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SKYLAB PROGRAM
CSM VERIFICATION ANALYSIS REPORT

Part Name: EPS Radiator
Part Number: V37-458010 & V37-310010
Date: September 1970

Prepared by:
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Space Division
North American Rockwell

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<td>SCHAFFER, J.L.*VANDERPOL, G.A.</td>
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**ABSTRACT**

This document describes the application of the SINDA computer program for the transient thermodynamic simulation of the Apollo fuel cell/radiator system for the limit condition of the proposed Skylab mission. Results are included for the thermal constraints imposed upon the Pratt and Whitney fuel cell power capability by the Block II EPS radiator system operating under the Skylab fixed attitude orbits.
FOREWORD

The thermal analysis of Skylab fuel cell and radiator system capability, in support of Contract SA500, NAS9-150, was conducted between October 1969 and June 1970. Results of this work are contained in this report, which was prepared by J. L. Schaefer and G. A. Vanderpol of CSM Operations Analysis, Mission Requirements and Evaluation group. The original models of the electrical power system (EPS) radiator and Block I fuel cell, and the CINDA computer program were furnished by H. Cazemier and W. Simon of NASA-MSC. Early checkout runs were limited to leased Univac 1108 service and IBM 7094 emulation, which were slow and expensive. With the assistance of P. Jepsen of Aero and Thermal Projects, Scientific Programming, the IBM 360/SINDA program was obtained and converted to Space Division's IBM 360 formats. E. R. Arnold provided considerable assistance in developing the Block II fuel cell model for the SINDA program.
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1. INTRODUCTION

1.1 PURPOSE OF ANALYSIS

The range of output power capability for the Apollo fuel cell system is established by the requirement to operate within the command module (CM) bus voltage range of 26.5 to 31 volts and by the thermal constraints imposed by the fuel cell stack, condenser, and radiator temperature limits. This report considers only the thermal constraints in establishing the fuel cell power capability for Skylab missions. Under high transient-power levels, CM voltage requirements may be more limiting.

Early in 1969, NASA-MSC personnel furnished for the Skylab study the computer program, the Chrysler Improved Numerical Differencing Analyzer for Third Generation computers (CINDA-3G) (Reference 1), and heat transfer models of the Block II electrical power system (EPS) and the Allis-Chalmers fuel cell system. Subsequently at NR several major changes were made to these models and the CINDA program. The preliminary Allis-Chalmers model became obsolete after the decision was made to use the Pratt and Whitney (PW) Block II fuel cell for the Skylab mission. Therefore, a completely new PW fuel cell model had to be developed for CINDA. Several modifications were made to the EPS radiator model to provide closer correlation with qualification test data (Reference 2) and to include heat transfer between the radiator panels and the service module (SM) structure. Finally, the original CINDA-3G program, which was developed for use on the Univac 1108, was replaced with an advanced program version, Systems Improved Numerical Differencing Analyzer for Third Generation Computers (SINDA-3G), which had been converted (Reference 3) for operation on the IBM 360/75 computer.

1.2 VERIFICATION ANALYSIS REQUIREMENTS

Verification analysis requirements consist of a computer simulation. The simulation determines the effect of the thermal constraints on power capability with one fuel cell and with two fuel cells and with full and five-eighths EPS radiator area operation under the two extremes for Skylab fixed orbit environmental conditions. The SINDA-3G computer program is required for the eight cases of computer simulation. Results for each of the eight cases must be within the acceptable fuel cell temperature limits stated for the flight measurements.
2. CONCLUSIONS

Analysis results indicate the EPS radiator subsystem has sufficient capability to reject the waste heat associated with the fuel cell power levels required for Skylab missions while maintaining the fuel cells within nominal temperature levels. The computer simulation considered sun-vector orbit plane angles (β) of 0.0 and 73.5 degrees for one and two fuel cells operating with full and five-eighths radiator areas. The maximum and minimum power levels evaluated in this study are listed in Table 1. Results are discussed in Section 4.4 of this report.

Table 1. Summary of Results for Fuel Cell/Radiator Power Capability for an Earth Orbit of 235 Nautical Miles

<table>
<thead>
<tr>
<th>Fuel Cells (number operating)</th>
<th>Radiator Area (operating panels)</th>
<th>Minimum Total Current (amperes)</th>
<th>Maximum Total Current (amperes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>8</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>40</td>
<td>90</td>
</tr>
<tr>
<td>1</td>
<td>8</td>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>25</td>
<td>50</td>
</tr>
</tbody>
</table>
3. RECOMMENDATIONS

Based upon results of this analysis, qualification and development test results, and Block II flight data, Block II fuel cell and EPS radiator subsystem capabilities are sufficient to meet Skylab mission requirements. No further testing or analysis is recommended.
4. ANALYSIS

4.1 ANALYTICAL MODELS

General Fuel Cell Model Considerations

The Pratt and Whitney fuel cell combines oxygen and hydrogen to produce electricity, heat, and water. The overall chemical reaction can be written as

\[ \text{H}_2 + \frac{1}{2} \text{O}_2 \rightarrow \text{H}_2\text{O} + \text{Energy} \]

The quantity of reactants required to produce a given amount of energy can be determined from Faraday's Laws of Electrolysis. As stated in Reference 4, these are:

1. The mass of a substance liberated in an electrolysis cell is proportional to the quantity of electricity passing through the cell.

2. When the same quantity of electricity is passed through different cells, the masses of the substances liberated are proportional to their electrochemical equivalents.

The combined laws can be used to express the amount of water produced per unit time in terms of current flow:

\[ \dot{W}_{\text{H}_2\text{O}} = \frac{I \times M}{F \times n} \]  \hspace{1cm} (1)

where:

- \( I \) = current (amperes)
- \( M \) = molecular weight
- \( F \) = Faraday's constant—96500 amp-sec/gm equivalent
- \( n \) = gm equivalent/gm mole
- \( \dot{W} \) = weight flow per unit of time
The following values of specific fuel consumption have been determined from the above equation:

\[ 0.0230 \text{ lb H}_2\text{O per amp-hr} \]
\[ 0.0204 \text{ lb O}_2\text{ per amp-hr} \]
\[ 0.00257 \text{ lb H}_2\text{ per amp-hr} \]

Figure 1 depicts the basic schematic of the fuel cell thermodynamic components. Two coolant loops are used to remove the excess heat and water. The stack contains the 31 individual fuel cell elements, each of which consists of two electrodes and the KOH electrolyte, where the chemical reaction of hydrogen and oxygen occurs. Electrically the cells are connected in series. Each is capable of approximately 1 volt, depending on electrolyte condition and load. The temperature of the stack is maintained in the range of 390 to 460 °F by means of the primary regenerator and bypass valve. The condenser and water separator are responsible for the water removal and the resulting water concentration in the electrolyte. The temperature range at which water is nominally condensed is 155 to 165 °F.

This temperature range is controlled by the secondary regenerator bypass valve and the secondary regenerator. After some of the waste heat is used to heat the incoming reactants in the oxygen and hydrogen preheaters, the EPS radiators reject the excess heat to space. The analytical modeling for each major component is discussed in more detail in the next sections.

**Voltage Output**

The fuel cell terminal voltage is a function of load current, stack temperature, and electrolyte (KOH) water concentration. Reference 5 provides nominal fuel cell performance curves that depict voltage as a function of current and parametric values of stack (surface) temperature. These curves were expressed in the general polynomial form

\[ V_t = A_1 + A_2 I + A_3 I^2 + A_4 I^3 + A_5 TS + A_6 (TS) (I) \]
\[ + A_7 (TS)(I^2) + A_8 TS^2 + A_9(I)(TS^2) + A_{10} TS^3 \]  \hspace{1cm} (2)

where

\[ V_t \] is voltage based on current and stack temperature (volts)

\[ A_1 \ldots A_{10} \] are coefficients

\[ I = \text{load current (amperes)} \]

\[ TS = \text{stack temperature (°F)} \]
TEMPERATURE CONTROL OF BYPASS VALVE ECS INTERFACE RADIATOR INTERFACE WATER SEPARATOR Z=Z=3 PRIMARY REGENERATOR fc£=E3i

Figure 1. Fuel Cell Fluid and Component Schematic
A standard least squares surface fit bivariate polynomial routine was used in calculating the coefficients of this equation. The input data for the bivariate routine, as shown in Table 2, are the Reference 5 data corrected to a common KOH-water concentration of 0.75. The coefficients established from these data are given in Table 3. The resulting value, $V_t$, is corrected for the KOH-water concentration effect in the SINDA program by the following equation:

$$V = V_t - 0.241 (0.75 - PCKOH)$$  \hspace{1cm} (3)

where

$V = \text{fuel cell voltage based on current, stack temperature, and KOH-water concentration (volts)}$

$V_t = \text{voltage based on current and stack temperature (volts)}$

$PCKOH = \text{the weight ratio of KOH to KOH + water}$

The value of $V$ is used in the program as the fuel cell terminal voltage.

Table 2. Input Data for Bivariate Routine

<table>
<thead>
<tr>
<th>Current (amperes)</th>
<th>Stack Temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>380</td>
</tr>
<tr>
<td>15.0</td>
<td>30.0</td>
</tr>
<tr>
<td>20.0</td>
<td>29.1</td>
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<tr>
<td>25.0</td>
<td>28.3</td>
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<td>30.0</td>
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<td>35.0</td>
<td>26.7</td>
</tr>
<tr>
<td>40.0</td>
<td>26.0</td>
</tr>
<tr>
<td>45.0</td>
<td>25.3</td>
</tr>
<tr>
<td>50.0</td>
<td>24.6</td>
</tr>
</tbody>
</table>
Table 3. Output Coefficients From Bivariate Routine

<table>
<thead>
<tr>
<th>A1</th>
<th>5.583364</th>
<th>A6</th>
<th>4.686233 x 10^{-3}</th>
</tr>
</thead>
<tbody>
<tr>
<td>A2</td>
<td>-1.308438</td>
<td>A7</td>
<td>-3.573639 x 10^{-7}</td>
</tr>
<tr>
<td>A3</td>
<td>2.054927 x 10^{-3}</td>
<td>A8</td>
<td>-1.525995 x 10^{-5}</td>
</tr>
<tr>
<td>A4</td>
<td>-1.333418 x 10^{-5}</td>
<td>A9</td>
<td>-4.889387 x 10^{-6}</td>
</tr>
<tr>
<td>A5</td>
<td>9.694690 x 10^{-2}</td>
<td>A10</td>
<td>-1.292755 x 10^{-7}</td>
</tr>
</tbody>
</table>

Primary Loop Thermodynamics

Excess heat and steam produced in the chemical reaction in the stack are removed by the recirculating stream of hydrogen and water. The energy balance computation for the stack is based upon the total energy of reaction as input to the stack and the electrical power, stack temperature change, recirculating fluid temperature change, and fuel cell heat loss as output energy. The reaction energy is determined by

\[ Q_{GENAT} = 51600 \times SFCH2 \]  

(4)

where

\[ Q_{GENAT} = \text{reaction energy (Btu/hr)} \]
\[ SFCH2 = \text{hydrogen consumption rate (lb/hr)} \]
\[ 51600 \text{ Btu/lb is the lower heating value of hydrogen} \]

The heat balance on the stack is given by

\[ Q_{STORD} = Q_{GENAT} - QH2 - QO2 - QELECT - QRS - QSM \]  

(5)

where

\[ Q_{STORD} = \text{heat gained in the stack (Btu/hr)} \]
\[ Q_{GENAT} = \text{reaction energy (Btu/hr)} \]
\[ QH2 = \text{heat gained by the consumed hydrogen (Btu/hr)} \]
\[ QO2 = \text{heat gained by the consumed oxygen (Btu/hr)} \]
\[ QELECT = \text{electrical energy output (Btu/hr)} \]

\[ QRS = \text{heat gained by the recirculating hydrogen-water stream (Btu/hr)} \]

\[ QSM = \text{heat lost by the stack to the SM structure (Btu/hr)} \]

A similar equation can be expressed for the primary loop heat balance:

\[ QCOND = QGENAT - QELECT - QSM - QH2O \] (6)

where

\[ QCOND = \text{heat transferred across the condenser (Btu/hr)} \]

\[ QH2O = \text{energy in the condensed water above the 70 F datum (Btu/hr)} \]

\[ QGENAT, QELECT, \text{ and } QSM \text{ are as previously defined.} \]

After the two equations are balanced, the temperature can be determined in the primary loop by the following three equations:

\[ TSE = TSTACK + (QSTORD \times DTIMEU/30.) \] (7)

where

\[ TSE = \text{the new stack temperature (°F)} \]

\[ TSTACK = \text{the previous stack temperature (°F)} \]

\[ QSTORD = \text{the stack heat gain (Btu/hr)} \]

\[ DTIMEU = \text{the time step (hr)} \]

\[ 30. = \text{the stack mass-specific heat product (Btu/?F)} \]

\[ TSI = TSE - QSR/(WDTCPI + WDTCP2) \] (8)

where

\[ TSI = \text{recirculating stream temperature at stack inlet (°F)} \]

\[ TSE = \text{recirculating stream temperature at stack outlet (°F)} \]

(as well as the stack temperature)
QSR = heat gained by the recirculating hydrogen-water stream (Btu/hr)

WDTCP1 = the mass-specific heat product of the water in the recirculating stream

WDTCP2 = the mass-specific heat product of the hydrogen in the recirculating stream

TCIP = TCEP - (QCOND - CONST2)/(WDTCP1 + WDTCP2) (9)

where

TCIP = recirculating stream temperature at condenser primary inlet (°F)

TCEP = recirculating stream temperature at condenser primary outlet (°F)

CONST2 = heat of vaporization of the condensed water

QCOND, WDTCP1, WDTCP2 are as previously defined.

The TCEP is determined in the condenser subroutine, which is described in the next section.

The mass balance in the primary loop is determined by assuming a constant volume delivery of 3 cfm at 60 psia for the primary pump for calculating the specific volume of the hydrogen and water at the stack inlet and outlet and at the condenser inlet and outlet. The partial pressure of water is first determined at the condenser exit, based upon the condenser exit temperature and a saturated steam condition. At the stack, the recirculating steam enters at this same condition and leaves at the temperature and the partial pressure of water in the electrolyte. Figure 2 illustrates the relationship of the electrolyte temperature, partial pressure of water, and KOH concentration. The program computes the equilibrium water pressure at the condition of electrolyte temperature and concentration at the beginning of the time step. This pressure is assumed to equal the partial pressure of water in the hydrogen-water stream at the stack exit at the end of the time step. Thus, the water balance is determined from the following equations:

\[ WH202P = 190.0230 \times DTIMEEU \] (10)
Figure 2. Water Pressure of KOH Electrolyte

CONCENTRATION = \frac{\text{LB KOH}}{\text{LB KOH} + \text{LB H}_2\text{O}}
where

\[ WH202P = \text{weight of water produced within the time step (lb)} \]

\[ I = \text{current (amps)} \]

\[ DTIMEU = \text{time step (hours)} \]

0.0230 is the conversion factor for pounds of water produced per ampere-hour

\[ WH2025 = WH2026 + WH202P \times RATE \]  \hspace{1cm} (11)

where

\[ WH2025 = \text{weight of water in the electrolyte at the end of the time step (lb)} \]

\[ WH2026 = \text{weight of water in the electrolyte at the start of the time step (lb)} \]

\[ RATE = \text{the percent of water produced during the time step that remains in the stack. RATE is calculated by an iterative balance between the water specific volume at the stack inlet and at the stack outlet and the water production rate.} \]

\[ PCKOH = \frac{22.0}{22.0 + WH2025} \]  \hspace{1cm} (12)

where

\[ PCKOH = \text{electrolyte concentration (ratio of KOH weight to total electrolyte weight)} \]

\[ \text{KOH weight is 22.0 pounds} \]

\[ \text{WH2025 is as previously defined} \]

\[ \text{The mass balance of water at the condenser uses the specific volume of water determined at the stack outlet as the specific volume of water at the condenser inlet. The specific volume of water at the condenser outlet is determined by the condenser primary exit temperature, TCEP, and a saturated steam condition.} \]
The amount of water condensed is found as follows:

$$DMASS = (180./SVOL11) \times DTIMEU - (180./SVOL21) \times DTIMEU$$ \hspace{1cm} (13)

where

- $DMASS =$ water condensed (lb)
- $SVOL11 =$ specific volume of water at the condenser outlet (cu ft/lb)
- $SVOL12 =$ specific volume of water at the condenser inlet (cu ft/lb)
- $DTIMEU =$ time step (hours)

The mass balance for the reactants is based on providing the necessary flow to support the theoretical consumption rates without consideration of minor variations in regulated pressure:

$$SFCH2 = 8.292 \times 10^{-5} \times 31 \times I$$ \hspace{1cm} (14)

$$SFCO2 = 7.94 \times SFCH2$$ \hspace{1cm} (15)

where

- $SFCH2 =$ hydrogen specific fuel consumption (lb/hr)
- $SFCO2 =$ oxygen specific fuel consumption (lb/hr)

The energy balance involving the consumed reactants is discussed in the Reactant Preheater section.

**Condenser**

The condenser is a counterflow heat exchanger interfacing the primary and secondary loops of the fuel cells. The condenser transfers the heat of the hydrogen-water mixture of the primary loop to the water-ethylene glycol mixture of the secondary loop. The normal operating range of the condenser exit temperature on the primary side (TCEP), which controls the secondary regenerator bypass valve, is 155 to 165 F.

Several schemes were considered for defining condenser performance. The method used, in view of simplicity of interface between the primary and secondary loops, was the balance of heat flow across the condenser. Data describing the condenser were obtained from Reference 6 and are provided in Figure 3 in the form of condenser performance curves. A multiple linear
Figure 3. Condenser Performance Curves
regression scheme was then used to curve-fit the data. The following equation was obtained:

\[ T_{CEP} - T_{CES} = (1./\text{WDWG}) \times (49.229 + 0.68747 \times Q_{COND} + 9.0145 \times 10^{-7} \times Q_{COND}^2) \]  

(16)

where

\begin{align*}
T_{CEP} &= \text{condenser primary side exhaust temperature (°F)} \\
T_{CES} &= \text{condenser secondary side exhaust temperature (°F)} \\
\text{WDWG} &= \text{water-glycol flow rate (lb/hr)} \\
Q_{COND} &= \text{heat flow across the condenser (Btu/hr)}
\end{align*}

The program makes successive approximations to balance the heat flow across the condenser. A value of \( Q_{COND} \) is calculated from the primary loop parameters. Then the condenser glycol and gas exit temperatures are varied in accordance with Equation (16) until the heat lost to the glycol equals the \( Q_{COND} \) calculated from the primary loop.

**Secondary Regenerator and Bypass Valve Models**

The secondary regenerator is modeled as a two-port network. The empirical relationships used for this model are typical for a counterflow heat exchanger and were taken from Reference 7. The hot outlet temperature, \( t_{h2} \), can be written as

\[ t_{h2} = \left( \frac{C_c}{C_h} \right) \epsilon \left( t_{c1} - t_{h1} \right) + t_{h1} \]  

(17)

where

\begin{align*}
C_c &= W_c C_p(T) \\
C_h &= W_h C_p(T) \\
W_c, W_h &= \text{co coolant flow rates on cold and hot sides (lb/hr)} \\
C_p(T) &= \text{coolant specific heat (a function of temperature)} \\
\epsilon &= \text{regenerator effectiveness} \\
t_{c1} &= \text{cold side inlet temperature (°F)} \\
t_{h1} &= \text{hot side inlet temperature (°F)}
\end{align*}
Figure 4 is a diagram of the regenerator with assigned terms.

From Equation (17), the capacity ratio, \( \frac{C_c}{C_h} \), can be rewritten as

\[
\frac{C_c}{C_h} = \frac{\dot{W}_c \left( \frac{1}{t_{c2} - t_{c1}} \right) \int_{t_{c1}}^{t_{c2}} C_p \, dT}{\dot{W}_h \left( \frac{1}{t_{h1} - t_{h2}} \right) \int_{t_{h2}}^{t_{h1}} C_p \, dT} = \frac{\dot{W}_c \Delta T_h \Delta h_c}{\dot{W}_h \Delta T_c \Delta h_h}
\]  

(18)

where

\( t_{c2} = \) cold-side outlet temperature (°F)

\( \Delta T = \) change in temperature (°F)

\( \Delta h = \) change in enthalpy (Btu/lb)

Since the flow on the cold side of the regenerator is regulated by the secondary bypass valve, which is controlled by the primary condenser exit temperature, the portion of the cold-side flow that is bypassed must be considered. The relationship of the bypass flow rate, \( \dot{W}_{BP} \), and the bypassed fraction, \( \alpha = \dot{W}_{BP}/\dot{W}_h \), and the cold- and hot-side flow rates are given by the following equations:

\[
\dot{W}_h = \dot{W}_c + \dot{W}_{BP}
\]  

(19)

\[
\dot{W}_c/\dot{W}_h = 1 - \alpha
\]  

(20)
Equation (18) can then be rewritten by using the above expressions to give

\[
\frac{C_C}{C_h} = (1 - \epsilon) \frac{\Delta T_h \Delta h_c}{\Delta T_c \Delta h_h} = \beta
\]  

(21)

The parameters \( \epsilon \) and \( \beta \), together with the factor \( \tau_{ij} \), to represent the time response, define the relationship between the inlet and outlet temperatures of the regenerator:

\[
\begin{bmatrix}
  t_{C2} \\
  t_{h2}
\end{bmatrix} =
\begin{bmatrix}
  (1 - \epsilon) \tau_{11} & \epsilon \tau_{12} \\
  \epsilon \beta \tau_{21} & (1 - \epsilon \beta) \tau_{22}
\end{bmatrix}
\begin{bmatrix}
  t_{C1} \\
  t_{h1}
\end{bmatrix}
\]  

(22)

This relation is solved in the program by a group of subroutines that update sliding arrays, move backward in the arrays to simulate delay, and perform integration. Figure 5 illustrates the relationship of the secondary regenerator cold-side inlet temperature to the regenerator effectiveness for various coolant flow rates. The data above an inlet of 70 degrees have been extrapolated.

The secondary bypass valve characteristics are shown in Figure 6. The program keeps track of the TCE in ascending or descending order and correspondingly interpolates on the correct curve.

**Radiator System**

The fuel cell and radiator system consists of eight 5-square-foot panels located on the CSM fairing. For the Skylab mission only two of the fuel cell and radiator coolant loops will be filled and connected for two-fuel-cell operation. While the radiator model discussion in this section is for the basic three-fuel-cell operational mode, two-fuel-cell operation for Skylab is simulated by using a zero flow pump characteristic for the third cell. For one-fuel-cell contingency operation, zero flow pump characteristics are used for two of the three cells. Reduced radiator area operation for low-power operation for Skylab missions is the same as for other Apollo missions: The bypass valve is actuated, and the last three panels are bypassed, and five-panel (five-eighths) radiator operation is achieved.

The original radiator model was included with the data deck for the CINDA program received from NASA (Reference 8). The model included a nodal network for each of the eight radiator panels and the coolant delivery and bypass lines. Figure 7 illustrates the nodal model that is typical for a single radiator panel. The solid and fluid node and conductor numbers shown in this figure represent panel 1 in the radiator system model. The corresponding node capacitance and conductor valves are given in Table 4. The
Figure 6. Secondary Bypass Valve Characteristics
Table 4. Capacitance and Conductance Values

<table>
<thead>
<tr>
<th>Solid Node Number</th>
<th>Solid Node Capacitance $\rho C_p V$ (Btu/°F)</th>
<th>Solid Conductor Number</th>
<th>Conductor Value $KA/L$ (Btu/Hr°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>701</td>
<td>0.043269</td>
<td>701</td>
<td>0.199691</td>
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<tr>
<td>702</td>
<td>0.037088</td>
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<td>0.176766</td>
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<tr>
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<td>703</td>
<td>0.090127</td>
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<tr>
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<td>0.098515</td>
<td>704</td>
<td>0.121294</td>
</tr>
<tr>
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<td>705</td>
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<td>0.072776</td>
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<td>0.010989</td>
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</tr>
</tbody>
</table>

Original values for the solid conductors were increased ten percent after it was found that the foil was two to three times thicker than required by the original specifications (Reference 9). Loss of heat through the radiator panel edges to the SM structure was accounted for by adding another solid node to the nodal network to represent the SM structure. Each of the solid-edge nodes of the eight radiator panels was tied to this SM structure node by a solid conductor. A structure temperature within a ±150 °F range and an infinite capacitance is assigned the structure node, depending upon the environment being simulated.
The fuel cell/radiator coolant is a water-ethylene glycol solution composed of 62.5 percent ethylene glycol by weight. The coolant properties used in the analysis as functions of temperature are density (Figure 8); conductivity (Figure 9); specific heat (Figure 10); viscosity (Figure 11); and relative enthalpy (Figure 12). The coolant pump characteristic, flow versus pressure drop in the radiator loop, is shown as Figure 13. The pressure drop in the radiator loop is calculated by using the Fanning equation with a dynamic head loss factor in the subroutine (Reference 8).

**Reactant Preheaters**

In the secondary loop, the water-glycol, after exiting from the condenser, flows through the reactant preheaters before passing into the secondary regenerator. The basic equations simulating the reactant preheaters were taken from Reference 10, with corrections made to preserve compatibility with the secondary loop model.

The effectivity of the oxygen preheater is shown in Figure 14 and expressed as

\[
\text{EFF} = 0.53 + 0.002 \times \text{WDWG} + 0.018 \times \text{WDO2}
\]  

(23)

where

\[
\begin{align*}
\text{EFF} &= \text{effectivity} \\
\text{WDWG} &= \text{water-glycol flow rate (lb/hr)} \\
\text{WDO2} &= \text{oxygen flow rate (lb/hr)}
\end{align*}
\]

The oxygen preheater outlet temperature can then be found from Equations (23) and (24):

\[
\text{TO2O} = \text{TO2I} + (\text{TWGOI} - \text{TO2I}) \times \text{EFF}
\]

(24)

where

\[
\begin{align*}
\text{TO2O} &= \text{oxygen outlet temperature (°R)} \\
\text{TO2I} &= \text{oxygen inlet temperature assumed constant = 530°R} \\
\text{TWGOI} &= \text{water-glycol temperature at condenser outlet (°R)}
\end{align*}
\]
Figure 8. Density of Water-Glycol Mixture

Figure 9. Conductivity of Water-Glycol Mixture
Figure 10. Specific Heat of Water-Glycol Mixture

Figure 11. Viscosity of Water-Glycol Mixture
Figure 12. Relative Enthalpy of Water-Glycol Mixture

Figure 13. Water-Glycol Pump Characteristic
From Equation (25), the change in enthalpy of the water-glycol flowing through the oxygen preheater can be obtained:

\[ DH_{O2} = (T_{O2I} - T_{O2O})(0.152 + 0.000225(T_{O2O} + T_{O2I})) \times \frac{W_{D02}}{W_{DGW}} \]  

(25)

\[ DH_{O2} = \text{enthalpy change of the water-glycol through the oxygen preheater (Btu/lb)} \]

The temperature of the water-glycol \( (T_{WGHI}) \) exiting the oxygen preheater is found from the change in enthalpy and preheater water-glycol inlet temperature.

The effectivity of the hydrogen preheater is assumed constant at 0.75 (Figure 15). Equation (26) is similar to Equation (24) and gives the hydrogen preheater outlet temperature:

\[ T_{H2O} = T_{H2I} + 0.75 \times (T_{WGHI} - T_{H2I}) \]

(26)
where

\[ \text{TH}_20 = \text{hydrogen outlet temperature (°R)} \]

\[ \text{TH}_2I = \text{hydrogen inlet temperature, assumed constant = 530°R} \]

\[ \text{TWGHI} = \text{water-glycol temperature at hydrogen preheater inlet (°R)} \]

The enthalpy change of the water-glycol flowing through the hydrogen preheater is then

\[ \text{DHH}_2 = (\text{TH}_2I-\text{TH}_2O) \times 3.47 \times \frac{\text{WDH}_2}{\text{WDWG}} \]  \hspace{1cm} (27)

where

\[ \text{WDH}_2 = \text{hydrogen flow rate (lb/hr)} \]

\[ \text{DHH}_2 = \text{enthalpy change in the water-glycol through the hydrogen preheater (Btu/lb)} \]

The temperature of the water-glycol exiting the hydrogen preheater can then be found from the enthalpy change and the water-glycol temperature.
entering the preheater. The water-glycol exit temperature is taken as the inlet temperature of the hot side of the secondary regenerator.

**Fuel Cell Heat Loss to Structure**

The fuel cell heat loss to the SM structure is based upon information given in Reference 5. The data as shown in Reference 5 are plots of fuel cell heat loss as a function of stack temperature for three parametric structure temperatures: 30, 80 and 130 F. These data were replaced with the following linear equation, which is used in the SINDA fuel cell model:

\[ Q_{SM} = 3.25 \times TS - 1.6 \times TA - 882. \]  

where

- \( Q_{SM} \) = fuel cell heat loss to structure (Btu/hr per cell)
- \( TS \) = fuel cell stack temperature (°F)
- \( TA \) = ambient structure temperature (°F)

The ambient temperature is assigned as an independent parameter, based upon space environmental conditions. A temperature of 30 F is selected for extreme cold conditions; 130 F for extreme hot conditions, and 80 F for nominal conditions. There is no attempt to determine the direct heat conduction through the fuel cell cone mount nor to determine the heat radiation from the pressure jacket and accessory package components. The program does not attempt to determine the changes in the ambient structure temperature resulting from such heating. The equation is accurate to within ±4 percent of the data from Reference 5.

**4.2 PROGRAM DEFINITION**

The CINDA-3G (Chrysler Improved Numerical Differencing Analyzer for Third-Generation Computers) computer program was developed by the Thermodynamics Section of the Aerospace Physics Branch of the Chrysler Corporation Space Division at the National Aeronautics and Space Administration's Michoud Assembly Facility. The CINDA-3G program, written to run on the Univac 1108, was converted by the Computer Science Branch of the Idaho Nuclear Corporation to run on the IBM 360/75 computer. The converted program, called SINDA-3G (Systems instead of Chrysler), provides a variety of methods for the solution of thermal analog models presented in a network format. The network representation is unique in that it has a one-to-one correspondence to both the physical model and the mathematical model. The program allows the models to be developed through use of combinations of FORTRAN statements, user-initiated subroutines, and the numerous subroutines contained within the program. These program subroutines can be used for handling interrelated complex phenomena such as
sublimation; diffuse radiation within enclosures; simultaneous, one-dimensional, incompressible, fluid flow, including valving and transport delay effects; and similar areas associated with heat transfer and fluid flow.

In the hands of a competent engineering analyst, the SINDA-3G program is a powerful tool for analyzing thermal systems.

4.3 MODEL AND PROGRAM INPUT

Data Deck Setup

A SINDA-3G program deck contains two main blocks: a data block and an operations block. Each block is subdivided into four blocks. The four data blocks are entitled the NODE DATA, CONDUCTOR DATA, CONSTANTS DATA, and ARRAY DATA. The four operations blocks are designated EXECUTION, VARIABLES 1, VARIABLES 2, and OUTPUT CALLS.

Card columns 12 through 80 comprise the data field. The instruction field (operations blocks) consists of columns 12 through 72. The program processes the problem data into FORTRAN common data and converts instructions into FORTRAN source language. They are then passed on to the system FORTRAN compiler. Instruction cards containing an F in column 1 are passed on exactly as received. Discussion of the operations blocks will follow discussion of the data blocks.

Data input to the data blocks may be one or more integers, floating numbers (with or without the E exponent designation), or alphanumeric words of up to six characters each. The reading of a word or number continues until a comma is encountered. Then the next word or number is read. Words or numbers may not be broken between cards, and a new card is equivalent to starting with a comma. Therefore, no continuation designation is required. When sequential commas are encountered, the program places floating-point zero values between them. Reading continues until the terminal column is reached or a dollar sign is encountered. Comments for a data card can be placed after a dollar sign and are not processed by the program.

The first card in each of the four data blocks must be started in column 8 with the mnemonic code BCD (binary coded decimal), then an integer (1 through 9) in column 12, and the name of the data block starting in column 13. Each data block must be terminated with a mnemonic END card.
The NODE DATA block contains the data describing all nodes in the network. Each set of node data is grouped similar to the following code:

\[
\text{column 12} \\
N\#, \ Ti, \ Ca
\]

where

\begin{align*}
N\# &= \text{integer node number} \\
Ti &= \text{initial node temperature} \\
Ca &= \text{node capacitance}
\end{align*}

All nodes are numbered by the program sequentially (from 1 on) in the order received. The user input number is designated the actual node number. The program assigned number is termed the relative node number.

Second in the group of data blocks is the CONDUCTOR DATA block. In the nodal network, nodes are joined together with conductors. The three types of conductors used in the SINDA-3G program are conduction (solid), convection, and radiation conductors. Conductors are input to the program with the code:

\[
\text{column 12} \\
G\#, \ NA, \ NB, \ Cn
\]

where

\begin{align*}
G\# &= \text{integer conductor number} \\
NA &= \text{one adjoining node number} \\
NB &= \text{the other adjoining node number} \\
Cn &= \text{conductance value}
\end{align*}

If more than one conductor has the same constant value, they may share the same conductor number and value. This is accomplished by placing two or more pairs of integer-adjoining node numbers between the conductor number and value.

The data for the CONSTANTS DATA block are always input as doublets, the constant name or number followed by its value. They are divided into two types, control constants and user constants, and may be intermingled within the block. User constants receive a number. Control constants have alphanumeric names.
The ARRAY DATA block is the last of the four data blocks. Input of
data into this block is exceedingly simple. The array number is listed,
followed by the sequential listing of the data, and terminated with an END
(data END, not mnemonic). The interpolation and matrix subroutines of the
program make extensive use of these arrays. The SPACE option in the
ARRAY DATA block is an easy way for the user to specify a large number of
locations, which are initialized by the preprocessor program as floating-
point zeros. When this option is used, the array number is listed, followed
by the word SPACE and the number of locations to be initialized, and
terminated with an END.

While the four data blocks provide the data for the program, the four
operations blocks determine the program control. This they do through the
use of various operations and instructions. The four operations blocks,
EXECUTION, VARIABLES 1, VARIABLES 2, and OUTPUT CALLS, are
preprocessed by the SINDA-3G program and passed on to the system
FORTRAN compiler as four separate subroutines entitled EXECTN, VARBL1,
VARBL2, and OUTCAL, respectively. Figure 16 illustrates the basic flow
diagram for the solution of the network.

When the FORTRAN compilation is successfully completed, control is
passed to the EXECTN subroutine. It sequentially performs the operations
in the same order as input by the user in the EXECUTION block. None of
the operations specified in the other three blocks is performed unless it is
called for either directly by name in the EXECUTION block or internally by
some other called for subroutine. All operations and instructions listed in
EXECUTION block and performed by the program are executed only once.
Because of this feature, the EXECTN subroutine can be used to initialize
constants and variables, fabricate new arrays, establish steady-state
parameters, and perform other operations that are completed only once
during the duration of the program.

The operations in the VARIABLES 1 block can be considered pre-
solution operations. These operations may include construction of
temperature arrays, establishment of heating rates, calculation of heating
sources, or other basic operations required for solution of the thermal
nodal network.

In the same respect, the VARIABLES 2 block operations may be
thought of as post-solution operations. VARIABLES 2 allows the user to
look at the recently solved network. Typical operations of the VARBL2
subroutine may include integration of flow rates, corrections of empirical
relationships to reflect thermal solution of the nodal network, updating of
conductances to account for changes in node temperatures, etc.
Figure 16. Basic Flow Chart for Network Solution Subroutines

OPERATION | DESCRIPTION
-----------|-------------------
CTS        | CALCULATE TIME STEP
VARBL1     | VARIABLES 1 OPERATIONS
SN         | SOLVE NETWORK
VARBL2     | VARIABLES 2 OPERATIONS
OUTCAL     | OUTPUT CALLS OPERATIONS
MTC        | MODIFY TIME CONTROL
EI         | ERASE ITERATION

CHECK | REVERSE DIRECTION IF
1     | BACKUP NONZERO
2     | RELAXATION CRITERIA NOT MET
3     | TIME OR TEMP CHANGE TOO LARGE
4     | BACKUP NONZERO
5     | NOT TIME TO PRINT
6     | PROBLEM STOP TIME NOT REACHED
The operations in the OUTPUT CALLS block are performed on the output interval specified by the user in the program. Since the operations are performed only at the output interval, OUTPUT CALLS typically contains only instructions for outputting information.

The aforementioned data and operations blocks constitute a SINDA-3G program data deck. The deck must be terminated with the following card:

```
column 8 12
BCD 3END OF DATA
```

The user has the option to use the subroutines contained in the SINDA-3G library or to write his own. When non-SINDA-3G subroutines are being called, the data communication is obtained through subroutine arguments similar to any other subroutine.

Sample Problem Input Data

The listing of the sample input data is included in the appendix. The data are presented in the same order as stated in the Data Deck Setup section: the node data first, followed by the conductor data and constants data, and concluded with the array data.

The node data includes the solid temperature nodes for the eight radiator panels, the water-glycol fluid temperature nodes for the three-fuel-cell system, the fluid pressure nodes, and the edge sink and environmental sink nodes for the eight panels.

The 11 solid (conduction) conductors are the first of the data listed in the conductor data. Next are the convection conductors and the pressure and fluid flow conductors for the three systems. The conductor data are concluded with the five radiation conductors.

The constants data contain the 472 constants used in the program. These constants are listed by their actual number rather than the program-assigned relative numbers.

Listed in the last section of the problem input data are the array data. Eighty-four arrays are listed, with most arrays containing data and the remaining arrays using the SPACE option to allocate program storage locations.

Following the input data is a listing of the main program (EXECTN, VARBL1, VARBL2, and OUTCAL) and the 12 user-written subroutines.
Sample Problem Output

Figure 17 illustrates a typical problem output listing. The listing is headed with the title "Systems Improved Numerical Differencing Analyzer * SINDA * North American Rockwell Corporation - Space Division" and followed by 11 output interval data sets. Each output interval data set is started with four asterisks. The first data line contains five control constants with their values listed to the right of each constant. The last three constants have the relative node number enclosed in parentheses. The control constants are:

- **TIME** Present mission time (hr)
- **DTIMEU** Last time step used for transient network problem (hr)
- **CSGMIN** Most recent minimum stability criteria for the network
- **DTMPCC** Maximum diffusion temperature change calculated over the last time step
- **ARLXCC** Maximum arithmetic relaxation change calculated over the last iteration

The next four lines of output are associated with the primary loop operation. The first two lines list the titles, with the values following. The titles are defined as follows:

- **SYSTEM** Fuel cell system in operation (for Skylab configuration only two fuel cell systems are used, systems 1 and 3)
- **POWER** Fuel cell power output (watts)
- **CURRENT** Fuel cell output current (amps)
- **VOLTAGE** Fuel cell output voltage (volts)
- **TSI** Stack inlet temperature (°F)
- **TSE** Stack exit temperature (°F)
- **TCIP** Condenser inlet temperature, primary loop (°F)
- **TCEP** Condenser exit temperature, primary loop (°F)
- **QCOND** Heat flow across the condenser (Btu/hr)
W-COND  Weight rate of water condensed (lb/hr)

WS-RATE  Percent of water produced in the time interval that remains in the stack (%)

TO2     Oxygen reactant temperature at stack inlet (°F)

TH2     Hydrogen reactant temperature before mixing with the primary recirculation stream (°F)

PCKOH   Electrolyte concentration ratio

Secondary loop operations are listed in the next four lines, with the titles followed by their values. The titles represent:

FLOW RATE  Water glycol flow rate (lb/hr)

QRAD     Heat flow across the radiators (Btu/hr)

TRADIN   Temperature of the radiator inlet (°F)

TRADOUT  Temperature of the radiator outlet (°F)

DPRAD    Pressure drop through the radiator loop (psi)

TSRCI    Temperature of the secondary regenerator at the cold-side inlet (°F)

TSRCE    Temperature of the secondary regenerator at the cold-side exit (°F)

TSRHI    Temperature of the secondary regenerator at the hot-side inlet (°F)

TSRHE    Temperature of the secondary regenerator at the hot-side exit (°F)

TCIS     Condenser inlet temperature, secondary loop (°F)

TCES     Condenser exit temperature, secondary loop (°F)

BPFS     Bypassed ratio at the secondary regenerator

The final data group lists the radiator inlet and outlet temperature for the eight radiator panels for all three systems. The temperatures are listed in degrees Fahrenheit. The four asterisks following this data group designate the start of a new output interval data set.
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<th>TRADOUT</th>
<th>DPRAD</th>
<th>TSRCI</th>
<th>TSREC</th>
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</table>

Figure 17. Sample Problem Output

- 39, 40 -

SD 70-266
4.4 ANALYTICAL RESULTS

Three temperature levels are monitored to determine if the fuel cells are operating within the specified limits. These temperatures are measured at the condenser primary exit, the radiator exit, and the stack. The nominal condenser primary exit temperature range is 155 to 165 F, with allowable cycling to 200 F. The caution and warning (C&W) alarms for the condenser exit are set for 150 F and 175 F. For the analysis, the acceptable minimum power operation was defined for condenser operation as between 150 and 155 F. The acceptable maximum power operation was defined as between 165 and 200 F. The stack and radiator exit temperatures are less limiting than the condenser exit temperature. This is evidenced by results in which seven of the eight cases reached the condenser exit limits. The remaining case was limited by the stack temperature.

The nominal stack temperature range is 390 to 460 F, with the C&W alarms at 360 F and 475 F. For the analysis, the acceptable minimum stack temperature range was 360 to 390 F. The maximum was defined as 460 to 475 F. The radiator exit-temperature nominal range is 0 to 120 F, with allowable high-temperature cycling to 180 F. The C&W alarm is set only for the minimum temperature condition of -30 F. Only the acceptable minimum radiator temperature range was defined for the analysis. This range, -30 to 0 F, was not encountered in any of the eight cases.

Two environmental heating profiles were used for the heat that is radiated to radiator panels. The hotter environment, which was used for the maximum power cases, has a \( \beta \) angle of 73.5 degrees for a circular earth orbit of 235 nautical miles with the vehicle in a Z-local vertical attitude hold. The colder environment for the minimum power cases uses a \( \beta \) angle of 0 degrees for the same orbit and attitude conditions.

The power levels shown in Tables 1, 5 and 6 represent the expected power requirements for the Skylab missions. One-fuel-cell operation and five-eighths radiator area are contingency operation modes that are considered irreversible. That is, once the contingency mode is selected, a return to normal two-fuel-cell or full-area operation is never required.

With the exception of Case 2, the power levels shown in Table 5 can be raised slightly by operation at the condenser C&W limit of 175 F. Operation to 200 F is acceptable for peak cycling conditions. However, once the nominal bypass limit of 165 F is exceeded, a slight increase in power results in a significant temperature rise. Case 3, one fuel cell, full area at 60 amperes, is the only case where the stack temperature limits the power. In this case, a greater increase in power is available if operated to the stack temperature C&W limit of 475 F.
For all of the minimum power cases listed in Table 6, slightly lower power capability is possible by operating down to the condenser C&W limit of 150 F. The temperatures shown in Tables 5 and 6 are orbital extremes except where differences occurred between fuel cells in two-fuel-cell operation. Then the value shown is the average between the two cells at the orbital extreme condition.

Table 5. System Temperatures for High Power Levels

<table>
<thead>
<tr>
<th>Case</th>
<th>Angle (deg)</th>
<th>Number of Fuel Cells in Operation</th>
<th>Radiator Area (operating panels)</th>
<th>Total Fuel Cell Current Level (amps)</th>
<th>Temperatures (°F)</th>
</tr>
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<tbody>
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<td>Condenser Exit</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>Stack</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Radiator Inlet</td>
</tr>
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<td>Radiator Outlet</td>
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Table 6. System Temperatures for Low Power Levels

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<th>Number of Fuel Cells in Operation</th>
<th>Radiator Area (operating panels)</th>
<th>Total Fuel Cell Current Level (amps)</th>
<th>Temperatures (°F)</th>
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5. REFERENCES


APPENDIX: INPUT DATA, MAIN PROGRAM LISTING, AND USER SUBROUTINE LISTINGS

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$ND0530

$ND0540

$ND0550
**Space Division**

**North American Rockwell**

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**REM RADIATOR SOLID TEMPERATURE NODES (PANEL 7)**

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**REM RADIATOR SOLID TEMPERATURE NODES (PANEL 8)**

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**REM FLUID TEMPERATURE ARITHMETIC NODES**

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**REM FLUID TEMPERATURE NODES - MIXING (SYSTEMS 1, 2, 3)**

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**REM EDGE SINK TEMPERATURE NODE FOR PANELS 1 TO 8**

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**SD 70-266**
REM PRESSURE CONDUCTORS (SYSTEM 1)

REM PRESSURE CONDUCTORS (SYSTEM 2)

- 49 -
SD 70-266
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FLUID FLOW CONDUCTORS (SYSTEM 3)

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725, 902, 727, 902, 746, 902, 748, 902
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750, 903, 771, 903, 774, 904, 795, 904
798, 905, 819, 905, 822, 906, 843, 906
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RADIATION CONDUCTOR - NUMBER 904
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777, 904, 780, 904, 783, 904, 786, 904, 789, 904, 792, 904
801, 905, 804, 905, 807, 905, 810, 905, 813, 905, 816, 905

RADIATION CONDUCTOR - NUMBER 905
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729, 902, 732, 902, 735, 902, 738, 902, 741, 902, 744, 902
753, 903, 756, 903, 759, 903, 762, 903, 765, 903, 768, 903
777, 904, 780, 904, 783, 904, 786, 904, 789, 904, 792, 904
801, 905, 804, 905, 807, 905, 810, 905, 813, 905, 816, 905

...
REM -K22 IS NO. OF CONVECTION CONDUCTORS PER SYSTEM
24, 13 $ NO. OF THERMAL FLUID FLOW CONDUCTORS PER SYSTEM
25, 6944444E-2 $ CONVERSION FROM PSF TO PSI

REM CONSTANTS USED IN OUTPUT CALLS
26, 27, 16, 28, 29, STEMP, 30, 192, 31, 701, 32, 33, NO USE

REM MULTIPLYING FACTORS FOR PRESSURE CONDUCTORS
526, 55, 2666, 527, 148, 1534, 528, 265, 9462, 529, 108, 265
580, 68, 8717, 581, 158, 5055

REM COMPRESSED PRESSURE CONDUCTORS
582, 583, 584, 585, 586, 587, 588, 589, 590, 591, 592, 593
594, 595, 596

REM INITIAL SOLID NODE TEMP
594, 150.0
Space Division
North American Rockwell

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**END**

**BCD 3ABf**

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17 $ INCIDENT HEAT FOR PANEL 5 - BTU/HR FT**2
0.30, 32, 37, 0.05, 35.41, 0.10, 35.32, 0.15, 41.00, 0.20, 42.32
0.25, 45.20, 0.30, 46.56, 0.35, 47.34, 0.40, 47.51, 0.45, 47.06
0.50, 46.02, 0.55, 44.91, 0.60, 42.33, 0.65, 39.83, 0.70, 37.34
0.75, 34.95, 0.80, 35.82, 0.85, 43.35, 0.90, 32.37, 1.45, 32.37
1.50, 44.76, 1.55, 49.71, END
18 $ INCIDENT HEAT FOR PANEL 6 - BTU/HR FT**2
0.30, 49.71, 0.05, 54.38, 0.10, 58.86, 0.15, 63.97, 0.20, 66.54
0.25, 69.42, 0.30, 71.50, 0.35, 77.27, 0.40, 72.96, 0.45, 72.28
0.50, 70.67, 0.55, 68.82, 0.60, 66.01, 0.65, 61.18, 0.70, 56.88
0.75, 57.29, 0.80, 56.54, 0.85, 47.14, 0.90, 49.71, 1.45, 49.71
1.50, 66.63, 1.55, 49.71, END
19 $ INCIDENT HEAT FOR PANEL 7 - BTU/HR FT**2
0.30, 56.74, 0.05, 62.08, 0.10, 67.19, 0.15, 71.88, 0.20, 75.95
0.25, 79.25, 0.30, 81.62, 0.35, 82.99, 0.40, 83.29, 0.45, 97.50
0.50, 90.67, 0.55, 77.87, 0.60, 74.21, 0.65, 69.84, 0.70, 64.93
0.75, 59.69, 0.80, 64.60, 0.85, 81.75, 0.90, 56.74, 1.45, 56.74
1.50, 75.86, 1.55, 56.74, END
20 $ INCIDENT HEAT FOR PANEL 8 - BTU/HR FT**2
0.00, 31.81, 0.05, 34.80, 0.10, 37.66, 0.15, 40.29, 0.20, 42.57
0.25, 44.42, 0.30, 45.73, 0.35, 46.52, 0.40, 46.68, 0.45, 46.25
0.50, 45.22, 0.55, 43.65, 0.60, 41.60, 0.65, 39.15, 0.70, 36.40
0.75, 33.64, 0.80, 33.53, 0.85, 42.39, 0.90, 31.81, 1.45, 31.81
1.50, 39.90, 1.55, 31.81, END
21 $ SPACE, 56, END
22 $ SPACE, 81, END $ REYNOLDS NUMBER
23 $ SPACE, 81, END
24 $ RELATIVE ENTHALPY OF GLYCOL-WATER, BTU/LBM
-460.0, 1, 0.0, -40.3, 1, 131.0, -40.3, 1, 137.12, -30.1, 1, 143.36, -20.1, 1, 149.73
-10.1, 1, 156.22, 0.0, 1, 162.83, 10.1, 1, 169.54, 20.1, 1, 176.37, 30.1, 1, 183.3
40.1, 190.33, 50.1, 197.46, 60.1, 204.69, 70.1, 212.01, 80.1, 219.43
90.1, 226.93, 100.1, 234.51, 110.1, 242.17, 120.1, 249.91, 130.1, 257.71
140.1, 265.58, 150.1, 273.52, 160.1, 281.53, 170.1, 289.58, 180.1, 297.7
190.1, 305.86, 200.1, 314.08, 210.1, 323.29, 220.1, 332.50, 230.1, 341.71, 240.1, 350.92
250.1, 359.69, 260.1, 368.45, 270.1, 377.21, 280.1, 386.97, 290.1, 396.73
END
25 $ SPACE, 48, END
26 $ DO LOOP INDICES - INITIAL VALUE
0.1, 1.6, 2.1, END
27 $ DO LOOP INDICES - TEST VALUE
0.1, 1.6, 2.1, END
28 $ DO LOOP INDICES - INCREMENT
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29 $ SPACE, 10, END
30 $ SPACE, 10, END
31 $ SPACE, 10, END
32 $ SPACE, 10, END
33 $ SPACE, 10, END
34 $ SPACE, 10, END
35 $ BYPASS OPTION - SYSTEM 1
0.0, 6.21, 1, END
36 $ BYPASS OPTION - SYSTEM 2
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37 $ BYPASS OPTION - SYSTEM 3
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38 $ HEAT TRANSFER COEFFICIENT - AREA TERM
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140, 202, 234, 253, 275, 300, 323, 350, 387, 0.0, 0.0, 0.0
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<td>0.19</td>
<td>0.19</td>
</tr>
<tr>
<td>20.00</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
</tr>
</tbody>
</table>

**Note:** This table represents a sample of a larger dataset and is not the complete document.
### Space Division
North American Rockwell

**43**  
CURRENT - AMPS - SYSTEM 3

<table>
<thead>
<tr>
<th>44</th>
<th>PARTIAL PRESSURE OF WATER IN STACK - PSIA</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>0.05, 0.60, 0.65, 0.70, 0.75, 0.80, 0.85, 0.90</td>
</tr>
<tr>
<td>15</td>
<td>350.0, 27.0, 15.6, 8.0, 3.7, 1.6, 0.0, 0.0</td>
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<tr>
<td>16</td>
<td>390.0, 36.0, 21.0, 11.4, 5.6, 2.4, 1.0, 0.0</td>
</tr>
<tr>
<td>17</td>
<td>440.0, 47.0, 29.0, 16.0, 8.0, 3.6, 1.4, 0.0</td>
</tr>
<tr>
<td>18</td>
<td>490.0, 50.0, 33.0, 21.0, 10.8, 4.8, 1.9, 0.0</td>
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<tr>
<td>19</td>
<td>640.0, 79.0, 51.0, 29.0, 14.6, 6.6, 2.7, 1.5</td>
</tr>
<tr>
<td>20</td>
<td>640.0, 102.0, 66.0, 38.0, 19.0, 8.9, 3.6, 1.3</td>
</tr>
<tr>
<td>21</td>
<td>640.0, 128.0, 86.0, 50.0, 25.0, 11.9, 4.8, 1.7</td>
</tr>
<tr>
<td>22</td>
<td>500.0, 160.0, 104.0, 65.0, 32.5, 15.6, 6.3, 2.2</td>
</tr>
<tr>
<td>23</td>
<td>520.0, 200.0, 134.0, 93.0, 42.0, 20.6, 8.4, 3.0</td>
</tr>
<tr>
<td>24</td>
<td>560.0, 250.0, 170.0, 104.0, 55.0, 27.5, 11.3, 4.2</td>
</tr>
<tr>
<td>25</td>
<td>560.0, 310.0, 210.0, 130.0, 70.0, 36.0, 15.0, 5.9</td>
</tr>
<tr>
<td>26</td>
<td>580.0, 380.0, 260.0, 160.0, 89.0, 46.0, 20.0, 8.0</td>
</tr>
<tr>
<td>27</td>
<td>630.0, 470.0, 320.0, 195.0, 113.0, 60.0, 27.0, 10.7</td>
</tr>
</tbody>
</table>

**45**  
ENTHALPY OF SUPERHEATED STEAM - BTU/LBM

| 5  | 126.0, 152.9, 170.0, 182.8, 193.2 |
| 200.0, 1150.0, 1149.2, 1148.3, 1147.5, 1146.6 |
| 220.0, 1159.1, 1158.5, 1157.7, 1157.0, 1156.2 |
| 240.0, 1168.2, 1167.6, 1167.0, 1166.3, 1165.7 |
| 260.0, 1177.3, 1176.8, 1176.3, 1175.7, 1175.1 |
| 280.0, 1186.4, 1185.9, 1185.5, 1185.0, 1184.5 |
| 300.0, 1195.6, 1195.2, 1194.7, 1194.3, 1193.9 |
| 320.0, 1204.8, 1204.4, 1204.0, 1203.6, 1203.2 |
| 340.0, 1213.9, 1213.5, 1213.1, 1212.9, 1212.5 |
| 360.0, 1223.1, 1222.8, 1222.5, 1222.2, 1221.9 |
| 380.0, 1232.3, 1232.1, 1231.8, 1231.5, 1231.2 |
| 400.0, 1241.6, 1241.3, 1241.0, 1240.8, 1240.6 |

**46**  
SPACE, 1, END
**47**  
SPACE, 30, END
**48**  
SPACE, 30, END

ENTHALPY GLYCOL-WATER VS TEMP
SAVED TIME STEPS
RAD OUTLET TEMPS
SECONDARY REGEN COLD INLET TEMPS
SECONDARY BYPASS VALVE POSITION
SECONDARY REGEN HOT INLET TEMPS
SECONDARY REGEN GAINS, SYS 1
SECONDARY REGEN GAINS, SYS 2
SECONDARY REGEN GAINS, SYS 3
SECONDARY REGEN COLD SIDE DELAYS

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SD’70-266
### Secondary Regen Hot Outlet Temps

<table>
<thead>
<tr>
<th>Flow Rate (l/min)</th>
<th>Rad Press Drop (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>68.4</td>
</tr>
<tr>
<td>5.0</td>
<td>65.2</td>
</tr>
<tr>
<td>10.0</td>
<td>61.9</td>
</tr>
<tr>
<td>15.0</td>
<td>58.7</td>
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<tr>
<td>20.0</td>
<td>55.4</td>
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<td>52.2</td>
</tr>
<tr>
<td>30.0</td>
<td>48.9</td>
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<tr>
<td>35.0</td>
<td>45.6</td>
</tr>
<tr>
<td>40.0</td>
<td>42.4</td>
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<tr>
<td>45.0</td>
<td>39.1</td>
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<tr>
<td>50.0</td>
<td>35.9</td>
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<tr>
<td>55.0</td>
<td>32.6</td>
</tr>
<tr>
<td>60.0</td>
<td>29.3</td>
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<td>26.1</td>
</tr>
<tr>
<td>70.0</td>
<td>22.9</td>
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<tr>
<td>75.0</td>
<td>19.6</td>
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<td>80.0</td>
<td>16.3</td>
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<tr>
<td>85.0</td>
<td>13.0</td>
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<tr>
<td>95.0</td>
<td>6.5</td>
</tr>
<tr>
<td>100.0</td>
<td>3.3</td>
</tr>
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</table>
MAIN PROGRAM LISTING

BCD EXECUTION
COMMON/ALPHA/ WM2026(3)
COMMON/BRAVO/COND(3), D MASS(3), WTH230(3)
COMMON/CHAR/ J,M,N
COMMON/Delta/ INDEX1
COMMON/ECHO/ IPPOINT
DIMENSION X(100)
DIMENSION XK(I)
EQUIVALENCE (XK(I),K(I))
NDIM=1000

SCALDEP(A4,K1) $SCALE VISCOSITY
SPLIT(K2,A1+1,A5+1,A6+1) $SEPARATE DENSITY FROM TEMP
ARYINV(K2,A6+1) $INVERT DENSITY
JOIN(K2,A5+1,A6+1,A1+1) $ INVERSE DENSITY VS TEMP
SPLIT(K2,A2+1,A5+1,A6+1) $SEPARATE CONDUCTIVITY FROM TEMP
SPLIT(K2,A3+1,A5+1,A7+1) $SEPARATE SPECIFIC HEAT FROM TEMP
DIVARY(K2,A6+1,A7+1,A7+1) $CONDUCTIVITY / SPECIFIC HEAT
JOIN(K2,A5+1,A7+1,A2+1) $CONDUCTIVITY/SPECIFIC HEAT VS TEMP
SPLIT(K2,A4+1,A5+1,A6+1) $SEPARATE DENSITY VS TEMP
ARYINV(K2,A6+1) $INVERSE VISCOSITY
JOIN(K2,A5+1,A6+1,A4+1) $INVERSE VISCOSITY VS TEMP
SPLIT(K916,A24+1,A47+1,A49+1) $SEPARATE TEMP FROM ENTHALPY
JOIN(K916,A48+1,A47+1,A49+1) $ENTHALPY VS TEMP

REM
REM DATA ARRAY IS NOW IN PROPER FORM FOR PROGRAM USAGE
REM
REM THE FOLLOWING INITIALIZES THE ENTIRE SOLID TEMPERATURE
REM NETWORK TO COMPENSATE FOR VARYING INITIAL CONDITIONS. THE
REM TEMPERATURE VALUE IS INPUT AS CONSTANT NUMBER K598,
STFSQS(K598,K599,T701)

IPOINT = 1
INDEX1 = 0
J = XK(398) + 0.0001
M = XK(399) + 0.0001
N = XK(400) + 0.0001
DO 100 I = J, M, N
WH2026(I) = (XK(I + 325)/325) - XK(I + 325)
100 CONTINUE

REM*****BEGIN INITIALIZATION OF SECONDARY LOOP COMPONENTS*****
REM FIRST INITIALIZE CONSTANT LOCATIONS
DO 110 I = J, M, N
REM INITIALIZE SEC BP VLV STAT POS TO INITIAL DYNAMIC VALUE
XK(I+365)=XK(I+374)
RTST=XK(I+331)
DIDEGI(RTST,A10,TTEST)
XK(I+374)=TTEST
XK(I+381)=(1./XK(I+5))
REM SET REG HOT INLET = COND GLY OUT
110 XK(I+391)=XK(I+388)
REM SET REG COLD INLET = RAD OUTLET
STFSQS(T618,A1,K890)
STFSQS(T636,1,K891)
STFSQS(T654,1,K892)
REM TIME STEP
STFSQS(.002,K913,A50+1)
REM NOW SOLVE SYSTEM IN STEADY STATE
DO 300 I = J, M, N
TF(I-2) = 120, 130, 140
300 CONTINUE

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SD 70-266
120  D3DEGl(K890,K896,K6,A38,RTEST)
     D1DEGl(K890,A3,STEST)
     D1DEGl(K896,A3,TTEST)
GO TO 145
130  D3DEGl(K891,K897,K7,A38,RTEST)
     D1DEGl(K891,A3,STEST)
     D1DEGl(K897,A3,TTEST)
GO TO 145
140  D3DEGl(K892,K898,K8,A39,RTEST)
     D1DEGl(K892,A3,STEST)
     D1DEGl(K898,A3,TTEST)
145  FLOWC=(1.-XK(I+374))*XK(I+5)
     UA=RTFST
     CPC=STFST
     CPH=TTEST
     BETA=CC/CH
     RNTU=UA/CC
     ET=EXP(-RNTU*(1.-BETA))
     EFF=(1.-ET)/(1.-BETA*ET)
     RTFST=EFF
     STFST=EFF
     TTEST=EFF
     UT=FLOWC*67.*XK(361)
GO TO 150
147  VTEST=1000.
150  CONTINUE
155  IF(I=2) 155,160,165
     STFSQS(RTEST,K912,K914,A66+1)
     STFSQS(STEST,K912,K912,A67+1)
     STFSQS(TTEST,K912,K912,A68+1)
     STFSQS(UTEST,K912,K912,A69+1)
     STFSQS(VTEST,K912,K912,A78+1)
GO TO 170
160  STFSQS(RTEST,K912,K912,A70+1)
     STFSQS(STEST,K912,K912,A71+1)
     STFSQS(TTEST,K912,K912,A72+1)
     STFSQS(UTEST,K912,K912,A73+1)
     STFSQS(VTEST,K912,K912,A78+1)
GO TO 170
165  STFSQS(RTEST,K912,K912,A74+1)
     STFSQS(STEST,K912,K912,A75+1)
     STFSQS(TTEST,K912,K912,A76+1)
     STFSQS(UTEST,K912,K912,A77+1)
     STFSQS(VTEST,K912,K912,A80+1)
170  CONTINUE
    RFM INITIALIZE REMAINDER OF CONSTANTS
    REM COND GLY IN = REG COLD OUT
    XK(I+403)=XK(I+377)
    REM INITIALIZE REMAINING ARRAYS
    IF(I=3) 200,210,220
200  STFSQS(K890,K914,A51+1) $RAD OUT
     STFSQS(K890,K912,A54+1) $REG COLD IN
     STFSQS(K879,K912,A57+1) $BP VLV FRAC
     STFSQS(K893,K915,A60+1) $COND GLY OUT
     STFSQS(K893,K912,A63+1) $REG HOT IN
     STFSQS(K899,K914,A81+1) $REG HOT OUT
GO TO 230
210  STFSQS(K891,K914,A52+1)
       STFSQS(K891,K912,A55+1)
       STFSQS(K890,K912,A58+1)
       STFSQS(K894,K915,A61+1)
       STFSQS(K944,K912,A64+1)
       STFSQS(K900,K914,A82+1)
       GO TO 230

220  STFSQS(K892,K914,A53+1)
       STFSQS(K892,K912,A56+1)
       STFSQS(K895,K912,A59+1)
       STFSQS(K895,K912,A61+1)
       STFSQS(K901,K914,A83+1)

230 CONTINUE
       REM END OF INITIALIZATION LOOP*****************************

300 CONTINUE
       VARBL2 $ ANALYZE PRESSURE NETWORK AND OBTAIN FLOW RATES
       CNFRWD $ PERFORM TRANSIENT ANALYSIS

COMMON/ALPHA/ W2026(3)      F
COMMON/BRAVO/QCONO(3),DMASS(3),W230(13)    F
COMMON/CHARLIE/J,M,N            F
COMMON/FOXTROT/ PCK04(3)       F
DIMENSION SVOL1I3),W202P(3),PRES3I3),SVOL3I3),
       W2030I3),SVOL2I3),DSPVOL(3),SFCH2I3),SFCD2I3),
       QGENATI3),QH2I3),QO2I3),OELECTI3),PARPH2I3),SVOL32I3),
       W2DCP2I3),QRSI3),QSTORDI3),SVOL2I3),QSI3),
       QRFACI3),QH2O(3),QOUTI3),QINI3),DELTAQI3),
       TSKIN1I3),TFS013),TSKIN2I3),WH202DI3),DIFFI3),
       W2DCP1I3),W2025I3)

DIMENSION XKI3)

EQUIVALENCE (XKI3),K13)

REM INTERPOLATE DO LOOP INDEX ARRAYS

       D1DEG1TIMI3),A26,K902) $ J
       D1DEG1TIMI3),A27,K903) $ M
       D1DEG1TIMI3),A28,K904) $ N

REM CHANGE INDICES FROM FLOATING POINT TO INTEGER
       FIX(K902,K26)      $ J
       FIX(K903,K28)      $ M
       FIX(K904,K32)      $ N

J=K(26) F
M=K(28) F
N=K(32) F

DO 667 I = 1, 3
  667 XKI3) = 469) = XKI3) + 51
DO 668 I = 1, 3
  668 XKI3) = 0.0001
DO 669 I = J, M, N
  669 XKI3) = 469) D1DEG1TIMI3),A41,K854) $ SYSTEM 1
       D1DEG1TIMI3),A44,K855) $ SYSTEM 2
       D1DEG1TIMI3),A43,K856) $ SYSTEM 3

DO 500 I = J, M, N
  500 DT = 10.
IF (I - 2) 1, 2, 3
  1 D1DEG2(K836, A39, K920)
  2 D1DEG2(K837, A39, K921)
  3 D1DEG2(K838, A39, K922)
GO TO 4
  4 D1DEG2(K837, A40, K930)
  5 D1DEG2(K838, A40, K934)
Space Division
North American Rockwell

CONTINUE

SVOL1(I) = XK(I+425)

DRATE = 0.05

IOLD = 1

DO 90 JJ = 1, 100

WH202P(I) = XK(I+349)*XK(I+349)*DTIMEU

WH2025(I) = WH2026(I) + XK(I + 345)*WH202P(I)

PCKOH(I) = XK(I+325)/XK(I+325) + WH2025(I)

XK(I+424) = PCKOH(I)

IF (I - 2) .LT. 22 .OR. 23

GO TO 24

22 D2DEG2(K929, K847, A44, K926)

GO TO 24

23 D2DEG2(K931, K849, A44, K928)

CONTINUE

PRES3LI) = XK(I+421)

SVOL3LI) = (XK(335)*XK(I+342) + 460.)/(PRES3LI)*144.)

DMASS(I) = (1.0 - XK(I+345))*WH202P(I)

WH2030(I) = XK(I+336)*DTIMEU/SVOL3LI)

WH2020(I) = WH2030(I) - DMass(I)

SVOL21(I) = (X) + 336)*DTIMEU/WH2021(I)

DSPVOL(I) = SVOL21(I) - SVOL21(I)

IF (ABSDSPVOL(I) - XK(353)) .EQ. 100, 100, 35

IF (DSPVOL(I)) .EQ. 45, 100, 50

MULT = 1

INEW = IOLD

IOLD = -1

GO TO 60

50 MULT = -1

INEW = IOLD

IOLD = 1

GO TO 60

XK(I+345) = XK(I + 345) + DRATE*MULT

IF (INEW - IOLD) 70, 90, 70

70 DRATE = DRATE/2.0

CONTINUE

WRITE (6, 95) F

95 FORMAT (79H ITERATIVE SCHEME DID NOT FIND A SOLUTION WITHIN SPECIFIED NUMBER OF ITERATIONS) F

CONTINUE

WH2026(I) = WH2026(I)

XK(I+353) = XK(I+353) - 24.1*(.75 - PCKOH(M)

XK(I+349) = XK(I+349) + 3.43*(XK(I+342) - XK(I+463))

QGENAT(I) = 5.1600*SFCh2(I)

QH2(I) = SFCh2(I)*3.43*XK(I + 342) - XK(I + 463)

QFLECT(I) = 3.41276*XK(I+349)*XK(I+342) - 1.292758E-2*XK(I+342)**2

PARPH2(I) = 60. - PRES3LI)

SVOL32(I) = (XK(336)*XK(I + 342) + 460.)/(PARPH2(I)*144.)

WDTCP1(I) = (XK(I+336)/SVOL31(I))*0.445

WDTCP2(I) = (XK(I+336)/SVOL32(I))*0.48

QRS(I) = (WDTCP1(I)*WDTCP2(I))*XK(I+342) - XK(I+339))

QSM(I) = 3.25*XK(I + 342) - 1.6*XK(I + 439) - 882.

QSTORO(I) = QGENAT(I) - QH2(I) - QD2(I) - QFLECT(I) - QRS(I) - QSM(I)

XK(I+342) = XK(I+342) + (QSTORO(I)*DTIMEU)/XK(358)
SVOL12(I) = (XK(336)+XK(I+331)+460.)/PARK2(I)*144.1

WTH230(I) = (XK(I+336)+SVOL12(I)-XK(I+349)+XK(I+443))*DTIMEU

QREACT(I) = (XK(I+445)*DMAS11(I))/DTIMEU +

1 + DMAS11(I)*DMAS11(I)/DTIMEU

QH27(I) = (DMAS11(I)*XK(I+31)-XK(I+439))/1.0/DTIMEU

CONST1 = 3.44*WTH230(I)/DTIMEU * XK(I+336)/XK(I+415)*1.0

1

CONST2 = 1.60*DMAS11(I)/DTIMEU

CONST3 = ((XK(I + 336)/SVOL12(I))*3.44 + XK(I + 349))/1.0

1

1

CONST4 = -1.2*XK(I + 339) - 882.

XK(I*450) = XK(I + 339) - (XK(I + 339) - XK(I + 331))*CONST3

QCOND2(I) = (XKII + 371) - XKII + 331)*CONST1 + CONST2

QOUT(I) = QREACT(I)

QIN(I) = QCOND2(I) + QH27(I) + QSECT(I) + QS32(I) + QSTOR32(I)

DELTAG(I) = QOUT(I) - QIN(I)

IF (ABSDELTAG(I) - XKU + 339)) 180, 180, 165

165 IF (ABSQH27 - XK(I + 339)) 180, 180, 165

168 DT = -DT/2.

CONTINUE

18C CONTINUE

XK(I + 345) = DMAS11(I)/DTIMEU

XK(I + 345) = XK(I + 345)/100.

50C CONTINUE

REM INTERPOLATE BYPASS OPTION ARRAY

DIPEG(TIME, A35, K905) $ SYSTEM 1

DIOFG(TIME, A36, K906) $ SYSTEM 2

DIPEG(TIME, A37, K907) $ SYSTEM 3

REM CHANGE BYPASS FROM FLOATING POINT TO INTEGER

FIX(K905, K9) $ SYSTEM 1

FIX(K906, K10) $ SYSTEM 2

FIX(K907, K11) $ SYSTEM 3

REM INTERPOLATE HEAT FLUX ARRAYS

RTEST = TIME

IF (TIME < 1.55) RTEST = TIME - 1.55*FLOAT(1/FIX(TIME/1.55))

1

D1ICY(K600, RTFST, A13, K12) $ PANEL 1

D1ICY(K600, RTFST, A14, K13) $ PANEL 2

D1ICY(K600, RTFST, A15, K14) $ PANEL 3

D1ICY(K600, RTFST, A16, K15) $ PANEL 4

D1ICY(K600, RTFST, A17, K16) $ PANEL 5

D1ICY(K600, RTFST, A18, K17) $ PANEL 6

D1ICY(K600, RTFST, A19, K18) $ PANEL 7

D1ICY(K600, RTFST, A20, K19) $ PANEL 8

REM APPLY INCIDENT HEAT

REM

ARYMPY(K20, A12+1, K12, Q701) $ PANEL 1

ARYMPY(K20, A12+1, K13, Q725) $ PANEL 2

ARYMPY(K20, A12+1, K14, Q749) $ PANEL 3

ARYMPY(K20, A12+1, K15, Q773) $ PANEL 4

ARYMPY(K20, A12+1, K16, Q797) $ PANEL 5

ARYMPY(K20, A12+1, K17, Q821) $ PANEL 6

ARYMPY(K20, A12+1, K18, Q845) $ PANEL 7

ARYMPY(K20, A12+1, K19, Q869) $ PANEL 8

REM

REM BUILD A TEMPERATURE ARRAY TO EVALUATE THERMAL FLUID FLOW COND

REM

BLDARY(A9+1, T601, T602, T603, T604, T605, T606, T607, T608, T609

T610, T611, T612, T613, T614, T615, T616, T617, T618

T619, T620, T621, T622, T623, T624, T625, T626, T627

BLDARY(A9+28, T628, T629, T630, T631, T632, T633, T634, T635, T629

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SD 70-266
REM COMPUTE (K-FACTOR)/2*(DENSITY*(A**2))
D1M1(A0,A0+1,A1,K701,A23+1)
DIVARY(A23,G501,A22+1,G501)
ADDARY(A23,A23+1,G501,G501)
REM - ALL CONSTANTS FOR PRESSURE DROP HAVE BEEN COMPUTED -- SUM
REM FOR RESPECTIVE SYSTEMS AND SOLVE FOR DLP
REM
REM IN THE FOLLOWING SYSTEMS COMPRESSIONS A FLAG HAS BEEN SET
REM TO INDICATE FLOW DIRECTION THROUGH THE BYPASS VALVES -- THE
REM SYSTEM COMPLIANCE IS CALCULATED ACCORDINGLY
REM
REM FLAG FOR SYSTEM 1 = K9 (O-RADIATOR + 1-BYPASS)
REM FLAG FOR SYSTEM 2 = K10 (O-RADIATOR + 1-BYPASS)
REM FLAG FOR SYSTEM 3 = K11 (O-RADIATOR + 1-BYPASS)
REM
REM COMPRESS PRESSURE NETWORK FOR SYSTEM 1
REM
SUMARY(K3,G501,K582)
SUMARY(K4,G516,K583)
IF(K9.EQ.0).K(117)=K(116) F
IF(K9.EQ.1)KK(117)=G(86) F
ADD(K582,K584,G526,K595)
REM
REM COMPRESS PRESSURE NETWORK FOR SYSTEM 2
REM
SUMARY(K3,G528,K586)
SUMARY(K4,G543,K587)
IF(K10.EQ.0)K(121)=K(120) F
IF(K10.EQ.1)KK(121)=G(113) F
ADD(K586,K588,G553,K589)
REM
REM COMPRESS PRESSURE NETWORK FOR SYSTEM 3
REM
SUMARY(K3,G555,K590)
SUMARY(K4,G570,K591)
IF(K11.EQ.0)K(125)=K(124) F
IF(K11.EQ.1)K(125)=G(140) F
ADD(K590,K592,G580,K593)
SCALE(K25,K585,K585,K589,K593,K593)
ARINDV(3.K6.1.KB21) $INVERT FLOW RATES
REM
SAVE TIME STEP
REM FIRST TIME STEP, DTIMEU=0., SO DON'T STORE IT
IF(DTIMEU.EQ.0) GO TO 5 F
SLPARY(1.0,1.50)
5 CONTINUE F
DD 700 I=J,M,N
IF(I-2) 10,11,12 F
10 SLPARY(T618,A51)
D1DEG1(T618,A1,RTEST)
MLTPLY(K821,RTEST,K864,TTEST)
DELAY1(A50,A51,TTEST,K890,ITEST)
SLPARY(K890,A54)
ARYST0(K912,VTEST,A57+1)
GO TO 13 F
11 SLPARY(T636,A52)
D1DEG1(T636,A1,RTEST)
MLTPLY(K822,RTEST,K864,TTEST)
DELAY1(A50,A52,TTEST,K891,1TEST)
SLPARY(K891,A55)
ARYST0(K912,VTEST,A58+1)
GO TO 13 F
12 SLPARY(T654,A53)
D1DEG1(T654,A1,RTEST)
MLTPLY(K823,RTEST,K864,TTEST)
GO TO 13 F
DELAY (A50, A53, TTEST, K892, ITEST)
SLPARY (K92, A55)
ARYST0 (K92, VTEST, A59+1)

13 CONTINUE

REM DETERMINE BYPASSED FRACTION
RTEST = XK(1+351)
STFST = XK(1+365)
VTEST = XK(1+456)
IF (K(1+369) < 20, 30, 30)

20 IF (RTEST .LE. TTEST) GO TO 35
25 DI0EG1 (RTEST, A10, UTEST)
IF (UTEST .LE. VTEST) GO TO 39
K(I+369) = 1
DI0EG1 (RTEST, A10, UTEST)
VTEST = UTEST
GO TO 39

30 IF (RTEST .GE. TTEST) GO TO 25
35 DI0EG1 (RTEST, A11, UTEST)
IF (UTEST .GE. VTEST) GO TO 39
K(I+369) = -1
DI0EG1 (RTEST, A11, UTEST)
VTEST = UTEST
GO TO 39

39 CONTINUE

XK(1+456) = VTEST
IF (1-2) 40, 41, 42

40 SLPARY (VTEST, A57)
CNVLTN (A50, A57, 0, 2, K879)
GO TO 43

41 SLPARY (VTEST, A58)
CNVLTN (A50, A58, 0, 2, K880)
GO TO 43

42 SLPARY (VTEST, A59)
CNVLTN (A50, A59, 0, 2, K881)

43 CONTINUE

REM DETERMINE COLD SIDE REGENERATOR FLOW
FLORG = (1. - XK(1+374)) * XK(1+5)
REM DETERMINE REGENERATOR COLD SIDE DELAY
REM IF RP FRACTION IS LARGE, SET FLORG TO A SMALL FINITE VALUE
IF (XK(1+381) > 0.001) FLORG = 1.0 - XK(1+381) * XK(1+5)
TTEST = (XK(1+385) + XK(1+377)) / 2.
DI0EG1 (TTEST, A1, RTEST)
TTEST = XK(385) * (1.0 - FLORG) * RTEST * XK(361)
REM SLIDE DELAY INTO ARRAY AND DETERMINE DELAY, COND. OUTLET TO
REM REGEN HOT INLET
IF (1-2) 70, 80, 90

70 SLPARY (TTEST, A78)
DI0EG1 (K893, A1, RTEST)
MLTPLY (K821, RTEST, K867, TTEST)
TTEST = TTEST - DTIME
REM DELAY (A50, A60, TTEST, K896, ITEST) DELETED DUE TO INSTABILITY
CNVLTN (A50, A60, 0, 2, K896)
XK(392) = XK(392) + 460.
XK(464) = XK(460) + (XK(392) - XK(460)) * .53 + .002 * XK(6) + .018
1 XK(462)

DH = (XK(460) - XK(464)) * (.152 + .000225 * (XK(464) + XK(460)))
1 * XK(462) / XK(6)
X = 116440.5 + 2401.364 * DH + XK(392) * (682.4676 + XK(392))
TON = SQRT (X) - 341.2338
XK(461) = XK(461) + .75 * TON + XK(461)
DH = (XK(461) - XK(467)) * 3.47 * XK(461) / XK(6)
X = 116440.5 + 2401.364 * DH + TON * (682.4676 + TON)
XK(392) = SQRT (X) - 341.2338 - 460.
XK(464) = XK(464) - 460.
XK(467) = XK(467) - 460.

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GO TO 100

SLPARY(K896,A63)

SLPARY(TTEST,A79)
D1DEGI(K894,A1,RTEST)
MLTPLY(K823,RTEST,K897,TTEST)
TTEST=TTEST-OTIMEU

 REM DELAY (A50,A61,TTEST,K897,TTEST) DELETED DUE TO INSTABILITY
CNVLTN(A50,A61,0.2,K897)
XK(393) = XK(393) + 460.
XK(465) = XK(460) + (XK(393) - XK(460)) * 1.53 + .002 * XK(7) + .018 * F
1 XK(462)
DH = (XK(460) - XK(465)) * (.152 + .0000225 * (XK(465) + XK(460)))
F
X = 116440.5 + 2401.364 * DH + XK(393) * (682.4676 + XK(393))
F
TDW = SQRT(X) - 341.2338
F
XK(469) = XK(461) + .75 * (TDW - XK(461))
F
DH = (XK(461) - XK(469)) * 3.47 * XK(463) / XK(7)
F
X = 116440.5 + 2401.364 * DH + TDW * (682.4676 + TDW)
F
XK(393) = SQRT(X) - 341.2338 - 460.
F
XK(465) = XK(465) - 460.
F
XK(468) = XK(468) - 460.
F
SLPARY(K896,A63)
GO TO 100

SLPARY(TTEST,A80)
D1DEGI(K895,A1,RTEST)
MLTPLY(K823,RTEST,K897,TTEST)
TTEST=TTEST-OTIMEU

 REM DELAY (A50,A62,TTEST,K898,TTEST) DELETED DUE TO INSTABILITY
CNVLTN(A50,A62,0.2,K898)
XK(394) = XK(394) + 460.
XK(466) = XK(460) + (XK(394) - XK(460)) * 1.53 + .002 * XK(8) + .018 * F
1 XK(462)
DH = (XK(460) - XK(466)) * (.152 + .0000225 * (XK(466) + XK(460)))
F
X = 116440.5 + 2401.364 * DH + XK(394) * (692.4676 + XK(394))
F
TDW = SQRT(X) - 341.2338
F
XK(469) = XK(461) + .75 * (TDW - XK(461))
F
DH = (XK(461) - XK(469)) * 3.47 * XK(463) / XK(8)
F
X = 116440.5 + 2401.364 * DH + TDW * (682.4676 + TDW)
F
XK(394) = SQRT(X) - 341.2338 - 460.
F
XK(465) = XK(465) - 460.
F
XK(469) = XK(469) - 460.
F
SLPARY(K898,A65)

GO TO 100

CONTINUE

 REM COMPUTE REGEN HOT SIDE DELAY
TTEST=(XKII+394) + XK(II+391) / 2.
D1DEGI(TTEST,A1,RTEST)
XK(391) = XK(385) * XK(II+316) * RTEST * XK(1364)
F
REM FIND TERMINAL ENTHALPIES AND UA OF EACH REGENERATOR
F1F(1-2) 110,120,130

110 D3DEGI(K890,K896,K6,A38,RTEST) $UA
D1DEGI(K896,A24,STEST) $HH1
D1DEGI(K899,A24,TTEST) $HH2
D1DEGI(K890,A24,UTEST) $HC1
D1DEGI(K822,A24,VTEST) $HC2
GO TO 140

120 D3DEGI(K891,K897,K7,A38,RTEST) $UA
D1DEGI(K897,A24,STEST) $HH1
D1DEGI(K900,A24,TTEST) $HH2
D1DEGI(K891,A24,UTEST) $HC1
D1DEGI(K883,A24,VTEST) $HC2
GO TO 140

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CONTINUE

REM COMPUTE TEMPERATURE AND ENTHALPY DROPS ON EACH SIDE
UA=PTEST
HH1=STEST
HH2=TTEST
HC1=UTEST
HC2=VTFST
DHH=ABS(HH1-HH2)
DHC=ABS(HC1-HC2)
DTH=ABS(XK(1+391)-XK(1+394))
DTC=ABS(XK(1+385)-XK(1+377))
CC=FLORGC*(1./DTC)*DHC
CH = XM I«-5)*(1./DTH)*OHH
BETA=CC/CH
RNTU=UA/CC
ET=EXP(-RNTU*(1.-BFTA))
FFFF=1./ET
REM COMPUTE REGEN GAINS BASED ON REGEN INLET CONDITIONS
RTEST=1.-EFF
STEST=EFF
TTEST=EFF*BETA
UTFST=1.-TTEST
REM SLIDE GAIN CONSTANTS INTO ARRAYS AND
REM DETERMINE TRANSIENT OUTLET TEMPS
FOR I=1,2 150,160,170
SLPARY(RTEST,A66) 150
SLPARY(STEST,A67) 150
SLPARY(TTEST,A68) 150
SLPARY(UTFST,A69) 150
DELAY2(A50,A54,A79,VTEST,JTEST) 150
CNVLTE(A50,A54,A66,JTEST,1,RTEST) 150 $OUTPUT T11
CNVLTE(A50,A63,A67,0,1,STEST) 150 $OUTPUT T12
DELAY1(A50,A63,A33,VTEST,JTEST) 150
CNVLTE(A50,A54,A68,0,1,TTEST) 150 $OUTPUT T21
CNVLTE(A50,A63,A69,JTEST,1,UTEST) 150 $OUTPUT T22
VTFST=TTEST+UTEST
SLPARY(VTEST, A81) 150
GO TO 180 150

160 SLPARY(RTEST,A70) 160
SLPARY(STEST,A71) 160
SLPARY(TTEST,A72) 160
SLPARY(UTFST,A73) 160
DELAY2(A50,A55,A79,VTEST,JTEST) 160
CNVLTE(A50,A55,A70,JTEST,1,RTEST) 160 $OUTPUT T11
CNVLTE(A50,A64,A71,0,1,STEST) 160 $OUTPUT T12
DELAY1(A50,A64,A33,VTEST,JTEST) 160
CNVLTE(A50,A55,A72,0,1,TTEST) 160 $OUTPUT T21
CNVLTE(A50,A64,A73,JTEST,1,UTEST) 160 $OUTPUT T22
VTEST=TTEST+UTEST
SLPARY(VTEST, A82) 160
GO TO 180 160

170 SLPARY(RTEST,A74) 170 $SYSTEM 3
SLPARY(STEST,A75) 170
SLPARY(TTEST,A76) 170
SLPARY(UTFST,A77) 170
DELAY2(A50,A56,A80,VTEST,JTEST) 170
CNVLTE(A50,A56,A74,JTEST,1,RTEST) 170 $OUTPUT T11
CNVLTE(A50,A65,A75,0,1,STEST) 170 $OUTPUT T12
DELAY1(A50,A65,A33,VTEST,JTEST) 170
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VAR RTEST,A76,0,1,UTEST)
$OUTPUT T21
CNVLTE(A50,A56,A76,0,1,UTEST)
CNVLTE(A50,A65,A77,TEST,1,UTEST)
$OUTPUT T22

VTENS=TEST+UTEST
SLPARY(VTEST,A83)
REM COLD + HOT TRANSIENT OUTLET TEMPS
140 X(1)+377)=TEST+STEST
X(1)+394)=TEST+UTEST
TEST=((X(1)+391)+X(1)+394)/2.
TEST=((X(1)+377)+X(1)+385)/2.
DIDEGL(TEST,A3,VTEST)
X(1)+377)=X(1)+385)+((X(1)+391)-X(1)+394)*UTEST)/
I ((1.-X(1)+374))*TEST)
IF(X(1)+377),GT,X(1)+391)) X(1)+377)=X(1)+391)
X(1)+377)=(X(1)+377)+(X(1)+322)/2.
X(1)+322)=X(1)+377
REM COMPUTE DELAY TO RAD INLET AND SET RAD INLET TEMP
IF(I-1) 190,200,210
190 DIDEGL(K899,A1,TEST)
MLTPLY(K821,TEST,K969,TTEST)
DELAY(A50,A81,TTEST,T601,TTEST)
GO TO 220
200 DIDEGL(K900,A1,TEST)
MLTPLY(K822,TEST,K969,TTEST)
DELAY(A50,A82,TTEST,T619,TTEST)
GO TO 220
210 DIDEGL(K901,A1,TEST)
MLTPLY(K823,TEST,K969,TTEST)
DELAY(A50,A83,TTEST,T637,TTEST)
220 CONTINUE
REM COMPUTE CONDENSER INLET TEMP
IF(X(1)+374),GT,X(1)+381) GO TO 290
RTEST=X(1)+385
STEST=X(1)+377
DIDEGL(UTEST,A24,TTEST)
DIDEGL(TEST,A24,TTEST)
DIDEGL(UTEST,A24,TTEST)
DIDEGL(UTEST,A49,TTEST)
TEMP OUT OF VALVE
X(1)+3403)=RTEST
GO TO 300
290 X(1)+3403)=X(1)+385
300 CONTINUE
IF(INDEX2) 450,450,301
301 INDEX2 = 1
DTMP=X(1)+447
ITSN=X(1)+331
X(1)+365)=X(1)+331
310 T20LD=X(1)+331
T30LD=X(1)+331
1FF=1 320,330,340
320 DIDEGL(K908,A24,TEST)
DIDEGL(K993,A24,TEST)
GO TO 350
330 DIDEGL(K909,A24,TEST)
DIDEGL(K894,A24,TEST)
GO TO 350
340 DIDEGL(K910,A24,TEST)
DIDEGL(K989,A24,TEST)
350 CONTINUE
IF(INDEX2) 100) 354,354,445
354 QGLY=XX(I)+5)*(TEST-TEST)
QGAS=XX(I)+371)XX(I)+331)
351 QGAS=DTGAS*(3.44*WTH230(I)/DTIMEU+XX(I)+336)/XX(I)+415)*1.01F
I+(O1MASS(I)*1150.+O1MASS(I)*DTGAS*1.01/DTIMEU

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North American Rockwell

```fortran
152 XK(1 + 331) = XK(1 + 388) - XK(1 + 316) * (4.97297949 +
1 * 0.0074969198 * QGAS + 9.0145E-7 * QGAS ** 2)
1 IF (ARS(IOGLY - QGAS), LT, XK(407)) GO TO 450
1 ISGNV = ISGN
1 IF (QGAS, LT, QGAS) ISGN = 1
1 IF (QGAS, GT, QGAS) ISGN = -1
1 TINCR = DTEMP * ISGN
1 IF (ISGN, EQ, ISGNV) GO TO 440
1 XK(I + 331) = T20LD
1 XK(I + 388) = T40LD
1 DTEMP = DTEMP / 2.0
1 INDEX2 = INDEX2 + 1
1 GO TO 310

440 XK(I + 388) = XK(I + 398) + TINCR
1 INDEX2 = INDEX2 + 1
1 GO TO 310

445 WRITE (6, 446)
446 FORMAT (1H0, 74HC
1 IE0 NUMBER OF ITERATIONS)

450 QCOND(1) = QGAS
1 IF (I - 2) 451, 452, 453
1 SLPARY(KA93, A601)
1 GO TO 750
1 SLPARY(KA94, A611)
1 GO TO 750
1 SLPARY(KA95, A621)
1 REM END OF LOOP******************************

700 CONTINUE
1 INDEX1 = 1
1 REM**********************************************************************************************
1 END

ACD OUTPUT CALLS
COMMON/FRADVO/QCOND(3), DMAS5(3), MTH230(3)
COMMON/CHARLE/ J, £, N
COMMON/ECHO/ IPOINT
COMMON/FRXVTR/ PCKOH(3)
DIMENSION ATEMP(50)
DIMENSION XK(1)
DIMENSION CRTAR1(200), CRTAR2(200), CRTAR3(200), CRTAR4(200),
1 CRTAR5(72), CRTAR6(72), CRTAR7(63)
DIMENSION DATE(21)
DATA (111, 1)/
DATA CRTARS/ 'MISS', 'TON', 'TIME', ' - ', 'MIN', '13*', ' '/
DATA CRTARS/ 'SYST', 'EM T', 'EMPE', 'RATU', 'RES', ' - ', 'DEG', '1
1 * ', 'ID* ', '1/1
EQUIVALENCE (XK(1), K(1))
CALL CAMRAV(9)
TIME = 0.0
DO 100 N1 = 1, 63
CRTAR7(N1) = TIME
TIME = TIME + 3.0
100 CONTINUE

REM SOLVE FOR RADIATOR PRESSURE DROP
MLTPLY(K6, K5, K595, K682) $ RAD P PRESS DROP FOR SYSTEM 1
MLTPLY(K7, K7, K598, K683) $ RAD P PRESS DROP FOR SYSTEM 2
MLTPLY(K8, K9, K593, K684) $ RAD P PRESS DROP FOR SYSTEM 3
DIDEK1(K6, 62, 684, K6) $ FLOW RATE - SYSTEM 1
DIDEK1(K6, 62, 684, K7) $ FLOW RATE - SYSTEM 2
DIDEK1(K6, 62, 684, K8) $ FLOW RATE - SYSTEM 3

REM FLUID HEAT LOSS FOR SYSTEM 1
QWTR(16, A9+, G401, A25+11)
REM FLUID HEAT LOSS FOR SYSTEM 2
QWTR(16, A9+19, G619, A25+17)
```

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REM FLUID HEAT LOSS FOR SYSTEM 3
QMTRI(16, A9+37, G637, A25+33)
IF(K(9).EQ.1) GO TO 1
SUMARY(16, A25+1, K801)
GO TO 2
1 CONTINUE
SUMARY(10, A25+1, K801)
2 IF(K(10).EQ.1) GO TO 3
SUMARY(16, A25+17, K802)
GO TO 4
3 CONTINUE
SUMARY(10, A25+17, K802)
4 IF(K(11).EQ.1) GO TO 5
SUMARY(16, A25+33, K803)
GO TO 6
5 CONTINUE
SUMARY(10, A25+33, K803)
6 CONTINUE
CALL DATOUT
WRITE(6,11)
11 FORMAT(5X,99HSYSTEM POWER CURRENT VOLTAGE TSI TSE F
1 TCIP TCEP WC-COND WC-RATE, 3X, F
2 12H02 TH2) F
WRITE(6,12) F
12 FORMAT(14X,99HWATTS AMPS VOLTS DEGF DEGF DEGF DEGF F
1 DEGF BTU/HR LB/HR PERCENT, 3X, 12H02 DEGF DEGF, /) F
DO 13 I=J,M,N F
13 WRITE(6,14) I, XK(I+412), XM(I+349), XK(I+353), XKU+339), F
2 XK(I+342), XKU+450, F
WRITE (6, 15) F
15 FORMAT I//7X,120HPANEL I PANEL 2 PANEL 3 PANEL 4 PANEL 5 PANEL 6 PANEL 7 PANEL 8, /, 5X, 123HIN OUT IN OUT IN OUT IN OUT, /) F
DO 21 II = 73, 200 F
21 ATEMPU1) = T(I) F
DO 22 12 = 73, 224 F
22 ATEMPU2) = T(I) F
00 23 13 = 225, 240 F
23 ATEMPU3) = T(13) F
WRITE (6, 25) IATEMPIKT), KT = I, 16) F
WRITE (6, 25) (ATEMP(KT), KT = 17, 32) F
WRITE (6, 25) (ATEMP(KT), KT = 33, 48) F
25 FORMAT (IX, 16F8.1) F
5P = 125 F
CRTAR1(POINT) = XK(343)
CRTAR2(POINT) = XK(332)
CRTAR3(POINT) = T(244)
CRTAR4(POINT) = T(241)
IF (POINT.EQ.NP) GO TO 30
POINT = POINT + 1
GO TO 50
30 CONTINUE
IF (ITIT.EQ.0) CALL DATEV(DATE)
IF (ITIT.GT.0) GO TO 50
CALL GRF3TV(-1,38,CRTAR5,CRTAR6,-63,CRTAR7,CRTAR1(1),200.,0.,
1 500.,0.,1)
CALL RITE2V(331,1010,1023,90,2,20,1,'SYSTEM 1 - 30 AMPS',IRLY)
CALL PRINTV8,DATE,943,995)
CALL GRF3TV(3,63,CRTAR5,CRTAR6,-63,CRTAR7,CRTAR7(1),200.,0.,
1 500.,0.,1)
CALL GRFSTV0,55,CRTAR5,CRTAR6,-63,CRTAR7,CRTAR3(11),200.,0.,
1 500.,0.,1)
CALL GRFSTV0,44,CRTAR5,CRTAR6,-63,CRTAR7,CRTAR4(11),200.,0.,
1 500.,0.,1)
CALL GRFSTV-1,38,CRTAR5,CRTAR6,-63,CRTAR7,CRTAR1(63),200.,0.,
1 500.,0.,1)
CALL RITE2V(331,1010,1023,90,2,20,1,'SYSTEM 1 - 25 AMPS',IRLY)
CALL PRINTV8,DATE,943,995)
CALL GRFSTV0,63,CRTAR5,CRTAR6,-63,CRTAR7,CRTAR2(63),200.,0.,
1 500.,0.,1)
CALL GRFSTV0,55,CRTAR5,CRTAR6,-63,CRTAR7,CRTAR3(63),200.,0.,
1 500.,0.,1)
CALL GRFSTV0,44,CRTAR5,CRTAR6,-63,CRTAR7,CRTAR4(63),200.,0.,
1 500.,0.,1)
ITIT = 2
50 CONTINUE
END
USER SUBROUTINE LISTINGS

0001 SUBROUTINE CNVLTN(DT,VI,NST,NFC,V2)
0002 DOUBLE PRECISION DTDP,DTNS,VI,J,VIJP1,VAV,TMT,TMT0,V2DP,XSFER,
0003 SCALE,RISB,RMXSB
0004 DIMENSION DT(1),VI(1)
0005 EQUIVALENCE(D,N)

C VI MUST BE DIMENSIONED NOT LONGER THAN
C (DIMENSION OF DT)+1

C
0006 D = DT(1)
0007 IDT = N
0008 D = VI(1)
0009 IV1 = N
0010 NT = IDT+1-IV1
0011 IF(NT) 169,5,5
0012 NST = IOT+1
0013 25 V2DP = 0.0000
0014 TMT = 0.0000
0015 "************************************************************
0016 MXSB = 10
0017 "************************************************************
0018 RMXSB = MXSB
0019 NSTM1 = NST-1
0020 DO RO I=1,NSTM1
0021 J = NST-I+1
0022 OTDP = DT(J)
0023 JS = J-NT
0024 V1J = VI(JS)
0025 VIJP1 = VI(JS+1)
0026 DTNS = OTDP/RMXSB
0027 TMTO = TMT
0028 DO 70 ISB=1,MXSB
0029 IF(ISB-1) 30,30,40
0030 TMT = TMT*0.5DO0*DTNS
0031 TMT = TMT+DTNS
0032 RISB = ISB
0033 "************************************************************
0034 SCALE = RISB/RMXSB
0035 VAW = VIJP1+(VIJP1-V1J)*SCALE
0036 70 V2DP = V2DP*XSFER(NFC,TMT)*VAV*DTNS
0037 TMT = TMT0*DTDP
0038 CONTINUE
0039 80 WRITE(6,170)
0040 170 FORMAT(43H ERROR IN DIMENSIONING OF ARRAYS FOR CNVLTN)
0041 RETURN
0042 END

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SUBROUTINE CNVLTE(DT, VI, GAIN, NST, NFCN, V2)

DOUBLE PRECISION DTDP, DTNS, VIJ, V1JP1, VAV, GJ, GJP1, GAV, TMT, TMT0, 

V2DP, XSFER, SCALF, RISR, RMXSB

DIMENSION DT(I), VI(I), GAIN(I)

EQUIVALENCE (D, N)

C

C VI AND GAIN MUST BE DIMENSIONED EQUAL LENGTH AND MAY
C NOT BE LONGER THAN (DIMENSION OF DT)+1

C

0 = DT(I)

IDT = N

0 = VI(I)

IV1 = N

0 = GAIN(I)

IG = N

NT = IDT+1-IV1

IF(NT) 169,5,5

5 NT = IDT+1-IG

IF(NT) 169,10,10

10 IF(IG-IV1) 169,1

15 IF(NST) 20,20,25

20 NST = IDT+1

25 V2DP = 0.0D0

0019 TMT = 0.0D0

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

MXSB = 10

MXSB = MXSB

NSTM1 = NST-1

DO 80 I=1, NSTM1

J = NST-I+1

DTOP = DT(J)

JS = J-NT

VIJ = VI(JS)

V1JP1 = VIJJS+1)

GJ = GAIN(JS)

GJP1 = GAINJS+1)

DTNS = DTOP/RMXSB

TMT0 = TMT

DO 70 ISB=1, MXSB

30 TMT = TMT+0.5D0*DTNS

GO TO 45

40 TMT = TMT+DTNS

45 RISR = ISB

SCALE = RISR/RMXSB

VAV = VIJP1+(VIJP1-VI1)*SCALE

GAV = GJP1+(GJP1-GJ)*SCALE

70 V2DP = V2DP+XSFER(NFCN, TMTI)*VAV*GAV*DTNS

TMT = TMT0+DTDP

80 CONTINUE

40 V2 = V2DP

CONTINUE

END

F0RMAT(43H ERROR IN DIMENSIONING OF ARRAYS FOR CNVLTE)

RETURN

END
SUBROUTINE DELAY1(TAR, ARR, TAU, VAL, INDX)

DIMENSION TAR(1), ARR(1)

EQUIVALENCE(D,N)

D = TAR(1)
ITAR = N + 1
D = ARR(1)
IARR = N + 1
JTAR = ITAR
JARR = IARR

DT = TAU - TAR(JTAR)
ITAR = JTAR + 1

IF (JTAR - 2) 100, 20, 20
JARR = JARR + 1
IF (JARR - 2) 200, 30, 30

IF (DT) 60, 60, 40

DT = DT - TAR(JTAR)
GO TO 10

INDX = JARR
VAL = ARR(JARR)
RETURN

C
C ERROR MESSAGES
C

100 WRITE (6, 101)
101 FORMAT (50H DELAY1 ERROR—TAU EXCEEDS SUM OF SAVED TIME STEPS)

200 WRITE (6, 201)
201 FORMAT (28H DELAY1 ERROR—ARR TOO SMALL)

250 WRITE (6, 250) DTIME
250 FORMAT (12H THE TIME IS , F10.5)

END

SUBROUTINE DELAY2(TAR, ARR, TAU, VAL, INDX)

DIMENSION TAR(1), ARR(1), TAU(1)

EQUIVALENCE(D,N)

D = TAR(1)
ITAR = N + 1
D = ARR(1)
IARR = N + 1
SUMDT = 0.0
TAUAVG = 0.0

J = ITAR + 1 - IARR
IF(J) 69, 10, 69

10 IF(IARR - ITAU) 69, 20, 69

20 DO 50 I = 1, ITAR
50 SUMDT = SUMDT + TAR(M)
200 TAUAV = (TAU(M) + TAU(M + 1))/2.0
201 TAUAVG = TAUAVG + TAUAV*TAR(M)

50 CONTINUE

WRITE (6, 51)
FORMAT (43H MEAN TAU OUT OF RANGE OF TAR SUM IN DELAY?)
VAL = ARR(M)
INDX = M
RETURN
WRITE (6, 70)
FORMAT (43H ERROR IN DIMENSIONING OF ARRAYS FOR DELAY?)
RETURN
END
SUBROUTINE SLARY(ARYN, ARYI)
DIMENSION ARY(I)
EQUIVALENCE (D, N)
D = ARY(1)
IC = N
GO TO 10, IC
ARY(I) = ARY(I+11)
ARY(I+11) = ARYN
RETURN
END

SUBROUTINE ARYSTOIN(X, A)
DIMENSION A(I)
X = A(N)
RETURN
END

DOUBLE PRECISION FUNCTION XSFER(NFCN, T)
DOUBLE PRECISION T
XSFER = 0.0000
C ***************
C NFCN = 1 IS SECONDARY REGENERATOR FUNCTION
IF(NFCN.NE.1) GO TO 10
IF(T.GT.0.5277D0) RETURN
XSFER = (1.0000/0.5277D-02)*DEXP(-T/0.5277D-02)
RETURN
C ***************
10 CONTINUE
C NFCN = 2 IS SECONDARY BYPASS VALVE FUNCTION
IF(NFCN.NE.2) GO TO 20
IF(T.GT.0.2833D0) RETURN
XSFER = (1.0000/0.2833D-02)*DEXP(-T/0.2833D-02)
RETURN
C ***************
20 CONTINUE
RETURN
END

SUBROUTINE DATOUT
COMMON/FIXCON/ N
COMMON/TITLE/ H
DIMENSION Nil, H(20)
N(28) = 15
N(29) = N(29) + 1
WRITE (6, 100) Nil, H
FORMAT (1H1, 116X, 4HPAGE, 2X, 17 / 4X, 121HSYSTEMS IMPROVED NUMERICAL DIFFERENCING ANALYZER * SINDA * NORTHAMERICAN ROCKWELL CORPORATION - SPACE DIVISION, //, 5X, 20A6//)
RETURN
END

SUBROUTINE HEADNG
COMMON/FIXCON/ N
COMMON/TITLE/ H
DIMENSION Nil, H(20)
N(28) = 15
N(29) = N(29) + 1
WRITE (6, 100) Nil, H
FORMAT (1H1, 116X, 4HPAGE, 2X, 17 / 4X, 121HSYSTEMS IMPROVED NUMERICAL DIFFERENCING ANALYZER * SINDA * NORTHAMERICAN ROCKWELL CORPORATION - SPACE DIVISION, //, 5X, 20A6//)
RETURN
END

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SD 70-266
SUBROUTINE GPF3TVIL,ISYM,BCDXY,NP,X,Y,XMAX,XMIN,YMAX,YMIN

GRAF3V PLOTS 1,2, OR 3 GRIDS PER PAGE IN THE SC 4020

*** NOTATION ***

L NO. OF GRAPHS PER FRAME (1, 2, OR 3).

IF L IS NEGATIVE - FRAME WILL BE ADVANCED AND NP POINTS WILL BE PLOTTED ON GRID NO. 1.

IF L IS POSITIVE - NP POINTS WILL BE PLOTTED ON GRID 2 OR 3.

IF L IS ZERO - NP POINTS WILL BE PLOTTED ON PREVIOUS GRID.

ISYM PLOTTING SYMBOL.

BCDX ALPHA-NUMERIC CHARACTERS FOR THE X AXIS, BCDY FOR THE Y AXIS. THESE ARRAYS ARE LIMITED TO 72 CHARACTERS EACH AND THE LAST ALPHABETICAL SYMBOL IS TAKEN AS THE LAST LETTER OF THE ALPHABET.

NP NUMBER OF POINTS TO BE PLOTTED.

IF NP IS NEGATIVE - THE POINTS WILL BE CONNECTED, THUS THE VALUES OF X MUST BE IN ASCENDING ORDER.

XMAX MAXIMUM VALUE OF X, YMAX MAXIMUM VALUE OF Y.

XMIN MINIMUM VALUE OF X, YMIN MINIMUM VALUE OF Y.

DIMENSION XI(500), Y(500), BCDX(18), BCDY(18)

NZ = IABS(NP)

IF NZ .EQ. 0 GO TO 60

10 IF (XR .NE. 0.0) GO TO 15

15 IF (YB .NE. 0.0) GO TO 25

20 XT = XMIN

25 YT = YMIN

30 IF (L .LT. 0) LI = 1

40 IF (L .GT. 0) LI = 2

50 IF (LI .EQ. 1) GO TO 10

60 CALL MARGIN(L, NCX)

70 CALL DX0YV(L, XI, XR, NCX, NZ, IER)

80 CALL DX0YV(L, YI, YT, NCY, NZ, IER)

90 CALL GR3TV(L, XI, XR, YI, YT, NCX, NCY, NZ, N, M, I, J, ISYM, IER)

100 CALL PRINTV(NCX, VIC, IX, IY)

110 CALL PRINTV(NCY, VIC, IX, IY)

120 CALL APLOTV(NZ, X, Y, 1, 1, 1, ISYM, IER)

130 IF (NP .GT. 0) GO TO 60

140 DO 50 KK = 1, NZ

150 NXI = NXI(XKK)

160 NXY = NYI(YKK)

170 CALL LINESV(NXI, NXY, NX, NY, NKA1)

180 CONTINUE

190 DO RETURN

200 END
SUBROUTINE MARGNR(L1,ML3)

C MARGNR SETS THE MARGINS FOR PLOTTING 1, 2, OR 3 GRIDS PER FRAME

DIMENSION L(6,3),IN(3)

DATA L /24,357,690,24,524,24,690,357,24,524,24,24,178,511,844,262,180/  
      MARG0010 MARG0020 MARG0030

IF(L1.GE.0) GO TO 10

K = -L1
N = 1
IC = N + IN(K)

ML3 = L(IC,3)

CALL SETMIV(24,0,L(IC,1),L(IC,2))

N = N + 1
RETURN

END

FUNCTION NBLANC(WORD,N)

NBLANC DETERMINES NO. OF CHARACTERS IN A HOLLERITH LABEL
IF THERE ARE NO CHARACTERS, NBLANC = 0

DIMENSION WORD(101)
DATA BLANK /*/

DO 10 M = 1,N

I = M - N

IF(WORD(I).EQ.BLANK) GO TO 20

10 CONTINUE

I = 0

20 NBLANC = 4*I

RETURN

END