

NASA Contractor Report CR-191132

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

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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 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

TEMPERATURE RANGE (K)	FLUID USED	CONTAINER MATERIAL
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

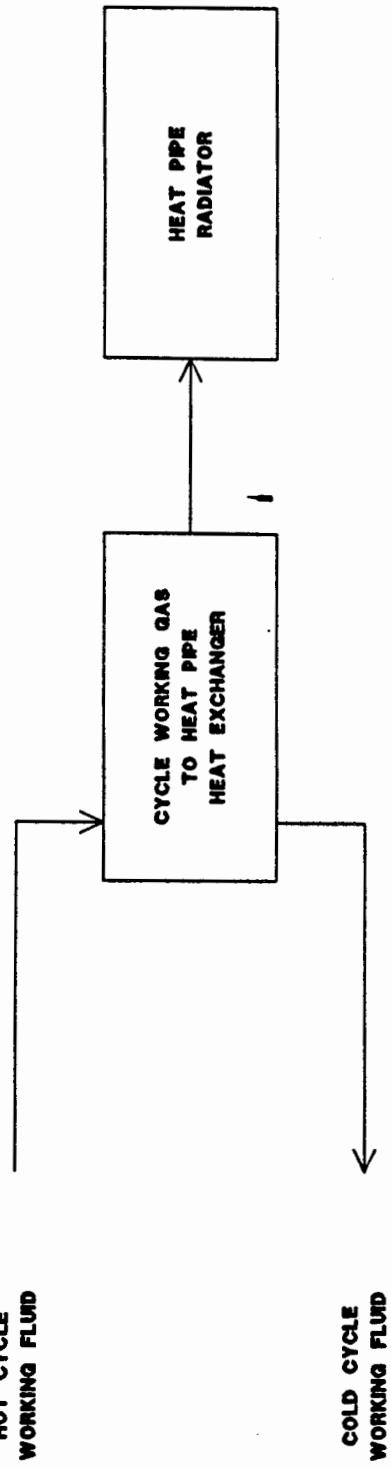
Figure 4 presents an overall logic flow diagram for the Brayton and Rankine cycle heat rejection subsystems. Figure 4 illustrates the steps required to estimate the performance and mass of a subsystem for rejecting heat to space. The steps required to accomplish this objective are:

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.
5. Compute the performance of the heat exchanger/manifold or condenser as needed.
6. 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

HOT CYCLE
WORKING FLUID

NASA/CR—191132



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Figure 1: DIRECT GAS COOLED BRAYTON RADIATOR

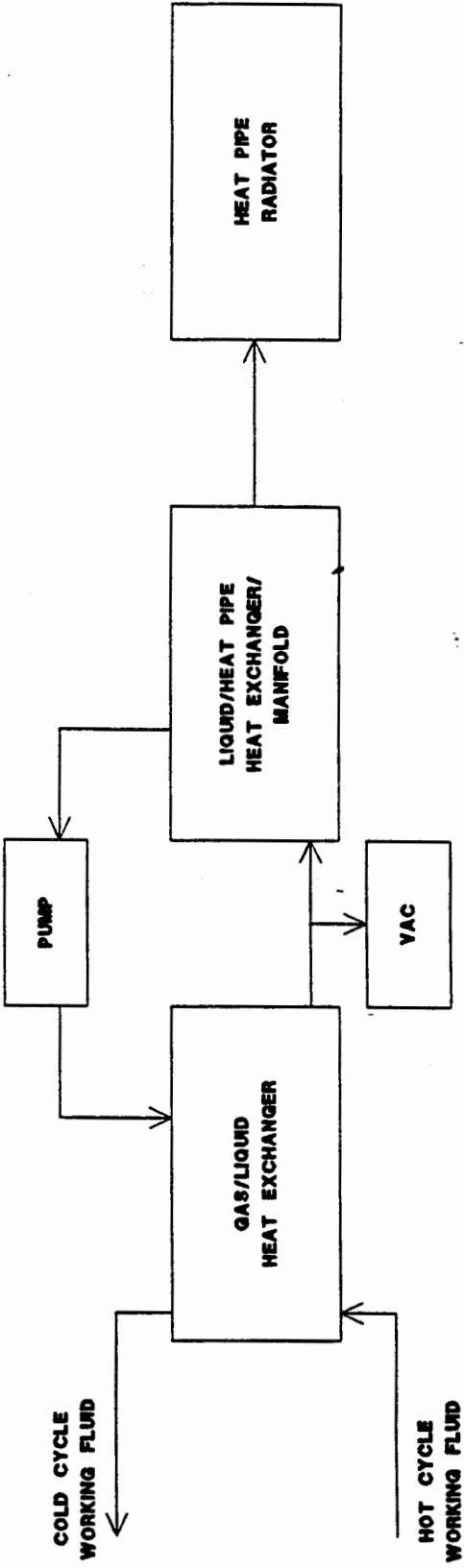


Figure 2: LIQUID LOOP COOLED BRAYTON RADIATOR

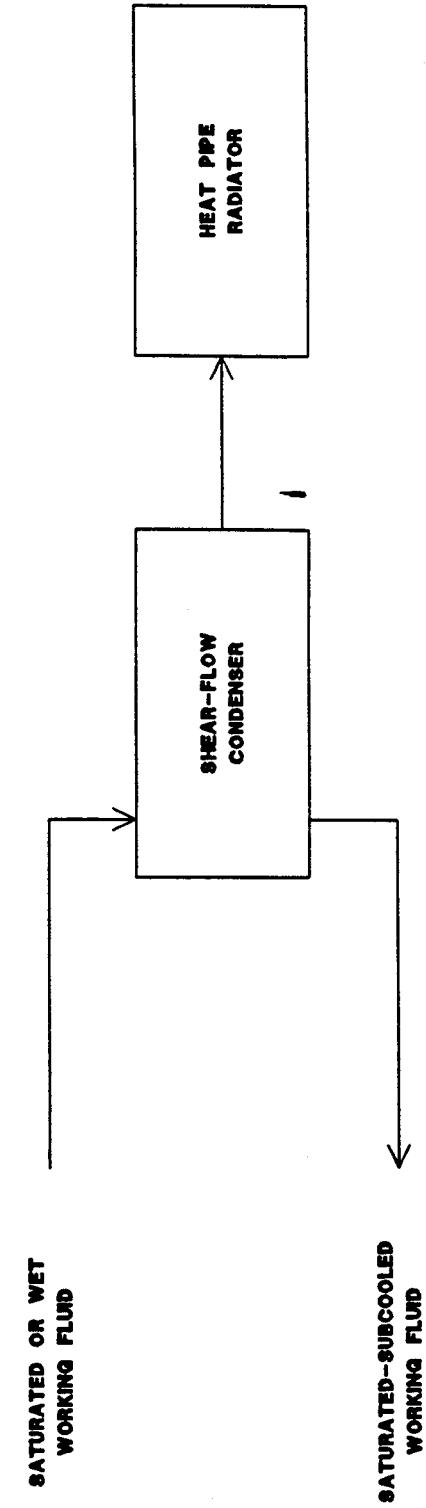
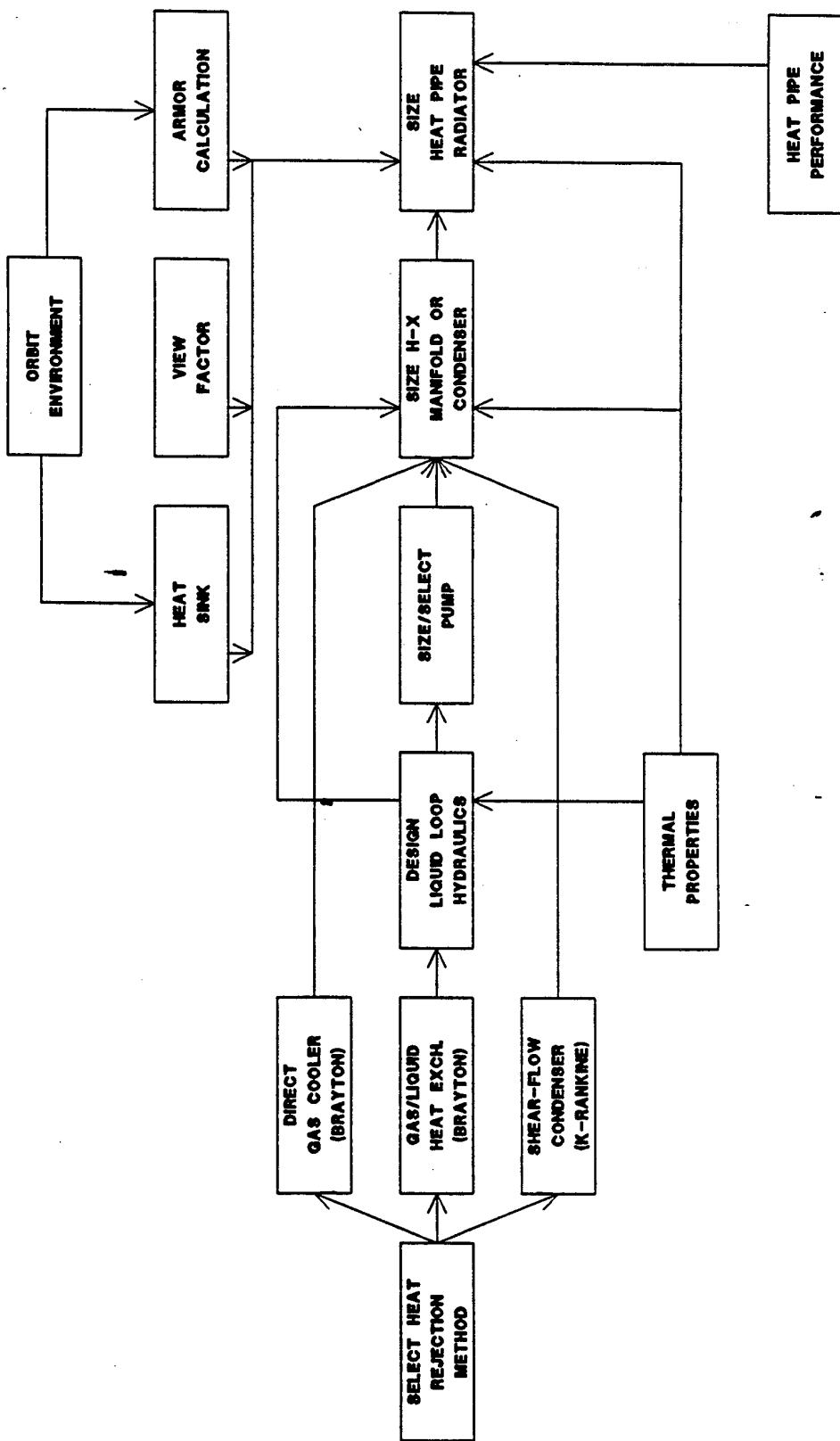


Figure 3: RANKINE CYCLE SHEAR FLOW CONDENSER

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.

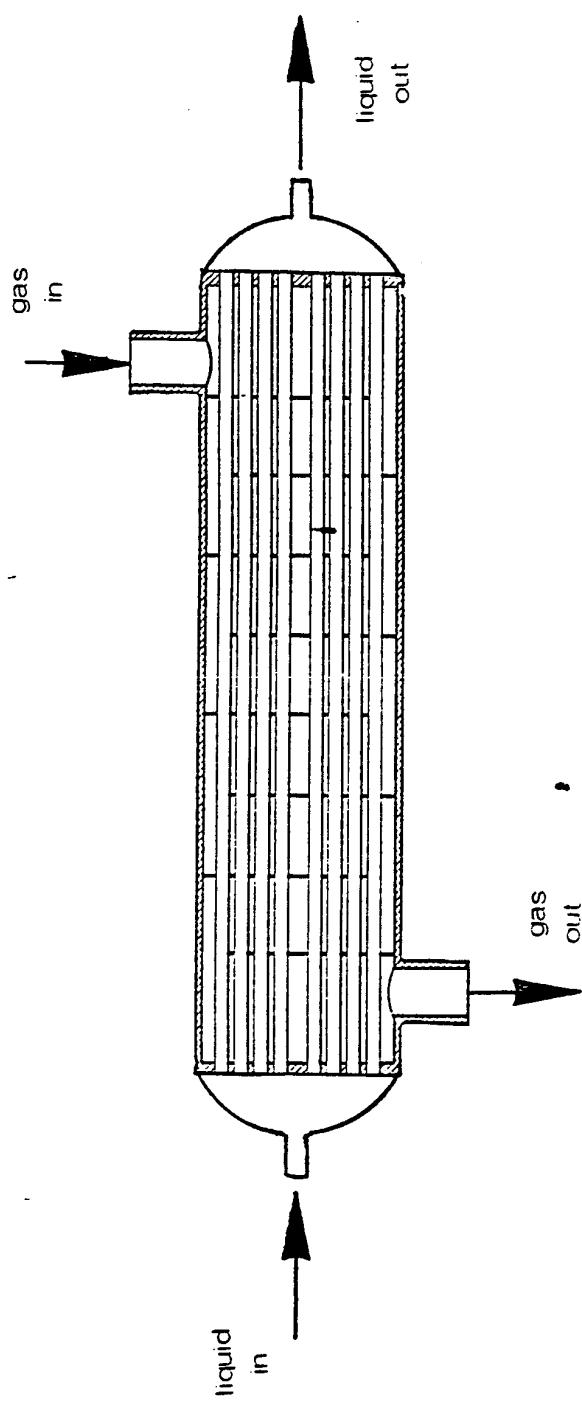
5. Size a heat pipe radiator to accommodate the temperature drops seen in the loop equipment train and to accommodate the system heat rejection loads.

6. Printout component sizes and masses.

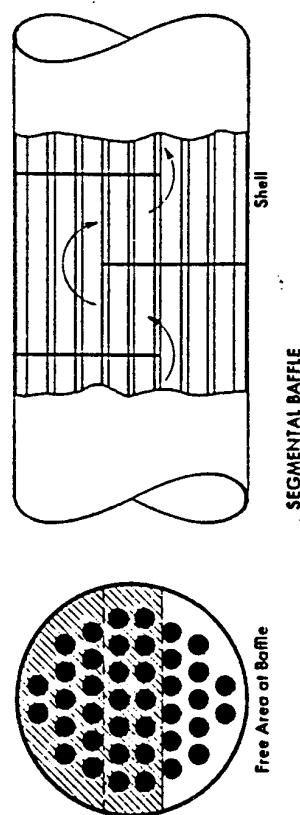
An option selected by the flag, Iselec, can be activated to supply most of the variables needed to run a case is included. A detailed listing of the variables required by the various options is included in Appendix A, the users manual.

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 HTREI 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.

$$N_u = 7.0 + 0.025 * (Re_d * Pr)^{0.8}$$

----- (1)

where:

N_u = Nusselt Number

Re_d = Reynolds Number based on diameter

Pr = 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.

$$f = \frac{0.25}{[LOG_{10}(\frac{e}{3.7*d} + \frac{5.74}{R_{ed}^{0.9}})]^{2.0}}$$

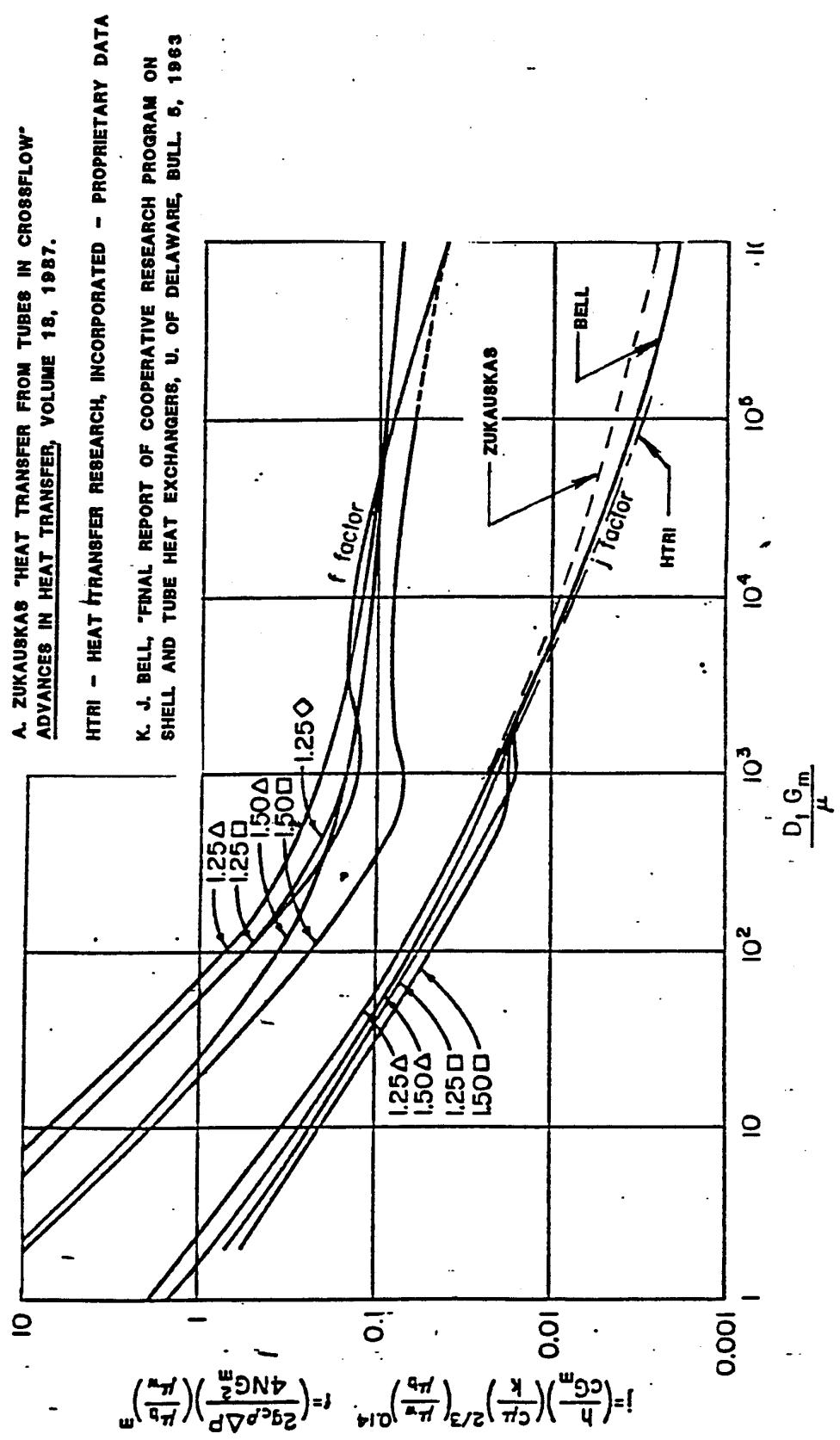
----- (2)

where:

e = Mean Surface roughness height

d = Tube Diameter

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_{pump} = Pump and Power Control Mass (Kg)

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

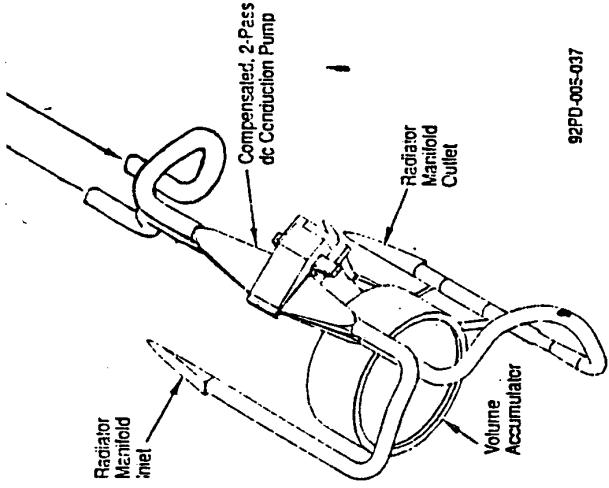
Equation 3 is based on several designs for DC conduction EM pumps which featured a two throat configuration. One of the throats is plumbed to the cold leg of the loop, while the other is plumbed to the hot leg. A detailed analysis of the performance and mass of EM pumps is given by Baker and Tessier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



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Figure 7: TYPICAL Nak LOOP PLUMBING FOR POWER SYSTEM HEAT REJECTION

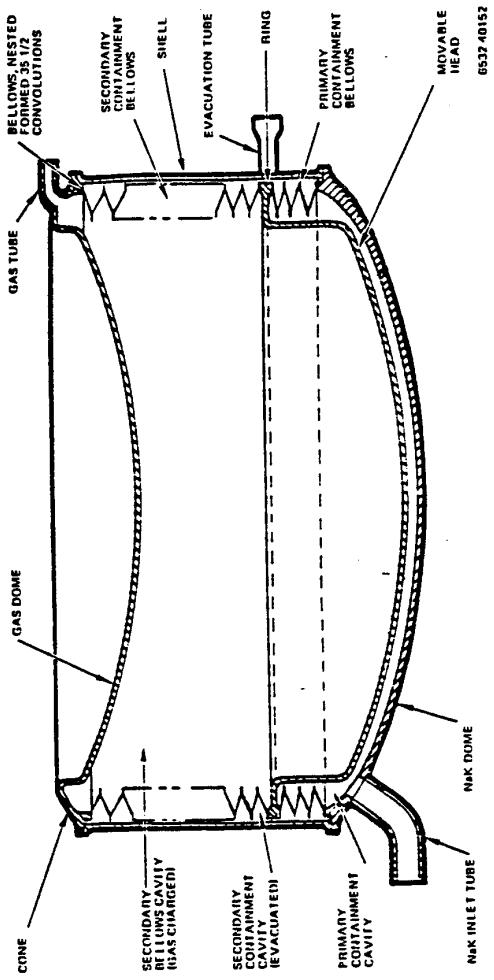


Figure 8: VOLUME ACCUMULATOR UNIT DESIGN CONCEPT DETAILS

where:

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

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

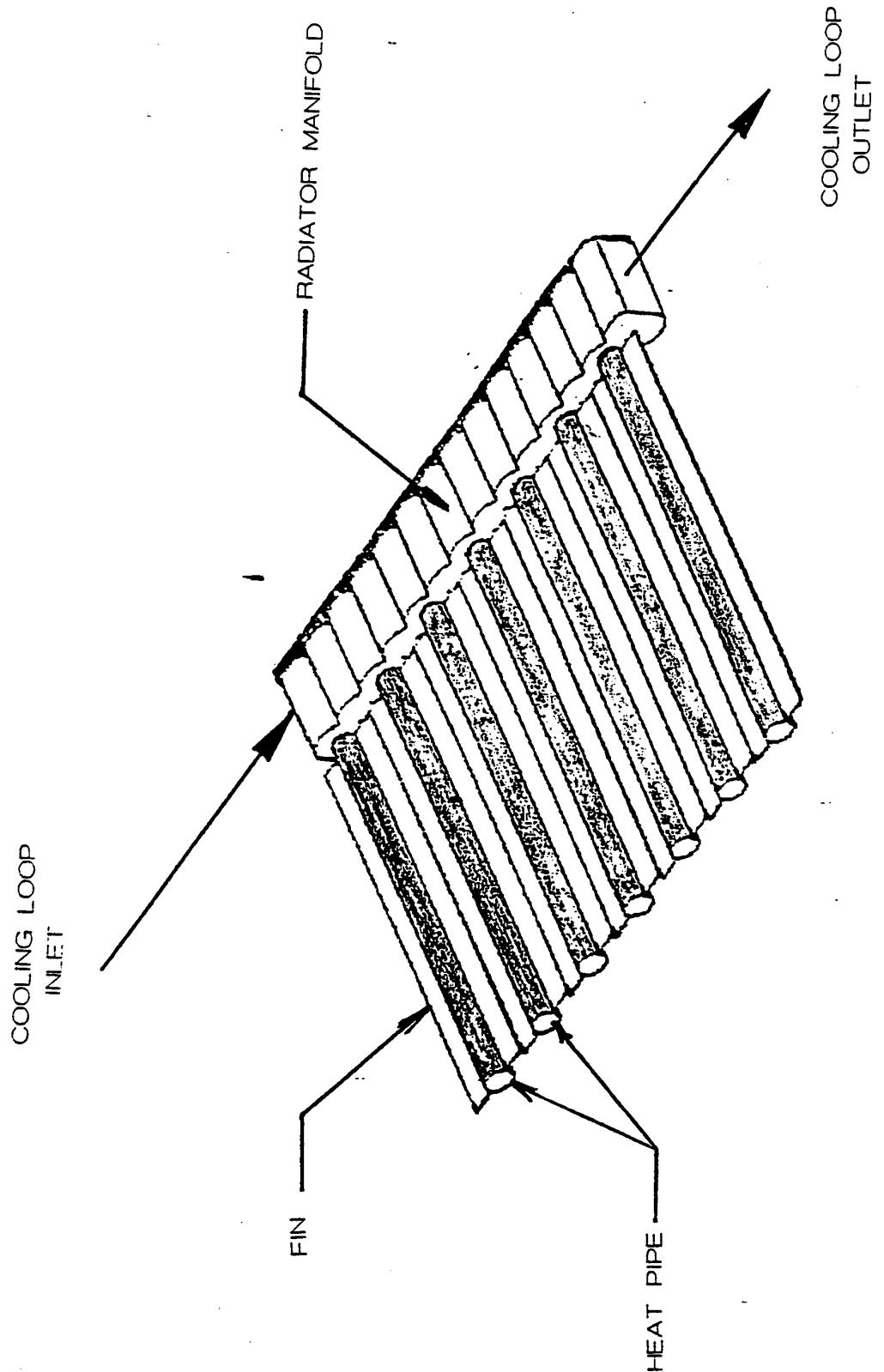


Figure 9: GAS/LIQUID HEAT PIPE, FIN AND MANIFOLD CONFIGURATION

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

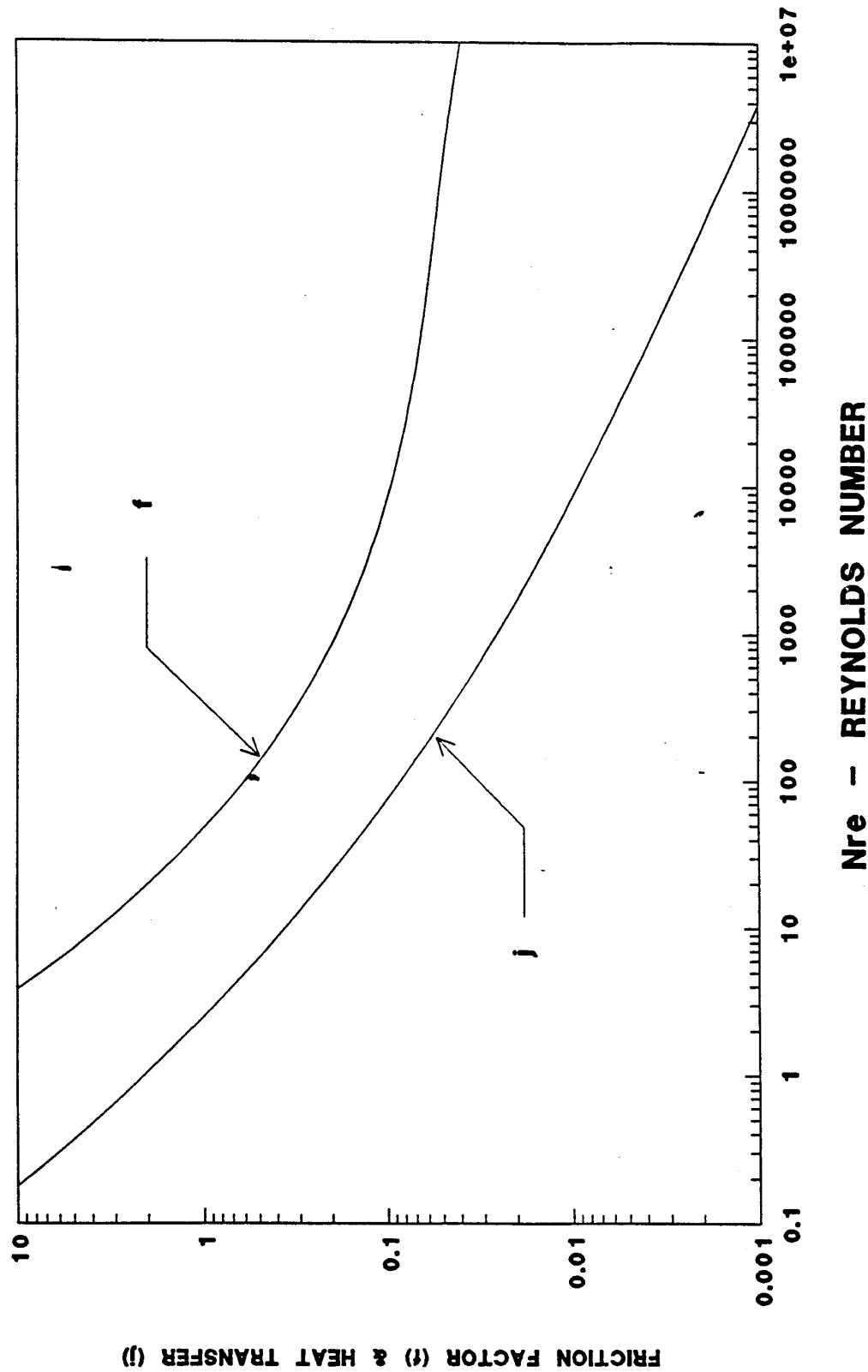


Figure 10: MANIFOLD SHELL-SIDE HEAT TRANSFER AND PRESSURE DROP

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

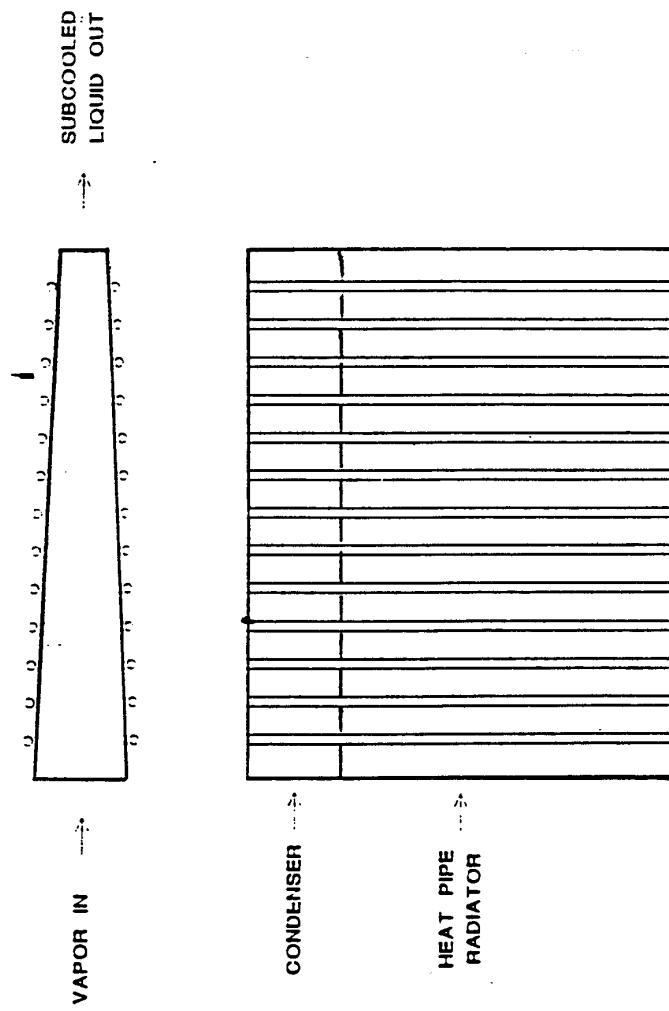


Figure 11: SHEAR CONTROLLED FLOW CONDENSER AND HEAT PIPE RADIATOR FLOW SCHEMATIC

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 HRENVR 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:

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

$$+ \frac{1.3 * 10^{-16}}{(m + (10^{+6} * m^{2.0}))^{0.85}} \right] * \left(\frac{1.0}{R_{\text{sun}}^{1.5}} \right)$$

... (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:

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

and

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

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 = 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:

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

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 HRENVR, described above and the materials dependent parameters are given in Table 3. The empirical relationship used is:

$$\delta = \gamma_r a \left[\frac{\rho_p}{\rho_a} \right]^{1/2} \left[\frac{V_p}{C_a} \right]^{2/3} \left[\frac{6}{\pi \rho_p} \right]^{1/3} \left[\frac{E \alpha A_{vt}}{-\ln(P_o)} \right]^{1/3 \beta} \left[\frac{2}{2\beta + 2} \right]^{1/3 \beta} \left[\frac{T}{T_r} \right]^{1/6} \quad \dots (7)$$

where:

γ_r = Room temperature cratering coefficient (from Table 3)

a = Rear surface damage thickness factor (from Table)

ρ_p = Impacting particle specific gravity (values are built in to the subroutine)

ρ_a = Armor specific gravity - (Grams/cu-Cm)

V_p = Impacting particle velocity (values are built in to subroutine)

C_a = Armor sonic velocity

A_{vt} = 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

δ = 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 γ_r</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 HRENVR. 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:

$$U = \sum_{H=J+1}^K \left(\frac{K!}{(K-H)! (H)!} \right) (P)^H (1-P)^{K-H} \quad \dots (8)$$

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.

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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, Rsum
Yrlnch, Time
Pin, Tin, Xmw, Tout
Qrad

If desired, IENflg, Halt, HINCL, Rsum, 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)
Rsum = 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
Dhpip,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,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)
Dhpip = HEAT PIPE INSIDE DIAMETER (Cm)
Ifuid = 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 ABSORPTIVITY
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 ("")
TKbraz = 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)

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,Rsum
Yrlnch,Time

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

IHXflg,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,TKbraz
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)
Iffluid = 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 ABSORPTIVITY
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 FKUID
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 (ASSUMMED EQUALLY SPACED)
WDOTT = 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
Dhpip,Ifluid,Imatl,Theta
D2rad,Thickm,Thickf,Thick
Em,Alpha,Hap,HArad
Tkfin,Rhocating,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
Alpha = RADIATOR SURFACE ABSORPTIVITY
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)
RHOpip = 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)
Thtpip = 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

NASA/CR—191132

B-1.

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 (KwC) = 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.)= 1.000000
RADIATOR ACTUAL AREA (FRACTION)= 2.000000
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	AVERAGE EVAPORATOR TEMP (K)	Radiator FIN Thick (Cm)	Emissivity Coating Thick (Cm)
(Kw)			
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 (Kw)= 250.000
 MOLECULAR WEIGTH 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.)= 1.000000
RADIATOR ACTUAL AREA (FRACTION)= 2.000000
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

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TOTAL HEAT REJECTED	AVERAGE EVAPORATOR TEMP (K)	Radiator FIN Thick (Cm)	Emissivity Coating Thick (Cm)
(Kwt) 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 WEIGHT 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 REDUNDENT 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 ABSOPTIVITY= 0.500000
RADIATOR PROJ. AREA (FRACT. OF TOT.)= 1.000000
RADIATOR ACTUAL AREA (FRACTION)= 2.000000
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 (Kw)	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.
26.6852	1.3352	8.4793	0.0000
O.D.ARMOR	I.D.ARMOR	Structure	TOTAL RADIATOR
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 REDUNDENT 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 FLOWRATE (KG/Hr) = 442.541

MANIFOLD DUTY (Kw) = 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 Dhpip,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,Hman

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 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) = 0.849774
 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 MTL (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 WEIGHT 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.
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
5.000000		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,Rsum
C Yrlnch,Time

C GAM,ARSF,Earm,PROB
C CONFIG,Xntubes,Xnexpip,Xlflat
C Dhpip,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,WDOTT,AKTUBE

C Iflg2,Hman,Gap,Pitch
C Dcan,Dhp,Rc,Rb
C Tf,TKfina,TKcan,TKbraze
C TKhp,Xnf,Xnw,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.)= 1.000000
 RADIATOR ACTUAL AREA (FRACTION)= 2.000000
 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 WEIGHT 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 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 Dhpip,Ifluid,Imatl,Theta
C D2rad,Thickm,Thickf,Thick
C Em,Alpha,Hap,HArad
C Tkfin,Rhocoating,Rhofin,RHOarm
C Xladiab,Xmchmas

C Cman,Hman,Gap,THICKins
C RHOins,Tout,Tbraze,TKcan
C TKbraze,TKhp,Pin,Tin
C Xin,RHOrip,RHOcan,RHObraze
C THICKman,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 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) = 0.849774
 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 (cone-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.SPACE(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

F77L-EM/32 - Lahey Extended-Memory FORTRAN 77, Version 3.01 09/28/92 14:45:36
Page 1

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
```

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

```

11 C
12 C
13 C
14 SUBROUTINE HREJEC(Iselec,Iprob,IENflg,Pin,Tin,Tout,Qrad)
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 OPEN(5,FILE='RADAT')
52 C
53 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.

```

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

```

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      Yrlnch = 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      Qrad = 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     HArad = 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     Xmchmas = 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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SUBROUTINE HRMAST Compiling Options:/NO/N7/B/NC/ND/NF/H/H1/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1
Source file Listing

```
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 WEIGHT 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 DUCMAS = 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 Overall (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 TCOUT = 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)
```

SUBROUTINE HRMAST 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

```
170 C RHOSF = 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 RHOT = 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 Tkak = 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 DPIPE = 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 Tkak = NAK INLET TEMPERATURE (deg-R)
202 C Whak = NAK FLOWRATE (LBS/SEC)
203 C DPPPIPE = PIPING SYSTEM 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 TWM = 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 Rel = CONDENSATE FILM REYNOLDS NUMBER
218 C VCF = VISCOSITY CORRECTION FACTOR , (BULK /WALL)**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
```

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

```

223 C      HS = 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      HGO = 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,Rhocating,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

```

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

```
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,Wman
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,Wman,Qrad,XMANmas,DPman,DTfilm,XMNMAN)
293      DTman = Tin-Tout
294      CALL TMEAN(Tin,DTman,DTfilm,Trad)
295 C
296      CALL HRRAD(Qrad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,Imat1,
297      &Theta,D2rad,Thickm,Thickf,Thick,Em,IENflg,Halt,HINCL,Rsun,Yrlinch,
298      &Alpha,Hap,Harad,TKfin,Rhocoating,Rhofin,RHOarm,Xladiab,CONFIG,
299      &Xmchmas,PROB,GAM,ARSF,Earm,Time,Qrejected,Thickf2,Thickm2,
300      &Aradiator,Aradefect,Wthick2,Xnart2,Artid2,
301      &Artwall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xmpipes,Xmfluid,
302      &Xmfin,Xmcoating,Xmarmor,Xmarmorid,Xstructure,
303      &Xnetradmasst2,Wx(2))
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 = Wman/(RHOgas*Apipe)
308      CALL HRDUCT(XN9,R9,Dp,SUMLEN,Vpipe,Tin,Pin,THICKP,RHOPIP,
309      &THICKI,RHOINS,Xmw,DPDUCT,DUCMAS)
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(Qrad,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,Aradefect,Wthick2,Xnart2,Artid2,
320      &Artwall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xmpipes,Xmfluid,
321      &Xmfin,Xmcoating,Xmarmor,Xmarmorid,Xstructure,
322      &Xnetradmasst2)
323      CALL ORBPRT(IENflg,Halt,HINCL,Rsun,Yrlinch)
324 C
325      CALL HMNPRT(Iflg2,Hman,Gap,Pitch,XNpipes,XNexpipes,Dcan,
326      &Dhp,Rc,Rb,Tf,TKfin,TKcan,TKbraze,TKhp,XNf,RHOcan,RHObraze,
327      &THICKman,Pin,Tin,Wman,Qrad,Xmw,XMANmas,DPman,DTfilm,XMNMAN)
```

SUBROUTINE HRMAST 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

```

328 C
329     CALL DUCPRT(XN9,R9,Dp,SUMLEN,Vpipe,Tin,Pin,THICKP,RHOPIP,
330     &THICKI,RHOINS,XMN,DPDUCT,DUCMAS)
331 C
332     WRITE (6,*) 'MASS SUMMARY FOR DIRECT BRAYTON SYSTEM'
333     WRITE (6,*) '
334     WRITE (6,*) 'HEAT PIPE COOLED GAS MANIFOLD MASS (Lbs) =',XMNMAN
335     WRITE (6,*) 'MANIFOLD DUCTING MASS (LBS) =',DUCMAS
336     WRITE (6,*) 'RADIATOR MASS (LBS) =',Xnetradmasst2
337     XMSYST = XMNMAN + 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 NAK 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,HINCL,Rsun
349     READ (5,*) Yrinch,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,Imat1,Theta
356     READ (5,*) D2rad,Thickm,Thickf,Thick
357     READ (5,*) Em,Alpha,Hap,Harad
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,*) IHXflg,UEST,TCIN,TCOUT
364     READ (5,*) WDOTS,AMWS,TINS,DENINS
365     READ (5,*) DENSSH,DTUBE,PR,TTUBE
366     READ (5,*) ANPLATES,WDOTT,AKTUBE
367 C
368 C INPUTS REQUIRED TO DEFINE HEAT PIPE MANIFOLD
369 C
370     READ (5,*) Iflg2,Hman,Gap,Pitch
371     READ (5,*) Dcan,Dhp,Rc,Rb
372     READ (5,*) Tf,TKfin,TKcan,TKbraze
373     READ (5,*) TKhp,XNf,Xmw,RHOcan
374     READ (5,*) RHObraze,THICKman,Wman
375 C
376     READ (5,*) XN9,R9,Dp,SUMLEN
377     READ (5,*) THICKP,RHOPIP,THICKI,RHOINS
378 C
379     Cman = PI*D2rad

```

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

```

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(IHXflg,UEST,THIN,THOUT,PHOT,TCIN,TCOUT,WDOTS,AMW
389      &S,TINS,DENINS,DENSSH,DTUBE,PR,TTUBE,ANPLATES,WDOTT,AKTUBE,Q
390      &DOT,DPSHELL,ANTUBES,DPTUBE,DOTL2,ALSHEL,AMSHELL,AMPLATES,
391      &AMTUBES,AMINSUL,AMHEADS,AMSTRT,ANETMASS,XMNHEX,HSHELL,AFRIC,UNEW,
392      &RETUBE,THC,AMTSHT)
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,Wman,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 = Wman/(3600.0*RHONAK*Apipe)
401      Tnak = Tin
402      Pnak = Pin
403      CALL HRPIPE(XN9,R9,Dp,SUMLEN,Vpipe,Tnak,Pnak,THICKP,RHOPIP,THICKI,
404      &RHOINS,DPPPIPE,PIPnak,PIPMAS)
405 C
406      Wnak = Wman
407      DPHX = DPTUBE
408      DPMANIF = DPman
409      CALL PUMP(Tnak,Wnak,DPPPIPE,DPHX,DPMANIF,DPLOOP,Phyd,XMPUMP)
410 C
411      CALL VACMAS(Tnak,XMNPPIP,XMNMAN,XMNHEX,XMVAC,XMVAC)
412 C
413      DTman = Tin-Tout
414      CALL TMEAN(Tin,DTman,DTfilm,Trad)
415      CALL HRRAD(Qrad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,Imat1,
416      &Theta,D2rad,Thickm,Thickf,Thick,Em,IENflg,Halt,HINCL,Rsun,Yrlinch,
417      &Alpha,Hap,HArad,TKfin,Rhocoating,Rhofin,RHOarm,Xladiab,CONFIG,
418      &Xchmas,PROB,GAM,ARSF,Earm,Time,Qrejected,Thickf2,Thickm2,
419      &Aradiator,Aradeffect,Wthick2,Xnart2,Artid2,
420      &Artwall2,Thick2,Xlevap2,Xladi2,Xlapec2,Xltot2,Xmpipes,Xmfluid,
421      &Xmfin,Xmcoating,Xmarmor,Xmarmorid,Xstructure,
422      &Xnetradmasst2,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      &mat1,Theta,D2rad,Thickm,Thickf,Thick,Em,
430      &Alpha,Hap,HArad,TKfin,Rhocoating,Rhofin,RHOarm,Xladiab,
431      &Xchmas,PROB,GAM,ARSF,Earm,Time,Qrejected,Thickf2,Thickm2,
432      &Aradiator,Aradeffect,Wthick2,Xnart2,Artid2,
```

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

```

433      &Artwall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xpipes,Xfluid,
434      &Xmfin,Xmcoating,Xarmor,Xarmorid,Xstructure,
435      &Xnetradmasst2)
436      CALL ORBPRT(IENflg,Halt,HINCL,Rsun,Yrlnch)
437 C
438      CALL HMNPRT(Iflg2,Hmn,Gap,Pitch,XNpipes,Xnexpipes,Dcan,
439      &Dhp,Rc,Rb,Tf,TKfin,TKcan,TKbraze,TKhp,XNf,RHOcan,RHObraze,
440      &THICKman,Pin,Tin,Hmn,Grad,XMW,XMANmas,DPman,DTfilm,XMNMAN)
441      WRITE (6,*) '
442 C
443      CALL PIPRPT(XN9,R9,Dp,SUMLEN,Vpipe,Tnak,Pnak,THICKP,RHOPIP,
444      &THICKI,RHOINS,DPIPE,PIPNAK,PIPMAS)
445      WRITE (6,*) '
446      CALL NSHPRT(INXflg,QDOT,THIN,THOUT,TCIN,TCOUT,WDOTS,DENSSH,
447      &DTUBE,TTUBE,WDOTT,AKTUBE,DPSHELL,ANTUBES,DPTUBE,DTL2,ALSHEL,
448      &AMSHELL,AMPLATES,AMTUBES,ANETMASS,XMNHEX,HSHELL,AFRIC,UNEW,RETUBE,
449      &THC,AMINSUL,AMHEADS,AMTSHT,AMSTRTR)
450      WRITE (6,*) '
451      CALL PNPRT(Tin,WDOTT,DPIPE,DPTUBE,DPMAN,DPLOOP,Phyd,
452      &XNPUMP)
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) =',XMNHEX
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 + XMNHEX + 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

```

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

```

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,Wman
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,Wman,Qrad,XMANmas,DPman,DTFsup,
505      &Ar,Gt,V,Dh,Cgt,Rel,HI,Xtt,Rev,
506      &DTFcon,DTFsub,DTfilm)
507 C
508      DTman = Tin-Tout
509      CALL TMEAN(Tin,DTman,DTfilm,Trad)
510 C
511      CALL HRRAD(Qrad,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,Earn,Time,Qrejected,Thickf2,Thickm2,
515      &Aradiator,Aradeffect,Wthick2,Xnart2,Artid2,
516      &Artwall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xmpipes,Xmfluid,
517      &Xmfin,Xmcoating,Xmarmor,Xmarmorid,Xstructure,
518      &Xnetradmasst2,Wx12)
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(Qrad,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,Earn,Time,Qrejected,Thickf2,Thickm2,
528      &Aradiator,Aradeffect,Wthick2,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,HI,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,Wman,Qrad,XMANmas,DPman,

```

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

```
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          Yrlinch = 2000.0
559 C          Time = 10.0*365.0*24.0*3600.0
560 1001 READ (5,*) IENflg,Halt,HINCL,Rsun
561      READ (5,*) Yrlinch,Time
562      IF (IENflg.EQ.0) THEN
563          Halt = 1000.0
564          HINCL = 30.0
565          Rsun = 1.0
566          Yrlinch = 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
```

SUBROUTINE HRMAST 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

```

590      ENDIF
591 C
592 C      SET MANIFOLD GAS VELOCITY TO DESIGN MANIFOLD
593 C
594 1005 Vgasman = 35.0
595  Iflg2 = 1
596  DTman = Tin-Tout
597  DTfilm = 50.0
598  CALL TMEAN(Tin,DTman,DTfilm,Tbar)
599  CALL RADFLG(Tin,Ifluid,Imatl)
600  Alpha = 0.5
601  Hap = 1.0
602  HAred = 2.0
603 C  WRITE (6,*) 'Vgasman,Iflg2,DTman,DTfilm=',Vgasman,Iflg2,DTman,DTfi
604 C  &lm
605 C  WRITE (6,*) 'Tin,Tbar,Ifluid,Imatl=',Tin,Tbar,Ifluid,Imatl
606  CALL HRTSNK(IENfig,Halt,HINCL,Rsun,Yrinch,Alpha,Hap,HAred,Tsink)
607 C  WRITE (6,*) 'Alpha,Hap,HAred,Tsink=',Alpha,Hap,HAred,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*  
611  &*4.0)))
612  Aactual = 0.5*Aradest
613 C  WRITE (6,*) 'Em,Etarad,Aradest,Aactual=',Em,Etarad,Aradest,Aactual
614  DUMlen = 20.0
615  Width = Aactual/DUMlen
616  Cman = Width
617  Xntubes = (12.0*Width)/3.5
618 C  WRITE (6,*) 'DUMlen,Width,Cman,Xntubes=',DUMlen,Width,Cman,Xntubes
619  Xnexpip = 0.1*Xntubes
620  Pitch = 3.5/12.0
621  Dcan = 0.090333
622 C  WRITE (6,*) 'Xnexpip,Pitch,Dcan=',Xnexpip,Pitch,Dcan
623  Dhp = 0.083333
624  Rc = 0.043500
625  Rb = 0.043333
626  Tf = 0.000833
627 C  WRITE (6,*) 'Dhp,Rc,Rb,Tf=',Dhp,Rc,Rb,Tf
628  TKfin = 112.0
629  TKcan = 10.0
630  TKbraze = 28.0
631  T0 = Tin/1.8-273.2
632 C  WRITE (6,*) 'TKfin,TKcan,TKbraze,T0=',TKfin,TKcan,TKbraze,T0
633  CALL Wallprop(Imatl,T0,Wallden,Tcwall)
634  TKhp = 242.0*Tcwall
635  XNpipes = Xntubes
636 C  WRITE (6,*) 'Wallden,Tcwall,TKhp=',Wallden,Tcwall,TKhp
637  XNexpipes = Xnexpip
638  XMW = XMW
639  Pman = Pin
640 C  WRITE (6,*) 'XNpipes,XNexpipes,XMW,Pman=',XNpipes,XNexpipes,XMW,Pm
641 C  &an
642  Tman = Tin

```

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

```

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      Wman = (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,Wman,Gap=',Tcond,Pr,Wman,Gap
655      1008 Amin = (Gap*Hman) - (Dcan*Hman)
656      Vman = Wman/(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,Dhps=',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,*) 'Wman,Qrad=',Wman,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,Wman,Qrad,XMANmas,DPman,DTfilm,XMANMAN)
685      Qrad = Qrad
686      Tred = Tbar
687      Xntubes = (12.0*Width)/3.5
688      Xnexpip = 0.1*Xntubes
689      Xlflat = Hman*12.0
690      Dhpipe = 1.0
691      CALL RADFLG(Tbar,Ifluid,Imatl)
692      1100 THETA = 0.0
693      D2rad = Width/PI
694      Thickm = 0.0

```

SUBROUTINE HRMAST 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

```

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      Xmchmas = 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,Trad)
710      CALL HRRAD(Grad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,Imat,
711      &Theta,D2rad,Thickm,Thick,Em,IENflg,Melt,HINCL,Rsun,Yrlnch,
712      &Alpha,Hap,HArad,TKfin,Rhocoating,Rhofin,RHOarm,Xladiab,CONFIG,
713      &Xmchmas,PROB,GAM,ARSF,Earm,Time,Rejected,Thickf2,Thickm2,
714      &Aradiator,Aradeffect,Wthick2,Xnart2,Artid2,
715      &Arwall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xmpipes,Xmfluid,
716      &Xmfin,Xmcoating,Xarmor,Xarmorid,Xstructure,
717      &Xnetradmasst2,Wx(2)

718 C
719      XN9 = 12.0
720      Vpipe = 100.0
721      PGAS = Pin
722      TGAS = Tin
723      CALL HEXEPR(XMH,PGAS,TGAS,GMA,CP,RHOgas,AMU,AK,PR)
724      Dp = 12.0*SQRT((1.27324*Wman)/(RHOgas*Vpipe))
725 C      WRITE (6,*) 'RHOgas =',RHOgas
726 C      WRITE (6,*) 'Dp =',Dp
727      SUMLEN = 12.0*Dp
728      THICKP = PGAS*Dp/(2.0*5000.0)
729      IF (THICKP.GT.0.03125) THEN
730      THICKP = THICKP
731      ELSE
732      THICKP = 0.03125
733      ENDIF
734      THICKI = 4.0
735      RHOPIP = 505.0
736      RHOINS = 16.0
737      R9 = 4.0*Dp
738      CALL HRDUCT(XN9,R9,Dp,SUMLEN,Vpipe,TGAS,PGAS,THICKP,RHOPIP,
739      &THICKI,RHOINS,XMH,DPDUCT,DUCHAS)
740 C
741 C      WRITE (6,*) '*** HEAT REJECTION SYSTEM FOR A BRAYTON CYCLE SYSTEM
742      &IN WHICH CYCLE WASTE HEAT IS REJECTED DIRECTLY FROM THE CYCLE WORK
743      &ING FLUID IN A HEAT PIPE COOLED GAS MANIFOLD ***'
744      WRITE (6,*) '
745      WRITE (6,*) 'INPUT FOR OPTION NUMBER 1'

```

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

```
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,*) Yrlinch,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,Rhocoeating,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,Hman
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   Yrlinch,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,Rhocoeating,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,Hman'
790      WRITE (6,*) ' '
791      WRITE (6,*) 'C   XN9,R9,Dp,SUMLEN'
792      WRITE (6,*) 'C   THICKP,RHOPIP,THICKI,RHOINS'
793      CALL RADPRT(Qrad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,I
794      &matl,Theta,D2rad,Thickm,Thickf,Thick,Em,
795      &Alpha,Hap,HArad,Tkfin,Rhocoeating,Rhofin,RHOarm,Xladiab,
796      &Xmchmas,PROB,GAM,ARSF,Earm,Time,Qrejected,Thickf2,Thickm2,
797      &Aradiator,Aradeffect,Wthick2,Xhart2,Artid2,
798      &Artwall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xmpipes,Xmfluid,
799      &Xmfin,Xmcoating,Xmarmor,Xmarmorid,Xstructure,
```

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

```

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,Wman,Qrad,XMW,XMANmas,DPman,DTfilm,XMNMAN)
806      WRITE (6,*) ' '
807 C
808      CALL DUCPRT(XN9,R9,Dp,SUMLEN,Vpipe,Tin,Pin,THICKP,RHOPIP,
809      &THICKI,RHOINS,XMN,DPDUCT,DUCMAS)
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) =',DUCMAS
815      WRITE (6,*) 'RADIATOR MASS (LBS) =',Xnetradmasst2
816      XMSYST = XMNMAN + DUCMAS + 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 IHXflg = 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      TCOUT = 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,*) 'IHXflg,UEST,THIN,THOUT,PHOT,TCOUT,TCIN =',IHXflg,
841 C      &UEST,THIN,THOUT,PHOT,TCOUT,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      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

```

SUBROUTINE HRMAST Compiling Options:/N0/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/N21
 Source file Listing

```

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(IHXflg,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,ALSHEL,AMSHELL,AMPLATES,
866      &AMTUBES,AMINSUL,AMHEADS,AMSTRT,ANETHASS,XMNHEX,HSELL,AFRIC,UNEW,
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,Rsum,Yrlinch,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 = Trad/1.8-273.2
903      CALL Wallprop(Imatl,T0,Wallden,Tcwall)

```

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

```
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      XMW = Xmw
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 - (Vliqman/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,TKfi
934      &n,TKcan,TKbraze,TKhp,XNf,XNpipes,XNexpipes,Xmw,Pin,Tin,RHOcan,RH
935      &Obraze,THICKman,Wman,Qrad,XMANmas,DPman,DTfilm,XMNMAN)
936      XN9 = 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      SUMLEN = 60.0*(Qrad/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,SUMLEN =',Vpipe,Wpipe,Dp,SUMLEN
950      C WRITE (6,*) '*****'
951      CALL HRPIPE(XN9,R9,Dp,SUMLEN,Vpipe,Tin,Pin,THICKP,RHOPIP,THICKI,
952      &RHOINS,DPPipe,PIPNAK,PIPMS)
953
954      Qrad = Qrad
955      Trad = Tbar
```

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

```

956      Xntubes = (12.0*Width)/3.5
957      Xnexpip = 0.1*Xntubes
958      Xlflat = 18.00
959      Dhpipeline = 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,Tred)
979      CALL HRRAD(Qrad,Tred,Xntubes,Xnexpip,Xlflat,Dhpipeline,Ifluid,Imatl,
980      &Theta,D2rad,Thickm,Thickf,Thick,Em,IENflg,Halt,HINCL,Rsun,Yrlinch,
981      &Alpha,Hap,HArad,Tkfin,Rhocoating,Rhofin,RHOarm,Xladiab,CONFIG,
982      &Xmchmas,PROB,GAM,ARSF,Earm,Time,Qrejected,Thickf2,Thickm2,
983      &Aradiator,Aradeflect,Wthick2,Xart2,Artid2,
984      &Artwall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xmpipes,Xmfluid,
985      &Xmfin,Xmcoating,Xmarmor,Xmarmorid,Xstructure,
986      &Xnetradness2,Wxl2)
987 C
988 C
989      WDOTT = Wpipe
990      CALL PUMP(Tin,WDOTT,DPIPE,DPTUBE,DPman,DPLOOP,Phyd,XMPUMP)
991 C
992      CALL VACMAS(Tin,PIPNAK,XNNMAN,XNNHEX,XNNVAC,XMVAC)
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     DEFINE ORBIT
1006     WRITE (6,*) IENflg,Halt,HINCL,Rsun
1007     WRITE (6,*) Yrlinch,Time

```

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

```

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,Thickm,Thickf,Thick
1014      WRITE (6,*) Em,Alpha,Hap,HArad
1015      WRITE (6,*) Tkfin,Rhocoeating,Rhofin,RHOarm
1016      WRITE (6,*) Xladiab,Xmchmas
1017      WRITE (6,*) '
1018  C   DEFINE HEAT SINK HEAT EXCHANGER
1019      WRITE (6,*) IHXflg,UEST,TCIN,TCOUT
1020      WRITE (6,*) WDOTS,AMWS,TINS,DENINS
1021      WRITE (6,*) DENSSH,DTUBE,PR,TTUBE
1022      WRITE (6,*) ANPLATES,WDOTT,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,Wman
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,Thickm,Thickf,Thick'
1042      WRITE (6,*) 'C     Em,Alpha,Hap,HArad'
1043      WRITE (6,*) 'C     Tkfin,Rhocoeating,Rhofin,RHOarm'
1044      WRITE (6,*) 'C     Xladiab,Xmchmas'
1045      WRITE (6,*) '
1046      WRITE (6,*) 'C     IHXflg,UEST,TCIN,TCOUT'
1047      WRITE (6,*) 'C     WDOTS,AMWS,TINS,DENINS'
1048      WRITE (6,*) 'C     DENSSH,DTUBE,PR,TTUBE'
1049      WRITE (6,*) 'C     ANPLATES,WDOTT,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,Wman'
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(Grad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,I
1061      &metl,Theta,D2rad,Thickm,Thickf,Thick,Em,
1062      &Alpha,Hap,Harad,TKfin,Rhocoating,Rhoair,Xladiab,
1063      &Xmchmas,PROB,GAM,ARSF,Earm,Time,Rejected,Thickf2,Thickw2,
1064      &Aradiator,Aradeffect,Wthick2,Xnart2,Arid2,
1065      &Artwall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xmpipes,Xmfluid,
1066      &Xmfin,Xmcoating,Xmarmor,Xmarmorid,Xstructure,
1067      &Xnetradmasst2)
1068      CALL ORBPRT(IENflg,Halt,HINCL,Rsun,Yrlnch)
1069 C
1070      CALL HMNPRT(IFlg2,Nman,Gap,Pitch,XNpipes,Xnexpipes,Dcan,
1071      &Dhp,Rc,Rb,Tf,TKfin,TKcan,TKbraze,TKhp,XNf,RHOcan,RHObraze,
1072      &THICKman,Pin,Tin,Wman,Grad,XMW,XMANmas,DPman,DTfilm,XMNMAN)
1073      WRITE (6,*) '
1074 C
1075      CALL PIPPRT(XN9,R9,Dp,SUMLEN,Vpipe,Tin,Pin,THICKP,RHOPIP,
1076      &THICKI,RHOINS,DPIPE,PIPNAK,PIPMAS)
1077      WRITE (6,*) '
1078      CALL HSHXPT(IHXflg,QDOT,THIN,THOUT,TCIN,TCOUT,WDOTS,DENSSH,
1079      &DTUBE,TTUBE,WDOTT,AKTUBE,DPSHELL,ANTUBES,DPTUBE,DOTL2,ALSHEL,
1080      &AMSHELL,AMPLATES,AMTUBES,AMETMAS,XMNHEX,HSHELL,AFRIC,UNEW,RETUBE,
1081      &THC,AMINSUL,AMHEADS,AMTSHT,AMSTRT)
1082      WRITE (6,*) '
1083 C
1084      CALL PMPPRT(Tin,WDOTT,DPIPE,DPTUBE,DPMAN,DPLOOP,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) =',ANETMAS
1091      WRITE (6,*) 'HEAT EXCHANGER NaK MASS (LBS) =',XMNHEX
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 = ANETMAS + XMNHEX + 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

```

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

```

1112      CALL Tmean(Tin,DTman,DTfilm,Tbar)
1113      Alpha = 0.5
1114      Hap = 1.0
1115      HAred = 2.0
1116      CALL HRTSNK(IENflg,Halt,HINCL,Rsun,Yrlnch,Alpha,Hap,HAred,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**4.0)))
1122      Aactual = 0.5*Aradest
1123      DUMLEN = 10.0
1124      Width = Aactual/DUMLEN
1125      C      WRITE (6,*) 'Etarad,Aradest,Aactual,Width = ',Etarad,Aradest,Aactual,Width
1126 C      &al,Width
1127 C      Qrad = Qrad
1128      Trad = Tbar
1129      Xntubes = (12.0*Width)/2.0
1130      Xnexpip = 0.1*Xntubes
1131      Xflat = 18.00
1132      Dhpipe = 1.0
1133      CALL RADFLG(Tbar,Ifluid,Imatl)
1134      C      WRITE (6,*) 'Qrad,Trad,Xntubes,Xnexpip,Ifluid,Imatl = ',Qrad,Trad,
1135 C      &Xntubes,Xnexpip,Ifluid,Imatl
1136      C      1500 THETA = 0.0
1137      C      Can = Width
1138      C      THICKins = 4.0/12.0
1139      C      Tbraze = 0.002/12.0
1140      C      TKcan = 10.0
1141      C      TKbraze = 35.0
1142      C      TKhp = 10.0
1143      C      XNpipes = Xntubes
1144      C      XNexpipes = Xnexpip
1145      C      RHOpip = 505.0
1146      C      RHOCan = 505.0
1147      C      RHObraze = 525.0
1148      C      THICKman = 0.0625/12.0
1149      C      Thtpip = 0.020/12.0
1150      C      Xin = 1.0
1151      C      WRITE (6,*) 'INPUT TO 1ST CALL TO KPRP (Xin,Pin,Tin) = ',Xin,Pin,Tin
1152      C      &n
1153      C      CALL KPRP(Xin,Pin,Tin,DL,DV,HF,HG,HFG,SF,SG,SFG,VF,VG)
1154      C      WRITE (6,*) 'OUTPUT FROM KPRP (DL,DV,HF,HFG,SF,SG,SFG,VF,VG) = ',
1155 C      &DL, DV, HF, HFG, SF, SG, SFG, VF, VG
1156      C      CALL KTRN(Xin,Pin,Tin,Cl,Cv,TKL,TKv,Prl,Prv,VL,Vv)
1157      C      Tsat = (-7633.6)/( ALOG10(Pin)-5.279)
1158      IF (Tin.GT.Tsat) DHNET=CV*(Tin-Tsat)+HFG+CL*(Tsat-Tout)
1159      IF (Tin.EQ.Tsat) DHNET=(Xin*HFG)+CL*(Tsat-Tout)
1160      IF (Tin.LT.Tsat) DHNET=CL*(Tsat-Tout)
1161      Wman = 3413.0*Qrad/DHNET
1162      Gap = 3.0/12.0
1163

```

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

```

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 CONMAN(Ifluid,Cman,Hman,Gap,THICKins,RHOins,Tout,
1171      &Tbraze,TKcan,TKbraze,TKhp,XNpipes,XNexpipes,Pin,Tin,Xin,RHOpip,
1172      &RHOCan,RHOBrake,THICKman,Thtpip,Hman,Grad,XMANmas,DPman,DTFsup,
1173      &Ar,Gt,V,Dh,Cgt,Rel,Hl,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      ENDIF
1183      1506 Hman = Hman
1184 C      WRITE (6,*) ****
1185
1186      1508 CONTINUE
1187      CALL CONMAN(Ifluid,Cman,Hman,Gap,THICKins,RHOins,Tout,
1188      &Tbraze,TKcan,TKbraze,TKhp,XNpipes,XNexpipes,Pin,Tin,Xin,RHOpip,
1189      &RHOCan,RHOBrake,THICKman,Thtpip,Hman,Grad,XMANmas,DPman,DTFsup,
1190      &Ar,Gt,V,Dh,Cgt,Rel,Hl,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      ENDIF
1200      1510 Gap = Gap
1201      CALL CONMAN(Ifluid,Cman,Hman,Gap,THICKins,RHOins,Tout,
1202      &Tbraze,TKcan,TKbraze,TKhp,XNpipes,XNexpipes,Pin,Tin,Xin,RHOpip,
1203      &RHOCan,RHOBrake,THICKman,Thtpip,Hman,Grad,XMANmas,DPman,DTFsup,
1204      &Ar,Gt,V,Dh,Cgt,Rel,Hl,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/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1
Source file Listing

```
1216      Xladiab = 0.0
1217      Xmchmas = 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,DTman,DTfilm,Trad)
1224 C      WRITE (6,*) 'Trad, Ifluid, Imatl =',Trad,Ifluid,Imatl
1225 C      WRITE (6,*) 'Grad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,Imatl,
1226 C      &Theta,D2rad,Thickm,Thickf,Thick,Em,IENflg,Halt,Hincl,Rsun,Yrlnch,
1227 C      &Alpha,Hap,Harad,Tkfin ===',Grad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe
1228 C      &,Ifluid,Imatl,Theta,D2rad,Thickm,Thickf,Thick,Em,IENflg,Halt,Hincl
1229 C      &,Rsun,Yrlnch,Alpha,Hap,Harad,Tkfin
1230      CALL HRRAD(Grad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,Imatl,
1231      &Theta,D2rad,Thickm,Thickf,Thick,Em,IENflg,Halt,HINCL,Rsun,Yrlnch,
1232      &Alpha,Hap,Harad,Tkfin,Rhocating,Rhoftn,RHOarm,Xladiab,CONFIG,
1233      &Xmchmas,PROB,GAM,ARSF,Earm,Time,Qrejected,Thickf2,Thickm2,
1234      &Aradiator,Aradeffect,Wthick2,Xlart2,Artid2,
1235      &Arwall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xmpipes,Xmfluid,
1236      &Xmfin,Xmcoating,Xmarmor,Xmarmorid,Xstructure,
1237      &Xntradmasst2,Wx12)
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,Thickm,Thickf,Thick
1257      WRITE (6,*) Em,Alpha,Hap,Harad
1258      WRITE (6,*) Tkfin,Rhocating,Rhoftn,RHOarm
1259      WRITE (6,*) Xladiab,Xmchmas
1260      WRITE (6,*) ' '
1261 C      DEFINE CONDENSER
1262      WRITE (6,*) Cman,Hman,Gap,THICKins
1263      WRITE (6,*) RHOins,Tout,Tbraze,TKcan
1264      WRITE (6,*) TKbraze,TKhp,Pin,Tin
1265      WRITE (6,*) Xin,RHOrip,RHOcan,RHObraze
1266      WRITE (6,*) THICKman,Thtpip,Uman
1267      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

```

1268 C
1269     WRITE (6,*) 'C      IENflg,Halt,HINCL,Rsum'
1270     WRITE (6,*) 'C      Yrlinch,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,Rhocoeating,Rhofin,RHOarm'
1278     WRITE (6,*) 'C      Xladiab,Xmchmas'
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,Wman'
1285     WRITE (6,*) '      ,'
1286     CALL RADPRT(Qrad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,I
1287     &matl,Theta,D2rad,Thickm,Thickf,Thick,Em,
1288     &Alpha,Hap,HArad,Tkfin,Rhocoeating,Rhofin,RHOarm,Xladiab,
1289     &Xmchmas,PROB,GAM,ARSF,Earm,Time,Qrejected,Thickf2,Thickm2,
1290     &Aradiator,Aradefect,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,Rsum,Yrlinch)
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,XNpipes,XNexpipes,Pin,Tin,Xin,RHOpip,
1299     &RHOcan,RHObraze,THICKman,Thtpip,Wman,Qrad,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

```

SUBROUTINE RADFLG 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

```
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
```

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SUBROUTINE RADFLG 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

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

SUBROUTINE RADPRT 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

```

1369 C
1370 C
1371 C
1372     SUBROUTINE RADPRT(Qrad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,I
1373 &matl,Theta,D2rad,Thickn,Thickf,Thick,Em,
1374 &Alpha,Hap,HArad,Tkfin,Rhocoating,Rhofin,RHOarm,Xladiab,
1375 &Xmchmas,PROB,GAM,ARSF,Earm,Time,Rejected,Thickf2,Thickm2,
1376 &ARadiator,Aradeffect,Wthick2,Xnart2,Artid2,
1377 &Artwall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xmpipes,Xmfluid,
1378 &Xmfin,Xmcoating,Xmarmor,Xmarmorid,Xstructure,
1379 &Xnetradmes2)
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) =',Qrad
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 ABSORPTIVITY=',Alpha
1406     WRITE (6,*) 'RADIATOR PROJ. AREA (FRAC. OF TOT.)=',Hap
1407     WRITE (6,*) 'RADIATOR ACTUAL AREA (FRACTION)=',HArad
1408     WRITE (6,*) 'THERMAL COND. OF FIN MATERIAL (BTU/HR-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)'
```

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SUBROUTINE RADPRT 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

```
1421      WRITE (*,2555) Qrejected,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,Aradefect
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) Dhpip,e, 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
```

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SUBROUTINE ORBPRT 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

```
1442 C
1443 C
1444 C
1445 SUBROUTINE ORBPRT(IENflg,Halt,HINCL,Rsun,YrInch)
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) =',HINCL
1452 WRITE (6,*) 'DISTANCE FROM SUN (AU) =',Rsun
1453 WRITE (6,*) 'YEAR SATELLITE LAUNCHED =',YrInch
1454 WRITE (6,*) '
1455 RETURN
1456 END
```

SUBROUTINE HMNPRT Compiling Options:/N0/N7/B/NC/ND/NF/H/N1/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/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,Qrad,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 MTL (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) =',Qrad
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,*) 'NAK INVENTORY MASS (Lbs) =',XMNMAN
1494      WRITE (6,*) 'NET MASS OF HEAT PIPE MANIFOLD (Lbs) =',XMANmas
1495      WRITE (6,*) '
1496 C
1497      RETURN
1498 END

```

SUBROUTINE DUCPRT 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

```

1499 C
1500 C
1501 C
1502      SUBROUTINE DUCPRT(XN9,R9,Dp,SUMLEN,Vpipe,TGAS,PGAS,THICKP,RHOPIP,
1503 &THICKI,RHOINS,XMW,DPDUCT,DUCMAS)
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)=',SUMLEN
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)=',DPDUCT
1520      WRITE (6,*) 'DUCT SYSTEM MASS (LBS)=',DUCMAS
1521 C
1522      RETURN
1523      END

```

SUBROUTINE PIPPRT 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

```

1524 C
1525 C
1526 C
1527 SUBROUTINE PIPPRT(XN9,R9,Dp,SUMLEN,Vpipe,Tnak,Pnak,THICKP,RHOPIP,
1528 &THICKI,RHOINS,DPIPE,PIPNAK,PIPHAS)
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)=',DPIPE
1544 WRITE (6,*) 'PIPE SYSTEM MASS (LBS)=',PIPHAS
1545 WRITE (6,*) 'PIPE NAK MASS (LBS) =',PIPNAK
1546 WRITE (6,*) ' '
1547 C
1548 RETURN
1549 END

```

SUBROUTINE HSHXPT 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

```

1550 C
1551 C
1552 C
1553 SUBROUTINE HSHXPT(IHXflg,QDOT,THIN,THOUT,TCIN,TCOUT,WDOTS,DENSSH,
1554 &DTUBE,TTUBE,WDOTT,AKTUBE,DPSHELL,ANTUBES,DPTUBE,DTOL2,ALSHEL,
1555 &AMSHELL,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 =',IHXflg
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,*) 'DTOL2 (Inches) =',DTOL2
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) =',AMSHELL
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

```

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SUBROUTINE PMPPRT 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 PMPPRT(Tnak,Unak,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)=' ,Unak
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
```

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SUBROUTINE VACPRT Compiling Options:/N0/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/N21
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
```

SUBROUTINE CONPRT 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

```

1627 C
1628 C
1629 SUBROUTINE CONPRT(Ar,Gt,V,Dh,Cgt,Rel,Hi,Xtt,Rev,
1630 &Ifluid,Cman,Hman,Gap,THICKins,RHOins,Tout,
1631 &TBraze,TKcan,TKbraze,TKhp,XNpipes,XNexpipes,Pin,Tin,Xin,RHOpip,
1632 &RHOcan,RHObraze,THICKman,Thtpip,Wman,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 REDUNDENT 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 &TBraze
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) =',TKbraze
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) =',RHObraze
1655 WRITE (6,*) 'HEAT PIPE WALL MATERIAL DENSITY (Lb/cu-Ft) =',RHOpip
1656 WRITE (6,*) 'HEAT PIPE WORKING FLUID NUMBER =',Ifluid
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) =',Wman
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

```

SUBROUTINE CONPRT 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

```
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 =',Rel
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 HRENVR 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

```
1691 C
1692 C
1693 C
1694 SUBROUTINE HRENVR(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 (GN^B/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 ENDIF
1721 DO 12 J=1,2
1722 IF (J.EQ.1) THEN
1723 XM=1E-06
1724 ELSE
1725 XM=1.0
1726 ENDIF
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 ENDIF
1736 12 CONTINUE
1737 Alpha1 = AX2
1738 Beta1 = (AX1-AX2)/6.0
1739 C *** COMPUTE EARTH SHIELDING FACTOR, FOCUSING FACTOR ***
1740 C
1741 C Rorb = 6378.0 + Halt
1742 C
```

SUBROUTINE HRENVR 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      Qsunx = 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 (Yrlinch.LT.2011) THEN
1769      Q = 0.02
1770      G1 = (1.0+Q)**(Yrlinch-1988.0)
1771      ELSE
1772      Q = 0.04
1773      G1 = ((1.0+Q)**23.0)*((1.0+Q)**(Yrlinch-2011.0))
1774      ENDIF
1775      P = 0.05
1776      G2 = 1.0 + (P*(Yrlinch-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))+&(0.000014*(HINCL**3.0))
1787      DUM4 = (F1*G1)+(F2*G2)
1788      ANT = 3.168896E-08*(HD*PHI*PSI*DUM4)
1789      IF (J.EQ.1) THEN
1790      AX1 = ALOG10(ANT)
1791      ELSE
1792      AX2 = ALOG10(ANT)
1793      ENDIF
```

SUBROUTINE HRENVR 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

```
1795    14 CONTINUE
1796      Alpha2 = AX2
1797      Beta2 = (AX1-AX2)/6.0
1798      Ealpha2 = 1.0*Alpha2
1799      IF (Ealpha2.GT.EalphaM) THEN
1800          Ealpha = 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)))**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 HRAMR 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

```
1836 C
1837 C
1838 C
1839 SUBROUTINE HRAMR(IENflg,Halt,HINCL,Rsun,Yrlinch,GAM,ARSF,Earm,RHO
1840 &arm,Atarget,Time,Prob,Temp,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 Yrlinch = 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 HRENVR
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 CALL HRENVR(IENflg,Halt,HINCL,Rsun,Yrlinch,Ealpha,Beta,Qsunx)
1874 Ca = 0.003657*SQRT(Earm*32.174/RHOarm)
1875 A1 = GAM*ARSF*SQRT((RHOP*62.4)/RHOarm)*((Vp/Ca)**0.666667)
1876 A2 = ((6.0/(3.141593*RHOP))**0.333333)
1877 A3 = (1.0/(3.0*Beta))
1878 A4 = (Ealpha*Atarget*Time/(- ALOG(Prob)))**A3
1879 A5 = (2.0/(2.0*BETA+2.0))**A3
1880 A6 = (Temp/300.0)**0.166667
1881 TARM = A1*A2*A4*A5*A6
1882 Tharm = TARM/2.54
1883 C RETURNS THICKNESS IN INCHES
1884 RETURN
1885 END
```

SUBROUTINE HRTSNK 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

```
1886 C
1887 C
1888 C
1889 SUBROUTINE HRTSNK(IENflg,Halt,HINCL,Rsun,Yrlnch,Alpha,Hap,HArad,Ts
1890 &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 CALL HRENR(IENflg,Halt,HINCL,Rsun,Yrlnch,Alpha,Beta,Qsunx)
1914 IF (Rsun.EQ.1.0) THEN
1915 Sc = 443.0
1916 Er = 74.2
1917 Ee = 65.9
1918 ELSE
1919 Sc = Qsunx
1920 Er = 0.0
1921 Ee = 0.0
1922 ENDIF
1923 R = 6378.0
1924 AK = (R/(R+HAlt))**2.0
1925 Qs = Sc*Alpha*Hap
1926 Qr = AK*Er*Hap
1927 Qe = AK*Ee*Hap
1928 Qrad = Qs+Qr+Qe
1929 Qflux = Qrad/HArad
1930 SIGMA = 1.714E-09
1931 Tsink = ((Qflux/SIGMA)**0.25)
1932 C RETURNS Tsink IN (deg-R)
1933 RETURN
1934 END
```

SUBROUTINE FLUIDPROP 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

```
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
```

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

```

1987      CONTINUE
1988      ENDIF
1989      IF (T0.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 (T0.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      Surften=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*T0-8.982149E-06*T0**2.0
2008      P0=2.24732E-06*T0**4.22186
2009      Vapden=2.35726E-07*EXP(0.01767*T0)
2010      Surften=77.8092-0.208046*T0
2011      Xlhv=200.529+2.93522*T0-8.30692E-03*T0**2.0
2012 8057 Xk=1.324
2013      Xmw=18.0
2014      Tcfluid=0.000918+1.572E-06*Tk
2015      RETURN
2016 C SODIUM
2017 8030 IF (T0.LE.450.0) THEN
2018      GOTO 8100
2019      ELSE
2020      CONTINUE
2021      ENDIF
2022      IF (T0.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*T0**2.0+X2*T0+X1)
2035      Surften=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

```

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 SUBROUTINE FLUIDPROP 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

```

2039      Tcfluid=.2389*(1.0796-.0007057*Tk+2.188E-07*Tk**2.0)
2040      RETURN
2041      C      LITHIUM
2042      8040 IF (T0.LE.800.0) THEN
2043          GOTO 8100
2044      ELSE
2045          CONTINUE
2046      ENDIF
2047      IF (T0.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      P0 = EXP(-8.347+0.02045*Tk-4.14E-06*Tk**2.0)/P9
2058      Surften=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      Xm=6.94
2062      Tcfluid=.000012*T0+.10688
2063      RETURN
2064      C      POTASSIUM
2065      8060 IF (T0.LE.100.0) THEN
2066          GOTO 8100
2067      ELSE
2068          CONTINUE
2069      ENDIF
2070      IF (T0.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      P0=750.06*EXP(9.191863-9030.992/Tk-433033.8/Tk**2.0)
2080      Surften=141.48-0.07392*Tk
2081      Xlhv=0.23889*(2269.1-0.13184*Tk-0.0002003*Tk**2.0)
2082      Xk=1.63
2083      Xm=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 (T0.LE.10.0) THEN
2090          GOTO 8100

```

SUBROUTINE FLUIDPROP 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

```
2091      ELSE
2092      CONTINUE
2093      ENDIF
2094      IF (T0.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
```

SUBROUTINE FLUIDPROP 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

```
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) = 99160.0
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
```

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

```
2195      Whgp(94) = 5793000.0
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
```

SUBROUTINE FLUIDPROP 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

```

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

```

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

```

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 (T0.LE.-60.0) THEN
2330      GOTO 8100
2331      ELSE
2332      CONTINUE
2333      ENDIF
2334      IF (T0.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      Xliqvisc=(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      Vapvisc=-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)))

```

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SUBROUTINE FLUIDPROP 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

```
2351      P0 = 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
&Tk**3.0)-(4.734199E-07*Tk**4)
2355      Xk=1.33
2356      Xm=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/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1
Source file Listing

```
2360 C
2361 C
2362 C
2363 SUBROUTINE Tsat(Ifluid,P0,T0)
2364 C
2365 C CALCULATE TEMPERATURE FROM PRESSURE
2366 C
2367 COMMON /RAD3/ Roonden(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 Ps=0.0142232*P0
2430 Ts=(4618.37/(13.89430- ALOG(Ps)))+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 &06-273.2
2442 RETURN
2443 END
```

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

```
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 9200 Wallden=19.35
2494 Tcwall=0.298-0.000024*T0
2495 RETURN
```

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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
```

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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/NQ1/NQ2/NQ3/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 C RHO = 58.54299-(0.008208*T)
2556 C CP = 0.26478 - (0.000089*(T)) + (4.093060E-08*(T**2.0)) -
2557 & (4.532164E-12*(T**3.0))
2558 C VIS = 0.000822 - (1.142635E-06*(T)) + (6.125737E-10*(T**2.0)) -
2559 & (1.130181E-13*(T**3.0))
2560 C TK = 7.313351 + (0.013983*(T)) - (7.660423E-06*(T**2.0)) +
2561 & (1.189370E-09*(T**3.0))
2562 C RETURN
2563 CEND
```

SUBROUTINE HEXEPR 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

```

2564 C
2565 C
2566 C
2567 SUBROUTINE HEXEPR(Anummix,Pmix,Tmix,Gma,Cpmix,Rhomix,Amumix,Akmix,
2568 &Prmix)
2569 C PROPERTIES OF HELIUM-XENON MIXTURES
2570 C T IN deg-R
2571 C WRITE (6,*) 'Amumix,Pmix,Tmix=',Amumix,Pmix,Tmix
2572 Gma=1.667
2573 Am1=4.0
2574 Am2=131.3
2575 X2=(Amumix-Am1)/(Am2-Am1)
2576 X1=1.0-X2
2577 Cpmix=4.97/Amumix
2578 Rhomix=144.0*Pmix*Amumix/(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*SQRT(1.0+(Am1/Am2))
2636          Dum2=1.0+SQRT(Amu1/Amu2)*(Am2/Am1)**0.25
2637          Psi12=Dum2**2.0/Dum1
2638          Dum3=Amu2/Amu1*(Am1/Am2)
2639          Psi121=Dum3*Psi12
2640          Dum4=1.0+Psi12*(X2/X1)
2641          Dum5=1.0+Psi121*(X1/X2)
2642          Amumix=Amu1/Dum4+Amu2/Dum5
2643          Dum6=2.82843*SQRT(1.0+(Am1/Am2))
2644          Dum7=(1.0+SQRT(Ak1/Ak2)*(Am1/Am2)**0.25)**2.0
2645          Dum8=2.82843*SQRT(1.0+(Am2/Am1))
2646          Dum9=(1.0+SQRT(Ak2/Ak1)*(Am2/Am1)**0.25)**2.0
2647          Alam12=Dum7/Dum8
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          Pmix=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) =',Gma
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

```

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SUBROUTINE HEXEPR 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

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

SUBROUTINE HRRAD 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

```
2672 C
2673 C
2674 C
2675 SUBROUTINE HRRAD(Qrad,Trad,Xntubes,Xnexpip,Xlflat,Dhpipe,Ifluid,
2676 &Imat1,Theta,D2rad,Thickm,Thickf,Thick,Em,IENflg,Halt,HINCL,Rsun,
2677 &Yrlinch,Alpha,Hap,HArad,Tkfin,Rhocoating,Rhofin,RHOarm
2678 &,Xladiab,CONFIG,Xmchmas,PROB,GAM,ARSF,Earm,Time,Qrejected,
2679 &Thickf2,Thickm2,Aradiator,Aradeffect,Wthick2,Xnart2,Artid2,
2680 &Artwall2,Thick2,Xlevap2,Xladi2,Xlspec2,Xltot2,Xmpipes,Xmfluid,
2681 &Xmfin,Xmcoating,Xmarmor,Xmarmorid,Xstructure,
2682 &Xnetradmasst2,Wx(2)
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),Whgp(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 Qrad = 3413.0*Qrad
2692 C
2693 Angle2=Theta
2694 Dhpipe=2.54*Dhpipe
2695 CALL HRTSNK(IENflg,Halt,HINCL,Rsun,Yrlinch,Alpha,Hap,HArad,Tsink)
2696 Xlspec=6.0
2697 Xnpunit = 1.0
2698 Ixincr=50
2699 Wvoid2=0.5
2700 Wthick2=0.0020*Dhpipe
2701 Artwall2=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=D2rad
2722 ELSE
2723 D3=Drad(I-1)
```

SUBROUTINE HRRAD 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

```

2724      ENDIF
2725  1110 Hnet=Xlspec*COS(Angle2/57.29578)
2726  1120 D1=D2rad+(2.0*Xlspec*SIN(Angle2/57.29578))
2727  1130 D2=Drad(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=(Qrad/Xntubes)*0.2931
2747      CALL HRHTPP(Imati,Ifluid,Xlevap,Xladi,Xlcond,Pipid,Wall,Tstrtk,Qs
2748      Itart,Wthick2,Wvoid2,Artwall2,Artid2,Xhart2,T(I),Fluidcharge,Totalm
2749      Zass)
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

```

SUBROUTINE HRRAD 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

```

2776 C      HEAT PIPE RADIATOR MASS ALGORITHM
2777 1720 Xlradiat=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)*SQR(((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 Xmfir=Space7*Thickf*Xlradiat*Rhofin*(Xntubes+Xnexpip)
2791 1890 Xmfluid=Xmfluid*(Xntubes+Xnexpip)
2792 1900 Acoating=3.141593/2.0*(Dv7+Thick+Thickm/2.0)*Thickm+Space7*Thickm
2793 1910 Xmcoating=Acoating*Xlradiat*Rhocoating*(Xntubes+Xnexpip)
2794 1930 Atube=Dv7*Xlradiat
2795 1940 Jj=IFIX(Xnexpip*Xnpunit)
2796 1950 Kkkk=IFIX(Xntubes)+Jj
2797 1960 P7=Pnew(Pdesi,Jj,Kkkk)
2798 1970 Prob=1.0-P7
2799 Temp = T(49)
2800 Atarget = Atube/10.764961
2801 1980 CALL HRARMR(IENflg,Halt,HINCL,Rsum,Yrlinch,GAM,ARSF,Earm,RHOarm,At
2802 &target,Time,Prob,Temp,Tharm)
2803 WRITE (6,*) 'Tharm (inches) =' , Tharm
2804 Thickarm=Tharm/12.0
2805 2050 Xmarmor=Thickarm*Dv7*Xlradiat*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=Thickarm2*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/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/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+Xmarmor+
2840 1Xmarmorid+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) Xmarmor,Xmarmorid,Xstructure,Xnetradmasst2
2850 C      WRITE (*,*) 'AREA(sq-M) =',Aradiator/10.764961,'Mass(Kg) =',Xnetra
2851 C      1dmasst2/2.2046,'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*Acomp) =',0.104916*A
2855 C      &radiator
2856 RETURN
2857 END

```

SUBROUTINE HRHTPP 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

```

2858 C
2859 C
2860 C
2861 2980 SUBROUTINE HRHTPP(Imat1,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),Whp(159)
2865     3030 Pipod=Pipid+2.0*Wall
2866 C3040 WICK STRUCTURE # 1
2867     3050 Wcaprad=0.001
2868     3060 Wperm=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(Imat1,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(Imat1,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)

```

SUBROUTINE HRNTPP 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

```
2911 3880 T0=Textevap-Dtewall-Dtewick
2912      CALL Fluidprop(Ifluid,T0,Xliqden,Vapden,Xliqvisc,Vapvisc,P0,Surfte
2913      1n,Xlhv,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,Xlhv,Xk,Xmw,Tcfluid)
2922 C
2923 3970 X1=P0*p9
2924 3980 Dtevap2=T0+273.2
2925 3990 X9=0.0000436*Xlhv*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 4050 Tbev=Textevap-Dtewall-Dtewick-Dtevap
2939 4060 T0=Tbev
2940      CALL Fluidprop(Ifluid,T0,Xliqden,Vapden,Xliqvisc,Vapvisc,P0,Surfte
2941      1n,Xlhv,Xk,Xmw,Tcfluid)
2942 4080 Pbev=P0*p9
2943 4100 Evapcapforce=2.0*Surften*COS(Wetangle/57.29578)/Wcaprad
2944 4120 Esonic=0.474*Effarea*Xlhv*SQRT(Vapden*Pbev)
2945 4130 IF (Q0.LT.Esonic) THEN
2946      GOTO 4180
2947      ELSE
2948      GOTO 5710
2949      ENDIF
2950 4180 Axvapvel=Q0/(Vapden*Effarea*Xlhv)
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/(Effarea**2.0*Xlhv**2.0*Vapden)
2955 4240 IF (Pbev**2.0.LT.Pbev**2.0*C7*Xle*Ff/Effdiam*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
```

SUBROUTINE HRHTPP 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

```

2963      ELSE
2964 4260 GOTO 5750
2965      ENDIF
2966 4270 Dpveviscous=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-Dpveviscous
2970 4300 IF (X0.GT.0.0) THEN
2971      GOTO 4400
2972      ELSE
2973      GOTO 5790
2974      ENDIF
2975 4400 Dplearrt=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 Dpewick=Xliqvisc*Xlengthflow*(Q0/(2.0*Xnart))/(Wperm*Xliqden*Xlhv
2979 1*Xle*Wthick)
2980 4450 P0=(Pbev-(Dpveinertial+Dpveviscous))/P9
2981 4460 Peav=P0*P9
2982 4470 CALL Tsat(Ifluid,P9,P0,T0)
2983 4480 Teav=T0
2984      CALL Fluidprop(Ifluid,T0,Xliqden,Vapden,Xliqvisc,Vapvisc,P0,Surft
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 Eamach=Axvapvel/Velsound
2989 4550 IF (Eamach.LT.1.0) THEN
2990      GOTO 4570
2991      ELSE
2992 4560 GOTO 5830
2993      ENDIF
2994 4570 Eamach=Eamach
2995 4580 IF (Xla.EQ.0) THEN
2996      GOTO 4950
2997      ELSE
2998      CONTINUE
2999      ENDIF
3000 4600 Adbcapforce=2.0*Surften*COS(Wetangle/57.29578)/Wcaprad
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/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1
Source file Listing

```

3015 4680 GOTO 4710
3016 4690 Ff=0.046/Aaxreyn**0.2
3017 4710 P7=Peav
3018 4720 IF (Eamach.GT.0.15) THEN
3019  GOTO 4750
3020  ELSE
3021  CONTINUE
3022  ENDIF
3023 4730 Dpvaviscous=2.0*Ff*Xla/Effdiam*Vapden*Axvapvel**2.0
3024 4740 GOTO 4790
3025 4750 Sonicflag=0.0
3026 4760 CALL Xmach(Eamach,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)/(Artperr*Xliqden*Xlhv*3.141593*Ar
3034 1tid**2.0/4.0)
3035 4820 P0=(Peav-Dpvaviscous)/P9
3036 4830 Pacv=P0*p9
3037 4840 Acmach=Xm8
3038 4850 CALL Tsat(Ifluid,P9,P0,T0)
3039  CALL Fluidprop(Ifluid,T0,Xliqden,Vapden,Xliqvisc,Vapvisc,P0,Surfte
3040 1n,Xlhv,Xk,Xmw,Tcfluid)
3041 4880 IF (Acmach.GT.0.15) THEN
3042  GOTO 5000
3043  ELSE
3044  CONTINUE
3045  ENDIF
3046 4900 Axvapvel=Q0/(Vapden*Effarea*Xlhv)
3047 4910 Velsound=SQRT(Xk*8.3144E+07*(Teav+273.2)/Xmw)
3048 4920 Acmach=Axvapvel/Velsound
3049 4930 GOTO 5000
3050 4950 Pacv=Peav
3051 4970 Acmach=Eamach
3052 5000 CONTINUE
3053 5020 Condcapforce=2.0*Surften*COS(Wetangle/57.29578)/Wcaprad
3054 5060 Axvapvel=Q0/(Vapden*Effarea*Xlhv)
3055 5070 Caxreyn=Vapden*Axvapvel*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

```

SUBROUTINE HRHTPP 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

```

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*Axpvel**2.0
3072 5160 Dpvcinertial=-0.5*Vapden*Axpvel**2.0
3073 5180 Dplcart=Xliqvisc*(Xlc/2.0)*(Q0/Xnart)/(Arperm*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))/(Wperm*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     ENDIF
3085 5270 GOTO 6030
3086 5290 CALL Tsat(Ifluid,P9,P0,T0)
3087 5300 Tfcv=T0
3088     Ztot=FLOAT(1)
3089 5320 Dtccond=Dtevap*(Xle/Xlc)*(Ztot/50.0)
3090 5340 T0=Tfcv-Dtccond
3091     CALL Fluidprop(Ifluid,T0,Xliqden,Vapden,Xliqvisc,Vapvisc,P0,Surft
3092 1n,Xlhv,Xk,Xmw,Tcfluid)
3093 5360 CALL Wallprop(Imati,T0,Wallden,Tcwall)
3094 5370 Tcwick=Tcwall
3095 5390 Tcfilledwick=Tcwick*(1.0-Wvoid*(1.0-Tcfluid/Tcwick))
3096 5400 Dtcwick=Q0*ALOG(Pipid/(2.0*Vaprad))/(2.0*3.141593*Tcfilledwick*Xlc
3097 1)*(Ztot/50.0)
3098 5420 T0=Tfcv-Dtccond-Dtcwick
3099 5430 CALL Wallprop(Imati,T0,Wallden,Tcwall)
3100 5440 Dtcwall=Q0*ALOG(Pipod/Pipid)/(Tcwall*2.0*3.141593*Xlc)*(Ztot/50.0)
3101 5460 Textcond=Tfcv-Dtccond-Dtcwick-Dtcwall
3102 5465 Condenserdp=Dpvcviscous+Dpvcinertial+Dplcart+Dplcwick
3103 5490 IF (Condcapforce.LT.Condenserdp) THEN
3104     GOTO 5950
3105     ELSE
3106     CONTINUE
3107     ENDIF
3108 5500 X=Dpvcviscous-Dpvcinertial
3109 5510 IF (X.LT.0.0) THEN
3110     X=0.0
3111     ELSE
3112     CONTINUE
3113     ENDIF
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

```

SUBROUTINE HRNTPP 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

```

3119      CONTINUE
3120  5570 ENDIF
3121  5580 IF (Xleftoverc+Adbcapforce-Condcapforce.LT.Dplviscous+Dplaart) TH
3122    1EN
3123    GOTO 5990
3124    ELSE
3125    CONTINUE
3126    ENDIF
3127  5600 Xleftovera=Xleftoverc+Adbcapforce-Condcapforce-Dplviscous-Dplaart
3128  5605 Evapcapforcedp=Dpviscous+Dpveinertial+Dpleart+Dplewick
3129  5610 IF (Xleftovera+Evapcapforce-Adbcapforce.LT.Evapcapforcedp) THEN
3130    GOTO 6030
3131    ELSE
3132  5630 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 (*,*) 'SQRT 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 Arteryvolume=Xnart*3.141593*(Artod**2.0-Artid**2.0)/4.0*Xlp
3153  6120 Arterymass=Arteryvolume*(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

```

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SUBROUTINE XMACH Compiling Options:/N0/N7/B/NC/ND/NF/H/N1/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1
Source file Listing

3211 END

FUNCTION PNEW 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

```
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     *** VARIABLES 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,Dupdold,Dudp,Dudpnew,F,U,A,Pnew
3225 C         Pold=0.03
3226 C         Dudpold=10.0
3227 C         9510 F=U
3228 C         Dudp=0
3229 C         DO 9512 H=J+1,K,1
3230 C         A=Xlnfac(K)-Xlnfac(K-H)-Xlnfac(H)+H*ALOG(Pold)+(K-H)*ALOG(1-Pold)
3231 C         IF (A.GT.-50.0) THEN
3232 C             A=EXP(A)
3233 C             F=F+A
3234 C             Dudp=Dudp+A*(H/Pold-(K-H)/(1-Pold))
3235 C         ELSE
3236 C             CONTINUE
3237 C         ENDIF
3238 C         9512 CONTINUE
3239 C         Dudpnew=(Dudp+Dupdold)/2
3240 C         IF (ABS(F/Dudpnew).LT.0.005) THEN
3241 C             Pnew=Pold-F/Dudpnew
3242 C         ELSE
3243 C             Pnew=Pold-0.4*F/Dudpnew
3244 C         ENDIF
3245 C         Dudpold=Dudpnew
3246 C         IF (Pnew.GT.0.99999) THEN
3247 C             Pnew=0.1+0.9*Pold
3248 C         ELSE
3249 C             CONTINUE
3250 C         ENDIF
3251 C         IF (Pnew.LT.0.00001) THEN
3252 C             Pnew=0.1*Pold
3253 C         ELSE
3254 C             CONTINUE
3255 C         ENDIF
3256 C         Error=ABS((Pnew-Pold)/Pold)
3257 C         Pold=Pnew
3258 C         IF (Error.GT.0.000001) THEN
3259 C             GOTO 9510
3260 C         ELSE
3261 C             CONTINUE
3262 C         ENDIF
3263 C         Pnew=Pnew
```

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

3264 RETURN
3265 END

FUNCTION XLNFACT 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
```

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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
```

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SUBROUTINE ACONE 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

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

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SUBROUTINE AVIEW 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

```
3333 C
3334 C
3335 C
3336 SUBROUTINE AVIEW(Ds,Dl,Ht,Acone,Vfct)
3337 R1 = Ds/2.0
3338 R2 = Dl/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/N7/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 X12=1.0+(R2/R1)**2.0+(H1/R1)**2.0
3369 X13=1.0+(R3/R1)**2.0+(H2/R1)**2.0
3370 F1to2=0.5*(X12-SQRT((X12**2.0)-(4.0*(R2/R1)**2.0)))
3371 F1to3=0.5*(X13-SQRT((X13**2.0)-(4.0*(R3/R1)**2.0)))
3372 A1x=3.141593*(D1**2.0)/4.0
3373 Daa=SQRT(((H2-H1)**2.0)+((D2/2.0-D3/2.0)**2.0))
3374 Dab=3.141593*(D2+D3)/2.0
3375 Aa=Daa*Dab
3376 Vf=(A1x/Aa)*(F1to2-F1to3)
3377 RETURN
3378 END

```

SUBROUTINE HRSHEL 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

```

3379 C
3380 C
3381 C
3382 SUBROUTINE HRSHEL(IHXflg,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,ALSHEL,AMSHELL,AMPLATES,
3385 &AMTUBES,AMINSUL,AMHEADS,AMSTRT,ANETMASS,XNNHEX,HSHELL,AFRIC,UNEW,
3386 &RETUBE,THC,AMTSHT)
3387 WRITE (6,*) '
3388 WRITE (6,*) 'DATA INPUT LIST FROM HRSHEL'
3389 WRITE (6,*) 'IHXflg,UEST,THIN,THOUT,PHOT,TCIN,TCOUT,WDOTS,AMWS,
3390 &TINS,DENINS,DENSSH,DTUBE,PR,TTUBE,ANPLATES,WDOTT,AKTUBE,QDOT =',
3391 &IHXflg,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      IHXflf = 1, THEN TUBE SIDE FLUID IS LITHIUM
3404 C      IHXflg = 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/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/H/NX/N
Source file Listing

```

3432 C
3433 C      ***** TUBE-SIDE FLUID PROPERTYIES
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),IHXFLG
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)+((QQ/2.0)**2.0)
3477 C      AARG = -(QQ/2.0)+SQRT(QBIG)
3478 C      ABIG = (ABS(AARG))**0.333333
3479 C      BBRG = -(QQ/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

```

SUBROUTINE HRSHEL Compiling Options:/N0/N7/B/NC/ND/NF/H/NI/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      HS1 = 0.415*CPSF*GXT*FFBH*AJFAC
3508      HS2 = (AKTST/(CPSF*VISCST))**0.66667
3509      HSHELL = HS1*HS2
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 = WDOTT/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*VISCST)
3520      DTUBEI = DTUBE-(2.0*TTUBE)
3521      PRTUBE = (3600*VISCST*CPT)/AKTT
3522      IF (PRTUBE-0.1) 330,330,340
3523  330  THC = (12.0*AKTT/DTUBEI)*(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/DTUBEI)
3528      GOTO 450
3529  400  AK = 0.0001
3530      AKD = AK/DTUBEI
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/DTUBEI)*(RETUBE**0.8)*(PRTUBE**0.4)
3534  435  GOTO 450
3535  440  IF (RETUBE-2000.0) 442,442,445
    
```

← IF () -, 0, +

*line 97
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SUBROUTINE HRSHEL 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

```

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    ANPLATES = ANPLATES*(2.0*3.141593*((DOTL**2.0)/4.0)*TMIN*(DENSSH/1
3570    &1728.0))
3571    AMTSHT = 2.0*3.141593*((DOTL**2.0)/4.0)*2.0*TMIN*(DENSSH/1728.0)
3572    ANTUBES = 0.785398*((DTUBE**2.0)-(DTUBEI**2.0))*ALSHEL*ANTUBES*(
3573    1DENSSH/1728.0)
3574    AMSTRT = 0.05*(AMINSUL+AMHEADS+AMSSHELL+ANPLATES+AMTSHT+ANTUBES)
3575    ANETHMASS = AMINSUL+AMHEADS+AMSSHELL+ANPLATES+AMTSHT+ANTUBES+AMSTRT
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 =',ANTUBES
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

```

SUBROUTINE HRSHEL 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

```

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) =',AMTSHT
3598 C   WRITE (6,*) 'TUBE MASS (Lbs) =',AMTUBES
3599 C   WRITE (6,*) 'STRUCTURE AND BRACKETS MASS (Lbs) =',AMSTRT
3600 C   WRITE (6,*) 'Net Mass of Shell and Tube Unit (Lbs) =',ANETMASS
3601 VNAK1 = 0.785398*(DTUBE**2.0)*ALSHEL*ANTUBES
3602 VNAK2 = 0.523599*(DOTL**3.0)
3603 XMNHEX = (VNAK1+VNAK2)*(RHOT/1728.0)
3604 RETURN
3605 END

```

SUBROUTINE HPMAN 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

```

3606 C
3607 C
3608 C
3609      SUBROUTINE HPMAN(Ifluid,Iflg2,Cman,Hman,Gap,Pitch,Dcan,Dhp,Rc,
3610      &Rb,Tf,TKfin,TKcan,TKbraze,TKhp,Xnf,XNpipes,XNexpipes,XMw,Pman,Tman
3611      &,RHOCan,RHObraze,THICKman,Wman,Qrad,XMANmas,DPman,DTfilm,XMNMAN)
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 REDUNDANT 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 WEIGHT OF MANIFOLD WORKING FLUID
3645 C
3646 C      OUTPUT VARIABLES
3647 C          XMANmas = MANIFOLD MASS (Lbs)
3648 C          DPman = MANIFOLD PRESSURE DROP (PSIA)
3649 C          DTfilm = MANIFOLD FILM TEMPERATURE DROP (deg-R)
3650 C
3651      Qman = 3413.0*Qrad
3652      PI = 3.14159265
3653      Ao = (PI*Dcan*(1.0-(Xnf*Tf))*Hman) + (2.0*Xnf*Hman*((Pitch*Gap)-
3654      &((PI/4.0)*(Dcan**2.0))))
3655      Afo = Ao - (PI*Dcan*Hman*(1.0-(Xnf*Tf)))
3656      X = 12.0*(Gap-Dcan)/2.0
3657      Xe = X*((1.0+(12.0*Tf))/(2.0*X))*(1.0+(0.35* ALOG(X/(12.0*Dcan))))
```

SUBROUTINE HPMAN 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

```

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 10 CALL HEXEPR(XM, Pman, Tman, GAMMA, CP, RHO, AMU, TK, Prmix)
3665 C      GOTO 30
3666 20 CALL XNAKPR(Tman, RHO, CP, AMU, TK)
3667 30 AMU = 3600.0*AMU
3668      Amin = ((Gap-Dcan)*Hman) - (Gap*XNf*Tf)
3669      Gmax = 3600.0*Hman/Amin
3670      REYman = Gmax*Dcan/AMU
3671 C      WRITE (6,*) 'Amin, Gmax, REYman =',Amin,Gmax,REYman
3672      Fiso = 10.0**((1.714012)-(1.349954*(ALOG10(REYman)))+(0.216271*
3673      &((ALOG10(REYman)**2.0))-(0.012421*((ALOG10(REYman))**3.0)))
3674      XJ = 10.0**((0.321848)-(0.840808*(ALOG10(REYman)))+(0.081598*(
3675      &ALOG10(REYman)**2.0))-(0.004631*((ALOG10(REYman))**3.0)))
3676 C      WRITE (6,*) 'Fiso, XJ =',Fiso,XJ
3677      Pr = AMU*CP/TK
3678      Hcman = XJ*CP/Gmax/(Pr**0.6667)
3679      Gc = 4.16975E+08
3680      XNt = XNpipes+XNexpipes
3681 C      WRITE (6,*) 'Pr, Hcman, Gc, XNt =',Pr,Hcman,Gc,XNt
3682 C      MANIFOLD PRESSURE DROP
3683      Vmax = Gmax/(3600.0*RHO)
3684      Qmax = RHO*(Vmax**2.0)/(2.0*32.174*144.0)
3685      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      Qflux = Qman/(PI*Dcan*Hman*XNt)
3688      T0 = (Tman/1.8) - 273.2
3689 C      WRITE (6,*) 'Vmax, Qmax, DPman, Qflux, T0 =',Vmax,Qmax,DPman,Qflux,
3690 C      &T0
3691      CALL Fluidprop(Ifluid,T0,Xliqden,Vapden,Xliqvisc,Vapvisc,P0,Surf
3692      &ten,Xlhv,Xk,Xmwfluid,Tcfluid)
3693 C      WRITE (6,*) 'THERMAL COND OF HEAT PIPE FLUID IS (**) =',Tcfluid
3694      Hevap = (Tcfluid/0.00413656)/(0.010*Dhp)
3695 C      FINISH UP FIN CALCULATION
3696      IF (Tf.LE.0.0) THEN
3697      Ha = Hcman
3698      GOTO 50
3699      ELSE
3700      XM = SQRT((2.0*Hcman)/(TKfin*Tf))
3701      Xe=Xe/12.0
3702      Efin = (1.0/(XM*Xe))*TANH(XM*Xe)
3703      Ecorr = 1.2*Efin - 0.2
3704      IF (Ecorr.LE.0.1) THEN
3705      Ecorr = Efin
3706      GO TO 45
3707      ELSE
3708      CONTINUE
3709      ENDIF

```

SUBROUTINE HPMAN 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

```
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. XMNNMAN = VOLnak*RHO
3743. C   WRITE (6,*) 'Cman,Hman,Gap,XNt,Dcan =',Cman,Hman,Gap,XNt,Dcan
3744. C   WRITE (6,*) 'XMANmas,VOLnak,XMNNMAN =',XMANmas,VOLnak,XMNNMAN
3745. RETURN
3746. END
```

SUBROUTINE HRPIPE 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

```
3747 C
3748 C
3749 C
3750 SUBROUTINE HRPIPE(XN9,R9,Dp,SUMLEN,Vpipe,Tnak,Pnak,
3751 &THICKP,RHOPIP,THICKI,RHOINS,DPIPE,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      RHOPIP = PIPE WALL DENSITY (LB/cu-FT)
3766 C      THICKI = PIPE INSULATION THICKNESS (INCHES)
3767 C      RHOINS = PIPE INSULATION DENSITY (LB/cu-FT)
3768 C      DPIPE = 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 IF (THICKP.EQ.0.0).THICKP = (Pnak*Dp)/15000.0
3773 CALL XNAKPR(Tnak,RHO,CP,VIS,TK)
3774 REnak = Vpipe*Dp*RHO/(12.0*VIS)
3775 Qnak = RHO*(Vpipe**2.0)/(2.0*32.174*144.0)
3776 X1 = ALOG10(R9/Dp)
3777 BETA = -0.589233-(1.334185*X1)+(2.424496*(X1**2.0))-(1.272074*(X1*
3778 &*3.0))+0.148518*(X1**4.0)
3779 AK9 = 10.0**BETA
3780 X2 = ALOG10(REnak)
3781 CfC = 6.723115-(1.517276*(X2))+(0.093726*(X2**2.0))
3782 DPelbo = XN9*CfC*AK9*Qnak
3783 ROUGH = 0.0001
3784 FR1 = (ALOG10((ROUGH/(3.7*Dp))+(5.74/(REnak**0.9))))**2.0
3785 FRIC = 0.25/FR1
3786 DPP = FRIC*(SUMLEN/Dp)*Qnak
3787 DPIPE = DPelbo+DPP
3788 C
3789 C      PIPING MASS ALGORITHM
3790 C
3791 DOp = Dp + (2.0*THICKP)
3792 Dip = Dp
3793 Axp = 0.785398*((DOp**2.0)-(Dip**2.0))
3794 XMPIPES = Axp*SUMLEN*(RHOPIP/1728.0)
3795 DOI = DOp + (2.0*THICKI)
3796 AXPins = 0.785398*((DOI**2.0)-(DOp**2.0))
3797 XMPINS = AXPins*SUMLEN*(RHOINS/1728.0)
3798 XMEL = XN9*0.785398*R9*2.0*Axp*(RHOPIP/1728.0)
```

F77L-EM/32 - Lahey Extended-Memory FORTRAN 77, Version 3.01 09/28/92 14:45:36
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SUBROUTINE HRPIPE 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

```
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*SMLLEN*(RHO/1728.0)
3803      Xnak2 = AXnak*XN9*0.785398*R9*2.0*(RHO/1728.0)
3804      PIPNAK = Xnak1+Xnak2
3805      RETURN
3806      END
```

F77L-EM/32 - Lahey Extended-Memory FORTRAN 77, Version 3.01 09/28/92 14:45:36
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SUBROUTINE PUMP Compiling Options:/N0/N7/B/NC/ND/NF/H/N1/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1
Source file Listing

```
3807 C
3808 C
3809 C
3810      SUBROUTINE PUMP(Tnak,Wnak,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      Wnak = NAK FLOWRATE (LBS/SEC)
3819 C      DPIPE = PIPING SYSTEM 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*(Wnak/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
```

SUBROUTINE VACMAS 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

```
3835 C
3836 C
3837 C
3838 SUBROUTINE VACMAS(Tnak,XMNP1P,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 XMNP1P = 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 = XMNP1P+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/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1
Source file Listing

```

3872 C
3873 C
3874 C
3875 SUBROUTINE HRDUCT(XN9,R9,Dp,SUMLEN,Vpipe,TGAS,PGAS,THICKP,RHOPIP,
3876 &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 RHOPIP = 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 DDUCT = DUCT SYSTEM PRESSURE DROP (PSID)
3895 C DUCMAS = DUCT SYSTEM MASS (LBS)
3896 C
3897 CALL HEXEPR(XMW,PGAS,TGAS,GMA,CP,RHO,VIS,TK,PRGAS)
3898 REnak = Vpipe*Dp*RHO/(12.0*VIS)
3899 Qnak = RHO*(Vpipe**2.0)/(2.0*32.174*144.0)
3900 X1 = ALOG10(R9/Dp)
3901 BETA = -0.589233-(1.334185*X1)+(2.424496*(X1**2.0))-(1.272074*(X1*  
3902 &*3.0))+(-0.148518*(X1**4.0))
3903 AK9 = 10.0**BETA
3904 X2 = ALOG10(RENak)
3905 Cfc = 6.723115-(1.517276*(X2))+(0.093726*(X2**2.0))
3906 DPelbo = XN9*Cfc*AK9*Qnak
3907 ROUGH = 0.0001
3908 FR1 = (ALOG10((ROUGH/(3.7*Dp))+(5.74/(REnak**0.9))))**2.0
3909 FRIC = 0.25/FR1
3910 DPP = FRIC*(SUMLEN/Dp)*Qnak
3911 DDUCT = DPelbo+DPP
3912 C
3913 C PIPING MASS ALGORITHM
3914 C
3915 DOp = Dp + (2.0*THICKP)
3916 DIP = Dp
3917 AXP = 0.785398*((DOp**2.0)-(DIP**2.0))
3918 XMPipes = AXP*SUMLEN*(RHOPIP/1728.0)
3919 DOI = DOp + (2.0*THICKI)
3920 AXPin = 0.785398*((DOI**2.0)-(DOp**2.0))
3921 XMPins = AXPin*SUMLEN*(RHOINS/1728.0)
3922 XMEL = XN9*0.785398*R9*AXP*(RHOPIP/1728.0)
3923 XMELin = XN9*0.785398*R9*AXPin*(RHOINS/1728.0)

```

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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      DUCHAS = XMPIPES+XMPINS+XMEL+XMELin
3925      RETURN
3926      END
```

SUBROUTINE CONMAN 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

```

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,RHOpip,
3932      &RHOcan,RHObraze,THICKman,Thtpip,Wman,Qrad,XMANmas,DPman,DTFsup,
3933      &Ar,Gt,V,Dh,Cgt,Rel,HL,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,*) 'RHOpip,RHOcan,RHObraze,THICKman,Thtpip =',RHOpip,RHOc
3942 C      &an,RHObraze,THICKman,Thtpip
3943 C      WRITE (6,*) 'Wman,Qrad =',Wman,Qrad
3944 C
3945 C      COMMON /CNFL/ DL, DV, VF, VG, HF, HG, HFG, SF, SG,
3946 C                  & 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      Wman = MANIFOLD FLOWRATE (LBS/HR)
3971 C      Qman = MANIFOLD AND RADIATOR HEAT LOAD (BTU/HR)
3972 C      XMW = MOLECULAR WEIGHT 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*Qrad

```

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 SUBROUTINE COMMAN 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

```

3980 C
3981 C      MANIFOLD CONVECTIVE HEAT TRANSFER COEFFICIENT
3982 C
3983 CALL KPRP(Xin,Pin,Tin,DL,DV,HF,HG,HFG,SF,SG,SFG,VF,VG)
3984 CALL KTRN(Xin,Pin,Tin,Cl,Cv,TKl,TKv,Prl,Prv,Vl,Vv)
3985 C      WRITE (6,*) 'Xin,Pin,Tin,DL,DV,HF,HG,HFG,SF,SG,SFG,VF,VG =',Xin,
3986 C      &Pin,Tin,DL,DV,HF,HG,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 Ax = Gap*Hman
3993 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 Ac = 2.0*(Hman*Cman)/(XNpipes+XNexpipes)
3999 DX = Ac/Hman
4000 Wman = Wman
4001 X = Xin
4002 CH = Hman
4003 CW = Gap
4004 ETA = 0.000005
4005 Qflux = Qman/(2.0*Hman*Cman)
4006 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 Tsat = (-7633.6)/( ALOG10(Pin)-5.279)
4013 C      WRITE (6,*) 'Tsat FROM 3650 (R) =',Tsat
4014 IF (Tin.GT.Tsat) THEN
4015 Qdesup = Wman*Cv*(Tin - Tsat)
4016 Qcondn = Wman*HFG
4017 Qsubc = Qman - Qdesup - Qcondn
4018 C      WRITE (6,*) 'Qdesup,Qcondn,Qsubc FROM 3661=',Qdesup,Qcondn,Qsubc
4019 JNSUP = (Qdesup/Qman)*JHP
4020 JNCON = (Qcondn/Qman)*JHP
4021 JNSUB = (Qsubc/Qman)*JHP
4022 IF (JNSUP.EQ.0) JNSUP = 1
4023 IF (JNCON.EQ.0) JNCON = 1
4024 IF (JNSUB.EQ.0) JNSUB = 1
4025 C      WRITE (6,*) 'JNSUP, JNCON, JNSUB =',JNSUP,JNCON,JNSUB
4026 GO TO 70
4027 ELSE
4028 GO TO 20
4029 ENDIF
4030 20 IF (Tin.EQ.Tsat) THEN
4031 Qdesup = 0.0

```

SUBROUTINE CONMAN 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

```

4032      Qsubc = Wman*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(Wman, CH, CW, DX, ETA, Hc, DPnet1,Ar,Gt,V,Dh,Rev,HL)
4060 C      WRITE (6,*) 'INFO FROM AFTER CVAP CALL IN CONMAN'
4061 C      WRITE (6,*) 'Wman,CH,CW,DX,ETA,Hc,DPnet1,Ar,Gt,V,Dh,Rev,HL =',Wman
4062 C      &CH,CW,DX,ETA,Hc,DPnet1,Ar,Gt,V,Dh,Rev,HL
4063      Hcman = Hc
4064      Tman = Tin
4065      T0 = (Tman/1.8) - 273.2
4066      CALL Fluidprop(1fluid,T0,Xliqden,Vapden,Xliqvisc,Vapvisc,P0,Surf
4067      &ten,Xlhv,Xk,Xmmfluid,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

```

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

```

4084      CALL COND(Wman, X, CH, CW, DX, ETA, Hc, DPnet2,Ar,Gt,V,Dh,Cgt,Rel,
4085      & Hl,Xtt,Rev)
4086 C      WRITE (6,*) 'INFO FROM AFTER COND CALL IN CONMAN'
4087 C      WRITE (6,*) 'Wman,X,CH,CW,DX,ETA,Hc,DPnet2,Ar,Gt,V,Dh,Rev,Cgt,Rel,
4088 C      &Hl,Xtt,Rev =',Wman,X,CH,CW,DX,ETA,Hc,DPnet2,Ar,Gt,V,Dh,Rev,Cgt,Rel
4089 C      &,Hl,Xtt,Rev
4090      Hcman = Hc
4091      Tman = Tin
4092      T0 = (Tman/1.8) - 273.2
4093      CALL Fluidprop(Ifluid,T0,Xliqden,Vapden,Xliqvisc,Vapvisc,P0,Surf
4094      &ten,Xlhv,Xk,Xmffluid,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 = Thtrpip/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(Wman, CH, CW, DX, ETA, Hc, DPnet3,Ar,Gt,V,Dh,Rev,Hl)
4111 C      WRITE (6,*) 'INFO FROM AFTER CLIQ CALL IN CONMAN'
4112 C      WRITE (6,*) 'Wman,CH,CW,DX,ETA,Hc,DPnet3,Ar,Gt,V,Dh,Rev,Hl =',
4113 C      &Wman,CH,CW,DX,ETA,Hc,DPnet3,Ar,Gt,V,Dh,Rev,Hl
4114      Hcman = Hc
4115      Tman = Tin
4116      T0 = (Tman/1.8) - 273.2
4117      CALL Fluidprop(Ifluid,T0,Xliqden,Vapden,Xliqvisc,Vapvisc,P0,Surf
4118      &ten,Xlhv,Xk,Xmffluid,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 = Thtrpip/TKhp
4127      D6 = 1.0/Hevap
4128      Usup = 1.0/(D2+D3+D4+D5+D6)
4129      DTFsub = D1*(D2+D3+D4+D5+D6)
4130 C      WRITE (6,*) 'Qflux, Usup, DTFsub =',Qflux,Usup,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)

```

SUBROUTINE COMMAN 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

```
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      XMbraze = Vbraz*RHObraz
4151 C      TOTAL FLAT HEAT PIPE EVAPORATOR MASS
4152      Vheatpip = 4.0*Hman*Cman*Thetpip
4153      XMheatpip = RHOpip*Vheatpip
4154 C      WRITE (6,*) 'Vman,XMwall,Vbraz,XMbraze,Vheatpip,XMheatpip =',Vman,
4155 C      &XMwall,Vbraz,XMbraze,Vheatpip,XMheatpip
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      XMANmas = XMwall+XMbraze+XMheatpip+XMins+XMLiqin
4164 C      WRITE (6,*) 'Vins,XMins,Vliq,XMLiqin,XMANmas =',Vins,XMins,Vliq,
4165 C      &XMLiqin,XMANmas
4166      IF (JNCON.EQ.0) Cgt=0.0
4167      IF (JNCON.EQ.0) Xtt=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:/NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/M/NX/NZ1
Source file Listing

```
4170 C
4171 C
4172 C
4173 C
4174 SUBROUTINE CLIQ (Wman,HM,WL,DX,ETA,Hs,DPnet3,Ar,Gt,V,Dh,
4175 & Rel,HL)
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 = HM * WL
4190 Dh = (4.0*Ar)/((2.0*HM)+(2.0*WL))
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** HL - SHEAR-CONTROLLED LIQUID FILM HEAT TRANSFER COEFFICIENT
4203 HL = (7.0 + 0.025*(Rel * PrL)**0.8 )* (TKL/Dh)
4204 Hs = HL
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,HL,Hs,DpL,FFL =',V,Rel,HL,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
```

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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/NC/ND/NF/H/HI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1
Source file Listing

```

4225 C
4226 C
4227 C
4228     SUBROUTINE COND (Wman,Y,HM,WM,DX,ETA,Hs,DPnet2,Ar,Gt,V,Dh,
4229     & Cgt,Rel,Hi,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 C     &,VL,VV =',DL,DV,VF,VG,HF,HG,HFG,SF,SG,SFG,CL,CV,TKL,TKV,PrL,Prv,VL
4240 C     &,VV
4241 C** HEAT TRANSFER
4242 C** FLOW CROSS-SECTIONAL AREA (sq ft)
4243     Ar = HM * WM
4244 C     WRITE (6,*) 'Ar =',Ar
4245     Dh = (4.0*Ar)/((2.0*HM)+(2.0*WM))
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 = Wman / 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 = Wman*(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** HL - SHEAR-CONTROLLED LIQUID FILM HEAT TRANSFER COEFFICIENT
4271 C** HL = 0.022*(Rel)**0.8 * (Pr)**0.4 * (TKL/Dh) * VCF
4272     HL = (7.0 + 0.025*(Rel * PrL)**0.8 )* (TKL/Dh)
4273 C     WRITE (6,*) 'HL =',HL
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

```

SUBROUTINE COND 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

```
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      DPl = Gt**2.0/Gc*( ((1.0-Y)/Dle+Y/DVe) - ((1.0-Y)/Dli+Y/DVi) )
4295
4296 C** VAPOR REYNOLDS NUMBER
4297   Rev = Wman*Y*Dh/(Ar*V)
4298 C      WRITE (6,*) 'Rev =',Rev
4299
4300 C** CALCULATE FRICTION FACTORS
4301   FFl = FF(Dh, ETA, Rel)
4302   FFv = FF(Dh, ETA, Rev)
4303
4304 C** LIQUID PRESSURE DROP (psia)
4305   DPl = FFl*(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,*) 'FFl,FFv,DPl,DPv =',FFl,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:/NO/N7/B/NC/ND/NF/H/NI/NK/NL/P/NQ1/NQ2/NQ3/R/S/NT/W/NX/NZ1
Source file Listing

```
4325 C
4326 C
4327 C
4328     SUBROUTINE CVAP (Wman,HH,W,M,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, PrL, 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,PrL,Prv
4338 C     &,VL,Vv =',DL,DV,VF,VG,HF,HG,HFG,SF,SG,SFG,CL,CV,TKL,TKV,PrL,Prv,VL
4339 C     &,Vv
4340 C** HEAT TRANSFER
4341 C** FLOW CROSS-SECTIONAL AREA (sq ft)
4342     Ar = HH * W
4343     Dh = (4.0*Ar)/((2.0*HM)+(2.0*WM))
4344 C** Gt - MASS FLUX (lbm/h sq ft)
4345 C** M - FLOW RATE PER TUBE (lbm/h)
4346     Gt = Wman / 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 = Wman*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
```

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FUNCTION FF 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

```
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
```

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SUBROUTINE KPRP 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

```
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
```

SUBROUTINE KPRP 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

```
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/NQ1/NQ2/NQ3/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
```

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13. ABSTRACT (Maximum 200 words)			
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 a 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.			
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