Potassium-Rankine Power Conversion Subsystem Modeling for Nuclear Electric Propulsion (Task Order 18)

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Prepared for
Lewis Research Center
Under Contract NAS3 25808
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) magnetoplasma dynamic 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 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 the 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.
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<td>98</td>
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1.0 SUMMARY

NASA LeRC is currently developing a Fortran based model of a complete nuclear electric propulsion (NEP) vehicle that would be used for piloted and cargo missions to the Moon or Mars. The proposed vehicle design will use either a Brayton or K-Rankine power conversion cycle to generate electric power. Two thruster types are also being studied, ion and MPD. In support of this NEP model, Rocketdyne is developing power conversion, heat rejection, and power management and distribution models. These models will be incorporated into the NEP vehicle model and be driven by a master module to be written by NASA LeRC. The purpose of this report is to document the K-Rankine Power Conversion Subsystem (PCS) model and component models.

The K-Rankine PCS model is designed to provide performance characteristics based on externally defined parameters such as turbine inlet temperature, condensing temperature, etc. These characteristics will then be used by the master NEP module to determine the NEP vehicle performance characteristics and to conduct system level trades. It is intended that the models developed during this study be used only for conceptual design studies requiring "ballpark" performance estimates.
2.0 INTRODUCTION

The potassium-Rankine power conversion subsystem model presented in this report was developed to evaluate potential NEP concepts which utilize a potassium-Rankine PCS. The model is valid for turbine inlet temperatures ranging from 1200 K to 1600 K, turbine inlet to condenser temperature ratios ranging from 1.25 to 1.6, power levels ranging from 100 kWe to 10 MWe, and lifetimes ranging from 2 to 10 years. The subsystem modeled is shown in Figure 1. This configuration was chosen based on past experience developed during the Multimegawatt program and the Ultra High Power System study. Inherent assumptions contained in this model are that the heat source is a lithium cooled reactor and that a heat pipe radiator is available for heat rejection. It should be noted, that this model has its roots with the ALKASYS program presented in reference 1, but is many generations removed. Rocketdyne has extensively modified its version of this code that only mild similarities, if any, exists between this code and the one presented in Reference 1.

The potassium-Rankine model subroutines are encoded in Fortran 77 and located on the accompanying computer disk. Table 1 lists all files contained on the disk and Figure 2 shows how they interrelate. These include eleven fortran source code files which can be distinguished by the file extension "FOR", one object file titled "CORELATE.OBJ", one input file entitled "KRANK.IN", and the executable file "KRANK.EXE". The fortran source code "CORELATE.FOR" has not been included since it contains proprietary information as will be further explained later.

Generally, the user runs a case in the following way; (1) the user creates an input file with the desired input data, (2) KRANK is typed to run the case, (3) the generated output is examined. It is best to create a new input file by editing an existing input file. This can be accomplished with any ASCII editor. The input file "KRANK.IN" is available for this purpose. The user may wish to view the input file "KRANK.IN" and note its form. After creating an input file, the user types KRANK to start a run. "KRANK.EXE" is an executable file that reads the input file KRANK.IN, directs the ensuing computations, then directs the output to KRANK.OUT. This file is temporary; the NEP system driver to be written by NASA LeRC will replace it.
The program structure is illustrated in Figures 2 and 3. The K-Rankine submodule, "KRANK.FOR", receives the input data, directs the ensuing computations, then directs the output data back to the data processor. The temporary files "MNRANK.FOR", "PRINP.FOR", and "PROUT.FOR" act as the NEP system driver to be written by NASA LeRC. These files read the data from "KRANK.IN", send it to "KRANK.FOR", then receive the output data from "KRANK.FOR" and send it to the output file "KRANK.OUT".

The input data is contained in a 61 element array entitled "PRIN", and the output data is contained in a 526 element array entitled "PROUT". Element definitions and cross references for the input and output arrays are given in the appendices.

3.0 GENERAL DESCRIPTION OF POWER SYSTEM MODEL

The KRANK program calculates performance and design characteristics and mass estimates for the major components which make up the potassium-Rankine power conversion subsystem. Design and performance characteristics are determined by
detailed engineering procedures rather than by empirical algorithms. Mass estimates are developed using basic design principles augmented in some cases by empirical coefficients.

Table 1. Files Included on Enclosed Diskette

<table>
<thead>
<tr>
<th>File Name</th>
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</thead>
<tbody>
<tr>
<td>BOILER.FOR</td>
</tr>
<tr>
<td>KKRANK.FOR</td>
</tr>
<tr>
<td>KTAGEN.FOR</td>
</tr>
<tr>
<td>KTHROMO.FOR</td>
</tr>
<tr>
<td>MNRANK.FOR</td>
</tr>
<tr>
<td>PIPING.FOR</td>
</tr>
<tr>
<td>PRINP.FOR</td>
</tr>
<tr>
<td>PRO.P.FOR</td>
</tr>
<tr>
<td>PROUT.FOR</td>
</tr>
<tr>
<td>PUMP.FOR</td>
</tr>
<tr>
<td>STRENGTH.FOR</td>
</tr>
<tr>
<td>SYSTEM.FOR</td>
</tr>
<tr>
<td>CORELATE.OBJ</td>
</tr>
<tr>
<td>KKRANK.IN</td>
</tr>
<tr>
<td>KKRANK.EXE</td>
</tr>
</tbody>
</table>

In the potassium-Rankine power conversion subsystem, shown in Figure 1, the
The principal flow of potassium vapor leaving the boiler is to the main turbine. A relatively small stream is diverted to the turbine of the turbo feed pump. The main turbine is divided into high-pressure stages and low-pressure stages. Upon exhausting the high-pressure stages, the wet potassium vapor is routed through a reheater to re-vaporize entrained moisture and re-superheat the vapor stream, upon which the vapor stream leaving the reheater is routed to the low-pressure turbine. Upon exhausting from the low-pressure turbine stages, the vapor is condensed in a shear flow controlled condenser. Latent heat of vaporization is rejected by the condenser to the heat rejection subsystem. Condensate leaving the condenser is directed to a Rotary Fluid Management Device (RFMD). The RFMD provides two phase fluid management and pressurizes the condensate to ensure that sufficient net positive suction head (NPSH) is provided to the main turbo-feedpump. The turbo-feedpump re-pressurizes the liquid potassium received from the RFMD and directs it to the boiler.

The thermodynamic analysis of the potassium-Rankine cycle consists of determining energy and mass balances of the working fluid around each of the cycle components and the entire cycle by using specifications for equipment per-
formance and thermodynamic and transport properties for the working fluid. These properties are calculated in subroutines developed from data presented in Reference 2. The energy and mass balances are first calculated on a per mass basis of prime vapor and are subsequently adjusted to the full size system.

3.1 BOILER AND REHEATER

Boiler and Reheater mass and performance are calculated using essentially the same algorithms. The boiler/reheater algorithm is based on a shell and tube once through boiler with liquid lithium on the shell side and potassium on the tube side. For simplicity, straight tubes are assumed. The tubes contain twisted tape inserts, with a 3:1 pitch to diameter ratio, for improved boiling characteristics. In order to keep boiler/reheater mass to a minimum and still retain good heat transfer, the tube to tube pitch to diameter ratio was set to a low value of 1.375 thus eliminating unnecessary lithium inventory.

For calculational purposes, the boiler/reheater is divided into three sections; preheater, boiling, and superheater. The preheater is where liquid potassium entering the boiler is heated to saturation conditions. Note that the reheater does not have a preheating section. The boiling section is the section of the tube in which the liquid is transformed into a vapor. The superheater is where additional thermal energy is added to the saturated vapor.

The boiler/reheater computation is accomplished as follows. Based on an assumed number of tubes and a user input tube diameter, the tube sections are sized (length) based on heat transfer considerations. Next, pressure losses are determined and compared to a user defined maximum allowed pressure loss. If the pressure losses deviate too greatly from the maximum allowed, then the number of tubes is adjusted accordingly and the computation is repeated.

Shell side heat transfer is based on Dwyer's equation for liquid metals flowing parallel through equilateral triangular tube bundles (Ref. 3). Preheater heat transfer is based on Dwyer's equation for liquid metals in circular pipes (Ref. 3). Boiling heat transfer is based on single tube boiler, boiling potassium experiments (Ref. 4). While superheater heat transfer is based on Petukhov's equation for circular pipes (Ref. 5).
Pressure losses for the shell side and the tube side of the preheater and the superheater are based on Darcy's friction equation (Ref. 6). Pressure losses in the boiling section of the tubes is based on procedures outlined in Reference 7.

Boiler/Reheater weights are determined by querying the materials strength algorithm for the creep strength and density of the appropriate material. The materials strength algorithm determines the correct material to use based on user inputs and primary coolant temperatures. From these parameters, the Boiler/Reheater algorithm sizes and determines the weights of the various components which make up the Boiler/Reheater.

Application note: The potential for a temperature cross occurs when the user attempts to use too close of an approach temperature. A temperature cross will cause a run time error and terminate the program. If a temperature cross should occur, decreasing the turbine inlet temperature should alleviate the problem.

Furthermore, the potential for a run time error will occur if too large a boiler and/or reheater pressure loss(es) are specified by the user. If too large a pressure loss is specified, a negative pressure will be tabulated for tube pressure. This usually cause an error in the KTHRMO subroutine. To remedy this, the specified pressure losses should be decreased.

3.2 TURBINES

The main power turbine is a multi-stage axial reaction turbine. The stages are divided roughly in half to form a high-pressure and a low-pressure turbine on the same shaft. Vapor reheat is implemented between the high-pressure and low-pressure turbines to maintain a minimum vapor quality within the turbine stages. The algorithm for determining number of turbine stages and conditions at each stage are very similar to those used in Reference 1. It has been found by Rocketdyne experience that these algorithms produce results which agree reasonably well with more detailed turbine calculations.

The input values affecting the turbine model along with their recommended values are given in the appendices. From these parameters, number of stages,
efficiency and thermodynamic conditions at each stage, and turbine mass are developed.

A basic assumption in determining the number of turbine stages required is that equal temperature drops occur across each stage. The turbine stage computation begins by first determining the last-stage enthalpy drop to produce the given spouting velocity. The number of turbine stages is set equal to the integer nearest to 1.1 times the isentropic enthalpy difference between turbine inlet saturation temperature and condenser temperature divided by the last-stage enthalpy drop. This accounts for the fact that the enthalpy drop is greater for the last stage than for the average stage in a turbine having equal temperature drops across all stages.

Each stage of the turbine is assumed to have an aerodynamic efficiency equal to the input value for dry-stage efficiency. As the mass and energy balance analysis progresses, the actual efficiency for each stage is then assumed to be the aerodynamic efficiency degraded by one percentage point per percent of average moisture in the stage. In addition, a value for turbine exhaust losses, caused by the last stage leaving velocity, is specified in the input. This exhaust loss is applied to both the high-pressure turbine and the low-pressure turbine.

Turbine weight is based on a Rocketdyne correlation modified to correspond with the Multimegawatt turbines. Weight scaling for cases where different materials are used is based on a creep strength to density scaling factor. Materials properties are obtained from the materials strength routine.

**Application note:** Varying input parameters beyond their recommended values or ranges without prior detailed knowledge of turbo-machinery design and limitations may give erroneous results.

### 3.3 Alternator

This section discusses the development of the generator design algorithms, KTAGEN.FOR, in support of the power conversion systems code development. Specifically, numerous point design studies have been completed and algorithms
developed to support generator sizing in the full-up system evaluation code.

3.3.1 Study Guidelines

All generator designs studied are high performance, high reliability TPTL [two-pole toothless] PM [permanent magnet] type. Both ring wound [RW]/variable cross-section conductor [VCSC] and conventionally wound TPTL configurations were investigated. Specific operating requirements imposed are summarized in Table 2, below.

The TPTL machines were designed to achieve maximum rotor speed consistent with high-reliability (.99+) and 2 to 10 year life. Some advances beyond the state-of-the-art could reasonably be assumed since the use dates range form 2000 to 2015. Although the determination of design speed for a turbo-generator is probably dictated by the generator, the generator speed was also limited to the maximum turbine design speed profile shown in Table 2. No overspeed allowance was included.

<table>
<thead>
<tr>
<th>Table 2. Generator Design Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator Power Output (kVA)</td>
</tr>
<tr>
<td>Generator Type</td>
</tr>
<tr>
<td>Maximum Speed (krpm)</td>
</tr>
<tr>
<td>Voltage (RMSv 1-l)</td>
</tr>
<tr>
<td>Power Factor</td>
</tr>
<tr>
<td>Gap Conditions:</td>
</tr>
<tr>
<td>Viscosity (lb/ft-hr)</td>
</tr>
<tr>
<td>Temp. (°F)</td>
</tr>
<tr>
<td>Press. (psia)</td>
</tr>
<tr>
<td>Density (lb_m/ft³)</td>
</tr>
<tr>
<td>Voltage Regulation</td>
</tr>
<tr>
<td>Insulation Class</td>
</tr>
<tr>
<td>Rotor Magnet L/D</td>
</tr>
</tbody>
</table>

The generator designs are primarily intended for use in a Potassium turbo-generator power system. The rotor/wire-support gap is assumed filled with Potassium vapor at the conditions listed in Table 2.
A 220 deg C insulation system was selected as the reference system. Some deration of the operating temperature may be required to achieve the more ambitious reliability and life goals. Generator sizing, however, can be accomplished at the nominal 220 deg C for hot-spot temperature. Insulation thickness was based on a potential of 50 volts/mil.

Two generator cooling assumes direct stator cooling with an organic coolant (e.g. n-Heptane, Dowtherm, etc.).

The generator designs considered produce 3-phase alternating current at an RMS line-to-line voltage of either 1400 or 8000. The relationship of desired voltage to generator power level is shown in Table 2.

The generator designs evaluated were optimized for an assumed transformer interface. The projected power factor for all cases is 0.90 lagging. This interface is more likely than a rectifier interface for an NEP application. The power factors for use in design are included in Table 2.

Overall generator conversion efficiency (including windage) is the salient parameter affecting system optimization. The TPTL designs were optimized to maximum efficiency with a mass/efficiency trade ratio of approximately 0.2 pounds/kWe generator mass/% generator efficiency.

3.3.2 Generator Design Results

A total of twenty-one point designs were completed using an AiResearch Los Angeles Division [ALAD] proprietary design code. From the results of these studies the VCSC-RW PMG configuration was selected for inclusion in the deliverable generator sizing code. The point designs were reduced to algorithm form to predict performance, mass, and size as a function of design kVA, rotor surface speed and desired output voltage.

a) A maximum allowable generator rotor surface speed of 700 ft/sec was established by ALAD. Above this speed, the primary flux gap widens rapidly due to the hoop thickness required to retain the rotor magnet.
b) A reference rotor L/D of 2.5 was selected for the study. The algorithms developed are assumed valid in the range of $2 \leq L/D \leq 3$ when corrected for $L/D$ not equal 2.5.

c) The algorithms are assumed valid in the range of output voltage from 1 to 10 kV $l_l$, RMS and the range of power factor from 0.7 to 1.0.

d) The design analyses were completed assuming 500 °F operating temperature for both rotor and stator. These assumptions effect magnet aging design margin, electrical insulation life, and conductor resistivity.

e) The alternator will be integrated for use with direct stator cooling using an organic coolant such a Dowtherm A, N-Heptane, etc.

The cases run represent three separate data sets run at the power levels defined in Table 2 and the configuration below:

Set A - Conventionally Wound TPTL PMG at 700 ft/sec surface speed

Set B - Ring Wound/Variable Cross-section Conductor TPTL PMG at 700 ft/sec surface speed

Set C - Ring Wound/Variable Cross-section Conductor TPTL PMG at 500 ft/sec surface speed

Data sets A and B were run concurrently with common groundrules to establish the preferred configuration [ring wound or conventional] for continued study.

Tables 3 and 4 summarize the geometries and performance which resulted from the comparison. It can readily be seen that the VCSC-RW TPTL PM machine is the preferred choice for all power ratings studied. The higher efficiency, lower mass, and higher operating speed are made possible by the higher machine air gap flux density resulting from the VCSC-RW design. In addition, better winding space utilization and higher reliability are achieved since the concentrated individual phase windings are located in physically separate 60 degree phase
sectors. The borders of these phase sectors are insulated phase-to-phase, while within the sector only turn-to-turn and winding-to-ground insulation is required.

In contrast, stator windings using conventional slotted configurations use two coil sides per slot. These coil sides are associated with different phase windings. Full phase-to-phase voltage potential exists between the coil sides as well as between the phase windings which cross over each other in the end turns. Even though fully insulated, areas of phase windings in contact still exist. This condition limits stator robustness, particularly in severe environments and high voltage designs, and reduces stator reliability.

Table 3. Design Summary for Conventionally Wound TPTL Generators Operating at 700 ft/sec Surface Speed

<table>
<thead>
<tr>
<th>Power (kW)</th>
<th>50</th>
<th>100</th>
<th>200</th>
<th>500</th>
<th>1,000</th>
<th>2,000</th>
<th>5,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>kVA (kVA)</td>
<td>56</td>
<td>111</td>
<td>222</td>
<td>556</td>
<td>1,111</td>
<td>2,222</td>
<td>5,556</td>
</tr>
<tr>
<td>N (rpm)</td>
<td>54,500</td>
<td>48,200</td>
<td>34,200</td>
<td>25,000</td>
<td>18,400</td>
<td>13,700</td>
<td>10,240</td>
</tr>
<tr>
<td>V base (l-n RMS)</td>
<td>808</td>
<td>808</td>
<td>808</td>
<td>808</td>
<td>4,620</td>
<td>4,620</td>
<td>4,620</td>
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<tr>
<td>Rotor Dia. (in)</td>
<td>2.94</td>
<td>3.55</td>
<td>4.69</td>
<td>6.42</td>
<td>8.72</td>
<td>11.71</td>
<td>15.67</td>
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<td>Stator OD (in)</td>
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<td>6.52</td>
<td>8.53</td>
<td>11.05</td>
<td>13.51</td>
<td>17.7</td>
<td>22.7</td>
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<td>Length (in)</td>
<td>12.37</td>
<td>14.20</td>
<td>18.60</td>
<td>24.30</td>
<td>33.60</td>
<td>44.30</td>
<td>59.50</td>
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<td>Magnet L/D</td>
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<td>2.51</td>
<td>2.5</td>
<td>2.45</td>
<td>2.53</td>
<td>2.5</td>
<td>2.58</td>
</tr>
<tr>
<td>X (P.U.)</td>
<td>0.121</td>
<td>0.119</td>
<td>0.129</td>
<td>0.114</td>
<td>0.131</td>
<td>0.130</td>
<td>0.137</td>
</tr>
<tr>
<td>EM Mass (lbm)</td>
<td>38.48</td>
<td>65.03</td>
<td>146.3</td>
<td>358.2</td>
<td>724</td>
<td>1682</td>
<td>4101</td>
</tr>
<tr>
<td>Rotor Mass (lbm)</td>
<td>15.58</td>
<td>26.52</td>
<td>61</td>
<td>152</td>
<td>395</td>
<td>940</td>
<td>2314</td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td>95.08</td>
<td>95.88</td>
<td>96.14</td>
<td>96.65</td>
<td>95.4</td>
<td>95.8</td>
<td>96.35</td>
</tr>
<tr>
<td>Losses (kW)</td>
<td>2.56</td>
<td>4.3</td>
<td>8.03</td>
<td>17.3</td>
<td>48.3</td>
<td>88.2</td>
<td>189.3</td>
</tr>
<tr>
<td>Tip Speed (ft/s)</td>
<td>700</td>
<td>700</td>
<td>700</td>
<td>700</td>
<td>700</td>
<td>700</td>
<td>700</td>
</tr>
<tr>
<td>B (kL/in^2)</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>140</td>
<td>140</td>
<td>140</td>
</tr>
</tbody>
</table>

The ring wound stator configuration that uses single-layer variable cross-section conductors readily lends itself the optimization of the winding to achieve high machine air gap flux density, efficient cooling, and maximum reliability. The most valuable space for an electrical machine [motor or generator] is the area between the surface of the rotor magnet and the ID of the
laminated iron flux return path. The smallest possible distance between them yields the highest air gap flux density which leads to the smallest machine mass and size. For the ring wound configuration, the space around the ends of the OD of the flux collector ring is available for much larger conductor segments. Using a high current density Litz wire conductor in the air gap area that is connected to a much larger conductor used for the remainder of the winding results in an enhanced electromagnetic and thermal design. The large cross-section, low current density conductor segment can provide a heat sink and more thermal mass for the winding and thus more effective cooling of the higher current density Litz conductor segment. Lower total winding resistance will result in lower $I^2R$ losses and higher efficiency.

Table 4. Design Summary for Ring-Wound TPTL Generators Operating at 700 ft/sec Surface Speed

<table>
<thead>
<tr>
<th>Power (kW)</th>
<th>50</th>
<th>100</th>
<th>200</th>
<th>500</th>
<th>1,000</th>
<th>2,000</th>
<th>5,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>kVA (kVA)</td>
<td>56</td>
<td>111</td>
<td>222</td>
<td>556</td>
<td>1,111</td>
<td>2,222</td>
<td>5,556</td>
</tr>
<tr>
<td>N (rpm)</td>
<td>80,000</td>
<td>62,000</td>
<td>47,500</td>
<td>32,500</td>
<td>23,000</td>
<td>16,500</td>
<td>11,400</td>
</tr>
<tr>
<td>$V_{ave}$ (1-n RMS)</td>
<td>808</td>
<td>808</td>
<td>808</td>
<td>808</td>
<td>4,620</td>
<td>4,620</td>
<td>4,620</td>
</tr>
<tr>
<td>Rotor Dia. (in)</td>
<td>2.01</td>
<td>2.59</td>
<td>3.38</td>
<td>4.92</td>
<td>6.98</td>
<td>9.72</td>
<td>14.07</td>
</tr>
<tr>
<td>Stator OD (in)</td>
<td>3.82</td>
<td>4.80</td>
<td>6.10</td>
<td>8.60</td>
<td>10.80</td>
<td>14.50</td>
<td>20.00</td>
</tr>
<tr>
<td>Length (in)</td>
<td>6.20</td>
<td>7.40</td>
<td>9.80</td>
<td>14.30</td>
<td>19.00</td>
<td>27.20</td>
<td>38.00</td>
</tr>
<tr>
<td>Magnet L/D</td>
<td>2.49</td>
<td>2.49</td>
<td>2.5</td>
<td>2.5</td>
<td>2.49</td>
<td>2.5</td>
<td>2.51</td>
</tr>
<tr>
<td>$X_{com}$ (P.U.)</td>
<td>0.120</td>
<td>0.120</td>
<td>0.130</td>
<td>0.130</td>
<td>0.130</td>
<td>0.120</td>
<td>0.130</td>
</tr>
<tr>
<td>EM Mass (lb&lt;sub&gt;m&lt;/sub&gt;)</td>
<td>14.08</td>
<td>29.40</td>
<td>62.00</td>
<td>182.7</td>
<td>375.0</td>
<td>993.0</td>
<td>3105.0</td>
</tr>
<tr>
<td>Rotor Mass (lb&lt;sub&gt;m&lt;/sub&gt;)</td>
<td>4.82</td>
<td>10.32</td>
<td>23.00</td>
<td>71.0</td>
<td>198.0</td>
<td>536.0</td>
<td>1630.0</td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td>96.39</td>
<td>96.68</td>
<td>96.80</td>
<td>96.97</td>
<td>96.44</td>
<td>96.3</td>
<td>96.97</td>
</tr>
<tr>
<td>Losses (kW)</td>
<td>1.86</td>
<td>3.44</td>
<td>6.60</td>
<td>15.6</td>
<td>36.9</td>
<td>77.0</td>
<td>156.0</td>
</tr>
<tr>
<td>Tip Speed (ft/s)</td>
<td>700</td>
<td>700</td>
<td>700</td>
<td>700</td>
<td>700</td>
<td>700</td>
<td>700</td>
</tr>
<tr>
<td>$B_{com}$ (kL/in&lt;sup&gt;2&lt;/sup&gt;)</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>80</td>
<td>140</td>
<td>140</td>
<td>140</td>
</tr>
</tbody>
</table>

Table 5 contains design specifics for a series of VCSC-RW TPTL designs operating at 500 ft/sec surface speed. The units are surprisingly low in mass and exhibit small rotor sizes as well. This excellent result at 500 ft/sec is attributed to the much reduced thickness required for the magnet retaining hoop.
and the resulting large increase in gap flux density. In most cases, rotor sizes are comparable to their 700 ft/sec counterparts and total masses are generally lower.

Table 6 contains a summary of the materials of construction assumed in the point design study and performance algorithm. Table 6 also comments on assumed technology levels relative to today's attainable values.

No technology advancement beyond properties available today were assumed for the point design study or in the resulting algorithm.

| Table 5. Design Summary for Ring-Wound TPTL Generators Operating at 500 ft/sec Surface Speed |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Power (kW)                      | 50    | 100    | 200    | 500    | 1,000  | 2,000  | 5,000  |
| kVA (kVA)                       | 56    | 111    | 222    | 556    | 1,111  | 2,222  | 5,556  |
| N (rpm)                         | 61,200 | 47,300 | 36,800 | 25,700 | 18,000 | 14,050 | 9,700  |
| \( V_{\text{rms}} \) (1-n RMS)  | 808   | 808    | 808    | 808    | 4,620  | 4,620  | 4,620  |
| Rotor Dia. (in)                 | 1.87  | 2.42   | 3.11   | 4.46   | 6.37   | 8.16   | 11.81  |
| Stator OD (in)                  | 4.00  | 5.60   | 6.50   | 9.10   | 10.80  | 13.30  | 18.70  |
| Length (in)                     | 5.60  | 7.20   | 9.00   | 13.00  | 17.70  | 22.70  | 32.80  |
| Magnet L/D                      | 2.51  | 2.50   | 2.50   | 2.50   | 2.50   | 2.50   | 2.50   |
| \( X_{\text{com}} \) (P.U.)    | 0.130 | 0.130  | 0.130  | 0.130  | 0.120  | 0.130  | 0.130  |
| EM Mass (lb)                    | 14.56 | 29.63  | 60.12  | 168.0  | 348.9  | 729.7  | 2131.0 |
| Rotor Mass (lb)                 | 3.89  | 8.40   | 17.70  | 51.9   | 152.0  | 316.0  | 960.0  |
| Efficiency (%)                  | 96.55 | 96.71  | 96.76  | 96.88  | 96.29  | 96.49  | 96.69  |
| Losses (kW)                     | 1.77  | 3.40   | 6.69   | 16.1   | 38.6   | 72.7   | 171.4  |
| Tip Speed (ft/s)                | 500   | 500    | 500    | 500    | 500    | 500    | 500    |
| \( B_{\text{com}} \) (kL/in²)  | 80    | 80     | 80     | 80     | 140    | 140    | 140    |

3.3.3 Algorithm Development

With the selection of the VCSC-RW TPTL configuration, fourteen valid point designs remained from which to formulate a conceptual design algorithm GENSIZE for turbo-generator systems. This data is contained in Tables 4 and 5 and
represents seven power levels and two rotor surface speeds.

<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
<th>Salient Info.</th>
<th>Technology Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotor Magnet</td>
<td>Samarium-Cobalt</td>
<td>30 MGO</td>
<td>Comm. Avail., Select Mat'l</td>
</tr>
<tr>
<td>Rotor Hoop</td>
<td>Inconel</td>
<td>180 ksi</td>
<td>Comm. Avail., Special Order</td>
</tr>
<tr>
<td>Outer Condctrs</td>
<td>Copper</td>
<td></td>
<td>Comm. Available</td>
</tr>
<tr>
<td>Inner Condctrs</td>
<td>Litz Wire</td>
<td></td>
<td>Comm. Available</td>
</tr>
<tr>
<td>Stator Insultn</td>
<td>Pyre-ML</td>
<td>Organic</td>
<td>Comm. Available</td>
</tr>
<tr>
<td>Flux Ret. Path 50-750 kWe</td>
<td>Si-steel [3.5%]</td>
<td>80 kL/in²</td>
<td>Comm. Available</td>
</tr>
<tr>
<td>Flux Ret. Path 750-5000 kWe</td>
<td>Hyperco</td>
<td>140 kL/in²</td>
<td>Comm. Available</td>
</tr>
<tr>
<td>Support Struct</td>
<td>Polyamide</td>
<td></td>
<td>Comm. Available</td>
</tr>
</tbody>
</table>

In order to develop the appropriate algorithms for size, mass and dimension, classical generator/motor scaling laws were applied to compute appropriate sizing coefficients. All algorithms considered design kVA, design voltage and rotor surface speed as the salient independent parameters. By applying the classical ND²L [proportional to kVA] law the rotor diameter sizing coefficient could be determined. Overall dimensions [overall length and OD] were similarly converted to algorithm form. The four relevant equations contained in the generator sizing routine are as follows:

\[
D_{\text{rotor}} = \left(\frac{U_{\text{vp}}}{700}\right)^{0.468} \times (40.65 + 6.6E-4 \times V \times (U_{\text{vp}}/700)^{0.25})\times \text{kVA}^{0.075} \times \left[\frac{\text{kVA}}{(N \times (L/D)_{\text{rotor}})}\right]^{1/3}
\]

[1]

\[
M_m = 1.938 \times \left(\frac{U_{\text{vp}}}{700}\right)^{0.591} \times (1.0467 - 3.3E-5 \times V) \times \frac{D_{\text{rotor}}^{2.856}}{(L/D)_{\text{rotor}} + 0.48}/2.98
\]

[2]

\[
D_{\text{stator}} = \left(\frac{U_{\text{vp}}}{700}\right)^{2.4} \times (2.14 - 0.12 \times \text{kVA}^{0.175} - 2.25E-5 \times V) \times D_{\text{rotor}}
\]

[3]

\[
L_{\text{cle}} = (2.98 - 0.02 \times D_{\text{rotor}}) \times D_{\text{rotor}} \times ((L/D)_{\text{rotor}} + 0.48)/2.98
\]

[4]

Where;

- \(D_{\text{rotor}}\) = Rotor Outside Diameter [including sleeve], inches
- \((L/D)_{\text{rotor}}\) = Rotor L/D; Magnet Length/Sleeve OD
Tables 4 and 5 also contain mass and dimensional data computed from the equations above. The values computed from the developed algorithms generally agree within a few percent with the point design values and represent attainable designs which can be built with today's technology.

Details of routine function and assumptions are available from the code annotation contained in Appendix I in the subroutine KTAGEN.FOR.

3.4 TURBO-FEEDPUMP

The turbo-feedpump algorithm models a single centrifugal stage with an inducer, and a partial admission axial impulse turbine. It was determined early on in this program that detailed turbine modeling would be too prohibitive for the intended purposes of the program. Therefore, based on Rocketdyne's experience with turbopumps, it was assumed that the turbine would have 10% partial admission and would be 45% efficient.

Pump modeling begins by calculating the pump speed. The pump speed is determined through iteration between the NPSH margin and inducer flow coefficient. Iteration is continued until a design is found which has a tip speed equal to or less than the maximum set by life or material tip speed considerations. The multi-megawatt design had an inducer tip speed limit of 170 ft/sec and this is currently implemented in this program. Within the inducer tip
speed limit loop, the NPSH margin and flow coefficient are varied to meet the tip speed constraint. An inducer tip diameter limit of 0.5 inches is set as an absolute minimum based on the minimum inlet pipe diameter which would be used in the system. Standard design practices are used in the speed selection loop to determine the operating speed. Thermodynamic suppression head is accounted for through the use of the potassium properties routines. The breakdown suction specific speed which is dependent on the inducer flow coefficient is also varied according to Rocketdyne’s suction specific speed versus flow coefficient correlation. Upon reaching a suitable operating speed the inducer size and state properties at the inlet and discharge are calculated.

The centrifugal stage is sized using the speed and pump discharge pressure with an assumed impeller head coefficient of 0.35. Efficiency is calculated using Rocketdyne’s efficiency versus specific speed correlation and accounts for pump size and seal clearance effects.

The turbopump weight correlation is based on a Rocketdyne correlation and modified to account for the increase in weight due to material density variation and configuration requirements for this type of turbopump. Weight scaling for cases where different materials are used is based on a creep strength to density scaling factor.

Application note: The pump program uses many proprietary correlations developed by Rocketdyne. The source code for these correlations has not been included. These correlations are contained in the object code CORELATE.OBJ. When linking the various object modules together to form the main program, this object code must be included.

3.5 RFMD AND VOLUME ACCUMULATOR

The RFMD and volume accumulator are located at the condenser outlet. These two components provide two-phase fluid inventory management for the potassium Rankine cycle in a microgravity environment. The RFMD also provides NPSH to the boiler feedpump.
Both the RFMD and volume accumulator performance and mass characteristics models are tied to the Multimegawatt design (Ref. 11). Weights for cases where different materials are used are adjusted with a creep strength to density ratio scaling factor obtained from the materials properties routine. The RFMD model uses the same head and flow coefficients and efficiency as the multimegawatt RFMD design. RFMD mass is estimated by using a simple D²L law while the accumulator mass is scaled linearly with potassium inventory. Input values for the RFMD are flow coefficient, head coefficient, and efficiency. There are no input values for the volume accumulator.

Application note: Since pitot pump behavior is uncertain with a change of flow and head coefficients, it is strongly recommended that the user not change these values.

3.6 PIPING

Size and weight is calculated for each run of pipe represented in the potassium-Rankine flow diagram, Figure 1. Pipe inside diameters are calculated from volumetric flow rates and input values for design velocities for lines carrying vapor, wet mixture, or liquid. Wall thickness for each pipe is then calculated from pressure within the pipe, the inside diameter, and the design allowable stress for the pipe. Four alloys, Nb-1%Zr, ASTAR 811C, TZM, and 316SS, are included in the model as available piping materials. For the appropriate alloy and temperature for each pipe run, design-allowable stress is calculated in a subroutine based on available creep data for the alloys as described later in section 3.8.

3.7 THERMODYNAMIC AND TRANSPORT PROPERTIES

The heart of the potassium-Rankine system model is the potassium thermodynamic properties routines. The potassium vapor thermodynamic properties routines for saturated and superheated vapor uses a four coefficient Virial equation based on extensive pressure, volume, temperature (PVT) data (Ref. 2). Additional potassium thermodynamic properties routines were also obtained from Reference 2. Furthermore, potassium transport properties and lithium thermodynamic and transport properties were obtained from Reference 3.
3.8 MATERIALS STRENGTH PROPERTIES

Creep strength algorithms are available for the tantalum based alloy ASTAR 811C, Nb-1%Zr, the molybdenum based alloy TZM, and for 316 stainless steel. Algorithms for ASTAR 811C and Nb-1%Zr were obtained from Reference 8, while the TZM creep strength algorithm was deduced from data obtained from Reference 9. The creep strength algorithm for 316SS was obtained from Reference 11. Above 1350 K, ASTAR 811C has superior creep strength to density characteristics with respect to the other three materials. Below 1350 K TZM is the material of choice based on its creep strength to density ratio. Nb-1%Zr has excellent properties at lower temperatures although its creep strength to density ratio is not as good as TZM. Its ease of fabricability and compatibility with alkali metals may make it the material of choice in situations where creep concerns are not too great. 316SS is included for low temperature operating regimes where a familiar material with vast amounts of experience is desired. In general, for the potassium-Rankine operating temperature ranges, 316SS has poor creep strength characteristics.

Application note: The algorithm for Nb-1%Zr creep is based on experimental data in the temperature range of 1250 K to 1450 K with no guarantee of creep predictions outside this temperature range (Ref. 8). The recommended temperature range for the ASTAR 811C creep strength algorithm is 1300 K to 1800 K (Ref. 8). The TZM algorithm was developed from data ranging in temperature from 1075 K to 1475 K. Results cannot be guaranteed when this algorithm is used outside this range. The recommended temperature range of the 316SS creep strength algorithm is 645 K to 865 K (Ref. 10).

4.0 CONCLUSIONS AND RECOMMENDATIONS

The potassium-Rankine power conversion subsystem model presented in this report will give reasonable predictions of subsystem performance when the input parameters are kept within their recommended ranges. These ranges are 1200 K to 1600 K for turbine inlet temperature, 1.25 to 1.6 for turbine inlet/condenser temperature ratios, 100 kW, to 10 MW, for power level, 2 to 10 years for lifetime, plus any other parameter values which have been mentioned in this report.
The potassium-Rankine power conversion subsystem model was designed to be as user friendly as possible given the development time allowed. There are some difficult areas in the code which can cause run time errors if the user is not careful. These are in the boiler/reheater module, and the piping module. If too close of an approach temperature is used between reactor outlet temperature and boiler outlet temperature, then a temperature cross may occur in the boiler/reheater module causing a run time error. This can be remedied by either raising the reactor outlet temperature or lowering the boiler outlet temperature. Also, when computing pressure losses in low pressure piping runs the potential for calculating a negative pressure exists which will also cause a runtime error. This can be resolved by either increasing the condensor temperature or decreasing the pipe flow velocity. Furthermore, negative pressures may be calculated if too large a pressure drop is specified for the boiler or the reheater resulting in run time errors. Run time errors caused by negative pressures usually show up in the KTHRMO subroutine, making it difficult to track the cause of the error. The potassium-Rankine code would be vastly improved if error trapping procedures were added to detect and point to the cause of the error allowing corrections to be made with ease. Follow-on work should include development of error trapping procedures to be added to the potassium-Rankine code.
5.0 REFERENCES


### APPENDIX A
#### RECOMMENDED VALUES/RANGES FOR INPUT PARAMETERS

<table>
<thead>
<tr>
<th>Input Parameter</th>
<th>Recommended Value/Range</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General Parameters</strong></td>
<td></td>
</tr>
<tr>
<td>System full power life (years)</td>
<td>1 - 10</td>
</tr>
<tr>
<td>Flow velocity in vapor lines (m/sec)</td>
<td>140.0</td>
</tr>
<tr>
<td>Flow velocity in wet vapor lines (m/sec)</td>
<td>50.0</td>
</tr>
<tr>
<td>Flow velocity in liquid lines (m/sec)</td>
<td>3.5</td>
</tr>
<tr>
<td>Temperature for material switch (K)</td>
<td>1350.0</td>
</tr>
<tr>
<td>High Temperature material</td>
<td>1.0</td>
</tr>
<tr>
<td>Low Temperature material</td>
<td>3.0</td>
</tr>
<tr>
<td>1 - ASTAR 811C</td>
<td></td>
</tr>
<tr>
<td>2 - Nb-1%Zr</td>
<td></td>
</tr>
<tr>
<td>3 - TZM</td>
<td></td>
</tr>
<tr>
<td>4 - 316SS</td>
<td></td>
</tr>
<tr>
<td>Thermal cond., high temp. alloy (W/m-K)</td>
<td>53.6</td>
</tr>
<tr>
<td>Thermal cond., low temp. alloy (W/m-K)</td>
<td>53.6</td>
</tr>
<tr>
<td># operating units</td>
<td>3.0</td>
</tr>
<tr>
<td># total units</td>
<td>4.0</td>
</tr>
<tr>
<td><strong>Reactor Parameters</strong></td>
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</tr>
<tr>
<td>Reactor outlet temperature (K)</td>
<td>1550.0</td>
</tr>
<tr>
<td>Reactor inlet temperature (K)</td>
<td>1450.0</td>
</tr>
<tr>
<td><strong>Electrical Parameters</strong></td>
<td></td>
</tr>
<tr>
<td>System net power output (kWe)</td>
<td>10 - 10,000</td>
</tr>
<tr>
<td>Alternator efficiency</td>
<td>0.97</td>
</tr>
<tr>
<td>Fraction of alternator gross output used for -</td>
<td></td>
</tr>
<tr>
<td>Lithium pumps</td>
<td>NA</td>
</tr>
<tr>
<td>Potassium feed pumps</td>
<td>NA</td>
</tr>
<tr>
<td>Other loads</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Alternator Parameters</strong></td>
<td></td>
</tr>
<tr>
<td>Power factor</td>
<td>0.7 - 0.9</td>
</tr>
<tr>
<td>Voltage (volts)</td>
<td>1000 - 10,000</td>
</tr>
<tr>
<td>Aspect ratio (L/D)</td>
<td>2 - 3</td>
</tr>
<tr>
<td>Coolant inlet temperature (K)</td>
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</tr>
<tr>
<td>Coolant outlet temperature (K)</td>
<td>522.2</td>
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<tr>
<td>Coolant heat capacity (kJ/kg-K)</td>
<td>2.1</td>
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### Turbine Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbine inlet saturation temp. (K)</td>
<td>1000 - 1600</td>
</tr>
<tr>
<td>Turbine inlet - quality if &lt;= 1</td>
<td>1 - 100</td>
</tr>
<tr>
<td>- superheat, K, if &gt; 1</td>
<td></td>
</tr>
<tr>
<td>Condensing temperature (K)</td>
<td>750 - 1300</td>
</tr>
<tr>
<td>Turbine dry stage efficiency</td>
<td>.85</td>
</tr>
<tr>
<td>Turbine exhaust losses (kJ/kg)</td>
<td>11.63</td>
</tr>
<tr>
<td>Turbine last stage tip velocity (m/sec)</td>
<td>366.0</td>
</tr>
<tr>
<td>Condenser subcooling (K)</td>
<td>2.0</td>
</tr>
<tr>
<td>Turbine inlet stator angle</td>
<td>14.0</td>
</tr>
<tr>
<td>Spouting velocity (m/sec)</td>
<td>389.0</td>
</tr>
<tr>
<td>Layers of Multifoil Insulation</td>
<td>20</td>
</tr>
<tr>
<td>Condenser pressure drop (kPa)</td>
<td>0 - 35</td>
</tr>
</tbody>
</table>

### Feed Pump Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pump turbine efficiency</td>
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</tr>
</tbody>
</table>

### RFMD Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure rise through RFMD (kPa)</td>
<td>3.5 - 140</td>
</tr>
<tr>
<td>RFMD pump efficiency</td>
<td>.32</td>
</tr>
<tr>
<td>RFMD motor efficiency</td>
<td>.45</td>
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</tbody>
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### Boiler Parameters

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APPENDIX B
INPUT PARAMETER DEFINITIONS

ALPHAT  Turbine inlet stator angle
BFP      Power for potassium pumps (kWe)
BPL      Other loads (kWe)
BPP      Power for lithium pumps (kWe)
CPCLNT   Generator coolant specific heat (kJ/kg-K)
DEFF     Turbine dry stage efficiency
DIARH    Reheater tube diameter (cm)
DIATB    Boiler tube diameter (cm)
DPCON    Condenser pressure losses (kPa)
DPMAXB   Max. K side pressure losses (kPa)
DPMAXR   Max. K side pressure losses (kPa)
DPRFMD   RFMD pressure rise (kPa)
DTRH     Superheat added during reheat (K)
DUM1     Undefined, not used
DUM2     Undefined, not used
DUM3     Undefined, not used
DUM4     Undefined, not used
EFRFMD   RFMD pump efficiency
EMRFMD   RFMD motor efficiency
EXLOSS   Turbine exhaust losses (kJ/kg)
FPL      System full power life (years)
GEFF     Alternator efficiency
GENASP   Generator Length/Diameter aspect ratio
KA       Thermal conductivity of high temp. material (W/m-K)
KB       Thermal conductivity of low temp. material (W/m-K)
KWNET    PCS net power (kWe)
LG(i)     Length of line number i (m)
NOTUBB   Initial guess of number of boiler tubes required
NOTUBR   Initial guess of number of boiler tubes required
NUMOP    Number of operating PCS units
NUMTOT   Total number of PCS units
PTEFF    Pump turbine efficiency
PWRFCTR  Generator power factor - lagging
RSTT     Spouting velocity (m/sec)
SCCON    Condensate subcooling (K)
TBOIL    Turbine inlet saturation temp. (K)
TCON     Condensing temp. (K)
TINCLNT  Generator coolant inlet temperature (K)
TMAT     Temperature for material switch (K)
TOUTCLNT Generator coolant outlet temperature (K)
TRIN     Reactor inlet temp. (K)
TROUT    Reactor outlet temp. (K)
VELL     Liquid lines flow velocity (m/sec)
VELM     Wet vapor lines flow velocity (m/sec)
VELV     Vapor lines flow velocity (m/sec)
VOLTAGE  Generator voltage, 1-l rms (volts)
VTIP     Last stage tip velocity (m/sec)
XBOIL    Turbine inlet quality/superheat (K)
XMATC    Code for low temperature material selection
XMATH    Code for high temperature material selection
XMFI     Layers of multifoil insulation
## APPENDIX C
### INPUT PARAMETER ARRAY CROSS REFERENCE

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MFIWTR  Reheater multifoil insulation weight (kg)
MF(11)  Line flow rate (kg/sec)
MMAIN  Main potassium flow rate (kg/sec)
MQADD  Heat addition to PCS (kWt)
MQREJ  Heat rejected by PCS (kWt)
NS  Number of turbine stages
NSTAGE  Number of turbo-pump stages
PAB  Boiler tube pitch (cm)
PAR  Reheater tube pitch (cm)
PCSACM  PCS volume accumulator mass (kg)
PDIS  Turbo-pump discharge pressure (kPa)
PENG  Turbo-pump inlet pressure (kPa)
PHI(NSTG)  Turbo-pump stage flow coefficient
PLE(11)  Line exit pressure (kPa)
PLI(11)  Line inlet pressure (kPa)
PLNTEF  Plant efficiency
PP(0:15)  Turbine stage exhaust pressure (kPa)
PRSTAG  Turbine stage number for reheat
PSI(NSTG)  Turbo-pump head coefficient
PUMPEFF  Turbo-pump efficiency
RPM  Turbine speed (rpm)
SLE(11)  Line exit entropy (kJ/kg-K)
SLI(11)  Line inlet entropy (kJ/kg-K)
SPMASS  PCS specific mass (kg/kWe)
SRH  Reheat entropy (kJ/kg-K)
SSMARG  Turbo-pump NPSH margin
SVRH  Reheat specific volume (m³/kg)
SVVLE(11)  Line exit specific volume (m³/kg)
SVVLII(11)  Line inlet specific volume (m³/kg)
SVV(0:15)  Turbine stage exhaust specific volume (m³/kg)
S(0:15)  Turbine stage exhaust entropy (kJ/kg-K)
TENG  Turbo-pump inlet temp. (K)
THSB  Boiler shell hickness (cm)
THSR  Reheater shell thickness (cm)
TIPSPOG  Alternator rotor tip speed (m/sec)
TITCON  Turbine inlet temp. / condensing temp. ratio
TKTUBB  Boiler tube thickness (cm)
TKTUBR  Reheater tube thickness (cm)
TLE(11)  Line exit temp. (K)
TLLII(11)  Line inlet temp. (K)
TORQ  Turbo-pump torque (Nt-m)
TOKE  Turbo-pump torque (Nt-m)
TOTHP  Turbo-pump power (kW)
TOTWT  Total line mass (kg)
TRBPWR  Turbine power (kW)
TSATRH  Reheat saturation temp. (K)
TSAT(0:15)  Turbine stage saturation temp. (K)
TTP(NSTG)  Turbo-pump stage temp. (K)
TTRH  Degress superheat added to reheated vapor (k)
TT(0:15)  Turbine stage exhaust temp. (K)
TURBWT  Turbine weight (kg)
UTLIM  Turbo-pump inducer tip speed limit (m/sec)
UT(NSTG)  Turbo-pump stage tip speed (m/sec)
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APPENDIX F
OUTPUT PARAMETER ARRAY CROSS REFERENCE

MMAIN          PROUT(1)
TT(0:15)       PROUT(2 - 17)
PP(0:15)       PROUT(18 - 33)
H(0:15)        PROUT(34 - 49)
S(0:15)        PROUT(50 - 65)
X(0:15)        PROUT(66 - 81)
SVV(0:15)      PROUT(82 - 97)
TL(11)         PROUT(98 - 108)
TLE(11)        PROUT(109 - 119)
PL(11)         PROUT(120 - 130)
PLE(11)        PROUT(131 - 141)
HLI(11)        PROUT(142 - 152)
HLE(11)        PROUT(153 - 163)
SLI(11)        PROUT(164 - 174)
SLE(11)        PROUT(175 - 185)
XLI(11)        PROUT(186 - 196)
XLE(11)        PROUT(197 - 207)
SVVLI(11)      PROUT(208 - 218)
SVVLE(11)      PROUT(219 - 229)
MF(11)         PROUT(230 - 240)
WALL(11)       PROUT(241 - 251)
W(11)          PROUT(252 - 262)
WT(11)         PROUT(263 - 273)
WTINV(11)      PROUT(274 - 284)
ID(11)         PROUT(285)
DPTOTB        PROUT(286)
WTKTOT        PROUT(287)
TOTWT         PROUT(288)
TTRH          PROUT(289)
DPTOTR        PROUT(290)
NS            PROUT(291 - 301)
WTMFI(11)      PROUT(302)
MFITOT        PROUT(303)
PENG          PROUT(304)
TENG          PROUT(305)
FMDEL         PROUT(306)
PDIS          PROUT(307)
UTLIM         PROUT(308 - 322)
TTP(NSTG)      PROUT(323)
XNPWSHA       PROUT(324 - 338)
DT(NSTG)       PROUT(339 - 353)
UT(NSTG)       PROUT(354 - 368)
PHI(NSTG)      PROUT(369)
NSTAGE        PROUT(370 - 384)
PSI(NSTG)      PROUT(385)
XN            PROUT(386)
TOTHP         PROUT(387)
PUMPEFF        PROUT(388)
SSMARG        PROUT(389 - 403)
XNSSTG(NSTG)   PROUT(404)
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## APPENDIX G
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WF.PUMP PROUT(404)
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WT(11)  PROUT(252 - 262)
XLE(11)  PROUT(197 - 207)
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XN  PROUT(385)
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XNSSTG(NSTG) PROUT(389 - 403)
XRH  PROUT(415)
XTHKB  PROUT(442)
XTHKR  PROUT(465)
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5 MWe K-Rankine Electric Power System, 7 Year Life, Sept. 8, 1993

**General Parameters**

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**Reactor Parameters**

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<tbody>
<tr>
<td>Pump turbine efficiency</td>
<td>0.45</td>
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**RFMD Parameters**

<table>
<thead>
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<th>Value</th>
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<tr>
<td>Pressure rise through RFMD (kPa)</td>
<td>105.0</td>
</tr>
<tr>
<td>RFMD pump efficiency</td>
<td>0.32</td>
</tr>
<tr>
<td>RFMD motor efficiency</td>
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**Boiler Parameters**

<table>
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<tr>
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<th>Value</th>
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<tbody>
<tr>
<td>Maximum K side pressure drop (kPa)</td>
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<tr>
<td>Boiler tube diameter (cm)</td>
<td>1.27</td>
</tr>
<tr>
<td>Number of boiler tubes</td>
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</table>

**Reheat Parameters**

<table>
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<tr>
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<th>Value</th>
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<tbody>
<tr>
<td>Maximum reheater pressure loss (kPa)</td>
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<tr>
<td>Superheat after reheat K</td>
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<tr>
<td>Reheater tube diameter (cm)</td>
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<tr>
<td># tubes in reheater</td>
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**Line Parameters**

<table>
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<td>Boiler Outlet</td>
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</tr>
<tr>
<td>Turbine Inlet</td>
<td>1.0</td>
</tr>
<tr>
<td>Pump Turbine Inlet</td>
<td>1.0</td>
</tr>
<tr>
<td>HP Turbine Outlet</td>
<td>1.0</td>
</tr>
<tr>
<td>Pump Turbine Outlet</td>
<td>1.0</td>
</tr>
<tr>
<td>Reheater Inlet</td>
<td>1.0</td>
</tr>
<tr>
<td>Reheater Outlet</td>
<td>1.0</td>
</tr>
<tr>
<td>Condenser Inlet</td>
<td>1.0</td>
</tr>
<tr>
<td>Condenser Outlet</td>
<td>1.0</td>
</tr>
<tr>
<td>Feed Pump Inlet</td>
<td>1.0</td>
</tr>
<tr>
<td>Feed Pump Outlet</td>
<td>1.0</td>
</tr>
</tbody>
</table>
POWER CONVERSION CYCLE PARAMETERS

Turbine inlet temp = 1500.0 K
Superheat/Quality = 50.00 K
Tip velocity = 366.0 m/sec
No. of stages = 8
Generator efficiency = 96.6 %

Turbine Conditions at Each Stage

<table>
<thead>
<tr>
<th>ns</th>
<th>Temp (K)</th>
<th>Tsat (K)</th>
<th>Pres (kPa)</th>
<th>Quality</th>
<th>Enthalpy (kJ/kg)</th>
<th>Entropy (kJ/kg-K)</th>
<th>Sp Vol (m3/kg)</th>
<th>Eff</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1500.0</td>
<td>1450.0</td>
<td>1577.27</td>
<td>1.0000</td>
<td>2905.0</td>
<td>4.2650</td>
<td>0.17</td>
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<td>1</td>
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<td>1400.0</td>
<td>1243.93</td>
<td>0.9860</td>
<td>2800.1</td>
<td>4.2788</td>
<td>0.20</td>
<td>0.8500</td>
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<tr>
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<td>1350.0</td>
<td>963.26</td>
<td>0.9624</td>
<td>2747.3</td>
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<tr>
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<td>1300.0</td>
<td>730.84</td>
<td>0.9457</td>
<td>2706.0</td>
<td>4.3073</td>
<td>0.40</td>
<td>0.8008</td>
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<tr>
<td>4</td>
<td>1250.0</td>
<td>1250.0</td>
<td>541.93</td>
<td>0.9457</td>
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<td>1195.5</td>
<td>1190.7</td>
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<td>1.0000</td>
<td>2797.8</td>
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<td>0.8500</td>
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<td>7</td>
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<td>1143.8</td>
<td>262.44</td>
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<td>1096.9</td>
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<td>1.10</td>
<td>0.8110</td>
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</tbody>
</table>

POWER CONVERSION CYCLE CHARACTERISTICS

Generator output = 5112.95 kWe
Thermal input = 27557.22 kWt
Condenser reject = 22259.96 kWt
Generator losses = 59.62 kWe

Cycle efficiency = 19.20 %
Plant efficiency = 18.55 %
Main vapor flow = 4.15 kg/sec

SCHEDULE OF PIPING RUNS

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Temp (K)</th>
<th>Press (kPa)</th>
<th>Enthalpy (kJ/kg)</th>
<th>Entropy (kJ/kg-K)</th>
<th>Quality</th>
<th>Sp Vol (m3/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Boiler Outlet</td>
<td>1501.9</td>
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<td>4.2643</td>
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<tr>
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<td>Pump Turbine Inlet</td>
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<td>1577.27</td>
<td>2905.0</td>
<td>4.2650</td>
<td>1.0000</td>
<td>0.170</td>
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<tr>
<td>4</td>
<td>HP Turbine Outlet</td>
<td>1499.0</td>
<td>1584.43</td>
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<td>4.2643</td>
<td>1.0000</td>
<td>0.170</td>
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<tr>
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<td>541.93</td>
<td>2706.0</td>
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<td>0.9457</td>
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<tr>
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<td>Flow (kg/sec)</td>
<td>Length (m)</td>
<td>ID (cm)</td>
<td>Wall (cm)</td>
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<tr>
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<td>------------------------------</td>
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<td>1.00</td>
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<td>1.00</td>
<td>12.35</td>
<td>0.051</td>
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<td>1.00</td>
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**Weights**

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<th>No.</th>
<th>Description</th>
<th>Pipe Wt (kg)</th>
<th>K Wt (kg)</th>
<th>MFI Wt (kg)</th>
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<tr>
<td>1</td>
<td>Boiler Outlet</td>
<td>4.84</td>
<td>0.030</td>
<td>0.015</td>
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<td>Turbine Inlet</td>
<td>4.65</td>
<td>0.029</td>
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<td>Pump Turbine Inlet</td>
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<td>0.003</td>
<td>0.005</td>
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<td>4</td>
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<td>0.022</td>
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<tr>
<td>10</td>
<td>Feed Pump Inlet</td>
<td>1.29</td>
<td>1.185</td>
<td>0.009</td>
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<tr>
<td>11</td>
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<td>1.29</td>
<td>1.185</td>
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**Totals**

126.73 14.947 0.730
### CHARACTERISTICS OF ALTERNATOR

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<tbody>
<tr>
<td>Voltage</td>
<td>1000.0 Volts</td>
</tr>
<tr>
<td>Power</td>
<td>1704.3 kWe</td>
</tr>
<tr>
<td>Rotor Diameter</td>
<td>19.1 cm</td>
</tr>
<tr>
<td>Weight</td>
<td>349.4 kg</td>
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<tr>
<td>Total Length</td>
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</tr>
<tr>
<td>Sizing Coef.</td>
<td>22.9</td>
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<tr>
<td>Cooling Load</td>
<td>59.6 kWt</td>
</tr>
<tr>
<td>Clnt inlet Temp.</td>
<td>511.1 K</td>
</tr>
<tr>
<td>Design Life</td>
<td>7.0 yrs</td>
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### CHARACTERISTICS OF TURBINE

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<tbody>
<tr>
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<tr>
<td>Power</td>
<td>1762.3 kW</td>
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<tr>
<td>Speed</td>
<td>20054.4 rpm</td>
</tr>
<tr>
<td>Stator angle</td>
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</table>

### TURBO-FEEDPUMP CHARACTERISTICS

<table>
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<th>Value</th>
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<tbody>
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<td>Mass flow rate</td>
<td>4.15 kg/sec</td>
</tr>
<tr>
<td>Discharge pressure</td>
<td>1662.6 kPa</td>
</tr>
<tr>
<td>Discharge temp</td>
<td>1037.4 K</td>
</tr>
<tr>
<td>Horsepower</td>
<td>15.1 kW</td>
</tr>
<tr>
<td>Efficiency</td>
<td>60.3 %</td>
</tr>
<tr>
<td>Specific speed</td>
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</tr>
<tr>
<td>Stage number</td>
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<tr>
<td>NPSH</td>
<td>16.1 m</td>
</tr>
<tr>
<td>Inducer head coef</td>
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</tr>
<tr>
<td>Inducer tip speed</td>
<td>51.7 m/sec</td>
</tr>
<tr>
<td>Impeller flow coef</td>
<td>0.1000</td>
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<tr>
<td>Impeller tip speed</td>
<td>77.8 m/sec</td>
</tr>
<tr>
<td>Inlet pressure</td>
<td>210.6 kPa</td>
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<tr>
<td>Inlet temp</td>
<td>1034.6 K</td>
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<td>Tip speed limit</td>
<td>51.8 m/sec</td>
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<td>Torque</td>
<td>4.3 Nt-m</td>
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<tr>
<td>Weight</td>
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<tr>
<td>Inducer tip diameter</td>
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<tr>
<td>Impeller tip diameter</td>
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</tr>
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<td>Impeller head coef</td>
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### BOILER CHARACTERISTICS

**General Dimensions**

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<th>Value</th>
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<tr>
<td>Height</td>
<td>596.9 cm</td>
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<tr>
<td>Tube sheet diameter</td>
<td>67.3 cm</td>
</tr>
<tr>
<td>Tube sheet thickness</td>
<td>11.3 cm</td>
</tr>
<tr>
<td>Diameter</td>
<td>70.4 cm</td>
</tr>
<tr>
<td>Shell thickness</td>
<td>1.6 cm</td>
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</table>

**Tube dimensions**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of boiler tubes</td>
<td>849.0</td>
</tr>
<tr>
<td>Boiling length</td>
<td>355.6 cm</td>
</tr>
<tr>
<td>Total tube length</td>
<td>510.5 cm</td>
</tr>
<tr>
<td>Tube wall thickness</td>
<td>0.057 cm</td>
</tr>
<tr>
<td>Preheat length</td>
<td>30.5 cm</td>
</tr>
<tr>
<td>Superheat length</td>
<td>124.5 cm</td>
</tr>
<tr>
<td>Tube inside diameter</td>
<td>1.27 cm</td>
</tr>
<tr>
<td>Tube pitch</td>
<td>1.904 cm</td>
</tr>
</tbody>
</table>
Summary of Heat Transfer Coefficients

Li side = 4.6 kW/m²-K  K preheat = 14.2 kW/m²-K
K boiling = 39.7 kW/m²-K  K superheat = 0.3 kW/m²-K

Summary of Pressures

Li side pressure drop = 1.55 kPa  Boiler inlet pressure = 1661.6 kPa
Boiler outlet pressure = 1591.5 kPa  Boiler pressure drop = 70.05 kPa

Summary of boiler weights

Shell = 3416.3 kg  Boiler tubes = 2408.6 kg
Twisted tapes = 722.6 kg  Tube sheets = 699.0 kg
Heads = 206.2 kg  Multifoil insulation = 8.6 kg
Total dry weight = 7461.3 kg  Weight of Potassium = 172.5 kg
Weight of lithium = 401.8 kg  Wet weight of boiler = 8035.6 kg

REHEATER CHARACTERISTICS

General Dimensions

Height = 111.8 cm  Diameter = 53.1 cm
Tube sheet diameter = 52.7 cm  Shell thickness = 0.2 cm
Tube sheet thickness = 3.4 cm

Tube dimensions

Number of re heater tubes = 531.0  Preheat length = 0.0 cm
Boiling length = 5.1 cm  Superheat length = 50.8 cm
Total tube length = 55.9 cm  Tube inside diameter = 1.27 cm
Tube wall thickness = 0.051 cm  Tube pitch = 1.886 cm

Summary of Heat Transfer Coefficients

Li side = 5.9 kW/m²-K  K preheat = 14.8 kW/m²-K
K boiling = 39.7 kW/m²-K  K superheat = 0.4 kW/m²-K

Summary of Pressures

Li side pressure drop = 0.96 kPa  Reheater inlet pressure = 537.8 kPa
Reheater outlet pressure = 502.8 kPa  Reheater pressure drop = 35.06 kPa

Summary of re heater weights

Shell = 57.4 kg  Reheater tubes = 156.6 kg
Twisted tapes = 47.0 kg  Tube sheets = 130.9 kg
Heads = 13.7 kg  Multifoil insulation = 0.9 kg
Total dry weight = 406.5 kg  Weight of Potassium = 1.0 kg
Weight of lithium = 27.2 kg  Wet weight of re heater = 434.7 kg

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## MASS OF POWER CONVERSION SUBSYSTEM

<table>
<thead>
<tr>
<th>Component</th>
<th>Mass (KG)</th>
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</thead>
<tbody>
<tr>
<td>Boiler (wet)</td>
<td>8035.6</td>
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<tr>
<td>Reheater (wet)</td>
<td>434.7</td>
</tr>
<tr>
<td>Turbines</td>
<td>1530.4</td>
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<tr>
<td>Alternator</td>
<td>1397.6</td>
</tr>
<tr>
<td>Feed Turbo-pumps</td>
<td>317.9</td>
</tr>
<tr>
<td>RFMDs</td>
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<tr>
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<td>K inventory</td>
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<td>Accumulators</td>
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<td><strong>Total</strong></td>
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## SYSTEM PERFORMANCE CHARACTERISTICS

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<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Mass (kg/kWe)</td>
<td>2.568</td>
</tr>
<tr>
<td>Net Efficiency (%)</td>
<td>17.998</td>
</tr>
<tr>
<td>Gross Efficiency (%)</td>
<td>18.405</td>
</tr>
<tr>
<td>TIT/TCON</td>
<td>1.381</td>
</tr>
</tbody>
</table>
PROGRAM MNRANK

IMPLICIT DOUBLE PRECISION (A-H,O-Z)

CHARACTER TITLE(13)*80,LLBL(11)*25,FNAME(50)*50,CLNTYPE*10,
  &
  GENTYPE*20,INTTYPE*20,ERRORG*64,WARNINGG*64

****** ####################################################################

COMMON /INPUT/ PRIN(61)
COMMON /OUTPUT/ PROUT(526)
COMMON/CONFIG/ GENTYPE,INTTYPE,CLNTYPE
COMMON/DIAGNOS/ ERRORG,WARNINGG

****** ####################################################################

OPEN (1,FILE='KRANK.IN',STATUS='OLD')
OPEN (6,FILE='KRANK.OUT',STATUS='UNKNOWN',FORM='FORMATTED')

****** ####################################################################

CALL PRINP(TITLE,LLBL,FNAME)
CALL KRank
CALL PROUTP(TITLE,LLBL,FNAME)

ENDFILE (6)
CLOSE (1,STATUS='KEEP')
CLOSE (6,STATUS='KEEP')

END
SUBROUTINE PRINP(TITLE,LLBL,FNAME)
IMPLICIT DOUBLE PRECISION (A-H,O-Z)
CHARACTER TITLE(13)*80,LLBL(11)*25,FNAME(50)*50
COMMON /INPUT/ PRIN(61)
READ (1,5) TITLE(1),TITLE(2)
5 FORMAT(/,A80,///A80,/) DO 10 I = 1,7
10 READ (1,*) FNAME(I),PRIN(I) DO 11 I = 8,9
11 READ (1,*) FNAME(I) DO 12 I = 10,13
12 READ (1,*) FNAME(I),PRIN(I)
C read reactor parameters
READ (1,20) TITLE(3)
20 FORMAT(/,A80,/) DO 25 I = 14,15
25 READ(I,*) FNAME(1),PRIN(1)
C READ ELECTRICAL PARAMETERS
READ (1,40) TITLE(4)
40 FORMAT(/,A80,/) DO 45 I = 16,17
45 READ(I,*) FNAME(1),PRIN(I)
45 READ (1,*) FNAME(18) READ(I,*) FNAME(I),PRIN(I)
C READ ALTERNATOR PARAMETERS
READ (1,60) TITLE(5)
60 FORMAT(/,A80,/) DO 65 I = 22,27
65 READ(I,*) FNAME(1),PRIN(1)
C READ TURBINE PARAMETERS
READ (1,70) TITLE(6)
70 FORMAT(/,A80,/) DO 75 I = 28,29
75 READ(I,*) FNAME(I),PRIN(I)
75 READ(I,*) FNAME(30) READ(I,*) FNAME(I),PRIN(I)
C READ FEED PUMP PARAMETERS
READ (1,85) TITLE(7)
85 FORMAT(/,A80,/)
READ(1,*) FNAME(40),PRIN(40)

C read RFMD parameters

READ (1,90) TITLE(8)
90 FORMAT(/,A80,/)  
READ(1,*) (FNAME(I),PRIN(I),I=41,43)

C READ BOILER PARAMETERS

READ (1,100) TITLE(9)
100 FORMAT(/,A80,/)  
READ(1,*) (FNAME(I),PRIN(I),I=44,46)

C READ REHEAT PARAMETERS

READ (1,110) TITLE(10)
110 FORMAT(/,A80,/)  
READ(1,*) (FNAME(I),PRIN(I),I=47,50)

C READ LINE PARAMETERS

READ (1,120) TITLE(11),TITLE(12),TITLE(13)
120 FORMAT(/,A80,/,A80,/A80/)  
READ(1,*) (LLBL(I),PRIN(I+50),I=1,11)

RETURN
END
SUBROUTINE PROUTP (TITLE, LLBL, FNAME)

IMPLICIT DOUBLE PRECISION (A-H,O-Z)

DOUBLE PRECISION LGENTOT, MASSGEN, KVA, KWOUT, KA, KB, NUMOP, NUMTOT, &
KWNET, NOTUBB, NOTUBR, LG, MMAIN, MF, ID, MFITOT, &
MQADD, MQREJ, LPHB, LBOILB, LSHB, LTOTB, MFITWB, LPHR, &
LBOILR, LSHR, LTOTR, MFITWR, MFLOPT

CHARACTER TITLE(13)*80, LLBL(11)*25, FNAME(50)*50, CLNTYPE*10, &
GENTYPE*20, INTTYPE*20, ERRORG*64, WARNINGG*64

INTEGER REHEAT, RSTAGE

DIMENSION PRIN(61), PROUT(526)

***** ***************************************************************************************

PARAMETER (NSTG=15)

COMMON /INPUT/ FPL, VELV, VELM, VELL, TMAT, XMATH, XMATC, DUM1, DUM2, KA, &
KB, NUMOP, NUMTOT, TROUT, TRIN, KWNET, GEFF, DUM3, BPP, BFP, &
BPL, PWFCCTR, VOLTAGE, GENASP, TINCLNT, TOUTCLNT, &
CPCLNT, TBOIL, XBOIL, DUM4, TCONS, DEFF, EXLOSS, VTIPO, &
SCCON, ALPHAT, RSTT, XMF1, DPCON, PTEFF, DFRFMD, EFRFMD, &
EHRFMD, DPMAXB, DIATB, NOTUBB, DPMAXR, DTHR, DIARH, &
NOTUBR, LG(11)

COMMON /OUTPUT/MMAIN, TT(15), PP(15), H(15), S(15), X(15), &
SVV(15), TLI(15), TLE(15), PLI(15), PLE(15), HLI(15), &
HLE(15), SLI(15), SLE(15), XLI(15), XLE(15), SVVL(15), &
SVVLE(15), MF(15), WALL(15), WT(15), WTKINV(15), ID(15), &
DPTOTB, WTKTOT, TOTWT, TTRH, DPTOTR, NS, WTMF(15), &
MFITOT, PENG, TENG, FMDEL, PDIS, UTLP, TTP(NSTG), XNPSHA, &
DT(NSTG), UT(NSTG), PHI(NSTG), NSTAGE, PSI(NSTG), XN, &
TTHP, PUMP, SSMARG, XNPSSTG(NSTG), WFPUMP, TORQ, &
KWOUT, ALTW, CYCEFF, PCSACM, MQADD, MQREJ, PRSTAG, &
WTRFMD, WTBURB, XRH, EFF(0:15), DLPPB, WBOILB, WTBETB, &
DLPR, WRT, WTWETR, HTBB, DOUTB, DTSB, THSB, XTHKB, LPHB, &
LBOILB, LSHB, LTOTB, TKTUBB, PAB, HLILIB, HKPHB, HKBOIB, &
HKSHB, WSHELB, WTBUEB, WTAEB, WTTSB, WTCLOB, MFITWB, &
WTPOTB, WTLIB, HTBR, DOUTER, DTSR, THSR, XTHKR, LPHR, &
LBOILR, LSHR, LTOTR, TKTUBR, PAR, HLILIR, HKPHIR, HKBOIR, &
HKSHR, WSHELR, WTBURER, WTAER, WTTSR, WTCCLOR, MFITWR, &
WTPOTR, WTLIR, WTPCS, SPMASS, EFFNET, EFFGRS, WTPUMP, &
TITCON, PLNTF, GNLOSS, TORQUE, TRBPWR, XI, TURBWT, RPM, &
SVRH, TSTARI, HRH, SRH, TSAT(15), VTIP, DGENRTR, KVA, &
DGENSTR, LGENTOT, MASSGEN, TIPSPDG, COE, COOLING, WCLNT

COMMON /SYSTM/ MFLOPT, CFSLI(11), CFSL(11), DELPL(11), DELHL(11), MF1, &
TPUMP, HPUMP, SFPUMP, VFPUMP, WKFMD, PI, G, TOL, XLAMIN, &
XLAMOUT, EFFIND, HCIND, XKLOSS, PT(NSTG), PS(NSTG), &
HT(NSTG), XINT(NSTG), HSP(NSTG), ST(NSTG), TS(NSTG), &
RHO(NSTG), CM(NSTG), XNSS, DH(NSTG), B2(NSTG), &
F3S(NSTG), XMARG, XNPSHA, XNPSHOP, HD(NSTG),

47
& EFFP(0:NSTG), HP(NSTG), XIMPNSS, XNSSIMP, QBOILL,
& QRHLSS, PEFF, RPMT, VPOTSB, VPOTSR, XRHEAT, PTI, FRACRH,
& RSTAGE, TTI, FLOC, TBLOUT, TBLIN, TRHOUT, TRHIN,
& REHEAT, MATH, MATC, RPMA

COMMON/CONFIG/GENTYPE, INTTYPE, CLNTTYPE
COMMON/DIAGNOS/ERRORG, WARNING

*****  ******************************************

EQUIVALENCE (FPL, PRIN(1)), (MMAIN, PROUT(1))

WRITE (6, 10) TITLE(1), TITLE(2), (FNAME(I), PRIN(I), I=1, 7),
& (FNAME(I), I=8, 9), (FNAME(I), PRIN(I), I=10, 13)
10 FORMAT(/, A80, //, A80, //, 7(T6, A50, T60, F10.1, /), 2(T6, A50, /),
& 4(T6, A50, T60, F10.1, /))

C WRITE REACTOR INPUT PARAMETERS

WRITE (6, 20) TITLE(3), (FNAME(I), PRIN(I), I=14, 15)
20 FORMAT(/, A80, //, 2(T6, A50, T60, F10.1, /))

C WRITE ELECTRICAL PARAMETERS

WRITE (6, 30) TITLE(4), (FNAME(I), PRIN(I), I=16, 17), FNAME(18),
& (FNAME(J), PRIN(J), J=19, 21)
30 FORMAT(/, A80, //, T6, A50, T60, F10.1, //, T6, A50, T60, F10.2, //, T6, A50, /
& 3(T6, A50, T60, F10.1, /))

C WRITE ALTERNATOR PARAMETERS

WRITE (6, 35) TITLE(5), (FNAME(I), PRIN(I), I=22, 27)
35 FORMAT(/, A80, //, 6(T6, A50, T60, F10.1, /))

C WRITE TURBINE PARAMETERS

WRITE (6, 40) TITLE(6), (FNAME(I), PRIN(I), I=28, 29), FNAME(30),
& (FNAME(J), PRIN(J), J=31, 39)
40 FORMAT(/, A80, //, 2(T6, A50, T60, F10.1, /), T6, A50, /,
& T6, A50, T60, F10.1, //, T6, A50, T60, F10.2, /,
& 7(T6, A50, T60, F10.1, /))

C WRITE FEED PUMP PARAMETERS

WRITE (6, 50) TITLE(7), FNAME(40), PRIN(40)
50 FORMAT(/, A80, //, T6, A50, T60, F10.2, /)

C WRITE RFMD PARAMETERS

WRITE (6, 60) TITLE(8), (FNAME(I), PRIN(I), I=41, 43)
60 FORMAT(/, A80, //, T6, A50, T60, F10.1, //, 2(T6, A50, T60, F10.2, /))

C WRITE BOILER PARAMETERS
WRITE (6,70) TITLE(9),(FNAME(I),PRIN(I),I=44,46)
.70 FORMAT(/,A80,//,T6,A50,T60,F10.1,/,T6,A50,T60,F10.2,/,&
T6,A50,T60,F10.1,/)  
C WRITE REHEAT PARAMETERS
WRITE (6,80) TITLE(10),(FNAME(I),PRIN(I),I=47,50)
80 FORMAT(/,A80,/,2(T6,A50,T60,FIO.1,/)T6, A50,T60,FIO.2,/,&
T6,ASO,T60,FIO.I,/)  
C WRITE LINE PARAMETERS
WRITE (6,90) TITLE(11),TITLE(12),TITLE(13),&
(LLBL(I),PRIN(I+50),I=1,11)
90 FORMAT(/,A80,//,A80,/A80,//,II(T6,A25,T66,FIO.1,/))  
C WRITE OUTPUT FILE
WRITE (6,100) TT(O),TBOIL,XBOIL,TCON,VTIPO,DEFF*IOO.,NS,&
PTEFF*IOO.,GEFF*IOO.,SCCON
100 FORMAT(/,T35,'POWER CONVERSION CYCLE PARAMETERS',//,&
T10, 'Turbine inlet temp = ',F8.1,' K',T55,&
'Saturation temp = ',F8.1,' K',/,&
T10, 'Superheat/Quality = ',F8.2, ' K',T55,&
'Condensor temp = ',F8.1,' K',/,&
T10,'Tip velocity = ',F8.1,' m/sec',T55,&
'Dry stage eff = ',F8.1,' %',/,&
T10, 'No. of stages = ',I8,T55,&
'Pump turbine eff = ',F8.1,' %',/,&
T10,'Generator efficiency = ',F8.1,' %',T55,&
'Condenser subcooling = ',F8.1,' K',/)  
WRITE(6,110) TT(O),TBOIL,PP(O),X(O),H(O),S(O),SVV(O)
110 FORMAT(/,T35,'TURBINE CONDITIONS AT EACH STAGE',//,&
T5, 'ns',T12,'Temp',T22,'Tsat',T32,'Pres',T41, 'Quality',T50,&
'Enthalpy',T61,'Entropy',T72,'Sp Vol',T84,'Eff',/,&
T12,'(K)',T22,'(K)',T32,'(kPa)',T50,'(kJ/kg)',T60,&
'(kJ/kg-K)',T72,'(m3/kg)',//,T5, 'O',2FIO.1,IFIO.2,1FIO.4,& &
FIO.1,1FIO.4,1FIO.2,1FIO.4)  
DO 130 N = 1,RSTAGE
WRITE(6,120) N,TT(N),TSAT(N),PP(N),X(N),H(N),S(N),SVV(N),EFF(N)
120 FORMAT(T5,I2,2F10.1,1F10.2,1F10.4,1F10.1,1F10.4,1F10.2,1F10.4)
130 CONTINUE
WRITE (6,140) TTRH,TSATRH,PRSTAG,XRH,HRH,SRH,SVRH
140 FORMAT(T5,'RH',2F10.1,1F10.2,1F10.4,1F10.1,1F10.4,1F10.2,1F10.4)  
DO 160 N = RSTAGE+1,NS
WRITE(6,150) N,TT(N),TSAT(N),PP(N),X(N),H(N),S(N),SVV(N),EFF(N)
150 FORMAT(T5,I2,2F10.1,1F10.2,1F10.4,1F10.1,1F10.4,1F10.2,1F10.4)
CONTINUE

WRITE(6,170)
170 FORMAT(/,T32,'POWER CONVERSION CYCLE CHARACTERISTICS'/)

WRITE(6,180) KWOUT, CYCEFF*100., MQADD, PLNTEF*100., MQREJ, & MMAIN, GNLOSS
180 FORMAT(TIO, 'Generator output = ', FI0.2, ' kWe', T55, & 'Cycle efficiency = ', F7.2, '% / & TIO, 'Thermal input = ', FI0.2, ' kWt', T55, & 'Plant efficiency = ', F7.2, '% / & TIO, 'Condensor reject = ', FI0.2, ' kWt', T55, & 'Main vapor flow = ', F7.2, ' kg/sec / & TIO, 'Generator losses = ', FI0.2, ' kWe',//)

WRITE(6,190)
190 FORMAT(/,T39,'SCHEDULE OF PIPING RUNS',/,T39, & 'Thermodynamic Properties',//, & T33,'Temp',T42,'Press',T51,'Enthalpy', & T62,'Entropy',T72,'Quality',T83,'Sp Vol' / & 'No.',T9,'Description',T33,(K)',T42,(kPa),T51, & '(kJ/kg)',T61,'(kJ/kg-K)',T82,'(m3/kg)',/)

DO 220 I = 1,11
WRITE(6,200) I, LLBL(I), _ TLI(1), PLI(1), HLI(1), SLI(1), XLI(1), SVVLI(1)
200 FORMAT(13,T8,A19,T38,3F10.2,1F10.3)

WRITE(6,210) TLE(1), PLE(1), HLE(1), SLE(1), XLE(1), SVWLE(1)
210 FORMAT(T4,T28,1F10.1,1F10.2,1F10.3)

DO 220 CONTINUE

WRITE(6,230)
230 FORMAT(/,T37,'Flows & Dimensions',//, & T44,'Flow',T53,'Length',T65,'ID',T74,'Wall',/, & T10,'No.',T9,'Description',T41,'(kg/sec)',T54, & '(m)',T64,'(cm)',T74,'(cm)',/)

WRITE(6,240) (I, LLBL(I), MF(I), LG(I), ID(I), WALL(I), I=I,11)
240 FORMAT(II(TIO, 13,T8,A19,T38,3F10.2,1F10.3,/) & T8,72('_'))

WRITE(6,250)
250 FORMAT(/,T47,'Weights',//, & T52,'Pipe Wt',T64,'K Wt',T73,'MFI Wt',/ & T10,'No.',T9,'Description',T53,'(kg)',T64,'(kg)', & T74,'(kg)',/)

WRITE(6,260) (I, LLBL(I), WT(I), WTKINV(I), WTMFI(I), I=I,11)
260 FORMAT(II(TIO, 13,T8,A19,48,1F10.2,2F10.3,/) & T8,72('_'))

WRITE(6,270) TOTWT, WTKTOT, MFITOT
270 FORMAT(/,T10,'Totals',T48,1F10.2,2F10.3,/)
& GENASP,COE,100.0*GEFF,COOLING,WCLNT,TINCLNT,TOUTCLNT,FPL

275 FORMAT (/,T37,'CHARACTERISTICS OF ALTERNATOR',/)
& 2(T10,A64,/,T10,A20,11X,A20,12X,A10,/,)
& T10,'Voltage       = ',F8.1,' Volts',T55,
& 'Volt-Amperes    = ',F8.1,' kVA',/,
& T10,'Power        = ',F8.1,' kWe',T55,
& 'Speed          = ',F8.1,' rpm',/,
& T10,'Rotor Diameter = ',F8.1,' cm',T55,
& 'Tip Speed      = ',F8.1,' m/s',/,
& T10,'Weight       = ',F8.1,' kg',T55,
& 'Stator Diameter = ',F8.1,' cm',/,
& T10,'Total Length = ',F8.1,' cm',T55,
& 'Aspect Ratio   = ',F8.1,/
& T10,'Sizing Coef. = ',F8.1,T55,
& 'Efficiency     = ',F8.1,%/, /
& T10,'Cooling Load = ',F8.1,' kWt',T55,
& 'Coolant Flow   = ',F8.1,' kg/s',/,
& T10,'Clnt inlet Temp. = ',F8.1,' K',T55,
& 'Clnt outlet Temp. = ',F8.1,' K',/,
& T10,'Design Life = ',F8.1,' yrs')

WRITE(6,280) XXI, VTI P, TRBPWR, TORQUE, RPM, RSTT, ALPHAT, TURBWT
&
280 FORMAT(/,T36,'CHARACTERISTICS OF TURBINE' /)
& T10,'Constant xx1  = ',F8.2,T55,
& 'Tip velocity    = ',F8.1,' m/sec',/,
& T10,'Power        = ',F8.1,' kW',T55,
& 'Torque         = ',F8.1,' Nt-m',/,
& T10,'Speed        = ',F8.1,' rpm',T55,
& 'Spouting velocity = ',F8.1,' m/sec',/,
& T10,'Stator angle = ',F8.1,' deg',T55,
& 'Turbine weight = ',F8.1,' kg',/)

WRITE(6,290) fmdel,peng,pdis,teng,ttp(2),utlim,ttotp,torq, &
pumpeff*100., xn,xnsstg(2),wpump,nstage,ssmarg*100., &
xnpsha,phi(1),psi(1),dt(1),ut(1),dt(2),phi(2), &
psi(2),ut(2)

290 format(/T36,'TURBO-FEEDPUMP CHARACTERISTICS',/)
& T10,'Mass flow rate = ',F8.2,' kg/sec',T55,
& 'Inlet pressure   = ',F8.1,' kPa',/,
& T10,'Discharge pressure = ',F8.1,' kPa',T55,
& 'Inlet temp       = ',F8.1,' K',/,
& T10,'Discharge temp = ',F8.1,' K',T55,
& 'Tip speed limit  = ',F8.1,' m/sec',/,
& T10,'Horsepower    = ',F8.1,' kW',T55,
& 'Torque          = ',F8.1,' Nt-m',/,
& T10,'Efficiency    = ',F8.1,%',T55,
& 'Speed           = ',F8.1,' rpm',/,
& T10,'Specific speed = ',F8.1,T55,
& 'Weight          = ',F8.1,' kg',/,
& T10,'Stage number = ',I8,T55,
& 'NPSH margin     = ',F8.1,%'./
TIO,'NPSH = ',F8.1,' m',/T55,
& TIO,'Inducer flow coef = ',F8.4,/,T55,
& TIO,'Inducer head coef = ',F8.4,T55,
& TIO,'Inducer tip diameter = ',F8.2,' cm',/T55,
& TIO,'Inducer tip speed = ',F8.1,' m/sec',T55,
& TIO,'Impeller flow coef = ',F8.4,T55,
& TIO,'Impeller head coef = ',F8.4,/,T55,
& TIO,'Impeller tip speed = ',F8.1,' m/sec',/)

WRITE(6,300) HTBB,DOUTEB,DTSB,THSB,XTHKB

300 FORMAT(/,T40,'BOILER CHARACTERISTICS',/),T42,'General Dimensions',
&//,T10,'Height = ',F8.1,' cm',T55,
& 'Diameter = ',F8.1,' cm',/,
& TIO,'Tube sheet diameter = ',F8.1,' cm',T55,
& 'Shell thickness = ',F8.1,' cm',/,
& TIO,'Tube sheet thickness = ',F8.1,' cm')

WRITE(6,310) NOTUBB,LPHB, LBOILB,LSHB, LTOTB,DIATB,TKTUBB,PAB

310 FORMAT(/,T43,'Tube dimensions',//,
& TIO,'Number of boiler tubes = ',F8.1,T55,
& 'Preheat length = ',F8.1,' cm',/,
& TIO,'Boiling length = ',F8.1,' cm',T55,
& 'Superheat length = ',F8.1,' cm',/,
& TIO,'Total tube length = ',F8.1,' cm',T55,
& 'Tube inside diameter = ',F8.2,' cm',/,
& TIO,'Tube wall thickness = ',F8.3,' cm',T55,
& 'Tube pitch = ',F8.3,' cm')

WRITE(6,320) HLI LIB, HKPHB, HKBOILB, HKSHB

320 FORMAT(/,T32,'Summary of Heat Transfer Coefficients',//,
& TIO,'Li side = ',F8.1,' kW/m2-K',T55,
& 'K preheat = ',F8.1,' kW/m2-K',/,
& TIO,'K boiling = ',F8.1,' kW/m2-K',T55,
& 'K superheat = ',F8.1,' kW/m2-K')

WRITE(6,330) DLPBB,PLE(II),PLI(I),DPTOTB

330 FORMAT(/,T41,'Summary of Pressures',//,
& TIO,'Li side pressure drop = ',F8.2,' kPa',T55,
& 'Boiler inlet pressure = ',F8.1,' kPa',/,
& TIO,'Boiler outlet pressure = ',F8.1,' kPa',T55,
& 'Boiler pressure drop = ',F8.2,' kPa')

WRITE(6,340) WSHELB,WTUBE B, WTAPEB, WTTSB,
& WTCLOB, MFIWTB, WBOILB, WPTOTB, WTLIB, WTWETB

340 FORMAT(/,T38,'Summary of boiler weights',//,
& TIO,'Shell = ',F8.1,' kg',T55,
& 'Boiler tubes = ',F8.1,' kg',/,
& TIO,'Twisted tapes = ',F8.1,' kg',T55,
& 'Tube sheets = ',F8.1,' kg',/,
& TIO,'Heads = ',F8.1,' kg',T55,
& 'Multifoil insulation = ',F8.1,' kg',/,
& TIO,'Total dry weight = ',F8.1,' kg',T55,
& 'Weight of Potassium = ',F8.1,' kg')
C Now for the reheater

WRITE(6,350) HTBR,DOUTER,DTSR,THSR,XTHKR
350 FORMAT(//,T39,'REHEATER CHARACTERISTICS',//,
& T42,'General Dimensions',//,
& T10,'Height = ',F8.1,' cm',T55,
& 'Diameter = ',F8.1,' cm',/,
& T10,'Tube sheet diameter = ',F8.1,' cm',T55,
& 'Shell thickness = ',F8.1,' cm',/,
& T10,'Tube sheet thickness = ',F8.1,' cm' )

WRITE(6,360) NOTUBR,LPHR,LBOILR,LSHR,LTOTR,DIARH,TKTUBR,PAR
360 FORMAT(//,T43,'Tube dimensions',//,
& T10,'Number of reheater tubes = ',F8.1,T55,
& 'Preheat length = ',F8.1,' cm',/,
& T10,'Boiling length = ',F8.1,' cm',T55,
& 'Superheat length = ',F8.1,' cm',/,
& T10,'Total tube length = ',F8.1,' cm',T55,
& 'Tube inside diameter = ',F8.2,' cm',/,
& T10,'Tube wall thickness = ',F8.3,' cm',/,
& 'Tube pitch = ',F8.3,' cm' )

WRITE(6,370) HLILIR,HKPHR,HKBOIR, HKSHR
370 FORMAT(/,T32,'Summary of Heat Transfer Coefficients',//,
& T10,'Li side = ',F8.1,' kW/m2-K',T55,
& 'K preheat = ',F8.1,' kW/m2-K',/,
& T10,'K boiling = ',F8.1,' kW/m2-K',T55,
& 'K superheat = ',F8.1,' kW/m2-K' )

WRITE(6,380) DLPBR,PLE(6),PLI(7),DPTOTR
380 FORMAT(/,T41,'Summary of Pressures',//,
& T10,'Li side pressure drop = ',F8.2,' kPa',T55,
& 'Reheater inlet pressure = ',F8.1,' kPa',/,
& T10,'Reheater outlet pressure = ',F8.1,' kPa',T55,
& 'Reheater pressure drop = ',F8.2,' kPa' )

WRITE(6,390) WSHELR,WTUBER,WTAPER,WTTSR,
& WTCOR,MIWTR,WRHT,WTPOTR,WTLIR,WTWETR
390 FORMAT(/T37,'Summary of reheater weights',//,
& T10,'Shell = ',F8.1,' kg',T55,
& 'Reheater tubes = ',F8.1,' kg',/,
& T10,'Twisted tapes = ',F8.1,' kg',T55,
& 'Tube sheets = ',F8.1,' kg',/,
& T10,'Heads = ',F8.1,' kg',T55,
& 'Multifoil insulation = ',F8.1,' kg',/,
& T10,'Total dry weight = ',F8.1,' kg',T55,
& 'Weight of Potassium = ',F8.1,' kg',/,
& T10,'Weight of lithium = ',F8.1,' kg',T55,
& 'Wet weight of reheater = ',F8.1,' kg' )

C SYSTEM OUTPUT

53
WRITE (6,400) WTWETB, WTWETR, WTURBN, ALTWT, WTPUMP, & WTRFMD, TOTWT, WTKTOT, PCSACM, WTPCS

400 FORMAT(/,T34,'MASS OF POWER CONVERSION SUBSYSTEM',//, & T29, 'Component ', T64, 'Mass (KG)', //, & T29, 'Boiler (wet)' , T64, F8.1, /, & T29, 'Reheater (wet)' , T64, F8.1, /, 2 T29, 'Turbines', T64, F8.1, /, & T29, 'Alternator', T64, F8.1, /, & T29, 'Feed Turbo-pumps', T64, F8.1, /, & T29, 'RFMDs', T64, F8.1, /, & T29, 'K piping', T64, F8.1, /, & T29, 'K inventory', T64, F8.1, /, & T29, 'Accumulators', T64, F8.1, //, & T29, 'Total', T64, F8.1,//)

WRITE(6,410) SPMASS, EFFNET, EFFGRS, TITCON

410 FORMAT(/,T34,'SYSTEM PERFORMANCE CHARACTERISTICS',//, & T29, 'Specific Mass (kg/kWe)', T64, F8.3, /, & T29, 'Net Efficiency (%)', T64, F8.3, /, & T29, 'Gross Efficiency (%)', T64, F8.3, /, & T29, 'TIT/TCON', T64, F8.3, /)

RETURN
END
SUBROUTINE KRANK
IMPLICIT DOUBLE PRECISION (A-H,O-Z)

DOUBLE PRECISION LGENTOT,MASSGEN,KVA,KWOUT,KA,NUMOP,NUMTOT,
& KUNET,NOTUBB,NOTUBR,LG,MMAIN,MF,IDL,MFITOT,
& MQADD,MQREJ,LPHB,LBOILB,LSHB,LTOTB,MIWTB,LPHR,
& LBOILR,LSHR,LTOTR,MIWTR,MFIWT,MFIWT

CHARACTER CLNTYPE*10,GENTYPE*20,INTTYPE*20,ERRORG*64,WARNINGG*64
INTEGER REHEAT,RSTAGE

PARAMETER (NSTG=15)

COMMON /INPUT/ FPL,VELV,VELM,VELL,TMAT,XMATC,DUM1,DUM2,KA,
& KB,NUMOP,NUMTOT,TROUT,TRIN,KUNET,GEFF,DUM3,BPP,BFP,
& BPL,PWRCTR,VOLTAGE,GENASP,TINCLNT,TOUTCLNT,
& CPCLNT,TBOIL,XBOIL,DUM4,TCON,DEFF,EXLOSS,VTIPO,
& SCCON,ALPHAT,RSTT,XMFI,DPCON,PTEFF,DRFM,ERFM,
& ENRFM,DPMAXB,DIATB,NOTUBB,DPMAXR,DTRH,DIARH,
& NOTUBR,LG(11)

COMMON /OUTPUT/MMAIN,TT(O:IS),PP(O:IS),H(O:IS),S(O:IS),X(0:15),
& SVV(O:15),TLI(11),TLE(11),PLE(11),HLI(11),
& HLI(11),SLD(11),SLE(11),XLI(11),XLE(11),SVWLI(11),
& SVVELI(11),MF(11),WALL(11),WT(11),WTIN(11),ID(11),
& DPTOTB,WTKB,TOBTB,TOBTB,NS,WTMBF(11),
& MFIWT,MENG,TFM,FMDEL,PDIS,UTLIM,TPP(NSTG),XNPSHA,
& DT(NSTG),UT(NSTG),PSI(NSTG),NSTAGE,PSI(NSTG),XN,
& TOTHP,PUMPEF,SSMARG,XNSSTG(NSTG),WFUPP,TORG,
& KWOUT,ALTWT,CECFF,PCSACM,MQADD,MQREJ,PSTAG,
& WTRFD,MWTURB,XRH,EFF(0:15),DLPBB,WBOILB,WTRRWB,
& DLRBB,WRH,WTWTR,HTBB,DOUTB,DSB,THSB,THKBB,PHBB,
& LBOILB,LSHB,LTOTB,TKTB,PAB,HLILB,HPHB,KBOLB,
& HKSHB,WSHEL,B,TWUBE,WTAPE,WTSSB,WCTLB,MFINTB,
& WTPOTB,WTLIB,HTRB,DUTER,DTSR,THSR,THKB,LPHR,
& LBOILR,LSHR,LTOTR,TKTB,PAR,HLIR,HPHR,HKBIR,
& HKSRR,WSHEL,TWUBER,WTAPE,WTSSR,WCLUD,MFINTR,
& WTPOTR,WTLIR,WTPCS,SPMAS,EFFNET,EFFGRS,WTPUMP,
& TITCON,PLNTEF,GNLOSS,TOUR,TBPWR,XX1,TURBRT,RPW,
& SVRH,TASRH,HRH,SRH,TAS(0:15),VTIP,DFENTR,KVA,
& DGENSTR,LGENTOT,MASSGEN,TIPS,RH,NSTG,COE,COOLING,WCLNT

COMMON /SYSTM/ MFIOPT,CFSLI(11),FSLE(11),DELPL(11),DEHNL(11),MF1,
& TUPDATE,HPUMP,SFPUMP,VFPUMP,KRFCMD,PI,G,TOL,XLAMIN,
& XLAMOUT,EFFIND,HCLUD,KXLOSS,LT(NSTG),PS(NSTG),
& HT(NSTG),XIHT(NSTG),HS(NSTG),ST(NSTG),TS(NSTG),
& RHO(NSTG),CM(NSTG),XNS,DX(NSTG),B2(NSTG),
& F2S(NSTG),XMARG,XCNPHS,A,XCNPSC,HD(NSTG),
& EFFP(0:NSTG),HP(NSTG),XIMPSS,XNOPS,QBOIL,
& QRLSS,PEFF,RPMT,VPOTS,VPOTS,XPRESS,PTI,FRACRH,
& RSTAGE,TTI,TFW,FLOC,TLBOUT,TLBUN,TRHOUT,TRHIN,
& REHEAT,MATH,MATC,RPMA

55
COMMON/CONFIG/GENTYPE, INTTYPE, CLNTTYPE
COMMON/DIAGNOS/ERRORG, WARNINGG

***** #########################################################

C CONVERT UNITS OF GENERAL INPUT PARAMETERS

VELV = VELV*3.281DO
VELM = VELM*3.281DO
VELL = VELL*3.281DO
TMAT = TMAT*1.8DO
KA = KA/1.73DO
KB = KB/1.73DO
MATH = IDINT(XMATH)
MATC = IDINT(XMATC)

C CONVERT UNITS OF REACTOR INPUT PARAMETERS

TROU = 1.8DO*TROU
TRIN = 1.8DO*TRIN
KWOUT = (KWNET + BPP + BFP + BPL)*1.02DO

C CONVERT UNITS OF ALTERNATOR INPUT PARAMETERS

TINCLNT = 1.8DO*TINCLNT
TOUTCLNT = 1.8DO*TOUTCLNT
CPCLNT = CPCLNT/4.185DO

C CONVERT UNITS OF TURBINE INPUT PARAMETERS

TBOIL = TBOIL*1.8DO
IF (XBOIL .GT. 1) XBOIL = XBOIL*1.8DO
TCON = TCON*1.8DO
SCCON = SCCON*1.8DO
MFI = IDINT(XMFI)
EXLOSS = 0.43*EXLOSS
VTIPO = 3.28*VTIPO
RSTT = 3.28*RSTT
DPCON = 0.145*DPCON

C CONVERT UNITS OF RFMD INPUT PARAMETERS

DPRFMD = 0.145*DPRFMD

C CONVERT UNITS

DPMAXB = 0.145*DPMAXB
DPBOIL = DPMAXB
DIATB = 0.3937*DIATB

C CONVERT UNITS

DPMAXR = 0.145*DPMAXR
DPRH = DPMAXR
DTRH = DTRH*1.8
DIARH = 0.3937*DIARH

C convert units

DO 10 I = 1, 11
10 LG(I) = 3.28*LG(I)

***** *************************************************************

C CALL PROCESS SUBROUTINES

DO 20 J = 1, 10

CALL SYSTEM
CALL GENRTR

TAVLI = (TRIN + TROUT)/2.DO
CALL LIPORT (TAVLI, MULI, KLI, CPLI, RHOLI, P)
PMIN = P*14.696DO
FLOC = (MQADD + QBOILL + QRHLSS)/(CPLI*(TROUT - TRIN))
KWOUT = (KWNET + BPP + BFP + BPL)*1.02DO

***** *************************************************************

TBLIN = TROUT
TBLOUT = TROUT*FRACRH + (1.DO - FRACRH)*TRIN

REHEAT = 0
CALL BOILER

TRHOUT = TRIN
TRHIN = TBLOUT
REHEAT = 1

CALL BOILER

20 CONTINUE

***** *************************************************************

C CONVERT MASS UNITS

WTWETB = WTWETB/2.205DO
WTURBN = WTURBN/2.205DO
WTPUMP = WTPUMP/2.205DO
TOTWT = TOTWT/2.205DO
WTKTOT = WTKTOT/2.205DO
MFITOT = MFITOT/2.205DO
ALTWT = ALTWT/2.205DO
WTWETR = WTWETR/2.205DO
WTRFMD = WTRFMD/2.205DO
PCSACM = PCSACM/2.205DO
C TOTAL MASS

\[ WTPCS = WTURBN + ALTWT + WTPUMP + TOTWT + WTKTOT + MFITOT + \]
\[ & PCSACM + WTRFMD + WTWETB + WTWETR \]

C Compute system performance characteristics

\[ PWRT = (MQADD + QBOILL + QRHLSS) \times 3.6D0/3.413D0 \]
\[ SPMASS = WTPCS/KWNET \]
\[ EFFNET = KWNET/PWRT*1.D2 \]
\[ EFFGRS = KWOUT/PWRT*1.D2 \]
\[ TITCON = TBOIL/TCON \]

***** ************

C CONVERT UNITS OF GENERAL INPUT PARAMETERS

\[ VELV = VELV/3.281D0 \]
\[ VELM = VELM/3.281D0 \]
\[ VELL = VELL/3.281D0 \]
\[ TMAT = TMAT/1.8D0 \]
\[ KA = KA*1.73D0 \]
\[ KB = KB*1.73D0 \]

C CONVERT UNITS OF REACTOR INPUT PARAMETERS

\[ TROUT = TROUT/1.8D0 \]
\[ TRIN = TRIN/1.8D0 \]

C CONVERT UNITS OF ALTERNATOR INPUT PARAMETERS

\[ TINCLNT = TINCLNT/1.8D0 \]
\[ TOUTCLNT = TOUTCLNT/1.8D0 \]
\[ CPCLNT = CPCLNT*4.185D0 \]

C CONVERT UNITS OF TURBINE INPUT PARAMETERS

\[ TBOIL = TBOIL/1.8D0 \]
\[ IF (XBOIL .GT. 1) XBOIL = XBOIL/1.8D0 \]
\[ TCON = TCON/1.8D0 \]
\[ SCCON = SCCON/1.8D0 \]
\[ EXLOSS = EXLOSS/0.43 \]
\[ VTIPO = VTIPO/3.28 \]
\[ VTIP = VTIP/3.28 \]
\[ RSTT = RSTT/3.28 \]
\[ DPCON = DPCON/0.145 \]

C CONVERT UNITS OF RFMD INPUT PARAMETERS

\[ DPRFMD = DPRFMD/0.145 \]

C CONVERT UNITS

\[ DPMAXB = DPMAXB/0.145 \]
DPBOIL = DPMAXB
DIATB = DIATB/0.3937

C CONVERT UNITS

DPMAXR = DPMAXR/0.145
DPRH = DPMAXR
DTRH = DTRH/1.8
DIARH = DIARH/0.3937

C convert units

DO 30 I = 1,11
30 LG(I) = LG(I)/3.28

C CONVERT OUTPUT UNITS TO SI

MMAIN = MMAIN/2.205

DO 40 I = 0,15
TT(I) = TT(I)/1.8
TSAT(I) = TSAT(I)/1.8
PP(I) = PP(I)/0.145
H(I) = H(I)*2.325
S(I) = S(I)*4.185
SVV(I) = SVV(I)*0.0624
40 CONTINUE

DO 50 I = 1,11
TLI(I) = TLI(I)/1.8
TLE(I) = TLE(I)/1.8
PLI(I) = PLI(I)/0.145
PLE(I) = PLE(I)/0.145
HLI(I) = HLI(I)*2.325
HLE(I) = HLE(I)*2.325
SLI(I) = SLI(I)*4.185
SLE(I) = SLE(I)*4.185
SVVLI(I) = SVVLI(I)*0.0624
SVVLE(I) = SVVLE(I)*0.0624
MF(I) = MF(I)/2.205
WALL(I) = WALL(I)*2.54
WT(I) = WT(I)/2.205
WTINV(I) = WTINV(I)/2.205
ID(I) = ID(I)*2.54
WTMF(I) = WTMF(I)/2.205
50 CONTINUE

DO 60 I = 1,NSTG
TTP(I) = TTP(I)/1.8
DT(I) = DT(I)*2.54
UT(I) = UT(I)*0.3048
60 CONTINUE

DPTOTB = DPTOTB/0.145
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WTTSR = WTTSR/2.205
WTCLOR = WTCLOR/2.205
MFIRTR = MFIRTR/2.205
WTPOTR = WTPOTR/2.205
WTLIR = WTLIR/2.205
TORQUE = TORQUE*1.356
TRBPWR = TRBPWR*0.745
TURBWT = TURBWT/2.205
MASSGEN = MASSGEN/2.205
WFPU = WFPUMP/2.205
SVRH = SVRH*0.0624
TSATRH = TSATRH/1.8
HRH = HRH*2.325
SRH = SRH*4.185
DGENRTR = DGENRTR*2.54
TIPSPDG = TIPSPDG*0.3048
DGENSTR = DGENSTR*2.54
LGENTOT = LGENTOT*2.54
WCLNT = WCLNT/2.205

RETURN
END
SUBROUTINE SYSTEM

C TYPE STATEMENTS BY COMMON BLOCKS

IMPLICIT DOUBLE PRECISION (A-Y)

INTEGER I,J,K,M,N,RSTAGE, NP,NS,MFI, KRH, KSH, NSRH,NSTG,NSTAGE, &
REHEAT, MATH, MATC, NMATH, NMATC

***** *************************************************************

C DIMENSIONS BY COMMON BLOCKS

DIMENSION TY(11), DELHT(0:15), FLOW(0:15), MFLO(0:15), WORKS(15)

***** *************************************************************

PARAMETER (NSTG=15)

COMMON /INPUT/ FPL, VELV, VELM, VELL, TMAT, XMATH, XMATC, DUM1, DUM2, KA,
&
KB, NUMOP, NUMTOT, TROUT, TRIN, KNET, GEFF, DUM3, BPPL, BPB,
&
BPL, PQRFCR, VOLTAGE, GENASP, TINCLNT, TOUTCLNT,
&
CPCNLNT, TBOIL, XBOIL, DUM4, TCON, DEFF, GXLOSS, VTPO,
&
SCCON, ALPHAT, RSTT, XMF1, DPMCON, PTEFF, DPMFD, EMRFD, &
EMRFD, DPMAXB, DIATB, NOTUBB, DPMAXR, DTRH, DIARH,
&
NOTUBL, LG(11)

COMMON /OUTPUT/ MMAIN, TT(0:15), PP(0:15), H(0:15), S(0:15), X(0:15),
&
SVV(0:15), TL(0:15), TLE(11), PLE(11), HLI(11),
&
HL(11), SLI(11), SLE(11), XLI(11), XLE(11), SVVL(11),
&
SVVLE(11), MF(11), WALL(11), WT(11), WTKINV(11), ID(11),
&
DPTOTB, WTKTOT, TOTNT, TRHR, DPTOTR, NS, WTMB(11),
&
MFITOT, PENG, TENG, FMDL, PDIS, UTILM, TTP(NSTG), XNPSHA,
&
DT(NSTG), UT(NSTG), PHI(NSTG), NSTAGE, PSI(NSTG), XN,
&
TOTHP, PUMPFE, SSMARG, XNSSSTG(NSTG), WFPUMP, TORQ,
&
KWOUT, ALTWT, CYCEFF, PCSACM, MQADD, MQREJ, PRSTAG,
&
WTRFMD, WTBURB, XRH, EFF(0:15), DLPBB, WBOILB, WTWEB,
&
DLBPR, WRHT, WWTWTR, HTBB, DOUTEB, DTSB, XTHKB, LPHB,
&
LBOILB, LSHB, LTOB, TKTUBB, PAB, HLHILB, HKPHB, HKBOIB,
&
HKSHB, WSHEL, WTUBE, WTAPEB, WTTSB, WTCLOB, MFIBT,
&
WTPSIT, WTLIB, HTBB, DOUTER, DTSR, THSR, XTHKB, LPHR,
&
LBOIRL, LSHR, LTOIR, TKTUBR, PAR, HLIHLR, HKPHR, HKBOIR,
&
HKSHR, WSHEL R, WTBUR, WTPB, WTSR, WTCLOB, MFIBTR,
&
WTPOR, WTLIR, WTPCS, SPMASS, EFFNET, EFFGRS, WTPUMP,
&
TITCON, PLNTF, GNLOSS, TORQUE, TRBPWR, X2X, TURBWT, RPM,
&
SRVH, TSATRH, HRH, SRH, TSAT(0:15), VTIP, DGENTRK, KVA,
&
DGENMR, LENTOT, MASHGEN, TIMPSDG, COE, COOLING, WCLNT

COMMON /SYSTM/

MFLOPT, CFSLI(11), CFSLI(11), DELPL(11), DELHL(11), MFI,
&
TPUMP, HPUMP, SFPPUMP, VFPUMP, WKRFD, PI, G, TOL, XLMAMIN,
&
XLAMOUT, EFFIND, HCIND, XLKLOSS, PT(NSTG), PS(NSTG),
&
HT(NSTG), XIHT(NSTG), HSP(NSTG), ST(NSTG), TS(NSTG),
&
RHO(NSTG), CM(NSTG), XNSS, DH(NSTG), B2(NSTG),
&
F3S(NSTG), XMARG, XNPSHA, XNPSSH, HD(NSTG),

62
PI = 3.141592654
KRH = 0

C TEST FOR SUPERHEAT

T = TBOIL
KSH = 0
CALL KTHRMO(KSH,T,P,VF,VG,HF,HG,HFG,SF,SG,SFG)
TT(O) = T
PP(O) = 14.696*P
H(O) = HF + XBOIL*HFG
S(O) = SF + XBOIL*SFG
X(O) = XBOIL
SVV(O) = VF + X(O)*(VG - VF)

IF (XBOIL .GT. 1.DO) THEN
  T = TBOIL + XBOIL
  KSH = 1
  CALL KTHRMO(KSH,T,P,VF,VG,HF,HG,HFG,SF,SG,SFG)
  TT(O) = T
  H(O) = HG
  S(O) = SG
  X(O) = 1.DO
  SVV(O) = VG
ENDIF

TTI = TT(O)
PTI = PP(O)

T = TCON
KSH = 0
CALL KTHRMO(KSH,T,P,VF,VG,HF,HG,HFG,SF,SG,SFG)

SFCON = SF
SFGCON = SFG
HFCON = HF
HFGCON = HFG

XX = (S(O) - SFCON)/SFGCON
HH = HFCON + XX*HFGCON
D = H(O) - HH - DRISD1 + DRISD2

L = RSTT**2.DO/(64.348*778.16) - 1.25
XNS = 1.1DO*D/L
NS = NINT(XNS)
XRHEAT = DFLOAT(NS)/2.DO

160 DELTS = (TBOIL - TCON)/NS
TEMP = TBOIL

DO 170 N=1,NS
TEMP = TEMP - DELTS
T = TEMP
KSH = 0
CALL KTHRMO(KSH,T,P,VF,VG,HF,HG,HFG,SF,SG,SFG)
PP(N) = 14.696*P
170 CONTINUE

DO 295 N = 1,NS
P = PP(N)/14.696
CALL TFROMP(P,TSAT(N))
KSH = 0
CALL KTHRMO(KSH,TSAT(N),P,VF,VG,HF,HG,HFG,SF,SG,SFG)

C TEST FOR SUPERHEAT

HIN = H(N-1)
SIN = S(N-1)

173 IF(SIN .GT. SG) THEN
CALL TFREIG(SIN,P,T,HG,SG,VF)
EFF(N) = DEFF
H(N) = HIN - (HIN - HG)*EFF(N)
CALL TFRMHG(H(N),P,T,SG,VG,VF)
TT(N) = T
X(N) = 1.0
S(N) = SG
SVV(N) = VG
ELSE

180 XS = (SIN - SF)/SFG
HS = HF + XS*HFG
H(N) = (HIN - (HIN - HS)*(DEFF - 1.0 + X(N-1)/2.0 -
& HF/(2.0*HFG)))/(1.0 + (HIN - HS)/(2.0*HFG))

IF (H(N) .GE. HG) THEN
EFF(N) = DEFF
X(N) = 1.0
H(N) = HIN - EFF(N)*(HIN - HS)
CALL TFRMHG(H(N),P,T,SG,VG,VF)
S(N) = SG
TT(N) = T
SVV(N) = VG
ELSE

ELSE
\[ X(N) = \frac{(H(N) - HF)}{HFG} \]
\[ \text{EFF}(N) = \text{DEFF} - \frac{1.0}{2} \left( \frac{X(N-1) + X(N)}{2} \right) \]
\[ \text{TT}(N) = \text{TSAT}(N) \]
\[ \text{S}(N) = SF + X(N) \cdot SFG \]
\[ \text{SVV}(N) = VF + X(N) \cdot (VG - VF) \]

ENDIF

ENDIF

IF (N .EQ. RSTAGE) THEN
    \[ H(N) = H(N) + \text{EXLOSS} \]
    \[ X(N) = \frac{(H(N) - HF)}{HFG} \]
    \[ \text{SVV}(N) = VF + X(N) \cdot (VG - VF) \]
    \[ \text{S}(N) = SF + X(N) \cdot SFG \]
ENDIF

181 \[ \text{DELHT}(N) = H(N-1) - H(N) \]

IF (DFLOAT(N) .GE. XRHEAT) .AND. (KRH .EQ. 0) THEN
    KRH = 1
    RSTAGE = N
    \[ \text{PLI}(4) = PP(N) \]
    \[ \text{TLI}(4) = TT(N) \]
    \[ \text{HLI}(4) = H(N) \]
    \[ \text{SLI}(4) = S(N) \]
    \[ \text{XLI}(4) = X(N) \]
    \[ \text{SVVLI}(4) = SVV(N) \]
    \[ \text{XQUAL} = \frac{(S(0) - SF)}{SFG} \]
    \[ \text{HHQUAL} = HF + XQUAL \cdot HFG \]
    \[ \text{DRISDI} = HHQUAL - HH \]
    IF (PLE(7) .EQ. 0.0) PLE(7) = PP(N)
    \[ \text{PRSTAG} = PP(N) - \text{DELPL}(4) - \text{DELPL}(6) - \text{DELPL}(7) - \text{DPTOTR} \]
    \[ P = \text{PRSTAG}/14.696 \]
    CALL TFROMP(P,T)
    \[ \text{TSATRH} = T \]
    \[ \text{TTRH} = T + \text{DTRH} \]
    \[ \text{KSH} = 1 \]
    CALL KTHRMO(KSH,TTRH,P,VF,VG,HF,HG,HFG,SF,SG,SFG)
    IF (HLI(7) .EQ. 0.0) HLI(7) = HG
    IF (HLE(6) .EQ. 0.0) HLE(6) = H(N)
    \[ \text{DELRH} = HLI(7) - HLE(6) \]
    \[ \text{HRH} = HG \]
    \[ \text{SRH} = SG \]
    \[ \text{XRH} = 1.0 \]
    \[ \text{SVRH} = VG \]
    GOTO 300
ENDIF

295 CONTINUE

300 CONTINUE

\[ XX = \frac{(SRH - SFCON)}{SFGCON} \]
\[ HH = HFCON + XX \cdot HFGCON \]
\[ D = \text{HRH} - HH \]
\text{DRISD2} = D \\
L = \text{RSTT} \times 2.0 / (64.348 \times 778.16) - 1.25 \\
\text{XNSRH} = 1.1 \times D / L \\
\text{NSRH} = \text{NINT(} \text{XNSRH} \text{)} \\
\text{NS} = \text{RSTAGE} + \text{NSRH} \\
310 \text{ DELTS} = (\text{TSATRH} - \text{TCON}) / \text{NSRH} \\
\text{TEMP} = \text{TSATRH} \\
\text{DO 320 } N = \text{RSTAGE} + 1, \text{NS} \\
\text{TEMP} = \text{TEMP} - \text{DELTs} \\
T = \text{TEMP} \\
\text{KSH} = 0 \\
\text{CALL KTHRMO(KSH,T,P,VF,VG,HF,HG,HFG,SG,SFG)} \\
\text{PP}(N) = 14.696 \times P \\
320 \text{ CONTINUE} \\
\text{DO 330 } N = \text{RSTAGE} + 1, \text{NS} \\
P = \text{PP}(N) / 14.696 \\
\text{CALL TFROMP(P,TSAT(N))} \\
\text{KSH} = 0 \\
\text{CALL KTHRMO(KSH,TSAT(N),P,VF,VG,HF,HG,HFG,SG,SFG)} \\
\text{C TEST FOR SUPERHEAT} \\
\text{HIN} = \text{H(N-1)} \\
\text{SIN} = \text{S(N-1)} \\
\text{XIN} = \text{X(N-1)} \\
\text{IF (((N-1) .EQ. RSTAGE) THEN} \\
\text{HIN} = \text{HRH} \\
\text{SIN} = \text{SRH} \\
\text{XIN} = \text{XRH} \\
\text{ENDIF} \\
340 \text{ IF(SIN .GT. SG) THEN} \\
\text{CALL TFRMSG (SIN,P,T, HG, VG, VF)} \\
\text{EFF}(N) = \text{DEFF} \\
\text{H}(N) = \text{HIN} - (\text{HIN} - \text{HG}) \times \text{EFF}(N) \\
\text{CALL TFRMHG (H}(N),P,T,SG,VG,VF) \\
\text{TT}(N) = T \\
\text{X(N)} = 1.0 \\
\text{S(N)} = SG \\
\text{SVV(N)} = VG \\
\text{ELSE} \\
350 \text{ XS} = (\text{SIN} - \text{SF}) / \text{SFG} \\
\text{HS} = \text{HF} + \text{XS} \times \text{HFG} \\
\text{H}(N) = (\text{HIN} - (\text{HIN} - \text{HS}) \times (\text{DEFF} - 1.0 + \text{XIN}/2.0 - \\
& \text{HF}/(2.0 \times \text{HFG}))) / (1.0 + (\text{HIN} - \text{HS}) / (2.0 \times \text{HFG})) \\
\text{IF (H}(N) .GE. HG) THEN
EFF(N) = DEFF
X(N) = 1.0
H(N) = HIN - EFF(N)*(HIN - HS)
CALL TFRMHG (H(N),P,T,SG,VG,VF)
S(N) = SG
TT(N) = T
SVV(N) = VG

ELSE

X(N) = (H(N) - HF)/HFG
EFF(N) = DEFF - 1.0 + (XIN + X(N))/2.0
TT(N) = TSAT(N)
S(N) = SF + X(N)*SFG
SVV(N) = VF + X(N)*(VG - VF)
ENDIF
ENDIF

IF (N .EQ. NS) THEN
H(N) = H(N) + EXLOSS
X(N) = (H(N) - HF)/HFG
SVV(N) = VF + X(N)*(VG - VF)
S(N) = SF + X(N)*SFG
ENDIF

360 DELHT(N) = HIN - H(N)
330 CONTINUE

IF (PLI(5) .EQ. 0.0) PLI(5) = PLI(4)
390 PTOUT = PLI(5)
IF (PLE(3) .EQ. 0.0) PLE(3) = PP(0)
PTIN = PLE(3)
IF (TLE(3) .EQ. 0.0) TLE(3) = TT(0)
TIN = TLE(3)
IF (HLE(3) .EQ. 0.0) HLE(3) = H(0)
HIN = HLE(3)
IF (SLE(3) .EQ. 0.0) SLE(3) = S(0)
SIN = SLE(3)
P = PTOUT/14.696
CALL TFROMP(P,T)
KSH = 0
CALL KTHRM0(KSH,T,P,VF,VG,HF,HG,HFG,SF,SG,SFG)
TLI(5) = T
XS = (SIN - SF)/SFG
HS = HF + XS*HFG
HLI(5) = HIN - (HIN - HS)*PTEFF
XLI(5) = (HLI(5) - HF)/HFG
SLI(5) = SF + XLI(5)*SFG
SVLII(5) = VF + XLI(5)*(VG - VF)
IF (TLE(IO) .EQ. 0.0) TLE(IO) = TCON - SCCON
T = TLE(IO)
THW = T
IF (PLE(IO) .EQ. 0.0) PLE(IO) = PP(NS) + DPRFMD
PHW = PLE(10)
P = PHW/14.696
CALL KTHRML (T,P,VF,HF, SF)
VFHW = VF
HHW = HF
SHW = SF

IF (PLI(11) .EQ. 0.0) PLI(11) = PP(0)
FMDEL = MF(10)
IF (FMDEL .EQ. 0.0) FMDEL = 5.0
PENG = PLE(10)
TENG = TLE(10)
PDIS = PLI(11)
CALL PSIZE
TREF = 2.7D3
NMATH = 1
NMATC = 2
CALL STRNTH (TREF, TMAT, NMATH, NMATC, FPL, SIGPV, RHOAST)
STRHO = SIGPV/RHOAST
CALL STRNTH (TT(0), TMAT, MATH, MATC, FPL, SIGPV, RHOAST)
WFPUMP = WFPUMP*SIGPV/(RHOAST*STRHO)

455 WORKP = TOTH*550.DO/(778.DO*FMDEL)
WRKSHT = WORKP
HPUMP = HHW + WRKSHT
HH = HPUMP
T = THW
P = PLI(11)/14.696
CALL TFRMHF(HH,T,P,VF,SF)
TPUMP = T
TFW = TPUMP
VFPUMP = VF
SF = SF
FLOWPT = WRKSHT/(HIN - HLI(5))
FLOW(0) = 1.0 - FLOWPT
WORK = 0.0

DO 545 I = 1,NS
FLOW(I) = FLOW(I-1)
IF (I .EQ. (RSTAGE + 1)) FLOW(I) = FLOW(I-1) + FLOWPT
WORKS(I) = FLOW(I)*DELHT(I)
WORK = WORK + WORKS(I)
545 CONTINUE

IF (HLI(1) .EQ. 0.0) HLI(1) = H(0)
IF (HLE(11) .EQ. 0.0) HLE(11) = HPUMP
555 QADD = HLI(1) - HLE(11) + DELRH
IF (HLE(8) .EQ. 0.0) HLE(8) = H(NS)
IF (HLI(9) .EQ. 0.0) HLI(9) = HHW
QREJ = FLOW(NS)*(HLE(8) - HLI(9))
CYCEFF = WORK/QADD

C
C 'SIZE TURBINE CYCLE FOR DESIRED OUTPUT

68
C FACTOR LB/SEC

1230 MMAIN = KWOUT*3413.0/(WORK*GEFF*3600.0*NUMOP)
    MFLOPT = MMAIN*FLOWPT

    DO 1250 I = 1,NS
    MFLO(I) = FLOW(I)*MMAIN
    1250 CONTINUE

    MQADD = QADD*MMAIN
    MQREJ = QREJ*MMAIN

C '**** PIPING DESIGN ****

CALL PIPER

1450 CONTINUE

PCSACM = (WTKTOT*SVVLE(9) + VPOTS B + VPOTSR)*2.5D0*13.5D0

CFSRFM = (CFSLE(9) + CFSLI(10))/2.DO
HEAD = 32.174D0*1.44D2*DFRFMD*(SVVLE(9) + SVVLI(10))/2.DO
PWRFMD = HEAD*MF(10)*3.6D3/(32.174D0*778.DO*3.414D3*EFRFMD*EMRFMD)
RPMRFM = 4.5DO*HEAD**0.75DO/DSQRT(PI*CFSRFM)
WTRFMD = 6.01D4*2.205D0*PWRFMD/RPMRFM
TREF = 1.89D3
NMATH = 1
NMATC = 2
CALL STRNTH (TREF, TMAT, NMATH, NMATC, FPL, SIGPV, RHOAST)
STRHO = SIGPV/RHOAST
CALL STRNTH (TCON, TMAT, MATH, MATC, FPL, SIGPV, RHOAST)
WTRFMD = WTRFMD*SIGPV/(RHOAST*STRHO)

C
C 'SIZE TURBINE
C

VTIP = VTIPO
DO 2050 DJINT = 1,100
ALPHAR = PI*ALPHAT/I.SD2
XXI = RSTT*(DSIN(ALPHAR))*(PI/4.DO)*0.75DO
DTIP = 1.2D1*DSQRT(CFSLI(8)/XXI)
RPM = 2.2918D2*VTIP/DTIP
ALPHAO = ALPHAT
ALPHAT = 77.6234/RPM**0.175736
ERROR = DABS(ALPHAT - ALPHAO)
IF (ERROR.LT.1.D-2) GOTO 2060
2050 CONTINUE
2060 CONTINUE

IF (RPM .EQ. 0.DO) GOTO 2070
IF (RPM .GT. RPM) THEN
ALPHAT = 77.6234/RPM**0.175736

ALPHAR = PI*ALPHAT/1.8D2
VTIP = RPM/15.DO*DSQRT(PI*CFSLI(8)/(3.DO*RSTT*DSIN(ALPHAR)))
XXI = RSTT*(DSIN(ALPHAR))*(PI/4.DO)*0.75DO
DTIP = 1.2D1*DSQRT(CFSLI(8)/XXI)
RPM = RPM
ENDIF

2070 TORQUE = WORK*MMAIN*778.DO*30.DO/(RPMT*PI)
TRBPWR = TORQUE*(RPMT*PI)/(3.DI*5.D2)
TURBWT = 17.82DO*TORQUE**0.6D0
TREF = 2.7D3
NMATH = 1
NMATC = 2
CALL STRNTH (TREF, TMAT, NMATH, NMATC, FPL, SIGPV, RHOAST)
STRHO = SIGPV/RHOAST
CALL STRNTH (TT(0), TMAT, MATH, MATC, FPL, SIGPV, RHOAST)
TURBWT = TURBWT*SIGPV/(RHOAST*STRHO)

C
'C FRACTION OF HEAT FROM REHEATER AND POTASSIUM FLOW TO REHEATER
C'
FRACRH = (MMAIN*NUMOP*DELRH + QRLSS)/(MQADD*NUMOP + QRLSS + QBOILL)

PLNTEF = CYCEFF*GEFF
GNLOSS = KWOUT*(I./GEFF-1.)/NUMOP

TOTWT = NUMTOT*TOTWT
WTKTOT = NUMTOT*WTKTOT
MFITOT = NUMTOT*MFITOT
WTURBN = NUMTOT*TURBWT
WTPUMP = NUMTOT*WFPUMP
TOTHT = NUMTOT*TOTHT
PCSACM = NUMTOT*PCSACM
WTTRFD = NUMTOT*WTTRFD
MQADD = NUMOP*MQADD
MREJ = NUMOP*MREJ

RETURN
END
SUBROUTINE BOILER

IMPLICIT DOUBLE PRECISION (A-H,O-Z)
DOUBLE PRECISION LGENTOT,MASSGEN,KVA,KWOUT,KA,KB,NUMOP,NUMTOT,
& KNET,NOTUBB,NOTUBR,LLG,MMAIN,MF,ID,MFITOT,
& MQADD,MRQREJ,LPHB,LBOILB,LSHB,LTOTB,MIWTB,LPHR,
& LIOILR,LISR,LTOTR,MIWTR,MFOPT,MULTI,MUF1,MUF2,
& MUG1,MUG2,MUHP,MUSH,KKPH,KKSH,IDLUBE,KL1,KTUBE,
& NLI,KK,NUPH,NUSH,NOTUB1,NOTUBO

CHARACTER TITLE(13)*80,LLBL(II)*25,FNAME(50)*50,CLNTYPE*10,
& GENTYPE*20,INTTYPE*20,ERRORG*64,WARNINGG*64

INTEGER REHEAT,RSTAGE

C DIMENSIONS BY COMMON BLOCKS

**********************************************************************

PARAMETER (NSTG=15)

COMMON /INPUT/ FPL,VELV,VELM,VELL,TMAT,XMATH,XMATC,DUM1,DUM2,KA,
& KB,NUMOP,NUMTOT,TROUT,TRIN,KNET,GEFF,DUM3,BPP,BFP,
& BPL,PFRCFT, VOLTAGE,GENASP,TINECLNT,TOUCLNT,
& CPCLNT,BOILX,BOILM,TCON,DEFF,EXLOSS,VTIMO,
& SCON,ALPHAT,RSTT,XMFI,DFCON,PTEFF,DFRMFD,DFRFMD,
& EMRFMD,DFPMB,DIATB,NOTUBB,LG(II)

COMMON /OUTPUT/MMAIN,TT(0:IS),PP(O:I5),H(O:IS),S(O:IS),X(O:I5),
& SVV(O:IS),TLI(II),PLE(II),XLI(II),XLE(II),SVVL(II),
& SVVLE(II),MF(II),WALL(II),WT(II),WTKINV(II),ID(II),
& DPTOTB,WTKB,TOTW,TRHR,DPTOTR,NS,WTMBR(II),
& MFITOT,PENG,TENG,FMDL,PDIS,UTILM,TPF(NSTG),XNPSHA,
& DT(NSTG),UP(NSTG),PHI(NSTG),NSTATE,PSI(NSTG),XN,
& TOPTH,PUMP,EFF,SSMARG,XNSSTG(NSTG),WFPUMP,TORQ,
& KOUT,ALTWT,ECYF,PCSAC,MQADD,MRQREJ,PSTAG,
& WTRFM,WTURBN,XRH,EFF(0:15),DLPB,WOILB,WTWEB,
& DLPB,WRHT,WTWETR,HTBB,DOUTE,DTSB,THSB,XTHKB,LPB,
& LBOILB,LSHB,LTOTB,TKTUB,PP,PAB,HLILB,HKPHB,HKBOILB,
& HKSHB,WSHEL,WTUDE,WTABE,WTTSB,WTCLOB,MFIWTB,
& WTPOTB,WTLIB,HTBR,DOUTE,DSR,THSR,XTHKR,LPHR,
& LBOILR,LSHR,TLTBR,KTTRB,PAR,HLILR,HKPHR,HKBOIR,
& HKSHR,WSHEL,WTUBER,WTAPER,WTTSR,WTCLOR,MFIWTR,
& WTPOTR,WTLIR,WTPCS,SPMASS,EFFNET,EFFGRS,WTPUMP,
& TITCON,PLNTEF,GENLOSS,TOURQ,TRBPWR,XXI,TURBWT,RRM,
& SVRH,TSAFHR,HRHRH,SRH,TSAF(0:15),TVP,TGENR,KVA,
& DGENSTR,LGENTOT,MASSGEN, TIPEPDG, COE, COOLING, WCLNT

COMMON /SYSTM/

MFLO,CFSLI(II),CFSLI(II),DELPL(II),DELHL(II),MFI,
& TPUMP,HPPM,FPUMP,VPUMP,WKRFMD,PI,G,TOL,XXMIN,
& XMOUT,EFFIND,HIND,XXLOSS,PT(NSTG),PS(NSTG),
& HT(NSTG),XHTH(NSTG),HSP(NSTG),X(NSTG),TS(NSTG),
& RHO(NSTG),CM(NSTG),XNSS,OH(NSTG),B2(NSTG),71
& F3S(NSTG), XMARG, XNPHSA, XNPISHO, HD(NSTG),
& EFFP(0:NSTG), HP(NSTG), XIMPNSS, XNSSIMP, QBOILL,
& QRHLSS, PEFF, RPMT, VPOTSB, VPOTSR, XRHEAT, PTI, FRACRH,
& RSTAGE, TTI, TFW, FLOC, TBLOUT, TBLIN, TRHOUT, TRHIN,
& REHEAT, MATH, MATC, RPMA

COMMON/CONFIG/GENTYPE, INTTYPE, CLNTTYPE
COMMON/DIAGNOS/ERRORG, WARNINGG

***** *************************************************************

DATA LTOT /1.44D2/
PI = 3.141592654D0

IF (REHEAT .EQ. 0) THEN

TLIOUT = TBLOUT
TLIIN = TBLIN
TIN = TLE(11)
TOUT = TLI(1)
POUT = PLI(1)
IDTUBE = DIATB
NOTUB1 = NOTUBB
HIN = HLE(11)
HOUT = HLI(1)
PIN = PLE(11)
XIN = XLE(11)
XOUT = XLI(1)
DPMAX = DPMAXB

ELSE

TLIOUT = TRHOUT
TLIIN = TRHIN
TIN = TLE(6)
TOUT = TLI(7)
POUT = PLI(7)
IDTUBE = DIARH
NOTUB1 = NOTUBR
HIN = HLE(6)
HOUT = HLI(7)
PIN = PLE(6)
XIN = XLE(6)
XOUT = XLI(7)
DPMAX = DPMAXR

ENDIF

NOTUBO = 0.DO
WXOT = MMAIN*NUMOP
WXOC = FLOC
CALL STRNTH (TLIIN, TMAT, MATH, MATC, FPL, SIGPV, RHOAST)
C INITIAL GUESS OF TUBE LENGTH (IN)

\[
\text{TKTUB} = \frac{\text{POUT} \times \text{IDTUBE}}{\text{SIGPV}}
\]

If \( \text{TKTUB} < 2.0 \times 10^{-2} \), then \( \text{TKTUB} = 2.0 \times 10^{-2} \).

\[
\text{ODTUBE} = (\text{IDTUBE} + 2.0 \times \text{TKTUB})
\]

C INITIALIZE TUBE DIA, PITCH(PA), AVG HELIX DIA(DC), NUMBER OF TUBES PER CIRCLE(NTC), NUMBER OF CIRCLES(NC)

\[
\text{PA} = 1.375 \times \text{ODTUBE}
\]

C LITHIUM SIDE

\[
\text{TAVLI} = \frac{(\text{TLIOUT} + \text{TLIIN})}{2.0}
\]

CALL LIPORT(TAVLI, MULI, KLI, CPLI, RHOLI, P)

If \( \text{TLIIN} > \text{TMAT} \), then \( \text{KTUBE} = \frac{\text{KA}}{(1.2 \times 10^3 \times 3.6 \times 10^3)} \)

If \( \text{TLIIN} \leq \text{TMAT} \), then \( \text{KTUBE} = \frac{\text{KB}}{(1.2 \times 10^3 \times 3.6 \times 10^3)} \)

DO 90 1 = 1, 100

C TUBE PITCH IS A FUNCTION OF DELTA P, LENGTH & HELIX ANGLE

\[
\text{VLI} = \frac{\text{WXOC} \times 1.44 \times 10^2}{(\text{RHOLI} \times \text{NOTUB} \times \text{ODTUBE}^2 \times 8.51931 \times 10^-1)}
\]

\[
\text{RELI} = 1.0847 \times 10^2 \times \text{ODTUBE} \times \text{VLI} \times \text{RHOLI} / \text{MULI}
\]

\[
\text{FELI} = (1.82 \times 10^2 \times \text{DLOG10(RELI)} - 1.64 \times 10^2)^{-2.0}
\]

If \( \text{RELI} < 2.0 \times 10^3 \), then \( \text{FELI} = 6.4 \times 10^1 / \text{RELI} \)

\[
\text{PRLI} = \text{CPLI} \times \text{MULI} / \text{KLI}
\]

\[
\text{EDDY} = -7.2767 \times 10^1 + 1.5054 \times 10^1 \times \text{DLOG10(RELI)} +
\]

\[
-7.2749 \times 10^1 \times (\text{DLOG10(RELI)})^2 \times 2.0
\]

\[
\text{EDDY} = 10.0 \times \text{EDDY}
\]

\[
\text{PSIBAR} = 1.0 \times 1.82g / (\text{PRLI} \times \text{EDDY} \times 1.44)
\]

If \( \text{PSIBAR} \leq 0.0 \), then \( \text{PSIBAR} = 0.0 \)

\[
\text{NULI} = 1.19936 \times 10^1 + 2.74889 \times 10^2 / (\text{PSIBAR} \times \text{RELI} \times \text{PRLI}) \times 0.8 \times 10^0
\]

If \( \text{NULI} \leq 1.22 \times 10^2 \), then \( \text{NULI} = 1.22 \times 10^2 \)

If \( \text{RELI} \leq 1.2 \times 10^2 \), then \( \text{NULI} = 4.8 \times 10^1 / 1.1 \times 10^1 \)

\[
\text{HLILI} = 0.15 \times \text{NULI} \times \text{KL} / (\text{ODTUBE} \times 1.2 \times 10^3)
\]

\[
\text{DLPB} = (\text{FELI} \times \text{LTOT} / (1.0847 \times 10^2 \times \text{ODTUBE}) + 1.5 \times 10^0) 
\]

\[
& (\text{VLI} \times 2.0 \times \text{RHOLI} / 6.4348 \times 10^1)
\]

\[
\text{DLPB} = \text{DLPB} / 1.44 \times 10^2
\]

C CALCULATE TUBE SPACING, MUST BE GREATER THAN TWICE THE TUBE DIA

C potassium side; boiler

\[
\text{PBOILI} = \text{PIN} - \text{DPHH}
\]

\[
\text{P} = \text{PBOILI} / 14.696 \times 10^0
\]

CALL TFROMP(\text{P}, \text{TBOILI})

\text{KSH} = 0

CALL KTHRMO(\text{KSH}, \text{TBOILI}, \text{P}, \text{VF}, \text{VG}, \text{H}, \text{HF}, \text{HFG}, \text{SF}, \text{SG}, \text{SGF})

\text{PBOILI} = 14.696 \times 10^0 \times \text{P}

\text{HBOILI} = \text{HF} + \text{XIN} \times \text{HFG}

\text{RHOBFI} = 1.0 \times \text{VF}
RHOBGI = 1.0/VG
CALL KXPORT (TBOILI1,MUF1,KK,CP,RHOF1)
CALL KVPORT (KSH,TBOILI1,P,MUG1,KK,CP,RHOF1)
VF1 = WXOT*1.44D2/(PI*IDTUBE**2.DO*NOTUBI*RHOBFI/4.DO)
RELI = IDTUBE*VF1*RHOBFI*3.D2/MUF1
VG1 = WXOT*1.44D2/(PI*IDTUBE**2.DO*NOTUBI*RHOBGI/4.DO)
REG1 = IDTUBE*VG1*RHOBGI*3.D2/MUG1

PBOIL2 = PBOIL1 - DPBOIL
P = PBOIL2/14.696DO
CALL TFROMP (P,TBOIL2)
KSH = 0
CALL KTHRMO(KSH,TBOIL2,P,VF,VG,HF,HG,HFG,SF,SG,SFG)
PBOIL2 = P*14.696DO
HBOIL2 = HF + XOUT*HFG
RHOBFI = 1.0/VF
RHOBGI = 1.0/VG
CALL KXPORT (TBOIL2,MUF2,KK,CP,RHOF2)
CALL KVPORT (KSH,TBOIL2,P,MUG2,KK,CP,RHOF2)
VF2 = WXOT*1.44D2/(PI*IDTUBE**2.DO*NOTUBI*RHOBF2/4.DO)
REL2 = IDTUBE*VF2*RHOBF2*3.D2/MUF2
VG2 = WXOT*1.44D2/(PI*IDTUBE**2.DO*NOTUBI*RHOBG2/4.DO)
REG2 = IDTUBE*VG2*RHOBG2*3.D2/MUG2

RHOBFA = (RHOBFI + RHOBF2)/2.DO
RHOBGA = (RHOBGI + RHOBG2)/2.DO
REL = (RELI + REL2)/2.DO*(1.DO - XOUT/2.DO - XIN/2.DO)
REG = (REG1 + REG2)/2.DO*(XOUT/2.DO + XIN/2.DO)

C PREHEAT

TAVEPR = (TIN + TBOILI)/2.DO
CALL KXPORT(TAVEPR,MUPH,KKPH,CPPH,RHOPH)
VPH = WXOT*1.44D2/(PI*IDTUBE**2.DO*NOTUBI*RHOPH/4.DO)
REPH = IDTUBE*VPH*RHOPH*3.D2/MUPH
FEPH = (1.82DO*DLOG10(REPH) - 1.64DO)**(-2.DO)
IF (REPH .LT. 2.D3) FEPH = 6.4DO/REPH
PRPH = CPPH*MUPH/KKPH
EDDY = - 6.115D-1 + 2.7792D-1*DLOG10(RELI) +
& 6.4292D-2*(DLOG10(RELI))**2.DO
EDDY = 10.DO**EDDY
PSIBAR = 1.DO - 1.82DO/(PRPH*EDDY**1.4DO)
IF (PSIBAR.LT.0.DO) PSIBAR = 0.DO

NUPH = 7.DO + 2.5D-2*(PSIBAR*REPH*PRPH)**0.8DO
IF (REPH .LT. 2.D3) NUPH = 4.8DO/1.1D1
HKPH = NUPH*KKPH/(IDTUBE*1.2D1*3.6D3)

C BOILING

HKBOIL = 1.35D-2

C SUPERHEAT
TAVESH = (TOUT + TBOIL2)/2.DO
PAVESH = POUT + DPSH/2.DO
P = PAVESH/14.696DO
KSH = 1
CALL KVPORT (KSH, TAVESH, P, MUSH, KKSH, CPSH, RHOSH)
VSH = WXOT*1.44D2/(PI*IDTUBE**2.DO*NOTUBI*RHOSH/4.DO)
RESH = IDTUBE*VSH*RHOSH**3.52/MUSH
FESH = (1.82D0*DLOG10(RESH) - 1.64D0)**(-2.DO)
IF (RESH .LT. 2.D3) FESH = 6.4D1/RESH
PRSH = CPSH*MUSH/KKSH
NUSH = ((FESH/8.DO)*RESH*PRSH)/
+ (1.07D0 + 1.27D1*DSQRT(FESH/8.DO)*(PRSH**(2.DO/3.DO) - 1.DO))
IF (RESH .LT. 2.D3) NUSH = 1.1D1/3.DO
HKSH = NUSH*KKSH/(IDTUBE*1.2D1*3.6D3)

C Compute overall heat transfer coefficients

UIPH = 1.DO/(1.DO/HKPH + IDTUBE*DLOG(ODTUBE/IDTUBE)/(2.DO*KTUBE)
+ IDTUBE/(HLILI*ODTUBE))
UIBOIL = 1.DO/(1.DO/HKBOIL + IDTUBE*DLOG(ODTUBE/IDTUBE)
+ (2.DO*KTUBE) + IDTUBE/(HLILI*ODTUBE))
UISH = 1.DO/(1.DO/HKSH + IDTUBE*DLOG(ODTUBE/IDTUBE)/(2.DO*KTUBE)
+ IDTUBE/(HLILI*ODTUBE))
QPH = WXOT*(HBOILI - HIN)
QBOIL = WXOT*(HBOIL2 - HBOILI)
QSH = WXOT*(HOUT - HBOIL2)

C Compute log mean temperature differences

T2 = TLIIN - QSH/(WXOC*CPLI)
T1 = T2 - QBOIL/(WXOC*CPLI)
DTLMPH = ((T1-TBOIL1)-(TLIOUT-TIN))/DLOG((T1-TBOIL1)/(TLIOUT-TIN))
DTLMBL = ((T2-TBOIL2)-(T1-TBOIL1))/DLOG((T2-TBOIL2)/(T1-TBOIL1))

IF (TOUT .GT. TBOIL2) THEN
DTLMSH = ((TLIIN-TOUT)-(T2-TBOIL2))/DLOG((TLIIN-TOUT)/(T2-TBOIL2))
ELSE
DTLMSH = 0.DO
ENDIF

C Compute tube lengths & number of reheater tubes required

LPH = QPH/(UIPH*DTLMPH*PI*IDTUBE*NOTUBI)
LBOIL = QBOIL/(UIBOIL*DTLMBL*PI*IDTUBE*NOTUBI)
IF (TOUT .GT. TBOIL2) THEN
LSH = QSH/(UISH*DTLMSH*PI*IDTUBE*NOTUBI)
ELSE
LSH = 0.DO
ENDIF
LTOT = LPH + LBOIL + LSH

c compute pressure drops in boiler tubes
c first the superheater

***** ****************************

DPSH = (FESH*(LSH/IDTUBE) + 1.0)*(VSH**2.0*RHOSH/6.4348D1)
DPSH = DPSH/1.44D2

***** ****************************

C next the boiling section

PARAM = DSQRT(RHOBFA/RHOBGA)
R1 = (1.0 + PARAM*XOUT)**2.0 - 1.0
DPINRT = R1*VPH**2.0*RHOPH/3.2174D1
DPINRT = DPINRT/1.44D2

C R2 = (1.0/PARAM - 1.0)/(PARAM - 1.0) +
C & (PARAM - 1.0/PARAM)/(XOUT*(PARAM - 1.0)**2.0) +
C & DLOG(1.0 + XOUT*(PARAM - 1.0))

C DPGRAV = R2*RHOPH*LBOIL*1.65D-1/1.44D2

FEBOIL = (6.667D-1 + 1.28D-3*DSQRT(REL))/REG**2.0D-1
DPDRAG = FEBOIL*(LBOIL/IDTUBE)*(VPH**2.0*RHOPH/3.2174D1)*
& (R1 + 2.0)
DPDRAG = DPDRAG/1.44D2

DPBOIL = DPINRT + DPDRAG

C Now compute pressure drop in the preheater

DPPH = (FEPH*(LPH/IDTUBE) + 0.5D0)*(VPH**2.0*RHOPH/6.4348D1)
DPPH = DPPH/1.44D2

DPTOT = DPBOIL + DPPH + DPSH
PIN = POUT + DPTOT

FUNC2 = DPTOT - DPMAX
CHECK = -0.7D0*DPMAX

IF ((FUNC2 .GT. 1.0D1) .OR. (FUNC2 .LT. CHECK)) THEN
NOTUB1 = NOTUB1*DSQRT(DPTOT/DPMAX)
NOTUB = NOTUB1*NUMTOT/NUMOP
PIN = POUT
DPBOIL = 0.0D0
DPPH = 0.0D0
DPSH = 0.0D0
GOTO 90
ENDIF

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IF (NOTUBO.EQ.0.DO) THEN
  FUNC1 = FUNC2
  NOTUBO = NOTUBI
  NOTUBI = NOTUBI*DSQRT(DPTOT/DPMAX)
  NOTUB = NOTUBI*NUMTOT[NUMOP
  GOTO 90
ENDIF

IF (JTUBE .EQ. 1) GOTO 75
IF (DABS(FUNC2).GE.1.D-6) THEN
  DELTA = FUNC2*(NOTUB - NOTUBO)/(FUNC2 - FUNC1)
  IF (DELTA .GT. NOTUBI) DELTA = DELTA/2.DO
  NOTUBO = NOTUBI
  NOTUBI = NOTUBI - DELTA
  FUNC1 = FUNC2
  NOTUB = NOTUBI*NUMTOT[NUMOP
  GOTO 80
ENDIF

IF (JTUBE .EQ. 0) THEN
  J = NINT(NOTUBI[NUMOP)
  NOTUBI = DFLOAT(J)*NUMOP
  NOTUB = NOTUBI*NUMTOT[NUMOP
  JTUBE = 1
  GOTO 80
ENDIF

75 IF (ABS(LTOT - HTTUB).LT.0.5D0) GO TO 99

80 HTTUB = LTOT

90 CONTINUE

99 JTUBE = 0

C ****************************
C ********************  MODIFIED 8-16-88  ********************
C volume of the tube sheets

  XNOTUB = DFLOAT(NOTUB)
  DTS = 1.444DO*ODTUBE*DSQRT(XNOTUB)
C Routine for determining tube sheet thickness

  A1 = (DTS - ODTUBE)/2.DO
  A2 = DSQRT(NOTUB*PA**2.DO*DSIN(PI/3.DO)/PI) +
    (ODTUBE - PA)/2.DO
  ASHEET = DMINI(A1,A2)
  BSHEET = DTS/2.DO
  KSheet = BSHEET/ASHEET
  PPrime = ASHEET*DSQRT(PI/(NOTUB*DSIN(PI/3.DO)))
  ETASHT = (PPrime - ODTUBE)/PPrime
  FSTAR = 0.556DO*KSHEET**(0.39DO*DLOG(ETASHT))
  OMEGA1 = 1.5/ETASHT
  OMEGA2 = 2.0

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\[
\begin{align*}
\text{OMEGA} & = \text{DMINI(OMEGA1,OMEGA2)} \\
\text{H1SHT} & = \text{DTS*FSTAR*DSQRT(PIN/(OMEGA*SIGPV*ETASHT))} \\
\text{H2SHT} & = \text{PIN*ASHEET/(1.6DO*SIGPV*(PA - ODTUBE)/PA)} \\
\text{XTHK} & = \text{DMAXI(H1SHT,H2SHT)} \\
VTS & = (\text{DTS**2.DO - NOTUB*ODTUBE**2.DO})*\pi*\text{XTHK}/2.DO
\end{align*}
\]

calculate the length of the boiler, lcl=3'' + dia of tube sheet

\[
\begin{align*}
\text{LCL} & = \text{DTS/2.DO + XTHK} \\
\text{HTB} & = \text{LTOT + 2.DO*LCL}
\end{align*}
\]

C CALCULATE THE VOLUME OF METAL PARTS - DENSITY = 0.31 lb/in3
c volume of the shell

\[
\begin{align*}
\text{THS} & = \text{PIN*DTS/(2.DO*SIGPV)} \\
\text{SIXTENH} & = 1.DO/16.DO \\
\text{IF (THS.LT.SIXTENH) THS = SIXTENH} \\
\text{DOUTER} & = \text{DTS + 2.DO*THS}
\end{align*}
\]
c assume 18 inches added to accomodate reheat tubes

\[
\begin{align*}
\text{VSHELL} & = (\pi/4.DO)*(\text{DOUTER**2.DO - DTS**2.DO})*\text{HTB}
\end{align*}
\]
c volume of the tubes

\[
\begin{align*}
\text{VTUBE} & = \text{NOTUB*(LTOT + 2.DO*XTHK)*(PI/4.DO)*} \\
& (\text{ODTUBE**2.DO - IDTUBE**2.DO})
\end{align*}
\]
c volume of closure, assume spherical end caps
c assume a flat end plate closure

\[
\begin{align*}
\text{VCLO} & = (\pi/2.DO)*(\text{DOUTER**2.DO})*\text{THS} \\
\text{VMFI} & = \pi/4.DO*((\text{DOUTER} + 1.06D-2*\text{MFI})**2.DO - \text{DOUTER**2.DO})* \\
& (\text{LTOT} + \text{XTHK}) \\
\text{VMFI} & = \text{VMFI} + \pi/6.DO*((\text{DOUTER} + 1.06D-2*\text{MFI})**3.DO - \\
& \text{DOUTER**3.DO})
\end{align*}
\]

\[
\begin{align*}
\text{WTShell} & = \text{VShell*RH OA ST} \\
\text{WTube} & = \text{WTUBE*RH OA ST} \\
\text{Wtape} & = \text{WTUBE*0.3DO} \\
\text{WTS} & = \text{VTS*RH OA ST} \\
\text{WTCLO} & = \text{VCLO*RH OA ST} \\
\text{MFIWT} & = \text{VMFI*9.2D-3}
\end{align*}
\]

\[
\begin{align*}
\text{WBOIL} & = \text{WTShell + WTUBE + WTAPE + WTS + WTCLO + MFIWT} \\
\text{VTOT} & = \text{VShell + WTUBE + VTS + VCLO}
\end{align*}
\]
calculate the volume of the Lithium

\[
\begin{align*}
\text{VCYL} & = (\pi/4.DO)*\text{DTS**2.DO*LTOT}
\end{align*}
\]
take out primary helix tubes and shroud and reheater tubes
V2 = NOTUB*LTOT*(PI/4.DO)*ODTUBE**2.DO
VLI = VCYL - V2

c compute weight of potassium in the boiler

FACTOR = 1.DO - (XIN + XOUT)/2.DO
V2 = V2*(((LPH + LBOIL*FACTOR)/LTOT)*(IDTUBE/ODTUBE)**2.DO
VHEAD = PI*DTS**3.DO*FACTOR/6.DO
VPOTAS = (VHEAD + V2)/(12.DO**3.DO*NUMTOT)
WTPOTS = VPOTAS*RHOPH*NUMOP

WTLI = VLI*RHOLI/1.2D1**3.DO
WTWET = WBOIL + WTLI + WTPOTS

c compute heat losses

TRADAV = (TLIIN**5.DO - TLIOUT**5.DO)/(TLIIN - TLIOUT)
QLOSS = PI*DOUTER*HTB*0.2DO*3.305D-15*TRADAV
QLOSS = QLOSS/DFLOAT(MFI)
TRADAV = TRADAV**0.25DO

c parameter transformation

IF (REHEAT .EQ. 0) THEN
  NOTUBB = NOTUBI
  QBOILL = QLOSS
  PLE(11) = PIN
  DLPBB = DLPB
  DPTOTB = DPTOT
  WBOILB = WBOIL
  WTWETB = WTWET
  VPOTSB = VPOTAS
  HTBB = HTB
  DOUTEB = DOUTER
  DTSB = DTS
  THSB = THS
  XTHKB = XTHK
  LPHB = LPH
  LBOILB = LBOIL
  LSHB = LSH
  LTOTB = LTOT
  TKTUBB = TKTUB
  PAB = PA
  HLILIB = HLILI
  HKPHB = HKPH
  HKBOIB = HKBOIL
  HKSHB = HKSH
  WSHELB = WSHHELL
  WTUBE = WTUBE
  WTAPEB = WTAPE
  WTTSB = WTTTS
  WTCLOB = WTCLO
  MFIWTB = MFIWT
  WTPOTB = WTPOTS

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WTLIB = WTLI
ELSE
NOTUBR = NOTUB1
QRHLSS = QLOSS
PLE(6) = PIN
DLPBR = DLBP
DPTOTR = DPTOT
WRHT = WBOIL
WTWETR = WTWET
VPOTSR = VPOTAS
HTBR = HTB
DTSR = DTS
THSR = THS
XTHKR = XTHK
LPHR = LPH
LBOILR = LBOIL
LSHR = LSH
LTOTR = LTOT
TKTUBR = TKTUB
PAR = PA
HLILIR = HLILI
HKPHR = HKPH
HKBOIR = HKBOIL
HKSHR = HKSH
WSHELIR = WTSHELL
WTUBER = WTUBE
WTAPER = WTAPE
WTTSR = WTTS
WTCLOR = WTCLO
MFIWTR = MFIWT
WTPOTR = WTPOTS
WTLIR = WTLI
ENDIF
RETURN
END
subroutine psize

*******************************************************************************
* this program is a generalized conceptual design program
* for a centrifugal stage + inducer are sized
* ghp 2/92
*******************************************************************************

implicit double precision (a-h,o-z)

DOUBLE PRECISION KA,KB,NUMOP,NUMTOT,KWNET,NOTUBB,
& NOTUBR, LG, MMAIN, MFLOPT, MF, ID, MFITOT, KWOUT,
& MQADD, MQREJ, LPHB, LBOILB, LSHB, LTOTB, MFIWTB, LPHR,
& LBOILR, LSHR, LTOTR, MFITWR

INTEGER REHEAT, RSTAGE

PARAMETER (NSTG=15)

COMMON /INPUT/ FPL, VELV, VELM, VELL, TMAT, XMATH, XMATC, DUM1, DUM2, KA,
& KB, NUMOP, NUMTOT, TROUT, TRIN, KWNET, GEFF, DUM3, BPP, BFP,
& BPL, PWRFCTR, VOLTAGE, GENASP, TINCLNT, TOUTCLNT,
& CPCLNT, TBOIL, XBOIL, DUM4, TCON, DEFF, EXLOSS, VTIPO,
& SCCON, ALPHAT, RSTT, XMFI, DPCON, PTEFF, DPRFMD, EPRFMD,
& EMRFMD, DPMAXB, DIATB, NOTUBB, DPMAXR, DTRH, DIARH,
& NOTUBR, LG(II)

COMMON /OUTPUT/ MMAIN, TT(0:15), PP(0:15), H(0:15), S(0:15), X(0:15),
& SVV(0:15), TL1(II), TLE(II), PLI(II), PLE(II), HL1(II),
& HLE(II), SLI(II), SLE(II), LL(II), XLE(II), SVVL(II),
& SVVLE(II), MF(II), WALL(II), WT(II), WTKINV(II), ID(II),
& DPTOTB, WTKT, TOTWT, TTRH, DPTOTR, NS, WTMFII(II),
& MFITOT, PENG, TENG, FMDEL, PDIS, UTLIM, TTP(NSTG), XNPSHA,
& DT(NSTG), UT(NSTG), PHI(NSTG), NSTAGE, PSI(NSTG), XN,
& TOTH, PUMPEFF, SSMARG, XNSSTG(NSTG), WFPUMP, TORQ,
& KWOUT, ALTWT, CYCEFF, PCSACM, MQADD, MQREJ, PRSTAG,
& WTRFMD, WTRB, XRH, EFF(0:15), DLPBB, WBOILB, WTWEBT,
& DLPBR, WRHT, WTWTR, HTBB, DOUTEB, DTSB, THSB, XTHKB, LPHB,
& LBOILB, LSHB, LTOTB, TKTUBB, PAB, HLILIB, HKPHB, HKBOIB,
& HKSHB, WSHLB, WTUBEB, WTAPEB, WTTSB, WTCLOB, MFIWTB,
& WTPOTB, WTLIB, HTBR, DOUTEB, DTSR, THSR, XTHKR, LPHR,
& LBOILR, LSHR, LTOTR, TKTURB, PAR, HLILIR, HKPHR, HKBOIR,
& HKSHR, WSHLR, WTUBER, WTAPER, WTTSR, WTCLOB, MFITWR,
& WTPOTR, WTLIR, WTPCS, SPMASS, EFFNET, EFFGRS, WTPUMP,
& TITCON, PLNTF, GNLOSS, TORQUE, TRBPWR, XXI, TURBWT, RPM,
& SVRH, TSATRH, HRH, SRH, TSAT(0:15), VTP, DGENRTR, KVA,
& DGENSE, LGENTOT, MASSES, TIPSDG, COE, COOLING, WCLNT

COMMON /SYSTM/ MFLOPT, CSFLI(II), CSLFLE(II), DELPL(II), DELHL(II), MFI,
& TPUMP, HPUMP, SFPUMP, VFIC, WRFMD, PI, G, TOL, XLAMIN,
& XLAMOUT, EFFIND, HIND, XKLOSS, PT(NSTG), PS(NSTG),
& HT(NSTG), XIHT(NSTG), HSP(NSTG), ST(NSTG), TS(NSTG),
set constants

\[ g = 32.174 \]
\[ \text{tol} = 0.0000001 \]

set default values

\[ \text{ssmarg} = 2.00 \]
\[ \text{psi}(1) = 0.10 \]
\[ \text{phi}(1) = 0.14 \]
\[ \text{effp}(1) = 0.848 \]
\[ \text{utlim} = 170.0 \]

\[ \text{do 100 i = 2, nstg} \]
\[ \text{phi}(i) = 0.1 \]
\[ \text{psi}(i) = 0.35 \]
\[ \text{effp}(i) = 0.848 \]

\[ \text{continue} \]
\[ \text{xlain = 0.3} \]
\[ \text{xlaout = 0.6} \]

begin pump sizing

call indsize

call correlate(5,torq,wpump)

return
end
subroutine indsize

*******************************************************************************

*    This subroutine evaluates the size and state conditions  *
*    on and around the inducer.  ghp 2/92                               *

*******************************************************************************

implicit double precision (a-h,o-z)

DOUBLE PRECISION KA, KB, NUMOP, NUMTOT, KWNET, NOTUBB,
               NOTUBR, LG, MMAIN, MFLOPT, MF, ID, MFIOT, KWOUT,
               MQADD, MQRER, LPHB, LBOILB, LSHB, LTOTB, MFIWTB, LPHR,
               LBOILR, LSHR, LTOTR, MFIWTR

INTEGER REHEAT, RSTAGE

PARAMETER (NSTG=15)

COMMON /INPUT/  FPL, VELV, VELM, VELL, XMATH, XMATC, DUM1, DUM2, KA,
                 KB, NUMOP, NUMTOT, TROUT, TRIN, KWNET, GEFF, DUM3, BPP, BFP,
                 BPL, PWRFCTR, VOLTAGE, GENASP, TINCLNT, TOUTCLNT,
                 CPCLNT, TBOIL, DUM4, TCN, DEFF, EXLOSS, VTIPO,
                 SCCON, ALPHAT, RSTT, XMFI, DPCON, PTEFF, DPRFM, ERFMD,
                 EMRFMD, DPMAB, DIATB, NOTUBB, DPMAR, DTRH, DIARH,
                 NOTUBR, LG(I)

COMMON /OUTPUT/  MMAIN, TT(0:15), PP(0:15), H(0:15), S(0:15), X(0:15),
                  SVV(0:15), TLI(11), TLE(11), PII(11), PLE(11), HLI(11),
                  HLE(11), SII(11), SLE(11), XLI(11), XLE(11), SVVLI(11),
                  SVVLE(11), MF(11), WALL(11), WT(11), WTKINV(11), ID(11),
                  DPTOTB, WTOTB, TOTWT, TTRH, DPTOTR, NS, WTMFI(11),
                  MFIOT, PENG, TENG, FMDEL, PDIS, UTLIM, TTP(NSTG), XNPSHA,
                  DT(NSTG), UT(NSTG), PHI(NSTG), NSTAGE, PSI(NSTG), XN,
                  TOTHP, PUMPEFF, SSMARG, XNSSTG(NSTG), WFPUMP, TORQ,
                  KWOUT, ALTWT, CYCEFF, PCsACM, MQADD, MQRER, PRSTAG,
                  WTRFM, WTRBN, XRH, EFF(0:15), DLPB, WBOILB, WTWETB,
                  DLPBR, WRHT, WTWTR, HTBB, DOUTEB, DTSB, THSB, XTHKB, LPHB,
                  LBOILR, LSHR, LTOTB, TKTUBB, PAB, HLILIB, HKPHB, HKBOIR,
                  HKSHB, WSHLIB, WTBEB, WTAEB, WTTSB, WTCLOB, MFIWTR,
                  WTPOTB, WTLIB, HTBR, DOUTER, DTSR, THSR, XTHR, LPHR,
                  LBOILR, LSHR, LTOTR, TKTURB, PAR, HLILIR, HKPHR, HKBOIR,
                  HKSHR, WSHLH, WTBUR, WTAER, WTTSR, WTCLR, MFIWTR,
                  WTPOTR, WTLIR, WTPCS, SPMASS, EFFNET, EFFGRS, WTPUMP,
                  TITCON, PLNTF, GNLOSS, TORQUE, TRBPRW, XXI, TURBWT, RPM,
                  SVRH, TSATRH, RH, SRH, TSAT(0:15), VTI, DGRENTR, KVAR,
                  DGREN, LGENTOT, MAASS, TIPS, COE, COOIL, WCLNT

COMMON /SYSTM/  MFLOPT, CFSLI(11), CFSLE(11), DELPL(11), DELHL(11), MFI,
                 TPUMP, HPUMP, SFSPUMP, VFSPUMP, WKRFMD, PI, G, TOL, XLMANIN,
                 XLAMOUT, EFFIND, HCIND, XKLOSS, PT(NSTG), PS(NSTG),
                 HT(NSTG), XIHT(NSTG), HSP(NSTG), ST(NSTG), TS(NSTG),
                 RHO(NSTG), CM(NSTG), XNSS, DH(NSTG), B2(NSTG),
determine inlet conditions at engine interface

call ept2d(peng, teng, rhoeng, kfluid)
call ept2h(peng, teng, heng, steng, kfluid)

flow rate for pump allows for variation through stages later

f3s(I) = (fmdel/rhoeng)

begin iteration on inducer size

dindg = 0.0
cm(1) = 0.0
tshg = 1000.0
ttp(I) = teng
rho(I) = rhoeng
ht(I) = heng
vduct = 0.0
30 pt(I) = peng + (0.5*xkloss*rho(I)*vduct**2.0)*(1./g*144.)
ps(I) = pt(I) - (cm(1)**2.0*rho(I))/(2.*g*144.)
call ept2h(pt(I), ttp(I), ht(I), steng, kfluid)
hsp(I) = ht(I) - (cm(1)**2./(2.*g*778.26))
call eph2s(pt(I), ht(I), st(I), ttp(I))
call eph2d(ps(I), hsp(I), rho(I), ttp(I))
call et2vap(ttp(I), dum, pvapor, kfluid)

xnpsha = ((pt(I)-pvapor)/rho(I))*144.

size inducer given flow coefficient, inlet conditions, and margin

31 call corelate(1, phi(1), xnsstr)

xnsstr = xnsstr*dsqrt(1.-xlamin**2.)
tsh1 = 0.5*pvapor/rho(1)*144.
tsh2 = (1./(2.*g))*cm(1)**2.
if (tsh2 .eq. 0.00) tsh2 = tsh1
if (tsh1 .le. tsh2) tsh = tsh1
if (tsh2 .le. tsh1) tsh = tsh2
xnpshop = xnpsha/(1.+ssmarg)
xn = (xnsstr2o*((xnpshop+tsh)**(3./4.)))/dsqrt(f3s(I)*448.83)
\[
dt(1) = ((4.*60./\pi**2.)*(f3s(1)/(xn*(1-xlamin**2.)*
\&
phi(1))))**(1./3.)
\]

if (dt(1) .lt. 0.5/12.) then
  dt(1) = 0.5/12.
endif

ut(1) = (\pi/60.)*(xn*dt(1))
cm(1) = phi(1)*ut(1)

if (dabs(tshg-tsh) .gt. 0.00001 ) then
  tshg = tsh
  goto 31
endif

if (ssmarg .gt. 5.00 .and. dt(1) .le. 0.5/12.) then
  dt(1) = 0.5/12.
  xn = (utlim/dt(1))*(60./\pi)
  ut(1) = (\pi/60.)*(xn*dt(1))
  phi(1) = 0.14
  call corelate(1,phi(1),xnsstar)
  xnssh2o = xnsstar*dsqrt(1.-xlamin**2.)
  xnpshbd = (xn*dsqrt(f3s(1)*448.83)/xnssh2o)**(4./3.)
  if (tsh .gt. xnpshbd) then
    xnpshbd = xnpshbd
  else
    xnpshbd = xnpshbd - tsh
  endif
  ssmarg = (xnpsha/xnpshbd)-1.
endif

if (ut(1) .gt. utlim) then
  phi(1) = phi(1) + 0.001
  if (phi(1) .gt. 0.200d0) then
    phi(1) = 0.140d0
    ssmarg = ssmarg + 0.1
  endif
  goto 31
endif

xnss = xn*dsqrt(f3s(1)*448.83)/xnpsha**0.75
pungi = pt(1) + (0.5*xkloss*rho(1)*vduct**2.)*(1./(g*144.))
suction performance correction for small pumps

if (dt(1) .lt. 2.778/12.) xnss = xnss*0.48*dsqrt(dt(1)/.64)

if (dabs(dindg-dt(1)) .gt. .0001) then
  dindg = dt(1)
go to 30
endif

n = 1
call convrg3(n,peng,pungi,pt(1),tol,k,500)
if (k) 10, 20, 30
10 print 11, n
11 format(10x, 'error at loop', i3/) stop
20 call eph2t(ps(1), hsp(1), ts(1), ttp(1))
calculate discharge of first inducer
dh(2) = dt(1)*xlamout

pt(2) = (0.25*ut(1)**2.*rho(1))/(g*144.) + pt(1)
if (pt(2) .ge. pdis) then
  psi(1) = (pdis-pt(1))/rho(1)*g*144./ut(1)**2
endif
pt(2) = (psi(1)*ut(1)**2.*rho(1))/(g*144.) + pt(1)
ps(2) = pt(2) - cm(2)**2./(2.*g)*rho(1)/144.
gh = ht(1) + (pt(2)-pt(1))/rho(1)*144./778.26
call isen(pt(2), gh, st(1), 1, tol, xiht(2), ttp(1))
ht(2) = (xih(2)-ht(1))/effp(1) + ht(1)
hsp(2) = ht(2) - (cm(2)**2./(2.*g))/778.26
call eph2t(pt(2), ht(2), ttp(2), ttp(1))
call eph2s(pt(2), ht(2), st(2), ttp(2))
call eph2t(ps(2), hsp(2), ts(2), ttp(2))
call eph2d(ps(2), hsp(2), rho(2), ts(2))

hp(1) = (xih(2)-ht(1))*778.26/effp(1)*fmdel/550.0
tothp = hp(1)
assume one stage centrifugal with an inducer
if (dabs(pt(2)-pdis) .lt. 1.0) then
  pt(2) = pdis
endif
if (pt(2) .lt. pdis) then
  numstg = 1
70 numstg = numstg + 1
do 60 jstage = 2, numstg
in = jstage
i = in + 1
dtg = 0.0
50 continue
pt(i) = pt(2) + (jstage - 1)*(pdis - pt(2))/(numstg - 1)

ps(i) = pt(i) - cm(i)**2./(2.*g)*rho(i-1)/144.
gh = ht(i-1) + (pt(i)-pt(i-1))/rho(i-1)*144./778.26
call isen(pt(i), gh, st(i-1), 0, tol, xiht(i), ttp(i-1))
ht(i) = (xih(i)-ht(i-1))/effp(in) + ht(i-1)
hsp(i) = ht(i) - (cm(i)**2.)/(2.*g))/778.26
call eph2t(pt(i), ht(i), ttp(i), ttp(i-1))
call eph2s(pt(i), ht(i), st(i), ttp(i-1))
call eph2t(ps(i),hsp(i),ts(i),ttp(i))
call eph2d(ps(i),hsp(i),rho(i),ts(i))

c size centrifugal stage

    hd(in) = 1.10*(xiht(i)-ht(i-1))*778.26
    dt(in) = (60./(xn*pi))*dsqrt(hd(in)*g/psi(in))
    ut(in) = (dt(in)/2.)*(2.*pi/60.)*xn
    b2(in) = f3s(1)/(pi*dt(in)*ut(in)*phi(in))
    cm(i) = f3s(1)/(pi*dt(in)*b2(in))

c re-evaluate efficiency

    xnsstg(in) = xn*dsqrt(f3s(1)*448.83)/(hd(in)/1.)**0.75
    if (xnsstg(in) .lt. 300) go to 70
    call corelate(2,xnsstg(in),effp(in))

c if (dt(1)/dt(in) .ge. 0.90) then
    dt(in) = dt(1)
    ut(in) = (dt(in)/2.)*(2.*pi/60.)*xn
    psi(in) = hd(in)*g/ut(in)**2
    effp(in) = 0.848
    endif

c if (dt(in) .lt. 5.0/12.0 .and. dt(1) .ne. dt(in)) then
    xks = (5./12./dt(in))**1.5*(0.004/0.004)*
       (dt(1)/dt(in)/0.49)
    xkb = 0.0
    call corelate(3,xks,xkb)
    if (xkb .lt. 0) xkb = 0.1
    effp(in) = effp(in)*xkb
    endif

c if (dt(in) .ge. 5.0/12.0 .and. dt(1) .ne. dt(in)) then
    xks = (0.005/(dt(in)*12.))*(dt(1)/dt(in)/0.49)
    xkb = 0.0
    call corelate(4,xks,xkb)
    effp(in) = effp(in)*xkb
    endif

c loop around stage to correct efficiency

    if (dabs(dtg-dt(in)) .gt. 0.0001) then
    dtg = dt(in)
    if (dt(1)/dt(in) .gt. 0.80) then
       psi(in) = psi(in) - 0.01
    endif
    goto 50
    endif

c calculate pump power requirement

    hp(in) = (xiht(i)-ht(i-1))*778.26/effp(in)*fmdel/550.0
    tothp = tothp + hp(in)
nstage = in

else
    nstage = 1
    effp(in) = 0.848
endif

setup the analysis of the stages

do 100 in = 1, nstage
    dt(in) = dt(in)*12.
    dh(1) = dt(1)*xlamin
    dh(in) = dt(in)*xlamout
    continue
100

calculate pump efficiency

in = nstage+1
gh = ht(1) + (pt(in)-pt(1))*144./rho(1)/778.26
call isen(pt(in),gh,st(1),in,tol,xiht(in+1),ttp(in))
pumpeff = (xiht(in+1)-ht(1))/(ht(in)-ht(1))
	nreturn

dend
subroutine isen(pres, gh, strue, n, tol, hout, temp)

-material****************************************************************************************************

* Calculates isentropic enthalpy - ghp 2/92
* material****************************************************************************************************

implicit double precision (a-h,o-z)

tol = 0.0001

if (dabs(gh) .lt. 1.0e-10) gh = 1.0e-10*(-1.0*dabs(gh)/gh)
call eph2s(pres, gh, gs, temp)
call convrg3(n, strue, gs, gh, tol, k, 500)
if (k) 11, 13, 10
11  print 12, n
12  format(10x,'error at loop ',i3/)
    stop
13  hout = gh

return
end
SUBROUTINE CONVRG3 (L, X, Y, Z, TOL, K, N)

IMPLICIT DOUBLE PRECISION (A-H,O-Z)
DIMENSION DL(0:25),M(0:25),VL(0:25)

C INSTRUCTIONS:
C L IS THE LOOP NUMBER IF USING NESTED LOOPING
C X AND Y ARE THE VARIABLES TO BE COMPARED
C Z IS THE VARIABLE TO BE CHANGED TO CONVERGE X AND Y
C TOL IS THE TOLERANCE LIMIT OF COMPARISON
C K IS A FLAG SET WITHIN THE SUBROUTINE TO DETECT CONVERGENCE
  - ERROR SUCH AS NUMBER OF ITERATIONS EXCEEDED
  0 CONVERGING COMPLETED
  + GO BACK INTO SUBROUTINE, NOT CONVERGED
C N IS MAXIMUM NUMBER OF ITERATIONS TO BE ALLOWED

DATA DL,M,VL/26*0.DO,26*0,26*0.DO/
LI:L
XI:X
YI=Y
ZI=Z
IF(ZI) 20,30,20
20 W=Z1
GOTO 40
30 W=X1
40 D=X1-Y1
  IF(ABS(D)-ABS(TOL)) 50,50,60
50 KI = 0
55 M(LI)=0
GOTO 220
60 IF(M(LI)) 70,70,80
70 V=1.01*W
M(LI)=1
GOTO 190
80 IF(M(LI)-N) 110,110,90
90 PRINT*,','-CONVRG- ITERATIONS EXCEEDED'
K1 = -1
GO TO 140
110 M(LI)=M(LI)+1
B=DL(LI)-D
  IF(B) 160,120,160
120 CONTINUE
K1=-2
140 PRINT*,',','LOOP NO.=',L1,' ERROR INDICATOR=',K1
PRINT*,',','ARG. ARE::',XI,Y1,Z1
DO 155 I=1,25
155 M(I)=0
GOTO 220
160 C=D*(W-VL(LI))/B
  IF(ABS(C)<.2*ABS(W)) 180,180,170
170 V=W+.2*SIGN(W,C)
GOTO 190
180 V=W+C
program propfunct

******************************************************************************

* *
* This program is an interface between the pump sizing *
* program and the properties routines. The correct property *
* routine must be bound along with this program to the main *
* pump sizing program. This method is similar to that used in *
* the gas path program. ghp 2/92 *
* *
******************************************************************************

subroutine ept2d(p,t,density,kfluid)

******************************************************************************

* *
* This subroutine determines the density from p and t *
* *
******************************************************************************

implicit double precision (a-h,o-z)

call vfromt(t,vf)

density = 1.0/vf

return
end
190  K1=1
    VL(L1)=W
    DL(L1)=D
    IF(Z1) 200,210,200
200  Z=V
    GOTO 220
210  X=V
220  K=K1
    RETURN
    END
subroutine eph2d(p,h,density,temp)

*****************************************************************************
* This subroutine determines the density from p and h
*****************************************************************************
implicit double precision (a-h,o-z)
patm = p/14.696
        call tfrmhf(h,temp,patm,vf,sf)
density = 1.0/vf

return
end
subroutine ept2h(p,t,enthalpy,st,kfluid)

********************************************************************
* This subroutine determines the enthalpy from p and t             *
********************************************************************

implicit double precision (a-h,o-z)

    patm = p/14.696
    call kthrml(t,patm,vf,hf,sf)
    enthalpy = hf

return
end
subroutine eph2s(p,h,entropy,temp)

******************************************************************************
* This subroutine determines the entropy from p and h                       *
******************************************************************************

implicit double precision (a-h,o-z)

patm = p/14.696
call tfrmhf(h,temp,patm,vf,entropy)

return
end
subroutine eph2t(p,h,temp,templ)

**************************************************************************
* This subroutine determines the temperature from p and h           *
**************************************************************************

implicit double precision (a-h,o-z)

patm = p/14.696
call tfrmhf(h,templ,patm,dum,duml)
temp = templ

return
end
subroutine et2vap(t,dum,pvap,kfluid)

******************************************************************************
* This subroutine determines the vapor pressure for the given t *
******************************************************************************

implicit double precision (a-h,o-z)

ksh = 0
    call kthrm0(ksh,t,pvap,dum1,dum2,dum3,dum4,dum5,dum6,dum7,
    &                  dum8)
    pvap = pvap*14.696

return
end
SUBROUTINE PIPER
IMPLICIT DOUBLE PRECISION (A-Z)
INTEGER I,J,K,L,M,N,KSH,MFI,NS,MATH,MATC,REHEAT,RSTAGE,NSTG

***** ****************************

PARAMETER (NSTG=15)

COMMON /INPUT/ FPL,VELV,VELM,YEL,TMAT,XMATC,DUM1,DUM2,KA,
& KB,NMOP,NMOT,TROUT,TRIN,KWNT,GEFF,DUM3,BPP,BFP,
& BPL,PWRFCTR,VOLTAGE,GENASP,TINCLNT,TOUTCLNT,
& CCLNT,DUM1,XM2,BOIL,DUM4,TCON,DEFF,EXLOSS,VTIPO,
& SCON,ALPHAT,RSTT,XMFI,DPCON,PEFF,DFRMF,EFIRMF,
& EMRFMD,DFMAXBE,DIATB,NOTUBB,DFMAXTR,DRTR,DIARH,
& NOTURB,LF(11)

COMMON /OUTPUT/MMAIN,TT(0:15),PP(0:15),H(0:15),S(0:15),X(0:15),
& SVV(0:15),TLI(11),TLE(11),PLI(11),PLE(11),HLI(11),
& HLE(11),SLI(11),SLE(11),XLI(11),XML(11),SVVLI(11),
& SVVLE(11),MF(11),WALL(11),WT(11),WTINV(11),ID(11),
& DPTOT,WSHUB,WTUB,WTOR,WSHUL,WTUL,WF,HLI,HLI,PKH,PKH,
& HKSHB,WSHUB,WTUB,WTURB,WTUR,WTUS,MTUW,MTUW,
& WTPOT,WTUB,WSHUB,WTUB,WTURB,WTURB,MTUW,MTUW,
& WTPOT,WTUB,WSHUB,WTUB,WTURB,WTURB,MTUW,MTUW,
& HREL,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,
& HREL,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,
& DT(NSTG),UT(NSTG),PHI(NSTG),NSTAGE,PSI(NSTG),XN,
& DOTDP,PMPF,SSMARG,XNSSTG(NSTG),WFPUMP,TOQ,
& KWOUT,ALTM,F,CEFF,PCSACM,MQADD,MQREJ,PRSTAG,
& WTRFMF,WTURB,SRH,EFF(0:15),DLPBB,WBOILB,WTWETB,
& DLPR,WRH,WTWET,HTBB,DOUTE,DT,SB,THSB,XTHKB,LPHB,
& LBOILB,LHSH,LTOTB,KTUBB,PAB,HLI,PKH,PKH,
& HKSHB,WSHUB,WTUB,WTURB,WTURB,WTUS,MTUW,MTUW,
& WTPOT,WTUB,WSHUB,WTUB,WTURB,WTURB,MTUW,MTUW,
& WTPOT,WTUB,WSHUB,WTUB,WTURB,WTURB,MTUW,MTUW,
& HREL,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,
& HREL,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,
& DT(NSTG),UT(NSTG),PHI(NSTG),NSTAGE,PSI(NSTG),XN,
& DOTDP,PMPF,SSMARG,XNSSTG(NSTG),WFPUMP,TOQ,
& KWOUT,ALTM,F,CEFF,PCSACM,MQADD,MQREJ,PRSTAG,
& WTRFMF,WTURB,SRH,EFF(0:15),DLPBB,WBOILB,WTWETB,
& DLPR,WRH,WTWET,HTBB,DOUTE,DT,SB,THSB,XTHKB,LPHB,
& LBOILB,LHSH,LTOTB,KTUBB,PAB,HLI,PKH,PKH,
& HKSHB,WSHUB,WTUB,WTURB,WTURB,WTUS,MTUW,MTUW,
& WTPOT,WTUB,WSHUB,WTUB,WTURB,WTURB,MTUW,MTUW,
& WTPOT,WTUB,WSHUB,WTUB,WTURB,WTURB,MTUW,MTUW,
& HREL,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,
& HREL,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,
& DT(NSTG),UT(NSTG),PHI(NSTG),NSTAGE,PSI(NSTG),XN,
& DOTDP,PMPF,SSMARG,XNSSTG(NSTG),WFPUMP,TOQ,
& KWOUT,ALTM,F,CEFF,PCSACM,MQADD,MQREJ,PRSTAG,
& WTRFMF,WTURB,SRH,EFF(0:15),DLPBB,WBOILB,WTWETB,
& DLPR,WRH,WTWET,HTBB,DOUTE,DT,SB,THSB,XTHKB,LPHB,
& LBOILB,LHSH,LTOTB,KTUBB,PAB,HLI,PKH,PKH,
& HKSHB,WSHUB,WTUB,WTURB,WTURB,WTUS,MTUW,MTUW,
& WTPOT,WTUB,WSHUB,WTUB,WTURB,WTURB,MTUW,MTUW,
& WTPOT,WTUB,WSHUB,WTUB,WTURB,WTURB,MTUW,MTUW,
& HREL,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,
& HREL,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,
& DT(NSTG),UT(NSTG),PHI(NSTG),NSTAGE,PSI(NSTG),XN,
& DOTDP,PMPF,SSMARG,XNSSTG(NSTG),WFPUMP,TOQ,
& KWOUT,ALTM,F,CEFF,PCSACM,MQADD,MQREJ,PRSTAG,
& WTRFMF,WTURB,SRH,EFF(0:15),DLPBB,WBOILB,WTWETB,
& DLPR,WRH,WTWET,HTBB,DOUTE,DT,SB,THSB,XTHKB,LPHB,
& LBOILB,LHSH,LTOTB,KTUBB,PAB,HLI,PKH,PKH,
& HKSHB,WSHUB,WTUB,WTURB,WTURB,WTUS,MTUW,MTUW,
& WTPOT,WTUB,WSHUB,WTUB,WTURB,WTURB,MTUW,MTUW,
& WTPOT,WTUB,WSHUB,WTUB,WTURB,WTURB,MTUW,MTUW,
& HREL,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,
& HREL,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,
& DT(NSTG),UT(NSTG),PHI(NSTG),NSTAGE,PSI(NSTG),XN,
& DOTDP,PMPF,SSMARG,XNSSTG(NSTG),WFPUMP,TOQ,
& KWOUT,ALTM,F,CEFF,PCSACM,MQADD,MQREJ,PRSTAG,
& WTRFMF,WTURB,SRH,EFF(0:15),DLPBB,WBOILB,WTWETB,
& DLPR,WRH,WTWET,HTBB,DOUTE,DT,SB,THSB,XTHKB,LPHB,
& LBOILB,LHSH,LTOTB,KTUBB,PAB,HLI,PKH,PKH,
& HKSHB,WSHUB,WTUB,WTURB,WTURB,WTUS,MTUW,MTUW,
& WTPOT,WTUB,WSHUB,WTUB,WTURB,WTURB,MTUW,MTUW,
& WTPOT,WTUB,WSHUB,WTUB,WTURB,WTURB,MTUW,MTUW,
& HREL,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,
& HREL,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,
& DT(NSTG),UT(NSTG),PHI(NSTG),NSTAGE,PSI(NSTG),XN,
& DOTDP,PMPF,SSMARG,XNSSTG(NSTG),WFPUMP,TOQ,
& KWOUT,ALTM,F,CEFF,PCSACM,MQADD,MQREJ,PRSTAG,
& WTRFMF,WTURB,SRH,EFF(0:15),DLPBB,WBOILB,WTWETB,
& DLPR,WRH,WTWET,HTBB,DOUTE,DT,SB,THSB,XTHKB,LPHB,
& LBOILB,LHSH,LTOTB,KTUBB,PAB,HLI,PKH,PKH,
& HKSHB,WSHUB,WTUB,WTURB,WTURB,WTUS,MTUW,MTUW,
& WTPOT,WTUB,WSHUB,WTUB,WTURB,WTURB,MTUW,MTUW,
& WTPOT,WTUB,WSHUB,WTUB,WTURB,WTURB,MTUW,MTUW,
& HREL,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,
& HREL,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,SHRE,
& DT(NSTG),UT(NSTG),PHI(NSTG),NSTAGE,PSI(NSTG),XN,
& DOTDP,PMPF,SSMARG,XNSSTG(NSTG),WFPUMP,TOQ,
& KWOUT,ALTM,F,CEFF,PCSACM,MQADD,MQREJ,PRSTAG,
MF(1) = MMAIN
MF(2) = MF(1) - MFLOPT
MF(3) = MFLOPT
MF(4) = MF(2)
MF(5) = MF(3)
DO 1455 J = 6,11
   MF(J) = MF(1)
1455 CONTINUE

TLE(2) = TT(0)
PLE(2) = PP(0)
HLE(2) = H(0)
SLE(2) = S(0)
XLE(2) = X(0)
SVVLE(2) = SVV(0)
CFSLE(2) = MF(2)*SVVLE(2)

CALL SIZEPP (CFSLE(2),VELV,TLE(2),TMAT,FPL,PLE(2),LG(2),MF(2),
          WALL(2),WT(2),WTKINV(2),WTMFI(2),ID(2),MFI)

VISCOS = 1.98227D-2 + 1.36364D-5*TLE(2)
DENSIT = 1.0/SVVLE(2)
CALL HEADLOSS (DENSIT,ID(2),VELV,VISCOS,LG(2),DELPL(2))
CALL QLOSS (TLE(2),LG(2),ID(2),MF(2),MFI,DELHL(2))

PLI(2) = PLE(2) + DELPL(2)
HLI(2) = HLE(2) + DELHL(2)
P = PLI(2)/14.696
CALL TFROMP (P,T)
KSH = 0
CALL KTHRMO (KSH,T,P,VF,VG,HF,HG,HFG,SF,SG,SFG)

IF (HLI(2) .GT. HG) THEN
   HH = HLI(2)
   CALL TFRMHG (HH,P,T,SG,VG,VF)
   TLI(2) = T
   SLI(2) = SG
   SVVLI(2) = VG
   XLI(2) = 1.0
ELSE
   XLI(2) = (HLI(2) - HF)/HFG
   TLI(2) = T
   SLI(2) = SF + SFG*XLI(2)
   SVVLI(2) =VF + XLI(2)*(VG - VF)
ENDIF
CFSLI(2) = MF(2)*SVVLI(2)

TLE(1) = TLI(2)
PLE(1) = PLI(2)
HLE(1) = HLI(2)
SLE(1) = SLI(2)
XLE(1) = XLI(2)
SVVLE(1) = SVVLI(2)
CFSLE(1) = MF(1)*SVVLE(1)

CALL SIZEPP (CFSLE(1),VELV,TLE(1),TMAT,FPL,PLE(1),LG(1),MF(1),
& WALL(1),WT(1),WTKINV(1),WTMFI(1),ID(1),MFI)

VISCOS = 1.98227D-2 + 1.36364D-5*TLE(1)
DENSIT = 1.0/SVVLE(1)
CALL HEADLOSS (DENSIT,ID(1),VELV,VISCOS,LG(1),DELPL(1))
CALL QLOSS (TLE(1),LG(1),ID(1),MF(1),MFI,DELHL(1))

PLI(1) = PLE(1) + DELPL(1)
HLI(1) = HLE(1) + DELHL(1)
P = PLI(1)/14.696
CALL TFROMP (P,T)
KSH = 0
CALL KTHRMO (KSH,T,P,VF,VG,HF,HG,HFG,SF,SG,SFG)

IF (HLI(1) .GT. HG) THEN
  HH = HLI(1)
  CALL TFRMHG (HH,P,T,SG,VG,VF)
  TLI(1) = T
  SLI(1) = SG
  SVVLI(1) = VG
  XLI(1) = 1.0
ELSE
  XLI(1) = (HLI(1) - HF)/HFG
  TLI(1) = T
  SLI(1) = SF + SFG*XLI(1)
  SVVLI(1) = VF + XLI(1)*(VG - VF)
ENDIF

CFSLI(1) = MF(1)*SVVLI(1)

TLI(3) = TLE(1)
PLI(3) = PLE(1)
HLI(3) = HLE(1)
SLI(3) = SLE(1)
XLI(3) = XLE(1)
SVVLI(3) = SVVLE(1)
CFSLI(3) = MF(3)*SVVLI(3)

CALL SIZEPP (CFSLI(3),VELM,TLI(3),TMAT,FPL,PLI(3),LG(3),MF(3),
& WALL(3),WT(3),WTKINV(3),WTMFI(3),ID(3),MFI)

VISCOS = 1.98227D-2 + 1.36364D-5*TLI(3)
DENSIT = 1.0/SVVLI(3)
CALL HEADLOSS (DENSIT,ID(3),VELM,VISCOS,LG(3),DELPL(3))
CALL QLOSS (TLI(3),LG(3),ID(3),MF(3),MFI,DELHL(3))

PLE(3) = PLI(3) - DELPL(3)
HLE(3) = HLI(3) - DELHL(3)
P = PLE(3)/14.696
CALL TFROMP (P,T)
KSH = 0

100
CALL KTHRMO (KSH,T,P,VF,VG,HF,HG,HFG,SF,SG,SFG)

IF (HLE(3) .GT. HG) THEN
  HH = HLE(3)
  CALL TFRMHG (HH,P,T,SG,VG,VF)
  TLE(3) = T
  SLE(3) = SG
  SVVLE(3) = VG
  XLE(3) = 1.0
ELSE
  XLE(3) = (HLE(3) - HF)/HFG
  TLE(3) = T
  SLE(3) = SF + SFG*XLE(3)
  SVVLE(3) = VF + XLE(3)*(VG - VF)
ENDIF

CFSLE(3) = MF(3)*SVVLE(3)
CFSLI(4) = MF(4)*SVVLI(4)

CALL SIZEPP (CFSLI(4),VELV,TLI(4),TMAT,FPL,PLI(4),LG(4),MF(4),
& WALL(4),WT(4),WTKINV(4),WTMFI(4),ID(4),MFI)

VISCOS = 1.98227D-2 + 1.36364D-5*TLI(4)
DENSIT = 1.0/SVVLI(4)
CALL HEADLOSS (DENSIT,ID(4),VELV,VISCOS,LMG(4),DELPL(4))
CALL QLOSS (TLI(4),LMG(4),ID(4),MF(4),MFI,DELHL(4))

PLE(4) = PLI(4) - DELPL(4)
HLE(4) = HLI(4) - DELHL(4)
P = PLE(4)/14.696
CALL TFROMP (P,T)
KSH = 0
CALL KTHRMO (KSH,T,P,VF,VG,HF,HG,HFG,SF,SG,SFG)

IF (HLE(4) .GT. HG) THEN
  HH = HLE(4)
  CALL TFRMHG (HH,P,T,SG,VG,VF)
  TLE(4) = T
  SLE(4) = SG
  SVVLE(4) = VG
  XLE(4) = 1.0
ELSE
  XLE(4) = (HLE(4) - HF)/HFG
  TLE(4) = T
  SLE(4) = SF + SFG*XLE(4)
  SVVLE(4) = VF + XLE(4)*(VG - VF)
ENDIF

CFSLE(4) = MF(4)*SVVLE(4)
CFSLI(5) = MF(5)*SVVLI(5)

CALL SIZEPP (CFSLI(5),VELM,TLI(5),TMAT,FPL,PLI(5),LG(5),MF(5),
& WALL(5),WT(5),WTKINV(5),WTMFI(5),ID(5),MFI)
VISCOS = 1.98227D-2 + 1.36364D-5*TLI(5)
DENSIT = 1.0/SVVLI(5)
CALL HEADLOSS (DENSIT,ID(5),VELM,VISCOS,LG(5),DELPL(5))
CALL QLOSS (TLI(5),LG(5),ID(5),MF(5),MFI,DELHL(5))

PLI(5) = PLE(5) + DELPL(5)
HLE(5) = HLI(5) - DELHL(5)
P = PLE(5)/14.696
CALL TFROMP (P,T)
KSH = 0
CALL KTHRMO (KSH,T,P,VF,VG,HF,HG,HFG,SF,SG,SFG)

IF (HLE(5) .GT. HG) THEN
HH = HLE(5)
CALL TFRMHG (HG,P,T,SG,VG,VF)
TLE(5) = T
SLE(5) = SG
SVVLE(5) = VG
XLE(5) = 1.0
ELSE
XLE(5) = (HLE(5) - HF)/HFG
TLE(5) = T
SLE(5) = SF + SFG*XLE(5)
SVVLE(5) = VF + XLE(5)*(VG - VF)
ENDIF
CFSLE(5) = MF(5)*SVVLE(5)

PLI(6) = PLE(4)
HLI(6) = (MF(4)*HLE(4) + MF(5)*HLE(5))/(MF(4) + MF(5))
P = PLI(6)/14.696
CALL TFROMP (P,T)
KSH = 0
CALL KTHRMO (KSH,T,P,VF,VG,HF,HG,HFG,SF,SG,SFG)

IF (HLI(6) .GT. HG) THEN
HH = HLI(6)
CALL TFRMHG (HH,P,T,SG,VG,VF)
TLI(6) = T
SLI(6) = SG
SVVLI(6) = VG
XLI(6) = 1.0
ELSE
XLI(6) = (HLI(6) - HF)/HFG
TLI(6) = T
SLI(6) = SF + SFG*XLI(6)
SVVLI(6) = VF + XLI(6)*(VG - VF)
ENDIF
CFSLI(6) = MF(6)*SVVLI(6)

CALL SIZEPP (CFSLI(6),VELV,TLI(6),TMAT,FPL,PLI(6),LG(6),MF(6), &
WALL(6),WT(6),WTKINV(6),WTMFI(6),ID(6),MFI)
VISCOS = 1.98227D-2 + 1.36364D-5*TLI(6)
DENSIT = 1.0/SVVLI(6)
CALL HEADLOSS (DENSIT,ID(6),VELV,VISCOS,LG(6),DELPL(6))
CALL QLOSS (TLI(6),LG(6),ID(6),MF(6),MFI,DELHL(6))

PLE(6) = PLI(6) - DELPL(6)
HLI(6) = HLI(6) - DELHL(6)
P = PLE(6)/14.696
CALL TFROMP (P,T)
KSH = 0
CALL KTHRMO (KSH,T,P,VF,VG,HF,HG,HFG,SG,SGF)

IF (HLE(6) .GT. HG) THEN
  HH = HLE(6)
  CALL TFRMHG (HH,P,T,SG,VG,VE)
  TLE(6) = T
  SLE(6) = SG
  SVVLE(6) = VG
  XLE(6) = 1.0
ELSE
  XLE(6) = (HLE(6) - HF)/HFG
  TLE(6) = T
  SLE(6) = SF + SFG*XLE(6)
  SVVLE(6) = VF + XLE(6)*(VG - VF)
ENDIF
CFSLE(6) = MF(6)*SVVLE(6)

PLI(7) = PLE(6) - DPTOTR
TLE(7) = TTRH
T = TLE(7)
P = PLE(7)/14.696
KSH = 1
CALL KTHRMO (KSH,T,P,VF,VG,HF,HG,HFG,SG,SGF)
HLE(7) = HG
SLE(7) = SG
XLE(7) = 1.0
SVVLE(7) = VG
CFSLE(7) = MF(7)*SVVLE(7)

CALL SIZEPP (CFSLE(7),VELV,TLE(7),TMAT,FPL,PLE(7),LG(7),MF(7),
&WALL(7),WT(7),WTKINV(7),WTMFI(7),ID(7),MFI)

VISCOS = 1.98227D-2 + 1.36364D-5*TLI(7)
DENSIT = 1.0/SVVLE(7)
CALL HEADLOSS (DENSIT,ID(7),VELV,VISCOS,LG(7),DELPL(7))
CALL QLOSS (TLI(7),LG(7),ID(7),MF(7),MFI,DELHL(7))

PLE(7) = PLI(7) - DELPL(7)
HLI(7) = HLE(7) + DELHL(7)
P = PLI(7)/14.696
CALL TFROMP (P,T)
KSH = 0
CALL KTHRMO (KSH,T,P,VF,VG,HF,HG,HFG,SG,SGF)
IF (HLI(7) .GT. HG) THEN
    HH = HLI(7)
    CALL TFRMHG (HH,P,T,SG,VG,VF)
    TLI(7) = T
    SLI(7) = SG
    SVVLI(7) = VG
    XLI(7) = 1.0
ELSE
    XLI(7) = (HLI(7) - HF)/HFG
    TLI(7) = T
    SLI(7) = SF + SFG*XLI(7)
    SVVLI(7) = VF + XLI(7)*(VG - VF)
ENDIF
CFSLI(7) = MF(7)*SVVLI(7)

TLI(8) = TT(NS)
PLI(8) = PP(NS)
HLI(8) = H(NS)
SLI(8) = S(NS)
XLI(8) = X(NS)
SVVLI(8) = SVV(NS)
CFSLI(8) = MF(8)*SVVLI(8)

CALL SIZEPP (CFSLI(8),VELV,TLI(8),TMAT,FPL,PLI(8),LG(8),MF(8),
               WALL(8),WT(8),WTKINV(8),WTMFI(8),ID(8),MFI)

VISCOS = 1.98227D-2 + 1.36364D-5*TLI(8)
DENSIT = 1.0/SVVLI(8)
CALL HEADLOSS (DENSIT,ID(8),VELV,VISCOS,LG(8),DELPL(8))
CALL QLOSS (TLI(8),LG(8),ID(8),MF(8),MFI,DELHL(8))

PLE(8) = PLI(8) - DELPL(8)
HLE(8) = HLI(8) - DELHL(8)
P = PLE(8)/14.696
CALL TFRMP (P,T)
KSH = 0
CALL KTHRMO (KSH,T,P,VG,HF,HG,HFG,SF,SG,SFG)

IF (HLE(8) .GT. HG) THEN
    HH = HLE(8)
    CALL TFRMHG (HH,P,T,SG,VG,VF)
    TLE(8) = T
    SEL(8) = SG
    SVVLE(8) = VG
    XLE(8) = 1.0
ELSE
    XLE(8) = (HLE(8) - HF)/HFG
    TLE(8) = T
    SEL(8) = SF + SFG*XLE(8)
    SVVLE(8) = VF + XLE(8)*(VG - VF)
ENDIF
CFSLE(8) = MF(8)*SVVLE(8)

PLI(9) = PLE(8) - DPCON
P = PLI(9)/14.696
CALL TFROMP (P,T)
KSH = 0
CALL KTHRMO (KSH,T,P,VF,VG,HF,HG,HFG,SG,SFG)
TLI(9) = T - SCON
T = TLI(9)
CALL KTHRML (T,P,VF,HF,SG)
HLI(9) = HF
SLI(9) = SF
XLI(9) = 0.0
SVVLI(9) = VF
CFSLI(9) = MF(9)*SVVLI(9)

CALL SIZEPP (CFSLI(9),VELL,TLI(9),TMAT,FPL,PLI(9),LG(9),MF(9),
& WALL(9),WT(9),WTINV(9),WTMFI(9),ID(9),MFI)

CALL KXPORT (TLI(9),VISCOS,KK,CP,RHOF)
DENSIT = RHOF
CALL HEADLOSS (DENSIT,ID(9),VELL,VISCOS,LG(9),DELPL(9))
CALL QLOSS (TLI(9),LG(9),ID(9),MF(9),MFI,DELHL(9))

PLE(9) = PLI(9) - DELPL(9)
HLE(9) = HLI(9) - DELHL(9)
HH = HLE(9)
P = PLE(9)/14.696
CALL TFRMHF(HH,T,P,VF,SV)
TLE(9) = T
SLE(9) = SF
XLE(9) = 0.0
SVVLE(9) = VF
CFSLE(9) = MF(9)*SVVLE(9)

PLI(10) = PLI(9) + DPRFD
WKRFMD = DPRFD*144.0*SVVLE(9)/778.0
HLI(10) = HLE(9) + WKRFMD/EFRFMD
HH = HLI(10)
P = PLI(10)/14.696
CALL TFRMHF (HH,T,P,VF,SV)
TLI(10) = T
SLE(10) = SF
XLE(10) = 0.0
SVVLI(10) = VF
CFSLI(10) = MF(10)*SVVLI(10)

CALL SIZEPP (CFSLI(10),VELL,TLI(10),TMAT,FPL,PLI(10),LG(10),
& MF(10),WALL(10),WT(10),WTINV(10),WTMFI(10),ID(10),MFI)

CALL KXPORT (TLI(10),VISCOS,KK,CP,RHOF)
DENSIT = RHOF
CALL HEADLOSS (DENSIT,ID(10),VELL,VISCOS,LG(10),DELPL(10))
CALL QLOSS (TLI(10),LG(10),ID(10),MF(10),MFI,DELHL(10))

PLE(10) = PLI(10) - DELPL(10)
HLE(10) = HLI(10) - DELHL(10)
HH = HLE(10)
P = PLE(10)/14.696
CALL TFRMHF(HH,T,P,VF,SF)
TLE(10) = T
SLE(10) = SF
XLE(10) = 0.0
SVVLE(10) = VF
CFSLE(10) = MF(10)*SVVLE(10)

TLI(11) = TPUMP
HLI(11) = HPUMP
SLI(11) = SFPUMP
XLI(11) = 0.0
SVVLI(11) = VFPUMP
CFSLI(11) = MF(11)*SVVLI(11)

CALL SIZEPP (CFSLI(11),VELL,TLI(11),TMAT,FPL,PLI(11),LG(11),
& MF(11),WALL(11),WT(11),WTINV(11),WTMFI(11),ID(11),MFI)

CALL KXPORT (TLI(11),VISCOS,KK,CP,RHOFL)
DENSIT = RHOFL
CALL HEADLOSS (DENSIT,ID(11),VELL,VISCOS,LG(11),DELPL(11))
CALL QLOSS (TLI(11),LG(11),ID(11),MF(11),MFI,DELHL(11))

PLE(11) = PLI(1) + DPTOTB
PLI(11) = PLE(11) + DELPL(11)
HLE(11) = HLI(11) - DELHL(11)
HH = HLE(11)
P = PLE(11)/14.696
CALL TFRMHF(HH,T,P,VF,SF)
TLE(11) = T
SLE(11) = SF
XLE(11) = 0.0
SVVLE(11) = VF
CFSLE(11) = MF(11)*SVVLE(11)

TOTWT = 0.DO
WTKTOT = 0.DO
MFITOT = 0.DO

DO 1705 I = 1,11
WTKTOT = WTKTOT + WTKINV(I)
TOTWT = TOTWT + WT(I)
MFITOT = MFITOT + WTMFI(I)
1705 CONTINUE

RETURN
END
SUBROUTINE SIZEPP (CFS, VEL0, TR, TMAT, FPL, PL, LG, MF, & WALL, WT, WTKINV, WTMFI, ID, MFI)

IMPLICIT DOUBLE PRECISION (A-H,O-Z)
DOUBLE PRECISION ID, LG, MF

DATA PI /3.141592654/
DATA SEP, THK, RHOMFI /5.D-3, 3.D-4, 0.1626D0/

ID = 12.0*DSQRT(4.0*CFS/(PI*VELO))
CALL STRNTH (TR, TMAT, MATH, MATC, FPL, SIGPV, RHO)
SIGMAL = SIGPV
IF (SIGMAL .EQ. 0) GO TO 10
WALL = PL*ID/(2.0*SIGMAL)
IF (WALL .LT. 0.02) WALL = 0.02
WT = 37.7*LG*RHO*WALL*(ID + WALL)
WTKINV = MF*LG/VELO
WTMFI = PI*LG*((ID + 2.DO*MFI*(SEP + THK))**2.DO - ID**2.DO)/4.DO
WTMFI = WTMFI*RHOMFI/(SEP/THK + 1.DO)
IF (ID .EQ. 0.0) THEN
WT = 0.DO
WTKINV = 0.DO
WTMFI = 0.DO
ENDIF

10 RETURN

END
SUBROUTINE HEADLOSS (DENSIT, ID, VEL0, VISCOS, LG, DELP)
IMPLICIT DOUBLE PRECISION (A-H, O-Z)
DOUBLE PRECISION ID, LG

REYNLD = 3.D2*ID*VEL0*DENSIT/VISCOS

IF (REYNLD.EQ.0.DO) THEN
FRIC = 0.DO
ELSE
FRIC = (1.82*DLOG10(REYNLD) - 1.64)**(-2.0)
ENDIF

IF (FRIC.EQ.0.DO) THEN
DELP = 0.DO
ELSE
DELP = FRIC*(LG*(12.0/ID))*(VEL0**2.0/64.348)*
&DENSIT/1.44D2)
ENDIF

RETURN
END
SUBROUTINE QLOSS (TR, LG, ID, MF, MFI, QLOST)

IMPLICIT DOUBLE PRECISION (A-H,O-Z)
DOUBLE PRECISION ID, LG, MF

DATA SIGMA, EPS, PI /4.7547D-13, 0.2, 3.141592654/

XMFI = DFLOAT(MFI)
IF (MFI .EQ. 0.0) XMFI = 1.0
AREA = PI*ID*LG/12
QLOST = AREA*EPS*S<IGMA*TR**4.0/MF
QLOST = QLOST/XMFI

RETURN
END
C REM SUBROUTINE RETURNS THERMODYNAMIC PROPERTIES OF POTASSIUM FROM T

SUBROUTINE KTHRMO (KSH,T,P,VF,VG,HF,HFG,SF,SG,SFG)
IMPLICIT DOUBLE PRECISION (A-H,O-Z)

IF (KSH.EQ.0) THEN
  P = 10.0**((6.12758 - 8128.77/T - 0.53299*DLOG10(T))
ENDIF

RHOFL = 52.768 - 7.4975D-3*(T-459.67) - 0.5255D-6*(T-459.67)**2.0
& + 0.0498D-9*(T-459.67)**3.0
VF = 1.0/RHOFL
B = -T*10.0**(-3.8787 + 4890.7/T)
DBDT = B/T*(1.0 - 4890.7*DLOG(1.0)/T)
C = 10.0**((0.5873 + 6385.7/T)
DCDT = -6385.7*DLOG(1.0)/T**2.0
D = -1.0*10**((1.4595 + 7863.8/T)
DDDT = -7863.8*DLOG(1.0)/T**2.0
V1 = 0.7302*T/P
DO 10 I=1,100
  FUNC = P*V1/(0.7302*T) - (1.0 + B/V1 + C/V1**2 + D/V1**3)
  SLOPE = P/(0.7302*T) + (B/V1**2 + 2.0*C/V1**3 + 3.0*D/V1**4)
  V2 = V1 - FUNC/SLOPE
  IF (DABS(FUNC) .LT. 1.D-6) GO TO 20
  V1 = V2
10 CONTINUE
20 VG = V2

HFG = (1.987/0.7302)*P*(8128.77*DLOG(1.0)/T - 0.53299)*
& (VG/39.0983 - VF)
HGO = 998.95 + 0.127*T + 24836.0*DEXP(-39375.0/T)
DELHRT = T/VG*((DBDT - B/T) + 1.0/VG*(DCDT/2.0 - C/T) +
& 1.0/VG**2.0*(DDDT/3.0 - D/T))
HG = HGO - (1.9872*T/39.0983)*DELHRT
HF = HG - HFG
SFG = HFG/T
SG0 = 0.18075 + 0.127*DLOG(T) + 0.7617*DEXP(-31126.0/T)
DELSR = T/VG*((DBDT + B/T) + 1.0/(2.0*VG)*(DCDT + C/T) +
& 1.0/(3.0*VG**2.0)*(DDDT + D/T) - DLOG(P*VG/(0.7302*T))
SG = SG0 - (1.987/39.0983)*(DLOG(P) + DELSR)
SF = SG - SFG
VG = VG/39.0983

RETURN
END
SUBROUTINE KTHRML (T,P2,VF,HF, SF)

IMPLICIT DOUBLE PRECISION (A-H, O-Z)

KSH = 0
CALL KTHRM0 (KSH, T, P1, VF, VG, HF1, HG, HFG, SF1, SG, SFG)
RHOFL = 1.0/VF
DRHODT = -7.4975D-3 - 2.0*0.5255D-6*(T-459.67) 
& + 3.0*0.0498D-9*(T-459.67)**2.0
HF = HF1 + (1.0 + T*DRHODT/RHOFL)*(P2 - P1)/RHOFL*(1.9872/0.7302)
SF = SF1 + DRHODT*(P2 - P1)/RHOFL**2.0*(1.9872/0.7302)

RETURN
END
SUBROUTINE VFROMT(T,VF)

IMPLICIT DOUBLE PRECISION (A-H,O-Z)

RHOFL = 52.768 - 7.4975D-3*(T-459.67) - 0.5255D-6*(T-459.67)**2.0
& + 0.0498D-9*(T-459.67)**3.0
VF = 1.0/RHOFL

RETURN
END
SUBROUTINE TFROMP(P,TEMP)

IMPLICIT DOUBLE PRECISION (A-H,O-Z)

C CALCULATES SATURATION TEMPERATURE (R) FROM GIVEN PRESSURE (ATM)

TI = 1000.
DO 6315 I = 1,100
FUNC = DLOG10(P) - 6.12758 + 8128.77/TI + 0.53299*DLOG10(TI)
SLOPE = -8128.77/TI**2.0 + 0.53299*DLOG10(DEXP(1.D0))/TI
T2 = TI - FUNC/SLOPE
IF (DABS(FUNC) .LT. 1.D-6) GO TO 6345
TI = T2
6315 CONTINUE
6345 TEMP = T2
RETURN
END
SUBROUTINE TFRMHG (HG,P,T,SG,VG,VF)
C Calculates superheated vapor temperature from enthalpy and temperature

IMPLICIT DOUBLE PRECISION (A-H,O-Z)

C Get initial temperature guess

CALL TFROMP(P,T1)
KSH = 1
T2 = 1.05*T1
CALL KTHRMO (KSH,T1,P,VF,VG,HF,HG1,HFG,SG,SFG)
FUNCTION1 = HG - HG1

DO 10 J = 1,100
CALL KTHRMO (KSH,T2,P,VF,VG,HF,HG2,HFG,SG,SFG)
FUNCTION2 = HG - HG2
DELTA = (T2 - T1)*FUNCTION2/(FUNCTION2 - FUNCTION1)
T1 = T2
T2 = T2 - DELTA
FUNCTION1 = FUNCTION2
IF (DABS(FUNCTION2) .LT. 1.D-6) GOTO 20
10 CONTINUE
20 T = T2
RETURN
END
SUBROUTINE TFRMSG (SG,P,T,HG,VG,VF)
IMPLICIT DOUBLE PRECISION (A-H,O-Z)

CALL TFROMP(P,T1)
KSH = 1
T2 = 1.05*T1
CALL KTHRMO (KSH,T1,P,VF,VG,HF,HG,HFG,SF,SG1,SFG)
FUNC1 = SG - SG1

DO 10 J = 1,100
CALL KTHRMO (KSH,T2,P,VF,VG,HF,HG,HFG,SF,SG2,SFG)
FUNC2 = SG - SG2
DELTA = (T2 - T1)*FUNC2/(FUNC2 - FUNC1)
T1 = T2
T2 = T2 - DELTA
FUNC1 = FUNC2
IF (DABS(FUNC2) .LT. 1.D-6) GOTO 20
10 CONTINUE
20 T = T2
RETURN
END
SUBROUTINE TFRMHF(H,T,P,VF,SF)

IMPLICIT DOUBLE PRECISION (A-H,O-Z)

C CALCULATES TEMP (R) FROM HF & P

CALL TFROMP(P,T)
T1 = T
T2 = 1.05*T
CALL KTHRML (T1,P,VF,HF,SF)
FUNC1 = H - HF
DO 10 J = 1,100
CALL KTHRML (T2,P,VF,HF,SF)
FUNC2 = H - HF
DELTA = (T2 - T1)*FUNC2/(FUNC2 - FUNC1)
T1 = T2
T2 = T2 - DELTA
FUNC1 = FUNC2
IF (DABS(FUNC2) .LT. 1.D-6) GOTO 20
10 CONTINUE
20 CONTINUE
T = T2

RETURN
END
SUBROUTINE KXPORT(TR,MU,K,CP,RHOFL)
IMPLICIT DOUBLE PRECISION (A-H,O-Z)
DOUBLE PRECISION MU,K

***** LIQUID POTASSIUM TRANSPORT PROPERTIES SUBROUTINE *****

TF = TR - 459.67
TC = TR/1.8 - 273.15
MU = DEXP(1353.9D0/TR - 1.9206D0)
K = 32.2036D0 - 7.6789D-3*TR
CP = 0.22713 - 64.848D-6*TR + 23.178D-9*TR**2.0
RHOFL = 52.768 - 7.4975D-3*TF - 5.255D-7*TF**2.0 + 4.98E-11*TF**3.0

RETURN
END
SUBROUTINE KVPORT(KSH, TR, P, MU, K, CP, RHOFL)
IMPLICIT DOUBLE PRECISION (A-H, O-Z)
DOUBLE PRECISION MU, K

***** POTASSIUM VAPOR TRANSPORT PROPERTIES SUBROUTINE *****

MU = 1.0282D-2 + 2.5649D-5*TR - 3.125D-9*TR**2.DO
K  = 1.8786D-3 + 4.3527D-6*TR - 5.2198D-10*TR**2.DO
CP = 0.22713 - 64.848D-6*TR + 23.178D-9*TR**2.0
CALL KTHRMO (KSH, TR, P, VF, VG, HF, HG, HFG, SF, SG, SFG)
RHOFL = 1.DO/VG
KSH1 = KSH
KSH = 1
TR2 = TR + 1.D-2
CALL KTHRMO (KSH, TR2, P, VF, VG, HF, HG2, HFG, SF, SG, SFG)
TR1 = TR - 1.D-2
CALL KTHRMO (KSH, TR1, P, VF, VG, HF, HG1, HFG, SF, SG, SFG)
CP = (HG2 - HG1)/2.D-2
KSH = KSH1

RETURN
END
SUBROUTINE LIPORT(TR,MU,K,CP,RHOFL,PSAT)
IMPLICIT DOUBLE PRECISION (A-H,O-Z)
DOUBLE PRECISION MU,K

C '***** LIQUID LITHIUM TRANSPORT PROPERTIES SUBROUTINE *****

MU = DEXP(1183.0D/0/TR - 1.05415)
K = 30.319D0 - 4.2284D-3*TR
IF (TR .LE. 1500.D0) THEN
   CP = 1.2024D0 - 2.5008D-4*TR + 7.4405D-8*TR**2.D0
ELSE
   CP = 1.0058D0 - 7.0749D-6*TR - 2.9533D-10*TR**2.D0
ENDIF
RHOFL = 34.388D0 - 3.4473D-3*TR + 2.0664D-7*TR**2.D0
PSAT = DEXP(11.095D0 - 31976.D0/TR)

RETURN
END
SUBROUTINE STRNTH (TT, TMAT, MATH, MATC, FPL, SIGPV, RHO)

IMPLICIT DOUBLE PRECISION (A-H, O-Z)

C ***** DESIGN STRENGTH SUBROUTINE *****

TT = TT / 1.8D0
TMAT = TMAT / 1.8D0
IF (TT .EQ. 0.0D0) RETURN
IF (TT .GT. TMAT) THEN
  IF (MATH .EQ. 1) GOTO 10
  IF (MATH .EQ. 2) GOTO 20
  IF (MATH .EQ. 3) GOTO 30
  IF (MATH .EQ. 4) GOTO 100
ELSE
  IF (MATC .EQ. 1) GOTO 10
  IF (MATC .EQ. 2) GOTO 20
  IF (MATC .EQ. 3) GOTO 30
  IF (MATC .EQ. 4) GOTO 100
ENDIF

C ASTAR 811C

10 RHO = 0.604D0
   CH = -13.834D0
   A = -3.112D4
   B = 1.918D4
   C = -4.498D3
   D = 4.776D4
   GOTO 40

C Nb-1%Zr

20 RHO = 0.31D0
   CH = -7.392D0
   A = -2.879D0 * TT
   B = 0.0D0
   C = 0.0D0
   D = 1.8276D4
   GOTO 40

C TZM

30 RHO = 0.37D0
   CH = -22.0356D0
   A = -77.43D0
   B = -2530.33D0
   D = 39963.9D0
   GOTO 70

40 THET = DLOG10(FPL*8.76D3)
   SIGMA = 4.0D0
   DO 50 I = 1, 100

120
\[ \theta = \phi + (a \cdot \sigma + b \cdot \sigma^2 + c \cdot \sigma^3 + d)/T \]
\[ \text{func} = \theta - \theta \]
\[ \text{fprime} = -(a + 2 \cdot b \cdot \sigma + 3 \cdot c \cdot \sigma^2)/T \]
\[ \delta = \text{func}/\text{fprime} \]
\[ \sigma = \sigma - \delta \]

If \( |\text{dabs(func)}| < 1 \cdot 10^{-6} \)

Goto 60

50 CONTINUE

60 SIGPV = (1 \cdot \sigma_{i}^{2} \cdot \sigma) \cdot 14.696 \cdot 101325 DO 130

70 \theta = \log{(f \cdot 8.76D3)}
\[ \sigma = 4 \cdot \text{DO} \]
DO 80 I = 1, 100
\[ \theta = \phi + (a \cdot \sigma + b \cdot \log(\sigma_{i}) + d)/T \]
\[ \text{func} = \theta - \theta \]
\[ \text{fprime} = -(a + b/(\sigma_{i} \cdot \log(\sigma_{i})))\cdot T \]
\[ \delta = \text{func}/\text{fprime} \]
\[ \sigma_{i} = \sigma_{i} - \delta \]

If \( |\text{dabs(func)}| < 1 \cdot 10^{-6} \)

Goto 90

80 CONTINUE

90 SIGPV = 1 \cdot \sigma_{i} \cdot \text{SIGMA}
Goto 130

C 316 Stainless Steel

100 \rho = 0.285 \text{DO}
\[ \text{TIME} = f \cdot 8.76D3 \]
DO 110 I = 1, 100
IF (I = 1)
\[ \text{TIME}_{i} = 63.502D0 - 18.889D0 \cdot \log(\sigma_{i}) - 0.06812D0 \cdot T + \]
\[ & 0.01963D0 \cdot T \cdot \log(\sigma_{i}) \]

C Solve for type I creep

\[ \text{emidot} = -44.39D0 + 7.867 \cdot \log(\sigma_{i}) + 0.0312D0 \cdot T - \]
\[ & 8.887D-7 \cdot T \cdot \sigma_{i} \]
\[ \text{emidot} = 1 \cdot \sigma_{i}^{2} \cdot \text{emidot} \]
\[ p_{1} = 1 \cdot \sigma_{i}^{2} \cdot \text{emidot}^{0.87D0} \]
\[ c_{1} = 0.76D0 \cdot \text{emidot}^{0.03D0} \]
\[ \text{el} = c_{1} \cdot p_{1} \cdot \text{TIME}_{i} / (1 \cdot \sigma_{i} + p_{1} \cdot \text{TIME}_{i}) + \text{emidot} \cdot \text{TIME}_{i} \]

C Solve for type II creep

\[ \text{emidot} = -5.164D0 - 9.13D0 \cdot \log(\sigma_{i}) - 0.01551D0 \cdot T + \]
\[ & 0.02052D0 \cdot T \cdot \log(\sigma_{i}) \]
\[ \text{emidot} = 1 \cdot \sigma_{i}^{2} \cdot \text{emidot} \]
\[ p_{2} = 3.45D0 \cdot \text{emidot}^{0.87D0} \]
\[ c_{2} = 0.64D0 \cdot \text{emidot}^{0.03D0} \]
\[ BC = EI \cdot P^2 - C^2 \cdot P^2 - EM2DOT \]
\[ TIMEC = (BC + DSQRT(BC^**2 \cdot DO + 4 \cdot DO \cdot EI \cdot P^2 \cdot EM2DOT))/ (2 \cdot DO \cdot P^2 \cdot EM2DOT) \]
\[ TIME2 = TIME - TIMEI + TIMEC \]
\[ IF (TIME2 .LT. TIME) TIME2 = TIME \]
\[ EC = C^2 \cdot P^2 \cdot TIME2/(I \cdot DO + P^2 \cdot TIME2) + EM2DOT \cdot TIME2 \]
\[ FUNC = EC - 1 \cdot DO \]
\[ IF (I .EQ. 1) THEN \]
\[ SIGMA1 = SIGMA \]
\[ SIGMA = 2 \cdot D1 \]
\[ FUNC1 = FUNC \]
\[ GOTO 110 \]
\[ ENDIF \]
\[ DELTA = (SIGMA - SIGMA1) \cdot FUNC/(FUNC - FUNC1) \]
\[ SIGMA1 = SIGMA \]
\[ SIGMA = SIGMA - DELTA \]
\[ FUNC1 = FUNC \]
\[ IF (DABS(FUNC) .LT. 1 \cdot D - 6) GOTO 120 \]
\[ 110 CONTINUE \]
\[ 120 SIGPV = SIGMA \cdot 14.696D0/0.101325D0 \]
\[ 130 TT = TT \cdot 1.8D0 \]
\[ TMAT = TMAT \cdot 1.8D0 \]
\[ RETURN \]
\[ END \]
A potassium-Rankine power conversion system model was developed under Contract No. NAS3-25808 for the NASA-LeRC. This model predicts potassium-Rankine performance for turbine inlet temperatures (TIT) from 1200 - 1600 K, TIT to condenser temperature ratios from 1.25-1.6, power levels from 100 to 10,000 kWe, and lifetimes from 2-10 years. The model is for a Rankine cycle with reheat for turbine stage moisture control. The model assumes heat is supplied from a lithium heat transport loop. The model does not include a heat source or a condenser/heat rejection system model. These must be supplied by the user.