0305,0315,0329,0336,0371,0444,0503 /
DATA (X(1,4),I=1,204 )/1526,1235,3,1039,5,898,5,791,9,708,5,
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518,375,17,627,16,938,16,303,15,715,15,170,14,663,14,189,13,746,
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710,498,10,258,10,029,9,810,9,601,9,401,9,209,9,025,8,848,8,678,
88,515,8,359,8,208,8,062,7,922,7,787,7,656,7,529,7,407,7,289,7,175,
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0      6,044,5,966,5,890,5,816,5,743,5,673,5,604,
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92,479,2,454,2,429,2,404,2,380,2,356,2,333,2,310,2,288,2,264,2,242,2,218,
DATA (X(1,4),I=205,295)/2,134,2,087,2,042,2,1,999,2,1,957,1,918,3,
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 9.0858., 0753., 0588., 0503.
 DATA (X(I,5), I=1,90) 1/21.21, 27.36, 32.52, 36.97, 40.89, 44.41, 47.60,
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 DATA (X(I,5), I=91, 271) 1/266.45, 267.50, 268.55, 269.58, 270.60, 271.61,
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 DATA (X(I,5), I=272, 295) 1/578.6, 585.4, 592.1, 598.7, 605.2, 611.6, 624.1,
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 2770.1, 785.4, 802.5, 825.0, 872.4, 902.7,
 DATA (X(I,6), I=1, 174) 1/1085., 1087.7, 1090., 1091.9, 1093.6, 1095.1,
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91192.9, 1193.0, 1193.1, 1193.2, 1193.3, 1193.4, 1193.5, 1193.6, 1193.8	
DATA (X(I,6), I=175, 295) / 1193.9, 1194.1, 1194.3, 1194.5, 1194.7,	
11194.9, 1195.1, 1195.3, 1195.5, 1195.7, 1195.8, 1196.0, 1196.2, 1196.4,	
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21167.9, 1162.1, 1155.9, 1149.4, 1142.4, 1135.1, 1127.4, 1119.2, 1110.4,	
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4902.7	
DATA (X(I,7), I=1, 107) / .0422, .0542, .0641, .0725, .0799, .0865, .0924,	
1.1028, .1117, .1194, .1263, .1326, .1435, .1528, .1610, .1683, .1749, .1809,	
2.1864, .1916, .1963, .2008, .2109, .2198, .2276, .2347, .2411, .2472, .2528,	
3.2581, .2629, .2674, .2718, .2759, .2798, .2835, .2903, .2967, .3027, .3083,	
X.3120,	
4.3135, .3184, .3231, .3275, .3317, .3356, .3395, .3431, .3466, .3500, .3533,	
5.3564, .3594, .3621, .3652, .3680, .3707, .3733, .3758, .3783, .3807, .3831,	
6.3854, .3876, .3898, .3919, .3940, .3960, .3980, .4000, .4019, .4038, .4057,	
7.4075, .4093, .4110, .4127, .4144, .4161, .4177, .4193, .4209, .4225, .4240,	
8.4255, .4270, .4285, .4300, .4314, .4328, .4342, .4356, .4369, .4383, .4396,	
9.4409, .4422, .4435, .4447, .4460, .4472, .4484, .4496, .4508, .4520, .4531,	
DATA (X(I,7), I=108, 295) / .4543, .4554, .4565, .4576, .4587, .4598, .4609,	
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2.4721, .4731, .4740, .4750, .4759, .4768, .4778, .4787, .4796, .4805, .4814,	
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4.4916, .4924, .4932, .4940, .4948, .4956, .4964, .4972, .4980, .4987, .4995,	
5.5002, .5010, .5018, .5025, .5032, .5040, .5047, .5054, .5061, .5069, .5076,	
6.5083, .5090, .5097, .5104, .5111, .5118, .5124, .5131, .5138, .5145, .5151,	
7.5178, .5191, .5204, .5216, .5229, .5241, .5254, .5266, .5278, .5290, .5302,	
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I 5697, .5719, .5740, .5760, .5781, .5801, .5821,	
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2.6184, .6214, .6243, .6272, .6301, .6329, .6356, .6383, .6410, .6436, .6462,	

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 DATA (X(I),I)=1.89 1/2,1163,2.0970,2.0812,2.0678,2.0563,2.0462,
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 41.7918,1.7876,1.78,1.773,1.7665,1.7605,1.7566,1.7549,1.7497,
 X 1.7449,
 51.7403,1.736,1.7319,1.728,1.7242,1.7206,1.7172,1.7139,1.7108,
 61.7078,1.7048,1.702,1.6993,1.6967,1.6941,1.6917,1.6893,1.687,
 71.6848,1.6826,1.6805,1.6784,1.6763,1.6743,1.6724,1.6706,1.6687,
 81.6669,1.6652,1.6634,1.6617,1.6601,1.6585,1.6569,1.6553,1.6538,
 91.6523,1.6509,1.6494,1.648,1.6466,1.6452,1.6438,1.6425,1.6412,
 DATA (X(I),I)=90,176 1/1.6399,1.6387,1.6374,1.6362,1.635,1.6338,
 11.6326,1.6315,1.6303,1.6292,1.6281,1.6270,1.6259,1.6248,1.6238,
 21.6228,1.6217,1.6207,1.6197,1.6187,1.6177,1.6168,1.6158,1.6149,
 31.6139,1.6130,1.6121,1.6112,1.6103,1.6094,1.6085,1.6076,1.6068,
 41.6060,1.6051,1.6043,1.6035,1.6026,1.6018,1.6010,1.6002,1.5994,
 51.5986,1.5978,1.5971,1.5963,1.5956,1.5948,1.5941,1.5934,1.5927,
 61.5919,1.5912,1.5905,1.5898,1.5891,1.5885,1.5878,1.5871,1.5865,
 71.5858,1.5851,1.5844,1.5838,1.5831,1.5825,1.5819,1.5812,1.5806,
 81.5800,1.5793,1.5787,1.5781,1.5775,1.5769,1.5763,1.5757,1.5751,
 91.5745,1.5740,1.5734,1.5728,1.5722,1.5716,1.5710,1.5705,1.5699,
 DATA (X(I),I)=177,295 1/1.5694,1.5683,1.5672,1.5661,1.5650,1.5640,
 11.563,1.5621,1.561,1.56,1.559,1.558,1.557,1.5561,1.5551,1.5542,
 21.5532,1.5523,1.5514,1.5506,1.5497,1.5488,1.5479,1.5471,1.5462,
 31.5453,1.5432,1.5412,1.5392,1.5372,1.5353,1.5334,1.5316,1.5298,
 41.5280,1.5263,1.5246,1.5229,1.5212,1.5196,1.5180,1.5164,1.5149,
 51.5133,1.5118,1.5104,1.5075,1.5046,1.5019,1.4992,1.4966,1.4941,
 61.4916,1.4891,1.4867,1.4844,1.4821,1.4799,1.4777,1.4755,1.4734,
 71.4713,1.4693,1.4673,1.4653,1.4634,1.4616,1.4596,1.4577,1.4558,
 81.454,1.4521,1.4509,1.4489,1.4469,1.4449,1.4429,1.4409,1.4389,
 91.4369,1.4349,1.4329,1.4309,1.4289,1.4269,1.4249,1.4229,1.4209,
 91.4181,1.4153,1.4126,1.4099,1.4072,1.4046,1.4020,1.3995,1.3970,
 X 1.3945,1.3921,1.3897,1.3873,1.3848,1.3823,
 X 1.3667,1.3612,1.3559,
 1.3506,1.3454,1.3402,1.3351,1.3299,1.3249,1.3199,1.3149,
 21.2949,1.2899,1.2849,1.2799,1.2749,1.2699,1.2649,1.2599,1.2549,1.2499,
 31.1946,1.1702,1.1415,1.1368,1.0852,1.0580,
 DATA (X(I),I)=1,177 1/21,21.27,36,32,52,36,07,40,89,44,41,47,60,
 153,21,58,07,62,36,66,21,69,70,75,87,81,20,85,91,90,13,93,98,97,51,
 2100,78,103,82,106,67,109,36,115,45,120,85,125,70,130,12,134,17,
 3137,94,141,45,144,74,147,84,150,77,153,54,156,19,158,72,161,14,
 4165,70,169,02,173,27,177,57,180,02,181,06,184,37,187,61,190,50,
 5193,36,196,10,198,73,201,26,203,71,206,07,208,34,210,54,212,67,
 6214,74,216,77,218,73,220,63,222,49,224,31,226,07,227,80,229,49,
 7231,14,232,77,234,36,235,90,237,42,238,91,240,37,241,81,243,22,

8244.60.245.97.247.32.248.63.249.93.251.21.252.46.253.70.254.92,
9256.12.257.32.258.49.259.63.260.77.261.90.263.00.264.10.265.18,
K 266.24.267.29.268.34.269.36.270.38.271.39,
1272.38.273.37.274.34.275.30.276.25.277.19.278.12.279.05.279.96,
2280.86.281.76.282.65.283.52.284.39.285.26.286.11.286.96.287.80,
3288.63.289.45.290.27.291.08.291.88.292.68.293.47.294.25.295.03,
4295.80.296.57.297.33.298.08.298.82.299.57.300.30.301.03.301.75,
5302.47.303.19.303.90.304.61.305.30.306.00.306.69.307.38.308.05,
6308.73.309.41.310.07.310.73.311.39.312.05.312.70.313.35.313.99,
7314.63.315.26.315.89.316.52.317.15.317.77.318.38.318.99.319.60,
8320.21.320.80.321.40.322.00.322.59.323.18.323.77.324.35.324.93,
9325.51.326.08.326.65.327.22.327.78.328.34.328.90.329.45.330.01 /
DATA (X(1,9),I=178,295)/331.10.332.18.333.26.334.23.335.39.336.44,
1337.47.338.49.339.51.340.52.341.52.342.51.343.50.344.46.345.42,
2346.38.347.34.348.29.349.22.350.15.351.07.351.98.352.89.353.79,
3354.68.356.88.359.05.361.18.363.27.365.32.367.34.369.33.371.29,
4373.23.375.14.377.01.378.86.380.68.382.48.384.26.386.01.387.74,
5389.45.391.13.392.79.396.06.399.26.402.40.405.46.408.05.411.39,
6414.27.417.10.419.88.422.6.425.3.427.9.430.5.433.435.5.438.1
7440.5.442.9.445.2.447.6.452.2.456.6.460.9.465.2.469.4.473.4.477.4,
8481.3.485.1.488.8.492.5.496.2.499.7.503.2.506.6.510.0.513.3.516.6,
9519.9.523.1.526.2.529.3.532.4.535.4.538.4.545.8.552.9.559.9.566.7,
L 573.4.580.586.4.592.7.599.605.1.617.1
1628.7.640.1.651.2.662.2.673.1.683.9.694.8.706.7.717.3.728.8.741.1,
2753.8.767.7.783.4.803.7.846.1.872.9 /
DATA(X(1,10),I=1,174) /1028.5.1030.6.1032.3.1033.7.1035.1036.1,
11037.1.1038.9.1040.5.1041.9.1043.1.1044.3.1046.2.1047.9.1049.4,
21057.1051.9.1054.0.1054.1.1055.0.1055.9.1056.7.1058.6.1060.2,
31021.7.1063.1.1064.3.1065.4.1066.4.1067.4.1068.3.1069.2.1070.7,
41070.8.1071.5.1072.2.1073.5.1074.7.1075.8.1076.9.1077.5.1077.8,
51078.7.1079.5.1080.4.1081.2.1081.9.1082.6.1083.3.1083.9.1084.6,
61085.1.1085.7.1086.3.1086.8.1087.3.1087.8.1088.3.1088.7.1089.2,
71089.6.1090.1.1090.5.1090.9.1091.3.1091.6.1092.0.1092.4.1092.7,
81093.1.1093.4.1093.7.1094.1.1094.4.1094.7.1095.0.1095.3.1095.5,
91095.8.1096.1.1096.4.1096.7.1097.0.1097.2.1097.4.1097.7.1097.9,
M 1098.2.1098.4.1098.6.1098.8.1099.1.1099.3,
11099.5.1099.8.1100.0.1100.2.1100.4.1100.6.1100.8.1101.0.1101.2,
21101.4.1101.6.1101.7.1101.9.1102.1.1102.2.1102.4.1102.6.1102.8,
31102.9.1103.1.1103.2.1103.4.1103.6.1103.7.1103.9.1104.1.1104.2,
41104.4.1104.5.1104.6.1104.7.1104.9.1105.0.1105.2.1105.3.1105.4,
51105.6.1105.7.1105.9.1106.0.1106.1.1106.3.1106.4.1106.5.1106.6,
61106.7.1106.8.1106.9.1107.1.1107.2.1107.3.1107.4.1107.5.1107.6,
71107.7.1107.8.1107.9.1108.0.1108.1.1108.2.1108.3.1108.4.1108.5,
81108.6.1108.7.1108.8.1108.9.1109.0.1109.1.1109.2.1109.3.1109.4,
91109.5.1109.6.1109.7.1109.8.1109.9.1110.0.1110.1.1110.2 /
DATA(X(1,10),I=175,295)/1110.3.1110.4.1110.5.1110.6.1110.7.1110.9,
11111.0.1111.2.1111.4.1111.5.1111.7.1111.8.1111.9.1112.0.1112.2,
21112.3.1112.4.1112.5.1112.6.1112.8.1112.9.1113.0.1113.1.1113.2,
31113.3.1113.5.1113.6.1113.7.1114.0.1114.2.1114.4.1114.6.1114.8,

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41115.0,11115.3,11115.4,11115.6,11115.8,11116.0,11116.1,11116.3,11116.4,
51116.6,11116.7,11116.8,11116.9,11117.0,11117.1,11117.4,11117.6,11117.8,
61117.9,11118.0,11118.2,11118.3,11118.4,11118.5,11118.6,11118.7,
71118.7,11118.7,11118.7,11118.7,11118.7,11118.6,11118.6,11118.4,
81118.3,11118.2,11118.0,11117.7,11117.5,11117.3,11117.0,11116.7,11116.3,
91116.0,11115.6,11115.2,11114.8,11114.4,11114.0,11113.6,11113.1,1112.6,
N      1112.1,1111.5,1111.2,1099.8,1097.5,1095.4,1093.3,
11108.1,1106.4,1104.7,1103.1,1101.2,1099.4,1097.5,1095.4,1093.3,
21091.2,1086.7,1081.8,1076.8,1071.4,1065.6,1059.6,1053.1,1046.7
31038.6,1030.6,1021.9,1012.3,1001.2,988.2,972.7,949.9,898.4,872.9 /
4 IF (M-4)*(M-8)17.57
5 DO 6 I=1,295
6 CONTINUE
7 IF (V-X(I,M))6,12,12
8 IF (M-10)10,9,10
9 DO 91 I=236,295
10 IF (V-X(I,M))91,12,12
11 CONTINUE
12 DO 14
13 IF (V,LT,X(1,M)) GO TO 15
14 DO 11 I=2,295
15 IF (V-X(I,M))12,12,11
16 CONTINUE
17 IF (V,LT,X(1,M)) I=1
18 IF (M,EG,60,OR,M,EG,80) I=235
19 DO 14
20 DO 13 J=1,10
21 IF (V-X(I,M))120,121,120
22 STVD(J) = X(I-1,1)+(V-Y(I-1,M))/(X(I,M) - Y(I-1,M))*(Y(I,1)-X(I-1,
XJ))
23 GO TO 13
24 STVD(J)=X(I,1)
25 CONTINUE
26 RETURN
27 IF (M,EG,1) WRITE(3,900) V,X(I,M)
28 IF (M,EG,2) WRITE(3,901) V,X(I,M)
29 IF (M,EG,3) WRITE(3,902) V,X(I,M)
30 IF (M,EG,4) WRITE(3,903) V,X(I,M)
31 IF (M,EG,5) WRITE(3,904) V,X(I,M)
32 IF (M,EG,6) WRITE(3,905) V,X(I,M)
33 IF (M,EG,7) WRITE(3,906) V,X(I,M)
34 IF (M,EG,8) WRITE(3,907) V,X(I,M)
35 IF (M,EG,9) WRITE(3,908) V,X(I,M)
36 IF (M,EG,10) WRITE(3,909) V,X(I,M)
37 V = X(I,M)
38 GO TO 12

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000 FORMAT( 8H PRESSURE LIMITS OF STEAM TABLE ARE 20 TO 3206.2, P
1PFSSURE ENTERING TABLE WAS, 1PE12.5, 24H BUT HAS BEEN CHANGED TO,
2E12.5 )
001 FORMAT( 76H TEMP. LIMITS OF STEAM TABLE ARE 53.14 TO 705.4, TFM
1P. ENTERING TABLE WAS, 1PE12.5, 24H BUT HAS BEEN CHANGED TO, E12.5 )
002 FORMAT( 84H SPEC VOL L LIMITS OF STEAM TABLE ARE .01603 TO .0503,
1SPEC VOL L ENTERING TABLE WAS, 1PE12.5, 24H BUT HAS BEEN CHANGED TO,
2E12.5 )
003 FORMAT( 84H SPEC VOL V LIMITS OF STEAM TABLE ARE 1526, TO .0503,
1SPEC VOL V ENTERING TABLE WAS, 1PE12.5, 24H BUT HAS BEEN CHANGED TO,
2E12.5 )
004 FORMAT( 84H ENTHALPY L LIMITS OF STEAM TABLE ARE 21.21 TO 902.7,
1ENTHALPY L ENTERING TABLE WAS, 1PE12.5, 24H BUT HAS BEEN CHANGED TO,
2E12.5 )
005 FORMAT( 84H ENTHALPY V LIMITS OF STEAM TABLE ARE 902.7 TO 1204.6,
1ENTHALPY V ENTERING TABLE WAS, 1PE12.5, 24H BUT HAS BEEN CHANGED TO,
2E12.5 )
006 FORMAT( 84H ENTROPY L LIMITS OF STEAM TABLE ARE .0422 TO 1.0580,
1ENTROPY L ENTERING TABLE WAS, 1PE12.5, 24H BUT HAS BEEN CHANGED TO,
2E12.5 )
007 FORMAT( 84H ENTROPY V LIMITS OF STEAM TABLE ARE 2.1163 TO 1.058,
1ENTROPY V ENTERING TABLE WAS, 1PE12.5, 24H BUT HAS BEEN CHANGED TO,
2E12.5 )
008 FORMAT( 84H ENERGY L LIMITS OF STEAM TABLE ARE 21.210 TO 872.90,
1ENERGY L ENTERING TABLE WAS, 1PE12.5, 24H BUT HAS BEEN CHANGED TO,
2E12.5 )
009 FORMAT( 84H ENERGY V LIMITS OF STEAM TABLE ARE 872.90 TO 1118.7,
1ENERGY V ENTERING TABLE WAS, 1PE12.5, 24H BUT HAS BEEN CHANGED TO,
2E12.5 )
END

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SUBROUTINE PROPS(T,PV)
  DIMENSION PV(7),P(7,68),TP(68)
  PROPS IS A SUBROUTINE CONTAINING WATER PROPERTIES AT ATMOSPHERIC
  PRESSURE. THE CALL STATEMENT IS..

  C CALL PROPS(T,PV)

  C
  C WHERE...
  C T = TEMPERATURE IN DEGREES FAHRENHEIT
  C PV(1) = DENSITY IN LB/FT**3
  C PV(2) = SPECIFIC HEAT AT CONSTANT PRESSURE IN (BTU/LR-F)
  C PV(3) = DYNAMIC VISCOSITY IN (LR/FT-HR)
  C PV(4) = KINEMATIC VISCOSITY IN (FT**2/HR)
  C PV(5) = THERMAL CONDUCTIVITY IN (BTU/HR-FT-F)
  C PV(6) = PRANDTL NUMBER (DIMENSIONLESS)
  C PV(7) = SPECIFIC VOLUME (FT**3/LB)
  DATA(TP(K),K=1,68)/32.,40.,50.,60.,70.,80.,90.,100.,110.,120.,130
  1.,140.,150.,160.,170.,180.,190.,200.,210.,220.,230.,240.,250.,260.
  2.,270.,280.,290.,300.,310.,320.,330.,340.,350.,360.,370.,380.,390.,
  3400.,410.,420.,430.,440.,450.,460.,470.,480.,490.,500.,510.,520.,
  4530.,540.,550.,560.,570.,580.,590.,600.,610.,620.,630.,640.,650.,
  5660.,670.,680.,690.,700./
  DATA(P(1,K),K=1,68)/
  162.42,162.42,62.38,62.34,62.27,62.19,62.11,62.06,61.84,61.73,61.53,
  261.39,61.20,61.01,60.79,60.57,60.35,60.13,59.88,59.63,59.38,59.10,
  358.82,58.51,58.24,57.93,57.64,57.31,56.98,56.66,56.31,55.96,55.59,
  455.20,54.85,54.46,54.05,53.65,53.25,52.80,52.36,51.92,51.55,51.02,
  550.50,50.00,49.50,49.02,48.31,47.85,47.17,46.51,45.87,45.25,44.64,
  643.86,42.92,42.40,41.49,40.40,39.53,38.46,37.31,35.97,34.48,32.79,
  730.49,27.1/
  DATA(P(2,K),K=1,68)/1.01,13*1.,
  11.001,1.002,1.003,1.004,1.005,1.007,1.009,1.010,1.013,1.018,1.021,
  21.023,1.027,1.030,1.033,1.037,1.041,1.045,1.050,1.054,1.059,1.064,
  31.070,1.076,1.082,1.090,1.098,1.105,1.115,1.126,1.138,1.151,1.166,
  41.18,1.2,1.224,1.25,1.28,1.313,1.35,1.388,1.43,1.475,1.51,1.575,
  51.64,1.75,1.86,1.99,2.18,2.26,2.6,2.85,3.16/
  DATA(P(3,K),K=1,68)/4.325,3.745,3.17,2.71,2.36,2.08,1.85,1.66,
  11.49,1.36,1.24,1.14,1.04, .970, .900, .840, .786, .738, .695, .654, .618,
  2.585, .555, .528, .504, .482, .463, .448, .434, .421, .401, .389, .377, .366,
  3.355, .345, .336, .327, .318, .310, .302, .295, .287, .281, .274, .268, .262,
  4.256, .250, .245, .240, .235, .230, .226, .221, .217, .213, .209, .204, .201,
  5.197, .192, .189, .185, .181, .178, .174, .169/
  DATA(P(4,K),K=1,68)/.0695, .0601, .05082, .04347, .03790, .03345,
  1.02970, .02678, .02409, .02203, .02002, .01857, .01699, .01590, .01481,

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2.01387,.01302,.01227,.01161,.01097,.01041,.00990,.00944,.00902,
3.00865,.00832,.00803,.00782,.00762,.00743,.00712,.00695,.00678,
4.00663,.00647,.00633,.00622,.00610,.00597,.00587,.00577,.00568,
5.00557,.00551,.00543,.00536,.00529,.00522,.00517,.00512,.00509,
6.00505,
7.00494,.00493,.00491,.00496,.00498,.00499,.00506,.00514,.00525,
8.00543,.00571,.00624/
DATA( P(5,K),K=1,68)/.319,.325,.331,.338,.345,.351,.357,.363,.367,
1.372,.375,.379,.382,.385,.387,.390,.391,.393,.394,.395,.396,
2.396,.396,.396,.396,.395,.395,.394,.393,.392,.391,.390,.388,.386,
3.384,.382,.380,.377,.374,.371,.368,.365,.362,.359,.355,.352,.348,
4.344,.339,.334,.329,.324,.318,.311,.304,.298,.292,.288,.281,.276,
5.269,.264,.257,.251,.245,.238,.231/
DATA( P(6,K),K=1,68)/.711,.619,.577,.8.018,.6.841,.5.926,.5.182,
14.573,.4.060,.3.656,.3.307,.3.008,.2.723,.2.519,.2.328,.2.158,.2.017,.1.885,
21.773,.1.667,.1.579,.1.492,.1.420,.1.357,.1.299,.1.245,.1.204,.1.168,.1.138,
31.111,.1.065,.1.040,.1.015,.9940,.9740,.9540,.9410,.9260,.9130,.9040,
4.8940,
5.8860,.8770,.8690,.8600,.8580,.850,
5.898,.914,.932,.959,.986,.1.021,.1.054,.1.09,.1.116,.1.173,.1.249,.1.328,
61.425,.1.566,.1.626,.1.689,.2.084,.2.312/
DATA( P(7,K),K=1,68)/
1. .01602,.01602,.01603,.01604,.01606,.01608,.01610,.01613,
2.01617,.01620,.01625,.01629,.01634,.01639,.01645,.01651,.01657,
3.01663,.01670,.01677,.01684,.01692,.01700,.01709,.01717,.01726,
4.01735,.01745,.01755,.01765,.01776,.01787,.01799,.01811,.01823,
5.01836,.01850,.01864,.01878,.01894,.01910,.01926,.01940,.01960,
6.01980,.02000,.02020,.02040,.02070,.02090,.02120,.02150,.02180,
7.0221,.0224,.0228,.0232,.0236,.0241,.0247,.0253,.0260,.0268,.0278,
8.0290,.0305,.0328,.0369/
IF(T.LT.32..OR.T.GT.700.) WRITE(3,1)
DO 10 K=2,68
IF(T-TP(K))15,15,10
10 CONTINUE
15 DO 30 I = 1,7
IF(T-TP(K))18,20,18
18 P22 = (P(I,K)-P(I,K-1))/(TP(K)-TP(K-1))
PV(I) = P(I,K-1) + (T-TP(K-1))*P22
IF(PV(I).LT..00001) -PV(I) = P(I,K-1)
GO TO 30
20 PV(I) = P(I,K)
30 CONTINUE
RETURN
1 FORMAT (/10X 50HH2O PROPERTY TABLES TEMPERATURE LIMITS EXCEEDED
1 //)
END

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SUBROUTINE GRIDS(V,AFL,PD,DS,EN,G,XMU,WPAP,DPO,CORF,II,XONEL)
C THIS ROUTINE CALCULATES PRESSURE DROP ACROSS PIN
C SUPPORT GRIDS BY A. N. DE STORNEUR (DRAG COEFFICIENTS)
C CHECK TO DETERMINE CORE TYPE
  IF(DEL)5,5,6
    5 GDEL = 0.
    6 CONTINUE
  IF(CORE,GT,.0)GO TO 30
  CHECK TO DETERMINE THE GRID TYPE
    8 IF(DS,LT,.000001) DS = (PD-DPO)/1.02
    PINS = EN
  IF(II-2)20,10,40
  HONEYCOMB GRID TYPE
    10 GA = AFL-(2.*PD*DS-DS**2)*EN
    G2 = AFL*G/GA
    GRE = DS*G2/XMU
    XGRE = GRE/1.E+4
    GC = .769*EXP(-.319*XGRE)=-.00635*XGRE+4.483E-5*XGRE**2+1.8758A
    GO TO 50
  C CIRCULAR WIRES POINTED IN FLOW DIRECTION OR PERPENDICULAR
    20 GA = AFL-PD*DS*EN
    G2 = AFL*G/GA
    GRE = DS*G2/XMU
    XGRE = GRE/1.E+4
    IF(II)29,29,28
    28 GC = .802*EXP(-.21897*XGRE)=-3.49E-3*XGRE+1.76F-5*XGRE**2+1.686A
    29 GC=4.688E-7*XGRE**4-7.90E-5*XGRE**3+4.6583E-3*XGRE**2-1.1334E-1
    2 *XGRE+1.9156
    GO TO 50
  C CHECK TO DETERMINE GRID TYPE FOR TRIANGULAR PIN ARRAY
    30 PINS = EN/2.
    33 IF(DS,LT,.000001) DS = (PD-DPO)/1.02
    IF(II-2)35,31,40
  HONEYCOMB GRID TYPE
    31 GA = AFL-(PD*DS-.5*DS**2)*EN
    G2 = AFL*G/GA
    GRE = DS*G2/XMU
    XGRE = GRE/1.E+4
    GC = .769*EXP(-.319*XGRE)=-.00635*XGRE+4.483E-5*XGRE**2+1.8758A
    GO TO 50
  C FOR TRIANGULAR PIN ARRAY ARRANGEMENT
  C CIRCULAR WIRES POINTED IN FLOW DIRECTION OR PERPENDICULAR
    35 GA = AFL -.5*PD*DS*EN

```

```

G2 = AFL*G/GA
GRE = DS*G2/XMU
XGRE = GRE/1.E+4
IF(11)38,38,37
37 GC = .802*EXP(-.21897*XGRE)-3.40E-3*XGRF+1.76F-5*XGRE**2+1.6866
GO TO 50
38 GC=4.688E-7*XGRE**4-7.900E-5*XGRE**3+4.6583E-3*XGRE**2-1.1334E-1
2 *XGRE+1.9156
GO TO 50
SPRAL-WIRE SPACERS
40 CONTINUE
DS = (PD-DPO)/1.02
GA = AFL-3.14*DS**2/4.*EN
G2 = AFL*G/GA
GRE = DS*G2/XMU
XGRE = GRE/1.E+4
GA = (-3.14*(DPO+DS)*DS*X/WRAP)*PINC+AFI
GC = .705*EXP(-.4996*XGRE)-3.64E-3*XGRF+2.6270E-5*XGRE**2+.49065
50 DEL = GC*(V*G2)**2*(AFL-GA)*62.4/(64.4*AFL*144.*3600.**2)
IF(11,E0,3)GO TO 52
RETURN
52 GDEL1 = DEL
DFL = DEL-GDEL1
GDEL = GDEL1
RETURN
END

```

```

SURROUTINE FPI OT(N,IXMAX,M,X,Y,XMAXI,C,IVERM,IHORM)
C
C CLYDE FROM EY JR - ROOM 20, 3702 BLDG, 300 AREA, EXT. 3717
C
C DIMENSION X(M,IXMAX),Y(M,IXMAX),A(45,100),C(M),AL(34),XMAXI(M)
C
C THIS ROUTINE IS AN ON LINE PLOTTER FOR UP TO 5 CURVES IN THE FIRST
C QUADRANT.
C
C INPUT EXPLANATION
C
C X = THE VARIABLE ALONG THE ARCSISSA. (MUST BE POSITIVE)
C
C Y = THE ORDINATE VARIABLE AT MESH POINT X. (MUST BE POSITIVE)
C
C XMAXI = THE MAXIMUM VALUE OF X.
C
C C = THE MAXIMUM VALUE OF Y.
C
C N = THE NUMBER OF CURVES TO BE REPRESENTED.
C
C IXMAX = THE NUMBER OF MESH POINTS ALONG X. (10 INCREMENTS = 11 POINTS.)
C
C M = THE DIMENSION OF C IN THE CALLING PROGRAM.
C
C IVERM = THE NUMBER OF VERTICAL SPACES TO BE USED FOR THE PLOT + 5.
C
C IHORM = THE NUMBER OF HORIZONTAL SPACES TO BE USED FOR THE PLOT + 4.
C
C IF IVERM AND IHORM ARE LESS THAN 32 AND 35, RESPECTIVELY, THEY ARE
C SET TO 45 AND 106, RESPECTIVELY, BY THE CODE.
C
C DATA (AL(1),1,1,34)/1HR,1HF,1HT,1HE,1HW,1HA,1HR,1HA,1HP,1HS,1H
1F,1HL,1HN,1HO,1HT,1HS,1HN,1HE,1HM,1HI,1HD,1H*,1H0,1H1,1H2,1H3,1H4,
21H5,1H6,1H7,1H8,1H9,1H1 /
C DATA BLANK/6H /
C DATA ET,E2,E3 /1HX,1HY,1H./
C CALL SFTIO(3,2)
C IVERM = IVERM
C IHORM = IHORM
C N = N
C IXMAX=IXMAX
C IF(IVERM.LT.32 ) IVERM = 45
C IF(IHORM.LT.35 ) IHORM = 106

```

```

IVERT = IVERM+4
IHOR = IHORM+5
IVERT = IVERT-1
HOR = THOR-1
DO 2 J=1,N
DO 2 J=1,IXMAX
X(I,J) = X(I,J)/YMAX(I)
2 Y(I,J) = Y(I,J)/C(I)
DO 10 I=1,IVERM
DO 10 J=1,IHORM
10 A(I,J) = BLANK
DO 20 J=1,IVERT
A(J,6) = AL(23)
20 A(J,IHORM) = AL(23)
IF(IVERT.NE.41) GO TO 26
DO 25 J=1,41,4
A(J,6) = E3
25 A(J,106) = E3
26 IEND = IHOR+4
DO 30 J=6,IEND
A(1,J) = AL(23)
30 A(IVERT,J) = AL(23)
IF(IEND.NE.105) GO TO 36
DO 35 J=6,96,10
A(1,J) = E3
35 A(41,J) = E3
36 CONTINUE
ISTART = (VERT-25)/2.+501
IEND = ISTART + 12
DO 40 I=ISTART,IEND
40 A(I,2) = AL(22-I+ISTART)
IRFG = ISTART + 15
IEND = ISTART + 23
A(IEND+3,2) = E2
DO 50 I=IRFG,IEND
50 A(I,2) = AL(9-I+IRFG)
DO 60 I=1,N
DO 60 J=1,IXMAX
IF(Y(I,J).LT.0.) GO TO 60
I1 = HOR*X(I,J)+6.501
I2 = VERT*(1.0-Y(I,J))+1.501
A(I2,I1) = AL(I+24)
60 CONTINUE
R = 0.0
DO 70 I=1,11
I1 = VERT*R+1.501
IF(I.GT.1.AND.I.LT.11) A(I1,3) = E3
A(I1,4) = AL(35-I)
70 R = R+.1

```

```

R = 0.
DO 66 I=1,11
  I2 = HOR*8+6.501
  IF(I.GT.1.AND.I.T.11) A(I*VERT+2,I2-1) = E3
  A(I*VERT+2,I2) = AL(23+I)
66 R = R+.1
  ISTART = (HOR-25.)/2.+501
  IEND = ISTART+12
  DO 67 I = ISTART, IEND
    67 A(I*VERM,I) = AL(22-I+ISTART)
    IPEG = ISTART+15
    IEND = ISTART+23
    A(I*VERM,IEND+3) = E1
  DO 66 I=IBEG, IEND
    66 A(I*VERM,I) = AL(a-I+IBEG)
  DO 80 I=1, IVERM
    80 WRITE(3,90)(A(I,J),J=1,I*HORM)
  WRITE(3,95)
  WRITE(3,100)(F1,I,XMAXI(I),E2,I,C(I),I-1,N)
90 FORMAT(120A1)
95 FORMAT(1H )
100 FORMAT(17H  MULTIPLIERS = ,3(5X,A1,Y1.2H =,1PER,2.5X,A1,Y1.2H =,
18A.2))
  RETURN
END

```



```

-----SUBROUTINE HOLE(TCLK,TFOK,PHI,RGI,QDOTI,FUDENS,QK,THETA,QDOTK,IQ,
1QTHETA)
-----DIMENSION QDOTS(23),QDOTK(23),QDOTI(23),RGI(23),QK(201),RXI(23)
1Q = 21
DO 25 I=1,IQ
25 RXI(I) = RGI(I)
IF(FUDENS.LT..95) GO TO 3
FUD = .95
GO TO 4
3 FUD = FUDENS
4 CALL SIMPIN(IQ,RXI,QDOTI,QDOTS)
DO 5 I=1,IQ
NL = IQ-I+1
IF(THETA-RXI(I)) 6,8,5
5 CONTINUE
6 DO 7 I=1,NL
RXI(IQ-I+2) = RXI(IQ-I+1)
7 QDOTS(IQ-I+2) = QDOTS(IQ-I+1)
NL = IQ-NL+1
IQ = IQ+1
GO TO 17
8 NL = IQ-NL+1
17 IF(THETA)9,9,2
2 RXI(NL) = THETA
QDOTS(NL)=(THETA-RXI(NL-1))/(.05*(QDOTS(NL)-QDOTS(NL-1))+QDOTS(NL-1
1)
9 CONK = PHI/(QDOTS(IQ)-QDOTS(NL))
QDOTS(23) = QDOTS(NL)
IF(THETA)18,18,10
10 DO 11 I=1,NL
11 QDOTS(I) = 0.0
18 KL = NL+1
DO 12 I=KL,IQ
12 QDOTS(I) = (QDOTS(I)-QDOTS(23))/RXI(I)
1LTH = IQ-KL+2
13 CALL SIMPIN(1LTH,RXI(NL),QDOTS(NL),QDOTK(NL))
QDOTK(23) = QDOTK(NL)
DO 19 I=1,NL
19 QDOTK(I) = 0.0
DO 20 I=KL,IQ
20 QDOTK(I) = (QDOTK(I)-QDOTK(23))*CONK
30 DO 14 I=1,IQ
LN = I
IF(TFOK+QDOTK(IQ)-QDOTK(IQ-I+1)-TCLK)14,14,16

```

```
14 CONTINUE
   IF (THETA.GT.QTHETA) GO TO 16
   THETA = QTHETA
   RETURN
16 THETA = (TFCK-TCLK) / (QDOTK(IQ)-QDOTK(IQ-LN+1)) * (RXI(IQ)-
   LN+1)) + RXI(IQ)
21 THETA = SQRT(FUD/.95*QTHETA**2+THETA**2*(1.-FUD/.95))
   RETURN
   END
```

```

SUBROUTINE SLIP4 (XM,SLIP,XI)
DIMENSION Y(7),X(22,7)

C      THIS ROUTINE CALCULATES SLIP FACTOR FOR GRAVITATIONAL PRESSURE DROP
C
C      DATA (XI,1), I=1,22) / 0.0,01,015,02,03,04,05,06,
1.07,08,09,10,15,20,30,40,50,60,70,80,90,1.0 /
DATA(X(1,2),I=1,22)/1.0,793,721,663,571,502,450,402,373,
1.343,319,298,224,180,131,098,084,071,061,054,049,044/
DATA (X(1,3), I=1,22)/1.0,842,784,736,658,597,549,508,475,
1.446,421,399,319,268,206,167,142,123,109,098,089,081/
DATA (X(1,4), I=1,22)/1.0,915,877,845,787,738,696,660,627,
1.599,573,549,460,399,317,269,228,201,180,163,149,136/
DATA (X(1,5), I=1,22)/ 1.0,956,937,918,882,850,823,795,771,
1.746,724,705,624,558,468,406,357,321,291,267,248,229/
DATA (X(1,6), I=1,22)/1.0,991,966,960,947,923,910,892,879,
1.860,848,836,774,718,637,575,525,482,444,413,389,364/
DATA (X(1,7), I=1,22)/ 1.0,994,992,990,979,974,970,963,957,
1.952,948,941,916,889,843,803,767,733,702,675,651,626/
DATA (Y(J),J=1,7)/ 384,246,40,20,9,8,4,95,2,15/
DO 200 I = 1,22
XFIND = XM - X(I,1)
IQF = I
IF (XFIND) 210,205,200
200 CONTINUE
205 XRAT = 1.0
GO TO 220
210 XRAT = (XM - X(IQF-1,1))/(X(IQF,1)-X(IQF-1,1))
220 DO 230 J = 1,7
YGAM = Y(J) - SLIP
IGAM = J
IF (YGAM) 250,240,230
230 CONTINUE
240 YRAT = 1.0
GO TO 260
250 YRAT = (Y(IGAM-1)-SLIP)/(Y(IGAM-1)-Y(IGAM))
260 IF (XRAT.GT..999) GO TO 270
Z1 = X(IQF-1,IGAM-1)+(X(IQF,IGAM-1)-X(IQF-1,IGAM-1))*XRAT
Z2 = X(IQF-1,IGAM)+(X(IQF,IGAM)-X(IQF-1,IGAM))*XRAT
GO TO 280
270 Z1 = X(IQF,IGAM-1)
Z2 = X(IQF,IGAM)
280 IF (YRAT.GT..999) GO TO 290
XI = Z1 + YRAT * (Z2-Z1)

```

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RETURN
290 XI = X(IQF, IGAM)
RETURN
END

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