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MINET Code Documentation

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Brookhaven National Laboratory

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Abstract

The MINET computer code, developed for the transient analysis of fluid flow and heat transfer, is documented in this four-part reference. In Part 1, the MINET models, which are based on a momentum integral network method, are described. The various aspects of utilizing the MINET code are discussed in Part 2, The User's Manual. The third part is a code description, detailing the basic code structure and the various subroutines and functions that make up MINET. In Part 4, example input decks, as well as recent validation studies and applications of MINET are summarized.

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FOREWORD

Version 1 of the MINET computer code, as documented in this report, is currently a very usable and useful code, and reflects a considerable development and validation effort. However, further improvements and enhancements are continually being incorporated in the code library. In particular, a control system model and a "rotor" module are currently under development, and will be in Version 2 of MINET, available around late 1984 or early 1985. We will make every effort to keep this document as up-to-date as possible, at least for those copies that the authors have distributed directly. Should you wish to know whether the copy you have is up-to-date, or what improvements have been made recently, please contact us.

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Drs. Charles Kelber and Robert Curtis and Mr. Phillip Wood, all of the United States Nuclear Regulatory Commission (USNRC), have been very supportive throughout the development of MINET, and of our Balance of Plant Modeling Program. Drs. R.J. Cerbone, and W.Y. Kato of BNL have been equally supportive, and particularly helpful in focusing the effort and organizing our presentation of the capabilities of the MINET code.

Preparation of a document of this size requires a major effort, beyond that made by the authors. Mr. Robert Kennett was helpful in our efforts to generate a large part of this report using computer graphics. Finally, the text, equations, tables, and much of the organization of this document are due to the patience and skill of an exceptional secretary, Mrs. Carmen Falkenbach.

VARIABLES USED IN MINET EQUATIONS

a_i - coefficients of pump head curve

A_h - heat transfer area in heat exchanger h

A_i - flow area for node i

A_{max_v} - maximum (full open) flow area through valve v

At_h - tube cross-sectional area in heat exchanger h

A_v - flow area through valve v

Cpt_i - specific heat of heat exchanger tube material in node i

D_{eq} - equivalent hydraulic diameter

D_I - inner diameter of HX tube

D_o - outer diameter of HX tube

E_b - enthalpy at boundary module b

E_i - node average enthalpy for node i

E_{IM} - enthalpy entering segment from bordering module IM

E_j - enthalpy at nodal interface j

E_{mi} - enthalpy at inlet interface of segment m

E_{mo} - enthalpy at outlet interface of segment m

E_n - average enthalpy in accumulator n

E_{OM} - enthalpy in segment outlet bordering module OM

f_i - friction factor in node i

f_{bi} - adjustment factor for heat transfer bridge i

f_{ts}^{eff} - turbine stage efficientcy adjustment factor

fa_h - heat transfer area correction factor for heat exchanger h

fk_i - impedance coefficient for node i

$f\ell_n$ - liquid level in accumulator n

fv_n - volume fraction of liquid in accumulator n

Fk_{tb} - modified Stadola constant for turbine stage

fv_v - stem power factor for valve v (area = $(\text{stem})^{fv_v} \cdot A_{max_v}$)

g - gravitational constant

H_p - head for pump p

h_i - heat transfer coefficient inside tube

h_o - heat transfer coefficient outside tube

Hp - Pump Head

H_{ref} - head for pump p at rated frequency and flow rate

i - node number

I_m - inertial term for segment m

j - interface number

k - current time step number

k_i - heat exchanger tube conductivity in node i

K_v - loss coefficient for valve v

ℓ - advanced time step number

M_d - number of segments in network d

Mf_d - first segment number in network d

$M\ell_d$ - last segment number in network d

n - node number relative to the first node in segment; volume number

N_d - number of volumes in network d

N_m - numbers of nodes in segment m

Nb_d - number of boundary modules in network d

Nbi_d - number of inlet boundary modules in network d

Nbo_d - number of outlet boundary modules in network d

Nf_m - first node in segment m

NH_m - number of heat exchangers in segment m

$N\ell_m$ - last node in segment m

P_b - pressure at boundary module b

P_{IM} - pressure in module at inlet of segment M

P_m - pressure in segment m

P_{mi} - pressure at inlet of segment m

P_{mo} - pressure at outlet of segment m

P_n - pressure in volume n

P_{OM} - pressure in module at outlet of segment M

Pi_b - pressure at inlet boundary module

Po_b - pressure at outlet boundary module

Q_i - heat transfer rate into node i

Q_m - heat transfer into segment m

Q_n - heating rate in volume n

QA_h - total heat transfer rate in heat exchanger h

QA_m - total heat transfer rate in segment m

r_m - pressure change across segment m

S_v - stem position for valve v

Sd_v - demanded stem position for valve v

t - time

Tc_i - HX tube wall centerline temperature for node i

V_i - volume of node i

V_n - volume of volume n

W_b - mass flow rate at boundary module b

W_i - mass flow rate at node i

W_j - mass flow rate at nodal interface j

W_m - segment m average mass flow rate

W_m^{est} - estimated advanced time mass flow rate for segment m

W_{mi} - segment m inlet mass flow rate

W_{mo} - segment m outlet mass flow rate

W_r - relative flow rate through pump

Wc_m - choked mass flow rate limit for segment m

Wi_b - mass flow rate at inlet boundary module b

Wo_b - mass flow rate at outlet boundary module b

W_p - mass flow rate through pump p

W_{ref} - reference flow rate through pump p

W_v - mass flow rate through valve v

Z_{mi} - elevation at inlet of segment m

Z_{mo} - elevation at outlet of segment m

α_i - pressure loss factor for node i

α_m - pressure loss factor for segment m

β_m - pressure loss term for segment m

δ_{ip} - 1 if pump at node i, otherwise, = 0

δ_{iv} - 1 if valve at node i, otherwise, = 0

ΔPa_i - pressure change due to acceleration

ΔPf_i - pressure change due to friction

ΔPg_i - pressure change due to gravity

ΔPk_i - pressure change due to form loss across node

ΔP_{nm} - presure difference between segment m junction and volume n average pressure

ΔP_p - pressure change across pump p

ΔP_v - pressure change across valve v

ΔX_i - length of node i

ΔZ_i - elevation change across node i

ξ - relative convergence criteria

ρ - density

ρ_n - accumulator n average density

ρt_i - tube wall density in node i

Ω_n - interior angle between vertical and a radian to the liquid level in a cylindrical volume (see Fig. 1.2-2)

τ_i - tube wall temperature time constant in node i

τ_p - pump coastdown time constant for pump p

τ_t - turbine coastdown time constant

τ_v - valve time constant for valve v

ω - pump impeller speed in rpm

ωd_p - demanded impeller speed in pump p

ω_t - turbine speed

ωd_t - turbine demand speed

ω_{ref} - reference impeller speed in pump p

χ - fluid quality

INTRODUCTION

MINET (Momentum Integral NETwork) is a computer code developed for the transient analysis of intricate fluid flow and heat transfer networks, such as those found in the balance of plant in power generating facilities. It can be utilized as a stand-alone code, or interfaced to another computer code for concurrent analysis. Through such coupling, a computer code currently limited by either the lack of required component models or large computational needs can be extended to more fully represent the thermal hydraulic system, thereby reducing the need for estimating essential transient boundary conditions.

MINET is based on a momentum integral network method, which is an extension of the momentum integral method [1]. This method uses a two-plus equation representation of the thermal-hydraulic behavior of a system of heat exchangers, pumps, pipes, valves, tanks, etc. It is computationally faster than the three equation methods used in RELAP [2] and its descendents, yet represents the compression and expansion of water/steam due to changes in enthalpy and pressure.

The MINET representation of a system comprises one or more networks of volumes, segments, and boundaries. Networks are linked together via heat exchangers only, i.e., heat can transfer between networks, but fluids cannot. Volumes are used to represent tanks or other voluminous components, as well as locations in the system where significant flow divisions or combinations occur. Segments are composed of one or more pipes, pumps, heat exchangers (inside or outside of tubes), turbines and/or valves, each represented by one or more nodes. Boundaries are simply points where the network interfaces with the user or another computer code.

MINET calculations are performed at two levels, i.e., the network level (volumes), and the segment level. Equations conserving mass and energy are used to calculate the pressure and enthalpy within volumes. An integral momentum equation is used to calculate the segment average flow rate. In-segment distributions of mass flow rate and enthalpy are calculated using local equations of mass and energy. The segment pressure is taken to be the linear average of the pressure at both ends.

The computational speed and power of the MINET method results largely from the local suppression of sonics in flow segments. It is implicitly assumed that the propagation of pressure waves in pipes, pumps, heat exchangers, and valves takes place on a time scale much smaller (milliseconds) than the transient of interest (seconds to minutes). Of course, such an assumption would be incorrect regarding the large break loss-of-coolant accident (LOCA) often postulated for light water reactor primary loops. However, for balance of plant systems, one is generally more interested in representing slower transients and overall plant behavior than large break LOCA's.

With few exceptions, the system being represented is closed, and accessed only through the boundary modules. The exceptions involve certain variables which are control system related, e.g., pump and turbine speed and valve positions. Boundary modules receive user input data (or data from another code) regarding pressure or flow rate and temperature (used only if in-flow). MINET calculations advance the other module variable (flow rate or pressure) and temperature (if out-flow).

The current MINET version uses a homogeneous equilibrium model of two phase flow, supplemented by various two phase correlations. Extension of the method to include an improved representation of the two phase phenomena, whether through slip, drift, or two fluid models, should be straightforward. This is because the intricacies of these models are less likely to pose difficulties in the numerics of MINET than codes where local pressures are calculated via time-dependent equations.

This document includes four major topics; 1) model descriptions, 2) a user's guide, 3) a code description, and 4) an example problem and applications section. These four areas are included in this documentation because of two strong characteristics of the MINET code; 1) its generality and 2) its potential applications.

The first reason for such a lengthy description of MINET is that, as a fully generalized code, it is designed to continue calculations even under conditions of severe distortion. Thus, the user must take some care to state his problem correctly, or MINET may actually analyze an unintended or unrelated problem. The extent to which MINET is documented herein is to allow the user to gain sufficient knowledge to properly exercise the code's capabilities.

The second reason for detailing the MINET models and code description is that potential applications far exceed those allowed by the currently available component modules. With the component modules easily accessible to the user, a relatively minor code modification could allow the user to represent a component feature that we have not yet considered.

However, one must realize that the details provided in this documentation are not sufficient to allow an actual reproduction of MINET. Several parts of MINET are very sophisticated and would require a major effort to duplicate.

Furthermore, the momentum integral network method used in MINET contains numerical subtleties that require special handling. Thus, it is strongly recommended that a potential user start with MINET and make modifications to the existing code than to try to develop a special purpose code based on this documentation.

1. MINET MODELS

1.1 MOMENTUM INTEGRAL NETWORK METHOD

The method employed in the MINET code is a major extension of a momentum integral method developed by Meyer [1]. Meyer integrated the momentum equation over several linked nodes, called a segment, and used a segment average pressure, evaluated from the pressures at both ends. Nodal mass and energy conservation determined nodal flows and enthalpies, accounting for fluid compression and thermal expansion.

In MINET, a network structure was built around Meyer's momentum integral model for the flow segment. In this extended method, a system is represented using one or more flow networks, connected to one another only through heat exchangers. Each network is composed of segments, volumes, and boundaries. Segments contain one or more pipes, pumps, heat exchangers, turbines and valves, each of which is represented using one or more nodes. Volumes represent voluminous components and significant flow junctions. Volumes and boundaries are connected by segments.

The calculation of pressures in MINET centers on the volumes. Here, equations for the conservation of mass and energy are used to advance volume pressure and enthalpy

$$V_n \frac{d\rho_n}{dt} = \sum^{\text{Inlets}} W_{mo} - \sum^{\text{Outlets}} W_{mi} \quad , \qquad (1.1\text{-}1)$$

and

$$V_n \frac{d(\rho_n E_n)}{dt} = \sum^{\text{Inlets}} W_{mo} E_{mo} - \sum^{\text{Outlets}} W_{mi} E_{mi} + Q_n + V_n \frac{dP_n}{dt} \qquad (1.1\text{-}2)$$

The equation of state is used to express the density time derivative in terms of pressure and enthalpy,

$$\frac{d\rho_n}{dt} = \left(\frac{d\rho_n}{dP_n}\right) \frac{dP_n}{dt} + \left(\frac{d\rho_n}{dE_n}\right) \frac{dE_n}{dt} \tag{1.1-3}$$

Note that the mass flow rate and enthalpy exiting the volumes are those entering the segment, and the same parameters exiting the segment are inlet values for the volumes.

Segment inlet and outlet pressures are calculated from those in bordering modules. If a boundary module is at the end of a segment, the pressure at that end is equal to the boundary module pressure. For the case of a volume at the segment end, the pressure differential between the volume port where the segment connects and the position where the volume average pressure is defined must be calculated. As volumes are considered to be stagnant, i.e., zero flow rate, only elevation head needs to be considered:

$$P_{mi} = P_{IM} - \rho g\ (Z_{mi} - Z\ (P_{IM})), \tag{1.1-4}$$

$$P_{mo} = P_{OM} - \rho g\ (Z_{mo} - Z\ (P_{OM})). \tag{1.1-5}$$

When the volume contents are taken to be homogeneously distributed, the volume average pressure is defined at the center. If the volume contents are separated into liquid and vapor regions, the volume average pressure is located near the middle of the liquid region. Equations (1.1-4) and (1.1-5) still apply, but greater care must be taken because the density differences between the region necessitate evaluating the elevation head in two pieces, i.e., above and below the liquid level.

The segment pressure is taken to be the average of the pressures at both ends, i.e.,

$$P_m = (P_{mi} + P_{mo})/2 \tag{1.1-6}$$

It is at this segment average pressure that saturation properties are calculated for the entire segment, a step that results in significant computational savings.

Similarly, a segment average flow rate, W_m can be defined as

$$W_m = \sum_{i=Nf_m}^{N\ell_m} \left(\frac{\Delta X_i}{A_i} W_i \right) / I_m \quad , \tag{1.1-7}$$

where I_m is the segment inertia, defined as

$$I_m = \sum_{i=Nf_m}^{N\ell_m} \left(\frac{\Delta X_i}{A_i} \right) . \tag{1.1-8}$$

This segment average flow rate is advanced using the segment integral momentum equation:

$$I_m \frac{dW_m}{dt} = P_{mi} - P_{mo} + r_m \quad , \tag{1.1-9}$$

where r_m is the total pressure change across the segment.

$$r_m = \sum_{i=Nf_m}^{N\ell_m} (\Delta Pg_i + \Delta Pf_i + \Delta Pa_i + \delta_{iv} \Delta P_v + \delta_{ip} \Delta P_p + \Delta Pk_i). \tag{1.1-10}$$

The first three terms on the right hand side of Eq. (1.1-10) are pressure changes due to gravity, friction, and acceleration:

$$\Delta Pg_i = -\rho_i g \Delta Z_i, \tag{1.1-11}$$

$$\Delta Pf_i = -f_i |W_i| W_i \; \Delta X_i / 2\rho_i A_i^2 \; D_{eq}, \tag{1.1-12}$$

and

$$\Delta Pa = \left\{ \frac{W_j{}^2}{\rho j} - \frac{W_{j+1}{}^2}{\rho j+1} \right\} / A_i{}^2. \tag{1.1-13}$$

The fourth and fifth terms are the contributions due to valves and pumps in the segment, and will be discussed in later sections. The sixth term is the form loss pressure change, and is used to account for miscellaneous losses due to bends, obstructions, etc. In MINET this term is calculated as:

$$\Delta Pk_i = \frac{-fk_i |W_m| W_m}{2\rho \; A^2 \; D_{eq}} \tag{1.1-14}$$

when fk_i is a nodal loss coefficient, which is calculated from the user input module loss coefficient. In practice, this coefficient is selected to match pressures and flow rates to steady state operating conditions, and is maintained at the same value for transient calculations.

The enthalpy of flow entering a segment from a volume or boundary module is determined by conditions in that bordering module. If the flow is coming from a boundary module or a volume with homogeneously distributed contents, the segment inlet enthalpy is set to the enthalpy in the bordering module. If the flow is entering from a volume with two separated regions, each at saturation conditions, the segment inlet enthalpy is set to saturated liquid or vapor enthalpy, depending on whether the segment connects below (liquid) or above (vapor) the liquid level.

In-segment distributions of mass flow rate and enthalpy are calculated using nodal mass and energy equations:

$$V_i \frac{d\rho_i}{dt} = W_j - W_{j+1} \quad , \tag{1.1-15}$$

$$V_i \frac{d(\rho_i E_i)}{dt} = W_j E_j - W_{j+1} E_{j+1} + Q_i + V_i \frac{dP_m}{dt} \tag{1.1-16}$$

where, for a segment node:

$$\frac{d\rho_i}{dt} = \left(\frac{\partial \rho_i}{\partial P_m}\right) \frac{dP_m}{dt} + \left(\frac{\partial \rho_i}{\partial E_i}\right) \frac{dE_i}{dt} \tag{1.1-17}$$

At this point, all of the basic equations essential to MINET have been written. While certain auxiliary equations are needed for the various modules (see Section 1.2), the equations listed above form the core for our basic method. The method by which these equations are used to advance the representation in time is relatively straightforward.

In systems which can be represented by MINET, heat exchangers are frequently shared by segments in two networks, with the flow from one segment passing through the tubes and the flow from the other passing on the outside. In order to decouple these segments during a transient time step, the tube temperatures are treated explicitly in the heat transfer calculations, and are not advanced until the end of the step.

With the segments and networks thus decoupled, MINET transient calculations proceed in a three step process, repeated for each network. The initial step is to march through the network segments, loading the segment matrix equation:

$$\underline{\underline{A}}_S \, \underline{x}_S = \underline{\underline{B}}_S \, \underline{y}_S \quad , \tag{1.1-18}$$

and solving for the segment response matrix, $\underline{\underline{B}}_s'$ ($=\underline{\underline{A}}_s^{-1}\ \underline{\underline{B}}_s$). For a segment s with N_s nodes, $2N_s+2$ linearized equations are loaded, including N_s nodal mass conservation equations, a segment momentum equation, and a total of N_s+1 donor-cell differenced nodal energy equations and segment inlet enthalpy boundary conditions. Vector $\underline{x}_s$ contains nodal interface enthalpies and flows, and vector $\underline{y}_s$ includes changes in enthalpy and pressure in the modules at the segment ends.

The second stage is to march through the network volumes, loading the network matrix equation

$$\underline{\underline{C}}_n\ \underline{v}_n = \underline{D}_n \quad , \tag{1.1-19}$$

and solving to advance volume enthalpies and pressures. For a network n with N_n volumes, N_n conservation of mass and N_n conservation of energy equations are loaded. The terms for the mass and energy entering and exiting the volumes are evaluated using the segment response matrices, $\underline{\underline{B}}_s$, thereby linking the volumes.

The final step is to march through the network segments, using the solution from Eq. (1.1-19) to determine vector $\underline{y}_s$. The segment response matrix, $\underline{\underline{B}}_s$, is then multiplied by $\underline{y}_s$, and the nodal interface enthalpies and flows are advanced. After segment conditions are advanced in all networks, the heat exchanger tube temperatures are advanced.

Two features of the method account for the flexibility and speed of MINET. First, segment nodes connect only to immediately adjacent nodes, causing matrix $\underline{\underline{A}}_s$ to be banded, except for the momentum equation. This allows the storage of matrix $\underline{\underline{A}}_s$, and the solution of Eq. (1.1-18), in close-packed form, i.e., with large blocks of zeroes suppressed. Thus, the complexity of the flow network is absorbed entirely in Eq. (1.1-19), where the matrices are lower order. Second, because a segment average pressure is used, saturation properties are evaluated once per segment per step.

1.2 MINET COMPONENT MODULES

Various component models, called "modules", are available in MINET, with multiple options available for each. These modules were developed to be compatible with the basic MINET methodology, and are similar to models found in other systems codes. Each MINET module can be used to represent one or more parallel components, in which the mass flow rate is divided equally among the parallel units.

1.2.1 PIPE

Pipes are the simplest components, and require minimal user input. The user has the option of specifying a non-zero heat source, which can be altered during the transient through value vs. time tables.

1.2.2 PUMP

A pump is modeled as a pipe with an additional pressure gradient term, due to the action of the pump. The pressure change across a pump is proportional to the pump head,

$$\Delta P_p = \rho_p g H_p \ . \tag{1.2-1}$$

The intricate relationship between the pump head, the relative pump speed, and the relative mass flow rate, is generally available in the form of homologous pump curves. For the pump model currently used in MINET, the pump head is given by:

$$H(\omega,W) = H_{ref}\,(\omega_{ref}, W_{ref}) \cdot \left(\frac{\omega}{\omega_{ref}}\right)^2 \cdot \tag{1.2-2}$$

$$\left\{a_1 + a_2\,W_r + a_3\,W_r^{\,2} + a_4\,W_r^{\,3} + a_5\,W_r^{\,4}\right\},$$

where reference conditions are user input head, flow, and speed at some known operating condition, H is the pump head at given speed ω and relative flow W_r, given by:

$$W_r = \frac{W}{W_{ref} \cdot (\omega/\omega_{ref})} \tag{1.2-3}$$

Equations 1.2-2 and 1.2-3 effectively reproduce the classic head curves shown in Figure 1.2-1 [3]. Thus, by specifying three reference conditions and the Head vs. Flow characteristics at a given speed, the user is implying a family of curves valid for all flow rates and speeds.

1.2.3 VALVE

Representation of valves depends on whether choking conditions exist. If the flow is unchoked, a form loss is calculated for the valve,

$$\Delta P_v = -K_v|W_v|W_v/2\rho_v A_v^2, \tag{1.2-4}$$

where K_v is the loss coefficient. The valve flow area is calculated from the valve stem position, and user input maximum flow area and stem power coefficient:

$$A_v = (S_v)^{fv}\, Amax_v \quad . \tag{1.2-5}$$

The user has the option of neglecting the choke flow calculation, as one might do with a valve controlled to regulate flow rate. If a choked flow calculation is called for, MINET will use an extended Henry-Fauske [4] model if subcooled, a Moody [5] model in two-phase flow, or an isentropic model if superheated, to calculate the choked mass velocity G_c $(=W/A)$. The valve flow area given by Eq. (1.2-5) is used to multiply this choked mass velocity to obtain a choked mass flow rate. If the mass flow rate through the valve at a given time is below the choked flow rate, calculations proceed normally.

In the case when the mass flow rate exceeds the choked flow limit, the mass flow rate must be set to the choke flow rate for the next step. Because

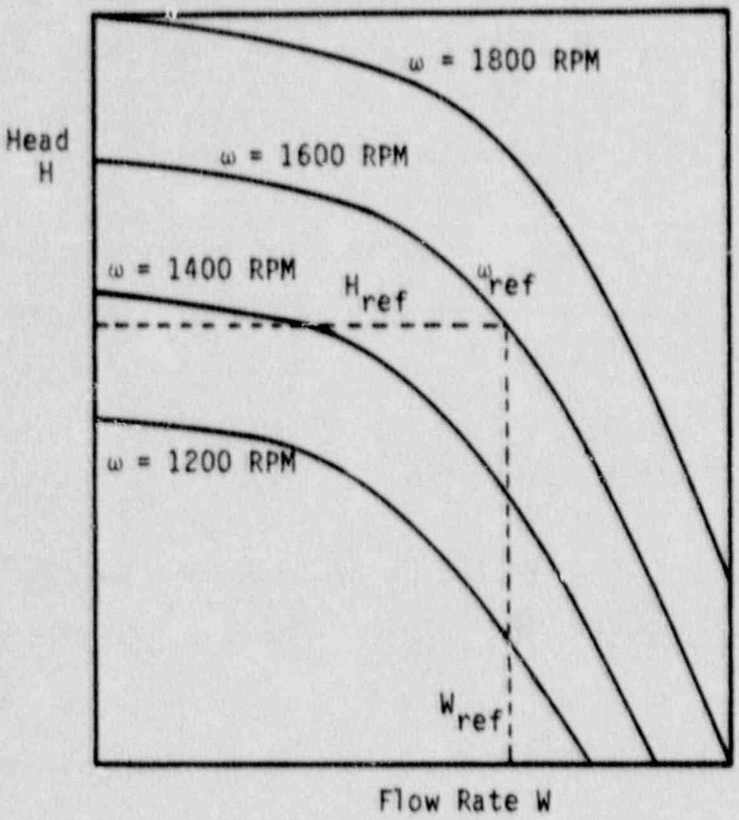


Figure 1.2-1. Pump Curves, Head vs Flow At Various Speeds [3]

this contradicts the segment integral momentum equation, care must be taken to isolate any valve where choking is allowed in a segment by itself. If choking occurs, the segment momentum equation is overwritten with the choke flow limit:

$$W_m = Wc_m. \tag{1.2-6}$$

1.2.4 VOLUME

While much of the volume behavior is represented by Eqs. (1.1-1) and (1.1-2), additional equations are needed. Because the heating term, Q_n, in Eq. (1.1-2) is a user input and distributed uniformly throughout the volume, this does not present a problem.

If the user wants the contents of a volume separated into saturated liquid and vapor regions, one does so by specifying the L3PSEP parameter equal to 2 or 3 (separated in transient only). For volumes with uniform cross sectional area (i.e., dA/dz = 0.0), e.g., an upright drum, the volume fraction, fv_n, is equal to the level fraction, $f\ell_n$.

The quality, x, can be calculated as:

$$x = 1/\left(1 + \frac{\rho_f}{\rho_g}\left(\frac{fv_n}{1 - fv_n}\right)\right) , \tag{1.2-7}$$

when ρ_f and ρ_g are saturated liquid and vapor density, respectively.

One of the input options allows the user to specify volumes as horizontal cylinders. In the case where the contents of a horizontal cylinder are separated into two saturated regions, the relationship between the liquid level and the volume fraction occupied by liquid is not trivial. We define interior angle Ω_n (Figure 1.2-2) as the angle between the vertical and a vector

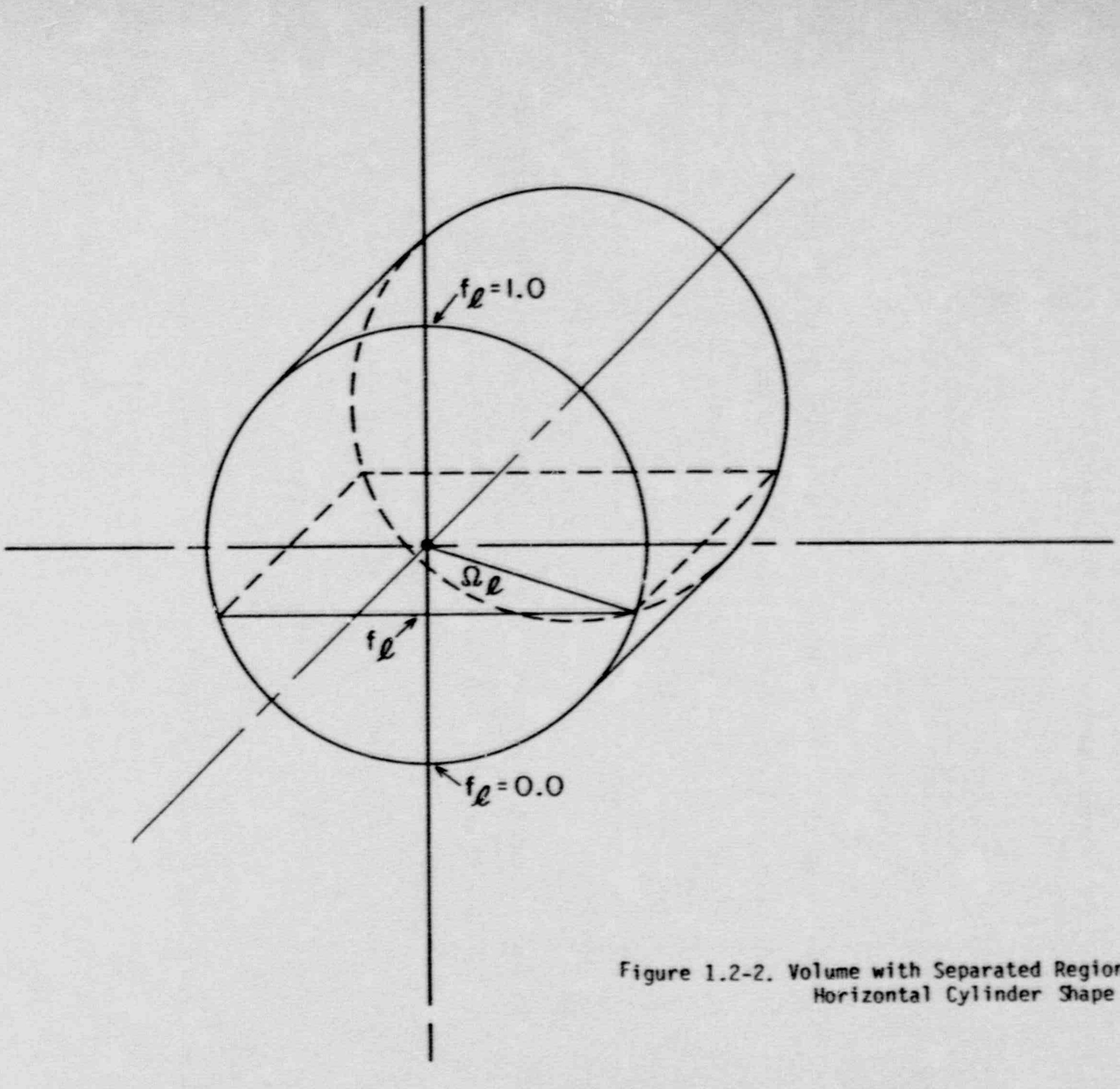


Figure 1.2-2. Volume with Separated Regions and Horizontal Cylinder Shape

running from the volume center line to the liquid level at the volume wall, such that:

$$f\ell_n = \frac{1 - \cos \Omega_n}{2} \qquad (1.2\text{-}8)$$

It can be shown that the volume fraction occupied by the liquid region is related to interior angle Ω_n by the expression:

$$fv_n = \left(\Omega_n - \frac{\sin 2\Omega_n}{2}\right)/\pi \qquad (1.2\text{-}9)$$

During steady state calculations, where $f\ell_n$ is user input, Eq. (1.2-8) is solved for Ω_n, Eq. (1.2-9) provides fv_n, and Eq. (1.2-7) gives the quality, which in turn is used to set the volume average enthalpy. In the transient calculations, the enthalpy is advanced directly, and the same three equations are used in the reverse order to obtain the liquid level, $f\ell_n$.

1.2.5 HEAT EXCHANGERS

Heat exchangers are among the most difficult plant components to represent, principally because of the complexity of two phase flow and heat transfer phenomena. A secondary complicating factor is the dependence of heat transfer on geometrical considerations, given the variety of heat exchanger designs. In addition to the heat exchangers designed for power plant use, there are several more exotic designs used in experimental systems. Representation of the experimental heat exchangers is desirable because much of the data useful for code verification comes from such units.

1.2.5.1 BASIC HEAT EXCHANGER MODULE REPRESENTATION

It is assumed that a single tube can be used to represent the heat exchanger. However, one could use more than one such tube by running parallel lines between volumes placed at both ends of the heat exchanger. The unit cell consists of the fluid inside the tube, the tube wall, and the fluid outside the tube, yet attributable to that tube, as shown in Figure 1.2-3.

The heat exchanger is divided into a user specified number of axial nodes, each containing two fluid nodes, and a tube node. One such node is shown in Figure 1.2-4.

For many heat exchanger calculations, the heat transfer process is uniform on each side of the tube. Thus, one calculates heat transfer Q between the tube centerline temperature (axial average) and the nodal average fluid temperature [6]:

$$Q = \pi \cdot D \cdot U \cdot (TC - T(\bar{E})) , \qquad (1.2\text{-}10)$$

where;

$$U = \frac{1}{\frac{1}{h} + \frac{\psi}{2k}} , \qquad (1.2\text{-}11)$$

and geometric factor ψ depends on whether the heat transfer occurs inside or outside the tube, i.e.,

$$\psi = \begin{cases} D_I \ell n \, (D_C/D_I) \\ D_O \ell n \, (D_O/D_C) \end{cases} \qquad (1.2\text{-}11a)$$

For heat exchangers involving multiple heat transfer regimes, the nodal calculation can become relatively complex. Ideally, the user will increase his nodalization for such a case. However, the MINET model can handle up to 5 heat transfer regions in a node, although some inaccuracy is likely to result.

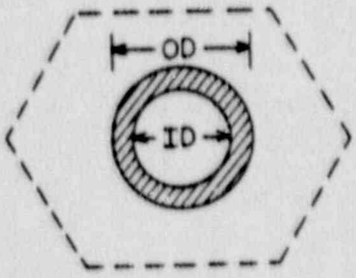


Figure 1.2-3. The Heat Exchanger Unit Cell

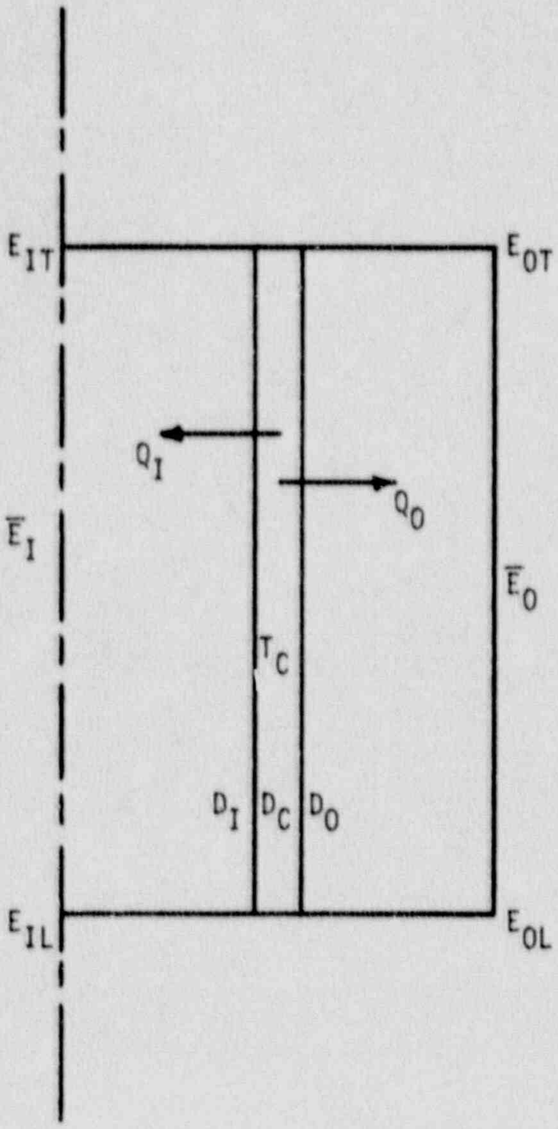


Figure 1.2-4. Heat Exchanger Node

The basic problem which arises with multiple heat transfer regimes in a node is that the axial temperature distribution becomes important (i.e., a distribution that can only be estimated using nodal parameters). The inlet, center, and outlet fluid enthalpies can be used, to a degree, to determine the local heat transfer regime. However, the tube temperature does not have a proper axial distribution, and to impose one would introduce numerical problems. (MINET allows for up to a 1°K distribution in tube temperature, primarily to handle nodes in which the fluid temperatures are very close to one another).

The MINET approach is to divide the node using "switch" enthalpies, which indicate when the heat transfer regime is to be changed. Calculations proceed from the node inlet to the node outlet, until the node outlet enthalpy falls into the enthalpy bracket of the heat transfer regime of the last portion of the node. The total node heat transfer, Q_i, is the sum of the Q's from the various modes:

$$Q_n = \sum^{\text{modes}} f_{\text{mode}} \cdot Q_{\text{mode}} \quad , \qquad (1.2\text{-}12)$$

where f_{mode} is the fraction of the node in which heat transfer is by a given mode.

The heat exchanger is made up of several of these nodes, linked by the fluid enthalpies passing from node to node. Tube temperatures are in no way linked from node to node.

Heat transfer correlations used in MINET are given in Section 1.5. Substitution of alternate correlations is possible, although the correlation switching logic should be considered when doing so.

In the steady state calculations, it is assumed that the user's knowledge of plant conditions is more accurate than the MINET heat transfer correlations. A heat transfer area correction factor is used to resolve any discrepancies. If the correction factor is significantly different than 1.0, either the plant conditions are unrealistic or the correlations are inappropriate.

1.2.5.2 HEAT EXCHANGER TYPES

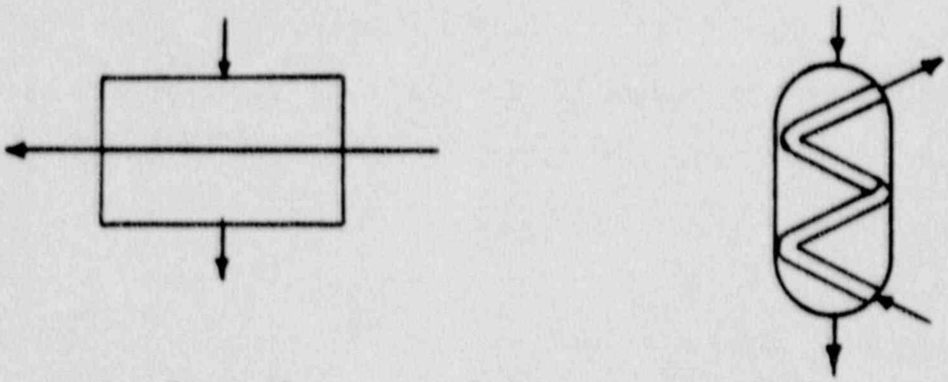
Several heat exchanger types may be represented using the current MINET heat exchanger module, as shown in Figure 1.2-5. Representation of yet other types is also possible, provided the user can factor it into the current heat exchanger routines, which are moderately intricate.

On the appropriate heat exchanger performance specification record of the MINET input deck, the user designates variable F3CCFL as -1.0, 0.0 or +1.0. A value of -1.0 indicates a counter-current heat exchanger, typically the most common type. Setting F3CCFL to +1.0 indicates a parallel flow unit, a relatively uncommon type because of its lower efficiency. If F3CCFL is set to 0.0, the heat exchanger is treated as a cross flow unit of the tube-in-tank type.

On the heat exchanger geometric record, two helical coil parameters are input, D3COIL and F3ITOO. D3COIL is the diameter of the coils, used to adjust the frictional losses, and must be set to 0.0 for straight tube units. Variable F3ITOO is the ratio of the flow length inside the tubes to that outside, which is useful in representing coil in tank units, and must be set to 1.0 for non-coil or co-axial coil units.

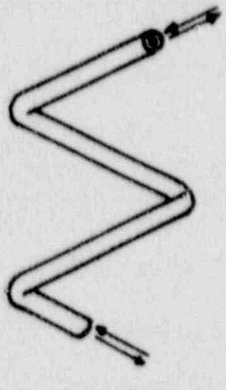
a. Counter Flow

b. Parallel Flow



c. Cross Flow

d. Coil-In-Tank



e. Co-Axial H-Coil

Figure 1.2-5. MINET Heat Exchanger Options

Of the five MINET heat exchanger options illustrated in Figure 1.2-5, all but the cross flow unit have sequential nodalization for the fluid passing outside the tube. Thus, for most cases, a heat exchanger with n nodes will have n tube nodes and 2n fluid nodes. For the cross flow option, only 1 node is used to represent the fluid outside the tubes, with 1/n of the flow assigned to each of the tube nodes. It is assumed that the enthalpy drop across each path is the same, which implicitly means that a small amount of flow distribution is allowed. However, for a tube in tank unit, the fluid outside the tubes is generally relatively slow moving, and these approximations are fairly safe. Of course, cross flow heat exchangers exist where a full two-dimensional treatment is needed, but for that case, the user would have to utilize a more sophisticated heat exchanger module than is currently available in MINET.

1.2.5.3 TUBE CONFIGURATION

While heat exchanger tubes are usually aligned in a hex arrangement, other configurations are possible, particularly in experimental units. For this reason, the three grid arrangements shown in Figure 1.2-6 are available as user input for each heat exchanger.

The flow area, A_O, for the outside region of the unit cell must be determined from the tube configuration, as well as the tube outer diameter (OD), and the pitch to diameter ratio (POD). Specifications for the three MINET options are given in Table 1.2-1.

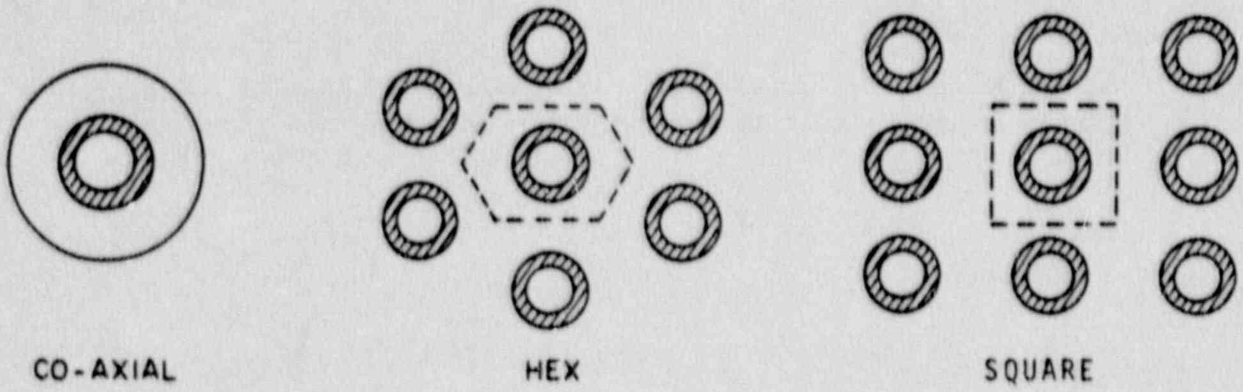


Figure 1.2-6. Heat Exchanger Tube Configuration Options

Table 1.2-1. Flow Areas for Heat Exchanger Tube Configurations

Grid Descriptions*	A_0
Co-Axial (1)	$\pi\ OD^2\ (POD^2 - 1)/4$
Square (4)	$OD^2\ (POD^2 - \pi/4)$
Hex (6)	$OD^2\ (2\sqrt{3}\ POD^2 - \pi)/4$

*Note: The number given parenthetically indicates the number of equidistant tubes that are closest to the reference (center) tube (see Fig. 1.2-6). This number is required as input for each heat exchanger.

1.2.5.4 STRUCTURE

Heat exchangers contain a certain amount of structure which can, due to its heat capacitance, alter the dynamic response of fluid passing outside the tubes. Furthermore, in the case of the EBR-II facility [7], a situation exists where a core tube is inserted into the tubes (to increase the flow velocity). Such masses can be represented in MINET, using the structural mass and metal type, the heat transfer area, and a simple energy equation that is explicitly integrated in time.

1.2.6 TURBINE STAGE

Turbines are generally modeled on two levels, detailed or thermodynamic. Turbine designers, by necessity, develop models based on geometric data. These models are very complicated, and, even if incorporated into a system code would require design data is very difficult to obtain. Thus, system models generally resort to thermodynamic models, which rely on some knowledge of operating characteristics in order to project performance at various conditions. In the MINET code, the turbine stage model is based on 1) several semi-empirical relations, 2) one geometrical characteristic that can easily be defaulted (to 15.0 degrees), and 3) turbine performance at reference (design) conditions.

For a turbine stage, the flow-pressure relationship is approximated using a modified Stadola equation [8]:

$$W_{stage} = K_{stage} \sqrt{\rho_{in} P_{in} \left[1 - \left(\frac{P_{out}}{P_{in}} \right)^2 \right]} \; . \qquad (1.2\text{-}13)$$

In MINET, K is determined for reference conditions and used to calculate the pressure drop across the stage ($P_{in} - P_{out}$). As MINET assumes that $W_{in} = W_{out}$ for the turbine and requires that the turbine stage be represented by a single node segment, then $W_{stage} = W_{seg}$.

The turbine inlet enthalpy is input from the adjoining module. The outlet enthalpy is calculated from the isentropic enthalpy change and the stage efficiency:

$$E_{out} = E_{in} - \eta_{stage} \cdot (E_{in} - E_{out,isentrop}), \qquad (1.2\text{-}14)$$

where the isentropic outlet enthalpy can easily be calculated using the inlet pressure and enthalpy, the outlet pressure, and steam table functions.

Expressions are available in MINET for the turbine stage efficiency of two common stage types: 1) impulse (first stage) and 2) 50% impulse, 50% reaction. The expressions are:

$$\eta = 4\,(V_B/V_F)\,(\cos\alpha - V_B/V_F) \quad , \qquad (1.2\text{-}15)$$

for the impulse and

$$\eta = 2\left(\frac{V_B}{V_F}\right)\left[\frac{\sqrt{2}\cos\alpha}{2} - \left(\frac{V_B}{V_F}\right) + \cos\alpha\sqrt{1 + \left(\frac{V_B}{V_F}\right)^2 - \sqrt{2}\cos\left(\frac{V_B}{V_F}\right)}\,\right], \qquad (1.2\text{-}16)$$

for the impulse reaction, where α is the absolute angle of approach of steam with respect to the blades, expressed in degrees (approx. 15 degrees). Velocity V_B is a measure of the turbine blade velocity and velocity V_F is the fluid velocity entering the moving blades. Since the kinetic energy is neglible entering and leaving the stage, the kinetic energy entering the moving blades is equal to the static enthalpy drop across the stage, which implies:

$$V_F = C \cdot (E_{in} - E_{out})^{1/2} \qquad (1.2\text{-}17)$$

If we assume that the turbine is being operated at optimum conditions at plant reference conditions, then the efficiency function, Eq. (1.2-15) or (1.2-16), is maximized at that point, and:

$$\frac{V_B}{V_F} = \frac{1}{2}\cos\alpha \qquad (1.2\text{-}18)$$

or

$$\frac{V_B}{V_F} = \sqrt{\frac{\dfrac{1}{\cos^2\alpha} - 1 + \dfrac{\cos^2\alpha}{2} - \dfrac{\sqrt{2}}{2}\cos\alpha}{\dfrac{1}{\cos^2\alpha} - 1}} \qquad (1.2\text{-}19)$$

Thus, the velocity ratio at reference conditions can be estimated, along with the pressures, enthalpies, flows, and speed (in RPM). Using these reference values, one can easily project the velocity ratio at any time using:

$$\left(\frac{V_B}{V_F}\right) = \left(\frac{V_B}{V_F}\right)_{ref} \cdot \left(\frac{V_{F\ ref}}{V_F}\right) \cdot \left(\frac{V_B}{V_{B\ ref}}\right) , \tag{1.2-20}$$

where

$$\frac{V_{F\ ref}}{V_F} = \sqrt{\frac{(E_{in} - E_{out})_{ref}}{(E_{in} - E_{out})}} , \tag{1.2-21}$$

and

$$\frac{V_B}{V_{B\ ref}} = \frac{\text{Turbine Speed}}{\text{Speed at Ref Cond}} \tag{1.2-22}$$

This completes the turbine stage equation set, which provides a static thermodynamic representation suitable for systems simulation. In practice, a work adjustment factor (comparable to the heat exchanger area correction factor) enters during the steady state to match the enthalpy drop across the turbine to that needed to satisfy the rest of the system. Thus, the stage efficiency in Eq. (1.2-14) is adjusted by:

$$\eta_{stage} = \eta \cdot \eta_{adjust} \tag{1.2-23}$$

to account for deviations from the ideal efficiencies given by Eqs. (1.2-15) and (1.2-16).

The power provided to the generator and out to the electrical grid is calculated using a user input turbine stage to generator efficiency η_{gen}:

$$\text{Power} = \sum_{i}^{\text{stages}} \eta_{gen} \cdot \eta_{stage} \cdot W_{stage} \cdot \Delta E_{stage} \qquad (1.2\text{-}24)$$

1.2.7 BOUNDARIES

Boundaries are simply interfaces between the system represented by MINET and the external world. The user can specify boundary conditions in tabular form, interface to another computer code which will exchange boundary conditions with MINET, or incorporate a controller that couples the boundary condition to the situation somewhere in the system being represented by MINET.

For the steady-state or initial conditions, the user must specify flow rates for inlet boundary modules. (The modules' form loss factors are to be used to adjust the pressure/flow distribution as necessary.) The user also specifies temperatures or enthalpies for inlet boundaries. A temperature/enthalpy condition may be specified as "fixed" for an outlet boundary, but only if there is a heat source available for MINET to adjust.

For the transient, the user may specify either pressure or flow at any boundary, and MINET will always calculate the other parameter. Temperature or enthalpy should be specified for all boundaries, although MINET will only use this temperature when the flow is entering the system from the outside.

A boundary module represents all parallel units. Thus, for example, if the boundary connects to 3 parallel pipes carrying a total of 300 kg/sec, the flow at the boundary is 300 kg/sec.

1.3 MINET STEADY STATE CALCULATIONS

A four step iterative process is used to determine steady state conditions in a system represented by MINET. The approach is built around the network structure of the underlying MINET methodology, and is somewhat different than classical marching or relaxation methods. The iterative process is begun with only estimates on system pressures, flows, and heat transfer rates, as well as user specified boundary conditions.

A system is represented as one or more flow networks, which are connected only through heat transfer. The user can intentionally or unintentionally force the transfer of a given amount of heat transferred between networks through specification of the problem. The first step of the iterative process is to determine which of these heat transfer bridges have to be adjusted and by how much.

Given a distribution of flows and pressures in a flow network, as well as the heat transfer into or out of various portions of the network, one can determine the enthalpies throughout. The second step in the iterative process is to calculate system enthalpies.

The third step in the MINET steady state calculations is to march through the system modules, calculating local enthalpy distributions and pressure drops. Adjustments in heat exchanger area correction factors and turbine stage efficiencies are calculated during this phase.

The fourth step in the process is to adjust network pressures and flows for each network in the system. This step includes re-evaluation of pressure drops in isolated pumps, valves, and turbines (always isolated), as the pressure change across these components can be very large, and highly dependent on segment pressure.

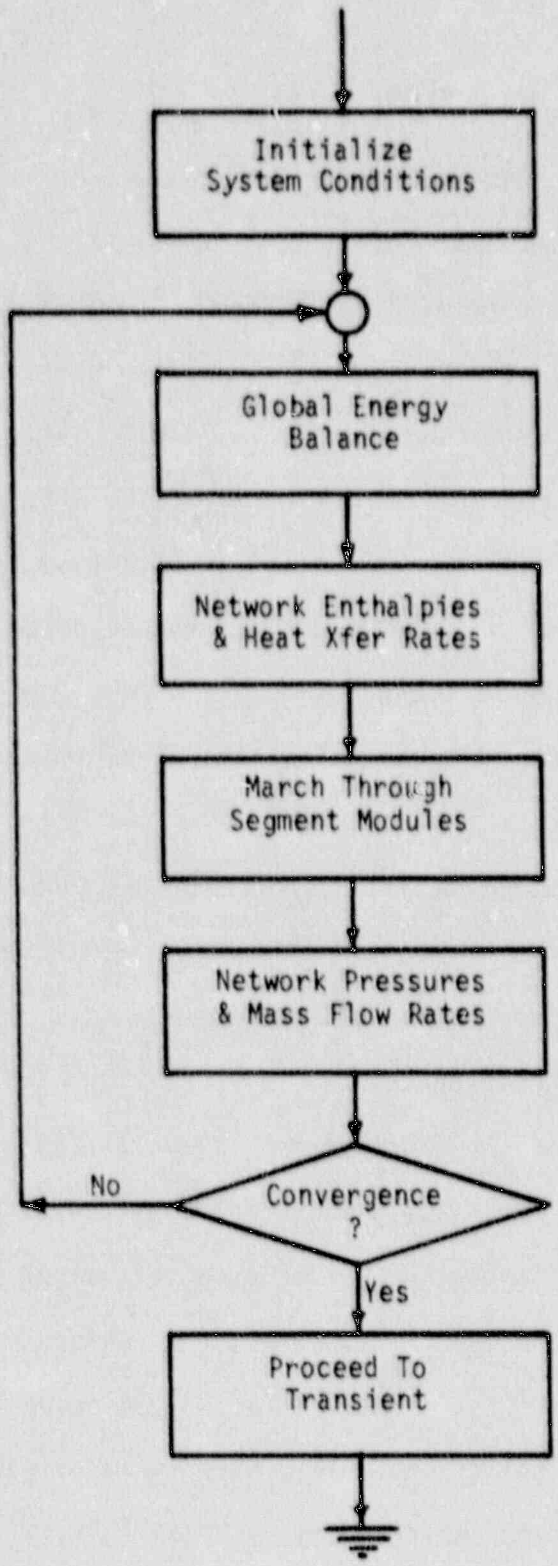


Figure 1.3-1. Steady-State Solution Strategy

The four step process is repeated until system enthalpies are no longer changing significantly from step to step. (When first testing an input deck, it is wise to set L3PRON = -1 on the 4000 card to get a print out after step 4 on each steady state iterative pass.)

1.3.1 GLOBAL ENERGY BALANCE

The MINET user inputs estimates of heating or total heat transfer (work done in the turbine looks like heating in this part of the calculation) for each module. A heat exchanger removes heat from one part of the system and adds it to another. The user also constrains the total heat transfer between parts of the system whenever he opts to fix a temperature at an outlet boundary or utilizes a volume that has separated contents, i.e., steam over water. In the separated volume case, the energy constraint enters because, for given pressures and flows, the total energy leaving the volume is fixed by saturation conditions. Thus, to assure an energy balance, the sum of the flow energy entering the volume must equal the flow energy leaving the volume.

An example of this global energy balance usage can be illustrated using Figures 1.3-2 and 1.3-3. Figure 1.3-2 is a schematic of a simple recirculation steam generator system, which utilizes an evaporator (301), a superheater (302), and a steam drum (101). Because the enthalpy at 404 is fixed, the subnetwork between 403 and 404 must give off energy at a rate of W_3 (E_3 - E_4). The steam drum creates a sub-network in the recirculation (recirc) line, because it must draw enough energy to raise the enthalpy of W_1 from E_1 to E_g. This situation is illustrated in Figure 1.3-3, where the 403-404 sub-network is designated number 3, the recirc line is number 1, and

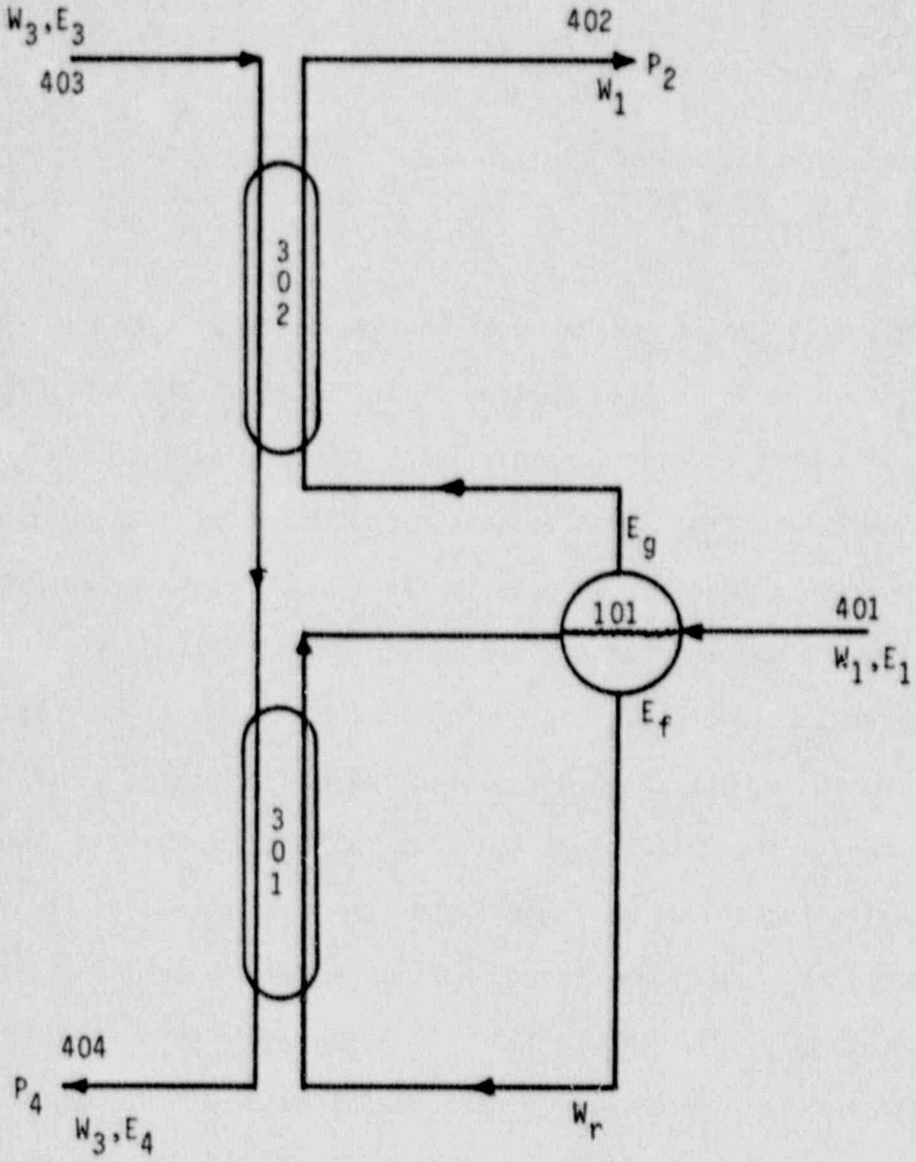


Figure 1.3-2. Example 1 for Global Energy Balance

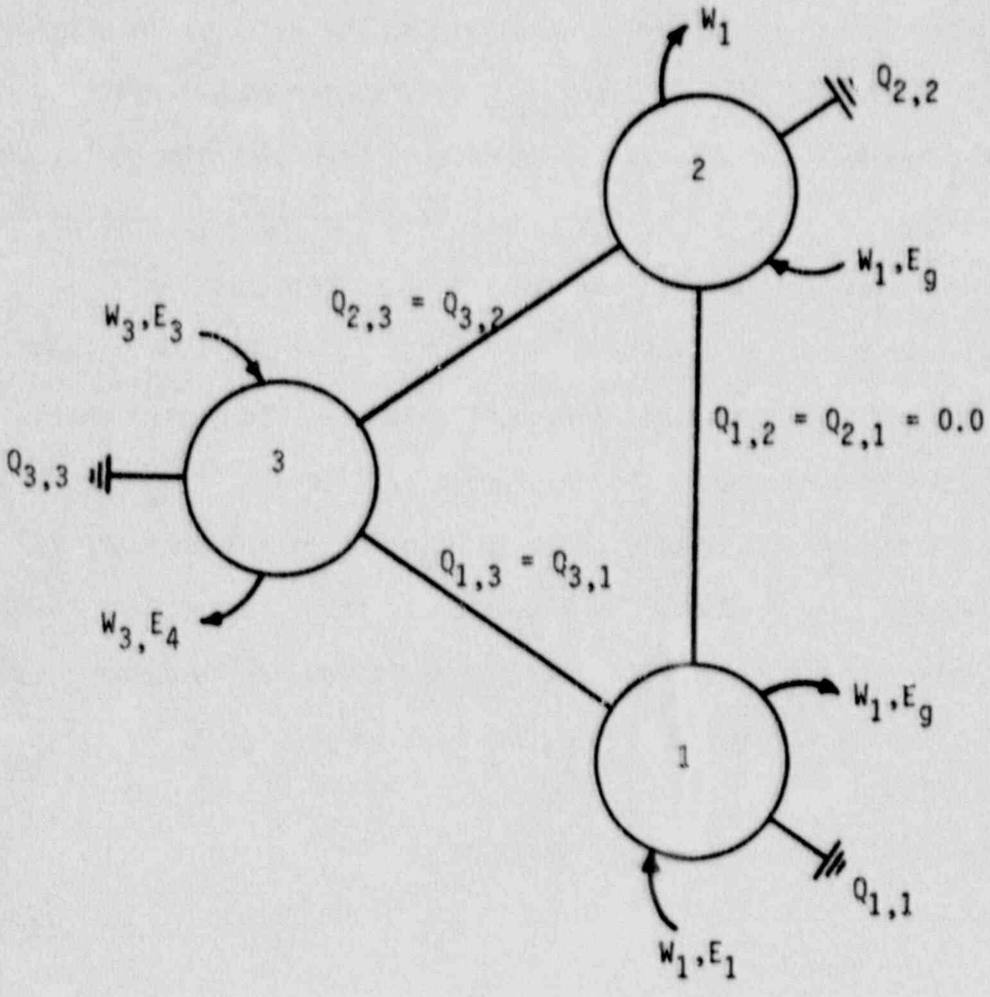


Figure 1.3-3. Sub-Network Abstract for Example 1

the superheater line is number 2. Each sub-network has flows in and out, heat transfer to ground (e.g., pipe heating), and heat transfer to all other sub-networks. Of the nine sub-network bridges, 3 are redundant ($|Q_{1,3}| = |Q_{3,1}|$), leaving six that could be adjusted to satisfy sub-network 1 and 3 constraints. If we assume there is no pipe (pump, valve, volume) heating, the bridges to ground have Q = 0. Thus, we must use bridges 1, 3 and 2, 3 to satisfy closed sub-network 1 and 3 constraints. We set $Q_{1,3}$ to provide energy to raise E_1 to E_g, and set $Q_{2,3}$ to transfer enough heat for the sub-network 3 outlet enthalpy to be E_4. Note that the outlet enthalpy of sub-network 2 is not directly constrained, which is no problem for an open sub-network, as the user did not specify an outlet enthalpy.

A second example, illustrated in Figures 1.3-4 and 1.3-5, shows how flow splitting can complicate the process of balancing the system energy. This example consists of 3 boundaries, 3 pipes (1,2,3) and a volume (110) with homogenously distributed contents. The enthalpy at outlet boundary 412 is fixed, and only pipe 1 is heated. The situation is shown in abstract in Figure 1.3-5, where $Q_{1,2} = 0.0$. With the flow splitting in the volume, each sub-network receives a fraction of Q_1, the heating in pipe 1.

$$Q_{1,1} = \frac{W_2}{W_1} \cdot Q_1 \qquad (1.3\text{-}1)$$

$$Q_{2,2} = \frac{(W_1 - W_2)}{W_1} Q_1 \qquad (1.3\text{-}2)$$

Thus, in order to get E_2 as the fluid enthalpy at 412, we must adjust Q_1. Of course, this will also put the enthalpy at 413 at E_2, but because this is an open or floating sub-network (enthalpy not constrained), this is not a problem.

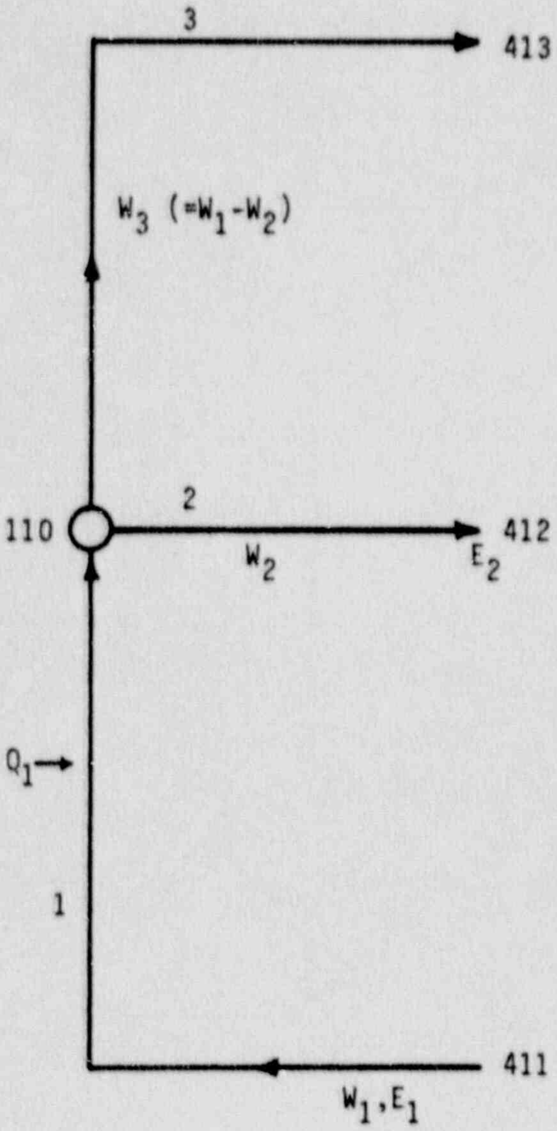


Figure 1.3-4. Example 2, Flow Splitting Considerations

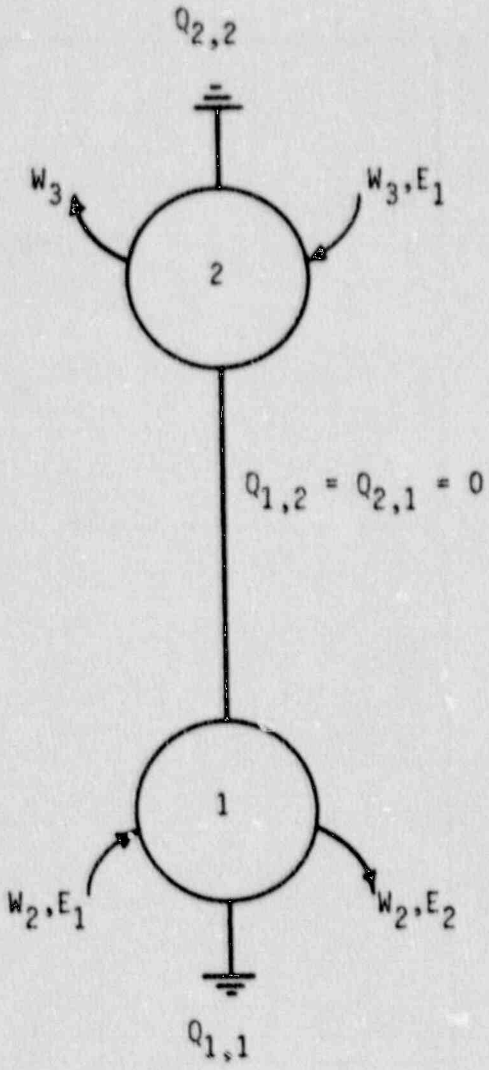


Figure 1.3-5. Example 2 Sub-Network Abstract

These examples are made in order to illustrate the reasons for some of the steps taken in the MINET steady state global energy balancing. The approach utilized is designed to work for situations that we envision coming up. However, the procedure contains many subtleties, including those to handle cases where multiple solutions are possible.

1.3.1.1 FLOW TRACEBACK

The process of flow traceback is important for a case like Example 2, where a heat source is shared by multiple sub-networks. Flow traceback is performed simply by beginning with outlet boundaries or separated volumes and tracing back to the source - either an inlet boundary or a separated volume. The fraction of flow from each segment or volume going to each sub-network is thus calculated.

For Example 1 (Figs. 1.3-2 and 1.3-3), there are no shared (by sub-networks) segments or volumes, and the flow fractions are either 1.0 or 0.0, and are quite obvious.

In Example 2 (Figs. 1.3-4 and 1.3-5), the segment with pipe 3 is entirely in sub-network 2, and the pipe 2 segment is in sub-network 1. However, only W_2/W_1 of volume 110 and the pipe 1 segment are in sub-network 1. The remaining $(W_1 - W_2)/W_1$ of the flow passes to sub-network 2, contributing to its energy balance.

1.3.1.2 PRINCIPAL SUB-NETWORK

When a segment or volume is shared by more than one sub-network it is necessary to assign it to a sub-network for possible adjustment. The goal is to make certain that the energy balance for each sub-network can be satisfied. Of course, if the heating in one segment is adjusted, it it reflected in all sub-networks according to the flow fraction passing that way.

The process of assigning principal subnet numbers to the segment involves 4 considerations. These are as follows:

1) If there is only 1 sub-network in the network, each segment and volume is assigned to that sub-network.
2) If the fraction of flow going from a volume or segment to a sub-network is 1.0, then that volume or segment is assigned to the sub-network.
3) If a volume or segment is shared by an open (floating outlet temperature) and a closed (fixed outlet temperature) sub-network, it is always assigned to the closed sub-network. This is because the closed sub-network may need an adjustment in heat transfer, and the open sub-network never need be adjusted.
4) When a volume or a segment is shared by two or more closed sub-networks it is assigned to the most needy. The highest priority is to insure that each closed network has at least one heat source available for adjustment. If each of the sharing sub-networks is already assured of at least one source, then the shared volume or segment is assigned to the sub-network with the smallest total heat transfer.

We return to Example 2 (Figs. 1.3-4 and 1.3-5) to illustrate the use of these rules. There are 2 sub-networks in the flow network, so rule 1 does not apply. We can use rule 2 to assign the pipe 1 segment to subnet 1 (KPRNC (Seg. 2) = subnet 1) and the pipe 3 segment to subnet 2. We must use rule 3 for the pipe 1 segment, and assign it to the closed sub-network (no. 1). As a result, a heat source is assigned to sub-network 1 which can be adjusted to give outlet enthalpy E_2.

To illustrate rule 4, we consider a case where the enthalpy at 413 is also fixed, and the heating in pipe 3 is non-zero. As in the simpler case, pipe segments 2 and 3 are assigned to sub-networks 1 and 2, respectively, according to rule 2. Rule 3 no longer applies, because both sub-networks are now closed. In applying rule 4, we find that the heating in pipe 3 has already been assigned to sub-network 2, while sub-network 1 has yet to receive a heat source. Therefore, the heating in the pipe 1 segment is assigned to sub-network 1.

1.3.1.3 SUMMING UP BRIDGE HEATING

At this stage, each segment and volume has been assigned to a sub-network (the "principal" one), for the purpose of adjustment. Heating in pipes, valves, volumes, pumps, and turbines (work) are really between the sub-network and ground. Thus, to find the total bridge heating between sub-network i and ground, $Q_{i,i}$, we simply sum the heating terms in all segments and volumes with i as the principal sub-networks.

In general, heat exchangers link flow networks, and therefore subnets. Thus, the heat exchangers form bridges between subnets, as determined by the principal sub-network number for the segments attached to the insides and outsides of the tubes. The total heat transferred through all heat exchangers between any given pair of sub-networks is summed to give the total bridge heating $Q_{j,k}$. Note that for hypothetical cases where heat exchangers link merely different parts of a sub-network (or even a segment), the addition and subtraction will cancel out, having no net impact of the global energy balance.

1.3.1.4 DETERMINING KEY BRIDGES TO ADJUST

In order to guarantee the outlet enthalpies of the fixed sub-networks, a like number of non-zero heat transfer bridges must be available for adjustment. If this is not the case, MINET will halt the calculations, because the problem is over specified.

The process of identifying the key bridges (to be adjusted) begins with an elimination process. A bridge is eliminated from consideration if:

1) It has a total bridge heating $Q_{i,j}$ of 0.
2) It connects two free sub-networks, and thus can do nothing for fixed sub-networks.
3) It connects a free sub-network with the ground.

If, after eliminating these three types of bridges, there are less bridges left than the number of fixed sub-networks, the calculations cease. When there are exactly enough heating bridges available for the fixed sub-networks, they are tagged and calculations proceed to the next phase.

Should there be more useful bridges than are needed, MINET carefully picks a set of key bridges that 1) will provide a solution, and 2) are the larger ones, so that any adjustment will be minimized. The process is one of assigning essential bridges to the needy sub-networks until more than one bridge is available for each remaining needy sub-network. At this point, the smallest unassigned bridge remaining is fixed. This process is repeated until the necessary number of heat transfer bridges are left for adjustment.

1.3.1.5 SUMMING SUB-NETWORK FLOW ENERGIES

In this phase of the calculations, the total flow energy (mass flow rate x enthalpy) going into and out of each sub-network is calculated. As all network outlet boundaries with free floating temperatures are assigned to an open or free sub-network, their contributions are totalled to get the flow energy out of the free sub-network. Inlet boundaries can contribute to multiple subnets, as determined by the segment flow fractions that were determined in the flow traceback phase. For sub-networks with incoming flow from a separated volume, enthalpies are easily determined from saturation conditions. The total flow energy leaving a sub-network that terminates at a separated volume can be calculated by summing the flow energy leaving the volume (at saturation), as the two sums must be equal at steady state (once adjusted for volume heating).

1.3.1.6 BALANCING THE SYSTEM

At this stage in the calculations, the groundwork has been set to fulfill the energy balance needs of each of the sub-networks. One heat transfer bridge is to be adjusted for each fixed (or closed) sub-network in the system. This amounts to finding a multiplier f_B, such that $f_B \cdot Q_{j,k}$ fulfills the need for a given fixed sub-network. Concurrently, the total flow energy leaving each of the floating (or open) sub-networks is calculated.

Appropriate equations for each sub-network are loaded into the matrix equation

$$\underline{\underline{E}} \cdot \underline{x} = \underline{F} \, , \tag{1.3-3}$$

where $\underline{\underline{E}}$ is a square matrix dimensioned to the number of system sub-networks, $\underline{x}$ and $\underline{F}$ are vectors of the same dimension. The components of state vector $\underline{x}$ are outlet flow energies of the floating (open) sub-networks and the bridge adjustment factors:

$$\underline{X} = \left\{ \sum WE_{o,i}^{flt}, \ldots, \ldots\ldots\ldots, f_{Bj}, \ldots \right\} \tag{1.3-4}$$

One equation is loaded into Eq. 1.3-3 per sub-network. For a floating sub-network i, the equation is of the form

$$\sum WE_{o,i}^{flt} - \sum_{j}^{N_{float}} f_{Bj} \cdot ff \cdot Q_j = \sum WE_{I,i} + \sum_{k}^{N_{fix}} ff \cdot Q_k, \tag{1.3-5}$$

where ff is the flow fraction from the volume or segment contributing to the subnet, Q is the heating, and f_{Bj} is the adjustment factor assigned to adjustable bridge j. Note that this means that adjustment factors constrained by the fixed sub-network requirements are factored into the floating sub-networks any time the two share a heat source.

For a fixed sub-network, the equation to be loaded into Eq. 1.3-3 is of the form

$$-\sum_{j}^{N_{float}} f_{Bj} \cdot ff \cdot Q = \sum WE_{I,i} + \sum_{k}^{N_{fix}} ff \cdot Q_k - \sum WE_{o,i}^{fix}, \tag{1.3-6}$$

where the total flow energy leaving, which is fixed, now appears on the right hand side.

Once loaded, Eq. (1.3-3) is solved for the flow energy leaving the floating sub-networks and the bridge adjustment factors for the fixed sub-networks. The former are of little use, but the latter (factors) are critical to assuring system wide energy balances.

The bridge adjustment factors apply to only a few of the heat transfer bridges, which are identified by the sub-networks they connect. It is a routine matter to trace back to the segments and volumes assigned to the adjusted bridge and factor the heating terms. For heating in pipes, pumps, valves, volumes, and turbines, this factor is carried through the steady state (although adjusted from iteration to iteration) and into the transient. For a heat exchanger, it is absorbed into the heat transfer area correction factor, which again carries through the transient.

1.3.1.7 BALANCING IN PERSPECTIVE

The approach outlined in this section was developed to resolve real world problems, and is important to determining a reasonable steady state solution. There are subleties involved in the solution of complex systems, particularly one with multiple solutions (i.e., excess heat transfer bridges). It is possible that flaws can be found in the current logic and that improvements can be made. However, the experiences gained thus far indicate that a user input error is far more likely than a logical error in the code.

A summary of the global balance and adjustment factors is printed with the steady state results. This printout should be carefully checked when testing a new deck. If the adjustment factors are significantly different than 1.0, the input should be reviewed for errors.

1.3.2 NETWORK ENTHALPY DISTRIBUTION (ENET)

Once the global energy balancing has been completed, enthalpies can be determined throughout each network. This straightforward process begins with a summing of the heat transfer into each segment

$$QSEG = \sum^{\text{modules}} f_{Bj} \cdot Q_{mod}, \qquad (1.3\text{-}7)$$

where f_{Bj} could vary from heat exchanger to heat exchanger, depending on which sub-networks it connects.

The principal step in the ENET balance is the coupling of segment inlet enthalpy constraints and volume energy balance equations in a matrix equation of the form:

$$\underline{\underline{A}}\ \underline{x} = \underline{B} \qquad (1.3\text{-}8)$$

Square matrix $\underline{\underline{A}}$ and vectors $\underline{x}$ and $\underline{B}$ are dimensioned equal to the number of segments plus volumes. State vector $\underline{x}$ consists of segment inlet enthalpies and volume enthalpies:

$$\underline{x} = \text{col} \left\{ E_{mi}, \ldots\ldots, E_{ni}, \ldots\ldots \right\} \qquad (1.3\text{-}9)$$

Network segment inlet enthalpies are constrained by one of three equation types:

$$E_{m,in} - E_n = 0 \ , \qquad (1.3\text{-}10)$$

$$E_{m,in} = f(E_f, E_g) \ , \qquad (1.3\text{-}11)$$

or

$$E_{m,in} = E_{Bc} \ . \qquad (1.3\text{-}12)$$

The first equation (1.3-10) applies when the segment begins at a volume with homogeneously distributed contents. Equation (1.3-11) applies when the segment inlet connects to a volume with separated regions, so that the incoming enthalpy is at saturation. The third equation (1.3-12) applies when an inlet boundary module is at the segment inlet, in which case the enthalpy is fixed.

The volume energy balance equation is essentially

$$\sum^{OP} \left(WE\right)_{out}^{vol} - \sum^{IP} \left(WE\right)_{in}^{vol} = f_{Bi} \cdot Q_{vol}, \tag{1.3-13}$$

where OP are the outlet ports and IP are the inlet ports. At this stage, the right hand term is known and the flow rates on the left side are known (current iterative values) for any segment. The volume outlet enthalpy is the inlet enthalpy for the attached segment, and is therefore available in state vector $\underline{x}$. The volume inlet enthalpies are segment outlet enthalpies, which are known from the equation

$$\left(WE\right)_{out}^{seg} = \left(WE\right)_{in}^{seg} + QSEG, \tag{1.3-14}$$

where QSEG is as calculated in Eq. (1.3-7).

The equation actually loaded in matrix Eq. (1.3-8) is a combination of Eqs. (1.3-13) and 1.3-14), i.e.,

$$\sum^{OP} W_m E_{mi} - \sum^{IP} W_m E_{mi} = f_{Bi} \cdot Q_{vol} + \sum^{IP} Q_m. \tag{1.3-15}$$

The volume energy equation, Eq. (1.3-15), is loaded unless the volume contents are separated. In this case, the volume enthalpy is determined by saturation conditions and the liquid level

$$E_{vol} = \text{fcn}\,(E_f, E_g, \text{level}). \tag{1.3-16}$$

Note that the separated volume energy balance was already used in the summing of sub-network flow energies (see Sect. 1.3.1.5). To use it in Eq. (1.3-8) would not only be redundant, it would do nothing to constrain the volume enthalpy, and matrix $\underline{A}$ would be singular.

Once segment inlet enthalpies are known, module inlet and outlet enthalpies can be defined. This is done by simply marching through the segments, incrementing the enthalpies using module heating, adjustment factors, and segment flow rate.

1.3.3 MODULE MARCH

The step of marching through all of the modules in each segment is necessary for the correct calculation of the segment pressure loss, r_m. Because the pressure loss terms are sometimes dependent on the square of the mass flow rate, two segment loss parameters, α_m and β_m are calculated such that

$$r_m = \beta_m - \alpha_m |W_m| W_m. \tag{1.3-17}$$

The terms of Eq. (1.1-10) are represented by α_m and β_m. Gravitational losses, which are independent of flow rate, accelerative losses, which are small, the pump contribution at steady state speed and zero flow rate, and the turbine stage contribution are included in the β_m term.

$$\beta_m = \sum_{i=Nf_m}^{N\ell_m} \Delta Pg_i + \Delta Pa_i + \delta_{ip}\,\rho_i g\, H_p\,(\omega,W) + \delta_{it}\,\frac{Pi}{(Pi+Po)} \cdot \rho_i \cdot fk_t \tag{1.3-18}$$

Frictional losses, valve form losses, and the module form losses, are included in α_m:

$$\alpha_m = \sum_{i=Nf_m}^{N\ell_m} f_i/2\rho_i A_i D_i + \delta_{iv}\, K_v/2\rho_i A_v^2 + \frac{fk_i}{2\rho A^2 D_{eq}} \tag{1.3-19}$$

At the onset of calculations for a given heat exchanger, flow rates, pressures, inlet and outlet enthalpies, and total heat transfer rate are already known. To force the heat transfer rate, as indicated by correlations, tube conductivities, and heat transfer areas, to provide the required total heat transfer rate, an area correction factor, Fa_h, is used. Fa_h is used to factor the total heat transfer area up or down, as needed.

The steady state heat exchanger calculations include several layers of iterative schemes, with the area correction factor being the outermost. The next lower level is the nodal energy balance, where the heat transferred across the node is forced to match the flow and enthalpy change(s). This iteration is complicated by the allowance of up to five different heat transfer regimes within the node, with the switch interfaces determined within the iteration. Below the nodal energy balance calculation is the tube wall node centerline temperature iteration, which sets equal the heat fluxes between the tube centerline and the two fluids. The lowest iteration calculation is for the tube wall temperature, which is calculated from the tube centerline temperature and fluid conditions, and is done so within the heat transfer correlation functions.

The heat exchanger calculations, especially in the steady state, are complicated by the various heat exchanger options. These schemes have been adjusted, re-adjusted, and continue to be tested to insure that they work for all options. The subtleties involved are too extensive to fully document, and should not be taken lightly by the user. Serious problems with steady state non-convergence, if not due to an input error, can usually be resolved by increasing the heat exchanger nodalization. It should be noted that any low level failure to converge is significant only on the last pass of higher level iterative schemes, when they are less likely to occur.

Module heating, adjusted during the global energy balance phase (Sect. 1.3.1) is used to determine the enthalpy distribution in pipes, pumps, and valves. For pipes, which can have more than one node, the heating per node is assumed to be uniform.

The work done in the turbine, also subject to adjustment during the global energy balance (Sect. 1.3.1) phase, is used to determine the enthalpy change across the turbine stage. Using the Stadola constant, determined from reference conditions, and the current flow rate, the pressure drop across the stage is calculated. The isentropic enthalpy change and ideal stage efficiency are then calculated for current conditions. This is compared to the work requirement coming from global balance consideration, and an efficiency adjustment factor is calculated

$$f_{ts}^{eff} = \Delta E_{global} / (\eta_{theory} \cdot \Delta E_{isentropic}). \qquad (1.3\text{-}20)$$

This factor is like the heat exchanger area correction factor in that a value near 1.0 indicates a good match. The last step is to multiply the work done in the turbine by the generator efficiency to get the power delivered to the electric grid.

1.3.4 NETWORK PRESSURES AND FLOWS (PRFLOW)

The fourth and final step in the MINET steady state iterative process is to adjust the pressure and flow distribution in each system network. This is done by coupling, in a matrix equation, a number of equations equal to the number of network volumes, N_v plus segments (N_m) plus inlet boundary modules (N_{ib}):

$$\underline{\underline{C}}\ \underline{x} = \underline{D}, \tag{1.3-21}$$

where $\underline{x}$ is the state vector:

$$x = \text{column} \left\{ W_{seg}, \ldots\ldots, P_{vol}, \ldots\ldots, P_{Bc}^{\text{inlet}} \right\} . \tag{1.3-22}$$

The first Nv equations are mass balances for each network volume:

$$\sum^{\text{Inlets}} W_{seg} - \sum^{\text{Outlets}} W_{seg} = 0 , \tag{1.3-23}$$

where the flow rates passing through the volume ports are the segment flow rates, W_{seg}, which are in state vector $\underline{x}$.

The next N_m equations are segment momentum balances, which can be simplified as

$$P_{m,out} - P_{m,in} + \alpha_m |W_m| W_m = \beta_m, \tag{1.3-24}$$

where α_m and β_m are the segment pressure loss parameters described in Section 1.3.3, and $P_{m,in}$ and $P_{m,out}$ are segment inlet and exit pressures, respectively. Because segment pressures are not in state vector $\underline{x}$, these terms have to be written in terms of either volume pressures or boundary pressures, depending on which is attached at the end of the segment

$$P_m = P_{Bc}, \tag{1.3-25}$$

or

$$P_m = P_{vol} + \Delta P_g. \tag{1.3-26}$$

When the segment is attached to a boundary, the end pressure is identical to the boundary pressure, which is known if an outlet, or in state vector $\underline{x}$ if an inlet. For a volume, the segment pressure must be calculated from the volume pressure and the gravitational head between the volume average value (in $\underline{x}$) and the junction level.

Because Eq. (1.3-24) is second order in segment flow, two steps are taken. First, Eq. (1.3-24) is actually loaded in Eq. (1.3-21) in linearized form. Second, Equation (1.3-21) is solved iteratively until the segment flows are no longer varying significantly from step to step.

Finally, the segment loss parameters, α_m and β_m can be large and sensitive to changes in flow and pressure in some pumps, valves, and turbines. If the user has isolated one of these components in a segment, these parameters will be updated during the iterative solution of Eq. (1.3-21).

The remaining N_{ib} equations are trivial, and merely connect the flow through inlet boundaries to the flow in the adjoining segment:

$$W_m = W_{ib}. \tag{1.3-27}$$

Equation (1.3-21) is solved to adjust segment flows, volume pressures, and inlet boundary module pressure. Immediately following, segment inlet and outlet pressures and outlet boundary module flows are adjusted.

1.4 TRANSIENT CALCULATIONS

The transient calculations are based on the momentum integral network method described earlier. Adjustment factors determined during the steady state calculations are applied consistently in the transient computations. Transients are driven by changes at the boundaries, via the pump and turbine speeds or valve positions, and through the heat sink term in non-heat exchanger modules. All of these parameters can be controlled through user-input value vs. time tables. Alternately, pumps and turbines can be tripped and coasted down and valves can be tripped open and closed in response to pressure (safety/relief) or flow (check). A compatible generic control system is planned, although not currently available.

The overall time step procedure is illustrated in Figure 1.4-1. The initial step is to advance the boundary conditions to the end of the current step, which is consistent with the semi-implicit differencing in MINET. Network calculations are then performed for each network in the system, with the heat exchanger tube temperatures lagged, so as to temporarily decouple the networks. Within a given network, all segment response matrices are first determined (see following section), which effectively predict the response throughout the segments to changes in the volumes and boundary conditions. Once these matrices are known throughout a network, the volumes can be coupled and advanced in time, and the segments can then be advanced. After all networks have been advanced, the heat exchanger tube temperatures are advanced.

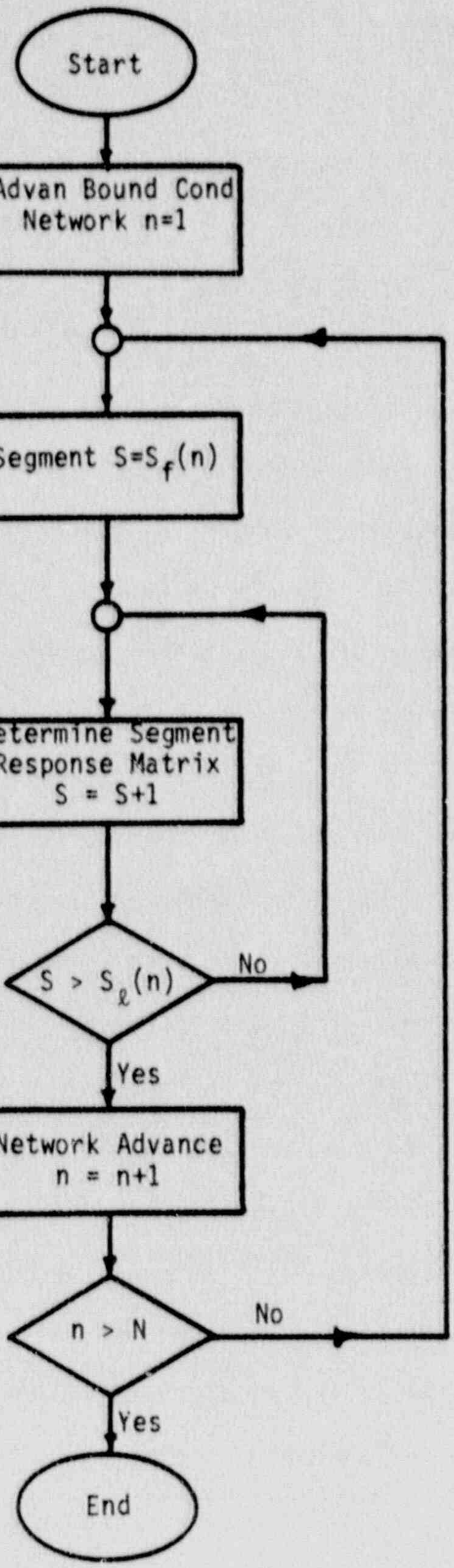


Figure 1.4-1. Transient Time Step Process

1.4.1 TIME STEP PREPARATION

At the beginning of a time step, several parameters including the time step size, must be set. The time step to be taken, Δt^{ℓ}, advances the steam generator variables from current (t^{k}) values to advanced time values (t^{ℓ}).

Most of the equations are integrated semi-implicitly in time, which allows time steps larger than the equation time constants to be used without introducing instabilities. However, the heat exchanger tube temperature is treated explicitly in the wall heat conduction equation, and thus, that equation has a limiting time constant τ_i:

$$\tau_i = \rho t_i \, Cpt_i At_h / fa_h \, (D_o \, h_o + D_i \, h_i) \qquad (1.4\text{-}1)$$

While time constant τ_i in Eq. 1.4-1 is generally the limiting one, time constants for the heat exchanger structure temperature, the pump and turbine speeds and valve positions are also considered. Further, the rate of change in key enthalpies and pressures is also considered, and rapid changes can cause the time step size to be reduced. It should be noted that the increase in time step size, from one step to the next, is limited to 50%.

The second significant task in preparing for a time step is the updating of boundary modules and module heating. The only means of updating these required parameters at present is via user input value vs. time tables, which are interpolated to get current values. If the user has chosen to control any pumps, turbines, or valves in similar fashion, the appropriate tables are used at this time to update the corresponding pump and turbine speeds or valve positions.

There are two alternate means of controlling pump speeds, turbine speeds, and valve positions. A limited control option is available in MINET which manually trips and coasts down pumps and turbines or releases and resets safety valves on pressure settings and check valves on flow conditions. These limited control options are used to update pump and turbine speeds or valve positions when that module is updated. A more sophisticated control system model is planned, but not currently available. For the present, a special purpose controller can be inserted using code updates, should the user choose to do so.

1.4.2 SEGMENT CALCULATIONS

In this part of the transient calculations, the segment response matrix must be determined for the current segment pressures, local enthalpies, mass flow rates, heat fluxes, as well as pump and turbine speeds, and valve positions. The segment response matrix indicates the response of local enthalpies and mass flow rates to current conditions and changes in pressure and enthalpy in bordering modules.

1.4.2.1 LOADING THE SEGMENT EQUATIONS

At this point in the calculations, values are known for most variables, at the k step. Time, boundary module parameters, module heating, and, depending on the control option specified, pump speeds, turbine speeds, and valve positions, are known for the ℓ step. The segment matrix equation is to be used, in conjunction with the network solution, to advance local enthalpies and mass flow rates to the advanced time step, ℓ. The equation is of the form

$$\underline{\underline{A}}\ \underline{x} = \underline{\underline{B}}\ \underline{y}, \qquad (1.4\text{-}2)$$

where, for a segment with N_m nodes, $\underline{\underline{A}}$ is a $2N_m + 2$ square matrix, $\underline{\underline{B}}$ is a $(2N_m + 2) \times 5$ matrix, $\underline{x}$ is a $2N_m + 2$ vector, and $\underline{y}$ is a 5 vector. The $\underline{x}$ vector is composed of nodal interface values:

$$\underline{x} = \text{col}\ \left\{ \Delta E_{mi},\ W_{mi}, \ldots,\ \Delta E_j,\ W_j, \ldots,\ \Delta E_{mo},\ W_{mo} \right\}. \qquad (1.4\text{-}3)$$

Vector $\underline{y}$ is made up of changes in the enthalpy and pressure in the modules connecting to the inlet and outlet of the segment, and unity:

$$\underline{y} = \text{col}\ \left\{ \Delta E_{IM},\ \Delta P_{IM},\ \Delta E_{OM},\ \Delta P_{OM},\ 1 \right\} \qquad (1.4\text{-}4)$$

1.4.2.1.1 NON-TURBINE SEGMENTS

For segments that do not contain turbines (turbines are always isolated in a segment), the standard momentum integral network equations are loaded. The $2N_m + 2$ equations loaded into matrices $\underline{\underline{A}}$ and $\underline{\underline{B}}$ depend on the conditions within the segment at step k. One momentum equation or choke flow constraint must be used for each segment,

$$I_m \frac{dW_m}{dt} = P_{mi} - P_{mo} + \beta_m - \sum_{i=Nf_m}^{N\ell_m} \alpha_i |W_i| W_i, \qquad (1.4\text{-}5)$$

$$\text{if } W_m{}^{est} < Wc_m,$$

or

$$W_m = Wc_m, \qquad \text{if} \qquad W_m{}^{est} \geq Wc_m, \qquad (1.4\text{-}6)$$

where $W_m{}^{est}$ is the segment flow rate estimated with P_{mi} and P_{mo} remaining constant. Zero, one, or two equations must be written to constrain the segment end enthalpy when flow is entering the segment:

$$E_{mi} = E_{IM}, \quad \text{if} \quad W_{mi} \geq 0, \tag{1.4-7}$$

and

$$E_{mi} = E_{OM}, \quad \text{if} \quad W_{mo} \leq 0. \tag{1.4-8}$$

Mass must be conserved in each of the nodes

$$V_i \left(\frac{\partial \rho_i}{\partial E_i}\right) \frac{dE_i}{dt} = W_j - W_{j+1} - V_i \left(\frac{\partial \rho_i}{\partial P_m}\right) \frac{dP_m}{dt} \tag{1.4-9}$$

This accounts for N_m mass equations, giving $N_m + 1$, $N_m + 2$, or $N_m + 3$ equations, depending on the direction of flow at the segment end. The remaining $N_m + 1$, N_m, or $N_m - 1$ remaining equations come from the nodal energy equations.

That $N_m + 1$, N_m, or $N_m - 1$ equations are needed is seemingly in conflict with the ready availability of energy equations for the N_m nodes. At this pont it is enthalpies at the nodal interfaces that are required, and the relationship between the constraint of these enthalpies and the nodal energy equations is not trivial.

The nodal energy equation can be written as:

$$V_i \left\{ \rho_i + E_i \left(\frac{\partial \rho_i}{\partial E_i}\right) \right\} \frac{dE_i}{dt} = W_j E_j - W_{j+1} E_{j+1} + Q_i - V_i \left\{ 1 - E_i \left(\frac{\partial \rho_i}{\partial P_m}\right) \right\} \frac{dP_m}{dt} \tag{1.4-10}$$

Before loading a conservation of mass equation, Eq. (1.4-9), into the matrix equation, the node average enthalpy time derivative term must first be eliminated. The nodal energy equation, Eq. (1.4-10) can be used to isolate the node average enthalpy time derivative:

$$\frac{dE_i}{dt} = \frac{\left\{ W_j E_j - W_{j+1} E_{j+1} + Q_i + V_i \left[1 - E_i \left(\frac{\partial \rho_i}{\partial P_m}\right) \right] \frac{dP_m}{dt} \right\}}{V_i \left\{ \rho_i + E_i \left(\frac{\partial \rho_i}{\partial E_i}\right) \right\}} \tag{1.4-11}$$

This expression is substituted into eq. (1.4-9) to obtain a conservation of mass equation used for all nodes. Equation (1.4-11) is eventually used to advance the node average enthalpies.

In order to use Eq. (1.4-10) to advance the nodal interface enthalpy, the derivative of node average enthalpy with respect to time has to be expressed in terms of the interface enthalpies. If the obvious replacement is made, i.e.,

$$\frac{dE_i}{dt} = 0.5 \left(\frac{dE_j}{dt} + \frac{dE_{j+1}}{dt} \right) \tag{1.4-12}$$

a not so obvious result occurs. Because the time constant for enthalpy transport is relatively long, a non-physical numerical "rocking" occurs, in which outlet enthalpies swing rapidly in response to changes in inlet enthalpy.

The donor-cell differencing scheme is used in lieu of the averaging indicated by Eq. (1.4-12). The assumption is that the rate of change in enthalpy throughout the node (except the inlet section) is uniform in response to changes in inlet enthalpy, and thus,

$$\frac{dE_{j+1}}{dt} = \frac{dE_i}{dt} \tag{1.4-13}$$

The donor cell differenced form of the conservation of energy is written:

$$V_i \left\{ \rho_i + E_i \left(\frac{\partial \rho_i}{\partial E_i} \right) \right\} \frac{dE_{j+1}}{dt} = W_j E_j - W_{j+1} E_{j+1} + Q_i + V_i \left[1 - E_i \left(\frac{\partial \rho_i}{\partial P_m} \right) \right] \frac{dP_m}{dt} \tag{1.4-14}$$

Thus, for a node with flow entering one end and exiting the other, Eq. (1.4-14) effectively projects changes in outlet enthalpy in response to changes in the inlet enthalpy, for current nodal conditions. This is true regardless of whether the flow direction is the same as steady state (forward flow), or the opposite (reversed flow). Of course, when the flow is reversed, the j-th interface is the node outlet, and Eq. (1.4-14) is written for dE_j/dt:

$$V_i \left\{\rho_i + E_i \left(\frac{\partial \rho_i}{\partial E_i}\right)\right\} \frac{dE_j}{dt} = W_j E_j - W_{j+1} E_{j+1} + Q_i + V_i \left[1 - E_i \left(\frac{\partial \rho_i}{\partial P_m}\right)\right] \frac{dP_m}{dt} \qquad (1.4\text{-}15)$$

When flow is not passing through a node, it is either entering (converging) or exiting (diverging) both ends. Neither condition is stable, i.e., likely to continue through the time step. For a diverging flow node, we assume the rate of change in enthalpy is uniform throughout the node, and therefore load both Eq. (1.4-14) and Eq. (1.4-15) into the matrix equation.

For a converging flow node, the enthalpy at both interfaces is determined from outside the node. Thus it is unnecessary to use the nodal energy equation to constrain interface enthalpy.

Thus, a node contributes zero, one, or two constraints on interface enthalpy, depending on whether the flow is converging, through, or diverging, respectively. For a converging flow segment, there must be one more converging node than diverging node. Similarly, a diverging flow segment must contain one more diverging flow node than converging node. A flow-through segment has an equal number of converging and diverging nodes. Therefore, the nodal energy equations account for $N_m - 1$, N_m, or $N_m + 1$ constraints, as are required.

The nodal equations are thus loaded into the matrices of Eq. (1.4-2) in semi-implicit form, i.e.,

$$y^{\ell} = f(x^{\ell}). \qquad (1.4\text{-}16)$$

The loading logic is summarized in Table (1.4-1).

With the complexity involved in choosing the equation to be used in loading the segment matrix equation, care must be taken that mass and energy are conserved for each node. Because the nodal mass conservation equations are, in fact, responding to changes in node average enthalpy and segment pressure, and adjusting mass flow rates accordingly, mass is indeed being conserved. Energy is also being conserved, since Eq. (1.4-11) is subsequently used to advance the node average enthalpy in converging in diverging nodes. For flow-through nodes, back averaging of the nodal interface enthalpies is used to get the new node average enthalpy, as is standard with donor-cell differencing.

1.4.2.1.2 TURBINE SEGMENTS

As was discussed in Section 1.2.6, the MINET model for a turbine stage is based on operating characteristics and thermodynamics, rather than geometry. The model is also quasi-static. The reason for this type of modeling approach is that given the location of the turbine in the plant system, and its substantial complexity, it is best to take a simplified approach for this application.

While the equations loaded into the segment matrix equation (1.4-2) are slightly different for the one node segment containing a turbine stage, they are made to look very much like those in regular segments. Basically there are three differences:

Table 1.4-1 Logic Used in Loading Segment Matrix Equation

Row	I	Load
1	$W_{mi}^{k}>0$	$\Delta E_{mi}^{\ell} = E_{IM}^{\ell} - E_{mi}^{k} + \Delta E_{IM}^{\ell}$
.	.	.
.	.	.
.	.	.
.	.	.
2n-1	$W_{j}^{k}<0$	$(C_3-W_j^k)\Delta E_j^{\ell} - C_7 W_j^{\ell} + W_{j+1}^{k}\Delta E_{j+1}^{\ell} + C_8 W_{j+1}^{\ell} = -C_4 \Delta P_m^{\ell} + Q_i^k - \left(\frac{\delta Q_i}{\delta W_i}\right) W_i^k$
2n	Any	$-C_5 W_j^k \Delta E_j^{\ell} + \left\{1-C_5 E_j^k - C_6\right\} W_j^{\ell} \; C_5 W_{j+1}^{k} \Delta E_{j+1}^{\ell} + \left\{C_5 E_{j+1}^{k} - C_6 - 1\right\} W_{j+1}^{\ell} = (C_2 - C_4 C_5)\Delta P_m^{\ell} + C_5 Q_i^k - 2C_6 W_i^k$
2n+1	$W_{j+1}^{k}>0$	$-W_j^k \Delta E_j^{\ell} - C_7 W_j^{\ell} + (W_{j+1}^{k}+C_3)\Delta E_{j+1}^{\ell} + C_8 W_{j+1}^{\ell} = -C_4 \Delta P_m^{\ell} + Q_i^k - \left(\frac{\delta Q_i}{\delta W_i}\right) W_i^k$
.	.	.
.	.	.
.	.	.
.	.	.
$2N_m+1$	$W_{mo}^{k}<0$	$\Delta E_{mo}^{\ell} = E_{CM}^{k} - E_{mo}^{k} + \Delta E_{OM}^{\ell}$
$2N_m+2$	$W_m^{est} \geq Wc_m^k$	$\sum_{i=Nf_m}^{N\ell_m} \left\{\left[\frac{\Delta X_i}{A_i \Delta t^{\ell}} + \left(\alpha_i^k + Fk_m \frac{\Delta X_i / A_i}{I_m}\right) \lvert W_i^k \rvert\right] \frac{(W_j^{\ell} + W_{j+1}^{\ell})}{2}\right\} = \frac{I_m W_m^k}{\Delta t^{\ell}} + P_{IM}^{\ell} - P_{OM}^{\ell} + \beta_m^k$
	$W_m^{est} > Wc_m^k$	$\sum_{i=Nf_m}^{N\ell_m} \left\{\frac{\Delta X_i}{2A_i} (W_j^{\ell} + W_{j+1}^{\ell})\right\} = I_m \, Wc_m^k$

Table 1.4-1 (Continued)

where

$$C_1 = \frac{V_i}{\Delta t} \left(\frac{\partial \rho_i}{\partial E_i}\right)^k , \quad C_2 = \frac{V_i}{\Delta t} \left(\frac{\partial \rho_i}{\partial P_m}\right)^k , \quad C_3 = \frac{V_i}{\Delta t} \left[\rho_i + E_i \left(\frac{\partial \rho_i}{\partial E_i}\right)\right] - \frac{\partial Q_i}{\partial E_i} , \quad C_4 = \frac{V_i}{\Delta t} \left[E_i \left(\frac{\partial \rho_i}{\partial P_m}\right) - 1\right] ,$$

$$C_5 = C_1/C_3 , \quad C_6 = C_5 \left(\frac{\partial Q_i}{\partial W_i}\right) /2 , \quad C_7 = E_j^k + \left(\frac{\partial Q_i}{\partial W_i}\right) /2 , \quad C_8 = E_{j+1}^k - \left(\frac{\partial Q_i}{\partial W_i}\right) /2$$

1) The flow gradient across the segment is forced to zero by setting the density derivatives to zero. This is done because the dynamic response of flow in the turbine is very fast, and the flow out will nearly match the flow in.

2) The heating term in Eq. (1.4-11) is set to the current work being done on the turbine, which is generally negative, and causes a reduction in enthalpy.

3) The modified Stadola Equation, Eq. (1.2-13), is used in place of the momentum equation by setting β to zero and altering the definition of α in Eq. (1.4-5) to

$$\alpha = \frac{P_{in}}{((P_{in} + P_{out}) \cdot \rho_{in} \cdot Fk_{tb}^{2})} \qquad (1.4\text{-}17)$$

The segment inertia I is also zeroed out, converting Eq. (1.4-5) to a steady state equation.

1.4.2.2 SOLVING FOR THE SEGMENT RESPONSE MATRIX

Once the matrices of Eq. (1.4-2) have been loaded, the segment response matrix is available as:

$$\underline{\underline{B}}' = \underline{\underline{A}}^{-1}\, \underline{\underline{B}}. \qquad (1.4\text{-}18)$$

While the expression of the segment response matrix as the inverse of matrix $\underline{\underline{A}}$ times matrix $\underline{\underline{B}}$ is simple enough, the computation involved can be significant, especially for large matrices. Because of the large number of zeros in the $\underline{\underline{A}}$ matrix, MINET loads and solves the segment matrix equation in close-packed form. This step saves data storage space and significantly increases computational speed. Since a form of Gaussian elimination is still used to solve for the segment response matrix, there is little need to detail the process beyond making the following points.

1) Matrix $\underline{\underline{A}}$ is stored and solved as a six column matrix with $2N_m + 1$ rows plus a $2N_m + 2$ column matrix with one row (the momentum equation).
2) While the entries of matrix $\underline{\underline{A}}$ change somewhat under various flow conditions, the solver is general enough to handle any situation.
3) The solver is several times faster than full Gaussian elimination.

1.4.2.3 BOUNDARY ADJUSTED SEGMENT RESPONSE MATRIX

Before continuing on to evaluate the segment response matrices for the other segments, two steps are taken. First, matrix $\underline{\underline{A}}$ is discarded (data storage area de-allocated), as it is no longer useful. Second, advanced time (step ℓ) values are already known for the boundary modules, and these values are factored into the segment response matrix at this time. For a boundary module at the segment inlet with pressure and enthalpy specified as boundary conditions, these changes can be factored into column 5 of the matrix:

$$\left\{B^k_{i,5} = B^k_{i,5} + B^k_{i,1}\,\Delta E^{\ell}_{IM} + B^k_{i,2}\,\Delta P^{\ell}_{IM}\right\},\ i = 1,\ldots,2N_m + 2 \qquad (1.4\text{-}19)$$

When mass flow rate is the bondary condition for the inlet boundary module, the change in pressure must be inferred from the equation for W_{mi} (after ΔE^{ℓ}_{IM} is factored in),

$$\Delta P^{\ell}_{IM} = \left\{W^{\ell}_{IM} - B_{2,5} - B_{2,3}\,\Delta E^{\ell}_{OM} - B_{2,4}\,\Delta P^{\ell}_{OM}\right\}/B_{2,2} \qquad (1.4\text{-}20)$$

This change in pressure is then factored into all of the rows.

$$\left\{B^{k}_{i,5} = B^{k}_{i,5} + (W^{\ell}_{IM} - B_{2,5})B_{i,2}/B_{2,2}\right\} \quad , i = 1,\ 2N_m + 2 \qquad (1.4\text{-}21)$$

$$\left\{B^{k}_{i,3} = B^{k}_{i,3} - B_{2,3} \cdot B_{i,2}/B_{2,2}\right\} \quad , i = 1,\ 2N_m + 2 \qquad (1.4\text{-}22)$$

$$\left\{B^{k}_{i,4} = B^{k}_{i,4} - B_{2,4} \cdot B_{i,2}/B_{2,2}\right\} \quad , i = 1,\ 2N_m + 2 \qquad (1.4\text{-}23)$$

If the mass flow rate is specified for a boundary module at the outlet end of a segment, it is the last row of the segment response matrix that is used to infer the change in outlet pressure. For the case when both ends of a segment connect to boundary modules, only the fifth column of the boundary adjusted segment response matrix is effectively non-zero, and the advancement of segment parameters to step ℓ could be done immediately.

All of the segments in a network side are completed, and the boundary adjusted segment response matrices are stored, before the network volume pressure and enthalpy calculations are performed. First, however, the module advancement process, performed while the segment matrix equation is being loaded, will be discussed.

1.4.3 MODULE CONDITIONS UPDATE

In the transient calculations, the module level variables are advanced at the same time that the segment equations are being loaded. This saves on data storage space and reduces code complexity.

Essentially, there are two types of module level characteristics that must be known for segment level calculatons to proceed correctly. These are pressure drops and heat transfer (or work) rates.

As was the case in steady state calculations, the pressure losses are broken into two parts, a constant term, β_m (see Eq. (1.3-18)), and a term proportional to the square of the mass flow rate, α. However, during transients, there is often wide variation in local mass flow rate, and the use of a segment loss factor, α_m, is impractical. Instead, a local loss factor, α_i, is evaluated for each node and is loaded into the segment momentum equation (see last row in Table 1.4-1). This local α_i is defined consistently with Eq. (1.3-19), i.e.,

$$\alpha_i = \frac{f_i}{2\rho_i A_i D_i} + \delta_{iv} K_v/2\rho_i A_v^2 + \frac{Fk_i}{2\rho A^2 D_{eq}} \tag{1.4-24}$$

Pressure losses due to gravity, friction, and acceleration are evaluated at each segment node, for current time enthalpies, mass flow rates, and pressures. For the pump, turbine, and valve modules (one node each), an additional contribution is made to the pressure drop. In order to evaluate these pressure drop terms accurately, advanced time values of relative pump and turbine speed and valve stem position are needed. If a speed or valve position has already been set, the module calculation can proceed. If alternate means of controlling pump and turbine speeds and valve position were specified, the speed or position must yet be advanced in time.

For a pump, the relative demand speed, $\omega d_p{}^\ell$, is first calculated. The advanced time relative pump speed, ω^ℓ, is calculated via the differential equation

$$\tau_p \left(\frac{d\omega_p}{dt}\right)^\ell = \omega d_p{}^\ell - \omega_p{}^k , \qquad (1.4\text{-}25)$$

where τ_p is the user input pump time constant. If the relative pump speed drops below the user-input pump seizure speed, it is set to zero. The relative demand speed can be tripped, i.e., changed from 1 to 0, at a user input time, through the limited MINET control option or other control system action.

For a valve, the relative demand stem position, S_d is first calculated. The advanced time valve stem position is calculated using the equation

$$\tau_v \left(\frac{ds}{dt}\right)^\ell = S_d^\ell - S^k \qquad (1.4\text{-}26)$$

where τ_v is the appropriate user-input time constant. The stem position is limited by the user-input minimum "leak" position and full open. Furthermore, it is not allowed to cross past the current demand position during the step. The limited MINET internal controller is useful for safety valves which open ($S_d = 1.0$) and close ($S_d = 0.0$) at set pressures and time constants (τ_{vo} and τ_{vc}). In an alternate option, the user can specify a check valve, in which case the demand position responds to local flow rather than pressure.

For a turbine stage, the relative demand speed, ωd_t^ℓ, is first calculated. The advanced time relative pump speed, ω_t^ℓ, is calculated via the differential equation

$$\tau_t \left(\frac{d\omega_t}{dt}\right)^\ell = \omega d_t^\ell - \omega_t^k \tag{1.4-27}$$

where τ_t is the user input turbine time constant. Should the turbine speed drop below the seizure speed from user input, the speed is set to zero. The turbine can be tripped at a given time through user input, which resets the demand speed from 1 to 0.

The calculation of current time heat transfer rates is a more involved process, partly because the tube wall temperature depends on conditions in two otherwise disconnected segments. Because the time constants in the heat transfer process are not small, explicit treatment of the tube temperature, Tc^k, is possible.

When heat exchangers are analyzed during the segment marches, the heat transfer rate is evaluated using current fluid characteristics and tube wall temperatures,

$$Q_i^k = \pi D \Delta X_i \cdot h_i^k \left(E_i^k, P_m^k, Tc_i^k\right) \cdot \left(Tc_i^k - T\left(E_i^k, P_m^k\right)\right). \tag{1.4-28}$$

The dependence of the heat flux on fluid enthalpy and mass flow rate are evaluated so that heat flux can be integrated implicitly with respect to these variables:

$$Q_i^\ell = Q_i^k + \frac{dQ_i^k}{dE_i} \Delta E_i^\ell + \frac{dQ_i^k}{dW_i} \Delta W_i^\ell \tag{1.4-29}$$

Only after all other system calculations are completed is the tube temperature advanced

$$Tc_i^{\ell} = Tc_i^{k} - \frac{\Delta t^k fa_h \; (D_I \; Q_{Ii}^{\ell} + D_O \; Q_{Oi}^{\ell})}{At_h \; \rho t_i \; Cpt_i} \tag{1.4-30}$$

where subscript I and O refer to inside and outside the tube, respectively.

The explicit treatment of the tube wall temperatures greatly simplifies the calculational process, effectively decoupling the networks briefly while system variables are being advanced. However, it also introduces the time constant given in Eq. (1.4-1), which follows directly from Eqs. (1.4-28) and (1.4-30).

1.4.4 NETWORK VOLUME CALCULATIONS

Once the segment response matrices have been determined for all of the segments in one network, the volume pressures and enthalpies can be determined. Conservation equations for mass and energy in each of the N_d network volumes are coupled in the matrix equation,

$$\underline{\underline{C}} \; \underline{V} = \underline{\underline{D}}, \tag{1.4-31}$$

where $\underline{\underline{C}}$ is a $2N_d$ square matrix, $\underline{\underline{D}}$ is a $2N_d$ vector, and $\underline{V}$ is the $2N_d$ vector

$$\underline{V} = \text{col} \left\{ \Delta E_1, \Delta P_1, \ldots, \Delta E_{N_d}, \Delta P_{N_d} \right\} . \tag{1.4-32}$$

The individual equations loaded into Eq. (1.4-31) are implicit forms of Eqs. (1.1-1) and (1.1-2), with Eq. (1.1-3) used to eliminate the density time derivatives.

$$\frac{V_n}{\Delta t}\left(\frac{\partial \rho_n}{\partial E_n}\right)^k \Delta E_n{}^\ell + \frac{V_i}{\Delta t}\left(\frac{\partial \rho_n}{\partial P_n}\right) \Delta P_n{}^\ell = \overset{\text{Inlets}}{\Sigma\, W_{mo}} - \overset{\text{Outlets}}{\Sigma\, W_{mi}} \qquad (1.4\text{-}33)$$

$$\frac{V_n}{\Delta t}\left\{\rho_n + E_n\left(\frac{\partial \rho_n}{\partial E_n}\right)^k\right\}\Delta E_n{}^\ell + \frac{V_n}{\Delta t}\left[E_n{}^k\left(\frac{\partial \rho_n}{\partial P_n}\right)^k - 1\right]\Delta P_n{}^\ell \qquad (1.4\text{-}34)$$

$$\overset{\text{Inlets}}{\Sigma\, W_{mo}{}^\ell E_{mo}{}^\ell} - \overset{\text{Outlets}}{\Sigma\, W_{mi}{}^\ell E_{mi}{}^\ell} + Q_n{}^\ell$$

The process of loading Eqs. (1.4-33) and (1.4-34) into Eq. (1.4-31) is straightforward, with the exception of the inflows and outflows. Here the segment response matrices must be used to obtain the advanced time segment inlet and outlet mass flow rate and enthalpy as a function of changes in bordering pressures and enthalpies. As a simplification, for this part of the process it is assumed that the change in pressure at the segment boundary is equal to the change in pressure in the bordering volumes (even though the absolute pressures may be different). Thus, for a segment taking flow out of volume 1 and into volume 2, the second row of the segment response matrix is retrieved (volume outflow is segment inflow). Then, for the first volume mass equation, the first four columns of the segment response matrix, row 2, are added to the first four columns of matrix C, row 1. This accounts for changes in the mass flow rate going into the segment in response to changes in enthalpy and pressure in the inlet and outlet bordering volume. The fifth column entry of row 2 of the segment response matrix is then subtracted from the first row of vector D. Note that if the segment were connected at this outlet to a boundary module instead of a volume, the third and fourth columns of the segment response matrix would be ignored.

Loading Eq. (1.4-34) is slightly more difficult because the flow energy terms must be linearized.

$$W^{\ell}E^{\ell} = E^{k}W^{\ell} + W^{k}\Delta E^{\ell}. \qquad (1.4\text{-}35)$$

Rows must be extracted from the segment response matrix for both W^{ℓ} and ΔE^{ℓ}, and substituted in Eq. (1.4-35). Second order "Δ" terms are dropped. The remaining terms are then loaded into Eq. (1.4-31).

After equations for all volumes in the network have been loaded into the matrices, Eq. (1.4-31) is solved for vector $\underline{V}$. This is done using full Gaussian elimination, as these matrices are generally small and have mostly nonzero elements.

$$\underline{V} = \underline{\underline{C}}^{-1}\ \underline{D} \qquad (1.4\text{-}36)$$

Vector $\underline{V}$ contains changes in the network volume enthalpies and pressure during the time step.

1.4.5 ADVANCING NETWORK VARIABLES

Volume enthalpies and pressures are advanced using the changes indicated in vector $\underline{V}$. If the contents of the volume are separated, the new level is then calculated. Using vector $\underline{V}$ and the boundary module adjusted segment response matrix, all of the nodal interface enthalpies and mass flow rates are then advanced.

The advancement of segment inlet and outlet enthalpy and mass flow is straightforward, as they are equal to the values for the just advanced interface enthalpies and mass flow rate at the inlet and outlet of the segment.

Similarly, the boundary module enthlapies and mass flow rates can be advanced, where appropriate, using segment inlet and outlet enthalpies and flows.

Segment inlet/outlet pressures and boundary module pressure are not always as easy to advance. If the segment connects to a volume, the segment inlet/outlet pressure is calculated using the advanced volume pressure and elevation head. In the case where the pressure option was chosen as the user input parameter for the boundary module, the pressure at the boundary module is advanced already, and the adjoining segment pressure is adjusted to match it. It is the case where one or both ends of the segment connect to boundary modules and where mass flow rate boundary conditions were specified that is most difficult. For such a boundary module at the segment inlet, Eq. (1.4-20) must be used (these matrix B entries are carefully preserved). A similar expression is used when a mass flow rate boundary condition is specified at the segment outlet. When a segment has mass flow rate boundary conditions on both ends, Eq. (1.4-20) and the equivalent at the segment outlet are coupled and solved for the pressure at both ends.

Once the segment inlet and outlet pressures have been advanced, a new segment average pressure is calculated. This advanced time pressure is compared against the current value, thus giving the change over the time step, to be used in advancing the node average enthalpies. The node average energy equation used is the linearized form of Eq. (1.4-11):

$$\begin{aligned}\Delta E_i = \Big\{ & -C_4 \Delta P_m^\ell + W_j^\ell E_j^\ell - W_{j+1}^\ell E_{1+1}^\ell \\ & + Q_i^k + \left(\frac{\partial Q_i}{\partial W_i}\right) \Delta W_i^\ell \Big\} / C_3\end{aligned} \qquad (1.4\text{-}37)$$

where C_3 and C_4 are as given in Table (1.4-1). If the flow is passing through the node at the beginning of the step, the node average enthalpy is over-written with the linear average of the junction enthalpies on either end. This is a standard step in the donor-cell differencing scheme used for the flow-through nodes. Thus, Eq. (1.4-37) is actually used (and is critical) only for converging and diverging flow nodes.

1.5 MINET CONSTITUTIVE RELATIONS

The equations detailed in previous sections were obtained from a physical and mathematical representation of the system, and its components. These are supplemented by various empirical and semi-empirical relations generally referred to as correlations. These constitutive relations are used to determine fluid and material properties, heat transfer and conductivity, as well as friction factors.

The constitutive relations used in MINET reflect, to some degree, on past, current, and intended applications. Should the user wish to make substitutions, the relevant functions are easily identified and can easily be modified.

1.5.1 FLUID PROPERTIES

The MINET fluid property functions provide values of dependent variables, e.g., density and temperature, as a function of the MINET independent variables, enthalpy and pressure. Properties are currently in place for water/steam, sodium, air, and NaK. The functions for water and steam are far more extensive than the others, as they span the subcooled, saturation, and superheated states, and are accurate over a wide range of pressure. Sodium and NaK are assumed to be subcooled and incompressible, but thermally expandable. Air is assumed to be an ideal gas.

Most of the fluid properties are programmed to parallel each other, allowing the use of the generic fluid functions listed in Table 1.5-1. These six functions can be called with the fluid enthalpy (or temperature, if ENTH3C), pressure, fluid type, and the side parameter. The side parameter is used to take advantage of the segment average saturation properties, and can have values of 1, 2, or 3 meaning (1) inside the tubes or pipes, (2) outside the heat exchanger tubes, or (3) "other". In several cases, these functions are trivial for fluids other than water/steam, but their use simplifies the code logic, justifying the occasional overkill.

Table 1.5-1 Generic Fluid Properties

Name	Function
TEMP3C	T (E, P, Fluid, Side)
ENTH3C	E (T, P, Fluid, Side)
RHO3C	ρ (E, P, Fluid, Side)
DRDE3C	$\partial\rho/\partial E$ (E, P, Fluid, Side)
DRDP3C	$\partial\rho/\partial P$ (E, P, Fluid, Side)
VISC3C	μ (E, P, Fluid, Side)

1.5.1.1 WATER AND STEAM

Because of storage considerations, functional fit steam tables are used in MINET, as opposed to tabular data. Many of these functions are based on those cited in the RETRAN-02 code documentation [9], and were simply converted from British Units to S.I. units. They were reported to be accurate from 0.7 KPa to 22.114 MPa (critical) within 1%, and usually are much closer to 1964 ASME tabular values. The S.I. versions incorporated in MINET appear to be equally accurate.

1.5.1.1.1 SATURATION PROPERTIES

A small number of MINET steam table functions are purely saturation properties, as opposed to subcooled or superheated properties evaluated at saturation conditions. These include saturation enthalpies, entropies, and surface tension.

The functions for saturated liquid and vapor enthalpies are given by the relations [9]

$$E_f(P) = \begin{cases} \sum_{i=0}^{8} CF1_i(\ln(P'))^i & \text{if} \quad 0.1 \text{ PSIA} < P' < 950 \text{ PSIA} \\ \sum_{i=0}^{8} CF2_i(\ln(P'))^i & \text{if} \quad 850 \text{ PSIA} < P' < 2550 \text{ PSIA} \\ \sum_{i=0}^{8} CF3_i((PCRIT-P')^{0.41})^i & \text{if} \quad 2550 \text{ PSIA} < P' \leq 3208.2 \text{ PSIA} \end{cases} \tag{1.5-1}$$

and

$$E_g(P) = \begin{cases} \sum_{i=0}^{11} CG1_i(\ln(P'))^i & \text{if} \quad 0.1 \text{ PSIA} < P' < 1500 \text{ PSIA} \\ \sum_{i=0}^{8} CG2_i(\ln(P'))^i & \text{if} \quad 950 \text{ PSIA} < P' < 2650 \text{ PSIA} \\ \sum_{i=0}^{6} CG3_i((PCRIT-P')^{0.41})^i & \text{if} \quad 2550 \text{ PSIA} < P' \leq 3208.2 \text{ PSIA} \end{cases} \tag{1.5-2}$$

where

$$P' \text{ (PSIA)} = P \text{ (Pa)}/6892.86, \tag{1.5-3}$$

and E is enthalpy in Joules/Kg. The coefficient for Eqs. (1.5-1) and (1.5-2) are given in Table 1.5-2. To insure a smooth transition, the functions are interpolated near the switch points, e.g., between 850 and 950 PSIA for saturated liquid enthalpy.

The saturated entropy functions are given by

$$S_f(P) = \sum_{i=1}^{j} A(i)\, P^{i-1}, \tag{1.5-4}$$

and

$$S_g(P) = \sum_{i=1}^{j} B(i)\, P^{i-1}, \tag{1.5-5}$$

where P is pressure in Pa, S is entropy in J/KG/K, and coefficients A and B are as given in Table 1.5-3 [10].

The surface tension, σ, for the surface between the liquid and vapor phases of saturated water is expressed as a function of saturation temperature in a correlation by Schmidt [9]:

$$\sigma = \frac{a_1\, (T_k - T)^2}{1 + \beta\, (T_K - T)} + \sum_{n=2}^{5} a_n\, (T_K - T)^n\ , \tag{1.5-6}$$

Table 1.5-2 Saturated Enthalpy Coefficients

i	$CF1_i$	$CF2_i$	$CF3_i$
0	1.621428516E5	1.955844733E9	2.107363079E6
1	7.763094766E4	8.460623122E8	-3.318768201E4
2	5.39222795E3	-1.077986251E9	3.540715284E3
3	4.281234467E2	2.629092545E8	-1.622150763E3
4	-1.220103831E1	-1.011860544E5	4.054431208E2
5	6.694244345	-9.069046525E6	-5.395663361E1
6	4.078995306	1.557815108E6	3.940288541
7	-1.00828835	-1.100366955E5	-1.5013799E-1
8	7.735557653E-2	2.942680883E3	2.332985206E-3

i	$CG1_i$	$CG2_i$	$CG3_i$
0	2.572176571E6	-5.196900383E9	2.107350942E6
1	3.342331204E4	2.863881997E9	1.293711324E4
2	1.865053933E3	-4.602800148E3	7.987925031E3
3	37.6168376	4.326332190E4	-1.49012646E3
4	-3.491669097	-6.433021266E3	1.376661588E2
5	0	2.4098148E6	-6.339230554
6	0	-4.985602203E5	1.164472972E-1
7	0	3.932121054E4	-
8	0	-1.131441328E3	-
9	-2.878833357E-2	-	-
10	6.989102705E-3	-	-
11	-4.747120847E-4	-	-

Table 1.5-3 Saturated Entropy Coefficients

Interval:					
P(Pa) Lower:	6.893E2	6.893E3	6.893E4	6.893E5	6.893E6
P(pa) Upper:	6.893E3	6.893E4	6.893E5	6.893E6	2.206E7
i	A(i)	A(i)	A(i)	A(i)	A(i)
1	-2.54745E2	2.38789E2	8.02999E2	1.44017E3	-2.20848E4
2	5.53165E-1	6.20416E-2	7.47844E-3	1.10989E-3	1.442656E-2
3	-2.60122E-4	-2.82744E-6	-3.32931E-8	-5.90071E-10	-3.49733E-9
4	7.94604E-8	8.55421E-11	9.91732E-14	2.25130E-16	4.62936E-16
5	-1.40433E-11	-1.51647E-15	-1.73103E-19	-5.41747E-23	-3.59341E-23
6	1.30802E-15	1.42790E-20	1.60476E-25	7.82891E-30	1.63582E-30
7	-4.95878E-20	-5.49668E-26	-6.08564E-32	-6.18745E-37	-4.04720E-38
8	-	-	-	2.05140E-44	4.20332E-46

Interval:					
P(Pa) Lower:	6.893E2	6.893E3	6.893E4	6.893E5	6.893E6
P(pa) Upper:	6.893E3	6.893E4	6.893E5	6.893E6	2.206E7
i	B(i)	B(i)	B(i)	B(i)	B(i)
1	9598.322/4	7.91753E3	7.91753E3	7.18409	3.72952E4
2	- .970369	-8.59705E-3	-8.59705E-3	-9.78648E-4	-1.79198E-2
3	4.7138E-4	4.06828E-8	4.06828E-8	5.51919E-10	4.31043E-9
4	-1.44925E-7	-1.23303E-13	-1.23303E-13	-2.15887E-16	-5.65901E-16
5	2.5653E-11	2.16846E-19	2.16846E-19	5.26786E-23	4.36308E-23
6	-2.38994E-15	-2.01815E-25	-2.01815E-25	-7.68853E-30	-1.97567E-30
7	9.05962E-20	7.66976E-32	7.66976E-32	6.12538E-37	4.86766E-38
8	-	-	-	-2.04492E-44	-5.03894E-46

where σ is in N/M^2 and T is in K. Values for the constants in Eq. (1.5-6) are:

T_K = 647.3 K
a_1 = 1.160936807E-4
a_2 = 1.121404688E-6
a_3 = -5.75280518E-9
β = 0.83
a_4 = 1.28627465E-11
a_5 = -1.14971929E-14

As this saturation function is dependent on T, we must first determine the saturation temperature using the pressure and saturated liquid enthalpy, using the subcooled temperature function discussed in the next section.

1.5.1.1.2 SUBCOOLED WATER PROPERTIES

There are six functions that provide the subcooled water parameters, corresponding to the pressure and subcooled enthalpy. These functions include temperature, density, thermal conductivity, absolute viscosity, specific heat, and entropy, although the latter two are not really independent functions, as such.

The subcooled water temperature can be expressed as [9]:

$$T = \sum_{i=0}^{1} \sum_{j=0}^{3} CT1_{ij} \, P^i E^j, \qquad (1.5\text{-}7)$$

where P is pressure in Pa, E is enthalpy in J/KG, T is in K, and coefficients $CT1_{ij}$ are as given in Table 1.5-4.

Table 1.5-4 Coefficients $CT1_{ij}$ for Eq. 1.5-7

i/j	0	1	2	3
0	273.42	2.332E-4	1.907097E-11	-2.067247E-17
1	2.708826E-7	-1.9388325E-12	2.411277E-18	-7.558857E-25

The specific heat is equal to the derivative of enthalpy with respect to temperature, expressed in J/KG/K. The function is determined by taking the derivative of Eq. (1.5-7) with respect to enthalpy and inverting.

The density is determined by inverting a function fitted for the specific volume [9]:

$$\rho = 1/\exp \sum_{i=0}^{2} \sum_{j=0}^{4} CN1_{ij} P^{i} E^{j} , \qquad (1.5\text{-}8)$$

where ρ is the density in KG/M^3, and the coefficients $CN1_{ij}$ are as given in Table 1.5-5.

The thermal conductivity in W/M/K is represented using the expression [11].

$$K_{\ell} = \sum_{i=0}^{3} A_i EN^{i} , \qquad (1.5\text{-}9)$$

when EN is normalized enthalpy, E(J/KG)/5.815E5, and coefficients A_i are given in Table 1.5-6.

Table 1.5-5 Coefficients $CN1_{ij}$ for Eq. 1.5-8

i/j	0	1	2	3	4
0	-6.891704	-1.63856E-7	7.96312E-13	-7.279005E-19	2.739196E-25
1	-6.98704E-10	4.83059E-15	-1.873972E-20	2.20968E-26	-8.7246E-33
2	-3.831966E-17	1.30374E-22	-8.100242E-29	-6.027144E-35	5.32613E-41

Table 1.5-6 Coefficients A_i for Eq. 1.5-9

i	A_i
0	.5737386
1	.2536104
2	-.1154683
3	.0138747

The absolute viscosity, μ $(N \cdot S/M^2)$, for subcooled water is given by the three part function:

$$\mu = \begin{cases} \sum_{i=0}^{4} FKL1_i \, (XI)^i - (P-PCON) \sum_{i=0}^{3} FKL2_i & , \; E^i < .276E6 \\ \sum_{i=0}^{3} FKL3_i \, E^i + (P-PCON) \sum_{i=0}^{3} FKL4_i \, E^i , & .276E6 < E < .394E6 \\ \sum_{i=0}^{4} FKL5_i \, Z^i & , \; E > .394E6 \end{cases} \qquad (1.5\text{-}10)$$

where

PCON = 6.894575E5
XI = 8.5812897E-6* (E-4.265884E4)
η = 6.484504E-6* (E-5.53588E4)
Z = 3.89208E-6* (E-4.014676E5)

and coefficients are as shown in Table 1.5-7 [9].

Table 1.5-7 Coefficient FKL for Eq. (1.5-10)

i	FKL1	FKL2	FKL3	FKL4	FKL5
0	1.29947E-3	-6.5959E-12	4.452605E-3	-3.80635E-11	3.026032E-4
1	-9.26403E-4	6.763E-12	-6.988008E-9	3.92852E-16	-1.836607E-4
2	3.81047E-4	-2.88825E-12	1.52102303E-14	-1.25858E-21	7.567076E-5
3	-8.219444E-5	4.4525E-13	-1.23032E-20	1.2860181E-27	-1.647879E-5
4	7.022438E-6	-	-	-	1.4164576E-6

Subcooled entropy is calculated using the thermodynamic identity [12]:

$$Tds = dE - dP/\rho \qquad (1.5\text{-}11)$$

and the saturated liquid entropy function, S_f. First, S_f is calculated at the given pressure, then S is calculated using the change in enthalpy from saturation:

$$S = S_f + \int_{E_f}^{E} \frac{1}{T} dE \ . \qquad (1.5\text{-}12)$$

Because temperature is roughly linear with respect to enthalpy, the integral in Eq. (1.5-12) can be approximated using a few intervals, evaluating an interval average temperature for each.

1.5.1.1.3 SUPERHEATED STEAM PROPERTIES

Six functions provide superheated steam properties, corresponding to pressure and superheated enthalpy. Included are functions for temperature, density, thermal conductivity, absolute viscosity, specific heat, and entropy, although the specific heat and entropy are not truly independent of the others.

The superheated steam temperature can be expressed as [9]:

$$T = \sum_{i=0}^{4} \sum_{j=0}^{4} CT3_{ij} P^i E^j \qquad (1.5\text{-}13)$$

where P is pressure in Pa, E is enthalpy in J/KG, T is in K, and coefficients $CT3_{ij}$ are as given in Table 1.5-8. By taking the derivative of Eq. 1.5-13 with respect to enthalpy and inverting, we get the specific heat function.

The density is determined by inverting a function that was fitted for specific volume [9]:

$$\rho = 1/(\sum_{i=-1}^{2} \sum_{j=0}^{2} CN2_{ij} P^i E^j) , \qquad (1.5\text{-}14)$$

where ρ is the density in KG/M^3, and the coefficients $CN2_{ij}$ are as given in Table 1.5-9.

Thermal conductivity in W/M/K is determined using the expression [11]:

$$K_\nu = \sum_{i=0}^{3} X1_i T^i + \rho (\sum_{i=0}^{2} X2_i T^i + \frac{2.1482E5 \cdot \rho}{T^{4.2}}), \qquad (1.5\text{-}15)$$

where T is temperature in C, ρ is density in KG/m^3, and coefficients $X1_i$ and $X2_i$ are as given in Table 1.5-10. Before Eq. (1.5-15) is utilized, the density and temperature are calculated from the enthalpy and pressure, and 273.15 is subtracted from the temperature (K).

Table 1.5-8 Coefficient $CT3_{ij}$ for Eq. (1.5-13)

i/j	0	1	2	3	4
0	-6.29534E3	6.757606E-3	-2.750097E-9	5.380348E-16	-3.97061E-23
1	1.01245E-2	-1.15508E-8	4.956197E-15	-9.465447E-22	6.782646E-29
2	-1.267194E-9	1.472029E-15	-6.42424E-22	1.247552E-28	-9.0904E-36
3	5.560932E-17	-6.54272E-23	2.89918E-29	-5.727995E-36	4.252915E-43
4	-8.430666E-25	1.008109E-30	-4.55535E-37	9.199409E-44	-6.99126E-51

Table 1.5-9 Coefficients $CN2_{ij}$ for Eq. (1.5-14)

i/j	0	1	3
-1	-6.0375846E5	.33347807	-1.66807553E-8
0	2.3829985E-2	-1.4478263E-8	2.14067927E-15
1	-5.84125397E-10	3.28542173E-16	-4.14237911E-23
2	1.0280145E-17	-5.95310121E-24	8.81492754E-31

Table 1.5-10 Coefficients $X1_i$ and $X2_i$ for Eq. (1.5-15)

i	$X1_i$	$X2_i$
0	1.76E-2	1.0351E-4
1	5.87E-5	.4198E-6
2	1.04E-7	-2.771E-11
3	-4.51E-11	-

The superheated steam absolute viscosity ($N \cdot S/M^2$) is also a function of density and temperature in C, which must first be calculated from the pressure and enthalpy. A three part function is used [9]:

$$\mu_V = \begin{cases} V1 - \rho\,(1.858E\text{-}7 - 5.9E\text{-}10 \cdot T) & T(C) < 300 \\ V1 + \rho \left\{ \sum_{i=0}^{3} F_i\, T^i + \sum_{i=0}^{3} G_i T^i \cdot \sum_{i=0}^{2} A_i \rho^i \right\} & 300 < T(C) < 375 \\ V1 + \rho \sum_{i=0}^{2} A_i\, \rho^i & T(C) > 375 \end{cases} \tag{1.5-16}$$

where A_i, F_i and G_i are as given in Table 1.5-11 and

$$V1 = .407E\text{-}7 \cdot T(C) + 8.04E\text{-}6. \tag{1.5-17}$$

Table 1.5-11 Coefficients A_i, F_i, and G_i for Eq. (1.5-16)

i	A_i	F_i	G_i
0	3.53E-8	-.2885E-5	.176E3
1	6.765E-11	.2427E-7	-1.6
2	1.021E-14	-.6789333E-10	.0048
3	-	.6317037E-13	- .474074074E-5

Superheated steam entropy is also calculated using the thermodynamic identity [12]:

$$Tds = dE - dP/\rho \tag{1.5-18}$$

and the saturated vapor entropy, S_g. Entropy S is calculated using the change in enthalpy from saturation

$$S = S_g + \int_{Eg}^{E} \frac{1}{T} dE. \tag{1.5-19}$$

The integral in Eq. (1.5-19) is approximated using 5 intervals in order to accurately account for non-linearities in temperature versus enthalpy.

1.5.1.1.4 PROPERTIES AT SATURATION

Saturated enthalpy, entropy, and surface tension are evaluated using fitted functions given in Section 1.5.1.1.1. However, several saturation properties are evaluated by other means.

Saturated fluid and vapor densities, thermal conductivities, specific heats, and dynamic viscosities are evaluated using saturated fluid and vapor enthalpies and functions described in Sections 1.5.1.1.2 and 1.5.1.1.3. The saturation temperature is evaluated at the saturated fluid enthalpy using the subcooled temperature function, Eq. (1.5-7).

Derivatives of saturated fluid and vapor enthalpy and density are also needed. These are evaluated by perturbing the pressure, re-evaluating saturated enthalpies and densities, and differencing, e.g.,

$$\frac{\partial E_f}{\partial P} = \frac{E_f' - E_f}{P' - P} \qquad (1.5\text{-}20)$$

1.5.1.1.5 PROPERTIES IN WATER/STEAM MIX

MINET currently uses a homogeneous equilibrium model (HEM) of two phase flow, which means both phases are assumed to move at the same speed. Using this simple representation, the quality is defined as:

$$X = \frac{E - E_f}{E_{fg}} , \qquad (1.5\text{-}21)$$

were $E_{fg} = E_g - E_f$.

The mixture entropy can be calculated from the quality, and saturated fluid and vapor entropies. The expression is

$$S = (1 - X)\, S_f + X S_g \quad . \qquad (1.5\text{-}22)$$

Mixture specific volume can be calculated using the same quality weighting as used in Eq. (1.5-22). Density, the inverse of specific volume, is therefore

$$\rho = 1 \Bigg/ \left\{ \frac{(1 - X)}{\rho_f} + \frac{X}{\rho_g} \right\} . \qquad (1.5\text{-}23)$$

The derivatives of density with respect to enthalpy and pressure are also needed, and can be determined analytically using Eqs. (1.5-21) and (1.5-23). It can be shown that the derivative with respect to enthalpy is

$$\frac{\partial\rho}{\partial E} = -\rho^2\left(\frac{1}{\rho_g} - \frac{1}{\rho_f}\right)\bigg/(E_g - E_f)\ . \qquad (1.5\text{-}24)$$

Similarly, the derivative with respect to pressure is

$$\frac{\partial\rho}{\partial p} = \rho^2\left\{\frac{(1-x)}{\rho_f^2}\,\frac{\partial\rho_f}{\partial p} + \frac{x}{\rho_g^2}\,\frac{\partial\rho_g}{\partial p} - \left(\frac{1}{\rho_g} - \frac{1}{\rho_f}\right)\frac{\partial x}{\partial p}\right\}\ , \qquad (1.5\text{-}25)$$

where

$$\frac{\partial x}{\partial p} = -\left\{x\left(\frac{\partial E_g}{\partial p} - \frac{\partial E_f}{\partial p}\right) + \frac{\partial E_f}{\partial p}\right\}\bigg/(E_g - E_f). \qquad (1.5\text{-}26)$$

1.5.1.2 SODIUM

MINET sodium properties were taken from the Super System Code (SCC), an LMFBR transient analysis code [11]. Because of this, many of the functions are expressed in terms of temperature, which is a state variable in SSC, unlike MINET. Further, because subcooled sodium is essentially incompressible, pressure does not appear in any of the functions.

The relation between subcooled sodium enthalpy and temperature is given by

$$E = \sum_{i=0}^{3} c_i\, T^i\ , \qquad (1.5\text{-}27)$$

where E is in J/KG, T is in K, and c_i are as given in Table 1.5-12. To determine temperature in terms of enthalpy, we solve for the only real root of Eq. (1.5-27). The specific heat is determined by taking the derivative of Eq. (1.5-27), to get $c_p = \partial E/\partial T$.

The density of subcooled sodium is approximated using the function

$$\rho = \sum_{i=0}^{3} R_i T^i \quad , \qquad (1.5\text{-}28)$$

where density is in KG/M^3, and T is in K, and R_i are as given in Table 1.5-13. The derivative of density with respect to enthalpy is determined by taking the derivative of (1.5-28) with respect to temperature and dividing by the specific heat.

Thermal conductivity is determined using the function

$$k = \sum_{i=0}^{2} CK_i T^i \quad , \qquad (1.5\text{-}29)$$

where T is in K, k is in W/M/K, and CK_i are as shown in Table 1.5-14 [13].

Absolute viscosity, in $N \cdot S/M^2$, is determined using

$$\mu = 10^{(-2.4892 - 220.65/T - 0.4925 \log 10\ T)} \quad , \qquad (1.5\text{-}30)$$

where T is in K [13].

Table 1.5-12 Coefficients C_i for Eq. (1.5-27)

i	C_i
0	-67511.0
1	1630.22
2	-.41674
3	1.54279E-4

Table 1.5-13 Coefficients R_i for Eq. (1.5-28)

i	R_i
0	1011.597
1	- .22051
2	-1.92243E-5
3	5.63769E-9

Table 1.5-14 Coefficients CK_i for Eq. (1.5-29)

i	CK_i
0	109.7
1	-.064499
2	1.1728E-5

1.5.1.3 AIR

The MINET air properties are most accurate at atmospheric pressure, and are based on the ideal gas law

$$\rho = P/RT \quad , \qquad (1.5\text{-}31)$$

where T is in K, P in Pa, ρ in KG/M^3, and R = 287.0 J/KG/K [14].

The air enthalpy at atmospheric pressure is determined using

$$E = \sum_{i=0}^{3} CA_i \, T^i \quad , \qquad (1.5\text{-}32)$$

where coefficients CA_i are as given in Table 1.5-15. Temperature is calculated from enthalpy by taking the only real cubic root of Eq. (1.5-32). Specific heat is determined by taking the derivative of Eq. (1.5-32) with respect to temperature.

Table 1.5-15 Coefficients CA_i for Eq. (1.5-32)

i	CA_i
0	161800.2
1	984.36
2	0.012504
3	4.6751E-5

With the density determined by Eq. (1.5-31), the derivative of density with respect to pressure is

$$\partial\rho/\partial P = 1/RT \quad . \tag{1.5-33}$$

The density derivative with respect to enthalpy is

$$\partial\rho/\partial E = \frac{-P}{287.T^2}/C_p \quad , \tag{1.5-34}$$

where C_p is the specific heat.

The thermal conductivity of air in W/M/K is determined using the expression

$$k = \sum_{i=0}^{3} CK_i \, T^i \quad , \tag{1.5-35}$$

where coefficients CK_i are as given in Table 1.5-16.

Table 1.5-16 Coefficients CK_i for Eq. (1.5-35)

i	CK_i
0	-9.153E-5
1	1.03E-4
2	-6.633E-8
3	3.056E-11

Absolute viscosity is calculated from

$$\mu = \sum_{i=0}^{3} CV_i \, T^i \quad , \tag{1.5-36}$$

where μ is in $N \cdot S/M^2$ and CV_i are as given in Table 1.5-17.

Table 1.5-17 Coefficients CV_i for Eq. (1.5-37)

i	CV_i
0	4.735E-6
1	4.932E-8
2	-9.0E-12
3	-3.639E-15

1.5.1.4 NaK

MINET NaK (eutectic) functions were determined from information provided in Sodium - Nak Engineering Handbook, Vol. 1 by Faust [15]. Subcooled NaK is virtually incompressible, so the state functions are independent of P.

The relation between NaK temperature and enthalpy is given by the function

$$E = \sum_{i=0}^{3} CK_i \, T^i \quad , \tag{1.5-37}$$

where E is in J/KG, T is in K, and CK_i are as given in Table 1.5-18. To determine temperature in terms of enthalpy, we solve for the only real root of Eq. (1.5-37). The specific heat is determined by taking the derivative of Eq. (1.5-37) with respect to temperature.

Table 1.5-18 Coefficients CK_i for Eq. (1.5-37)

i	CK_i
0	0
1	1098.6
2	-.27858
3	1.14527E-4

The density of subcooled NaK is approximated as

$$\rho = \sum_{i=0}^{2} RK_i \, T^i \quad , \tag{1.5-38}$$

where ρ has units of KG/M^3, and RK_i are given in Table 1.5-19. By taking the derivative of Eq. (1.5-38) with respect to temperature and dividing by specific heat, we get the density derivative with respect to enthalpy.

Table 1.5-19 Coefficients RK_i for Eq. (1.5-38)

i	RK_i
0	937.01
1	-.2095
2	-2.346E-5

Thermal conductivity is determined using the relation

$$k = \sum_{i=0}^{2} KK_i \, T^i \quad , \qquad (1.5\text{-}39)$$

where k is in W/M/K and KK_i are as in Table 1.5-20.

Table 1.5-20 Coefficients KK_i for Eq. (1.5-39)

i	KK_i
0	14.109
1	0.03271
2	-2.2E-5

Absolute viscosity, in N · S/M^2, is determined using a two part fitted function

$$\mu = \begin{cases} 1.16E\text{-}5\rho^{1/3} e^{.688\rho/T} , & T < 673 \\ 8.2E\text{-}6\rho^{1/3} e^{.979\rho/T} , & T > 673 \end{cases} \qquad (1.5\text{-}40)$$

where ρ is density in KG/M^3 and T is temperature in K.

1.5.2 HEAT TRANSFER CORRELATIONS

A library of heat transfer correlations for current fluid types and conditions are discussed in this section. While this group is not all inclusive, many systems can be represented with an acceptably small error. Modifications and additions may be made to this library with relative ease, and a continuing expansion of the library can be expected. The heat transfer correlation is frequently cited in terms of the non-dimensional Nusselt number

$$Nu = hD/k \quad . \tag{1.5-41}$$

This is easily converted to h using the diameter D and thermal conductivity k.

1.5.2.1 WATER AND STEAM

Because the heat transfer properties of water/steam vary significantly with conditions, a collection of correlations is used, each with its own range. The six principal modes and their MINET identifier numbers are: 1 - subcooled convection, 2 - subcooled nucleate boiling, 3 - forced convection vaporization, 4 - film boiling, 5 - superheated convection, 6 - condensation. If multiple heat transfer regimes occur in one node, MINET will generate a combined identifier, e.g., mode 123 means started in subcooled convection, passed through subcooled nucleate boiling and into forced convection vaporization.

1.5.2.1.1 SUBCOOLED CONVECTION

Heat transfer mode 1 is subcooled forced convection. The Nusselt number for this model is given as [16]:

$$Nu = 0.023\, Re^{0.8}\, Pr^{0.4} \quad , \tag{1.5-42}$$

where Re is the Reynolds number and Pr is the Prandl number.

1.5.2.1.2 SUBCOOLED NUCLEATE BOILING

The heat transfer for subcooled nucleate boiling is given as [17]:

$$h = S \cdot h_{NB} + F \cdot h_c \quad , \tag{1.5-43}$$

where the nucleate boiling coefficient h_{NB} is given as:

$$h_{NB} = 0.00122 \left\{ \frac{K_\ell^{0.79} \, C_\ell^{0.45} \, \rho_\ell^{0.49}}{\Omega^{0.5} \, \mu_\ell^{0.29} \, \lambda_{fg}^{0.24} \, \rho^{0.24}} \right\} \Delta P^{0.75} \quad , \tag{1.5-44}$$

where

C_ℓ = specific heat of liquid

K_ℓ = thermal conductivity of liquid

Ω = surface tension

λ_{fg} = latent heat of vaporization, and

ΔP = difference in saturation pressure corresponding to the wall superheat.

The Reynolds number correction factor F, and the nucleate boiling suppression factor S are represented as:

$$F = \begin{cases} 2.84 \, \frac{1}{X_{tt}}^{0.45} \quad , & \frac{1}{X_{tt}} < 2. \\ 2.57 + 0.7643 \, \frac{1}{X_{tt}} \quad , & \frac{1}{X_{tt}} \geq 2. \end{cases} \tag{1.5-45}$$

$$S = \begin{cases} 1.05 - 1.3 \times 10^{-5}\ Re\ , & Re \leq 2.5 \times 10^{4} \\ 0.83 - 4.3 \times 10^{-6}\ Re\ , & 2.5 \times 10^{4} < Re \leq 10^{5} \\ 0.32 \exp(-1.92 \times 10^{-6}\ Re), & 10^{5} < Re \leq 6 \times 10^{5} \\ 0.09 & , Re > 6 \times 10^{5} \end{cases} \tag{1.5-46}$$

and

$$Re = Re_{\ell}\ F^{1.25}\ ,$$

where X_{tt} is the Lockhart/Martinelli [18] parameter:

$$\frac{1}{X_{tt}} = \left(\frac{x}{1-x}\right)^{0.9} \cdot \left(\frac{\rho_{\ell}}{\rho_{v}}\right)^{0.5} \cdot \left(\frac{\mu_{v}}{\mu_{\ell}}\right)^{0.10} \tag{1.5-47}$$

The convective coefficient h_c is calculated from the Dittus Boelter equation based on liquid thermodynamic properties [16].

1.5.2.1.3 FORCED CONVECTION VAPORIZATION

The same correlation [17] is used for forced convection vaporization as is used for subcooled nucleate boiling. See Section 1.5.2.1.2.

1.5.2.1.4 FILM BOILING

The heat transfer for film boiling regime is given as [19]:

$$Nu = 0.0193\ Re_{\ell}^{0.8}\ Pr_{\ell}^{1.23} \left(\frac{\rho_B}{\rho_g}\right)^{0.68} \left(\frac{\rho_{\ell}}{\rho_g}\right)^{0.068}\ , \tag{1.5-48}$$

where subscripts ℓ and g denote, respectively, liquid and vapor phase at saturation and subscript B indicates a bulk property of the steam/water mixture.

1.5.2.1.5 SUPERHEATED CONVECTION

For superheated steam, the following heat transfer correlation for forced convection is used [20]:

$$Nu = 0.0133 \, Re^{0.84} \, Pr^{0.333} \tag{1.5-49}$$

Fluid properties used in Eq. (1.5-49) are evaluated at the film temperature, taken as the average of the tube wall and fluid temperatures.

1.5.2.1.6 CONDENSATION

It is assumed that all condensation is filmwise, as it is difficult to induce the more efficient dropwise condensation in any practical way in a power plant [21]. Three condensation correlations are employed in MINET, according to the geometry.

1.5.2.1.6.1 CONDENSATION ON VERTICAL SURFACES

This "correlation" is based on a simple representation [6]:

$$Q = k_f \frac{\Delta T}{\delta} \quad , \tag{1.5-50}$$

where k_f is the fluid conductivity, δ is the thickness of the film layer, and ΔT is the difference between the wall temperature and the saturation temperature. Knowing the flow area, the flow fraction that is fluid, relative densities, and the wall surface area, one can easily determine the film thickness, assuming it is uniform. The current MINET "correlation" will represent condensation inside or outside tubes or pipes, and could be extended to other geometries.

1.5.2.1.6.2 CONDENSATION INSIDE HORIZONTAL TUBES

Condensate flowing inside tubes tends to pool at the bottom, causing a non-trivial distribution of film. To handle this case, a correlation by Chato [21] was converted to SI units and applied:

$$h = 0.9821 \left[\frac{\rho_f \left(\rho_f - \rho_g\right) k_f^3 E'_{fg}}{\mu_f \Delta T\ D} \right]^{1/4} , \qquad (1.5\text{-}51)$$

where

$$E'_{fg} = E_g - E_f + \frac{3}{8} c_{pf} \left(T_{sat} - T_{wall}\right) \qquad (1.5\text{-}52)$$

1.5.2.1.6.3 CONDENSATION ON HORIZONTAL TUBE BANKS

Representation of this type of condensation becomes somewhat more empirical, as the film thickness will vary with tube position, etc. A correlation by Chen [21] was converted to SI units and incorporated as:

$$h = 1.288 \cdot \left[1 + 0.2 \frac{c_{pf} \Delta T}{E_{fg} (n-1)} \right] \cdot \left[\frac{\rho_f (\rho_f - \rho_g) k_f^3 E'_{fg}}{n D \mu \Delta T} \right]^{1/4} , \tag{1.5-53}$$

where n is the number of tubes stacked vertically, and other parameters are as described in the two previous correlations.

1.5.2.1.7 CRITICAL HEAT FLUX

When the heat flux due to nucleate boiling exceeds a critical heat flux level, surface boiling ceases and heat transfer is by film boiling. Because film boiling is far less efficient, it is important to locate and simulate this transition point. At this time, one has to rely on various empirical correlations to determine this location. There are currently three options in MINET, one of which must be chosen by the user for each side of each heat exchanger.

1.5.2.1.7.1 SODIUM/STEAM GENERATORS

A correlation was determined by Harty [22] for sodium to water heat exchangers, particularly those planned for the Clinch River plant. The steam/water quality at the DNB point is given by:

$$X_{DNB} = \frac{4.38 \times 10^4 \rho_\ell}{E_{fg} \rho_g \sqrt{G/1350.0}} \qquad \text{for } q > 6.3 \times 10^5 \qquad (1.5\text{-}54)$$

or

$$X_{DNB} = \frac{4.38 \times 10^4 \rho_\ell \cdot (6.3 \times 10^5/q)^{1.5}}{E_{fg} \rho_g \sqrt{G/1350.0}} \qquad \text{for } q < 6.3 \times 10^5 \quad , \qquad (1.5\text{-}55)$$

where E_{fg} is the latent heat of vaporization (J/kg), G is the mass flow rate per unit area (kg/s m^2), and q is in W/m^2 and calculated in forced convection vaporization.

1.5.2.1.7.2 WATER/STEAM GENERATORS

For the steam generators commonly used in pressurized water reactor systems, i.e., hot primary water to cooler secondary water and steam, the MacBeth [23] correlation is used. The water/steam quality at CHF is

$$x = 1.0 - 5.1933 \frac{\overline{q} D^{0.1}}{E_{fg} G^{0.51}} \quad , \qquad (1.5\text{-}56)$$

where q is in W/M^2 and evaluated in the forced convection vaporization regime, D is the equivalent hydraulic diameter, E_{fg} is the latent heat of vaporization (J/kg), G is the mass flow rate per unit area (kg/s/M^2).

1.5.2.1.7.3 FIXED QUALITY

The user has the option of locking the CHF quality at $x = 0.75$, which is particularly useful for helical coil steam generators, because the CHF point is smeared by the sloped flow path. This option should also be used whenever CHF is unlikely to occur, because it is simpler than the other options, and thus requires less calculations and reduces the likelihood of errors [24].

1.5.2.2 SODIUM HEAT TRANSFER CORRELATIONS

For liquid metal flow in a pipe or tube, Aoki's correlation [25] for heat transfer is used:

$$Nu = 6.0 + 0.025 \, (\bar{\phi} \, Pe)^{0.8} \quad , \qquad (1.5\text{-}57)$$

where

$$\bar{\phi} = \frac{0.014(1 - e^{-71.8x})}{x} \quad ,$$

$$x = \frac{1}{Re^{0.45} \, Pr^{0.2}} \quad .$$

In the laminar region,

$$Nu = 4.36 \qquad \text{for } Re \leq 3000 \quad . \qquad (1.5\text{-}58)$$

For the shell side of a heat exchanger, the Nusselt number is obtained from the Graber-Rieger correlation [26]:

$$Nu = A + B\,Pe^{C} \qquad \begin{array}{l} 110 \leq Pe \leq 4300 \\ 1.25 \leq P/D \leq 1.95 \end{array} \qquad (1.5\text{-}59)$$

where

$$A = 0.25 + 6.2(P/D) \quad ,$$

$$B = -0.007 + 0.032\,(P/D) \quad ,$$

and

$$C = 0.8 - 0.024(P/D) \quad .$$

The range of applicability is also indicated above. For Pe < 110, we use a constant value for Nu (evaluated using Equation (1.5-59) at Pe = 110).

1.5.2.3 NaK HEAT TRANSFER CORRELATION

The NaK heat transfer film coefficient [27] is:

$$h = 0.625\left(\frac{k}{De}\right)^{0.6} (G\,C_p)^{0.4} \quad [J/m^2 Sec°k]$$

(1.5 [illegible]

where k is the thermal conductivity of the NaK or sodium, De is the equivalent diameter based on the total flow area and the total heated perimeter, and G is the mass flow of NaK.

1.5.2.4 AIR HEAT TRANSFER CORRELATION

The heat transfer correlation for air in the laminar and transition regimes flowing across heated tube bundles is based on results given in graphical form [6]. The graph actually contains five ϕ vs Re curves for various tube configurations, where

$$h = \phi \cdot \left(\frac{c_p \cdot G}{P_r^{\,2/3}} \right) , \qquad (1.5\text{-}61)$$

and c_p is heat capacity, G is mass velocity, Pr is the Prandtl number, and h is the heat transfer correlation, applicable below Re = 6000. As MINET can make minor adjustments through the heat transfer area correction factor, it was necessary only to approximate these curves as

$$\begin{aligned} \phi &= Re^{-0.535} - 0.022 , \quad Re < 200 \\ \phi &= Re^{-0.66} + 0.0067 , \quad Re > 200. \end{aligned} \qquad (1.5\text{-}62)$$

For turbulent flow (Re > 6000) over banks of tubes or pipes, regardless of their configuration, experimental data agree well with [6]:

$$h = 0.33\, k\, Re^{0.6}\, Pr^{0.3}/D. \qquad (1.5\text{-}63)$$

Thus, the heat transfer coefficient for air in MINET is applicable from the laminar and through turbulent regimes, across banks of pipes or tubes.

1.5.3 FRICTION

The pressure change due to friction is given by the relation:

$$\Delta P_f = - \phi_{TP} \cdot f \cdot L \cdot G^2/2 \rho \, Deq \quad , \tag{1.5-64}$$

where f is the friction factor, ϕ_{TP} is the Thom two-phase multiplier (when applicable), L is length, G is mass velocity, ρ is density, and Deq is the equivalent hydraulic diameter, given by:

$$Deq = \frac{4 \cdot \text{flow area}}{\text{wetted perimeter}} \tag{1.5-65}$$

In the transition and turbulent regions, the following relation [28] is used

$$f = 0.0055 \left(1 + \left[20000 \cdot \epsilon + \frac{10^6}{Re} \right]^{1/3} \right) \quad , \tag{1.5-66}$$

where ϵ is the relative roughness factor by Moody [21]. The roughness of various piping materials is given in Table 1.5-21. Relative roughness is determined by dividing the roughness by the diameter D. The friction factor for laminar flow is given by [21]:

$$f = \frac{64}{Re} \quad . \tag{1.5-67}$$

The two-phase multiplier, ϕ_{TP} in Eq. (1.5-64) is a fitted function of data provided by Thom [29]:

$$\phi_{TP} = Y_i(x) \left(\frac{P}{P_i} \right)^q \quad , \tag{1.5-68}$$

Table 1.5-21 Roughness e(M) of Various Piping Materials

Material	e(M)
Drawn Tubing	1.5×10^{-6}
Commercial Steel	4.6×10^{-5}
Wrought Iron	4.6×10^{-5}
Asphalted Cast Iron	1.2×10^{-4}
Galvanized Iron	1.5×10^{-4}
Cast Iron	2.6×10^{-4}
Concrete	3×10^{-4} to 3×10^{-3}
Riveted Steel	10^{-3} to 10^{-2}

Note: Relative Roughness $\epsilon = \frac{e(M)}{Diam(M)}$

where $Y_i(x)$ is a 5 part fitted function (vs. quality):

$$Y_i(x) = \begin{cases} 1 + 101.35x - 3.5x^2 & , P = 1.72 \text{ MPa} \\ 1 + 37.86x - 0.56x^2 & , P = 4.14 \text{ MPa} \\ 1 + 13.852x + 0.478x^2 & , P = 8.62 \text{ MPa} \\ 1 + 4.704x + 0.96x^2 & , P = 14.5 \text{ MPa} \\ 1 + .5032x + 3.1898x^2 - 2.2129x^3 & , P = 20.7 \text{ MPa} \end{cases} \qquad (1.5\text{-}69)$$

Parameter q is for interpolating or extrapolating from Eq. (1.5-69), and is defined as:

$$q = \frac{\ln\left(Y_{i+1}(x)/Y_i(x)\right)}{\ln\left(P_{i+1}/P_i\right)} \quad . \qquad (1.5\text{-}70)$$

Thus, if one wanted to calculate ϕ_{TP} at P = 3 MPa and x = 0.3, he would calculate Y_1 (= 31.1), Y_2 (= 12.31), q (= -1.06), and finally ϕ_{TP} (= 17.25).

1.5.4 CRITICAL FLOW

Three critical flow models are available in MINET, Extended Henry-Fauske [4] for subcooled water, Moody [5], and isentropic for superheated steam. To minimize on storage and computations, functions fitted for use in the RETRAN-02 Code [9] were converted to SI units and used in MINET.

For the subcooled region, the critical mass velocity G ($kg/M^2/sec$) is given as a function of enthalpy E (J/kg) and pressure P (pa) by the fitted Extended Henry Fauske relation:

$$G^{HF} = \begin{cases} \sum_{j=0}^{5} \sum_{i=0}^{5} H1_{ij}\, E^i\, P^j & , \quad P < 2.067858E6 \\ \sum_{j=0}^{5} \sum_{i=0}^{5} H2_{ij}\, E^i\, P^j & , \quad P > 2.067858E6 \end{cases} \quad , \qquad (1.5\text{-}71)$$

where the coefficients are as given in Tables 1.5-22 and 1.5-23.

In the two phase region, the critical mass velocity is given by the fitted Moody relation:

$$G^{MDY} = \begin{cases} EXP \sum_{j=0}^{5} \sum_{i=0}^{5} M1_{ij}\, E^i\, P^j & , \quad P < 1.378572E6 \\ \sum_{j=0}^{5} \sum_{i=0}^{5} M2_{ij}\, E^i P^j & , \quad P > 1.378572E6 \end{cases} \qquad (1.5\text{-}72)$$

where the coefficients are a given in Tables 1.5-24 and 1.5-25.

To avoid discontinuities at the saturated fluid interface, the functions are interpolated as suggested in the RETRAN-02 [9] guide:

Table 1.5-22 Coefficients $H1_{ij}$ for Extended Henry-Fauske, Eq. 1.5-71

i/j	0	1	2	3	4	5
0	5.844785E+4	-1.817882E-1	-1.146214E-5	2.11432E-11	-1.253541E-17	2.429848E-24
1	-6.144985E-1	1.233208E-5	7.7054E-11	-1.659309E-16	1.028924E-22	-2.037626E-29
2	1.181158E-6	-7.884145E-11	-1.769177E-16	4.955322E-22	-3.26443E-28	6.643456E-35
3	3.746133E-12	1.958905E-16	1.271247E-22	-6.810723E-28	4.913027E-34	-1.037707E-40
4	-1.432334E-17	-2.069124E-22	4.757484E-29	4.142854E-34	-3.460373E-40	7.697998E-47
5	1.161263E-23	7.472281E-29	-6.2246E-35	-8.333039E-41	9.032233E-47	-2.161096E-53

Table 1.5-23 Coefficients $H2_{ij}$ for Extended Henry-Fauske, Eq. 1.5-71

i/j	0	1	2	3	4	5
0	5.857132E+4	2.380976E-2	-3.550971E-9	4.076189E-16	-2.256098E-23	4.214328E-31
1	-1.396223E-1	-6.599120E-8	2.157757E-14	-2.772088E-21	1.56244E-28	-2.957623E-36
2	2.303321E-7	2.360698E-13	-6.773429E-20	7.950999E-27	-4.247985E-34	7.890548E-42
3	-1.710519E-13	-3.246034E-19	8.518386E-26	-9.341207E-33	4.798508E-40	-8.778709E-48
4	-8.882528E-20	2.38065E-25	-5.45305E-32	5.424395E-39	-2.610384E-46	4.617507E-54
5	5.478637E-26	-6.687134E-32	1.416759E-38	-1.30096E-45	5.822964E-53	-9.827271E-61

Table 1.5-24 Coefficients $M1_{ij}$ for Moody, Eq. 1.5-72

i/j	0	1	2	3	4	5
0	9.1254883	7.055917E-5	-2.958198E-10	5.573495E-16	-4.648165E-22	1.384205E-28
1	-1.175828E-5	-1.570065E-10	8.163449E-16	-1.646365E-21	1.415426E-27	-4.282857E-34
2	1.423839E-11	1.775119E-16	-1.007318E-21	2.080396E-27	-1.804020E-33	5.478421E-40
3	-9.215581E-18	-9.760617E-23	5.979624E-28	-1.259719E-33	1.100075E-39	-3.350315E-46
4	2.914638E-24	2.601702E-29	-1.710693E-34	3.666980E-40	-3.221719E-46	9.835850E-53
5	-3.550224E-31	-2.692578E-36	1.893676E-41	-4.122780E-47	3.641617E-53	-1.114157E-59

Table 1.5-25 Coefficients $M2_{ij}$ for Moody, Eq. 1.5-72

i/j	0	1	2	3	4	5
0	3.153195E-4	1.113838E-1	-1.654592E-8	-2.197688E-16	1.339861E-22	-6.026818E-30
1	-1.246415E-1	-2.331657E-7	4.931444E-14	-1.200296E-21	-2.120770E-28	1.193308E-35
2	1.718246E-7	1.945935E-13	-5.237650E-20	2.346933E-27	1.210697E-34	-9.446506E-42
3	-1.085987E-13	-7.786264E-20	2.584825E-26	-1.495814E-33	-2.888144E-41	3.767468E-48
4	3.223748E-20	1.459423E-26	-6.038175E-33	4.046313E-40	2.186939E-48	-7.642817E-55
5	-3.647161E-27	-9.886719E-34	5.388276E-40	-3.976274E-47	5.537702E-56	6.371815E-62

$$G_{crit} = \begin{cases} G^{HF} \quad , \quad E < ES \\ (1-Y) \cdot G^{HF} + Y \cdot G^{MDY} \; , \; ES < E < EF \\ G^{MDY} \quad , \quad E > EF \quad , \end{cases} \qquad (1.5\text{-}73)$$

where

$$Y = \frac{E - ES}{EF - ES} \; , \qquad (1.5\text{-}74)$$

and

$$ES = \sum_{n=0}^{8} A_n P^n \quad , \qquad (1.5\text{-}75)$$

where A_n are as shown in Table 1.5-26.

Table 1.5-26 Coefficients A_n for Eq. 1.5-75

n	A_n
0	3.964721E5
1	0.4987001
2	-2.254622E-7
3	6.337852E-14
4	-1.039562E-20
5	1.010939E-27
6	-5.735412E-35
7	1.735412E-42
8	-2.222367E-50

In the superheated region, the classic isentropic approach is used. Thus, the critical mass velocity is given by:

$$G_{crit} = \sqrt{- \left(\frac{\partial P}{\partial \upsilon}\right)_{So}} \; , \qquad (1.5\text{-}76)$$

where the derivative is for pressure with respect to specific volume at constant entropy.

1.5.5 STRUCTURE PROPERTIES

Density (kg/M^3), thermal conductivity (J/(sec·M·K)), and specific heat (J/kg/K) are available in MINET for 10 common structural materials [30]. Values are provided in Tables 1.5-27 through 1.5-29. The specific heat for stainless steel is

$$C_p = 380.962 + 0.535104 \cdot T - 6.10413E\text{-}4 \cdot T^2 + 3.02469E\text{-}7 \cdot T^3. \qquad (1.5\text{-}77)$$

Table 1.5-27 Conductivity of Structural Materials

No.	Type	k (J/(sec · M · K))
1	Stainless Steel	$9.01748 + .0162997 \cdot T - 4.80329E\text{-}6 \cdot T^2 + 2.18422E\text{-}9 \cdot T^3$
2	2 1/4 Chrom-Moly	$49.341695 - 0.0171228 \cdot T$
3	Admiralty Metal	146.01
4	90 - 10 Cu-Ni	84.24
5	80 - 20 Cu-Ni	51.48
6	70 - 30 Cu-Ni	40.25
7	Monel	29.58
8	Inconnel	18.72
9	Carbon Steel	59.9
10	Aluminum	179.71

Table 1.5-28 Specific Heat of Structural Materials

No.	Type	$C_p/C_{p,\text{ Steel}}$ (-)
1	Stainless Steel	1.0
2	2 1/4 Chrom-Moly	1.0
3	Admiralty Metal	0.84
4	90 - 10 Cu-Ni	0.85
5	80 - 20 Cu-Ni	0.86
6	70 - 30 Cu-Ni	0.87
7	Monel	0.93
8	Inconnel	0.96
9	Carbon Steel	1.0
10	Aluminum	1.95

Table 1.5-29 Density of Structural Materials

No.	Type	ρ (KG/M^3)
1	Stainless Steel	7849.8
2	2 1/4 Chrom-Moly	7833.35
3	Admiralty Metal	8490.6
4	90 - 10 Cu-Ni	8971.2
5	80 - 20 Cu-Ni	9211.5
6	70 - 30 Cu-Ni	9451.8
7	Monel	8811.0
8	Inconnel	8330.4
9	Carbon Steel	7849.8
10	Aluminum	2723.4

1.6 CONTROL SYSTEM MODELS

Models for a generic control system representation are under development.

2. USERS GUIDE

In this section, the essential information needed for running the MINET code is provided. Other portions of this MINET documentation will provide important information, which could prove useful in setting up and testing your input deck. In employing the MINET code, the user should keep a few points in mind.

1) MINET is a developmental computer code and unexpected results may occur, although these will continually decrease in frequency. A serious problem should always be reported to the code developers so it can be corrected on a permanent basis.

2) MINET is written on two levels, the module level and the working level. The user will find that investigating the valve module, for instance, is relatively easy, as that portion of the code is easy to identify and read. Modification of such a model is quite feasible, in many cases. On the other hand, the working level of MINET is very sophisticated and should be avoided by the user. Fortunately, the working levels have been well tested, where as, at the module level, user options are continually being added and modified.

3) There is a negative aspect to the freedom provided the user in simulating a system using MINET, or any other generalized system code. That is, as long as the system described does not violate physical laws, MINET will analyze the case as stated by the user. Thus, if the user incorrectly states the problem, MINET will attempt (and often succeed) to solve the stated problem as is. As a result, what appears to be the wrong answer may, instead, be the right answer to the wrong question.

2.1 MACHINE AND STORAGE CONSIDERATIONS

The MINET code was designed, developed, and tested with the goal of minimizing machine dependencies and storage requirements, so as to facilitate its implementation on any medium to large scale high-speed computer. As a result, one may expect only minor difficulties in adapting MINET to a given computer (with the possible exceptions discussed in [24]).

MINET was developed and tested on a CDC 7600 computer, and was designed to execute in small core memory (SCM). Thus, the code has been routinely executed using 160, 000 octal (around 57,000 base ten) 60-bit words of SCM. (For an extremely large test problem, one of the large arrays was transferred into large core memory (LCM), a fairly simple process that slows execution speed by 10-20%.) In order to use SCM, MINET is segmented, i.e., subdivided into computational modules that swing in and out of SCM as needed. The segmentation tree currently used is shown in Figure 2.1-1. For many of the larger computers, such steps to segment the code and otherwise limit the use of core space will most likely be unnecessary.

For a machine using a 32-bit word, the use of double precision is required for at least part of the code. This has not proved to be a problem, thus far.

MINET currently uses seven input/output device numbers, as shown in Table 2.1-1. It should be noted that these unit numbers are assigned at a high logical level and can be re-assigned with little difficulty. When MINET is interfaced with another host code, the host can set the I/O device numbers so as to avoid conflicts with its current usages of the devices.

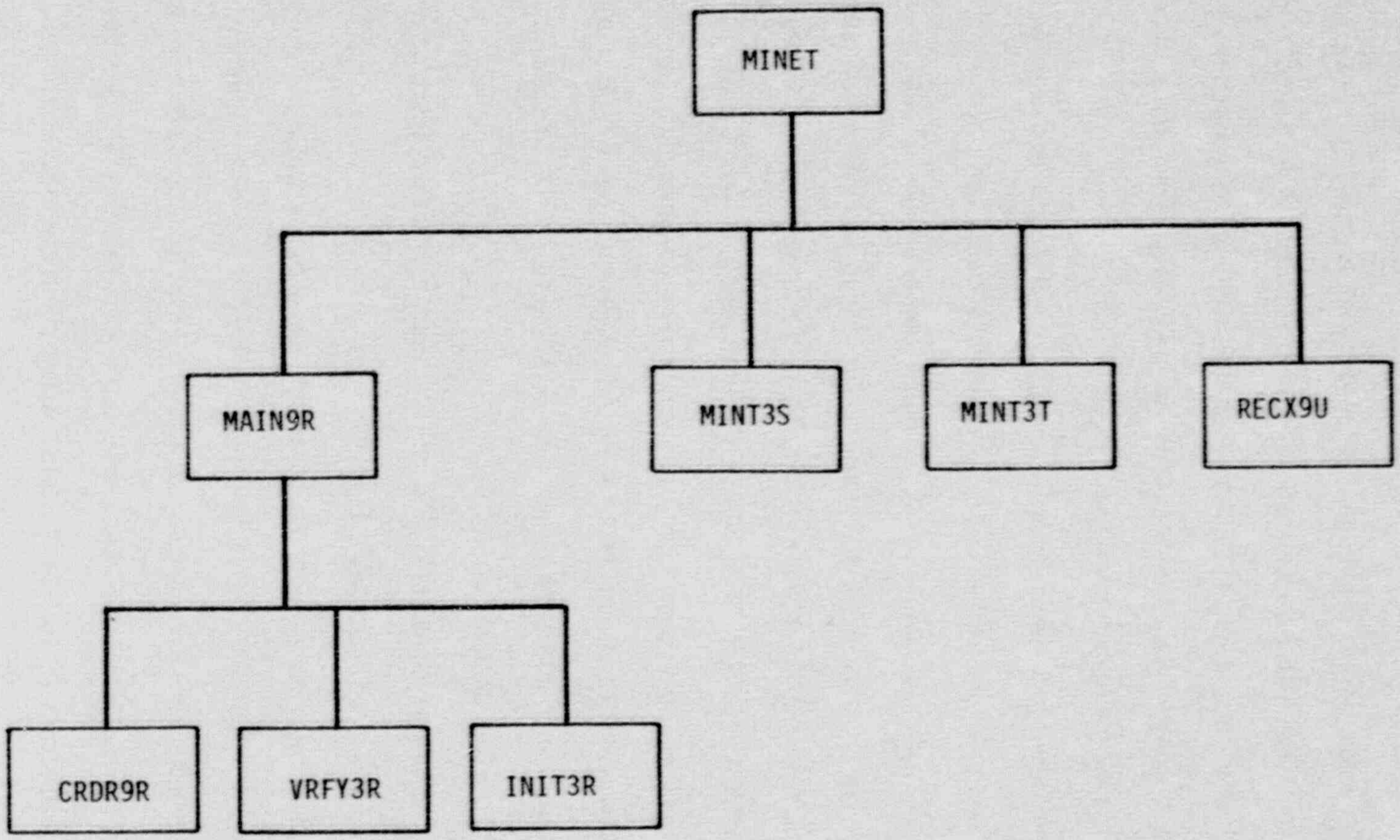


Figure 2.1-1. Current Segmentation for CDC-7600 Use

Table 2.1-1 Current I/O Device # Utilization

Device No.	Current Usage
5	Input Deck, i.e., Card Images
6	Formatted Print Out, e.g., from PRNT3C
7	Scratch Area (Reduces Storage)
8	Scratch Area (Reduces Storage)
9	Transaction Output, e.g., Plot Data
10	Save, i.e., Info. for Re-Start
11	Restore, i.e, Info. for Re-Start

2.2 BUILDING AN INPUT DECK

Building a MINET Input Deck is relatively simple for a small system, and quite manageable even for a large and intricate system. An operating system is a little easier to represent than a hypothetical system, because one is less likely to attempt to create non-physical conditions, i.e., it is more fool-proof.

2.2.1 THE SYSTEM

Power plant thermal-hydraulic systems can be almost infinitely large and complex, particularly if one includes all the auxiliary and clean-up systems. Experimental configurations can be very simple. Both extremes may be represented using MINET, if a few basic rules are followed.

System boundaries must be chosen so that a reasonably accurate set of transient boundary conditions can be specified. An ideal boundary condition would be the pressure outside a relief valve, e.g., atmospheric pressure. A low, or a very predictable flow rate into a large tank is also a desirable boundary condition.

One MUST INCLUDE AT LEAST ONE INLET AND ONE OUTLET BOUNDARY IN EACH FLUID NETWORK. MINET needs these for reference. For a closed loop one should open it slightly by adding tightly closed (e.g. 10^{-6} relative) valves to boundaries. While this may seem a nuisance in isolated cases, it is a convention that allows MINET to do the generalized steady state solution that is missing from many other systems codes.

A fairly common component is a "separator" or tank where water occupies the lower portion with steam above, which is called a "separated volume" in MINET terminology. Under these conditions any flow leaving the volume will be either saturated or a mixture of saturated liquid and steam, as determined by the water level at the pipe entrance. This introduces the subtle fact that the sum of the flows entering the volume must have a certain flow energy (W·E) for the system to be at equilibrium. To assure this, MINET will need a source of energy to adjust (see Section 1.3.1). The user should make certain that for each separated volume, there is a source of heating somewhere upstream, or the problem will effectively be overconstrained.

A situation similar to the separated volume comes up when the user fixes the temperature at an outlet boundary module. Again, if the user makes this constraint, a source of heating must be available for adjustment.

Of the MINET component modules, usages are relatively straightforward, particularly for the pipes. The valves and pumps are simply one node pipes, plus an extra term in the momentum equation due to a loss across the valve opening or a gain due to the pumping action. An optional choke flow calculation can be performed for the valve, and should be for valves to atmosphere. The heat exchanger simply represents the active heat transfer area, and other modules should be used for plena, downcomers, or separators. The turbine stage module is a simple in/out module, and should be used for parts of the turbine when accounting for extraction lines to the feedwater heaters. That is, for a turbine with an extraction line from the center, use two turbine stage modules with a volume in between, from which the extraction line is run off.

Usage of the volume for a tank or a point where multiple lines diverge or merge, e.g., a tee, is fairly obvious. What is subtle is the need to use a volume because of its dynamically calculated pressure. Any module that has a large (> 25% relative) pressure drop should be bracketed by volumes and/or boundaries. This is always true for turbine stages and valves where choking is expected. It can also be true for a large pump or valve, but need not be so for all valves or pumps. In the use of MINET, a major factor in the speed and accuracy of the calculations is the correct and optimum usage of the volume modules (and the heat exchanger nodalization, as well).

2.2.2 SYSTEM SCHEMATIC

At this stage the system to be represented should be drawn schematically using the basic MINET components. Module IDs should be attached, preferably using a "naming" convention such as the ones illustrated in Section 4. Each port of each module should be assigned a number. Elevations should be noted at each module interface.

It is highly recommended that photo-copies be made of the system schematic. They are very useful in interpreting MINET output, and are needed when extracting and piecing together information from common block dumps, which are automatically produced following an unexpected job termination (see Section 2.6).

2.2.3 INPUT DECK

This section provides a description of the input file, and will be updated from time to time. In the next section, a computer generated input description is provided, and it is likely to be updated more frequently.

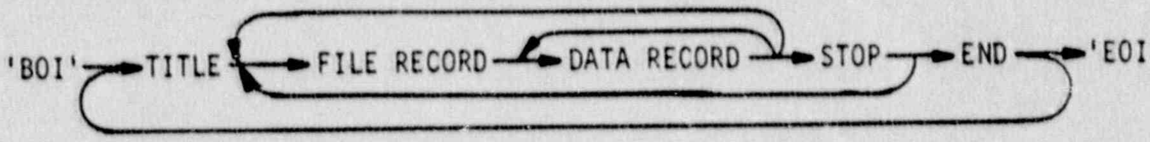
The structure of the MINET input is drawn on the same modular lines as that which dominates the calculational portion of the code. The basic component of the input is the input record or card-image record. The entire sequence of input records constitutes the input file.

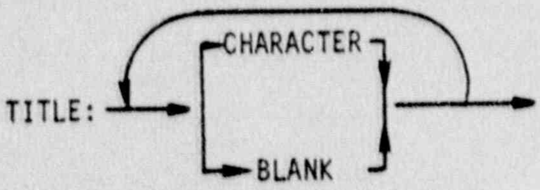
Input is processed by MINET in a three-fold operation. The interpreter, built around a version of the GENRD [31] processor, makes the initial pass over the input. Verification follows, checking for consistency within the data set and against the criteria detailed in the data dictionary. An inconsistency at this point causes the program to enter an error mode and generates a diagonistic message on the output file. The program is terminated at the end of this stage if any error has been detected. As a further check, all card-images are entered on the output file as they are interpreted, as are all decoded values assigned to all parameters.

With the verification complete, the third processor proceeds to initialize a series of internal parameters on the basis of the defined input. The steady state calculations are then initiated.

The list of input required to initialize MINET consists of a series of free-format card-image records. These records contain control specifications and/or data in columns 1 through 72. The record format is 'free' in the sense that as long as the sequence of data conforms to the ordering detailed in this document, the physical placement of data fields as well as their degree of numerical accuracy is determined solely by the user.

A very rudamentary psuedo-grammar forms the basis on which the MINET input is constructed. The overall scheme in which this grammar operates is described in Figure 2.2-1. Its syntax is defined as follows:





TITLE:

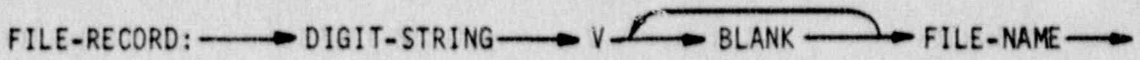
A title will appear as part of the banner heading on major pages of the output file. It is limited to one record's length but may extend beyond the seventy-two (72) character limit to eighty (80) characters. Although a required portion of the input, this record is provided solely as a means of associating an input with the resulting calculation. The user may choose any degree of functionality desired to assign to the titles, since it is not otherwise processed.

```
BEGIN
   GET NEXT-RECORD
   WHILE NEXT-RECORD IS NOT 'EOI'  DO
      PROCESS TITLE
      GET NEXT-RECORD
      WHILE NEXT-RECORD IS NOT 'END"  DO
         WHILE NEXT-RECORD IS NOT 'STOP"  DO
            IF NEXT-RECORD IS FILE-RECORD
            THEN
               CLOSE PREVIOUSLY OPENED DATA FILE (IF OPENED FILE EXISTS)
               OPEN NEW DATA FILE
               GET NEXT-RECORD
            ELSE
               IF NEXT-RECORD IS DATA-RECORD
               THEN
                  PROCESS DATA
                  GET NEXT-RECORD
               ELSE
                  ERROR CONDITION
                  GET NEXT-RECORD
         END
         INITIATE PROCESSING (TO EXTENT SPECIFIED)
         GET NEXT-RECORD
      END
   END
END-STOP
```

Figure 2.2-1 Psuedo-Grammer Format of MINET Input File

FILE RECORD:

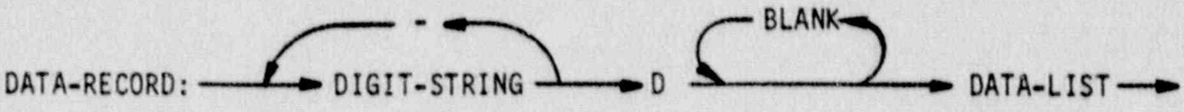
To open a data file, the following pseudo-grammar is appropriate:



The numeric sequence accumulated in this field is used to identify differing versions (V) of similar input files. It is provided as a convenience and is subsequently ignored by the processor. The FILE-NAME provides an associative link between the data of the accompanying data file and a particular computational module(s).

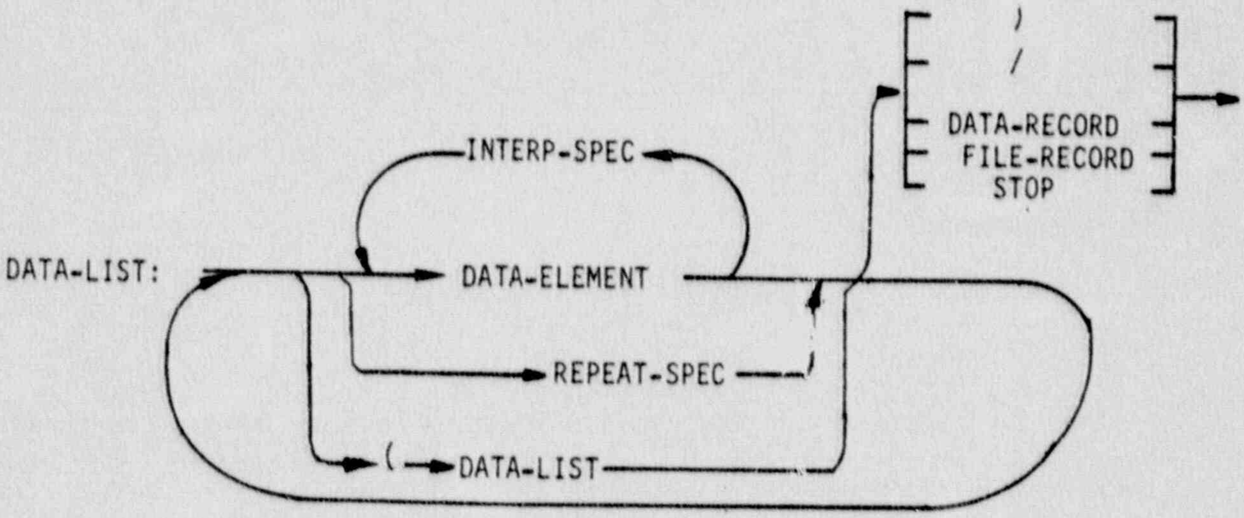
DATA RECORD:

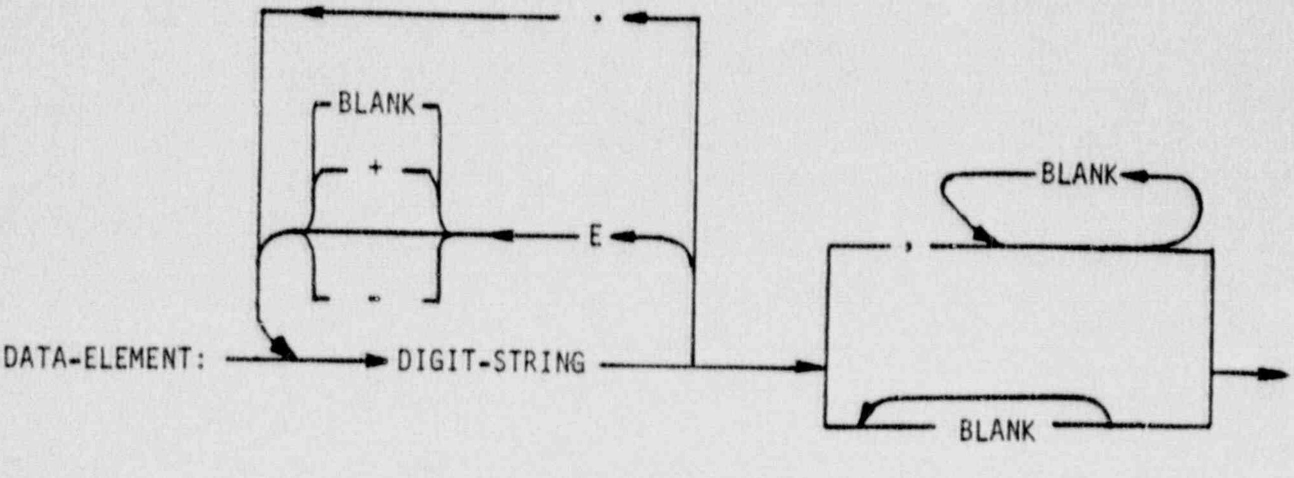
The pseudo-grammar for an individual DATA-RECORD is:



For a DATA-RECORD to be properly processed, its DIGIT-STRING (or strings) must be among the set of defined record numbers of the corresponding data file. A list of all valid record numbers can be found later in this section.

A DATA-RECORD is completely processed before the next record is interpreted. A DATA-RECORD is implicitly defined to have a maximum length equal to one or more card-images (72 characters). It is terminated either by a slash (/) or by a column seventy-two (72) preceeding a DATA-RECORD, a FILE-RECORD or a STOP, as described below. Information following a slash (/) is not processed, nor is any information beyond column seventy-two (72). As a result, the user may find this to be a convenient place to annotate the data files. Within a given data partition, several options are available as described below:





Two shorthand constructs are provided for the specification of input. The

INTERP-SPEC: ——→ DIGIT-STRING ——→ 'I'

and the

REPEAT-SPEC: ——→ DIGIT-STRING ——→ 'R'

Both are used to assign numeric data to consecutive memory locations. The REPEAT-SPEC stores a sequence of one or more constants. For example:

7.2, 3R

is equivalent to

7.2, 7.2, 7.2

and

(1.0, 15, 0.72), 4R

is equivalent to

1.0, 15, 0.72, 1.0, 15, 0.72, 1.0, 15, 0.72, 1.0, 15, 0.72

The 'I" specification provides a means of inserting one or more equally spaced values between two real (or two integer) end points. For example,

11, 7I, 19

is equivalent to

11, 12, 13, 14, 15, 16, 17, 18, 19

and

1.0, 3I, 2.0

is equivalent to

1.0, 1.25, 1.50, 1.75, 2.0

The integer preceding the 'I' specifies the number of equally spaced values to be inserted between the end points. The terminal points bound the sequence and are not strictly considered to be members of it, therefore, 11, 7I, 19 and not 11, 9I, 19 and 1.0, 3I, 2.0 and 1.0, 5I, 2.0 in the preceding examples. A check is made to determine the data type (real or integer) of the end points. Both points must be of the same type. If an integer interpolation is indicated, the resulting increment must also be of integer type.

2.2.3.1 INPUT RECORD DESCRIPTION (See Also Sec. 2.2.3.2)

Record 1D - Pipe Geometric Record

The first three parameters, pipe ID, inlet port number, and outlet port number are assigned by the user, to be used in communicating with MINET. The pipe length and diameter (inner) are self explanatory. The roughness factor is the ratio of the width of surface roughness over the pipe diameter, and typically runs from 10^{-3} for a small commercial grade tube to 5×10^{-6} for a very large drawn tube (pipe) (see Table 2.2-1). Any number of nodes may be used per pipe, and fluid transport time should be a principal factor in the choosing. The path parameter indicates how many identical components are being represented, and the total flow will be divided equally between the paths for determining pressure losses, etc.

Record 101D - Valve Geometric Record

The first several parameters for the valve geometric record are the same as for the pipe record, except only one node can be used for a valve. The maximum flow area through the valve when fully open is likely to be slightly less than the pipe flow area, if it is unknown. As a zero flow rate causes

Table 2.2-1 Roughness e(M) of Various Piping Materials

Material	e(M)
Drawn Tubing	1.5×10^{-6}
Commercial Steel	4.6×10^{-5}
Wrought Iron	4.6×10^{-5}
Asphalted Cast Iron	1.2×10^{-4}
Galvanized Iron	1.5×10^{-4}
Cast Iron	2.6×10^{-4}
Concrete	3×10^{-4} to 3×10^{-3}
Riveted Steel	10^{-3} to 10^{-2}

Note: Relative Roughness $\epsilon = \frac{e(M)}{Diam(M)}$

severe computational difficulties (less than or greater than is no problem), one should never close a valve beyond a minimum leakage level as given by the minimum stem position (recommended 10^{-6}). Finally the relation between the relative flow area and relative stem position will vary from valve to valve, with the general relation given by

$$A = S^{f} \quad , \qquad (2.2\text{-}1)$$

where f is the stem power factor, a user input. A value of 1.0 is usually a good estimate, although knowledge of valve design would facilitate a better guess.

Record 201D - Pump Geometric Record

The parameters for the pump geometric record are the same as for the pipe. Again, only one node may be used for the pump.

Record 301D - Heat Exchanger Geometric Record

The first several parameters are again the same as on the pipe geometric record, although several additional parameters are needed in this case. The inlet and outlet ID for the flowpath outside the tubes are again user assigned names for communication only. The outer diameter refers to the tube between the fluids. Pitch to diameter refers to the ratio of the tube center to center spacing over the tube outer diameter, and should be set to the ratio of the inner diameter of the outer tube to the outer diameter of the inner tube for the rare case of co-axial tubes. The number of tubes is per heat exchanger, and is multiplied (in MINET) by the number of paths in determining the flow per path. Ten structural materials are currently in the MINET library, and modifications and/or additions should require minimal effort. Tube configurations such as co-axial (1), square (4), and hex (6) (also called triangular) are available as options, and alternate configurations could be substituted by modifying subroutine MODL3C. The helical coil heat exchanger diameter refers to coil (not tube) diameter, is used in modifying the frictional loss, and should be set to zero for a straight tubed unit. Fluid passing through tubes coiled or otherwise curved through a tank, travel farther than the tank fluid, and the ratio is input, and is again 1.0 for straight tubes. A core tube, albeit rare, can be inserted inside a heat exchanger tube to increase the (annular) velocity of the inner fluid. The diameter of such a tube is used to modify the flow area and account for heat storage, and it should be set to zero if there is no core tube. The mass and surface area of the heat exchanger structure, summed over all parallel units, is used to calculate heat storage in the transient.

Record 401D - Inlet Boundary Module Geometric Record

Only the boundary module ID number and an outlet port number need to be input. Essentially the user is controlling the inlet port, and need not assign it a number.

Record 402D - Outlet Boundary Module Geometric Record

Only the boundary module ID number and an inlet port number need to be output. Again, the user is controlling the other port, i.e., the outlet.

Record 501D - Volume Geometric Record

The volume ID is input on this record, but the port identification numbers appear on other cards because their count is not generally known. The shape parameter is really important only if the contents are separated, in which case the level fraction vs. volume fraction relation must be known. The user should set the parameter to one if the horizontal area does not depend on height, to two if the component is a drum on its side, and contact the code developers for assistance otherwise. It is possible to represent a tank using more than one volume module (plus pipes), and this impacts some of the remaining input parameters. The volume of the volume is the space in the component represented by the MINET volume module. Volume height refers to the total height of the physical component, and is used so that the relative water level is referenced to the whole component volume and not just that portion represented by the module. The minimum and maximum relative levels are the MINET module bottom and top values relative to the component dimensions, e.g., 0.5 and 1.0 for a module representing the top half of a tank. The volume elevation is the vertical midpoint for the physical component. The path parameter is as it was for the pipes. The separation parameter is set to 1 for homogeneous (usual), 2 for separated, and 3 for homogeneous at steady state but could become separated during the transient. The third option should be chosen only if the contents will be entirely liquid or vapor under steady state conditions.

Record 511D - Volume Inlet Port Geometric Record

The volume module ID number and an ID number for an incoming port are specified. An inlet port is one through which fluid is entering the volume under steady state conditions.

Record 512D - Volume Outlet Port Geometric Record

The volume module ID number and an ID number for an outgoing port are specified. An outlet port is one through which fluid is leaving the volume under steady state conditions.

Record 601D - Turbine Stage Geometric Record

The turbine stage module ID number, and identifier numbers for the inlet and outlet ports are specified. The absolute angle of approach of steam with respect to the blades is also needed, but this number is very likely to be close to 15.0 (degrees), and an extensive search to determine a better value is unlikely to be necessary.

Record 801D - Network Geometric Record

The system is composed of one or more fluid networks, which are connected only by heat exchangers. On this record the fluid type for a given network is specified. As the network has no identifier number, the user need only specify any boundary or volume module in the network on this record. Note there will only be enough of these records input to assign a fluid type to each network.

Record 901D - Junction Record

This record is used to specify the elevation of a junction, and the modules and ports to be connected. One must be careful when connecting to a volume with separated contents that the junction is located dimensionally within the volume and not some computer round-off error (e.g., 10^{-14}) outside. Otherwise, unexpected results can occur when the tank runs dry or full.

Record 1001D - Pipe Performance Record

On this OPTIONAL record, the pipe identifier number and a form loss coefficient are input. Generally, one should assume a value of zero (the default), unless a better value is known or some adjustment is needed to obtain user desired steady state flows and pressures.

<u>Record 1101D</u> - Valve Performance Record

Again, the valve module identification number and form loss coefficient for the pipe-like portion are input. The valve form loss coefficient, for the gate opening, would typically be 0.5 to 1.0 for a simple valve, but could be much larger (i.e., greater than 1.0) for a series or group of valves represented as one. The choking parameter is used to specify whether a choke flow calculation should be done, in which case the valve should be in a (one-node) segment by itself. The last five parameters are a mini-control system useful in simulating the action of safety/relief or check valves. The J3VPRS parameter is the key, for if it is negative, the option is declined, and the last four parameters are meaningless and can be set to 0.0. If J3VPRS = 0, for a check valve, the next four parameters are: 1) the flow (per valve) below which trips closed (e.g., 0.0); 2) the time constant for doing so; 3) the flow above which it will trip back open (e.g., 0.1) and 4) the time constant for doing so. If J3VPRS is positive, it indicates a volume identification number where the pressure is being monitored. In this case the trip levels are for the pressure at which it trips open, and the pressure at which it trips closed.

<u>Record 1201D</u> - Pump Performance Record

The first two parameters are the pump module identification number and the form loss coefficient for the pipe-like portion. The next three parameters, as well as the five values of A3PUMP, indicate the pump head as a function of flow (per pump) and pump speed. For each pump there will be some reference or rated head at some reference speed and flow rate. The polynomial coefficients A indicate the relative head vs relative flow at the reference speed. Typically, the relative head will be about 1.2 at zero flow, 1.0 at 1.0 relative flow, around 0.7 at 2.0 relative flow, and fall to zero around 3.0 relative flow. The last two parameters on this input record are used to coastdown the pump after a trip, with the first being a time constant and the second is the period until the pump rotor locks, i.e., stops moving entirely.

<u>1301D</u> - Heat Exchanger Performance Record

The first three entries on this record are the module identification number, and form loss coefficients for inside and outside the tubes, the latter of which can be large due to support structure. The level type parameters specify the critical heat flux (CHF) criterion, an index of 1 being an Atomics International correlation for sodium to water heat exchangers, 2 being MacBeth for PWR steam generators, and 3 being a quality of 0.75. If CHF is not expected, specify option 3, as it is more efficient to execute than the others. The counter/cross/parallel flow multiplier should be set to -1.0 for counter flow, 0.0 for cross flow, and 1.0 for parallel flow condition.

<u>1601D</u> - Turbine Performance Record

The turbine module ID is the first entry on this card, which actually more fully describes the turbine than the geometric card does, as the MINET turbine model is based on known performance rather than geometrical details. The stage type may be specified as an impulse type (generally only for the first stage) or the impulse reaction type (the rest). The efficiency of the generator is not currently a very significant parameter, and should be set to around 0.95. The next five parameters are used to make inferences about the pressure change across the turbine stage, and can be estimated easily from a plant design conditions diagram. The inlet temperature is the only tricky parameter, and that should be set at least a couple of degrees (K) above the saturation temperature for the inlet pressure, if it is not known precisely. The last two parameters on this record are as they were for the pump in record 1201D.

2001D - Pipe Initial Condition Record

This optional record is used if the pipe is receiving a non-zero heat addition (0 = default). The module identification number and the total heat input over all parallel pipes are input.

2101D - Valve Initial Condition Record

The valve module identification number and total heating over all parallel valves represented are the first two entries on this card. The remaining entry is the initial valve stem position, which should be between the minimum valve stem position (record 101D) and full open, i.e., 1.0.

2201D - Pump Initial Condition Record

Again, the first two parameters are the pump module identification number and the heat input for all the parallel pumps being represented. The remaining parameter is the pump speed in revolutions per minute (RPM).

2301D - Heat Exchanger Initial Condition Record

The first parameter is the heat exchanger module identification number. The second parameter is the amount of heat being transferred from the fluid passing outside the tubes to the fluid within, and is the sum over all parallel heat exchanger paths.

2401D - Boundary Module Initial Condition Record

The boundary module identification number is the first entry. The boundary status options are 0 for an inlet boundary, 1 for an outlet boundary where MINET calculates the temperature, and 2 for an outlet boundary where the temperature is fixed by input (on this card). The next parameter indicates whether the enthalpy type input is actually an enthalpy (1), a temperature (2), or a quality (3). Note that a temperature boundary condition may be easier to determine, but is dangerous if it is close to the saturation temperature. The enthalpy type parameter is next, followed by the initial flow and pressure. MINET will use the flow and enthalpy for an incoming boundary and the pressure and perhaps (on status) enthalpy for an outlet boundary. The unused parameter may be used as an initial guess, so a reasonable value should be input.

2501D - Volume Initial Condition Record

Once again, the first two parameters are the module identification number and the total heating for all the volumes being represented. The third parameter is the initial water level in a separated homogeneous volume. The remaining parameter is an estimate of the initial pressure in the volume.

2511D - Volume Outlet Port Initial Condition Record

The first two parameters are module and port identification numbers. The remaining parameter is the estimated flow leaving through the volume port, and is the sum over all parallel volumes being represented as one.

2601D - Turbine Stage Initial Condition Record

The first parameter input is the turbine module identification number, which is followed by the initial turbine speed in RPM. The third parameter is the work done on the turbine stage (expressed in J/S), e.g., -1.0E8 J/S.

3011D - Pipe Heat Input Table Record

This is an optional record, with the default being that the pipe heating is maintained at the initial value. The first parameter is the module identification number. The remaining parameters are pairs of time and heating entries which are placed into a table and interpolated to determine pipe heating at any point in time.

3111D - Valve Heat Input Table Record

This record exactly parallels record 3011D.

3121D - Valve Position Table Record

This, again, is an optional record. If it is not included, either the steady state position will be maintained, or the safety/relief or check valve control option will be used. The first entry is the valve module identification number, which is followed by paired data points that are used to create a position vs. time table.

3201D - Pump Transient Record

This record can be used to trip a pump at a given point in time. The entries are the module identification number and the trip time. Note, that if the user does not want the pump to trip, the trip time can be set to an arbitrarily large value.

3211D - Pump Heat Input Table Record

This record exactly parallels Record 3011D.

3221D - Pump Speed Table Record

This is another optional record, which may be omitted if the steady state speed is to be maintained until the trip time, as set in Record 3201D. If used, the record contains the module identification record, and pairs of time and pump speed table entries.

3411D - Boundary Condition Table Record

The first parameter is again the module identification number. Pressure or flow may be input, as indicated by the second parameter, 1 for flow, 2 for pressure. Again, a temperature or quality can be input instead of enthalpy, as keyed by the third parameter. The remaining fields, in groups of three, are time, enthalpy/temperature/quality, and flow/pressure to be used in tabular form.

3511D - Volume Heat Input Table Record

This record exactly parallels Record 3011D.

3601D - Turbine Trip Record

The turbine module identification number and the trip time are input on this record.

3611D - Turbine Speed Table Record

This record exactly parallels Record 3221D.

4000D - Run Control Record

The sole entry is the end of transient time.

4100D - Print Control Record

The first parameter is used to get frequent prints during the calculational process, and should be set to -1 for the first run of any deck, so as to get prints during the steady state calculations. This parameter can also be used for debug purposes. If, for example, a problem occurs at time step 3014, set this parameter to 3000 during the next job re-run submission to get prints at every step approaching the critical one. The second parameter, the print detail key, is set to 1 for the least detail and 3 for the most detail (3 is generally recommended). The remaining paired data entries indicate the print frequency up to a designated time, with less frequent prints generally needed as the transient progresses.

4200D - Context Save Control

The first parameter keys a restart. If it is zero, a new steady state will be calculated from the input data. If it is one, a restart file will be read in to handle the initialization. The second parameter indicates how many print intervals should pass between restart file writes. The user is also referred to Section 2.9.

2.2.3.2 INPUT RECORDS (Computer Generated)

The input record description on the following pages are computer generated. While the descriptions are somewhat brief, this section is easier to keep up to date, and generally supercedes descriptions in other parts of this code documentation.

Figure 2.2-2 Input Record Contents

```
TITLE CARD,E.O., MINET DECK XI, GJV 102083
OV MINETD
1D PIPE GEOMETRIC RECORD/
  MODID       -   MODULE ID ASSIGNED TO PIPE
  INLETID     -   PORT IDENTIFIER ASSIGNED TO INLET PORT
  OUTLETID    -   PORT IDENTIFIER ASSIGNED TO OUTLET PORT
  X3MOD       M   LENGTH OF MODULE
  Y3ID        M   DIAMETER OF MODULE
  E3PSI       -   SURFACE ROUGHNESS FACTOR,ROUGHNESS/SURFACE
  N3NODE      -   NUMBER OF NODES TO BE USED FOR MODULE
  N3PATH      -   NUMBER OF PARALLEL UNITS BEING REPRESENTED
101D VALVE GEOMETRIC RECORD/
  MODID       -   MODULE ID ASSIGNED TO VALVE
  INLETID     -   PORT IDENTIFIER ASSIGNED TO INLET PORT
  OUTLETID    -   PORT IDENTIFIER ASSIGNED TO OUTLET PORT
  X3MOD       M   LENGTH OF MODULE (PIPE-LIKE PORTION)
  Y3ID        M   DIAMETER OF MODULE (PIPE-LIKE PORTION)
  E3PSI       -   SURFACE ROUGHNESS FACTOR,ROUGHNESS/SURFACE
  N3NODE      -   FOR VALVE,MUST USE 1 NODE
  N3PATH      -   NUMBER OF PARALLEL UNITS BEING REPRESENTED
  A3VMAX      M2  MAXIMUM FLOW AREA THRU VALVE WHEN OPEN
  S3VMIN      -   MINIMUM VALVE POSITION,RELATIVE,MUST GT 0.0
  F3STOA      -   FACTOR,POSITION TO AREA,AREA=POSITN**F3STOA
201D PUMP GEOMETRIC RECORD/
  MODID       -   MODULE ID ASSIGNED TO PUMP
  INLETID     -   PORT IDENTIFIER ASSIGNED TO INLET PORT
  OUTLETID    -   PORT IDENTIFIER ASSIGNED TO OUTLET PORT
  X3MOD       M   LENGTH OF MODULE (PIPE-LIKE PORTION)
  Y3ID        M   DIAMETER OF MODULE (PIPE-LIKE PORTION)
  E3PSI       -   SURFACE ROUGHNESS FACTOR,ROUGHNESS/SURFACE
  N3NODE      -   NUMBER OF NODES,FOR PUMP USE 1 NODE
  N3PATH      -   NUMBER OF PARALLEL UNITS BEING REPRESENTED
301D HEAT EXCHANGER GEOMETRIC RECORD/
  MODID       -   MODULE ID ASSIGNED TO HEAT EXCHANGER
  INLETID     -   PORT ID ASSIGNED TO INLET PORT,INSIDE TUBE
  OUTLETID    -   PORT ID ASSIGNED TO OUTLET PORT,INSIDE TUBE
  X3MOD       M   LENGTH OF MODULE (ACTIVE HT XFER LENGTH)
  Y3ID        M   INNER DIAMETER OF HT XFER TUBES
  E3PSI       -   SURFACE ROUGHNESS FACTOR INSIDE TUBES
  N3NODE      -   NUMBER OF AXIAL NODES TO BE USED
  N3PATH      -   NUMBER OF PARALLEL UNITS BEING REPRESENTED
  INLETID     -   PORT ID ASSIGNED TO INLET PORT,OUTSIDE TUBE
  OUTLETID    -   PORT ID ASSIGNED TO OUTLET PORT,OUTSIDE TUB
  Y3OD        M   OUTER DIAMETER OF HEAT TRANSFER TUBE
  F3TBPD      -   PITCH TO DIAMETER RATIO(TUBE SPACING/DIAMR)
  N3TUBE      -   NUMBER OF TUBES PER HEAT EXCHANGER
  M3TYPE      -   MATERIAL TYPE IN TUBING
  I3GRID      -   NO. TUBES EQUADISTANT FROM CENTR TUB,1,4,6
  D3COIL      M   HELICAL COIL DIAMETER, 0 FOR STRAIGHT TUBES
  F3ITOO      -   RATIO OF FLOW LENGTH INSIDE TUBE TO OUTSIDE
  Y3CORO      M   DIAMETER OF CORE TUBE (ZERO IF NONE)
  M3CORT      -   MATERIAL TYPE OF CORE TUBE
  M3STRC      -   MATERIAL TYPE OF HX SHELL AND STRUCTURE
  A3STRC      M2  SURFACE AREA BETWEEN STRUCTURE-FLUID,SUM-PATH
  B3STRC      KG  MASS OF STRUCTURE,SUMMED OVER PARALEL PATHS
 **M3TYPE,M3CORT,M3STRC OPTIONS;
   1-ST STEEL      2-2.25 CH-MLY  3-ADMRLTY  4-90-10 CU-NI
   5-80-20 CU-NI   6-70-30 CU-NI  7-MONEL    8-INCONNEL
   9-CARBON STEEL 10-ALUMINUM
401D INLET BOUNDARY MODULE GEOMETRIC RECORD/
  MODID       -   MODULE ID ASSIGNED TO INLET BOUNDARY
  OUTLETID    -   PORT ID ASSGND TO BND OUTLET (SYSTEM INLET)
402D OUTLET BOUNDARY MODULE GEOMETRIC RECORD/
  MODID       -   MODULE ID ASSIGNED TO OUTLET BOUNDARY
  INLETID     -   PORT ID ASSGND TO BND INLET (SYSTEM OUTLET)
501D VOLUME GEOMETRIC RECORD/
  MODID       -   MODULE ID ASSIGNED TO VOLUME
  L3VSHP      -   COMPONENT SHAPE,1-VERT CYL OR BOX,2-HRZ CYL
  V3VOL       M3  VOLUME WITHIN MODULE (PORTION OF COMPONENT)
  Y3VOL       M   TOTAL HEIGHT OF COMPONENT
  F3VMIN      -   REL HEIGHT OF MODULE LOW PNT W.R.T. COMPNET
  F3VMAX      -   REL HEIGHT OF MODULE HI PNT W.R.T. COMPONET
  Z3VOL       M   ELEVATION OF COMPONENT VERTICAL MIDPOINT
  N3PATH      -   NUMBER OF PARALLEL UNITS BEING REPRESENTED
```

```
  L3PSEP      -   1-HOMOGENEOUS,2-SEPARATED PHASES,3=1SS-2TRN
511D VOLUME INLET PORT GEOMETRIC RECORD/
  MODID       -   MODULE ID ASSIGNED TO VOLUME
  INLETID     -   PORT ID ASSIGNED TO INCOMING VOLUME PORT
512D VOLUME OUTLET PORT GEOMETRIC RECORD/
  MODID       -   MODULE ID ASSIGNED TO VOLUME
  OUTLETID    -   PORT ID ASSIGNED TO OUTGOING VOLUME PORT
601D TURBINE STAGE GEOMETRIC RECORD/
  MODID       -   MODULE ID ASSIGNED TO TURBINE STAGE
  INLETID     -   PORT ID ASSIGNED TO INLET PORT
  OUTLETID    -   PORT ID ASSIGNED TO OUTLET PORT
  ALPHA     DEGRE ABS ANGL OF APROCH STEAM W.R.T. BLADE,EG-15
801D NETWORK GEOMETRIC RECORD/
  MODID       -   MODULE ID OF ANY BNDRY OR ACCUMLTR IN NETWK
  IFTYPN      -   FLUID TYPE,1-H20,2-SODIUM,3-AIR,4-NAK
901D JUNCTION RECORD/
  Z3JCTN      M   ELEVATION OF INTERFACE BETWEEN MODULE PORTS
  MODID1      -   MODULE ID OF FIRST MODULE
  PORTID1     -   PORT ID OF FIRST MODULE
  MODID2      -   MODULE ID OF SECOND MODULE
  PORTID2     -   PORT ID OF SECOND MODULE
1001D PIPE PERFORMANCE RECORD/
  MODID       -   MODULE ID OF PIPE
  F3KMI       -   LOSS COEFFICIENT (K) FOR MODULE
1101D VALVE PERFORMANCE RECORD     (IF CHOKED,MUST ISOLATE)/
  MODID       -   MODULE ID OF VALVE
  F3KMI       -   MODULE LOSS COEFFICIENT-PIPE-LIKE SECTION
  F3VALV      -   LOSS COEFFICIENT ACROSS VALVE OPENING
  I3CHOK      -   CHOKE FLOW OPTION,0-NONE,1-CHOKING EXPECTED
  J3VPRS      -   VOLUME WHERE  PRESSR TAKEN,NOT USED= -999
  P3VOPN      PA  PRESSURE AT WHICH VALVE TRIPS OPEN
  S3VOPN      S   VALVE OPENING TIME CONSTANT
  P3VCLO      PA  PRESSURE AT WHICH VALVE TRIPS SHUT
  S3VCLO      S   VALVE CLOSING TIME CONSTANT
  ** ALTERNATE USE OF LAST PARAMETERS ** FOR CHECK VALVE
  J3VPRS=0 FOR CHECK VALVE
  P3VOPN=FLOW/PATH (KG/S) TO OPEN
  P3VCLO=FLOW/PATH (KG/S) TO CLOSE
1201D PUMP PERFORMANCE RECORD/
  MODID       -   MODULE ID OF PUMP
  F3KMI       -   MODULE LOSS COEFFICIENT
  W3REFF    KG/S  REFERENCE FLOW RATE (PER UNIT)
  H3REF       M   REFERENCE PUMP HEAD
  F3REF     RPM   REFERENCE PUMP SPEED
  A3PUMP(1)   -   HEAD(SPEED,FLOW)=H3REF*(SPEED/F3REF)**2
        (2)   -       *(A3PUMP(1)+A3PUMP(2)*WRATIO
        (3)   -       +A3PUMP(3)*WRATIO**2+A3PUMP(4)*WRATIO**3
        (4)   -       +A3PUMP(5)*WRATIO**4),
        (5)   -         WHERE WRATIO=W/(W3REFF*(SPEED/F3REF))
  S3PTAU      S   PUMP COASTOWN TIME CONSTANT,SPD=SPDO*E-T/TAU
  S3PSEZ      S   PUMP SEIZURE TIME AFTER TRIP
1301D HEAT EXCHANGER PERFORMANCE RECORD/
  MODID       -   MODULE ID OF HEAT EXCHANGER
  F3KMI       -   MODULE LOSS COEF, INSIDE TUBES
  F3KMO       -   MODULE LOSS COEF,OUTSIDE TUBES
  I3LVTI      -   DNB/DRYOUT OPTION,1-DNB,2-DRYOUT,3-X=0.75
  I3LVTO      -   SAME AS I3LVTI,BUT APPLIED OUTSIDE TUBES
  F3CCFL      -   FLOW DIRECTION,1.PARRLL,0.CROSS,-1.COUNTER
1601D TURBINE PERFORMANCE RECORD/
  MODID       -   MODULE ID FOR TURBINE
  I3TTYP      -   TURBINE STAGE TYPE,1-IMPULSE,2-IMPULS-REACT
  E3FGEN      -   EFFICIENCY TO ELECTRICAL GRID
  W3TREF    KG/S  REFERENCE FLOW RATE
  P3ITRF     PA   REFERENCE INLET PRESSURE
  P3OTRF     PA   REFERENCE OUTLET PRESSURE
  T3ITRF     K    REFERENCE INLET TEMPERATURE
  R3TSRF    RPM   REFERENCE SPEED
  S3TTAU     S    COASTDOWN TIME CONSTNT,SPD=SPDO*EXP(-T/TAU)
  S3TSEZ     S    SEIZURE TIME (AFTER TRIP)
2001D PIPE INITIAL CONDITION (ALL QMOD'S SUBJECT TO ADJUST.)/
  MODID       -   MODULE ID OF PIPE
  Q3MOD      J/S  HEAT PUT INTO MODULE,SUM OVER PARALEL UNITS
2101D VALVE INITIAL CONDITION RECORD/
  MODID       -   MODULE ID OF VALVE
  Q3MOD      J/S  HEAT PUT INTO MODULE,SUM OVER PARALEL UNITS
```

```
  S3VPOS      -    INITIAL STEM POSITION,RELATIVE,0.-CLSD,1.OP
2201D PUMP INITIAL CONDITION RECORD/
  MODID       -    MODULE ID OF PUMP
  Q3MOD      J/S   HEAT PUT INTO MODULE,SUM OVER PARALEL UNITS
  F3PUMP     RPM   INITIAL PUMP SPEED
2301D HEAT EXCHANGER INITIAL CONDITION RECORD/
  MODID       -    MODULE ID OF HEAT EXCHANGER
  Q3MOD      J/S   TOTAL HT XFER,OUT TO IN,SUM OVR PARLEL UNTS
2401D BOUNDARY MODULE INITIAL CONDITION RECORD/
  MODID       -    MODULE ID OF BOUNDARY
  K3EBST      -    BOUNDARY STATUS,0-INLET,1-FLOATING,2-FIXED
  K3EBC       -    E3BC FLAG,1-ENTHALPY,2-TEMPERATURE,3-QUALTY
  E3BC      J/KG,K ENTHALPY,TEMPERATURE,OR QUALITY (IF H2O)
  W3BC      KG/S MASS FLOW (TOTAL)    USED FOR INLETS ONLY
  P3BC        PA  PRESSURE            USED FOR OUTLETS ONLY
2501D VOLUME INITIAL CONDITION RECORD/
  MODID       -    MODULE ID OF VOLUME
  Q3MOD      J/S   HEAT PUT INTO MODULE,SUM OVER PARALEL UNITS
  F3LQLV      -    RELATIVE LIQUID LEVEL VS COMPONET HEIGHT
  P3VOL       PA   ESTIMATED VOLUME PRESSURE AT STEADY STATE
2511D VOLUME OUTLET PORT INITIAL CONDITION RECORD/
  MODID       -    MODULE ID OF VOLUME
  OUTLETID    -    OUTLET PORT ID OF VOLUME
  W3VOUT    KG/S ESTIMATE OF FLOW EXITING,SUM OVER PARL PATH
2601D TURBINE STAGE INITIALIZATION RECORD/
  MODID       -    MODULE ID OF TURBINE STAGE
  R3TS       RPM   INITIAL TURBINE SPEED
  Q3MOD      J/S   WORK DONE ON TURBINE STAGE
3011D PIPE HEAT INPUT TABLE RECORD (REPEAT 2 AND 3 ENTRIES)/
  MODID       -    MODULE ID OF PIPE
  S3QT        S    TIME OF TABLE ENTRY
  Q3MDT      J/S   HEAT INPUT FOR CORRESPONDING TIME
3111D VALVE HEAT INPUT TABLE RECORD (REPEAT 2 AND 3 ENTRIES)/
  MODID       -    MODULE ID OF VALVE
  S3QT        S    TIME OF TABLE ENTRY
  Q3MDT      J/S   HEAT INPUT FOR CORRESPONDING TIME
3121D VALVE POSITION TABLE RECORD-OPTIONAL (REPEAT ENTR 2,3)/
  MODID       -    MODULE ID OF VALVE
  S3VTIM      S    TIME OF VALVE POSITION TABLE ENTRY
  S3VPSN      -    RELATIVE VALVE STEM POSITION
3201D PUMP TRANSIENT RECORD (CAN BE OVER-RULED BY 3221D REC)/
  MODID       -    MODULE ID OF PUMP
  S3PTRP      S    TIME AT WHICH PUMP IS TRIPPED
3211D PUMP HEAT INPUT TABLE RECORD (REPEAT ENTRIES 2,3)/
  MODID       -    MODULE ID OF PUMP
  S3QT        S    TIME OF TABLE ENTRY
  Q3MDT      J/S   HEAT INPUT AT CORRESPONDING TIME
3221D PUMP SPEED TABLE RECORD-OPTIONAL (REPEAT ENT 2,3)/
  MODID       -    MODULE ID OF PUMP
  S3PTIM      S    TIME OF TABLE ENTRY
  R3PMPT     RPM   PUMP SPEED AT CORRESPONDING TIME
3411D BOUNDARY CONDITION TABLE RECORD (REPEAT ENT 4,5,6)/
  MODID       -    MODULE ID OF BOUNDARY
  I3BCTP      -    KEY,1-FLOW SPECIFIED, 2-PRESSURE SPEC.
  K3ETAB      -    KEY FOR ETAB,1-ENTHALP,2-TEMP,3-QUALTY
  S3TAB       S    TIME OF TABLE ENTRY
  E3TAB     J/KG,K  ENTH,TEMP,OR QUAL ENTRY
  P3WTAB    KG/S,PA FLOW OR PRESSURE TABLE ENTRY
3511D VOLUME HEAT INPUT TABLE RCD (REPEAT 2,3 ENTRIES)/
  MODID       -    MODULE ID OF VOLUME
  S3QT        S    TIME OF TABLE ENTRY
  Q3MDT      J/S   HEAT INPUT AT CORRESPONDING TIME
3601D TURBINE TRIP RECORD (CAN BE OVERRULED BY 3611D RECRD)/
  MODID       -    MODULE ID OF TURBINE STAGE
  S3TSTP      S    TURBINE TRIP TIME
3611D TURBINE SPEED TABLE RECORD-OPTIONAL (REPEAT ENTRY 2,3)/
  MODID       -    MODULE ID OF TURBINE STAGE
  S3TSTB      S    TIME OF TURBINE SPEED TABLE ENTRY
  R3TSTB     RPM   TURBINE SPEED AT CORRESPONDING TIME
4000D RUN CONTROL CARD/
  S3END       S    END OF TRANSIENT SIMULATION
4100D PRINT CONTROL RECORD (REPEAT ENTRYS 3,4)/
  L3PRON      -    STEP NO. TO START FREQUENT PRNTS,-1 FOR SS
  L3PRNT      -    KEYS PRINT DETAIL,1-BRIEF,2-MIDL,3-DETAILED
  S3PRIN      S    PRINT INTERVAL
```

```
  S3PLIM      5   TIME LIMIT FOR CORRESPONDING PRINT INTERVAL VALUE
42000 CONTEXT SAVE CONTROL RECORD/
  L3REST      -   CONTEXT RESTORE CONTROL,0-NO RESTORE,1-RESTORE CONTEXT
  N3SINT      -   CONTEXT SAVE CONTROL,DEFINES PRINT COUNT BETWEEN SAVES

STOP
END
```

2.3 STEADY STATE PROCESSING AND PITFALLS

MINET contains a fully generalized steady state analysis package, unlike many systems codes. This approach has great advantages in that it allows widespread MINET applications, but has the disadvantage that one has to follow specified rules, and cannot just alter one local parameter (e.g., fix a heat exchanger pressure), without affecting other variables.

Flow rates are specified for inlet boundary modules and pressures are specified for the outlets, and at least one of each must appear somewhere in each network. All other flows and pressures are calculated, and the user can influence these directly only through the form loss factor. This should be viewed as an iterative process, and a few runs may be necessary before the steady state has the desired flow and pressure distributions.

The enthalpy and heat transfer distribution calculations include some adjustment factors that bear watching. Bridge factors, used to adjust the heat transfer rates between sub-networks, are critical in satisfying energy constraints, but can be troublesome when a large and a small heat transfer bridge are adjusted together. The heat exchanger heat transfer area correction factor compensates for inaccuracies in heat transfer coefficients. In both cases, the closer these adjustment factors are to 1.0, the better.

Our experience has been that the most difficult period in testing an input deck is before the first steady state printout, which comes after the first outer iteration has been completed, if L3PRON = -1. Until the first print, one must rely on common block dumps to pursue errors, which is tedious at best. Perhaps the best approach is to build a simple, yet physically correct, system first, and make adjustments later.

2.4 RUNNING THE TRANSIENT

Any time a new deck is run, or there is a change in steady state conditions, a "null", or "steady state", transient should be run. This means setting all transient boundary conditions so as to maintain a steady state. Such a transient should be run for about 20 seconds, and the results should be checked to verify that conditions are holding near the initial conditions. If conditions are not holding, a transient should not be run until the reason for such behavior is fully understood and judged to be acceptable.

In specifying boundary conditions, the user should avoid making large step changes, as these are non-physical and strain the code numerics. Previous experience indicates the most likely error of this type occurs when the user inputs flow with pressure indicated or pressure with flow indicated, either of which can be highly disruptive.

We recommend that the user utilize the MINET restart option to accomplish a transient in pieces, particularly for a long transient. This not only reduces the likelihood of wasting resources if non-physical conditions occur, but also can be very helpful in gaining job priority on a shared computer.

Generally, one should start with frequent print-outs and decrease the print frequency as the transient progresses. If a problem develops at some point well into the transient, the transient should be rerun with a high print frequency and maximum detail. A late-developing problem will usually trace to an event occuring in recently preceding time steps.

The basic MINET numerics are stable under most flow conditions, including forward reversal, convergence, and divergence. Instabilities can be introduced through parameters calculated explicitly, e.g., heat exchanger tube temperatures, valve positions, pump speeds. The current MINET modules are quite stable, and have proved to be that way for several test cases. However, one must be careful in specifying time constants or inserting a "hard-wired" control system, as one can introduce stability problems. As instabilities also pose problems in physical systems, various means are often used to delay component response. Should the user choose to ignore these delays as a simplification, he may force MINET to analyze under unstable conditions.

2.5 ERROR MESSAGES AND SUGGESTED RESPONSE

Current error messages and their meanings are listed in Table 2.5-1. While the interpretation given in the table is brief, it should be adequate, in general. For some cases, it is necessary to elaborate further:

103 - Area Correction Factor

This error can have two possible causes, one which is serious and one which is minor. If current system-wide conditions are sufficiently off, they can occasionally cause problems in a heat exchanger, with this error as a possible outcome. The solution is to adjust the system-wide conditions via boundary conditions, loss coefficients, and module heating. If the error is occurring in a heat exchanger and the conditions appear plausible, it is best to increase the nodalization. Otherwise, this type of error can be difficult to resolve and contact with the code developer is in order.

111 - Big System

Subroutine SUBN3S contains a series of nested "do loops" that should be large enough for most systems. However, for a very large system it may be necessary to nest more "do loops" in the routine. It will be quite obvious how to do so from looking at the subroutine.

Table 2.5-1 Error Messages and Meanings

ERR No	Source	Nature of Error
103	HX3S	Failed to Converge on Area Correction Factor; Check Initial Conditions
104	EVLV3S	Water Level Outside Range for Volume; Check FLQLV, FMIN, FMAX
105	MINT3S	Failed to Converge on Global Steady State Balance; Adjust Conditions
110	PRFL3S	Failed to Converge on Flow/Pressure Distribution; Adjust Loss Coefficients
111	SUBN3S	System Too Big for SUBN3S, Extend Subroutine (EASY)
118	SUBN3S	Problem With Segment Assignment; Check System Layout
119	SUBN3S	Problem With Volume Assignment; Check System Layout
120	HX3S	Temperatures Cross In Heat Exchangers; Check Conditions
125	BKEY3S	System Overconstrained; Reduce Constraints Or Add Heat Sources
139	HX3S	Trying to Transfer Heat From Cold to Hot, Check Conditions
141	ETX3C	Quality OK As Boundary Condition Only If Water/Steam
201	F V3T	Failed To Converge on New Water Level; Check Level and Enthalpy

118, 119 - Segment Linkages

This problem is somewhat hypothetical in that it has never occurred to date. If it should arise, it would indicate trouble in the way the network is linked together. Contact with the code developer should be made.

120, 139 - Heat Exchanger Problems

The MINET heat exchanger module is programmed to recognize these impossible conditions and avoid the potential difficulty in performing a full iterative solution. Instead, a linear heat transfer is assumed, to generate enthalpy distributions and reasonable pressure drops, in the hopes that on the next pass conditions will be more physically correct. If this fix occurs on the last steady state iteration, the area correction factor will be identically 1.0000000, and any transient that follows will be questionable at best.

2.6 RECOVERING FROM AN ABNORMAL JOB TERMINATION

If a problem is not discovered through routine error checks, and instead leads to a fatal error, e.g., divide by zero, a run can be terminated abruptly in a "crash." As testing of MINET continues, such an occurrence will become increasingly unlikely. However, at this time, an abnormal termination is a very real possibility, and may be expected to occur from time to time.

The key to determining the reason for a crash is maximizing the amount of information about conditions at and just prior to the job termination time. This includes recent printouts, common block dumps, computer system diagnostics regarding the crash, and debug write statements subsequently inserted into the code.

In general, the immediate reason for a crash will be uncovered in a relatively short time. Often it will trace to an input error not yet detected.

The worst case is when the reason for an abnormal condition cannot be traced to the source. At this stage, knowledge of the code processing can be important, and we recommend that the user contact the code developer.

In order for the MINET developers to trace a problem, several pieces of information are needed. If the code was modified in any way, a revised listing will be needed. The input deck and output from the ill-fated run are needed. Content of the common blocks is useful. Finally, a schematic drawing of the representation is necessary.

2.7 INTERPRETING THE OUTPUT

In order to interpret printed MINET output, one needs a schematic of the system. This is necessary to interpret module ID numbers and visualize the configuration.

Three levels of print detail are available, designated 1 for the shortest, 2 for moderate detail, and 3 for full detail. These are described further below. Example outputs can be found in Section 4 of this report.

2.7.1 PRINT OPTION 1

The heading gives the current simulation time, the length of the most recent time step, and the transient time step number. Knowledge of the step number can be most useful when a problem develops at some point well into the transient, so that one can rerun the transient with heavy print detail turned on for the previous few seconds.

Conditions at the system boundaries appear next, with the boundary ID, the network number (MINET assigns), the flow, enthalpy, pressure and temperature, as well as the fluid type, given for each boundary module. If water is in the network, it is wise to watch the enthalpy and temperature if conditions are anywhere near saturation.

In the steady state print only, a summary of the system sub-networks follows. Recall that sub-networks are added whenever a separated volume or an outlet boundary module with a fixed temperature is used. This printout merely indicates what adjustments had to be made to satisfy these additional constraints. A bridge is simply a heat transfer connection, Q_{ij}, between sub-networks or a sub-network and "ground," i.e., i=j. If the adjustment factors are near 1.0, this edit can be ignored. If this factor differs substantially from unity, the user should investigate why.

The next part of the printout is for the system volumes. Volume ID, pressure, enthalpy, temperature, water level, heat input, network number (MINET assigned), and the number of regions specified in the volume are given. The number of regions will be one for homogeneous, two for separated, or three for initially homogeneous, but separated during the transient. The water level is meaningful only for water/steam in a separated volume.

Next to appear in the printout is the segment condition summary. The segments are listed by their MINET number, which the code assigns while it is processing the input. At the right-hand side of the print, module ID numbers are given for the modules connecting at the segment inlet and outlet, which are helpful in identifying the segments. Segment parameters printed include: segment inlet, outlet, and average flow rate; inlet and outlet enthalpy and pressure; and pressure loss parameters α and β.

2.7.2 PRINT OPTION 2

When print option 2 is specified, additional print is provided to give in-segment distributions. Because the segment module IDs are printed for each segment, one can easily resolve any uncertainty as to which segment is which. For each node in each segment, the inlet, average, and outlet enthalpy, the inlet and outlet flow, the inlet, average, and outlet temperature, the average density, and the total heating (work) added to the node are given. Node number and nodal interface numbers are also provided, which are needed for the plot option.

2.7.3 PRINT OPTION 3

By specifying print option 3, the user gets, in addition, a description of conditions at the module level. For each module, the module number (MINET assigned), the module type ordinate number (MINET assigned, e.g., the 4th valve), module ID number (user assigned), and the number of parallel units being represented by one (user assigned) are given. These numbers are also needed for specifying variables for plotting.

For valves, the current valve position is given, along with the current choke flow limit. A large value for the choked flow limit may mean the choking option was declined, in which case MINET sets the choke limit extremely high so it will not be exceeded.

For pumps, the current pump speed, flow rate, and pump head are given. The flow rate is per parallel unit.

For heat exchangers, the area correction factor is first given, which indicates how closely the MINET heat transfer correlations agree with the steady state conditions. A value near 1.0 is desirable, but a value of exactly 1.0 indicates there may have been a problem in the steady state (see Section 2.5).

Also given for heat exchangers is a node-by-node detailing of current conditions. The tube node number, and the node numbers for the fluids passing inside and outside the tubes are given. Heat transfer per meter and node average temperatures are given, as are the heat transfer modes inside and outside the tubes, and the temperatures for the core tubes and structure. For water and steam, multiple heat transfer modes can occur in one node, in which case mode 45 would indicate that heat transfer began as film boiling (4) and passed on to superheat (5), for instance. It happens, occasionally, that a heat exchanger will be processed from opposite ends in the transient and steady state, in which case the mode could switch to 54, which represents a physical situation provided the total heat transfer is about the same. (Note: if, during the transient, the tube structure temperature swings wildly, it may indicate that the heat transfer area to structure mass ratio is too big.)

For the turbine module, current speed, efficiency, and "power from the generator" are printed. Note that the "power from the generator" will usually be negative, and the turbine usually provides power to the generator.

2.8 THE PLOT OPTIONS

As a user-option, MINET will (during normal printouts) write current values of key variables into a transactions file, which can be used for generating plots and other forms of output. This effort is still under development.

The user will be able to specify subsets of the variables listed in Table 2.8-1, or the table in its entirety. As a result, a chronologically ordered set of values will become available in the transactions file.

Access to the contents of the transaction file will be by a post-processor, which, for now, will be designated "RECALL". In the initial version of RECALL, the user will have to specify the variable name and the value (e.g., node number) of interest. It is hoped that, in later versions, one may gain access through more basic parameters, such as module ID number and other externally meaningful parameters.

Table 2.8-1 PLOTFILE Parameters

Variable	Group	Parameter
D3QDWB	Node	Node Heating Derivative w.r.t. Pressure
T3JUNC	Node Inf	Nodal Interface (Junction) Temperature
T3TC	HX Nod	HX Tube Node Temperature
Q3PMI	HX Nod	Heating Per Meter, Inside Tube
Q3PMO	HX Nod	Heating Per Meter, Outside Tube
T3CORT	HX Nod	Core Tube Temperature
T3STRC	HX Nod	Structure Temperature
R3PUMP	Pump	Pump Speed, Relative to Reference
R3DMND	Pump	Pump Demand Speed, Relative
F3PUMP	Pump	Pump Speed in RPM
W3PUMP	Pump	Mass Flow Rate Per Pump
H3PUMP	Pump	Pump Head in Meters
S3VPOS	Valve	Valve Position, Relative
W3VALC	Valve	Mass Flow Rate at Choking
S3DMD	Valve	Valve Demand Position, Relative
P3VOL	Volume	Volume Average Pressure (Pa)
E3VOL	Volume	Volume Average Enthalpy (J/KG)
F3LQLV	Volume	Relative Liquid Level
T3VOL	Volume	Volume Temperature
R3VOL	Volume	Volume Average Density
D3VRE	Volume	Derivative of Vol Ave Dens w.r.t. Enthalpy
D3VRP	Volume	Derivative of Vol Ave Dens w.r.t. Pressure
E3BC	Boundary	Boundary Module Enthalpy
P3BC	Boundary	Boundary Pressure
W3BC	Boundary	Boundary Flow
T3BC	Boundary	Boundary Temperature
X3BC	Boundary	Boundary Quality
S3DELT	GLOBAL	Current Time Step Size
S3TAUM	GLOBAL	Minimum Time Constant Calculated
A3LPHA	Segment	Segment Pressure Loss Multiplier
B3ETA	Segment	Segment Pressure Loss Exclusive of Flow Squared
E3INSL	Segment	Segment Inlet Enthalpy
E3OTSL	Segment	Segment Outlet Enthalpy
P3INSL	Segment	Segment Inlet Pressure
P3OTSL	Segment	Segment Outlet Pressure
W3SEG	Segment	Segment Average Mass Flow Rate
W3INSL	Segment	Segment Inlet Mass Flow Rate
W3OTSL	Segment	Segment Outlet Mass Flow Rate
R3TS	Turbine	Turbine Speed in RPM
E3FTSG	Turbine	Turbine Operating Efficiency
P3WRGN	Turbine	Power from Generator (Negative If Turbine Operating)
R3TSDM	Turbine	Turbine Demand Speed in RPM
E3WSSG	Node Inf	Enthalpy at Nodal Interface
W3WSSG	Node Inf	Mass Flow Rate at Nodal Interface
E3CB	Node	Node Average Enthalpy
D3DRDP	Node	Node Average Density Derivative w.r.t. Pressure
D3DRDE	Node	Node Average Density Derivative w.r.t. Enthalpy
T3CB	Node	Node Average Temperature
Q3CB	Node	Node Heating (In = Positive)
R3CB	Node	Node Average Density
D3QDEB	Node	Node Heating Derivative w.r.t. Enthalpy

2.9 RESTART

The MINET transient restart option can be very useful, particularly once a transient simulation has begun. It should be employed routinely for transients of significant duration, both as failure insurance and to improve access to shared computers where expected execution time influences job priority.

When a restart file is written, values for all relevant variables are transferred to the output device. A simulation can then be started up again from that point, by initializing current values from information in the restart file.

The user controls the frequency at which restart files are written. This is done through parameter N3SINT on input record 4200, which indicates how many printouts (see record 4100) take place between restart file writes. When a restart file is written, the previous contents are overwritten. Thus, with a 60 second run, having prints every 2 seconds and N3SINT = 5, a restart file will be written at 10, 20, 30, 40, 50, and 60 seconds. At the end of the run, only values for t = 60 seconds will be in the "save" (restart) file.

When the user wants to restart a run, the restore file is specified to be the restart save file from the previous run, and parameter L3REST on input record 4200 is set to 1. Thus, continuing the example in the previous paragraph, the job would be continued from conditions at t = 60 seconds.

Control of the restart option and the input/output device number is kept at a very high level in the MINET program logic. This facilitates transference of control to a host code, such as SSC [11], so that coordination and conflict problems can be resolved.

3. MINET CODE DESCRIPTION

The ideal computer code is written so that it can always be treated as a black box, i.e., details of the internals can be totally ignored. Unfortunately, a computer code with the size and scope of MINET is nearly impossible to perfect to such a degree. We tried to do the next best thing, i.e., to develop a code that is highly modular and quite readable so the user has a chance to cope with problems that may arise. This section of the MINET code documentation is written to facilitate the understanding of the MINET program, but can in no way describe every facit of the code.

Computer code documentation can be provided in three ways: (1) written, (2) computer generated, and (3) imbedded in the computer code. Much of this document is handwritten, which has the advantage of clarity and the disadvantage that it is cumbersome to update. Computer generated documentation can be tedious to develop, but is easy to update. In-code descriptions are particularly useful when reading the program library, but are not much use in formal reports. In order to keep this section as current as possible, much of it is computer generated.

3.1 CODE STANDARDS AND PHILOSOPHY

3.1.1 PROGRAMMING LANGUAGE

ANSI USA Standard FORTRAN language (ANSI X3.9-1966) is used as a basis for MINET code development. Some exceptions have, however been necessary for the sake of expedience. These fall into two categories:

- Required features not defined within the standard (character manipulation) have been implemented in such a way that machine dependencies due to work size can be overcome on most systems by global means rather than numerous local modifications.
- Overly-restrictive language limitations (indexing expressions, etc.) have been relaxed based on reasonable assumptions about the extensions available in most available compilers.

3.1.2 SUPPORT SOFTWARE

No external support libraries or system-dependent procedures are required.

3.1.3 GLOBAL COMMONs

All FORTRAN COMMON declarations with identical labels are implemented with identical variable lists wherever they appear. This avoids confusion due to "aliasing" of COMMON locations.

3.1.4 NAMING CONVENTION

Certain conventions have been established governing the choice of variable, labelled COMMON, and subprogram names.

- global variables are identified by having a numeric character in the second position according to the following rules:
  1. 9 signifies variables associated with utility and driver code
  2. 3 signifies variables associated with MINET computational code

- labelled global COMMON names use a numeric character in the next-to-last position following the above rules for global variables. The last character of global COMMON names is chosen according to the rules:

  1. V signifies a block containing only REAL types
  2. I signifies a block containing only INTEGER types
  3. P signifies a block containing only global container POINTER types
  4. U signifies a block containing implementation variables for utility code

  SUBROUTINE names use a numeric character in the next-to-last position according to the rules:

  1. 9 signifies driver and utility code
  2. 3 signifies computational code

  The last character of SUBROUTINE and FUNCTION names is chosen according to which of the major code divisions they belong:

  1. R signifies Reader code
  2. S signifies Steady-state code
  3. T signifies Transient code
  4. U signifies Universal code which is used in more than one division
  5. C signifies COMMON code used in both the steady-state and the transient calculations

3.1.5 DESIGN PHILOSOPHY

The objective of the design philosophy adopted for MINET is to make the finished code easy to maintain and modify. Two major approaches, MODULARITY and the use of DATA MANAGEMENT UTILITIES have been used to accomplish this objective.

- The MODULAR approach involves dividing the code design into smaller parts, called modules, such that each can be dealt with individually. Although many methods exist for performing modular design, the end result exhibits similar desirable characteristics:
  - modules exhibit high strength in that the module contents are closely related by the operations they perform.
  - modules exhibit low coupling in that the contents and functions of any one module have minimal relationship to those of another.
- DATA MANAGEMENT UTILITIES are groups of subroutines designed to implement abstract data types not available in the programming language being used (FORTRAN in this case). Each abstract data type consists of a structured data object, such as a list, and a group of operations, such as CREATE, DELETE, INSERT, etc. All access to the data is performed by calls to members of a subroutine group, each of which performs one of the operations. Advantages include:
  - Data structures can be constructed to best fit the problem being solved so that computational code logic is cleaner.

- Potentially messy and confusing implementation details are effectively "hidden" from upper-level computational code.
- Flexibility is enhanced because the actual implementation of the abstract data types can be changed as needs require without having any effect on the upper-level code.
- Errors are easily detected by inserting appropriate parameter tests in members of the subroutine group.

3.2 CODE STRUCTURE

MINET is a carefully structured code, using modular subroutines and highly specific functions, as well as carefully managed common blocks. Argument lists are occasionally used to improve code modularity, but much of the code data resides in the global common blocks. Low level functions and subroutines rarely access the global common blocks, and never alter any of the values. This careful structuring and data management makes MINET relatively easy to read, understand, and modify.

3.2.1 TIER CHART & CROSS REF MAP

A computer generated tier chart is provided in the pages to follow. While the format by which the chart continues from page to page is far from ideal, the chart (as shown) is easy to keep up to date and should not be overly difficult to interpret. A subroutine and function cross reference map is included in the pages that follow the tier chart.

Figure 3.2-1 Tier Chart

```
$ = RECURSIVE TREE, * = PREVIOUSLY PRINTED TREE
                        .CHARCTR
                        .COMDUM
                        .       .PRTCON
                        .GCPR9U..
                        .
                        .       .GCTE9U
                        .GCTP9U..
                        .
                .ABEND1..
                .       .       .CHARCTR
                .       .INFO....
                .       .
                .       .       .CHARCTR
                .       .       .CODEB
                .       .       *INFO
                .       .SDUMP...
                .       .       .INSTRUC
                .       .       .SSWTCH
                .       .
                .       .SSWTCH
                .       .       .CHARCTR
                .       .TRACE1..
                .
        .ABEND...
        .
        .       .COMDUM
        .       .DISPLA
        .       *GCPR9U
        .       *GCTP9U
        .EXIT9U..
        .       .REMARK
        .       .SSWTCH
        .       .       *TRACE1
        .       .TRACE...
        .       .
        .       .INGC9U
        .INIT3U..
        .
        .               .SECOND
        .       .PAGE9U..
        .       .       .       .TIME
        .       .       .SSCTIM..
        .       .
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.         .                   .                   .         .         .         *VAIR3C
.         .                   .                   .         .         .
.         .                   .                   .         .         .         .         *TMNK3C
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.         .                   .                   .         .         .         .
.         .                   .                   .         .         .HTNK3C..
.         .                   .                   .         .         .         .         *TMNK3C
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.         .                   .                   .         .         .
.         .                   .                   .         .HTC3C...
.         .                   .                   .         .         .         .SQRT
.         .                   .                   .         .         .HWCN3C..
.         .                   .                   .         .         .
.         .                   .                   .         .         .         .         .DENV3D
.         .                   .                   .         .         .         .CONV3K..
.         .                   .                   .         .         .         .         .TMPV3T
.         .                   .                   .         .         .         .
.         .                   .                   .         .         .         .CPV3C
.         .                   .                   .         .         .HWFB3C..
.         .                   .                   .         .         .         .         .CPV3C
.         .                   .                   .         .         .         .         *ESTV3H
.         .                   .                   .         .         .         .ENTV3H..
.         .                   .                   .         .         .         .         .TMPV3T
.         .                   .                   .         .         .         .
.         .                   .                   .         .         .         *VISV3N
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.         .                   .                   .         .         *HWFC3C
.         .                   .                   .         .         .         .CONL3K
.         .                   .                   .         .         .         .CPL3C
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.         .                   .                   .         .         .         .         .ROOT3C
.         .                   .                   .         .         .         .PSAT3P..
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.         .                   .                   .         .         .         .
.         .                   .                   .         .         .HWNB3C..
.         .                   .                   .         .         .         .SQRT
.         .                   .                   .         .         .         .VISL3N
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.         .                   .                   .         .         .         .CPV3C
.         .                   .                   .         .         .HWSC3C..
.         .                   .                   .         .                   *ENTV3H
.         .                   .                   .         .                   *VISV3N
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.         .                   .                   .         *TEMP3C
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.         .                   .         .         *TEMP3C
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.         .                   .         .         .XDNB3C..
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.         .                   .         .         .XDRY3C
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.         .                   .         .         *TEMP3C
.         .                   .         .         *XDNB3C
.         .                   .         .         .XDRY3C
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.         .                   .         *QPM3C
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.         .                   .         .TCLM3C
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.         .                   *RHO3C
.         .         .HX3S....
.         .         .         .ROOT3C
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.         .         .         .         .DENV3D
.         .         .         .         *ESTL3H
.         .         .         .SATO3C..
.         .         .         .         *ESTV3H
.         .         .         .         .STEN3S
.         .         .         .         .TMPL3T
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.         .         .         *VISC3C
.         .         .         .
.         .         .         .ALOG
.         .         .MODL3C..
.         .         .         .SQRT
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.         .         .         *RHO3C
.         .         .PIPE3S..
.         .         .         *TEMP3C
.         .         .
.         .         .PUMP3S
.         .MRCH3S..
.         .         .SATM3C
.         .         .         .CONL3K
.         .         .         .CPL3C
.         .         .         *DENL3D
.         .         .         .DENV3D
.         .         .         *ESTL3H
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.         .         .SATP3C..
.         .         .         *ESTV3H
.         .         .         .STEN3S
.         .         .         .TMPL3T
.         .         .         .VISL3N
.         .         .         *VISV3N
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.         .         .                   .ENA3C
.         .         .                   .ENNK3C
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.         .         .                   .ENTL3H..
.         .         .                   .         .TMPL3T
.         .         .                   .
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.         .         .         .         *ESTV3H
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.         .         .         .         *ESTV3H
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.         .         .         .ESW3C...
.         .         .         .         .SOWT3C
.         .         .         .         .         *ESTL3H
.         .         .         .         .         *ESTV3H
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.         .         .         .         .SWAT3C..
.         .         .         .                   .SOWT3C
.         .         .         .                   .TMPL3T
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.         .         .         .
.         .         .         *RHO3C
.         .         .TBSG3S..
.         .         .         .SQRT
.         .         .         *SWAT3C
.         .         .         *TEMP3C
.         .         .         .
.         .         .         .         *ESTL3H
.         .         .         .         *ESTV3H
.         .         .         .         .GFSK3C
.         .         .         .CRIT3C..
.         .         .         .         .         .EXP
.         .         .         .         .GMDY3C.
.         .         .         .         .
.         .         .         .         .         .DENV3D
.         .         .         .         .         *ESW3C
.         .         .         .         .GSUP3C..
.         .         .         .                   .SQRT
.         .         .         .                   *SWAT3C
.         .         .         .
.         .         .VALV3S..
.         .         .
.         .         .ADDA9U
.         .         .         *DENL3D
.         .         .         .DENV3D
.         .         .         *ESTL3H
.         .         .DPSV3C..
.         .         .         *ESTV3H
.         .         .         *RHO3C
.         .         .
.         .         .ERR9U
.         .         .GETA9U
.         .         .INA9U
.         .         *LEQ9U
.         .         *MODL3C
.         .         *NEWA9U
.         .         *PIPE3S
.         .PRFL3S..
.         .         .PUMP3S
.         .         .PUTA9U
.         .         .RELA9U
.         .         *RHO3C
.         .         .SATM3C
.         .         *SATP3C
.         .         .SQRT
.         .         *VALV3S
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          .MINT3S..
          .         .         *PAGE9U
          .         .PRNT3C..
          .         .         *TEMP3C
          .         .
          .         .         .ADDA9U
          .         .         .GETA9U
          .         .         .INA9U
          .         .         *LEQ9U
          .         .QBAL3S..
          .         .         *NEWA9U
          .         .         .PUTA9U
          .         .         .RELA9U
          .         .
          .         .QBRC3S
          .         .SECOND
          .         .         .ERR9U
          .         .SUBN3S..
          .         .         .FRAC3S
          .         .
          .         .                   *DENL3D
          .         .                   .DENV3D
          .         .                   .         *CPAR3C
          .         .                   .DREA3C..
          .         .                   .         *TAIR3C
          .         .                   .
          .         .                   .         *HCPN3C
          .         .                   .DREN3C..
          .         .                   .         *TNA3C
          .         .                   .
          .         .         .DRDE3C..
          .         .         .         .         *CPNK3C
          .         .         .         .DRNK3C..
          .         .         .         .         *TMNK3C
          .         .         .         .
          .         .         .         *ESTL3H
          .         .         .         *ESTV3H
          .         .         .
          .         .         .         *DENL3D
          .         .         .         .DENV3D
          .         .         .         .         *TAIR3C
          .         .         .         .DRPA3C..
          .         .         .         .
          .         .         .DRDP3C..
          .         .         .         *ESTL3H
          .         .         .         *ESTV3H
          .         .         .         .
          .         .VOLM3S..
          .         .         *RHO3C
          .         .         *TEMP3C
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          .         .         .DENV3D
          .         .         *ESTL3H
          .         .WESM3S..
          .         .         *ESTV3H
          .         .         .         *ENTH3C
          .         .         .         .ERR9U
          .         .         .         *ESTL3H
          .         .         .ETX3C...
          .         .         .         *ESTV3H
          .         .         .         *TEMP3C
          .         .         .
          .         .         *VOLF3C
          .         .
.MINET..
          .                   .DENS3C
          .         .ADTB3T..
          .         .         .HCAP3C
          .
          .                   *DPSV3C
          .         .         *DRDE3C
          .         .         *DRDP3C
          .         .         .         .ACOS
          .         .         .         .COS
          .         .         .         *DENL3D
          .         .         .         .DENV3D
          .         .         .         .ERR9U
          .         .         .FLV3T...
          .         .         .         *ESTL3H
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.         .         .         *ESTV3H
.         .         .         .SIN
.         .         .         *VOLF3C
.         .         .
.         .         .GETA9U
.         .ADVN3T..
.         .         .GETM9U
.         .         .PUTA9U
.         .         .RELA9U
.         .         *RHO3C
.         .         *TEMP3C
.         .
.         .INA9U
.         .         .         .CRKR3T
.         .         .CRKR9U..
.         .         .
.         .         .         *BCOR3C
.         .         .         .DENS3C
.         .         .         *DP3C
.         .         .         *DRDE3C
.         .         .         *DRDP3C
.         .         .         .HCAP3C
.         .         .         *IMOD3C
.         .         .HX3T....
.         .         .         .         .ADDA9U
.         .         .         .         .ADDM9U
.         .         .         .LOAD3T..
.         .         .         .         .PUTA9U
.         .         .         .         .PUTM9U
.         .         .         .
.         .         .         *QPM3C
.         .         .         *RHO3C
.         .         .         .TCLM3C
.         .         .         .TCRG3C
.         .         .         *VISC3C
.         .         .
.         .         .         .ADDA9U
.         .         .         .ADDM9U
.         .         .         *DENL3D
.         .         .         .DENV3D
.         .         .         *ESTL3H
.         .         .IOSG3T..
.         .         .         *ESTV3H
.         .         .         .GETA9U
.         .         .         *NEWA9U
.         .         .         .PUTA9U
.         .         .         *VOLF3C
.         .         .
.         .         *MODL3C
.         .         .         *DP3C
.         .         .         *DRDE3C
.         .         .         *DRDP3C
.         .         .PIPE3T..
.         .         .         *LOAD3T
.         .         .         *RHO3C
.         .         .
.         .         .         *RHO3C
.         .         .PUMP3T..
.         .         .
.         .MRCH3T..
.         .         .SATM3C
.         .         *SATP3C
.         .         .         .ADDA9U
.         .         .         .GETA9U
.         .         .SGBC3T..
.         .         .         .PUTA9U
.         .         .         .RELA9U
.         .         .
.         .         .         *ESW3C
.         .         .         *LOAD3T
.         .         .         *RHO3C
.         .         .TBSG3T..
.         .         .         .SQRT
.         .         .         *SWAT3C
.         .         .
.         .         .         *CRIT3C
.         .         .VALV3T..
.         .         .         *RHO3C
.         .
.MINT3T..
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.         .         .ADDA9U
.         .         .GETM9U
.         .         *LEQ9U
.         .NET3T . . .
.         .         *NEWA9U
.         .         .PUTA9U
.         .         .RELA9U
.         .
.         .         *ETX3C
.         .PREP3T . .
.         .         . INTP9U
.         .
.         *PRNT3C
.         .         *ESTL3H
.         .         *ESTV3H
.         .VOLS3T . .
.                   *FLV3T
.
*PRNT3C
.         *IPTS3R
.         *PAGE9U
.RECX3U . .
.         .         *EXIT9U
.         .REGC9U . .
.
.         *PAGE9U
.SVCX3U  .
.         .SVGC9U
.
.         .SDEL9T
.TIME3T . .
```

Figure 3.2-2 Subroutine/Function Cross Ref Map

```
.............................................................................................................................
. ROUTINE . REFERENCED FROM                    . REFERENCES TO                      . COMMON DEFINED $ = NOT REFERENCED     .
.............................................................................................................................
. ABEND   . MINET                              . ABEND1                             .                                       .
.............................................................................................................................
. ABEND1  . ABEND                              . CHARCTR COMDUM  ENDFIL. GCPR9U     . ABEND                                 .
.         .                                    . GCTP9U  INFO    OUTCI.  OUT R.     .                                       .
.         .                                    . SDUMP   SPA.    SSWTCH  TRACE1     .                                       .
.............................................................................................................................
. ABORT   .                                    . ABEND1                             .                                       .
.............................................................................................................................
. ACOS    . FLV3T   VOLF3C                     .                                    .                                       .
.............................................................................................................................
. ADDA9U  . ENET3S  IOSG3T  LOAD3T  NET3T      .                                    . ADAB9U                                .
.         . PRFL3S  QBAL3S  SGBC3T             .                                    .                                       .
.............................................................................................................................
. ADDM9J  . IOSG3T  LOAD3T                     . SPA.                               . ADAB9U                                .
.............................................................................................................................
. ADTB3T  . MINT3T                             . DENS3C  HCAP3C                     . GLOB3I  GLOB3V  HX3P    LNK3P         .
.         .                                    .                                    . MODL3P  NODL3P  VD9V                  .
.............................................................................................................................
. ADVN3T  . MINT3T                             . DPSV3C  DRDE3C  DRDP3C  FLV3T      . BC3P    GLOB3V  LNK3P   MODC3P        .
.         .                                    . GETA9U  GETM9U  GOTOER. PUTA9U     . NET3P   NODL3P  SEG3P   TRND3P        .
.         .                                    . RELA9U  RHO3C   TEMP3C             . VD9V    VOL3P                         .
.............................................................................................................................
. ALOG    . CBRT3C  ESTL3H  ESTV3H  MODL3C     .                                    .                                       .
.         . THOM3C                             .                                    .                                       .
.............................................................................................................................
. ALOG10  . VSNA3C                             .                                    .                                       .
.............................................................................................................................
. ATAN2   . CBRT3C                             .                                    .                                       .
.............................................................................................................................
. BCOR3C  . HXND3S  HX3T                       . COND3C  GOTOER. HWFC3C  OUTFI.     . MOD3I   MOD3V   SATM3V                .
.         .                                    . QPM3C   POOT3C  SPA.    TEMP3C     .                                       .
.         .                                    . XDNB3C  XDRY3C                     .                                       .
.............................................................................................................................
. BKEY3S  . MINT3S                             . ERR9U                              . GLOB3I  SNET3P  VD9V                  .
.............................................................................................................................
. BND3R   . NET3R                              . INTG9U  MID9U   MORD3R  NCLS3R     .                                       .
.         .                                    . OUTFI.  PGCI9U  PGCR9U  REAL9U     .                                       .
.         .                                    . TABL9R                             .                                       .
.............................................................................................................................
. CAIR3C  . HTCA3C                             . TAIR3C                             .                                       .
.............................................................................................................................
. CALC3R  . INIT3R                             . OUTFI.                             . GLOB3I  LNK3P   VALV3P  VD9V          .
.............................................................................................................................
. CBRT3C  . TAIR3C  TMNK3C  TNA3C              . ALOG    ATAN2   COS     EXP        .                                       .
.         .                                    . SIN     SPA.    SQRT    XTOI$      .                                       .
.............................................................................................................................
. CDINPT  . GENRD                              . DCODNC  ERRMSG  INTERP  INTNDG     . ITERP                                 .
.         .                                    . ISETHM  ITRPCK  NAMEWD  NNBLNK     .                                       .
.         .                                    . NSKIP   READHM  REPEAT             .                                       .
.............................................................................................................................
. CDNK3C  . HTNK3C                             . TMNK3C                             .                                       .
.............................................................................................................................
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..........................................................................................................................................
. ROUTINE . REFERENCED FROM                         . REFERENCES TO                           . COMMON DEFINED $ = NOT REFERENCED       .
..........................................................................................................................................
. CHARCTR . ABENDI    INFO      SDUMP     TRACEI    .                                         .                                         .
..........................................................................................................................................
. CODEB   . SDUMP                                   .                                         .                                         .
..........................................................................................................................................
. COMDUM  . ABENDI    EXIT9U                        . OUTCI.                                  . GLOB3I    GLOB3V    MOD3I     MOD3V     .
.         .                                         .                                         . NODE3I    NODE3V    SATM3V    SATP3V    .
..........................................................................................................................................
. COND3C  . BCOR3C    IMOD3C    QPM3C               .                                         .                                         .
..........................................................................................................................................
. CONL3K  . HWFC3C    HWNB3C    SATO3C    SATP3C    .                                         .                                         .
..........................................................................................................................................
. CONV3K  . HWFB3C    HWSC3C                        . DENV3D    TMPV3T    XTOY$               .                                         .
..........................................................................................................................................
. COS     . CBRT3C    FLV3T     TURB3R              .                                         .                                         .
..........................................................................................................................................
. CPAR3C  . DREA3C    HTCA3C                        . TAIR3C                                  .                                         .
..........................................................................................................................................
. CPL3C   . ENTL3H    HWFC3C    HWNB3C    SATO3C    .                                         .                                         .
.         . SATP3C                                  .                                         .                                         .
..........................................................................................................................................
. CPNK3C  . DRNK3C    HTNK3C                        . TMNK3C                                  .                                         .
..........................................................................................................................................
. CPV3C   . ENTV3H    HWFB3C    HWSC3C              .                                         .                                         .
..........................................................................................................................................
. CRDR9R  . MAIN9R                                  . GENRD     GETF9R    INRD3R    OUTCI.    . DATA9     SCRH9I    UNIT9U              .
.         .                                         . READ3R    STOP.                         .                                         .
..........................................................................................................................................
. CRIT3C  . VALV3S    VALV3T                        . ESTL3H    ESTV3H    GFSK3C    GMDY3C    . SATM3V                                  .
.         .                                         . GSUP3C                                  .                                         .
..........................................................................................................................................
. CRKR3T  . CRKR9U                                  . SPA.                                    .                                         .
..........................................................................................................................................
. CRKR9U  . MRCH3T                                  . CRKR3T                                  . ADAB9U                                  .
..........................................................................................................................................
. CROS3S  . HX3S                                    . TEMP3C                                  . MOD3I     MOD3V     NODE3I    NODE3V    .
..........................................................................................................................................
. CTRL3R  . DMOD3R                                  . INTG9U    REAL9U    TABL9R              . GLOB3I    TIME3I    TIME3V              .
..........................................................................................................................................
. DATE    . SSCDAT                                  .                                         .                                         .
..........................................................................................................................................
. DCODNC  . CDINPT                                  . GOTOER.   INTNDG    XTOI$               .                                         .
..........................................................................................................................................
. DEFP3R  . DMOD3R                                  . DSIZ9U    GETD9U    MID9U     OUTFI.    . DCON9U    LNKS3I                        .
.         .                                         . PUTD9U    SPA.                          .                                         .
..........................................................................................................................................
. DENL3D  . DPSV3C    DRDE3C    DRDP3C    ENET3S    . EXP                                     .                                         .
.         . EVLV3S    FLV3T     IOSG3T    RHO3C     .                                         .                                         .
.         . SATO3C    SATP3C    WESM3S              .                                         .                                         .
..........................................................................................................................................
. DENS3C  . ADTB3T    HX3T                          .                                         .                                         .
..........................................................................................................................................
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. ROUTINE . REFERENCED FROM                     . REFERENCES TO                       . COMMON DEFINED $ = NOT REFERENCED .
. DENV3D  . CONV3K  DPSV3C  DRDE3C  DRDP3C  .                                     .                                   .
.         . ENET3S  EVLV3S  FLV3T   GSUP3C  .                                     .                                   .
.         . IOSG3T  RHO3C   SATO3C  SATP3C  .                                     .                                   .
.         . VISV3N  WESM3S                  .                                     .                                   .
. DISPLA  . EXIT9U                          .                                     .                                   .
. DMOD3R  . READ3R                          . CTRL3R  DEFP3R  DSIZ9U  GETD9U  . DCON9U   SCRH3R   UNIT3I              .
.         .                                 . GETI9R  GETR9R  GOTOER. INSL9U  .                                   .
.         .                                 . KPRT3R  LINK3R  LOCL9U  MTYP9U  .                                   .
.         .                                 . NEWL9U  NEWM9U  OUTCI.  OUTFI.  .                                   .
.         .                                 . PUTD9U  PUTR9U  RELL9U          .                                   .
. DPSV3C  . ADVN3T  PRFL3S                  . DENL3D  DENV3D  ESTL3H  ESTV3H  . VD9V     VOL3P                       .
.         .                                 . RHO3C                           .                                   .
. DP3C    . HX3S    HX3T    PIPE3S  PIPE3T  . RHO3C   THOM3C  VISC3C  XTOY$   . MOD3I    MOD3V    NODE3V   SATM3V     .
. DRDE3C  . ADVN3T  HX3T    PIPE3T  VOLM3S  . DENL3D  DENV3D  DREA3C  DREN3C  . SATM3V                              .
.         .                                 . DRNK3C  ESTL3H  ESTV3H  GOTOER. .                                   .
. DRDP3C  . ADVN3T  HX3T    PIPE3T  VOLM3S  . DENL3D  DENV3D  DRPA3C  ESTL3H  . SATM3V                              .
.         .                                 . ESTV3H  GOTOER.                 .                                   .
. DREA3C  . DRDE3C                          . CPAR3C  TAIR3C                  .                                   .
. DREN3C  . DRDE3C                          . HCPN3C  TNA3C                   .                                   .
. DRNK3C  . DRDE3C                          . CPNK3C  TMNK3C                  .                                   .
. DRPA3C  . DRDP3C                          . TAIR3C                          .                                   .
. DSIZ9U  . DEFP3R  DMOD3R  FSTO3R  GETI9R  . INPT9U  NSIZ9U                  .                                   .
.         . GETM3R  KPRT3R  MARK3R  NBR3R   .                                 .                                   .
.         . NET3R   NXTM3R  NXTO3R  ORDR3R  .                                 .                                   .
.         . PCNT3R  PUMP3R  TABL9R  TURB3R  .                                 .                                   .
.         . VALV3R  ZPRT3R                  .                                 .                                   .
. EAIR3C  . ENTH3C                          .                                 .                                   .
. ENA3C   . ENTH3C                          .                                 .                                   .
. ENDFIL. . ABENDI                          .                                 .                                   .
. ENET3S  . MINT3S                          . ADDA9U  DENL3D  DENV3D  ESTL3H  . BC3P     GLOB3I   HX3P     LNK3P      .
.         .                                 . ESTV3H  EVLV3S  GETA9U  INA9U   . MODC3P   MODL3P   NET3P    SEG3P      .
.         .                                 . LEQ9U   NEWA9U  PUTA9U  VOLF3C  . SNET3P   VD9V     VOL3P               .
. ENNK3C  . ENTH3C                          .                                 .                                   .
. ENTH3C  . ETX3C   TBSG3S                  . EAIR3C  ENA3C   ENNK3C  ENTL3H  . SATM3V                              .
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. ROUTINE . REFERENCED FROM                       . REFERENCES TO                     . COMMON DEFINED $ = NOT REFERENCED   .
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.         .                                       . ENTV3H  ESTL3H  ESTV3H  GOTOER.   .                                     .
.         .                                       . TMPL3T                            .                                     .
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. ENTL3H  . ENTH3C                                . CPL3C   ESTL3H  SPA.    TMPL3T    .                                     .
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. ENTV3H  . ENTH3C  HWFB3C  HWSC3C                . CPV3C   ESTV3H  SPA.    TMPV3T    .                                     .
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. ERRMSG  . CDINPT  GENRD                         . EXIT9U  GOTOER. OUTC!.            .  ITERP                              .
.......................................................................................................................
. ERR9U   . BKEY3S  ETX3C   EVLV3S  FLV3T         . OUTCI.                            .  UNIT9U                             .
.         . HX3S    MINT3S  PRFL3S  SUBN3S        .                                   .                                     .
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. ESTL3H  . CRIT3C  DPSV3C  DRDE3C  DRDP3C        . ALOG    XTOY$                     .                                     .
.         . ENET3S  ENTH3C  ENTL3H  ESW3C         .                                   .                                     .
.         . ETX3C   EVLV3S  FLV3T   !OSG3T        .                                   .                                     .
.         . PSAT3P  RHO3C   SATO3C  SATP3C        .                                   .                                     .
.         . SWAT3C  TEMP3C  VISC3C  VOLS3T        .                                   .                                     .
.         . WESM3S                                .                                   .                                     .
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. ESTV3H  . CRIT3C  DPSV3C  DRDE3C  DRDP3C        . ALOG    XTOY$                     .                                     .
.         . ENET3S  ENTH3C  ENTV3H  ESW3C         .                                   .                                     .
.         . ETX3C   EVLV3S  FLV3T   IOSG3T        .                                   .                                     .
.         . RHO3C   SATO3C  SATP3C  SWAT3C        .                                   .                                     .
.         . TEMP3C  VISC3C  VOLS3T  WESM3S        .                                   .                                     .
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. ESW3C   . GSUP3C  TBSG3S  TBSG3T                . ESTL3H  ESTV3H  SFWT3C  SGWT3C    .                                     .
.         .                                       . SPA.    SWAT3C                    .                                     .
.......................................................................................................................
. ETX3C   . PREP3T  WESM3S                        . ENTH3C  ERR9U   ESTL3H  ESTV3H    .  BC3P      MODL3P    VD9V             .
.         .                                       . GOTOER. TEMP3C                    .                                     .
.......................................................................................................................
. EVLV3S  . ENET3S                                . DENL3D  DENV3D  ERR9U   ESTL3H    .  VD9V      VOL3P                    .
.         .                                       . ESTV3H  VOLF3C                    .                                     .
.......................................................................................................................
. EXIT9U  . ERRMSG  GETD9U  GETF9U  GETN9U        . COMDUM  DISPLA  GCPR9U  GCTP9U    .                                     .
.         . GETR9U  INTG9U  MAIN9R  MID9U         . REMARK  SSWTCH  STOP.   TRACE     .                                     .
.         . MINET   MVGA9U  NEWA9U  NEWN9U        .                                   .                                     .
.         . NPNT9U  NXTA9U  PGCI9U  PGCR9U        .                                   .                                     .
.         . PUTF9R  PUTF9U  PUTI9R  PUTN9U        .                                   .                                     .
.         . PUTR9R  REAL9U  REGC9U  RLID9U        .                                   .                                     .
.         . ZPRT3R                                .                                   .                                     .
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. EXP     . CBRT3C  DENL3D  GMDY3C  HNAI3C        .                                   .                                     .
.         . PUMP3R  TURB3R  VSNK3C                .                                   .                                     .
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. FLV3T   . ADVN3T  VOLS3T                        . ACOS    COS     DENL3D  DENV3D    .  VD9V      VOL3P                    .
.         .                                       . ERR9U   ESTL3H  ESTV3H  SIN       .                                     .
.         .                                       . VOLF3C                            .                                     .
.......................................................................................................................
. FRAC3S  . SUBN3S                                .                                   .  GLOB3I    LNK3P     SEG3P     SNET3P .
.         .                                       .                                   .  VD3V      VOL3P                    .
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. ROUTINE  . REFERENCED FROM                    . REFERENCES TO                      . COMMON DEFINED $ = NOT REFERENCED   .
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. FSTO3R   . ORDR3R                             . DSIZ9U   GETD9U   PUTD9U   SPA.    . LNKS3I                              .
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. FTNRP2.  . MINET                              .                                    .                                     .
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. GCER9U   . INIT3R                             . GCTE9U   OUTCI.   SPA.             . GC9U                                .
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. GCPR9U   . ABENDI   EXIT9U                    . OUTCI.   PRTCON                    . GC9U      VD9V                      .
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. GCTE9U   . GCER9U   GCTP9U                    . GOTOER.  OUTCI.                    . GC9U                                .
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. GCTP9U   . ABENDI   EXIT9U                    . GCTE9U   OUTCI.                    . GC9U                                .
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. GENRD    . CRDR9R   READ3R                    . CDINPT   ERRMSG   GOTOER.  INPCI.  . SAVE                                .
.          .                                    . INTNDG   ISTOP    ITRPCK   NNBLNK  .                                     .
.          .                                    . OUTCI.   REWIND.  SPA.             .                                     .
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. GETA9U   . AJVN3T   ENET3S   IOSG3T   PRFL3S  .                                    . ADAB9U                              .
.          . QBAL3S   SGBC3T                    .                                    .                                     .
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. GETB3U   .                                    . GOTOER.  SPA.                      . BC3P      GLOB3I    LNK3P     VD9V  .
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. GETD9U   . DEFP3R   DMOD3R   FSTO3R   GETF9R  . EXIT9U   GETN9U   INPT9U           . DCON9U                              .
.          . GETI9R   GETM3R   GETR9R   INSL9U  .                                    .                                     .
.          . LINK3R   LSTI9U   LSTM3R   MARK3R  .                                    .                                     .
.          . MORD3R   NBR3R    NCLS3R   NXTI9U  .                                    .                                     .
.          . NXTM3R   NXTO3R   ORDR3R   PCNT3R  .                                    .                                     .
.          . PUTI9R   RELL9U   RISU9R           .                                    .                                     .
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. GETF9R   . CRDR9R                             . GETD9U   LOCR9U                    . DCON9U    ISUV9R                    .
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. GETF9U   . GETR9U   MVGA9U   REAL9U   RLID9U  . EXIT9U   NXTA9U                    . NDAB9U                              .
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. GETI9R   . DMOD3R                             . DSIZ9U   GETD9U   GETR9U   RLID9U  . ISUV9R                              .
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. GETM3R   . LINK3R                             . DSIZ9U   GETD9U   LOCL9U   OUTCI.  . DCON9U    LNKS3I    UNIT3I          .
.          .                                    . SPA.                               .                                     .
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. GETM9U   . ADVN3T   NET3T                     . SPA.                               . ADAB9U                              .
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. GETN9U   . GETD9U   INTG9U   MID9U    MTYP9U  . EXIT9U   NXTA9U                    . NDAB9U                              .
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. GETR9R   . DMOD3R                             . GETD9U   LOCL9U                    . DCON9U    ISUV9R                    .
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. GETR9U   . GETI9R   PUTI9R                    . EXIT9U   GETF9U   INPT9U           . DCON9U                              .
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. GFSK3C   . CRIT3C                             . SPA.                               .                                     .
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. GMDY3C   . CRIT3C                             . EXP      SPA.                      .                                     .
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. GOTOER.  . ADVN3T   BCOR3C   DCODNC   DMOD3R  .                                    .                                     .
.          . DRDE3C   DRDP3C   ENTH3C   ERRMSG  .                                    .                                     .
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. ROUTINE  . REFERENCED FROM                      . REFERENCES TO                       . COMMON DEFINED $ = NOT REFERENCED       .
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.          . ETX3C    GCTE9U   GENRD    GETB3U    .                                     .                                         .
.          . HTC3C    IMOD3C   INSTRUC  MRCH3S    .                                     .                                         .
.          . MRCH3T   NET3R    PRNT3C   PUMP3T    .                                     .                                         .
.          . PUTB3U   READ3R   RHO3C    ROOT3C    .                                     .                                         .
.          . SEG3R    TBSG3T   TEMP3C   VISC3C    .                                     .                                         .
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. GSUP3C   . CRIT3C                               . DENV3D   ESW3C    SQRT     SWAT3C   .                                         .
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. HCAP3C   . ADTB3T   HX3T                        .                                     .                                         .
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. HCIT3C   . HTC3C                                . OUTFI.   SPA.     XTOY$             . SATM3V                                  .
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. HCOT3C   . HTC3C                                . OUTFI.   SPA.     SQRT     XTOY$    . SATM3V                                  .
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. HCPN3C   . DREN3C   HNAF3C   HNAI3C             . TNA3C                               .                                         .
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. HNAF3C   . HTC3C                                . HCPN3C   TKNA3C   VSNA3C   XTOY$    .                                         .
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. HNAI3C   . HTC3C                                . EXP      HCPN3C   TKNA3C   VSNA3C   .                                         .
.          .                                      . XTOY$                               .                                         .
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. HTCA3C   . HTC3C                                . CAIR3C   CPAR3C   VAIR3C   XTOY$    .                                         .
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. HTC3C    . QPM3C                                . GOTOER.  HCIT3C   HCOT3C   HNAF3C   . MOD3I     MOD3V     SATM3V              .
.          .                                      . HNAI3C   HTCA3C   HTNK3C   HWCN3C   .                                         .
.          .                                      . HWFB3C   HWFC3C   HWNB3C   HWSC3C   .                                         .
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. HTNK3C   . HTC3C                                . CDNK3C   CPNK3C   XTOY$             .                                         .
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. HWCN3C   . HTC3C                                . SQRT                                . SATM3V                                  .
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. HWFB3C   . HTC3C                                . CONV3K   CPV3C    ENTV3H   OUTFI.   . SATM3V                                  .
.          .                                      . SPA.     VISV3N   XTOY$             .                                         .
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. HWFC3C   . BCOR3C   HTC3C    IMOD3C             . CONL3K   CPL3C    VISL3N   XTOY$    .                                         .
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. HWNB3C   . HTC3C                                . CONL3K   CPL3C    PSAT3P   SPA.     . SATM3V                                  .
.          .                                      . SQRT     VISL3N   XTOY$             .                                         .
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. HWSC3C   . HTC3C                                . CONV3K   CPV3C    ENTV3H   OUTFI.   . SATM3V                                  .
.          .                                      . SPA.     VISV3N   XTOY$             .                                         .
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. HXND3S   . HX3S                                 . BCOR3C   IMOD3C   OUTFI.   QPM3C    . MOD3I     MOD3V     NODE3I    NODE3V    .
.          .                                      . ROOT3C   TCLM3C   TCRG3C   TEMP3C   .                                         .
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. HX3R     . SEG3R                                . INTG9U   JDAT3R   MARK3R   MID9U    .                                         .
.          .                                      . MORD3R   NCLS3R   NXTM3R   OUTFI.   .                                         .
.          .                                      . PGCI9U   PGCR9U   PUTJ3R   REAL9U   .                                         .
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. HX3S     . MRCH3S                               . CROS3S   DP3C     ERR9U    HXND3S   . HX3P      MOD3I     MOD3V     NODE3I    .
.          .                                      . OUTFI.   RHO3C    ROOT3C   SATM3C   . NODE3V    NODL3P    VD9V                .
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. ROUTINE  . REFERENCED FROM                     . REFERENCES TO                         . COMMON DEFINED $ = NOT REFERENCED       .
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.          .                                     . SATO3C   SPA.     TEMP3C   VISC3C     .                                         .
.          .                                     . XTOY$                                 .                                         .
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. HX3T     . MRCH3T                              . BCOR3C   DENS3C   DP3C     DRDE3C     . GLOB3V    HX3P      MOD3I     MOD3V     .
.          .                                     . DRDP3C   HCAP3C   IMOD3C   LOAD3T     . NODE3V    NODL3P    VD9V                .
.          .                                     . QPM3C    RHO3C    SPA.     TCLM3C     .                                         .
.          .                                     . TCRG3C   VISC3C   XTOY$               .                                         .
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. IGA9U    . IPTS3R                              . JGCT9U                                . GC9U                                    .
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. ILNK3R   . INRD3R                              . UNIQ9U                                . LNKS3I                                  .
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. IMOD3C   . HXND3S   HX3T                       . COND3C   GOTOER.  HWFC3C   QPM3C      . MOD3I     MOD3V     SATM3V              .
.          .                                     . TEMP3C   XDNB3C   XDRY3C              .                                         .
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. INA9U    . ENET3S   MINT3T   PRFL3S   QBAL3S   .                                       . ADAB9U                                  .
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. INFO     . ABENDI   SDUMP                      . CHARCTR                               . ABEND                                   .
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. INGC9U   . INIT3U                              .                                       . GC9U      VD9V                          .
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. INIT3R   . MAIN9R                              . CALC3R   GCER9U   IPTS3R   MVGC9U     . SCRH3R    TIME3I                        .
.          .                                     . SYS3R                                 .                                         .
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. INIT3S   . MINT3S                              .                                       . BC3P      GLOB3I    LNK3P     NET3P     .
.          .                                     .                                       . SEG3P     VD9V      VOL3P               .
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. INIT3U   . MINET                               . INGC9U                                . UNIT3I                                  .
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. INIT9U   . MINET                               . INPCI.   PAGE9U   SSCDAT              . DATA9     UNIT9U                        .
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. INL9U    . INRD3R                              . UNIQ9U                                . LDAB9U    MDAB9U                        .
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. INM9U    . INRD3R                              . UNIQ9U                                . MDAB9U                                  .
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. INN9U    . INRD3R                              .                                       . DCON9U    NDAB9U                        .
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. INOR3R   . SYS3R                               . UNIQ9U                                . ORD3I                                   .
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. INPBI.   . RECX3U   REGC9U                     .                                       .                                         .
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. INPBR.   . REGC9U                              .                                       .                                         .
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. INPCI.   . GENRD    INIT9U   LIST3R   READHM   .                                       .                                         .
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. INPT9U   . DSIZ9U   GETD9U   GETR9U   INTG9U   .                                       . DCON9U    NDAB9U                        .
.          . MID9U    PUTD9U   PUTR9U   REAL9U   .                                       .                                         .
.          . RLID9U                              .                                       .                                         .
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. INRD3R   . CRDR9R                              . ILNK3R   INL9U    INM9J    INN9U      . DCON9U    SCRH3R    UNIT3I              .
.          .                                     . ISU9R    IUNI9U   NEWL9U   PUTF9R     .                                         .
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. ROUTINE . REFERENCED FROM                     . REFERENCES TO                     . COMMON DEFINED $ = NOT REFERENCED .
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.         .                                     . PUTI9R  PUTR9R  REPS9R            .                                   .
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. INSL9U  . DMOD3R  PUTF9R  PUTI9R  PUTR9R      . GETD9U  PUTD9U                    . DCON9U   LDAB9U                   .
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. INSTRUC . SDUMP                               . GOTOER.                           .                                   .
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. INTERP  . CDINPT                              . SPA.                              .                                   .
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. INTG9U  . BND3R   CTRL3R  HX3R    JDAT3R      . EXIT9U  GETN9U  INPT9U            . DCON9U                            .
.         . KPRT3R  NET3R   PIDS3R  PIPE3R      .                                   .                                   .
.         . PUMP3R  TURB3R  VALV3R  VOL3R       .                                   .                                   .
.         . ZPRT3R                              .                                   .                                   .
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. INTNDG  . CDINPT  DCODNC  GENRD   NAMEWD      . SPA.                              .                                   .
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. INTP9U  . PREP3T                              .                                   .                                   .
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. IOSG3T  . MRCH3T                              . ADDA9U  ADDM9U  DENL3D  DENV3D    . BC3P     GLOB3V   LNK3P    MODL3P   .
.         .                                     . ESTL3H  ESTV3H  GETA9U  NEWA9U    . SEG3P    VALV3P   VD9V     VOL3P    .
.         .                                     . PUTA9U  VOLF3C                    .                                   .
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. IPTS3R  . INIT3R  RECX3U                      . IGA9U                             . BC3P     HX3P     LNK3P    MODC3P   .
.         .                                     .                                   . MODL3P   NET3P    NODL3P   PUMP3P   .
.         .                                     .                                   . SEG3P    SNET3P   TIME3P   TRND3P   .
.         .                                     .                                   . TURB3P   VALV3P   VOL3P             .
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. IRPT9U  .                                     .                                   . DCON9U   NDAB9U                   .
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. ISETHM  . CDINPT                              .                                   .                                   .
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. ISTOP   . GENRD                               . NNBLNK  SPA.                      .                                   .
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. ISU9R   . INRD3R                              . NEWL9U  NEWM9U  PUTD9U  PUTR9U    . DCON9U   ISUV9R                   .
.         .                                     . UNIQ9U                            .                                   .
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. ITRPCK  . CDINPT  GENRD                       .                                   .                                   .
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. IUNI9U  . INRD3R                              .                                   . UNID9I                            .
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. JBNAME  .                                     .                                   .                                   .
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. JDAT3R  . HX3R    NET3R                       . INTG9U                            . ORD3I                             .
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. JGCT9U  . IGA9U   LPNT9U  PGCI9U  PGCR9U      . SPA.                              . GC9U                              .
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. KPRC3S  . MINT3S                              . PRHX3S                            . GLOB3I   LNK3P    MODC3P   NET3P    .
.         .                                     .                                   . SEG3P    SNET3P   VD9V     VOL3P    .
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. KPRT3R  . DMOD3R  VOL3R                       . DSIZ9U  INTG9U  MID9U   OUTFI.    . LNKS3I                            .
.         .                                     . PUTD9U  SPA.    UNIQ9U            .                                   .
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. ROUTINE  . REFERENCED FROM                       . REFERENCES TO                       . COMMON DEFINED $ = NOT REFERENCED  .
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. LCNT9U   .                                       . MTYP9U   NXTI9U                     .  DCON9U                             .
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. LEQ3C    . LEQ9U                                 . SPA.                                .                                     .
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. LEQ9U    . ENET3S   NET3T    PRFL3S   QBAL3S     . LEQ3C                               .  ADAB9U                             .
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. LINK3R   . DMOD3R                                . GETD9U   GETM3R   MID9U    OUTCI.   .  LNKS3I    UNIT3I                   .
.          .                                       . OUTFI.   PUTD9U   PUTR9U            .                                     .
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. LIST3R   . VRFY3R                                . INPCI.   OUTCI.   PAGE9U   REWIND.  .  UNIT3I                             .
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. LNKN9U   . NEWD9U   RELD9U                       .                                     .  NDAB9U                             .
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. LOAD3T   . HX3T     PIPE3T   TBSG3T              . ADDA9U   ADDM9U   PUTA9U   PUTM9U   .  GLOB3V    MOD3V     NODE3V    SEG3P .
.          .                                       . SPA.                                .  VD9V                               .
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. LOCL9U   . DMOD3R   GETM3R   GETR9R              . MID9U    NXTI9U                     .  DCON9U                             .
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. LOCR9U   . GETF9R   PUTI9R                       . NXTI9U   RLID9U                     .  DCON9U                             .
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. LPNT9U   . PUMP3R   TABL9R                       . JGCT9U   NSIZ9U                     .  GC9U                               .
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. LSIZ9U   . SYS3R                                 . NXTI9U                              .  DCON9U                             .
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. LSTI9U   .                                       . GETD9U   MID9U                      .  DCON9U    LDAB9U                   .
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. LSTM3R   . NET3R    SEG3R                        . GETD9U                              .  ORD3I                              .
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. MAIN9R   . MINET                                 . CROR9R   EXIT9U   INIT3R   RISU9R   .                                     .
.          .                                       . VRFY3R                              .                                     .
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. MARK3R   . HX3R     NET3R    VOL3R               . DSIZ9U   GETD9U   PUTD9U   SPA.     .  ORD3I                              .
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. MDST3S   . MINT3S                                .                                     .  GLOB3I    HX3P      LNK3P     MODC3P .
.          .                                       .                                     .  SEG3P     SNET3P    VD9V                .
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. MID9U    . BND3R    DEFP3R   HX3R     KPRT3R     . EXIT9U   GETN9U   INPT9U            .  DCON9U    MDAB9U                   .
.          . LINK3R   LOCL9U   LSTI9U   NBR3R      .                                     .                                     .
.          . NET3R    ORDR3R   PIPE3R   PUMP3R     .                                     .                                     .
.          . SEG3R    TURB3R   VALV3R   VOL3R      .                                     .                                     .
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. MINET    .                                       . ABEND    EXIT9U   FTNRP2.  INIT3U   .  UNIT9U                             .
.          .                                       . INIT9U   MAIN9R   MINT3S   MINT3T   .                                     .
.          .                                       . OUTFI.   PRNT3C   RECX3U   STOP.    .                                     .
.          .                                       . SVCX3U   TIME3T                     .                                     .
..........................................................................................................................
. MINT3S   . MINET                                 . BKEY3S   ENET3S   ERR9U    INIT3S   .  GLOB3I    GLOB3V    UNIT3I           .
.          .                                       . KPRC3S   MDST3S   MRCH3S   OUTCI.   .                                     .
.          .                                       . OUTFI.   PRFL3S   PRNT3C   QBAL3S   .                                     .
.          .                                       . QBRG3S   SECOND   STOP.    SUBN3S   .                                     .
.          .                                       . VOLM3S   WESM3S                     .                                     .
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. ROUTINE . REFERENCED FROM                 . REFERENCES TO                   .  COMMON DEFINED $ = NOT REFERENCED .
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. MINT3T  . MINET                           . ADTB3T  ADVN3T  INA9U   MRCH3T  .  GLOB3I  GLOB3V                    .
.         .                                 . NET3T   PREP3T  PRNT3C  VOLS3T  .                                    .
....................................................................................................................
. MODL3C  . MRCH3S  MRCH3T  PRFL3S          . ALOG    SQRT                    .  HX3P    LNK3P   MODC3P  MODL3P    .
.         .                                 .                                 .  MOD3I   MOD3V   VD9V              .
....................................................................................................................
. MORD3R  . BND3R   HX3R    NET3R   PIPE3R  . GETD9U                          .  ORD3I                             .
.         . PUMP3R  SEG3R   TURB3R  VALV3R  .                                 .                                    .
.         . VOL3R                           .                                 .                                    .
....................................................................................................................
. MRCH3S  . MINT3S                          . GOTOER. HX3S    MODL3C  OUTFI.  .  GLOB3I  LNK3P   NET3P   SEG3P     .
.         .                                 . PIPE3S  PUMP3S  SATM3C  SATP3C  .  VD9V                              .
.         .                                 . TBSG3S  VALV3S                  .                                    .
....................................................................................................................
. MRCH3T  . MINT3T                          . CRKR9U  GOTOER. HX3T    IOSG3T  .  GLOB3V  LNK3P   NET3P   SEG3P     .
.         .                                 . MODL3C  PIPE3T  PUMP3T  SATM3C  .  VD9V                              .
.         .                                 . SATP3C  SGBC3T  TBSG3T  VALV3T  .                                    .
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. MTYP9U  . DMOD3R  LCNT9U  NET3R   SEG3R   . GETN9U                          .  MDAB9U                            .
....................................................................................................................
. MVGA9U  . MVGC9U                          . EXIT9U  GETF9U  NSIZ9U  OUTFI.  .  GC9U    VD9V                      .
.         .                                 . RELN9U                          .                                    .
....................................................................................................................
. MVGC9U  . INIT3R                          . MVGA9U                          .  GC9U                              .
....................................................................................................................
. NAMEWD  . CDINPT                          . INTNDG  SPA.                    .                                    .
....................................................................................................................
. NBR3R   . ORDR3R                          . DSIZ9U  GETD9U  MID9U   OUTFI.  .  DCON9U  LNKS3I                    .
.         .                                 . SPA.                            .                                    .
....................................................................................................................
. NCLS3R  . BND3R   HX3R                    . GETD9U                          .  ORD3I                             .
....................................................................................................................
. NET3R   . SYS3R                           . BND3R   DSIZ9U  GOTOER. INTG9U  .  DCON9U                            .
.         .                                 . JDAT3R  LSTM3R  MARK3R  MID9U   .                                    .
.         .                                 . MORD3R  MTYP9U  NXTM3R  ORDR3R  .                                    .
.         .                                 . OUTFI.  PGCI9U  PGCR9U  PUTJ3R  .                                    .
.         .                                 . SEG3R   SPA.    VOL3R           .                                    .
....................................................................................................................
. NET3T   . MINT3T                          . ADDA9U  GETM9U  LEQ9U   NEWA9U  .  GLOB3V  LNK3P   MODC3P  NET3P     .
.         .                                 . PUTA9U  RELA9U                  .  SEG3P   VD9V    VOL3P             .
....................................................................................................................
. NEWA9U  . ENET3S  IOSG3T  NET3T   PRFL3S  . EXIT9U  SPA.                    .  ADAB9U                            .
.         . QBAL3S                          .                                 .                                    .
....................................................................................................................
. NEWD9U  . PUTD9U  PUTR9U                  . LNKN9U  NEWN9U  NXTN9U          .                                    .
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. NEWL9U  . DMOD3R  INRD3R  ISU9R   PUTF9R  . NEWM9U  PUTD9U                  .  DCON9U  LDAB9U                    .
....................................................................................................................
. NEWM9U  . DMOD3R  ISU9R   NEWL9U  ORDR3R  . NEWN9U  PUTN9U                  .  MDAB9U                            .
.         . PUTR9R                          .                                 .                                    .
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. ROUTINE  . REFERENCED FROM                  . REFERENCES TO                    . COMMON DEFINED $ = NOT REFERENCED  .
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. NEWN9U   . NEWD9U  NEWM9U  NEWR9U  PGCI9U   . EXIT9U                           . DCON9U  NDAB9U                     .
.          . PGCR9U                           .                                  .                                    .
.......................................................................................................................
. NEWR9U   . PUTF9R  PUTI9R                   . NEWN9U  PUTF9U                   . MDAB9U                             .
.......................................................................................................................
. NID9U    . RELD9U                           .                                  . NDAB9U                             .
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. NNBLNK   . CDINPT  GENRD   ISTOP            .                                  .                                    .
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. NPNT9U   . SYS3R                            . EXIT9U  SPA.                     . GC9U                               .
.......................................................................................................................
. NSIZ9U   . DSIZ9U  LPNT9U  MVGA9U           .                                  . DCON9U  NDAB9U                     .
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. NSKIP    . CDINPT                           .                                  .                                    .
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. NXTA9U   . GETF9U  GETN9U  PUTF9U  PUTN9U   . EXIT9U                           . DCON9U  NDAB9U                     .
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. NXTI9U   . LCNT9U  LOCL9U  LOCR9U  LSIZ9U   . GETD9U                           . LDAB9U                             .
.          . RISU9R  SYS3R                    .                                  .                                    .
.......................................................................................................................
. NXTM3R   . HX3R    NET3R   PIPE3R  PUMP3R   . DSIZ9U  GETD9U  RELM9U           . DCON9U  ORD3I                      .
.          . TURB3R  VALV3R  VOL3R            .                                  .                                    .
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. NXTN9U   . NEWD9U  RELD9U  RELM9U           .                                  . NDAB9U                             .
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. NXTO3R   . ORDR3R                           . DSIZ9U  GETD9U  PUTD9U  SPA.     . LNKS3I                             .
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. ORDR3R   . NET3R                            . DSIZ9U  FSTC3R  GETD9U  MID9U    . DCON9U  ORD3I                      .
.          .                                  . NBR3R   NEWM9U  NXTO3R  OUTFI.   .                                    .
.          .                                  . PUTD9U  RELM9U  UNIQ9U           .                                    .
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. OUTBI.   . SVCX3U  SVGC9U                   .                                  .                                    .
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. OUTBR.   . SVGC9U                           .                                  .                                    .
.......................................................................................................................
. OUTCI.   . ABENDI  COMDUM  CRDR9R  DMOD3R   .                                  .                                    .
.          . ERRMSG  ERR9U   GCER9U  GCPR9U   .                                  .                                    .
.          . GCTE9U  GCTP9U  GENRD   GETM3R   .                                  .                                    .
.          . LINK3R  LIST3R  MINT3S  PAGE9U   .                                  .                                    .
.          . PRNT3C  PRTA9U  PRTCOM  READHM   .                                  .                                    .
.          . READ3R  RECX3U  SDUMP   SVCX3U   .                                  .                                    .
.          . TRACEI                           .                                  .                                    .
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. OUTCR.   . ABENDI  PRTA9U                   .                                  .                                    .
.......................................................................................................................
. OUTFI.   . BCOR3C  BND3R   CALC3R  DEFP3R   .                                  .                                    .
.          . DMOD3R  HCIT3C  HCOT3C  HWFB3C   .                                  .                                    .
.          . HWSC3C  HXND3S  HX3R    HX3S     .                                  .                                    .
.          . KPRT3R  LINK3R  MINET   MINT3S   .                                  .                                    .
.          . MRCH3S  MVGA9U  NBR3R   NET3R    .                                  .                                    .
.          . ORDR3R  PIPE3R  PUMP3R  RISU9R   .                                  .                                    .
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. ROUTINE . REFERENCED FROM                         . REFERENCES TO                         . COMMON DEFINED $ = NOT REFERENCED   .
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.         . SDUMP     SEG3R     SYS3R     TCRG3C    .                                       .                                     .
.         . TURB3R    VALV3R    VOLS3T    VOL3R     .                                       .                                     .
.............................................................................................................................
. PAGE9U  . INIT9U    LIST3R    PRNT3C    RECX3U    . OUTCI.    SECOND    SSCTIM            . DATA9     UNIT9U                    .
.         . SVCX3U                                  .                                       .                                     .
.............................................................................................................................
. PCNT3R  . SYS3R     VOL3R                         . DSIZ9U    GETD9U    SPA.              . LNKS3I                              .
.............................................................................................................................
. PGCI9U  . BND3R     HX3R      NET3R     PIPE3R    . EXIT9U    JGCT9U    NEWN9U    PUTN9U  . GC9U                                .
.         . PUMP3R    SEG3R     TURB3R    VALV3R    .                                       .                                     .
.         . VOL3R                                   .                                       .                                     .
.............................................................................................................................
. PGCR9U  . BND3R     HX3R      NET3R     PIPE3R    . EXIT9U    JGCT9U    NEWN9U    PUTF9U  . GC9U                                .
.         . PUMP3R    SEG3R     TABL9R    TURB3R    .                                       .                                     .
.         . VALV3R    VOL3R                         .                                       .                                     .
.............................................................................................................................
. PIDS3R  . SEG3R     VOL3R                         . INTG9U                                . ORD3I                               .
.............................................................................................................................
. PIPE3R  . SEG3R                                   . INTG9U    MID9U     MORD3R    NXTM3R  .                                     .
.         .                                         . OUTFI.    PGCI9U    PGCR9U    REAL9U  .                                     .
.         .                                         . TABL9R                                .                                     .
.............................................................................................................................
. PIPE3S  . MRCH3S    PRFL3S                        . DP3C      RHO3C     SPA.      TEMP3C  . MOD3I     MOD3V     NODE3V    NODL3P  .
.         .                                         .                                       . VD9V                                .
.............................................................................................................................
. PIPE3T  . MRCH3T                                  . DP3C      DRDE3C    DRDP3C    LOAD3T  . MOD3I     MOD3V     NODE3V    NODL3P  .
.         .                                         . RHO3C     SPA.                        . VD9V                                .
.............................................................................................................................
. PREP3T  . MINT3T                                  . ETX3C     INTP9U                      . BC3P      GLOB3I    GLOB3V    LNK3P   .
.         .                                         .                                       . MODC3P    PUMP3P    TRND3P    TURB3P  .
.         .                                         .                                       . VALV3P    VD9V                        .
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. PRFL3S  . MINT3S                                  . ADDA9U    DPSV3C    ERR9U     GETA9U  . BC3P      GLOB3I    LNK3P     NET3P   .
.         .                                         . INA9U     LEQ9U     MODL3C    NEWA9U  . SEG3P     TURB3P    VALV3P    VD9V    .
.         .                                         . PIPE3S    PUMP3S    PUTA9U    RELA9U  . VOL3P                               .
.         .                                         . RHO3C     SATM3C    SATP3C    SQRT    .                                     .
.         .                                         . VALV3S                                .                                     .
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. PRHX3S  . KPRC3S                                  . SPA.                                  . HX3P      LNK3P     SEG3P     VD9V    .
.............................................................................................................................
. PRNT3C  . MINET     MINT3S    MINT3T              . GOTOER.   OUTCI.    PAGE9U    TEMP3C  . BC3P      GLOB3I    GLOB3V    HX3P    .
.         .                                         .                                       . LNK3P     MODC3P    MODL3P    NET3P   .
.         .                                         .                                       . NODL3P    PUMP3P    SEG3P     SNET3P  .
.         .                                         .                                       . TURB3P    UNIT3I    VALV3P    VD9V    .
.         .                                         .                                       . VOL3P                               .
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. PRTA9U  .                                         . OUTCI.    OUTCR.                      . ADAB9U    UNIT3I                    .
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. PRTCOM  .                                         . OUTCI.    SPA.                        .                                     .
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. PRTCON  . GCPR9U                                  . OUTCI.    SPA.                        .                                     .
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. ROUTINE . REFERENCED FROM                     . REFERENCES TO                      . COMMON DEFINED $ = NOT REFERENCED  .
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. PSAT3P  . HWNB3C                              . ESTL3H  ROOT3C  SPA.    TMPL3T     .                                    .
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. PUMP3R  . SEG3R                               . DSIZ9U  EXP     INTG9U  LPNT9U     .                                    .
.         .                                     . MID9U   MORD3R  NXTM3R  OUTFI.     .                                    .
.         .                                     . PGCI9U  PGLR9U  REAL9U  SPA.       .                                    .
.         .                                     . TABL9R                             .                                    .
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. PUMP3S  . MRCH3S  PRFL3S                      .                                    . MOD3I   MOD3V   NODL3P  FUMP3P     .
.         .                                     .                                    . VD9V                               .
.........................................................................................................................
. PUMP3T  . MRCH3T                              . GOTOER. RHO3C                      . GLOB3V  MOD3I   MOD3V   NODL3P     .
.         .                                     .                                    . PUMP3P  VD9V                       .
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. PUTA9U  . ADVN3T  ENET3S  IOSG3T  LOAD3T      .                                    . ADAB9U                             .
.         . NET3T   PRFL3S  QBAL3S  SGBC3T      .                                    .                                    .
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. PUTB3U  .                                     . GOTOER. SPA.                       . BC3P    GLOB3I  LNK3P   VD9V       .
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. PUTD9U  . DEFP3R  DMOD3R  FSTO3R  INSL9U      . INPT9U  NEWD9U  PUTN9U             . DCON9U                             .
.         . ISU9R   KPRT3R  LINK3R  MARK3R      .                                    .                                    .
.         . NEWL9U  NXTO3R  ORDR3R  PUTF9R      .                                    .                                    .
.         . PUTI9R  PUTJ3R  PUTR9R  REPS9R      .                                    .                                    .
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. PUTF9R  . INRD3R                              . EXIT9U  INSL9U  NEWL9U  NEWR9U     . ISUV9R                             .
.         .                                     . PUTD9U                             .                                    .
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. PUTF9U  . NEWR9U  PGCR9U  PUTF9U              . EXIT9U  NXTA9U                     . NDAB9U                             .
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. PUTI9R  . INRD3R                              . EXIT9U  GETD9U  GETR9U  INSL9U     . DCON9U  ISUV9R                     .
.         .                                     . LOCR9U  NEWR9U  PUTD9U  PUTR9U     .                                    .
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. PUTJ3R  . HX3R    NET3R   VOL3R               . PUTD9U                             . ORD3I                              .
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. PUTM9U  . LOAD3T                              . SPA.                               . ADAB9U                             .
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. PUTN9U  . NEWM9U  PGCI9U  PUTD9U              . EXIT9U  NXTA9U                     . NDAB9U                             .
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. PUTR9R  . INRD3R                              . EXIT9U  INSL9U  NEWM9U  PUTD9U     . DCON9U  ISUV9R                     .
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. PUTR9U  . DMOD3R  ISU9R   LINK3R  PUTI9R      . INPT9U  NEWD9U  PUTF9U             . DCON9U                             .
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. QBAL3S  . MINT3S                              . ADDA9U  GETA9U  INA9U   LEQ9U      . GLOB3I  HX3P    LNK3P   MODC3P     .
.         .                                     . NEWA9U  PUTA9U  RELA9U             . NET3P   SEG3P   SNET3P  VD9V       .
.         .                                     .                                    . VOL3P                              .
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. QBRG3S  . MINT3S                              .                                    . GLOB3I  HX3P    LNK3P   MODC3P     .
.         .                                     .                                    . NET3P   SEG3P   SNET3P  VD9V       .
.         .                                     .                                    . VOL3P                              .
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  QPM3C   . BCOR3C  HXND3S  HX3T    IMCO3C      . COND3C  HTC3C   TEMP3C             . MOD3I   MOD3V                      .
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. ROUTINE  . REFERENCED FROM                         . REFERENCES TO                         . COMMON DEFINED $ = NOT REFERENCED  .
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. RAIR3C   . RHO3C                                   . TAIR3C                                .                                    .
..................................................................................................................
. READHM   . CDINPT                                  . INPCI.    OUTCI.    REWIND.   SETFMT  .                                    .
.          .                                         . SPA.                                  .                                    .
..................................................................................................................
. READ3R   . CRDR9R                                  . DMOD3R    GENRD     GOTOER.   OUTCI.  .  SCRH9I    UNIT3I                  .
..................................................................................................................
. REAL9U   . BND3R     CTRL3R    HX3R      PIPE3R    . EXIT9U    GETF9U    INPT9U            .  DCON9U                            .
.          . PUMP3R    TABL9R    TURB3R    VALV3R    .                                       .                                    .
.          . VOL3R     ZPRT3R                        .                                       .                                    .
..................................................................................................................
. RECX3U   . MINET                                   . INPBI.    IPTS3R    OUTCI.    PAGE9U  .  GLOB3I    GLOB3V    UNIT3I        .
.          .                                         . REGC9U                                .                                    .
..................................................................................................................
. REGC9U   . RECX3U                                  . EXIT9U    INPBI.    INPBR.            .  GC9U      VD9V                    .
..................................................................................................................
. RELA9U   . ADVN3T    NET3T     PRFL3S    QBAL3S    .                                       .  ADAB9U                            .
.          . SGBC3T                                  .                                       .                                    .
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. RELD9U   .                                         . LNKN9U    NID9U     NXTN9U    RELN9U  .  DCON9U                            .
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. RELL9U   . DMOD3R    RISU9R                        . GETD9U    RELM9U                      .  DCON9U    LDAB9U                  .
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. RELM9U   . NXTM3R    ORDR3R    RELL9U              . NXTN9U    RELN9U                      .  DCON9U                            .
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. RELN9U   . MVGA9U    RELD9U    RELM9U              .                                       .  DCON9U    NDAB9U                  .
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. REMARK   . EXIT9U                                  .                                       .                                    .
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. REPEAT   . CDINPT                                  . SPA.                                  .                                    .
..................................................................................................................
. REPS9R   . INRD3R                                  . PUTD9U                                .  ISUV9R                            .
..................................................................................................................
. REWIND.  . GENRD     LIST3R    READHM    SVCX3U    .                                       .                                    .
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. RHNK3C   . RHO3C     VSNK3C                        . TMNK3C                                .                                    .
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. RHO3C    . ADVN3T    DPSV3C    DP3C      HX3S      . DENL3D    DENV3D    ESTL3H    ESTV3H  .  SATM3V                            .
.          . HX3T      PIPE3S    PIPE3T    PRFL3S    . GOTOER.   RAIR3C    RHNK3C    RNA3C   .                                    .
.          . PUMP3T    TBSG3S    TBSG3T    VALV3T    .                                       .                                    .
.          . VOLM3S                                  .                                       .                                    .
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. RISU9R   . MAIN9R                                  . GETD9U    NXTI9U    OUTFI.    RELL9U  .  DCON9U    ISUV9R                  .
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. RLID9U   . GETI9R    LOCR9U                        . EXIT9U    GETF9U    INPT9U            .  DCON9U    MDAB9U                  .
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. RNA3C    . RHO3C                                   . TNA3C                                 .                                    .
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. ROOT3C   . BCOR3C    HXND3S    HX3S      PSAT3P    . GOTOER.                               .                                    .
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. SATM3C   . HX3S      MRCH3S    MRCH3T    PRFL3S    .                                       .  SATM3V    SATP3V                  .
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. ROUTINE . REFERENCED FROM                    . REFERENCES TO                       . COMMON DEFINED $ = NOT REFERENCED   .
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. SATO3C  . HX3S                               . CONL3K  CPL3C   DENL3D  DENV3D  . SATM3V                              .
.         .                                    . ESTL3H  ESTV3H  STEN3S  TMPL3T  .                                     .
.         .                                    . VISL3N  VISV3N                  .                                     .
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. SATP3C  . MRCH3S  MRCH3T  PRFL3S             . CONL3K  CPL3C   DENL3D  DENV3D  . SATP3V                              .
.         .                                    . ESTL3H  ESTV3H  STEN3S  TMPL3T  .                                     .
.         .                                    . VISL3N  VISV3N                  .                                     .
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. SDEL9T  . TIME3T                             .                                 . TIME3I   TIME3P   VD9V              .
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. SDUMP   . ABEND1                             . CHARCTR CODE8   INFO    INSTRUC . ABEND                               .
.         .                                    . OUTCI.  OUTFI.  SSWTCH          .                                     .
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. SECOND  . MINT3S  PAGE9U                     .                                 .                                     .
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. SEG3R   . NET3R                              . GOTOER. HX3R    LSTM3R  MID9U   .                                     .
.         .                                    . MORB3R  MTYP9U  OUTFI.  PGCI9U  .                                     .
.         .                                    . PGCR9U  PIDS3R  PIPE3R  PUMP3R  .                                     .
.         .                                    . SPA.    TURB3R  VALV3R  ZPRT3R  .                                     .
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. SETFMT  . READHM                             .                                 .                                     .
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. SFWT3C  . ESW3C   SWAT3C                     .                                 .                                     .
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. SGBC3T  . MRCH3T                             . ADDA9U  GETA9U  PUTA9U  RELA9U  . BC3P     GLOB3V   LNK3P    SEG3P    .
.         .                                    . SPA.                            . TRND3P   VD9V                       .
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. SGWT3C  . ESW3C   SWAT3C                     .                                 .                                     .
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. SIN     . CBRT3C  FLV3T   VOLF3C             .                                 .                                     .
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. SPA.    . ABEND1  ADDM9U  BCOR3C  CBRT3C     .                                 .                                     .
.         . CRKR3T  DEFP3R  ENTL3H  ENTV3H     .                                 .                                     .
.         . ESW3C   FSTO3R  GCER9U  GENRD      .                                 .                                     .
.         . GETB3U  GETM3R  GETM9U  GFSK3C     .                                 .                                     .
.         . GMDY3C  HCIT3C  HCOT3C  HWFB3C     .                                 .                                     .
.         . HWNB3C  HWSC3C  HX3S    HX3T       .                                 .                                     .
.         . INTERP  INTNDG  ISTOP   JGCT9U     .                                 .                                     .
.         . KPRT3R  LEQ3C   LOAD3T  MARK3R     .                                 .                                     .
.         . NAMEWD  NBR3R   NET3R   NEWA9U     .                                 .                                     .
.         . NPNT9U  NXTO3R  PCNT3R  PIPE3S     .                                 .                                     .
.         . PIPE3T  PRHX3S  PRTCOM  PSAT3P     .                                 .                                     .
.         . PUMP3R  PUTB3U  PUTM9U  READHM     .                                 .                                     .
.         . REPEAT  SEG3R   SGBC3T  SWAT3C     .                                 .                                     .
.         . TRACE1  ZPRT3R                     .                                 .                                     .
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. SQRT    . CBRT3C  GSUP3C  HCOT3C  HWCN3C     .                                 .                                     .
.         . HWNB3C  MODL3C  PRFL3S  TBSG3S     .                                 .                                     .
.         . TBSG3T  XDNB3C                     .                                 .                                     .
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. SSCDAT  . INIT9U                             . DATE                            .                                     .
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. ROUTINE . REFERENCED FROM                     . REFERENCES TO                       . COMMON DEFINED $ = NOT REFERENCED   .
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. SSCTIM  . PAGE9U                              . TIME                                .                                     .
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. SSWTCH  . ABEND1   EXIT9U   SDUMP             .                                     .                                     .
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. STEN3S  . SATO3C   SATP3C                     .                                     .                                     .
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. STOP.   . CRDR9R   EXIT9U   MINET    MINT3S   .                                     .                                     .
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. SUBN3S  . MINT3S                              . ERR9U    FRAC3S                     . BC3P     GLOB3I   NET3P    SNET3P   .
.         .                                     .                                     . VD9V     VOL3P                      .
.............................................................................................................................
. SVCX3U  . MINET                               . OUTBI.   OUTCI.   PAGE9U   REWIND.  . GLOB3I   GLOB3V   UNIT3I            .
.         .                                     . SVGC9U                              .                                     .
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. SVGC9U  . SVCX3U                              . OUTBI.   OUTBR.                     . GC9U     VD9V                       .
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. SWAT3C  . ESW3C    GSUP3C   TBSG3S   TBSG3T   . ESTL3H   ESTV3H   SFWT3C   SGWT3C   .                                     .
.         .                                     . SPA.     TMPL3T   TMPV3T            .                                     .
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. SYS3R   . INIT3R                              . INOR3R   LSIZ9U   NET3R    NPNT9U   . DCON9U   GLOB3I   GLOB3V            .
.         .                                     . NXTI9U   OUTFI.   PCNT3R            .                                     .
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. TABL9R  . BND3R    CTRL3R   PIPE3R   PUMP3R   . DSIZ9U   LPNT9U   PGCR9U   REAL9U   .                                     .
.         . TURB3R   VALV3R   VOL3R             .                                     .                                     .
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. TAIR3C  . CAIR3C   CPAR3C   DREA3C   DRPA3C   . CBRT3C                              .                                     .
.         . RAIR3C   TEMP3C   VAIR3C            .                                     .                                     .
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. TBSG3S  . MRCH3S                              . ENTH3C   ESW3C    RHO3C    SQRT     . MOD3I    MOD3V    NODE3V   NODL3P   .
.         .                                     . SWAT3C   TEMP3C                     . SEG3P    TURB3P   VD9V              .
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. TBSG3T  . MRCH3T                              . ESW3C    GOTOER.  LOAD3T   RHO3C    . GLOB3V   MOD3I    MOD3V    NODE3V   .
.         .                                     . SQRT     SWAT3C                     . NODL3P   SEG3P    TURB3P   VD9V     .
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. TCLM3C  . HXND3S   HX3T                       .                                     .                                     .
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. TCRG3C  . HXND3S   HX3T                       . OUTFI.                              .                                     .
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. TEMP3C  . ADVN3T   BCOR3C   CROS3S   ETX3C    . ESTL3H   ESTV3H   GOTOER.  TAIR3C   . SATM3V                              .
.         . HXND3S   HX3S     IMOD3C   PIPE3S   . TMNK3C   TMPL3T   TMPV3T   TNA3C    .                                     .
.         . PRNT3C   QPM3C    TBSG3S   VOLM3S   .                                     .                                     .
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. THOM3C  . DP3C                                . ALOG     XTOY$                      .                                     .
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. TIME    . SSCTIM                              .                                     .                                     .
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. TIME3T  . MINET                               . SDEL9T                              . GLOB3V   TIME3I   TIME3V            .
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. TKNA3C  . HNAF3C   HNAI3C                     . TNA3C                               .                                     .
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. TMNK3C  . CDNK3C   CPNK3C   DRNK3C   RHNK3C   . CBRT3C                              .                                     .
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. ROUTINE  . REFERENCED FROM                       . REFEFENCES TO                         . COMMON DEFINED $ = NOT REFERENCED   .
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.          . TEMP3C   VSNK3C                       .                                       .                                     .
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. TMPL3T   . ENTH3C   ENTL3H   PSAT3P   SATO3C     .                                       .                                     .
.          . SATP3C   SWAT3C   TEMP3C              .                                       .                                     .
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. TMPV3T   . CONV3K   ENTV3H   SWAT3C   TEMP3C     .                                       .                                     .
.          . VISV3N                                .                                       .                                     .
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. TNA3C    . DREN3C   HCPN3C   RNA3C    TEMP3C     . CBRT3C                                .                                     .
.            TKNA3C   VSNA3C                       .                                       .                                     .
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. TRACE    . EXIT9U                                . TRACE1                                .                                     .
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. TRACE1   . ABEND1   TRACE                          CHARCTR OUTC1.   SPA.                 . ABEND                               .
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. TURB3R   . SEG3R                                 . COS      DSIZ9U   EXP      INTG9U     .                                     .
.          .                                       . MID9U    MORD3R   NXTM39   OUTFI.     .                                     .
.          .                                       . PGCI9U   PGCR9U   REAL9U   TABL9R     .                                     .
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. UNIQ9U   . ILNK3R   INL9U    INM9U    INOR3R     .                                       . UNID9I                              .
.          . ISU9R    KPRT3R   ORDR3R              .                                       .                                     .
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. VAIR3C   . HTCA3C   VISC3C                       . TAIR3C                                .                                     .
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. VALV3R   . SEG3R                                 . DSIZ9U   INTG9U   MID9U    MORD3R     .                                     .
.          .                                       . NXTM3R   OUTFI.   PGCI9U   PGCR9U     .                                     .
.          .                                       . REAL9U   TABL9R                       .                                     .
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. VALV3S   . MRCH3S   PRFL3S                       . CRIT3C   XTOY$                        . MOD3I    MOD3V    NODL3P   VALV3P  .
.          .                                       .                                       . VD9V                                .
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. VALV3T   . MRCH3T                                . CRIT3C   RHO3C    XTOY$               . GLOB3V   MOD3I    MOD3V    NODL3P  .
.          .                                       .                                       . VALV3P   VD9V     VOL3P             .
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. VISC3C   . DP3C     HX3S     HX3T                  ESTL3H   ESTV3H   GOTOER.  VAIR3C     . SATM3V                              .
.          .                                       . VISL3N   VISV3N   VSNA3C   VSNK3C     .                                     .
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. VISL3N   . HWFC3C   HWNB3C   SATO3C   SATP3C     .                                       .                                     .
.          . VISC3C                                .                                       .                                     .
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. VISV3N   . HWFB3C   HWSC3C   SATO3C   SATP3C     . DENV3D   TMPV3T                       .                                     .
.          . VISC3C                                .                                       .                                     .
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. VOLF3C   . ENET3S   EVLV3S   FLV3T    IOSG3T     . ACOS     SIN                          .                                     .
.          . WESM3S                                .                                       .                                     .
.........................................................................................................................
. VOLM3S   . MINT3S                                . DRDE3C   DRDP3C   RHO3C    TEMP3C     . GLOB3I   NET3P    VD9V     VOL3P   .
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. VOLS3T   . MINT3T                                . ESTL3H   ESTV3H   FLV3T    OUTFI.     . GLOB3I   VD9V     VOL3P             .
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. VOL3R    . NET3R                                 . INTG9U   KPRT3R   MARK3R   MID9U      .                                     .
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. ROUTINE . REFERENCED FROM                 . REFERENCES TO                   . COMMON DEFINED $ = NOT REFERENCED       .
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.         .                                 . MORD3R  NXTM3R  OUTFI.  PCNT3R  .                                         .
.         .                                 . PGCI9U  PGCR9U  PIDS3R  PUTJ3R  .                                         .
.         .                                 . REAL9U  TABL9R  ZPRT3R          .                                         .
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. VRFY3R  . MAIN9R                          . LIST3R                          .                                         .
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. VSNA3C  . HNAF3C  HNAI3C  VISC3C          . ALOG10  TNA3C   XTOY$           .                                         .
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. VSNK3C  . VISC3C                          . EXP     RHNK3C  TMNK3C  XTOY$   .                                         .
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. WESM3S  . MINT3S                          . DENL3D  DENV3D  ESTL3H  ESTV3H  . BC3P      GLOB3I    LNK3P     MODL3P    .
.         .                                 . ETX3C   VOLF3C                  . NET3P     SEG3P     SNET3P    VD9V      .
.         .                                 .                                 . VOL3P                                   .
.........................................................................................................................
. XDNB3C  . BCOR3C  IMOD3C                  . SQRT    XTOY$                   .                                         .
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. XDRY3C  . BCOR3C  IMOD3C                  . XTOY$                           .                                         .
.........................................................................................................................
. XTOI$   . CBRT3C  DCODNC                  .                                 .                                         .
.........................................................................................................................
. XTOY$   . CONV3K  DP3C    ESTL3H  ESTV3H  .                                 .                                         .
.         . HCIT3C  HCOT3C  HNAF3C  HNAI3C  .                                 .                                         .
.         . HTCA3C  HTNK3C  HWFB3C  HWFC3C  .                                 .                                         .
.         . HWNB3C  HWSC3C  HX3S    HX3T    .                                 .                                         .
.         . THOM3C  VALV3S  VALV3T  VSNA3C  .                                 .                                         .
.         . VSNK3C  XDNB3C  XDRY3C          .                                 .                                         .
.........................................................................................................................
. ZPRT3R  . SEG3R   VOL3R                   . DSIZ9U  EXIT9U  INTG9U  REAL9U  . LNKS3I                                  .
.         .                                 . SPA.                            .                                         .
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3.2.2 SUBROUTINE AND FUNCTION DESCRIPTION

A computer generated subroutine and function description is provided in Table 3.2-1. Following each name are two letters. The first indicates module type (S denotes subroutine, F denotes function), while the second letter indicates to which major code division each module belongs (U -utility, P -property, S -steady-state, T - transient, C - common to S and T, I - input processor). Also included is a brief description of each module's use.

3.2.3 FOCUS ON SELECTED AREAS

There are several areas in the MINET code that require somewhat greater explanation than is provided elsewhere in this document. In some cases the explanation is needed because of local complexities that can be very confusing, if not fully explained. In other cases, a large number of functions and/or utilities can be overwhelming until they are integrated conceptually into a special purpose package. In this section, we will try to bridge some of the gaps, in order to clarify certain points.

Table 3.2-1 Subroutine & Function Description

```
ABEND  S U SUPPLEMENT CDC SYSTEM ERROR DIAGONISTICS AFTER CRASH
ABENDI S U CALLED BY ABEND AFTER A FATAL EXECUTION ERROR
ADDA9U S U ADDS ENTRY TO CURRENT VALUE IN DESIGNATED POSITION IN DESGNTD ARRAY
ADDM9U S U ADDS FLOATING POINT DATA VALUE TO CURRENT SPCD ENTRY IN SPCFD ARRAY
ADTB3T S T ADVANCES HEAT EXCHNGER TUBE TEMPERATURES AT END OF TIME STEP
ADVN3T S T ADVANCES NETWORK CONDITIONS AFTER NETWORK VOLUME EQNS ARE SOLVED
BCOR3C S C BOUNDS THE ENTHALPY FOR CURRENT HEAT TRANSFER MODES, SETTING SWTCHPTS
BKEY3S S S DETERMINES WHICH HEAT TRANSFER BRIDGES ARE TO BE ADJUSTED
BND3R  S I PROCESS BOUNDARY MODULE INPUT DATA
CAIR3C F P CALCULATES AIR THERMAL CONDUCTIVITY
CALC3R S I PERFORM INPUT PROCESSOR POST-PARSE CALCULATION
CBRT3C S U SOLVES FOR ROOTS OF CUBIC POLYNOMIAL
CDINPT S I DECODES AND STORES FREE-FORMAT INPUT
CDNK3C F P THERMAL CONDUCTIVITY OF NAK
CHARCTR  U PART OF ABEND ERROR DIAGONOSTIC PACKAGE
CODE8  F U RETURNS NUMBER IN BASE 8,INITIALLY IN BASE 10
COMCUM S U WRITES OUT CONTENTS OF COMMON BLOCKS NOT WITHIN GLOBAL CONTAINER ARAY
COND3C F P THERMAL CONDUCTIVITY OF STRUCTURAL MATERIALS,INCL HX TUBING
CONL3K F P THERMAL CONDUCTIVITY OF SUBCOOLED WATER FOR ENTHALPY,PRESSURE
CONV3K F P THERMAL CONDUCTIVITY OF SUPERHEATED STEAM FOR ENTHALPY,PRESSURE
CPAR3C F P SPECIFIC HEAT OF AIR,CONSISTANT WITH TEMPERATURE FUNCTION
CPL3C  F P SPECIFIC HEAT OF SUBCOOLED WATER FOR GIVEN ENTHALPY,PRESSURE
CPNK3C F P SPECIFIC HEAT OF NAK
CPV3C  F P SPECIFIC HEAT OF SUPERHEATED STEAM FOR GIVEN ENTHALPY,PRESSURE
CRDR9H S I CONTROLS PROCESS OF READING INPUT CARDS
CRIT3C F P CRITICAL FLOW RATE FOR WATER/STEAM.CALLS CFSK3C,GMDY3C,GSUP3C.
CRKR3T S T SOLVE SEGMENT MATRIX EQUATION
CRKR9U S U CONVERTS ARRAYS FROM SEGMENT MATRIX EQN AND CALLS CRKR3T TO SOLVE
CROS3S S S WHEN NON-PHYSICAL HX CONDITION,CROS3S SET NODAL ENTHALPIES AT ESTIMAT
CTRL3R S I PROCESSES THE RUN CONTROL INPUT RECORDS
DCODNC S I DECODES ARRAY B TO FORM NUMERIC CONSTANT.PART OF FREE-FORMAT READ PAK
DEFP3R S I DEFINES A NEW PORT FOR MODULE
DENL3D F P DENSITY OF SUBCOOLED WATER FOR GIVEN ENTHALPY,PRESSURE
DENS3C F P DENSITY OF STRUCTURAL MATERIALS,INCL HT XCHNGR TUBING
DENV3D F P DENSITY OF SUPERHEATED STEAM FOR GIVEN ENTHALPY,PRESSURE
DMOD3R S I CONSTRUCTS NEW DATA MODULE FOR GIVEN DATA RECORD
DPSV3C S C CALCULATES PRESSURE DIFFERENCE BETWEEN JUNCTION AND VOLUME AVERAGE
DP3C   S C DETERMINES PRESSURE CHANGE PARAMETRS FOR NOD;GRAV,FRIC,ACCEL,FORM
DRDE3C F P DERIVATIVE OF DENSITY WITH RESPECT TO ENTHALPY FOR GENERIC FLUID
DRDP3C F P DERIVATIVE OF DENSITY WITH RESPECT TO PRESSURE FOR GENERIC FLUID
DREA3C F P DERIVATIVE OF DENSITY WITH RESPECT TO ENTHALPY FOR AIR
DREN3C F P DERIVATIVE OF DENSITY WITH RESPECT TO ENTHALPY FOR SODIUM
DRNK3C F P DERIVATIVE OF DENSITY WITH RESPECT TO ENTHALPY FOR NAK
DRPA3C F P DERIVATIVE OF DENSITY WITH RESPECT TO PRESSURE FOR AIR
DSIZ9U S U RETURNS THE SIZE OF THE SPECIFIED DATA FIELD IN SPECIFIED MODULE
EAIR3C F P ENTHALPY OF AIR FOR GIVEN TEMPERATURE,PRESSURE
ENA3C  F P ENTHALPY OF SODIUM FOR GIVEN TEMPERATURE,PRESSURE
ENET3S S S DETERMINES STEADY STATE ENTHALPY AND HEAT TRANSFER DISTRIBUTION
DEGP3R F P DERIVATIVE OF SATURATED STEAM ENTHALPY WITH RESPECT TO PRESSURE
ENNK3C F P ENTHALPY OF NAK FOR GIVEN TEMPERATURE,PRESSURE
ENTH3C F P ENTHALPY OF GENERIC FLUID FOR GIVEN TEMPERATURE,PRESSURE,FLUID TYPE
ENTL3H F P ENTHALPY OF SUBCOOLED WATER FOR TEMPERATURE,PRESSURE
ENTV3H F P ENTHALPY OF SUPERHEATED STEAM FOR TEMPERATURE,PRESSURE
ERRMSG S I WRITES ERROR MESSAGE,CALLED BY CDINPT AND GENRD
ERR9U  S U WRITES A NON-TERMINAL ERROR MESSAGE IN WRITTEN OUTPUT FILE
ESTL3H F P ENTHALPY OF SATURATED LIQUID WATER FOR GIVEN PRESSURE
ESTV3H F P ENTHALPY OF SATURATED VAPOR WATER FOR GIVEN PRESSURE
ESW3C  F P ENTHALPY OF WATER/STEAM FOR GIVEN ENTROPY,PRESSURE
ETX3C  S C LOADS BOUNDARY ENTHALPY,TEMPERATURE,AND QUALITY ARRAYS
EVLV3S S S CALCULATES VOLUME AVERAGE ENTHALPY GIVEN LIQUID LEVEL,VOLUME SHAPE
EXIT9U S U TERMINATION ROUTINE,IF CRASHED,IT PRINTS COMMON BLOCK VALUES
FLV3T  S T ADVANCES THE LIQUID LEVEL IN VOLUME WITH SEPARATED PHASES
FRAC3S S S USED WITH SUBN3S TO TRACE BACK FLUID SOURCE FOR SEGMENTS,VOLUMES
FSTO3R S I RETURNS PORT IDENTIFIER OF FIRST OUTLET PORT IN MODULE
GCER9U S U TEST FOR GLOBAL CONTAINER ALLOCATION ERRORS
GCPR9U S U PRINTS THE ENTIRE GLOBAL CONTAINER ARRAY
GCTP9U S U PRINTS THE ENTIRE GLOBAL CONTAINER TABLE
GENRD  S I THE MAIN CONTROL UNIT OF THE CARD INPUT PROCESSOR
GETA9U S U RETRIEVES ENTRY IN DESIGNATED POSITION IN DESIGNATED ARRAY
GETB3U S U HOST CODE INTERFACE TO RETURN DATA VALUE ASSOCIATD WITH BOUNDARY
GETD9U S U RETRIEVES VALUES FROM THE MODULE DATA AREA SPECIFIED
GETF9R S I OPEN A FILE SPECIFICATION ENTRY CORRESPONDING TO GIVEN FILE ID
GETF9U S U RETRIEVES FLOAT PT DATA FROM NODAL STORAGE AREA DESIGNATED
GCTE9U S U PRINTS ENTRY IN GLOBAL CONTAINER ARRAY
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GETI9R S I GET PARAMETERS FOR NEXT ITEM SPECIFICATION IN CURRNT OPN RCRD SPCFCTN
GETM3R S I GET MODULE FROM GEOMETRIC DATA LIST
GETM9U S U GETS DATA ENTRY VALUE FROM SPECIFIED PLACE IN SPECIFIED ARRAY
GETN9U S U RETRIEVES A GROUP OF INTEGER VALUES FROM NODAL STORAGE AREA DESGNATED
GETR9R S I RETRIEVES DATA FROM RECORD SPECIFICATION ENTRY
GETR9U S U RETRIEVES REAL VALUES FROM DESIGNATED MODULE DATA AREA
GFSK3C F P CRITICAL MASS VELOCITY FOR SUBCOOLED WATER,USES EXTENDD HENRY-FAUSKE
GMDY3C F P CRITICAL MASS VELOCITY FOR WATER/STEAM MIX,USES MOODY MODEL
GSUP3C F P CRITICAL MASS VELOCITY FOR SUPERHEATED STEAM,ISENTROPIC MODEL
HCAP3C F P HEAT CAPACITY (SPC HT) OF STRUCTURAL MATERIALS
HCIT3C F P HEAT TRANSFER COEFFICIENT CONDENSING INSIDE HORIZONTAL TUBES
HCOT3C F P HEAT TRANSFER COEFFICIENT CONDENSING OUTSIDE (ON) HORZNTL TUBE BANKS
HCPN3C F P HEAT CAPACITY/SPECIFIC HEAT OF SODIUM
HNAF3C F P HEAT TRANSFER COEFFICIENT FOR SODIUM PASSING OUTSIDE TUBES
HNAI3C F P HEAT TRANSFER COEFFICIENT FOR SODIUM PASSING INSIDE TUBES
HTCA3C F P HEAT TRANSFER COEFFICIENT FOR AIR PASSING OVER HEATED TUBES
HTC3C  F P HEAT TRANSFER COEFFICIENT FOR GENERIC FLUID;CALLS OTHER H FUNCTIONS
HTNK3C F P HEAT TRANSFER COEFFICIENT FOR NAK,INSIDE OR OUTSIDE TUBES
HWCN3C F P HEAT TRANSFER COEFFICIENT IN CONDENSING MODE,VERT SURFAC,FILM THICKNS
HWFB3C F P HEAT TRANSFER COEFFICIENT FOR FILM (WATER) BOILING,BISHOP CORRELATION
HWFC3C F P HEAT TRANSFER COEFFICIENT FOR SUBCOOLED WATER BY FORCED CONVECTION
HWNB3C F P HEAT TRANSFER COEFFICIENT FOR NUCLEATE BOILING,INCL SUBCOOLD/TWO-PHAS
HWSC3C F P HEAT TRANSFER COEFFICIENT FOR SUPERHEATED (STEAM) CONVECTION
HXND3S S S PERFORMS NODAL ENERGY BALANCE CALCULATION FOR HX NODES
HX3R   S I PROCESSES HEAT EXCHANGER MODULE INPUT DATA
HX3S   S S HEAT EXCHANGER TEMPERATURE AND HEAT TRANSFER CALCULATIONS
HX3T   S T TRANSIENT CALCULATIONS FOR HT XCHNGR,NODE AVERAGE HEAT TRANSFER CALCD
IGA9U  F U RETURNS GLOBAL ARRAY POINTER CORRESPONDING TO GIVEN CHARACTER STRING
ILNK3R S I INITIALIZE MODULE LINKAGE FUNCTION CODE
IMOD3C S C DETERMINES APPROPRIATE HEAT TRANSFER CORRELATION UNDER GIVEN CNDTIONS
INA9U  S U INITIALIZES THE ARRAY DATA ABSTRACTION
INFO   S U CALLED BY ABENDI,SDUMP.CONVERT WORD TO CHARACTER STRING.
INGC9U S U INITIALIZES THE GLOBAL CONTAINER MANAGEMENT UTILITY
INIT3R S I CONTROLS INITIALIZATION OF MINET INPUT DATA
INIT3S S S INITIALIZE VOLUME,SEGMENT FLOWS,PRESSURES,ENTHALPIES FOR ITERATIVE
INIT3U S U INITIALIZE I/O UNIT NUMBERS,GLOBAL CONTAINER ARRAY
INIT9U S U READS THE TITLE CARD IN THE INPUT DECK
INL9U  S U INITIALIZES LIST TYPE DATA ABSTRACTION
INM9U  S U INITIALIZES THE MODULE DATA ABSTRACTION
INN9U  S U INITIALIZE NODE DATA ABSTRACTION
INOR3R S I INITIALIZE MODULE ORDERING CODE
INPT9U F U SCANS NODE CHAIN FOR NODE WITH GIVEN ID,RETURNS ARRAY POINTER
INRD3R S I INITIALIZES MINET INPUT DATA READER
INSL9U S U PLACES AN ITEM IN LIST AFTER LAST PREVIOUS ENTRY
INSTRUCS U PART OF ABEND PACK. DECODES SUBROUTINE INSTRUCTIONS.
INTERP S I PERFORMS THE REAL-INTERPOLATE OPERATION,PART OF FREE-FORMAT READ PAKG
INTG9U F U RETURNS AN INTEGER VALUE FROM DESIGNATED PLACE IN MODULE DATA AREA
INTNDG F I CHECKS IF ARRAY CONTAINS DIGIT STRING FOLLOWED BY NON DIGIT.FREE FRMT
INTP9U S U INTERPOLATES TABULAR FUNCTIONS
IOSG3T S T SETS UP SEGMENT RESPONSE MATRICE,LOADS SEG IN,OUT EQUATIONS,MOMENTUM
IPTS3R S I SUBROUTINE SETS I POINTERS FOR VARIABLE IN GLOBAL CONTAINER
IRPT9U F U SCANS NODE CHAIN FOR NODE WITH GIVEN REAL NO. ID,RETURNS ARRAY POINTR
ISETHM F I CALCS PARAMTRS NEEDED TO PROCS A HOLERITH MESSG ON CARD IMAGE
ISTOP  F I TESTS IF FIRST NON-BLANK CHARCTRS ON CARD SPELL STOP
ISU9R  S I INITIALIZES INPUT SPECIFICATION UNIT MODULE CODE
ITRPCK F I CHECKS INTERPOLATE FLAG TO DECIDE IF REAL-INTERP OPRATN CAN BE PRFRMD
IUNI9U S U INITIALIZES A UNIQUE NUMBER GENERATOR
JBNAME S U RETURNS JOBNAME TO THE USER
JDAT3R S I RETURNS INTEGER DATUM ASSOCIATED WITH MODULE
JGCT9U F U RETRIEVE THE INDEX(OF THE ARRAY ENTRY IN CONTAINER) FOR VARIABL NAMED
KPRC3S S S SETS THE PRINCIPAL SUBNET NO. FOR SEGMENTS,VOLUMES,HEAT EXCHANGERS
KPRT3R F I RETURNS DATA AREA ID FOR PORT PREVIOUSLY DEFINED BY DEFP3R
LCNT9U F U RETURNS A COUNT OF THE NO. OF ITEMS IN LIST OF GIVEN MODULE TYPE
LEQ3C  S U SOLVES A SYSTEM OF LINEAR EQNS (MATRIX) BY GAUSSIAN ELIMINATION
LEQ9U  S U SOLVES MATRIX EQUATION OF ARRAY DATA ABSTRCTION FORM,CALLS LEQ3C
LINK3R S I GENERATES GEOMETRIC LINKS FOR SYSTEM DATA MODULES
LIST3R S I PRINTS FORMATTED LISTING OF MINET INPUT DATA FILE
LNKN9U S U INSERTS LINK INFO INTO NODAL STORAGE SPACE,DIRECTS TO NEXT ONE
LOAD3T S T LOADS NODAL CONSERVATION EQNS INTO SEGMENT MATRIX EQN
LOCL9U F U SCAN THE LIST TO FIND ITEM WITH GIVEN MODID,RETURN THE POINTER
LOCR9U F U LOCATE THE MODULE WITH REAL TYPE ID DESIGNATED,RETURN THE POINTER
LPNT9U F U RETURNS LENGTH OF GLOBAL CONTAINER ARRAY
LSIZ9U F U RETURNS SIZE OF LIST,WHERE SIZE IS THE NUMBER OF ITEMS CONTAINED
LSTI9U F U RETURNS THE POINTER FOR THE PREVIOUS ITEM IN LIST
LSTM3R S I RETURNS POINTER TO LAST-VISITED MODULE IN ORDER SET
```

```
MAIN9R S I INPUT PROCESSOR SUB-DRIVER
MARK3R F I RETURN MODULE MARK STATUS FOR GIVEN MARK VALUE
MDST3S S S SETS MODULE PRESSURES,FLOWS,AND ENTHALPIES
MID9U  F U RETURNS THE MODULE ID INDICATED BY GIVEN POINTER
MINET  P C MAIN PROGRAM,CALLS DRIVERS AND MANAGES EXECUTION
MINT3S S S DRIVER FOR STEADY STATE CALCULATIONS
MINT3T S T DRIVER FOR TRANSIENT CALCULATIONS
MODL3C S C CALCULATES MODULE SCRATCH PARAMETERS FRM MOD VALUES,EG,AREA FRM DIAM
MORD3R F I RETURN MODULE ORDINAL WITHIN MODULE ORDER SET
MRCH3S S S MARCHES THROUGH SEGMENT MODULES,INITIALIZING AND CALCING PRESR LOSSES
MRCH3T S T MARCHES THROUGH SEGMENT MODULES, DETERMING SEGMENT RESPONSE MATRICES
MTYP9U F U RETURNS AN INTEGER ENCODED TYPE NUMBER FOR MODULE GIVEN BY POINTER
MVGA9U S U MOVE ENTIRE GLOBAL ARRAY FROM DYNAMIC STORAGE INTO CONTAINER
MVGC9U S U MOVES THE GLOBAL CONTAINER FROM DYNAMIC TO STATIC STORAGE
NAMEWD F I CHECKS IF L CHRCTRS,IN ARRAY A,FORM LETTER-ALFANUMRC STRING.FREE FRMT
NB[illegible]R  S I RETURNS LINK TO PORT IN NEIGHBORING MODULE,AS DEFINED BY INPUT LNKAGS
NCLS3R F I RETURNS PORT CLASS NUMBER FOR MODULE IN CURRENT ORDER SET
NET3R  S I PROCESSES NETWORK INPUT DATA
NET3T  S T CALCULATE NEW PRESSURES AND ENTHALPIES FOR NETWORK VOLUMES
NEWA9U S U CONSTRUCTS A MATRIX IN DATA ABSTRACTION STORAGE ARRAY
NEWD9U F U CREATES A NEW DATA AREA FOR MODULE,ASSIGNS GIVEN DATA ID
NEWL9U S U CREATES A NEW INSTANCE OF LIST,RETURNING A POINTER FOR IT
NEWM9U F U CONSTRUCTS NEW INSTANCE OF MODULE WITH GIVEN ID AND TYPE
NEWN9U F U CREATES NEW NODE STORAGE SPACE AND RETURNS POINTER FOR IT
NEWR9U F U CREATES NEW INSTANCE OF MODULE WITH REAL TYPE MODULE ID
NID9U  F U RETURNS THE NODE ID VALUE FOR GIVEN NODE
NNBLNK F I SEARCHES GIVEN ARRAY FOR A NON-BLANK CHARACTER.PART OF FREE-FORMAT PK
NPNT9U F U ALLOCATES A NEW POINTER INTO THE GLOBAL CONTAINER ARRAY
NSIZ9U F U RETURNS THE SIZE OF THE DATA AREA ALLOTED FOR GIVEN NODE
NSKIP  F I PERFORMS THE SKIP-WORDS OPERATION. CALLED BY CDINPT
NXTA9U F U RETURNS POINTER TO NEXT ATOM IN CHAIN,IF LAST ATOM,EXTENDS THE CHAIN
NXTI9U F U RETURNS THE POINTER FOR THE NEXT ITEM IN THE LIST
NXTM3R S I RETURNS POINTER TO NEXT MODULE IN ORDER SET
NXTN9U F U RETURNS THE VALUE IN THE NEXT FIELD OF THE GIVEN NODE DATA AREA
NXTO3R S I RETURNS PORT ID OF NEXT AVAIL OUTLT PRT CORRESPNDING TO GIVN INLT PRT
ORDR3R S I INITIALIZES ORDERED SET OF MODULES USING BACKTRACK REVERSAL
PAGE9U S U PRINTS THE PAGE HEADING
PCNT3R S I RETURN MODULE PORT COUNTS,E.G.NO. INLET,OUTLET,FREE INLET,FREE OUTLET
PGCI9U S U PUTS AN INTEGER VALE IN NAMED GLOBAL CONTAINER ARRAY
PGCR9U S U PUTS A REAL VALUE IN NAMED GLOBAL CONTAINER ARRAY
PIDS3R F I RETURNS INLET AND OUTLET PORT IDENTIFIERS FOR CURRENT MOD . IN ORDER
PIPE3R S I PROCESSES PIPE MODULE INPUT DATA
PIPE3S S S INITIALIZES THE PIPE MODULES,PIPE-PART OF VALVE AND PUMP MODULES
PIPE3T S T PERFORMS TRANSIENT CALCULATION FOR PIPE MODULE,PIPE-PART OF VALV,PUMP
PREP3T S T STARTS TIME STEP CALCULATIONS,ADVANCES BOUNDARY CONDITIONS,ETC
PRFL3S S S PERFORMS STEADY STATE NETWORK PRESSURE AND FLOW BALANCE
PRHX3S S S TAGS HEAT EXCHANGER SIDE WITH SUBNET NUMBER
PRNT3C S C PRINTS OUT CURRENT CONDITIONS IN SYSTEM,STEADY STATE AND TRANSIENT
PRTA9U S U FORMATTED PRINTER FOR ARRAYS IN DATA ABSTRACTION FORM
PRTCOM S U PRINTS OUT COMMON AREA WITH VARIABLE NAMES
PSAT3P F P SATURATION PRESSURE (WATER) FOR GIVEN TEMPERATURE (AND PRES. ESTIMAT)
PUMP3R S I PROCESSES PUMP MODULE INPUT DATA
PUMP3S S S INITIALIZES CONDITIONS IN PUMP MODULE,DETERMINES PRESSURE CONTRIBUTON
PUMP3T S T PERFORMS TRANSIENT PUMP CALCULATIONS,CURRENT HEAD CONTRIBUTION
PUTA9U S U PLACES ENTRY INTO DESIGNATED POSITION IN DESIGNATED MATRIX
PUTB3U S U HOST CODE INTERFACE TO ASSIGN DATA VALUE ASSOCD WITH BOUDARY
PUTD9U S U PLACES A GROUP OF VALUES IN DATA AREA FOR MODULE
PUTF9R S I PUT NEW FILE SPECIFICATION ENTRY IN DATA BASE
PUTF9U S U PLACES A GROUP OF FLOATING PT DATA INTO NODAL STORAGE AREA DESIGNATED
PUTI9R S R PUT NEW INTGR ITEM SPECIFCTN ENTRY IN CURRNTL OPEN RECORD SPECIFICTN
PUTJ3R S I STORE INTEGER DATUM VALUE ASSOCIATED WITH MODULE
PUTM9U S U PUTS DATA ENTRY IN ARRAY,IN GIVEN POSITION
PUTN9U S U PLACES A GROUP OF INTEGER DATA INTO NODAL STORAGE AREA INDICATED
PUTR9R S I PUT NEW RECORD SPECIFCTN ENTRY IN CURRNTL OPEN FILE SPECIFICATION
PUTR9U S U PLACES A GROUP OF VALUE IN DESIGNATED MODULE DATA AREA
QBAL3S S S ADJUSTS ENERGY TRANSFERS NEEDED TO FIT SUBNET NEEDS
QBRG3S S S DETERMINES Q3HBRG(I,J)=TOTAL Q TRANSFERRED INTO SNT I FROM SUBNET J
QPM3C  F C DETERMINE HEAT TRANFER FROM TUBE CENTER TO FLUID,PER METER OF TUB LNG
RAIR3C F P DENSITY OF AIR
READHM S I READS HOLERITH MESSAGE,FROM CARD IMAGE,INTO WORD ARRAY
READ3R S I PROCESSES INPUT FROM THE FREE-FORMAT INPUT CARDS
REAL9U F U RETURNS A REAL VALUE FROM DESIGNATED PLACE IN MODULE DATA AREA
RECX3U S U RESTORES GLOBAL L VARIABLES AND ARRAYS FROM RESTART FILE
REGC9U S U RESTORE GLOBAL CONTAINER CONTEXT FROM SAVE FILE
RELA9U S U RELEASES PREVIOUSLY USED STORAGE SPACE IN DATA ABSTRACTION DATA ARRAY
```

```
RELD9U S U RELEASES DATA AREA OF SPECIFIED MODULE DATA FIELD
RELL9U S U RELEASES INSTANCE OF LIST DESIGNATED BY GIVEN POINTER
RELM9U S U RELEASES ENTIRE MODULE,AS SPECIFIED
RELN9U S U RELEASES STORAGE AREA PREVIOUSLY USED FOR GIVEN NODE
REPEAT S I PERFORMS REPEAT-STORAG OPRATN OF CONSTANT OR SET OF CONSTANTS,FREE-FM
REPS9R S I SET BEGINNING OF REPEAT SEQUENCE TO NEXT ITEM
RHNK3C F P DENSITY OF EUTECTIC NAK
RHO3C  F P DENSITY OF GENERIC FLUID,CALLS OTHER DENSITY FUNCTIONS
RISU9R S I RELEASE INPUT SPECIFICATION UNIT DATA STORAGE AREA
RLID9U F U RETURNS A REAL TYPE MODULE ID FOR MODULE INDICATED BY POINTER
RNA3C  F P DENSITY OF SODIUM
ROOT3C S U SOLVES FOR ROOTS OF CUBIC POLYNOMIAL
SATM3C S C TRANSFERS REFERENCE SATURATION PROPERTIES ONTO 1SIDE OF MODULE
SATO3C S C CALCULATES SATURATION PROPERTIES FOR OTHER SIDE OF HX,IE,NOT SEGMENT
SATP3C S C LOADS SATURATION PROPERTIES FOR REFERENCE PRESSURE
SDEL9T F T RETURNS PRINT TIME INTERVAL FOR GIVEN TIME VALUE
SDUMP  S U CALLED BY ABEND1 AFTER CRASH,DUMPS SMALL CORE MEMORY CONTENTS
SEG3R  S I PROCESSES FLOW SEGMENT INPUT DATA
SETFMT S I CONVERTS DECIMAL INTEGER TO P CONSECUTIVE HOLERITH CONSTANTS,FREE-FMT
SFWT3C F P ENTROPY OF SATURATED WATER FOR GIVEN PRESSURE
SOBC3T S T FACTORS BOUNDARY MODULE PRES,FLOW INTO SEGMENT RESPONSE MATRIX
SGWT3C F P ENTROPY OF SATURATED STEAM FOR GIVEN PRESSURE
SSCDAT F U MACHINE DEPENDENT ROUTINE DETERMINES CURRENT TIME
SSCTIM S U MACHINE DEPENDENT ROUTINE DETERMINES CURRENT DATE
STEN3S F P SURFACE TENSION BETWEEN WATER/STEAM AT GIVEN TEMPERATURE(SATURATION)
SUBN3S S S TRACES BACK FLOW SOURCES FOR EACH SUBNETWORK
SVCX3U S U SAVES CONTEXT OF GLOBAL VARIABLES AND ARRAYS FOR POSSIBLE RESTART
SV3C9U S U SAVE GLOBAL CONTAINER CONTEXT ON SAVE FILE DEFINED BY INGCSJ CALL
SWAT3C F P ENTROPY OF WATER/STEAM FOR GIVEN ENTHALPY,PRESSURE
SYS3R  S I PROCESS GLOBAL SYSTEM INPUT DATA
TABL3R S I MOVE TABLE DATA FOR INPUT DATA RECORD TO GLOBAL CONTAINER
TAIR3C F P CALCULATES AIR TEMPERATURE AT GIVEN ENTHALPY,P=ATOMSH PRESSR
TBSG3S S S INITIALIZES TURBINE STAGE CONDITIONS
TBSG3T S T PERFORMS TRANSIENT CALCULATIONS FOR TURBINE STAGE
TCLM3C F C FUNCTION SETS NODE END TUBE TEMPS CONSISTANT WITH TC,FLUID TEMPS,LMTS
TCRG3C S C CALCULATES TUBE TEMPERATURE AT AXIAL POSN,ALLOWNG SLIGHT AXIAL DISTRB
TEMP3C F P TEMPERATURE OF GENERIC FLUID FOR GIVEN ENTHALPY,PRESSURE,FLUID TYPE
THOM3C F P CALCULATES THOM TWO-PHASE FRICTION MULTIPLIER
TIME3T S T RETURNS EVENT TIMING INFORMATION,END,PRINT,STORE,SAVE
TKNA3C F P THERMAL CONDUCTIVITY OF SODIUM
TMNK3C F P TEMPERATURE OF EUTECTIC NAK
TMPL3N F P TEMPERATURE OF SUBCOOLED WATER FOR GIVEN ENTHALPY,PRESSURE
TMPV3N F P TEMPERATURE OF SUPERHEATED STEAM FOR GIVEN ENTHALPY,PRESSURE
TNA3C  F P TEMPERATURE OF SODIUM
TRACE  S U CALLED FROM ABEND,TRACES THROUGH SUBROUTINE CALLS
TRACE1 S U TRACEBACK STARTING AT GIVEN ADDRESS,PART OF ABEND PACKAGE
TURB3R S I PROCESSES TURBINE MODULE INPUT DATA
UNIQ9U S U GENERATES A UNIQUE NUMBER,INITIALIZED BY IUNI9U CALL
VAIR3C F P DYNAMIC VISCOSITY OF AIR
VALV3R S I PROCESSES VALVE MODULE INPUT DATA
VALV3S S S INITIALIZES VALVE CONDITIONS
VALV3T S T PERFORMS TRANSIENT CALCULATIONS FOR VALVE MODULE
VISC3C F P DYN VISCOSITY OF GENETIC FLUID,GIVEN ENTHALPY,PRESSURE,FLUID TYPE
VISL3N F P DYNAMIC VISCOSITY OF SUBCOOLED WATER FOR GIVEN ENTHALPY,PRESSURE
VISV3N F P DYN VISCOSITY OF SUPERHEATED STEAM FOR GIVEN ENTHALPY,PRESSURE
VOLF3C F C CALCULATES VOLUME FRACTION BETWEEN TWO LEVELS IN HORIZONTAL CYLINDER
VOLM3S S S LOOPS THRU NETWORK VOLUMES,LOADING PROPS FOR PRNT3C AND TRANSIENT
VOLS3T S T ADVANCES CONDITIONS IN VOLUME MODULE,PARTICULARLY THE LEVEL
VOL3R  S I PROCESS VOLUME MODULE INPUT DATA
VRFY3R S I MAIN DRIVER FOR MINET INPUT DATA VERIFICATION
VSNA3C F P DYNAMIC VISCOSITY OF SODIUM
VSNK3C F P DYNAMIC VISCOSITY OF NAK
WESM3S S S SUMS UP FLOW ENERGY (FLOW X ENTHALPY) IN AND OUT EACH SUBNETWORK
XDNB3C F P DETERMINES FLOW QUALITY AT DNB,ATOMICS INTRNL FOR SODIUM TO WATER
XDRY3C F P DETERMINES FLOW QUALITY AT DRYOUT,MACBETH FOR WATER TO WATER
ZPRT3R F I RETURNS ELEVATION OF MODULE PORT
```

3.2.3.1 INPUT PROCESSOR

The input processor forms an interface between the user and the computational code. Its main task is one of translation. On the user side, it must accept textual input describing the system which is to be modelled. This must be transformed into equivalent data in the correct form for use by the computational code. This task must be accomplished correctly for all combinations of valid input data as defined by the program specification. Further, the input processor must be able to handle incorrect input data in such a way that,

- the run does not terminate due to run-time error
- appropriate error messages are issued to the user
- remaining input is processed for further errors before the run is terminated

This applies to both simple syntactic errors as well as more subtle global consistency and semantic errors.

Other functions include generating formatted and unformatted listings of input data, listing optional features selected through the input data, and generating internal data storage maps.

3.2.3.1.1 DESIGN CONSIDERATIONS

A major design consideration for the MINET Input Processor is the requirement for a host-code interface. This interface allows MINET reader functions to be controlled by other codes in place of the stand-alone MINET program. Especially critical are those functions, normally controlled by input for the stand-alone code, which require control from the external host in the interfaced version. It should be noted that subroutines MAIN9R and CRDR9R in the stand-alone version perform functions that would be replaced by host-code in the interfaced version.

3.2.3.1.2 INPUT PROCESSOR SUBTASKS

Input processor activity is divided into several subtasks which are invoked by either a stand-alone main driver or host-code. Each subtask is controlled by a separate subroutine whose name appears in parentheses after the subtask name.

- The READ (READ3R) subtask controls the reading of data from the input file. This requires various file management operations including positioning, reading of logical data records, and testing for end conditions. During this process, syntactic and data field type errors are identified and appropriate error messages are issued with the unreformatted input data listing.
- VERIFICATION (VRFY3R) consists of a group of error tests designed to detect missing data, semantic errors, and global data inconsistencies.
- DATA INITIALIZATION consists of allocating storage and loading computational data from input data, subject to a predefined interpretation process. This is the most difficult task performed by the Input Processor because of the extreme flexibility required for representing the generalized class of systems to be modelled. Various types of input data errors may be detected during these

processes, requiring appropriate error messages to be issued to the user. In the case of storage overflow error during the allocation process, it is necessary to provide the user with an estimate of the additional storage required before terminating the run. This allows the user to determine exactly how much additional storage is needed to accommodate the data set.

3.2.3.1.3 MAJOR SUBROUTINES

The following descriptions summarize the functions performed by the major Input Processor subroutines. They are grouped according to the subtasks outlined above. Details are purposely left out for the sake of clarity.

3.2.3.1.3.1 MAIN DRIVER

MAIN9R controls the sequencing of the Input Processor subtasks (see also Figure 3.2-1). It first calls CRDR9R, a secondary driver which controls the reading of input data from the INPUT file. The verification subtask is then invoked by calling VRFY3R. Finally, the DATA INITIALIZATION subtask is invoked by calling INIT3R. An error count parameter is tested after each of the calls, and the run is terminated if it is nonzero. On return, an integer-encoded context restore ("restart") flag is passed back to the calling code to indicate whether or not the input data contained a context restore request.

CRDR9R sets up the proper conditions prior to the beginning of the actual data reading. It first calls INRD3R to initialize Input Processor internal code, then it positions the INPUT file at the beginning of the MINET data and calls READ3R to do the reading. If an input file error is detected before the call to READ3R, an error message is issued and the run is terminated.

3.2.3.1.3.2 READER INITIALIZATION SUBTASK

INRD3R initializes various internals of the Input Processor. These include:

- global constants
- internal utilities
- MINET input file content definition (using ISU)
- data lists (using LIST data abstraction)

3.2.3.1.3.3 READ SUBTASK

READ3R controls the actual MINET input data file reading process. Consecutive records are read from the INPUT file until either an end-of-file condition or an end of MINET data is encountered. File access is indirect in that calls are made to a file manager, GENRD, which passes back one complete MINET input record at a time, along with flags to signal end conditions. This is done to unburden READ3R of the need to perform low-level syntax analysis related to the external INPUT file definition. It also simplifies read logic at this level by covering up the asynchronous nature of the read process created by continuation lines and varying end conditions. Each record is then passed to a record-processing subroutine, DMOD3R, unless GENRD flags a syntax error. In this case an error message is issued and the entire record is ignored.

DMOD3R tests interpreted input record data fields for errors and passes them to the appropriate destination for further processing. Error tests include:

- invalid record number
- incorrect record length
- duplicate record conflict
- incorrect data field type
- intra-record port identifier conflict
- module identifier type disagreement

3.2.3.1.3.4 VERIFICATION SUBTASK

VRFY3R performs error tests for missing data, semantic errors, and global data inconsistencies. LIST3R is called to write a formatted listing of input data record fields to the OUTPUT file. On return, a data error count is passed back to the calling code.

LIST3R writes a formatted listing of input data record fields as they were interpreted by the Input File Manager. In order to simplify processing logic and to minimize global data storage, the listing is actually generated earlier by DMOD3R and written to a scratch file. LIST3R only has to write a header and copy the scratch file contents to OUTPUT.

3.2.3.1.3.5 DATA INITIALIZATION SUBTASK

INIT3R controls the initialization of global computational data. If the MINET input data does not contain a context restore ("restart") request, then SYS3R is called to process system data. The global container is then loaded and the pointers are defined. Finally, CALC3R is called to perform secondary processing of global data not possible earlier. On return, an integer context restore flag, indicating whether or not the input data contained a restore request, is passed back to the calling code. An error count is also returned.

CALC3R performs secondary processing of global data which can only be done after the initial data loading process.

IPTS3R sets global container pointers residing in global COMMON blocks. The pointer values are obtained from the Global Container Manager function IGA9U.

SYS3R processes system related input data. It is the top level of a group of subroutines designed to perform the task of interpreting the input to construct a representation of system structure. The approach used is related to that of parsing used by compilers to interpret high-level computer languages. It consists of traversing the entire set of system modules, following the interconnections defined by the input data, so that each module is visited at least once. Specific subroutines are called depending on module type to process module input data and to identify system structures. Proceeding in this way, computational data is allocated and initialized at the same time the system structures are being interpreted.

The basic rules governing the identification of system structures are:

1. each SYSTEM is comprised of one or more NETWORKs
2. each NETWORK is comprised of at least one inlet and one outlet BOUNDARY, one or more SEGMENTs, and zero or more VOLUMEs

3. each segment is comprised of one or more of the following:

   - PIPE
   - HEAT EXCHANGER
   - PUMP
   - VALVE
   - TURBINE

4. the above system modules may be interconnected arbitrarily as long as

   - no module is connected to itself
   - connections are only made between inlets and outlets
   - each connection links exactly two modules
   - all modules are fully connected

The entire group of system subroutines are given in the following list, where indenting is used to indicate the calling structure.

```
SYS3R
   NET3R
      BND3R
      SEG3R
         HX3R
         PIPE3R
         PUMP3R
         TURB3R
         VALV3R
      VOL3R
```

In operation, SYS3R first performs initialization of global counter variables for the system. Then it scans the data module list for network boundary modules. These are defined as modules with exactly one outlet and no inlets. Each boundary of this type is used as a starting point for a new network parse invoked by calling NET3R. This process is repeated until all networks have been parsed. Finally, the Global Container Manager function NPNT9U is invoked to allocate global container space used for steady state and transient computations but not directly initialized from the input.

3.2.3.2 STEADY STATE

There are three subroutines in the steady state portion of MINET in need of further elaboration. These routines are HX3S, HXND3S, and PRFL3S. The first two, which are used in determining the steady state temperature distributions in the heat exchangers, contain many subtleties and should be modified only as a last resort.

3.2.3.2.1 HX3S

Subroutine HX3S controls the steady state heat exchanger calculations, and is called twice for each heat exchanger module. On the first pass it initializes the temperature distributions on <u>both</u> sides of the unit. During the second pass, the second side pressure drop, corresponding to the temperature distribution calculated in the first pass, is determined. As the second pass is relatively simple, we focus here on the first pass, which proceeds as shown in Figure 3.2-3.

By the time that HX3S is called, the heat exchanger flows, pressures, and inlet and outlet temperatures have already been set, at least for the current iteration, based on system conditions. One of the first steps in the HX3S calculations is to check for two non-physical conditions, i.e., (1) temperature cross and (2) violation of the second law of thermodynamics. In either non-physical case, an error flag is set and an error message is written. However, the calculations continue in any case, because of the chance that on the next system wide iteration the conditions may become physically realistic.

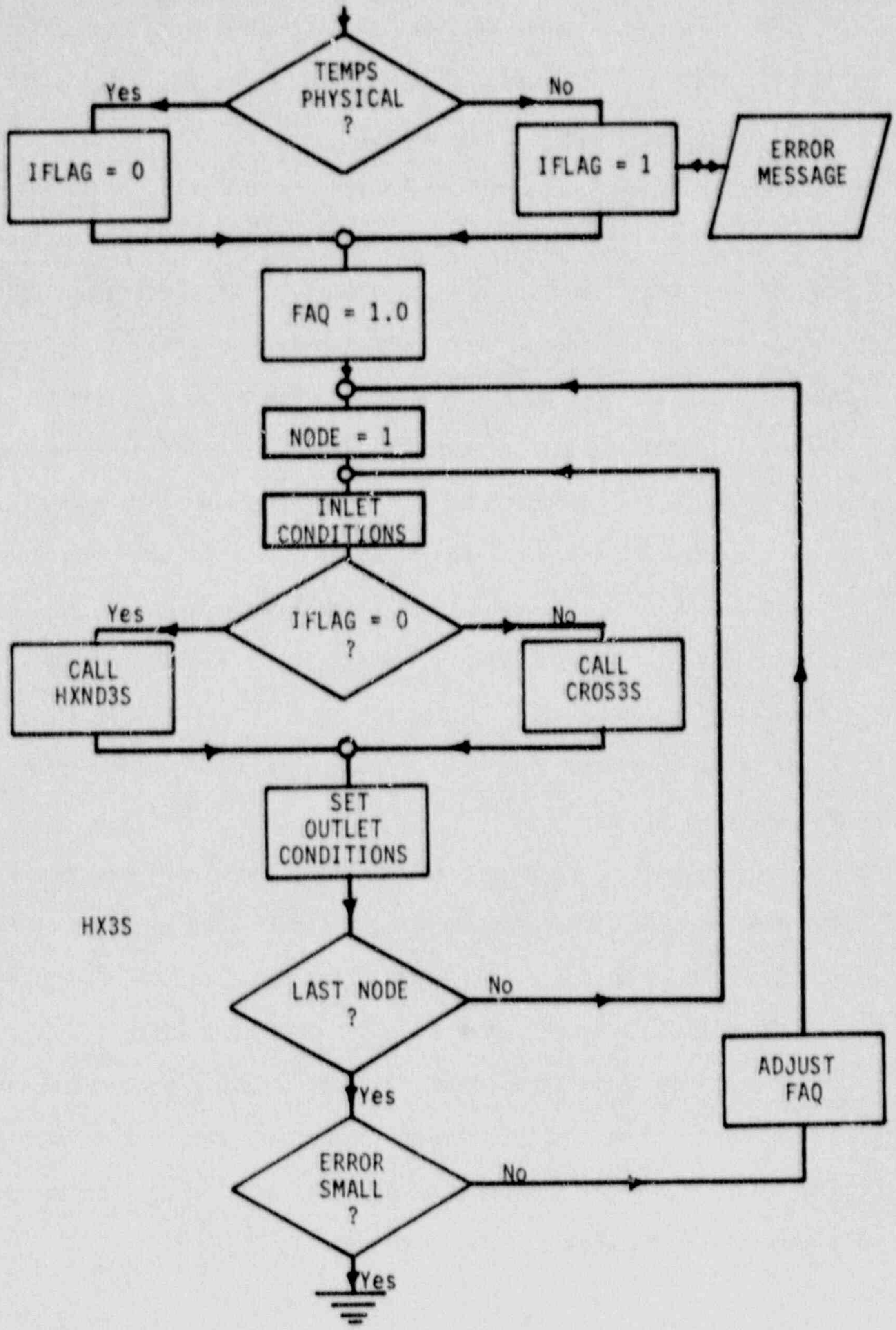


Figure 3.2-3 Flow Chart for Subroutine HX3S

To begin the calculations, the heat transfer area correction factor, FAQ, is set to 1.0. If the error flag was set, there is no iteration on FAQ, i.e., it is 1.0 for the single pass taken.

All the nodes in the heat exchanger are analyzed sequentially, with the node inlet conditions determined from either module inlet parameters, or the outlet conditions from the previous node. Under physical conditions, subroutine HXND3S is called to determine the node heat transfer and resulting enthalpy gradient. If, on the other hand, the error flag was set, subroutine CROS3S is called to set the enthalpy gradient indicated by module inlet and outlet conditions, assuming a linear heat transfer rate along the module.

When calculations have been completed for all the nodes, the calculated module outlet enthalpy is compared to the one required by system wide considerations. If the conditions are physically realistic, and yet there is some disagreement between the needed heat transfer rates and the rate indicated by correlations, the heat transfer area correction factor is adjusted for the next iteration.

Experience to date indicates that the number of iterations needed to determine the area correction factors is significant in terms of the total computation time needed for the steady state solution. Further, this factor consistently falls between .65 and 1.1 for various physically correct (experimental, operational, or designed) systems. Should problems arise with the calculation of the area correction factor, one should look very closely at the input heat exchanger geometric conditions, and the conditions coming from elsewhere in the steady state calculations.

3.2.3.2.2 HXND3S

Subroutine HXND3S performs the steady state calculations for each of the heat exchanger nodes, as long as the heat exchanger boundary conditions are physically possible. The basic calculational process is indicated in Figure 3.2-4.

At the time when HXND3S is called, only conditions at the node inlet (for both sides of the tube) are known. From these conditions, conditions at the node outlet, as well as the node average tube temperature are estimated. Using these estimates, the heat transfer rates on both sides of the tube are evaluated. Multiple heat transfer modes are possible, with up to five mode regions allowed. Energy balance requires that the heat transfer rates be equal on both sides of the tube, and the tube temperature is adjusted iteratively until this is true. Finally, the enthalpy gradient across the node and the heat transfer rate have to be consistent, so outlet conditions are adjusted iteratively until the agreement is close.

Subroutine HXND3S tends to be the point of discovery for many types of errors that slip through the routine error checks. This routine contains many subtleties that have been closely reviewed on a number of occasions. One should assume an error flagged in or near HXND3S is really caused elsewhere, at least until proven otherwise. This is particularly true for systems where the user is only estimating key parameters.

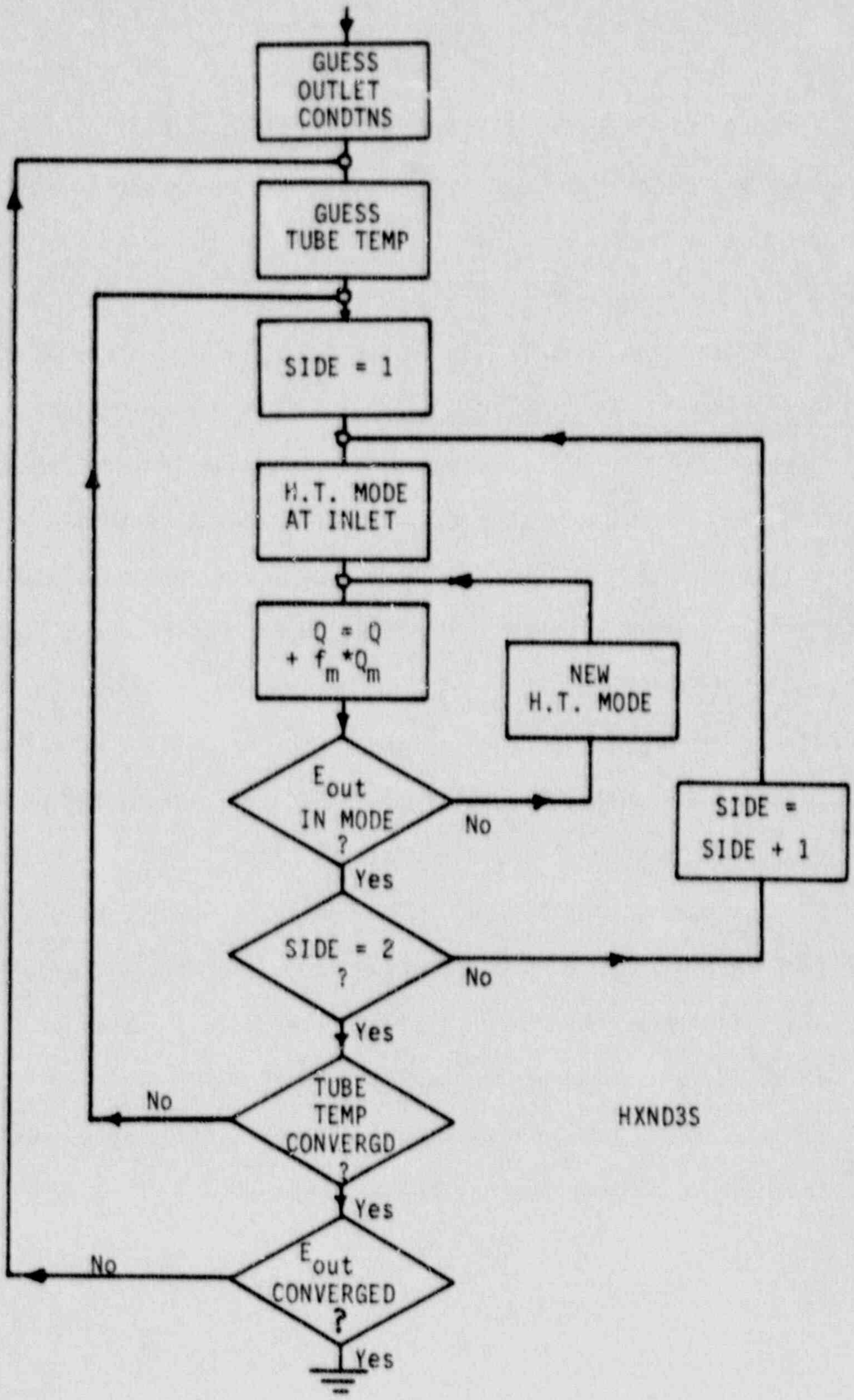


Figure 3.2-4 Flow Chart for Subroutine HXND3S

3.2.3.2.3 PRFL3S

Subroutine PRFL3S adjusts the pressures and mass flow rates in each of the system networks at the end of each system iteration. The calculational process is indicated in Figure 3.2-5.

Subroutine PRFL3S is essentially the iterative solution of a matrix equation that approximates the W^2 factor in a linearized matter. From iteration to iteration, only the flow rate contribution and the pressure gradient in isolated pumps, valves, and turbine stages, are updated. The pressure gradients through pipes, heat exchangers and imbedded pumps and valves are updated only during system iterations.

The most likely problem to arise in the execution of this subroutine is the calculation of negative pressures. While such pressures are forced to be positive, other complications can develop under these extreme conditions. The best solution is to adjust the form loss factors (including valve losses) and the initial guesses on the volume and inlet boundary pressures.

3.2.3.3 TRANSIENT

Most of the transient subroutines are relatively straightfoward, and can be understood using information provided elsewhere in this documentation. The exception is subroutine HX3T.

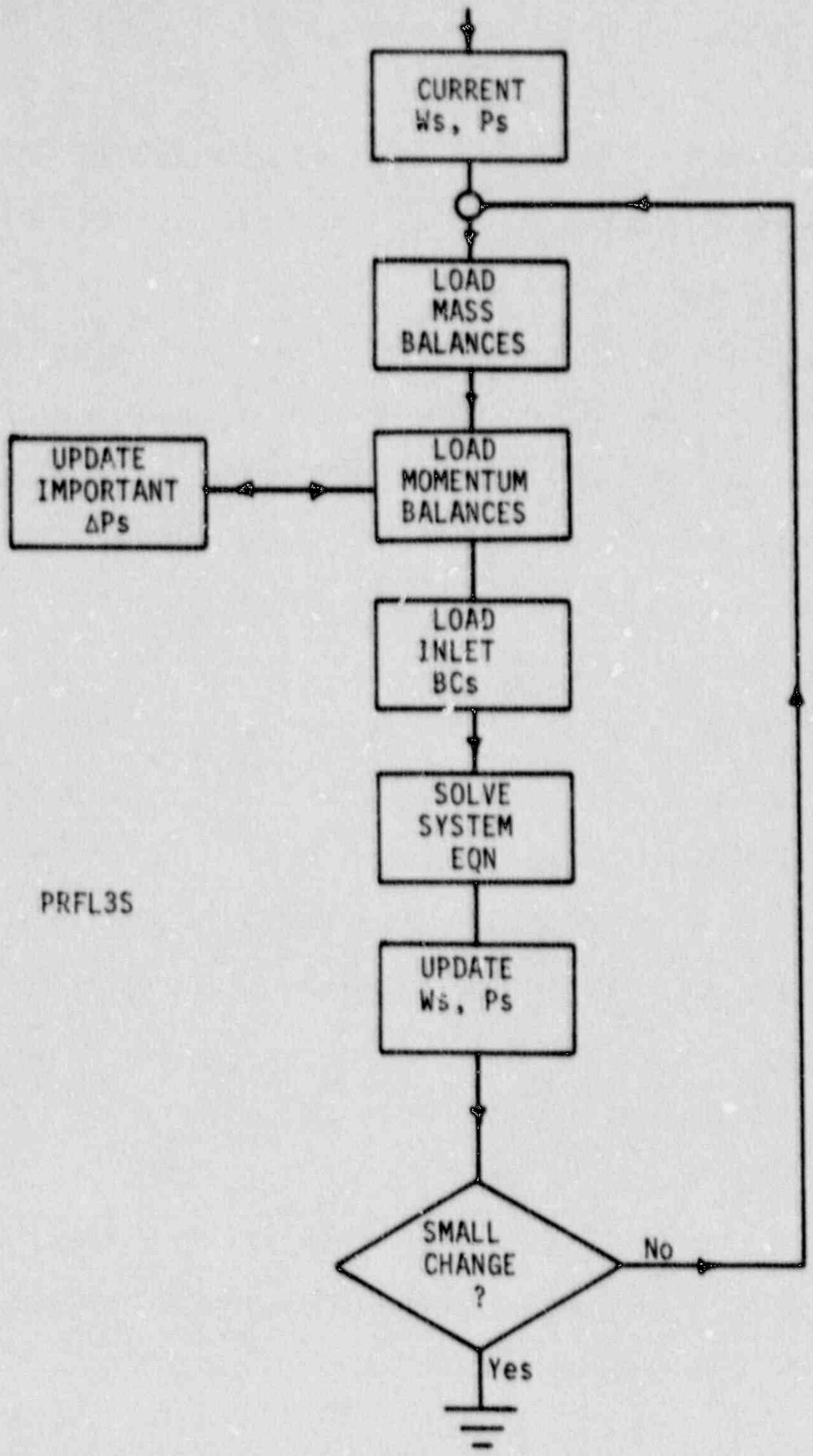


Figure 3.2-5 Flow Chart for Subroutine PRFL3S

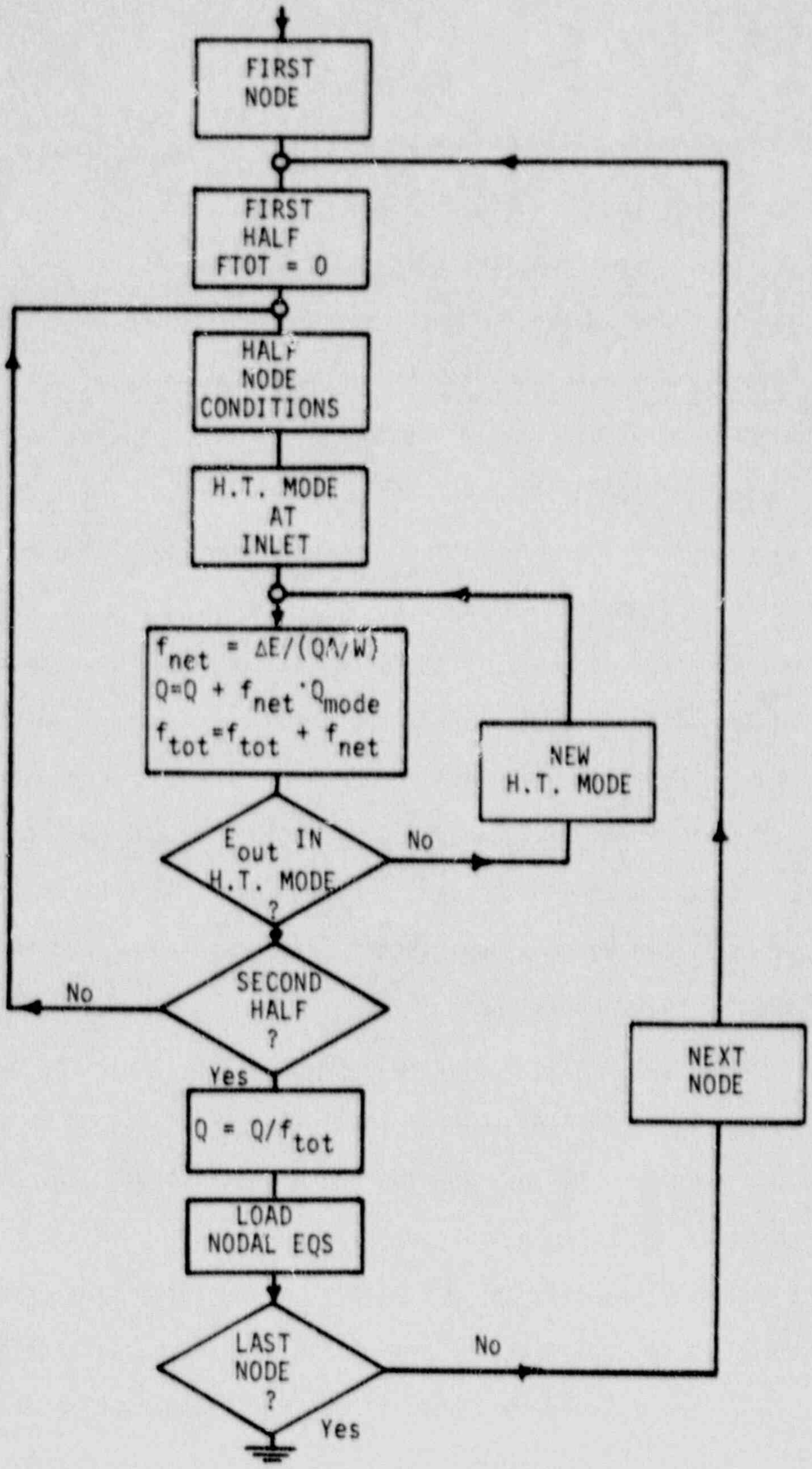
3.2.3.3.1 HX3T

Subroutine HX3T performs the transient heat exchanger calculations. The process is shown in Figure 3.2-6.

Two factors complicate the calculations. First, it is possible to have node average enthalpies that are not the average of conditions at the ends. This happens when the flow was either converging or diverging in the node during the previous step, so donor cell differencing was not used. Second, because the node heating and enthalpy gradient can be inconsistent due to transient effects, determination of the proportion of the node in each heat transfer mode is more complicated.

Each node is calculated in two halves, with the assumption that the average enthalpy is unrelated to the enthalpy at either end. The heat transfer mode is determined at the half-node inlet and changed as often as necessary (up to 5 regimes for the whole node) to the half-mode outlet, for both the first half-node and the second half-node. The node fraction in a given mode is estimated using a quasi-steady energy balance, and the total heating is divided by the total weighting.

The heat transfer mode weighting is best explained by example. Consider a node with subcooled water at the inlet, the onset of boiling exactly at the node average enthalpy, and boiling at the outlet. Further, assume that the enthalpy rise across the node is twice what is indicated by the heating and the mass flow rate. When considering the first half node, which is subcooled, we would determine that a heat transfer length approaching the whole node ($f_{net} \approx 1.0$) would be needed to get the enthalpy rise across only the first



HX3T

Figure 3.2-6 Flow Chart for Subroutine HX3T half. Similarly, in the second half-node, the heat transfer rate would be such that a length approaching the whole node would be needed to get the enthalpy rise across the second half-node (again, $f_{nat} \approx 1.0$). Thus, the quasi-steady heat flux would be exactly enough for the given flow and enthalpy gradient. However, this must be divided by the total required node fraction, f_{tot} (≈ 2.0), to get the actual heating in the node. The node heating and other node conditions are loaded in the segment matrix equation.

3.2.3.4 PROPERTY PACKAGE

More than 10% of the MINET subroutines and functions are property related. This group of functions, which constitutes the MINET property library, are all in SI units. The library is easily extended, and will grow according to our needs. These functions are grouped by use in the tables provided in this section.

The structural property functions are in Table 3.2-2. There are currently ten structural materials in the imbedded tables. The "TYPE" parameter is determined by the user through specification of M3TYPE, M3CORT, and M3STRC on the 301D input record(s) (see Figure 2.2-2).

Table 3.2-2. Structure Property Functions

Conductivity	k = COND3C (TYPE, T)
Heat Capacity	c_p = HCAP3C (TYPE, T)
Density	ρ = DENS3C (TYPE, T)

General fluid property functions are in Table 3.2-3. These functions call the fluid-dependent property functions listed in the remaining tables. For a property that is identically 0.0, e.g., the derivative of the sodium density with respect to pressure, the function sets the value to 0.0. The fluid in each network is designated via the IFTYPN data specification in input record 801D.

Table 3.2-3 General Fluid Property Functions

Enthalpy	E = ENTH3C (T, P, FLUID, SIDE)
Temperature	T = TEMP3C (E, P, FLUID, SIDE)
Density	ρ = RHO3C (E, P, FLUID, SIDE)
Viscosity	μ = VISC3C (E, P, FLUID, SIDE)
Derivatives	
	$\partial\rho/\partial P$ = DRDP3C (E, P, FLUID, SIDE)
	$\partial\rho/\partial E$ = DRDE3C (E, P, FLUID, SIDE)
Heat Transfer	
	h = HTC3C (SIDE, MODE, E, G, Tube Temp, k, T) (Fluid Type Implicit Via Commons, SIDE)
	G = mass velocity = ρV k = thermal conductivity of tube

Water property functions are shown in Table 3.2-4. This is the largest set of property functions, both because of the two-phases and because our need has been greater. For instance, entropy functions are available only for water and steam because we have not wanted to run sodium, air, or NaK through the turbine module.

Sodium property functions are given in Table 3.2-5. These functions are simple and fast running because subcooled sodium is essentially incompressible.

Air property functions are listed in Table 3.2-6. These properties are accurate near atmospheric pressure, and are based largely on ideal gas behavior.

Table 3.2-4 Water Property Functions

Generic

Entropy	S = SWAT3C (E, P)
Enthalpy	E = ESW3C (S, P)

Liquid

Temperature	T = TMPL3T (E, P)
Density	ρ = DENL3D (E, P)
Enthalpy	E = ENTL3H (T, P)
Viscosity	μ = VISL3N (E, P)
Heat Cap	c_p = CPL3C (E, P)
T Cond	k_t = CONL3K (E, P)
Derivatv	$\partial\rho/\partial E$ = DRLH3D (E, P)
Derivatv	$\partial\rho/\partial P$ = DRLP3D (E, P)

Steam

Temperature	T = TMPV3T (E, P)
Density	ρ = DENV3D (E, P)
Enthalpy	E = ENTV3H (T, P)
Viscosity	μ = VISV3N (E, P)
Heat Cap	c_p = CPL3C (E, P)
T Cond	k_t = CONV3K (E, P)
Derivatv	$\partial\rho/\partial E$ = DRVH3D (E, P)
Derivatv	$\partial\rho/\partial P$ = DRVP3D (E, P)

Saturation

Liq Enthalpy	E_f = ESTL3H (P)
Stm Enthalpy	E_g = ESTV3H (P)
Liq Entropy	S_f = SFWT3C (P)
Stm Entropy	S_g = SGWT3C (P)
Surf Tension	σ = STEN3S (T_{sat})
Sat Pressure	P = PSAT3P (T, P_{guess})

Table 3.2-5 Sodium (Na) Property Functions

Subcooled

Temperature	T = TNA3C (E)
Enthalpy	E = ENA3C (T)
Density	ρ = RNA3C (E)
Viscosity	μ = VSNA3C (E)
Heat Cap	c_p = HCPN3C (E)
T Cond	k_t = TKNA3C (E)
Derivatv	$\partial\rho/\partial E$ = DREN3C (E)

NOTE: Assume $\partial\rho/\partial P = 0.0$

Table 3.2-6 Air Property Functions (Atmospheric)

Temperature	T = TAIR3C (E)
Enthalpy	E = EAIR3C (T)
Density	ρ = RAIR3C (E, P)
Viscosity	μ = VAIR3C (E)
Heat Cap	c_p = CPAR3C (E)
T Cond	k_t = CAIR3C (E)
Derivatv	$\partial\rho/\partial P$ = DRPA3C (E, P)
Derivatv	$\partial\rho/\partial E$ = DREA3C (E, P)

Properties for eutectic NaK are determined using the functions listed in Table 3.2-7. Eutectic NaK is also essentially incompressible in the subcooled state.

Table 3.2-7 NaK Property Functions

Subcooled

Temperature	T = TMNK3C (E)
Enthalpy	E = ENNK3C (T)
Density	ρ = RHNK3C (E)
Viscosity	μ = VSNK3C (E)
Heat Cap	c_p = CPNK3C (E)
T Cond	k_t = CDNK3C (E)
Derivatv	$\partial\rho/\partial E$ = DRNK3C (E)

NOTE: Assume $\partial\rho/\partial P = 0.0$

The current heat transfer functions are given in Table 3.2-8. This list is almost certain to increase in length as more heat exchanger types are considered.

Finally, some flow related functions are listed in Table 3.2-9. The friction factor functions, which are applicable for all fluid types, are imbedded (in-line functions) in subroutine DP3C. Critical flow models are currently limited to water/steam, but models for the other fluid could be incorporated easily. Note that the critical flow option can be bypassed for any given value by setting 13CHOK = 0 on the 1101D input record. As water/steam is the only fluid modeled with two-phases, the THOM two-phase (2-Φ) multiplier is the only one included at this time.

Table 3.2-8 Heat Transfer Correlations

Water/Steam

Forced Convection	H = HWFC3C (E, DEQ, G, P, EF)
Nucleate Boiling	H = HWNB3C (E, X, T, TC, D, DEQ, G, SIDE)
Film Boiling	H = HWFB3C (X, TC, CT, D, DEQ, G, SIDE)
Superhtd Convection	H = HWSC3C (T, TC, CT, D, DEQ, G, SIDE)
Condens On Vert Surf	H = HWCN3C (E, D, A, SIDE)
Conds In Horz Tubes	H = HCIT3C (TC, D, CT, SIDE)
Condens On Tube Banks	H = HCOT3C (TC, D, CT, NPATH, SIDE)

Critical Heat Flux:

DNB	X = XDNB3C (G, Q, RF, RG, EFG)
Dryout	X = XDRY3C (G, Q, D, EFG)

Sodium

Inside Tubes/Pipes	H = HNAI3C (E, G, DEQ)
Outside Tubes	H = HNAF3C (T, POD, G, DEQ)

Air

Across Tubes	H = HTCA3C (E, G, DEQ)

NaK

In/Out Tubes	H = HTNK3C (E, G, DEQ)

Key:

E = Enthalpy
T = Temperature
G = Mass Velocity
Tc = Tube Centerline Temp
Q = Heat Flux
P = Pressure
G = Mass Velocity = ρV
NPATH = No. Tubes in Bank
X = Quality
D = Diameter
DEQ = Equiv Hydrl Diam
POD = Pitch-to-Diam Ratio
SIDE = Side of Tubes
R = Density
CT = Thermal Conductivity

NOTE: Several Access Saturation Property Common Block, Also.

Table 3.2-9 Flow Related Functions

Generic

Friction Factor - Imbedded In DP3C

Water

Critical Flow	G = CRIT3C (E, P, SIDE)
Water	G = GFSK3G (E, P)
Two-Phase	G = GMCY3C (E, P)
Superheated	G = GSUP3C (E, P)
Two-Phase Multiplier	ϕ = THOM3C (P, X)

3.2.3.5 INTERNAL UTILITIES

Internal Utilities are procedures used internally by MINET to perform standardized functions such as equation solving, data management, or diagnostic analysis. Each utility is implemented as one or more subroutines, each of which performs one of a set of related functions on a shared data entity.

3.2.3.5.1 INPUT SPECIFICATION UTILITY (ISU)

ISU provides functions to construct and access standardized specifications for external data input files. These specifications are used by MINET during the Input Processing phase.

ISU input data specifications are based on the following hierarchy of abstract objects representing the major components of the generalized external input data file.

FILE - a group of RECORDs identified under a common character-encoded file identifier (FILEID).

RECORD - a sequence of one or more data ITEMs identified by an integer-encoded record number.

ITEM - a sequence of one or more data FIELDs.

FIELD - a character-encoded numeric data value of either INTEGER or REAL type.

ISU functions are implemented as a set of FORTRAN subprograms:

ISU9R - Initializes internal implementation data.

PUTF9R - Begins a new file specification entry.

PUTR9R - Begins a new record specification entry

PUTI9R - Puts a new item specification entry in the currently open record specification.

REPS9R - Begins a repeating sequence of record items.

GETF9R - Opens file specification for a given file identifier.

GETR9R - Opens record specification for a given record identifier.

GETI9R - Gets next item specification in currently open record.

RISU9R - Releases ISU internal data storage for re-use.

LSPC9R - Prints a formatted listing of all ISU specifications.

3.2.3.5.2 INPUT FILE MANAGER (IFM)

IFM provides functions supporting the interface between the external data input file and the data reading portion of the Input Processor.

IFM functions are currently being performed by GENRD [31], a free-format card input processor developed at Los Alamos National Laboratory. GENRD reads character-encoded MINET input records and decodes numeric fields, placing the resulting INTEGER and REAL type field values in arrays which are passed back to the calling code. Input record numbers, field counts, and syntactic error conditions flags are also passed back.

3.2.3.5.3 GLOBAL CONTAINER MANAGER (GCM)

GCM provides functions supporting the allocation and management of variably-dimensioned data storage residing in a globally-shared container array. Named blocks of contiguous array locations are allocated and referenced by means of pointers. Container maps and content listings are printed on request. The entire container content may be saved on an external file and restored on request.

3.2.3.5.3.1 GLOBAL CONTAINER ARRAY

The global container array, referred to as CONTAINER, consists of a large one-dimensional FORTRAN array residing in a labelled COMMON block. Program units, requiring access to the CONTAINER data, include a declaration of the labelled COMMON. They then either access the array elements directly or indirectly by way of locally declared dummy arrays which are EQUIVALENCED to the CONTAINER.

3.2.3.5.3.2 ALLOCATION MANAGEMENT

Allocation of named data blocks in the CONTAINER is performed by GCM in response to external requests. These fall into two categories:

- VIRTUAL allocation occurs implicitly with requests to load data in specific named data blocks. This is accomplished through a set of subroutines which treat the blocks as abstract data types although they also reside in the CONTAINER. Each request specifies a block name, a block index, and a data value to be loaded at the indexed location. Data may be loaded in this way, extending block size or overwriting previous data until block size is fixed by a pointer value request (call to NPNT9U).

- IMMEDIATE allocation occurs in response to requests in which the block size and name are given. Each request results in both an allocation and the return of a pointer.

3.2.3.5.3.3 SUBROUTINE SPECIFICATIONS

GCM functions are implemented by the following subprograms:

INGC9U - Initializes internal implementation data for GCM.

PGCI9U - Puts INTEGER value in specified location of named virtual container block.

PGCR9U - Puts REAL value in specified location of named virtual container block.

NPNT9U - Returns pointer to named container block.

LPNT9U - Returns length of named container block.

GCTP9U - Prints a t[illegible]f block names, lengths, and pointer values on OUTPUT [illegible] Allocation errors are flagged with diagnostic mes[illegible].

GCPR9U - Prints a[illegible]cted listing of container contents on OUTPUT file.

SVGC9U - Saves container contents on external SCRATCH file.

REGC9U - Restore container contents from external SCRATCH file previously generated by SVGC9U.

GCER9U - Tests for container allocation errors and prints an error summary on OUTPUT file.

3.2.3.5.4 DATA MANAGEMENT UTILITY (DMU)

DMU provides high-level data management functions operating on abstract data types not provided as part of the FORTRAN language.

3.2.3.5.4.1 NODE DATA TYPE

A NODE data type consists of an indexable array, each element of which may be of either REAL or INTEGER type. Associated with each NODE is a node identifier (NODEID) and a pointer which may be used to point to another node. NODEs may be created dynamically as required and then released when no longer needed, the storage resource being available for serial re-use. The NODE array storage is allocated dynamically on demand as data is stored in it, eliminating the need for any preallocation.

NODE functions are implemented by the following subprograms:

INN9U - Initializes internal implementation data.

NEWN9U - Creates a new NODE and returns a pointer to it.

LNKN9U - Links two NODEs by means of NODE pointer.

NXTN9U - Returns a pointer to the next NODE in a NODE chain.

PUTN9U - Stores an integer value in an indexed location of a NODE array.

GETN9U - Returns an integer value stored in an indexed location of a NODE array.

PUTF9U - Stores a REAL value in an indexed location of a NODE array.

GETF9U - Returns a REAL value stored in an indexed location of a NODE array.

INPT9U - Scans a NODE chain for a NODE with given NODEID and returns a pointer to it.

NSIZ9U - Returns the size of a NODE array.

NID9U - Returns the value of the NODEID for a given NODE.

RELN9U - Releases a NODE for re-use.

3.2.3.5.4.2 MODULE DATA TYPE

A MODULE data type consists of a set of NODEs grouped under a common module identifier (MODID). MODULE data is addressed by the coordinate pair (NODEID, index), where INDEX is an INTEGER index into the NODE array. This coordinate pair may be thought of as addressing a data area within the MODULE as data storage requests are made. MODULES may be created dynamically as required and then returned when they are no longer needed. NODE storage within each MODULE is created dynamically on demand as storage requests are made.

MODULE functions are implemented as a group of FORTRAN subprograms:

INM9U - Initializes internal implementation data.

NEWM9U - Creates a new MODULE and returns a pointer to it.

PUTD9U - Stores INTEGER data in a MODULE data area.

GETD9U - Returns INTEGER data values stored in a MODULE data area.

PUTR9U - Stores REAL data value in MODULE data area.

GETR9U - Returns REAL data values stored in a MODULE data area.

MID9U - Returns MODID associated with a MODULE.

DSIZ9U - Returns size of a given data area within a MODULE.

RELD9U - Releases specific data area storage within a MODULE.

RELM9U - Releases data storage for an entire MODULE.

3.2.3.5.4.3 LIST DATA TYPE

A LIST data type consists of a doubly-linked list of MODULEs, also called ITEMS. LISTs may be created and deallocated dynamically as required. When a new LIST is created, a pointer is generated which points to a dummy LIST header item. New ITEMs may be inserted in and deleted from the LIST by means of pointers.

LIST functions are implemented as a group of FORTRAN subprograms:

INL9U - Initializes internal implementation data; must be called once before LIST utility is used.

NEWL9U - Creates a new instance of a LIST type and returns a pointer to the dummy head item.

RELL9U - Deallocates entire LIST and resets head item pointer to NIL.

INSL9U - Inserts an item in LIST following a given ITEM.

NXTI9U - Returns a pointer to the successor of a given ITEM.

LSTI9U - Returns a pointer to the predecessor of a given ITEM.

LOCL9U - Returns a pointer to the next ITEM encountered having a specified INTEGER type MODID.

LOCR9U - Returns a pointer to the next ITEM encountered having a specified REAL type MODID.

LSIZ9U - Returns an INTEGER type count of the number of ITEMs in a given list, exclusive of the HEADER.

LCNT9U - Returns a count of the number of ITEMs in a given LIST having a given MODID.

3.2.3.5.4.4 ARRAY DATA TYPE

An ARRAY data type consists of a two-dimensional array of REAL type elements. Each element is addressed according to its ROW and COLUMN indices. ARRAYs may be created and deallocated dynamically as required. On creation, the ARRAY dimensions are specified as maximum ROW and COLUMN index values (MAXROW and MAXCOL). Each ARRAY is accessed by means of a pointer provided as part of the creation process.

ARRAY functions are implemented as a group of FORTRAN subprograms:

INA9U - Initializes internal implementation data; must be called once prior to first use of ARRAY utility; may also be called to deallocate and reinitialize entire ARRAY data storage.

NEWA9U - Creates a new instance of a ARRAY type and returns a pointer to it.

PUTA9U - Stores a REAL type value in a specified ELEMENT.
GETA9U - Returns a REAL type value stored in a specified ELEMENT.

ADDA9U - Adds a REAL type value to that stored in a specified ELEMENT.

PRTA9U - Prints the values of all ELEMENTs for a given ARRAY on the OUTPUT file.

LEQ9U - Solves a system of linear equations of the form Y=A*X, where A, Y, and X are pointers to ARRAY types.

3.3 CODE DATA STRUCTURE

3.3.1 LARGE STORAGE ARRAYS

In developing MINET, much effort was placed on optimizing the use of data storage, primarily because of the limited space available in small core memory in the CDC-7600 computer. There are only three significant arrays with fixed dimensions, and virtually all storage and computational space is contained within these arrays. Typically these arrays are dimensioned around 6000 words each, but through simple updates they could be changed to a much larger number, say 500,000 words. As a result, the code can be made to run an infinitely large and complex problem, as long as one has a computer with enough storage.

The first of these large arrays, referred to as the "container" (see Section 3.2.3.5.3), originated in the SSC code [11]. All of the variably dimensioned arrays, such as the pump head for each pump in the system, reside in the container array. This is accomplished by assigning a pointer into the container, referencing the location at which values for a given variable begin, and equivalencing each of the variable arrays to the container array. For example, one might have a pointer for the pump head, IH3PUM, with a value of 1092, in a deck with two pumps. The head for the first pump would be at location 1093 in the container, and the second pump head would be at location 1094. Of course, this is all fully automated and works quite smoothly.

The second of the large arrays is controlled by the Data Management Utility (see Section 3.2.3.5.4). It is used in the input processing phase to temporarily store incoming data, until it can be properly organized.

The third of these arrays is used for Array Data Type storage (see Section

3.2.3.5.4.4). It is used in performing various matrix calculations during the steady state and transient calculations.

There are a few variables that are not variably dimensioned. Almost always these are either scalars or of dimension 2, for the two sides of the heat exchangers. These fixed dimensioned values can in no way limit the size of the system that can be represented.

3.3.2 GLOBAL COMMONS AND USAGE (TABLE)

Many of the MINET variables reside in common blocks, which are shared by multiple subroutines and functions. In Table 3.3-1, the names of each subroutine and function having access to each of the common blocks is indicated.

3.3.3 NAMING CONVENTION

MINET was originally part of the larger SSC program library [11], and follows most of the naming conventions for that code. For this reason, the digit 3 appears in the second position in nearly all the MINET variables residing in common blocks. The naming convention for the initial letters of SSC variables is given in Table 3.3-2. Many of the variables in MINET do follow this convention, but we have, occasionally, strayed from these rules. The definitions provided in the next section, the data dictionary, take precedence.

3.3.4 DATA DICTIONARY

MINET variables are defined in the "Data Dictionary," shown in Table 3.3-3. Variables are listed alphabetically, along with their container pointer names, their dimensions, their definitions, and the name of the common block in which they reside.

Table 3.3-1 Common Block Usage

```
.............................................................................................................................
. COMMON  . DEFINED IN      $ = NOT REFERENCED                                                                          .
.............................................................................................................................
. ADAB9U  .  ADDA9U   ADDM9U   CRKR9U   GETA9U   GETM9U   INA9U    LEQ9U    NEWA9U   PRTA9U   PUTA9U   PUTM9U           .
.         .  RELA9U                                                                                                     .
.............................................................................................................................
. BC3P    .  ADVN3T   ENET3S   ETX3C    GETB3U   INIT3S   IOSG3T   IPTS3R   PREP3T   PRFL3S   PRNT3C   PUTB3U           .
.         .  SGBC3T   SUBN3S   WESM3S                                                                                   .
.............................................................................................................................
. DATA9   .  CRDR9R   INIT9U   PAGE9U                                                                                   .
.............................................................................................................................
. DCON9U  .  DEFP3R   DMOD3R   GETD9U   GETF9R   GETM3R   GETR9R   GETR9U   INN9U    INPT9U   INRD3R   INSL9U           .
.         .  INTG9U   IRPT9U   ISU9R    LCNT9U   LOCL9U   LOCR9U   LSIZ9U   LSTI9U   MID9U    NBR3R    NET3R            .
.         .  NEWL9U   NEWN9U   NSIZ9U   NXTA9U   NXTM3R   ORDR3R   PUTD9U   PUTI9R   PUTR9R   PUTR9U   REAL9U           .
.         .  RELD9U   RELL9U   RELM9U   RELN9U   RISU9R   RLID9U   SYS3R                                                .
.............................................................................................................................
. GC9U    .  GCER9U   GCPR9U   GCTE9U   GCTP9U   IGA9U    INGC9U   JGCT9U   LPNT9U   MVGA9U   MVGC9U   NPNT9U           .
.         .  PGCI9U   PGCR9U   REGC9U   SVGC9U                                                                          .
.............................................................................................................................
. GLOB3I  .  ADTB3T   BKEY3S   CALC3R   COMDUM   CTRL3R   ENET3S   FRAC3S   GETB3U   INIT3S   KPRC3S   MDST3S           .
.         .  MINT3S   MINT3T   MRCH3S   PREP3T   PRFL3S   PRNT3C   PUTB3U   QBAL3S   QBRG3S   RECX3U   SUBN3S           .
.         .  SVCX3U   SYS3R    VOLM3S   VOLS3T   WESM3S                                                               .
.............................................................................................................................
. GLOB3V  .  ADTB3T   ADVN3T   COMDUM   HX3T     IOSG3T   LOAD3T   MINT3S   MINT3T   MRCH3T   NET3T    PREP3T           .
.         .  PRNT3C   PUMP3T   RECX3U   SGBC3T   SVCX3U   SYS3R    TBSG3T   TIME3T   VALV3T                             .
.............................................................................................................................
. HX3P    .  ADTB3T   ENET3S   HX3S     HX3T     IPTS3R   MDST3S   MODL3C   PRHX3S   PRNT3C   QBAL3S   QBRG3S           .
.         .                                                                                                             .
.............................................................................................................................
. ISUV9R  .  GETF9R   GETI9R   GETR9R   ISU9R    PUTF9R   PUTI9R   PUTR9R   REPS9R   RISU9R                             .
.............................................................................................................................
. ITERP   .  CDINPT   ERRMSG                                                                                            .
.............................................................................................................................
. LDAB9U  .  INL9U    INSL9U   LSTI9U   NEWL9U   NXTI9U   RELL9U                                                        .
.............................................................................................................................
. LNKS3I  .  DEFP3R   FSTO3R   GETM3R   ILNK3R   KPRT3R   LINK3R   NBR3R    NXTO3R   PCNT3R   ZPRT3R                    .
.............................................................................................................................
. LNK3P   .  ADTB3T   ADVN3T   CALC3R   ENET3S   FRAC3S   GETB3U   INIT3S   IOSG3T   IPTS3R   KPRC3S   MDST3S           .
.         .  MODL3C   MRCH3S   MRCH3T   NET3T    PREP3T   PRFL3S   PRHX3S   PRNT3C   PUTB3U   QBAL3S   QBRG3S           .
.         .  SGBC3T   WESM3S                                                                                            .
.............................................................................................................................
. MDAB9U  .  INL9U    INM9U    MID9U    MTYP9U   NEWM9U   NEWR9U   RLID9U                                               .
.............................................................................................................................
. MODC3P  .  ADVN3T   ENET3S   IPTS3R   KPRC3S   MDST3S   MODL3C   NET3T    PREP3T   PRNT3C   QBAL3S   QBRG3S           .
.         .                                                                                                             .
.............................................................................................................................
. MODL3P  .  ADTB3T   ENET3S   ETX3C    IOSG3T   IPTS3R   MODL3C   PRNT3C   WESM3S                                      .
.............................................................................................................................
. MOD3I   .  BCOR3C   COMDUM   CROS3S   DP3C     HTC3C    HXND3S   HX3S     HX3T     IMOD3C   MODL3C   PIPE3S           .
.         .  PIPE3T   PUMP3S   PUMP3T   QPM3C    TBSG3S   TBSG3T   VALV3S   VALV3T                                      .
.............................................................................................................................
. MOD3V   .  BCOR3C   COMDUM   CROS3S   DP3C     HTC3C    HXND3S   HX3S     HX3T     IMOD3C   LOAD3T   MODL3C           .
.         .  PIPE3S   PIPE3T   PUMP3S   PUMP3T   QPM3C    TBSG3S   TBSG3T   VALV3S   VALV3T                             .
.............................................................................................................................
```

```
.....................................................................................................................
. COMMON   . DEFINED IN      $ = NOT REFERENCED                                                                     .
.....................................................................................................................
. NDAB9U   . GETF9U   GETN9U   INN9U    INPT9U   IRPT9U   LNKN9U   NEWN9U   NID9U    NSIZ9U   NXTA9U   NXTN9U     .
.          . PUTF9U   PUTN9U   RELN9U                                                                               .
.....................................................................................................................
. NET3P    . ADVN3T   ENET3S   INIT3S   IPTS3R   KPRC3S   MRCH3S   MRCH3T   NET3T    PRFL3S   PRNT3C   QBAL3S     .
.          . QBRG3S   SUBN3S   VOLM3S   WESM3S                                                                      .
.....................................................................................................................
. NODE3I   . COMDUM   CROS3S   HXND3S   HX3S                                                                        .
.....................................................................................................................
. NODE3V   . COMDUM   CROS3S   DP3C     HXND3S   HX3S     HX3T     LOAD3T   PIPE3S   PIPE3T   TBSG3S   TBSG3T     .
.          .                                                                                                        .
.....................................................................................................................
. NODL3P   . ADTB3T   ADVN3T   HX3S     HX3T     IPTS3R   PIPE3S   PIPE3T   PRNT3C   PUMP3S   PUMP3T   TBSG3S     .
.          . TBSG3T   VALV3S   VALV3T                                                                               .
.....................................................................................................................
. ORD3I    . INOR3R   JDAT3R   LSTM3R   MARK3R   MORD3R   NCLS3R   NXTM3R   ORDR3R   PIDS3R   PUTJ3R              .
.....................................................................................................................
. PUMP3P   . IPTS3R   PREP3T   PRNT3C   PUMP3S   PUMP3T                                                             .
.....................................................................................................................
. SATM3V   . BCOR3C   COMDUM   CRIT3C   DP3C     DRDE3C   DRDP3C   ENTH3C   HCIT3C   HCOT3C   KTC3C    HWCN3C     .
.          . HWFB3C   HWNB3C   HWSC3C   IMOD3C   RHO3C    SATM3C   SATO3C   TEMP3C   VISC3C                       .
.....................................................................................................................
. SATP3V   . COMDUM   SATM3C   SATP3C                                                                               .
.....................................................................................................................
. SAVE     . GENRD                                                                                                  .
.....................................................................................................................
. SCRH3R   . DMOD3R   INIT3R   INRD3R                                                                               .
.....................................................................................................................
. SCRH9I   . CRDR9R   READ3R                                                                                        .
.....................................................................................................................
. SEG3P    . ADVN3T   ENET3S   FRAC3S   INIT3S   IOSG3T   IPTS3R   KPRC3S   LOAD3T   MDST3S   MRCH3S   MRCH3T     .
.          . NET3T    PRFL3S   PRHX3S   PRNT3C   QBAL3S   QBRG3S   SGBC3T   TBSG3S   TBSG3T   WESM3S              .
.....................................................................................................................
. SNET3P   . BKEY3S   ENET3S   FRAC3S   IPTS3R   KPRC3S   MDST3S   PRNT3C   QBAL3S   QBRG3S   SUBN3S   WESM3S     .
.          .                                                                                                        .
.....................................................................................................................
. TIME3I   . CTRL3R   INIT3R   SDEL9T   TIME3T                                                                      .
.....................................................................................................................
. TIME3P   . IPTS3R   SDEL9T                                                                                        .
.....................................................................................................................
. TIME3V   . CTRL3R   TIME3T                                                                                        .
.....................................................................................................................
. TRND3P   . ADVN3T   IPTS3R   PREP3T   SGBC3T                                                                      .
.....................................................................................................................
. TURB3P   . IPTS3R   PREP3T   PRFL3S   PRNT3C   TBSG3S   TBSG3T                                                    .
.....................................................................................................................
. UNID9I   . IUNI9U   UNIQ9U                                                                                        .
.....................................................................................................................
. UNIT3I   . DMOD3R   GETM3R   INIT3U   INRD3R   LINK3R   LIST3R   MINT3S   PRNT3C   PRTA9U   READ3R   RECX3U     .
.          . SVCX3U                                                                                                 .
.....................................................................................................................
. UNIT9U   . CRDR9R   ERR9U    INIT9U   MINET    PAGE9U                                                             .
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. COMMON   . DEFINED IN      $ = NOT REFERENCED                                                                                     .
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
. VALV3P   .  CALC3R   IOSG3T   IPTS3R   PREP3T   PRFL3S   PRNT3C   VALV3S   VALV3T                                             .
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
. VD9V     .  ADTB3T   ADVN3T   BKEY3S   CALC3R   DPSV3C   ENET3S   ETX3C    EVLV3S   F[illegible]T    FRAC3S   GCPR9U      .
.          .  GETB3U   HX3S     HX3T     INGC9U   INIT3S   IOSG3T   KPRC3S   LOAD3T   M[illegible]3S   MODL3C   MRCH3S      .
.          .  MRCH3T   MVGA9U   NET3T    PIPE3S   PIPE3T   PREP3T   PRFL3S   PRHX3S   PRNT3C   PUMP3S   PUMP3T              .
.          .  PUTB3U   QBAL3S   QBRG3S   REGC9U   SDEL9T   SGBC3T   SUBN3S   SVGC9U   TBSG3S   TBSG3T   VALV3S              .
.          .  VALV3T   VOLM3S   VOLS3T   WESM3S                                                                             .
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
. VOL3P    .  ADVN3T   DPSV3C   ENET3S   EVLV3S   FLV3T    FRAC3S   INIT3S   IOSG3T   IPTS3R   KPRC3S   NET3T               .
.          .  PRFL3S   PRNT3C   QBAL3S   QBRG3S   SUBN3S   VALV3T   VOLM3S   VOLS3T   WESM3S                                .
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . .
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TABLE 3.3-2

Variable Naming Convention

A	Area	m^2
B	Mass	kg
C	Material properties; constants	
D	Density	kg/m^3
E	Energy; enthalpy	J; J/kg
F	Fractions, factors	-
G	Mass flow rate per unit area	$kg/s\ m^2$
H	Heat Transfer Coefficient	W/m^2K
L	Control flags, counters, etc.	
M	Maximum allowable dimension	
N	Actual dimension specified	
P	Pressure; power	N/m^2; W
Q	Surface heat flux; miscellaneous	W/m^2; --
R	Angular Measure, Relative Speed	radians
S	Time	s
T	Temperature	K (not C)
U	Velocity, angular velocity or speed	m/s; rpm
V	Volume, Viscosity	m^3, $N \cdot S/m^2$
W	Mass flow rate	kg/s
X	Distance (length or radius)	m
Y	Distance (width or diameter)	m
Z	Distance (height or axial direction)	m

Table 3.3-3 Data Dictionary

A3LPHA	IA3LPH	SGMNT	PR LOSS FACTOR,MULTIPLIES FLOW SQUARED	SEG3P
A3M	SCALAR	-	IDENTIFIER FOR SEGMENT MATRIX A	GLOB3P
A3NODE	-	2	FLOW AREA OF MODULE,PER PARRALEL PATH,PER TUB FOR HX	MOD3V
A3PUMP	IA3PUM	5PUMP	COEFFICIENTS OF HEAD VS SPEED,FLOW CURVE	PUMP3P
A3STRC	IA3STR	HX	SURFACE AREA BETWEEN STRUCTURE AND FLUID,SUM OVR PTHS	HX3P
B3ETA	IB3ETA	SGMNT	PR LOSS PARAMETER,INCLUDES GRAVITY	SEG3P
B3M	SCALAR	-	IDENTIFIER FOR SEGMENT MATRIX B	GLOB3V
B3STRC	IB3STR	HX	MASS OF STRUCTURE,SUMMED OVER ALL PARALLEL PATHS	HX3P
C3ATBS	IC3ATB	TURBN	COSINE OF ANGLE ALPHA,INPUT ON 601 CARD	TURB3P
C3M	IC3M	SGMNT	IDENTIFIER FOR SEGMENT MATRIX C	SEG3P
C3ONDF	-	-	THERMAL CONDUCTIVITY OF SATURATED FLUID	SATP3V
C3ONFM	-	2	THERMAL CONDUCTIVITY OF SATURATED FLUID	SATM3V
C3PLF	-	-	SPECIFIC HEAT OF SATURATED FLUID	SATP3V
C3PLFM	-	2	SPECIFIC HEAT OF SATURATED FLUID	SATM3V
C9ASTO	ARRAY	-	CONTAINER ARRAY FOR BLOCK STORAGE	ADAB9U
C9GNMS	ARRAY	-	GLOBAL CONTAINER BLOCK NAME TABLE	GC9U
C9GPTS	ARRAY	-	GLOBAL CONTAINER BLOCK POINTER TABLE	GC9U
C9NSTO	ARRAY	-	CONTAINER ARRAY FOR NODE DATA STORAGE	NDAB9U
C9VDIM	ANY	ALL	GLOBAL CONTAINER ARRAY	VD9V
D3ALOG	-	2	HX GEOMETRIC PARAM,1-LN(DCENT/DIAM,1),2-LN(DIAM,2/DC)	MOD3V
D3CENT	-	-	HX TUBE DIAMETER AT CENTER OF TUBE WALL,(OD+ID)/2	MOD3V
D3COI	-	-	HELICAL COIL DIAMETER,0.0 FOR STRAIGHT TUBE	MOD3V
D3COIL	ID3COI	HX	HELICAL COIL DIAMETER,0 IF STRAIGHT TUBES	MODL3P
D3DRDE	ID3DRE	NODE	DERVTIVE OF NOD AVE DENSTY WITH RSPCT TO ENTHALPY	NODL3P
D3DRDP	ID3DRP	NODE	DERIVATIVE OF NODE AVE DENSITY WITH RESPCT TO PRESSUR	NODL3P
D3EFDP	-	-	DERIVATIVE OF SATURATED FLUID ENTHALPY WRT PRESSURE	SATP3V
D3EFPM	-	2	DERIVATIVE OF SATURATED FLUID ENTHALPY WRT PRESSURE	SATM3V
D3EGDP	-	-	DERIVATIVE OF SATURATED VAPOR ENTHALPY WRT PRESSURE	SATP3V
D3EGPM	-	2	DERIVATIVE OF SATURATED VAPOR ENTHALPY WRT PRESSURE	SATM3V
D3EREF	ID3ERE	TURBN	SQUARE ROOT OF ENTHALPY DROP AT REFERENCE CONDITIONS	TURB3P
D3EQ	-	2	EQUIVALENT HYDRAULIC DIAMETER	MOD3V
D3QDEB	ID3QDE	NODE	DERIVATIVE OF HEAT TRANSFER(Q3CB) W.R.T. NOD AV ENTHP	NODL3P
D3QDWB	ID3QDW	NODE	DERIVATIVE OF HEAT TRANSFER(Q3CB) W.R.T. NOD AV FLOW	NODL3P
D3HPUM	ID3HPU	PUMP	DERIVATIVE OF PUMP HEAD W.R.T. MASS FLOW RATE	PUMP3P
D3IAM	-	2	DIAMETER,1-INSIDE PIPE OR TUBE,2-TUBE OUTER DIAMETER	MOD3V
D3M	SCALAR	-	IDENTIFIER FOR VOLUME MATRIX D	GLOB3V
D3QDE	-	-	DERIVATIVE OF HEAT TRANSFER RATE INTO NOD WRT ENTHALP	NODE3V
D3QDW	-	-	DERIVATIVE OF HEAT TRANSFER RATE INTO NOD WRT PRSSURE	NODE3V
D3RDE	-	-	DERIVATIVE OF NOD AVE DENSITY WRT ENTHALPY	NODE3V
D3RDP	-	-	DERIVATIVE OF NOD AVE DENSITY WRT PRESSURE	NODE3V
D3RFDP	-	-	DERIVATIVE OF SATURATED FLUID DENSITY WRT PRESSURE	SATP3V
D3RFPM	-	2	DERIVATIVE OF SATURATED FLUID DENSITY WRT PRESSURE	SATM3V
D3RGDP	-	-	DERIVATIVE OF SATURATED VAPOR DENSITY WRT PRESSURE	SATP3V
D3RGPM	-	2	DERIVATIVE OF SATURATED VAPOR ENTHALPY WRT PRESSURE	SATM3V
D3VRE	ID3VRE	VOLUM	VOL AVE DERIV OF DENSITY W.R.T. ENTHALPY	VOL3P
D3VRP	ID3VRP	VOLUM	VOL AVE DERIV OF DENSITY W.R.T. PRESSURE	VOL3P
D3Z	-	-	RATIO OF NODE LENTH TO AREA,USED FOR INERTIA	NODE3V
D3ZA	ID3ZA	NODE	LENGTH OVER AREA FOR NODE	NODL3P
E3BAR	-	2	NODE AVERAGE ENTHALPY	NODE3V
E3BC	IE3BC	BC	ENTHALPY OF FLUID PASSING THROUGH BOUNDARY MODULE	BC3P
E3CB	IE3CB	NODE	NODE AVERAGE ENTHALPY	NODL3P
E3F	-	-	SATURATED FLUID ENTHALPY	SATP3V
E3FGEN	IE3FGE	TURBN	EFFICIENCY TO ELECTRIAL GRID	TURB3P
E3FGM	-	2	E3GM-E3FM	SATM3V
E3FM	-	2	SATURATED FLUID ENTHALPY	SATM3V
E3FTSG	IE3FTS	TURBN	EFFICIENCY OF TURBINE STAGE AT GIVEN TIME	TURB3P
E3G	-	-	SATURATED VAPOR ENTHALPY	SATP3V
E3GM	-	2	SATURATED VAPOR ENTHALPY	SATM3V
E3IN	-	2	ENTHALPY AT NODE INLET	NODE3V
E3OUT	-	2	ENTHALPY AT NODE OUTLET	NODE3V
E3INSL	IE3INS	SGMNT	FLUID ENTH AT SEGMENT INLET	SEG3P
E3M	SCALAR	-	IDENTIFIER FOR VOLUME MATRIX E	GLOB3V
E3MII	IE3MII	MOD	ENTHALPY OF FLOW ENTERING MODULE,INSIDE TUBES IN HX	MODC3P
E3MIO	IE3MIO	HX NO	ENTHALPY OF FLUID ENTERING HX,TO PASS OUTSIDE TUBES	MODC3P
E3MODI	-	2	ENTHALPY OF FLUID ENTERING MODULE	MOD3V
E3MODO	-	2	ENTHALPY OF FLUID LEAVING MODULE	MOD3V
E3MOI	IE3MOI	MOD	ENTHALPY OF FLOW LEAVING MODULE,INSIDE TUBES OF HX	MODC3P
E3MOO	IE3MOO	HX NO	ENTHALPY OF FLUID LEAVING HX,AFTER PASSING OUTSID TBS	MODC3P
E3OTSL	IE3OTS	SGMNT	FLUID ENTH AT SEGMENT OUTLET	SEG3P
E3PS	-	2	SURFACE ROUGHNESS FACTOR	MOD3V
E3PSI	IE3PSI	MODUL	SURFACE ROUGHNESS TO DIAMETER RATIO	MODL3P
E3TAB	IE3TAB	NBCTB	ENTHALPY ENTRY FOR BOUNDARY TABLE	TRND3P
E3VOL	IE3VOL	VOLUM	VOLUME AVERAGE ENTHALPY	VOL3P
E3WSSG	IE3WSS	NDINF	ENTHALPY AT THE NODAL INTERFACE	NODL3P
F3AEFF	IF3AEF	TURBN	EFFICIENCY ADJUSTMENT FACTOR	TURB3P
F3AQ	IF3AQ	HX NO	AREA CORRECTION FACTOR,CALCD IN STEADY STATE HX CALCS	HX3P
F3CCF	-	2	FLOW DIRECTION MULTIPLIER,-1=COUNTER,0=CROSS,1=PARLL	MOD3V
F3CCFL	IF3CCF	HX	FLOW DIRECTION,1.-PARALLEL,0.-CROSS,-1.-COUNTER	MODL3P
F3HBRG	IF3HBR	SN*SN	HEAT TRANSFER BRIDGE FACTOR,=1 FOR NON-PRNCIPL BRIDG	SNET3P
F3INLV	IF3INL	SGMNT	REL POSITON OF SEGMENT INLET JUNCTION WITH VOLUM OR B	SEG3P

F3ITO	-	-	RATIO OF AXIAL FLOW LENGTH INSID TUB TO OUTSID,1-STRT	MOD3V
F3ITOO	IF3ITO	HX	RATIO OF LENGTH,INSIDE TUB TO OUTSIDE,0 FOR STRAT TUB	MODL3P
F3KMI	IF3KMI	MODUL	FORM LOSS FACTOR,INSIDE TUBES IF HEAT EXCHANGER (HX)	MODL3P
F3KMO	IF3KMO	HX	FORM LOSS FACTOR OUTSIDE HX TUBES	MODL3P
F3KMOD	-	2	MODULE FORM LOSS FACTOR	MOD3V
F3KSTB	IF3KST	TURBN	STADOLA CONSTANT FOR TURBINE STAGE	TURB3P
F3LQLV	IF3LQL	VOLUM	RELATIVE VERTICAL POSITION OF TOP OF LIQUID REGION	VOL3P
F3NPAT	-	-	NUMBER OF PARALLEL FLOW PATHS,INCL TUBS FOR HX	MOD3V
F3NTUB	-	-	NUMBER OF TUBES IN HEAT EXCHANGER	PUMP3P
F3OTLV	IF3OTL	SGMNT	REL POSITON OF SEGMENT OUTLT JUNCTION WITH	SEG3P
F3PUMP	IF3PUM	PUMP	CURRENT PUMP SPEED	PUMP3P
F3QSEG	IF3QSE	SGMNT	ADJUSTMENT FACTOR FOR NON-HX MODS IN SEGMENT(*QMOD)	SEG3P
F3QVOL	IF3QVO	VOLUM	HEATING ADJUST. FACTOR FOR VOLUME,SEE F3QSEG	VOL3P
F3REF	IF3REF	PUMP	REFERENCE PUMP SPEED IN RPM	PUMP3P
F3SGSN	IF3SGS	SG*SN	FRACTION OF SEGMENT FLOW GOING TO GIVEN SUBNETWORK	SNET3P
F3STGA	IF3STG	VALVE	AREA-STEM POWER,AREA=A3VMAX*S3VPOS**F3STGA	VALV3P
F3TBPD	IF3TBP	HX	PITCH-TO-DIAMETER RATIO FOR HX TUBES	MODL3P
F3VALV	IF3VAL	VALVE	FORM LOSS COEFFICIENT FOR VALVE OPENING	VALV3P
F3VLSN	IF3VLS	VL*SN	FRACTION OF VOLUME FLOW GOING TO GIVEN SUBNETWORK	SNET3P
F3VMAX	IF3VMA	VOLUM	RELATIVE POSITION OF MODULE MAX ELEV,REL TO COMPNT HT	VOL3P
F3VMIN	IF3VMI	VOLUM	RELATIVE POSITION OF MODULE MIN ELEV,REL TO COMPNT HT	VOL3P
G3BAR	-	2	NODE AVERAGE MASS VELOCITY,=W3BAR/AREA	NODE3V
H3PUMP	IH3PUM	PUMP	PUMP HEAD AT CURRENT CONDITIONS	PUMP3P
H3REF	IH3REF	PUMP	REFERENCE PUMP HEAD IN METERS	PUMP3P
I3BCTP	II3BCT	BC	KEYS PRESSURE FLOW ENTRY,1-FLOW,2-PRESSURE	TRND3P
I3CHOK	II3CHO	VALVE	CHOKING OPTION,0-IGNORE,1-CALCULATE CHOKE FLOW LIMIT	VALV3P
I3DLST	ARRAY	-	ARRAY OF POINTERS TO TEMPORARY INPUT STORAGE LISTS	SCRH3R
I3FTI	II3FTI	MODUL	FLUID TYPE IN MODULE,INSIDE TUBES IF HX	MODL3P
I3FTO	II3FTO	HX	FLUID TYPE PASSING OUTSIDE HX TUBES OF HX	MODL3P
I3FTYP	-	2	FLUID TYPE,1-WATER,2-NA,3-AIR,4-NAK	MOD3I
I3GRID	II3GRI	HX	HX TUBE CONFIGURATION,1-COAX,4-SQUAR,6-HEX(TRIANGULR)	MODL3P
I3LEVT	-	2	CRITICAL HEAT FLUX LEVEL TYPE,1-INSIDE,2-OUTSIDE TUBS	MOD3I
I3LVTI	II3LVI	HX	CRITICAL HEAT FLUX TYPE INSIDE TUBES	MODL3P
I3LVTO	II3LVO	HX	CRITICAL HEAT FLUX TYPE OUTSIDE TUBES	MODL3P
I3NFTP	II3NFT	NETWK	FLUID TYPE IN NETWORK,1-H2O,2-NA,3-AIR,4-NAK	NET3P
I3POPT	II3POP	PUMP	PUMP SPEED CONTROL OPTION INDICATOR	PUMP3P
I3SGVL	II3SGV	SGMNT	ORDINATE NUMBER OF LAST VALVE IN SEGMENT	SEG3P
I3TOPT	II3TOP	TURBN	TRANSIENT CONTROL OPTION FOR SPEED INDICATOR	TURB3P
I3TTYP	II3TTY	TURBN	TURBINE STAGE TYPE,1-IMPULSE,2-IMPULSE-REACTION	TURB3P
I3VOPT	II3VOP	VALVE	OPTION FOR CONTROLLING THE VALVE STEM POSITION	VALV3P
I9EITM	SCALAR	-	POINTER TO DEFAULT ERROR ITEM SPECIFICATION	ISUV9R
I9FSPC	SCALAR	-	POINTER TO CURRENTLY OPEN FILE SPECIFICATION	ISUV9R
I9FSTA	SCALAR	-	POINTER TO BEGINNING FIRST ALLOCATED BLOCK	ADAB9U
I9FSTT	SCALAR	-	FIRST POINTER TABLE LOCATION	ADAB9U
I9ISPC	SCALAR	-	POINTER TO CURRENTLY OPEN ITEM SPECIFICATION	ISUV9R
I9LSTA	SCALAR	-	POINTER TO BEGINNING OF LAST ALLOCATED BLOCK	ADAB9U
I9LSTT	SCALAR	-	LAST POINTER TABLE LOCATION	ADAB9U
I9MAXA	SCALAR	-	LAST ARRAY LOCATION AVAILABLE FOR BLOCK STORAGE	ADAB9U
I9NSTO	SCALAR	-	OFFSET TO OF NEXT FREE NODE DATA STORAGE LOCATION	NDAB9U
I9RSPC	SCALAR	-	POINTER TO CURRENTLY OPEN RECORD SPECIFICATION	ISUV9R
J3BMOD	IJ3BMO	BC	CONVERTS BOUNDARY ORDINATE NO. TO MODULE NO.	BC3P
J3FHXN	IJ3FHX	HX NO	FIRST TUBE NODE IN HX	LNK3P
J3FII	IJ3FII	MODUL	FIRST NODAL INTERFACE IN MODULE,INSIDE TUBES IF HX	LNK3P
J3FIO	IJ3FIO	HX NO	FIRST NODAL INTERFACE OUTSIDE TUBES	LNK3P
J3LHXN	IJ3LHX	HX NO	LAST TUBE NODE IN HX	LNK3P
J3LII	IJ3LII	MODUL	LAST NODAL INTERFACE IN MODULE,INSIDE TUBES IF HX	LNK3P
J3FINF	-	2	FIRST NODAL INTERFACE NO.,IF 2,THEN OUTSIDE HX TUBES	MOD3I
J3FNI	IJ3FNI	MODUL	FIRST NODE IN MODULE,INSIDE TUBES IF HX	LNK3P
J3FNO	IJ3FNO	HX NO	FIRST NODE,OUTSIDE TUBES	LNK3P
J3LNO	IJ3LNO	HX NO	LAST NODE,OUTSIDE TUBES	LNK3P
J3FNOD	-	2	FIRST NODE NO.,IF 2, THEN OUTSIDE HX TUBES	MOD3I
J3FTND	-	-	HX NODE NUMBER FOR FIRST NODE IN HX	MOD3I
J3LINF	-	2	LAST NODAL INTERFACE NO.,IF 2,THEN OUTSIDE HX TUBES	MOD3I
J3LIO	IJ3LIO	HX NO	LAST NODAL INTERFACE OUTSIDE TUBES	LNK3P
J3LNI	IJ3LNI	MODUL	LAST NODE IN MODULE,INSIDE TUBES IF HX	LNK3P
J3LNOD	-	2	LAST NODE NO.,IF 2,THEN OUTSIDE HX TUBES	MOD3I
J3LTND	-	-	HX NODE NUMBER FOR LAST NODE IN HX	MOD3I
J3MDID	IJ3MDI	MODUL	MODULE IDENTIFICATION NUMBER,EG,MODULE 9 HAS ID 501	LNK3P
J3ORD	IJ3ORD	MODUL	MODULE TYPE ORDINATE NUMBER,EG,MOD 24 IS VALV NO. 6	LNK3P
J3SIDE	IJ3SID	SGMDS	CONVERTS SEGMOD NO. TO SIDE,=2 IF OUTSIDE HX TUBES	LNK3P
J3SMOD	IJ3SMO	SGMDS	CONVERTS SEGMOD NO. TO MODULE NUMBER	LNK3P
J3VMOD	IJ3VMO	VOLUM	CONVERTS VOLUME ORDINAT NO. TO MODULE NUMBER	VOL3P
J3VPRS	IJ3VPR	VALVE	VOLUME WHERE PRSSUR MONITRD,ID INPUT,CONVRTD TO ORDNT	VALV3P
J9IFLD	SCALAR	-	INDEX OF ITEM FIELD COUNT IN K9ISPC	ISUV9R
J9IREP	SCALAR	-	INDEX OF FIRST REPEATING ITEM NUMBER ENTRY IN K9RSPX	ISUV9R
J9ITEM	SCALAR	-	INDEX OF CURRENT ITEM SPEC POINTER IN RECORD SPEC	ISUV9R
J9ITYP	SCALAR	-	INDEX OF ITEM TYPE ENTRY IN K9ISPC	ISUV9R
J9LNUM	SCALAR	-	INDEX OF LIST NUMBER ENTRY IN K9RSPX	ISUV9R
J9LSTI	SCALAR	-	INDEX OF LAST ITEM POINTER IN K9LNK2	LDAB9U
J9MID	SCALAR	-	INDEX OF MODULE ID IN HEADER NODE	MDAB9U

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J9MTYP SCALAR   -    INDEX OF MODULE TYPE ENTRY IN K9MHDR                     MDAB9U
J9MTYP SCALAR   -    INDEX OF RECORD MODULE TYPE IN K9RSPX                    ISUV9R
J9NDL  SCALAR   -    OFFSET TO NODE DATA LENGTH ENTRY                         NDAB9U
J9NFLD SCALAR   -    INDEX OF FIELD COUNT ENTRY IN K9RSPX                     ISUV9R
J9NID  SCALAR   -    OFFSET OF NODE ID                                        NDAB9U
J9NXTI SCALAR   -    INDEX OF NEXT ITEM POINTER IN K9LNK2                     LDAB9U
J9NXTN SCALAR   -    OFFSET OF LINK TO NEXT NODE                              NDAB9U
J9PTBL SCALAR   -    POINTER TABLE IDENTIFIER                                 ADAB9U
J9RLST SCALAR   -    INDEX OF RECORD SPECIFICATION LIST POINTER IN K9COMP     ISUV9R
J9RTYP SCALAR   -    INDEX OF RECORD TYPE ENTRY IN K9RSPX                     ISUV9R
J9UNIT SCALAR   -    INDEX OF ITEM UNITS ENTRY IN K9ISPC                      ISUV9R
K3BCSG IK3BCS  BC    SEGMENT NO.ATTCHD TO BOUNDRY,IF.LT.0 FLOW INTO SEGMNT    BC3P
K3EBC  IK3EBC  BC    TYPE OF THERMAL PARAM SPECFD,1-ENTH,2-TEMP,3-QUALITY     BC3P
K3EBST IK3EBS  BC    STATUS OF BOUNDARY,CLOSED/FIXED OUTLET TEMP IF K3EB=2    BC3P
K3ETAB IK3ETA  BC    KEYS ENTHALPY/TEMP/QUAL,1-ENTH,2-TEMP,3-QUAL             TRND3P
K3HBRG IK3HBR SN*SN  KEY TO HEAT TRANSFER BRIDGES,INDICATES IF ADJUSTABLE     SNET3P
K3NETW IK3NET  BC    NETWORK TO WHICH BOUNDARY ATTACHES                       BC3P
K3NTI  IK3NTI HX NO  NETWORK IN WHICH FLUID PASSING INSIDE TUBES BELONGS      HX3P
K3NTO  IK3NTO HX NO  NETWORK IN WHICH FLUID PASSING OUTSIDE TUBES BELONGS     HX3P
K3OPCL IK3OPC  SN    KEYS WHETHER SUBNET IS OPEN(1) OR CLOSED(2)=FXD OUT E    SNET3P
K3SGPR IK3SGP SGMNT  DESIGNATES SUBNT TO WHICH SGMNT PRINCIPALLY CONTRIBTS    SEG3P
K3SNI  IK3SNI HX NO  SUBNETWOR TO WHICH FLUID PASSNG INS. TUBES ASSIGNED      HX3P
K3SNO  IK3SNO HX NO  SUBNETWOR TO WHICH FLUID PASSNG OUTS. TUBES ASSIGNED     HX3P
K3VLPR IK3VLP VOLUM  DESIGNATES SBNT NO. TO WHICH VOLM PRNCPALLY CONTRBUTS    VOL3P
K9ASTO ARRAY    -    INTEGER EQUIVALENT TO C9ASTO                             ADAB9U
K9CLAS SCALAR   -    MODULE PORT CLASS DATA AREA                              LNKS3I
K9COMP SCALAR   -    FILE COMPONENT DATA AREA IDENTIFIER                      ISUV9R
K9DAID SCALAR   -    MODULE PORT DATUM DATA AREA IDENTIFIER
K9ELEV SCALAR   -    MODULE PORT ELEVATION DATA AREA                          LNKS3I
K9ISPC SCALAR   -    ITEM SPECIFICATION DATA AREA IDENTIFIER                  ISUV9R
K9LHDR SCALAR   -    IDENTIFIER FOR LIST HEADER MODULE                        LDAB9U
K9LNK2 SCALAR   -    LIST ITEM LINK DATA AREA IDENTIFIER                      LDAB9U
K9MHDR SCALAR   -    ID OF MODULE HEADER NODE                                 MDAB9U
K9NBRM SCALAR   -    MODULE PORT NEIGHBOR MODULE POINTER DATA AREA            LNKS3I
K9NBRP SCALAR   -    MODULE PORT NEIGHBOR PORT IDENTIFIER DATA AREA           LNKS3I
K9NSTO ARRAY    -    INTEGER EQUIVALENCE OF C9NSTO                            NDAB9U
K9PIDS SCALAR   -    MODULE PORT IDENTIFIER DATA AREA                         LNKS3I
K9RCMP SCALAR   -    RECORD COMPONENT DATA AREA IDENTIFIER                    ISUV9R
K9RSPX SCALAR   -    RECORD SPECIFICATION DATA AREA IDENTIFIER                ISUV9R
L3CNTR SCALAR   -    LENGTH OF GLOBAL CONTAINER ARRAY                         GLOB3I
L3PASS IL3PAS HX NO  USED IN STEADY STATE FOR HX STATUS,2 IF SECOND PASS      HX3P
L3PRNT SCALAR   -    PRINT OPTION,1-SUMMARY,2-SOME DETAIL,3-MOST DETAILED     GLOB3I
L3PRON SCALAR   -    STEP NUMBER TO BE REACHED BEFORE FREQUENT PRINTS         GLOB3I
L3PSEP IL3PSE VOLUM  VOLUME CONTENTS,1-HOMOGENEOUS,2-SEPARAT BY PHAS,3-1;2    VOL3P
L3TYPE IL3TYP MODUL  MODULE TYPE,1-PIP,2-HX,3-PMP,4-VOL,5-BC,6-VALV,7-TBSG    LNK3P
L3STEP SCALAR   -    TIME STEP NUMBER, 0=STEADY STATE                         GLOB3I
L3VSHP IL3VSH VOLUM  SHAPE OF VOLUME,1-VERT CYLNDR OR BOX,2-HORIZNTL CYLND    VOL3P
L9ASIZ ARRAY    -    GLOBAL CONTAINER BLOCK SIZE TABLE                         GC9U
L9ASIZ SCALAR   -    SIZE OF ATOM DATA AREA                                   NDAB9U
L9FSPC SCALAR   -    POINTER TO FILE SPECIFICATION LIST                       ISUV9R
L9GC   SCALAR   -    CURRENT SIZE OF GLOBAL CONTAINER SEGMENT                  GC9U
L9GCOU SCALAR   -    LOGICAL UNIT NUMBER OF GCM OUTPUT FILE                    GC9U
L9GCRE SCALAR   -    LOGICAL UNIT NUMBER OF GCM SEMENT RESTORE FILE            GC9U
L9GCSV SCALAR   -    LOGICAL UNIT NUMBER OF GCM SEGMENT SAVE FILE              GC9U
L9ISPC SCALAR   -    POINTER TO RECORD SPECIFICATION LIST                     ISUV9R
L9ISPC SCALAR   -    POINTER TO INPUT DATA ITEM SPECIFICATION LIST            ISUV9R
L9ISUI SCALAR   -    ISU STATUS FLAG                                          ISUV9R
L9NHDR SCALAR   -    LENGTH OF NODE HEADER                                    NDAB9U
L9NIL  SCALAR   -    NIL VALUE                                                DCON9U
L9NSTO SCALAR   -    MAXIMUM LENGTH OF NODE DATA STORAGE AREA                 NDAB9U
M3CORE IM3COR  HX    MATERIAL TYPE OF CORE TUBE                               HX3P
M3ODEL   -      2    MOST RECENT HEAT TRANSFER MODE                           NODE3I
M3ODET   -      2    TOTAL HEAT TRANSFER MODE FOR NODE                        NODE3I
M3ODI  IM3ODI HXNOD  HEAT TRANSFER MODE FOR FLUID INSIDE TUBE                 HX3P
M3ODO  IM3ODO HXNOD  HEAT TRANSFER MODE FOR FLUID OUTSIDE TUBE                HX3P
M3STRC IM3STR  HX    MATERIAL TYPE OF HX SHELL AND STRUCTURE                  HX3P
M3TYP    -      -    MATERIAL TYPE FOR HX TUBING                              MOD3I
M3TYPE IM3TYP  HX    STRUCTURAL MATERIAL TYPE FOR TUBING                      MODL3P
N3BCS  SCALAR   -    NUMBER OF BOUNDARY MODULES IN SYSTEM                     GLOB3I
N3ETID IN3ETI NETWK  IDENTIFICATION NUMBER OF NETWORK                         NET3P
N3FMLP IN3FML SGMNT  SEGMOD CNTR OF 1ST MODULE IN SEGMENT                     SEG3P
N3FNB  IN3FNB NETWK  ORDINATE NO. OF FIRST BOUNDARY MODULE IN NETWORK         NET3P
N3FNSG IN3FNS NETWK  ORDINATE NO. OF FIRST SEGMENT IN NETWORK                 NET3P
N3FNSN IN3FNN NETWK  ORDINATE NO. OF FIRST SUBNETWORK IN NETWORK              NET3P
N3FNVL IN3FNV NETWK  ORDINATE NO. OF FIRST VOLUME IN NETWORK                  NET3P
N3FP   IN3FP  VOLUM  ORDINATE NUMBER OF FIRST PORT ON VOLUME                  VOL3P
N3HXS  SCALAR   -    NUMBER OF HEAT EXCHANGERS IN SYSTEM                      GLOB3I
N3LMLP IN3LML SGMNT  SGMOD CNTR OF LST MODULE IN SEGMENT                      SEG3P
N3LNB  IN3LNB NETWK  ORDINATE NO. OF LAST BOUNDARY MODULE IN NETWORK          NET3P
N3LNSG IN3LNS NETWK  ORDINATE NO. OF LAST SEGMENT IN NETWORK                  NET3P
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N3LNSN IN3LNN NETWK ORDINATE NO. OF LAST SUBNETWORK IN NETWORK          NET3P
N3LNVL IN3LNV NETWK ORDINATE NO. OF LAST VOLUME IN NETWORK              NET3P
N3LVIN IN3LVI SGMNT NUMBER OF MODULE  ATTACHED TO SEGMENT INLET (VOL/BC)  SEG3P
N3LVOT IN3LVO SGMNT NUMBER OF MODULE  ATTACHED TO SEGMENT OUTLET(VOL/BC)  SEG3P
N3MODS SCALAR   -   NUMBER OF MODULES IN SYSTEM                         GLOB3I
N3NETS SCALAR   -   NUMBER OF NETWORKS IN SYSTEM                        GLOB3I
N3NB   IN3NB  NETWK NUMBER OF BOUNDARY MODULES IN NETWORK                NET3P
N3NODE IN3NOD MODUL NUMBER OF AXIAL NODES IN MODULE                     MODL3P
N3NODS   -      -   NUMBER OF AXIAL NODES IN MODULE                     MOD3I
N3NSEG IN3NSE NETWK NUMBER OF SEGMENTS IN NETWORK                       NET3P
N3NSNS IN3NSN NETWK NUMBER OF SUBNETWORS IN NETWORK                     NET3P
N3NSVL IN3NSV NETWK NUMBER OF SEPARATED VOLUMES IN NETWORK              NET3P
N3NVOL IN3NVO NETWK NUMBER OF VOLUMES IN NETWORK                        NET3P
N3OPSN SCALAR   -   NUMBER OF OPEN SUB-NETWORKS IN SYSTEM               GLOB3I
N3PATH IN3PAT MODUL NUMBER OF PARALLEL COMPONENTS REPRESENTED BY MODULE  MODL3P
N3PORT IN3POR VOLUM NUMBER OF PORTS ON VOLUME                           VOL3P
N3PT   IN3PT  PUMP  NUMBER OF ENTRIES IN PUMP SPEED TABLE               TRND3P
N3PUMS SCALAR   -   NUMBER OF PUMPS IN SYSTEM                           GLOB3I
N3QT   IN3CT  MODUL NUMBER OF TIME TABLE ENTRIES FOR MODULE HEATING     TRND3P
N3ROWS IN3ROW SGMNT NUMBER OF ROWS IN SEGMENT MATRIX EQ,2*(NODES+1)     SEG3P
N3SEGS SCALAR   -   NUMBER OF SEGMENTS IN SYSTEM                        GLOB3I
N3SNTS SCALAR   -   NUMBER OF SUB-NETWORKS IN SYSTEM                    GLOB3I
N3TAB  IN3TAB  BC   NUMBER OF TIME TABLE ENTRIES FOR BOUNDARY           TRND3P
N3TRBS SCALAR   -   NUMBER OF TURBIN-STAGE MODULES IN SYSTEM            GLOB3I
N3TSTB IN3TST TURBN NUMBER OF ENTRIES IN TURBINE SPEED TABLE            TRND3P
N3TUBE IN3TUB  HX   NUMBER OF TUBES IN HEAT EXCHANGER                   MODL3P
N3VALS SCALAR   -   NUMBER OF VALVES IN SYSTEM                          GLOB3I
N3VISB IN3VIS VOLUM SEGMENT NO. ATTCHD TO VOLM PORT,IF.LT.0 FLOW INTO SGM VOL3P
N3VOLS SCALAR   -   NUMBER OF VOLUMES IN SYSTEM                         GLOB3I
N3VT   IN3VT  VALV  NUMBER OF ENTRIES IN VALVE POSITION TABLE           TRND3P
N9MHDR SCALAR   -   SIZE OF K9MHDR                                      MDAB9U
N9SMAX SCALAR   -   MAXIMUM SIZE OF GLOBAL CONTAINER SEGMENT             GC9U
N9TMAX SCALAR   -   MAXIMUM SIZE OF GLOBAL CONTAINER BLOCK TABLES        GC9U
N9TSIZ SCALAR   -   CURRENT SIZE OF GLOBAL CONTAINER BLOCK TABLES        GC9U
P3BC   IP3BC   BC   PRESSURE AT BOUNDARY                                BC3P
P3INSL IP3INS SGMNT PR AT THE SEGMENT INLET                             SEG3P
P3ITRF IP3ITR TURBN REFERENCE INLET PRESSURE                            TURB3P
P3MDI  IP3MDI  MOD  PRESSURE IN MODULE (=SEGMENT AVE PRESSURE)          MODC3P
P3MDO  IP3MDO HX NO PRESSURE OF FLUID PASSING OUTSIDE HX TUBES          MODC3P
P3MOD    -      2   PRESSURE IN MODULE,2 FOR HX FLUID OUTSIDE TUBES     MOD3V
P3OD     -      -   HX TUBE PITCH TO DIAMETER RATIO                     MOD3V
P3OTRF IP3OTR TURBN REFERENCE OUTLET PRESSURE                           TURB3P
P3OTSL IP3OTS SGMNT PR AT THE SEGMENT OUTLET                            SEG3P
P3REF    -      -   PRESSURE AT WHICH SATURATION PROPERTIES EVALUATED   SATP3V
P3REFM   -      2   REFERENCE PRESSURE ON GIVEN SIDE OF TUBES           SATM3V
P3VCLO IP3VCL VALVE PRESSURE AT WHICH SAFETY/RELIEF VALVE CLOSES        VALV3P
P3VOL  IP3VOL VOLUM PRESSURE,AVERAGE FOR VOLUME                         VOL3P
P3VOPN IP3VOP VALVE PRESSURE AT WHICH SAFETY/RELIEF VALVE OPENS         VALV3P
P3WRGN IP3WRG TURBN POWER DELIVED TO GENERATOR AT GIVEN TIME            TURB3P
P3WTAB IP3WTA NBCTB PRESSURE/FLOW ENTRY FOR BOUNDARY TABLE              TRND3P
Q3BAR    -      2   NODAL HEAT TRANSFER RATE,INTO NODE                  NODE3V
Q3CB   IQ3CB  NODE  TOTAL HEAT TRANSFER RATE INTO NODE                  NODL3P
Q3HBRG IQ3HBR SN*SN ESTIMATED HEAT TRANSFER FROM SUBNET I TO SUBNET J   SNET3P
Q3MD     -      -   AMOUNT OF HEAT INTO MODUL PER SEC,OUT TO IN FOR HX  MOD3V
Q3MDT  IQ3MDT NMDTB HEATING ENTRY FOR MODULE HEATING TABLE              TRND3P
Q3PMI  IQ3PMI HXNOD HEAT TRANSFER PER METER OF TUBE,INSIDE TUBE         HX3P
Q3MOD  IQ3MOD  MOD  HEAT INPUT TO MODULE,HEAT OUT-TO-IN (TUBES) FOR HX  MODC3P
Q3PMO  IQ3PMO HXNOD HEAT TRANSFER PER METER OF TUBE,OUTSIDE TUBE        HX3P
Q3SEG  IQ3SEG SGMNT TOTL HT XFRD INTO SEGMENT,STEADY STATE AND UNAJUSTED  SEG3P
Q3SNET IQ3SNE  SN   TOTAL HEAT TRANSFERRED TO SUBNET                    SNET3P
Q3TOT    -      -   TOTAL HEAT TRANSFER RATE INTO NODE                  NODE3V
R3BAR    -      2   DENSITY AT NODE AVERAGE ENTHALPY                    NODE3V
R3CB   IR3CB  NODE  NODE AVERAGE DENSITY                                NODL3P
R3DMND IR3DMN PUMP  PUMP DEMAND SPEED,E.G.,AFTER TRIP DEMAND SPEED IS 0  PUMP3P
R3F      -      -   SATURATED FLUID DENSITY                             SATP3V
R3FM     -      2   SATURATED FLUID DENSITY                             SATM3V
R3G      -      -   SATURATED VAPOR DENSITY                             SATP3V
R3GM     -      2   SATURATED VAPOR DENSITY                             SATM3V
R3PMPT IR3PMP NPMTB PUMP SPEED ENTRY FOR PUMP SPEED TABLE               TRND3P
R3PUMP IR3PUM PUMP  PUMP SPEED,NORMALIZED TO REFERENCE PUMP             PUMP3P
R3PSEZ IR3PSE PUMP  RELATIVE SPEED AT WHICH PUMP SEIZES                 PUMP3P
R3TS   IR3TS  TURBN TURBINE SPEED IN RPM                                TURB3P
R3TSDM IR3TSD TURBN TURBINE DEMAND SPEED                                TURB3P
R3TSEZ IR3TSE TURBN TURBINE SPEED AT SEIZURE=EXP(-S3TSEZ/S3TTAU)        TURB3P
R3TSRF IR3TSR TURBN REFERENCE SPEED FOR TURBINE                         TURB3P
R3TSTB IR3TST NTBTB TURBINE SPEED ENTRY FOR TURBINE SPEED TABLE         TRND3P
R3VOL  IR3VOL VOLUM VOLUME AVERAGE DENSITY                              VOL3P
S3DELT SCALAR   -   CURRENT TIME STEP SIZE                              GLOB3V
S3DMD  IS3DMD VALVE DEMAND POSITION FOR VALVE,EG,1 FOR HIGH PRESSURE    VALV3P
S3END  SCALAR   -   END TIME FOR TRANSIENT                              GLOB3V
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S3PSEZ	IS3PSE	PUMP	TIME AFTER TRIP BEFORE PUMP SEIZES	PUMP3P
S3PTAU	IS3PTA	PUMP	PUMP COASTDOWN TIME CONSTANT	PUMP3P
S3PTIM	IS3PTI	NPMTB	TIME ENTRY FOR PUMP SPEED TABLE	TRND3P
S3PTRP	IS3PTR	PUMP	TIME AT WHICH PUMP IS TRIPPED	PUMP3P
S3QT	IS3QT	NMDTB	TIME ENTRY FOR MODULE HEATING TABLE	TRND3P
S3RTEN	-	-	SURFACE TENSION BETWEEN SATURATION PHASES	SATP3V
S3RTNM	-	2	SURFACE TENSION BETWEEN SATURATION PHASES	SATM3V
S3TAB	IS3TAB	NBCTB	TIME ENTRY FOR BOUNDARY TABLE	TRND3P
S3TAUM	SCALAR	-	MINIMUM TIME CONSTANT,USED TO SET NEW TIME STEP	GLOB3V
S3TIME	SCALAR	-	SIMULATION TIME,0.0=STEADY STATE	GLOB3V
S3TSEZ	IS3TSE	TURBN	SEIZURE TIME AFTER TRIP	TURB3P
S3TSTB	IS3TTB	NTBTB	TIME ENTRY FOR TURBINE SPEED TABLE	TRND3P
S3TSTP	IS3TST	TURBN	TURBINE TRIP TIME	TURB3P
S3TTAU	IS3TTA	TURBN	TURBINE COASTDOWN TIME CONSTANT	TURB3P
S3VCLO	IS3VCL	VALVE	VALVE CLOSING TIME CONSTANT	VALV3P
S3VMIN	IS3VMI	VALVE	MINIMUM VALVE STEM POSITION,MUST BE GT ZERO	VALV3P
S3VOPN	IS3VOP	VALVE	VALVE OPENING TIME CONSTANT	VALV3P
S3VPOS	IS3VPO	VALVE	RELATIVE VALVE STEM POSITION	VALV3P
S3VPSN	IS3VPS	NVLTB	VALVE POSITION ENTRY FOR VALVE POSITION TABLE	TRND3P
S3VTIM	IS3VTI	NVLTB	TIME ENTRY FOR VALVE POSITION TABLE	TRND3P
T3BAR	-	2	TEMPERATURE AT NODE AVERAGE ENTHALPY	NODE3V
T3BC	IT3BC	BC	TEMPERATURE OF FLUID PASSING THROUGH BOUNDARY	BC3P
T3CB	IT3CB	NODE	NODE AVERAGE TEMPERATURE	NODL3P
T3CENT	-	-	HX TUBE CENTER TEMPERATURE	NODE3V
T3CORT	IT3COR	HXNOD	TEMPERATURE OF CORE TUBE NODE	HX3P
T3IN	-	2	TEMPERATURE AT THE NODE INLET	PUMP3P
T3ITRF	IT3ITR	TURBN	REFERENCE INLET TEMPERATURE	TURB3P
T3JUNC	IT3JUN	NDINF	TEMPERATURE AT THE NODAL INTERFACE	NODL3P
T3OUT	-	2	TEMPERATURE AT THE NODE OUTLET	PUMP3P
T3SAT	-	-	SATURATION TEMPERATURE	SATP3V
T3SATM	-	2	SATURATION TEMPERATURE	SATM3V
T3STRC	IT3STR	HXNOD	TEMPERATURE OF STRUCTURE TUBE NODE	HX3P
T3TC	IT3TC	HXNOD	HEAT EXCHANGER TUBE NODE TEMPERATURE	HX3P
T3VOL	IT3VOL	VOLUM	VOLUME TEMPERATURE (K)	VOL3P
V3ISCF	-	-	DYNAMIC VISCOSITY OF SATURATED FLUID	SATP3V
V3ISCG	-	-	DYNAMIC VISCOSITY OF SATURATED VAPOR	SATP3V
V3ISFM	-	2	DYNAMIC VISCOSITY OF SATURATED FLUID	SATM3V
V3ISGM	-	2	DYNAMIC VISCOSITY OF SATURATED VAPOR	SATM3V
V3LND	-	-	TOTAL VOLUME IN NODE,INCLDS PARALLEL PATHS	NODE3V
V3VOL	IV3VOL	VOLUM	TOTAL VOLUME (METERS CUBED) OF MODULE	VOL3P
V3OLND	IV3OLN	NODE	VOLUME OF NODE	NODL3P
V3RATR	IV3RAT	TURBN	RATIO OF BLADE TO FLUID VELOCITY AT REFERENCE CONDTNS	TURB3P
W3BAR	-	2	NODE AVERAGE MASS FLOW RATE	NODE3V
W3BC	IW3BC	BC	TOTAL FLOW RATE THROUGH BOUNDARY (SUM OVER PATHS)	BC3P
W3EINS	IW3EIN	SN	SUM OF FLOW ENERGY (MASS FLW *ENTHLP) INTO SUBNETWRK	SNET3P
W3EOTS	IW3EOT	SN	SUM OF FLOW ENERGY (MSS FLW *ENTHLP) OUT OF SBNETWRK	SNET3P
W3IN	-	2	NODE INLET MASS FLOW RATE	NODE3V
W3INSL	IW3INS	SGMNT	FLW RATE AT SEGMENT INLET	SEG3P
W3MDI	IW3MDI	MOD	TOTAL MODULE FLOW,FOR HX FLOW ISIDE TUBES	MODC3P
W3MDO	IW3MDO	HX NO	MASS FLOW RATE PASSING OUTSIDE HX TUBES	MODC3P
W3MOD	-	2	FLOW RATE THROUGH MODULE	MOD3V
W3OTSL	IW3OTS	SGMNT	FLW RATE AT SEGMENT OUTLET	SEG3P
W3OUT	-	2	NODE OUTLET MASS FLOW RATE	NODE3V
W3PUMP	IW3PUM	PUMP	MASS FLOW RATE THROUGH PUMP,PER UNIT	PUMP3P
W3REFF	IW3REF	PUMP	PUMP REFERENCE MASS FLOW RATE,PER PARALLEL UNIT	PUMP3P
W3SEG	IW3SEG	SGMNT	SGMNT AVE MASS FLOW RATE	SEG3P
W3TREF	IW3TRE	TURBN	REFERENCE MASS FLOW RATE	TURB3P
W3VALC	IW3VAL	VALVE	CHOKED MASS FLOW RATE THROUGH VALVE	VALV3P
W3VOUT	IW3VOU	VOLUM	ESTIMATED MASS FLOW RATE OUT PORT AT STEADY STATE	VOL3P
W3WSSG	IE3WSS	NDINF	FLOW AT NODAL INTERFACE	NODL3P
X3BC	IX3BC	BC	QUALITY OF FLOW THROUGH BOUNDARY	BC3P
X3INER	IX3INE	SGMNT	TOTL SEG INERTIA,SUM LENGTH/AREA	SEG3P
X3MOD	IX3MOD	MODUL	LENGTH OF MODULE	MODL3P
X3NODE	-	2	LENTH OF NODE	MOD3V
Y3CORO	IY3COR	HX	DIAMETER OF HX CORE TUBE,0.0 IF NONE	HX3P
Y3ID	IY3ID	MODUL	INNER DIAMETER OF PIPE-LIKE PART OF MODULE	MODL3P
Y3OD	IY3OD	HX	OUTER DIAMETER OF HX TUBES	MODL3P
Y3VOL	IY3VOL	VOLUM	TOTAL HEIGHT OF COMPONENT	VOL3P
Z3MODI	IZ3MOI	MODUL	ELEVATION DIFFERENCE ACROSS MODULE,INSIDE HX TUBES	MODL3P
Z3MODO	IZ3MOO	HX	ELEVATION DIFFERENCE ACROSS HX,OUTSIDE TUBES	MODL3P
Z3NODE	-	2	ELEVATION DIFFERENCE ACROSS NODE	MOD3V
Z3VOL	IZ3VOL	VOLUM	ELEVATION OF COMPONENT VERTICAL MIDPOINT	VOL3P

4. MINET APPLICATIONS

There comes a time when an example or two is more useful than further description, and presumably by now that point has been reached. Thus, this final section of our MINET code documentation is intended to show how the code has been used thus far. This should provide the user with some useful ideas and approaches, as well as indicate just how far the code has been applied and tested. The latter could be important for a person planning an application that is beyond our current experience, which is a very real posssibility given the highly generalized nature of the MINET code.

Because one can develop infinitely different module configurations it is necessary to distinguish between the various system representations. This is done by designating a MINET Standard Input Deck name, e.g., Deck X2. Thus, after a new input deck has been developed and tested, it is documented and named as a standard input deck, with schematics of the module configurations and module identification numbers included. Approximately 15 such decks currently exist.

In this part of the MINET code documentation, five of these decks will be discussed. The first two, decks X1 and X2 are example decks which do not correspond to any particular system. As such, they can be examined in depth with no concerns as to proprietary information. The third deck, P2, resembles a PWR system and is interesting because it differs significantly from the other applications to date. Testing of this deck has not progressed to a degree where we would consider it appropriate for display, although preliminary findings were very encouraging. The fourth input deck, E1, is for part of the EBR-II system [7], and has been used repeatedly in code validation and checkout. There are features in this application that are unique, but because the input deck contains material that is of a proprietary nature, it cannot be shown. However, the system schematics of the MINET representation are of interest and are presented. The fifth standard deck discussed, C4, is actually from a combined SSC/MINET analysis of the Clinch River Breeder Reactor (CRBR) plant. The results generated using this deck were compared against those provided by the CRBR project as part of the recently terminated licensing effort. As the specific input deck for C4 is applicable to an older version of MINET, it is not shown.

The input decks shown are representative of others that have been and currently are in use. While not all of the past analysis can be shown in detail, one could properly assume that experience gained from all of the applications are reflected in the current MINET code library.

4.1 MINET DECK X1

MINET standard input deck X1 is a simple example deck that utilizes each of the MINET modules at least once. The system schematic is shown in Figure 4.1-1 with module ID's as shown in Figure 4.1-2. One can easily recognize two networks, two sub-networks, and four flow segments.

The input deck card images are shown in Figure 4.1-3. Note that records 1-901 specify the geometry of the system, with linkages specified in the 901 cards. The 1001 - 1601 cards are used to specify module performance, e.g., the 1601 card indicates how the turbine performs at reference conditions. In the 2000 series cards, initial conditions are specified. Transient boundary conditions enter through the 3000 series cards, although many of these cards are trivial for this deck, e.g., the 3011 cards. Finally, the run control parameters enter through the 4000 series cards.

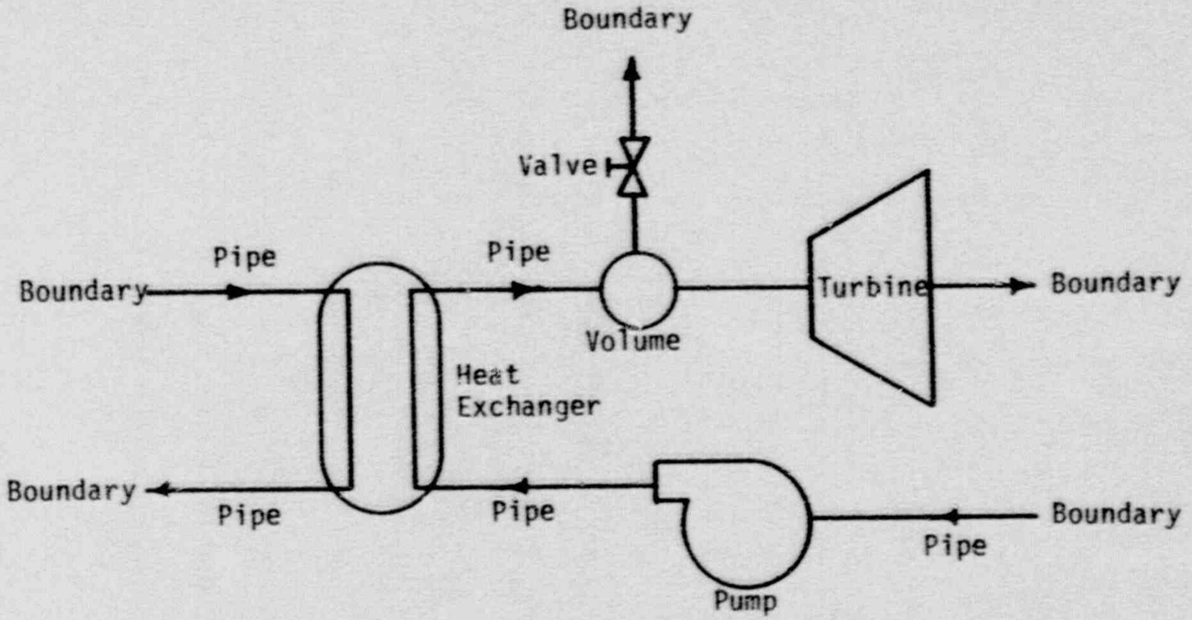

Figure 4.1-1. MINET Standard Deck X1, Example Case

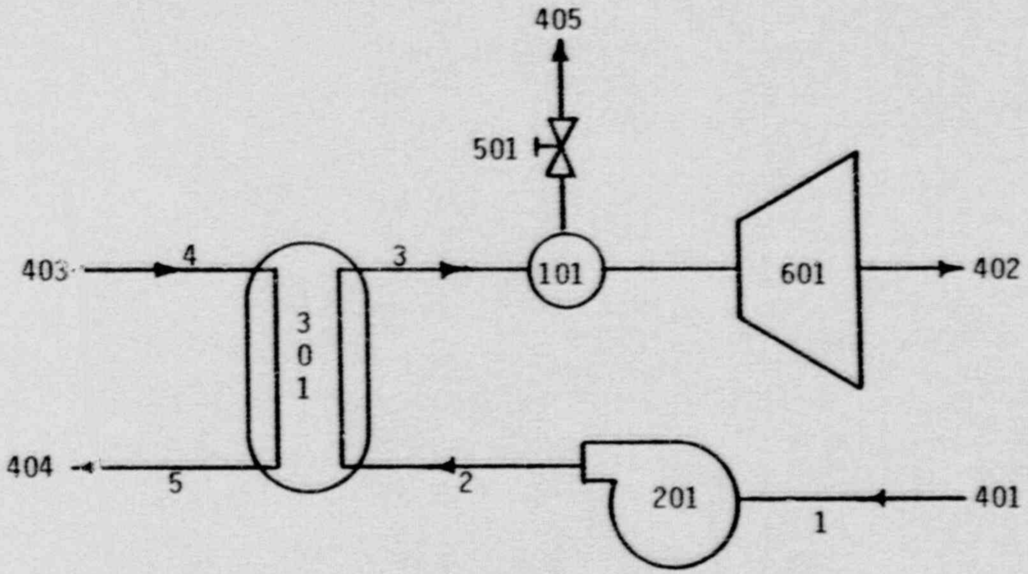

Figure 4.1-2. MINET Standard Deck X1, Module IDs

Figure 4.1-3 X1 Input Deck

```
STAND-ALONE MINET DECK X1. GJV 10/18/83
0V MINETD
1D 1,1,2,1.0,0.2,1.0E-6,1,2/
1D 2,1,2,1.0,0.3,1.0E-6,1,1/
1D 3,1,2,2.0,0.4,1.0E-6,1,1/
1D 4,1,2,2.0,1.0,1.0E-6,1,1/
1D 5,1,2,2.0,1.0,1.0E-6,1,1/
101D 501,1,2,1.5,0.15,1.0E-6,1,1,0.1,1.0E-6,1.0/
201D 201,1,2,1.0,0.3,1.0E-5,1,1/
301D 301,1,2,4.0,0.03,1.0E-6,12,1,3,4,0.045,1.5,34000,
     2,6,0.0,1.0,0.0,2,2,0.001,1000.0/
401D 401,1/
401D 403,1/
402D 402,1/
402D 404,1/
402D 405,1/
501D 101,1,0.5,0.2,0.0,1.0,6.0,1,1/
511D 101,1/
512D 101,2/
512D 101,3/
601D 601,1,2,15.0/
801D 401,1/
801D 403,2/
901D 1.0,401,1,1,1/
901D 1.0,1,2,201,1/
901D 2.0,201,2,2,1/
901D 2.0,2,2,301,1/
901D 6.0,301,2,3,1/
901D 6.0,3,2,101,1/
901D 6.0,101,3,601,1/
901D 6.0,601,2,402,1/
901D 6.1,101,2,501,1/
901D 7.0,501,2,405,1/
901D 6.0,403,1,4,1/
901D 6.0,4,2,301,3/
901D 2.0,301,4,5,1/
901D 2.0,5,2,404,1/
1001D 1,0.0/
1001D 2,0.0/
1001D 3,0.0/
1001D 4,0.0/
1001D 5,0.0/
1101D 501,0.0,1.0,2,101,12.0E6,4.0,2.0E6,6.0/
1201D 201,0.0,100.0,30.0,3600.0,1.0,0.0,0.0,0.0,0.0,9.0,35.0/
1301D 301,0.0,0.0,3,3,-1.0/
1601D 601,2,0.95,100.0,3.0E6,0.2E6,750.0,3600.0,8.0,20.0/
2001D 1,0.0/
2001D 2,0.0/
2001D 3,0.0/
2001D 4,0.0/
2001D 5,0.0/
2101D 501,0.0,1.0E-5/
2201D 201,0.0,3500.0/
2301D 301,2.7E+8/
2401D 401,0,1,0.3E6,100.0,1.0E6/
2401D 402,1,1,0.3E6,100.0,0.25E6/
2401D 403,0,1,1.08E6,1000.0,1.0E6/
2401D 404,2,1,0.8E6,1000.0,1.0E6/
2401D 405,1,2,750.0,0.001,0.13E6/
2501D 101,0.0,1.0,3.8E6/
```

```
2511D 101,2,0.01/
2511D 101,3,99.99/
2601D 601,3640.0,-4.0E7/
3011D 1,0.0,0.0,999.0,0.0/
3011D 2,0.0,0.0,999.0,0.0/
3011D 3,0.0,0.0,999.0,0.0/
3011D 4,0.0,0.0,999.0,0.0/
3011D 5,0.0,0.0,999.0,0.0/
3111D 501,0.0,0.0,999.0,0.0/
3201D 201,999.0/
3211D 201,0.0,0.0,999.0,0.0/
3411D 401,1,1,0.0,0.3E6,100.0,
                 2.0,0.3E6,95.0,
                 4.0,0.3E6,100.0,
             999.0,0.3E6,100.0/
3411D 402,2,1,0.0,0.3E6,0.25E6,
             999.0,0.3E6,0.25E6/
3411D 403,1,1,0.0,1.08E6,1000.0,
             999.0,1.08E6,1000.0/
3411D 404,2,1,0.0,0.8E6,1.0E6,
             999.0,0.8E6,1.0E6/
3411D 405,2,2,0.0,750.0,0.13E6,
             999.0,750.0,0.13E6/
3511D 101,0.0,0.0,999.0,0.0/
3601D 601,9999.0/
3611D 601,0.0,3640.0,999.0,3640.0/
4000D 1.0 /
4100D 99999, 3, 0.2, 1.0, 0.5, 5.0 /
4200D 0, 5 /
STOP
END
```

MINET steady state output for deck X1 is shown in Figure 4.1-4. Much of the output is self-explanatory, but some of it needs to be described in further detail, particularly the System Network and Sub-network (S.N. & S-N) part of the print. Using the boundary conditions edit, one can readily identify network 1 as the simple one to the left in Figure 4.1-1, and network 2 is the more complicated one on the right. In the first part of the S.N. & S-N edit, the sub-network numbers are indicated, as are the flow-energies (W·E) in and out. In the second part of the S.N. & S-N edit the adjustment of heat transfer bridges is indicated. Because we specified in the input that the enthalpy at boundary 404 is identically 0.8E6 J/kg, exactly 280. MW must be removed from sub-network 1 to sub-network 2. The estimate for the heat transfer rate for the heat exchanger was 270. MW, so MINET makes a 3.7% adjustment to the bridge.

In the segment edit, 4 segments are identified and the flows, enthalpies, and pressures at both ends are given, along with pressure loss parameters α and β. The ID's for the modules attaching to the segment inlet and outlet are given, and one can usually make an excellent guess as to which segment is which at this stage.

The next level of output provides detailed information on conditions along each of the flow segments. Any confusion regarding which segments are which can be easily resolved using the module ID's given in this edit. Note that the node and nodal interface numbers are provided, as well.

The level three print provides more detail on the modules, and should remove any doubt as to how the modules fit in the representation. The edit for the heat exchanger is particularly useful, and is written to give enough information so as to enable the user to visualize conditions quite completely.

For this particular example, much of the heat transfer takes place in the bottom node (water inlet), and the water/steam passes through subcooled convection, subcooled nucleate boiling, forced convection vaporization, and into film-boiling in this node. Note that because the heat exchanger was analyzed from the top down, i.e., hot fluid inlet to outlet, some of the numbering looks backward. Using the other module edits, one can determine the current pump speed and head, the valve position and choked flow limit, and the turbine stage speed, efficiency, and power produced (negative work done on turbine by definition).

MINET output at t = 0.2 second for deck X1 is shown in Figure 4.1-5. Note first that there is no sub-network edit, as it is relevant only for the steady state conditions. In the segment edit, one can see the impact of compression and expansion in many of the nodes as small steady state mismatches, resulting from errors left over from the iterative solutions, are resolved. The effect is small in segment 1, which contains incompressible but thermally expandable sodium, and larger in the water/steam segment 2. In particular, there is a significant flow divergence in node 18, where a difference of 17 kg/s is evident. If we trace node 18 into the module edit for the heat exchanger, we find that there has been a 10% increase in heating since the steady state, which explains the divergence. The reason for this 10% increase traces to the heat transfer mode at 0.2 seconds, which is now 234. Because the water/steam contents of the unit are now considered inlet to outlet, rather than outlet to inlet (steady state), there is a slight change in the tube temperature distribution which eliminates the subcooled convection mode in favor of subcooled nucleate boiling. In time, the system will go to a slightly altered steady state. The cause for this difference has been considered at length, and it was decided that the advantages involved with the current approach outweigh the disadvantages, and that the occasional small mismatch that arises is quite acceptable.

Figure 4.1-4 X1 Steady State Output

```
MINET. TIME=    0.00000  TIME STEP=0.00000  STEP NO.     0

 SYSTEM BOUNDARY CONDITIONS:
  ID  NETWORK  FLOW(KG/S)  ENTHALPY(MJ/KG)  PRESSURE(MPA)   TEMP(K)   FLUID
 ---  -------  ----------  ---------------  -------------  ---------  -----
 403     1      1000.000        1.080000          .967467   824.676    NA
 404     1      1000.000         .800000         1.000000   604.692    NA
 401     2       100.000         .300000         2.424984   344.261    H2O
 405     2          .005        3.100000          .130000   587.939    H2O
 402     2        99.995        2.699977          .250000   400.512    H2O

 SYSTEM NETWORKS AND SUB-NETWORKS
   NETWORK   SUB-NETWORK   SUM WE.IN(MW)   SUM WE.OUT(MW)
   -------   -----------   -------------   --------------
      1           1         1080.000000      800.000000
      2           2           30.000000      270.000000

  SUB-NETWORK BRIDGES
   SUBNET1   SUBNET2   Q.BRIDG(MW)   K.BRIDG   F.BRIDG
   -------   -------   -----------   -------   -------
      1         1         0.000000      0        1.000
      1         2       270.000000      1        1.037
      2         1      -270.000000      1        1.037
      2         2       -40.000000      0        1.000

 SYSTEM VOLUMES
  ID  PRESSURE(MPA)  ENTHALPY(MJ/KG)   TEMP(K)   LEVEL(RELATIVE)  HEAT INPUT(MJ/S)  NETWORK  REGIONS
 ---  -------------  ---------------  --------  ---------------  ----------------  -------  -------
 101     2.685830        3.100000     613.955       1.000000         0.000000          2      1

 SYSTEM SEGMENTS                           ALPHA IS IN MPA*SEC*SEC/KG/KG                                               CONNECTS TO:
SEG NETWK WIN(KG/S)  WOUT(KG/S) WBAR(KG/S)  EIN(MJ/KG) EOUT(MJ/KG)  PIN(MPA)   POUT(MPA)   ALPHA,SEG   BETA(MPA)    IN  OUT
--- ----- ---------  ---------- ----------  ---------- -----------  ---------  ---------  ----------  ----------   --- ---
 1     1  1000.000    1000.000   1000.000    1.080000     .800000     .967467   1.000000   .342E-10     .032567   403 404
 2     2   100.000     100.000    100.000     .300000    3.100000    2.424984   2.685830   .164E-06     .262485   401 101
 3     2      .005        .005       .605    3.100000    3.100000    2.685820    .130000   .955E+05    -.000046   101 405
 4     2    99.995      99.995     99.995    3 100000    2.699977    2.685830    .250000   .244E-03    0.000000   101 402
```

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                                   STAND-ALONE MINET DECK XI. GJV 10/18/83                                  PAGE    4
                                                                                        01/20/84  18.12.38  23.021 SEC.

 IN-SEGMENT DISTRIBUTIONS
SEG MODID NODE EIN(MJ/KG) EBAR(MJ/KG) EOUT(MJ/KG) WIN(KG/S) WOUT(KG/S)  TIN(K)   TBAR(K)   TOUT(K) DENS(KG/M3) QA(MJ/S) JIN JOUT
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------  -------   -------  ----------  -------  --- ----
  1     4    1   1.080000    1.080000    1.080000  1000.000   1000.000  824.676  824.676   824.676    819.835      0.000   1    2
  1   301    2   1.080000    1.076513    1.073026  1000.000   1000.000  824.676  821.904   819.132    820.503     -6.974   2    3
  1   301    3   1.073026    1.069193    1.065361  1000.000   1000.000  819.132  816.086   813.040    821.903     -7.665   3    4
  1   301    4   1.065361    1.061177    1.056993  1000.000   1000.000  813.040  809.716   806.393    823.435     -8.368   4    5
  1   301    5   1.056993    1.052742    1.048490  1000.000   1000.000  806.393  803.017   799.641    825.047     -8.503   5    6
  1   301    6   1.048490    1.045092    1.041693  1000.000   1000.000  799.641  796.943   794.246    826.507     -6.797   6    7
  1   301    7   1.041693    1.038433    1.035173  1000.000   1000.000  794.245  791.660   789.074    827.777     -6.520   7    8
  1   301    8   1.035173    1.032031    1.028888  1000.000   1000.000  789.074  786.581   784.089    828.997     -6.285   8    9
  1   301    9   1.028888    1.025872    1.022855  1000.000   1000.000  784.089  781.698   779.307    830.171     -6.033   9   10
  1   301   10   1.022855    1.019959    1.017063  1000.000   1000.000  779.307  777.012   774.717    831.296     -5.793  10   11
  1   301   11   1.017063    1.014282    1.011501  1000.000   1000.000  774.717  772.514   770.312    832.376     -5.562  11   12
  1   301   12   1.011501    1.008835    1.005170  1000.000   1000.000  770.312  768.202   766.092    833.412     -5.330  12   13
  1   301   13   1.006170     .903256     .800000  1000.000   1000.000  766.092  685.018   604.692    853.335   -205.829  13   14
  1     5   14    .800000     .800000     .800000  1000.000   1000.000  604.692  604.692   604.692    872.474      0.000  14   15
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------  -------   -------  ----------  -------  --- ----
  2     1   15    .300000     .300000     .300000   100.000    100.000  344.246  344.246   344.246    980.169      0.000  16   17
  2   201   16    .300000     .300000     .300000   100.000    100.000  344.246  344.246   344.246    980.169      0.000  17   18
  2     2   17    .300000     .300000     .300000   100.000    100.000  344.246  344.246   344.246    980.169      0.000  18   19
  2   301   19    .300000    1.332559    2.361702   100.000    100.000  344.246  498.073   498.073     60.582    206.170  19   20
  2   301   19   2.361702    2.388354    2.415006   100.000    100.000  498.073  498.073   498.073     16.455      5.330  20   21
  2   301   20   2.415006    2.442815    2.470625   100.000    100.000  498.073  498.073   498.073     15.859      5.562  21   22
  2   301   21   2.470625    2.499589    2.528553   100.000    100.000  498.073  498.073   498.073     15.282      5.793  22   23
  2   301   22   2.528553    2.558716    2.588879   100.000    100.000  498.073  498.073   498.073     14.724      6.033  23   24
  2   301   23   2.588879    2.620306    2.651733   100.000    100.000  498.073  498.073   498.073     14.185      6.285  24   25
  2   301   24   2.651733    2.684332    2.716932   100.000    100.000  498.073  498.073   498.073     13.665      6.520  25   26
  2   301   25   2.716932    2.750917    2.784901   100.000    100.000  498.073  498.073   498.073     13.163      6.797  26   27
  2   301   26   2.784901    2.827417    2.869933   100.000    100.000  498.073  506.569   521.342     12.425      8.503  27   28
  2   301   27   2.869933    2.911770    2.953608   100.000    100.000  521.342  536.663   552.665     11.343      8.368  28   29
  2   301   28   2.953608    2.991934    3.030261   100.000    100.000  552.665  567.842   583.449     10.483      7.665  29   30
  2   301   29   3.030261    3.065130    3.100000   100.000    100.000  583.449  597.969   612.750      9.808      6.974  30   31
  2     3   30   3.100000    3.100000    3.100000   100.000    100.000  612.750  612.750   612.750      9.518      0.000  31   32
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------  -------   -------  ----------  -------  --- ----
  3   501   31   3.100000    3.100000    3.100000      .006       .006  601.625  601.625   601.625      5.233      0.000  33   34
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------  -------   -------  ----------  -------  --- ----
  4   601   32   3.100000    2.899988    2.699977    99.994     99.994  613.955  514.871   400.512      6.589    -40.000  35   36
```

```
                         STAND-ALONE MINET DECK XI. GJV 10/18/83                                    PAGE    5
                                                                         01/20/84  18.12.38  23.047 SEC.

SYSTEM MODULES
 MODULE    1 IS B.C. NUMBER    1. MODID 403.NPATH=     0
 MODULE    2 IS PIPE NUMBER    1. MODID   4.NPATH=     1
 MODULE    3 IS H.X. NUMBER    1. MODID 301.NPATH=     1
  THE HEAT FLUX AREA CORRECTION FACTOR IS    .889565
   T NOD I NOD O NOD  QINR(KJ/S/M )   TINR(K)    T TUBE(K)  TOUTR(K)    QOUTR(KJ/S/M )  MODE.I  MODE.O T.CORE T.STRC
   ----- ----- -----  -------------  ---------  ---------  ---------  --------------  ------  ------ ------ ------
     1    18    13       20.41827    498.07257  657.65032  685.01788       -20.26723   4321         1   498.1  685.0
     2    19    12         .53059    498.07257  767.45891  768.20158         -.52134      4         1   498.1  768.2
     3    20    11         .55201    498.07257  771.74003  772.51431         -.54220      4         1   498.1  772.5
     4    21    10         .57458    498.07257  776.20422  777.01197         -.56419      4         1   498.1  777.0
     5    22     9         .59837    498.07257  780.85484  781.69800         -.58736      4         1   498.1  781.7
     6    23     8         .62344    498.07257  785.70060  786.58126         -.61178      4         1   498.1  786.6
     7    24     7         .64983    498.07257  790.73953  791.65985         -.63747      4         1   498.1  791.7
     8    25     6         .67761    498.07257  795.98119  796.94348         -.66453      4         1   498.1  796.9
     9    26     5         .84342    506.56920  801.74304  803.01660         -.87649     54         1   506.6  803.0
    10    27     4         .82944    536.66335  808.51688  809.71621         -.82221      5         1   536.7  809.7
    11    28     3         .76019    567.84234  814.97666  816.08586         -.75760      5         1   567.8  816.1
    12    29     2         .69156    597.96874  820.88970  821.90405         -.69047      5         1   598.0  821.9
 MODULE    4 IS PIPE NUMBER    2. MODID   5.NPATH=     1
 MODULE    5 IS B.C. NUMBER    2. MODID 404.NPATH=     0
 MODULE    6 IS B.C. NUMBER    3. MODID 401.NPATH=     0
 MODULE    7 IS PIPE NUMBER    3. MODID   1.NPATH=     2
 MODULE    8 IS PUMP NUMBER    1. MODID 201.NPATH=     1
  PUMP SPEED= 3500.000  PUMP FLOW=  100.000 KG/S  PUMP HEAD=    28.356 METERS
 MODULE    9 IS PIPE NUMBER    4. MODID   2.NPATH=     1
 MODULE   10 IS PIPE NUMBER    5. MODID   3.NPATH=     1
 MODULE   11 IS VOL. NUMBFR    1. MODID 101.NPATH=     1
 MODULE   12 IS VALV NUMBER    1. MODID 501.NPATH=     1
  RELATIVE VALVE POSITION IS    .0000100,AND CHOKE FLOW IS    .586E-02,AS DETERMINED USING OPTION  2
 MODULE   13 IS B.C. NUMBER    4. MODID 405.NPATH=     0
 MODULE   14 IS TBSG NUMBER    1. MODID 601.NPATH=     1
  SPEED IN RPM IS 3640.00, EFFICIENCY IS    .93018, POWER FROM GEN  -.380E+08
 MODULE   15 IS B.C. NUMBER    5. MODID 402.NPATH=     0
END SS TIME=23.06
MINET: END=1. PRINT=.2 STORE=.2 SAVE=1.
```

Figure 4.1-5 X1 t = 0.2s Output

```
                              STAND-ALONE MINET DECK XI. GJV 10/18/83                                              PAGE    6
                                                                                          01/20/84  18.12.39  23.295 SEC.

 MINET. TIME=      .20000  TIME STEP= .10000  STEP NO.     2

  SYSTEM BOUNDARY CONDITIONS:
   ID  NETWORK  FLOW(KG/S)  ENTHALPY(MJ/KG)  PRESSURE(MPA)   TEMP(K)   FLUID
  ---  -------  ----------  ---------------  -------------  ---------  -----
  403     1       1000.000        1.080000         .967463    824.676   NA
  404     1       1000.589         .800002        1.000000    604.694   NA
  401     2         99.500         .300000        2.422935    344.262   H20
  405     2           .006        3.099812         .130000    587.848   H20
  402     2         99.927        2.699712         .250000    400.512   H20

  SYSTEM VOLUMES
   ID  PRESSURE(MPA)  ENTHALPY(MJ/KG)    TEMP(K)   LEVEL(RELATIVE)  HEAT INPUT(MJ/S)  NETWORK  REGIONS
  ---  -------------  ---------------  ---------  ---------------  ----------------  -------  -------
  101       2.683863         3.099679    613.800         1.000000          0.000000        2     1

  SYSTEM SEGMENTS                              ALPHA IS IN MPA*SEC*SEC/KG/KG                                        CONNECTS TO:
 SEG NETWK WIN(KG/S)   WOUT(KG/S) WBAR(KG/S)  EIN(MJ/KG) EOUT(MJ/KG)  PIN(MPA)   POUT(MPA)  ALPHA,SEG  BETA(MPA)    IN OUT
 --- ----- ----------  ---------- ----------  ---------- -----------  ---------  ---------  ---------  ---------   --- ---
  1     1   1000.000    1000.589   1000.291    1.080000     .800002     .967463   1.000000  .342E-10    .032567   403 404
  2     2     99.500      99.920     99.635     .300000    3.099777    2.422935   2.683063  .167E-06    .262475   401 101
  3     2       .006        .006       .006    3.099798    3.099812    2.683854    .130000  .744E+05   -.000046   101 405
  4     2     99.927      99.927     99.927    3.099798    2.699712    2.683863    .250000  .244E-03   0.000000   101 402
```

```
                           STAND-ALONE MINET DECK X1. GJV 10/18/83                                              PAGE    7
                                                                                          01/20/84  18.12.39  23.304 SEC.

 IN-SEGMENT DISTRIBUTIONS
SEG MODID NODE EIN(MJ/KG) EBAR(MJ/KG) EOUT(MJ/KG) WIN(KG/S) WOUT(KG/S)   TIN(K)   TBAR(K)   TOUT(K) DENS(KG/M3) QA(MJ/S) JIN JOUT
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------- --------  -------- ----------- -------- --- ----
  1     4    1   1.080000    1.080000    1.080000  1000.000   1000.000  824.676  824.676   824.676    819.835     0.000   1    2
  1   301    2   1.080000    1.076513    1.073026  1000.000   1000.002  824.676  821.904   819.132    820.503    -6.962   2    3
  1   301    3   1.073026    1.069194    1.065361  1000.002   1000.007  819.132  816.086   813.040    821.903    -7.641   3    4
  1   301    4   1.065361    1.061177    1.056994  1000.007   1000.022  813.040  809.717   806.393    823.435    -8.296   4    5
  1   301    5   1.056994    1.052741    1.048487  1000.022    999.948  806.393  803.016   799.639    825.047    -8.831   5    6
  1   301    6   1.048487    1.045091    1.041694   999.948    999.967  799.639  796.943   794.247    826.507    -6.701   6    7
  1   301    7   1.041694    1.038434    1.035174   999.967    999.985  794.247  791.660   789.074    827.777    -6.440   7    8
  1   301    8   1.035174    1.032031    1.028889   999.985   1000.008  789.074  786.582   784.090    829.997    -6.182   8    9
  1   301    9   1.028889    1.025873    1.022856  1000.008   1000.029  784.090  781.699   779.308    830.171    -5.938   9   10
  1   301   10   1.022856    1.019960    1.017063  1000.029   1000.049  779.308  777.013   774.718    831.296    -5.705  10   11
  1   301   11   1.017063    1.014282    1.011501  1000.049   1000.066  774.718  772.515   770.312    832.376    -5.484  11   12
  1   301   12   1.011501    1.008836    1.006171  1000.066   1000.078  770.312  768.202   766.092    833.412    -5.273  12   13
  1   301   13   1.006171     .903097     .800022  1000.078   1000.585  766.092  684.893   604.709    853.366  -203.927  13   14
  1     5   14    .800022     .800012     .800002  1000.585   1000.585  604.709  604.701   604.694    872.472     0.000  14   15
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------- --------  -------- ----------- -------- --- ----
  2     1   15    .300000     .299999     .299998    99.500     99.500  344.247  344.247   344.246    980.169     0.000  16   17
  2   201   16    .299998     .299998     .299998    99.500     99.500  344.246  344.246   344.246    980.169     0.000  17   18
  2     2   17    .299998     .299998     .299998    99.500     99.501  344.246  344.246   344.246    980.169     0.000  18   19
  2   301   18    .299998    1.332413    2.364827    99.501    116.506  344.246  498.030   498.030     60.684   230.408  19   20
  2   301   19   2.364827    2.389928    2.415030   116.506    117.520  498.030  498.030   498.030     16.439     6.069  20   21
  2   301   20   2.415030    2.442640    2.470251   117.520    115.531  498.030  498.030   498.030     15.854     6.288  21   22
  2   301   21   2.470251    2.499197    2.528144   115.531    113.218  498.030  498.030   498.030     15.278     6.447  22   23
  2   301   22   2.528144    2.558314    2.588484   113.218    110.982  498.030  498.030   498.030     14.720     6.608  23   24
  2   301   23   2.588484    2.619923    2.651361   110.982    108.884  498.030  498.030   498.030     14.181     6.778  24   25
  2   301   24   2.651361    2.683999    2.716637   108.884    107.215  498.030  498.030   498.030     13.660     6.968  25   26
  2   301   25   2.716637    2.750638    2.784640   107.215    105.758  498.030  498.030   498.030     13.158     7.182  26   27
  2   301   26   2.784640    2.827135    2.869630   105.758    104.083  498.030  506.437   521.201     12.422     8.847  27   28
  2   301   27   2.869630    2.911476    2.953321   104.083    102.510  521.201  536.523   552.526     11.340     8.596  28   29
  2   301   28   2.953321    2.991665    3.030010   102.510    101.136  552.526  567.710   583.323     10.480     7.784  29   30
  2   301   29   3.030010    3.064893    3.099776   101.136     99.913  583.323  597.848   612.635      9.805     7.006  30   31
  2     3   30   3.099776    3.099776    3.099777    99.913     99.920  612.635  612.635   612.635      9.515     0.000  31   32
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------- --------  -------- ----------- -------- --- ----
  3   501   31   3.099798    3.099805    3.099812      .006       .006  601.524  601.527   601.530      5.232     0.000  33   34
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------- --------  -------- ----------- -------- --- ----
  4   601   32   3.099796    2.899755    2.699712    99.927     99.927  602.131  514.756   470.358      6.588   -39.979  35   36
```

```
                              STAND-ALONE MINET DECK XI. GJV 10/18/83                                   PAGE    8
                                                                              01/20/84  18.12.39  23.330 SEC.

SYSTEM MODULES
 MODULE    1 IS B.C. NUMBER    1. MODID 403.NPATH=    0
 MODULE    2 IS PIPE NUMBER    1. MODID   4.NPATH=    1
 MODULE    3 IS H.X. NUMBER    1. MODID 301.NPATH=    1
  THE HEAT FLUX AREA CORRECTION FACTOR IS     .889565
   T NOD I NOD O NOD  QINR(KJ/S/M )    TINR(K)    T TUBE(K)   TOUTR(K)    QOUTR(KJ/S/M )  MODE.I   MODE.O T.CORE T.STRC
   ----- ----- -----  -------------   ---------   ---------   ---------   --------------  ------   ------ ------ ------
     1    18    13        22.85401    498.03000  657.51994  684.89303       -20.22739     234          1   498.1  685.0
     2    19    12          .60197    498.03000  767.45522  768.20212         -.52306       4          1   498.1  768.2
     3    20    11          .62366    498.03000  771.73639  772.51495         -.54394       4          1   498.1  772.5
     4    21    10          .63952    498.03000  776.20087  777.01267         -.56586       4          1   498.1  777.0
     5    22     9          .65540    498.03000  780.85182  781.69875         -.58894       4          1   498.1  781.7
     6    23     8          .67231    498.03000  785.69791  786.58196         -.61320       4          1   498.1  786.6
     7    24     7          .69118    498.03000  790.73714  791.66047         -.63875       4          1   498.1  791.7
     8    25     6          .71241    498.03000  795.97903  796.94264         -.66471       4          1   498.1  796.9
     9    26     5          .87750    506.43659  801.74295  803.01570         -.87591      45          1   506.5  803.0
    10    27     4          .85263    536.52325  808.51553  809.71656         -.82292       5          1   536.6  809.7
    11    28     3          .77212    567.71007  814.97601  816.08599         -.75792       5          1   567.8  816.1
    12    29     2          .69492    597.84836  820.88950  821.90409         -.69057       5          1   597.9  821.9
 MODULE    4 IS PIPE NUMBER    2. MODID   5.NPATH=    1
 MODULE    5 IS B.C. NUMBER    2. MODID 404.NPATH=    0
 MODULE    6 IS B.C. NUMBER    3. MODID 401.NPATH=    0
 MODULE    7 IS PIPE NUMBER    3. MODID   1.NPATH=    2
 MODULE    8 IS PUMP NUMBER    1. MODID 201.NPATH=    1
  PUMP SPEED= 3500.000  PUMP FLOW=   99.750 KG/S  PUMP HEAD=    28.356 METERS
 MODULE    9 IS PIPE NUMBER    4. MODID   2.NPATH=    1
 MODULE   10 IS PIPE NUMBER    5. MODID   3.NPATH=    1
 MODULE   11 IS VOL. NUMBER    1. MODID 101.NPATH=    1
 MODULE   12 IS VALV NUMBER    1. MODID 501.NPATH=    1
  RELATIVE VALVE POSITION IS    .0000100,AND CHOKE FLOW IS    .586E-02,AS DETERMINED USING OPTION  2
 MODULE   13 IS B.C. NUMBER    4. MODID 405.NPATH=    0
 MODULE   14 IS TBSG NUMBER    1. MODID 601.NPATH=    1
  SPEED IN RPM IS 3640.00, EFFICIENCY IS    .93023, POWER FROM GEN  -.380E+08
 MODULE   15 IS B.C. NUMBER    5. MODID 402.NPATH=    0
MINET: END=1. PRINT=.4 STORE=.4 SAVE=1.
```

4.2 MINET DECK X2

MINET Standard Input Deck X2 is a simple balance of plant deck, with modules linked as they would be for simulating a typical balance of plant. The schematic drawings for this deck are shown in Figures 4.2-1 and 4.2-2.

The input deck itself is shown in Figure 4.2-3. It should be noted that this deck was fitted together using crude estimates for component sizings, as well as system conditions and performance. Thus, one should not judge this deck for its accuracy or physical correctness. However, as explained earlier, it is actually easier to develop a representation of a physical system because it is more likely that a user can inadvertently create a non-physical situation.

The output from Deck X2, at steady state, is shown in Figure 4.2-4. Most of the energy/work is done in the turbine, and this helps identify sub-network 1. Sub-network 2 is actually the line running from the condenser, through the feedwater train, to boundary 402. The remaining portion of the system is sub-network 1. Note that MINET chose to adjust the turbine work to meet the energy constraint imposed at the condenser, which is the correct choice, because of the magnitude of the source.

As one reviews the segment edit, it becomes easier to visualize the system. For instance, the bleed lines running from the turbines, through the feedwater heaters, and on to the condenser are in the last few segments considered.

In the module edit, one may observe the type of adjustment MINET can make to the heat exchanger area correction factor. In this case, we input a very small heat transfer rate across the feedwater heaters (cards 2301), and MINET chose not to factor it (factoring the turbines instead). Thus, there was a

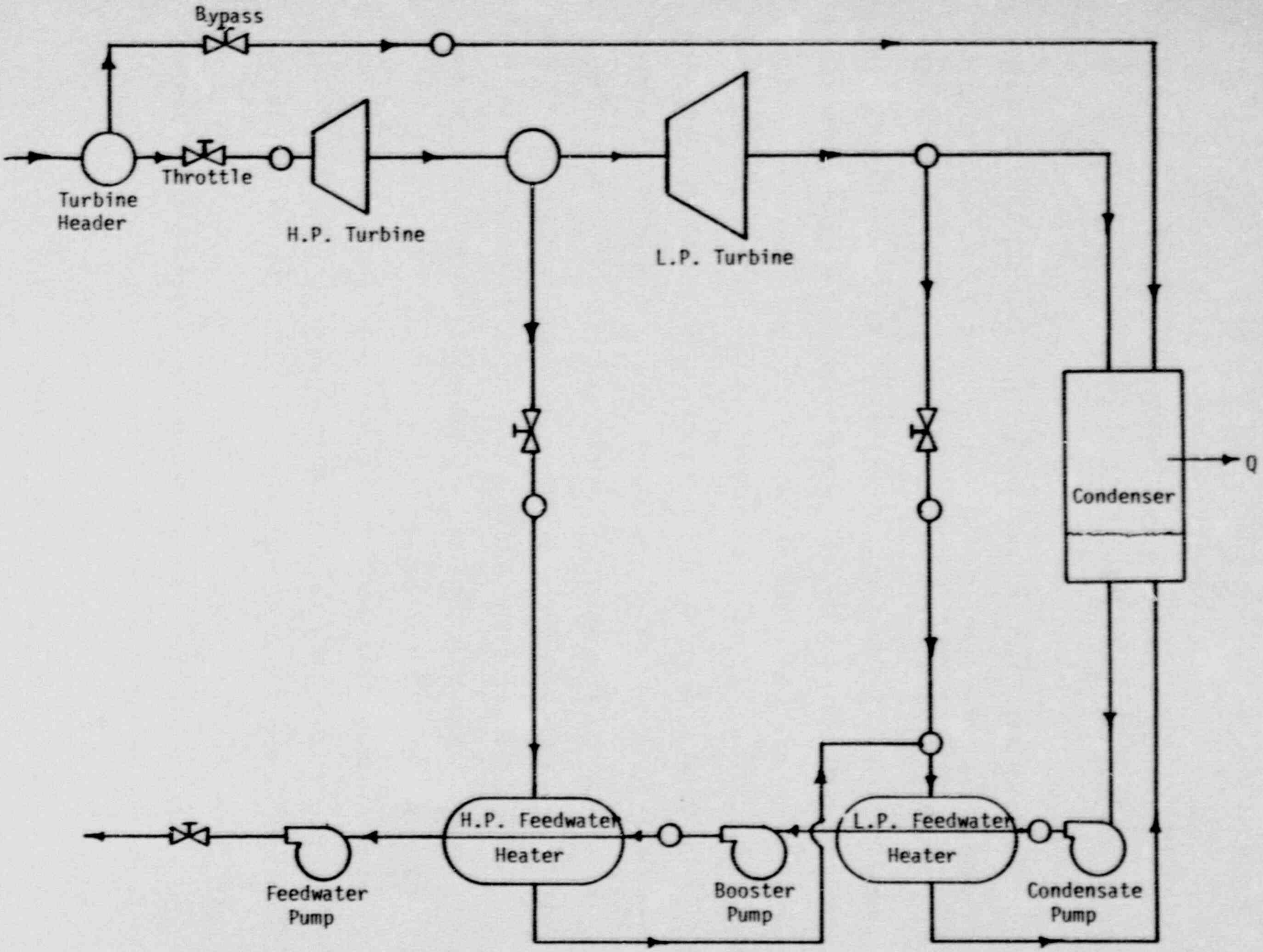

Figure 4.2-1. MINET Example Deck X2, Simple Balance of Plant

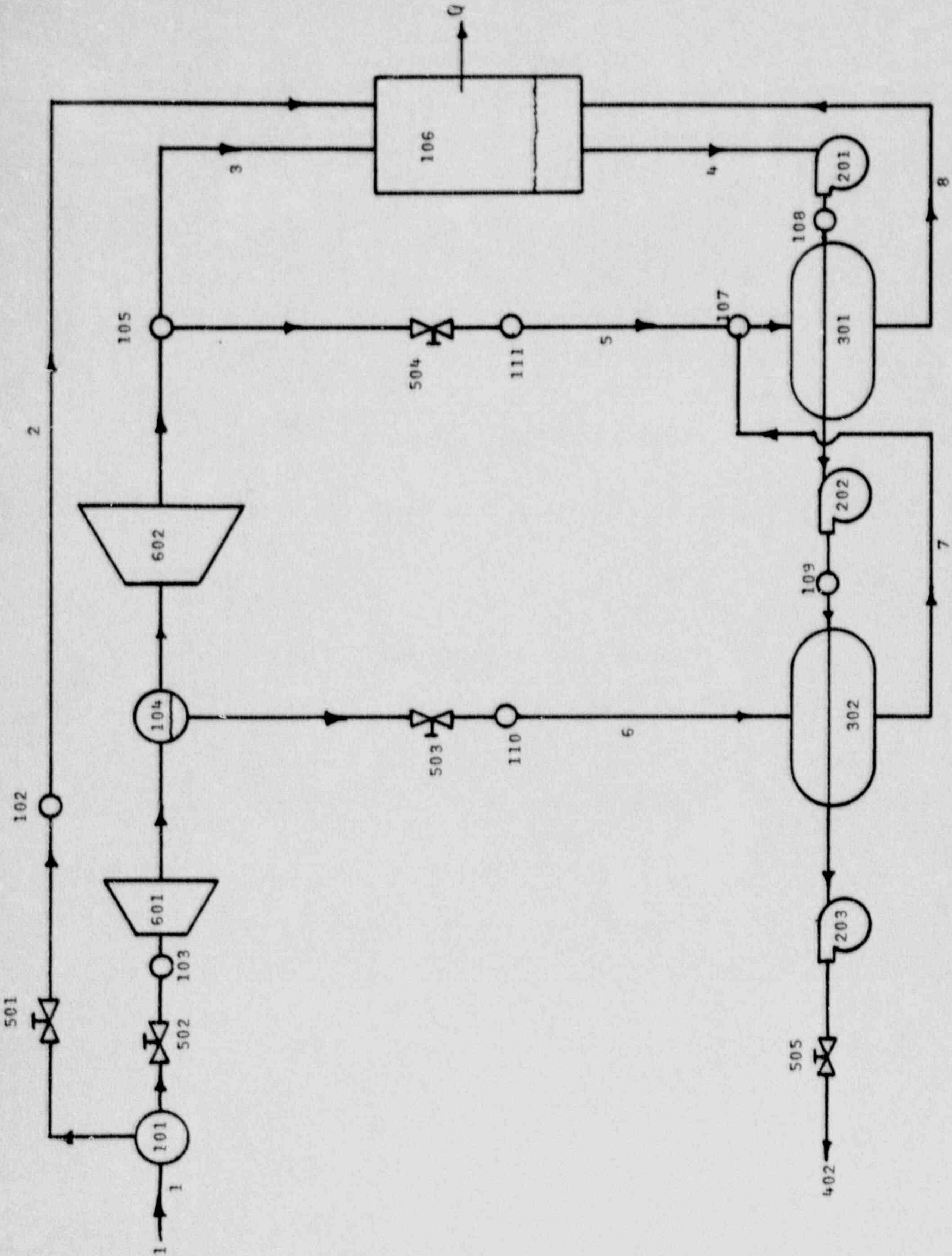

Figure 4.2-2. MINET Deck X2 Module IDs

Figure 4.2-3 X2 Input Deck

```
MINET DECK X2,EXAMPLE BOP DECK,GJV 11/24/83
DV MINETD
1D 1,1,2,1.0,1.0,1.0E-6,1,1/
1D 2,1,2,20.0,0.2,1.0E-6,3,1/
1D 3,1,2,7.0,1.2,1.0E-6,1,1/
1D 4,1,2,4.0,0.8,1.0E-6,1,1/
1D 5,1,2,8.0,0.3,1.0E-6,1,1/
1D 6,1,2,8.0,0.3,1.0E-6,1,1/
1D 7,1,2,14.0,0.2,1.0E-6,2,1/
1D 8,1,2,16.0,0.6,1.0E-6,3,1/
101D 501,1,2,5.0,0.3,1.0E-6,1,1,0.057,1.E-6,1.0/
101D 502,1,2,2.0,1.0,1.0E-6,1,1,0.636,1.E-6,1.0/
101D 503,1,2,6.0,0.3,1.0E-6,1,1,0.057,1.E-6,1.0/
101D 504,1,2,6.0,0.3,1.0E-6,1,1,0.057,1.E-6,1.0/
101D 505,1,2,4.0,0.8,1.0E-6,1,1,0.407,1.E-6,1.0/
201D 201,1,2,1.0,0.8,1.0E-6,1,3/
201D 202,1,2,1.0,0.8,1.0E-6,1,3/
201D 203,1,2,4.0,0.8,1.0E-6,1,3/
301D 301,1,2,20.0,0.03,1.E-6,3,3,3,4,0.04,1.5,625,2,
     4,0.0,1.0,0.0,2,2,1.0,5000.0/
301D 302,1,2,20.0,0.03,1.E-6,3,3,3,4,0.04,1.5,625,2,
     4,0.0,1.0,0.0,2,2,1.0,5000.0/
401D 401,1/
402D 402,1/
501D 101,2,2.0,1.0,0.0,1.0,10.0,1,1/
501D 102,2,1.0,0.5,0.0,1.0,10.0,1,1/
501D 103,2,1.0,0.5,0.0,1.0,10.0,1,1/
501D 104,2,2.0,1.0,0.0,1.0,10.0,1,1/
501D 105,2,1.0,0.5,0.0,1.0,10.0,1,1/
501D 106,1,20.0,4.0,0.0,1.0,6.0,1,2/
501D 107,1,1.0,0.2,0.0,1.0,3.5,3,1/
501D 108,2,1.0,0.5,0.0,1.0,2.0,3,1/
501D 109,2,1.0,0.5,0.0,1.0,2.0,3,1/
501D 110,1,1.0,0.2,0.0,1.0,6.0,3,1/
501D 111,1,1.0,0.2,0.0,1.0,6.0,3,1/
511D 101,1/
512D 101,2/
512D 101,3/
511D 102,1/
512D 102,2/
511D 103,1/
512D 103,2/
511D 104,1/
512D 104,2/
512D 104,3/
511D 105,1/
512D 105,2/
512D 105,3/
511D 106,1/
511D 106,2/
512D 106,3/
511D 106,4/
511D 107,1/
511D 107,2/
512D 107,3/
511D 108,1/
512D 108,2/
511D 109,1/
512D 109,2/
511D 110,1/
```

```
512D 110,2/
511D 111,1/
512D 111,2/
601D 601,1,2,15.0/
601D 602,1,2,15.0/
801D 401,1/
901D 10.0,401,1,1,1/
901D 10.0,1,2,101,1/
901D 10.0,101,2,501,1/
901D 10.0,501,2,102,1/
901D 10.0,102,2,2,1/
901D 10.0,2,2,106,2/
901D 10.0,101,3,502,1/
901D 10.0,502,2,103,1/
901D 10.0,103,2,601,1/
901D 10.0,601,2,104,1/
901D 10.4,104,2,602,1/
901D 10.0,602,2,105,1/
901D 10.0,105,2,3,1/
901D 8.0,3,2,106,1/
901D 4.0,106,3,4,1/
901D 2.0,4,2,201,1/
901D 2.0,201,2,108,1/
901D 2.0,108,2,301,1/
901D 2.0,301,2,202,1/
901D 2.0,202,2,109,1/
901D 2.0,109,2,302,1/
901D 2.0,302,2,203,1/
901D 2.0,203,2,505,1/
901D 2.0,505,2,402,1/
901D 9.51,104,3,503,1/
901D 6.1,503,2,110,1/
901D 5.9,110,2,6,1/
901D 3.0,6,2,302,3/
901D 1.0,302,4,7,1/
901D 3.5,7,2,107,2/
901D 10.0,105,3,504,1/
901D 6.1,504,2,111,1/
901D 5.9,111,2,5,1/
901D 3.6,5,2,107,1/
901D 3.4,107,3,301,3/
901D 1.0,301,4,8,1/
901D 4.0,8,2,106,4/
1001D 1,0.0/
1001D 2,1.E5/
1001D 3,0.1/
1001D 4,0.5/
1001D 5,0.0/
1001D 6,0.0/
1001D 7,0.0/
1001D 8,0.0/
1101D 501,0.0,10.0,1,101,15.0E6,5.0,14.0E6,6.0/
1101D 502,0.0,1.0,0,-999,0.0,0.0,0.0,0.0/
1101D 503,0.0,21.0,0,-999,0.0,0.0,0.0,0.0/
1101D 504,0.0,4.0,0,-999,0.0,0.0,0.0,0.0/
1101D 505,10.0,1.0,0,-999,0.0,0.0,0.0,0.0/
1201D 201,0.5,333.3,230.0,3600.0,1.0,0.0,0.0,0.0,0.0,10.0,60.0/
1201D 202,0.5,333.3,460.0,3600.0,1.0,0.0,0.0,0.0,0.0,10.0,60.0/
1201D 203,0.5,333.3,695.0,3600.0,1.0,0.0,0.0,0.0,0.0,10.0,60.0/
1301D 301,0.5,0.0,3,3,0.0/
```

```
1301D 302,0.5,0.0,3,3,0.0/
1601D 601,1,0.95,1000.0,10.0E6,5.0E6,795.0,3600.0,5.0,30.0/
1601D 602,2,0.95,950.0,5.0E6,8.0E5,545.0,3600.0,5.0,30.0/
2001D 1,0.0/
2001D 2,0.0/
2001D 3,0.0/
2001D 4,-1.E7/
2001D 5,0.0/
2001D 6,0.0/
2001D 7,0.0/
2001D 8,0.0/
2101D 501,0.0,1.E-5/
2101D 502,0.0,0.95/
2101D 503,0.0,0.2/
2101D 504,0.0,0.3/
2101D 505,0.0,0.95/
2201D 201,0.0,3600.0/
2201D 202,0.0,3600.0/
2201D 203,0.0,3600.0/
2301D 301,5.E6/
2301D 302,5.E6/
2401D 401,0,1,3.E6,1000.0,8.96E6/
2401D 402,1,1,1.E6,1000.0,13.E6/
2501D 101,0.0,0.5,8.958E6/
2501D 102,0.0,0.5,0.767E6/
2501D 103,0.0,0.5,8.92E6/
2501D 104,0.0,0.3,5.06E6/
2501D 105,0.0,0.5,1.80E6/
2501D 106,-2.1E9,0.3,0.772E6/
2501D 107,0.0,0.5,0.918E6/
2501D 108,0.0,0.5,2.82E6/
2501D 109,0.0,0.5,6.89E6/
2501D 110,0.0,0.5,2.68E6/
2501D 111,0.0,0.5,1.25E6/
2511D 101,2,0.003/
2511D 101,3,1000.0/
2511D 102,2,0.003/
2511D 103,2,1000.0/
2511D 104,2,975.3/
2511D 104,3,24.9/
2511D 105,2,949.3/
2511D 105,3,25.5/
2511D 106,3,1000.0/
2511D 107,3,50.4/
2511D 108,2,1000.0/
2511D 109,2,1000.0/
2511D 110,2,24.9/
2511D 111,2,25.5/
2601D 601,3600.0,-0.5E9/
2601D 602,3600.0,-0.44E9/
3011D 1,0.0,0.0,999.0,0.0/
3011D 2,0.0,0.0,999.0,0.0/
3011D 3,0.0,0.0,999.0,0.0/
3011D 4,0.0,-1.E7,999.0,-1.E7/
3011D 5,0.0,0.0,999.0,0.0/
3011D 6,0.0,0.0,999.0,0.0/
3011D 7,0.0,0.0,999.0,0.0/
3011D 8,0.0,0.0,999.0,0.0/
3111D 501,0.0,0.0,999.0,0.0/
3111D 502,0.0,0.0,999.0,0.0/
```

```
3111D 503,0.0,0.0,999.0,0.0/
3111D 504,0.0,0.0,999.0,0.0/
3111D 505,0.0,0.0,999.0,0.0/
3121D 501,0.0,1.0E-5,999.0,1.0E-5/
3121D 502,0.0,0.95,999.0,0.95/
3121D 503,0.0,0.2,999.0,0.2/
3121D 504,0.0,0.3,999.0,0.3/
3121D 505,0.0,0.95.999.0,0.95/
3201D 201,999.0/
3201D 202,999.0/
3201D 203,999.0/
3211D 201,0.0,0.0,999.0,0.0/
3211D 202,0.0,0.0,999.0,0.0/
3211D 203,0.0,0.0,999.0,0.0/
3411D 401,1,1,0.0,3.0E6,1000.0,
                999.0,3.0E6,1000.0/
3411D 402,2,1,0.0,1.0E6,13.E6,
                999.0,1.0E6,13.E6/
3511D 101,0.0,0.0,999.0,0.0/
3511D 102,0.0,0.0,999.0,0.0/
3511D 103,0.0,0.0,999.0,0.0/
3511D 104,0.0,0.0,999.0,0.0/
3511D 105.0.0,0.0,999.0,0.0/
3511D 106,0.0,-2.1E9,999.0,-2.1E9/
3511D 107,0.0,0.0,999.0,0.0/
3511D 108,0.0,0.0,999.0,0.0/
3511D 109,0.0,0.0,999.0,0.0/
3511D 110,0.0,0.0,999.0,0.0/
3511D 111,0.0,0.0,999.0,0.0/
3601D 601,999.0/
3601D 602,999.0/
4000D 100.0/
4100D 99999,3,100.0,1000.0/
4200D 0,999/
STOP
END
```

Figure 4.2-4 X2 Steady State Output

```
MINET. TIME=    0.00000  TIME STEP=0.00000  STEP NO.      0

 SYSTEM BOUNDARY CONDITIONS:
   ID  NETWORK  FLOW(KG/S)  ENTHALPY(MJ/KG)  PRESSURE(MPA)   TEMP(K)   FLUID
  ---  -------  ----------  ---------------  -------------  ---------  -----
  401     1      1000.000       3.000000         8.950371    631.118    H2O
  402     1      1000.000        .722319        13.000000    441.991    H2O

 SYSTEM NETWORKS AND SUB-NETWORKS
   NETWORK   SUB-NETWORK   SUM WE.IN(MW)    SUM WE.OUT(MW)
   -------   -----------   -------------    --------------
      1           1         3000.000000       722.318900
      1           2          722.318900       722.318900

  SUB-NETWORK BRIDGES
   SUBNET1   SUBNET2   Q.BRIDG(MW)    K.BRIDG   F.BRIDG
   -------   -------   -----------    -------   -------
      1         1      -3040.000000      1         .746
      1         2         10.000000      0        1.000
      2         1        -10.000000      0        1.000
      2         2        -10.000000      0        1.000

 SYSTEM VOLUMES
  ID  PRESSURE(MPA)   ENTHALPY(MJ/KG)    TEMP(K)    LEVEL(RELATIVE)  HEAT INPUT(MJ/S)  NETWORK  REGIONS
 ---  -------------   ---------------   ---------   ---------------  ----------------  -------  -------
 101     8.950209        3.000000        631.116        .500000           0.000000         1        1
 102      .800687        3.000000        548.915        .500000           0.000000         1        1
 106      .805760         .744538        443.906        .300000       -2100.000000         1        2
 108     2.850442         .712319        441.282        .500000           0.000000         1        1
 109     6.902158         .717319        441.790        .500000           0.000000         1        1
 103     8.912594        3.000000        630.809        .500000           0.000000         1        1
 104     5.049781        2.627025        537.313        .300000           0.000000         1        1
 105     1.806466        2.290409        480.359        .500000           0.000000         1        1
 111     1.266827        2.290409        463.576        .500000           0.000000         1        1
 107      .939212        2.357926        450.365        .500000           0.000000         1        1
 110     2.691431        2.627025        500.842        .500000           0.000000         1        1

 SYSTEM SEGMENTS                                      ALPHA IS IN MPA*SEC*SEC/KG/KG                                                  CONNECTS TO:
SEG NETWK WIN(KG/S)   WOUT(KG/S) WBAR(KG/S)  E(IN(MJ/KG) EOUT(MJ/KG)  PIN(MPA)   POUT(MPA)   ALPHA.SEG   BETA(MPA)    IN OUT
--- ----- ----------  ---------- ----------  ----------- -----------  ---------  ---------   ---------   ----------   --- ---
  1     1  1000.000    1000.000   1000.000     3.000000    3.000000   8.950371   8.950209   .162E-09    0.000000   401 101
  2     1      .003        .003       .003     3.000000    3.000000   8.950209    .800687   .773E+06    0.000000   101 102
  3     1      .003        .003       .003     3.000000    3.000000    .800687    .800358   .312E+02    0.000000   102 106
  4     1  1000.000    1000.000   1000.000      .722319     .712319    .811080   2.850442   .255E-08    2.041911   106 108
  5     1  1000.000    1000.000   1000.000      .712319     .717319   2.850442   6.902158   .398E-08    4.055691   108 109
  6     1  1000.000    1000.000   1000.000      .717319     .722319   6.902158  13.000000   .517E-07    6.149508   109 402
  7     1   999.997     999.997    999.997     3.000000    3.000000   8.950209   8.912594   .376E-07    0.000000   101 103
  8     1   999.997     999.997    999.997     3.000000    2.627025   8.912594   5.049781   .386E-05    0.000000   103 104
  9     1   975.051     975.051    975.051     2.627025    2.290409   5.049669   1.806456   .341E-05    0.000000   104 105
 10     1   949.666     949.666    949.666     2.290409    2.290409   1.806486    .800441   .112E-05     .000174   105 106
 11     1    25.384      25.384     25.384     2.290409    2.290409   1.806486   1.266819   .838E-03     .000401   105 111
 12     1    25.384      25.384     25.384     2.290409    2.290409   1.266836    .939206   .509E-03     .000169   111 107
 13     1    50.330      50.330     50.330     2.357926    2.258579    .939218    .811080   .506E-04    -.000040   107 106
 14     1    24.946      24.946     24.946     2.627025    2.627025   5.049517   2.691416   .379E-02     .000721   104 110
 15     1    24.946      24.946     24.946     2.627025    2.426612   2.691446    .939212   .282E-02     .000217   110 107
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                      MINET DECK X2,EXAMPLE BOP DECK,GJV 11/24/83                                      PAGE
                                                                                 01/20/84  18.11.32  14.154 SEC.

 IN-SEGMENT DISTRIBUTIONS
SEG MODID NODE EIN(MJ/KG) EBAR(MJ/KG) EOUT(MJ/KG) WIN(KG/S) WOUT(KG/S)   TIN(K)   TBAR(K)  TOUT(K) DENS(KG/M3) QA(MJ/S) JIN JOUT
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------  -------  ------- ----------- -------- --- ----
  1     1    1  3.000000    3.000000    3.000000   1000.000   1000.000  631.115  631.115  631.115     36.808     0.000   1    2
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------  -------  ------- ----------- -------- --- ----
  2   501    2  3.000000    3.000000    3.000000       .003       .003  595.506  595.506  595.506     19.919     0.000   3    4
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------  -------  ------- ----------- -------- --- ----
  3     2    3  3.000000    3.000000    3.000000       .003       .003  548.910  548.910  548.910      3.250     0.000   5    6
  3     2    4  3.000000    3.000000    3.000000       .003       .003  548.910  548.910  548.910      3.250     0.000   6    7
  3     2    5  3.000000    3.000000    3.000000       .003       .003  548.910  548.910  548.910      3.250     0.000   7    8
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------  -------  ------- ----------- -------- --- ----
  4     4    6   .722319     .717319     .712319   1000.000   1000.000  443.738  442.592  441.445    895.615   -10.000   9   10
  4   201    7   .712319     .712319     .712319   1000.000   1000.000  441.445  441.445  441.445    896.769     0.000  10   11
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------  -------  ------- ----------- -------- --- ----
  5   301    8   .712319     .713203     .714087   1000.000   1000.000  440.958  441.162  441.366    899.274     1.768  12   13
  5   301    9   .714087     .714918     .715749   1000.000   1000.000  441.366  441.557  441.749    898.881     1.662  13   14
  5   301   10   .715749     .716530     .717319   1000.000   1000.000  441.749  441.929  442.110    898.512     1.562  14   15
  5   202   11   .717319     .717319     .717319   1000.000   1000.000  442.110  442.110  442.110    898.331     0.000  15   16
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------  -------  ------- ----------- -------- --- ----
  6   302   12   .717319     .718158     .718997   1000.000   1000.000  441.308  441.503  441.697    902.484     1.678  17   18
  6   302   13   .718997     .719828     .720659   1000.000   1000.000  441.697  441.890  442.083    902.105     1.662  18   19
  6   302   14   .720659     .721482     .722319   1000.000   1000.000  442.083  442.274  442.468    901.730     1.646  19   20
  6   203   15   .722319     .722319     .722319   1000.000   1000.000  442.468  442.468  442.468    901.540     0.000  20   21
  6   505   16   .722319     .722319     .722319   1000.000   1000.000  442.468  442.468  442.468    901.540     0.000  21   22
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------  -------  ------- ----------- -------- --- ----
  7   502   17  3.000000    3.000000    3.000000    999.997    999.997  630.961  630.961  630.961     36.729     0.000  23   24
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------  -------  ------- ----------- -------- --- ----
  8   601   18  3.000000    2.813512    2.627025    999.997    999.997  630.808  565.662  537.307     34.570  -372.974  25   26
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------  -------  ------- ----------- -------- --- ----
  9   602   19  2.627025    2.458717    2.290409    975.048    975.048  537.306  514.208  480.344     21.219  -328.217  27   28
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------  -------  ------- ----------- -------- --- ----
 10     3   20  2.290409    2.290409    2.290409    949.668    949.668  464.865  464.865  464.865      8.865     0.000  29   30
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------  -------  ------- ----------- -------- --- ----
 11   504   21  2.290409    2.290409    2.290409     25.380     25.380  472.549  472.549  472.549     10.474     0.000  31   32
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------  -------  ------- ----------- -------- --- ----
 12     5   22  2.290409    2.290409    2.290409     25.380     25.380  457.353  457.353  457.353      7.495     0.000  33   34
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------  -------  ------- ----------- -------- --- ----
 13   301   23  2.357926    2.308252    2.258579     50.329     50.329  447.356  447.356  447.356      5.880    -5.000  35   36
 13     8   24  2.258579    2.258579    2.258579     50.329     50.329  447.356  447.356  447.356      6.071     0.000  36   37
 13     8   25  2.258579    2.258579    2.258579     50.329     50.329  447.356  447.356  447.356      6.071     0.000  37   38
 13     8   26  2.258579    2.258579    2.258579     50.329     50.329  447.356  447.356  447.356      6.071     0.000  38   39
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------  -------  ------- ----------- -------- --- ----
 14   503   27  2.627025    2.627025    2.627025     24.948     24.948  521.227  521.227  521.227     21.532     0.000  40   41
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------  -------  ------- ----------- -------- --- ----
 15     6   28  2.627025    2.627025    2.627025     24.948     24.948  480.585  480.585  480.585     10.036     0.000  42   43
 15   302   29  2.627025    2.526818    2.426612     24.948     24.948  480.585  480.585  480.585     10.641    -5.000  43   44
 15     7   30  2.426612    2.426612    2.426612     24.948     24.948  480.585  480.585  480.585     11.324     0.000  44   45
 15     7   31  2.426612    2.426612    2.426612     24.948     24.948  480.585  480.585  480.585     11.324     0.000  45   46
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                         MINET DECK X2.EXAMPLE BOP DECK.GJV 11/24/83                                         PAGE     5
                                                                              01/20/84  18.11.32  14.183 SEC.

SYSTEM MODULES
 MODULE   1 IS B.C. NUMBER   1. MODID 401.NPATH=    0
 MODULE   2 IS PIPE NUMBER   1. MODID   1.NPATH=    1
 MODULE   3 IS VOL. NUMBER   1. MODID 101.NPATH=    1
 MODULE   4 IS VALV NUMBER   1. MODID 501.NPATH=    1
  RELATIVE VALVE POSITION IS   .0000100.AND CHOKE FLOW IS    .114E-01.AS DETERMINED USING OPTION  1
 MODULE   5 IS VOL. NUMBER   2. MODID 102.NPATH=    1
 MODULE   6 IS PIPE NUMBER   2. MODID   2.NPATH=    1
 MODULE   7 IS VOL. NUMBER   3. MODID 106.NPATH=    1
 MODULE   8 IS PIPE NUMBER   3. MODID   4.NPATH=    1
 MODULE   9 IS PUMP NUMBER   1. MODID 201.NPATH=    3
  PUMP SPEED= 3600.000  PUMP FLOW=  333.333 KG/S  PUMP HEAD=   230.000 METERS
 MODULE  10 IS VOL. NUMBER   4. MODID 108.NPATH=    3
 MODULE  11 IS H.X. NUMBER   1. MODID 301.NPATH=    3
  THE HEAT FLUX AREA CORRECTION FACTOR IS     .084280
   T NOD I NOD O NOD  QINR(KJ/S/M )   TINR(K)   T TUBE(K)  TOUTR(K)    QOUTR(KJ/S/M )  MODE.I  MODE.O T.CORE T.STRC
   ----- ----- -----  ------------  ---------  ---------  ---------  --------------  ------  ------ ------ ------
     1     8    23        1.67515   441.16177  444.76255  447.35631        -1.67570      1         6   441.2  447.4
     2     9    23        1.57643   441.55710  444.94344  447.35631        -1.57684      1         6   441.6  447.4
     3    10    23        1.48315   441.92862  445.11261  447.35631        -1.48341      1         6   441.9  447.4
 MODULE  12 IS PUMP NUMBER   2. MODID 202.NPATH=    3
  PUMP SPEED= 3600.000  PUMP FLOW=  333.333 KG/S  PUMP HEAD=   460.000 METERS
 MODULE  13 IS VOL. NUMBER   5. MODID 109.NPATH=    3
 MODULE  14 IS H.X. NUMBER   2. MODID 302.NPATH=    3
  THE HEAT FLUX AREA CORRECTION FACTOR IS     .014175
   T NOD I NOD O NOD  QINR(KJ/S/M )   TINR(K)   T TUBE(K)  TOUTR(K)    QOUTR(KJ/S/M )  MODE.I  MODE.O T.CORE T.STRC
   ----- ----- -----  ------------  ---------  ---------  ---------  --------------  ------  ------ ------ ------
     4    12    29        9.47047   441.50254  462.18786  480.58461        -9.47205      1         6   441.5  480.6
     5    13    29        9.38049   441.89019  462.36753  480.58461        -9.38204      1         6   441.9  480.6
     6    14    29        9.29136   442.27405  462.54567  480.58461        -9.29289      1         6   442.3  480.6
 MODULE  15 IS PUMP NUMBER   3. MODID 203.NPATH=    3
  PUMP SPEED= 3600.000  PUMP FLOW=  333.333 KG/S  PUMP HEAD=   695.000 METERS
 MODULE  16 IS VALV NUMBER   2. MODID 505.NPATH=    1
  RELATIVE VALVE POSITION IS   .9500000.AND CHOKE FLOW IS    .100E+21.AS DETERMINED USING OPTION  0
 MODULE  17 IS B.C. NUMBER   2. MODID 402.NPATH=    0
 MODULE  18 IS VALV NUMBER   3. MODID 502.NPATH=    1
  RELATIVE VALVE POSITION IS   .9500000.AND CHOKE FLOW IS    .100E+21.AS DETERMINED USING OPTION  0
 MODULE  19 IS VOL. NUMBER   6. MODID 103.NPATH=    1
 MODULE  20 IS TBSG NUMBER   1. MODID 601.NPATH=    1
  SPEED IN RPM IS 3600.00. EFFICIENCY IS    .87166. POWER FROM GEN  -.354E+09
 MODULE  21 IS VOL. NUMBER   7. MODID 104.NPATH=    1
 MODULE  22 IS TBSG NUMBER   2. MODID 602.NPATH=    1
  SPEED IN RPM IS 3600.00. EFFICIENCY IS    .96414. POWER FROM GEN  -.312E+09
 MODULE  23 IS VOL. NUMBER   8. MODID 105.NPATH=    1
 MODULE  24 IS PIPE NUMBER   4. MODID   3.NPATH=    1
 MODULE  25 IS VALV NUMRER   4. MODID 504.NPATH=    1
  RELATIVE VALVE POSITION IS   .3000000.AND CHOKE FLOW IS    .100E+21.AS DETERMINED USING OPTION  0
 MODULE  26 IS VOL. NUMBER   9. MODID 111.NPATH=    3
 MODULE  27 IS PIPE NUMBER   5. MODID   5.NPATH=    1
 MODULE  28 IS VOL. NUMBER  10. MODID 107.NPATH=    3
 MODULE  29 IS PIPE NUMBER   6. MODID   8.NPATH=    1
 MODULE  30 IS VALV NUMBER   5. MODID 503.NPATH=    1
  RELATIVE VALVE POSITION IS   .2000000.AND CHOKE FLOW IS    .100E+21.AS DETERMINED USING OPTION  0
 MODULE  31 IS VOL. NUMBER  11. MODID 110.NPATH=    3
 MODULE  32 IS PIPE NUMBER   7. MODID   6.NPATH=    1
 MODULE  33 IS PIPE NUMBER   8. MODID   7.NPATH=    1
END SS TIME=14.2
MINET: END=100. PRINT=100. STORE=100. SAVE=100.
```

Figure 4.2-5 X2 t = 100.0s Output

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                                  MINET DECK X2.EXAMPLE BOP DECK,GJV 11/24/83                                PAGE     6
                                                                                  01/20/84  18.12.32  26.806 SEC.

MINET. TIME=  100.00000  TIME STEP= .40000  STEP NO.   201

 SYSTEM BOUNDARY CONDITIONS:
  ID  NETWORK  FLOW(KG/S)  ENTHALPY(MJ/KG)  PRESSURE(MPA)   TEMP(K)   FLUID
 ---  -------  ----------  ---------------  -------------  --------   -----
 401     1      1000.000       3.000000         8.944160    631.067    H20
 402     1      1001.907        .722428        13.000000    442.017    H20

 SYSTEM VOLUMES
  ID  PRESSURE(MPA)   ENTHALPY(MJ/KG)    TEMP(K)    LEVEL(RELATIVE)  HEAT INPUT(MJ/S)  NETWORK  REGIONS
 ---  -------------   ---------------   ---------   ---------------  ----------------  -------  -------
 101      8.944005         2.999875      631.928        .500000          0.000000          1        1
 102       .801834         3.000356      549.095        .500000          0.000000          1        1
 106       .806863          .745884      443.963        .290457      -2100.000000          1        2
 108      2.851191          .712509      441.325        .500000          0.000000          1        1
 109      6.902584          .717476      441.826        .500000          0.000000          1        1
 103      8.906424         2.999796      630.697        .500000          0.000000          1        1
 104      5.045985         2.627889      537.266        .300000          0.000000          1        1
 105      1.805257         2.293861      480.326        .500000          0.000000          1        1
 111      1.266732         2.290669      463.572        .500000          0.000000          1        1
 107       .939887         2.358611      450.396        .500000          0.000000          1        1
 110      2.691421         2.627028      500.842        .500000          0.000000          1        1

 SYSTEM SEGMENTS                            ALPHA IS IN MPA*SEC*SEC/KG/KG                                                CONNECTS TO:
SEG NETWK WIN(KG/S)   WOUT(KG/S) WBAR(KG/S)  EIN(MJ/KG) EOUT(MJ/KG)   PIN(MPA)   POUT(MPA)   ALPHA.SEG   BETA(MPA)    IN  OUT
--- ----- ----------  ---------- ----------  ---------- -----------  ----------  ----------  ----------  ----------   --- ---
  1    1   1000.000    1000.104   1000.052    3.000000    2.999977    8.944160    8.944005    .162E-09     .000007   401 101
  2    1     -.005        .012       .003     3.000186    3.000671    8.944005     .801834    .801E+06     .000000   101 102
  3    1      .004       -.001       .002     3.000261    2.782970     .801834     .801628    .754E+02   -.000000   102 106
  4    1   1001.955    1001.943   1001.950     .722462     .712508     .812016    2.851191    .254E-08    2.041811   106 108
  5    1   1001.941    1001.914   1001.928     .712508     .717476    2.851191    6.902584    .396E-08    4.055529   108 109
  6    1   1001.914    1001.907   1001.909     .717475     .722428    6.902584   13.000000    .515E-07    6.149333   109 402
  7    1   1000.340    1000.534   1000.437    2.999957    2.999927    8.944005    8.906424    .376E-07     .000013   101 103
  8    1   1000.636    1000.636   1000.636    2.999931    2.627606    8.906424    5.045985    .386E-05    0.000000   103 104
  9    1    976.696     976.696    976.696    2.627321    2.291828    5.045874    1.805257    .341E-05    0.000000   104 105
 10    1    951.626     951.900    951.763    2.291597    2.291274    1.805257     .801710    .111E-05     .000197   105 106
 11    1     25.254      25.273     25.264    2.291597    2.291027    1.805257    1.266723    .844E-03     .000412   105 111
 12    1     25.289      25.291     25.290    2.290509    2.290471    1.266740     .939881    .511E-03     .000171   111 107
 13    1     50.304      49.591     49.637    2.358463    2.261284     .939893     .812016    .520E-04   -.000048   107 106
 14    1     24.325      24.304     24.340    2.627321    2.627082    5.046121    2.691406    .398E-02     .000732   104 110
 15    1     24.370      25.011     24.878    2.627050    2.427495    2.691435     .939887    .283E-02     .000237   110 107
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                                                                                                    PAGE    7
                         MINET DECK X2.EXAMPLE BOP DECK,GJV 11/24/83                 01/20/84  18.12.33  26.825 SEC.

 IN-SEGMENT DISTRIBUTIONS
SEG MODID NODE EIN(MJ/KG) EBAR(MJ/KG) EOUT(MJ/KG) WIN(KG/S) WOUT(KG/S)  TIN(K)    TBAR(K)   TOUT(K) DENS(KG/M3) QA(MJ/S) JIN JOUT
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------   -------   ------- ----------- -------- --- ----
  1     1    1   3.000000    2.999989    2.999977  1000.000   1000.104  631.066   631.063   631.059      36.837    0.000   1    2
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------   -------   ------- ----------- -------- --- ----
  2   501    2   3.000186    2.999831    3.000671     -.005       .012  595.549   595.423   595.720      19.932    0.000   3    4
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------   -------   ------- ----------- -------- --- ----
  3     2    3   3.000261    3.000304    3.000346      .004       .003  549.050   549.069   549.089       3.251    0.000   5    6
  3     2    4   3.000346    3.000344    3.000342      .003       .001  549.089   549.088   549.087       3.251    0.000   6    7
  3     2    5   3.000342    2.891642    2.782970      .001      -.001  549.087   499.155   450.035       3.625    0.000   7    8
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------   -------   ------- ----------- -------- --- ----
  4     4    6    .722462     .717484     .712505  1001.955   1001.946  443.770   442.630   441.488     895.567  -10.000   9   10
  4   201    7    .712505     .712507     .712508  1001.946   1001.943  441.488   441.488   441.488     896.725    0.000  10   11
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------   -------   ------- ----------- -------- --- ----
  5   301    8    .712508     .713388     .714267  1001.941   1001.932  441.002   441.204   441.407     899.232    1.763  12   13
  5   301    9    .714267     .715095     .715922  1001.932   1001.924  441.407   441 598   441.788     898.841    1.659  13   14
  5   301   10    .715922     .716699     .7.7477  1001.924   1001.916  441.788   441.967   442.147     898.473    1.561  14   15
  5   202   11    .717477     .717476     .717476  1001.916   1001.914  442.147   442.147   442.146     898.295    0.000  15   16
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------   -------   ------- ----------- -------- --- ----
  6   302   12    .717475     .718311     .719146  1001.914   1001.912  441.344   441.538   441.732     902.450    1.678  17   18
  6   302   13    .719146     .719973     .720799  1001.912   1001.910  441.732   441.924   442.116     902.073    1.662  18   19
  6   302   14    .720799     .721618     .722436  1001.910   1001.908  442.116   442.305   442.495     901.699    1.646  19   20
  6   203   15    .722436     .722433     .722430  1001.908   1001.908  442.495   442.495   442.494     901.514    0.000  20   21
  6   505   16    .722430     .722429     .722428  1001.908   1001.907  442.494   442.494   442.493     901.515    0.000  21   22
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------   -------   ------- ----------- -------- --- ----
  7   502   17   2.999957    2.999942    2.999927  1000.340   1000.534  630.899   630.895   630.890      36.757    0.000  23   24
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------   -------   ------- ----------- -------- --- ----
  8   601   18   2.999931    2.813768    2.627606  1000.636   1000.636  614.574   565.659   558.369      34.606 -372.563  25   26
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------   -------   ------- ----------- -------- --- ----
  9   602   19   2.627321    2.459575    2.291828   976.696    976.696  514.175   514.175   514.175      21.249 -327.682  27   28
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------   -------   ------- ----------- -------- --- ----
 10     3   20   2.291597    2.291435    2.291274   951.626    951.900  464.879   464.879   464.879       8.877    0.000  29   30
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------   -------   ------- ----------- -------- --- ----
 11   504   21   2.291597    2.291312    2.291027    25.254     25.273  472.529   472.529   472.529      10.484    0.000  31   32
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------   -------   ------- ----------- -------- --- ----
 12     5   22   2.290509    2.290490    2.290471    25.289     25.291  457.373   457.373   457.373       7.500    0.000  33   34
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------   -------   ------- ----------- -------- --- ----
 13   301   23   2.358463    2.309884    2.261305    50.304     49.629  447.401   447.401   447.401       5.877   -4.793  35   36
 13     8   24   2.261305    2.261299    2.261293    49.629     49.617  447.401   447.401   447.401       6.064    0.000  36   37
 13     8   25   2.261293    2.261290    2.261287    49.617     49.604  447.401   447.401   447.401       6.053    0.000  37   38
 13     8   26   2.261287    2.261285    2.261284    49.604     49.591  447.401   447.401   447.401       6.063    0.000  38   39
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------   -------   ------- ----------- -------- --- ----
 14   503   27   2.627321    2.627202    2.627082    24.325     24.354  521.196   521.196   521.196      21.548    0.000  40   41
--- ----- ---- ---------- ----------- ----------- --------- ----------  -------   -------   ------- ----------- -------- --- ----
 15     6   28   2.627050    2.627046    2.627042    24.370     24.374  480.608   480.608   480.608      10.043    0.000  42   43
 15   302   29   2.627042    2.527268    2.427494    24.374     25.007  480.608   480.608   480.608      10.646   -4.931  43   44
 15     7   30   2.427494    2.427494    2.427495    25.007     25.009  480.608   480.608   480.608      11.327    0.000  44   45
 15     7   31   2.427495    2.427495    2.427495    25.009     25.011  480.608   480.608   480.608      11.327    0.000  45   46
```

```
                 MINET DECK X2.EXAMPLE BOP DECK,GJV 11/24/83                                PAGE    8
                                                              01/20/84  18.12.33  26.854 SEC.

SYSTEM MODULES
 MODULE   1 IS B.C. NUMBER   1. MODID 401.NPATH=    0
 MODULE   2 IS PIPE NUMBER   1. MODID   1.NPATH=    1
 MODULE   3 IS VOL. NUMBER   1. MODID 101.NPATH=    1
 MODULE   4 IS VALV NUMBER   1. MODID 501.NPATH=    1
  RELATIVE VALVE POSITION IS   .0000100,AND CHOKE FLOW IS    .114E-01.AS DETERMINED USING OPTION  1
 MODULE   5 IS VOL. NUMBER   2. MODID 102.NPATH=    1
 MODULE   6 IS PIPE NUMBER   2. MODID   2.NPATH=    1
 MODULE   7 IS VOL. NUMBER   3. MODID 106.NPATH=    1
 MODULE   8 IS PIPE NUMBER   3. MODID   4.NPATH=    1
 MODULE   9 IS PUMP NUMBER   1. MODID 201.NPATH=    3
  PUMP SPEED= 3600.000  PUMP FLOW=  332.619 KG/S  PUMP HEAD=   230.000 METERS
 MODULE  10 IS VOL. NUMBER   4. MODID 108.NPATH=    3
 MODULE  11 IS H.X. NUMBER   1. MODID 301.NPATH=    3
  THE HEAT FLUX AREA CORRECTION FACTOR IS    .084280
   T NOD I NOD O NOD  QINR(KJ/S/M )   TINR(K)    T TUBE(K)  TOUTR(K)    QOUTR(KJ/S/M )  MODE.I   MODE.O T.CORE T.STRC
   ----- ----- -----  -------------  ---------  ---------  ---------  --------------  ------   ------ ------ ------
     1     8    23         1.67362  441.20435  444.79757  447.40137        -1.66661      1          6  441.2  447.4
     2     9    23         1.57502  441.59772  444.97704  447.40137        -1.56844      1          6  441.6  447.4
     3    10    23         1.48183  441.96748  445.14490  447.40137        -1.47565      1          6  442.0  447.4
 MODULE  12 IS PUMP NUMBER   2. MODID 202.NPATH=    3
  PUMP SPEED= 3600.000  PUMP FLOW=  332.630 KG/S  PUMP HEAD=   460.000 METERS
 MODULE  13 IS VOL. NUMBER   5. MODID 109.NPATH=    3
 MODULE  14 IS H.X. NUMBER   2. MODID 302.NPATH=    3
  THE HEAT FLUX AREA CORRECTION FACTOR IS    .014175
   T NOD I NOD O NOD  QINR(KJ/S/M )   TINR(K)    T TUBE(K)  TOUTR(K)    QOUTR(KJ/S/M )  MODE.I   MODE.O T.CORE T.STRC
   ----- ----- -----  -------------  ---------  ---------  ---------  --------------  ------   ------ ------ ------
     4    12    29         9.46845  441.53793  462.19492  480.60844        -9.48827      1          6  441.5  480.6
     5    13    29         9.37887  441.52370  462.37392  480.60944        -9.39858      1          6  441.9  480.6
     6    14    29         9.29030  442.30540  462.55144  480.60844        -9.30972      1          6  442.3  480.6
 MODULE  15 IS PUMP NUMBER   3. MODID 203.NPATH=    3
  PUMP SPEED= 3600.000  PUMP FLOW=  332.636 KG/S  PUMP HEAD=   695.000 METERS
 MODULE  16 IS VALV NUMBER   2. MODID 505.NPATH=    1
  RELATIVE VALVE POSITION IS   .9500000,AND CHOKE FLOW IS    .100E+21.AS DETERMINED USING OPTION  0
 MODULE  17 IS B.C. NUMBER   2. MODID 402.NPATH=    0
 MODULE  18 IS VALV NUMBER   3. MODID 502.NPATH=    1
  RELATIVE VALVE POSITION IS   .9500000,AND CHOKE FLOW IS    .100E+21.AS DETERMINED USING OPTION  0
 MODULE  19 IS VOL. NUMBER   6. MODID 103.NPATH=    1
 MODULE  20 IS TBSG NUMBER   1. MODID 601.NPATH=    1
  SPEED IN RPM IS 3600.00, EFFICIENCY IS   .87139, POWER FROM GEN  -.354E+09
 MODULE  21 IS VOL. NUMBER   7. MODID 104.NPATH=    1
 MODULE  22 IS TBSG NUMBER   2. MODID 602.NPATH=    1
  SPEED IN RPM IS 3600.00, EFFICIENCY IS   .96412, POWER FROM GEN  -.311E+09
 MODULE  23 IS VOL. NUMBER   8. MODID 105.NPATH=    1
 MODULE  24 IS PIPE NUMBER   4. MODID   3.NPATH=    1
 MODULE  25 IS VALV NUMBER   4. MODID 504.NPATH=    1
  RELATIVE VALVE POSITION IS   .3000000,AND CHOKE FLOW IS    .100E+21.AS DETERMINED USING OPTION  0
 MODULE  26 IS VOL. NUMBER   9. MODID 111.NPATH=    3
 MODULE  27 IS PIPE NUMBER   5. MODID   5.NPATH=    1
 MODULE  28 IS VOL. NUMBER  10. MODID 107.NPATH=    3
 MODULE  29 IS PIPE NUMBER   6. MODID   8.NPATH=    1
 MODULE  30 IS VALV NUMBER   5. MODID 503.NPATH=    1
  RELATIVE VALVE POSITION IS   .2000000,AND CHOKE FLOW IS    .100E+21.AS DETERMINED USING OPTION  0
 MODULE  31 IS VOL. NUMBER  11. MODID 110.NPATH=    3
 MODULE  32 IS PIPE NUMBER   7. MODID   6.NPATH=    1
 MODULE  33 IS PIPE NUMBER   8. MODID   7.NPATH=    1
```

far greater heat transfer capacity in the feedwater heaters than was needed (according to the heat transfer correlation for condensation on horizontal tubes), so MINET factored the heat transfer area down significantly. Of course, if this type of adjustment occurs in a physically meaningful deck, the utilization of only 1.4% of the heat transfer area would be a sure sign of an error. However, for this deck, the adjustment is not particularly important.

The edit for Deck X2 after 100 seconds of null transient is shown in Figure 4.2-5. Perhaps the most interesting part of this edit is the small amount of flow redistribution which is still occurring to resolve errors leftover from the steady state iterative processes. This is a strong indication that the calculated steady state was fairly accurate, and that the conditions and the calculations are quite stable.

4.3 MINET DECK P2

MINET Deck P2 was developed to simulate part of a PWR system, as shown in Figures 4.3-1 and 4.3-2. This is a rather novel deck in that it is a very different representation than we envisioned during code development. The input deck was developed as part of a short term project by others outside the MINET development effort, as an alternative to the principal approach that was being pursued. As it turns out, their principal research path worked out and MINET Deck P2 was never fully verified. Even though we are not currently utilizing this representation, it has some unique features worth pointing out.

The first feature is the semi-closed system encompassing the high pressure injection (HPI) system, the reactor, the primary loop, and the pressurizer. Since an inlet and an outlet boundary are needed to use MINET, an extremely small leakage out the relief valve, and an equally small makeup from the HPI system were postulated. MINET determined the pressurizer pressure from the area of the slightly open relief valve, the low flow rate, and the choked flow rate for steam. Of course, the valve opening had to be adjusted to set the desired system pressure, but this turned out to be fairly easy to do. It should be noted that the reactor was simulated using a heated pipe, with a heat vs. time table used to simulate decay heat levels after scram.

The second interesting feature of Deck P2 is the representation of a U-tube steam generator, with the primary fluid entering the bottom of the steam generator, passing upward, then curving and coming back down and out the bottom. The secondary water enters through a downcomer, where it is mixed with re-circ flow and then passes upward through the unit, and on to the steam separators. In the MINET representation we used a counter-flow and a parallel-flow heat exchanger in parallel to simulate the U, and separated volumes for the steam separator and the downcomer. The code calculated some flow redistribution between the heat exchanger modules, which is reasonable.

While this application was never completed, there were several indications that MINET would have provided a reasonably good representation as long as one avoided severe conditions for which the more detailed codes are designed to handle. Again, this deck is shown not because we recommend the usage of MINET in this part of a reactor system, but because it contains interesting features.

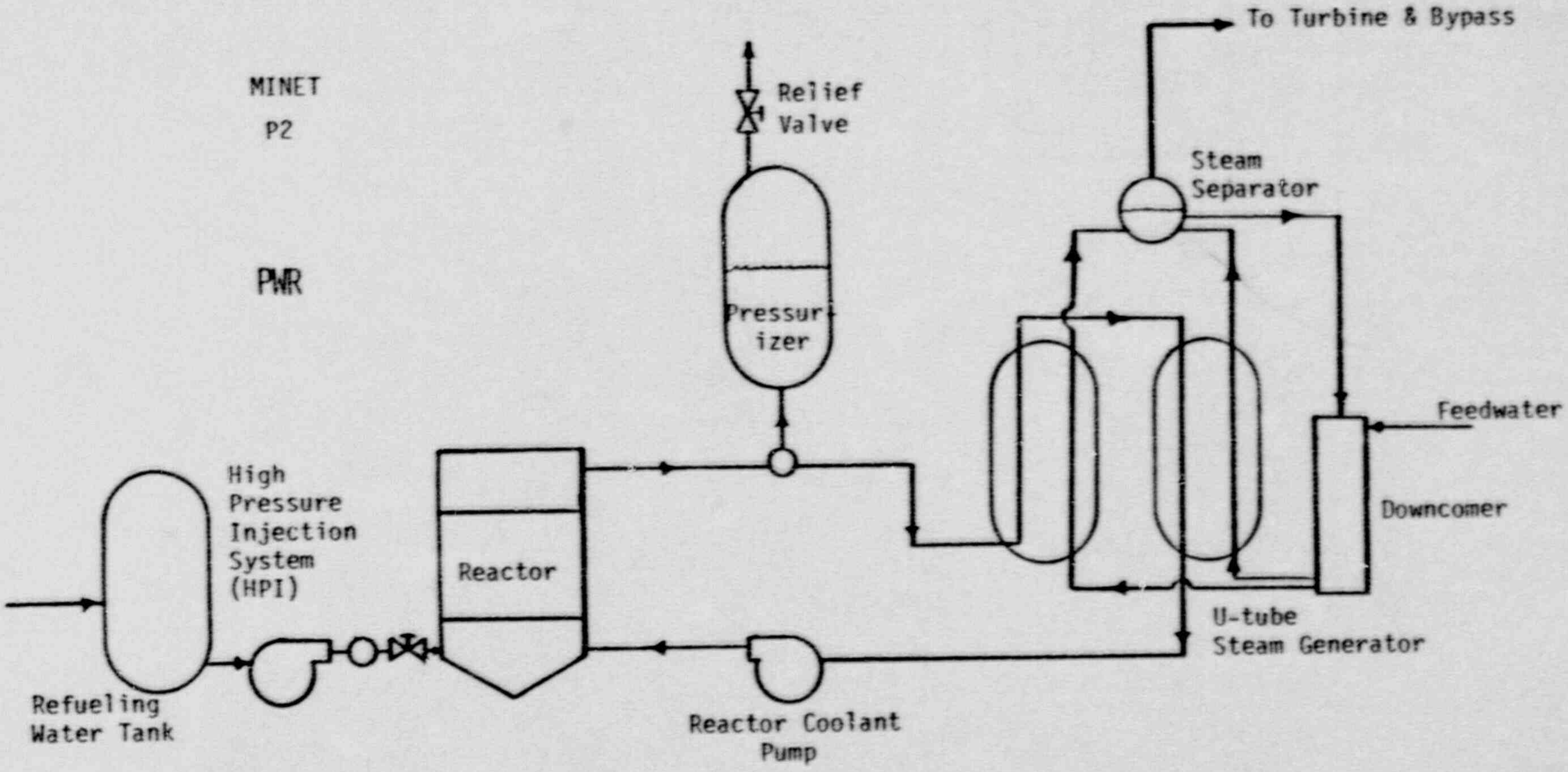


Figure 4.3-1. MINET Standard Deck P2

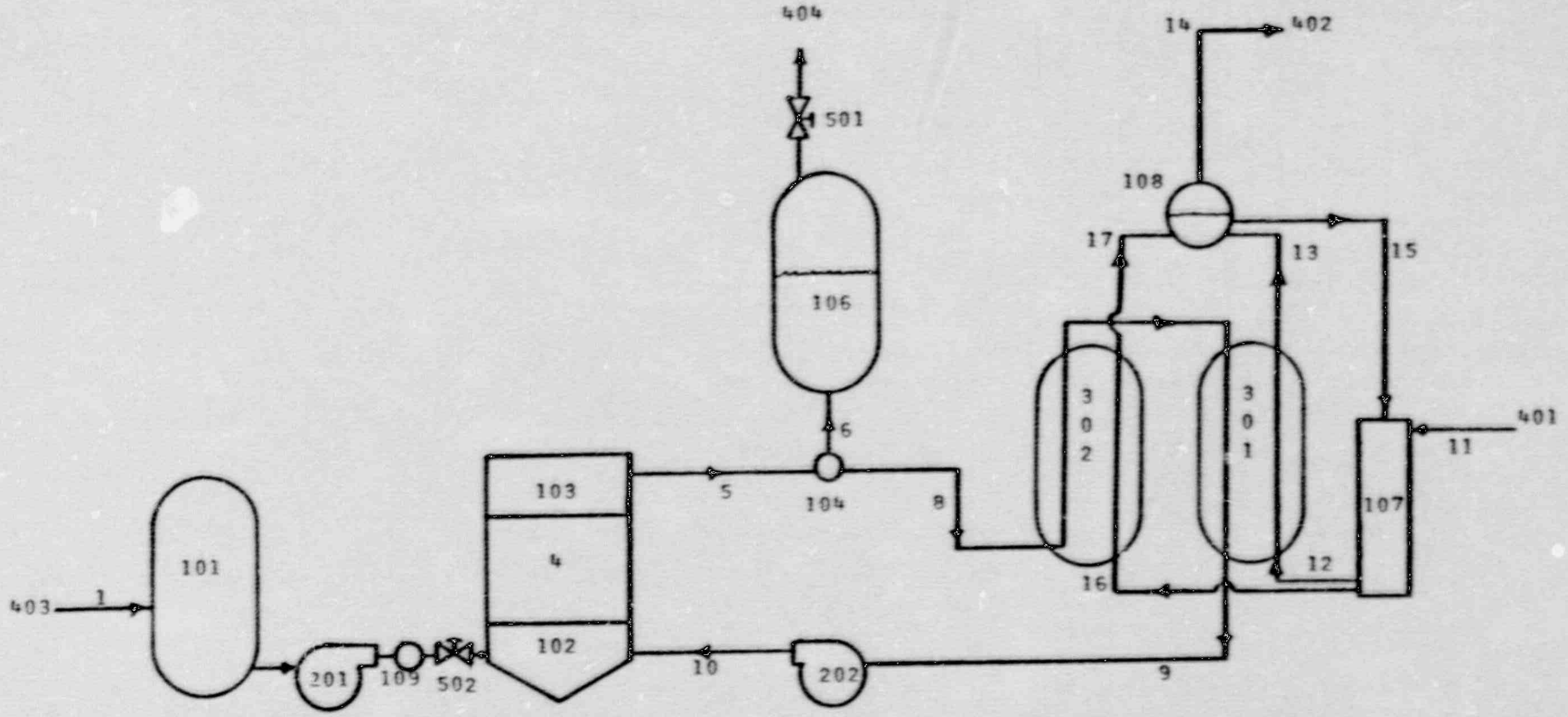


Figure 4.3-2. Deck P2 Module IDs

4.4 MINET DECK E1

MINET Deck E1, shown in Figures 4.4-1 and 4.4-2, is a representation of a part of the EBR-II system. It is a well tested deck, and has been validated against steady state and transient test data [7]. Unfortunately the data deck and output contain restricted data and distribution is currently very limited. However, that does not prevent a general discussion as to features of the MINET representation.

The MINET representation starts at the intermediate loop due to the way the SSC/MINET interface is accomplished. In general, boundaries were chosen according to the availability of data for boundary conditions. In particular, the intermediate loop mass flow rate and IHX outlet temperature, the feedwater flow rate and temperature, the drain (blowdown) flow rate, the turbine back pressure and the throttle and bypass valve behavior(s) were best known. (We did not know the flow out the auxiliary line, but managed to develop a good guess.)

Subcooled feedwater is injected into the bottom of the steam drum and mixed with saturated water coming down from the steam separators. This creates a stratified steam drum, with saturated steam on top, saturated water in the middle, and subcooled water on the bottom. In Deck E1, this is represented using two volumes and a short connecting pipe. Because the contents of the top volume are separated, and the drum is a horizontal cylinder in which the water level must be tracked, we have to use some of the volume module input options (the user should refer to Section 2.2.3, Record 501D). Since the location of the top of the subcooled region or the bottom of the saturated water region is not known precisely, a reasonable guess is used.

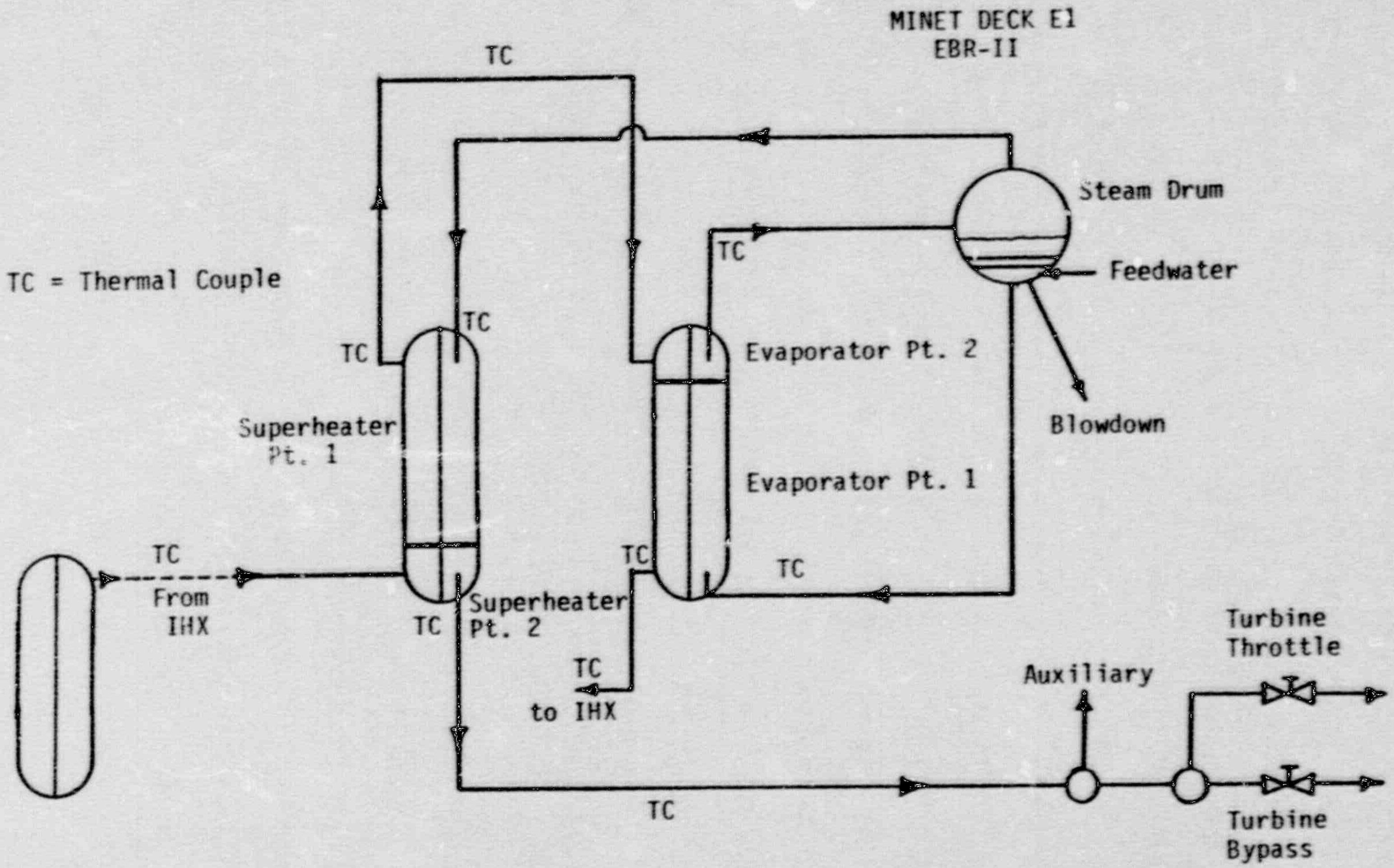
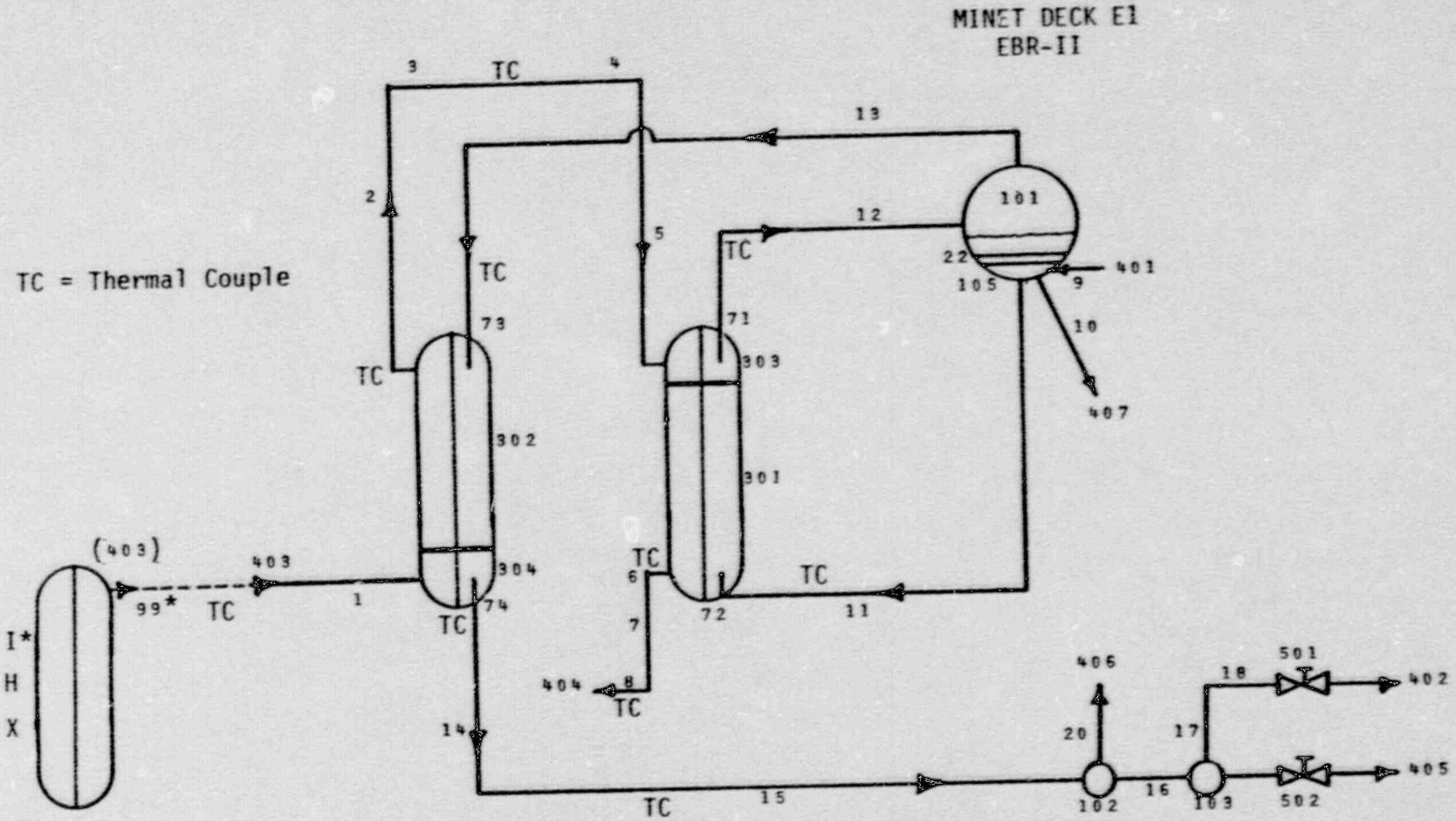


Figure 4.4-1. MINET Standard Deck E1. A One Loop EBR-II Deck



*Not included when run
with SSC

Figure 4.4-2. MINET Standard Deck E1 Module ID's

Note that the diameter of pipe 22 is chosen so as to give the right cross sectional area, and the length is consistent with the component height and the fraction not included in the two volumes.

The EBR-II steam generators have some unusual characteristics that lead us to split (axially) each one in two unequal pieces for the simulation. Under the test transient conditions, virtually all the heat transfer in the evaporator took place in the top 10% of the unit. Thus, we represented the bottom of the evaporator with a coarsely noded heat exchanger module, and the top with a heat exchanger module with fine nodalization.

The EBR-II superheaters are really modified evaporators. To increase the steam flow rate, they inserted core tubes into the steam flow area, creating annular flow and modeling problems. In order to model this, a special core tube model was incorporated, which results in some of the rather unusual data requirements on the 301 card.

In order to reduce thermal shock problems, EBR-II engineers inserted sleeves over the regular tubes near the sodium inlet. Thus, in MINET Deck E1, the superheaters are represented using two heat exchanger modules, both with core tubes, but with one having somewhat thicker tubes between the sodium and the steam.

4.5 MINET DECK C4

MINET was designed for ease of interfacing with other computer codes, partly as a result of its development as part of the SSC program. Thus, we will show one of the decks used in a combined SSC/MINET simulation of the Clinch River Breeder Reactor Plant (CRBRP) system. Because the version of

MINET currently used with SSC is a predecessor to the one documented herein, the input data itself is somewhat different and will not be shown.

MINET deck C4 is illustrated in Figure 4.5-1. Note the similarity between this system and the EBR-II system, particularly in the steam drum where the method of simulation is the same. Note also the large number of safety related lines, e.g., valves, auxiliary lines, and vents. Of course, these extra lines are easily represented using MINET. Their presence does, however, point up the need for considerable flexibility in doing licensing calculations for a plant where numerous safety systems may have to be represented.

This deck has also been well researched and tested, and results have been compared against those calculated indepenently. The MINET results substantially agreed with those generated independently, and all disagreements were successfully traced to limitations in the other calculations [32].

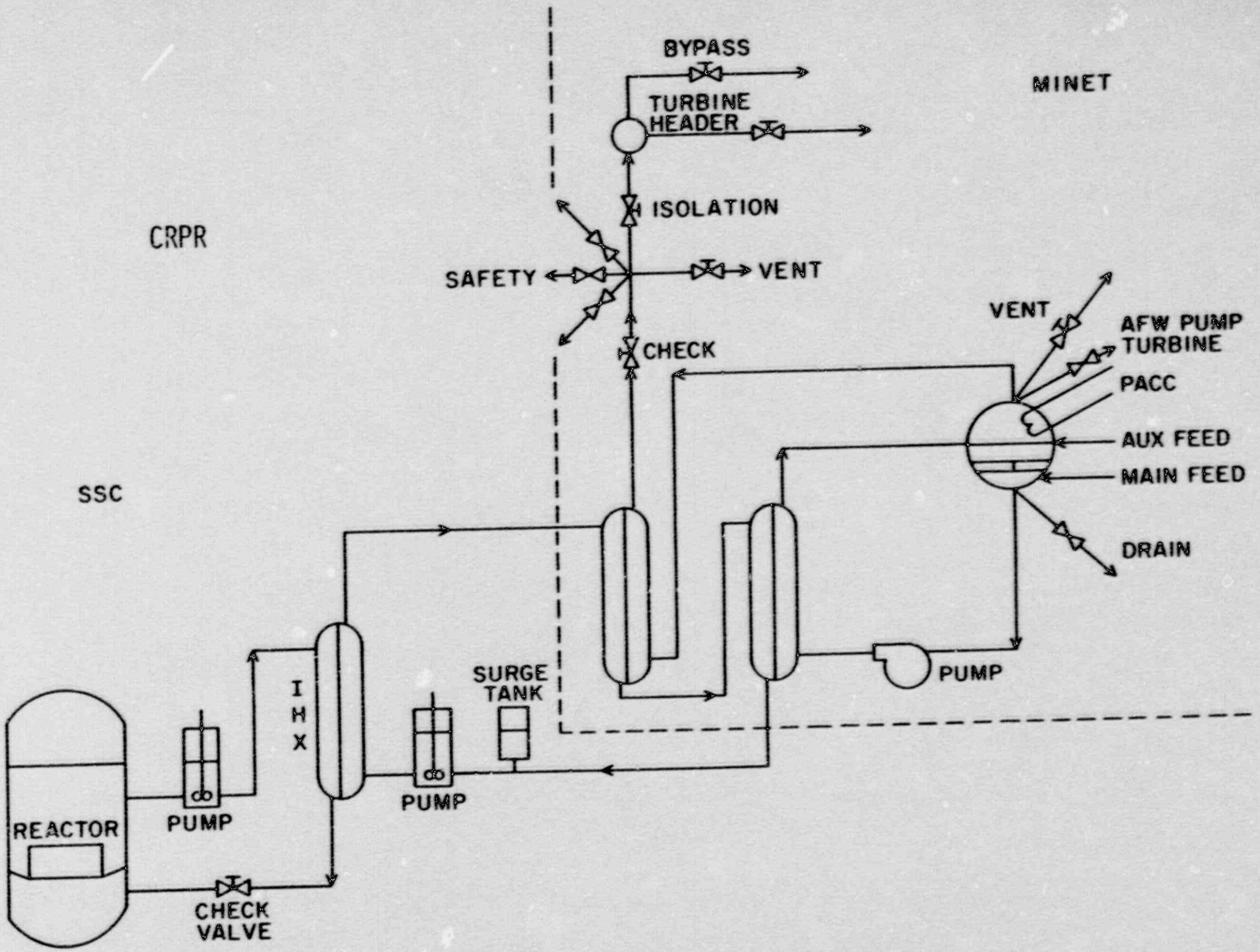


Figure 4.5-1 MINET Standard Deck C4

REFERENCES

1. J.E. Meyer, "Hydrodynamic Models for the Treatment of Reactor Thermal Transients," Nucl. Sci. Eng. 10, 269, 1961.

2. W.H. Rettig, et al., "RELAP4/MOD5 - A Computer Program for Transient Thermal-Hydraulic Analysis of Nuclear Reactors and Related Systems User's Manual," ANCR-NUREG-1335, Idaho National Engineering Laboratory, Sept., 1976.

3. R.L. Daugherty, Hydraulic Turbines, McGraw-Hill, New York, 1920.

4. R.E. Henry and H.R. Fauske, "The Two-Phase Critical Flow of One-Component Mixtures in Nozzles, Orifices and Short Tubes," ASME Transactions J. of Heat Transfer, 93, 1971.

5. F.J. Moody, "Maximum Flow Rate of a Single Component, Two-Phase Mixture," ASME Transactions J. of Heat Transfer, 87, 1965.

6. F. Kreith, Principles of Heat Transfer, Intext Educational Publishers, NY, 1973.

7. G.J. Van Tuyle, "MINET Validation Study Using EBR-II Test Data", Brookhaven National Laboratory Report, NUREG/CR-3603, BNL-NUREG-51733, 1983.

8. K.C. Kalnitsky and H.G. Kwatny, "A First Principles Model for Steam Turbine Control Analysis," Journal of Dynamic Systems, Measurements, and Control, Vol. 103, pp 61-68, March 1981.

9. "RETRAN-02 - A Program for Transient Thermal-Hydraulic Analysis of Complex Fluid Flow Systems," Vol. 1, EPRI NP-1850, May 1981.

10. P. B. Perez, "Polynomial Fits of the Saturation Entropy Tables for Water," 1983, University of Lowell, MA.

11. J.G. Guppy, et al., "Super System Code (SSC, Rev. 0), An Advanced Thermohydraulic Simulation Code for Transients in LMFBRs," Brookhaven National Laboratory Report, NUREG/CR-3169, BNL-NUREG-51650, April, 1983.

12. R.E. Sonntag and G.J. Van Wylen, Introduction to Thermodynamics: Classical and Statistical, John Wiley & Sons, Inc., New York, 1971.

13. A.K. Agrawal, et al, "An Advanced Thermohydraulic Simulation Code for Transients in LMFBRs (SSC-L Code)," Brookhaven National Laboratory Report, BNL-NUREG-50773, February 1978.

14. M.D. Burghhardt, Engineering Thermodynamic with Applications, 2nd Ed., Harper & Row, New York, 1982.

15. H.J. Bomelburg and C.R.F. Smith, "Sodium Chemistry and Physical Properties," in Sodium-NaK Engineering Handbook, Vol. 1, O.J. Faust, Ed., Gordon and Breach, Science Publishers, Inc. 1972.

16. F.W. Dittus and L.K. Boelter, Univ. of Calif. Publs. Eng. 2, 433, (1930).

17. J.G. Chen, "Correlation for Boiling Heat Transfer to Saturated Fluids in Convective Flow," I&EC Process Design and Development 5, 322, (1966).

18. R.W. Lockhart and R.C. Martinelli, "Proposed Correlation of Data for Isothermal Two-Phase, Two-Component Flow in Pipes," Chem. Eng. Prog. 45 (1), 39 (1949).

19. A.A. Bishop, R.O. Sandberg and L.S. Tong, "Forced Convection Heat Transfer at High Pressure after Critical Heat Flux," ASME Paper 65-HT-31, 1965.

20. J.B. Heineman, "An Experimental Investigation of Heat Transfer to Superheated Steam in Round and Rectangular Channels," ANL-6213, 1960.

21. W.M. Rohsenow and J.P. Hartnett, Handbook of Heat Transfer, McGraw-Hill Inc., New York, 1973.

22. R.B. Harty, "Modular Steam Generator Final Project Report," TR-097-330-010, September 1974.

23. R.V. Macbeth, "Application of a Local Conditions Hypothesis to World Data for Uniformly Heated Round Tubes and Rectangular Channels," AEEW-R 267, 1963.

24. A. Bloch, Murphy's Law: And Other Reasons Why Things Go Wrong, Price Stern, Los Angeles, 1977.

25. S. Aoki, "Current Liquid-Metal Heat Transfer Research in Japan," Progress in Heat & Mass Transfer, Vol. 7, pp. 569-573, edited by O.E. Dwyer, Pergamon Press, Inc., Elmsford, New York, 1973.

26. H. Graber and M. Rieger, "Experimental Study of Heat Transfer to Liquid Metals Flowing In-Line Through Tube Bundles," Progress in Heat & Mass Transfer, Vol. 7, pp 151-166, edited by O.E. Dwyer, Pergamon Press, Inc., Elmsford, New York, 1973.

27. B. Lubarsky and S.J. Kaufman, "Review of Experimental Investigations of Liquid-Metal Heat Transfer," NACA TN 3336, 1955.

28. S. Levy, "Fluid Flow," Ch. 15 in The Technology of Nuclear Reactor Safety, Vol. 2, edited by T.J. Thompson and J.G. Beckerly, the M.I.T. Press, Cambridge, MA, 1973.

29. J.R.S. Thom, "Prediction of Pressure Drop During Forced Circulation Boiling of Water," Int. J. Heat Mass Transfer, 7, 709-724, 1964.

30. General Electric, Heat Transfer Data Book, G.E. Co. Corporate Research & Development, Schenectady, NY, 1980.

31. C.W. Cox, "GENRD: A Free-Format Card Input Processor," Los Alamos Scientific Laboratory, LA-4793, January 1972.

32. G.J. Van Tuyle, J.G. Guppy, and T.C. Nepsee, "MINET - Transient Analysis of Fluid Flow and Heat Transfer Networks," Proceedings of 1983 International Computers in Engineering Conference, Vol. 1, Chicago, August 1983. Brookhaven National Laboratory Report, BNL-NUREG-32858, August 1983.

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10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

The MINET computer code, developed for the transient analysis of fluid flow and heat transfer, is documented in this four-part reference. In Part 1, the MINET models, which are based on a momentum integral network method, are described. The various aspects of utilizing the MINET code are discussed in Part 2, The User's Manual. The third part is a code description, detailing the basic code structure and the various subroutines and functions that make up MINET. In Part 4, example input decks, as well as recent validation studies and applications of MINET are summarized.

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