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P. 174

NASA Contractor Report CR-191132

# HEAT PIPE COOLED HEAT REJECTION SUBSYSTEM MODELLING FOR NUCLEAR ELECTRIC PROPULSION (TASK ORDER NO. 18)

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N94-24061

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G3/20 0203387

November 16, 1993

PREPARED FOR  
LEWIS RESEARCH CENTER  
UNDER CONTRACT NAS3 25808

(NASA-CR-191132) HEAT PIPE COOLED  
HEAT REJECTION SUBSYSTEM MODELLING  
FOR NUCLEAR ELECTRIC PROPULSION  
Final Report (Rockwell  
International Corp.) 174 p



## National Aeronautics and Space Administration



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## Foreword

Systems engineering efforts initiated by NASA's Lewis Research Center (LeRC) in FY92 under RTOP 593-72. for Nuclear Electric Propulsion (NEP), have enabled the development of detailed mathematical (computer) models to predict NEP subsystem performance and mass. The computer models are intended to help provide greater depth to NEP subsystem (and system) modeling, required for more accurately verifying performance projections and assessing the impact of specific technology developments.

The following **subsystem** models have been developed:

- 1) liquid-metal-cooled pin-type, and
- 2) gas-cooled NERVA (Nuclear Engine for Rocket Vehicle Applications) - derived for reactor/shield;
- 3) Potassium-Rankine, and
- 4) Brayton for power conversion;
- 5) heat rejection general model (includes direct Brayton, pumped loop Brayton, and shear flow condenser (Potassium-Rankine);
- 6) power management and distribution (PMAD) general model; and
- 7) ion electric engine, and
- 8) magnetoplasmadynamic thruster for the electric propulsion subsystem.

These subsystem models for NEP were authored by the Oak Ridge National Laboratory (ORNL) for the reactor (NASA CR-191133), by the Rocketdyne Division of Rockwell International for the Potassium Rankine (NASA CR-191134) and Brayton (NASA CR-191135) power conversion, heat rejection (NASA CR-191132), and power management and distribution (NASA CR-191136), and by Sverdrup Technology for thr thrusters (NASA CR-191137).

At the time of this writing, these eight VAX/FORTRAN source and executable codes are resident on one of LeRC's Scientific VAX computers.

## SUMMARY

NASA LeRC is currently developing a FORTRAN based computer model of a complete nuclear electric propulsion (NEP) vehicle that can be used for piloted and cargo missions to the Moon or Mars. Proposed designs feature either a Brayton or a K-Rankine power conversion cycle to drive a turbine coupled with rotary alternators. Both ion and MPD thrusters will be considered in the model. In support of the NEP model, Rocketdyne is developing power conversion, heat rejection, and power management and distribution (PMAD) subroutines. The subroutines will be incorporated into the NEP vehicle model which will be written by NASA LeRC. The purpose of this report is to document the heat pipe cooled heat rejection subsystem model and its supporting subroutines.

The heat pipe cooled heat rejection subsystem model is designed to provide estimates of the mass and performance of the equipment used to reject heat from Brayton and Rankine cycle power conversion systems. The subroutine models the ductwork and heat pipe cooled manifold for a gas cooled Brayton; the heat sink heat exchanger, liquid loop piping, expansion compensator, pump and manifold for a liquid loop cooled Brayton; and a shear flow condenser for a K-Rankine system. In each case, the final heat rejection is made by way of a heat pipe radiator. The radiator is sized to reject the amount of heat necessary.

The calculations proceed from first principles and normally will require that a relatively extensive amount of information be made available to the code. For normal use, a complete description of the component geometry must be specified. However, for preliminary design purposes, the code provides an option that will generate a workable design for the heat rejection system that can be used as the basis for further optimization.

The code computes the performance of each equipment item in the flow path. Performance for specific elements such as the heat exchanger, piping and manifolds is usually expressed as a pressure and a temperature drop. The pressure drops are summed to size the pumps, while the temperature drops are used to determine the mean effective temperature of the radiator which is then sized to reject the amount of heat required to operate the cycle at the specified conditions. Code output is in the form of labeled variable values and the output for each option includes a detailed mass summary of the equipment items in the selected flow path.

A detailed discussion of the derivation of the algorithms incorporated in the various subroutines used forms the major portion of the report. The model documentation includes as an appendix a detailed users manual which provides definition of the input variables required, subroutine usage instructions, and applications examples to illustrate the output resulting from invoking the different code options.





## 1.0 INTRODUCTION

The objective of this task was to characterize potential heat pipe based radiator subsystems for use in megawatt sized nuclear electrical propulsion systems. The approach to developing this characterization was to develop a mass/performance estimating computational methodology that proceeds from first principles to provide valid estimates of the performance and mass of candidate heat pipe based radiators and the auxiliary devices required to use them in both Brayton and Rankine system designs. Heat rejection subsystem characteristics of interest are radiator size (area, length, width, heat pipe lengths, heat exchanger dimensions) and mass. It was required that these characteristics be developed for both a potassium Rankine cycle with a constant temperature condensation process, as well as for a Brayton cycle with a varying temperature cooling process. Input variables to be considered in the characterization include temperature, working fluids, cycle type, radiator geometry and materials of construction.

It was deemed desirable to provide as many default values for variables as possible, in order to minimize the amount of effort required to use the program. This desire conflicts with the necessity of developing algorithms with sufficient detail to permit rational optimization when the code is used as part of an overall systems model. A compromise solution was developed in the form of an option to the basic code that determines a radiator design on a relatively simplified and non-optimized basis. The inputs developed as a result of running the optional portion of the code are intended to provide sufficient detail to the user who can then construct an operating model of the system which can then be optimized by manipulation of this more complete data set.

This report provides documentation of the methodology used in developing the heat rejection subsystem analysis subroutine and includes a discussion of the technical approach developed, the design of the main driver program, and the design and integration of the various equipment algorithms and supporting routines used. A users manual for the code and a complete FORTRAN source code listing are presented as Appendices. Users familiar with the analysis of space based heat rejection systems should be able to use the code with only the information given in the users manual, Appendix A.



## **2.0 TECHNICAL APPROACH**

### **2.1 Requirements**

The heat rejection subsystem will be required to operate over a wide range of temperatures and pressures, and with a variety of working fluids. The ranges of these parameters are shown in Table 1. These requirements are met primarily by supplying materials properties for materials used at the pressures and temperatures of interest. For the heat pipes, sufficient options are provided to cover an even larger range than required.

**TABLE 1  
HEAT REJECTION SUBSYSTEM  
GROUND RULES AND REQUIREMENTS**

---

Input parameter ranges of interest:

Power Conversion System Outlet Temperatures (k):

    K-Rankine: 750 - 1250

    Brayton: 300 - 1000

Power Conversion Working Fluids:

    K-Rankine

    Helium

    Helium-Xenon Mixtures

Power Levels: 100-50000 Kwt

Lifetime: 2 - 10 Years

---

Code options that provide for automated selection of heat pipe working fluids and containment materials will use the values in Table 2. The user, however, can specify any of the working fluids in Table 2 at any time. The code will run with the selected fluid if its use at the specified temperature is possible. Inappropriate selections will cause the code to stop with the appropriate heat pipe related error message.

**TABLE 2  
HEAT PIPE WORKING FLUID TEMPERATURE RANGES  
AND CONTAINMENT MATERIALS RECOMMENDED**

| <b>TEMPERATURE RANGE (K)</b> | <b>FLUID USED</b> | <b>CONTAINER MATERIAL</b> |
|------------------------------|-------------------|---------------------------|
| 250 - 305                    | AMMONIA           | ALUMINUM                  |
| 305 - 560                    | WATER             | MONEL (COPPER)            |
| 560 - 750                    | MERCURY           | 347 STAINLESS             |
| 750 - 950                    | POTASSIUM         | NIOBIUM                   |
| 950 - 1150                   | SODIUM            | NIOBIUM                   |
| 1150 - 1800                  | LITHIUM           | MOLYBDENUM                |

---

## 2.2 Subsystem Definitions

The code developed for the characterization of potential heat pipe cooled heat rejection subsystems is designed to be applicable to both the Brayton and Rankine cycle power conversion systems. Brayton systems have been proposed that feature both direct heat extraction from the cycle working fluid and heat extraction by use of a gas/liquid heat exchanger and a liquid loop as shown on the flow diagrams given as Figures 1 and 2. The direct heat extraction cycle uses a gas to heat pipe cooled heat exchanger/manifold to extract the heat directly from the cycle working fluid. In most cases the heat exchanger for this application will be finned on the gas side. In those cases in which a liquid loop is used, a fluid loop is placed between the cycle working fluid and the radiator, primarily to permit the transfer of heat without the use of extensive, high mass ducting. The radiator manifold/heat pipe heat exchanger will usually be unfinned in the liquid loop cooled systems. In general, the larger sized systems will favor the use of an intermediate loop in the heat rejection system. The Flow diagram for the Rankine cycle systems is shown in Figure 3. The Rankine cycle makes use of a shear-flow condenser because other types are not considered practical for use in the absence of a gravity field.

## 2.3 Overall Code Design

Figure 4 presents an overall logic flow diagram for the Brayton and Rankine cycle heat rejection subsystems. Figure 4 illustrates the steps required to estimate the performance and mass of a subsystem for rejecting heat to space. The steps required to accomplish this objective are:

1. Select the method of heat rejection to be used for the system. Three options will be available. The options are described above and illustrated in Figures 1, 2 and 3.
2. Compute the performance of the gas/liquid heat exchanger if required.
3. Compute the performance of the liquid loop system, if one is used.
4. Size or select the pump if one is used. The code will only provide for the use of a liquid metal (NaK) loop for secondary cooling. For liquid metals, an EM pump is most often specified. The mass and performance of the pump will generally be estimated from semi-empirical curves generated for other purposes.
4. Compute the performance of the heat exchanger/manifold or condenser as needed.
5. Size the heat pipe radiator.

Several of the equipment size performance estimating subroutines are supported by other subroutines which describe the operating environment or describe the thermal property variations with temperature or pressure. The interactions of these routines are

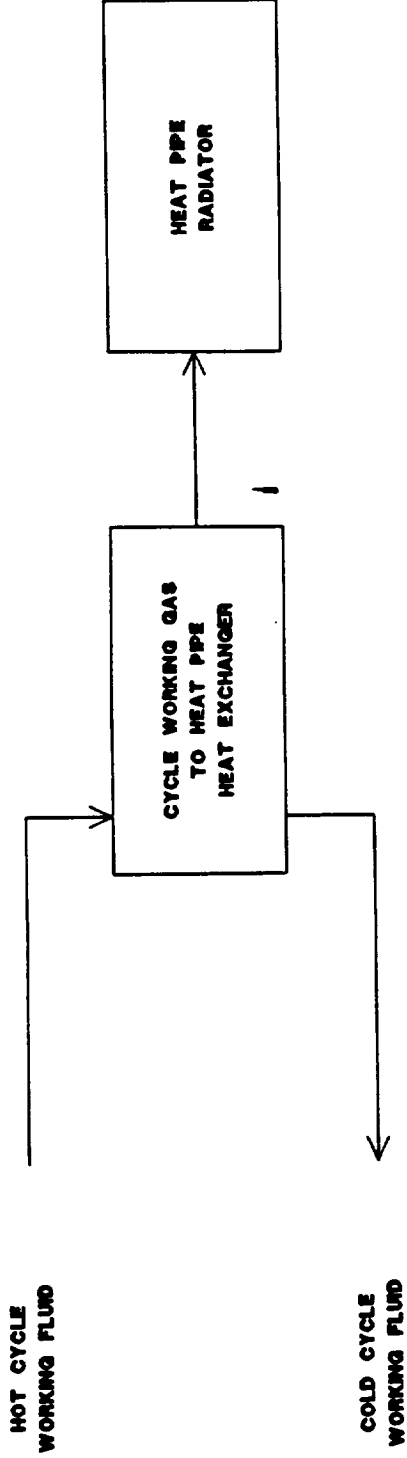


Figure 1: DIRECT GAS COOLED BRAYTON RADIATOR

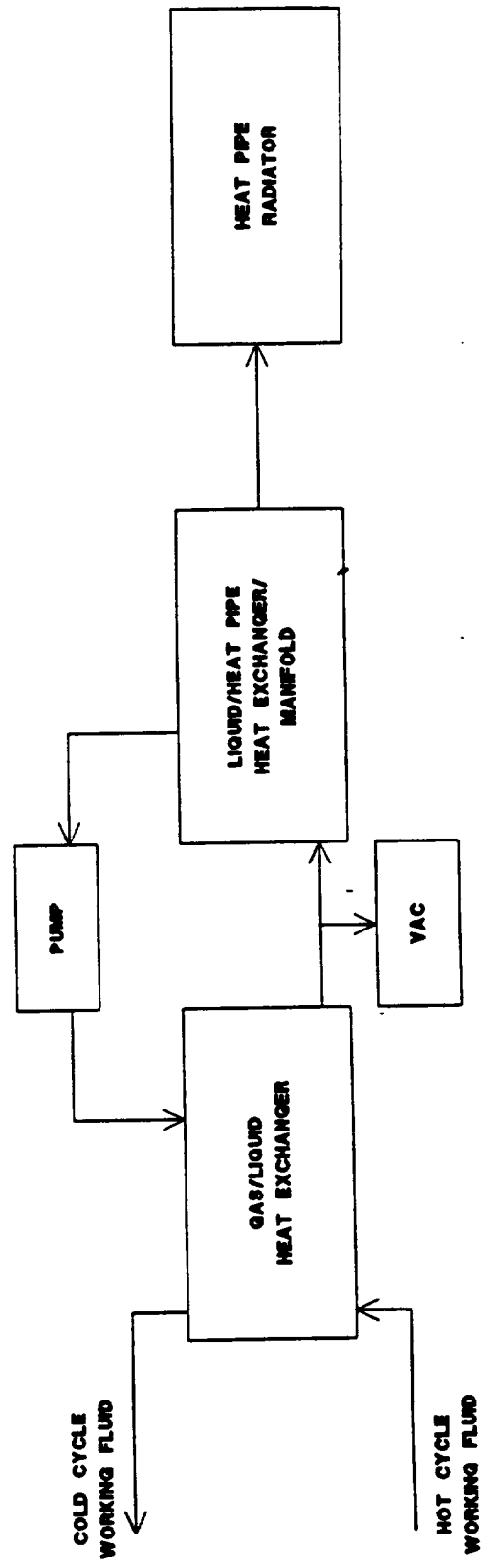
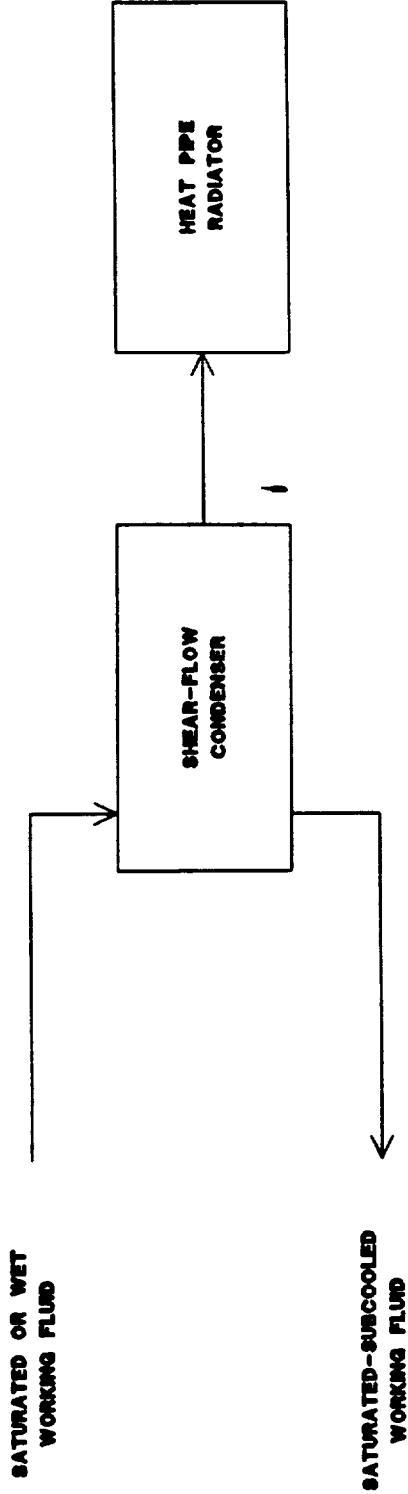
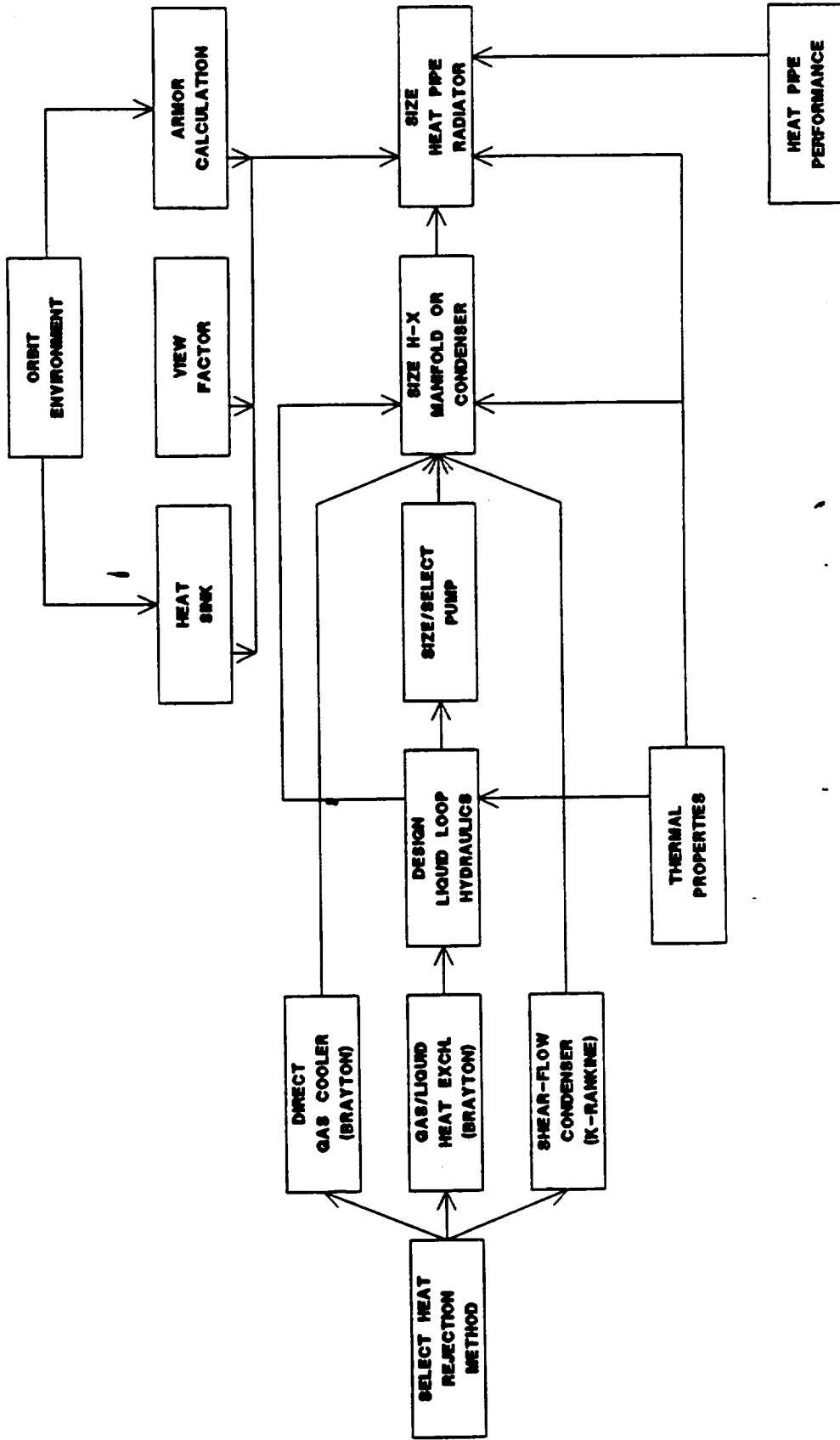


Figure 2: LIQUID LOOP COOLED BRAYTON RADIATOR



**Figure 3: RANKINE CYCLE SHEAR FLOW CONDENSER**



**FIGURE 4: OVERALL CODE LOGIC DIAGRAM**

shown on Figure 4. In the case of the main radiator subroutine, other subroutines are used to supply armor thickness calculations and heat pipe performance calculations as well as environment and thermal property estimates.

The overall approach to computing heat rejection system performance is to estimate the performance of each equipment element in the string and then design a radiator to be compatible with the specified equipment string and the heat rejection requirements for the power conversion system. Each equipment element results in a temperature loss which is reflected in the mean operating temperature of the radiator. In addition to a temperature drop, the mass of the subsystem and the performance of the power conversion system is affected by the pressure drop of each of the equipment elements. The pressure drop of each element is also computed and is available for use in the system code as well as for pump sizing purposes.

The mass and performance of each equipment element is estimated from first principles using well established thermo-hydraulic analysis methods. The analytical methods generally require that a relatively complete geometrical description of the component be supplied as input. Since such inputs are dependent on having a defined design concept available, it is seen as desirable to have an option in the code where a workable set of design parameters can be generated with only state point and system type inputs required. This option is supplied with the code and it consists of design rules based on previous experience. The option will not generally supply an optimized (namely, area constrained minimum mass) subsystem. However, the data from the option can be used in the primary section of the code to develop optimized configurations for the heat rejection subsystems of Brayton and Rankine power conversion subsystems.



### 3.0 EQUIPMENT SUBROUTINE/ALGORITHM DEVELOPMENT

#### 3.1 Main Driver Routine (HREJEC)

This subroutine, HREJEC, is the main driver routine which is used to organize the problem, read in the required data inputs, call the appropriate subroutines and print out the results. The logic of HREJEC is reflected in the flow diagram given as Figure 4. The following steps are followed in estimating the mass and performance of heat pipe cooled heat rejection systems in either Brayton or Rankine power conversion systems:

1. Select the heat rejection equipment train and define the equipment elements required. Three options are supplied and the flag, Iprob, is used to select the appropriate option, as:

- a) Direct cooled gas manifold for Braytons.
- b) Liquid loop (NaK only) cooled heat exchanger loop for Braytons.
- c) Shear flow condenser (Potassium only) directly cooled by heat pipes for Rankine cycles.

2. Analyze the Hydraulic loop for the pressure drops required by the heat sink heat exchanger, the liquid loop piping and the heat pipe cooled manifold, if a liquid loop is used.

3. Determine the weight of the pump required.

4. Determine the temperature drop associated with the heat pipe cooled liquid or gas manifold or shear flow condenser.

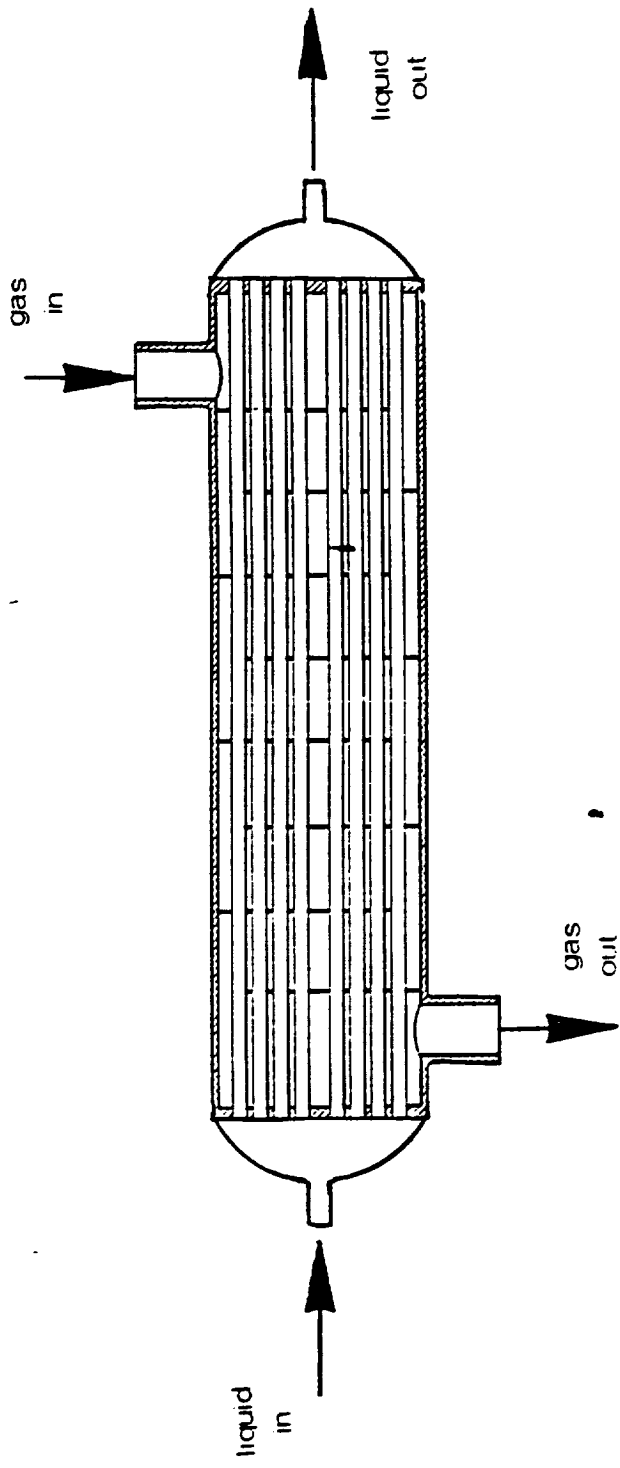
5. Size a heat pipe radiator to accommodate the temperature drops seen in the loop equipment train and to accommodate the system heat rejection loads.

6. Printout component sizes and masses.

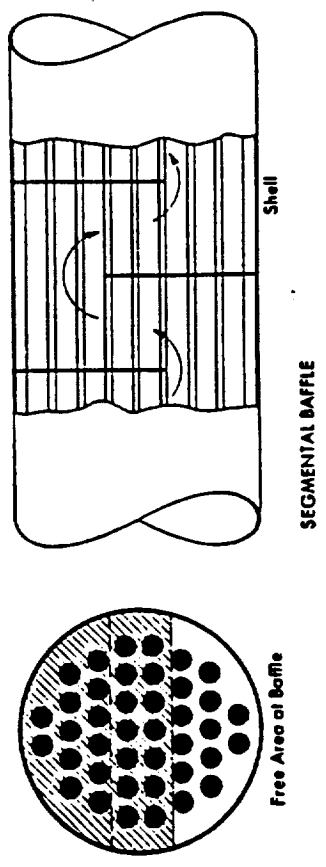
An option selected by the flag, Iselec, can be activated to supply most of the variables needed to run a case is included. A detailed listing of the variables required by the various options is included in Appendix A, the users manual.

#### 3.2 Heat Sink Heat Exchanger

The heat sink heat exchanger in a Brayton system is required to transfer heat from the gas working fluid to a liquid metal coolant loop. It has been demonstrated by numerous prior studies that the most mass efficient of the conventional heat exchanger designs that could be used for this purpose is the shell and tube configuration. A schematic of a typical shell and tube layout is shown in Figure 5. In its usual embodiment, the gas stream is confined to the shell side, while the liquid metal is confined to the tube side



**BASIC HEAT EXCHANGER LAYOUT**



**DESIGN AND FLOW DETAILS**

**Figure 5: SHELL AND TUBE HEAT EXCHANGER GEOMETRY AND FLOW PATHS**

of the heat exchanger. Since the gas and liquid streams in the Brayton application are at relatively low pressures, the use of relatively thin shells and tube materials is possible.

The heat sink heat exchanger size estimating subroutine is based on a computation of the overall heat transfer coefficient developed in a shell and tube heat exchanger with gas on the shell side of the exchanger and liquid on the tube side. The details of the computation roughly follow the development due to Bell [1]. Most of the construction details are assumed to be optimum with this method and the distance between tube rows in the direction perpendicular to the flow is assumed to be equal to the tube pitch. Several correlations are available for the heat transfer and friction factor coefficients on the shell side. The ranges of these correlations is shown on Figure 6. The correlation due to Bell was selected for use in the heat rejection subsystem design and analysis code since it is relatively conservative and nearly identical to the proprietary HTRI correlation. The tube side heat transfer correlation used is due to Lyon as quoted by Kreith [2]. This is the generally accepted correlation for the heat transfer to liquid metals under conditions of uniform heat flux. The Lyon correlation is represented by equation 1, below.

$$N_u = 7.0 + 0.025 * (Re_d * P_r)^{0.8} \quad \text{----- (1)}$$

where:

- $N_u$  = Nusselt Number
- $Re_d$  = Reynolds Number based on diameter
- $P_r$  = Prandtl Number

The friction factor for the turbulent flow of liquids or gases in tubes is given by an equation due to Miller [3]. This relation, as given by equation 2, gives a reasonably good representation of the Moody diagram and has the advantage of being an explicit expression, thereby not requiring an iterative calculation.

$$f = \frac{0.25}{\left[ \log_{10} \left( \frac{e}{3.7 * d} + \frac{5.74}{Re_d^{0.9}} \right) \right]^{2.0}} \quad \text{----- (2)}$$

where:

- $e$  = Mean Surface roughness height
- $d$  = Tube Diameter

A. ZUKAUSKAS 'HEAT TRANSFER FROM TUBES IN CROSSFLOW'  
 ADVANCES IN HEAT TRANSFER, VOLUME 18, 1987.

HTRI - HEAT TRANSFER RESEARCH, INCORPORATED - PROPRIETARY DATA

K. J. BELL, 'FINAL REPORT OF COOPERATIVE RESEARCH PROGRAM ON  
 SHELL AND TUBE HEAT EXCHANGERS, U. OF DELAWARE, BULL. 5, 1963

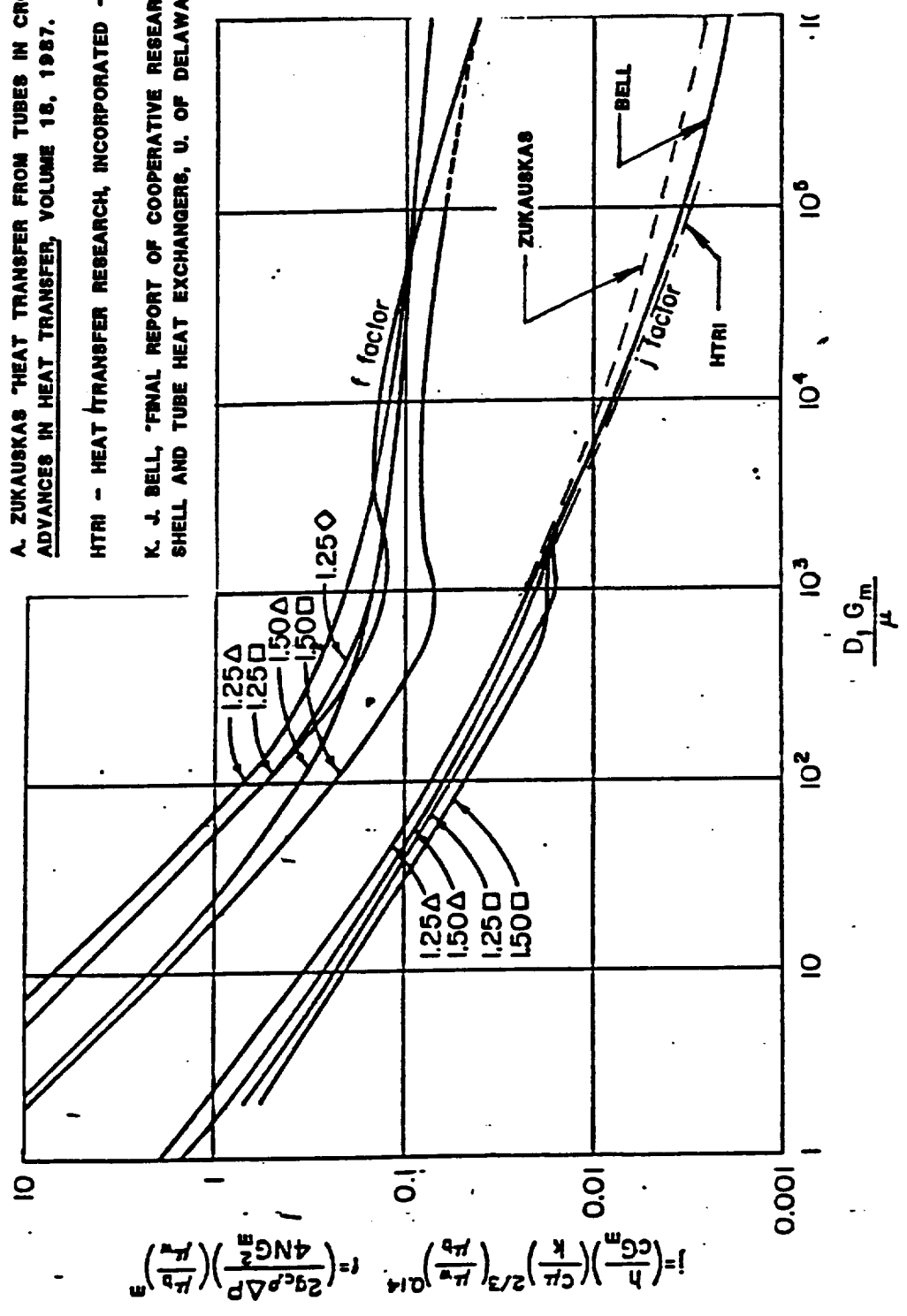


Figure 6: SHELL-SIDE HEAT TRANSFER COEFFICIENT CORRELATION COMPARISON

The calculation proceeds by guessing an overall heat transfer coefficient, sizing the exchanger and then checking if the guess was correct. If the resulting exchanger is larger than required, the code reduces the overall diameter and repeats the calculation until a reasonably close approximation to the required exchanger duty is found. Conversely, if the resulting exchanger is smaller than required, the code increases the overall diameter and repeats the calculation, as above. Once the proper overall size is determined, the code proceeds to compute the mass of the component parts of the heat exchanger. Shell thickness is derived from an empirical representation of the results of prior calculations. Masses are computed by simple density times part volume relations. The components included are the insulation, heat exchanger heads, shell, plates, tubesheets, and tubes. The supporting structure for the heat exchanger is estimated as five percent of the overall mass of the heat exchanger unit. It is to be noted that the material thicknesses used for the design of these heat exchangers are near the absolute minimum possible and are representative of heat exchangers operated under very precisely defined conditions, manufactured using state of the art techniques and fully utilizing the latest in materials advances. As a result they will be very expensive to fabricate and develop. A more economical unit on the other hand will have significantly higher mass.

### 3.3 NaK Piping

The heat absorbed by the heat rejection heat exchanger is transferred to a heat pipe cooled manifold by a piping system. The piping system affects system mass by providing resistance to the pump, requiring a volume of metal to provide fluid containment and finally by requiring an inventory of fluid with which to transfer the heat and incidentally keep the piping system filled. Aerospace liquid metal loop systems are usually designed not to exceed a certain maximum flow velocity. This velocity is usually less than about 10 to 12 meters/second. In order to minimize erosion problems with velocities of this magnitude, it is necessary to have an extremely low oxygen content in the flowing fluid. A usually satisfactory value for pipe wall thickness is given by assuming schedule 10 pipe. The use of thinner sections should be carefully evaluated.

The pressure drop in the NaK piping system is estimated from input values of flowrate, pipe diameter, pipe length and number of 90 degree bends in the system. Pipe bend resistances are estimated by use of an empirical equation derived from a cross plot of bend resistance data published by Miller [3]. Pipe friction factors are estimated by means of equation 2. Masses are computed by simple density times part volume relations. The elements included in the mass estimate are the pipe insulation, pipe material and the volume of NaK contained in the piping.

### 3.4 EM Pump

NaK circulation in the liquid metal heat transfer loop is provided for by an electromagnetic (EM) pump. A sketch of a typical NaK loop based heat rejection plumbing layout showing the integration of EM pump, the volume accumulator and the radiator inlets and outlets is shown in Figure 7. Rocketdyne has performed detailed EM pump design and configuration selection studies over the past several years. The results of these studies can be roughly correlated by an expression for pump mass as a function of hydraulic pumping power required to operate a NaK loop. This expression is given as:

$$M_{\text{pump}} = 16.783 + 0.1465 * P_{\text{hyd}}$$

---- (3)

where:

$M_{\text{pump}}$  = Pump and Power Control Mass (Kg)

$P_{\text{hyd}}$  = Hydraulic Power Required to Operate Loop (Watts)

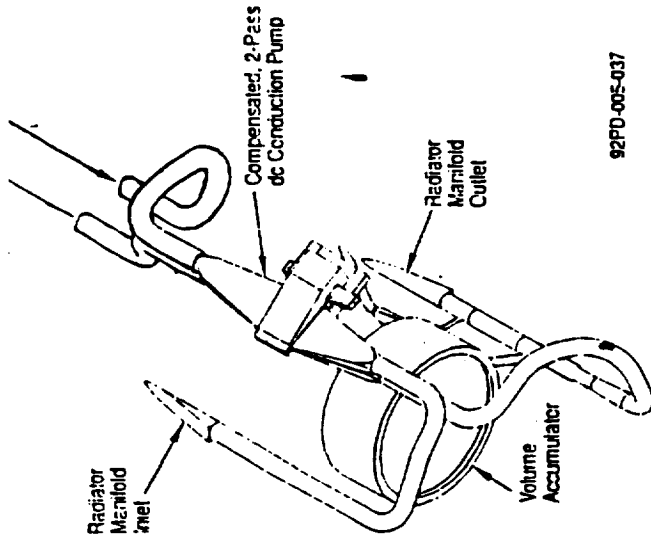
Equation 3 is based on several designs for DC conduction EM pumps which featured a two throat configuration. One of the throats is plumbed to the cold leg of the loop, while the other is plumbed to the hot leg. A detailed analysis of the performance and mass of EM pumps is given by Baker and Tessier [4].

### 3.5 Expansion Compensator

The expansion compensator or volume accumulator unit (VAU) provides for NaK expansion during system startup and provides for overpressure on the NaK to prevent the initiation of local boiling. The VAU is usually located on the radiator manifold outlet line (the lowest temperature point in the system) and is connected to the main branch line by smaller diameter tubing. The design of VAU's is based on the amount of NaK volume change expected in the heat transfer loop between a nominal 311 K temperature level and the maximum operating temperature of the loop. A safety factor of 1.2 is customarily applied to the estimate of NaK volume change. Rocketdyne has conducted several design and selection studies of VAU's for other programs. Details of a typical VAU design are given in Figure 8. The mass of material used in these designs is well correlated by the following equation:

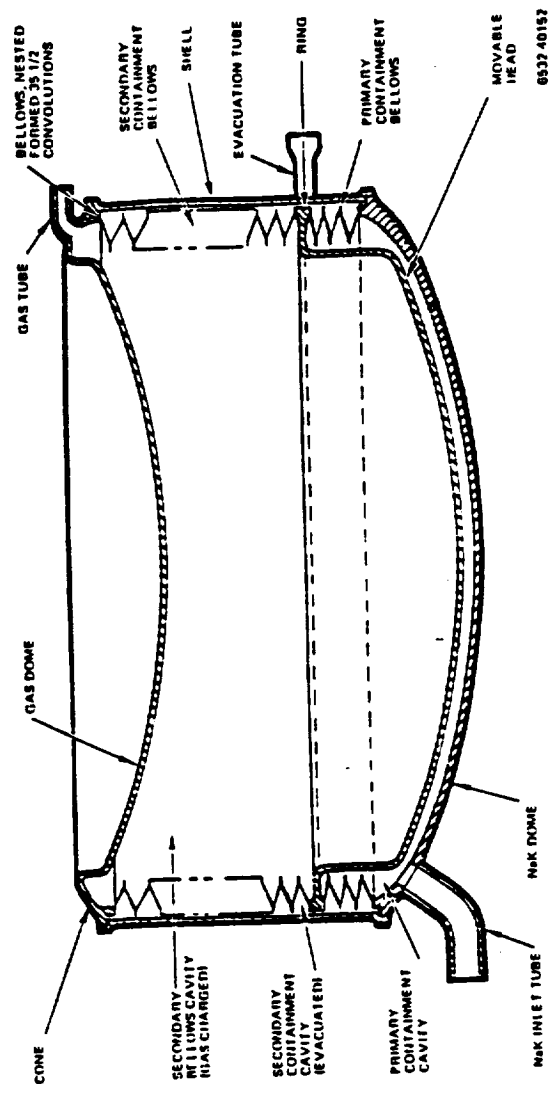
$$M_{\text{vac}} = 0.4536 * [10.0^{(0.66 * \log_{10}(\frac{V_{\text{acc}}}{0.0164} - 0.28))}]$$

---- (4)



92PD-005-037

**Figure 7: TYPICAL NaK LOOP PLUMBING FOR POWER SYSTEM HEAT REJECTION**



**Figure 8: VOLUME ACCUMULATOR UNIT DESIGN CONCEPT DETAILS**

where:

$$\begin{aligned} V_{\text{acc}} &= \text{Loop volume change (Liters)} \\ M_{\text{vac}} &= \text{Mass of volume accumulator unit (dry) (Kg)} \end{aligned}$$

A detailed computer code for the analysis of the performance and mass of VAU units of the type illustrated in Figure 8 is given by Whitaker and Shimazaki [5].

### 3.6 Gas/Liquid Heat Pipe Manifold

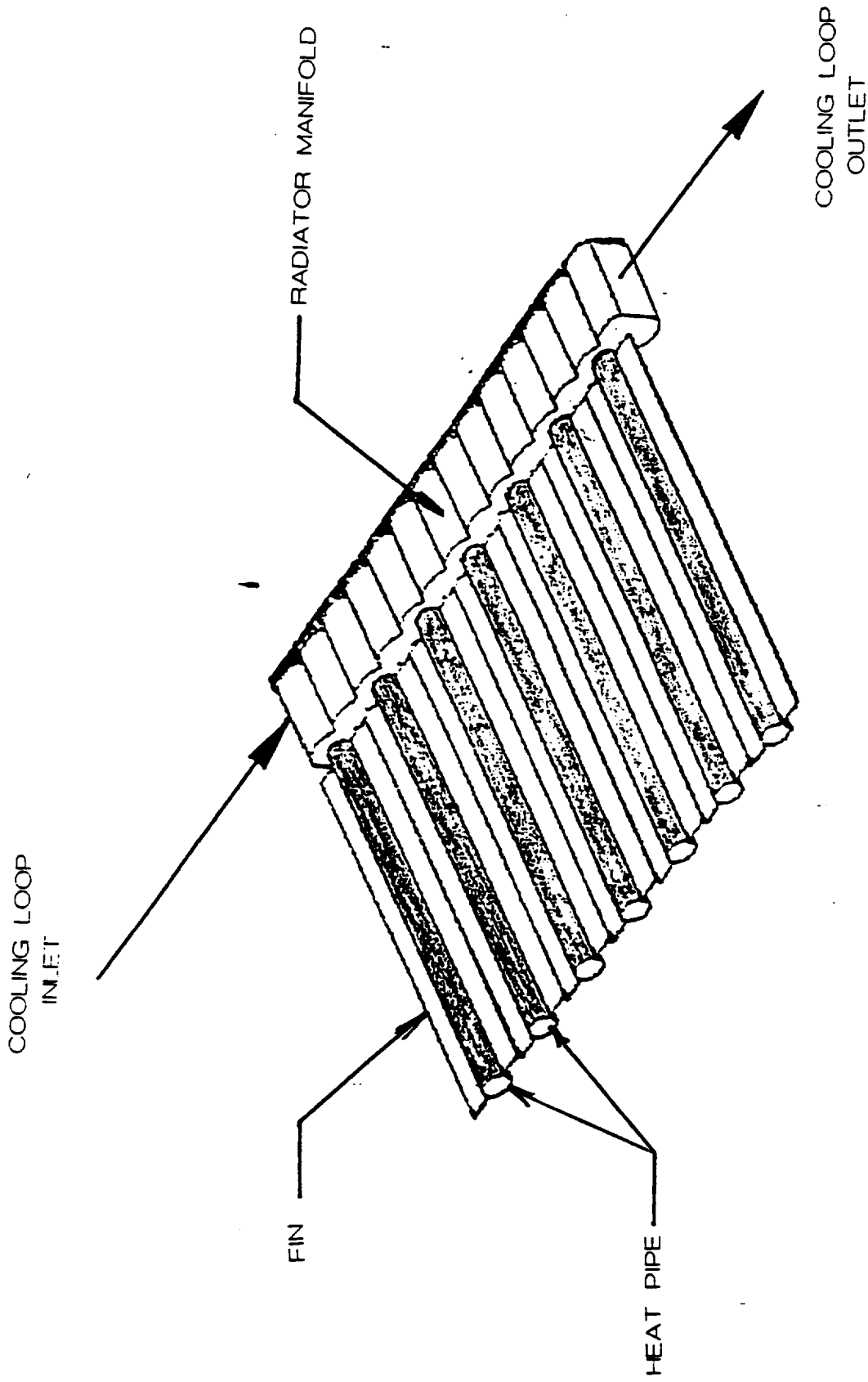
Heat is transferred to the heat pipe/fin assemblies by means of a heat pipe cooled manifold. The basic configuration of the manifold is a single line of tubes contained in a shroud. Braze cans are used to provide for the attachment of the heat pipe fin assemblies into the shroud. It is assumed that the flow pattern in the manifold can be tailored to simulate the flow in a heat exchanger tube bundle. Tailoring the flow in this manner will require that an undulating wall shape be used to contain the flow. A close approximation to the required shape of this wall can be determined with CFD methods. A diagram of the manifold layout is given in Figure 9.

The heat transfer and friction factor correlation used for the manifold is given as Figure 10. This correlation is adapted from the correlation given by Bell [1] for the case where a large number of tube rows is used. Heat transfer through the walls of the manifold is by conduction through a braze can, a braze joint, the heat pipe wall to the evaporating fluid of the heat pipe. An option is provided for the use of fins around the braze cans. This may be useful in cases where gas is used in the manifold. The fins are assumed to span the entire manifold since the use of unfinned areas would result in bypassing of the flow which is not accounted for in this code.

The heat balance across the wall of a can/ braze joint/ heat pipe assembly is solved to give the film temperature drop through the manifold. A closed form expression was derived to estimate this parameter. The heat flux used for the estimation of average film temperature drop was the average heat flux value. In practice, the film temperature drop will be highest at the manifold inlet and decreasing toward the manifold outlet. The average value, however, will give the average film temperature drop which is used to estimate the average radiator operating temperature.

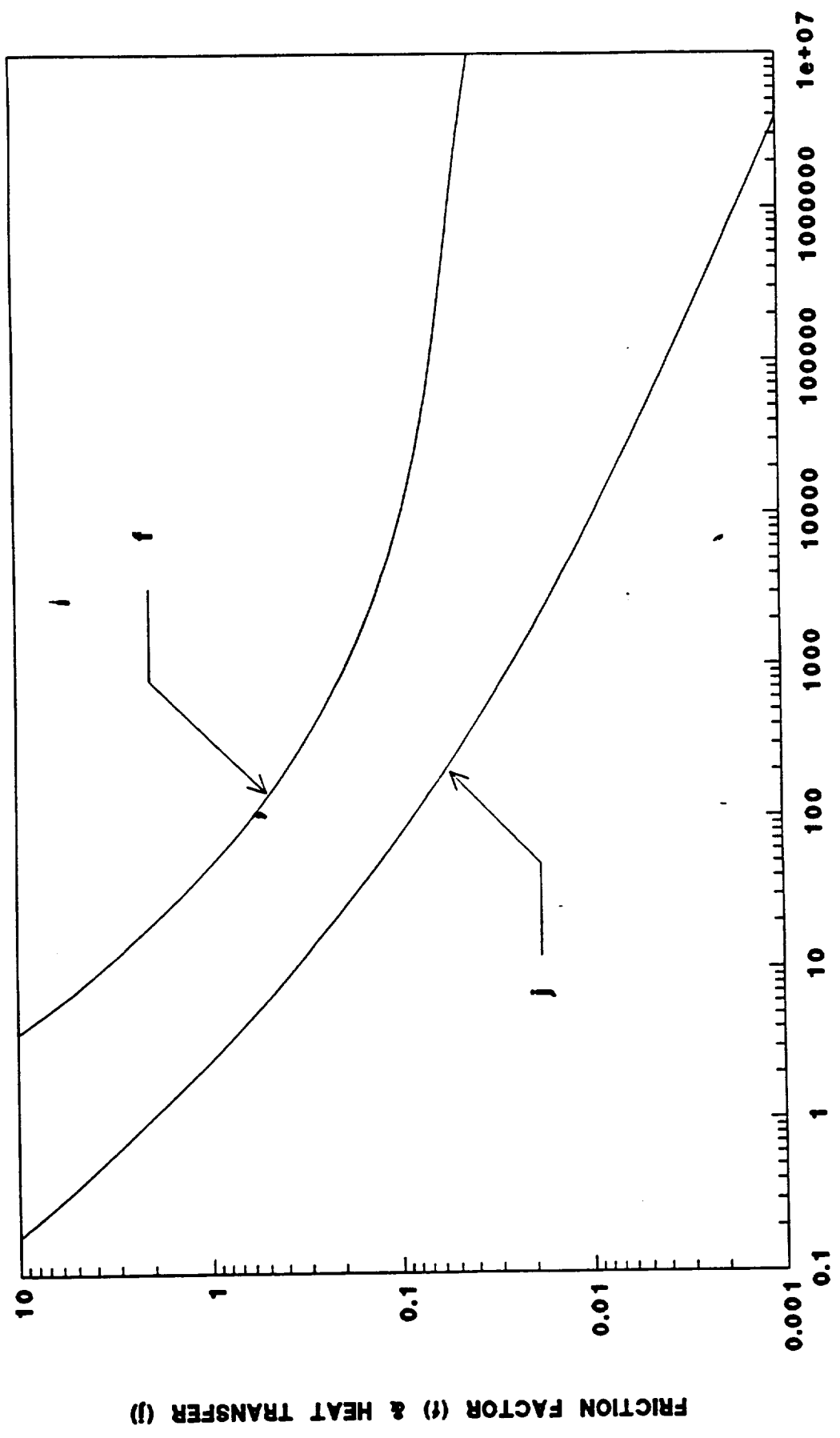
Manifold mass is computed by simple density times part volume relations. The elements included in the mass estimate are the manifold braze can mass, manifold container wall mass, manifold braze mass, and for liquid cooled manifolds, the mass of the NaK inventory in the manifold. It is expected that it will usually be desirable to leave the manifold uninsulated. Armor mass for the





**Figure 9: GAS/LIQUID HEAT PIPE, FIN AND MANIFOLD CONFIGURATION**

**HEAT TRANSFER (j) AND PRESSURE DROP (f)  
FACTORS FOR MULTI-ROW TUBE BUNDLES**



**Nre - REYNOLDS NUMBER**  
**Figure 10: MANIFOLD SHELL-SIDE HEAT TRANSFER AND PRESSURE DROP**

manifold is not included in the above calculation since the manifold is assumed to be shielded from its environment by other components on the spacecraft.

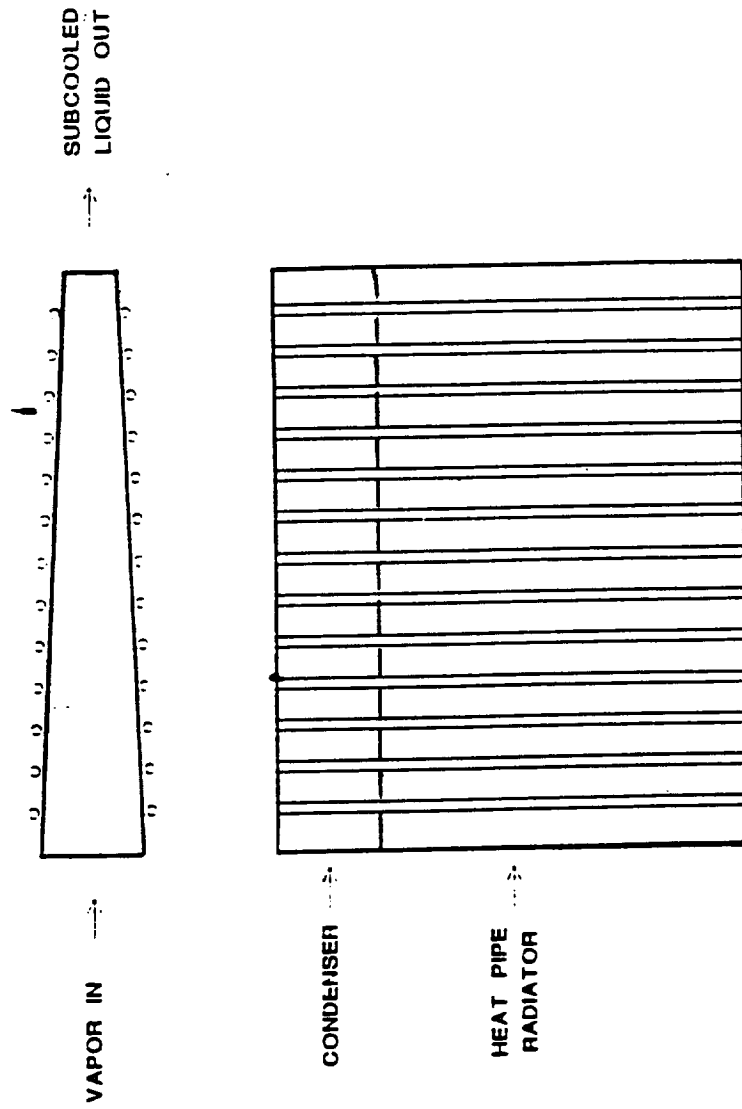
### 3.7 Shear Flow Condenser/Manifold

The K-Rankine cycle requires a condenser to directly reject waste heat from the cycle. A shear flow device has been identified as being the most likely candidate for this application since its operation does not require the presence of a gravity field. A flow schematic for a heat pipe cooled shear flow condenser is given in Figure 11.

The approach to analyzing the performance of the shear flow condenser is similar to the one used for the convectively cooled manifolds. The code first estimates the proportion of the manifold that is required for subcooling and the portion required for condensing the wet or saturated inlet flow. The manifold routine cannot accommodate superheated flow, due to the fact that either large surface areas or flow dilution must be used to provide desuperheating. A separate piece of equipment is usually used in commercial or utility practice. The code then computes an average film temperature drop for condensing and for subcooling in a manner similar to that used for the convective manifolds. An average value for film temperature drop is then found by averaging the above values weighted by the number of heat pipes involved in each process. Condenser pressure drop is computed for the condensing region and for the subcooling region and then added.

The model used to estimate shear flow condensation is based on computing the condensation of pure vapors inside horizontal tubes. At high Reynolds numbers, the heat transfer rate is controlled by the vapor flow heat transfer coefficient to the continuously forming film on the duct wall. The thickness of this film increases with flow manifold length. Gas phase heat transfer coefficients are estimated by the use of common empirical relations. The model is assumed to be valid provided that the flow is in the shear flow regime. A test is provided in the calculations to determine if the flow is in the shear flow regime, however, the code only issues a warning that the manifold is operating in an invalid flow regime. If such an event occurs, the results of the condensing manifold performance estimating routine is invalid and the user must make a change to the design. This change will usually consist of increasing the local vapor flow velocity in the manifold.

Manifold mass is computed by simple density times part volume relations. The elements included in the mass estimate are the manifold wall mass, manifold to heat-pipe braze mass, the mass of any manifold insulation, and the mass of the NaK inventory in the subcooler portion of the manifold. Armor mass for the manifold is not included in the above calculation since the manifold is



**Figure 11: SHEAR CONTROLLED FLOW CONDENSER AND HEAT PIPE RADIATOR FLOW SCHEMATIC**

assumed to be shielded from its environment by other components on the spacecraft.

### 3.8 Gas Ducting

Cycle reject heat can be transferred to a heat pipe cooled gas manifold by a gas ducting system. The gas ducting system affects system mass by providing resistance to the Brayton compressor and by requiring a volume of metal to provide fluid containment. Aerospace gas ducting systems are usually designed not to exceed a certain maximum flow velocity. This velocity is usually less than about 30 to 40 meters/second in order to avoid excessive pressure drop. A usually satisfactory value for pipe wall thickness is given by assuming the duct will be fabricated from 1/16" sheet steel. The use of thinner sections should be carefully evaluated.

The pressure drop in the gas ducting system is estimated from input values of flowrate, pipe diameter, pipe length and number of 90 degree bends in the system. Pipe bend resistances are estimated by use of an empirical equation derived from a cross plot of bend resistance data published by Miller [3]. Pipe friction factors are estimated by means of equation 2. Masses are computed by simple density times part volume relations. The elements included in the mass estimate are the duct insulation and duct material.

### 3.9 Heat Pipe Radiator

Cycle waste heat is ultimately rejected by the heat pipe/fin radiator surface. The code determines the size of the heat pipe and fin assembly necessary to reject the specified amount of cycle waste heat. The heat pipe radiator subroutine is based on a detailed calculation of the amount of heat that can be radiated from the condenser section of a finned heat pipe. The code can be adapted to use any heat pipe working fluid for which the appropriate fluid physical properties are available. The calculations in the subroutine start with an initial estimate of the length of heat pipe required. The heat pipe length is sectioned into a prespecified number of segments which are treated as isothermal. The amount of heat radiated from a particular segment is computed and compared to the various heat pipe performance limits that apply at the particular length step. The saturation temperature is then adjusted and the heat rejection from the next step is computed. The overall length of heat pipe is adjusted to radiate the correct amount of heat by iterating on the amount of heat rejected. The subroutine uses the calculations for a single heat pipe to scale the results for the entire radiator. The evaporator inlet temperature for this single heat pipe is taken as the fourth power average temperature of the radiator.

The effect of temperature variation in the spanwise direction along the radiator surface is evaluated using the numerical results of Lieblein [6] for radiating fins of constant cross section. The

radiating efficiency presented by Lieblein was empirically represented by a relationship developed by Nervenga and Zarotti [7]. This expression yields an estimate of the fin efficiency directly, without iterations or table lookups, saving considerable computer run time.

The radiator is generally assumed to be radiating from both sides as in a flat plate configuration. However, cylindrical and conical geometries are available as options.

The use of heat pipes to dissipate waste heat from the cycle offers an opportunity to use redundant heat pipes to offset radiator armor. Using this approach, the code uses the binomial equation to estimate the required heat pipe reliability as a function of system reliability and redundancy. The value of heat pipe reliability is then used in the expression developed by Haller and Lieblein [8] to estimate the armor or heat pipe wall thickness required to provide sufficient meteorite protection to meet the heat pipe reliability requirement.

Masses are computed by simple density times part volume relations. The elements included in the mass estimate are the heat pipe container tube, the heat pipe wick, the heat pipe working fluid, the fins, the armor and an allowance for radiator structural support. This allowance is taken as 10 % of the mass of the radiator components.

## 4.0 SUPPORTING SUBROUTINE/ALGORITHM DEVELOPMENT

### 4.1 Orbit/Environment

Subroutine HRENVN computes the values of the meteorite or debris flux constants and the solar flux constant for use in the armor sizing subroutine and the heat sink temperature estimating subroutine. The meteorite and debris information is based on the 1990 Kessler model. The solar constant is scaled from 1.0 AU by the inverse ratio of the AU's from the sun, squared.

Kessler gives the meteorite flux model for space not influenced by the earth's gravitational field as:

$$N_t = \left[ \frac{1.0}{(2200 * m^{0.306} + 15.0)^{4.38}} + \frac{1.3 * 10^{-9}}{(m + (10^{11} * m^{2.0}) + (10^{27} * m^{4.0}))} \right. \\ \left. + \frac{1.3 * 10^{-16}}{(m + (10^6 * m^{2.0}))^{0.85}} \right] * \left( \frac{1.0}{R_{sun}^{1.5}} \right)$$

... (5)

where:

$N_t$  = Number of particles of mass, m, or greater per square meter per second.

m = Particle mass in grams.

$R_{sun}$  = Distance from sun (AU's)

The orbits that are influenced by the earth's gravitational field are taken to be those between LEO and GEO. For these orbits, the earth focusing factor and the earth shielding factor are applied as:

$$ShieldingFactor = 0.5 * (1.0 + \cos[\arcsin(\frac{R_e}{R_e + H})])$$

and

$$FocusingFactor = 1.0 + (\frac{R_e}{r})$$

and for the region influenced by the gravitational attraction of the earth:

$$N_t = \frac{N_t}{0.565}$$

where:

$R_e$  = Earth Radius + 100 KM atmosphere (6478 KM)

$H^e$  = Height above Earth's atmosphere (Orbit altitude - 100 KM)

$r$  = Orbit Radius (from earth center) = Orbit Altitude + 6378 KM.

The debris flux model is given by Kessler as:

$$N_t = 3.168896 * 10^{-8} * [H * \phi * \psi * (F_1 * g_1 + F_2 * g_2)]$$

... (6)

where:

$$g_1 = (1.0 + q)^{t-1988}$$

$q = 0.02$ , if  $q < 2011$ .

$t$  = Year Vehicle Launched

or:

$$g_1 = (1 + q)^{23} * (1 + q')^{t-2011}$$

$q = q' = 0.04$ , if  $q > 2011$ .

and:

$$g_2 = 1.0 + (p * (t - 1988))$$

where:

$p$  = Assumed annual growth rate of mass in orbit

Also:

$$F_1 = \frac{1.22 * 10^{-5}}{d^{2.5}}$$

and:

$$F_2 = \frac{8.1 * 10^{10}}{(d + 700)^6}$$

where:

$$d = \left( \frac{6.0 * m}{2.8 * \pi} \right)^{0.3623}, m > 0.3076 \text{ gram}$$

or:



$$d = \left( \frac{6.0 * m}{4.7 * \pi} \right)^{0.3333}, m < 0.3076 \text{ gram}$$

and:

$$\phi_1 = 10.0 \left( \frac{H}{200} - \frac{S}{140} - 1.5 \right)$$

where:

$$S = 87.2$$

and:

$$\phi = \frac{\phi_1}{(\phi_1 + 1)}$$

and:

$$H = \left[ 10.0 \exp \left( \frac{-(\log_{10}(d) - 0.78)^2}{0.637^2} \right) \right]^{0.5}$$

and for:  $28.5 < i < 80.0$  degrees

$$\psi = -0.313471 + (0.084327 * i) - (0.00186 * i^2) + (0.000014 * i^3)$$

where:

$i$  = Orbit inclination in degrees.

The meteorite flux constants for use in the armor requirements equation evaluated in subroutine ARMOR are estimated from the meteorite model and from the debris model for orbits from LEO to GEO. The larger of the two values is used. For orbits beyond GEO, debris is not usually found, therefore only the meteorite flux is considered.

The solar flux is scaled as a function of distance from the sun in AU, as:

$$Q_{sun} = 1353.0 * \left( \frac{1.0}{R} \right)^2; \text{watts/meter}^2$$

This flux is used in the HTSINK routine to estimate the effective sink temperature seen by the radiator.

## 4.2 Thermal Properties

The code makes extensive use of thermal properties in its many subroutines. The majority of the properties required to run the code are built in as curve-fit subroutines. There are several places in the code where the same thermal properties are used under different names and come from different subroutines. These cases developed from the fact that several existing subroutines/algorithms were used to describe some of the components in the system. The routines often used different systems of units and had their own property generating subroutines. These were preserved in order to take advantage of the calibration and development that the routines had at the time of their application. Making all of the subroutines in the code use the same property subroutines will be an area of ongoing code development.

## 4.3 Armor Thickness Estimates

Subroutine HRARMR computes the amount of armor required in order to provide a specific non-puncture probability in the specified orbit for the specified mission duration. Armor thickness is computed from a semi-empirical relationship developed by Haller and Leiblien [8]. The equation developed requires that specific functions of the armor material be input and that specific meteorite and orbital debris parameters be specified. The orbital parameters are computed in subroutine HRENVF, described above and the materials dependent parameters are given in Table 3. The empirical relationship used is:

$$\delta = \gamma_r a \left[ \frac{\rho_p}{\rho_a} \right]^{1/2} \left[ \frac{V_p}{C_a} \right]^{2/3} \left[ \frac{6}{\pi \rho_p} \right]^{1/3} \left[ \frac{E \alpha A_v t}{-\ln(P_o)} \right]^{1/3\beta} \left[ \frac{2}{2\beta + 2} \right]^{1/3\beta} \left[ \frac{T}{T_r} \right]^{1/6}$$

... (7)

where:

- $\gamma_r$  = Room temperature cratering coefficient (from Table 3)
- $a$  = Rear surface damage thickness factor (from Table)
- $\rho_p$  = Impacting particle specific gravity (values are built in to the subroutine)
- $\rho_a$  = Armor specific gravity - (Grams/cu-Cm)
- $V_p$  = Impacting particle velocity (values are built in to subroutine)
- $C_a$  = Armor sonic velocity
- $A_v$  = Target area
- $t$  = Exposure time (mission duration)
- $P_o$  = Probability of non-puncture (ie; for example 0.9, 0.99, 0.999)
- $T$  = Average armor temperature
- $\delta$  = Armor thickness (units depend on other units used)

**TABLE 3**  
**CRATERING COEFFICIENT VALUES AND DAMAGE THICKNESS FACTORS FOR**  
**SELECTED MATERIALS**

| <u>TARGET MATERIAL</u> | <u>CRATERING COEFFICIENT <math>\gamma_r</math></u> |
|------------------------|--|
| 356 - T51 Aluminum     | 2.15   |
| 7075 - T6 Aluminum     | 2.00   |
| 2024 - T6 Aluminum     | 1.70   |
| Nb + 1% Zr             | 1.81   |
| 316 - Stainless Steel  | 2.19   |
| A- 286                 | 1.77   |
| Inconel - 718          | 1.85   |
| L - 605                | 2.00   |
| Vanadium               | 1.71   |
| Tantalum               | 1.77   |
| TZM - Molybdenum       | 2.00   |
| Carbon-Carbon          | 1.70   |

Damage Thickness Factors for Incipient Dimple, Spall and Perforation

| <u>Material</u>       | <u>Dimple</u> | <u>Spall</u> | <u>Perforation</u> |
|-----------------------|---------------|--------------|--------------------|
| 2024 - T6 Aluminum    | 2.5           | 2.3          | 1.7                |
| 316 - Stainless Steel | 2.35          | 1.9          | 1.4                |
| A - 286               | 2.80          | 2.0          | 1.65               |
| Nb + 1% Zr            | 4.5           | 4.0          | 1.7                |
| Inconel - 718         | 3.0           | 2.5          | 1.75               |
| Cobalt Alloy L-605    | 2.5           | 2.1          | 1.7                |
| Titanium              | 3.1           | 2.6          | 1.65               |
| Vanadium              | 3.6           | 2.5          | 1.55               |
| TZM - Molybdenum      | 3.25          | 3.0          | 1.85               |
| Carbon/Carbon         | 2.5           | 2.3          | 1.70               |

**Notes:**

1. For heat pipe radiator "perforation" is usual design approach.
2. For pumped loop radiator "dimple" is preferred, but "spall" will usually be acceptable.

#### 4.4 Sink Temperature Estimates

Subroutine HRTSNK computes the maximum sink temperature experienced by a body in a given orbit. The sink temperature is a function of the solar constant, which is determined by subroutine HRENVF. In earth orbit, the energy reflected from the earth and the energy radiated by the earth are significant. Values of the earth reflected and earth emitted radiation are built into the code and used to determine the environmental flux constant for LEO to GEO orbits.

#### 4.5 Statistical Equation Solution Routines

An appropriate relationship with which to estimate the reliability of a heat pipe as a function of system reliability and redundancy is the binomial equation, which can be stated as:

$$U = \sum_{H=J+1}^K \left( \frac{K!}{(K-H)! (H)!} \right) (P)^H (1-P)^{K-H}$$

... (8)

where:

- P = Probability of failure of a single heat pipe
- K = Number of heat pipes in the radiator
- J = Number of additional redundant heat pipes
- U = Probability of system failure

The binomial equation assumes that the probabilities of failure will be binomially distributed among the individual heat pipes. The values of U, K, and J are specified and the subroutine/function PNEW iteratively solves equation 8 to determine P, the probability of failure of an individual heat pipe which is then used in the armor thickness equation discussed above.

## 5.0 CONCLUSIONS/RECOMMENDATIONS

It is believed that the heat pipe cooled heat rejection subsystem model presented will yield performance and mass results of adequate accuracy for system analysis purposes. The code will accommodate designs for which relatively complete dimensional and operating data are available or it will use a minimum input data set to generate a relatively complete, but not optimized design to use as the basis for optimization studies.

Improvements in several areas of the model are suggested. The use of the various thermal properties routines should be made more consistent so as to eliminate redundant property generating routines; the code can be condensed considerably by eliminating many of the comments and output routines; and the code could probably be made to run considerably faster by the use of improved methods of obtaining numerical convergence. However, the implementation of these changes should be deferred until the code is used in a systems context, so that the actual need for some of the improvements can be better prioritized. A second area of interest may be to couple this code with one of the currently available general optimization codes to produce a relatively complete optimization for the minimum input data case.

## REFERENCES

1. K. J. Bell, "Final Report of Cooperative Research Program on Shell and Tube Heat Exchangers", University of Delaware Engineering Experiment Station, Bulletin # 5, January 1963.
2. F. Kreith, Principles of Heat Transfer, International Textbook Company, Scranton, Pennsylvania, 1958.
3. D. S. Miller, Internal Flow Systems, Volume 5 in the BHRA Fluid Engineering Series, British Hydromechanics Research Associates, 1978.
4. R. S. Baker and M. J. Tessier, Handbook of Electromagnetic Pump Technology, Elsevier Science Publishing Co., New York, 1987.
5. W. D. Whitaker and T. T. Shimazaki, "Volume Accumulator Design Analysis Computer Codes", Atomics International Division of Rockwell International, available as NASA-CR-121246, National Aeronautics and Space Administration, Washington, D. C., contract number AT(04-3)-701, June 30, 1973.
6. S. Lieblein, "Analysis of Temperature Distribution and Radiant Heat Transfer Along a Rectangular Fin of Constant Thickness", NASA TN D-196, NASA Lewis Research Center, Cleveland, OH., 1959.
7. N. Nervegna and G. L. Zarotti, "Space Radiator Design: A Non-Linear Programming Approach", in Proc. 1976 Heat Transfer and Fluid Mechanics Institute, A. A. McKillop, J. W. Baughn and H. A. Deyer, eds., Stanford University Press, Stanford, CA, 1976.
8. H. C. Haller and S. Lieblein, "Analytical Comparison of Rankine Cycle Space Radiators Constructed of Central, Double, and Block-Vapor-Chamber Fin Tube Geometries", NASA TD D-4411, NASA Lewis Research Center, Cleveland, OH., 1968.

**APPENDIX A**  
**OPERATING INSTRUCTIONS FOR THE HREJEC CODE**

The HREJEC subroutine is designed to estimate the performance and mass of heat rejection subsystems used on space based nuclear power systems. The subroutine offers six options which are selected by the use of the flags Iselec and Iprob. The selection logic is as follows:

IF Iselec = 1, THEN THE CODE WILL SUPPLY MOST OF THE VARIABLE VALUES NEEDED. IF Iselec = 2, THEN THE USER MUST SUPPLY MOST OF THE VARIABLE VALUES NEEDED

IF Iprob = 1, CODE IS SET UP FOR A DIRECT COOLED BRAYTON CONFIGURATION. (Figure A-1)

IF Iprob = 2, CODE IS SET UP FOR A LIQUID LOOP COOLED BRAYTON CONFIGURATION. (Figure A-2)

IF Iprob = 3, CODE IS SET UP FOR A SHEAR FLOW CONDENSER IN A POTASSIUM RANKINE CYCLE. (Figure A-3)

The subroutine HREJEC is entered by use of the following call statement in the main or driver program:

CALL HREJEC(Iselec,Iprob,IENflg,Pin,Tin,Tout,Qrad)

In addition to the flags Iselec and Iprob, a flag called IENflg is used to select the environment desired. IENflg is defined as follows:

IENflg = FLAG TO SET ENVIRONMENT DESIRED  
= 1, EARTH ORBIT, LEO TO GEO USES GREATER OF DEBRIS OR METEORITE FLUX, NO DEBRIS ABOVE 2000 Km.  
= 2, BEYOND EARTH ORBIT, 0.25 TO 2.00 AU

The other variables in the call statement are defined as follows:

Pin = CYCLE WORKING FLUID INLET PRESSURE (Grams/sq-Cm)  
Tin = CYCLE WORKING FLUID INLET TEMPERATURE (K)  
Tout = CYCLE WORKING FLUID OUTLET TEMPERATURE (K)  
Qrad = CYCLE TOTAL HEAT REJECTION RATE REQUIRED (Kwt)

In addition to the CALL statement the main program must provide for the opening of a data file called RADAT. The contents of RADAT provide the balance of the data needed to run HREJEC. For the cases that will use the minimum amount of input data to run HREJEC (Iselec = 1), the contents of RADAT are as follows:

IENflg, Halt, HINCL, Rsun  
Yrlnch, Time  
Pin, Tin, Xmw, Tout  
Qrad

If desired, IENflg, Halt, HINCL, Rsun, Yrlnch, and Time may be set equal to zero and the code will use built-in default values for these parameters. If IENflg is not equal zero, then the required parameters are defined as:

Halt = ORBIT ALTITUDE (km)  
HINCL = ORBIT INCLINATION ANGLE (28.5 TO 80.0 degrees, ONLY)  
Rsun = DISTANCE FROM SUN (AU)  
Yrlnch = YEAR IN WHICH VEHICLE IS PLACED IN ORBIT  
Time = MISSION DURATION (Secs)  
Pin = CYCLE WORKING FLUID INLET PRESSURE (Grams/sq-Cm)  
Tin = CYCLE WORKING FLUID INLET TEMPERATURE (K)  
Xmw = MOLECULAR WEIGHT OF CYCLE WORKING FLUID  
Tout = CYCLE WORKING FLUID OUTLET TEMPERATURE (K)  
Qrad = CYCLE TOTAL HEAT REJECTION RATE REQUIRED (Kwt)



For normal cases where a reasonable definition of the design is available, then the contents of RADAT will vary depending on the case being considered. If Iprob = 1, then the contents of RADAT are as follows:

IENflg,Halt,HINCL,Rsun  
Yrlnch,Time

GAM,ARSF,Earm,PROB  
CONFIG,Xntubes,Xnexpip,Xlflat  
Dhpipe,Ifluid,Imatl,Theta  
D2rad,Thickm,Thickf,Thick  
Em,Alpha,Hap,HArad  
Tkfin,Rhocoating,Rhofin,RHOarm  
Xladiab,Xmchmas

Iflg2,Hman,Gap,Pitch  
Dcan,Dhp,Rc,Rb  
Tf,TKfina,TKcan,TKbraze  
TKhp,XNf,Xmw,RHOcan  
RHObraze,THICKman,Wman

XN9,R9,Dp,SUMLEN  
THICKP,RHOIP,THICKI,RHOINS

The required parameters are defined as:

#### ORBIT DESCRIPTION

Halt = ORBIT ALTITUDE (km)  
HINCL = ORBIT INCLINATION ANGLE (28.5 TO 80.0 degrees, ONLY)  
Rsun = DISTANCE FROM SUN (AU)  
Yrlnch = YEAR IN WHICH VEHICLE IS PLACED IN ORBIT  
Time = MISSION DURATION (Secs)

#### RADIATOR DESCRIPTION

GAM,ARSF = PENETRATION CONSTANTS - FUNCTIONS OF THE SPECIFIC MATERIAL (SEE Table 3)  
Earm = YOUNGS MODULUS OF ARMOR Grams/sq-Cm)  
PROB = NON-PUNCTURE PROBABILITY (0.9, 0.99, 0.999, ETC.)  
CONFIG = 1.0, THEN RADIATOR IS A FLAT PLATE, ELSE IS A CONE OR CYLINDER  
Xntubes = NUMBER OF PRIMARY HEAT PIPE IN RADIATOR  
Xnexpip = NUMBER OF REDUNDENT HEAT PIPES  
Xlflat = HEAT PIPE EVAPORATOR LENGTH (Cm)  
Dhpipe = HEAT PIPE INSIDE DIAMETER (Cm)  
Ifluid = HEAT PIPE WORKING FLUID ID NUMBER (SEE Table 2 for recommendations)  
Imatl = HEAT PIPE LINER MATERIAL ID NUMBER (SEE Table 2 for recommendations)  
Theta = CONE ANGLE FOR CONICAL RADIATOR (DEGREES)  
D2rad = MANIFOLD DIAMETER FOR CONICAL RADIATOR OR MANIFOLD  
LENGTH DIVIDED BY 3.141593 FOR FLAT PLATE (Cm)  
Thickm = RADIATOR EMISSIVITY CONTROL COATING THICKNESS (Cm)  
Thickf = RADIATOR FIN THICKNESS (Cm)  
Thick = HEAT PIPE WALL or LINER THICKNESS (Cm)  
Em = RADIATOR SURFACE EMISSIVITY  
Alpha = RADIATOR SURFACE ABSOPTIVITY  
Hap = RADIATOR PROJECTED AREA (TOWARD SUN) (FRACTION OF TOTAL)  
HArad = RADIATOR ACTUAL AREA (USUALLY = 1.0)  
Tkfin = THERMAL CONDUCTIVITY OF FIN MATERIAL (Watts/(Cm-K))  
Rhocoating = COATING MATERIAL DENSITY (Grams/CC)  
Rhofin = FIN MATERIAL DENSITY (Grams/CC)  
RHOarm = ARMOR DENSITY (Grams/CC)  
Xladiab = LENGTH OF ADIABATIC PORTION OF THE HEAT PIPE (Cm)  
Xmchmas = MASS OF RADIATOR DEPLOYMENT MECHANISM (KG)

#### HEAT PIPE COOLED MANIFOLD DESCRIPTION

Iflg2 = FLAG TO SET MANIFOLD WORKING FLUID  
1 = He-Xe MIXTURE  
2 = NaK  
Hman = MANIFOLD HEIGHT (Cm)  
Gap = MANIFOLD WIDTH (Cm)  
Pitch = DISTANCE BETWEEN CAN (HEAT PIPES) CENTERLINES (Cm)  
Dcan = OUTSIDE DIAMETER OF MANIFOLD BRAZE CANS (Cm)  
Dhp = INSIDE DIAMETER OF HEAT PIPE (Cm)  
Rc = MANIFOLD BRAZE CAN INSIDE RADIUS (Cm)  
Rb = BRAZE JOINT INSIDE RADIUS (Cm)  
Tf = FIN THICKNESS (Cm)  
TKfina = THERMAL CONDUCTIVITY OF FIN MATERIAL (Watts/(Cm-K))  
TKcan = THERMAL CONDUCTIVITY OF MANIFOLD CAN MATERIAL ("")  
TKbraze = THERMAL CONDUCTIVITY OF MANIFOLD BRAZE ALLOY ("")  
TKhp = THERMAL CONDUCTIVITY OF HEAT PIPE WALL MATERIAL ("")  
XNf = TOTAL NUMBER OF FINS FOR THE MANIFOLD HEIGHT  
Xmw = MOLECULAR WEIGTH OF MANIFOLD WORKING FLUID  
RHOcan = DENSITY OF MANIFOLD MATERIAL (Grams/CC)  
RHObraze = DENSITY OF BRAZE MATERIAL (Grams/CC)  
THICKman = MANIFOLD MATERIAL THICKNESS (Cm)  
Wman = MANIFOLD FLOWRATE (KG/HR)

#### DUCTING DESCRIPTION

XN9 = NUMBER OF 90 DEGREE ELBOWS OR EQUIVALENT IN DUCT SYSTEM  
R9 = AVERAGE RADIUS FOR 90 DEGREE ELBOWS (Cm)  
Dp = INSIDE DUCT DIAMETER (Cm)  
SUMLEN = TOTAL LENGTH OF DUCT SYSTEM (Cm)  
THICKP = DUCT WALL THICKNESS (Cm)  
RHOPIP = DUCT WALL DENSITY (Grams/CC)  
THICKI = DUCT INSULATION THICKNESS (Cm)  
RHOINS = DUCT INSULATION DENSITY (Grams/CC)

If Iprob = 2, then the contents of RADAT are as follows:

IENflg,Halt,HINCL,Rsun  
Yrlnch,Time

GAM,ARSF,Earm,PROB  
CONFIG,Xntubes,Xnexpip,Xlflat  
Dhpipe,Ifluid,Imatl,Theta  
D2rad,Thickm,Thickf,Thick  
Em,Alpha,Hap,HArad  
Tkfin,Rhocoating,Rhofin,RHOarm  
Xladiab,Xmchmas

IXflg,UEST,TCIN,TCOUT  
WDOTS,AMWS,TINS,DENINS  
DENSSH,DTUBE,PR,TTUBE  
ANPLATES,WDOTT,AKTUBE

Iflg2,Hman,Gap,Pitch  
Dcan,Dhp,Rc,Rb  
Tf,TKfina,TKcan,TKbraze  
TKhp,XNf,Xmw,RHOcan  
RHObraze,THICKman,Wman

XN9,R9,Dp,SUMLEN  
THICKP,RHOPIP,THICKI,RHOINS

The required parameters are defined as:

#### ORBIT DESCRIPTION

Halt = ORBIT ALTITUDE (km)  
HINCL = ORBIT INCLINATION ANGLE (28.5 TO 80.0 degrees, ONLY)  
Rsun = DISTANCE FROM SUN (AU)  
Yrlnch = YEAR IN WHICH VEHICLE IS PLACED IN ORBIT  
Time = MISSION DURATION (Secs)

#### RADIATOR DESCRIPTION

GAM,ARSF = PENETRATION CONSTANTS - FUNCTIONS OF THE SPECIFIC MATERIAL (SEE Table 3)  
Earm = YOUNGS MODULUS OF ARMOR Grams/sq-Cm  
PROB = NON-PUNCTURE PROBABILITY (0.9, 0.99, 0.999, ETC.)  
CONFIG = 1.0, THEN RADIATOR IS A FLAT PLATE, ELSE IS A CONE OR CYLINDER  
Xntubes = NUMBER OF PRIMARY HEAT PIPE IN RADIATOR  
Xnexpip = NUMBER OF REDUNDENT HEAT PIPES  
Xlflat = HEAT PIPE EVAPORATOR LENGTH (Cm)  
Dhpipe = HEAT PIPE INSIDE DIAMETER (Cm)  
Ifluid = HEAT PIPE WORKING FLUID ID NUMBER (SEE Table 2 for recommendations)  
Imatl = HEAT PIPE LINER MATERIAL ID NUMBER (SEE Table 2 for recommendations)  
Theta = CONE ANGLE FOR CONICAL RADIATOR (DEGREES)  
D2rad = MANIFOLD DIAMETER FOR CONICAL RADIATOR OR MANIFOLD  
LENGTH DIVIDED BY 3.141593 FOR FLAT PLATE (Cm)  
Thickm = RADIATOR EMISSIVITY CONTROL COATING THICKNESS (Cm)  
Thickf = RADIATOR FIN THICKNESS (Cm)  
Thick = HEAT PIPE WALL or LINER THICKNESS (Cm)  
Em = RADIATOR SURFACE EMISSIVITY  
Alpha = RADIATOR SURFACE ABSOPTIVITY  
Hap = RADIATOR PROJECTED AREA (TOWARD SUN) (FRACTION OF TOTAL)  
HArad = RADIATOR ACTUAL AREA (USUALLY = 1.0)  
Tkfin = THERMAL CONDUCTIVITY OF FIN MATERIAL (Watts/(Cm-K))  
Rhocoating = COATING MATERIAL DENSITY (Grams/CC)  
Rhofin = FIN MATERIAL DENSITY (Grams/CC)  
RHOarm = ARMOR DENSITY (Grams/CC)  
Xladiab = LENGTH OF ADIABATIC PORTION OF THE HEAT PIPE (Cm)  
Xmchmas = MASS OF RADIATOR DEPLOYMENT MECHANISM (KG)

#### HEAT SINK HEAT EXCHANGER DESCRIPTION

IHXflf = 1, THEN TUBE SIDE FLUID IS LITHIUM  
IHXflg = 2, THEN TUBE SIDE FLUID IS NaK-78  
UEST = INITIAL VALUE OF Uoverall (Watts/sqCm-K)  
TCIN = COLD SIDE Inlet Temperature (K)  
TCOUT = COLD SIDE Outlet Temperature (K)  
WDOTS = SHELL SIDE FLUID Flowrate (KG/Sec)  
AMWS = MOLECULAR WEIGHT OF SHELL SIDE FLUID  
TINS = OD INSULATION THICKNESS (Cm)  
DENINS = OD INSULATION DENSITY (Grams/CC)  
DENSSH = SHELL MATERIAL Density (Grams/CC)  
DTUBE = Outside TUBE Diameter - (Cm)  
PR = TUBE PITCH RATIO  
TTUBE = TUBE Wall Thickness (Cm)  
ANPLATES = NUMBER OF SHELL SIDE BAFFLES (ASSUMED EQUALLY SPACED)  
WOOTT = TUBE -SIDE Fluid Flowrate (KG/SEC)  
AKTUBE = TUBE Wall Thermal Conductivity (Watts/Cm-K)

## HEAT PIPE COOLED MANIFOLD DESCRIPTION

Iflg2 = FLAG TO SET MANIFOLD WORKING FLUID  
1 = He-Xe MIXTURE  
2 = NaK  
Hman = MANIFOLD HEIGHT (Cm)  
Gap = MANIFOLD WIDTH (Cm)  
Pitch = DISTANCE BETWEEN CAN (HEAT PIPES) CENTERLINES (Cm)  
Dcan = OUTSIDE DIAMETER OF MANIFOLD BRAZE CANS (Cm)  
Dhp = INSIDE DIAMETER OF HEAT PIPE (Cm)  
Rc = MANIFOLD BRAZE CAN INSIDE RADIUS (Cm)  
Rb = BRAZE JOINT INSIDE RADIUS (Cm)  
Tf = FIN THICKNESS (Cm)  
TKfina = THERMAL CONDUCTIVITY OF FIN MATERIAL (Watts/(Cm-K))  
TKcan = THERMAL CONDUCTIVITY OF MANIFOLD CAN MATERIAL ("")  
TKbraze = THERMAL CONDUCTIVITY OF MANIFOLD BRAZE ALLOY ("")  
TKhp = THERMAL CONDUCTIVITY OF HEAT PIPE WALL MATERIAL ("")  
Xnf = TOTAL NUMBER OF FINS FOR THE MANIFOLD HEIGHT  
Xmw = MOLECULAR WEIGHT OF MANIFOLD WORKING FLUID  
RHOcan = DENSITY OF MANIFOLD MATERIAL (Grams/CC)  
RHObraze = DENSITY OF BRAZE MATERIAL (Grams/CC)  
THICKman = MANIFOLD MATERIAL THICKNESS (Cm)  
Wman = MANIFOLD FLOWRATE (KG/HR)

## NaK PIPING DESCRIPTION

XN9 = NUMBER OF 90 DEGREE ELBOWS OR EQUIVALENT IN DUCT SYSTEM  
R9 = AVERAGE RADIUS FOR 90 DEGREE ELBOWS (Cm)  
Dp = INSIDE DUCT DIAMETER (Cm)  
SUMLEN = TOTAL LENGTH OF DUCT SYSTEM (Cm)  
THICKP = DUCT WALL THICKNESS (Cm)  
RHOPIP = DUCT WALL DENSITY (Grams/CC)  
THICKI = DUCT INSULATION THICKNESS (Cm)  
RHOINS = DUCT INSULATION DENSITY (Grams/CC)

If Iprob = 3, then the contents of RADAT are as follows:

IENflg,Halt,HINCL,Rsun  
Yrlnch,Time

GAM,ARSF,Earm,PROB  
CONFIG,Xntubes,Xnexpip,Xlflat  
Dhpipe,Ifluid,Imatl,Theta  
D2rad,Thickm,Thickf,Thick  
Em,Alpha,Hap,HArad  
Tkfin,Rhocoating,Rhofin,RHOarm  
Xladiab,Xmchmas

Cman,Hman,Gap,THICKins  
RHOins,Tout,Tbraze,TKcan  
TKbraze,TKhp,Pin,Tin  
Xin,RHOpip,RHOcan,RHObraze  
THICKman,Thtpip,Wman

The required parameters are defined as:

## ORBIT DESCRIPTION

Halt = ORBIT ALTITUDE (km)  
HINCL = ORBIT INCLINATION ANGLE (28.5 TO 80.0 degrees, ONLY)  
Rsun = DISTANCE FROM SUN (AU)  
Yrlnch = YEAR IN WHICH VEHICLE IS PLACED IN ORBIT  
Time = MISSION DURATION (Secs)

## RADIATOR DESCRIPTION

GAM,ARSF = PENETRATION CONSTANTS - FUNCTIONS OF THE SPECIFIC MATERIAL (SEE Table 3)  
Earm = YOUNGS MODULUS OF ARMOR Grams/sq-Cm  
PROB = NON-PUNCTURE PROBABILITY (0.9, 0.99, 0.999, ETC.)  
CONFIG = 1.0, THEN RADIATOR IS A FLAT PLATE, ELSE IS A CONE OR CYLINDER  
Xntubes = NUMBER OF PRIMARY HEAT PIPE IN RADIATOR  
Xnexpip = NUMBER OF REDUNDENT HEAT PIPES  
Xlflat = HEAT PIPE EVAPORATOR LENGTH (Cm)  
Dhpipe = HEAT PIPE INSIDE DIAMETER (Cm)  
Ifluid = HEAT PIPE WORKING FLUID ID NUMBER (SEE Table 2 for recommendations)  
Imatl = HEAT PIPE LINER MATERIAL ID NUMBER (SEE Table 2 for recommendations)  
Theta = CONE ANGLE FOR CONICAL RADIATOR (DEGREES)  
D2rad = MANIFOLD DIAMETER FOR CONICAL RADIATOR OR MANIFOLD  
LENGTH DIVIDED BY 3.141593 FOR FLAT PLATE (Cm)  
Thickm = RADIATOR EMISSIVITY CONTROL COATING THICKNESS (Cm)  
Thickf = RADIATOR FIN THICKNESS (Cm)  
Thick = HEAT PIPE WALL or LINER THICKNESS (Cm)  
Em = RADIATOR SURFACE EMISSIVITY  
Alphe = RADIATOR SURFACE ABSOPTIVITY  
Hap = RADIATOR PROJECTED AREA (TOWARD SUN) (FRACTION OF TOTAL)  
HArad = RADIATOR ACTUAL AREA (USUALLY = 1.0)  
Tkfin = THERMAL CONDUCTIVITY OF FIN MATERIAL (Watts/(Cm-K))  
Rhocoating = COATING MATERIAL DENSITY (Grams/CC)  
Rhofin = FIN MATERIAL DENSITY (Grams/CC)  
RHOarm = ARMOR DENSITY (Grams/CC)  
Xladiab = LENGTH OF ADIABATIC PORTION OF THE HEAT PIPE (Cm)  
Xmchmas = MASS OF RADIATOR DEPLOYMENT MECHANISM (KG)

## CONDENSER/MANIFOLD DESCRIPTION

Cman = MANIFOLD FLAT LENGTH (Cm)  
Hman = MANIFOLD HEIGHT (Cm)  
Gap = AVERAGE MANIFOLD CONDENSER SURFACE SPACE (Cm)  
THICKins = MANIFOLD INSULATION THICKNESS (Cm)  
RHOins = MANIFOLD INSULATION DENSITY (Grams/CC)  
Tout = MANIFOLD OUTLET TEMPERATURE (K)  
Tbraze = MANIFOLD-HEAT PIPE BRAZE MATERIAL THICKNESS (Cm)  
TKcan = MANIFOLD WALL MATERIAL THERMAL CONDUCTIVITY (W/CmK)  
TKbraze = BRAZE MATERIAL THERMAL CONDUCTIVITY (W/CmK)      TKhp = HEAT PIPE WALL MATERIAL THERMAL  
CONDUCTIVITY (W/CmK)  
Pin = MANIFOLD INLET PRESSURE (Grams/sqCm)  
Tin = MANIFOLD INLET TEMPERATURE (K)  
Xin = MANIFOLD INLET VAPOR FRACTION (QUALITY)  
RHOip = HEAT PIPE WALL MATERIAL DENSITY (Grams/CC)  
RHOcan = MANIFOLD WALL MATERIAL DENSITY (Grams/CC)  
RHObraze = BRAZE MATERIAL DENSITY (Grams/CC)  
THICKman = MANIFOLD WALL MATERIAL THICKNESS (Cm)  
Thtip = HEAT PIPE WALL THICKNESS (Cm)  
Wman = MANIFOLD FLOWRATE (KG/Hr)

Sample input files are supplied on the disk that contains the source code for the HREJEC subroutine.

**APPENDIX B  
SAMPLE CASES**

CASE 1: DIRECT COOLED BRAYTON CONFIGURATION - HEAT REJECTION SYSTEM PHYSICAL DATA AVAILABLE

\*\*\*\*\*  
CONTENTS OF CALL: HREJEC(2, 1, 1, 5624.56, 411.1, 388.89, 250.0)  
\*\*\*\*\*

CONTENTS OF DATA FILE 'RADAT'

1, 1000.0, 30.0, 1.0  
2000.0, 0.315360E+09  
1.7, 1.7, 0.703070E+09, 0.931693  
1.0, 643.810, 64.381, 206.188  
2.54, 2, 8, 0.0  
1821.84, 0.0, 0.127, 0.762E-02  
0.8, 0.5, 1.0, 2.0  
0.849788, 0.0, 1.81009, 1.81009  
0.0, 0.0  
1, 206.188, 17.9933, 8.890  
2.75335, 2.53999, 1.32588, 1.32079  
0.253898E-01, 1.93842, 0.173073, 0.484604  
3.91193, 811.766, 40.0, 8.08932  
8.56988, 0.285537, 21.6435  
12.0, 149.684, 37.4211, 449.053  
0.299369, 8.08932, 10.16, 0.256295

\*\*\*\*\*

OUTPUT FROM HREJEC

\*\*\*\*\*

\*\*\* HEAT REJECTION SYSTEM FOR A BRAYTON CYCLE SYSTEM IN WHICH CYCLE WASTE HEAT IS REJECTED DIRECTLY FROM THE CYCLE WORKING FLUID IN A HEAT PIPE COOLED GAS MANIFOLD \*\*\*

RADIATOR DEFINITION INPUTS

GAMMA = 1.70000  
ARSF = 1.70000  
ARMOR DENSITY (Grams/CC) = 1.81009  
YOUNGS MODULUS OF ARMOR (Grams/CC) = 0.703070E+09  
EXPOSURE TIME OR MISSION DURATION (Secs) = 0.315360E+09  
NON-PUNCTURE PROBABILITY = 0.923846  
RADIATOR HEAT REJECTION RATE (KWt) = 250.0  
AVERAGE RADIATOR SURFACE TEMPERATURE (K) = 399.263  
NUMBER OF PRIMARY HEAT PIPE IN RADIATOR = 643.810  
NUMBER OF REDUNDENT HEAT PIPES= 64.3810  
HEAT PIPE EVAPORATOR LENGTH (Cm)= 206.188  
HEAT PIPE INSIDE DIAMETER (Cm)= 2.54000  
HEAT PIPE WORKING FLUID ID NUMBER= 2  
HEAT PIPE LINER MATERIAL ID NUMBER= 8  
CONE ANGLE FOR CONICAL RADIATOR (DEGREES)= 0.000000  
MANIFOLD DIAMETER FOR CONICAL RADIATOR OR MANIFOLD LENGTH DIVIDED BY 3.141593 FOR FLAT PLATE (Cm) = 1821.84  
RADIATOR EMISSIVITY CONTROL COATING THICK.(Cm)= 0.000000  
RADIATOR FIN THICKNESS (Cm)= 0.127000  
HEAT PIPE WALL or LINER THICKNESS (Cm)= 0.762000E-02  
RADIATOR SURFACE EMISSIVITY= 0.800000  
RADIATOR SURFACE ABSOPTIVITY= 0.500000  
RADIATOR PROJ. AREA (FRACT. OF TOT.)= 1.00000  
RADIATOR ACTUAL AREA (FRACTION)= 2.00000  
THERMAL COND. OF FIN MATERIAL (W/Cm-K) = 0.849773  
COATING MATERIAL DENSITY (Grams/CC)= 0.000000  
FIN MATERIAL DENSITY (Grams/CC)= 1.81009  
LENGTH OF ADIABATIC PORTION OF THE HEAT PIPE (Cm)= 0.000000  
MASS OF RADIATOR DEPLOYMENT MECHANISM (KG)= 0.000000

| TOTAL HEAT REJECTED (Kwt) | AVERAGE EVAPORATOR TEMP (K) | Radiator FIN Thick (Cm) | Emissivity Coating Thick (Cm) |
|---------------------------|-----------------------------|-------------------------|-------------------------------|
| 250.0000                  | 399.2626                    | 0.1270                  | 0.0000                        |

| Actual (one-side) Area(sq-Me.) | Effective Radiator Area(sq-Me) |
|--------------------------------|--------------------------------|
| 174.6257                       | 349.2515                       |

| HEAT PIPE DESIGN DETAILS - DIMS in Cm |            |             |              |          |           |
|---------------------------------------|------------|-------------|--------------|----------|-----------|
| Pipe ID                               | Wick Thick | #Arteries   | Art ID       | Art Wall | Pipe wall |
| 2.5400                                | 0.0129     | 7.6200      | 0.6452       | 0.0129   | 0.0076    |
| Evap Length                           | Adi Length | Cond Length | Total Length |          |           |
| 206.1880                              | 0.0000     | 305.1339    | 511.3219     |          |           |

| RADIATOR MASS BREAKDOWN - Mass in KG |           |           |                |  |
|--------------------------------------|-----------|-----------|----------------|--|
| Heat Pipes                           | Fluids    | FINS      | Emiss. Cont.   |  |
| 624.6960                             | 33.7311   | 315.4453  | 0.0000         |  |
| O.D.ARMOR                            | I.D.ARMOR | Structure | TOTAL RADIATOR |  |
| 342.0656                             | 342.0656  | 0.0000    | 1658.0040      |  |

IENflg (ORBIT SELECTION) = 1  
 IENflg=1, EARTH ORBIT (LEO-GEO)  
 IENflg=2, SOLAR ORBIT (0.5 to 2.0 AU)  
 ORBIT ALTITUDE (KM) = 1000.00  
 ORBIT INCLINATION ANGLE (Degrees) = 30.0000  
 DISTANCE FROM SUN (AU) = 1.00000  
 YEAR SATELLITE LAUNCHED = 2000.00

#### HEAT PIPE COOLED MANIFOLD DEFINITION VARIABLES

Iflg2 = 1  
 MANIFOLD HEIGHT (Cm)= 206.188  
 MANIFOLD WIDTH (Cm)= 17.9933  
 DIST. BETWN CAN(HEAT PIPES)C-LINES (Cm)= 8.89000  
 NUMBER OF HEAT PIPES IN RADIATOR= 643.810  
 NUMB. OF REDUNDENT HEAT PIPES IN RADIATOR= 64.3810  
 OUTSIDE DIAMETER OF BRAZE CANS(Cm)= 2.75335  
 INSIDE DIAMETER OF HEAT PIPE (Cm)= 2.53999  
 MANIFOLD BRAZE CAN INSIDE RADIUS (Cm)= 1.32588  
 BRAZE JOINT INSIDE RADIUS (Cm)= 1.32079  
 FIN THICKNESS (Cm)= 0.253898E-01  
 THERM. COND. OF FIN MATERIAL (W/(Cm-K))= 1.93842  
 THERM. COND. OF MANIFOLD CAN MATERIAL (W/CmK)= 0.173073  
 THERM. COND. OF MANIF. BRAZE ALLOY (W/CmK)= 0.484604  
 THERM. COND. OF HEAT PIPE WALL MATL (W/CmK)= 3.91193  
 TOTAL NUMBER OF FINS FOR THE MANIFOLD HEIGHT= 811.766  
 DENSITY OF MANIFOLD MATERIAL (Grams/CC)= 8.08932  
 DENSITY OF BRAZE MATERIAL (Grams/CC)= 8.56988  
 MANIFOLD MATERIAL THICKNESS (Cm)= 0.285537  
 MANIFOLD INLET PRESSURE (Grams/sq-Cm) = 5624.56  
 MANIFOLD INLET TEMPERATURE (K)= 411.100  
 MANIFOLD FLOWRATE (KG/HR)= 21.6435  
 MANIFOLD AND RADIATOR HEAT LOAD (Kwt)= 250.000  
 MOLECULAR WEIGH OF MANIFOLD WORKING FLUID= 40.0000

MANIFOLD PRESSURE DROP (Grams/sq-Cm) = 955.366  
 MANIFOLD FILM TEMPERATURE DROP (K) = 0.475179  
 NAK INVENTORY MASS (KG) = 131.482  
 NET MASS OF HEAT PIPE MANIFOLD (KG) = 6491.51



DUCTING INPUT VARIABLES

NUMB. OF 90 DEG. ELBOWS OR EQUIV.= 12.0000  
AVERAGE RADIUS FOR 90 DEGREE ELBOWS (Cm)= 149.684  
INSIDE DUCT DIAMETER (Cm)= 37.4211  
TOTAL LENGTH OF DUCT SYSTEM (Cm)= 449.053  
GAS VELOCITY IN DUCTS (M/SEC)= 30.4785  
GAS TEMPERATURE (K)= 411.100  
GAS PRESSURE (Grams/sq-Cm)= 5624.56  
DUCT WALL THICKNESS (Cm)= 0.299369  
DUCT WALL DENSITY (Grams/CC)= 8.08932  
DUCT INSULATION THICKNESS (Cm)= 10.1600  
DUCT INSULATION DENSITY (Grams/CC)= 0.256288  
GAS MOLECULAR WEIGHT= 0.000000  
DUCT SYSTEM PRESSURE DROP (Grams/sq-Cm) = 57.9987  
DUCT SYSTEM MASS (KG)= 1266.74  
MASS SUMMARY FOR DIRECT BRAYTON SYSTEM

HEAT PIPE COOLED GAS MANIFOLD MASS (KG) = 131.482  
MANIFOLD DUCTING MASS (KG) = 1266.74  
RADIATOR MASS (KG) = 1658.00

DIRECT BRAYTON SYSTEM MASS (KG) = 3056.23

CASE 2: LIQUID LOOP COOLED BRAYTON CONFIGURATION - HEAT REJECTION SYSTEM PHYSICAL DATA AVAILABLE

\*\*\*\*\*  
CONTENTS OF CALL: HREJEC(2, 2, 1, 5624.56, 466.7, 444.45, 250.0)  
\*\*\*\*\*

CONTENTS OF DATA FILE 'RADAT'

1, 1000.0, 30.0, 1.0  
2000.0, 0.315360E+09  
1.7, 1.7, 0.703070E+09, 0.944048  
1.0, 259.676, 25.9676, 45.720  
2.54, 2, 8, 0.0  
734.826, 0.0, 0.127, 0.762E-02  
0.8, 0.5, 1.0, 2.0  
0.849788, 0.0, 1.81009, 1.81009  
0.0, 0.0  
2, 10.1950, 416.672, 450.033  
21.6045, 40.0, 10.16, 24.0  
8.08932, 0.9525, 1.30, 0.5080E-01  
5.0, 8.16972, 0.173073  
2, 36.1541, 15.240, 8.89  
2.75335, 2.53999, 1.32588, 1.32079  
0.253898E-01, 1.93842, 0.173073, 0.484604  
3.91193, 180.0, 40.0, 8.08932  
8.56988, 0.285537, 8.16972  
12.00, 14.8324, 3.70810, 762.0  
0.254, 8.08932, 10.16, 0.384443

\*\*\*\*\*

OUTPUT FROM HREJEC

\*\*\*\*\*

\*\*\* HEAT REJECTION SYSTEM FOR A BRAYTON CYCLE SYSTEM IN WHICH CYCLE WASTE HEAT IS REJECTED TO A PUMPED NaK LOOP FROM THE CYCLE WORKING FLUID TO A HEAT PIPE COOLED LIQUID MANIFOLD \*\*\*

RADIATOR DEFINITION INPUTS

GAMMA = 1.70000  
ARSF = 1.70000  
ARMOR DENSITY (Grams/CC) = 1.81009  
YOUNGS MODULUS OF ARMOR (Grams/CC) = 0.703070E+09  
EXPOSURE TIME OR MISSION DURATION (Secs) = 0.315360E+09  
NON-PUNCTURE PROBABILITY = 0.934292  
RADIATOR HEAT REJECTION RATE (KWt) = 250.0  
AVERAGE RADIATOR SURFACE TEMPERATURE (K) = 419.225  
NUMBER OF PRIMARY HEAT PIPE IN RADIATOR = 259.676  
NUMBER OF REDUNDENT HEAT PIPES = 25.9676  
HEAT PIPE EVAPORATOR LENGTH (Cm) = 45.7200  
HEAT PIPE INSIDE DIAMETER (Cm) = 2.54000  
HEAT PIPE WORKING FLUID ID NUMBER = 2  
HEAT PIPE LINER MATERIAL ID NUMBER = 8  
CONE ANGLE FOR CONICAL RADIATOR (DEGREES) = 0.000000  
MANIFOLD DIAMETER FOR CONICAL RADIATOR OR MANIFOLD LENGTH DIVIDED BY 3.141593 FOR FLAT PLATE (Cm) = 734.826  
RADIATOR EMISSIVITY CONTROL COATING THICK.(Cm) = 0.000000  
RADIATOR FIN THICKNESS (Cm) = 0.127000  
HEAT PIPE WALL or LINER THICKNESS (Cm) = 0.762000E-02  
RADIATOR SURFACE EMISSIVITY = 0.800000  
RADIATOR SURFACE ABSOPTIVITY = 0.500000  
RADIATOR PROJ. AREA (FRACT. OF TOT.) = 1.00000  
RADIATOR ACTUAL AREA (FRACTION) = 2.00000  
THERMAL COND. OF FIN MATERIAL (W/Cm-K) = 0.849773  
COATING MATERIAL DENSITY (Grams/CC) = 0.000000  
FIN MATERIAL DENSITY (Grams/CC) = 1.81009  
LENGTH OF ADIABATIC PORTION OF THE HEAT PIPE (Cm) = 0.000000  
MASS OF RADIATOR DEPLOYMENT MECHANISM (KG) = 0.000000

| TOTAL HEAT REJECTED (KWt) | AVERAGE EVAPORATOR TEMP (K) | Radiator FIN Thick (Cm) | Emissivity Coating Thick (Cm) |
|---------------------------|-----------------------------|-------------------------|-------------------------------|
| 250.0000                  | 419.2248                    | 0.1270                  | 0.0000                        |

| Actual (one-side) Area(sq-Me.) | Effective Radiator Area(sq-Me.) |
|--------------------------------|---------------------------------|
| 130.8736                       | 261.7472                        |

| HEAT PIPE DESIGN DETAILS - DIMS in Cm |            |             |              |          |           |
|---------------------------------------|------------|-------------|--------------|----------|-----------|
| Pipe ID                               | Wick Thick | #Arteries   | Art ID       | Art Wall | Pipe wall |
| 2.5400                                | 0.0129     | 7.6200      | 0.6452       | 0.0129   | 0.0076    |
| Evap Length                           | Adi Length | Cond Length | Total Length |          |           |
| 45.7200                               | 0.0000     | 566.9699    | 612.6899     |          |           |

| RADIATOR MASS BREAKDOWN - Mass in KG |           |           |                |
|--------------------------------------|-----------|-----------|----------------|
| Heat Pipes                           | Fluids    | FINS      | Emiss. Cont.   |
| 301.8325                             | 16.2465   | 236.4111  | 0.0000         |
| O.D.ARMOR                            | I.D.ARMOR | Structure | TOTAL RADIATOR |
| 350.6339                             | 350.6339  | 0.0000    | 1255.7580      |

IENflg (ORBIT SELECTION) = 1  
     IENflg=1, EARTH ORBIT (LEO-GEO)  
     IENflg=2, SOLAR ORBIT (0.5 to 2.0 AU)  
 ORBIT ALTITUDE (KM) = 1000.00  
 ORBIT INCLINATION ANGLE (Degrees) = 30.0000  
 DISTANCE FROM SUN (AU) = 1.00000  
 YEAR SATELLITE LAUNCHED = 2000.00

#### HEAT PIPE COOLED MANIFOLD DEFINITION VARIABLES

Iflg2 = 2  
 MANIFOLD HEIGHT (Cm)= 36.1541  
 MANIFOLD WIDTH (Cm)= 15.2400  
 DIST. BETWN CAN(HEAT PIPES)C-LINES (Cm)= 8.89000  
 NUMBER OF HEAT PIPES IN RADIATOR= 259.676  
 NUMB. OF REDUNDENT HEAT PIPES IN RADIATOR= 25.9676  
 OUTSIDE DIAMETER OF BRAZE CANS(Cm)= 2.75335  
 INSIDE DIAMETER OF HEAT PIPE (Cm)= 2.53999  
 MANIFOLD BRAZE CAN INSIDE RADIUS (Cm)= 1.32588  
 BRAZE JOINT INSIDE RADIUS (Cm)= 1.32079  
 FIN THICKNESS (Cm)= 0.253898E-01  
 THERM. COND. OF FIN MATERIAL (W/(Cm-K))= 1.93842  
 THERM. COND. OF MANIFOLD CAN MATERIAL (W/CmK)= 0.173073  
 THERM. COND. OF MANIF. BRAZE ALLOY (W/CmK)= 0.484604  
 THERM. COND. OF HEAT PIPE WALL MATL (W/CmK)= 3.91193  
 TOTAL NUMBER OF FINS FOR THE MANIFOLD HEIGHT= 180.000  
 DENSITY OF MANIFOLD MATERIAL (Grams/CC)= 8.08932  
 DENSITY OF BRAZE MATERIAL (Grams/CC)= 8.56988  
 MANIFOLD MATERIAL THICKNESS (Cm)= 0.285537  
 MANIFOLD INLET PRESSURE (Grams/sq-Cm) = 5624.56  
 MANIFOLD INLET TEMPERATURE (K)= 466.700  
 MANIFOLD FLOWRATE (KG/HR)= 8.16972  
 MANIFOLD AND RADIATOR HEAT LOAD (KWt)= 250.000  
 MOLECULAR WEIGTH OF MANIFOLD WORKING FLUID= 40.0000

MANIFOLD PRESSURE DROP (Grams/sq-Cm) = 27.7819  
 MANIFOLD FILM TEMPERATURE DROP (K) = 36.1043  
 NAK INVENTORY MASS (KG) = 1001.46  
 NET MASS OF HEAT PIPE MANIFOLD (KG) = 585.325

#### PIPING DEFINITION VARIABLES

NUMB. OF 90 DEG. ELBOWS OR EQUIV.= 12.0000  
AVERAGE RADIUS FOR 90 DEGREE ELBOWS (Cm)= 14.8324  
INSIDE PIPE DIAMETER (Cm)= 3.70810  
TOTAL LENGTH OF PIPE SYSTEM (Cm)= 762.000  
NAK VELOCITY IN PIPES (M/SEC)= 9.14358  
NAK TEMPERATURE (K)= 466.700  
NAK PRESSURE (Grams/sq-Cm)= 5624.56  
PIPE WALL THICKNESS (Cm)= 0.254000  
PIPE WALL DENSITY (Grams/CC)= 8.08932  
PIPE INSULATION THICKNESS (Cm)= 10.1600  
PIPE INSULATION DENSITY (Grams/CC)= 0.384444  
PIPE SYSTEM PRESSURE DROP (Grams/sq-Cm)= 1696.15  
PIPE SYSTEM MASS (KG)= 210.384  
PIPE SYSTEM NaK MASS (KG) = 9.30602

#### HEAT SOURCE/SINK HEAT EXCHANGER DEFINITION

TUBE SIDE FLUID FLAG = 2  
Heat Rate or Duty (KWt) = 250.000  
HOT SIDE Inlet Temperature (K)= 466.700  
HOT SIDE Outlet Temperature (K)= 444.450  
COLD SIDE Inlet Temperature (K)= 416.672  
COLD SIDE Outlet Temperature (K)= 450.033  
SHELL SIDE FLUID Flowrate (KG/Hr)= 21.6045  
SHELL MATERIAL Density (Grams/CC)= 8.08934  
INSIDE TUBE Diameter (Cm)= 0.952500  
TUBE Wall Thickness (Cm)= 0.508000E-01  
TUBE -SIDE Fluid Flowrate (KG/Sec)= 8.16972  
TUBE Wall Thermal Conductivity(W/(Cm-K))= 0.173073  
SHELLSIDE DP (Grams/sq-Cm) = 620.628  
SHELLSIDE H (W/sqCm-K)= 21.5384  
FRIC-FAC = 0.265247  
UNEW (W/sqCm-K) = 10.2137  
NUMBER OF TUBES IN BUNDLE = 81.0937  
Tube Side Reynolds Number = 46448.2  
Tube Side Press. Drop(Grams/sq-Cm)= 79.1445  
Tube Side Hg (W/sqCm-K) = 38.0459  
TUBE WALL THICKNESS (Cm) = 0.508000E-01  
DOTL2 (Cm) = 13.5268  
LENGTH (Cm) = 81.2082

INSULATION MASS (KG) = 17.9806  
HEAD MASS (KG) = 0.348627  
SHELL MASS (KG) = 2.44039  
PLATE MASS (KG) = 0.128417  
TUBE SHEETS MASS (KG) = 0.348627  
TUBE MASS (KG) = 7.66617  
STRUCTURE AND BRACKETS MASS (KG) = 1.44564  
MASS OF NaK IN H-X (KG) = 4.99176  
Net Mass of Shell and Tube Unit(DRY)(KG)= 30.3585

#### NaK PUMP DEFINITION

NAK INLET TEMPERATURE (K)= 466.700  
NAK FLOWRATE (KG/SEC)= 8.16972  
PIPING SYSTEM PRESSURE DROP (G/SC)= 1696.15  
NAK SIDE HEAT EXCHANGER PRESSURE DROP (G/SC)= 79.1445  
NAK MANIFOLD PRESSURE DROP (G/SC)= 27.7819  
NaK LOOP PRESSURE DROP (G/SC) = 1803.08  
NaK LOOP PUMP POWER REQUIRED (HYDRAULIC) (WATTS) = 1738.59  
E-M PUMP MASS (DRY) (KG) = 271.508

NAK LOOP EXPANSION COMPENSATOR DEFINED

VOLUME ACCUMULATOR NaK MASS (KG) = 53.7542  
VOLUME ACCUMULATOR MASS (WET) (KG) = 110.184  
MASS SUMMARY FOR INDIRECT BRAYTON SYSTEM

HEAT SINK HEAT EXCHANGER MASS (KG)(DRY)= 30.3585  
HEAT EXCHANGER NaK MASS (KG) = 4.99176  
NaK PIPING SYSTEM MASS (KG)(DRY) = 210.384  
MASS OF NaK IN PIPING SYSTEM (KG) = 9.30602  
MASS OF EM PUMP (KG) (WET) = 271.508  
HEAT PIPE/NaK MANIFOLD MASS (KG) (DRY) = 585.325  
MASS OF NaK IN MANIFOLD (KG) = 1001.46  
EXPANSION COMPENSATOR MASS (KG) (DRY) = 110.184  
MASS OF NaK IN EXPANSION COMPENSATOR(KG)= 53.7542  
RADIATOR MASS (KG) = 1255.76

INDIRECT BRAYTON SYSTEM MASS (KG) (WET) = 3533.03

CASE 3: SHEAR FLOW CONDENSER IN A POTASSIUM RANKINE CYCLE - HEAT REJECTION SYSTEM PHYSICAL DATA AVAILABLE

\*\*\*\*\*  
CONTENTS OF CALL: HREJEC(2, 3, 1, 140.64, 855.56, 850.00, 250.0)  
\*\*\*\*\*

CONTENTS OF DATA FILE 'RADAT'  
1, 1000.0, 30.0, 1.0  
2000.0, 0.315360E+09  
1.7, 1.7, 0.703070E+09, 0.970672  
1.0, 41.3705, 4.13705, 43.2394  
2.54, 5, 7, 0.0  
66.8968, 0.0, 0.127, 0.762E-02  
0.8, 0.5, 1.0, 2.0  
0.849788, 0.0, 1.81009, 1.81009  
0.0, 0.0  
210.162, 43.2394, 1.05984, 10.16  
0.0, 850.0, 0.508E-02, 0.173073  
0.605756, 0.173073, 140.614, 855.560  
1.0, 8.08932, 8.08932, 8.40969  
0.158750, 0.508E-01, 442.892

\*\*\*\*\*

OUTPUT FROM HREJEC

\*\*\*\*\*

\*\*\* HEAT REJECTION SYSTEM FOR A RANKINE CYCLE SYSTEM IN WHICH CYCLE WASTE HEAT IS REJECTED DIRECTLY FROM THE  
CYCLE WORKING FLUID IN A HEAT PIPE COOLED CONDENSER \*\*\*

RADIATOR DEFINITION INPUTS

GAMMA = 1.70000  
ARSF = 1.70000  
ARMOR DENSITY (Grams/CC) = 1.81009  
YOUNGS MODULUS OF ARMOR (Grams/CC) = 0.703070E+09  
EXPOSURE TIME OR MISSION DURATION (Secs) = 0.315360E+09  
NON-PUNCTURE PROBABILITY = 0.961311  
RADIATOR HEAT REJECTION RATE (KWt) = 250.0  
AVERAGE RADIATOR SURFACE TEMPERATURE (K) = 827.144  
NUMBER OF PRIMARY HEAT PIPE IN RADIATOR = 41.3705  
NUMBER OF REDUNDANT HEAT PIPES = 4.13705  
HEAT PIPE EVAPORATOR LENGTH (Cm) = 43.2394  
HEAT PIPE INSIDE DIAMETER (Cm) = 2.54000  
HEAT PIPE WORKING FLUID ID NUMBER = 5  
HEAT PIPE LINER MATERIAL ID NUMBER = 7  
CONE ANGLE FOR CONICAL RADIATOR (DEGREES) = 0.000000  
MANIFOLD DIAMETER FOR CONICAL RADIATOR OR MANIFOLD LENGTH DIVIDED BY 3.141593 FOR FLAT PLATE (Cm) =  
66.8968  
RADIATOR EMISSIVITY CONTROL COATING THICK. (Cm) = 0.000000  
RADIATOR FIN THICKNESS (Cm) = 0.127000  
HEAT PIPE WALL or LINER THICKNESS (Cm) = 0.762000E-02  
RADIATOR SURFACE EMISSIVITY = 0.800000  
RADIATOR SURFACE ABSORPTIVITY = 0.500000  
RADIATOR PROJ. AREA (FRACT. OF TOT.) = 1.00000  
RADIATOR ACTUAL AREA (FRACTION) = 2.00000  
THERMAL COND. OF FIN MATERIAL (W/Cm-K) = 0.849773  
COATING MATERIAL DENSITY (Grams/CC) = 0.000000  
FIN MATERIAL DENSITY (Grams/CC) = 1.81009  
LENGTH OF ADIABATIC PORTION OF THE HEAT PIPE (Cm) = 0.000000  
MASS OF RADIATOR DEPLOYMENT MECHANISM (KG) = 0.000000

| TOTAL HEAT REJECTED (Kwt) | AVERAGE EVAPORATOR TEMP (K) | Radiator FIN Thick (Cm) | Emissivity Coating Thick (Cm) |
|---------------------------|-----------------------------|-------------------------|-------------------------------|
| 250.0000                  | 827.1442                    | 0.1270                  | 0.0000                        |

| Actual (one-side) Area(sq-Me.) | Effective Radiator Area(sq-Me) |
|--------------------------------|--------------------------------|
| 6.7057                         | 13.4114                        |

HEAT PIPE DESIGN DETAILS - DIMS in Cm

| Pipe ID     | Wick Thick | #Arteries   | Art ID       | Art Wall | Pipe wall |
|-------------|------------|-------------|--------------|----------|-----------|
| 2.5400      | 0.0129     | 7.6200      | 0.6452       | 0.0129   | 0.0076    |
| Evap Length | Adi Length | Cond Length | Total Length |          |           |
| 43.2394     | 0.0000     | 319.1042    | 362.3436     |          |           |

RADIATOR MASS BREAKDOWN - Mass in KG

| Heat Pipes | Fluids | FINS   | Emiss. Cont. | O.D.ARMOR | I.D.ARMOR | Structure | TOTAL RADIATOR |
|------------|--------|--------|--------------|-----------|-----------|-----------|----------------|
| 26.6852    | 1.3352 | 8.4793 | 0.0000       | 34.6265   | 34.6265   | 0.0000    | 105.7527       |

IENflg (ORBIT SELECTION) = 1  
 IENflg=1, EARTH ORBIT (LEO-GEO)  
 IENflg=2, SOLAR ORBIT (0.5 to 2.0 AU)  
 ORBIT ALTITUDE (KM) = 1000.00  
 ORBIT INCLINATION ANGLE (Degrees) = 30.0000  
 DISTANCE FROM SUN (AU) = 1.00000  
 YEAR SATELLITE LAUNCHED = 2000.00

HEAT PIPE COOLED CONDENSER DESCRIPTION

MANIFOLD FLAT LENGTH (Cm) = 210.162  
 MANIFOLD HEIGHT (Cm) = 43.2394  
 AVERAGE MANIFOLD COND.SURF.SPACE(Gap)(Cm)= 1.05984  
 MANIFOLD INSULATION THICKNESS (Cm) = 10.1600  
 MANIFOLD INSULATION DENSITY (Grams/CC) = 0.000000  
 NUMBER OF PRIMARY HEAT PIPES ATTACHED TO COOL CONDENSER SURFACE = 41.3705  
 NUMBER OF REDUNDANT HEAT PIPES USED TO COOL CONDENSER SURFACE = 4.13705  
 MANIFOLD WALL MATERIAL THICKNESS(Cm)= 0.158750  
 MANIFOLD-HEAT PIPE BRAZE MATERIAL THICKNESS (Cm) = 0.508000E-02  
 HEAT PIPE WALL THICKNESS (Cm) = 0.508000E-01  
 MANIFOLD WALL MAT. THERMAL COND. (W/CmK) = 0.173073  
 BRAZE MAT. THERMAL COND. (W/CmK) = 0.605756  
 HEAT PIPE WALL MAT. THERMAL COND. (W/CmK) = 0.173073  
 MANIFOLD WALL MATERIAL DENSITY (Grams/CC)= 8.08932  
 BRAZE MATERIAL DENSITY (Grams/CC) = 8.40969  
 HEAT PIPE WALL MATERIAL DENSITY(Grams/CC)= 8.08932  
 HEAT PIPE WORKING FLUID NUMBER = 5

MANIFOLD OPERATING CONDITIONS

INLET PRESSURE (G/SC) = 140.614  
 INLET TEMPERATURE (K) = 855.559  
 MEAN CONDENSER QUALITY = 1.00000  
 OUTLET TEMPERATURE (K) = 849.999  
 MANIFOLD FLOWREATE (KG/Hr) = 442.541  
 MANIFOLD DUTY (Kwt) = 250.000

COMPUTED RESULTS

MANIFOLD PRESSURE DROP (G/SC) = 6.96161  
MANIFOLD FILM TEMPERATURE DROP (K) = 25.6274  
CONDENSER CONDENSATE FLOW REGIME PARAMETER = 0.127759  
CONDENSER IS OPERATING IN SHEAR FLOW REGIME

CONDENSATE FILM REYNOLDS NUMBER = 1901.94  
MARTINELLI PARAMETER = 0.133079E-01  
VAPOR REYNOLDS NUMBER = 3803.88  
MANIFOLD MASS (KG) = 39.6255  
MASS SUMMARY FOR CONDENSING RANKINE SYSTEM

HEAT PIPE COOLED CONDENSER MASS (KG) = 39.6255  
RADIATOR MASS (KG) = 105.753

CONDENSING RANKINE SYSTEM MASS (KG) = 145.378



CASE 4: DIRECT COOLED BRAYTON CONFIGURATION - NO HEAT REJECTION SYSTEM PHYSICAL DATA AVAILABLE

\*\*\*\*\*  
 CONTENTS OF CALL: HREJEC(1, 1, 1, 5624.56, 411.1, 388.89, 250.0)  
 \*\*\*\*\*

CONTENTS OF DATA FILE 'RADAT'

0, 0.0, 0.0, 0.0  
 0.0, 0.0  
 5624.56, 411.1, 40.0, 388.89  
 250.0

\*\*\*\*\*  
 OUTPUT FROM HREJEC

\*\*\*\*\*  
 THE SIMPLIFIED DATA INPUT OPTION HAS BEEN SELECTED

\*\*\* HEAT REJECTION SYSTEM FOR A BRAYTON CYCLE SYSTEM IN WHICH CYCLE WASTE HEAT IS REJECTED DIRECTLY FROM THE  
 CYCLE WORKING FLUID IN A HEAT PIPE COOLED GAS MANIFOLD \*\*\*

INPUT FOR OPTION NUMBER 1

INPUT FOLLOWING DATA INTO FILE \*RADAT\* TO RUN OPT #1

|              |              |              |              |
|--------------|--------------|--------------|--------------|
| 1            | 1000.00      | 30.0000      | 1.00000      |
| 2000.00      | 0.315360E+09 |              |              |
| 1.70000      | 1.70000      | 0.703070E+09 | 0.990000     |
| 1.00000      | 643.810      | 64.3810      | 206.188      |
| 2.54000      | 2            | 8            | 0.000000     |
| 1821.84      | 0.000000     | 0.127000     | 0.762000E-02 |
| 0.800000     | 0.500000     | 1.00000      | 2.00000      |
| 0.849788     | 0.000000     | 1.81009      | 1.81009      |
| 0.000000     | 0.000000     |              |              |
| 1            | 206.188      | 17.9933      | 8.89000      |
| 2.75335      | 2.53999      | 1.32588      | 1.32079      |
| 0.253898E-01 | 1.93842      | 0.173073     | 0.484604     |
| 3.91193      | 811.766      | 40.0000      | 8.08932      |
| 8.56988      | 0.158750     | 21.6435      |              |
| 12.0000      | 149.684      | 37.4211      | 449.053      |
| 0.299369     | 8.08932      | 10.1600      | 0.256295     |

C IENflg,Halt,HINCL,Rsun  
 C Yrlnch,Time

C GAM,ARSF,Earm,PROB  
 C CONFIG,Xntubes,Xnexpip,Xlflat  
 C Dhpipe,Ifluid,Imatl,Theta  
 C D2rad,Thickm,Thickf,Thick  
 C Em,Alpha,Hap,HArad  
 C Tkfin,Rhocoating,Rhofin,RHOarm  
 C Xladiab,Xmchmas

C Iflg2,Hman,Gap,Pitch  
 C Dcan,Dhp,Rc,Rb  
 C Tf,TKfina,TKcan,TKbraze  
 C TKhp,XNf,Xmw,RHOcan  
 C RHObraze,THICKman,Wman

C XN9,R9,Dp,SUMLEN  
 C THICKP,RHOPIP,THICKI,RHOINS

RADIATOR DEFINITION INPUTS

GAMMA = 1.70000  
 ARSF = 1.70000  
 ARMOR DENSITY (Grams/CC) = 1.81009  
 YOUNGS MODULUS OF ARMOR (Grams/CC) = 0.703070E+09  
 EXPOSURE TIME OR MISSION DURATION (Secs) = 0.315360E+09  
 NON-PUNCTURE PROBABILITY = 0.931693  
 RADIATOR HEAT REJECTION RATE (Kwt) = 250.  
 AVERAGE RADIATOR SURFACE TEMPERATURE (K) = 399.262  
 NUMBER OF PRIMARY HEAT PIPE IN RADIATOR = 643.810  
 NUMBER OF REDUNDENT HEAT PIPES= 64.3810  
 HEAT PIPE EVAPORATOR LENGTH (Cm)= 206.188  
 HEAT PIPE INSIDE DIAMETER (Cm)= 2.54000  
 HEAT PIPE WORKING FLUID ID NUMBER= 2  
 HEAT PIPE LINER MATERIAL ID NUMBER= 8  
 CONE ANGLE FOR CONICAL RADIATOR (DEGREES)= 0.000000  
 MANIFOLD DIAMETER FOR CONICAL RADIATOR OR MANIFOLD LENGTH DIVIDED BY 3.141593 FOR FLAT PLATE (Cm) = 1821.84  
 RADIATOR EMISSIVITY CONTROL COATING THICK.(Cm)= 0.000000  
 RADIATOR FIN THICKNESS (Cm)= 0.127000  
 HEAT PIPE WALL or LINER THICKNESS (Cm)= 0.762000E-02  
 RADIATOR SURFACE EMISSIVITY= 0.800000  
 RADIATOR SURFACE ABSOPTIVITY= 0.500000  
 RADIATOR PROJ. AREA (FRACT. OF TOT.)= 1.00000  
 RADIATOR ACTUAL AREA (FRACTION)= 2.00000  
 THERMAL COND. OF FIN MATERIAL (W/Cm-K) = 0.849774  
 COATING MATERIAL DENSITY (Grams/CC)= 0.000000  
 FIN MATERIAL DENSITY (Grams/CC)= 1.81009  
 LENGTH OF ADIABATIC PORTION OF THE HEAT PIPE (Cm)= 0.000000  
 MASS OF RADIATOR DEPLOYMENT MECHANISM (KG)= 0.000000

| TOTAL HEAT REJECTED (Kwt) | AVERAGE EVAPORATOR TEMP (K) | Radiator FIN Thick (Cm) | Emissivity Coating Thick (Cm) |
|---------------------------|-----------------------------|-------------------------|-------------------------------|
| 250.0000                  | 399.2623                    | 0.1270                  | 0.0000                        |

| Actual (one-side) Area(sq-Me.) | Effective Radiator Area(sq-Me.) |
|--------------------------------|---------------------------------|
| 174.6265                       | 349.2531                        |

| HEAT PIPE DESIGN DETAILS - DIMS in Cm |            |             |              |          |           |  |
|---------------------------------------|------------|-------------|--------------|----------|-----------|--|
| Pipe ID                               | Wick Thick | #Arteries   | Art ID       | Art Wall | Pipe wall |  |
| 2.5400                                | 0.0129     | 7.6200      | 0.6452       | 0.0129   | 0.0076    |  |
| Evap Length                           | Adi Length | Cond Length | Total Length |          |           |  |
| 206.1884                              | 0.0000     | 305.1358    | 511.3242     |          |           |  |

| RADIATOR MASS BREAKDOWN - Mass in KG |           |           |                |  |
|--------------------------------------|-----------|-----------|----------------|--|
| Heat Pipes                           | Fluids    | FINS      | Emiss. Cont.   |  |
| 624.6988                             | 33.7312   | 315.4457  | 0.0000         |  |
| O.D.ARMOR                            | I.D.ARMOR | Structure | TOTAL RADIATOR |  |
| 357.6603                             | 357.6603  | 0.0000    | 1689.1960      |  |

IENflg (ORBIT SELECTION) = 1  
 IENflg=1, EARTH ORBIT (LEO-GEO)  
 IENflg=2, SOLAR ORBIT (0.5 to 2.0 AU)  
 ORBIT ALTITUDE (KM) = 1000.00  
 ORBIT INCLINATION ANGLE (Degrees) = 30.0000  
 DISTANCE FROM SUN (AU) = 1.00000  
 YEAR SATELLITE LAUNCHED = 2000.00

#### HEAT PIPE COOLED MANIFOLD DEFINITION VARIABLES

Iflg2 = 1  
MANIFOLD HEIGHT (Cm)= 206.188  
MANIFOLD WIDTH (Cm)= 17.9933  
DIST. BETWN CAN(HEAT PIPES)C-LINES (Cm)= 8.89000  
NUMBER OF HEAT PIPES IN RADIATOR= 643.810  
NUMB. OF REDUNDENT HEAT PIPES IN RADIATOR= 64.3810  
OUTSIDE DIAMETER OF BRAZE CANS(Cm)= 2.75335  
INSIDE DIAMETER OF HEAT PIPE (Cm)= 2.53999  
MANIFOLD BRAZE CAN INSIDE RADIUS (Cm)= 1.32588  
BRAZE JOINT INSIDE RADIUS (Cm)= 1.32079  
FIN THICKNESS (Cm)= 0.253898E-01  
THERM. COND. OF FIN MATERIAL (W/(Cm-K))= 1.93842  
THERM. COND. OF MANIFOLD CAN MATERIAL (W/CmK)= 0.173073  
THERM. COND. OF MANIF. BRAZE ALLOY (W/CmK)= 0.484604  
THERM. COND. OF HEAT PIPE WALL MATL (W/CmK)= 3.91193  
TOTAL NUMBER OF FINS FOR THE MANIFOLD HEIGHT= 811.766  
DENSITY OF MANIFOLD MATERIAL (Grams/CC)= 8.08932  
DENSITY OF BRAZE MATERIAL (Grams/CC)= 8.56988  
MANIFOLD MATERIAL THICKNESS (Cm)= 0.158750  
MANIFOLD INLET PRESSURE (Grams/sq-Cm) = 5624.56  
MANIFOLD INLET TEMPERATURE (K)= 411.100  
MANIFOLD FLOWRATE (KG/HR)= 21.6435  
MANIFOLD AND RADIATOR HEAT LOAD (KWt)= 250.000  
MOLECULAR WEIGTH OF MANIFOLD WORKING FLUID= 40.0000

MANIFOLD PRESSURE DROP (Grams/sq-Cm) = 955.353  
MANIFOLD FILM TEMPERATURE DROP (K) = 0.475178  
NAK INVENTORY MASS (KG) = 131.483  
NET MASS OF HEAT PIPE MANIFOLD (KG) = 3863.87

#### DUCTING INPUT VARIABLES

NUMB. OF 90 DEG. ELBOWS OR EQUIV.= 12.0000  
AVERAGE RADIUS FOR 90 DEGREE ELBOWS (Cm)= 149.684  
INSIDE DUCT DIAMETER (Cm)= 37.4211  
TOTAL LENGTH OF DUCT SYSTEM (Cm)= 449.053  
GAS VELOCITY IN DUCTS (M/SEC)= 30.4785  
GAS TEMPERATURE (K)= 411.100  
GAS PRESSURE (Grams/sq-Cm)= 5624.56  
DUCT WALL THICKNESS (Cm)= 0.299369  
DUCT WALL DENSITY (Grams/CC)= 8.08932  
DUCT INSULATION THICKNESS (Cm)= 10.1600  
DUCT INSULATION DENSITY (Grams/CC)= 0.256288  
GAS MOLECULAR WEIGHT= 0.000000  
DUCT SYSTEM PRESSURE DROP (Grams/sq-Cm) = 57.9988  
DUCT SYSTEM MASS (KG)= 1266.75  
MASS SUMMARY FOR DIRECT BRAYTON SYSTEM

HEAT PIPE COOLED GAS MANIFOLD MASS (KG) = 131.483  
MANIFOLD DUCTING MASS (KG) = 1266.75  
RADIATOR MASS (KG) = 1689.20

DIRECT BRAYTON SYSTEM MASS (KG) = 3087.43

CASE 5: LIQUID LOOP COOLED BRAYTON CONFIGURATION - NO HEAT REJECTION SYSTEM PHYSICAL DATA AVAILABLE

\*\*\*\*\*

CONTENTS OF CALL: HREJEC(1, 2, 1, 5624.56, 466.7, 444.45, 250.0)

\*\*\*\*\*

CONTENTS OF DATA FILE 'RADAT'

0, 0.0, 0.0, 0.0  
 0.0, 0.0  
 5624.56, 466.7, 40.0, 444.45  
 250.0

\*\*\*\*\*

OUTPUT FROM HREJEC

\*\*\*\*\*

THE SIMPLIFIED DATA INPUT OPTION HAS BEEN SELECTED

\*\*\* HEAT REJECTION SYSTEM FOR A BRAYTON CYCLE SYSTEM IN WHICH CYCLE WASTE HEAT IS REJECTED TO A PUMPED NaK LOOP FROM THE CYCLE WORKING FLUID TO A HEAT PIPE COOLED NaK MANIFOLD \*\*\*

INPUT FOR OPTION NUMBER 2

INPUT FOLLOWING DATA INTO FILE \*RADAT\* TO RUN OPT #2

|              |              |              |              |
|--------------|--------------|--------------|--------------|
| 1            | 1000.00      | 30.0000      | 1.00000      |
| 2000.00      | 0.315360E+09 |              |              |
| 1.70000      | 1.70000      | 0.703070E+09 | 0.990000     |
| 1.00000      | 259.676      | 25.9676      | 45.7200      |
| 2.54000      | 2            | 8            | 0.000000     |
| 734.826      | 0.000000     | 0.127000     | 0.762000E-02 |
| 0.800000     | 0.500000     | 1.00000      | 2.00000      |
| 0.849788     | 0.000000     | 1.81009      | 1.81009      |
| 0.000000     | 0.000000     |              |              |
| 2            | 10.1950      | 416.672      | 450.033      |
| 21.6045      | 40.0000      | 10.1600      | 24.0000      |
| 8.08932      | 0.952500     | 1.30000      | 0.508000E-01 |
| 5.00000      | 8.16972      | 0.173073     |              |
| 2            | 36.1541      | 15.2400      | 8.89000      |
| 2.75335      | 2.53999      | 1.32588      | 1.32079      |
| 0.253898E-01 | 1.93842      | 0.173073     | 0.484604     |
| 3.91193      | 180.000      | 40.0000      | 8.08932      |
| 8.56988      | 0.158750     | 8.16972      |              |
| 12.0000      | 14.8324      | 3.70810      | 762.000      |
| 0.254000     | 8.08932      | 10.1600      | 0.384443     |

C IENflg,Halt,HINCL,Rsun  
 C Yrlnch,Time

C GAM,ARSF,Earm,PROB  
 C CONFIG,Xntubes,Xnexpip,Xlflat  
 C Dhpipe,Ifluid,Imatl,Theta  
 C D2rad,Thickm,Thickf,Thick  
 C Em,Alpha,Hap,HARad  
 C Tkfin,Rhocoating,Rhofin,RHOarm  
 C Xladiab,Xmchmas

C IHXflg,UEST,TCIN,TCOUT  
 C WDOTS,AMWS,TINS,DENINS  
 C DENSSH,DTUBE,PR,TTUBE  
 C ANPLATES,WDOOT,AKTUBE

C Iflg2,Hman,Gap,Pitch  
 C Dcan,Dhp,Rc,Rb  
 C Tf,TKfina,TKcan,TKbraze  
 C TKhp,XNf,Xmw,RHOcan  
 C RHObraze,THICKman,Wman

C XN9,R9,Dp,SUMLEN  
 C THICKP,RHOPIP,THICKI,RHOINS

RADIATOR DEFINITION INPUTS

GAMMA = 1.70000  
 ARSF = 1.70000  
 ARMOR DENSITY (Grams/CC) = 1.81009  
 YOUNGS MODULUS OF ARMOR (Grams/CC) = 0.703070E+09  
 EXPOSURE TIME OR MISSION DURATION (Secs) = 0.315360E+09  
 NON-PUNCTURE PROBABILITY = 0.944048  
 RADIATOR HEAT REJECTION RATE (Kwt) = 250.  
 AVERAGE RADIATOR SURFACE TEMPERATURE (K) = 419.224  
 NUMBER OF PRIMARY HEAT PIPE IN RADIATOR = 259.676  
 NUMBER OF REDUNDENT HEAT PIPES= 25.9676  
 HEAT PIPE EVAPORATOR LENGTH (Cm)= 45.7200  
 HEAT PIPE INSIDE DIAMETER (Cm)= 2.54000  
 HEAT PIPE WORKING FLUID ID NUMBER= 2  
 HEAT PIPE LINER MATERIAL ID NUMBER= 8  
 CONE ANGLE FOR CONICAL RADIATOR (DEGREES)= 0.000000  
 MANIFOLD DIAMETER FOR CONICAL RADIATOR OR MANIFOLD LENGTH DIVIDED BY 3.141593 FOR FLAT PLATE (Cm) = 734.826  
 RADIATOR EMISSIVITY CONTROL COATING THICK.(Cm)= 0.000000  
 RADIATOR FIN THICKNESS (Cm)= 0.127000  
 HEAT PIPE WALL or LINER THICKNESS (Cm)= 0.762000E-02  
 RADIATOR SURFACE EMISSIVITY= 0.800000  
 RADIATOR SURFACE ABSOPTIVITY= 0.500000  
 RADIATOR PROJ. AREA (FRACT. OF TOT.)= 1.00000  
 RADIATOR ACTUAL AREA (FRACTION)= 2.00000  
 THERMAL COND. OF FIN MATERIAL (W/Cm-K) = 0.849774  
 COATING MATERIAL DENSITY (Grams/CC)= 0.000000  
 FIN MATERIAL DENSITY (Grams/CC)= 1.81009  
 LENGTH OF ADIABATIC PORTION OF THE HEAT PIPE (Cm)= 0.000000  
 MASS OF RADIATOR DEPLOYMENT MECHANISM (KG)= 0.000000

| TOTAL HEAT REJECTED (Kwt) | AVERAGE EVAPORATOR TEMP (K) | Radiator FIN Thick (Cm) | Emissivity Coating Thick (Cm) |
|---------------------------|-----------------------------|-------------------------|-------------------------------|
| 250.0000                  | 419.2245                    | 0.1270                  | 0.0000                        |

| Actual (one-side) Area(sq-Me.) | Effective Radiator Area(sq-Me.) |
|--------------------------------|---------------------------------|
| 130.8741                       | 261.7481                        |

| HEAT PIPE DESIGN DETAILS - DIMS in Cm |            |             |              |          |           |  |
|---------------------------------------|------------|-------------|--------------|----------|-----------|--|
| Pipe ID                               | Wick Thick | #Arteries   | Art ID       | Art Wall | Pipe wall |  |
| 2.5400                                | 0.0129     | 7.6200      | 0.6452       | 0.0129   | 0.0076    |  |
| Evap Length                           | Adi Length | Cond Length | Total Length |          |           |  |
| 45.7200                               | 0.0000     | 566.9722    | 612.6923     |          |           |  |

| RADIATOR MASS BREAKDOWN - Mass in KG |           |           |                |  |
|--------------------------------------|-----------|-----------|----------------|--|
| Heat Pipes                           | Fluids    | FINS      | Emiss. Cont.   |  |
| 301.8342                             | 16.2466   | 236.4112  | 0.0000         |  |
| O.D.ARMOR                            | I.D.ARMOR | Structure | TOTAL RADIATOR |  |
| 374.3636                             | 374.3636  | 0.0000    | 1303.2190      |  |

IENflg (ORBIT SELECTION) = 1  
 IENflg=1, EARTH ORBIT (LEO-GEO)  
 IENflg=2, SOLAR ORBIT (0.5 to 2.0 AU)  
 ORBIT ALTITUDE (KM) = 1000.00  
 ORBIT INCLINATION ANGLE (Degrees) = 30.0000  
 DISTANCE FROM SUN (AU) = 1.00000  
 YEAR SATELLITE LAUNCHED = 2000.00

HEAT PIPE COOLED MANIFOLD DEFINITION VARIABLES

Iflg2 = 2  
 MANIFOLD HEIGHT (Cm)= 36.1541  
 MANIFOLD WIDTH (Cm)= 15.2400  
 DIST. BETWN CAN(HEAT PIPES)C-LINES (Cm)= 8.89000  
 NUMBER OF HEAT PIPES IN RADIATOR= 259.676  
 NUMB. OF REDUNDENT HEAT PIPES IN RADIATOR= 25.9676  
 OUTSIDE DIAMETER OF BRAZE CANS(Cm)= 2.75335  
 INSIDE DIAMETER OF HEAT PIPE (Cm)= 2.53999  
 MANIFOLD BRAZE CAN INSIDE RADIUS (Cm)= 1.32588  
 BRAZE JOINT INSIDE RADIUS (Cm)= 1.32079  
 FIN THICKNESS (Cm)= 0.253898E-01  
 THERM. COND. OF FIN MATERIAL (W/(Cm-K))= 1.93842  
 THERM. COND. OF MANIFOLD CAN MATERIAL (W/CmK)= 0.173073  
 THERM. COND. OF MANIF. BRAZE ALLOY (W/CmK)= 0.484604  
 THERM. COND. OF HEAT PIPE WALL MATL (W/CmK)= 3.91193  
 TOTAL NUMBER OF FINS FOR THE MANIFOLD HEIGHT= 180.000  
 DENSITY OF MANIFOLD MATERIAL (Grams/CC)= 8.08932  
 DENSITY OF BRAZE MATERIAL (Grams/CC)= 8.56988  
 MANIFOLD MATERIAL THICKNESS (Cm)= 0.158750  
 MANIFOLD INLET PRESSURE (Grams/sq-Cm) = 5624.56  
 MANIFOLD INLET TEMPERATURE (K)= 466.700  
 MANIFOLD FLOWRATE (KG/HR)= 8.16972  
 MANIFOLD AND RADIATOR HEAT LOAD (Kwt)= 250.000  
 MOLECULAR WEIGH OF MANIFOLD WORKING FLUID= 40.0000  
  
 MANIFOLD PRESSURE DROP (Grams/sq-Cm) = 27.7819  
 MANIFOLD FILM TEMPERATURE DROP (K) = 36.1043  
 NAK INVENTORY MASS (KG) = 1001.46  
 NET MASS OF HEAT PIPE MANIFOLD (KG) = 343.698

PIPING DEFINITION VARIABLES

NUMB. OF 90 DEG. ELBOWS OR EQUIV.= 12.0000  
 AVERAGE RADIUS FOR 90 DEGREE ELBOWS (Cm)= 14.8324  
 INSIDE PIPE DIAMETER (Cm)= 3.70810  
 TOTAL LENGTH OF PIPE SYSTEM (Cm)= 762.000  
 NAK VELOCITY IN PIPES (M/SEC)= 9.14355  
 NAK TEMPERATURE (K)= 466.700  
 NAK PRESSURE (Grams/sq-Cm)= 5624.56  
 PIPE WALL THICKNESS (Cm)= 0.254000  
 PIPE WALL DENSITY (Grams/CC)= 8.08932  
 PIPE INSULATION THICKNESS (Cm)= 10.1600  
 PIPE INSULATION DENSITY (Grams/CC)= 0.384444  
 PIPE SYSTEM PRESSURE DROP (Grams/sq-Cm)= 1696.14  
 PIPE SYSTEM MASS (KG)= 210.384  
 PIPE SYSTEM NAK MASS (KG) = 9.30602

#### HEAT SOURCE/SINK HEAT EXCHANGER DEFINITION

TUBE SIDE FLUID FLAG = 2  
Heat Rate or Duty (KWt) = 250.000  
HOT SIDE Inlet Temperature (K)= 466.700  
HOT SIDE Outlet Temperature (K)= 444.450  
COLD SIDE Inlet Temperature (K)= 416.672  
COLD SIDE Outlet Temperature (K)= 450.033  
SHELL SIDE FLUID Flowrate (KG/Hr)= 21.6045  
SHELL MATERIAL Density (Grams/CC)= 8.08934  
INSIDE TUBE Diameter (Cm)= 0.952500  
TUBE Wall Thickness (Cm)= 0.508000E-01  
TUBE -SIDE Fluid Flowrate (KG/Sec)= 8.16972  
TUBE Wall Thermal Conductivity(W/(Cm-K))= 0.173073  
SHELLSIDE DP (Grams/sq-Cm) = 620.624  
SHELLSIDE H (W/sqCm-K)= 21.5383  
FRIC-FAC = 0.265246  
UNEW (W/sqCm-K) = 10.2136  
NUMBER OF TUBES IN BUNDLE = 81.0944  
Tube Side Reynolds Number = 46447.7  
Tube Side Press. Drop(Grams/sq-Cm)= 79.1433  
Tube Side Hg (W/sqCm-K) = 38.0457  
TUBE WALL THICKNESS (Cm) = 0.508000E-01  
DOTL2 (Cm) = 13.5269  
LENGTH (Cm) = 81.2085

INSULATION MASS (KG) = 17.9807  
HEAD MASS (KG) = 0.348632  
SHELL MASS (KG) = 2.44042  
PLATE MASS (KG) = 0.128418  
TUBE SHEETS MASS (KG) = 0.348632  
TUBE MASS (KG) = 7.66628  
STRUCTURE AND BRACKETS MASS (KG) = 1.44566  
MASS OF NaK IN H-X (KG) = 4.99182  
Net Mass of Shell and Tube Unit(DRY)(KG)= 30.3588

#### NaK PUMP DEFINITION

NAK INLET TEMPERATURE (K)= 466.700  
NAK FLOWRATE (KG/SEC)= 8.16972  
PIPING SYSTEM PRESSURE DROP (G/SC)= 1696.14  
NAK SIDE HEAT EXCHANGER PRESSURE DROP (G/SC)= 79.1433  
NAK MANIFOLD PRESSURE DROP (G/SC)= 27.7819  
NaK LOOP PRESSURE DROP (G/SC) = 1803.07  
NaK LOOP PUMP POWER REQUIRED (HYDRAULIC) (WATTS) = 1738.58  
E-M PUMP MASS (DRY) (KG) = 271.506

#### NAK LOOP EXPANSION COMPENSATOR DEFINED

VOLUME ACCUMULATOR NaK MASS (KG) = 54.2511  
VOLUME ACCUMULATOR MASS (WET) (KG) = 111.024  
MASS SUMMARY FOR INDIRECT BRAYTON SYSTEM

HEAT SINK HEAT EXCHANGER MASS (KG)(DRY)= 30.3588  
HEAT EXCHANGER NaK MASS (KG) = 4.99182  
NaK PIPING SYSTEM MASS (KG)(DRY) = 210.384  
MASS OF NaK IN PIPING SYSTEM (KG) = 9.30602  
MASS OF EM PUMP (KG) (WET) = 271.506  
HEAT PIPE/NaK MANIFOLD MASS (KG) (DRY) = 343.698  
MASS OF NaK IN MANIFOLD (KG) = 1001.46  
EXPANSION COMPENSATOR MASS (KG) (DRY) = 111.024  
MASS OF NaK IN EXPANSION COMPENSATOR(KG)= 54.2511  
RADIATOR MASS (KG) = 1303.22

INDIRECT BRAYTON SYSTEM MASS (KG) (WET) = 3340.20

CASE 6: SHEAR FLOW CONDENSER IN A POTASSIUM RANKINE CYCLE - NO HEAT REJECTION SYSTEM PHYSICAL DATA AVAILABLE

\*\*\*\*\*  
 CONTENTS OF CALL: HREJEC(1, 3, 1, 140.64, 855.56, 850.00, 250.0)  
 \*\*\*\*\*

CONTENTS OF DATA FILE 'RADAT'  
 0, 0.0, 0.0, 0.0 1.0  
 0.0, 0.0  
 133.6707, 850.0, 40.0, 754.5  
 2128.32

\*\*\*\*\*  
 OUTPUT FROM HREJEC  
 \*\*\*\*\*

THE SIMPLIFIED DATA INPUT OPTION HAS BEEN SELECTED

\*\*\* HEAT REJECTION SYSTEM FOR A RANKINE CYCLE SYSTEM IN WHICH CYCLE WASTE HEAT IS REJECTED DIRECTLY FROM THE CYCLE WORKING FLUID IN A HEAT PIPE COOLED CONDENSER \*\*\*

INPUT FOR OPTION NUMBER 3

INPUT FOLLOWING DATA INTO FILE \*RADAT\* TO RUN OPT #3

|          |              |              |              |         |
|----------|--------------|--------------|--------------|---------|
|          | 1            | 1000.00      | 30.0000      | 1.00000 |
| 2000.00  |              | 0.315360E+09 |              |         |
| 1.70000  | 1.70000      | 0.703070E+09 | 0.990000     |         |
| 1.00000  | 41.3662      | 4.13662      | 43.2447      |         |
| 2.54000  |              | 5            | 7 0.000000   |         |
| 66.8897  | 0.000000     | 0.127000     | 0.762000E-02 |         |
| 0.800000 | 0.500000     | 1.00000      | 2.00000      |         |
| 0.849788 | 0.000000     | 1.81009      | 1.81009      |         |
| 0.000000 | 0.000000     |              |              |         |
| 210.140  | 43.2447      | 1.05962      | 10.1600      |         |
| 0.000000 | 850.000      | 0.508000E-02 | 0.173073     |         |
| 0.605756 | 0.173073     | 140.614      | 855.600      |         |
| 1.00000  | 8.08932      | 8.08932      | 8.40969      |         |
| 0.158750 | 0.508000E-01 | 442.915      |              |         |

- C IENflg,Halt,HINCL,Rsun
- C Yrlnch,Time
- C GAM,ARSF,Earm,PROB
- C CONFIG,Xntubes,Xnexpip,Xlflat
- C Dhpipe,Ifluid,Imatl,Theta
- C D2rad,Thickm,Thickf,Thick
- C Em,Alpha,Hap,HArad
- C Tkfin,Rhocoating,Rhofin,RHOarm
- C Xladiab,Xmchmas
- C Cmen,Hman,Gap,THICKins
- C RHOins,Tout,Tbraze,TKcan
- C TKbraze,TKhp,Pin,Tin
- C Xin,RHOpip,RHOcan,RHObraze
- C THICKmen,Thtpip,Wman



RADIATOR DEFINITION INPUTS

GAMMA = 1.70000  
 ARSF = 1.70000  
 ARMOR DENSITY (Grams/CC) = 1.81009  
 YOUNGS MODULUS OF ARMOR (Grams/CC) = 0.703070E+09  
 EXPOSURE TIME OR MISSION DURATION (Secs) = 0.315360E+09  
 NON-PUNCTURE PROBABILITY = 0.970672  
 RADIATOR HEAT REJECTION RATE (Kwt) = 853250.  
 AVERAGE RADIATOR SURFACE TEMPERATURE (K) = 827.164  
 NUMBER OF PRIMARY HEAT PIPE IN RADIATOR = 41.3662  
 NUMBER OF REDUNDENT HEAT PIPES= 4.13662  
 HEAT PIPE EVAPORATOR LENGTH (Cm)= 43.2447  
 HEAT PIPE INSIDE DIAMETER (Cm)= 2.54000  
 HEAT PIPE WORKING FLUID ID NUMBER= 5  
 HEAT PIPE LINER MATERIAL ID NUMBER= 7  
 CONE ANGLE FOR CONICAL RADIATOR (DEGREES)= 0.000000  
 MANIFOLD DIAMETER FOR CONICAL RADIATOR OR MANIFOLD LENGTH DIVIDED BY 3.141593 FOR FLAT PLATE (Cm) = 2038.80  
 RADIATOR EMISSIVITY CONTROL COATING THICK.(Cm)= 0.000000  
 RADIATOR FIN THICKNESS (Cm)= 3.87096  
 HEAT PIPE WALL or LINER THICKNESS (Cm)= 0.232258  
 RADIATOR SURFACE EMISSIVITY= 0.800000  
 RADIATOR SURFACE ABSOPTIVITY= 0.500000  
 RADIATOR PROJ. AREA (FRACT. OF TOT.)= 1.00000  
 RADIATOR ACTUAL AREA (FRACTION)= 2.00000  
 THERMAL COND. OF FIN MATERIAL (W/Cm-K) = 0.849774  
 COATING MATERIAL DENSITY (Grams/CC)= 0.000000  
 FIN MATERIAL DENSITY (Grams/CC)= 1.81009  
 LENGTH OF ADIABATIC PORTION OF THE HEAT PIPE (Cm)= 0.000000  
 MASS OF RADIATOR DEPLOYMENT MECHANISM (KG)= 0.000000

| TOTAL HEAT REJECTED (Kwt) | AVERAGE EVAPORATOR TEMP (K) | Radiator FIN Thick (Cm) | Emissivity Coating Thick (Cm) |
|---------------------------|-----------------------------|-------------------------|-------------------------------|
| 250.0000                  | 827.1643                    | 0.1270                  | 0.0000                        |

| Actual (one-side) Area(sq-Me.) | Effective Radiator Area(sq-Me.) |
|--------------------------------|---------------------------------|
| 6.7048                         | 13.4097                         |

| HEAT PIPE DESIGN DETAILS - DIMS in Cm |            |             |              |          |           |  |
|---------------------------------------|------------|-------------|--------------|----------|-----------|--|
| Pipe ID                               | Wick Thick | #Arteries   | Art ID       | Art Wall | Pipe wall |  |
| 2.5400                                | 0.0129     | 7.6200      | 0.6452       | 0.0129   | 0.0076    |  |
| Evap Length                           | Adi Length | Cond Length | Total Length |          |           |  |
| 43.2447                               | 0.0000     | 319.0964    | 362.3411     |          |           |  |

| RADIATOR MASS BREAKDOWN - Mass in KG |           |           |                |  |
|--------------------------------------|-----------|-----------|----------------|--|
| Heat Pipes                           | Fluids    | FINS      | Emiss. Cont.   |  |
| 26.6823                              | 1.3351    | 8.4781    | 0.0000         |  |
| O.D.ARMOR                            | I.D.ARMOR | Structure | TOTAL RADIATOR |  |
| 38.6962                              | 38.6962   | 0.0000    | 113.8878       |  |

IENflg (ORBIT SELECTION) = 1  
 IENflg=1, EARTH ORBIT (LEO-GEO)  
 IENflg=2, SOLAR ORBIT (0.5 to 2.0 AU)  
 ORBIT ALTITUDE (KM) = 1000.00  
 ORBIT INCLINATION ANGLE (Degrees) = 30.0000  
 DISTANCE FROM SUN (AU) = 1.00000  
 YEAR SATELLITE LAUNCHED = 2000.00

#### HEAT PIPE COOLED CONDENSER DESCRIPTION

MANIFOLD FLAT LENGTH (Cm) = 210.140  
MANIFOLD HEIGHT (Cm) = 43.2447  
AVERAGE MANIFOLD COND.SURF.SPAC(Gap)(Cm)= 1.05962  
MANIFOLD INSULATION THICKNESS (Cm) = 10.1600  
MANIFOLD INSULATION DENSITY (Grams/CC) = 0.000000  
NUMBER OF PRIMARY HEAT PIPES ATTACHED TO COOL CONDENSER SURFACE = 41.3662  
NUMBER OF REDUNDENT HEAT PIPES USED TO COOL CONDENSER SURFACE = 4.13662  
MANIFOLD WALL MATERIAL THICKNESS(Cm)= 0.158750  
MANIFOLD-HEAT PIPE BRAZE MATERIAL THICKNESS (Cm) = 0.508000E-02  
HEAT PIPE WALL THICKNESS (Cm) = 0.508000E-01  
MANIFOLD WALL MAT. THERMAL COND. (W/CmK) = 0.173073  
BRAZE MAT. THERMAL COND. (W/CmK) = 0.605756  
HEAT PIPE WALL MAT. THERMAL COND. (W/CmK) = 0.173073  
MANIFOLD WALL MATERIAL DENSITY (Grams/CC)= 8.08932  
BRAZE MATERIAL DENSITY (Grams/CC) = 8.40969  
HEAT PIPE WALL MATERIAL DENSITY(Grams/CC)= 8.08932  
HEAT PIPE WORKING FLUID NUMBER = 5

#### MANIFOLD OPERATING CONDITIONS

INLET PRESSURE (G/SC) = 140.614  
INLET TEMPERATURE (K) = 855.599  
MEAN CONDENSER QUALITY = 1.00000  
OUTLET TEMPERATURE (K) = 849.999  
MANIFOLD FLOWRATE (KG/Hr) = 442.564  
MANIFOLD DUTY (KWt) = 250.000

#### COMPUTED RESULTS

MANIFOLD PRESSURE DROP (G/SC) = 6.96164  
MANIFOLD FILM TEMPERATURE DROP (K) = 25.6271  
CONDENSER CONDENSATE FLOW REGIME PARAMETER = 0.127761  
CONDENSER IS OPERATING IN SHEAR FLOW REGIME

CONDENSATE FILM REYNOLDS NUMBER = 1901.90  
MARTINELLI PARAMETER = 0.133113E-01  
VAPOR REYNOLDS NUMBER = 3803.80  
MANIFOLD MASS (KG) = 39.6261  
MASS SUMMARY FOR CONDENSING RANKINE SYSTEM

HEAT PIPE COOLED CONDENSER MASS (KG) = 39.6261  
RADIATOR MASS (KG) = 113.888

CONDENSING RANKINE SYSTEM MASS (KG) = 153.514

**APPENDIX C**  
**CODE LISTING**

PROGRAM HRCHEK Compiling Options:/NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```
1 PROGRAM HRCHEK
2 C
3 C DRIVER CODE TO CHECKOUT SUBROUTINE HRMAST
4 C
5 OPEN(5,FILE='CHKDAT')
6 READ (5,*) Iselec,Iprob,IENFLG
7 READ (5,*) Pin,Tin,Tout,Qrad
8 CALL HREJEC(Iselec,Iprob,IENflg,Pin,Tin,Tout,Qrad)
9 STOP
10 END
```

```
11 C
12 C
13 C
14 C      SUBROUTINE HREJEC(Iselec,Iprob,IENflg,Pin,Tin,Tout,Grad)
15 C
16 C      COMPUTATION OF THE PERFORMANCE AND MASS OF HEAT REJECTION SYSTEMS
17 C
18 C      CODE ESTIMATES THE MASS AND PERFORMANCE OF HEAT PIPE COOLED HEAT
19 C      REJECTION SYSTEMS THAT OPERATE AS THE MAIN HEAT REJECTION ELEMENTS
20 C      IN BRAYTON AND RANKINE CYCLE SPACE POWER SYSTEMS.
21 C
22 C      AN OPTION IS OFFERED WHEREBY THE CODE WILL SUPPLY MOST OF THE
23 C      INPUTS REQUIRED AND RETURN THE INPUTS FOR A DETAILED CASE WITH
24 C      WHICH THE USER CAN START HIS OPTIMIZATION STUDY.
25 C
26 C      *** CODE LOGIC AND COMPUTATION OUTLINE ***
27 C
28 C      THE FOLLOWING STEPS ARE FOLLOWED IN ESTIMATING THE MASS AND
29 C      PERFORMANCE OF HEAT PIPE COOLED HEAT REJECTION SYSTEMS IN EITHER
30 C      BRAYTON OR RANKINE CYCLE APPLICATIONS:
31 C      1. SELECT THE HEAT REJECTION EQUIPMENT TRAIN AND DEFINE THE
32 C      EQUIPMENT ELEMENTS REQUIRED. THREE OPTIONS ARE SUPPLIED:
33 C          A. DIRECT COOLED GAS MANIFOLD FOR BRAYTONS.
34 C          B. NaK LIQUID METAL COOLED H-X LOOP FOR BRAYTONS.
35 C          C. SHEAR FLOW CONDENSER WITH DIRECT HEAT PIPE COOLING
36 C      2. IF NECESSARY, AN AUXILIARY ROUTINE IS INCLUDED THAT
37 C      SUPPLIES NON-OPTIMIZED, BUT WORKABLE, INPUT VALUES FOR MOST
38 C      OF THE VARIABLES REQUIRED TO RUN THE VARIOUS SUBROUTINES.
39 C      3. ANALYZE THE HYDRAULIC LOOP REQUIRED FOR THE LIQUID
40 C      USED BY SOME OF THE SYSTEMS. THE H-X, PIPING AND MANIFOLD DELTA-P
41 C      IS DETERMINED IN THIS STEP.
42 C      4. DETERMINE THE WEIGHT OF THE PUMP REQUIRED.
43 C      5. ON PUMPED LOOP SYSTEMS, A HEAT PIPE TO FLUID HEAT
44 C      EXCHANGER IS ANALYZED
45 C      6. ON DIRECT SYSTEMS, A GAS TO HEAT PIPE FLUID HEAT EXCHANGER
46 C      IS ANALYZED.
47 C      7. A RADIATOR IS SIZED TO REJECT THE PROPER AMOUNT OF HEAT
48 C      AND ITS MASS IS DETERMINED.
49 C      8. CODE OUTPUT CONSISTS OF COMPONENT SIZES AND MASSES.
50 C
51 C      OPEN(5,FILE='RADAT')
52 C
53 C      PI = 3.14159265
54 C
55 C      IF Iselec = 1, THEN THE CODE WILL SUPPLY MOST OF THE VARIABLE
56 C      VALUES NEEDED. IF Iselec = 2, THEN THE USER MUST SUPPLY MOST
57 C      OF THE VARIABLE VALUES NEEDED
58 C
59 C
60 C      IF Iprob = 1, CODE IS SET UP FOR A DIRECT COOLED BRAYTON
61 C      CONFIGURATION.
62 C      IF Iprob = 2, CODE IS SET UP FOR A LIQUID LOOP COOLED
63 C      BRAYTON CONFIGURATION.
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64 C   IF Iprob = 3, CODE IS SET UP FOR A SHEAR FLOW CONDENSER IN A
65 C   POTASSIUM RANKINE CYCLE.
66 C
67 C   INPUTS TO DEFINE ORBITS
68 C
69 C   IENflg = FLAG TO SET ENVIRONMENT DESIRED
70 C           = 1, EARTH ORBIT, LEO TO GEO USES GREATER OF DEBRIS
71 C           OR METEORITE FLUX, NO DEBRIS ABOVE 2000 Km.
72 C           = 2, BEYOND EARTH ORBIT, 0.25 TO 2.00 AU
73 C   Halt = ORBIT ALTITUDE (km)
74 C   HINCL = ORBIT INCLINATION ANGLE (28.5 TO 80.0 degrees, ONLY)
75 C   Rsun = DISTANCE FROM SUN (AU)
76 C   Yrinch = YEAR IN WHICH VEHICLE IS PLACED IN ORBIT
77 C   Time = MISSION DURATION (Secs)
78 C
79 C   INPUTS TO DEFINE RADIATOR
80 C
81 C   GAM,ARSF = PENETRATION CONSTANTS - FUNCTIONS OF THE SPECIFIC MAT'L
82 C   RHOarm = ARMOR DENSITY (Lbs/cu-Ft)
83 C   Earm = YOUNGS MODULUS OF ARMOR (Lbs/sq-In)
84 C   Prob = NON-PUNCTURE PROBABILITY (0.9, 0.99, 0.999, ETC.)
85 C   Grad = RADIATOR HEAT REJECTION RATE (Kwt)
86 C   Trad = AVERAGE RADIATOR SURFACE TEMPERATURE (deg-R)
87 C   Xntubes = NUMBER OF PRIMARY HEAT PIPE IN RADIATOR
88 C   Xnexpip = NUMBER OF REDUNDENT HEAT PIPES
89 C   Xlflat = HEAT PIPE EVAPORATOR LENGTH (INCHES)
90 C   Dhpipe = HEAT PIPE INSIDE DIAMETER (INCHES)
91 C   Ifluid = HEAT PIPE WORKING FLUID ID NUMBER
92 C   Imatl = HEAT PIPE LINER MATERIAL ID NUMBER
93 C   Theta = CONE ANGLE FOR CONICAL RADIATOR (DEGREES)
94 C   D2rad = MANIFOLD DIAMETER FOR CONICAL RADIATOR OR MANIFOLD
95 C           LENGTH DIVIDED BY 3.141593 FOR FLAT PLATE
96 C   Thickm = RADIATOR EMISSIVITY CONTROL COATING THICKNESS (FEET)
97 C   Thickf = RADIATOR FIN THICKNESS (FEET)
98 C   Thick = HEAT PIPE WALL or LINER THICKNESS (FEET)
99 C   Em = RADIATOR SURFACE EMISSIVITY
100 C   Alpha = RADIATOR SURFACE ABSOPTIVITY
101 C   Hap = RADIATOR PROJECTED AREA (TOWARD SUN) (FRACTION OF TOTAL)
102 C   MARad = RADIATOR ACTUAL AREA (USUALLY = 1.0)
103 C   Tkfin = THERMAL CONDUCTIVITY OF FIN MATERIAL (BTU/HR-FT-R)
104 C   Rhocoating = COATING MATERIAL DENSITY (LB/cu-FT)
105 C   Rhofin = FIN MATERIAL DENSITY (LB/cu-FT)
106 C   Xladiab = LENGTH OF ADIABATIC PORTION OF THE HEAT PIPE (FEET)
107 C   Xachmas = MASS OF RADIATOR DEPLOYMENT MECHANISM (LBS)
108 C
109 C   INPUTS TO DEFINE HEAT PIPE COOLED MANIFOLD
110 C
111 C   Iflg2 = FLAG TO SET MANIFOLD WORKING FLUID
112 C           1 = He-Xe MIXTURE
113 C           2 = NaK
114 C   Hman = MANIFOLD HEIGHT (Feet)
115 C   Gap = MANIFOLD WIDTH (Feet)
116 C   Pitch = DISTANCE BETWEEN CAN (HEAT PIPES) CENTERLINES (Feet)

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117 C   XNpipes = NUMBER OF HEAT PIPES IN RADIATOR
118 C   XNExpipes = NUMBER OF REDUNDENT HEAT PIPES IN RADIATOR
119 C   Dcan = OUTSIDE DIAMETER OF MANIFOLD BRAZE CANS (Feet)
120 C   Dhp = INSIDE DIAMETER OF HEAT PIPE (Feet)
121 C   Rc = MANIFOLD BRAZE CAN INSIDE RADIUS (Feet)
122 C   Rb = BRAZE JOINT INSIDE RADIUS (Feet)
123 C   Tf = FIN THICKNESS (Feet)
124 C   TKfin = THERMAL CONDUCTIVITY OF FIN MATERIAL (BTU/Hr-Ft-R)
125 C   TKcan = THERMAL CONDUCTIVITY OF MANIFOLD CAN MATERIAL (B/HFR)
126 C   TKbraze = THERMAL CONDUCTIVITY OF MANIFOLD BRAZE ALLOY (")
127 C   TKhp = THERMAL CONDUCTIVITY OF HEAT PIPE WALL MATERIAL (")
128 C   XNf = TOTAL NUMBER OF FINS FOR THE MANIFOLD HEIGHT
129 C   RHOcan = DENSITY OF MANIFOLD MATERIAL (Lb/cu-Ft)
130 C   RHObraze = DENSITY OF BRAZE MATERIAL (Lb/cu-Ft)
131 C   THICKman = MANIFOLD MATERIAL THICKNESS (Feet)
132 C   Pman = MANIFOLD INLET PRESSURE (PSIA)
133 C   Tman = MANIFOLD INLET TEMPERATURE (deg-R)
134 C   Wman = MANIFOLD FLOWRATE (LBS/HR)
135 C   Qman = MANIFOLD AND RADIATOR HEAT LOAD (BTU/HR)
136 C   XMW = MOLECULAR WEIGH OF MANIFOLD WORKING FLUID
137 C
138 C   INPUTS TO DEFINE DUCTING
139 C
140 C   XN9 = NUMBER OF 90 DEGREE ELBOWS OR EQUIVALENT IN DUCT SYSTEM
141 C   R9 = AVERAGE RADIUS FOR 90 DEGREE ELBOWS (INCHES)
142 C   Dp = INSIDE DUCT DIAMETER (INCHES)
143 C   SUMLEN = TOTAL LENGTH OF DUCT SYSTEM (INCHES)
144 C   Vpipe = GAS VELOCITY IN DUCTS (FT/SEC)
145 C   Tgas = GAS TEMPERATURE (deg-R)
146 C   Pgas = GAS PRESSURE (psia)
147 C   THICKP = DUCT WALL THICKNESS (INCHES)
148 C   RHOPIP = DUCT WALL DENSITY (LB/cu-FT)
149 C   THICKI = DUCT INSULATION THICKNESS (INCHES)
150 C   RHOINS = DUCT INSULATION DENSITY (LB/cu-FT)
151 C   XMW = GAS MOLECULAR WEIGHT
152 C   DPDUCT = DUCT SYSTEM PRESSURE DROP (PSID)
153 C   DUCHAS = DUCT SYSTEM MASS (LBS)
154 C
155 C   INPUTS TO DEFINE HEAT SINK HEAT EXCHANGER
156 C
157 C   IHXflf = 1, THEN TUBE SIDE FLUID IS LITHIUM
158 C   IHXflg = 2, THEN TUBE SIDE FLUID IS NaK-78
159 C   ALMTD = Heat Exchanger Log Mean Temperature Difference
160 C   QDOT = Heat Rate or Duty (BTU/Hr)
161 C   UEST = INITIAL VALUE OF Uoverall (BTU/Hr-Ft-R)
162 C   (50 for GAS-GAS)
163 C   THIN = HOT SIDE Inlet Temperature (R)
164 C   THOUT = HOT SIDE Outlet Temperature (R)
165 C   TCIN = COLD SIDE Inlet Temperature (R)
166 C   TCOU = COLD SIDE Outlet Temperature (R)
167 C   WDOTS = SHELL SIDE FLUID Flowrate (Lbs/Sec)
168 C   DENSSH = SHELL MATERIAL Density (Lbs/Ft^3)
169 C   CPSF = SHELL-SIDE FLUID Specific Heat (BTU/Lb-R)

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170 C   RNOSF = SHELL-SIDE FLUID Density (Lbs/Ft^3)
171 C   AKTST = SHELL-SIDE FLUID Thermal Cond (BTU/Hr-Ft-R)
172 C   VISCST = SHELL-SIDE FLUID Viscosity (Cp)
173 C   DTUBE = Outside TUBE Diameter - (Inches)
174 C   TTUBE = TUBE Wall Thickness (Inches)
175 C   WDOTT = TUBE -SIDE Fluid Flowrate (Lbs/Sec)
176 C   AKTUBE = TUBE Wall Thermal Conductivity (BTU/Hr-Ft-R)
177 C   CPT = TUBE-SIDE FLUID Specific Heat (BTU/Lb-R)
178 C   RNOT = TUBE-SIDE FLUID Density (Lbs/Ft^3)
179 C   AKTT = TUBE-SIDE FLUID Thermal Cond (BTU/Hr-Ft-R)
180 C   VISCT = TUBE-SIDE FLUID Viscosity (Lb/Ft-Sec)
181 C
182 C   INPUTS TO DEFINE THE NAK PIPING SYSTEM
183 C
184 C   XN9 = NUMBER OF 90 DEGREE ELBOWS OR EQUIVALENT IN PIPE SYSTEM
185 C   R9 = AVERAGE RADIUS FOR 90 DEGREE ELBOWS (INCHES)
186 C   Dp = INSIDE PIPE DIAMETER (INCHES)
187 C   SUMLEN = TOTAL LENGTH OF PIPE SYSTEM (INCHES)
188 C   Vpipe = NAK VELOCITY IN PIPES (FT/SEC)
189 C   Tnak = NAK TEMPERATURE (deg-R)
190 C   Pnak = NAK PRESSURE (psia)
191 C   THICKP = PIPE WALL THICKNESS (INCHES)
192 C   RHOPIP = PIPE WALL DENSITY (LB/cu-FT)
193 C   THICKI = PIPE INSULATION THICKNESS (INCHES)
194 C   RHOINS = PIPE INSULATION DENSITY (LB/cu-FT)
195 C   DPPPIPE = PIPE SYSTEM PRESSURE DROP (PSID)
196 C   PIPMAS = PIPE SYSTEM MASS (LBS)
197 C
198 C   INPUTS TO DEFINE THE NAK PUMP
199 C
200 C   Pnak = NAK INLET PRESSURE (PSIA)
201 C   Tnak = NAK INLET TEMPERATURE (deg-R)
202 C   Wnak = NAK FLOWRATE (LBS/SEC)
203 C   DPPPIPE = PIPING SYSTED PRESSURE DROP (PSID)
204 C   DPHX = NAK SIDE HEAT EXCHANGER PRESSURE DROP (PSID)
205 C   DPMANIF = NAK MANIFOLD PRESSURE DROP
206 C
207 C   INPUTS TO DEFINE THE CONDENSER FOR A K-RANKINE CYCLE
208 C
209 C   Ar = FLOW CROSS-SECTIONAL AREA (sq ft)
210 C   Gt = MASS FLUX (lbm/h sq ft)
211 C   TUM = FLOW RATE PER TUBE(LIQUID PLUS VAPOR), lbm/h
212 C   V VAPOR VELOCITY, ft/s
213 C   Y = LOCAL VAPOR WEIGHT FRACTION FACTOR
214 C   Dh = HYDRAULIC DIAMETER
215 C   Cgt = TUBESIDE FLOW REGIME PARAMETER
216 C   IF Cgt < 0.3, SHEAR-CONTROLLED LIQUID FILM HEAT TRANSFER COEFFICIENT
217 C   ReI = CONDENSATE FILM REYNOLDS NUMBER
218 C   VCF = VISCOSITY CORRECTION FACTOR , (BULK /MALL)**0.14
219 C   Hl = SHEAR-CONTROLLED LIQUID FILM HEAT TRANSFER COEFFICIENT
220 C   Xtt = MARTINELLI PARAMETER, FORM FOR BOTH TURBULENT PHASES
221 C   Csh = CORRELATION FUNCTION FOR SHEAR-CONTROLLED FLOW HT & DP
222 C   Ftp = SHEAR-CONTROLLED FLOW TWO PHASE HEAT TRANSFER FACTOR

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223 C   He = SHEAR-CONTROLLED LIQUID FILM HEAT TRANSFER COEFFICIENT
224 C   Dpm = MOMENTUM PRESSURE DROP (psia)
225 C   Rev = VAPOR REYNOLDS NUMBER
226 C   DPl = LIQUID PRESSURE DROP (psia)
227 C   DPv = VAPOR PRESSURE DROP (psia)
228 C   FLF = TWO PHASE FRICTION LOSS FACTORS
229 C   DPf = FRICTION PRESSURE DROP (psia)
230 C   FF = FRICTION FACTOR
231 C   ETA = SURFACE ROUGHNESS, ft
232 C   P = SATURATION PRESSURE (psia)
233 C   DL = LIQUID DENSITY (lbm/cu ft)
234 C   VF = LIQUID SPECIFIC VOLUME (cu ft/lbm)
235 C   HFG = ENTHALPY OF VAPORIZATION (Btu/lbm)
236 C   NGO = REFERENCE ENTHALPY (Btu/lbm)
237 C   HG = ENTHALPY VAPOR STATE (Btu/lbm)
238 C   HF = ENTHALPY LIQUID STATE (Btu/lbm)
239 C   SFG = ENTROPY OF VAPORIZATION (Btu/lbm R)
240 C   SGO = REFERENCE ENTROPY STATE (Btu/lbm R)
241 C   SG = ENTROPY VAPOR STATE (Btu/lbm R)
242 C   SF = ENTROPY LIQUID STATE (Btu/lbm R)
243 C   VG = VAPOR SPECIFIC VOLUME (cu ft/lbm)
244 C   DV = VAPOR DENSITY (lbm/cu ft)
245 C   Cl = LIQUID HEAT CAPACITY (Btu/lbm)
246 C   VL = LIQUID VISCOSITY (lbm/ft-h)
247 C   XKL = LIQUID THERMAL CONDUCTIVITY (Btu/h-ft-R)
248 C   Pr = LIQUID PRANDTL NUMBER
249 C   VV = VAPOR VISCOSITY (lbm/ft-h)
250 C   XKV = VAPOR THERMAL CONDUCTIVITY (Btu/h-ft-R)
251 C
252     IF (Iselec.EQ.1) THEN
253       GO TO 1000
254     ELSE
255       GO TO 10
256     ENDIF
257   10 GO TO (100,200,300), Iprob
258 C   INPUTS REQUIRED TO DEFINE ORBIT
259 C
260   100 READ (5,*) IENflg,Halt,HINCL,Rsun
261     READ (5,*) Yrlnch,Time
262 C
263 C   INPUTS REQUIRED TO DEFINE RADIATOR
264 C
265     READ (5,*) GAM,ARSF,Earm,PROB
266     READ (5,*) CONFIG,Xntubes,Xnexpip,Xlflat
267     READ (5,*) Dhpipe,Ifluid,Imatl,Theta
268     READ (5,*) D2rad,Thickm,Thickf,Thick
269     READ (5,*) Em,Alpha,Hap,HARad
270     READ (5,*) Tkfin,Rhocoating,Rhofin,RHOarm
271     READ (5,*) Xladiab,Xmchmas
272 C
273 C   INPUTS REQUIRED TO DEFINE HEAT PIPE MANIFOLD
274 C
275     READ (5,*) Iflg2,Hman,Gap,Pitch

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276      READ (5,*) Dcan,Dhp,Rc,Rb
277      READ (5,*) Tf,TKfin,TKcan,TKbraze
278      READ (5,*) TKhp,XNf,Xmw,RHOcan
279      READ (5,*) RHObraze,THICKman,Uman
280 C
281 C      INPUTS REQUIRED TO DEFINE DUCTING
282 C
283      READ (5,*) XN9,R9,Dp,SUMLEN
284      READ (5,*) THICKP,RHOPIP,THICKI,RHOINS
285 C
286      Cman = PI*D2rad
287      XNpipes = Xntubes
288      XNexpipes = Xnexpip
289 C
290      CALL HPMAN(Ifluid,Iflg2,Cman,Hman,Gap,Pitch,Dcan,Dhp,Rc,Rb,Tf,TKfi
291 &n,TKcan,TKbraze,TKhp,XNf,XNpipes,XNexpipes,Xmw,Pin,Tin,RHOcan,RH
292 &Obraze,THICKman,Uman,Grad,XMANmas,DPman,DTfilm,XHMAN)
293      DTman = Tin-Tout
294      CALL TMEAN(Tin,DTman,DTfilm,Trad)
295 C
296      CALL HRRAD(Grad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,Imat1,
297 &Theta,D2rad,Thickm,Thickf,Thick,Em,IENflg,Halt,HINCL,Rsun,Yrlnch,
298 &Alpha,Hap,HARad,TKfin,Rhocoating,Rhofin,RHOarm,Xladiab,CONFIG,
299 &Xmchmas,PROB,GAM,ARSF,Earm,Time,Qrejected,Thickf2,Thickm2,
300 &Aradiator,Aradeffect,Uthick2,Xnart2,Artid2,
301 &Artwall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xmpipes,Xmfluid,
302 &Xmfin,Xmcoating,Xmarmor,Xmarmorid,Xstructure,
303 &Xnetradmas2,Wx12)
304 C
305      Apipe = (PI*(Dp**2.0))/(4.0*144.0)
306      CALL HEXEPR(XMW,Pin,Tin,Gma,CP,RHOGas,AMU,ATK,PR)
307      Vpipe = Uman/(RHOGas*Apipe)
308      CALL HRDUCT(XN9,R9,Dp,SUMLEN,Vpipe,Tin,Pin,THICKP,RHOPIP,
309 &THICKI,RHOINS,XMW,DPDUCT,DUCHMAS)
310 C
311      WRITE (6,*) '*** HEAT REJECTION SYSTEM FOR A BRAYTON CYCLE SYSTEM
312 &IN WHICH CYCLE WASTE HEAT IS REJECTED DIRECTLY FROM THE CYCLE WORK
313 &ING FLUID IN A HEAT PIPE COOLED GAS MANIFOLD ***'
314      WRITE (6,*) ' '
315      CALL RADPRT(Grad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,I
316 &mat1,Theta,D2rad,Thickm,Thickf,Thick,Em,
317 &Alpha,Hap,HARad,TKfin,Rhocoating,Rhofin,RHOarm,Xladiab,
318 &Xmchmas,PROB,GAM,ARSF,Earm,Time,Qrejected,Thickf2,Thickm2,
319 &Aradiator,Aradeffect,Uthick2,Xnart2,Artid2,
320 &Artwall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xmpipes,Xmfluid,
321 &Xmfin,Xmcoating,Xmarmor,Xmarmorid,Xstructure,
322 &Xnetradmas2)
323      CALL ORBPRT(IENflg,Halt,HINCL,Rsun,Yrlnch)
324 C
325      CALL HMPRT(Iflg2,Hman,Gap,Pitch,XNpipes,Xnexpipes,Dcan,
326 &Dhp,Rc,Rb,Tf,TKfin,TKcan,TKbraze,TKhp,XNf,RHOcan,RHObraze,
327 &THICKman,Pin,Tin,Uman,Grad,XMW,XMANmas,DPman,DTfilm,XHMAN)

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328 C
329 CALL DUCPRT(XN9,R9,Dp,SUMLEN,Vpipe,Tin,Pin,THICKP,RHOPIP,
330 &THICKI,RHOINS,XMN,DPUUCT,DUCHAS)
331 C
332 WRITE (6,*) 'MASS SUMMARY FOR DIRECT BRAYTON SYSTEM'
333 WRITE (6,*) ' '
334 WRITE (6,*) 'HEAT PIPE COOLED GAS MANIFOLD MASS (Lbs) =',XMMMAN
335 WRITE (6,*) 'MANIFOLD DUCTING MASS (LBS) =',DUCMAS
336 WRITE (6,*) 'RADIATOR MASS (LBS) =',Xnetradmasst2
337 XMSYST = XMMMAN + DUCMAS + Xnetradmasst2
338 WRITE (6,*) ' '
339 WRITE (6,*) 'DIRECT BRAYTON SYSTEM MASS (LBS) =',XMSYST
340 WRITE (6,*) ' '
341 STOP
342 C
343 C CASE WHERE A SECONDARY MAK LOOP IS USED TO TRANSFER HEAT BETWEEN
344 C THE CYCLE WORKING FLUID AND THE HEAT PIPE RADIATOR
345 C
346 C INPUTS REQUIRED TO DEFINE ORBIT
347 C
348 200 READ (5,*) IENflg,Halt,NINCL,Rsun
349 READ (5,*) Yrlnch,Time
350 C
351 C INPUTS REQUIRED TO DEFINE RADIATOR
352 C
353 READ (5,*) GAM,ARSF,Earm,PROB
354 READ (5,*) CONFIG,Xntubes,Xnexpip,Xlflat
355 READ (5,*) Dhpipe,Ifluid,Imatl,Theta
356 READ (5,*) D2rad,Thickm,Thickf,Thick
357 READ (5,*) Em,Alpha,Hap,MArad
358 READ (5,*) Tkfin,Rhocoating,Rhofin,RHOarm
359 READ (5,*) Xladiab,Xmchmas
360 C
361 C INPUTS REQUIRED TO DEFINE HEAT SINK HEAT EXCHANGER
362 C
363 READ (5,*) INXflg,UEST,TCIN,TCOUT
364 READ (5,*) WDOTS,AMMS,TINS,DENINS
365 READ (5,*) DENSSH,DTUBE,PR,TTUBE
366 READ (5,*) ANPLATES,WDOOT,AKTUBE
367 C
368 C INPUTS REQUIRED TO DEFINE HEAT PIPE MANIFOLD
369 C
370 READ (5,*) Iflg2,Hmen,Gap,Pitch
371 READ (5,*) Dcan,Dhp,Rc,Rb
372 READ (5,*) Tf,TKfin,TKcan,TKbraze
373 READ (5,*) TKhp,Xmf,Xmw,RHOcan
374 READ (5,*) RHObraze,THICKmen,Hmen
375 C
376 READ (5,*) XN9,R9,Dp,SUMLEN
377 READ (5,*) THICKP,RHOPIP,THICKI,RHOINS
378 C
379 Cmen = PI*D2rad

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SUBROUTINE HRMAST Compiling Options:/NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

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380      XNpipes = Xntubes
381      XNexpipes = Xnexpip
382      THIN = Tin
383      THOUT = Tout
384      PHOT = Pin
385      QDOT = Qrad
386      AMWS = Xmw
387 C
388      CALL HRSHEL(INXflg,UEST,THIN,THOUT,PHOT,TCIN,TCOUT,WDOTS,AMW
389      &S,TINS,DEINIS,DENSSH,DTUBE,PR,TTUBE,ANPLATES,WDOTT,AKTUBE,Q
390      &DOT,DPSHELL,ANTUBES,DPTUBE,DOTL2,ALSHL,AMSHL,ANPLATES,
391      &AMTUBES,AMINSUL,AMHEADS,AMSTR,ANETHASS,XMNHX,HSHELL,AFRIC,UNEV,
392      &RETUBE,THC,AMTSH)
393 C
394      CALL HPMAN(Ifluid,Iflg2,Cman,Hman,Gap,Pitch,Dcan,Dhp,Rc,Rb,Tf,TKfi
395      &n,TKcan,TKbraze,TKhp,Xnf,XNpipes,XNexpipes,Xmw,Pin,Tin,RHOcan,RH
396      &Obraze,THICKman,Hman,Qrad,XMANmas,DPman,DTfilm,XMNMAN)
397 C
398      Apipe = (PI*(Dp**2.0))/(4.0*144.0)
399      CALL XNAKPR(Tin,RHONAK,CP,VIS,TK)
400      Vpipe = Hman/(3600.0*RHONAK*Apipe)
401      Tnak = Tin
402      Pnak = Pin
403      CALL HRPIPE(XW9,R9,Dp,SUMLEN,Vpipe,Tnak,Pnak,THICKP,RHOIP,THICKI,
404      &RHOINS,DPPIPE,PIPnak,PIPMAS)
405 C
406      Wnak = Hman
407      DPHX = DPTUBE
408      DPMANIF = DPman
409      CALL PUMP(Tnak,Wnak,DPPIPE,DPHX,DPMANIF,DPLOOP,Phyd,XNPUMP)
410 C
411      CALL VACMAS(Tnak,XMNP,PM,XMNMAN,XMNHX,XMWVAC,XWVAC)
412 C
413      DTman = Tin-Tout
414      CALL TMEAN(Tin,DTman,DTfilm,Trad)
415      CALL HRRAD(Qrad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,Imatl,
416      &Theta,D2rad,Thickm,Thickf,Thick,Em,IENflg,Halt,HINCL,Rsun,Yrlnch,
417      &Alpha,Hap,HARad,TKfin,Rhocoating,Rhofin,RHOarm,Xladiab,CONFIG,
418      &Xmchmas,PROB,GAM,ARSF,Earm,Time,Qrejected,Thickf2,Thickm2,
419      &Aradiator,Aradeffect,Wthick2,Xnart2,Artid2,
420      &Artwall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xmpipes,Xmfluid,
421      &Xmfin,Xmcoating,Xarmor,Xarmorid,Xstructure,
422      &Xnetradmas2,Wxl2)
423 C
424      WRITE (6,*) '*** HEAT REJECTION SYSTEM FOR A BRAYTON CYCLE SYSTEM
425      &IN WHICH CYCLE WASTE HEAT IS REJECTED TO A PUMPED NaK LOOP FROM
426      &THE CYCLE WORKING FLUID TO A HEAT PIPE COOLED GAS MANIFOLD ***'
427      WRITE (6,*) ' '
428      CALL RADPRT(Qrad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,I
429      &matl,Theta,D2rad,Thickm,Thickf,Thick,Em,
430      &Alpha,Hap,HARad,TKfin,Rhocoating,Rhofin,RHOarm,Xladiab,
431      &Xmchmas,PROB,GAM,ARSF,Earm,Time,Qrejected,Thickf2,Thickm2,
432      &Aradiator,Aradeffect,Wthick2,Xnart2,Artid2,

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433      &Artwall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xmpipes,Xmfluid,
434      &Xmfin,Xmcoating,Xmarmor,Xmarmorid,Xstructure,
435      &Xnetradmasst2)
436      CALL ORBPRT(IENflg,Halt,HINCL,Rsun,Yrlnch)
437 C
438      CALL HMINPRT(Iflg2,Hman,Gap,Pitch,XMpipes,Xnexpipes,Dcan,
439      &Dhp,Rc,Rb,Tf,TKfin,TKcan,TKbraze,TKhp,Xnf,RHOcan,RHObraze,
440      &THICKman,Pin,Tin,Uman,Qrad,XMw,XMANmas,DPman,DTfilm,XMNMAN)
441      WRITE (6,*) ' '
442 C
443      CALL PIPPRT(XN9,R9,Dp,SUMLEN,Vpipe,Tnak,Pnak,THICKP,RHOPIP,
444      &THICK1,RHOINS,DPIPE,PIPNAK,PIPMAS)
445      WRITE (6,*) ' '
446      CALL HSHXPT(IHXflg,QDOT,THIN,THOUT,TCIN,TCOUT,WDOTS,DENSSH,
447      &DTUBE,TTUBE,WDOTT,AKTUBE,DPSHELL,ANTUBES,DPTUBE,DOTL2,ALSHEL,
448      &ANSHELL,AMPLATES,ANTUBES,ANETMASS,XMNHX,HSHELL,AFRIC,UNEW,RETUBE,
449      &THC,AMINSUL,AMHEADS,AMTSHT,AMSTRT)
450      WRITE (6,*) ' '
451      CALL PMPPRT(Tin,WDOTT,DPIPE,DPTUBE,DPMAN,DPLOOP,Phyd,
452      &XMPUMP)
453      CALL VACPRT(XMNVac,XMVAC)
454 C
455      WRITE (6,*) 'MASS SUMMARY FOR INDIRECT BRAYTON SYSTEM'
456      WRITE (6,*) ' '
457      WRITE (6,*) 'HEAT SINK HEAT EXCHANGER MASS (LBS)(DRY) =',ANETMASS
458      WRITE (6,*) 'HEAT EXCHANGER NaK MASS (LBS) =',XMNHX
459      WRITE (6,*) 'NaK PIPING SYSTEM MASS (LBS)(DRY) =',PIPMAS
460      WRITE (6,*) 'MASS OF NaK IN PIPING SYSTEM (LBS) =',PIPNAK
461      WRITE (6,*) 'MASS OF EM PUMP (LBS) (WET) =',XMPUMP
462      WRITE (6,*) 'HEAT PIPE/NaK MANIFOLD MASS (Lbs) (DRY) =',XMANmas
463      WRITE (6,*) 'MASS OF NaK IN MANIFOLD (LBS) =',XMNMAN
464      WRITE (6,*) 'EXPANSION COMPENSATOR MASS (LBS) (DRY) =',XMVAC
465      WRITE (6,*) 'MASS OF NaK IN EXPANSION COMPENSATOR (LBS) =',XMNVAC
466      WRITE (6,*) 'RADIATOR MASS (LBS) =',Xnetradmasst2
467      XMSYST = ANETMASS + XMNHX + PIPMAS + PIPNAK + XMPUMP + XMANmas
468      & + XMNMAN + XMVAC + XMNVAC + Xnetradmasst2
469      WRITE (6,*) ' '
470      WRITE (6,*) 'INDIRECT BRAYTON SYSTEM MASS (LBS) (WET) =',XMSYST
471      WRITE (6,*)
472      STOP
473 C
474 C   CASE WHERE A DIRECT CONDENSING SHEAR FLOW CONDENSER IS USED TO
475 C   REJECT HEAT FROM A RANKINE CYCLE
476 C
477 C   INPUTS REQUIRED TO DEFINE ORBIT
478 C
479      300 READ (5,*) IENflg,Halt,HINCL,Rsun
480      READ (5,*) Yrlnch,Time
481 C
482 C   INPUTS REQUIRED TO DEFINE RADIATOR
483 C
484      READ (5,*) GAM,ARSF,Earm,PROB

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SUBROUTINE HRMAST Compiling Options: /NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

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485     READ (5,*) CONFIG,Xntubes,Xnexpip,Xlflat
486     READ (5,*) Dhpipe,Ifluid,Imatl,Theta
487     READ (5,*) D2rad,Thickm,Thickf,Thick
488     READ (5,*) Em,Alpha,Hap,HARad
489     READ (5,*) Tkfin,Rhocoating,Rhofin,RHOarm
490     READ (5,*) Xladiab,Xmchmas
491   C
492   C   INPUTS REQUIRED TO DEFINE CONDENSER
493   C
494     READ (5,*) Cman,Hman,Gap,THICKins
495     READ (5,*) RHOins,Tout,Tbraze,TKcan
496     READ (5,*) TKbraze,TKhp,Pin,Tin
497     READ (5,*) Xin,RHOpip,RHOcan,RHObraze
498     READ (5,*) THICKman,Thtpip,Uman
499   C
500     XNpipes = Xntubes
501     XNexpipes = Xnexpip
502     CALL CONMAN(Ifluid,Cman,Hman,Gap,THICKins,RHOins,Tout,
503 &Tbraze,TKcan,TKbraze,TKhp,XNpipes,XNexpipes,Pin,Tin,Xin,RHOpip,
504 &RHOcan,RHObraze,THICKman,Thtpip,Uman,Grad,XMANmas,DPman,DTfsup,
505 &Ar,Gt,V,Dh,Cgt,Rel,NI,Xtt,Rev,
506 &DTfcon,DTfsub,DTfilm)
507   C
508     DTman = Tin-Tout
509     CALL TMEAN(Tin,DTman,DTfilm,Trad)
510   C
511     CALL HRRAD(Grad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,Imatl,
512 &Theta,D2rad,Thickm,Thickf,Thick,Em,IENflg,Halt,HINCL,Rsun,Yrlnch,
513 &Alpha,Hap,HARad,TKfin,Rhocoating,Rhofin,RHOarm,Xladiab,CONFIG,
514 &Xmchmas,PROB,GAM,ARSF,Earm,Time,Qrejected,Thickf2,Thickm2,
515 &Aradiator,Aradeffect,Uthick2,Xnart2,Artid2,
516 &Artwall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xmpipes,Xmfluid,
517 &Xmfin,Xmcoating,Xmarmor,Xmarmorid,Xstructure,
518 &Xnetradmasst2,Uxl2)
519   C
520     WRITE (6,*) '*** HEAT REJECTION SYSTEM FOR A RANKINE CYCLE SYSTEM
521 &IN WHICH CYCLE WASTE HEAT IS REJECTED DIRECTLY FROM THE CYCLE WORK
522 &ING FLUID IN A HEAT PIPE COOLED CONDENSER ***'
523     WRITE (6,*) ' '
524     CALL RADPRT(Grad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,I
525 &matl,Theta,D2rad,Thickm,Thickf,Thick,Em,
526 &Alpha,Hap,HARad,TKfin,Rhocoating,Rhofin,RHOarm,Xladiab,
527 &Xmchmas,PROB,GAM,ARSF,Earm,Time,Qrejected,Thickf2,Thickm2,
528 &Aradiator,Aradeffect,Uthick2,Xnart2,Artid2,
529 &Artwall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xmpipes,Xmfluid,
530 &Xmfin,Xmcoating,Xmarmor,Xmarmorid,Xstructure,
531 &Xnetradmasst2)
532     CALL ORBPRT(IENflg,Halt,HINCL,Rsun,Yrlnch)
533   C
534     CALL CONPRT(Ar,Gt,V,Dh,Cgt,Rel,NI,Xtt,Rev,
535 &Ifluid,Cman,Hman,Gap,THICKins,RHOins,Tout,
536 &Tbraze,TKcan,TKbraze,TKhp,XNpipes,XNexpipes,Pin,Tin,Xin,RHOpip,
537 &RHOcan,RHObraze,THICKman,Thtpip,Uman,Grad,XMANmas,DPman,

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```

538      &DTfilm)
539 C
540 C
541      WRITE (6,*) 'MASS SUMMARY FOR CONDENSING RANKINE SYSTEM'
542      WRITE (6,*) ' '
543      WRITE (6,*) 'HEAT PIPE COOLED CONDENSER MASS (Lbs) =',XMANmas
544      WRITE (6,*) 'RADIATOR MASS (LBS) =',Xnetradmasst2
545      XMSYST = XMANmas + Xnetradmasst2
546      WRITE (6,*) ' '
547      WRITE (6,*) 'CONDENSING RANKINE SYSTEM MASS (LBS) =',XMSYST
548      WRITE (6,*) ' '
549      STOP
550 C
551 1000 WRITE (6,*) 'THE SIMPLIFIED DATA INPUT OPTION HAS BEEN SELECTED'
552 C
553 C      READ INPUTS TO DEFINE ORBITS
554 C      IF IENflg = 0, THEN USE DEFAULTS OF:
555 C          Halt = 1000.0 Km
556 C          HINCL = 30.0
557 C          Rsun = 1.0
558 C          Yrlnch = 2000.0
559 C          Time = 10.0*365.0*24.0*3600.0
560 1001 READ (5,*) IENflg,Halt,HINCL,Rsun
561      READ (5,*) Yrlnch,Time
562      IF (IENflg.EQ.0) THEN
563          Halt = 1000.0
564          HINCL = 30.0
565          Rsun = 1.0
566          Yrlnch = 2000.0
567          Time = 10.0*365.0*24.0*3600.0
568          IENflg = 1
569      ELSE
570          Halt = Halt
571      ENDIF
572 C      READ IN DATA TO DEFINE PROBLEM
573      READ (5,*) Pin,Tin,Xmw,Tout
574      READ (5,*) Qrad
575 C
576 C      Pin = CYCLE WORKING FLUID INLET PRESSURE (PSIA)
577 C      Tin = CYCLE WORKING FLUID INLET TEMPERATURE (deg-R)
578 C      Xmw = CYCLE WORKING FLUID MOLECULAR WEIGHT (MW)
579 C      Tout = CYCLE WORKING FLUID OUTLET TEMPERATURE (deg-R)
580 C      Qrad = CYCLE TOTAL HEAT REJECTION RATE REQUIRED (KWt)
581 C      Time = MISSION TIME (SECONDS)
582 C
583 C      CODE WILL ATTEMPT TO ESTIMATE THE VALUES REQUIRED TO RUN THE FULL
584 C      CASE WHICH CAN BE USED AS THE STARTING POINT FOR A FULL ANALYSIS
585 C
586      IF (Iprob.EQ.1) THEN
587          GO TO 1005
588      ELSE
589          GO TO 1200

```

```

590      ENDF
591 C
592 C      SET MANIFOLD GAS VELOCITY TO DESIGN MANIFOLD
593 C
594      1005 Vgasman = 35.0
595      I_flg2 = 1
596      DTman = Tin-Tout
597      DTfilm = 50.0
598      CALL TMEAN(Tin,DTman,DTfilm,Tbar)
599      CALL RADFLG(Tin,I_flg2,Imatl)
600      Alpha = 0.5
601      Nap = 1.0
602      NArad = 2.0
603 C      WRITE (6,*) 'Vgasman,I_flg2,DTman,DTfilm=',Vgasman,I_flg2,DTman,DTfilm
604 C      &lm
605 C      WRITE (6,*) 'Tin,Tbar,I_flg2,Imatl=',Tin,Tbar,I_flg2,Imatl
606      CALL HRTSNK(I_flg2,Halt,NINCL,Reun,Yrlnch,Alpha,Nap,NArad,Tsink)
607 C      WRITE (6,*) 'Alpha,Nap,NArad,Tsink=',Alpha,Nap,NArad,Tsink
608      Em = 0.8
609      Etarad = 0.65+(0.0002*Tbar)
610      Aradest = (3413.0*Qrad)/(0.1713E-08*Em*Etarad*((Tbar**4.0)-(Tsink**4.0)))
611      Aactual = 0.5*Aradest
612 C      WRITE (6,*) 'Em,Etarad,Aradest,Aactual=',Em,Etarad,Aradest,Aactual
613 C      DUMlen = 20.0
614      Width = Aactual/DUMlen
615      Cman = Width
616      Xntubes = (12.0*Width)/3.5
617 C      WRITE (6,*) 'DUMlen,Width,Cman,Xntubes=',DUMlen,Width,Cman,Xntubes
618 C      Xnexpip = 0.1*Xntubes
619      Pitch = 3.5/12.0
620      Dcan = 0.090333
621 C      WRITE (6,*) 'Xnexpip,Pitch,Dcan=',Xnexpip,Pitch,Dcan
622 C      Dhp = 0.083333
623      Rc = 0.043500
624      Rb = 0.043333
625      Tf = 0.000833
626 C      WRITE (6,*) 'Dhp,Rc,Rb,Tf=',Dhp,Rc,Rb,Tf
627 C      TKfin = 112.0
628      TKcan = 10.0
629      TKbraze = 28.0
630      T0 = Tin/1.8-273.2
631 C      WRITE (6,*) 'TKfin,TKcan,TKbraze,T0=',TKfin,TKcan,TKbraze,T0
632 C      CALL Wallprop(Imatl,T0,Wallden,Tcwall)
633      TKhp = 242.0*Tcwall
634      XNpipes = Xntubes
635 C      WRITE (6,*) 'Wallden,Tcwall,TKhp=',Wallden,Tcwall,TKhp
636 C      XNexpipes = Xnexpip
637      XNW = Xnw
638      Pman = Pin
639 C      WRITE (6,*) 'XNpipes,XNexpipes,XNW,Pman=',XNpipes,XNexpipes,XNW,Pman
640 C      &en
641 C      Tman = Tin
642

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643      RHOcan = 505.0
644      RHObraze = 535.0
645      THICKman = 0.005208 + (0.000052*Pin)
646 C    WRITE (6,*) 'Tman,RHOcan,RHObraze,THICKman=',Tman,RHOcan,RHObraze,
647 C    &THICKman
648      CALL HEXEPR(XMw,Pman,Tman,Gma,Cp,Rho,Amu,Tcond,Pr)
649 C    WRITE (6,*) 'Gma,Cp,Rho,Amu=',Gma,Cp,Rho,Amu
650      Uman = (3413.0*Qrad)/(3600.0*Cp*(Tin-Tout))
651      Gap = (6.0*(12.0*Dcan))/12.0
652      Hman = 1.50
653      XNf = Hman*12.0*10.0
654 C    WRITE (6,*) 'Tcond,Pr,Uman,Gap=',Tcond,Pr,Uman,Gap
655 1008 Amin = (Gap*Hman) - (Dcan*Hman)
656      Vman = Uman/(Rho*Amin)
657      ERROR3 = (Vgasman/Vman)-1.0
658      IF (ERROR3.GT.0.1) THEN
659      ERROR3 = 0.1
660      ELSE
661      ERROR3=ERROR3
662      ENDIF
663      Hman = Hman*(1.0+(0.8*ABS(ERROR3)))
664      XNf = Hman*12.0*10.0
665 C    WRITE (6,*) 'ERROR3 =',ERROR3
666 C    WRITE (6,*) 'Hman =',Hman
667      IF (ABS(ERROR3).GT.0.0001) THEN
668      GO TO 1008
669      ELSE
670      GO TO 1009
671      ENDIF
672 1009 CONTINUE
673 C    WRITE (6,*) 'INPUTS FOR HPMAN FROM LINE 598'
674 C    WRITE (6,*) 'Ifluid,Iflg2,Cman,Hman=',Ifluid,Iflg2,Cman,Hman
675 C    WRITE (6,*) 'Gap,Pitch,Dcan,Dhp=',Gap,Pitch,Dcan,Dhp
676 C    WRITE (6,*) 'Rc,Rb,Tf,TKfin=',Rc,Rb,Tf,TKfin
677 C    WRITE (6,*) 'TKcan,TKbraze,TKhp,Xnf=',TKcan,TKbraze,TKhp,Xnf
678 C    WRITE (6,*) 'XNpipes,XNexpipes,Xmw,Pin=',XNpipes,XNexpipes,Xmw,Pin
679 C    WRITE (6,*) 'Tin,RHOcan,RHObraze,THICKman=',Tin,RHOcan,RHObraze,TH
680 C    &ICKman
681 C    WRITE (6,*) 'Uman,Qrad=',Uman,Qrad
682      CALL HPMAN(Ifluid,Iflg2,Cman,Hman,Gap,Pitch,Dcan,Dhp,Rc,Rb,Tf,TKfi
683 &n,TKcan,TKbraze,TKhp,Xnf,XNpipes,XNexpipes,Xmw,Pin,Tin,RHOcan,RH
684 &Obraze,THICKman,Uman,Qrad,XMANmas,DPman,DTfilm,XHMAN)
685      Qrad = Qrad
686      Trad = Tber
687      Xntubes = (12.0*Width)/3.5
688      Xnexpip = 0.1*Xntubes
689      Xlflat = Hman*12.0
690      Dhpip = 1.0
691      CALL RADFLG(Tber,Ifluid,Imatl)
692 1100 THETA = 0.0
693      D2rad = Width/PI
694      Thickm = 0.0

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695      Thickf = 0.050/12.0
696      Thick = 0.003/12.0
697      Em = 0.8
698      Tkfin = 49.1
699      Rhocoating = 0.0
700      Rhofin = 113.0
701      RHOarm = 113.0
702      Xladiab = 0.0
703      Xmachmas = 0.0
704      PROB = 0.99
705      GAM = 1.70
706      ARSF = 1.70
707      Earm = 10000000.0
708      CONFIG = 1.0
709      CALL TMEAN(Tin,DTman,DTfilm,Tred)
710      CALL HRRAD(Qrad,Tred,Xntubes,Xnexpip,Xlflat,Dhpipe,Iffluid,Imatl,
711      &Theta,D2rad,Thickm,Thickf,Thick,Em,IENflg,Halt,NINCL,Reun,Yrlnch,
712      &Alpha,Hap,HARad,TKfin,Rhocoating,Rhofin,RHOarm,Xladiab,CONFIG,
713      &Xmachmas,PROB,GAM,ARSF,Earm,Time,Qrejected,Thickf2,Thickm2,
714      &Aradiator,Aradeffect,Wthick2,Xnart2,Artid2,
715      &Artwall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xmpipes,Xmfluid,
716      &Xmfin,Xmcoating,Xarmor,Xarmorid,Xstructure,
717      &Xnetradmasst2,Wxl2)
718 C
719      XN9 = 12.0
720      Vpipe = 100.0
721      PGAS = Pin
722      TGAS = Tin
723      CALL HEXEPR(XMW,PGAS,TGAS,GMA,CP,RHOGas,AMU,AK,PR)
724      Dp = 12.0*SQRT((1.27324*Wman)/(RHOGas*Vpipe))
725 C
726 C      WRITE (6,*) 'RHOGas =',RHOGas
727 C      WRITE (6,*) 'Dp =',Dp
728      SUNLEN = 12.0*Dp
729      THICKP = PGAS*Dp/(2.0*5000.0)
730      IF (THICKP.GT.0.03125) THEN
731      THICKP = THICKP
732      ELSE
733      THICKP = 0.03125
734      ENDIF
735      THICK1 = 4.0
736      RHOPIP = 505.0
737      RHOINS = 16.0
738      R9 = 4.0*Dp
739      CALL HRODUCT(XN9,R9,Dp,SUNLEN,Vpipe,TGAS,PGAS,THICKP,RHOPIP,
740      &THICK1,RHOINS,XMW,DPRODUCT,DUCHAS)
741 C
742 C      WRITE (6,*) '*** HEAT REJECTION SYSTEM FOR A BRAYTON CYCLE SYSTEM
743      &IN WHICH CYCLE WASTE HEAT IS REJECTED DIRECTLY FROM THE CYCLE WORK
744      &ING FLUID IN A HEAT PIPE COOLED GAS MANIFOLD ***'
745      WRITE (6,*) ' '
746      WRITE (6,*) 'INPUT FOR OPTION NUMBER 1'

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747     WRITE (6,*) ' '
748     WRITE (6,*) 'INPUT FOLLOWING DATA INTO FILE *RADAT* TO RUN OPT #1'
749     WRITE (6,*) ' '
750 C    DEFINE ORBIT
751     WRITE (6,*) IENflg,Halt,HINCL,Rsun
752     WRITE (6,*) Yrlnch,Time
753     WRITE (6,*) ' '
754 C    DEFINE RADIATOR
755     WRITE (6,*) GAM,ARSF,Earm,PROB
756     WRITE (6,*) CONFIG,Xntubes,Xnexpip,Xlflat
757     WRITE (6,*) Dhpipe,Ifluid,Imatl,Theta
758     WRITE (6,*) D2rad,Thickm,Thickf,Thick
759     WRITE (6,*) Em,Alpha,Hap,HARad
760     WRITE (6,*) Tkfin,Rhocoating,Rhofin,RHOarm
761     WRITE (6,*) Xladiab,Xmchmas
762     WRITE (6,*) ' '
763 C    DEFINE HEAT PIPE MANIFOLD
764     WRITE (6,*) Iflg2,Hman,Gap,Pitch
765     WRITE (6,*) Dcan,Dhp,Rc,Rb
766     WRITE (6,*) Tf,TKfin,TKcan,TKbraze
767     WRITE (6,*) TKhp,XNf,Xmw,RHOcan
768     WRITE (6,*) RHObraze,THICKman,Wman
769     WRITE (6,*) ' '
770 C    DEFINE DUCTING
771     WRITE (6,*) XN9,R9,Dp,SUMLEN
772     WRITE (6,*) THICKP,RHOPIP,THICKI,RHOINS
773     WRITE (6,*) ' '
774     WRITE (6,*) 'C    IENflg,Halt,HINCL,Rsun'
775     WRITE (6,*) 'C    Yrlnch,Time'
776     WRITE (6,*) ' '
777     WRITE (6,*) 'C    GAM,ARSF,Earm,PROB'
778     WRITE (6,*) 'C    CONFIG,Xntubes,Xnexpip,Xlflat'
779     WRITE (6,*) 'C    Dhpipe,Ifluid,Imatl,Theta'
780     WRITE (6,*) 'C    D2rad,Thickm,Thickf,Thick'
781     WRITE (6,*) 'C    Em,Alpha,Hap,HARad'
782     WRITE (6,*) 'C    Tkfin,Rhocoating,Rhofin,RHOarm'
783     WRITE (6,*) 'C    Xladiab,Xmchmas'
784     WRITE (6,*) ' '
785     WRITE (6,*) 'C    Iflg2,Hman,Gap,Pitch'
786     WRITE (6,*) 'C    Dcan,Dhp,Rc,Rb'
787     WRITE (6,*) 'C    Tf,TKfin,TKcan,TKbraze'
788     WRITE (6,*) 'C    TKhp,XNf,Xmw,RHOcan'
789     WRITE (6,*) 'C    RHObraze,THICKman,Wman'
790     WRITE (6,*) ' '
791     WRITE (6,*) 'C    XN9,R9,Dp,SUMLEN'
792     WRITE (6,*) 'C    THICKP,RHOPIP,THICKI,RHOINS'
793     CALL RADPRT(Grad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,I
794 &matl,Theta,D2rad,Thickm,Thickf,Thick,Em,
795 &Alpha,Hap,HARad,TKfin,Rhocoating,Rhofin,RHOarm,Xladiab,
796 &Xmchmas,PROB,GAM,ARSF,Earm,Time,Qrejected,Thickf2,Thickm2,
797 &Aradiator,Aradeffect,Wthick2,Xnart2,Artid2,
798 &Artwall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xmpipes,Xmfluid,
799 &Xmfin,Xmcoating,Xmarmor,Xmarmorid,Xstructure,

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800      &Xnetradmasst2)
801      CALL ORBPRT(IENflg,Halt,HINCL,Rsun,Yrlnch)
802 C
803      CALL HMNPRT(Iflg2,Hman,Gap,Pitch,XNpipes,Xnexpipes,Dcan,
804      &Dhp,Rc,Rb,Tf,TKfin,TKcan,TKbraze,TKhp,XNf,RHOcan,RHObraze,
805      &THICKman,Pin,Tin,Uman,Grad,XMW,XMANmas,DPman,DTfilm,XMNMAN)
806      WRITE (6,*) ' '
807 C
808      CALL DUCPRT(XN9,R9,Dp,SUNLEN,Vpipe,Tin,Pin,THICKP,RHOPIP,
809      &THICKI,RHOINS,XMN,DPOUCT,DUCHAS)
810 C
811      WRITE (6,*) 'MASS SUMMARY FOR DIRECT BRAYTON SYSTEM'
812      WRITE (6,*) ' '
813      WRITE (6,*) 'HEAT PIPE COOLED GAS MANIFOLD MASS (Lbs) =',XMNMAN
814      WRITE (6,*) 'MANIFOLD DUCTING MASS (LBS) =',DUCHAS
815      WRITE (6,*) 'RADIATOR MASS (LBS) =',Xnetradmasst2
816      XMSYST = XMNMAN + DUCHAS + Xnetradmasst2
817      WRITE (6,*) ' '
818      WRITE (6,*) 'DIRECT BRAYTON SYSTEM MASS (LBS) =',XMSYST
819      WRITE (6,*) ' '
820 C
821      STOP
822 C
823      1200 IF (Iprob.EQ.3) THEN
824          GO TO 1400
825      ELSE
826          GO TO 1205
827      ENDIF
828      1205 INXflg = 2
829 C
830 C      DESIGN HEAT REJECTION HEAT EXCHANGER (HRHX)
831 C
832      UEST = 100.0
833      THIN = Tin
834      THOUT = Tout
835      PHOT = Pin
836      TCOU = THIN - 30.0
837      TCIN = THOUT - 50.0
838      CALL HEXEPR(XMW,PHOT,THIN,GMA,CP,RHO,AMU,TCOND,PR)
839      WRITE (6,*) ' '
840 C      WRITE (6,*) 'INXflg,UEST,THIN,THOUT,PHOT,TCOU,TCIN =',INXflg,
841 C      &UEST,THIN,THOUT,PHOT,TCOU,TCIN
842 C      WRITE (6,*) 'XMW,PHOT,THIN,GMA,CP,RHO,AMU,TCOND,PR =',XMW,PHOT,
843 C      &THIN,GMA,CP,RHO,AMU,TCOND,PR
844 C      WDOTS = (3413.0*Qrad)/(3600.0*CP*(THIN-THOUT))
845      AMWS = XMW
846      TINS = 4.0
847      DENINS = 24.0
848      DENSSH = 505.0
849      DTUBE = 0.375
850      PR = 1.3
851      TTUBE = 0.020

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852      ANPLATES = 5.0
853 C      WRITE (6,*) 'WDOTS,AMWS,TINS,DENINS,DENSSH,DTUBE,PR,TTUBE,ANPLATES
854 C      & =',WDOTS,AMWS,TINS,DENINS,DENSSH,DTUBE,PR,TTUBE,ANPLATES
855      CALL XNAKPR(TCIN,RHOnak,CPnak,VISnak,TKnak)
856 C      WRITE (6,*) 'TCIN,RHOnak,CPnak,VISnak,TKnak =',TCIN,RHOnak,CPnak,
857 C      &VISnak,TKnak
858      WDOTT = (3413.0*Qrad)/(3600.0*CPnak*(TCOUT-TCIN))
859      AKTUBE = 10.0
860      QDOT = 3413.0*Qrad
861 C      WRITE (6,*) 'WDOTT,AKTUBE,QDOT =',WDOTT,AKTUBE,QDOT
862 C      WRITE (6,*) 'CALLING HRSHEL'
863      CALL HRSHEL(INXflg,UEST,THIN,THOUT,PHOT,TCIN,TCOUT,WDOTS,AMW
864 &S,TINS,DENINS,DENSSH,DTUBE,PR,TTUBE,ANPLATES,WDOTT,AKTUBE,Q
865 &DOT,DPSHELL,ANTUBES,DPTUBE,DOTL2,ALSHL,AMSHL,AMPLATES,
866 &ANTUBES,AMINSUL,AMHEADS,AMSTR,ANETMASS,XMHX,HSHELL,AFRIC,UNEV,
867 &RETUBE,THC,AMTSHT)
868 C
869 C      SET MANIFOLD LIQUID VELOCITY TO DESIGN MANIFOLD
870 C
871      Vliqman = 30.0
872      Iflg2 = 2
873      DTman = Tin-Tout
874      DTfilm = 50.0
875      CALL TMEAN(Tin,DTman,DTfilm,Tbar)
876      CALL RADFLG(Tin,ifluid,imatl)
877      Alpha = 0.5
878      Hap = 1.0
879      HARad = 2.0
880      CALL HRTSNK(IENflg,Halt,HINCL,Rsun,Yrlnch,Alpha,Hap,HARad,Tsink)
881      Em = 0.8
882      Etarad = 0.65+(0.0002*Tbar)
883      Aradest = (3413.0*Qrad)/(0.1713E-08*Em*Etarad*((Tbar**4.0)-(Tsink*
884 &4.0)))
885      Aactual = 0.5*Aradest
886      DUMlen = 20.0
887      Width = Aactual/DUMlen
888      Cman = Width
889 C      WRITE (6,*) '*****FROM LINE 819*****'
890 C      WRITE (6,*) 'Etarad,Aradest,Aactual,Width,Cman=',Etarad,Aradest,A
891 C      &actual,Width,Cman
892      Hman = 1.5
893      Pitch = 3.5/12.0
894      Dcan = 0.090333
895      Dhp = 0.083333
896      Rc = 0.043500
897      Rb = 0.043333
898      Tf = 0.000833
899      TKfin = 112.0
900      TKcan = 10.0
901      TKbraze = 28.0
902      T0 = Tred/1.8-273.2
903      CALL Wallprop(imatl,T0,Wallden,Tcwall)

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904      TKhp = 242.0*Tcwall
905      XNf = 1.5*12.0*10
906      Xntubes = (12.0*Width)/3.5
907      Xnexpip = 0.1*Xntubes
908      XNpipes = Xntubes
909      XNexpipes = Xnexpip
910      XNW = Xnw
911      Pman = Pin
912      Tman = Tin
913      RHOcan = 505.0
914      RHObraze = 535.0
915      THICKman = 0.005208 + (0.000052*Pin)
916      Wman = WDOTT
917      GAP = 0.5
918      1208 CONTINUE
919      Amin = (Gap*Hman)-(Dcan-Hman)
920      DO 1209 I = 1,100,1
921      Vman = Wman/(Rho*Amin)
922      ERROR4 = 1.0 - (Vligman/Vman)
923      Amin = Amin*(1.0+(0.8*ERROR4))
924      C   WRITE (6,*) 'Vman,ERROR4,Amin =', Vman, ERROR4, Amin
925      IF (ABS(ERROR4).GT.0.01) THEN
926      GO TO 1209
927      ELSE
928      GO TO 1210
929      ENDIF
930      1209 CONTINUE
931      1210 Amin = Amin
932      Hman = (Amin+Dcan)/(Gap+1.0)
933      CALL HPMAN(Ifluid,Iflg2,Cman,Hman,Gap,Pitch,Dcan,Dhp,Rc,Rb,Tf,TKf1
934      &n,TKcan,TKbraze,TKhp,XNf,XNpipes,XNexpipes,Xnw,Pin,Tin,RHOcan,RH
935      &Obraze,THICKman,Wman,Grad,XMANmas,DPman,DTfilm,XPMAN)
936      XW9 = 12.0
937      C   SET PIPE VELOCITY AT 30.0 FT/SEC TO DESIGN NAK PLUMBING SYSTEM
938      CALL XNAKPR(Tman,RHO,CP,VIS,TK)
939      Vpipe = 30.0
940      Wpipe = Wman
941      Dp = SQRT((183.346*Wpipe)/(Rho*Vpipe))
942      SUNLEN = 60.0*(Grad/50.0)
943      THICKP = 0.10
944      RHOPIP = 505.0
945      THICKI = 4.0
946      RHOINS = 24.0
947      R9 = 4.0*Dp
948      C   WRITE (6,*) 'INPUTS FOR HRPIPE'
949      C   WRITE (6,*) 'Vpipe,Wpipe,Dp,SUNLEN =', Vpipe,Wpipe,Dp,SUNLEN
950      C   WRITE (6,*) '*****'
951      CALL HRPIPE(XW9,R9,Dp,SUNLEN,Vpipe,Tin,Pin,THICKP,RHOPIP,THICKI,
952      &RHOINS,DPIPE,PIPNAK,PIPMAS)
953
954      Grad = Grad
955      Trad = Tbar

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956      Xntubes = (12.0*Width)/3.5
957      Xnexpip = 0.1*Xntubes
958      Xlflat = 18.00
959      Dhpipe = 1.0
960      CALL RADFLG(Tbar,Ifluid,Imatl)
961 1300 THETA = 0.0
962      D2rad = Width/PI
963      Thickm = 0.0
964      Thickf = 0.050/12.0
965      Thick = 0.003/12.0
966      Em = 0.8
967      Tkfin = 49.1
968      Rhocoating = 0.0
969      Rhofin = 113.0
970      RHOarm = 113.0
971      Xladiab = 0.0
972      Xmchmas = 0.0
973      PROB = 0.99
974      GAM = 1.70
975      ARSF = 1.70
976      Earm = 10000000.0
977      CONFIG = 1.0
978      CALL TMEAN(Tin,DTman,DTfilm,Trad)
979      CALL HRRAD(Grad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,Imatl,
980      &Theta,D2rad,Thickm,Thickf,Thick,Em,IENflg,Halt,HINCL,Rsun,Yrlnch,
981      &Alpha,Hap,HArad,TKfin,Rhocoating,Rhofin,RHOarm,Xladiab,CONFIG,
982      &Xmchmas,PROB,GAM,ARSF,Earm,Time,Orejected,Thickf2,Thickm2,
983      &Aradiator,Aradeffect,Wthick2,Xnart2,Artid2,
984      &Artuall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xmpipes,Xmfluid,
985      &Xmfin,Xmcoating,Xmarmor,Xmarmorid,Xstructure,
986      &Xnetradmasst2,Wx(2)
987 C
988 C
989      MDOTT = Wpipe
990      CALL PUMP(Tin,MDOTT,DPPPIPE,DPTUBE,DPman,DPLOOP,Phyd,XMPUMP)
991 C
992      CALL VACMAS(Tin,PIPNAK,XHMMAN,XHNHEX,XHNVAC,XHVAC)
993 C
994 C
995 C
996 C
997      WRITE (6,*) '*** HEAT REJECTION SYSTEM FOR A BRAYTON CYCLE SYSTEM
998      &IN WHICH CYCLE WASTE HEAT IS REJECTED TO A PUMPED NaK LOOP FROM
999      &THE CYCLE WORKING FLUID TO A HEAT PIPE COOLED NaK MANIFOLD ***'
1000      WRITE (6,*) ' '
1001      WRITE (6,*) 'INPUT FOR OPTION NUMBER 2'
1002      WRITE (6,*) ' '
1003      WRITE (6,*) 'INPUT FOLLOWING DATA INTO FILE *RADAT* TO RUN OPT #2'
1004      WRITE (6,*) ' '
1005 C
1006      DEFINE ORBIT
1007      WRITE (6,*) IENflg,Halt,HINCL,Rsun
1007      WRITE (6,*) Yrlnch,Time

```

SUBROUTINE HRMAST Compiling Options:/NO/H7/B/NC/ND/NF/H/N1/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```

1008 WRITE (6,*) ' '
1009 C DEFINE RADIATOR
1010 WRITE (6,*) GAM,ARSF,Earm,PROB
1011 WRITE (6,*) CONFIG,Xntubes,Xnexpip,Xlflat
1012 WRITE (6,*) Dhpipe,Ifluid,Imatl,Theta
1013 WRITE (6,*) D2rad,Thicka,Thickf,Thick
1014 WRITE (6,*) Em,Alpha,Hap,ARad
1015 WRITE (6,*) Tkfin,Rhocoating,Rhofin,RHOarm
1016 WRITE (6,*) Xladiab,Xchmas
1017 WRITE (6,*) ' '
1018 C DEFINE HEAT SINK HEAT EXCHANGER
1019 WRITE (6,*) INXflg,UEST,TCIN,TCOUT
1020 WRITE (6,*) WDOTS,AMWS,TINS,DENINS
1021 WRITE (6,*) DENSSH,DTUBE,PR,TTUBE
1022 WRITE (6,*) ANPLATES,MDOTT,AKTUBE
1023 WRITE (6,*) ' '
1024 C DEFINE HEAT PIPE MANIFOLD
1025 WRITE (6,*) Iflg2,Hman,Gap,Pitch
1026 WRITE (6,*) Dcan,Dhp,Rc,Rb
1027 WRITE (6,*) Tf,TKfin,TKcan,TKbraze
1028 WRITE (6,*) TKhp,Xnf,Xmw,RHOcan
1029 WRITE (6,*) RHObraze,THICKman,Hman
1030 WRITE (6,*) ' '
1031 C DEFINE PIPING
1032 WRITE (6,*) XN9,R9,Dp,SUMLEN
1033 WRITE (6,*) THICKP,RHOPIP,THICKI,RHOINS
1034 WRITE (6,*) ' '
1035 WRITE (6,*) 'C IENflg,Halt,HINCL,Rsun'
1036 WRITE (6,*) 'C Yrlnch,Time'
1037 WRITE (6,*) ' '
1038 WRITE (6,*) 'C GAM,ARSF,Earm,PROB'
1039 WRITE (6,*) 'C CONFIG,Xntubes,Xnexpip,Xlflat'
1040 WRITE (6,*) 'C Dhpipe,Ifluid,Imatl,Theta'
1041 WRITE (6,*) 'C D2rad,Thicka,Thickf,Thick'
1042 WRITE (6,*) 'C Em,Alpha,Hap,ARad'
1043 WRITE (6,*) 'C Tkfin,Rhocoating,Rhofin,RHOarm'
1044 WRITE (6,*) 'C Xladiab,Xchmas'
1045 WRITE (6,*) ' '
1046 WRITE (6,*) 'C INXflg,UEST,TCIN,TCOUT'
1047 WRITE (6,*) 'C WDOTS,AMWS,TINS,DENINS'
1048 WRITE (6,*) 'C DENSSH,DTUBE,PR,TTUBE'
1049 WRITE (6,*) 'C ANPLATES,MDOTT,AKTUBE'
1050 WRITE (6,*) ' '
1051 WRITE (6,*) 'C Iflg2,Hman,Gap,Pitch'
1052 WRITE (6,*) 'C Dcan,Dhp,Rc,Rb'
1053 WRITE (6,*) 'C Tf,TKfin,TKcan,TKbraze'
1054 WRITE (6,*) 'C TKhp,Xnf,Xmw,RHOcan'
1055 WRITE (6,*) 'C RHObraze,THICKman,Hman'
1056 WRITE (6,*) ' '
1057 WRITE (6,*) 'C XN9,R9,Dp,SUMLEN'
1058 WRITE (6,*) 'C THICKP,RHOPIP,THICKI,RHOINS'
1059 WRITE (6,*) ' '

```



SUBROUTINE HRMAST Compiling Options:/NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file listing

```

1060 CALL RADPRT(Qrad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,I
1061 &matl,Theta,D2rad,Thick,Thickf,Thick,Em,
1062 &Alpha,Hap,HARad,TKfin,Rhocoating,Rhofin,RHOarm,Xladiab,
1063 &Xmachmas,PROB,GAM,ARSF,Earm,Time,Grjected,Thickf2,Thickm2,
1064 &Aradiator,Aradefect,Wthick2,Xnart2,Artid2,
1065 &Artwall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xmpipes,Xmfluid,
1066 &Xmfin,Xmcoating,Xmmarmor,Xmmarmorid,Xstructure,
1067 &Xnetradmasst2)
1068 CALL ORBPRT(IENflg,Halt,HINCL,Rsun,Yrlnch)
1069 C
1070 CALL HMPRT(Iflg2,Hman,Gap,Pitch,XNpipes,Xnexpipes,Dcan,
1071 &Dhp,Rc,Rb,Tf,TKfin,TKcan,TKbraze,TKhp,XNf,RHOcan,RHObraze,
1072 &THICKman,Pin,Tin,Uman,Grad,XMW,XMANmas,DPman,DTfilm,XNMAN)
1073 WRITE (6,*) ' '
1074 C
1075 CALL PIPRT(XN9,R9,Dp,SUMLEN,Vpipe,Tin,Pin,THICKP,RHOPIP,
1076 &THICKI,RHOINS,DPIPE,PIPNAK,PIPMAS)
1077 WRITE (6,*) ' '
1078 CALL HSHXPT(INXflg,QDOT,THIN,THOUT,TCIN,TCOUT,WDOTS,DENSSH,
1079 &DTUBE,TTUBE,WDOTT,AKTUBE,DPSHELL,ANTUBES,DPTUBE,DOTL2,ALSHEL,
1080 &AMSHELL,AMPLATES,AMTUBES,ANETMASS,XMNHX,MSHELL,AFRIC,UNEW,RETUBE,
1081 &THC,AMINSUL,AMHEADS,AMTSH,AMSTRT)
1082 WRITE (6,*) ' '
1083 C
1084 CALL PMPRT(Tin,WDOTT,DPIPE,DPTUBE,DPMAN,DLOOP,Phyd,
1085 &XMPUMP)
1086 CALL VACPRT(XMNVac,XMVAC)
1087 C
1088 WRITE (6,*) 'MASS SUMMARY FOR INDIRECT BRAYTON SYSTEM'
1089 WRITE (6,*) ' '
1090 WRITE (6,*) 'HEAT SINK HEAT EXCHANGER MASS (LBS)(DRY) =',ANETMASS
1091 WRITE (6,*) 'HEAT EXCHANGER NaK MASS (LBS) =',XMNHX
1092 WRITE (6,*) 'NaK PIPING SYSTEM MASS (LBS)(DRY) =',PIPMAS
1093 WRITE (6,*) 'MASS OF NaK IN PIPING SYSTEM (LBS) =',PIPNAK
1094 WRITE (6,*) 'MASS OF EM PUMP (LBS) (WET) =',XMPUMP
1095 WRITE (6,*) 'HEAT PIPE/NaK MANIFOLD MASS (Lbs) (DRY) =',XMANmas
1096 WRITE (6,*) 'MASS OF NaK IN MANIFOLD (LBS) =',XNMAN
1097 WRITE (6,*) 'EXPANSION COMPENSATOR MASS (LBS) (DRY) =',XMVAC
1098 WRITE (6,*) 'MASS OF NaK IN EXPANSION COMPENSATOR (LBS) =',XMNVAC
1099 WRITE (6,*) 'RADIATOR MASS (LBS) =',Xnetradmasst2
1100 XMSYST = ANETMASS + XMNHX + PIPMAS + PIPNAK + XMPUMP + XMANmas
1101 & + XNMAN + XMVAC + XMNVAC + Xnetradmasst2
1102 WRITE (6,*) ' '
1103 WRITE (6,*) 'INDIRECT BRAYTON SYSTEM MASS (LBS) (WET) =',XMSYST
1104 WRITE (6,*)
1105 STOP
1106 C
1107 1400 Iprob=3
1108 C
1109 C
1110 DTman = Tin-Tout
1111 DTfilm = 50.0

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```

1112     CALL Tmean(Tin,DTman,DTfilm,Tbar)
1113     Alpha = 0.5
1114     Nap = 1.0
1115     MArad = 2.0
1116     CALL MRTSNK(IENflg,Halt,HINCL,Rsun,Yrlnch,Alpha,Nap,MArad,Tsink)
1117 C    WRITE (6,*) 'RESULTS FROM SIMPLIFIED OPTION #3'
1118 C    WRITE (6,*) 'DTman,Tbar,Tsink =',DTman,Tbar,Tsink
1119     Em = 0.8
1120     Etarad = 0.65 + (0.0002*Tbar)
1121     Aradest = (3413.0*Qrad)/(0.1713E-08*Em*Etarad*((Tbar**4.0)-(Tsink*
1122     &*4.0)))
1123     Aactual = 0.5*Aradest
1124     DUMLEN = 10.0
1125     Width = Aactual/DUMLEN
1126 C    WRITE (6,*) 'Etarad,Aradest,Aactual,Width =',Etarad,Aradest,Aactu
1127 C    &at,Width
1128     Qrad = Qrad
1129     Trad = Tbar
1130     Xntubes = (12.0*Width)/2.0
1131     Xnexpip = 0.1*Xntubes
1132     Xlflat = 18.00
1133     Dhpipe = 1.0
1134     CALL RADFLG(Tbar,Ifluid,Imatl)
1135 C    WRITE (6,*) 'Qrad,Trad,Xntubes,Xnexpip,Ifluid,Imatl =',Qrad,Trad,
1136 C    &Xntubes,Xnexpip,Ifluid,Imatl
1137     THETA = 0.0
1138     Ccan = Width
1139     THICKins = 4.0/12.0
1140     Tbraze = 0.002/12.0
1141     TKcan = 10.0
1142     TKbraze = 35.0
1143     TKhp = 10.0
1144     Xmpipes = Xntubes
1145     XNexpipes = Xnexpip
1146     RHOip = 505.0
1147     RHOcan = 505.0
1148     RHObraze = 525.0
1149     THICKman = 0.0625/12.0
1150     Thtpip = 0.020/12.0
1151     Xin = 1.0
1152 C    WRITE (6,*) 'INPUT TO 1ST CALL TO KPRP (Xin,Pin,Tin) =',Xin,Pin,Ti
1153 C    &n
1154     CALL KPRP(Xin,Pin,Tin,DL,DV,HF,HG,HFG,SF,SG,SFG,VF,VG)
1155 C    WRITE (6,*) 'OUTPUT FROM KPRP (DL,DV,HF,HFG,SF,SG,SFG,VF,VG) =',
1156 C    &DL, DV, HF, HFG, SF, SG, SFG, VF, VG
1157     CALL KTRN(Xin,Pin,Tin,Cl,Cv,TKl,TKv,PrL,Prv,VL,Vv)
1158     Tsat = (-7633.6)/(ALOG10(Pin)-5.279)
1159     IF (Tin.GT.Tsat) DHNET=Cv*(Tin-Tsat)+HFG+Cl*(Tsat-Tout)
1160     IF (Tin.EQ.Tsat) DHNET=(Xin*HFG)+Cl*(Tsat-Tout)
1161     IF (Tin.LT.Tsat) DHNET=Cl*(Tsat-Tout)
1162     Uman = 3413.0*Qrad/DHNET
1163     Gap = 3.0/12.0

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1164      Hman = 2.0
1165      DPlimit = 0.05*Pin
1166      DTlimit = DTfilm
1167 C     WRITE (6,*) 'Hman,DPlimit =',Hman,DPlimit
1168 C     WRITE (6,*) 'DTlimit =',DTlimit
1169      1504 CONTINUE
1170      CALL COMMAN(Ifluid,Cman,Hman,Gap,THICKins,RHOins,Tout,
1171      &Tbraze,TKcan,TKbraze,TKhp,XNpipes,XNexpipes,Pin,Tin,Xin,RHOpip,
1172      &RHOCAN,RHObraze,THICKman,Thtpip,Uman,Grad,XMANmas,DPman,DTFsup,
1173      &Ar,Gt,V,Dh,Cgt,Rel,HI,Xtt,Rev,
1174      &DTFcon,DTFsub,DTfilmx)
1175      DTEROR = 1.0 - (DTlimit/DTfilmx)
1176      Hman = Hman*(1.0+(0.1*DTEROR))
1177 C     WRITE (6,*) 'DTEROR,Hman =',DTEROR,Hman
1178      IF (ABS(DTEROR).GT.0.01) THEN
1179      GO TO 1504
1180      ELSE
1181      GO TO 1506
1182      ENDDIF
1183      1506 Hman = Hman
1184 C     WRITE (6,*) '*****'
1185
1186      1508 CONTINUE
1187      CALL COMMAN(Ifluid,Cman,Hman,Gap,THICKins,RHOins,Tout,
1188      &Tbraze,TKcan,TKbraze,TKhp,XNpipes,XNexpipes,Pin,Tin,Xin,RHOpip,
1189      &RHOCAN,RHObraze,THICKman,Thtpip,Uman,Grad,XMANmas,DPman,DTFsup,
1190      &Ar,Gt,V,Dh,Cgt,Rel,HI,Xtt,Rev,
1191      &DTFcon,DTFsub,DTfilmx)
1192      DPEROR = 1.0 - (DPlimit/DPman)
1193      Gap=Gap*(1.0+(0.002*DPEROR))
1194 C     WRITE (6,*) 'DPEROR,GAP,Hman =',DPEROR,GAP,Hman
1195      IF (ABS(DPEROR).GT.0.01) THEN
1196      GO TO 1508
1197      ELSE
1198      GO TO 1510
1199      ENDDIF
1200      1510 Gap = Gap
1201      CALL COMMAN(Ifluid,Cman,Hman,Gap,THICKins,RHOins,Tout,
1202      &Tbraze,TKcan,TKbraze,TKhp,XNpipes,XNexpipes,Pin,Tin,Xin,RHOpip,
1203      &RHOCAN,RHObraze,THICKman,Thtpip,Uman,Grad,XMANmas,DPman,DTFsup,
1204      &Ar,Gt,V,Dh,Cgt,Rel,HI,Xtt,Rev,
1205      &DTFcon,DTFsub,DTfilm)
1206      Xlflat = 12.0*Hman
1207      D2rad = Width/PI
1208      Thickm = 0.0
1209      Thickf = 0.050/12.0
1210      Thick = 0.003/12.0
1211      Em = 0.8
1212      Tkfin = 49.1
1213      Rhocoating = 0.0
1214      Rhofin = 113.0
1215      RHOarm = 113.0
    
```

SUBROUTINE HRMAST Compiling Options:/NO/N7/B/MC/MD/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```

1216      Xladiab = 0.0
1217      Xmachmas = 0.0
1218      PROB = 0.99
1219      GAM = 1.70
1220      ARSF = 1.70
1221      Earm = 10000000.0
1222      CONFIG = 1.0
1223      CALL TMEAN(Tin,DTmn,DTfilm,Trad)
1224 C     WRITE (6,*) 'Trad, Ifluid, Imatl =',Trad,Ifluid,Imatl
1225 C     WRITE (6,*) 'Qrad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,Imatl,
1226 C     &Theta,D2rad,Thick,Thickf,Thick,Em,IENflg,Halt,HINCL,Rsun,Yrlnch,
1227 C     &Alpha,Hap,HARad,Tkfin ==',Qrad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe
1228 C     &,Ifluid,Imatl,Theta,D2rad,Thick,Thickf,Thick,Em,IENflg,Halt,HINCL
1229 C     &,Rsun,Yrlnch,Alpha,Hap,HARad,Tkfin
1230      CALL HRRAD(Qrad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,Imatl,
1231      &Theta,D2rad,Thick,Thickf,Thick,Em,IENflg,Halt,HINCL,Rsun,Yrlnch,
1232      &Alpha,Hap,HARad,TKfin,Rhocoating,Rhofin,RHOarm,Xladiab,CONFIG,
1233      &Xmachmas,PROB,GAM,ARSF,Earm,Time,Qrejected,Thick2,Thick2,
1234      &Aradiator,Aradeffect,Wthick2,Xnart2,Artid2,
1235      &Artwall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xmpipes,Xmfluid,
1236      &Xmfin,Xmcoating,Xarmor,Xarmorid,Xstructure,
1237      &Xnetradmasst2,Wxl2)
1238 C
1239 C
1240      WRITE (6,*) '*** HEAT REJECTION SYSTEM FOR A RANKINE CYCLE SYSTEM
1241      &IN WHICH CYCLE WASTE HEAT IS REJECTED DIRECTLY FROM THE CYCLE WORK
1242      &ING FLUID IN A HEAT PIPE COOLED CONDENSER ***'
1243      WRITE (6,*) ' '
1244      WRITE (6,*) 'INPUT FOR OPTION NUMBER 3'
1245      WRITE (6,*) ' '
1246      WRITE (6,*) 'INPUT FOLLOWING DATA INTO FILE *RADAT* TO RUN OPT #3'
1247      WRITE (6,*)
1248 C     DEFINE ORBIT
1249      WRITE (6,*) IENflg,Halt,HINCL,Rsun
1250      WRITE (6,*) Yrlnch,Time
1251      WRITE (6,*) ' '
1252 C     DEFINE RADIATOR
1253      WRITE (6,*) GAM,ARSF,Earm,PROB
1254      WRITE (6,*) CONFIG,Xntubes,Xnexpip,Xlflat
1255      WRITE (6,*) Dhpipe,Ifluid,Imatl,Theta
1256      WRITE (6,*) D2rad,Thick,Thickf,Thick
1257      WRITE (6,*) Em,Alpha,Hap,HARad
1258      WRITE (6,*) Tkfin,Rhocoating,Rhofin,RHOarm
1259      WRITE (6,*) Xladiab,Xmachmas
1260      WRITE (6,*) ' '
1261 C     DEFINE CONDENSER
1262      WRITE (6,*) Cmn,Hmn,Gap,THICKins
1263      WRITE (6,*) RHOins,Tout,Tbraze,TKcan
1264      WRITE (6,*) TKbraze,TKhp,Pin,Tin
1265      WRITE (6,*) Xin,RHOpip,RHOcan,RHObraze
1266      WRITE (6,*) THICKmn,Thtpip,Hmn
1267      WRITE (6,*) ' '

```

```

1268 C
1269 WRITE (6,*) 'C IENflg,Halt,HINCL,Rsun'
1270 WRITE (6,*) 'C Yrlnch,Time'
1271 WRITE (6,*) ' '
1272 WRITE (6,*) 'C GAM,ARSF,Earm,PROB'
1273 WRITE (6,*) 'C CONFIG,Xntubes,Xnexpip,Xlflat'
1274 WRITE (6,*) 'C Dhpipe,Ifluid,Imatl,Theta'
1275 WRITE (6,*) 'C D2rad,Thickm,Thickf,Thick'
1276 WRITE (6,*) 'C Em,Alpha,Hap,HARad'
1277 WRITE (6,*) 'C Tkfin,Rhocoating,Rhofin,RHOarm'
1278 WRITE (6,*) 'C Xladiab,Xachmas'
1279 WRITE (6,*) ' '
1280 WRITE (6,*) 'C Cman,Hman,Gap,THICKins'
1281 WRITE (6,*) 'C RHOins,Tout,Tbraze,TKcan'
1282 WRITE (6,*) 'C TKbraze,TKhp,Pin,Tin'
1283 WRITE (6,*) 'C Xin,RHOpip,RHOcan,RHObraze'
1284 WRITE (6,*) 'C THICKman,Thtpip,Uman'
1285 WRITE (6,*) ' '
1286 CALL RADPRT(Grad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,I
1287 &matl,Theta,D2rad,Thickm,Thickf,Thick,Em,
1288 &Alpha,Hap,HARad,TKfin,Rhocoating,Rhofin,RHOarm,Xladiab,
1289 &Xachmas,PROB,GAM,ARSF,Earm,Time,Rejected,Thickf2,Thickm2,
1290 &Aradiator,Aradeffect,Wthick2,Xnart2,Artid2,
1291 &Artwall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xmpipes,Xmfluid,
1292 &Xmfin,Xmcoating,Xmarmor,Xmarmorid,Xstructure,
1293 &Xnetradmasst2)
1294 CALL ORBPRT(IENflg,Halt,HINCL,Rsun,Yrlnch)
1295 C
1296 CALL CONPRT(Ar,Gt,V,Dh,Cgt,Rel,Hl,Xtt,Rev,
1297 &Ifluid,Cman,Hman,Gap,THICKins,RHOins,Tout,
1298 &Tbraze,TKcan,TKbraze,TKhp,Xmpipes,XNexpipes,Pin,Tin,Xin,RHOpip,
1299 &RHOcan,RHObraze,THICKman,Thtpip,Uman,Grad,XMANmas,DPman,
1300 &DTfilm)
1301 C
1302 C
1303 WRITE (6,*) 'MASS SUMMARY FOR CONDENSING RANKINE SYSTEM'
1304 WRITE (6,*) ' '
1305 WRITE (6,*) 'HEAT PIPE COOLED CONDENSER MASS (Lbs) =',XMANmas
1306 WRITE (6,*) 'RADIATOR MASS (LBS) =',Xnetradmasst2
1307 XMSYST = XMANmas + Xnetradmasst2
1308 WRITE (6,*) ' '
1309 WRITE (6,*) 'CONDENSING RANKINE SYSTEM MASS (LBS) =',XMSYST
1310 WRITE (6,*) ' '
1311 C
1312 STOP
1313 END

```

```
1314 C
1315 C
1316 C
1317 SUBROUTINE RADFLG(Tbar,ifluid,imatl)
1318 IF (Tbar.LT.450.0) THEN
1319 WRITE (6,*) 'RADIATOR TEMPERATURE TOO LOW TO CONTINUE CALCULATION'
1320 STOP
1321 ELSE
1322 GO TO 1410
1323 ENDIF
1324 1410 IF (Tbar.LT.549.0) THEN
1325 ifluid = 9
1326 imatl = 4
1327 GO TO 1500
1328 ELSE
1329 GO TO 1420
1330 ENDIF
1331 1420 IF (Tbar.LT.1008.0) THEN
1332 ifluid = 2
1333 imatl = 8
1334 GO TO 1500
1335 ELSE
1336 GO TO 1430
1337 ENDIF
1338 1430 IF (Tbar.LT.1350.0) THEN
1339 ifluid = 8
1340 imatl = 5
1341 GO TO 1500
1342 ELSE
1343 GO TO 1440
1344 ENDIF
1345 1440 IF (Tbar.LT.1710.0) THEN
1346 ifluid = 5
1347 imatl = 7
1348 GO TO 1500
1349 ELSE
1350 GO TO 1450
1351 ENDIF
1352 1450 IF (Tbar.LT.2070.0) THEN
1353 ifluid = 3
1354 imatl = 7
1355 GO TO 1500
1356 ELSE
1357 GO TO 1460
1358 ENDIF
1359 1460 IF (Tbar.LT.3240.0) THEN
1360 ifluid = 4
1361 imatl = 2
1362 GO TO 1500
1363 ELSE
1364 WRITE (6,*) 'TEMPERATURE ABOVE MAXIMUM HEAT PIPE OPERATING LIMIT'
1365 STOP
```

SUBROUTINE RADFLG     Compiling Options:/NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/WZ1  
Source file Listing

```
1366            ENDIF  
1367       1500 RETURN  
1368            END
```

```

1369 C
1370 C
1371 C
1372 SUBROUTINE RADPRT(Grad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,I
1373 &matl,Theta,D2rad,Thickm,Thickf,Thick,Em,
1374 &Alpha,Hap,Harad,TKfin,Rhocoating,Rhofin,RHOarm,Xladiab,
1375 &Xmchmas,PROB,GAM,ARSF,Earm,Time,Qrejected,Thick2,Thickm2,
1376 &Aradiator,Aradefect,Wthick2,Xnart2,Artid2,
1377 &Artwall2,Thick2,Xlevap2,Xladi2,Xlapec2,Xltot2,Xmpipes,Xmfluid,
1378 &Xmfin,Xmcoating,Xmarmor,Xmarmorid,Xstructure,
1379 &Xnetradmasst2)
1380 WRITE (6,*) ' '
1381 WRITE (6,*) 'RADIATOR DEFINITION INPUTS'
1382 WRITE (6,*) ' '
1383 WRITE (6,*) 'GAMMA =',GAM
1384 WRITE (6,*) 'ARSF = ',ARSF
1385 WRITE (6,*) 'ARMOR DENSITY (Lbs/cu-Ft) =',RHOARM
1386 WRITE (6,*) 'YOUNGS MODULUS OF ARMOR (Lbs/sq-In) =',Earm
1387 WRITE (6,*) 'EXPOSURE TIME OR MISSION DURATION (Secs) =',Time
1388 WRITE (6,*) 'NON-PUNCTURE PROBABILITY =',PROB
1389 WRITE (6,*) 'RADIATOR HEAT REJECTION RATE (KWt) =',Grad
1390 WRITE (6,*) 'AVERAGE RADIATOR SURFACE TEMPERATURE (deg-R) =',Trad
1391 WRITE (6,*) 'NUMBER OF PRIMARY HEAT PIPE IN RADIATOR =',Xntubes
1392 WRITE (6,*) 'NUMBER OF REDUNDENT HEAT PIPES=',Xnexpip
1393 WRITE (6,*) 'HEAT PIPE EVAPORATOR LENGTH (INCHES)='Xlflat
1394 WRITE (6,*) 'HEAT PIPE INSIDE DIAMETER (INCHES)='Dhpipe
1395 WRITE (6,*) 'HEAT PIPE WORKING FLUID ID NUMBER='Ifluid
1396 WRITE (6,*) 'HEAT PIPE LINER MATERIAL ID NUMBER='Imatl
1397 WRITE (6,*) 'CONE ANGLE FOR CONICAL RADIATOR (DEGREES)='Theta
1398 WRITE (6,*) 'MANIFOLD DIAMETER FOR CONICAL RADIATOR OR MANIFOLD LE
1399 &NGTH DIVIDED BY 3.141593 FOR FLAT PLATE (FEET) =',D2RAD
1400 WRITE (6,*) 'RADIATOR EMISSIVITY CONTROL COATING THICK.(FEET)='Th
1401 &ickm
1402 WRITE (6,*) 'RADIATOR FIN THICKNESS (FEET)='Thickf
1403 WRITE (6,*) 'HEAT PIPE WALL or LINER THICKNESS (FEET)='Thick
1404 WRITE (6,*) 'RADIATOR SURFACE EMISSIVITY='Em
1405 WRITE (6,*) 'RADIATOR SURFACE ABSOPTIVITY='Alpha
1406 WRITE (6,*) 'RADIATOR PROJ. AREA (FRACT. OF TOT.)='Hap
1407 WRITE (6,*) 'RADIATOR ACTUAL AREA (FRACTION)='Harad
1408 WRITE (6,*) 'THERMAL COND. OF FIN MATERIAL (BTU/NR-FT-R)='TKfin
1409 WRITE (6,*) 'COATING MATERIAL DENSITY (LB/cu-FT)='Rhocoating
1410 WRITE (6,*) 'FIN MATERIAL DENSITY (LB/cu-FT)='Rhofin
1411 WRITE (6,*) 'LENGTH OF ADIABATIC PORTION OF THE HEAT PIPE (FEET)='
1412 &,Xladiab
1413 WRITE (6,*) 'MASS OF RADIATOR DEPLOYMENT MECHANISM (LBS)='Xmchmas
1414 WRITE (6,*) ' '
1415 C
1416 2555 FORMAT (6F12.4)
1417 WRITE (*,*) ' '
1418 WRITE (*,*) 'TOTAL HEAT AVERAGE Radiator Emissivity'
1419 WRITE (*,*) 'REJECTED EVAPORATOR FIN Coating '
1420 WRITE (*,*) ' (KWt) TEMP (R) Thick (In) Thick (In)'
    
```



```
1421      WRITE (*,2555) Grejected,Trad,Thickf2,Thickm2
1422      WRITE (*,*) '      '
1423      WRITE (*,*) ' Actual      Effective'
1424      WRITE (*,*) '(one-side) Radiator'
1425      WRITE (*,*) 'Area(sq-Ft.) Area(sq-Ft)''
1426      WRITE (*,2555) Aradiator,Aradeffect
1427      WRITE (*,*) '      '
1428      WRITE (*,*) 'HEAT PIPE DESIGN DETAILS - DIMS in INCHES'
1429      WRITE (*,*) '      Pipe ID      Wick Thick      #Arteries      Art ID
1430      1 Art Wall      Pipe wall'
1431      WRITE (6,2555) Dhpipe,Wthick2,Xnart2,Artid2,Artwall2,Thick2
1432      WRITE (*,*) 'Evap Length      Adi Length      Cond Length      Total Length'
1433      WRITE (*,2555) Xlevap2,Xladi2,Xlspec2,Xltot2
1434      WRITE (*,*) '      '
1435      WRITE (*,*) 'RADIATOR MASS BREAKDOWN - Mass in Lbs.'
1436      WRITE (*,*) 'Heat Pipes      Fluids      FINS      Emiss. Cont.'
1437      WRITE (*,2555) Xmpipes,Xmfluid,Xmfin,Xmcoating
1438      WRITE (*,*) 'O.D.ARMOR      I.D.ARMOR      Structure      TOTAL RADIATOR '
1439      WRITE (*,2555) Xmarmor,Xmarmorid,Xstructure,Xnetradmasst2
1440      RETURN
1441      END
```

SUBROUTINE ORBPRT      Compiling Options:/NO/N7/B/MC/MD/NF/H/M1/MK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/WZ1  
Source file Listing

```
1442 C
1443 C
1444 C
1445       SUBROUTINE ORBPRT(IENflg,Halt,MINCL,Rsun,Yrlnch)
1446       WRITE (6,*) ' '
1447       WRITE (6,*) 'IENflg (ORBIT SELECTION) =',IENflg
1448       WRITE (6,*) '       IENflg=1, EARTH ORBIT (LEO-GEO)'
1449       WRITE (6,*) '       IENflg=2, SOLAR ORBIT (0.5 to 2.0 AU)'
1450       WRITE (6,*) 'ORBIT ALTITUDE (KM) =',Halt
1451       WRITE (6,*) 'ORBIT INCLINATION ANGLE (Degrees) =',MINCL
1452       WRITE (6,*) 'DISTANCE FROM SUN (AU) =',Rsun
1453       WRITE (6,*) 'YEAR SATELLITE LAUNCHED =',Yrlnch
1454       WRITE (6,*) ' '
1455       RETURN
1456       END
```

SUBROUTINE HMNPRT Compiling Options: /NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/WT/W/NX/NZ1  
 Source file Listing

```

1457 C
1458 C
1459 C
1460 SUBROUTINE HMNPRT(Iflg2,Hman,Gap,Pitch,XNpipes,Xnexpipes,Dcan,
1461 &Dhp,Rc,Rb,Tf,TKfin,TKcan,TKbraze,TKhp,Xnf,RHOcan,RHObraze,
1462 &THICKman,Pman,Tman,Wman,Grad,XMW,XMANmas,DPman,DTfilm,XMNMAN)
1463 C
1464 WRITE (6,*) 'HEAT PIPE COOLED MANIFOLD DEFINITION VARIABLES'
1465 WRITE (6,*) ' '
1466 WRITE (6,*) 'Iflg2 =',Iflg2
1467 WRITE (6,*) 'MANIFOLD HEIGHT (Feet)=' ,Hman
1468 WRITE (6,*) 'MANIFOLD WIDTH (Feet)=' ,Gap
1469 WRITE (6,*) 'DIST. BETWN CAN (HEAT PIPES) C-LINES (Feet)=' ,Pitch
1470 WRITE (6,*) 'NUMBER OF HEAT PIPES IN RADIATOR=' ,XNpipes
1471 WRITE (6,*) 'NUMB. OF REDUNDENT HEAT PIPES IN RADIATOR=' ,Xnexpipes
1472 WRITE (6,*) 'OUTSIDE DIAMETER OF MANIFOLD BRAZE CANS (Feet)=' ,Dcan
1473 WRITE (6,*) 'INSIDE DIAMETER OF HEAT PIPE (Feet)=' ,Dhp
1474 WRITE (6,*) 'MANIFOLD BRAZE CAN INSIDE RADIUS (Feet)=' ,Rc
1475 WRITE (6,*) 'BRAZE JOINT INSIDE RADIUS (Feet)=' ,Rb
1476 WRITE (6,*) 'FIN THICKNESS (Feet)=' ,Tf
1477 WRITE (6,*) 'THERM. COND. OF FIN MATERIAL (BTU/Hr-Ft-R)=' ,TKfin
1478 WRITE (6,*) 'THERM. COND. OF MANIFOLD CAN MATERIAL (B/HFR)=' ,TKcan
1479 WRITE (6,*) 'THERM. COND. OF MANIF. BRAZE ALLOY (B/HFR)=' ,TKbraze
1480 WRITE (6,*) 'THERM. COND. OF HEAT PIPE WALL MATL (B/HFR)=' ,TKhp
1481 WRITE (6,*) 'TOTAL NUMBER OF FINS FOR THE MANIFOLD HEIGHT=' ,Xnf
1482 WRITE (6,*) 'DENSITY OF MANIFOLD MATERIAL (Lb/cu-Ft)=' ,RHOcan
1483 WRITE (6,*) 'DENSITY OF BRAZE MATERIAL (Lb/cu-Ft)=' ,RHObraze
1484 WRITE (6,*) 'MANIFOLD MATERIAL THICKNESS (Feet)=' ,THICKman
1485 WRITE (6,*) 'MANIFOLD INLET PRESSURE (PSIA)=' ,Pman
1486 WRITE (6,*) 'MANIFOLD INLET TEMPERATURE (deg-R)=' ,Tman
1487 WRITE (6,*) 'MANIFOLD FLOWRATE (LBS/HR)=' ,Wman
1488 WRITE (6,*) 'MANIFOLD AND RADIATOR HEAT LOAD (BTU/HR)=' ,Grad
1489 WRITE (6,*) 'MOLECULAR WEIGHT OF MANIFOLD WORKING FLUID=' ,XMW
1490 WRITE (6,*) ' '
1491 WRITE (6,*) 'MANIFOLD PRESSURE DROP (PSID) =',DPman
1492 WRITE (6,*) 'MANIFOLD FILM TEMPERATURE DROP (deg-R) =',DTfilm
1493 WRITE (6,*) 'MAK INVENTORY MASS (Lbs) =',XMANmas
1494 WRITE (6,*) 'NET MASS OF HEAT PIPE MANIFOLD (Lbs) =',XMANmas
1495 WRITE (6,*) ' '
1496 C
1497 RETURN
1498 END

```

```
1499 C
1500 C
1501 C
1502     SUBROUTINE DUCPRT(XN9,R9,Dp,SUNLEN,Vpipe,TGAS,PGAS,THICKP,RHOPIP,
1503 &THICKI,RHOINS,XMW,DPOUCT,DUCHMAS)
1504 C
1505     WRITE (6,*) 'DUCTING INPUT VARIABLES'
1506     WRITE (6,*) ' '
1507     WRITE (6,*) 'NUMB. OF 90 DEG. ELBOWS OR EQUIV.=',XN9
1508     WRITE (6,*) 'AVERAGE RADIUS FOR 90 DEGREE ELBOWS (INCHES)=',R9
1509     WRITE (6,*) 'INSIDE DUCT DIAMETER (INCHES)=',Dp
1510     WRITE (6,*) 'TOTAL LENGTH OF DUCT SYSTEM (INCHES)=',SUNLEN
1511     WRITE (6,*) 'GAS VELOCITY IN DUCTS (FT/SEC)=',Vpipe
1512     WRITE (6,*) 'GAS TEMPERATURE (deg-R)=',TGAS
1513     WRITE (6,*) 'GAS PRESSURE (psia)=',PGAS
1514     WRITE (6,*) 'DUCT WALL THICKNESS (INCHES)=',THICKP
1515     WRITE (6,*) 'DUCT WALL DENSITY (LB/cu-FT)=',RHOPIP
1516     WRITE (6,*) 'DUCT INSULATION THICKNESS (INCHES)=',THICKI
1517     WRITE (6,*) 'DUCT INSULATION DENSITY (LB/cu-FT)=',RHOINS
1518     WRITE (6,*) 'GAS MOLECULAR WEIGHT=',XMW
1519     WRITE (6,*) 'DUCT SYSTEM PRESSURE DROP (PSID)=',DPOUCT
1520     WRITE (6,*) 'DUCT SYSTEM MASS (LBS)=',DUCHMAS
1521 C
1522     RETURN
1523     END
```

SUBROUTINE PIPPRT Compiling Options:/NO/N7/B/NC/ND/NF/H/N1/NK/ML/P/NQ1/NQ2/NQ3/R/S/NT/U/NX/MZ1  
Source file Listing

```
1524 C
1525 C
1526 C
1527     SUBROUTINE PIPPRT(XN9,R9,Dp,SUMLEN,Vpipe,Tnak,Pnak,THICKP,RHOPIP,
1528     &THICKI,RHOINS,DPPPIPE,PIPNAK,PIPMAS)
1529 C
1530     WRITE (6,*) 'PIPING DEFINITION VARIABLES'
1531     WRITE (6,*) ' '
1532     WRITE (6,*) 'NUMB. OF 90 DEG. ELBOWS OR EQUIV.=',XN9
1533     WRITE (6,*) 'AVERAGE RADIUS FOR 90 DEGREE ELBOWS (INCHES)=',R9
1534     WRITE (6,*) 'INSIDE PIPE DIAMETER (INCHES)=',Dp
1535     WRITE (6,*) 'TOTAL LENGTH OF PIPE SYSTEM (INCHES)=',SUMLEN
1536     WRITE (6,*) 'NAK VELOCITY IN PIPES (FT/SEC)=',Vpipe
1537     WRITE (6,*) 'NAK TEMPERATURE (deg-R)=',Tnak
1538     WRITE (6,*) 'NAK PRESSURE (psia)=',Pnak
1539     WRITE (6,*) 'PIPE WALL THICKNESS (INCHES)=',THICKP
1540     WRITE (6,*) 'PIPE WALL DENSITY (LB/cu-FT)=',RHOPIP
1541     WRITE (6,*) 'PIPE INSULATION THICKNESS (INCHES)=',THICKI
1542     WRITE (6,*) 'PIPE INSULATION DENSITY (LB/cu-FT)=',RHOINS
1543     WRITE (6,*) 'PIPE SYSTEM PRESSURE DROP (PSID)=',DPPPIPE
1544     WRITE (6,*) 'PIPE SYSTEM MASS (LBS)=',PIPMAS
1545     WRITE (6,*) 'PIPE SYSTEM NAK MASS (LBS) =',PIPNAK
1546     WRITE (6,*) ' '
1547 C
1548     RETURN
1549     END
```

```

1550 C
1551 C
1552 C
1553 SUBROUTINE HSHXPT(INXflg,QDOT,THIN,THOUT,TCIN,TCOUT,WDOTS,DENSSH,
1554 &DTUBE,TTUBE,WDOTT,AKTUBE,DPSHELL,ANTUBES,DPTUBE,DOTL2,ALSHEL,
1555 &MSHELL,AMPLATES,AMTUBES,ANETMASS,XMNHEX,HSHELL,AFRIC,UNEW,RETUBE,
1556 &THC,AMINSUL,AMHEADS,AMTSHT,AMSTRT)
1557 WRITE (6,*) ' '
1558 WRITE (6,*) 'HEAT SOURCE/SINK HEAT EXCHANGER DEFINITION'
1559 WRITE (6,*) ' '
1560 WRITE (6,*) 'TUBE SIDE FLUID FLAG =' ,INXflg
1561 WRITE (6,*) 'Heat Rate or Duty (BTU/Hr) =' ,QDOT
1562 WRITE (6,*) 'HOT SIDE Inlet Temperature (R)=' ,THIN
1563 WRITE (6,*) 'HOT SIDE Outlet Temperature (R)=' ,THOUT
1564 WRITE (6,*) 'COLD SIDE Inlet Temperature (R)=' ,TCIN
1565 WRITE (6,*) 'COLD SIDE Outlet Temperature (R)=' ,TCOUT
1566 WRITE (6,*) 'SHELL SIDE FLUID Flowrate (Lbs/Sec)=' ,WDOTS/3600.0
1567 WRITE (6,*) 'SHELL MATERIAL Density (Lbs/Ft^3)=' ,DENSSH
1568 WRITE (6,*) 'INSIDE TUBE Diameter (Inches)=' ,DTUBE
1569 WRITE (6,*) 'TUBE Wall Thickness (Inches)=' ,TTUBE
1570 WRITE (6,*) 'TUBE -SIDE Fluid Flowrate (Lbs/Sec)=' ,WDOTT
1571 WRITE (6,*) 'TUBE Wall Thermal Conductivity (BTU/Hr-Ft-R)=' ,AKTUBE
1572 WRITE (6,*) 'SHELLSIDE DP (PSID) =' ,DPSHELL
1573 WRITE (6,*) 'SHELLSIDE H (BTU/HR-sqFT-R)=' ,HSHELL
1574 WRITE (6,*) 'FRIC-FAC =' ,AFRIC
1575 WRITE (6,*) 'UNEW (BTU/HR-sqFT-R) =' ,UNEW
1576 WRITE (6,*) 'NUMBER OF TUBES IN BUNDLE =' ,ANTUBES
1577 WRITE (6,*) 'Tube Side Reynolds Number =' ,RETUBE
1578 WRITE (6,*) 'Tube Side Pressure Drop (PSID) =' ,DPTUBE
1579 WRITE (6,*) 'Tube Side Hg (BTU/HR-sq.Ft-R) =' ,THC
1580 WRITE (6,*) 'TUBE WALL THICKNESS (Inches) =' ,TTUBE
1581 WRITE (6,*) 'DOTL2 (Inches) =' ,DOTL2
1582 WRITE (6,*) 'LENGTH (Inches) =' ,ALSHEL
1583 WRITE (6,*) ' '
1584 WRITE (6,*) 'INSULATION MASS (Lbs) =' ,AMINSUL
1585 WRITE (6,*) 'HEAD MASS (Lbs) =' ,AMHEADS
1586 WRITE (6,*) 'SHELL MASS (Lbs) =' ,MSHELL
1587 WRITE (6,*) 'PLATE MASS (Lbs) =' ,AMPLATES
1588 WRITE (6,*) 'TUBE SHEETS MASS (Lbs) =' ,AMTSHT
1589 WRITE (6,*) 'TUBE MASS (Lbs) =' ,AMTUBES
1590 WRITE (6,*) 'STRUCTURE AND BRACKETS MASS (Lbs) =' ,AMSTRT
1591 WRITE (6,*) 'MASS OF NaK IN H-X (LBS) =' ,XMNHEX
1592 WRITE (6,*) 'Net Mass of Shell and Tube Unit(DRY)(Lbs)=' ,ANETMASS
1593 C
1594 RETURN
1595 END

```

SUBROUTINE PMPRT Compiling Options:/NO/N7/B/NC/ND/NF/H/N1/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```
1596 C
1597 C
1598 C
1599     SUBROUTINE PMPRT(Tnak,Wnak,DPIPE,DPHX,DPMANIF,DPLOOP,Phyd,
1600 &XMPUMP)
1601 C
1602     WRITE (6,*) ' '
1603     WRITE (6,*) 'NAK PUMP DEFINITION'
1604     WRITE (6,*) ' '
1605     WRITE (6,*) 'NAK INLET TEMPERATURE (deg-R)=' ,Tnak
1606     WRITE (6,*) 'NAK FLOWRATE (LBS/SEC)=' ,Wnak
1607     WRITE (6,*) 'PIPING SYSTEM PRESSURE DROP (PSID)=' ,DPIPE
1608     WRITE (6,*) 'NAK SIDE HEAT EXCHANGER PRESSURE DROP (PSID)=' ,DPHX
1609     WRITE (6,*) 'NAK MANIFOLD PRESSURE DROP (PSID)=' ,DPMANIF
1610     WRITE (6,*) 'NAK LOOP PRESSURE DROP (PSID) =' ,DPLOOP
1611     WRITE (6,*) 'NAK LOOP PUMP POWER REQUIRED (HYDRAULIC) (WATTS) =' ,
1612 &Phyd
1613     WRITE (6,*) 'E-M PUMP MASS (DRY) (LBS) =' ,XMPUMP
1614 C
1615     RETURN
1616     END
```

SUBROUTINE VACPRT Compiling Options:/NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```
1617 C
1618     SUBROUTINE VACPRT(XMNVac,XMVAC)
1619     WRITE (6,*) ' '
1620     WRITE (6,*) 'NAK LOOP EXPANSION COMPENSATOR DEFINED'
1621     WRITE (6,*) ' '
1622     WRITE (6,*) 'VOLUME ACCUMULATOR NAK MASS (Lbs) =',XMNVac
1623     WRITE (6,*) 'VOLUME ACCUMULATOR MASS (WET) (Lbs) =',XMVAC
1624 C
1625     RETURN
1626     END
```



```

1627 C
1628 C
1629     SUBROUTINE CONPRT(Ar,Gt,V,Dh,Cgt,Rel,Hl,Xtt,Rev,
1630     &If Fluid,Cman,Hman,Gap,THICKins,RHOins,Tout,
1631     &Tbrazе,TKcan,TKbrazе,TKhp,XNpipes,XNexpipes,Pin,Tin,Xin,RHOpip,
1632     &RHOcan,RHObrazе,THICKman,Thtpip,Uman,Qrad,XMANmas,DPman,
1633     &DTfilm)
1634 C
1635     WRITE (6,*) 'HEAT PIPE COOLED CONDENSER DESCRIPTION'
1636     WRITE (6,*) ' '
1637     WRITE (6,*) 'MANIFOLD FLAT LENGTH (Ft) =',Cman
1638     WRITE (6,*) 'MANIFOLD HEIGHT (Ft) =',Hman
1639     WRITE (6,*) 'AVERAGE MANIFOLD COND. SURF. SPACE(Gap)(Ft) =',Gap
1640     WRITE (6,*) 'MANIFOLD INSULATION THICKNESS (Ft) =',THICKins
1641     WRITE (6,*) 'MANIFOLD INSULATION DENSITY (Lbs/cu-Ft) =',RHOins
1642     WRITE (6,*) 'NUMBER OF PRIMARY HEAT PIPES ATTACHED TO COOL CONDENS
1643     &ER SURFACE =',XNpipes
1644     WRITE (6,*) 'NUMBER OF REDUNDANT HEAT PIPES USED TO COOL CONDENSER
1645     & SURFACE =',XNexpipes
1646     WRITE (6,*) 'MANIFOLD WALL MATERIAL THICKNESS (Ft) =',THICKman
1647     WRITE (6,*) 'MANIFOLD-HEAT PIPE BRAZE MATERIAL THICKNESS (Ft) =',
1648     &Tbrazе
1649     WRITE (6,*) 'HEAT PIPE WALL THICKNESS (Ft) =',Thtpip
1650     WRITE (6,*) 'MANIFOLD WALL MAT. THERMAL COND. (B/HFR) =',TKcan
1651     WRITE (6,*) 'BRAZE MAT. THERMAL COND. (B/HFR) =',TKbrazе
1652     WRITE (6,*) 'HEAT PIPE WALL MAT. THERMAL COND. (B/HFR) =',TKhp
1653     WRITE (6,*) 'MANIFOLD WALL MATERIAL DENSITY (Lb/cu-Ft) =',RHOcan
1654     WRITE (6,*) 'BRAZE MATERIAL DENSITY (Lb/cu-Ft) =',RHObrazе
1655     WRITE (6,*) 'HEAT PIPE WALL MATERIAL DENSITY (Lb/cu-Ft) =',RHOpip
1656     WRITE (6,*) 'HEAT PIPE WORKING FLUID NUMBER =',If Fluid
1657     WRITE (6,*) ' '
1658     WRITE (6,*) 'MANIFOLD OPERATING CONDITIONS'
1659     WRITE (6,*) ' '
1660     WRITE (6,*) 'INLET PRESSURE (psia) =',Pin
1661     WRITE (6,*) 'INLET TEMPERATURE (deg-R) =',Tin
1662     WRITE (6,*) 'MEAN CONDENSER QUALITY =',Xin
1663     WRITE (6,*) 'OUTLET TEMPERATURE (deg-R) =',Tout
1664     WRITE (6,*) 'MANIFOLD FLOWRATE (Lbs/Hr) =',Uman
1665     WRITE (6,*) 'MANIFOLD DUTY (KWt) =',Qrad
1666     WRITE (6,*) ' '
1667     WRITE (6,*) 'COMPUTED RESULTS'
1668     WRITE (6,*) ' '
1669     WRITE (6,*) 'MANIFOLD PRESSURE DROP (PSID) =',DPman
1670     WRITE (6,*) 'MANIFOLD FILM TEMPERATURE DROP (deg-R) =',DTfilm
1671     WRITE (6,*) 'FLOW CROSS-SECTIONAL AREA (sq ft)=',Ar
1672     WRITE (6,*) 'MASS FLUX (lbm/h sq ft)=',Gt
1673     WRITE (6,*) 'VAPOR VELOCITY, ft/s=',V
1674     WRITE (6,*) 'HYDRAULIC DIAMETER =',Dh
1675     WRITE (6,*) 'CONDENSER CONDENSATE FLOW REGIME PARAMETER =',Cgt
1676     IF (Cgt.LE.0.3) THEN
1677     WRITE (6,*) 'CONDENSER IS OPERATING IN SHEAR FLOW REGIME'
1678     ELSE

```

```
1679      WRITE (6,*) 'CONDENSER IS NOT OPERATING IN SHEAR FLOW REGIME'  
1680      WRITE (6,*) '*****'  
1681      ENDIF  
1682      WRITE (6,*) '      '  
1683      WRITE (6,*) 'CONDENSATE FILM REYNOLDS NUMBER =',ReI  
1684      WRITE (6,*) 'SHEAR-CONTROLLED LIQ. FILM HEAT TRANSFE. COEFF.=','Hl  
1685      WRITE (6,*) 'MARTINELLI PARAMETER =',Xtt  
1686      WRITE (6,*) 'VAPOR REYNOLDS NUMBER =',Rev  
1687      WRITE (6,*) 'MANIFOLD MASS (Lbs) =',XMANmas  
1688      C  
1689      RETURN  
1690      END
```

SUBROUTINE HRENV R Compiling Options:/NO/N7/B/NC/ND/NF/H/M1/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```

1691 C
1692 C
1693 C
1694 SUBROUTINE HRENV R(IENflg,Halt,HINCL,Rsun,Yrlnch,Ealpha,Beta,Qsunx)
1695 C
1696 C **** VARIABLES DEFINITION ****
1697 C
1698 C IENflg = FLAG TO SET ENVIRONMENT DESIRED
1699 C = 1, EARTH ORBIT, LEO TO GEO USES GREATER OF DEBRIS
1700 C OR METEORITE FLUX, NO DEBRIS ABOVE 2000 Km.
1701 C = 2, BEYOND EARTH ORBIT, 0.25 TO 2.00 AU
1702 C Halt = ORBIT ALTITUDE (km)
1703 C HINCL = ORBIT INCLINATION ANGLE (28.5 TO 80.0 degrees, ONLY)
1704 C Rsun = DISTANCE FROM SUN (AU)
1705 C Yrlnch = YEAR IN WHICH VEHICLE IS PLACED IN ORBIT
1706 C Ealpha = PRODUCT OF EARTH SHIELDING FACTOR AND METEORITE/DEBRIS
1707 C FLUX CONSTANT (GM^2/M^2-SEC)
1708 C Beta = METEORITE FLUX CONSTANT
1709 C Tsink = EFFECTIVE SINK TEMPERATURE (K)
1710 C
1711 GO TO (10,20),IENFLG
1712 C COMPUTE DATA FOR EARTH ORBIT (LEO TO GEO)
1713 10 IF (HINCL.LT.28.5.OR.HINCL.GT.80.0) THEN
1714 WRITE (6,*) 'INVALID ORBIT INCLINATION ANGLE WAS INPUT'
1715 WRITE (6,*) 'INPUT ORBIT INCLINATION ANGLE WAS (deg) =',HINCL
1716 WRITE (6,*) 'INCLINATION ANGLE MUST BE BETWEEN 28.5 AND 80 deg.'
1717 STOP
1718 ELSE
1719 CONTINUE
1720 ENDF
1721 DO 12 J=1,2
1722 IF (J.EQ.1) THEN
1723 Xm=1E-06
1724 ELSE
1725 Xm=1.0
1726 ENDF
1727 A1 = 1.0/(((2200.0*(Xm**0.306)+15)**4.38)
1728 A2 = 1.3E-09/(Xm+((1E11)*(Xm**2.0))+((1E27)*(Xm**4.0)))
1729 A3 = 1.3E-16/((Xm+((1E06)*(Xm**2.0)))**0.85)
1730 ANT = (A1+A2+A3)*(1.0/0.565)
1731 IF (J.EQ.1) THEN
1732 AX1 = ALOG10(ANT)
1733 ELSE
1734 AX2 = ALOG10(ANT)
1735 ENDF
1736 12 CONTINUE
1737 Alpha1 = AX2
1738 Beta1 = (AX1-AX2)/6.0
1739 C
1740 C *** COMPUTE EARTH SHIELDING FACTOR, FOCUSING FACTOR ***
1741 C
1742 Rorb = 6378.0 + Halt

```

SUBROUTINE HRENVF Compiling Options:/NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```

1743      Rearth = 6378.0 + 100.0
1744      Ge = 1.0 + (Rearth/Rorb)
1745      ETA = ASIN(Rearth/(Rearth+Halt-100.0))
1746      Sf = (1.0+COS(ETA))/2.0
1747      DUM9 = Ge*Sf*(10.0**Alpha1)
1748      EalphaM = ALOG10(DUM9)
1749      C *** COMPUTE DEBRIS FLUX ***
1750      IF (Halt.GT.2000.0) THEN
1751      WRITE (6,*) 'EARTH ORBIT IS ABOVE DEBRIS REGION'
1752      Ealpha = 10.0**EalphaM
1753      Beta = Beta1
1754      Qsurx = 443.0
1755      GO TO 30
1756      ELSE
1757      CONTINUE
1758      ENDIF
1759      J=0
1760      DO 14 J=1,2
1761      IF (J.EQ.1) THEN
1762      Xm = 1E-06
1763      D = (6.0*Xm/(4.7*3.141593))**0.333333
1764      ELSE
1765      Xm = 1.0
1766      D = (6.0*Xm/(2.8*3.141593))**0.362319
1767      ENDIF
1768      IF (Yrlnch.LT.2011) THEN
1769      Q = 0.02
1770      G1 = (1.0+Q)**(Yrlnch-1988.0)
1771      ELSE
1772      Q = 0.04
1773      G1 = ((1.0+Q)**23.0)*((1.0+Q)**(Yrlnch-2011.0))
1774      ENDIF
1775      P = 0.05
1776      G2 = 1.0 + (P*(Yrlnch-1988.0))
1777      F1 = 1.22E-05/(D**2.5)
1778      F2 = 8.1E+10/((D+700.0)**6.0)
1779      S = 87.2
1780      DUM1 = (Halt/200.0)+(S/140.0)-(1.5)
1781      PHONE = 10.0**DUM1
1782      PHI = PHONE/(PHONE+1.0)
1783      DUM2 = ((ALOG10(D)-0.78)**2.0)/(0.637**2.0)
1784      DUM3 = EXP(-DUM2)
1785      HD = SQRT(10.0**DUM3)
1786      PSI = -(0.313471)+(0.084327*HINCL)-(0.00186*(HINCL**2.0))+
1787      &(0.000014*(HINCL**3.0))
1788      DUM4 = (F1*G1)+(F2*G2)
1789      ANt = 3.168896E-08*(HD*PHI*PSI*DUM4)
1790      IF (J.EQ.1) THEN
1791      AX1 = ALOG10(ANt)
1792      ELSE
1793      AX2 = ALOG10(ANt)
1794      ENDIF

```

```

1795      14 CONTINUE
1796          Alpha2 = AX2
1797          Beta2 = (AX1-AX2)/6.0
1798          Ealpha2 = 1.0*Alpha2
1799          IF (Ealpha2.GT.EalphaM) THEN
1800              Alpha = 10.0**Ealpha2
1801              Beta = Beta2
1802          ELSE
1803              Ealpha = 10.0**EalphaM
1804              Beta = Beta1
1805          ENDIF
1806          Qsunx = 443.0
1807      C      WRITE (6,*) 'Ealpha =',ALOG10(Ealpha),'Beta =',Beta,'Qsun =',Qsunx
1808          GO TO 40
1809      20 CONTINUE
1810      C
1811      C      *** COMPUTES METEORITE FLUX AWAY FROM EARTH ORBIT ***
1812      C
1813          DO 22 J=1,2
1814              IF (J.EQ.1) THEN
1815                  Xm=1E-06
1816              ELSE
1817                  Xm=1.0
1818              ENDIF
1819              A1 = 1.0/((2200.0*(Xm**0.306)+15)**4.38)
1820              A2 = 1.3E-09/(Xm+((1E11)*(Xm**2.0))+((1E27)*(Xm**4.0)))
1821              A3 = 1.3E-16/(Xm+((1E06)*(Xm**2.)))**0.85)
1822              ANt = (A1+A2+A3)*(1.0/(Rsun**1.5))
1823              IF (J.EQ.1) THEN
1824                  AX1 = ALOG10(ANt)
1825              ELSE
1826                  AX2 = ALOG10(ANt)
1827              ENDIF
1828      22 CONTINUE
1829          Ealpha = 10.0**AX2
1830          Beta = (AX1-AX2)/6.0
1831          Qsunx = 443.0*((1.0/Rsun)**2.0)
1832      30 CONTINUE
1833      C      WRITE (6,*) 'Ealpha =',ALOG10(Ealpha),'Beta =',Beta,'Qsun =',Qsunx
1834      40 RETURN
1835      END

```

SUBROUTINE HRARMR Compiling Options: /NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/U/NX/NZ1  
Source file Listing

```

1836 C
1837 C
1838 C
1839 SUBROUTINE HRARMR(IENflg,Halt,HINCL,Rsun,YrInch,GAM,ARSF,Earm,RHO
1840 &arm,Atarget,Time,Prob,Tharm)
1841 C
1842 C *** THIS SUBROUTINE PREDICTS THE AMOUNT OF ARMOR REQUIRED
1843 C TO PROVIDE A SPECIFIED NON-PUNCTURE PROBABILITY IN THE
1844 C INTERPLANETARY ENVIRONMENT (EARTH-MARS) (NASA SP-8038, 1970) OR
1845 C IN EARTH ORBIT (LEO-GEO) USING KESSLERS 1990 DEBRIS MODEL ***
1846 C
1847 C *** ARMOR THICKNESS IS COMPUTED FROM THE EMPIRICAL RELATIONSHIP
1848 C PRESENTED BY HALLER AND LIEBLIEN (NASA-TN-D-4411), 1968. ***
1849 C
1850 C *** VARIABLES DEFINED ***
1851 C IENflg = FLAG TO SET ENVIRONMENT DESIRED
1852 C = 1, EARTH ORBIT, LEO-GEO
1853 C = 2, BEYOND EARTH ORBIT, 0.25 TO 2.00 AU
1854 C Halt = ORBIT ALTITUDE (Km)
1855 C HINCL = ORBIT INCLINATION ANGLE (Degrees)
1856 C Rsun = DISTANCE FROM SUN (AU)
1857 C YrInch = YEAR IN WHICH VEHICLE IS PLACED IN ORBIT
1858 C GAM,ARSF = PENETRATION CONSTANTS - FUNCTIONS OF THE SPECIFIC MAT'L
1859 C RHOarm = ARMOR DENSITY (Lbs/cu-Ft)
1860 C Earm = YOUNGS MODULUS OF ARMOR (Lbs/sq-In)
1861 C Atarget = TARGET EXPOSED AREA (Sq-Me)
1862 C Temp = RADIATOR TEMPERATURE (K)
1863 C Ealpha = METEORITE FLUX CONSTANT FROM HRENV
1864 C Time = EXPOSURE TIME (Secs)
1865 C Prob = NON-PUNCTURE PROBABILITY (0.9, 0.99, 0.999, ETC.)
1866 C IF (IENflg.EQ.2) THEN
1867 C RHOp = 0.5
1868 C Vp = 20.0
1869 C ELSE
1870 C RHOp = 4.7
1871 C Vp = 15.4
1872 C ENDIF
1873 C CALL HRENV(IENflg,Halt,HINCL,Rsun,YrInch,Ealpha,Beta,Qsurx)
1874 C Ca = 0.003657*SQRT(Earm*32.174/RHOarm)
1875 C A1 = GAM*ARSF*SQRT((RHOp*62.4)/RHOarm)*((Vp/Ca)**0.666667)
1876 C A2 = ((6.0/(3.141593*RHOp))**0.333333)
1877 C A3 = (1.0/(3.0*Beta))
1878 C A4 = (Ealpha*Atarget*Time/(-ALOG(Prob)))**A3
1879 C A5 = (2.0/(2.0*BETA+2.0))**A3
1880 C A6 = (Temp/300.0)**0.166667
1881 C TARM = A1*A2*A4*A5*A6
1882 C Tharm = TARM/2.54
1883 C RETURNS THICKNESS IN INCHES
1884 C RETURN
1885 C END

```

SUBROUTINE HRTSNK Compiling Options:/NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/WX/WZ1  
Source file Listing

```

1886 C
1887 C
1888 C
1889 C   SUBROUTINE HRTSNK(IENflg,Halt,HINCL,Rsun,Yrlnch,Alpha,Hap,HArad,Ts
1890 C   &ink)
1891 C   *** ROUTINE TO ESTIMATE THE MAXIMUM SINK TEMPERATURE SEEN BY A
1892 C   BODY IN ORBIT. EARTH REFLECTION AND EARTH RE-RADIATION IS
1893 C   CONSIDERED FOR BODIES IN LEO TO GEO EARTH ORBIT.
1894 C
1895 C   INPUTS DEFINITION
1896 C       IENflg = FLAG TO SET ENVIRONMENT DESIRED
1897 C           = 1, LEO TO GEO
1898 C           = 2, BEYOND EARTH ORBIT
1899 C       Halt = ORBIT ALTITUDE (Km)
1900 C       HINCL = ORBIT INCLINATION ANGLE
1901 C       Rsun = DISTANCE FROM SUN (AU)
1902 C       Yrlnch = YEAR IN WHICH VEHICLE IS PLACED IN ORBIT
1903 C       Alpha = RADIATOR SURFACE ABSORPTIVITY
1904 C       Hap = PROJECTED AREA (SQ-FEET)
1905 C       HArad = TOTAL RADIATING AREA (SQ-FEET)
1906 C   OUTPUT DEFINITION
1907 C       Tsink = EFFECTIVE SINK TEMPERATURE (K)
1908 C   ORBITAL CONSTANTS
1909 C       Sc = SOLAR CONSTANT
1910 C       Er = EARTH REFLECTION CONSTANT
1911 C       Ee = EARTH EMISSION CONSTANT
1912 C       R = EARTH RADIUS (N-MILES)
1913 C   CALL HRENVN(IENflg,Halt,HINCL,Rsun,Yrlnch,Ealpha,Beta,Qsunx)
1914 C   IF (Rsun.EQ.1.0) THEN
1915 C       Sc = 443.0
1916 C       Er = 74.2
1917 C       Ee = 65.9
1918 C   ELSE
1919 C       Sc = Qsunx
1920 C       Er = 0.0
1921 C       Ee = 0.0
1922 C   ENDIF
1923 C       R = 6378.0
1924 C       AK = (R/(R+Halt))**2.0
1925 C       Qs = Sc*Alpha*Hap
1926 C       Qr = AK*Er*Hap
1927 C       Qe = AK*Ee*Hap
1928 C       Qrad = Qs+Qr+Qe
1929 C       Qflux = Qrad/HArad
1930 C       SIGMA = 1.714E-09
1931 C       Tsink = ((Qflux/SIGMA)**0.25)
1932 C   RETURNS Tsink IN (deg-R)
1933 C   RETURN
1934 C   END

```

SUBROUTINE FLUIDPROP Compiling Options:/NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```
1935 C
1936 C
1937 C
1938 SUBROUTINE Fluidprop(Ifluid,T0,Xliqden,Vapden,Xliqvisc,Vapvisc,P0,
1939 1Surften,Xlhv,Xk,Xmw,Tcfluid)
1940 C
1941 C THERMODYNAMIC PROPERTIES USED FOR HEAT PIPE PERFORMANCE ESTIMATES
1942 C
1943 COMMON /RAD3/ Roomden(10),Whgp(159)
1944 Roomden(2)=1.000
1945 Roomden(3)=0.971
1946 Roomden(4)=0.534
1947 Roomden(5)=0.862
1948 Roomden(8)=13.546
1949 Roomden(9)=0.6120
1950 Tk=T0+273.2
1951 IF (Ifluid.EQ.2) THEN
1952 GOTO 8020
1953 ELSE
1954 CONTINUE
1955 ENDIF
1956 IF (Ifluid.EQ.3) THEN
1957 GOTO 8030
1958 ELSE
1959 CONTINUE
1960 ENDIF
1961 IF (Ifluid.EQ.4) THEN
1962 GOTO 8040
1963 ELSE
1964 CONTINUE
1965 ENDIF
1966 IF (Ifluid.EQ.5) THEN
1967 GOTO 8060
1968 ELSE
1969 CONTINUE
1970 ENDIF
1971 IF (Ifluid.EQ.8) THEN
1972 GOTO 8080
1973 ELSE
1974 CONTINUE
1975 ENDIF
1976 IF (Ifluid.EQ.9) THEN
1977 GOTO 8090
1978 ELSE
1979 CONTINUE
1980 ENDIF
1981 8100 WRITE (*,*) 'TEMPERATURE OF ',T0,'OUT OF RANGE FOR ',Ifluid
1982 GOTO 9000
1983 C WATER
1984 8020 IF (T0.LE.5.0) THEN
1985 GOTO 8100
1986 ELSE
```



```

1987      CONTINUE
1988      ENDIF
1989      IF (TO.GT.433.0) THEN
1990      GOTO 8100
1991      ELSE
1992      CONTINUE
1993      ENDIF
1994      Xliqvisc=0.0002414*10.0**(247.8/(Tk-140.0))
1995      Vapvisc=0.000001*10.0**(2.5989-(179.3/Tk))
1996      IF (TO.GT.200.0) THEN
1997      GOTO 8055
1998      ELSE
1999      CONTINUE
2000      ENDIF
2001      Xliqden = 0.01*10.0**(1.8079+(64.9/Tk))
2002      P0=10.0**(8.625109-(2152.69/Tk))
2003      Vapden=0.2193*(P0/760.0)/Tk
2004      Surfden=10.0**(1.06335+(259.17/Tk))
2005      Xlhv=10.0**(2.46008+(100.7/Tk))
2006      GOTO 8057
2007      8055 Xliqden=0.609675+3.02832E-03*TO-8.982149E-06*TO**2.0
2008          P0=2.24732E-06*TO**4.22186
2009          Vapden=2.35726E-07*EXP(0.01767*TO)
2010          Surfden=77.8092-0.208046*TO
2011          Xlhv=200.529+2.93522*TO-8.30692E-03*TO**2.0
2012      8057 Xk=1.324
2013          Xmw=18.0
2014          Tcfluid=0.000918+1.572E-06*Tk
2015          RETURN
2016      C
2017      8030 IF (TO.LE.450.0) THEN
2018      GOTO 8100
2019      ELSE
2020      CONTINUE
2021      ENDIF
2022      IF (TO.GT.1100.0) THEN
2023      GOTO 8100
2024      ELSE
2025      CONTINUE
2026      ENDIF
2027      Xliqden=1.0629-.0003167*Tk+7.244E-08*Tk**2.0
2028      Vapden=EXP(-36.89+.04218*Tk-1.507E-05*Tk**2.0)
2029      Xliqvisc=.006549-7.271E-06*Tk+2.52E-09*Tk**2.0
2030      Vapvisc=5.724E-05+1.749E-07*Tk-2.466E-11*Tk**2.0
2031      X1=-12.5847
2032      X2=.0354119
2033      X3=-1.53891E-05
2034      P0=EXP(X3*TO**2.0+X2*TO+X1)
2035      Surfden=193.2-.06442*Tk-7.388E-06*Tk**2.0
2036      Xlhv=1215.0-.2569*Tk+5.976E-06*Tk**2.0
2037      Xk=1.68
2038      Xmw=22.99

```

```

2039      Tcfluid=.2389*(1.0796-.0007057*Tk+2.188E-07*Tk**2.0)
2040      RETURN
2041      C      LITHIUM
2042      8040 IF (TO.LE.800.0) THEN
2043          GOTO 8100
2044          ELSE
2045          CONTINUE
2046          ENDIF
2047          IF (TO.GT.1800.0) THEN
2048          GOTO 8100
2049          ELSE
2050          CONTINUE
2051          ENDIF
2052          P9=1333.2
2053          Xliqden=.5512-9.929E-05*Tk+1.085E-08*Tk**2.0
2054          Vapden=EXP(-32.23+.021336*Tk-4.5573E-06*Tk**2.0)
2055          Xliqvisc=.0033036-7.5424E-07*Tk+3.0799E-12*Tk**2.0
2056          Vapvisc=-2.229E-05+1.8848E-07*Tk-3.296E-11*Tk**2.0
2057          PO = EXP(-8.347+0.02045*Tk-4.14E-06*Tk**2.0)/P9
2058          Surfden=486.8-.17573*Tk+1.1559E-05*Tk**2.0
2059          Xlhv=6396.0-1.401*Tk+1.8947E-04*Tk**2.0
2060          Xk=1.54
2061          Xmu=6.94
2062          Tcfluid=.000012*T0+.10688
2063          RETURN
2064      C      POTASSIUM
2065      8060 IF (TO.LE.100.0) THEN
2066          GOTO 8100
2067          ELSE
2068          CONTINUE
2069          ENDIF
2070          IF (TO.GT.900.0) THEN
2071          GOTO 8100
2072          ELSE
2073          CONTINUE
2074          ENDIF
2075          Xliqden=0.908358-2.2445E-04*Tk-1.2746E-08*Tk**2.0
2076          Vapden=EXP(0.8135742-8241.151/Tk-426986.1/Tk**2.0)
2077          Xliqvisc=-4.3906E-04+2.0287/Tk-541.09/Tk**2.0+164680.0/Tk**3.0
2078          Vapvisc=3.8701E-05+1.9825E-07*Tk-4.5283E-11*Tk**2.0
2079          PO=750.06*EXP(9.191863-9030.992/Tk-433033.8/Tk**2.0)
2080          Surfden=141.48-0.07392*Tk
2081          Xlhv=0.23889*(2269.1-0.13184*Tk-0.0002003*Tk**2.0)
2082          Xk=1.63
2083          Xmu=39.096
2084          T9=1.8*Tk-459.7
2085          Tcfluid=.16931*(.9669-4.7904E-04*T9+1.3778E-07*T9**2.0-2.4884E-11*
2086          &T9**3.0)
2087          RETURN
2088      C      NASA MERCURY AS USED BY THERMACORE
2089      8080 IF (TO.LE.10.0) THEN
2090          GOTO 8100

```

```
2091      ELSE
2092      CONTINUE
2093      ENDIF
2094      IF (TD.GT.800.0) THEN
2095      GOTO 8100
2096      ELSE
2097      CONTINUE
2098      ENDIF
2099      C    *** INSERT P-TABLE HERE ***
2100      C
2101      C    PRESSURE TABLE FOR MERCURY
2102      Whgp(1) = 0.05796
2103      Whgp(2) = 0.08958
2104      Whgp(3) = 0.1368
2105      Whgp(4) = 0.2067
2106      Whgp(5) = 0.3087
2107      Whgp(6) = 0.4562
2108      Whgp(7) = 0.6672
2109      Whgp(8) = 0.9658
2110      Whgp(9) = 1.384
2111      Whgp(10) = 1.965
2112      Whgp(11) = 2.763
2113      Whgp(12) = 3.850
2114      Whgp(13) = 5.317
2115      Whgp(14) = 7.280
2116      Whgp(15) = 9.885
2117      Whgp(16) = 13.31
2118      Whgp(17) = 17.79
2119      Whgp(18) = 23.59
2120      Whgp(19) = 31.05
2121      Whgp(20) = 40.57
2122      Whgp(21) = 52.64
2123      Whgp(22) = 67.84
2124      Whgp(23) = 86.85
2125      Whgp(24) = 110.5
2126      Whgp(25) = 139.7
2127      Whgp(26) = 175.5
2128      Whgp(27) = 219.3
2129      Whgp(28) = 272.4
2130      Whgp(29) = 336.5
2131      Whgp(30) = 413.6
2132      Whgp(31) = 505.7
2133      Whgp(32) = 615.2
2134      Whgp(33) = 744.9
2135      Whgp(34) = 897.7
2136      Whgp(35) = 1077.0
2137      Whgp(36) = 1286.0
2138      Whgp(37) = 1530.0
2139      Whgp(38) = 1813.0
2140      Whgp(39) = 2139.0
2141      Whgp(40) = 2514.0
2142      Whgp(41) = 2944.0
```

|      |                     |
|------|---------------------|
| 2143 | Whgp(42) = 3426.0   |
| 2144 | Whgp(43) = 3996.0   |
| 2145 | Whgp(44) = 4632.0   |
| 2146 | Whgp(45) = 5351.0   |
| 2147 | Whgp(46) = 6164.0   |
| 2148 | Whgp(47) = 7078.0   |
| 2149 | Whgp(48) = 8104.0   |
| 2150 | Whgp(49) = 9254.0   |
| 2151 | Whgp(50) = 10540.0  |
| 2152 | Whgp(51) = 11970.0  |
| 2153 | Whgp(52) = 13560.0  |
| 2154 | Whgp(53) = 15320.0  |
| 2155 | Whgp(54) = 17280.0  |
| 2156 | Whgp(55) = 19440.0  |
| 2157 | Whgp(56) = 21820.0  |
| 2158 | Whgp(57) = 24440.0  |
| 2159 | Whgp(58) = 27310.0  |
| 2160 | Whgp(59) = 30470.0  |
| 2161 | Whgp(60) = 33930.0  |
| 2162 | Whgp(61) = 37710.0  |
| 2163 | Whgp(62) = 41840.0  |
| 2164 | Whgp(63) = 46330.0  |
| 2165 | Whgp(64) = 51230.0  |
| 2166 | Whgp(65) = 56550.0  |
| 2167 | Whgp(66) = 62320.0  |
| 2168 | Whgp(67) = 68580.0  |
| 2169 | Whgp(68) = 75360.0  |
| 2170 | Whgp(69) = 82680.0  |
| 2171 | Whgp(70) = 90600.0  |
| 2172 | Whgp(71) = 99140.0  |
| 2173 | Whgp(72) = 108300.0 |
| 2174 | Whgp(73) = 118200.0 |
| 2175 | Whgp(74) = 128900.0 |
| 2176 | Whgp(75) = 140300.0 |
| 2177 | Whgp(76) = 152600.0 |
| 2178 | Whgp(77) = 165800.0 |
| 2179 | Whgp(78) = 179900.0 |
| 2180 | Whgp(79) = 194900.0 |
| 2181 | Whgp(80) = 211000.0 |
| 2182 | Whgp(81) = 228200.0 |
| 2183 | Whgp(82) = 246600.0 |
| 2184 | Whgp(83) = 266200.0 |
| 2185 | Whgp(84) = 287000.0 |
| 2186 | Whgp(85) = 309100.0 |
| 2187 | Whgp(86) = 332700.0 |
| 2188 | Whgp(87) = 357700.0 |
| 2189 | Whgp(88) = 384200.0 |
| 2190 | Whgp(89) = 412400.0 |
| 2191 | Whgp(90) = 442200.0 |
| 2192 | Whgp(91) = 473700.0 |
| 2193 | Whgp(92) = 507000.0 |
| 2194 | Whgp(93) = 542200.0 |

|      |                       |
|------|-----------------------|
| 2195 | Whgp(94) = 579300.0   |
| 2196 | Whgp(95) = 618400.0   |
| 2197 | Whgp(96) = 659700.0   |
| 2198 | Whgp(97) = 703000.0   |
| 2199 | Whgp(98) = 748700.0   |
| 2200 | Whgp(99) = 796600.0   |
| 2201 | Whgp(100) = 846800.0  |
| 2202 | Whgp(101) = 899600.0  |
| 2203 | Whgp(102) = 954800.0  |
| 2204 | Whgp(103) = 1013000.0 |
| 2205 | Whgp(104) = 1073000.0 |
| 2206 | Whgp(105) = 1136000.0 |
| 2207 | Whgp(106) = 1202000.0 |
| 2208 | Whgp(107) = 1271000.0 |
| 2209 | Whgp(108) = 1342000.0 |
| 2210 | Whgp(109) = 1417000.0 |
| 2211 | Whgp(110) = 1494000.0 |
| 2212 | Whgp(111) = 1575000.0 |
| 2213 | Whgp(112) = 1658000.0 |
| 2214 | Whgp(113) = 1745000.0 |
| 2215 | Whgp(114) = 1835000.0 |
| 2216 | Whgp(115) = 1927000.0 |
| 2217 | Whgp(116) = 2024000.0 |
| 2218 | Whgp(117) = 2123000.0 |
| 2219 | Whgp(118) = 2225000.0 |
| 2220 | Whgp(119) = 2331000.0 |
| 2221 | Whgp(120) = 2441000.0 |
| 2222 | Whgp(121) = 2553000.0 |
| 2223 | Whgp(122) = 2669000.0 |
| 2224 | Whgp(123) = 2788000.0 |
| 2225 | Whgp(124) = 2911000.0 |
| 2226 | Whgp(125) = 3037000.0 |
| 2227 | Whgp(126) = 3166000.0 |
| 2228 | Whgp(127) = 3299000.0 |
| 2229 | Whgp(128) = 3436000.0 |
| 2230 | Whgp(129) = 3576000.0 |
| 2231 | Whgp(130) = 3719000.0 |
| 2232 | Whgp(131) = 3867000.0 |
| 2233 | Whgp(132) = 4018000.0 |
| 2234 | Whgp(133) = 4173000.0 |
| 2235 | Whgp(134) = 4332000.0 |
| 2236 | Whgp(135) = 4495000.0 |
| 2237 | Whgp(136) = 4662000.0 |
| 2238 | Whgp(137) = 4834000.0 |
| 2239 | Whgp(138) = 5010000.0 |
| 2240 | Whgp(139) = 5191000.0 |
| 2241 | Whgp(140) = 5377000.0 |
| 2242 | Whgp(141) = 5568000.0 |
| 2243 | Whgp(142) = 5766000.0 |
| 2244 | Whgp(143) = 5969000.0 |
| 2245 | Whgp(144) = 6179000.0 |
| 2246 | Whgp(145) = 6396000.0 |

```
2247      Whgp(146) = 6620000.0
2248      Whgp(147) = 6853000.0
2249      Whgp(148) = 7094000.0
2250      Whgp(149) = 7345000.0
2251      Whgp(150) = 7607000.0
2252      Whgp(151) = 7880000.0
2253      Whgp(152) = 8165000.0
2254      Whgp(153) = 8465000.0
2255      Whgp(154) = 8779000.0
2256      Whgp(155) = 9110000.0
2257      Whgp(156) = 9460000.0
2258      Whgp(157) = 9830000.0
2259      Whgp(158) = 10220000.0
2260      Whgp(159) = 10640000.0
2261      A0 = 0.0060783
2262      A1 = -3.1546E-05
2263      A2 = 8.0436E-08
2264      A3 = -1.0538E-10
2265      A4 = 6.9127E-14
2266      A5 = -1.7981E-17
2267      Xliqvisc=A0+A1*Tk+A2*Tk**2.0+A3*Tk**3.0+A4*Tk**4.0+A5*Tk**5.0
2268      Xliqvisc=Xliqvisc*10.0
2269      A0 = -2.0271E-05
2270      A1 = 3.0869E-07
2271      A2 = -7.8612E-10
2272      A3 = 1.2985E-12
2273      A4 = -9.7932E-16
2274      A5 = 2.7985E-19
2275      Vapvisc=A0+A1*Tk+A2*Tk**2.0+A3*Tk**3.0+A4*Tk**4.0+A5*Tk**5.0
2276      Vapvisc=Vapvisc*10.0
2277      A0 = 7787.0
2278      A1 = 55.864
2279      A2 = -0.19524
2280      A3 = 3.0795E-04
2281      A4 = -2.3092E-07
2282      A5 = 6.631E-11
2283      Xliqden=A0+A1*Tk+A2*Tk**2.0+A3*Tk**3.0+A4*Tk**4.0+A5*Tk**5.0
2284      Xliqden=Xliqden*0.001
2285      A0 = -69.042
2286      A1 = 0.37673
2287      A2 = -8.7608E-04
2288      A3 = 1.0875E-06
2289      A4 = -6.8926E-10
2290      A5 = 1.7519E-13
2291      Vapden=A0+A1*Tk+A2*Tk**2.0+A3*Tk**3.0+A4*Tk**4.0+A5*Tk**5.0
2292      Vapden=EXP(Vapden)*0.001
2293      A0 = -58.282
2294      A1 = 0.36094
2295      A2 = -8.1354E-04
2296      A3 = 9.8676E-07
2297      A4 = -6.1379E-10
2298      A5 = 1.5358E-13
```

```

2299      P0=A0+A1*Tk+A2*Tk**2.0+A3*Tk**3.0+A4*Tk**4.0+A5*Tk**5.0
2300      P0=10.0*EXP(P0)/1333.2
2301      A0 = 0.67466
2302      A1 = -0.0015864
2303      A2 = 4.8201E-06
2304      A3 = -7.5378E-09
2305      A4 = 5.2245E-12
2306      A5 = -1.3472E-15
2307      SurfTen=A0+A1*Tk+A2*Tk**2.0+A3*Tk**3.0+A4*Tk**4.0+A5*Tk**5.0
2308      SurfTen=SurfTen*1000.0
2309      A0 = 316360.0
2310      A1 = -27.136
2311      A2 = -0.063935
2312      A3 = 1.7119E-04
2313      A4 = -1.6668E-07
2314      A5 = 4.4864E-11
2315      XlHv=A0+A1*Tk+A2*Tk**2.0+A3*Tk**3.0+A4*Tk**4.0+A5*Tk**5.0
2316      XlHv=0.001*XlHv/4.184139
2317      A0 = 4.0347
2318      A1 = 0.16674
2319      A2 = -5.1079E-06
2320      A3 = -1.7922E-09
2321      A4 = 1.1886E-12
2322      A5 = -3.0063E-16
2323      Tcfluid=A0+A1*Tk+A2*Tk**2.0+A3*Tk**3.0+A4*Tk**4.0+A5*Tk**5.0
2324      Tcfluid=0.001*Tcfluid/4.184139
2325      Xk=1.663
2326      Xmm=200.59
2327      RETURN
2328 C      AMMONIA
2329 8090 IF (TO.LE.-60.0) THEN
2330      GOTO 8100
2331      ELSE
2332      CONTINUE
2333      ENDIF
2334      IF (TO.GT.120.0) THEN
2335      GOTO 8100
2336      ELSE
2337      CONTINUE
2338      ENDIF
2339      Xliqden=1.887137-(1.165350E-02*Tk)+(3.96285E-05*Tk**2.0)-(5.02087
2340      &9E-08*Tk**3.0)
2341      Vapden=16.0654613573-(0.34110173779*Tk)+(2.92776494570E-03*Tk**2.
2342      &0)-(1.27231714826E-05*Tk**3.0)+(2.76697543450E-08*Tk**4.0)-(2.003
2343      &76015440E-11*Tk**5.0)-(2.31634291110E-14*Tk**6.0)+(3.54492347343E
2344      &-17*Tk**7.0)
2345      Xliqvsc=(8.162646E-02)-(9.845264E-04*Tk)+(4.593305E-06*Tk**2.0)-
2346      &(9.472753E-09*Tk**3.0)+(7.192006E-12*Tk**4.0)
2347      Vapvsc=-1.961381E-04+(2.789346E-06*Tk)-(1.024679E-08*Tk**2.0)+(1
2348      &.432595E-11*Tk**3.0)
2349      Tdummy=Tk*1.8
2350      Pdummy=EXP(13.89430-(4618.37/(Tdummy-19)))

```

SUBROUTINE FLUIDPROP Compiling Options:/NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/MX/NZ1  
Source file Listing

```
2351      PO = Pdummy*70.3077
2352      SurfTen=94.9794*(1-((Tk/405.56)**1.15191))
2353      Xlhv=-2296.721959+(39.685263*Tk)-(0.218296*Tk**2)+(5.240955E-04*T
2354      &k**3.0)-(4.734199E-07*Tk**4)
2355      Xk=1.33
2356      Xmw=17.03
2357      Tcfluid=-(2.441905E-04)+(1.284515E-05*Tk)-(2.651515E-08*Tk**2.0)
2358 9000 RETURN
2359      END
```



SUBROUTINE TSAT Compiling Options:/NO/N7/B/MC/ND/NF/H/NI/MK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```
2360 C
2361 C
2362 C
2363     SUBROUTINE Tsat(Ifluid,P9,P0,T0)
2364 C
2365 C     CALCULATE TEMPERATURE FROM PRESSURE
2366 C
2367     COMMON /RAD3/ Roomden(10),Whgp(159)
2368     IF (Ifluid.EQ.2) THEN
2369     GOTO 9110
2370     ELSE
2371     CONTINUE
2372     ENDIF
2373     IF (Ifluid.EQ.3) THEN
2374     GOTO 9220
2375     ELSE
2376     CONTINUE
2377     ENDIF
2378     IF (IFLUID.EQ.4) THEN
2379     GOTO 9230
2380     ELSE
2381     CONTINUE
2382     ENDIF
2383     IF (IFLUID.EQ.5) THEN
2384     GOTO 9120
2385     ELSE
2386     CONTINUE
2387     ENDIF
2388     IF (Ifluid.EQ.8) THEN
2389     GOTO 9170
2390     ELSE
2391     CONTINUE
2392     ENDIF
2393     IF (Ifluid.EQ.9) THEN
2394     GOTO 9180
2395     ELSE
2396     CONTINUE
2397     ENDIF
2398 C     WATER
2399     9110 IF (P0.LE.12750.0) THEN
2400     GOTO 9115
2401     ELSE
2402     CONTINUE
2403     ENDIF
2404     T0=(P0/2.24732E-06)**0.2368624
2405     RETURN
2406     9115 T0=-2152.69/((ALOG(P0)/2.30259)-8.625109)-273.2
2407     RETURN
2408 C     POTASSIUM
2409     9120 X=SQRT((-9030.9923)**2-4*(ALOG(P0/750.06)-9.191863)*433033.8)
2410     T0=(-9030.9923-X)/(2*(ALOG(P0/750.06)-9.191863))-273.2
2411     RETURN
```

SUBROUTINE TSAT Compiling Options:/NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```
2412 C   NASA MERCURY
2413 9170 Pnasa=P0*133.32
2414     DO 9171 I=2,159,1
2415     IF (Pnasa.GT.Whgp(I)) THEN
2416     GOTO 9171
2417     ELSE
2418     CONTINUE
2419     ENDIF
2420     GOTO 9172
2421 9171 CONTINUE
2422     WRITE (6,*) "NASA MERCURY PRESSURE TOO HIGH --- JOB ABORTED"
2423     RETURN
2424 9172 T1=280+(I-1)*5-5
2425     Xtk=T1+((Pnasa-Whgp(I-1))/(Whgp(I)-Whgp(I-1)))*5
2426     T0 = Xtk-273.2
2427     RETURN
2428 C   AMMONIA
2429 9180 Pa=0.0142232*P0
2430     Ts=(4618.37/(13.89430-ALOG(Pa)))+19
2431     T0 = (Ts/1.8)-273.2
2432     RETURN
2433 C   SODIUM
2434 9220 X1=-12.5847
2435     X2=.0354119
2436     X3=-1.53891E-05
2437     T0=(-X2+SQRT(X2**2-4*X3*(X1-ALOG(P0))))/(2*X3)
2438     RETURN
2439 C   LITHIUM
2440 9230 T0=(.02045-SQRT(4.18203E-04-1.656E-05*(ALOG(P0*P9)+8.347)))/8.28E-
2441     206-273.2
2442     RETURN
2443     END
```

SUBROUTINE WALLPROP Compiling Options:/NO/N7/B/MC/MD/NF/H/N1/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/MX/NZ1  
Source file Listing

```
2444 C
2445 C
2446 C
2447 SUBROUTINE Wallprop(Imatl,T0,Wallden,Tcwall)
2448 C
2449 C DENSITY AND THERMAL CONDUCTIVITY OF HEAT PIPE WALL MATERIALS*
2450 C USED IN HEAT PIPE PERFORMANCE CALCULATION SUBROUTINE
2451 C
2452 IF (Imatl.EQ.1) THEN
2453 GOTO 9200
2454 ELSE
2455 CONTINUE
2456 ENDIF
2457 IF (Imatl.EQ.2) THEN
2458 GOTO 9210
2459 ELSE
2460 CONTINUE
2461 ENDIF
2462 IF (Imatl.EQ.3) THEN
2463 GOTO 9220
2464 ELSE
2465 CONTINUE
2466 ENDIF
2467 IF (Imatl.EQ.4) THEN
2468 GOTO 9230
2469 ELSE
2470 CONTINUE
2471 ENDIF
2472 IF (Imatl.EQ.5) THEN
2473 GOTO 9240
2474 ELSE
2475 CONTINUE
2476 ENDIF
2477 IF (Imatl.EQ.6) THEN
2478 GOTO 9250
2479 ELSE
2480 CONTINUE
2481 ENDIF
2482 IF (Imatl.EQ.7) THEN
2483 GOTO 9260
2484 ELSE
2485 CONTINUE
2486 ENDIF
2487 IF (Imatl.EQ.8) THEN
2488 GOTO 9270
2489 ELSE
2490 CONTINUE
2491 ENDIF
2492 C TUNGSTEN
2493 C 9200 Wallden=19.35
2494 C Tcwall=0.298-0.000024*T0
2495 C RETURN
```

SUBROUTINE WALLPROP Compiling Options:/NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```
2496 C MOLYBDENUM
2497 9210 Wallden=10.22
2498 Tcwall=0.3488-0.0000617*(T0+273.2)
2499 RETURN
2500 C LOCKALLOY
2501 9220 Wallden=2.08
2502 Tcwall=0.5100611-4.19242E-04*T0
2503 RETURN
2504 C 2S-O ALUMINUM
2505 9230 Wallden=2.85
2506 Tcwall=0.376701+1.37458E-04*T0
2507 RETURN
2508 C 347-CRES
2509 9240 Wallden=8.03
2510 Tcwall=0.034393+3.2975E-05*T0
2511 RETURN
2512 C CARBON-CARBON
2513 9250 Wallden=1.86
2514 Tcwall=0.0362
2515 RETURN
2516 C NIOBIUM-0.1*ZIRCONIUM
2517 9260 Wallden=840.0*0.01
2518 Tcwall= 0.1075+T0/30000.0
2519 RETURN
2520 C COPPER
2521 9270 Wallden=8.96
2522 Tcwall=0.934
2523 RETURN
2524 END
```

SUBROUTINE XLITHP Compiling Options:/NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```
2525 C
2526 C
2527 C
2528     SUBROUTINE XLITHP(T,RHO,CP,VIS,TK)
2529 C
2530 C     THERMAL PROPERTIES OF LITHIUM LIQUID
2531 C     T = INPUT TEMPERATURE (deg-R)
2532 C     RHO = DENSITY (Lbs/cu-Ft)
2533 C     CP = SPECIFIC HEAT (BTU/LB-R)
2534 C     VIS = DYNAMIC VISCOSITY (Lb/Ft-Sec)
2535 C     TK = THERMAL CONDUCTIVITY (BTU/Hr-Ft-Sec)
2536 C
2537     RHO = 34.393537 - (0.003456*T) + (2.080291E-07*(T**2.0))
2538     CP = 1.356357 - (0.00068*T) + (5.006625E-07*(T**2.0)) - (1.805873E
2539     &-10*(T**3.0)) + (3.155294E-14*(T**4.0)) - (2.136471E-18*(T**5.0))
2540     VIS = 0.001085 - (1.326497E-06*T) + (7.245662E-10*(T**2.0)) - (1.7
2541     &74380E-13*(T**3.0)) + (1.632610E-17*(T**4.0))
2542     TK = 25.235376 + (0.001588*T)
2543     RETURN
2544     END
```

SUBROUTINE XNAKPR Compiling Options:/NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/MQ1/MQ2/MQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```
2545 C
2546 C
2547 C
2548 SUBROUTINE XNAKPR(T,RHO,CP,VIS,TK)
2549 C THERMAL PROPERTIES OF NaK LIQUID
2550 C T = INPUT TEMPERATURE (deg-R)
2551 C RHO = DENSITY (Lb/cu-Ft)
2552 C CP = SPECIFIC HEAT (BTU/Lb-R)
2553 C VIS = DYNAMIC VISCOSITY (Lb/Ft-Sec)
2554 C TK = THERMAL CONDUCTIVITY (BTU/Hr-Ft-R)
2555 RHO = 58.54299 - (0.008208*T)
2556 CP = 0.26478 - (0.000089*(T)) + (4.093060E-08*(T**2.0)) -
2557 & (4.532164E-12*(T**3.0))
2558 VIS = 0.000822 - (1.142435E-06*(T)) + (6.125737E-10*(T**2.0)) -
2559 & (1.130181E-13*(T**3.0))
2560 TK = 7.313351 + (0.013983*(T)) - (7.660423E-06*(T**2.0)) +
2561 & (1.189370E-09*(T**3.0))
2562 RETURN
2563 END
```

```
2564 C
2565 C
2566 C
2567     SUBROUTINE HEXEPR(Ammix,Pmix,Tmix,Gm,Cpmix,Rhomix,Ammix,Akmix,
2568 &Prmix)
2569 C     PROPERTIES OF HELIUM-XENON MIXTURES
2570 C     T IN deg-R
2571 C     WRITE (6,*) 'Ammix,Pmix,Tmix=',Ammix,Pmix,Tmix
2572     Gm=1.667
2573     Am1=4.0
2574     Am2=131.3
2575     X2=(Ammix-Am1)/(Am2-Am1)
2576     X1=1.0-X2
2577     Cpmix=4.97/Ammix
2578     Rhomix=144.0*Pmix*Ammix/(1545.0*Tmix)
2579     IF (Tmix.GT.1000.0) THEN
2580     GOTO 10
2581     ELSE
2582     Amuhe=5.7E-06+1.45E-08*Tmix
2583     GOTO 100
2584     ENDIF
2585 10 IF (Tmix.GT.1600.0) THEN
2586     GOTO 20
2587     ELSE
2588     Amuhe=8.867E-06+1.1333E-08*Tmix
2589     GOTO 100
2590     ENDIF
2591 20 Amuhe=1.1114E-05+9.930E-09*Tmix
2592 100 IF (Tmix.GT.1100.0) THEN
2593     GOTO 30
2594     ELSE
2595     Akhe=0.0403+8.471E-05*Tmix
2596     GOTO 200
2597     ENDIF
2598 30 IF (Tmix.GT.1800.0) THEN
2599     GOTO 40
2600     ELSE
2601     Akhe=0.0589+6.786E-05*Tmix
2602     GOTO 200
2603     ENDIF
2604 40 Akhe=0.0625+6.583E-05*Tmix
2605 200 IF (Tmix.GT.1200.0) THEN
2606     GOTO 50
2607     ELSE
2608     Amuxe=5.25E-06+2.1375E-08*Tmix
2609     GOTO 300
2610     ENDIF
2611 50 IF (Tmix.GT.2000.0) THEN
2612     GOTO 60
2613     ELSE
2614     Amuxe=1.0500E-05+1.7000E-08*Tmix
2615     GOTO 300
```

SUBROUTINE HEXEPR Compiling Options:/NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file listing

```

2616      ENDIF
2617      60 Amuxe=1.5500E-05+1.45E-08*Tmix
2618      300 IF (Tmix.GT.1200.0) THEN
2619          GOTO 70
2620      ELSE
2621          Akxe=0.00115+4.375E-06*Tmix
2622          GOTO 400
2623      ENDIF
2624      70 IF (Tmix.GT.2500.0) THEN
2625          GOTO 80
2626      ELSE
2627          Akxe=0.00252+3.2308E-06*Tmix
2628          GOTO 400
2629      ENDIF
2630      80 Akxe=0.00342+1.8000E-06*Tmix
2631      400 Amu1=Amuhe
2632          Amu2=Amuxe
2633          Ak1=Akhe
2634          Ak2=Akxe
2635          Dum1=2.82843*SQR(1.0+(Am1/Am2))
2636          Dum2=1.0+SQR(Amu1/Amu2)*(Am2/Am1)**0.25
2637          Psi12=Dum2**2.0/Dum1
2638          Dum3=Amu2/Amu1*(Am1/Am2)
2639          Psi21=Dum3*Psi12
2640          Dum4=1.0+Psi12*(X2/X1)
2641          Dum5=1.0+Psi21*(X1/X2)
2642          Amumix=Amu1/Dum4+Amu2/Dum5
2643          Dum6=2.82843*SQR(1.0+(Am1/Am2))
2644          Dum7=(1.0+SQR(Ak1/Ak2)*(Am1/Am2)**0.25)**2.0
2645          Dum8=2.82843*SQR(1.0+(Am2/Am1))
2646          Dum9=(1.0+SQR(Ak2/Ak1)*(Am2/Am1)**0.25)**2.0
2647          Alam12=Dum7/Dum6
2648          Alam21=Dum9/Dum8
2649          Dum10=(Am1+Am2)**2.0
2650          Dum11=2.41*(Am1-Am2)*(Am1-0.142*Am2)
2651          Dum12=2.41*(Am2-Am1)*(Am2-0.142*Am1)
2652          For12=Alam12*(1.0+Dum11/Dum10)
2653          For21=Alam21*(1.0+Dum12/Dum10)
2654          Dum13=1.0+For12*(X2/X1)
2655          Dum14=1.0+For21*(X1/X2)
2656          Akmix=Ak1/Dum13+Ak2/Dum14
2657          Pmfix=3600*Amumix*Cpmix/Akmix
2658      C      WRITE (6,*) ' '
2659      C      WRITE (6,*) 'THERMODYNAMIC PROPERTIES OF HELIUM-XENON MIXTURES'
2660      C      WRITE (6,*) ' '
2661      C      WRITE (6,*) 'Pressure (PSIA) =',Pmix
2662      C      WRITE (6,*) 'Temperature (deg-R) =',Tmix
2663      C      WRITE (6,*) 'Molecular Weight (MW) =',Amumix
2664      C      WRITE (6,*) ' '
2665      C      WRITE (6,*) 'Specific Heat Ratio (Gamma) =',Gmix
2666      C      WRITE (6,*) 'Specific Heat (Btu/Lb-R) =',Cpmix
2667      C      WRITE (6,*) 'Density (Lb/cu-Ft) =',Rhomix
2668      C      WRITE (6,*) 'Viscosity (Lb/Ft-Sec) =',Amumix

```



SUBROUTINE HEXEPR Compiling Options: /NO/N7/B/NC/ND/NF/H/N1/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```
2669 C    WRITE (6,*) 'Thermal Conductivity (BTU/Hr-Ft-R) =',Almix
2670 C    WRITE (6,*) 'Prandlt Number (o) =',Prmix
2671      END
```

SUBROUTINE HRRAD Compiling Options:/NO/N7/B/NC/ND/NF/H/M1/NK/NL/P/NQ1/WQ2/WQ3/R/S/NT/W/NX/MZ1  
Source file Listing

```

2672 C
2673 C
2674 C
2675     SUBROUTINE HRRAD(Grad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,
2676     &Imatl,Theta,D2rad,Thickm,Thickf,Thick,Em,IENflg,Halt,HINCL,Rsun,
2677     &Yrlnch,Alpha,Hap,HARad,Tkfin,Rhocoating,Rhofin,RHOarm
2678     &,Xladiab,CONFIG,Xchmas,PROB,GAM,ARSF,Earm,Time,Qrejected,
2679     &Thick2,Thick2,Aradiator,Aradefect,Uthick2,Xnart2,Artid2,
2680     &Artall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xmpipes,Xmfluid,
2681     &Xmfin,Xmcoating,Xmarmor,Xmarmorid,Xstructure,
2682     &Xnetradmasst2,Wx12)
2683 C
2684     DIMENSION Dv(99),Space(99),T(99),Drad(99)
2685     DIMENSION Qc(99),Qact(99),Eff(99)
2686     COMMON /RAD3/ Roomden(10),Wgpp(159)
2687 C
2688 C     IF CONFIG = 1.0, RADIATOR IS A FLAT PLATE, ELSE IS A CONE OR CYL.
2689 C
2690     Pdesi = 1.0 - PROB
2691     Grad = 3413.0*Grad
2692 C
2693     Angle2=Theta
2694     Dhpipe=2.54*Dhpipe
2695     CALL HRTSNK(IENflg,Halt,HINCL,Rsun,Yrlnch,Alpha,Hap,HARad,Tsink)
2696     Xlspec=6.0
2697     Xrpunit = 1.0
2698     Ixincr=50
2699     Wvoid2=0.5
2700     Wthick2=0.0020*Dhpipe
2701     Artall2=0.0020*Dhpipe
2702     Artid2=0.10*Dhpipe
2703     Xnart2=ANINT(3.141593*Dhpipe/2.54)
2704 C
2705     810 Dp=Dhpipe
2706         T(1)=Trad
2707     840 Dv7=Dp/2.54/12.0
2708     850 CONTINUE
2709     900 Qtot=0.0
2710         Aatot=0.0
2711         Vfbar=0.0
2712         DO 1520 I=1,50,1
2713             Xiv=FLOAT(I)
2714             Xinc=FLOAT(Ixincr)
2715             Dv(I)=Dv7
2716             Drad(I)=D2rad+2.0*Xlspec*SIN(Angle2/57.29578)*((Xiv)/Xinc)
2717     1060 Space(I)=3.141593*Drad(I)/Xntubes-Dv(I)
2718             Xlfrfin=12.0*Space(I)/2.0
2719     1070 Deltax=Xlspec/Xinc
2720     1090 IF (I.EQ.1) THEN
2721             D3=02rad
2722             ELSE
2723             D3=0rad(I-1)

```

```

2724      ENDIF
2725      1110 Hnet=Xlspec*COS(Angle2/57.29578)
2726      1120 D1=D2rad+(2.0*Xlspec*SIN(Angle2/57.29578))
2727      1130 D2=Orad(I)
2728      1140 IF (I.EQ.1) THEN
2729          H2=Hnet
2730      ELSE
2731          H2=Hnet-(Deltax*COS(Angle2/57.29578))*(Xiv-1.0)
2732      ENDIF
2733      1170 H1=H2-(Deltax*COS(Angle2/57.29578))
2734      1180 CALL View(D1,D2,D3,H1,H2,Aa,Vf)
2735          Vf=Vf
2736          IF (CONFIG.EQ.1.0) Vf = 1.0
2737      1190 Vfct=Vf
2738      1200 Vfbar=Vfbar+(Vf*Aa)
2739      1210 Aatot=Aatot+Aa
2740          Xlevap=2.54*Xlflat
2741          Xladi=12.0*2.54*Xladiab
2742          Xlcond=12.0*2.54*(Xlspec/Xinc)*Xiv
2743          Pipid=Ohpipe
2744          Wall=Thick*12.0*2.54
2745          Tstrtk=Trad/1.8
2746          Qstart=(Orad/Xntubes)*0.2931
2747          CALL NRHTPP(lmatl,lfluid,Xlevap,Xladi,Xlcond,Pipid,Wall,Tstrtk,Qs
2748          tart,Uthick2,Uvoid2,Artwall2,Artid2,Xnart2,T(I),Fluidcharge,Totalm
2749          2ass)
2750          T(I) = (T(I)+273.0)*1.8
2751          Tsubr=Tsink/T(I)
2752          Ahfin=Em*1.7212E-09*(T(I)**3.0)*(1.0+(Tsubr**2.0))*(1.0+Tsubr)
2753          Xm1=((Ahfin/(Tkfin*Thickf))**0.5)*(Xlfrfin))/12.0
2754          Fin1=(EXP(Xm1)-EXP(-Xm1))/(EXP(Xm1)+EXP(-Xm1))
2755          Fin2=(1.0-(1.58*(1.0-EXP(-0.2*Xm1)))*(1.0-Tsubr))
2756          Eff(I)=(1.0/Xm1)*Fin1*Fin2
2757      1460 Xmfluid=(Fluidcharge/1000.0)*2.2046
2758      1470 Xmpipes=((Totalmass-Fluidcharge)/1000.0)*2.2046
2759      1490 Qc(I)=Xlspec/Xinc*(1.0+Vfct)*(Dv(I)+Eff(I)*Space(I))*Em*4.77E-13
2760          1*(T(I)**4.0-Tsink**4.0)
2761      1500 Qact(I)=Qc(I)
2762      1510 Qtot=Qtot+Qact(I)
2763      1520 CONTINUE
2764      1530 Vfctbar=Vfbar/Aatot
2765      C1540 WRITE (6,*) 'Qtot =',Qtot*3600.0*Xntubes
2766      1570 Error7=Qrad/(Qtot*3600.0*Xntubes)-1.0
2767      1580 Xlspec=Xlspec*(1.0+0.8*(Error7))
2768      1600 IF (ABS(Error7).GT.0.0001) THEN
2769          Aatot=0.0
2770          Vfbar=0.0
2771          I=0
2772          GO TO 850
2773      ELSE
2774          CONTINUE
2775      ENDIF

```

```

2776 C HEAT PIPE RADIATOR MASS ALGORITHM
2777 1720 Xlradiator=Xlspec
2778 1730 Dv7 = 0.0
2779 1740 Space7 = 0.0
2780 DO 1780 I=1,50,1
2781 Dv7 = Dv7 + Dv(I)
2782 Space7 = Space7 + Space(I)
2783 1780 CONTINUE
2784 Dv7=Dv7/Xinc
2785 Space7=Space7/Xinc
2786 1820 Aradiator=3.141593*(Drad(1)/2.0+Drad(Ixincr)/2.0)*SQRT(((Xlspec*
2787 1COS(Theta/57.29578))**2.0)+(((Drad(Ixincr)/2.0)-(Drad(1)/2.0))**2.
2788 20))
2789 1870 Xmpipes=Xmpipes*(Xntubes+Xnexpip)
2790 1880 Xmfim=Space7*Thickf*Xlradiator*Rhofin*(Xntubes+Xnexpip)
2791 1890 Xmfliud=Xmfliud*(Xntubes+Xnexpip)
2792 1900 Acoating=3.141593/2.0*(Dv7+Thick+Thickm/2.0)*Thickm*Space7*Thickm
2793 1910 Xmcoating=Acoating*Xlradiator*Rhocoating*(Xntubes+Xnexpip)
2794 1930 Atube=Dv7*Xlradiator
2795 1940 Jj=IFIX(Xnexpip*Xnpunit)
2796 1950 Kkk=IFIX(Xntubes)+Jj
2797 1960 P7=Pnew(Pdesi,Jj,Kkk)
2798 1970 Prob=1.0-P7
2799 Temp = T(49)
2800 Atarget = Atube/10.764961
2801 1980 CALL HRRMR(IENflg,Halt,HINCL,Rsun,YrInch,GAM,ARSF,Earm,RHOarm,At
2802 &arget,Time,Prob,Temp,Tharm)
2803 WRITE (6,*) 'Tharm (Inches) =',Tharm
2804 Thickarm=Tharm/12.0
2805 2050 Xmarmor=Thickarm*Dv7*Xlradiator*Rhoarm*(Xntubes+Xnexpip)*3.141593/
2806 & 2.0
2807 2555 FORMAT (6F12.4)
2808 Thickf2=12.0*Thickf
2809 Thickm2=12.0*Thickm
2810 Qrejected=Qrad/3413.0
2811 C WRITE (*,*) ' '
2812 C WRITE (*,*) 'TOTAL HEAT AVERAGE Radiator Emissivity'
2813 C WRITE (*,*) 'REJECTED EVAPORATOR FIN Coating '
2814 C WRITE (*,*) ' (KWt) TEMP (R) Thick (In) Thick (In)'
2815 C WRITE (*,2555) Qrejected,Trad,Thickf2,Thickm2
2816 Xltot=Xlspec+((Xladi+Xlevap)/(2.54*12.0))
2817 Dv7=Dv7*12.0*2.54
2818 Thickarm2=Thickarm*12.0
2819 Aradeffect=(1.0+Vfctbar)*Aradiator
2820 C WRITE (*,*) ' '
2821 C WRITE (*,*) ' Actual Effective'
2822 C WRITE (*,*) '(one-side) Radiator'
2823 C WRITE (*,*) 'Area(sq-Ft.) Area(sq-Ft)'
2824 C WRITE (*,2555) Aradiator,Aradeffect
2825 Dhpipe=Dv7/2.54
2826 Thick2=Thick*12.0
2827 C WRITE (*,*) ' '
2828 C WRITE (*,*) 'HEAT PIPE DESIGN DETAILS - DIMS in INCHES'

```

SUBROUTINE HRRAD Compiling Options:/NO/N7/B/NC/ND/NF/H/N1/NK/NL/P/NO1/NO2/NO3/R/S/NT/U/NX/NZ1  
Source file Listing

```

2829 C   WRITE (*,*) '   Pipe ID   Wick Thick   #Arteries   Art ID
2830 C   1   Art Wall   Pipe wall'
2831 C   WRITE (6,2555) Dhpipe,Wthick2,Xnart2,Artid2,Artwall2,Thick2
2832     Xladi2=Xladi/2.54
2833     Xlevap2=Xlevap/2.54
2834     Xlspec2=Xlspec*12.0
2835     Xltot2=Xltot*12.0
2836     Xarmorid=Xarmor
2837     Wxl2=13.2141*((0.6072+0.1514*Aradiator)**0.5)-10.296525
2838     Xstructure=0.0
2839     Xnetradmasst2=Xmpipes+Xmfluid+Xmfin+2.0*Xmcoating+Xmchmas+Xarmor+
2840     1Xarmorid+Xstructure
2841 C   WRITE (*,*) 'Evap Length   Adi Length   Cond Length   Total Length'
2842 C   WRITE (*,2555) Xlevap2,Xladi2,Xlspec2,Xltot2
2843 C   WRITE (*,*) '
2844     Wxl2=13.2142*((0.6072+0.1514*Aradiator)**0.5)-10.296525
2845 C   WRITE (*,*) 'RADIATOR MASS BREAKDOWN - Mass in Lbs.'
2846 C   WRITE (*,*) 'Heat Pipes   Fluids   FINS   Emiss. Cont.'
2847 C   WRITE (*,2555) Xmpipes,Xmfluid,Xmfin,Xmcoating
2848 C   WRITE (*,*) 'O.D.ARMOR   I.D.ARMOR   Structure   TOTAL RADIATOR '
2849 C   WRITE (*,2555) Xarmor,Xarmorid,Xstructure,Xnetradmasst2
2850 C   WRITE (*,*) 'AREA(sq-M) =',Aradiator/10.764961,'Mass(Kg) =',Xnetra
2851 C   idmasst2/2.2046,'LENGTH(CM) =',Wxl2*12.0*2.54
2852 C   WRITE (*,*) 'ETA =',282.5/Aradiator,' MASS/AREA(#/sq-Ft.) =',(Xne
2853 C   &tradmasst2)/Aradiator
2854 C   WRITE (6,*) 'RADIATOR AREA REQUIRED (1.129412*Acamp) =',0.104916*A
2855 C   &radiator
2856 C   RETURN
2857 C   END

```

SUBROUTINE HRHTPP Compiling Options:/NO/N7/B/NC/ND/NF/H/N1/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```

2858 C
2859 C
2860 C
2861 2980 SUBROUTINE HRHTPP(Imatl,Ifluid,Xle,Xla,Xlc,Pipid,Wall,Tstrtk,Qsta
2862 1rt,Wthick2,Wvoid2,Artwall2,Artid2,Xnart2,Textcond,Fluidcharge,Tota
2863 2lmass)
2864 COMMON /RAD3/ Roomden(10),Whgp(159)
2865 3030 Pipod=Pipid+2.0*Wall
2866 C3040 WICK STRUCTURE # 1
2867 3050 Wcaprad=0.001
2868 3060 Mperm=0.0000005
2869 3070 Wvoid=Wvoid2
2870 3080 Wthick=Wthick2*2.54
2871 3090 Artwall=Artwall2*2.54
2872 3100 Artid=Artid2*2.54
2873 3110 Artod=Artid+2.0*Artwall
2874 3120 Vaprad=(Pipid-2.0*Wthick)/2.0
2875 3130 Xnart=Xnart2
2876 C
2877 C3140 CHECK ARTERY SPACING AND VAPOR SPACE
2878 3150 Circumf=3.141593*(2.0*Vaprad-Artod)
2879 3160 IF ((Xnart*Artod).GT.Circumf) THEN
2880 3170 WRITE (*,*) ' ARTERIES TOO CLOSELY SPACED -----'
2881 3180 ENDIF
2882 3190 Vaporarea=3.141593*(Vaprad**2.0-Xnart*Artod**2.0/4.0)
2883 3200 IF (Vaporarea.LE.0.0) THEN
2884 3210 WRITE (*,*) ' PIPE DIAMETER IS TOO SMALL --- VAPOR SPACE IS <= 0'
2885 3220 ENDIF
2886 C CALCULATE EFFECTIVE AND HYDRAULIC DIAMETERS
2887 3240 A=3.141593*(Vaprad**2.0-Xnart*Artod**2.0/4.0)
2888 3250 Effdiam=SQRT(4.0*A/3.141593)
2889 3260 Hydiam=4.0*A/(2.0*3.141593*Vaprad+Xnart*3.141593*Artod/2.0)
2890 P9=1333.2
2891 3280 Wetangle=0.0
2892 3290 Effarea=3.141596*Effdiam**2.0/4.0
2893 C
2894 3300 Artperm=Artid**2.0/32.0
2895 3730 Q=Qstart
2896 3740 Q0=Q/4.185
2897 3750 Textevap=Tstrtk-273.0
2898 3770 T0=Textevap
2899 C
2900 3780 CALL Wallprop(Imatl,T0,Wallden,Tcwall)
2901 3790 Dtewall=Q0*ALOG(Pipod/Pipid)/(Tcwall*2.0*3.141593*Xle)
2902 3810 T0=Textevap-Dtewall
2903 3820 CALL Fluidprop(Ifluid,T0,Xliqden,Vapden,Xliqvisc,Vapvisc,P0,Surfte
2904 1n,Xlhv,Xk,Xmw,Tcfluid)
2905 C
2906 3830 CALL Wallprop(Imatl,T0,Wallden,Tcwall)
2907 3840 Tcwick=Tcwall
2908 3860 Tcfilledwick=Tcwick*(1.0-Wvoid*(1.0-Tcfluid/Tcwick))
2909 3870 Dtewick=Q0*ALOG(Pipid/(2.0*Vaprad))/(Tcfilledwick*2.0*3.141593*Xle
2910 1)

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```

2911 3880 T0=Textevap-DteWall-DteWick
2912 CALL Fluidprop(Ifluid,T0,Xliqden,Vapden,Xliqvisc,Vapvisc,P0,Surfte
2913 1n,Xl hv,Xk,Xmw,Tcfluid)
2914 C
2915 3910 X0=P0*P9
2916 3920 DteVap1=T0+273.2
2917 3930 X8=Q0/((2.0*3.141593*Vaprad+Xnart*3.141593*Artod/2.0)*Xle)
2918 3940 J=0
2919 3950 T0=T0-0.1
2920 CALL Fluidprop(Ifluid,T0,Xliqden,Vapden,Xliqvisc,Vapvisc,P0,Surfte
2921 1n,Xl hv,Xk,Xmw,Tcfluid)
2922 C
2923 3970 X1=P0*P9
2924 3980 DteVap2=T0+273.2
2925 3990 X9=0.0000436*Xl hv*Xmw*(X0/SQRT(Xmw*DteVap1)-X1/SQRT(Xmw*DteVap2))
2926 4000 J=J+1
2927 4010 IF (J.GT.200) THEN
2928 GO TO 5670
2929 ELSE
2930 CONTINUE
2931 ENDIF
2932 4020 IF (X8.GT.X9) THEN
2933 GO TO 3950
2934 ELSE
2935 CONTINUE
2936 ENDIF
2937 4030 DteVap=DteVap1-DteVap2
2938 Tbev=Textevap-DteWall-DteWick-DteVap
2939 4060 T0=Tbev
2940 CALL Fluidprop(Ifluid,T0,Xliqden,Vapden,Xliqvisc,Vapvisc,P0,Surfte
2941 1n,Xl hv,Xk,Xmw,Tcfluid)
2942 4080 Pbev=P0*P9
2943 4100 Evapcapforce=2.0*Surften*COS(Wetangle/57.29578)/Vcaprad
2944 4120 Esonic=0.474*Effaree*Xl hv*SQRT(Vapden*Pbev)
2945 4130 IF (Q0.LT.Esonic) THEN
2946 GOTO 4180
2947 ELSE
2948 4140 GOTO 5710
2949 ENDIF
2950 4180 Axvapvel=Q0/(Vapden*Effaree*Xl hv)
2951 4190 Eaxreyn=Vapden*Axvapvel*Hydiam/Vapvisc
2952 4200 Ff=16.0/Eaxreyn
2953 4220 C7=3.141593**2.0/8.0
2954 4230 C4=C7*Q0**2.0/(Effaree**2.0*Xl hv**2.0*Vapden)
2955 4240 IF (Pbev**2.0.LT.Pbev**2.0*C7*Xle*Ff/Efdiam*Vapden*Axvapvel**2.0)
2956 1THEN
2957 GOTO 4250
2958 ELSE
2959 CONTINUE
2960 ENDIF
2961 4250 IF (4.0*C4*Pbev.LE.Pbev**2.0) THEN
2962 GOTO 4270

```

```

2963     ELSE
2964     4260 GOTO 5750
2965     ENDIF
2966     4270 Dpveiscous=Pbev-SQRT(Pbev**2.0-Pbev*2.0*C7*Xle*Ff/Effdiam*Vapden*
2967     1Axvapvel**2.0)
2968     4280 Dpveinertial=(Pbev-SQRT(Pbev**2.0-4.0*C4*Pbev))/2.0
2969     4290 X0=Pbev-Dpveinertial-Dpveiscous
2970     4300 IF (X0.GT.0.0) THEN
2971         GOTO 4400
2972     ELSE
2973         GOTO 5790
2974     ENDIF
2975     4400 Dpleart=Xliqvisc*(Xle/2.0)*(Q0/Xnart)/(Artperm*Xliqden*Xlhv*3.1415
2976     193*Artid**2.0/4.0)
2977     4420 Xlengthflow=3.141593*(Pipid-Wthick)/(2.0*Xnart)
2978     4430 Dplewick=Xliqvisc*Xlengthflow*(Q0/(2.0*Xnart))/(Mperm*Xliqden*Xlhv
2979     1*Xle*Wthick)
2980     4450 P0=(Pbev-(Dpveinertial+Dpveiscous))/P9
2981     4460 Peav=P0*P9
2982     4470 CALL Tset(Ifluid,P9,P0,T0)
2983     4480 Teav=T0
2984     CALL Fluidprop(Ifluid,T0,Xliqden,Vapden,Xliqvisc,Vapvisc,P0,Surfte
2985     1n,Xlhv,Xk,Xmw,Tcfluid)
2986     4520 Axvapvel=Q0/(Vapden*Effarea*Xlhv)
2987     4530 Velsound=SQRT(Xk*8.3144E+07*(Teav+273.2)/Xmw)
2988     4540 Eamech=Axvapvel/Velsound
2989     4550 IF (Eamech.LT.1.0) THEN
2990         GOTO 4570
2991     ELSE
2992         GOTO 5830
2993     ENDIF
2994     4570 Eamech=Eamech
2995     4580 IF (Xle.EQ.0) THEN
2996         GOTO 4950
2997     ELSE
2998         CONTINUE
2999     ENDIF
3000     4600 Adbcapforce=2.0*Surften*COS(Wetangle/57.29578)/Mcaprad
3001     4620 Axvapvel=Q0/(Vapden*Effarea*Xlhv)
3002     4630 Aaxreyn=Vapden*Axvapvel*Hydiam/Vapvisc
3003     4640 Ff=16.0/Aaxreyn
3004     4650 IF (Aaxreyn.LE.2100.0) THEN
3005         GOTO 4710
3006     ELSE
3007         CONTINUE
3008     ENDIF
3009     4660 IF (Aaxreyn.GT.30000.0) THEN
3010         GOTO 4690
3011     ELSE
3012         CONTINUE
3013     ENDIF
3014     4670 Ff=0.0791/Aaxreyn**0.25

```



SUBROUTINE HRHTPP Compiling Options:/NO/N7/B/MC/ND/NF/H/N1/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/U/NX/NZ1  
Source file Listing

```
3015 4680 GOTO 4710
3016 4690 Ff=0.046/Aaxreyn**0.2
3017 4710 P7=Peav
3018 4720 IF (Eamech.GT.0.15) THEN
3019     GOTO 4750
3020     ELSE
3021     CONTINUE
3022     ENDIF
3023 4730 Dpvviscous=2.0*Ff*Xla/Effdiam*Vapden*Axvapvel**2.0
3024 4740 GOTO 4790
3025 4750 Sonicflag=0.0
3026 4760 CALL Xmech(Eamech,P7,Ff,Xla,Effdiam,Xk,Xm8,Dplaviscous,Sonicflag)
3027 4770 IF (Sonicflag.EQ.0.0) THEN
3028     GOTO 4790
3029     ELSE
3030 4780 GOTO 5870
3031     ENDIF
3032 4790 CONTINUE
3033 4800 Dplaart=Xliqvisc*Xla*(Q0/Xnart)/(Artperm*Xliqden*Xlhw*3.141593*Ar
3034     tid**2.0/4.0)
3035 4820 P0=(Peav-Dpvviscous)/P9
3036 4830 Pacv=P0*P9
3037 4840 Acmech=Xm8
3038 4850 CALL Tst(Ifluid,P9,P0,T0)
3039     CALL Fluidprop(Ifluid,T0,Xliqden,Vapden,Xliqvisc,Vapvisc,P0,Surfte
3040     in,Xlhw,Xk,Xm8,Tcfluid)
3041 4880 IF (Acmech.GT.0.15) THEN
3042     GOTO 5000
3043     ELSE
3044     CONTINUE
3045     ENDIF
3046 4900 Axvapvel=Q0/(Vapden*Effarea*Xlhw)
3047 4910 Velsound=SQRT(Xk*8.3144E+07*(Teav+273.2)/Xm8)
3048 4920 Acmech=Axxvapvel/Velsound
3049 4930 GOTO 5000
3050 4950 Pacv=Peav
3051 4970 Acmech=Eamech
3052 5000 CONTINUE
3053 5020 Condcapforce=2.0*Surften*COS(Wetangle/57.29578)/Mcaprad
3054 5060 Axvapvel=Q0/(Vapden*Effarea*Xlhw)
3055 5070 Caxreyn=Vapden*Axxvapvel*Hydiam/Vapvisc
3056 5080 Ff=16.0/Caxreyn
3057 5090 IF (Caxreyn.LE.2100.0) THEN
3058     GOTO 5140
3059     ELSE
3060     CONTINUE
3061     ENDIF
3062 5100 IF (Caxreyn.GT.30000.0) THEN
3063     GOTO 5130
3064     ELSE
3065     CONTINUE
3066     ENDIF
```

```

3067 5110 Ff=0.0791/Caxreyn**0.25
3068 5120 GOTO 5140
3069 5130 Ff=0.046/Caxreyn**0.2
3070 5140 CONTINUE
3071 5150 Dpvcviscous=2.0*Ff*(Xlc/2.0)/Effdiam*Vapden*Axvapvel**2.0
3072 5160 Dpvcinertial=-0.5*Vapden*Axvapvel**2.0
3073 5180 Dplcart=Xliqvisc*(Xlc/2.0)*(Q0/Xnart)/(Artpen*Xliqden*Xlhv*3.1415
3074 193*Artid**2.0/4.0)
3075 5200 Xlengthflow=3.141593*(Pipid-Wthick)/(2.0*Xnart)
3076 5210 Dplcwick=Xliqvisc*Xlengthflow*(Q0/(2.0*Xnart))/(Upern*Xliqden*Xlhv
3077 1*Xlc*Wthick)
3078 5230 P0=(Pacv-(Dpvcinertial+Dpvcviscous))/P9
3079 5240 Pfcv=P0*P9
3080 5260 IF (Pfcv.GT.0.0) THEN
3081 GOTO 5290
3082 ELSE
3083 CONTINUE
3084 ENDF
3085 5270 GOTO 6030
3086 5290 CALL Tstat(Ifluid,P9,P0,T0)
3087 5300 Tfcv=T0
3088 Zot=FLOAT(1)
3089 5320 Dtcond=Dtevap*(Xle/Xlc)*(Zot/50.0)
3090 5340 T0=Tfcv-Dtcond
3091 CALL Fluidprop(Ifluid,T0,Xliqden,Vapden,Xliqvisc,Vapvisc,P0,Surfte
3092 1n,Xlhv,Xk,Xmw,Tcfluid)
3093 5360 CALL Wallprop(Imatl,T0,Wallden,Tcwall)
3094 5370 Tcwick=Tcwall
3095 5390 Tfilledwick=Tcwick*(1.0-Wvoid*(1.0-Tcfluid/Tcwick))
3096 5400 Dtcwick=Q0*ALOG(Pipod/Pipid)/(2.0*Vaprad)/(2.0*3.141593*Tfilledwick*Xlc
3097 1)*(Zot/50.0)
3098 5420 T0=Tfcv-Dtcond-Dtcwick
3099 5430 CALL Wallprop(Imatl,T0,Wallden,Tcwall)
3100 5440 Dtcwall=Q0*ALOG(Pipod/Pipid)/(Tcwall*2.0*3.141593*Xlc)*(Zot/50.0)
3101 5460 Textcond=Tfcv-Dtcond-Dtcwick-Dtcwall
3102 5465 Condenserdp=Dpvcviscous+Dpvcinertial+Dplcart+Dplcwick
3103 5490 IF (Condcapforce.LT.Condenserdp) THEN
3104 GOTO 5950
3105 ELSE
3106 CONTINUE
3107 ENDF
3108 5500 X=Dpvcviscous-Dpvcinertial
3109 5510 IF (X.LT.0.0) THEN
3110 X=0.0
3111 ELSE
3112 CONTINUE
3113 ENDF
3114 5530 Xleftoverc=Condcapforce-X-Dplcart-Dplcwick
3115 5540 IF (Xla.EQ.0.0) THEN
3116 5550 Xleftovera=0.0
3117 5560 GOTO 5610
3118 ELSE

```

```

3119      CONTINUE
3120 5570 ENDIF
3121 5580 IF (Xleftoverc+Adbcapforce-Condcapforce.LT.Dplaviscous+Dplaart) TH
3122      1EM
3123      GOTO 5990
3124      ELSE
3125      CONTINUE
3126      ENDIF
3127 5600 Xleftovera=Xleftoverc+Adbcapforce-Condcapforce-Dplaviscous-Dplaart
3128 5605 Evapcapforcedp=Dpveviscous+Dpveinertial+Dpleart+Dplewick
3129 5610 IF (Xleftovera+Evapcapforce-Adbcapforce.LT.Evapcapforcedp) THEN
3130      GOTO 6030
3131      ELSE
3132      GOTO 6060
3133      ENDIF
3134 5670 WRITE (*,*) 'TOO MUCH EVAPORATION DELTA-T'
3135 5710 WRITE (*,*) 'SONIC LIMIT EXCEEDED AT BEGINNING OF EVAPORATOR'
3136 5750 WRITE (*,*) 'SORT IS NEGATIVE IN EVAP VISC DELTA-P EQN'
3137 5790 WRITE (*,*) 'EVAP VAPOR DELTA-P IS TOO HIGH'
3138 5830 WRITE (*,*) 'SONIC LIMIT EXCEEDED AT E-A INTERFACE'
3139 5870 WRITE (*,*) 'SONIC LIMIT EXCEEDED IN ADIABATIC SECTION'
3140 5910 WRITE (*,*) 'TOO MUCH CONDENSER VAPOR DELTA-P'
3141 5950 WRITE (*,*) 'NOT ENOUGH CAPILLARY FORCE IN CONDENSER'
3142 5990 WRITE (*,*) 'NOT ENOUGH CAPILLARY FORCE IN ADIABATIC SECTION'
3143 6030 WRITE (*,*) 'NOT ENOUGH CAPILLARY FORCE IN THE EVAPORATOR'
3144      STOP
3145 6060 Xlp=Xle+Xla+Xlc
3146 6070 Pipevolume=3.141593*(Pipod**2.0-Pipid**2.0)/4.0*Xlp+2.0*3.141593*P
3147      1ipod**2.0/4.0*2.0*Wall
3148 6080 Pipemass=Pipevolume*Wallden
3149 6090 Wickvolume=3.141593*(Pipid**2.0-(2.0*Vaprad)**2.0)/4.0*Xlp+Xnart*3
3150      1.141593*(Artod**2.0-Artid**2.0)/4.0*Xlp
3151 6100 Wickmass=Wickvolume*(1.0-Wvoid)*Wallden
3152 6110 Arterylvolume=Xnart*3.141593*(Artod**2.0-Artid**2.0)/4.0*Xlp
3153 6120 Arterymass=Arterylvolume*(1.0-Wvoid)*Wallden
3154 6130 Fluidcharge=(Wickvolume*Wvoid+Xnart*3.141593*Artid**2.0/4.0)*Roomd
3155      1en(Ifluid)
3156 6140 Totalmass=Pipemass+Wickmass+Arterymass+Fluidcharge
3157 6160 RETURN
3158      END

```

SUBROUTINE XMACH Compiling Options:/NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```

3159 C
3160 C
3161 C
3162     SUBROUTINE Xmach(Eamach,P7,Ff,Xla,Effdiam,Xk,Xm8,Dplaviscous,Sonic
3163     &flag)
3164     7200 Xm7=Eamach
3165     7210 X7=Xm7
3166     7220 X3=4.0*Ff*Xla/Effdiam
3167     7260 X2=(1.0-Xm7**2.0)/(Xk*Xm7**2.0)+(Xk+1.0)/(2.0*Xk)*ALOG((Xk+1.0)*Xm
3168     17**2.0/(2.0*(1.0+(Xk-1.0)/2.0*Xm7**2.0)))
3169     7300 X1=X2-X3
3170     7310 IF (X1.GT.0.0) THEN
3171         GOTO 7400
3172     ELSE
3173         CONTINUE
3174     ENDIF
3175     7320 IF (X1.LT.0.0) THEN
3176         GOTO 7350
3177     ELSE
3178         CONTINUE
3179     ENDIF
3180     7330 Xm8=1.0
3181     7340 GOTO 7500
3182     7350 Sonicflag=1.0
3183     7360 RETURN
3184     7400 X4=0.1
3185     7410 Xm8=X7+X4*X7
3186     7420 X=(1.0-Xm8**2.0)/(Xk*Xm8**2.0)+(Xk+1.0)/(2.0*Xk)*ALOG((Xk+1.0)*Xm8
3187     1**2.0/(2.0*(1.0+(Xk-1.0)/2.0*Xm8**2.0)))
3188     7430 IF (ABS((X1-X)/X1).LE.0.001) THEN
3189         GOTO 7500
3190     ELSE
3191         CONTINUE
3192     ENDIF
3193     7440 X7=Xm8
3194     7450 IF (X.GT.X1) THEN
3195         GOTO 7410
3196     ELSE
3197         CONTINUE
3198     ENDIF
3199     7460 X4=0.01
3200     7470 Xm8=X7-X4*X7
3201     7480 GOTO 7420
3202     7500 IF (Xm8.LE.1.0) THEN
3203         GOTO 7550
3204     ELSE
3205         CONTINUE
3206     ENDIF
3207     7530 Sonicflag=1.0
3208     7550 Dplaviscous=P7-P7*Xm7/Xm8*SQRT((1.0+(Xk-1.0)/2.0*Xm7**2.0)/(1.0+(X
3209     1k-1.0)/2.0*Xm8**2.0))
3210     7560 RETURN

```

SUBROUTINE XMACH Compiling Options:/NO/N7/B/NC/ND/NF/H/N1/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/U/WX/NZ1  
Source file Listing

3211 END

FUNCTION PNEW Compiling Options:/N0/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```

3212 C
3213 C
3214 C
3215     FUNCTION Pnew(U,J,K)
3216 C
3217 C     FUNCTION TO CALCULATE HEAT PIPE FAILURE PROBABILITY
3218 C
3219 C     *** VARAIBLES DEFINITION ***
3220 C         U = 1.0 - Prob (0.1, 0.01, 0.001)
3221 C         J = INTEGER NUMBER OF REDUNDENT HEAT PIPES
3222 C         K = INTEGER NUMBER OF TOTAL HEAT PIPES (REQUIRED+REDUNDENT)
3223 C     INTEGER H
3224 C     REAL*8 Pold,Dudpold,Dudp,Dudpnew,F,U,A,Pnew
3225     Pold=0.03
3226     Dudpold=10.0
3227 9510 F=-U
3228     Dudp=0
3229     DO 9512 H=J+1,K,1
3230     A=Xlnfac(K)-Xlnfac(K-H)-Xlnfac(H)+H*ALOG(Pold)+(K-H)*ALOG(1-Pold)
3231     IF (A.GT.-50.0) THEN
3232     A=EXP(A)
3233     F=F+A
3234     Dudp=Dudp+A*(H/Pold-(K-H)/(1-Pold))
3235     ELSE
3236     CONTINUE
3237     ENDIF
3238 9512 CONTINUE
3239 9513 Dudpnew=(Dudp+Dudpold)/2
3240     IF (ABS(F/Dudpnew).LT.0.005) THEN
3241     Pnew=Pold-F/Dudpnew
3242     ELSE
3243     Pnew=Pold-0.4*F/Dudpnew
3244     ENDIF
3245     Dudpold=Dudpnew
3246     IF (Pnew.GT.0.99999) THEN
3247     Pnew=0.1+0.9*Pold
3248     ELSE
3249     CONTINUE
3250     ENDIF
3251     IF (Pnew.LT.0.00001) THEN
3252     Pnew=0.1*Pold
3253     ELSE
3254     CONTINUE
3255     ENDIF
3256     Error=ABS((Pnew-Pold)/Pold)
3257     Pold=Pnew
3258     IF (Error.GT.0.000001) THEN
3259     GOTO 9510
3260     ELSE
3261     CONTINUE
3262     ENDIF
3263     Pnew=Pnew

```

FUNCTION PNEW Compiling Options:/NO/N7/B/NC/ND/NF/H/N1/NK/ML/P/NQ1/NQ2/NQ3/R/S/NT/U/NX/NZ1  
Source file Listing

3264 RETURN  
3265 END

FUNCTION XLNFAC Compiling Options:/NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```
3266 C
3267 C
3268 C
3269 9700 FUNCTION Xlnfac(N)
3270 C REAL*8 F,Z,Xiz2,Xlnfac
3271 C FUNCTION TO CALCULATE THE LOG OF FACTORIALS OF WHOLE NUMBERS
3272 IF (N.EQ.0) THEN
3273 F=0.0
3274 ELSE
3275 CONTINUE
3276 ENDIF
3277 IF (N.EQ.1) THEN
3278 F=0.0
3279 ELSE
3280 CONTINUE
3281 ENDIF
3282 IF (N.EQ.2) THEN
3283 F=ALOG(2.0)
3284 ELSE
3285 CONTINUE
3286 ENDIF
3287 IF (N.EQ.3) THEN
3288 F=ALOG(6.0)
3289 ELSE
3290 CONTINUE
3291 ENDIF
3292 IF (N.EQ.4) THEN
3293 F=ALOG(24.0)
3294 ELSE
3295 CONTINUE
3296 ENDIF
3297 IF (N.EQ.5) THEN
3298 F=ALOG(120.0)
3299 ELSE
3300 CONTINUE
3301 ENDIF
3302 IF (N.GT.5) THEN
3303 Z=FLOAT(N+1)
3304 Xiz2=1./Z/Z
3305 F=(Z-.5)*ALOG(Z)-Z+.5*ALOG(2*3.141593)+1./(12*Z)*(1.-Xiz2/30*(1.-2
3306 1*Xiz2/7*(1.-3*Xiz2/4)))
3307 ELSE
3308 CONTINUE
3309 ENDIF
3310 Xlnfac=F
3311 RETURN
3312 END
```



SUBROUTINE TMEAN Compiling Options:/NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```
3313 C
3314 C
3315 C
3316 SUBROUTINE TMEAN(Tin,DTman,DTfilm,Tbar)
3317 Tref = Tin - DTfilm
3318 Z1 = (1.0-(DTman/Tref))**3.0
3319 Z2 = 1.0/((1.0/Z1)-1.0)
3320 Z3 = 3.0*Z2*(DTman/Tref)
3321 Tbar = (Z3*(Tref**4.0))**0.25
3322 RETURN
3323 END
```

SUBROUTINE ACONE Compiling Options:/NO/W7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```
3324 C
3325 C
3326 C
3327 SUBROUTINE ACONE(Rs,RI,Nt,Areacone)
3328 A = 3.141593*(Rs+RI)
3329 B = SQRT((Nt**2.0)+(RI-Rs)**2.0)
3330 Areacone = A*B
3331 RETURN
3332 END
```

SUBROUTINE AVIEW Compiling Options:/NO/N7/B/NC/ND/NF/H/N1/NK/NL/P/MQ1/MQ2/MQ3/R/S/NT/W/NX/MZ1  
Source file Listing

```
3333 C
3334 C
3335 C
3336     SUBROUTINE AVIEW(Ds,DI,Ht,Acone,Vfct)
3337     R1 = Ds/2.0
3338     R2 = DI/2.0
3339     Acone = 3.141593*(R1+R2)*SQRT((Ht**2.0)+((R2-R1)**2.0))
3340     Aend = 3.141593*(R2**2.0)
3341     A1 = 3.141593*(R1**2.0)
3342     DUM1 = 1.0 + ((R2/R1)**2.0) + ((Ht/R1)**2.0)
3343     DUM2 = 4.0*((R2/R1)**2.0)
3344     DUM3 = SQRT((DUM1**2.0)-DUM2)
3345     F1to2 = 0.5*(DUM1-DUM3)
3346     Vfct = (Aend/Acone)*(1.0-((A1/Acone)*F1to2))
3347     RETURN
3348     END
```

SUBROUTINE VIEW Compiling Options:/NO/W7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```
3349 C
3350 C
3351 C
3352 SUBROUTINE View(D1,D2,D3,H1,H2,Aa,Vf)
3353 C
3354 C CONICAL RADIATOR ID VIEW FACTOR - Cone ID to Space via
3355 C Large End Only
3356 C
3357 C **** VARIABLES DEFINITION ****
3358 C D1 = DIAMETER OF EXIT DISC
3359 C D2 = LARGE DIAMETER OF CONICAL ELEMENT
3360 C D3 = SMALL DIAMETER OF CONICAL ELEMENT
3361 C H1 = DISTANCE FROM TOP OF CONE TO SMALL DIAMETER PLANE
3362 C H2 = DISTANCE FROM TOP OF CONE TO LARGE DIAMETER PLANE
3363 C Aa = AREA OF ID OF CONICAL ELEMENT SURFACE
3364 C Vf = VIEW FACTOR OF CONICAL ELEMENT TO CONE END (LARGE DIA. END)
3365 C R1=D1/2.0
3366 C R2=D2/2.0
3367 C R3=D3/2.0
3368 C X12=1.0+(R2/R1)**2.0+(H1/R1)**2.0
3369 C X13=1.0+(R3/R1)**2.0+(H2/R1)**2.0
3370 C F1to2=0.5*(X12-SQRT((X12**2.0)-(4.0*(R2/R1)**2.0)))
3371 C F1to3=0.5*(X13-SQRT((X13**2.0)-(4.0*(R3/R1)**2.0)))
3372 C A1x=3.141593*(D1**2.0)/4.0
3373 C Daa=SQRT(((H2-H1)**2.0)+((D2/2.0-D3/2.0)**2.0))
3374 C Dab=3.141593*(D2+D3)/2.0
3375 C Aa=Daa*Dab
3376 C Vf=(A1x/Aa)*(F1to2-F1to3)
3377 C RETURN
3378 C END
```

```

3432 C
3433 C      ***** TUBE-SIDE FLUID PROPERTIES
3434 C
3435 C      CPT = TUBE-SIDE FLUID Specific Heat (BTU/Lb-R)
3436 C      RHOT = TUBE-SIDE FLUID Density (Lbs/Ft^3)
3437 C      AKTT = TUBE-SIDE FLUID Thermal Cond (BTU/Hr-Ft-R)
3438 C      VISCT = TUBE-SIDE FLUID Viscosity (Lb/Ft-Sec)
3439 C
3440 C
3441 C      SET FLUID THERMAL PROPERTIES
3442 C
3443 C      TBARR = (THIN+TCIN)/2.0
3444 C      GO TO (5,8),INXflg
3445 C      5 CALL XLITHP(TBARR,RHOT,CPT,VISCT,AKTT)
3446 C      CALL HEXEPR(AMWS,PHOT,TBARR,GAMMA,CPSF,RHOSF,VISCST,AKTST,PRMIX)
3447 C      GO TO 10
3448 C      8 CALL XNAKPR(TBARR,RHOT,CPT,VISCT,AKTT)
3449 C      CALL HEXEPR(AMWS,PHOT,TBARR,GAMMA,CPSF,RHOSF,VISCST,AKTST,PRMIX)
3450 C      10 WDOTS = 3600.0*WDOTS
3451 C      VISCST = VISCST/6.72E-4
3452 C      WRITE (6,*) 'TBARR,RHOT,CPT,VISCT,AKTT',TBARR,RHOT,CPT,VISCT,AKTT
3453 C      WRITE (6,*) 'AMWS,PHOT,TBARR,GAMMA,CPSF,RHOSF,VISCST,AKTST,PRMIX =
3454 C      &',AMWS,PHOT,TBARR,GAMMA,CPSF,RHOSF,VISCST,AKTST,PRMIX
3455 C      WRITE (6,*) 'WDOTS,VISCST =',WDOTS,VISCST
3456 C      A1 = (THIN-TCOUT) - (THOUT-TCIN)
3457 C      IF ((THIN-TCOUT).EQ.(THOUT-TCIN)) THEN
3458 C      ALMTD = THIN-TCOUT
3459 C      GO TO 15
3460 C      ELSE
3461 C      A2 = ALOG((THIN-TCOUT)/(THOUT-TCIN))
3462 C      ALMTD = A1/A2
3463 C      ENDIF
3464 C      15 PR = PR
3465 C      WRITE (6,*) 'A1, ALMTD, PR =', A1, ALMTD, PR
3466 C      GOTO 100
3467 C      35 UEST = UNEW
3468 C      100 AQ = -2.0*DTUBE
3469 C      BQ = (DTUBE**2.0)
3470 C      CQ1 = PR*DTUBE
3471 C      CQ2 = 144.0*QDOT*(CQ1**2.0)
3472 C      CQ3 = UEST*ALMTD*(9.869604)*DTUBE
3473 C      CQ = CQ2/CQ3
3474 C      PQ = -((AQ**2.0)/3.0)+BQ
3475 C      QQ = (2.0*((AQ/3.0)**3.0))- (AQ*BQ/3.0)+CQ
3476 C      QBIG = ((PQ/3.0)**3.0)+((CQ/2.0)**2.0)
3477 C      AARG = -(CQ/2.0)+SQRT(QBIG)
3478 C      ABIG = (ABS(AARG))**0.333333
3479 C      BBRG = -(CQ/2.0)-SQRT(QBIG)
3480 C      BBIG = (ABS(BBRG))**0.333333
3481 C      DOTL = ABIG + BBIG - (AQ/3.0)
3482 C      ALSHEL = (ANPLATES+1.0)*DOTL
3483 C      AVAL = 0.867

```

```

3379 C
3380 C
3381 C
3382 SUBROUTINE HRSHEL(INXflg,UEST,THIN,THOUT,PHOT,TCIN,TCOUT,WDOTS,AMW
3383 &S,TINS,DENINS,DENSSH,DTUBE,PR,TTUBE,ANPLATES,WDOTT,AKTUBE,Q
3384 &DOT,DPSHELL,ANTUBES,DPTUBE,DOTL2,ALSHL,ANSHL,ANPLATES,
3385 &ANTUBES,AMINSUL,AMHEADS,AMSTR,ANEYMASS,XMNHX,NSHELL,AFRIC,UNEW,
3386 &RETUBE,THC,AMTSHT)
3387 WRITE (6,*) ' '
3388 WRITE (6,*) 'DATA INPUT LIST FROM HRSHEL'
3389 WRITE (6,*) 'INXflg,UEST,THIN,THOUT,PHOT,TCIN,TCOUT,WDOTS,AMWS,
3390 &TINS,DENINS,DENSSH,DTUBE,PR,TTUBE,ANPLATES,WDOTT,AKTUBE,QDOT =',
3391 &INXflg,UEST,THIN,THOUT,PHOT,TCIN,TCOUT,WDOTS,AMWS,TINS,DENINS,
3392 &DENSSH,DTUBE,PR,TTUBE,ANPLATES,WDOTT,AKTUBE,QDOT
3393 C
3394 C SHELL AND TUBE HEAT EXCHANGER DESIGN SUBROUTINE
3395 C ROUTINE ASSUMES THAT LIQUID IS ON TUBE SIDE
3396 C GAS IS ON SHELL SIDE. BELL'S CORRELATION IS USED FOR
3397 C GAS SIDE HEAT TRANSFER - LYONS IS USED FOR TUBE SIDE
3398 C LIQUID METAL HEAT TRANSFER, McELLIOT, MCGEE AND LEPPERT
3399 C IS USED FOR OTHER FLUIDS (LIQUIDS AND GASES)
3400 C
3401 C ***** OVERALL PARAMETERS *****
3402 C
3403 C INXflg = 1, THEN TUBE SIDE FLUID IS LITHIUM
3404 C INXflg = 2, THEN TUBE SIDE FLUID IS NaK-78
3405 C ALMTD = Heat Exchanger Log Mean Temperature Difference
3406 C QDOT = Heat Rate or Duty (BTU/Hr)
3407 C UEST = INITIAL VALUE OF Uoverall (BTU/Hr-Ft-R)
3408 C (50 for GAS-GAS)
3409 C THIN = HOT SIDE Inlet Temperature (R)
3410 C THOUT = HOT SIDE Outlet Temperature (R)
3411 C TCIN = COLD SIDE Inlet Temperature (R)
3412 C COUT = COLD SIDE Outlet Temperature (R)
3413 C
3414 C ***** SHELL SIDE DATA *****
3415 C
3416 C WDOTS = SHELL SIDE FLUID Flowrate (Lbs/Sec)
3417 C DENSSH = SHELL MATERIAL Density (Lbs/Ft^3)
3418 C
3419 C ***** SHELL-SIDE FLUID PROPERTIES *****
3420 C
3421 C CPSF = SHELL-SIDE FLUID Specific Heat (BTU/Lb-R)
3422 C RHOSF = SHELL-SIDE FLUID Density (Lbs/Ft^3)
3423 C AKTST = SHELL-SIDE FLUID Thermal Cond (BTU/Hr-Ft-R)
3424 C VISCST = SHELL-SIDE FLUID Viscosity (Cp)
3425 C
3426 C ***** TUBE SIDE DATA *****
3427 C
3428 C DTUBE = Outside TUBE Diameter - (Inches)
3429 C TTUBE = TUBE Wall Thickness (Inches)
3430 C WDOTT = TUBE -SIDE Fluid Flowrate (Lbs/Sec)
3431 C AKTUBE = TUBE Wall Thermal Conductivity (BTU/Hr-Ft-R)

```

SUBROUTINE HRSHEL Compiling Options:/NO/N7/B/NC/ND/NF/H/W1/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ  
Source file Listing

```

3484      FFBN = 0.4307652 + (4.521962E-03*(DOTL)) - (6.335725E-05*(DOTL**2
3485      1.0)) + (3.716571E-07*(DOTL**3.0))
3486      GXT = 1560.0*(WDOTS/(DOTL**2.0))
3487      REXT = (DTUBE*GXT)/(29.0*VISCST)
3488      RC = 1.0
3489      IF (REXT-1000.0) 200,150,150
3490      150 RC = 1.0
3491      GOTO 300
3492      200 RC = 0.4812508 + (2.726048E-03*(REXT)) - (7.739889E-06*(REXT**2.)
3493      1) + (9.960931E-09*(REXT**3.0)) - (4.431738E-12*(REXT**4.0))
3494      300 FFBP =FFBN*RC
3495      FFBH = FFBP+0.125
3496      REXP = FFBP*REXT
3497      REXH = FFBH*REXT
3498      AREP = ALOG(REXP)/2.302585093
3499      AREH = ALOG(REXH)/2.302585093
3500      AFX = 1.397542 - (0.96108*(AREP)) + (0.064751*(AREP**2.0)) + (0.0
3501      106305*(AREP**3.0))
3502      AFRIC = 10.0**AFX
3503      AJX = -0.359018 - (0.259608*(AREH)) - (0.094385*(AREH**2.0)) + (0
3504      1.012556*(AREH**3.0))
3505      AJFAC = 10.0**AJX
3506      C  WRITE (6,*) 'j-FACTOR =',AJFAC
3507      NS1 = 0.415*CPSF*GXT*FFBH*AJFAC
3508      NS2 = (AKTST/(CPSF*VISCST))**0.66667
3509      NSHELL = NS1*NS2
3510      DPSF = 0.00875*((AJFAC*ALSHEL)/(AVAL*PR*DTUBE*0.4))
3511      DPSM = 0.001551191*((ALSHEL*1.0)/(0.4*DOTL))-1.0)
3512      DPSHELL = (0.3*(DPSF+DPSM)/RHOSF)*((GXT*FFBP)/10000.0)
3513      PT = PR*DTUBE
3514      ANTUBES = ((0.7854*(DOTL-DTUBE)**2.0)/(PT**2.0))
3515      WTUBE = MDOTT/ANTUBES
3516      AREAT = (0.7854*(DTUBE-(2.0*TTUBE))**2.0)/144.0
3517      VTUBE = WTUBE/(AREAT*RHOT)
3518      QTUBE = RHOT*(VTUBE**2.0)/(2.0*32.174*144.0)
3519      RETUBE = VTUBE*RHOT*DTUBE/(12.0*VISCT)
3520      DTUBE1 = DTUBE-(2.0*TTUBE)
3521      PRTUBE = (3600*VISCT*CPT)/AKTT
3522      IF (PRTUBE-0.1) 330,330,340
3523      330 THC = (12.0*AKTT/DTUBE1)*(7.0+(0.025*(RETUBE*PRTUBE)**0.8))
3524      GOTO 440
3525      340 IF (RETUBE-2000.0) 350,350,400
3526      350 TFRIC=64.0/RETUBE
3527      THC = 4.364*(12.0*AKTT/DTUBE1)
3528      GOTO 450
3529      400 AK = 0.0001
3530      AKD = AK/DTUBE1
3531      FRIC1 = ALOG10((AKD/3.7)+(5.74/(RETUBE**0.9)))**2.0
3532      TFRIC = 0.25/FRIC1
3533      THC = 0.026*(12.0*AKTT/DTUBE1)*(RETUBE**0.8)*(PRTUBE**0.4)
3534      435 GOTO 450
3535      440 IF (RETUBE-2000.0) 442,442,445

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← IF ( ) - , 0 , +

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- here }

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3536 442 TFRIC=64.0/RETUBE
3537 GOTO 450
3538 445 AK = 0.0001
3539 AKD = AK/DTUBEI
3540 FRIC1 = ALOG10((AKD/3.7)+(5.74/(RETUBE**0.9)))**2.0
3541 TFRIC = 0.25/FRIC1
3542 450 COND2 = 12.0*AKTUBE/TTUBE
3543 UNEW = 1.0/((1.0/THC)+(1.0/HSHELL)+(1.0/COND2))
3544 DPTUBE = (2.0*QTUBE) + ((TFRIC*(ALSHEL/DTUBEI))*QTUBE)
3545 CQ3 = UNEW*ALMTD*(9.869604)*DTUBE
3546 CQ = CQ2/CQ3
3547 QQ = (2.0*((AQ/3.0)**3.0)-(AQ*BQ/3.0) + CQ
3548 QBIG = ((PQ/3.0)**3.0) + ((QQ/2.0)**2.0)
3549 AARG = -(QQ/2.0)+SQRT(QBIG)
3550 ABIG = (ABS(AARG))**0.333333
3551 BBRG = -(QQ/2.0)-SQRT(QBIG)
3552 BBIG = (ABS(BBRG))**0.333333
3553 DOTL2 = ABIG + BBIG - (AQ/3.0)
3554 ERROR = ABS((DOTL-DOTL2)/DOTL)
3555 IF (ERROR - 0.001) 600,600,35
3556 600 TMINPR = PHOT*DOTL/(2.0*10000.0)
3557 TMINSC = (0.005*DOTL) + (0.0001*(DOTL**2.0))
3558 IF (TMINPR.GT.TMINSC) THEN
3559 TMIN = TMINPR
3560 GOTO 650
3561 ELSE
3562 TMIN = TMINSC
3563 ENDIF
3564 650 AMINSUL = (3.141593*DOTL*(DOTL+ALSHEL)*TINS*(DENINS/1728.0)) + (3.
3565 &141593*(DOTL2**2.0)*TINS*(DENINS/1728.0))
3566 C WRITE (6,*) 'TMIN (Inches) =',TMIN
3567 AMHEADS = 3.141593*(DOTL**2.0)*TMIN*(DENSSH/1728.0)
3568 AMSHELL = 3.141593*DOTL*(DOTL+ALSHEL)*TMIN*(DENSSH/1728.0)
3569 AMPLATES = AMPLATES*(2.0*3.141593*((DOTL**2.0)/4.0)*TMIN*(DENSSH/
3570 &1728.0))
3571 AMTSHT = 2.0*3.141593*((DOTL**2.0)/4.0)*2.0*TMIN*(DENSSH/1728.0)
3572 AMTUBES = 0.785398*((DTUBE**2.0)-(DTUBEI**2.0))*ALSHEL*AMTUBES*(
3573 1DENSSH/1728.0)
3574 ANSTRT = 0.05*(AMINSUL+AMHEADS+AMSHLL+AMPLATES+AMTSHT+AMTUBES)
3575 ANETMASS = AMINSUL+AMHEADS+AMSHLL+AMPLATES+AMTSHT+AMTUBES+ANSTRT
3576 C WRITE (6,*) '
3577 C WRITE (6,*) 'SHELL AND TUBE HEAT EXCHANGER DESIGN CODE'
3578 C WRITE (6,*) '
3579 C WRITE (6,*) 'SHELLSIDE DP =',DPSHELL
3580 C WRITE (6,*) 'SHELLSIDE H =',HSHELL
3581 C WRITE (6,*) 'FRIC-FAC =',AFRIC
3582 C WRITE (6,*) 'UNEW =',UNEW
3583 C WRITE (6,*) 'NUMBER OF TUBES IN BUNDLE =',AMTUBES
3584 C WRITE (6,*) 'Tube Side Reynolds Number =',RETUBE
3585 C WRITE (6,*) 'Tube Conductance =',COND2
3586 C WRITE (6,*) 'Tube Side Pressure Drop (PSID) =',DPTUBE
3587 C WRITE (6,*) 'Tube Side Hg (BTU/Hr-sq.Ft-R) =',THC
3588 C WRITE (6,*) 'TUBE DIA (Inches) =',DTUBE

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SUBROUTINE HRSHEL Compiling Options:/NO/N7/B/NC/ND/NF/H/N1/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```
3589 C WRITE (6,*) 'TUBE WALL THICKNESS (Inches) =', TTUBE
3590 C WRITE (6,*) 'DOTL2 (Inches) =', DOTL2
3591 C WRITE (6,*) 'LENGTH (Inches) =', ALSHEL
3592 C WRITE (6,*) ' '
3593 C WRITE (6,*) 'INSULATION MASS (Lbs) =', AMINSUL
3594 C WRITE (6,*) 'HEAD MASS (Lbs) =', AMHEADS
3595 C WRITE (6,*) 'SHELL MASS (Lbs) =', AMSHELL
3596 C WRITE (6,*) 'PLATE MASS (Lbs) =', AMPLATES
3597 C WRITE (6,*) 'TUBE SHEETS MASS (Lbs) =', AMTSH
3598 C WRITE (6,*) 'TUBE MASS (Lbs) =', AMTUBES
3599 C WRITE (6,*) 'STRUCTURE AND BRACKETS MASS (Lbs) =', AMSTR
3600 C WRITE (6,*) 'Net Mass of Shell and Tube Unit (Lbs) =', ANETMASS
3601 VNAK1 = 0.785398*(DTUBE**2.0)*ALSHEL*AMTUBES
3602 VNAK2 = 0.523599*(DOTL**3.0)
3603 XMHX = (VNAK1+VNAK2)*(RNOT/1728.0)
3604 RETURN
3605 END
```

```

3606 C
3607 C
3608 C
3609 C      SUBROUTINE HPMAN(Ifluid,Iflg2,Cman,Hman,Gap,Pitch,Dcan,Dhp,Rc,
3610 C      &Rb,Tf,TKfin,TKcan,TKbraze,TKhp,XNf,XNpipes,XNexpipes,XMW,Pman,Tman
3611 C      &,RHOCAN,RHOBRAZE,THICKMAN,WMAN,GRAD,XMANMSS,DPMAN,DTFILM,XHMAN)
3612 C
3613 C      SUBROUTINE TO DETERMINE THE MASS AND PERFORMANCE OF A MANIFOLD
3614 C      WHICH USES LIQUID OR GAS TO TRANSFER HEAT TO THE HEAT PIPES OF
3615 C      A HEAT PIPE RADIATOR. THE MANIFOLD CONFIGURATION CONSISTS OF
3616 C      A SINGLE ROW OF TUBE CANS (BRAZED TO HEAT PIPES) (FINS OPTIONAL)
3617 C
3618 C      INPUT VARIABLES REQUIRED
3619 C      Iflg2 = FLAG TO SET MANIFOLD WORKING FLUID
3620 C              1 = He-Xe MIXTURE
3621 C              2 = NaK
3622 C      Hman = MANIFOLD HEIGHT (Feet)
3623 C      Gap = MANIFOLD WIDTH (Feet)
3624 C      Pitch = DISTANCE BETWEEN CAN (HEAT PIPES) CENTERLINES (Feet)
3625 C      XNpipes = NUMBER OF HEAT PIPES IN RADIATOR
3626 C      XNEXpipes = NUMBER OF REDUDDENT HEAT PIPES IN RADIATOR
3627 C      Dcan = OUTSIDE DIAMETER OF MANIFOLD BRAZE CANS (Feet)
3628 C      Dhp = INSIDE DIAMETER OF HEAT PIPE (Feet)
3629 C      Rc = MANIFOLD BRAZE CAN INSIDE RADIUS (Feet)
3630 C      Rb = BRAZE JOINT INSIDE RADIUS (Feet)
3631 C      Tf = FIN THICKNESS (Feet)
3632 C      TKfin = THERMAL CONDUCTIVITY OF FIN MATERIAL (BTU/Hr-Ft-R)
3633 C      TKcan = THERMAL CONDUCTIVITY OF MANIFOLD CAN MATERIAL (B/HFR)
3634 C      TKbraze = THERMAL CONDUCTIVITY OF MANIFOLD BRAZE ALLOY (")
3635 C      TKhp = THERMAL CONDUCTIVITY OF HEAT PIPE WALL MATERIAL (")
3636 C      XNf = TOTAL NUMBER OF FINS FOR THE MANIFOLD HEIGHT
3637 C      RHOCAN = DENSITY OF MANIFOLD MATERIAL (Lb/cu-Ft)
3638 C      RHOBRAZE = DENSITY OF BRAZE MATERIAL (Lb/cu-Ft)
3639 C      THICKMAN = MANIFOLD MATERIAL THICKNESS (Feet)
3640 C      Pman = MANIFOLD INLET PRESSURE (PSIA)
3641 C      Tman = MANIFOLD INLET TEMPERATURE (deg-R)
3642 C      Wman = MANIFOLD FLOWRATE (LBS/HR)
3643 C      Qman = MANIFOLD AND RADIATOR HEAT LOAD (BTU/HR)
3644 C      XMW = MOLECULAR WEIGTH OF MANIFOLD WORKING FLUID
3645 C
3646 C      OUTPUT VARIABLES
3647 C      XMANMSS = MANIFOLD MASS (Lbs)
3648 C      DPMAN = MANIFOLD PRESSURE DROP (PSIA)
3649 C      DTFILM = MANIFOLD FILM TEMPERATURE DROP (deg-R)
3650 C
3651 C      Qman = 3413.0*Qrad
3652 C      PI = 3.14159265
3653 C      Ao = (PI*Dcan*(1.0-(XNf*Tf))*Hman) + (2.0*XNf*Hman*((Pitch*Gap)-
3654 C      &((PI/4.0)*(Dcan**2.0))))
3655 C      Afo = Ao - (PI*Dcan*Hman*(1.0-(XNf*Tf)))
3656 C      X = 12.0*(Gap-Dcan)/2.0
3657 C      Xe = X*((1.0+(12.0*Tf))/(2.0*X))*(1.0+(0.35*ALOG(X/(12.0*Dcan))))

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3658 C   WRITE (6,*) '88888*****88888*****88888*****88888'
3659 C   WRITE (6,*) 'Ao, Afo, X, Xe =',Ao,Afo,X,Xe
3660 C
3661 C   MANIFOLD CONVECTIVE HEAT TRANSFER COEFFICIENT
3662 C
3663 C   GOTO (10,20),Iflg2
3664 C   10 CALL HEXEPR(XMW,Pman,Tman,GAMMA,CP,RHO,AMU,TK,Prmix)
3665 C   GOTO 30
3666 C   20 CALL XNAKPR(Tman,RHO,CP,AMU,TK)
3667 C   30 AMU = 3600.0*AMU
3668 C   Amin = ((Gap-Dcan)*Hman) - (Gap*XMf*Tf)
3669 C   Gmax = 3600.0*Hman/Amin
3670 C   REYman = Gmax*Dcan/AMU
3671 C   WRITE (6,*) 'Amin, Gmax, REYman =',Amin,Gmax,REYman
3672 C   Fiso = 10.0**(((1.714012)-(1.349954*(ALOG10(REYman)))+(0.216271*
3673 C   &((ALOG10(REYman))**2.0))-(0.012421*(ALOG10(REYman))**3.0)))
3674 C   XJ = 10.0**((0.321848)-(0.840808*(ALOG10(REYman)))+(0.081598*((
3675 C   &ALOG10(REYman))**2.0))-(0.004631*(ALOG10(REYman))**3.0)))
3676 C   WRITE (6,*) 'Fiso, XJ =',Fiso,XJ
3677 C   Pr = AMU*CP/TK
3678 C   Hcman = XJ*CP*Gmax/(Pr**0.6667)
3679 C   Gc = 4.16975E+08
3680 C   XNt = XNpipes+XNexpipes
3681 C   WRITE (6,*) 'Pr, Hcman, Gc, XNt =',Pr,Hcman,Gc,XNt
3682 C   MANIFOLD PRESSURE DROP
3683 C   Vmax = Gmax/(3600.0*RHO)
3684 C   Qmax = RHO*(Vmax**2.0)/(2.0*32.174*144.0)
3685 C   DPman = (4.0*Fiso*XNt*((Gmax**2.0)/(288.0*Gc*RHO))) + (0.9*Qmax)
3686 C   HEAT PIPE EVAPORATOR HEAT TRANSFER COEFF (VERY VERY ROUGH)
3687 C   Qflux = Qman/(PI*Dcan*Hman*XNt)
3688 C   TO = (Tman/1.8) - 273.2
3689 C   WRITE (6,*) 'Vmax, Qmax, DPman,Qflux, TO =',Vmax,Qmax,DPman,Qflux,
3690 C   &TO
3691 C   CALL Fluidprop(Iffluid,TO,Xliqden,Vapden,Xliqvisc,Vapvisc,P0,Surf
3692 C   &ten,Xlhv,Xk,Xmrfuid,Tcfluid)
3693 C   WRITE (6,*) 'THERMAL COND OF HEAT PIPE FLUID IS (**)=',Tcfluid
3694 C   Hevap = (Tcfluid/0.00413656)/(0.010*Dhp)
3695 C   FINISH UP FIN CALCULATION
3696 C   IF (Tf.LE.0.0) THEN
3697 C   He = Hcman
3698 C   GOTO 50
3699 C   ELSE
3700 C   XM = SQRT((2.0*Hcman)/(TKfin*Tf))
3701 C   Xe=Xe/12.0
3702 C   Efin = (1.0/(XM*Xe))*TANH(XM*Xe)
3703 C   Ecorr = 1.2*Efin - 0.2
3704 C   IF (Ecorr.LE.0.1) THEN
3705 C   Ecorr = Efin
3706 C   GO TO 45
3707 C   ELSE
3708 C   CONTINUE
3709 C   ENDF

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3710 45 Ha = Hman*(1.0-(1.0-Ecorr)*(Afo/Ao))
3711  ENDIF
3712 C  WRITE (6,*) 'Hevap, XM, Efin, Ecorr, Ha =',Hevap, XM, Efin, Ecorr, Ha
3713 C  COMPUTE FILM TEMPERATURE DROP
3714 50 Rhp = Dhp/2.0
3715  Ro = Dcan/2.0
3716  D1 = Qflux/(2.0*PI*Rhp*Hman)
3717  D2 = 2.0*PI*Rhp*Hman/(Ha*Ao)
3718  D3 = Rhp*ALOG(Ro/Rc)/TKcan
3719  D4 = Rhp*ALOG(Rc/Rb)/TKbraze
3720  D5 = Rhp*ALOG(Rb/Rhp)/TKhp
3721  D6 = (1.0/Hevap)
3722  DTfilm = D1*(D2+D3+D4+D5+D6)
3723 C  WRITE (6,*) 'D1,D2,D3,D4,D5,D6 =',D1,D2,D3,D4,D5,D6
3724 C  WRITE (6,*) 'DTfilm =',DTfilm
3725 C  MASS ESTIMATE
3726 C  CAN MASS
3727  Vcan = (PI*Dcan*Hman*(Ro-Rc)) + ((PI/4.0)*(Dcan**2.0)*(Ro-Rc))
3728  XMcan = XNt*Vcan*RHOcan
3729 C  WRITE (6,*) 'Vcan, XMcan =',Vcan, XMcan
3730 C  MANIFOLD WALL MASS
3731  Vman = (((2.0*Hman)+(2.0*Gap))*Cman*THICKman) - (XNt*(PI/4.0)*(Dca
3732  &n**2.0)*THICKman)
3733  XMwall = Vman*RHOcan
3734 C  WRITE (6,*) 'Vman, XMwall =',Vman, XMwall
3735 C  BRAZE MASS
3736  Vbraze = (2.0*PI*Rc*Hman*(Rc-Rb))
3737  XMbraze = XNt*Vbraze*RHObraze
3738 C  WRITE (6,*) 'Vbraze, XMbraze =',Vbraze, XMbraze
3739 C  TOTAL MANIFOLD MASS
3740  XMANmas = XMcan+XMwall+XMbraze
3741  VOLnak = (Cman*Hman*Gap) - (XNt*0.785398*(Dcan**2.0)*Hman)
3742  XMNMAN = VOLnak*RHO
3743 C  WRITE (6,*) 'Cman, Hman, Gap, XNt, Dcan =',Cman, Hman, Gap, XNt, Dcan
3744 C  WRITE (6,*) 'XMANmas, VOLnak, XMNMAN =',XMANmas, VOLnak, XMNMAN
3745  RETURN
3746  END

```

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3747 C
3748 C
3749 C
3750 SUBROUTINE HRPIPE(XN9,R9,Dp,SUMLEN,Vpipe,Tnak,Pnak,
3751 &THICKP,RHOIP,THICKI,RHOINS,DPPPIPE,PIPNAK,PIPMAS)
3752 C
3753 C   NAK PIPING SYSTEM DESIGN AND MASS ESTIMATION ROUTINE
3754 C
3755 C   ***** VARIABLE DEFIED *****
3756 C
3757 C   XN9 = NUMBER OF 90 DEGREE ELBOWS OR EQUIVALENT IN PIPE SYSTEM
3758 C   R9 = AVERAGE RADIUS FOR 90 DEGREE ELBOWS (INCHES)
3759 C   Dp = INSIDE PIPE DIAMETER (INCHES)
3760 C   SUMLEN = TOTAL LENGTH OF PIPE SYSTEM (INCHES)
3761 C   Vpipe = NAK VELOCITY IN PIPES (FT/SEC)
3762 C   Tnak = NAK TEMPERATURE (deg-R)
3763 C   Pnak = NAK PRESSURE (psia)
3764 C   THICKP = PIPE WALL THICKNESS (INCHES)
3765 C   RHOIP = PIPE WALL DENSITY (LB/cu-FT)
3766 C   THICKI = PIPE INSULATION THICKNESS (INCHES)
3767 C   RHOINS = PIPE INSULATION DENSITY (LB/cu-FT)
3768 C   DPPPIPE = PIPE SYSTEM PRESSURE DROP (PSID)
3769 C   PIPMAS = PIPE SYSTEM MASS (LBS)
3770 C   PIPNAK = MASS OF NAK IN PIPE SYSTEM (LBS)
3771 C
3772 C   IF (THICKP.EQ.0.0) THICKP = (Pnak*Dp)/15000.0
3773 C   CALL XNAKPR(Tnak,RHO,CP,VIS,TK)
3774 C   RENak = Vpipe*Dp*RHO/(12.0*VIS)
3775 C   Qnak = RHO*(Vpipe**2.0)/(2.0*32.174*144.0)
3776 C   X1 = ALOG10(R9/Dp)
3777 C   BETA = -0.589233-(1.334185*X1)+(2.424496*(X1**2.0))-(1.272074*(X1*
3778 &*3.0))+0.148518*(X1**4.0))
3779 C   AK9 = 10.0**BETA
3780 C   X2 = ALOG10(RENak)
3781 C   Cfc = 6.723115-(1.517276*(X2))+(0.093726*(X2**2.0))
3782 C   DPelbo = XN9*Cfc*AK9*Qnak
3783 C   ROUGH = 0.0001
3784 C   FR1 = (ALOG10((ROUGH/(3.7*Dp)))+(5.74/(RENak**0.9))))**2.0
3785 C   FRIC = 0.25/FR1
3786 C   DPP = FRIC*(SUMLEN/Dp)*Qnak
3787 C   DPPPIPE = DPelbo+DPP
3788 C
3789 C   PIPING MASS ALGORITHM
3790 C
3791 C   DOp = Dp + (2.0*THICKP)
3792 C   DIp = Dp
3793 C   Axp = 0.785398*((DOp**2.0)-(DIp**2.0))
3794 C   XMPIPES = Axp*SUMLEN*(RHOIP/1728.0)
3795 C   DOi = DOp + (2.0*THICKI)
3796 C   AXPins = 0.785398*((DOi**2.0)-(DOp**2.0))
3797 C   XMPINS = AXPins*SUMLEN*(RHOINS/1728.0)
3798 C   XMEL = XN9*0.785398*R9**2.0*Axp*(RHOIP/1728.0)

```

SUBROUTINE HRPIPE Compiling Options: /NO/N7/B/MC/MD/NF/H/N1/NK/HL/P/NQ1/NQ2/NQ3/R/S/NT/U/WX/NZ1  
Source file Listing

```
3799      XMELin = XN9*0.785398*R9*2.0*AXPins*(RHOINS/1728.0)
3800      PIPMAS = XMPIPES+XMPINS+XMEL+XMELin
3801      AXnak = 0.785398*(Dip**2.0)
3802      Xnak1 = AXnak*SUNLEN*(RHO/1728.0)
3803      Xnak2 = AXnak*XN9*0.785398*R9*2.0*(RHO/1728.0)
3804      PIPNAK = Xnak1+Xnak2
3805      RETURN
3806      END
```

```
3807 C
3808 C
3809 C
3810 SUBROUTINE PUMP(Tnak,Unak,DPIPE,DPHX,DPMANIF,DPLOOP,Phyd,XMPUMP)
3811 C
3812 C PUMP MASS ESTIMATE
3813 C
3814 C
3815 C ***** VARIABLES DEFINED *****
3816 C
3817 C Tnak = NAK INLET TEMPERATURE (deg-R)
3818 C Unak = NAK FLOWRATE (LBS/SEC)
3819 C DPIPE = PIPING SYSTEMED PRESSURE DROP (PSID)
3820 C DPHX = NAK SIDE HEAT EXCHANGER PRESSURE DROP (PSID)
3821 C DPMANIF = NAK MANIFOLD PRESSURE DROP
3822 C Phyd = HYDRAULIC POWER REQUIRED FROM PUMP (WATTS)
3823 C XMPUMP = E-M PUMP MASS (LBS)
3824 C
3825 CALL XNAKPR(Tnak,RHO,CP,VIS,TK)
3826 GPM = 446.897*(Unak/RHO)
3827 DPLOOP = DPIPE+DPHX+DPMANIF
3828 Phyd = 0.435*DPLOOP*GPM
3829 XMPUMP = 37.0 + 0.323*Phyd
3830 C WRITE (6,*) ' '
3831 C WRITE (6,*) 'PUMP POWER REQUIRED (WATTS) (HYDRAULIC) =',Phyd
3832 C WRITE (6,*) 'PUMP MASS (Lbs) =',XMPUMP
3833 RETURN
3834 END
```

```

3835 C
3836 C
3837 C
3838 SUBROUTINE VACMAS(Tnak,XMNPiP,XMNMAn,XMNHEx,XMNVAc,XMVAc)
3839 C
3840 C VOLUME ACCUMULATOR MASS ESTIMATE
3841 C
3842 C VOLUME ACCUMULATOR NAK VOLUME IS ESTIMATED TO BE 1.20 TIMES THE
3843 C CHANGE IN LOOP NAK VOLUME BETWEEN 560 R AND THE OPERATING TEMP.
3844 C
3845 C ***** VARIABLES DEFINED *****
3846 C
3847 C Tnak = NAK TEMPERATURE (deg-R)
3848 C XMNPiP = NAK MASS IN PIPING SYSTEM (Lbs)
3849 C XMNMAn = NAK MASS IN RADIATOR MANIFOLD (Lbs)
3850 C XMNHEx = NAK MASS IN HEAT REJECTION HEAT EXCHANGER (Lbs)
3851 C XMNVAc = NAK VOLUME IN VOLUME ACCUMULATOR (cu-IN)
3852 C XMVAc = VOLUME ACCUMULATOR MASS (WET) (LBS)
3853 A11 = 560.0
3854 CALL XNAKPR(A11,RHOREF,CP,VIS,TK)
3855 CALL XNAKPR(Tnak,RHONAK,CP2,VIS2,TK2)
3856 XMNTOT = XMNPiP+XMNMAn+XMNHEx
3857 VOLACC = (((RHOREF-RHONAK)/RHONAK)*(XMNTOT/RHONAK)*1728.0)*1.2
3858 IF (VOLACC.LT.0.0) THEN
3859 XMNVAc = 0.0
3860 XMVAc = 0.0
3861 RETURN
3862 ELSE
3863 A12 = 0.66*ALOG10(VOLACC) - 0.28
3864 ENDIF
3865 XMmet = 10.0**A12
3866 XMNvac = (VOLACC/1728.0)*RHONAK
3867 XMVAc = XMmet+XMNvac
3868 C WRITE (6,*) 'VOLUME ACCUMULATOR NAK MASS (Lbs) =',XMNvac
3869 C WRITE (6,*) 'VOLUME ACCUMULATOR MASS (Lbs) =',XMVAc
3870 RETURN
3871 END

```



SUBROUTINE HRDUCT Compiling Options: /NO/H7/B/NC/ND/NF/H/M1/NK/NL/P/MQ1/MQ2/MQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```

3872 C
3873 C
3874 C
3875 C   SUBROUTINE HRDUCT(XN9,R9,Dp,SUMLEN,Vpipe,TGAS,PGAS,THICKP,RHOIP,
3876 C   &THICKI,RHOINS,XMW,DPDUCT,DUCMAS)
3877 C
3878 C   HE-XE DUCT MASS AND PRESSURE DROP FOR DIRECT CYCLE BRAYTON
3879 C
3880 C   ***** VARIABLES DEFINED *****
3881 C
3882 C   XN9 = NUMBER OF 90 DEGREE ELBOWS OR EQUIVALENT IN PIPE SYSTEM
3883 C   R9 = AVERAGE RADIUS FOR 90 DEGREE ELBOWS (INCHES)
3884 C   Dp = INSIDE DUCT DIAMETER (INCHES)
3885 C   SUMLEN = TOTAL LENGTH OF DUCT SYSTEM (INCHES)
3886 C   Vpipe = GAS VELOCITY IN DUCTS (FT/SEC)
3887 C   TGAS = GAS TEMPERATURE (deg-R)
3888 C   PGAS = GAS PRESSURE (psia)
3889 C   THICKP = DUCT WALL THICKNESS (INCHES)
3890 C   RHOIP = DUCT WALL DENSITY (LB/cu-FT)
3891 C   THICKI = DUCT INSULATION THICKNESS (INCHES)
3892 C   RHOINS = DUCT INSULATION DENSITY (LB/cu-FT)
3893 C   XMW = GAS MOLECULAR WEIGHT
3894 C   DPDUCT = DUCT SYSTEM PRESSURE DROP (PSID)
3895 C   DUCMAS = DUCT SYSTEM MASS (LBS)
3896 C
3897 C   CALL HEXEPR(XMW,PGAS,TGAS,GMA,CP,RHO,VIS,TK,PRGAS)
3898 C   RENak = Vpipe*Dp*RHO/(12.0*VIS)
3899 C   Qnak = RHO*(Vpipe**2.0)/(2.0*32.174*144.0)
3900 C   X1 = ALOG10(R9/Dp)
3901 C   BETA = -0.589233-(1.334185*X1)+(2.424496*(X1**2.0))-(1.272074*(X1*
3902 C   &*3.0))+(0.148518*(X1**4.0))
3903 C   AK9 = 10.0**BETA
3904 C   X2 = ALOG10(RENak)
3905 C   Cfc = 6.723115-(1.517276*(X2))+(0.093726*(X2**2.0))
3906 C   DPelbo = XN9*Cfc*AK9*Qnak
3907 C   ROUGH = 0.0001
3908 C   FR1 = (ALOG10((ROUGH/(3.7*Dp))+(5.74/(RENak**0.9))))**2.0
3909 C   FRIC = 0.25/FR1
3910 C   Dpp = FRIC*(SUMLEN/Dp)*Qnak
3911 C   DPDUCT = DPelbo+Dpp
3912 C
3913 C   PIPING MASS ALGORITHM
3914 C
3915 C   DOp = Dp + (2.0*THICKP)
3916 C   DiP = Dp
3917 C   Axp = 0.785398*((DOp**2.0)-(DiP**2.0))
3918 C   XMPIPES = Axp*SUMLEN*(RHOIP/1728.0)
3919 C   DOi = DOp + (2.0*THICKI)
3920 C   AXPins = 0.785398*((DOi**2.0)-(DOp**2.0))
3921 C   XMPINS = AXPins*SUMLEN*(RHOINS/1728.0)
3922 C   XMEL = XN9*0.785398*R9*AXp*(RHOIP/1728.0)
3923 C   XMELin = XN9*0.785398*R9*AXPins*(RHOINS/1728.0)

```

SUBROUTINE HRDUCT Compiling Options:/NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```
3924      DUCMAS = XMPIPES+XMPINS+XMEL+XMELin
3925      RETURN
3926      END
```

```

3927 C
3928 C
3929 C
3930 SUBROUTINE CONMAN(Ifluid,Cman,Hman,Gap,THICKins,RHOins,Tout,
3931 &Tbraze,TKcan,TKbraze,TKhp,XNpipes,XNexpipes,Pin,Tin,Xin,RHOip,
3932 &RHOCan,RHObraze,THICKman,Thtpip,Uman,Grad,XMANmas,DPman,DTFsup,
3933 &Ar,Gt,V,Dh,Cgt,Rel,Wl,Xtt,Rev,
3934 &DTFcon,DTFsub,DTfilm)
3935 C WRITE (6,*) 'FROM CONMAN - Ifluid,Cman,Hman,Gap,THICKins,RHOins ='
3936 C &,Ifluid,Cman,Hman,Gap,THICKins,RHOins
3937 C WRITE (6,*) 'Tout,Tbraze,TKcan,TKbraze,TKhp =',Tout,Tbraze,TKcan,
3938 C &TKbraze,TKhp
3939 C WRITE (6,*) 'XNpipes,XNexpipes,Pin,Tin,Xin =',XNpipes,XNexpipes,
3940 C &Pin,Tin,Xin
3941 C WRITE (6,*) 'RHOip,RHOCan,RHObraze,THICKman,Thtpip =',RHOip,RHOC
3942 C &an,RHObraze,THICKman,Thtpip
3943 C WRITE (6,*) 'Uman,Grad =',Uman,Grad
3944 C
3945 COMMON /CNFL/ DL, DV, VF, VG, HF, HG, HFG, SF, SG,
3946 & SFG, CL, Cv, TKl, TKv, Prl, Prv, Vl, Vv
3947 C SUBROUTINE TO DETERMINE THE MASS AND PERFORMANCE OF A CONDENSING
3948 C MANIFOLD FOR POTASSIUM WHICH TRANSFERS HEAT TO THE HEAT PIPES OF
3949 C A HEAT PIPE RADIATOR. THE MANIFOLD CONFIGURATION CONSISTS OF
3950 C A SQUARE PASSAGE WITH HEAT PIPES BRAZED TO ITS OD.
3951 C
3952 C VARIABLES
3953 C Ifluid = FLAG TO IDENTIFY HEAT PIPE WORKING FLUID
3954 C Cman = MANIFOLD CIRCUMFERENCE OR LENGTH (FEET)
3955 C Hman = MANIFOLD HEIGHT (FEET)
3956 C Gap = MANIFOLD WIDTH (Feet)
3957 C XNpipes = NUMBER OF PRIMARY HEAT PIPES IN RADIATOR
3958 C XNexpipes = NUMBER OF REDUNDENT HEAT PIPES IN RADIATOR
3959 C Tbraze = BRAZE JOINT THICKNESS (Feet)
3960 C TKcan = THERMAL CONDUCTIVITY OF MANIFOLD CAN MATERIAL (B/HFR)
3961 C TKbraze = THERMAL CONDUCTIVITY OF MANIFOLD BRAZE ALLOY (")
3962 C TKhp = THERMAL CONDUCTIVITY OF HEAT PIPE WALL MATERIAL (")
3963 C RHOCan = DENSITY OF MANIFOLD MATERIAL (Lb/cu-Ft)
3964 C RHObraze = DENSITY OF BRAZE MATERIAL (Lb/cu-Ft)
3965 C THICKman = MANIFOLD MATERIAL THICKNESS (Feet)
3966 C Thtpip = HEAT PIPE WALL THICKNESS (FEET)
3967 C Pin = MANIFOLD INLET PRESSURE (PSIA)
3968 C Tin = MANIFOLD INLET TEMPERATURE (deg-R)
3969 C Xin = MANIFOLD INLET QUALITY (LIQUID FRACTION)
3970 C Uman = MANIFOLD FLOWRATE (LBS/HR)
3971 C Qman = MANIFOLD AND RADIATOR HEAT LOAD (BTU/HR)
3972 C XMW = MOLECULAR WEIGH OF MANIFOLD WORKING FLUID
3973 C
3974 C OUTPUT VARIABLES
3975 C XMANmas = MANIFOLD MASS (Lbs)
3976 C DPman = MANIFOLD PRESSURE DROP (PSIA)
3977 C DTfilm = MANIFOLD FILM TEMPERATURE DROP (deg-R)
3978 C
3979 C Qman = 3413.0*Grad

```

```

3980 C
3981 C   MANIFOLD CONVECTIVE HEAT TRANSFER COEFFICIENT
3982 C
3983 C   CALL KPRP(Xin,Pin,Tin,DL,DV,HF,NG,HFG,SF,SG,SFG,VF,VG)
3984 C   CALL KTRN(Xin,Pin,Tin,Cl,Cv,TKl,TKv,Prl,Prv,Vl,Vv)
3985 C   WRITE (6,*) 'Xin,Pin,Tin,DL,DV,HF,NG,HFG,SF,SG,SFG,VF,VG =',Xin,
3986 C   &Pin,Tin,DL,DV,HF,NG,HFG,SF,SG,SFG,VF,VG
3987 C   WRITE (6,*) 'Cl,Cv,TKl,TKv,Prl,Prv,Vl,Vv =',Cl,Cv,TKl,TKv,Prl,Prv,
3988 C   &Vl,Vv
3989 C
3990 C
3991 C
3992 C   Ax = Gap*Hman
3993 C   Dh = (4.0*Ax)/((2.0*Gap)+(2.0*Hman))
3994 C
3995 C   NOTE THAT CONDENSER HAS TWO SIDES - 1/2 THE HEAT PIPES ARE
3996 C   ATTACHED TO ALTERNATING SIDES OF THE MANIFOLD BOX
3997 C
3998 C   Ac = 2.0*(Hman*Qman)/(XNpipes+XNexpipes)
3999 C   DX = Ac/Hman
4000 C   Wman = Wman
4001 C   X = Xin
4002 C   CH = Hman
4003 C   CW = Gap
4004 C   ETA = 0.000005
4005 C   Qflux = Qman/(2.0*Hman*Qman)
4006 C   JHP = IFIX(XNpipes+XNexpipes)
4007 C   WRITE (6,*) 'Ax,Dh,Ac,DX,Wman,X,CH,CW,ETA,Qflux,JHP =',Ax,Dh,Ac,DX
4008 C   &,Wman,X,CH,CW,ETA,Qflux,JHP
4009 C
4010 C   COMPUTE SATURATION TEMP: EQUATION IS FOR POTASSIUM ONLY
4011 C
4012 C   Tsat = (-7633.6)/(ALOG10(Pin)-5.279)
4013 C   WRITE (6,*) 'Tsat FROM 3650 (R) =',Tsat
4014 C   IF (Tin.GT.Tsat) THEN
4015 C     Qdesup = Wman*Cv*(Tin - Tsat)
4016 C     Qcondn = Wman*HFG
4017 C     Qsubc = Qman - Qdesup - Qcondn
4018 C   WRITE (6,*) 'Qdesup,Qcondn,Qsubc FROM 3661=',Qdesup,Qcondn,Qsubc
4019 C     JNSUP = (Qdesup/Qman)*JHP
4020 C     JNCON = (Qcondn/Qman)*JHP
4021 C     JNSUB = (Qsubc/Qman)*JHP
4022 C     IF (JNSUP.EQ.0) JNSUP = 1
4023 C     IF (JNCON.EQ.0) JNCON = 1
4024 C     IF (JNSUB.EQ.0) JNSUB = 1
4025 C   WRITE (6,*) 'JNSUP, JNCON, JNSUB =',JNSUP,JNCON,JNSUB
4026 C   GO TO 70
4027 C   ELSE
4028 C     GO TO 20
4029 C   ENDF
4030 C   20 IF (Tin.EQ.Tsat) THEN
4031 C     Qdesup = 0.0

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```

4032      Qsubc = Uman*Cl*(Tsat - Tout)
4033      Qcondn = Qman - Qsubc
4034 C     WRITE (6,*) 'Qdesup,Qcondn,Qsubc FROM 3674=',Qdesup,Qcondn,Qsubc
4035      JNSUP = 0
4036      JNCON = (Qcondn/Qman)*JHP
4037      JNSUB = JHP - JNCON
4038      IF (JNCON.EQ.0) JNCON = 1
4039      IF (JNSUB.EQ.0) JNSUB = 1
4040 C     WRITE (6,*) 'JNSUP, JNCON, JNSUB =',JNSUP,JNCON,JNSUB
4041      GO TO 80
4042      ELSE
4043      GO TO 30
4044      ENDIF
4045      30 IF (Tin.LT.Tsat) THEN
4046      Qdesup = 0.0
4047      Qcondn = 0.0
4048      Qsubc = Qman
4049 C     WRITE (6,*) 'Qdesup,Qcondn,Qsubc FROM 3687=',Qdesup,Qcondn,Qsubc
4050      JNSUP = 0
4051      JNCON = 0
4052      JNSUB = JHP
4053      IF (JNSUB.EQ.0) JNSUB = 1
4054 C     WRITE (6,*) 'JNSUP, JNCON, JNSUB =',JNSUP,JNCON,JNSUB
4055      GO TO 90
4056      ELSE
4057      GO TO 70
4058      ENDIF
4059      70 CALL CVAP(Uman, CH, CU, DX, ETA, Hc, DPnet1,Ar,Gt,V,Dh,Rev,H1)
4060 C     WRITE (6,*) 'INFO FROM AFTER CVAP CALL IN CONMAN'
4061 C     WRITE (6,*) 'Uman,CH,CU,DX,ETA,Hc,DPnet1,Ar,Gt,V,Dh,Rev,H1 =',Uman
4062 C     &,CH,CU,DX,ETA,Hc,DPnet1,Ar,Gt,V,Dh,Rev,H1
4063      Hcman = Hc
4064      Tman = Tin
4065      T0 = (Tman/1.8) - 273.2
4066      CALL Fluidprop(Ifluid,T0,Xliqden,Vapden,Xliqvisc,Vapvisc,P0,Surf
4067      &ten,Xlhv,Xk,Xmrfluid,Tcfluid)
4068      Hevap = (Tcfluid/0.00413656)/(0.0083)
4069      Ha = Hcman
4070 C     COMPUTE FILM TEMPERATURE DROP FOR DESUPERHEATER
4071      D1 = Qflux
4072      D2 = 1.0/Ha
4073      D3 = THICKman/TKcan
4074      D4 = Tbraze/TKbraze
4075      D5 = Thtpip/TKhp
4076      D6 = 1.0/Hevap
4077      Usup = 1.0/(D2+D3+D4+D5+D6)
4078      DTfsup = D1*(D2+D3+D4+D5+D6)
4079 C     WRITE (6,*) 'Qflux, Usup, DTfsup =',Qflux,Usup,DTfsup
4080 C     WRITE (6,*) 'Hevap,Ha,D1,D2,D3,D4,D5,D6,DTfsup =',Hevap,Ha,D1,D2,
4081 C     &D3,D4,D5,D6,DTfsup
4082 C
4083      80 X=Xin/2.0

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4084 CALL COND(Uman, X, CH, CW, DX, ETA, Hc, DPnet2, Ar, Gt, V, Dh, Cgt, Rel,
4085 & HI, Xtt, Rev)
4086 C WRITE (6,*) 'INFO FROM AFTER COND CALL IN COMMAN'
4087 C WRITE (6,*) 'Uman,X,CH,CW,DX,ETA,Hc,DPnet2,Ar,Gt,V,Dh,Rev,Cgt,Rel,
4088 C &HI,Xtt,Rev =', Uman, X, CH, CW, DX, ETA, Hc, DPnet2, Ar, Gt, V, Dh, Rev, Cgt, Rel
4089 C &, HI, Xtt, Rev
4090 Hcman = Hc
4091 Tman = Tin
4092 TO = (Tman/1.8) - 273.2
4093 CALL Fluidprop(Ifluid, TO, Xliqden, Vapden, Xliqvsc, Vapvisc, PO, Surf
4094 &ten, Xlhw, Xk, Xmrfluid, Tcfluid)
4095 Hevap = (Tcfluid/0.00413656)/(0.0083)
4096 Ha = Hcman
4097 C COMPUTE FILM TEMPERATURE DROP FOR CONDENSER
4098 D1 = Qflux
4099 D2 = 1.0/Ha
4100 D3 = THICKman/TKcan
4101 D4 = Tbraze/TKbraze
4102 D5 = Thtpip/TKhp
4103 D6 = 1.0/Hevap
4104 Ucon = 1.0/(D2+D3+D4+D5+D6)
4105 DTFcon = D1*(D2+D3+D4+D5+D6)
4106 C WRITE (6,*) 'Qflux, Ucon, DTFcon =', Qflux, Ucon, DTFcon
4107 C WRITE (6,*) 'Hevap, Ha, D1, D2, D3, D4, D5, D6, DTFcon =', Hevap, Ha, D1, D2,
4108 C &D3, D4, D5, D6, DTFcon
4109 C
4110 90 CALL CLIQ(Uman, CH, CW, DX, ETA, Hc, DPnet3, Ar, Gt, V, Dh, Rev, HI)
4111 C WRITE (6,*) 'INFO FROM AFTER CLIQ CALL IN COMMAN'
4112 C WRITE (6,*) 'Uman,CH,CW,DX,ETA,Hc,DPnet3,Ar,Gt,V,Dh,Rev,HI =',
4113 C &Uman, CH, CW, DX, ETA, Hc, DPnet3, Ar, Gt, V, Dh, Rev, HI
4114 Hcman = Hc
4115 Tman = Tin
4116 TO = (Tman/1.8) - 273.2
4117 CALL Fluidprop(Ifluid, TO, Xliqden, Vapden, Xliqvsc, Vapvisc, PO, Surf
4118 &ten, Xlhw, Xk, Xmrfluid, Tcfluid)
4119 Hevap = (Tcfluid/0.00413656)/(0.0083)
4120 Ha = Hcman
4121 C COMPUTE FILM TEMPERATURE DROP FOR SUBCOOLER
4122 D1 = Qflux
4123 D2 = 1.0/Ha
4124 D3 = THICKman/TKcan
4125 D4 = Tbraze/TKbraze
4126 D5 = Thtpip/TKhp
4127 D6 = 1.0/Hevap
4128 Usub = 1.0/(D2+D3+D4+D5+D6)
4129 DTFsub = D1*(D2+D3+D4+D5+D6)
4130 C WRITE (6,*) 'Qflux, Usub, DTFsub =', Qflux, Usub, DTFsub
4131 C WRITE (6,*) 'Hevap, Ha, D1, D2, D3, D4, D5, D6, DTFsub =', Hevap, Ha, D1, D2,
4132 C &D3, D4, D5, D6, DTFsub
4133 C
4134 C COMPUTE AVERAGE FILM DROP TO BE USED FOR RADIATOR DESIGN
4135 C
4136 ANSUP = FLOAT(JNSUP)

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```

4137      ANCON = FLOAT(JNCON)
4138      ANSUB = FLOAT(JNSUB)
4139      AHP = FLOAT(JHP)
4140      DTfilm = ((ANCON/AHP)*DTFcon)
4141      &+((ANSUB/AHP)*DTFsub)
4142      DPman = DPnet1+DPnet2+DPnet3
4143 C      WRITE (6,*) 'DTfilm, DPman =', DTfilm, DPman
4144 C      MASS ESTIMATE
4145 C      MANIFOLD METAL MASS
4146      Vman = (((2.0*Hman)+(2.0*Gap))*Cman*THICKman)
4147      XMwall = Vman*RHOcan
4148 C      MANIFOLD TO HEAT PIPE BRAZE MASS
4149      Vbraz = 2.0*Hman*Cman*Tbraz
4150      XMbraz = Vbraz*RHObraz
4151 C      TOTAL FLAT HEAT PIPE EVAPORATOR MASS
4152      Vheatpip = 4.0*Hman*Cman*Thtpip
4153      XMhtpip = RHOpip*Vheatpip
4154 C      WRITE (6,*) 'Vman, XMwall, Vbraz, XMbraz, Vheatpip, XMhtpip =', Vman,
4155 C      &XMwall, Vbraz, XMbraz, Vheatpip, XMhtpip
4156 C      INSULATION MASS
4157      Vins = ((2.0*Hman)+(2.0*Gap))*Cman*THICKins
4158      XMins = Vins*RHOins
4159 C      LIQUID INVENTORY IN MANIFOLD
4160      Vliq = FLOAT(JNSUB/JHP)*Hman*Gap*Cman
4161      XMliqin = DL*Vliq
4162 C      TOTAL MASS OF RADIATOR MANIFOLD
4163      XMAMmas = XMwall+XMbraz+XMhtpip+XMins+XMliqin
4164 C      WRITE (6,*) 'Vins, XMins, Vliq, XMliqin, XMAMmas =', Vins, XMins, Vliq,
4165 C      &XMliqin, XMAMmas
4166      IF (JNCON.EQ.0) Cgt=0.0
4167      IF (JNCON.EQ.0) Xt=0.0
4168      RETURN
4169      END

```

```

WARNING - REAL VARIABLE (USUP) assigned a value, never used, line 4077.
WARNING - REAL VARIABLE (UCON) assigned a value, never used, line 4104.
WARNING - REAL VARIABLE (USUB) assigned a value, never used, line 4128.
WARNING - REAL VARIABLE (ANSUP) assigned a value, never used, line 4136.

```

SUBROUTINE CLIQ Compiling Options:/N0/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```

4170 C
4171 C
4172 C
4173 C
4174     SUBROUTINE CLIQ (Wman,MM,MM,DX,ETA,Hs,DPnet3,Ar,Gt,V,Dh,
4175     & Rel,HI)
4176 C** CALCULATES HEAT TRANSFER & PRESSURE DROP FOR PURE VAPOR
4177 C** A TWO-PHASE FLUID (GAS-LIQUID) ** ADJUSTED FOR LIQUID METALS
4178     COMMON /CNFL/ DL, DV, VF, VG, HF, HG, HFG, SF, SG,
4179     & SFG, Cl, Cv, TKL, TKv, Prl, Prv, Vl, Vv
4180
4181 C     WRITE (6,*) 'DATA FROM CLIQ'
4182 C     WRITE (6,*) 'REVIEW CONTENTS OF COMMON'
4183 C     WRITE (6,*) 'DL,DV,VF,VG,HF,HG,HFG,SF,SG,SFG,Cl,Cv,TKL,TKv,Prl,Prv
4184 C     &,Vl,Vv =',DL,DV,VF,VG,HF,HG,HFG,SF,SG,SFG,Cl,Cv,TKL,TKv,Prl,Prv,Vl
4185 C     &,Vv
4186     Gc = 32.1739
4187 C** HEAT TRANSFER
4188 C** FLOW CROSS-SECTIONAL AREA (sq ft)
4189     Ar = MM * MM
4190     Dh = (4.0*Ar)/((2.0*MM)+(2.0*MM))
4191 C** Gt - MASS FLUX (lbm/h sq ft)
4192 C** M - FLOW RATE PER TUBE, (lbm/h)
4193     Gt = Wman / Ar
4194 C     WRITE (6,*) 'Gc,Ar,Dh,Gt =',Gc,Ar,Dh,Gt
4195
4196 C** LIQUID VELOCITY, ft/s
4197     V = Gt/( DL * 3600.0 )
4198
4199 C** CONDENSATE FILM REYNOLDS NUMBER
4200     Rel = Wman*Dh/(Ar*Vl)
4201
4202 C** HI - SHEAR-CONTROLLED LIQUID FILM HEAT TRANSFER COEFFICIENT
4203     HI = (7.0 + 0.025*(Rel * Prl)**0.8 )*( TKL/Dh)
4204     Hs = HI
4205
4206 C** PRESSURE DROP
4207 C** MOMENTUM PRESSURE DROP (psia)
4208 C** i = inlet, e = exit
4209 C     DPm = Gt**2.0/Gc*( ((1.0-Y)/Dle+Y/DVe) - ((1.0-Y)/Dli+Y/DVi) )
4210
4211 C** CALCULATE FRICTION FACTORS
4212     FFl = FF(Dh, ETA, Rel)
4213
4214 C** LIQUID PRESSURE DROP (psia)
4215     DPl = FFl*(DX/Dh)*Gt**2.0**((1.0)/(2.0*DL*Gc))
4216 C     WRITE (6,*) 'V,Rel,HI,Hs,DPl,FFl =',V,Rel,HI,Hs,DPl,FFl
4217     DPl = DPl/(144.0*3600.0**2.0)
4218
4219 C** DPf FRICTION PRESSURE DROP (psia)
4220     DPf = DPl
4221     DPnet3 = DPf

```



SUBROUTINE CLIQ Compiling Options:/NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```
4222 C   WRITE (6,*) 'DPl,DPf,DPnet3 =',DPl,DPf,DPnet3
4223     RETURN
4224     END
```

SUBROUTINE COND Compiling Options:/NO/N7/B/MC/ND/NF/H/N1/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1  
Source file Listing

```

4225 C
4226 C
4227 C
4228 SUBROUTINE COND (Uman,Y,MM,MM,DX,ETA,Hs,DPnet2,Ar,Gt,V,Dh,
4229 & Cgt,Rel,NI,Xtt,Rev)
4230 Gc=32.1739
4231 C** CALCULATES HEAT TRANSFER & PRESSURE DROP FOR
4232 C** A TWO-PHASE FLUID (GAS-LIQUID) ** ADJUSTED FOR LIQUID METALS
4233 COMMON /CNFL/ DL, DV, VF, VG, HF, HG, HFG, SF, SG,
4234 & SFG, Cl, Cv, TKl, TKv, Prl, Prv, Vl, Vv
4235
4236 C WRITE (6,*) 'INFO FROM COND'
4237 C WRITE (6,*) 'REVIEW CONTENTS OF COMMON'
4238 C WRITE (6,*) 'DL,DV,VF,VG,HF,HG,HFG,SF,SG,SFG,Cl,Cv,TKl,TKv,Prl,Prv
4239 & ,Vl,Vv =',DL,DV,VF,VG,HF,HG,HFG,SF,SG,SFG,Cl,Cv,TKl,TKv,Prl,Prv,Vl
4240 & ,Vv
4241 C** HEAT TRANSFER
4242 C** FLOW CROSS-SECTIONAL AREA (sq ft)
4243 Ar = MM * MM
4244 C WRITE (6,*) 'Ar =',Ar
4245 Dh = (4.0*Ar)/((2.0*MM)+(2.0*MM))
4246 C WRITE (6,*) 'Dh =',Dh
4247 C** Gt - MASS FLUX (lbm/h sq ft)
4248 C** M - FLOW RATE PER TUBE(LIQUID PLUS VAPOR), lbm/h
4249 Gt = Uman / Ar
4250 C WRITE (6,*) 'Gt =',Gt
4251
4252 C** VAPOR VELOCITY, ft/s
4253 C** Y - LOCAL VAPOR WEIGHT FRACTION FACTOR
4254 V = Y*Gt/(DV * 3600.0 )
4255 C WRITE (6,*) 'V =',V
4256
4257 C** Cgt - TUBESIDE FLOW REGIME PARAMETER
4258 C** IF Cgt < 0.3, SHEAR-CONTROLLED LIQUID FILM HEAT TRANSFER COEFFICIENT
4259 Cgt = (Dh*(Gc*(3600.0**2.0))*DV*(DL-DV)*((1-Y)/Y))**0.5/Gt
4260 C WRITE (6,*) 'Cgt =',Cgt
4261
4262 C** CONDENSATE FILM REYNOLDS NUMBER
4263 Rel = Uman*(1.0-Y)*Dh/(Ar*VL)
4264 C WRITE (6,*) 'Rel =',Rel
4265
4266 C** VISCOSITY CORRECTION FACTOR , (BULK VISCOSITY/WALL VISCOSITY)**0.14
4267 C** ASSUMED EQUAL TO 1
4268 C** VCF = 1.0
4269
4270 C** NI - SHEAR-CONTROLLED LIQUID FILM HEAT TRANSFER COEFFICIENT
4271 C** NI = 0.022*(Rel)**0.8 * (Pr)**0.4 * (TKl/Dh) * VCF
4272 NI = (7.0 + 0.025*(Rel * Prl)**0.8 )*(TKl/Dh)
4273 C WRITE (6,*) 'NI =',NI
4274
4275 C** Xtt - MARTINELLI PARAMETER, FORM FOR BOTH TURBULENT PHASES
4276 Xtt = ((1.0-Y)/Y)**0.9 * (DV/DL)**0.5 * (VL/VV)**0.1

```

```

4277 C   WRITE (6,*) 'Xtt =',Xtt
4278
4279 C**  Csh - CORRELATION FUNCTION FOR SHEAR-CONTROLLED FLOW HT & DP
4280      Csh = 2.75 *(1.0 + 2.0/Xtt**0.5)* (1.0 - DV/DL)**1.5
4281 C   WRITE (6,*) 'Csh =',Csh
4282
4283 C**  Ftp - SHEAR-CONTROLLED FLOW TWO PHASE HEAT TRANSFER FACTOR
4284      Ftp = (1.0 + Csh/Xtt + 1.0/Xtt**2.0)**0.5
4285 C   WRITE (6,*) 'Ftp =',Ftp
4286
4287 C**  Hs - SHEAR-CONTROLLED LIQUID FILM HEAT TRANSFER COEFFICIENT
4288      Hs = Ftp*Hl
4289 C   WRITE (6,*) 'Hs =',Hs
4290
4291 C**  PRESSURE DROP
4292 C**  MOMENTUM PRESSURE DROP (psia)
4293 C**  i = inlet, e = exit
4294 C   Dpm = Gt**2.0/Gc*( ((1.0-Y)/Dle+Y/DVe) - ((1.0-Y)/Dli+Y/DVi) )
4295
4296 C**  VAPOR REYNOLDS NUMBER
4297      Rev = Uman*Y*Dh/(Ar*VV)
4298 C   WRITE (6,*) 'Rev =',Rev
4299
4300 C**  CALCULATE FRICTION FACTORS
4301      FF1 = FF(Dh, ETA, Rel)
4302      FFv = FF(Dh, ETA, Rev)
4303
4304 C**  LIQUID PRESSURE DROP (psia)
4305      DPL = FF1*(DX/Dh)*Gt**2.0*(1.0-Y)**2.0*(1.0/(2.0*DL*Gc))
4306      DPL = DPL/(144.0*3600.0**2.0)
4307
4308 C**  VAPOR PRESSURE DROP (psia)
4309      DPv = FFv*(DX/Dh)*Gt**2.0*Y**2.0*(1.0/(2.0*DV*Gc))
4310      DPv = DPv/(144.0*3600.0**2.0)
4311
4312 C   WRITE (6,*) 'FF1,FFv,DPL,DPv =',FF1,FFv,DPL,DPv
4313 C**  FLF TWO PHASE FRICTION LOSS FACTORS
4314 C**  DPf FRICTION PRESSURE DROP (psia)
4315      IF (Rel.GT.2000.0) THEN
4316          FLF = (1.0 + Csh/Xtt + 1.0/Xtt**2.0)**0.5
4317          DPf = FLF**2.0 * DPL
4318      ELSE
4319          FLF = (1.0 + Csh*Xtt + Xtt**2.0)**0.5
4320          DPf = FLF**2.0 * DPv
4321      ENDIF
4322      DPnet2 = DPf
4323      RETURN
4324      END

```

SUBROUTINE CVAP Compiling Options:/N0/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/WX/NZ1  
Source file Listing

```

4325 C
4326 C
4327 C
4328 SUBROUTINE CVAP (Uman,MM,WM,DX,ETA, Hs, DPnet1,Ar,Gt,V,Dh,
4329 & Rev,Hl)
4330 Gc = 32.1739
4331 C** CALCULATES VAPOR HEAT TRANSFER & PRESSURE DROP FOR
4332 COMMON /CNFL/ DL, DV, VF, VG, HF, HG, HFG, SF, SG,
4333 & SFG, Cl, Cv, TKL, TKv, Pri, Prv, Vl, Vv
4334
4335 C WRITE (6,*) 'DATA FROM CVAP'
4336 C WRITE (6,*) 'REVIEW CONTENTS OF COMMON'
4337 C WRITE (6,*) 'DL,DV,VF,VG,HF,HG,HFG,SF,SG,SFG,Cl,Cv,TKL,TKv,Pri,Prv,
4338 & ,Vl,Vv =',DL,DV,VF,VG,HF,HG,HFG,SF,SG,SFG,Cl,Cv,TKL,TKv,Pri,Prv,Vl
4339 C & ,Vv
4340 C** HEAT TRANSFER
4341 C** FLOW CROSS-SECTIONAL AREA (sq ft)
4342 Ar = MM * WM
4343 Dh = (4.0*Ar)/((2.0*MM)+(2.0*WM))
4344 C** Gt - MASS FLUX (lbm/h sq ft)
4345 C** M - FLOW RATE PER TUBE (lbm/h)
4346 Gt = Uman / Ar
4347
4348 C** VAPOR VELOCITY, ft/s
4349 V = Gt/( DV * 3600.0 )
4350 C WRITE (6,*) 'Ar,Dh,Gt,V =',Ar,Dh,Gt,V
4351
4352 C** VAPOR REYNOLDS NUMBER
4353 Rev = Uman*Dh/(Ar*Vv)
4354
4355 C** Hl - SHEAR-CONTROLLED VAPOR FILM HEAT TRANSFER COEFFICIENT
4356 Hl = 0.022*(Rev)**0.8 * (Prv)**0.6 * (TKv/Dh)
4357 Ftp = 1.0
4358 Hs = Ftp*Hl
4359 C WRITE (6,*) 'Rev,Hl,Ftp,Hs =',Rev,Hl,Ftp,Hs
4360 C** PRESSURE DROP
4361 C** MOMENTUM PRESSURE DROP (psia)
4362 C** i = inlet, e = exit
4363 C DPm = Gt**2.0/Gc*( ((1.0-Y)/Dle+Y/DVe) - ((1.0-Y)/Dli+Y/DVi) )
4364
4365 C** CALCULATE FRICTION FACTORS
4366 FFv = FF(Dh, ETA, Rev)
4367
4368 C** VAPOR PRESSURE DROP (psia)
4369 DPv = FFv*(DX/Dh)*Gt**2.0*(1.0/(2.0*DV*Gc))
4370 DPv = DPv/(144.0*3600.0**2.0)
4371 C WRITE (6,*) 'FFv,DPv =',FFv,DPv
4372 C** DPf FRICTION PRESSURE DROP (psia)
4373 DPf = DPv
4374 DPnet1 = DPf
4375 RETURN
4376 END

```

FUNCTION FF Compiling Options:/NO/M7/B/NC/ND/NF/H/NI/NK/NL/P/NO1/NO2/NO3/R/S/NT/W/NX/WZ1  
Source file Listing

```
4377 C
4378 C
4379 C
4380     FUNCTION FF(Dh, ETA, RE)
4381 C**  FF, FRICTION FACTOR
4382 C**  ETA, SURFACE ROUGHNESS, ft
4383     FF = 0.25/(ALOG10(ETA/(3.7*Dh) + 5.74/RE**0.9))**2.0
4384     IF (RE.LE.2000.0) FF = 64.0/RE
4385     IF (RE.GT.2000.0 .AND. RE.LT.4000.0)
4386 &     FF = 0.032*(1.0 - (RE-2000.0)/2000.0) + FF*(RE-2000.0)/2000.0
4387     END
```

SUBROUTINE KPRP Compiling Options:/NO/W7/B/MC/MD/NF/H/NI/NK/NL/P/WQ1/WQ2/WQ3/R/S/NT/U/WX/WZ1  
Source file Listing

```

4388 C
4389 C
4390 C
4391 SUBROUTINE KPRP(X,P,T, DL, DV, HF, HG, HFG, SF, SG, SFG, VF, VG)
4392 C WRITE (6,*) 'FROM KPRP, X,P,T =', X, P, T
4393 C** REFERENCE: NAVAL RESEARCH LABORATORY (NRL REPORT 6233)
4394 C** = HIGH-TEMPERATURE PROPERTIES OF POTASSIUM*
4395 DATA XMW, R, TR / 39.0983, 1.986, 460.0 /
4396
4397 C** SATURATION PRESSURE (psia), page 14, equation 2
4398 IF(X.EQ.1) Pv= 10.0**(6.12758 - 8128.77/T - 0.53299*ALOG10(T))
4399
4400 C** LIQUID DENSITY (lbm/cu ft), page 18, equation 9
4401 DL = 52.768 - 7.4975E-3*(T-TR) - 0.5255E-6*(T-TR)**2.0
4402 & + 0.0498E-9*(T-TR)**3.0
4403
4404 C** LIQUID SPECIFIC VOLUME (cu ft/lbm)
4405 VF = 1.0/DL
4406
4407 C** CONSTANTS & DERIVATIVES OF VIRIAL EQUATION, page 29, equation 29
4408 B = -T*10.0**(-3.8787 + 4890.7/T)
4409 DB = B/T*(1.0 - 4890.7*ALOG(10)/T)
4410 C = 10.0**(0.5873 + 6385.7/T)
4411 DC = -6385.7*ALOG(10) * C/T**2.0
4412 D = -1.0*10**(1.4595 + 7863.8/T)
4413 DD = -7863.8*ALOG(10) * D/T**2.0
4414
4415 C** SOLVE FOR VOLUME VAPOR STATE BY VIRIAL EQUATION, 0.7302=GAS CONSTANT
4416 V1 = 0.7302*T/Pv
4417 DO 10 I=1,100
4418 FUNC = Pv*V1/(0.7302*T) - (1.0 + B/V1 + C/V1**2 + D/V1**3)
4419 SLOPE = Pv/(0.7302*T) + (B/V1**2 + 2.0*C/V1**3 + 3.0*D/V1**4)
4420 V2 = V1 - FUNC/SLOPE
4421 IF (ABS(FUNC) .LT. 1.0E-6) GO TO 20
4422 V1 = V2
4423 10 CONTINUE
4424 20 VG = V2
4425
4426 C** ENTHALPY OF VAPORIZATION (Btu/lbm)
4427 HFG = (R/0.7302)*Pv*(8128.77*ALOG(10.0)/T - 0.53299)*(VG/XMW-VF)
4428
4429 C** REFERENCE ENTHALPY (Btu/lbm), page 23, equation 10
4430 HGO = 998.95 + 0.127*T + 24836.0*EXP(-39375.0/T)
4431 DE = T/VG*((DB-B/T)+1.0/VG*(DC/2.0-C/T)+1.0/VG**2.0*(DD/3.0-D/T))
4432
4433 C** ENTHALPY VAPOR STATE (Btu/lbm), page 32, equation 26
4434 HG = HGO - (R*T/XMW)*DE
4435
4436 C** ENTHALPY LIQUID STATE (Btu/lbm), page 33
4437 HF = HG - HFG
4438
4439 C** ENTROPY OF VAPORIZATION (Btu/lbm R)
4440 SFG = HFG/T

```

```

4441
4442 C** REFERENCE ENTROPY STATE (Btu/lbm R), page 23, equation 11
4443     SGO = 0.18075 + 0.127*ALOG(T) + 0.7617*EXP(-31126.0/T)
4444     DS  = T/VG*((DB+B/T) + 1.0/(2.0*VG)*(DC+C/T) +
4445     &      1.0/(3.0*VG**2.0)*(DD+D/T)) - ALOG(Pv*VG/(0.7302*T))
4446
4447 C** ENTROPY VAPOR STATE (Btu/lbm R), page 32, equation 27
4448     SG = SGO - (R/XMW)*(ALOG(Pv) + DS)
4449
4450 C** ENTROPY LIQUID STATE (Btu/lbm R), page 33
4451     SF = SG - SFG
4452
4453 C** VAPOR SPECIFIC VOLUME (cu ft/lbm)
4454     VG = VG/XMW
4455
4456 C** VAPOR DENSITY (lbm/cu ft)
4457     DV = 1.0/VG
4458
4459     RETURN
4460     END
    
```

WARNING - REAL VARIABLE (P), a dummy argument, is never used, line 4391.

SUBROUTINE KTRN Compiling Options:/NO/N7/B/NC/ND/NF/H/N1/NK/NL/P/NO1/NO2/NO3/R/S/NT/W/NX/NZ1  
Source file listing

```
4461 C
4462 C
4463 C
4464 SUBROUTINE KTRN(X,P,T, Cl, Cv, TKl, TKv, Prl, Prv, VL, Vv)
4465 C** = TRANSPORT PROPERTIES OF POTASSIUM
4466
4467 C** LIQUID HEAT CAPACITY (Btu/lbm)
4468 Cl = 0.22713 - 64.848E-6*T + 23.178E-9*T**2.0
4469
4470 C** LIQUID VISCOSITY (lbm/ft-h)
4471 VL = EXP(1353.9/T - 1.9206)
4472
4473 C** LIQUID THERMAL CONDUCTIVITY (Btu/h-ft-R)
4474 TKl = 32.2036 - 7.6789E-3*T
4475
4476 C** LIQUID PRANDTL NUMBER
4477 Prl = Cl*VL/TKl
4478
4479 C** VAPOR CAPACITY (Btu/lbm)
4480 CALL KPRP(X,P,(T-0.01), DL, DV, HF, H1, HFG, SF, SG, SFG, VF, VG)
4481 CALL KPRP(X,P,(T+0.01), DL, DV, HF, H2, HFG, SF, SG, SFG, VF, VG)
4482 Cv = (H2-H1)/0.02
4483
4484 C** VAPOR VISCOSITY (lbm/ft-h)
4485 Vv = 1.0282E-2 + 2.5649E-5*T - 3.125E-9*T**2.0
4486
4487 C** VAPOR THERMAL CONDUCTIVITY (Btu/h-ft-R)
4488 TKv = 1.8786E-3 + 4.3527E-6*T - 5.2198E-10*T**2.0
4489
4490 C** VAPOR PRANDTL NUMBER
4491 Prv = Cv*Vv/TKv
4492
4493 RETURN
4494 END
```





# Report Documentation Page

|  |  |   |  |                            |            |
|--|--|---|--|----------------------------|------------|
| 1. Report No.<br><b>NASA CR-191132</b>   |  | 2. Government Accession No.                                 |  | 3. Recipient's Catalog No. |            |
| 4. Title and Subtitle<br><b>Heat Pipe Cooled Heat Rejection Subsystem Modeling for Nuclear Electric Propulsion (Task Order No. 18)</b>   |  |   | 5. Report Date<br><b>December 1993</b>   |                            |            |
|  |  |   | 6. Performing Organization Code<br><b>Rocketdyne Division<br/>Rockwell International</b> |                            |            |
| 7. Author(s)<br><b>Michael P. Moriarty</b>   |  |   | 8. Performing Organization Report No.  |                            |            |
|  |  |   | 10. Work Unit No.  |                            |            |
| 9. Performing Organization Name and Address<br><b>Rocketdyne Division<br/>Rockwell International<br/>6633 Canoga Avenue<br/>Canoga Park, California 91303</b>  |  |   | 11. Contract or Grant No.<br><b>NAS3-25808</b>   |                            |            |
|  |  |   | 13. Type of Report and Period Covered<br><b>Contractor Report<br/>Final</b>              |                            |            |
| 12. Sponsoring Agency Name and Address<br><b>National Aeronautics and Space Administration<br/>Lewis Research Center<br/>21000 Brookpark Road<br/>Cleveland, Ohio 44135</b>  |  |   | 14. Sponsoring Agency Code   |                            |            |
|  |  |   | 15. Supplementary Notes  |                            |            |
| 16. Abstract<br><p>NASA LeRC is currently developing a FORTRAN based computer model of a complete nuclear electric propulsion (NEP) vehicle that can be used for piloted and cargo missions to the Moon or Mars. Proposed designs feature either a Brayton or a K-Rankine power conversion cycle to drive a turbine coupled with rotary alternators. Both ion and MPD thrusters will be considered in the model. In support of the NEP model, Rocketdyne is developing power conversion, heat rejection, and power management and distribution (PMAD) subroutines. The subroutines will be incorporated into the NEP vehicle model which will be written by NASA LeRC. The purpose of this report is to document the heat pipe cooled heat rejection subsystem model and its supporting subroutines.</p> <p>The heat pipe cooled heat rejection subsystem model is designed to provide estimates of the mass and performance of the equipment used to reject heat from Brayton and Rankine cycle power conversion systems. The subroutine models the ductwork and heat pipe cooled manifold for a gas cooled Brayton; the heat sink heat exchanger, liquid loop piping, expansion compensator, pump and manifold for a liquid loop cooled Brayton; and a shear flow condenser for a K-Rankine system. In each case, the final heat rejection is made by way of a heat pipe radiator. The radiator is sized to reject the amount of heat necessary.</p> |  |   |  |                            |            |
| 17. Key Words (Suggested by Author(s))<br><b>Nuclear Electric Propulsion, Heat Rejection, Subroutines</b>  |  |   | 18. Distribution Statement<br><b>Unclassified-Unlimited Subject Category 44</b>          |                            |            |
| Security Classif. (of this report)<br><b>Unclassified</b>  |  | 20. Security Classif. (of this page)<br><b>Unclassified</b> |  | 21. No of pages            | 22. Price* |

