5-2004

Transportable Modular Balance of Plant Study for Small Nuclear Power Plants

Martin Rodney Williamson
University of Tennessee, Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Martin Rodney Williamson entitled "Transportable Modular Balance of Plant Study for Small Nuclear Power Plants." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Nuclear Engineering.

Lawrence W. Townsend, Major Professor

We have read this thesis and recommend its acceptance:

Laurence F. Miller, Fred R. Mynatt

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Fred R. Mynatt

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Acceptance for the Council:

Vice Chancellor and Dean of Graduate Studies

TRANSPORTABLE MODULAR BALANCE OF PLANT STUDY FOR SMALL NUCLEAR POWER PLANTS

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Martin Rodney Williamson
May 2004

A man's character is his fate

-Heraclitus

DEDICATION

This thesis is dedicated to my loving wife and best friend, Jenny, without whose love and support, not a word would have been written.

ACKNOWLEDGMENTS

I am enormously grateful to everyone who helped me during the creation of this thesis. I would like to acknowledge Dr. Laurence F. Miller and Dr. Fred R. Mynatt of The University of Tennessee Nuclear Engineering Department for agreeing to take time and effort to be on my thesis committee. I am grateful for the technical support and discussions with Ralph Boroughs, Project Manager at TVA, as well as those with Larry Conway of Westinghouse. Several colleagues (Joseph Bowling, Jarrod Edwards, T. Jay Harrison, Thomas Miller, and Aaron Sawyer) played a role in the creation of this thesis by sharing their knowledge and friendship with me while I attended UTK. This research was initiated under a grant from the United States Department of Energy NERI program. The Tennessee Valley Authority (TVA), Clean and Advanced Energy Division, sponsored the continuation of this research project under a contract with The University of Tennessee, Nuclear Engineering Department. Finally, I would like to thank Dr. Lawrence W. Townsend, my committee chair and faculty advisor, for giving me the opportunity to be a part of this research. Dr. Townsend has been an exceptional mentor by sharing his encompassing knowledge and giving me guidance throughout graduate school.

ABSTRACT

The purpose of this research is to develop a conceptual design for a balance of plant (BOP) layout to coordinate with small nuclear power plants and to demonstrate the feasibility of transporting this BOP via US waterways. The Westinghouse International Reactor, Innovative and Secure (IRIS) is used as the primary plant for the base-case study. IRIS is an advanced design pressurized water reactor (PWR) with a power rating of 1000MWt (approximately 335 MWe). A Matlab® script file, named BOSCO, automates the process of calculating the BOP component sizes for different initial conditions, enabling the use of different primary systems and/or initial conditions without difficulty. The results are used to create 3-D solid models of the components. These solid models are used to design a layout for a barge-mounted balance of plant. The feasibility of transporting the primary and the secondary systems via two separate barges traveling from the Gulf of Mexico to Chattanooga, TN has been analyzed. Limitations imposed by locks, dams, bridges, aerial power crossings, and river channel depths determine the maximum allowable barge dimensions. The final dimensions for both the reactor building and turbine-generator building barges are 30 meters wide, 100 meters long, with 2.74 meters draft. The reactor building barge displaces approximately 4992 metric tons, while the turbine-generator building barge displaces approximately 2195 metric tons. Figures containing visualizations of plant components layout and solid modeling have been developed and are presented. Further travel up the Tennessee River with a barge of these dimensions is currently restricted due to width limitations imposed by several locks and dams.

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NOMENCLATURE

A	Area
C	Coefficient of linear expansion
C_p	Specific heat
ΔT_{lm}	Log mean temperature difference
D	Tube diameter
F	Correction factor
g	Gravity
h	Heat transfer coefficient
H	Enthalpy
k	Thermal conductivity of tube wall material
L	Total tube length
L'	Tube length neglecting thermal expansion
μ	Dynamic viscosity
$\dot{m}$	Mass flow rate
N	Number
Nu	Nusselt number
Pr	Prandtl number
q	Heat transfer rate
ρ	Density
T	Temperature
U	Overall heat transfer coefficient

Acronyms

BOP	Balance of Plant
CAD	Computer Aided Drafting
CRDM	Control Rod Drive Mechanism
HP	High Pressure
IRIS	International Reactor Innovative & Secure
LMTD	Log Mean Temperature Difference
LOCA	Loss of Coolant Accident
LP	Low Pressure
MSR	Moisture Separator Reheater
NERI	Nuclear Energy Research Initiative
ORNL	Oak Ridge
PWR	Pressurized Water Reactor
RCS	Reactor Coolant System
RV	Reactor Vessel
SG	Steam Generator
TVA	Tennessee Valley Authority
US DOE	United States Department of Energy

Subscripts

c	Cold side
fg	Difference between fluid and gas
film	Film property
h	Hot side
i	Internal to the tube
in	Inlet side
l	Liquid or film property
o	External to the tube
out	Exit side
passes	Number of passes
room	Room temperature (70°F)
sat	Saturation temperature property
total	All tubes included in property
tube	Individual tube property
w	Wall property

1. INTRODUCTION

1.1 PROBLEM STATEMENT AND OBJECTIVES

The purpose of this research is to develop a conceptual design for a balance of plant (BOP) layout to coordinate with small nuclear power plants and to demonstrate the feasibility of transporting this BOP via US waterways. The Westinghouse International Reactor, Innovative and Secure (IRIS) is used as the primary system for the base-case study. IRIS is an advanced pressurized water reactor (PWR) with a power rating of 1000 MWt (approximately 335 MWe). The motivation for developing the concept is to create a layout for use in modularity, barge transport, and manufacturing studies. A Matlab® script file, named BOSCO, is developed for automating the process of calculating component sizes for various initial conditions. This also enables the use of different primary systems and/or initial conditions without difficulty. The results from BOSCO are used to create 3-D solid models of the components. The solid models were used to design a layout for a barge-mounted BOP. The feasibility of transporting the primary and the secondary systems via two separate barges traveling on the Mississippi, Ohio, and Tennessee River systems from the Gulf of Mexico to Knoxville, TN has been analyzed. Limitations imposed by locks, dams, bridges, aerial power crossings, and river depths determine the maximum allowable barge dimensions.

This work supersedes an earlier, preliminary design analysis [Williams, 2002]. The modifications made to the previous research include an increased and more conservative cold side inlet temperature for the condenser, a corrected condenser duty, more accurate condenser models, and changes to the number and sizes of feedwater heaters. The feedwater heaters were also reoriented to a vertical configuration in order to achieve better maintenance and repair conditions.

The parameters of the IRIS primary system are for 1000 MW thermal power. The parameters of most importance for this study are the steam generator entrance and exit conditions. The parameters used are taken from Conway [2003], at steady state operating conditions and thus the secondary plant calculations are also steady state. Using typical values for PWR type plants, a general BOP design, and IRIS steam generator values, an ORCENT2 [Oak Ridge National Laboratory, 2000] heat balance is carried out for the secondary side of the plant. ORCENT2 is an advanced generalized heat balance program which is used to calculate the complete heat and mass balances. Standard heat transfer equations are then used to calculate system performance and component sizes.

The BOP has six feed water heaters and dual reheat with one high pressure and one low-pressure tandem compound turbo-generator unit. Sizes and weights of the components and associated piping are estimated. The footprint is arbitrarily constrained by modularity requirements that the plant be transportable by barge from the mouth of the Mississippi River to any desired TVA sites along the Tennessee River or its tributaries. This requires that the components fit on a barge no larger than 400 feet long by 110 feet wide with a draft less than 9 feet. Navigation charts for the Mississippi River from its mouth to the mouth of the Ohio River, from the mouth of the Ohio River to the mouth of the Tennessee River, and for the Tennessee River from its mouth to Knoxville, Tennessee, have been searched and detailed listings of all potential obstructions (bridges, overhanging cables, locks and dams) and their relevant clearance parameters (height, width, etc.) and channel depth limitations have been tabulated.

1.2 ORGANIZATION OF THESIS

This work is described in the next nine chapters. Chapter two describes the background and an overview of the previous research that has been done to address this issue. Chapters three and four present descriptions of the codes BOSCO and ORCENT2. Chapter five explains the theory used in sizing the balance of plant components. Chapter six describes transportation issues for the barges. Chapters seven and eight give an overview of the solid modeling for the components and barges, respectively. Chapter nine presents two parametric studies using BOSCO. Chapter ten presents the conclusions reached during this research and recommendations for future work.

2. BACKGROUND INFORMATION

2.1 NERI PROJECT

The Nuclear Energy Research Initiative (NERI) is a United States Department of Energy (US DOE) program which awards research and development funding to universities, national laboratories, and industry for approved proposals. The University of Tennessee was awarded a three year research grant, number DE-FG07-00SF22168, whose goal was to "develop compact (100 to 400 MWe) Generation IV nuclear power plant design and layout concepts that maximize the benefits of factory based fabrication and optimal packaging, transportation and siting" [Mynatt, 2003]. Three teams were created to develop three designs that differed by reactor coolant type. This research focuses on the advanced pressurized water reactor (APWR) design concept utilizing the Westinghouse IRIS design.

2.2 WESTINGHOUSE IRIS

The Westinghouse IRIS design concept is a pressurized, light water cooled, medium power reactor that addresses the requirements defined by the US DOE for generation IV reactors, i.e. fuel cycle sustainability, enhanced safety, and improved economics. An international consortium including twenty organizations from nine countries, led by Westinghouse, is developing IRIS. The project began in 1999 as a part of the NERI program and has developed to a level where market entry is set in the 2012-2015 time frame [Carelli, 2003].

IRIS is an innovative reactor design with many new safety features, but its design is built using proven technology from Westinghouse's AP600 and AP1000 PWR designs. Current reactors cope and interfere with accident sequences chiefly by utilizing active means to assure that the consequences of accidents remain within acceptable limits while a limited amount of passive means are used. IRIS' "safety by design" approach eliminates the possibility of certain accidents occurring by designing the system with the accidents in mind. This approach has either eliminated or reduced the consequences of seven out the eight Condition IV design basis events that must be considered for PWRs. The key difference between IRIS and other PWR designs is that IRIS features an integral reactor vessel (RV) that contains all of the main reactor coolant system components (RCS). The RCS includes: eight small, spool type, reactor coolant pumps; eight modular, helical coil, once-through steam generators; a steel reflector which surrounds the core in the RV downcomer to reduce the neutron fluence on the RV; the control rod drive mechanisms (CRDMs); and a pressurizer located in the RV upper head. Since no large primary penetrations of the reactor vessel or large loop piping exist, the large-break loss of coolant accident has been eliminated. The probability of occurrence for the small break loss of coolant event is also reduced due to the integral design requiring less piping. The IRIS integral layout is shown in **Figure 2-1**.

The IRIS reactor core is being designed for a 48 month straight-burn cycle, making it more proliferation resistant since the fuel is significantly less accessible. This is accomplished using a standard enriched fuel (4.95 % UO_2) in a fuel assembly that is

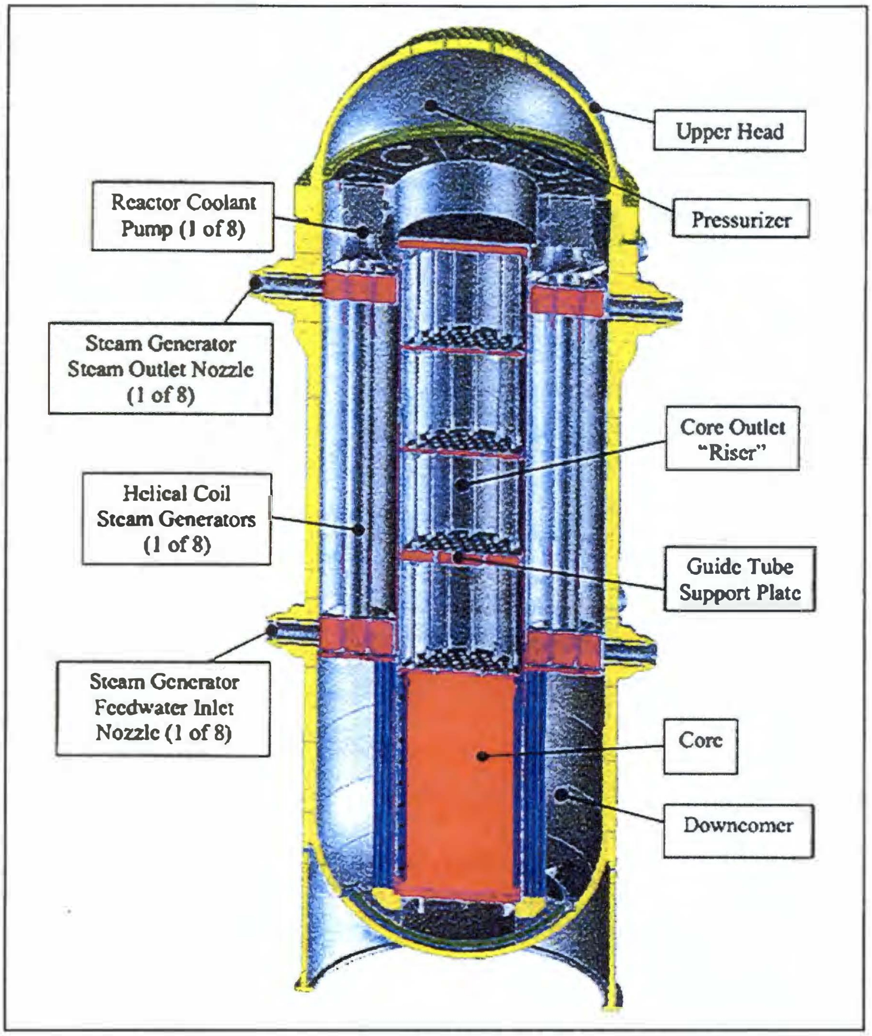

Figure 2-1. IRIS Reactor Vessel Internals
[Source: Westinghouse, 2002]

similar to a Westinghouse PWR assembly. The IRIS fuel assembly consists of 264 fuel rods in a 17 X 17 square array. Low-power density is achieved by employing a core configuration of 89 fuel assemblies with a 14-ft active fuel height, and a nominal thermal power of 1000 MWt. The IRIS primary system components are designed to have very high reliability. This is done to decrease the incidence of equipment failures and to reduce the frequency of required inspections or repairs. This allows IRIS to extend the need for scheduled maintenance outages to at least 48 months. Other results of the four-year maintenance cycle capability include an expected capacity factor exceeding 95 percent and reduced personnel requirements. All of these factors lead to significant reductions in operation and maintenance (O&M) costs.

The IRIS steam generators (SGs) are a once-through, helical-coil tube bundle design, with the primary fluid outside the tubes. Eight SG modules are located in the annular space between the core barrel and the reactor vessel. Each SG has 656 tubes, and the tubes and headers are designed for the full external RCS pressure. Feedwater enters the SG through a nozzle in the RV wall, then flows to the lower feedwater header and to the SG tubing, where it is heated to saturation temperature, boiled, and superheated as it reaches the upper steam header. Steam then exits the SG through the nozzle in the reactor vessel wall [Cinotti et al, 2002]. The primary coolant flow path is illustrated in **Figure 2-2**.

Due to the integral placement of the CRDMs, advantages in safety and operation are attained. Advantages include the elimination of corrosion cracking of the nozzle welds

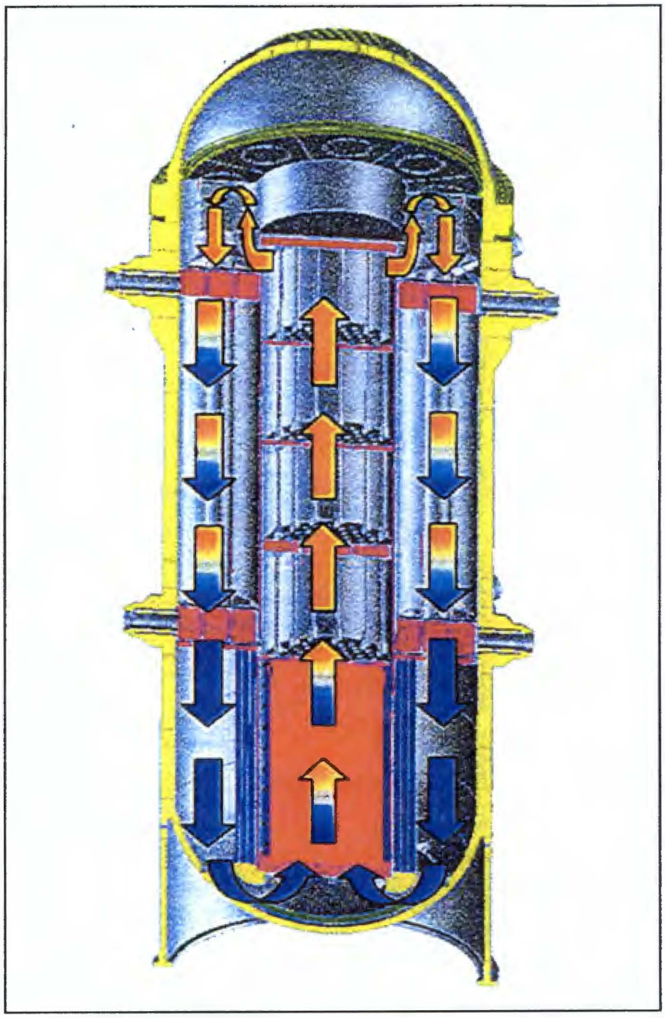

Figure 2-2. IRIS Main Flow Path
[Source: Westinghouse, 2002]

and seals, which are a recurring problem with current plant designs, due to the absence of CRDM penetrations in the upper head. The design basis accident of uncontrolled rod ejection (a Class IV accident) is eliminated because there is no 2000 psi pressure differential to drive out the CRDM extension shafts [Carelli, 2003].

3. BOSCO CODE DEVELOPMENT

Previous research focused on one set of initial conditions that were taken from the preliminary IRIS design [Williams, 2002]. Due to progress in the IRIS design, these initial conditions changed. A comparison of the preliminary IRIS design values used in Williams research and those of the current design are shown in **Table 3-1**.

Since the IRIS design is still being developed, it is important to be able to calculate the component sizes and parameters using different conditions without difficulty. A Matlab® script file, named BOSCO, was developed to automate the process of calculating the component sizes for different initial conditions, enabling the use of different primary systems and/or initial conditions without difficulty. Matlab® is an engineering analysis software package developed by MathWorks [Mathworks, 1992]. The heat transfer correlations discussed in Section 5.1 are coded using the Matlab® computational environment. **Figure 3-1** shows the process flow of BOSCO.

When BOSCO is run, the user is prompted to input five initial conditions that are used to create an ORCENT2 input file. The five user-defined input parameters are shown below, with the base case/IRIS input parameters shown in parenthesis.

1. Steam generator outlet steam temperature (IRIS = 602.6 °F)
2. Steam generator outlet steam pressure (IRIS = 841.0 psia)

Table 3-1. Comparison of Preliminary and Current IRIS Design Values

Source: [Conway, 2003]

Parameter	Preliminary IRIS Design Values	Current IRIS Design Values
Electrical Output	360 MWe	335 MWe
Secondary Side Inlet Temperature	413.6 °F	435.0 °F
Secondary Side Outlet Temperature	602.6 °F	602.6 °F
Steam Outlet Pressure	1015.28 psia	841.0 psia
Total Steam Flow	3,970,794 lbm/hr	3,990,543 lbm/hr
Circulating Water Inlet Temperature	70 °F	90 °F

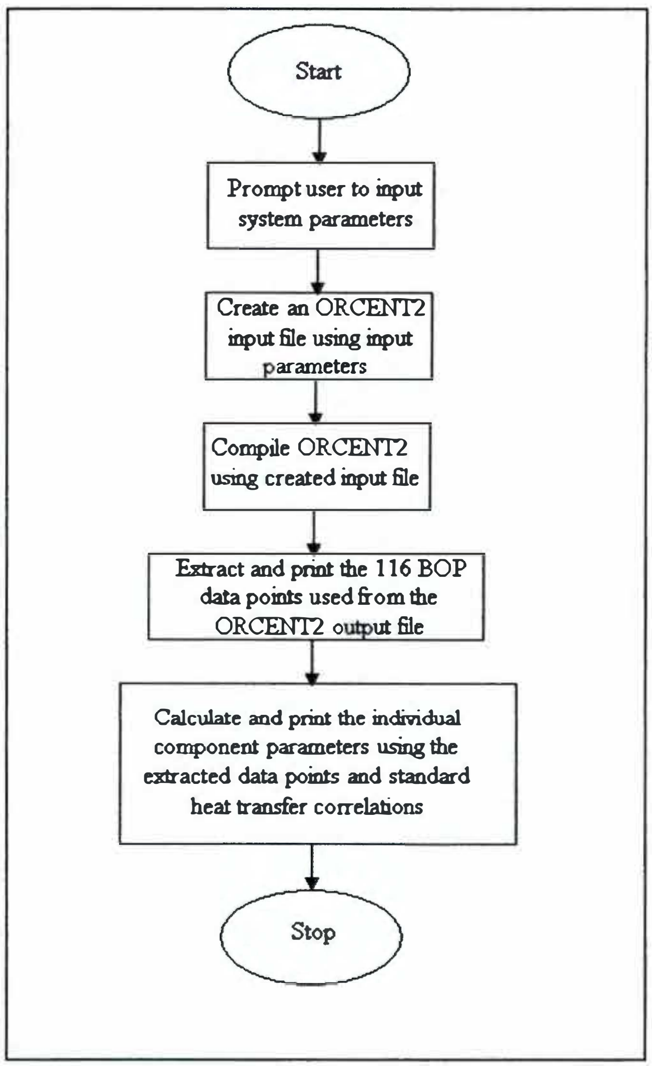

Figure 3-1. Flowchart for BOSCO

3. Steam generator outlet flow rate (IRIS = 3990543.3 lb/hr)
4. Plant electrical output (IRIS = 335.0 MWe)
5. Condenser cold-side inlet temperature from the heat sink (Base Case = 90 °F)

As shown in Figure 3-1, after creation of the input file, BOSCO compiles ORCENT2. ORCENT2 creates an output file which BOSCO opens in order to extract 116 data points which are used to calculate component sizes. BOSCO prints these data for the user to review. Next, BOSCO utilizes the equations explained in Section 5.1 as well as the extracted data points to calculate the component sizes and conditions. Finally, BOSCO prints an overview of the calculated data presented by component. The source code for BOSCO is presented in Appendix A, and the output from BOSCO for the base case is shown in Appendix B.

4. ORCENT2

BOSCO incorporates a modified code developed at the Oak Ridge National Laboratory (ORNL) named ORCENT2 which was released in 1979 [ORNL, 2000]. The program was written in FORTRAN IV for the IBM System 360 digital computers at ORNL and has since been updated to the FORTRAN 77 language. ORCENT2 is an advanced generalized heat balance program that is used to calculate the complete heat and mass balances. This program is designed for general-purpose studies of power plants using steam cycles with outputs larger than 100 MWe [ORNL, 2000]. In this work, ORCENT2 determines the system parameters used to size the balance of plant components.

4.1 ORCENT2 INPUT

Using typical values for PWR type plants, a general BOP design, and IRIS steam generator values, an ORCENT2 heat balance is carried out for the secondary side of the plant. The IRIS steam generator parameters used in the Base Case ORCENT2 input are shown in **Table 4-1**.

Table 4-1. IRIS Steam Generator Parameters

[Source: Conway, 2003]

Parameter	Value
Feedwater temperature (°C)	223.9
Exit Steam Pressure (MPa)	5.8
Exit Steam Temperature (°C)	317
Steam flow per Steam Generator (kg/s)	62.85
Total steam flow (kg/s)	502.8

The general features of the secondary system analyzed herein are as follows: one double flow high pressure (HP) turbine unit with a single extraction in tandem compound with one double flow low pressure (LP) turbine unit with five extraction points, dual reheat with moisture separations between HP and LP units, and six non-mixing feed water heaters. The reheat is produced by main steam extracted prior to the HP unit. The typical parameter values for PWR plants used in the ORCENT2 input include ORCENT2 default values for various pump efficiencies and the generator power factor. The base case ORCENT2 input deck is shown in Appendix C.

4.2 ORCENT2 METHODOLOGY

ORCENT2 is designed to determine the effects due to variations of the following parameters: main steam pressure and temperature; reheat steam pressure and temperature; steam generator and reheater pressure drops; condenser pressure; number of feedwater heaters; type of feedwater heaters; method of heater drain disposal; drain cooler approach; feedwater heater terminal temperature difference; steam extraction for the auxiliary steam turbine; turbine extraction pressures; different drive mechanisms for the best feedwater pump; and part-load performance calculation [Baily, 1967]. ORCENT2 performs calculations at valves-wide-open design conditions, maximum guaranteed rating conditions, and an approximation of part-load conditions for steam turbine cycles supplied with throttle steam characteristics of contemporary light water reactors [ORNL, 2000]. Turbine performance calculations are based on a method published by the General Electric Company [Baily, 1973].

4.3 ORCENT2 OUTPUT

ORCENT2 output includes the overall turbine cycle performance including turbine cycle efficiency and generator output. The output also contains individual component data including: mass flow rates, enthalpy rise/drop, inlet and outlet temperatures, and pressure rise/drop. The gross turbine cycle efficiency shown in **Table 4-2** includes all of the generator and mechanical losses, but does not include the losses due to reheat and feedwater heating. The net turbine cycle efficiency equals the gross efficiency minus the power required for the turbine driven feedwater pump. Output parameters for the base case system are shown in **Tables 4-2** through **4-6**.

Table 4-2. ORCENT2 Turbine Cycle Performance Output

Parameter	**Value**
Net Turbine Cycle Efficiency	34.38 %
Gross Turbine Cycle Efficiency	34.78 %
Generator Output (MWe)	343.725
Mechanical Losses (MW)	1.51
Generator Losses (MW)	4.51

Table 4-3. ORCENT2 Turbine Expansion Line Output

	Parameter	**1st Stage**	**2nd Stage**
Inlet	Reheater Flow Rate (kg/s)	3.82E+02	3.82E+02
	Reheater Pressure (bar)	1.13E+01	1.11E+01
	Reheater Temp. (°C)	1.85E+02	2.15E+02
	Reheater Enthalpy (J/kg)	2.78E+06	2.86E+06
Outlet	Reheater Flow Rate (kg/s)	3.82E+02	3.82E+02
	Reheater Pressure (bar)	1.11E+01	1.10E+01
	Reheater Temp. (°C)	2.15E+02	2.59E+02
	Reheater Enthalpy (J/kg)	2.86E+06	2.96E+06
	Duty (W)	2.90E+07	3.90E+07

Table 4-4. ORCENT2 Live Steam Reheater Output

	1st Stage	2nd Stage
Steam Flow Rate (kg/s)	1.58E+01	2.22E+01
Steam Enthalpy	2.82E+06	2.95E+06
Steam Pressure (bar)	2.73E+01	5.71E+01
Drain Temperature (°C)	2.29E+02	2.72E+02
Drain Enthalpy (J/kg)	9.84E+05	1.20E+06

Table 4-5. ORCENT2 Condenser Output

Parameter	Value
Pressure (bar)	1.01E-01
Condensate Flow Rate (kg/s)	3.84E+02
Condensate Temperature (°C)	4.61E+01

Table 4-6. ORCENT2 Feed Water Heaters Output

	FWH #1	FWH #2	FWH #3	FWH #4	FWH #5	FWH #6
FW Flow (kg/s)	5.03E+02	3.84E+02	3.84E+02	3.84E+02	3.84E+02	3.84E+02
FW Temperature Out (°C)	2.24E+02	1.80E+02	1.58E+02	1.41E+02	1.04E+02	7.19E+01
FW Temperature In (°C)	1.82E+02	1.58E+02	1.41E+02	1.04E+02	7.19E+01	4.68E+01
Extraction Stage Pressure (bar)	2.86E+01	1.13E+01	6.89E+00	4.41E+00	1.38E+00	4.14E-01
Extraction Steam Flow (kg/s)	4.09E+01	1.71E+01	1.21E+01	2.56E+01	2.01E+01	1.23E+01
Shell Pressure (bar)	2.63E+01	1.07E+01	6.34E+00	4.06E+00	1.27E+00	3.79E-01
Shell Temperature (°C)	2.27E+02	1.83E+02	1.61E+02	1.44E+02	1.06E+02	7.47E+01
Shell Drain Flow (kg/s)	7.89E+01	1.19E+02	1.24E+01	3.81E+01	5.96E+01	8.37E+01
Shell Drain Temperature (°C)	1.87E+02	1.83E+02	1.47E+02	1.09E+02	7.75E+01	5.24E+01
q (W)	9.46E+07	3.69E+07	2.79E+07	6.16E+07	5.13E+07	4.03E+07

The locations of the extraction points in the current configuration can be manipulated to help improve performance through reheating and feed water heating. The output conditions from ORCENT2, taken at each extraction point on the turbine expansion line, are used as initial conditions for the correlations discussed in Section 5.1. This assumes that there are no losses in the piping runs. The base case output from ORCENT2 is shown in Appendix D.

5. COMPONENT SIZING

The Log Mean Temperature Difference (LMTD) method is used to calculate the surface area required for adequate heat transfer in each component. For the condenser and reheat stages, the component lengths are calculated after assuming the number of tubes, tube diameters, and tube types. For the feedwater heaters, the numbers of tubes are calculated after assuming the lengths of the tubes, tube diameters, and tube types. This is done to accommodate restrictions on barge sizes, where the maximum length of the feedwater heaters is 10m. In order to assure good steam distribution, the lengths of feedwater heaters numbers 2, 3, and 6 were decreased to lower the length to diameter ratio [Avallone and Baumeister, 1996]. Factors used in the calculations include heat exchanger geometry, fluid parameters from ORCENT2 output, and thermo-physical properties. The heat exchangers are of a two-pass tube-in-shell design, using one inch outer diameter 20 BWG stainless steel tubes. A typical heat exchanger flow configuration is shown in **Figure 5-1**.

The results of the heat exchanger calculations not only give the sizes of the components, they also give the approximate weights of the units. Each unit's weight is approximated as the total weight of the combined tubes in addition to the weight of a pressure vessel to hold them. The pressure vessels are assumed to be one-inch thick steel.

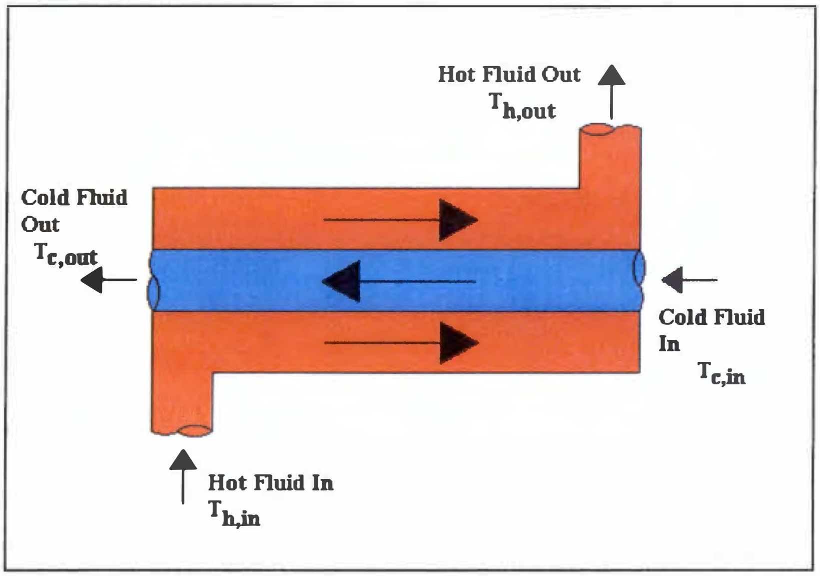

Figure 5-1. A typical heat exchanger physical process model

5.1 THEORY

Good estimates of the film, wall, and bulk temperatures are needed to evaluate the thermophysical properties of a given condensation system. Collier and Thome [1994] suggest using equations 5.1 and 5.2 to calculate the film and wall temperatures, where the bulk temperature is taken to be the water inlet temperature.

$$T_{film} = T_w + \frac{0.25(T_{sat} - T_w)}{2} \qquad \text{(Eqn. 5.1)}$$

$$T_w = T_{in} + 0.25(T_{sat} - T_{in}) \qquad \text{(Eqn. 5.2)}$$

All film properties are evaluated at the film temperatures, with a few given exceptions. The vapor density is taken at saturation temperature. The evaporation enthalpy is evaluated at saturation temperature, but an adjustment may be made to account for condensate subcooling. Collier and Thome suggest the following modification

$$H'_{fg} = H_{fg} + 0.68C_p(T_{sat} - T_w) \qquad \text{(Eqn. 5.3)}$$

The dynamic viscosity is calculated using a weighted average method, shown in equation 5.4.

$$\mu_l = \frac{3\mu_w + \mu_{sat}}{4} \qquad \text{(Eqn. 5.4)}$$

All thermophysical properties are taken from Todreas and Kazimi [1993].

For the LMTD method, an additional energy balance equation is required in order to solve for two equations and two unknowns. The first order energy balance for a simple counter flow heat exchanger is as follows:

$$q = \left[\dot{m}C_p(T_{in} - T_{out})\right]_h = \left[\dot{m}C_p(T_{in} - T_{out})\right]_c \qquad \text{(Eqn. 5.5)}$$

Therefore,

$$T_{c,out} = T_{c,in} + \frac{q}{\dot{m}_c C_{p,c}} \qquad \text{(Eqn. 5.6)}$$

and

$$T_{h,out} = T_{h,in} + \frac{q}{\dot{m}_h C_{p,h}} \qquad \text{(Eqn. 5.7)}$$

Equations 5.5, 5.6, and 5.7 assume negligible heat losses to surroundings and the heat capacities are constant across the heat exchanger. The LMTD method evaluates the required length of the heat exchanger tubing using the following strategy:

$$q = UA_i \Delta T_{lm} \qquad \text{(Eqn. 5.8)}$$

Where $A_i = \pi D_i L$ and the LMTD and the overall heat transfer coefficient are:

$$\Delta T_{lm} = \frac{(T_{h,in} - T_{c,out}) - (T_{h,out} - T_{c,in})}{\ln[(T_{h,in} - T_{c,out})/(T_{h,out} - T_{c,in})]} \qquad \text{(Eqn. 5.9)}$$

$$U = \frac{1}{\frac{1}{h_i} + \frac{A_i \ln(r_o / r_i)}{2\pi kL} + \frac{A_i}{A_o}\frac{1}{h_o}} \qquad \text{(Eqn. 5.10)}$$

In order to account for linear thermal expansion in the pipes, Avallone and Baumeister [1996] recommend using equation 5.11 as an approximation for the change in the pipe's length due to thermal expansion.

$$\Delta L = CL'(T_{h,in} - T_{room}) \qquad \text{(Eqn. 5.11)}$$

C is the coefficient of linear expansion and is defined as the increment of length in a unit of length for a rise in temperature of 1 °F. T_{room} is taken as room temperature, or 70 °F. The required length of the tubes neglecting thermal expansion (L') is calculated using equations 5.9 and 5.10 and is shown in equation 5.12.

$$L' = \frac{q}{U(2\pi D_i N_{tubes})F\Delta T_{lm}} \qquad \text{(Eqn. 5.12)}$$

The total length of the tubes is taken as the summation of equations 5.11 and 5.12.

$$L = L' + \Delta L \qquad \text{(Eqn. 5.13)}$$

Rearranging the terms of equations 5.12 and 5.13, the number of tubes required with a predetermined tube length is found and shown in equation 5.14.

$$N = \frac{q}{U(2\pi D_i L)F\Delta T_{lm}} \qquad \text{(Eqn. 5.14)}$$

In equations 5.12 and 5.14, F is a correction factor for multipass and cross-flow heat exchangers. Incropera and Dewitt [1996] have developed algebraic expressions for F for various shell-and-tube and cross-flow heat exchanger configurations, and the results are represented graphically in **Figure 5-2**. The parameters P, shown in equation 5.15, and R, equation 5.16, are required to determine the correction factor.

$$P = \frac{T_{c,out} - T_{c,in}}{T_{h,in} - T_{h,out}} \qquad \text{(Eqn. 5.15)}$$

$$R = \frac{T_{h,in} - T_{h,out}}{T_{c,out} - T_{c,in}} \qquad \text{(Eqn. 5.16)}$$

First, the inner pipe heat transfer coefficient (h_i) is calculated and then an iterative procedure is used to determine the outer pipe heat transfer correlation (h_o). The inside heat transfer coefficient is found using the following equation:

$$h_i = Nu_D \frac{k_c}{D_i} \qquad \text{(Eqn. 5.17)}$$

The Nusselt number is given by the following equation:

$$Nu_D = 0.023 Re_D^{0.8} Pr^{0.4} \qquad \text{(Eqn. 5.18)}$$

The Reynolds and Prandtl numbers for flow through the tubes are given by equations 5.19 and 5.20, respectively.

$$Re_D = \frac{4\dot{m}_c}{\pi D_i \mu} \qquad \text{(Eqn. 5.19)}$$

$$Pr = \frac{C_p \mu}{k} \qquad \text{(Eqn. 5.20)}$$

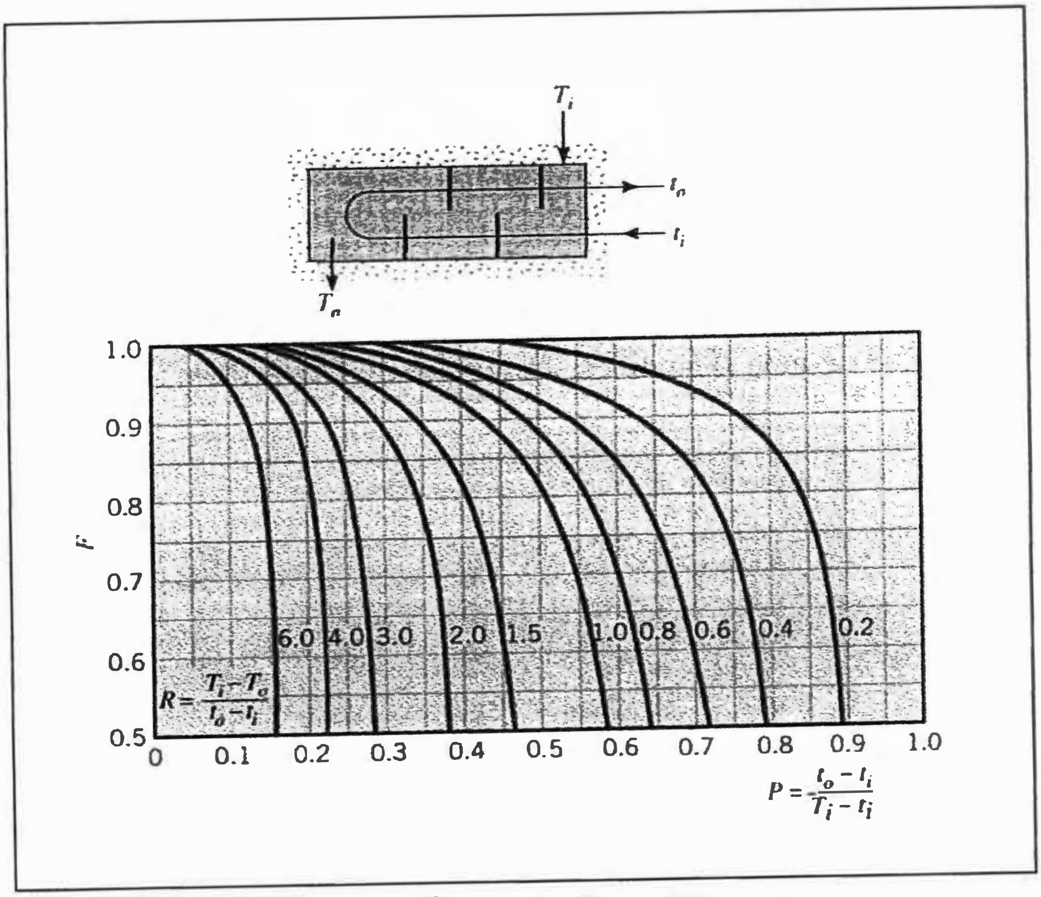

Figure 5-2. Correction Factor Diagram

[Source: Incropera, 1996]

The tubes in the condenser and reheaters are arranged in horizontal tube banks, while the tubes in the feedwater heaters are arranged vertically. For condensation outside the horizontal tubes, as in the condenser and reheaters, Incropera and Dewitt [1996] suggest using equation 5.21 for the outside heat transfer coefficient for a single horizontal tube.

$$\bar{h}_{o,tube} = 0.729 \left[\frac{g\, \rho_l\, (\rho_l - \rho_v)\, k_l^3\, h'_{fg}}{\mu_l\, (T_{sat} - T_i)\, D} \right]^{0.25} \qquad \text{(Eqn. 5.21)}$$

To account for the effects of dripping condensate and turbulence in the film, one must consider a stack of horizontal tubes and determine an average heat transfer coefficient to cover all tubes in the stack. This effect is shown in **Figure 5-3**.

Butterworth suggests using equation 5.22 for the average heat transfer coefficient given the single tube heat transfer coefficient [1990].

$$\bar{h}_{o,total} = \bar{h}_{o,tube} \left(\sqrt{N_{tubes} * N_{shells}} \right)^{-(1/6)} \qquad \text{(Eqn. 5.22)}$$

For condensation outside of vertical tubes, as in the feedwater heaters, the outside heat transfer coefficient is given by equation 5.23.

$$\bar{h}_o = \frac{\dfrac{4(T_{h,in} - T_{inner\ pipe\ surf})L}{\mu_l h'_{fg}} + \dfrac{5.2}{k_l}\left[\dfrac{\mu_l^2}{\rho_l(\rho_l - \rho_g)g}\right]^{1/3}}{\dfrac{1.08}{k_l}\left[\dfrac{\mu_l^2}{\rho_l(\rho_l - \rho_g)g}\right]^{1/3}\left(\dfrac{4(T_{h,in} - T_{inner\ pipe\ surf})L}{\mu_l h'_{fg}}\right)^{1.22}} \qquad \text{(Eqn. 5.23)}$$

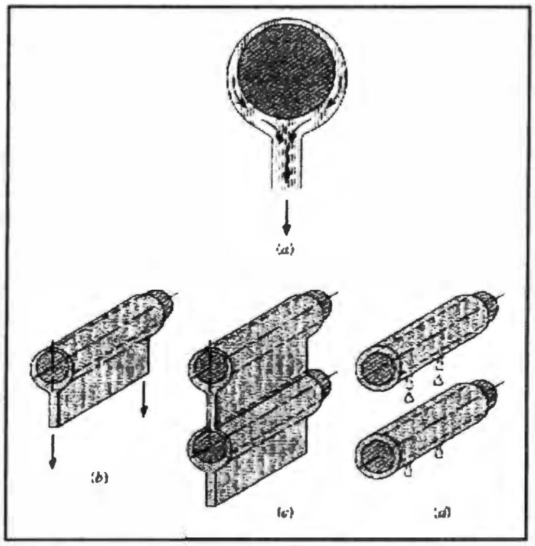

Figure 5-3. Dripping Effects

5.2 COMPONENT SIZE RESULTS

The heat transfer correlations are coded into BOSCO using the Matlab® computational environment. The results of the BOSCO calculations are shown in **Table 5-1**.

Table 5-1. Base Case Balance of Plant Parameters

	FW#1	FW#2	FW#3	FW#4	FW#5	FW#6	RH#1	RH#2	Condenser
T_{HI} (°C)	2.27E+02	1.83E+02	1.61E+02	1.44E+02	1.06E+02	7.47E+01	3.17E+02	3.17E+02	4.61E+01
T_{HO} (°C)	1.87E+02	1.83E+02	1.47E+02	1.09E+02	7.75E+01	5.24E+01	2.29E+02	2.72E+02	4.61E+01
T_{CI} (°C)	1.82E+02	1.58E+02	1.41E+02	1.04E+02	7.19E+01	4.68E+01	1.85E+02	2.15E+02	3.22E+01
T_{CO} (°C)	2.24E+02	1.80E+02	1.58E+02	1.41E+02	1.04E+02	7.19E+01	2.15E+02	2.59E+02	3.78E+01
m_{hot} (kg/s)	7.89E+01	1.19E+02	1.24E+01	3.81E+01	5.96E+01	8.37E+01	1.58E+01	2.22E+01	3.84E+02
m_{cold} (kg/s)	5.03E+02	3.84E+02	3.84E+02	3.84E+02	3.84E+02	3.84E+02	3.82E+02	3.82E+02	2.82E+04
v_{hot} (m/s)	4.57E+00	4.99E+01	5.83E+00	1.57E+01	7.03E+01	1.50E+02	9.40E-01	8.00E-01	1.55E+02
v_{cold} (m/s)	2.13E+00	2.13E+00	2.13E+00	2.13E+00	2.13E+00	2.13E+00	2.36E+01	1.41E+01	2.13E+00
q (Watts)	9.50E+07	3.70E+07	2.80E+07	6.20E+07	5.10E+07	4.00E+07	2.90E+07	3.90E+07	6.60E+08
# of Tubes	2.93E+03	9.57E+02	1.42E+03	2.46E+03	2.54E+03	5.17E+03	6.00E+02	1.00E+03	1.50E+04
Diameter of component (m)	2.33E+00	1.34E+00	1.63E+00	2.14E+00	2.18E+00	3.10E+00	1.06E+00	1.37E+00	8.00E+00
Length of Component (m)	1.00E+01	6.02E+00	8.02E+00	1.00E+01	1.00E+01	6.01E+00	3.13E+00	3.35E+00	9.15E+00
HT Area (m^2)	4.69E+03	9.19E+02	1.81E+03	3.93E+03	4.07E+03	4.96E+03	3.00E+02	5.35E+02	2.19E+04
Total Weight (tons)	4.15E+01	9.99E+00	1.78E+01	3.53E+01	3.64E+01	4.49E+01	4.03E+00	6.33E+00	2.07E+02

6. TRANSPORTATION LIMITATIONS

Size limitations on barges traveling on the Mississippi, Ohio, and Tennessee Rivers are analyzed to determine the feasibility of transporting a modular power plant to a site accessible by these river systems. Navigation charts for each of the rivers were reviewed to determine constraints imposed by channel depths, lock and dam dimensions, and overhead obstructions including cables and bridges. The limiting constraints for each of these river systems are presented. Excel spreadsheets listing all constraints from the Gulf of Mexico to Knoxville, TN are contained in Appendix E through Appendix G.

6.1 MISSISSIPPI RIVER SYSTEM

The Mississippi River travels upstream from the Gulf of Mexico at mile marker 0, and merges with the Ohio River at mile marker 981 in Alexander County, Kentucky. No locks exist between these points. The minimum vertical clearance is 25.6 meters (80 feet) minus gage at mile marker 369.1 caused by an aerial power crossing in Adams County, MS. The horizontal clearance constraint is 152.4 meters (500 feet) at mile marker 229.3 at the Baton Rouge Highway Bridge in Baton Rouge, LA. A series of dams maintain a minimum water depth of 2.74 meters (9 feet) in the channel of the river during low water conditions [U.S. Army Corps, 1998]. **Figure 6-1** shows the Baton Rouge Highway Bridge horizontal clearance obstruction.

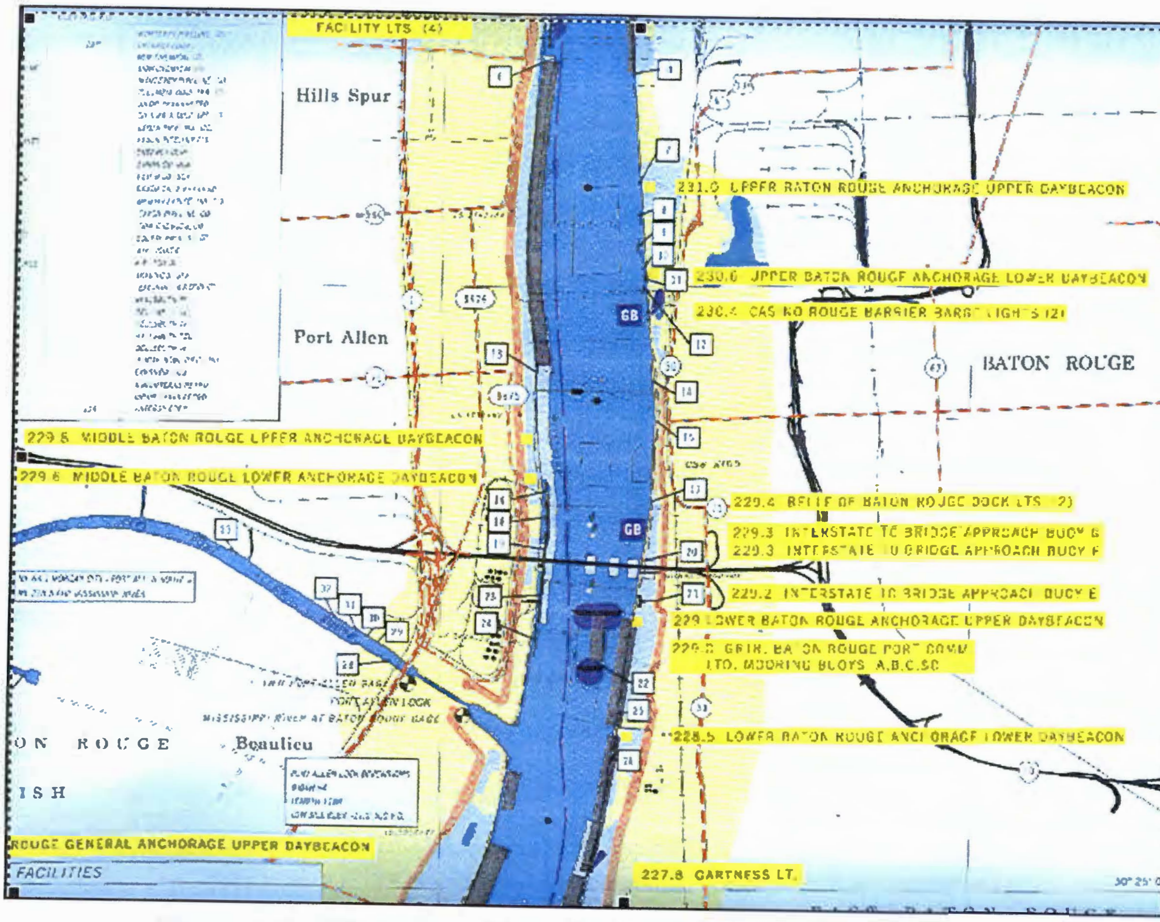

Figure 6-1. Mississippi River Horizontal Clearance Constraint

Table 6-1 shows pertinent information for the 10 narrowest horizontal clearance obstructions for the Mississippi River. **Table 6-2** shows the pertinent information for the 10 lowest vertical clearance obstructions for the Mississippi River.

6.2 OHIO RIVER SYSTEM

In Paducah, Kentucky, the Tennessee and the Ohio Rivers merge at mile marker 933. Forty-eight miles later, the Ohio River flows into the Mississippi River at mile marker 981. Two lock systems exist between these points, both with dimensions of 182.88 meters (600 feet) length and 33.53 meters (110 feet) width. The minimum vertical clearance is 27.7 meters (91 feet) minus gage at The Irvin S. Cobb Bridge at mile marker 937.3. The minimum water depth is maintained at 2.74 meters (9 feet) [U. S. Army Corps, 2003]. **Figure 6-2** shows the Lock and Dam #53, one of the limiting horizontal clearance obstructions.

Table 6-3 shows the pertinent information for the 5 narrowest horizontal clearance obstructions for the Ohio River. **Table 6-4** shows the pertinent information for the 5 lowest vertical clearance obstructions for the Ohio River.

6.3 TENNESSEE RIVER SYSTEM

The main navigable channel of the Tennessee River begins near Knoxville, TN and ends 652 miles later when it empties into the Ohio River in Paducah, KY. Over the course of the river's length, the elevation drops a total of 156.4 meters (513 feet). Nine main and four auxiliary locks exist on this river system. Three of the locks have limiting clear

Table 6-1. Mississippi River Horizontal Clearance Obstructions

Mile Marker	Structure Type	Horizontal Clearance (ft)	Closest City/County
229.3	Baton Rouge Hwy. Bridge	500	Baton Rouge, LA
977.7	Illinois Central R.R. Bridge	503	Cairo, IL
233.9	Baton Rouge R.R. and Hwy. 190 Bridge	748	Scotlandville, LA
95.7	Crescent City Connection Hwy. Bridge	750	Orleans Parish, LA
95.8	Crescent City Connection Hwy. Bridge	750	Orleans Parish, LA
106.1	Huey P. Long R.R. and Hwy. Bridge	750	Jefferson Heights, LA
145.9	Gramercy Bridge	750	Wallace, LA
167.4	Ascension - St. James Hwy. Bridge	750	Salsburg, LA
734.4	Memphis Hwy. Bridge	770	Crittenden County, AR
734.7	Harahan Railroad Bridge	770	Crittenden County, AR

Table 6-2. Mississippi River Vertical Clearance Obstructions

Mile Marker	Structure Type	Vertical Clearance (ft)	Closest City/County
369.1	Aerial Power Crossing	84	Adams County, MS
361.2	Aerial Power Crossing	93.5	Adams County, MS
434.7	Aerial Power Crossing	93.5	Madison Parish, LA
838.7	Interstate 55 Bridge	99.2	Dyer County, TN
977.7	Illinois Central R.R. Bridge	104.6	Cairo, IL
980.4	Cairo Hwy. Bridge	105.3	Alexander County, IL / Ballard County, KY
734.7	Harahan Railroad Bridge	108.3	Crittenden County, AR
736.6	Hernando Desoto Bridge	108.7	Crittenden County, AR
734.7	Burlington Northern R.R. Bridge	109	Crittenden County, AR
734.4	Memphis Hwy. Bridge	112.8	Adams County, MS

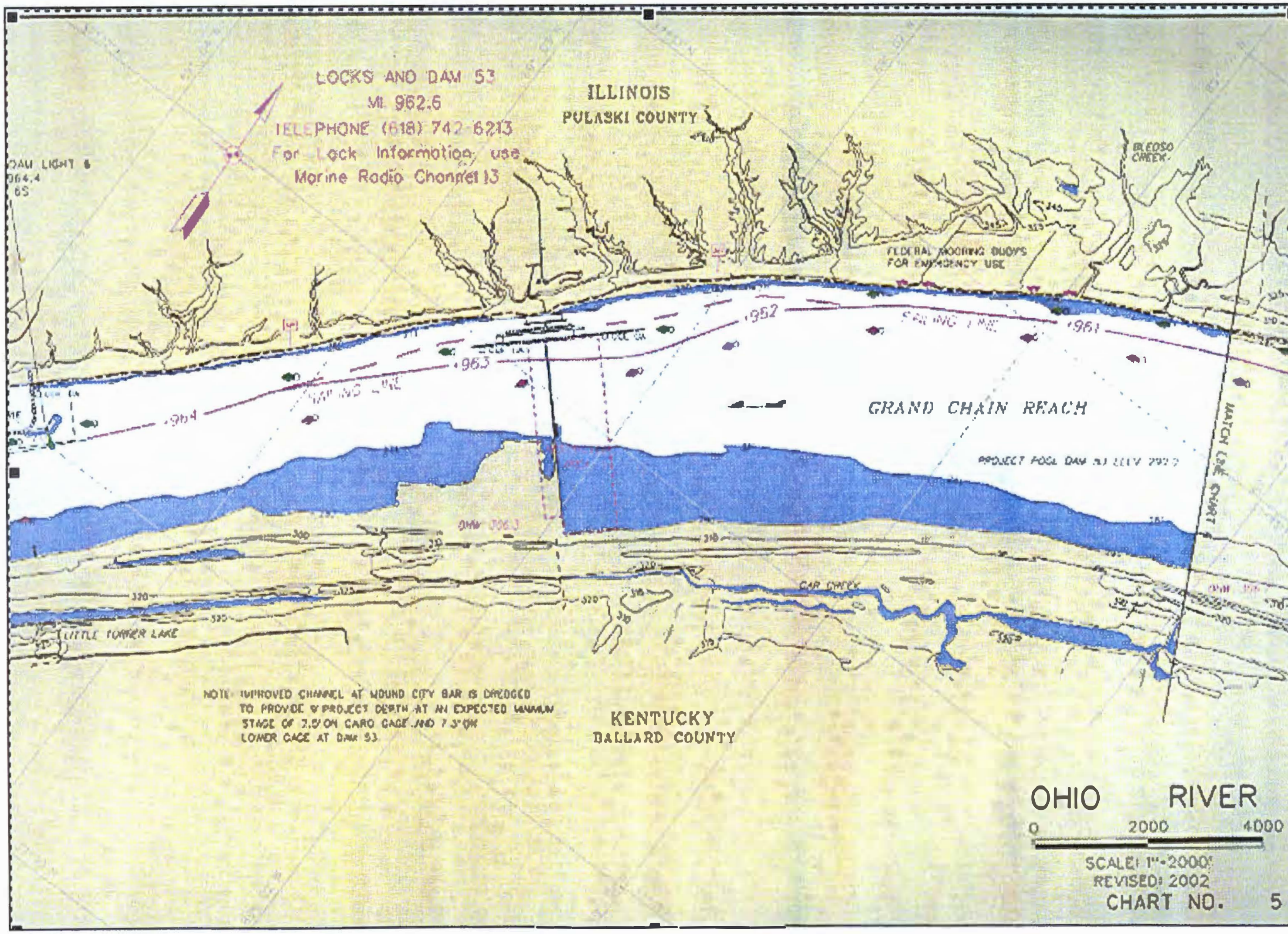

Figure 6-2. Ohio River Length and Width Limitation

Table 6-3. Ohio River Horizontal Clearance Obstructions

Mile Marker	Structure Type	Horizontal Clearance (ft)	Closest City/County
962.6	Lock and Dam #53	110	Ballard County, KY
939	Lock and Dam #52	110	McCracken County, KY
977.7	Illinois Central Railroad Bridge	500.5	Ballard County, KY
944.1	P. & I. Railroad Bridge	530	McCracken County, KY
937.3	Irvin S. Cobb Bridge	700	McCracken County, KY

Table 6-4. Ohio River Vertical Clearance Obstructions

Mile Marker	Structure Type	Vertical Clearance (ft)	Closest City/County
937.3	Irvin S. Cobb Bridge	91	McCracken County, KY
940.9	I-24 Hwy. Bridge	95.2	McCracken County, KY
944.1	P. & I. Railroad Bridge	98	McCracken County, KY
977.7	Illinois Central Railroad Bridge	104.6	Ballard County, KY
980.4	Cairo Hwy. Bridge (U.S. 60)	116.4	Ballard County, KY

chamber dimensions of 109.7 meters (360 feet) length by 18.3 meters (60 feet) width, which is considerably less than the dimensions of the other main locks of 182.88 meters (600 feet) length by 33.53 meters (110 feet) width. The first of these smaller locks is the Fort Loudoun Lock and Dam located at mile marker 602.3 in Lenoir City, TN, and the last is the Chickamauga Lock and Dam located at mile marker 471.0 in Chattanooga, TN. The Chickamauga Lock, however, is deteriorating and is likely to be replaced by a larger lock within the next several years. The minimum vertical clearance along the river is limited to 15.24 meters (50 feet) minus gage when the water is at pool stage at mile marker 647.3 at the Southern Railway Bridge in Knoxville, TN [U.S. Army Corps, 2000]. TVA maintains water levels sufficient to provide a minimum navigation channel depth of 2.74 meters (9 feet) throughout this navigable waterway [TVA, 2003]. **Figures 6-3** and **6-4** show the Southern Railway Bridge and the Chickamauga Lock and Dam, the limiting vertical and horizontal clearances, respectively.

Table 6-5 shows the pertinent information for the 10 narrowest horizontal clearance obstructions for the Tennessee River. **Table 6-6** shows the pertinent information for the 10 lowest vertical clearance obstructions for the Tennessee River.

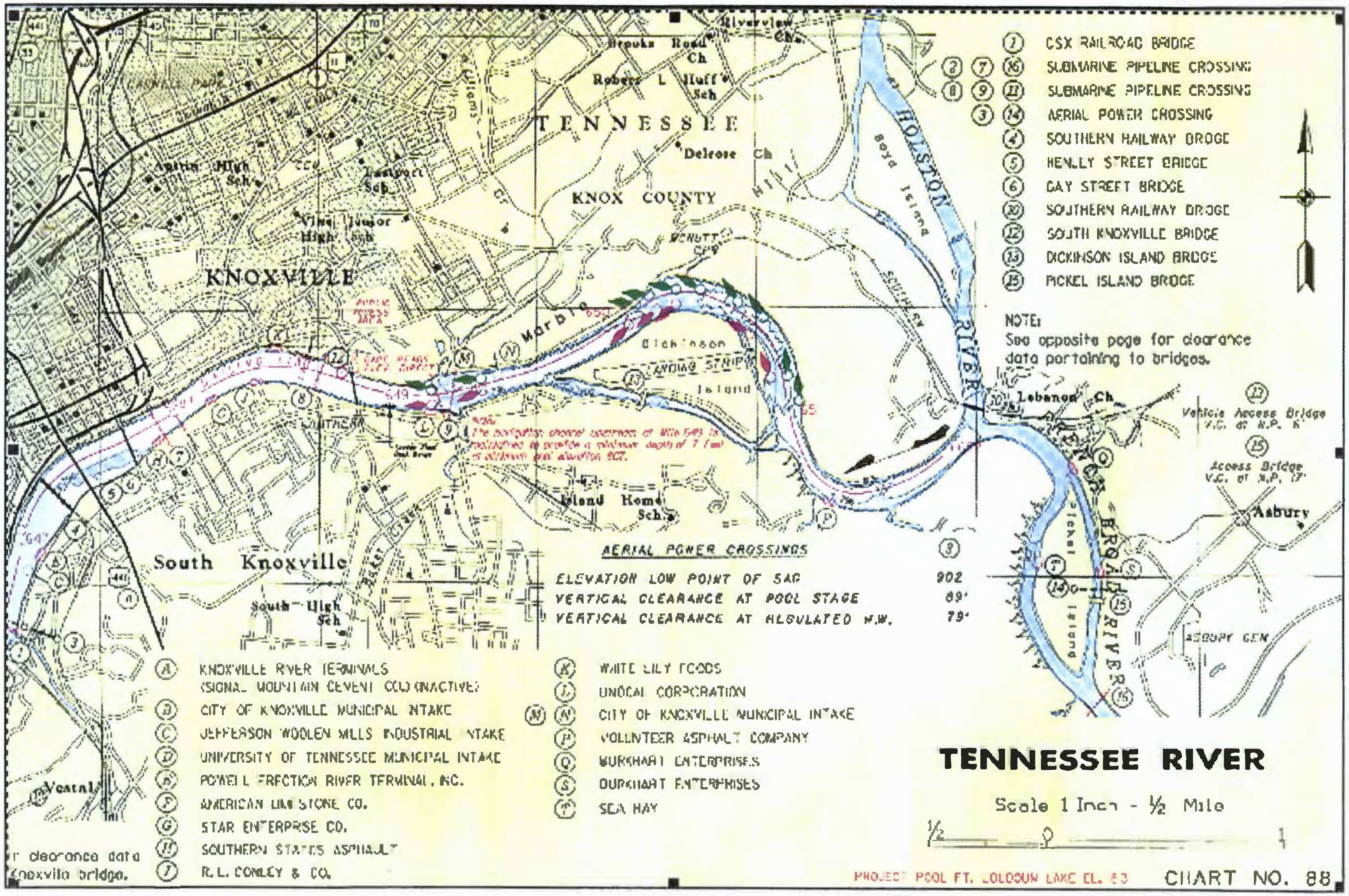

Figure 6-3. Tennessee River Vertical Clearance Obstruction

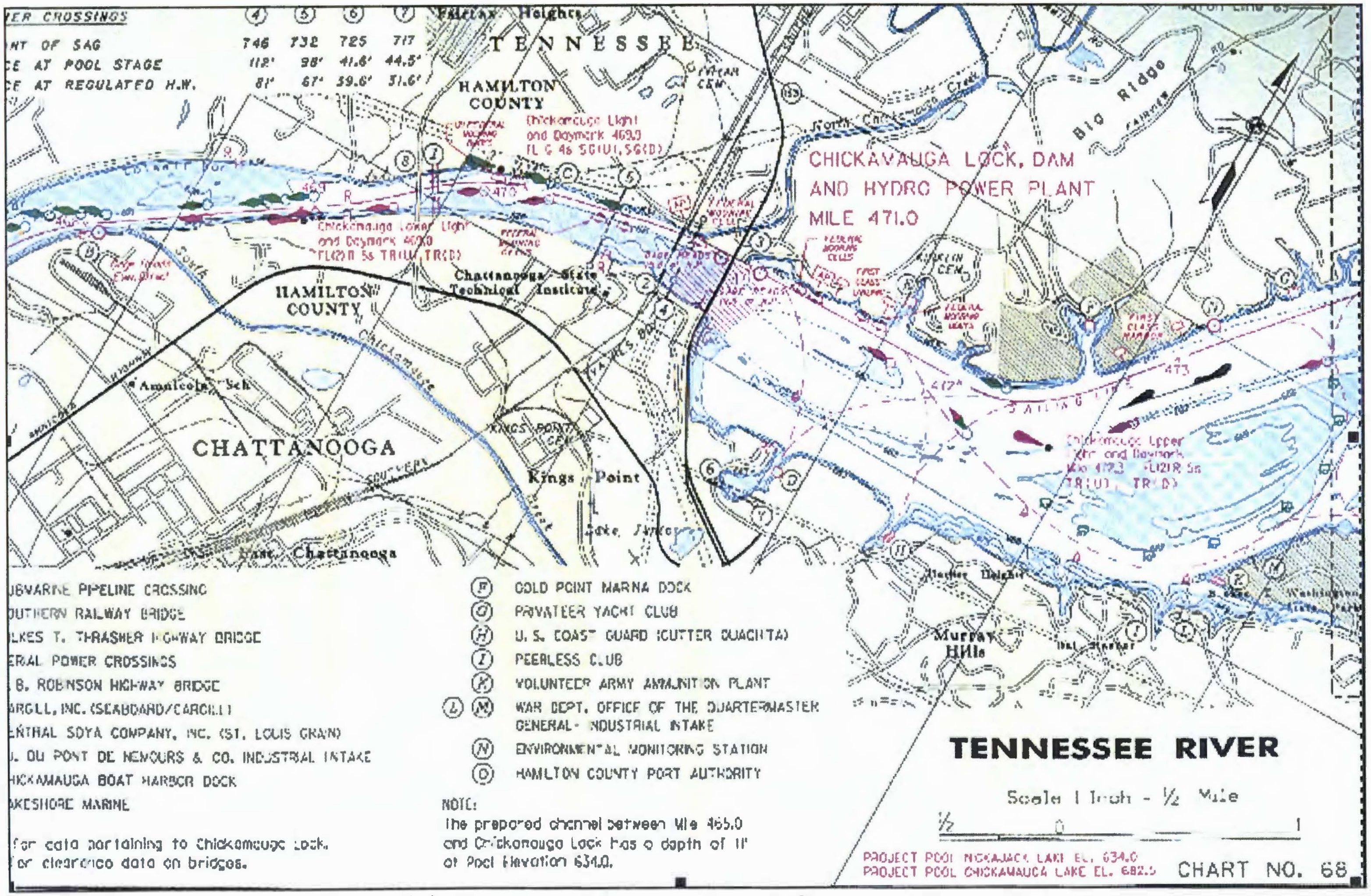

Figure 6-4. Tennessee River Horizontal Clearance Obstruction

Table 6-5. Tennessee River Horizontal Clearance Obstructions

Mile Marker	Structure Type	Horizontal Clearance (ft)	Closest City/County
471	Chickamauga Lock and Dam	60	Chattanooga, TN
529.9	Watts Bar Lock	60	Rhea County, TN
602.3	Fort Loudoun Lock and Dam Hwy. Bridge	60	Lenoir City, TN
22.4	Illinois Central Railroad Bridge	110	Gilbertsville, KY
22.5	Kentucky Lock and Dam Highway Bridge	110	Gilbertsville, KY
206.7	Pickwell Landing Lock and Dam Hwy. Bridge	110	Hardin County, TN
259.4	Wilson Dam Hwy. Bridge	110	East Florence, AL
259.5	Wilson Lock Access Bridge	110	East Florence, AL
274.8	Wheeler Lock and Dam Hwy. Bridge	110	Lawrence County, AL
349	Guntersville Lock, Dam, and Hydro P. Plant	110	Marshall County, AL

Table 6-6. Tennessee River Vertical Clearance Obstructions

Mile Marker	Structure Type	Vertical Clearance (ft)	Closest City/County
647.3	Southern Railway Bridge	50	Knox County, TN
385.8	B.B. Comer Hwy. Bridge	54.4	Jackson County, AL
358	Veterans Memorial Hwy. Bridge	56	Guntersville, AL
584.8	Interstate 75 Hwy. Bridge	57	Loundon County, TN
305	Capt. William J. Hudson Bridge (Steamboat Bill)	57	Morgan County, AL
309.6	Interstate 65 Hwy. Bridge	57	Morgan County, AL
645.1	James E. Karnes Hwy. Bridge	57	Knox County, TN
498.9	State Route 60 Hwy. Bridge	57	Hamilton County, TN
206.7	Pickwell Landing Lock and Dam Hwy. Bridge	57	Hardin County, TN
259.4	Wilson Dam Hwy. Bridge	57	East Florence, AL

7. INDIVIDUAL COMPONENT SOLID MODELING

The creation of three-dimensional virtual components in a computer aided drafting/design (CAD) environment is known as solid modeling. These virtual models reflect the overall geometries of their real counterparts and are useful in determining conflicting geometries and layouts, as well as determining rough masses of the components. Two software packages were used in the solid modeling process. The first CAD software package, SolidWorks® 2001, was used to model the individual components. The second CAD package, Innovation®, was used to assemble the individual components on transportable barges.

SolidWorks® 2001 has the capability of implementing parametric equations into the models in order to place constraints on one feature while varying another in the model or assembly. Parts are created for each component in the system, which then can be arranged in various layout configurations and connected with piping. The component models in this section, with the exception of the steam turbine and generator, differ from those created in the previous study [Williams, 2002]. This results from changes in the component sizes which in turn modify the piping runs. Only selected features such as general volumetric sizing and approximate connection points for piping are modeled in this study. This is sufficient to achieve a model of the plant layout for modularity and transportation studies. The following paragraphs describe the individual components as well as the component assembly in more detail. The simplified BOP features are shown in **Figure 7-1**.

7.1 STEAM TURBINES

The steam turbine used in this study is a condensing turbine. In a condensing turbine, the exhaust steam pressure is lower than atmospheric pressure. Condensing turbines of this size are normally multistage, with a small portion of the steam being extracted for feedwater heating. The turbine configuration used in this study is an axial-flow tandem compounded HP and LP turbine set. The term "tandem compounded" refers to the separate casings of the HP and LP stages of the turbine being coupled in series. The HP turbine unit has two stages of reheat and is double flow (meaning that the steam is equally split into two directions in order to expand). The HP turbine is much smaller than the LP turbine. This is due to the HP unit utilizing higher pressure, temperature, and quality steam which makes it much more efficient than the LP unit. There are three extraction points on the HP turbine. These extraction points lead to the moisture separator, feedwater heater number 1, and feedwater heater number 2. The LP turbine is also double flow. There are four extraction points in the LP turbine which feed into feedwater heaters 3-6 individually. **Figure 7-2** shows the cross section of a typical LP tandem-compound turbine. **Figure 7-3** shows the turbine created with SolidWorks® 2001.

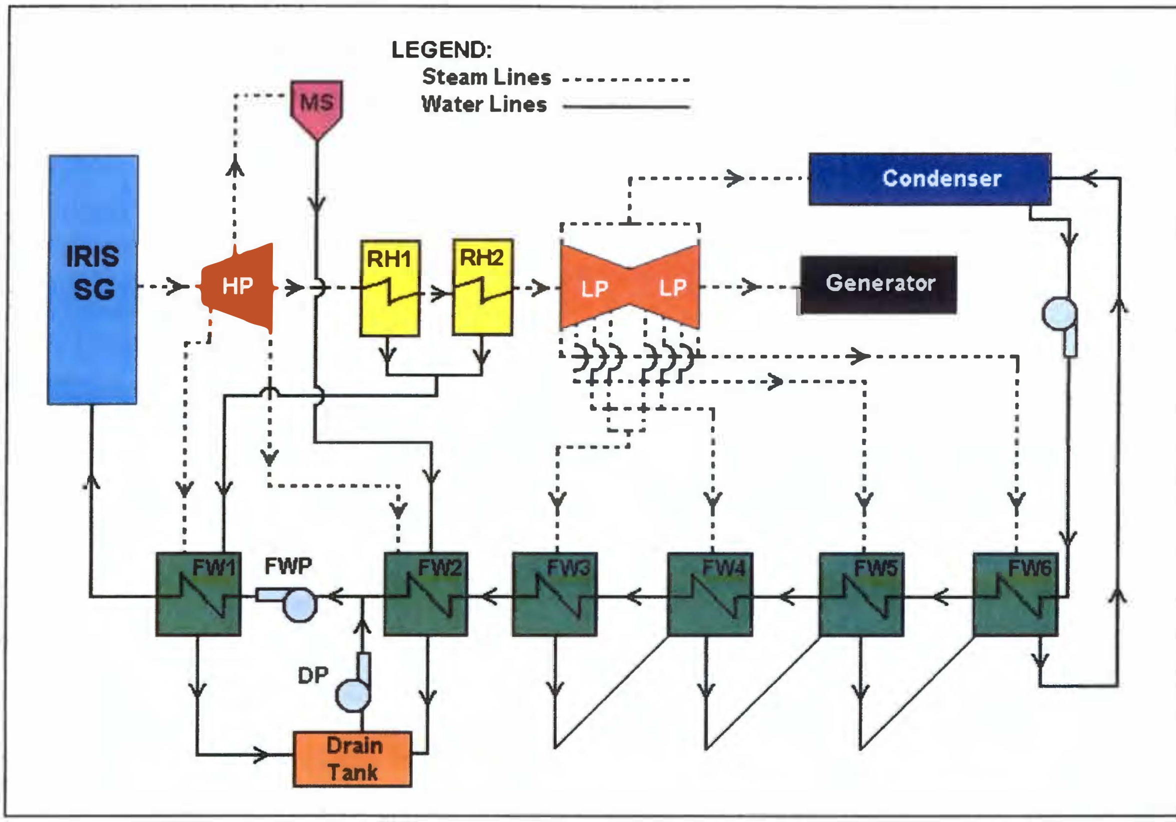

Figure 7-1. Simplified BOP Features

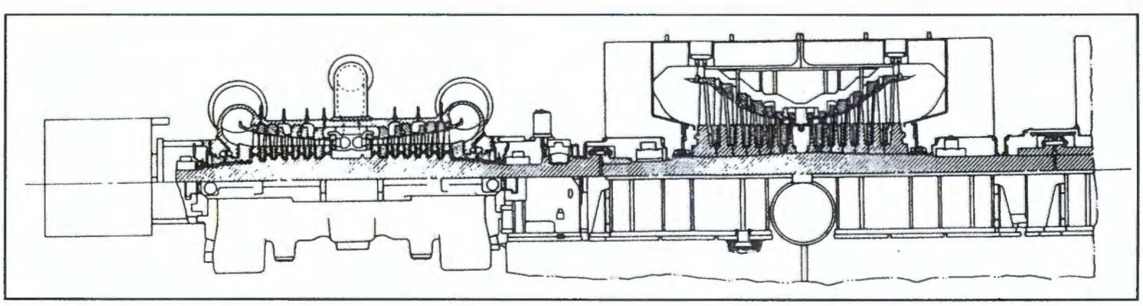

Figure 7-2. Tandem-compound turbine cross section
[Source: Avallone and Baumeister, 1996]

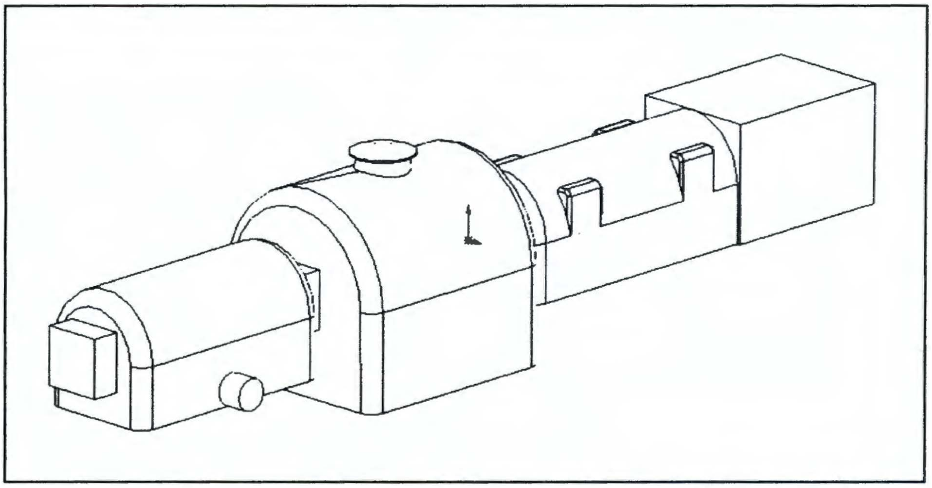

Figure 7-3. Turbine created with SolidWorks® 2001

7.2 MOISTURE SEPERATOR

The steam from the HP turbine is passed through a moisture separator, and the separated liquid is diverted to a feedwater heater number 2 while the vapor passes to the LP turbine. The moisture separator unit is usually combined with the reheater and called a moisture separator reheater (MSR). This moisture removal is important due to turbine blade corrosion and lubrication removal issues.

7.3 REHEATERS

Reheaters are used improve the thermodynamic gain in the Rankine cycle and to reduce heat loss due to moisture in the LP stages of the turbine. There are two stages of reheat, both of which are non-mixing counter flow heat exchangers. The reheaters utilize extracted steam from the HP turbine that has partially expanded. This steam is reheated to the maximum temperature and expanded, and then the steam is routed back to the turbine to continue the expansion until the condenser pressure is reached. The two stages of reheat are located between the HP and LP turbines in the flow diagram. Both stages of reheat drain off to feedwater heater number 1, which is closest to the steam generator. **Figure 7-4** shows a typical combination moisture separator and two-stage steam reheater cross section. **Figure 7-5** shows the reheater created with SolidWorks® 2001.

7.4 FEEDWATER HEATERS

Feedwater heaters serve two purposes. First, they increase the thermodynamic gains of the regenerative steam cycle to improve overall efficiency, and second, they raise water temperatures sufficiently to avoid thermal shock to the boiler metal. Steam is extracted from various turbine stages and directed to the feedwater heaters where the feedwater is preheated prior to entering the steam generator.

For this system, six feedwater heaters are used. These feedwater heaters are closed; meaning heat is transferred from the extracted steam to the feedwater without any mixing taking place, and they are in a two pass cross flow tube-in-shell arrangement. Steam traps at the bottom of each heater allowing the passage of saturated liquid only.

Feedwater heaters 1 and 3-6 are the flash drain type. In flash drained feedwater heaters, the extraction steam from the heater drain flashes down to the adjacent upstream heater. In the case of feedwater heater number 6, the condensate is flashed back to the condenser. Feedwater heater 2 is of the pumped drain type. The extraction moisture is pumped up to the feedwater pressure and combined with moisture separation liquid taken from the HP

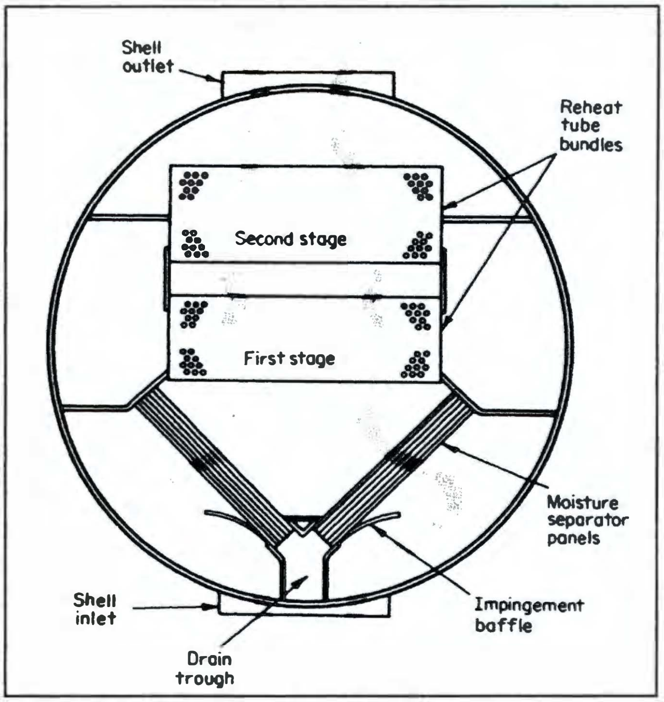

Figure 7-4. Combination moisture separator and two-stage steam reheater cross section

[Source: Avallone and Baumeister, 1996]

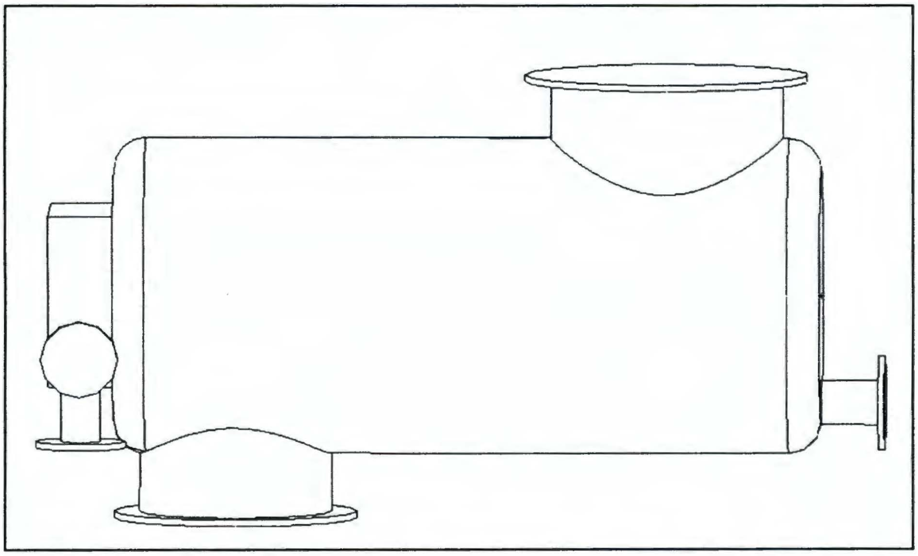

Figure 7-5. Reheater created with SolidWorks® 2001

turbine exhaust before it enters the main feedwater pump. Feedwater heater number 1 is the closest to the steam generator and feedwater heater number 6 is the closest to the condenser. Feedwater heaters 1 and 2 are HP feedwater heaters, which means that they raise the temperature of the feedwater by using steam exhausted from the HP turbine passing on the outside of the tubes. Feedwater heaters 3-6 are LP feedwater heaters. LP feedwater heaters heat feedwater flowing through the tubes with steam exhausted from the LP turbine. **Figure 7-6** shows a typical closed feedwater heater section. **Figure 7-7** shows a feedwater heater created with SolidWorks® 2001.

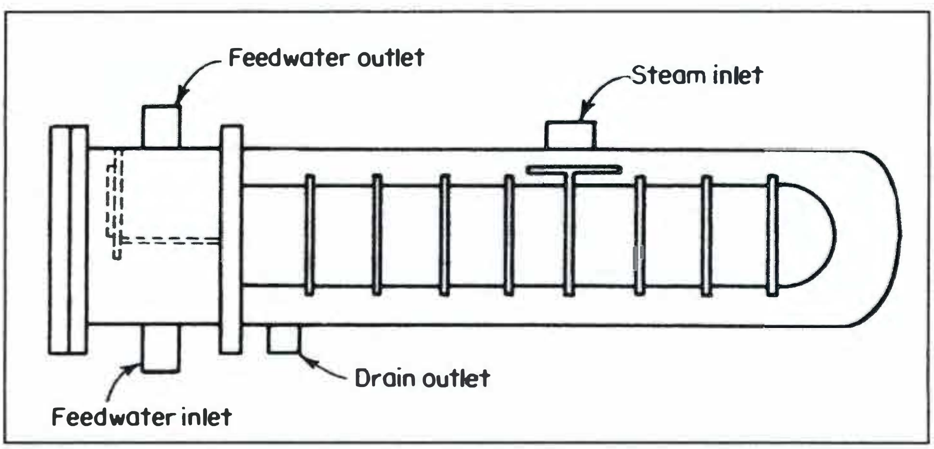

Figure 7-6. Closed feedwater heater section
[Source: Avallone and Baumeister, 1996]

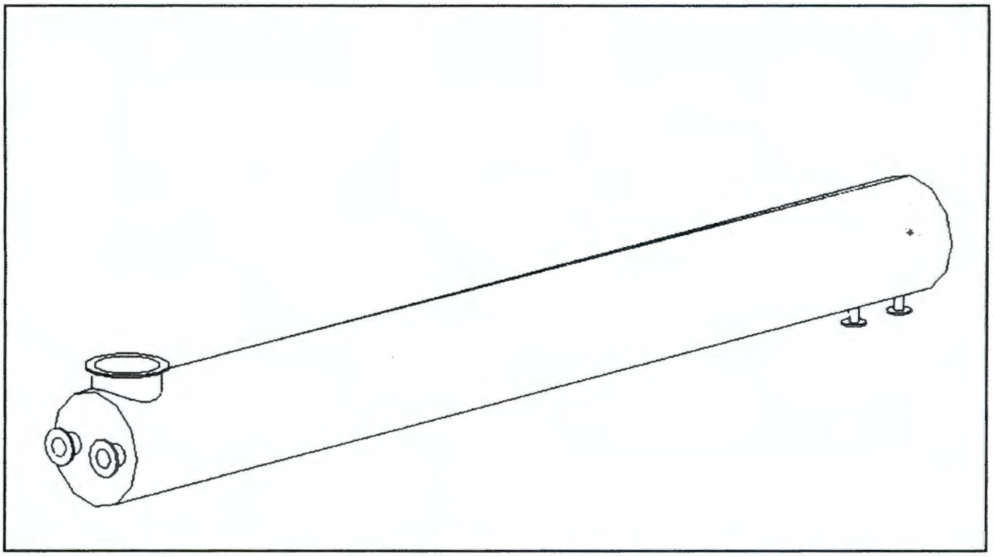

Figure 7-7. Feedwater heater created with SolidWorks® 2001

7.5 CONDENSER

The condenser serves four purposes: (1) to produce a vacuum or desired back pressure at the turbine exhaust for the improvement of the plant heat rate, (2) to condense turbine exhaust steam for use in the closed cycle, (3) to deaerate the condensate, and (4) to accept heater drains, makeup water, steam drains, and start-up and emergency drains. The latent heat removed by the condenser is transferred to cooling water which is usually supplied by a river, lake, cooling tower, or ocean. The condenser is a water-cooled surface condenser, and is attached to the LP exhaust of the turbine. It is in a one pass, cross flow, tube-in-shell arrangement with two water boxes on each end separated by tube sheets. Water flows inside the tubes while the vapor flows outside around the nest of tubes. The vapor condenses on the outside surface of the tubes and drips to the bottom of the condenser. **Figure 7-8** shows the cross-section of a surface condenser. **Figure 7-9** shows the condenser created with SolidWorks® 2001.

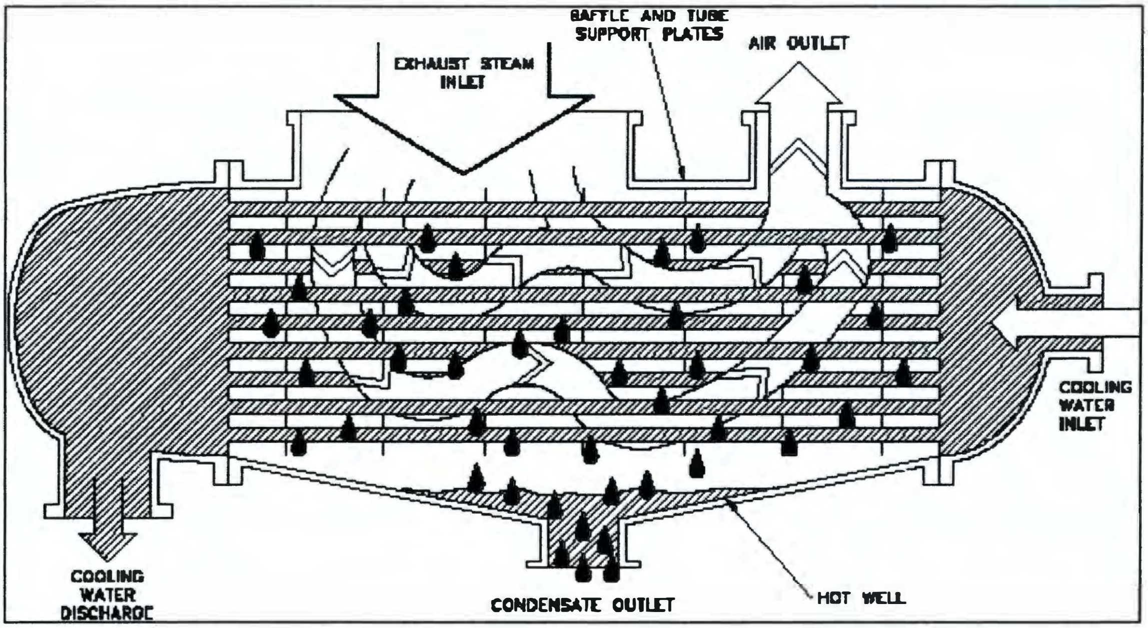

Figure 7-8. Surface condenser cross-section

[Source: http://www.tpub.com/content/doe/h1018v1/css/h1018v1_83.htm]

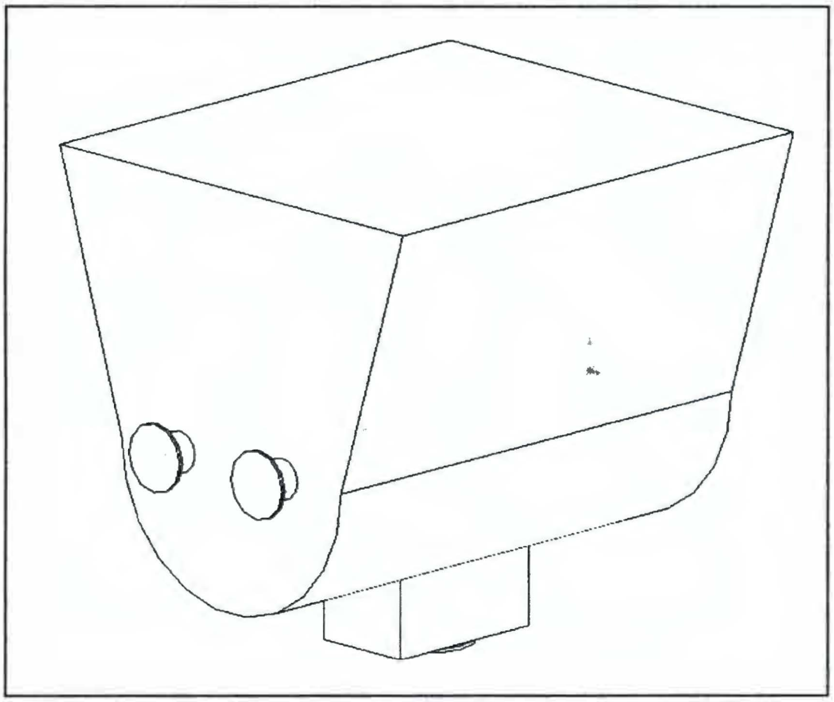

Figure 7-9. Condenser created with SolidWorks® 2001

8. BARGE BUILDING SOLID MODELING

As a part of the NERI project, Westinghouse assisted with the conceptual design and layout of the primary and secondary system barges (2003). The Westinghouse effort uses the sizes and designs for the components derived in this thesis. In order to create solid models of the barge buildings, Westinghouse utilized the software package Innovation®.

Due to the size restrictions imposed by the locks located in Chattanooga, Rhea County, and Lenoir City, Tennessee, the reference destination for transporting these barges is Chattanooga. Using the limitations imposed by the discussed river systems from the Gulf of Mexico to Chattanooga, the allowable dimensions of the barges are 30 meters wide, 70 meters long, with 2.74 meters draft. Also, the barges are limited to 17.07 (56') meters vertical clearance above the water surface by the Veterans Memorial Highway Bridge in Guntersville, Alabama. Using the barge dimensions and a freshwater density at 80 °F of 996.48 kg/m^3, the maximum displacement of either of the barges is 8.19E6 kg. This weight limitation imposes restrictions on how much structural support and shield concrete can be placed in the barge modules during transportation. Therefore, these barges will employ steel structures that can be used as forms for the addition of needed concrete after the barge has been floated into its final position and founded.

Plant layout design is achieved through various stages of prioritized features. First, each component is placed and arranged from the viewpoint of functionality. Next, the modularization aspects of design are implemented. Finally, considerations of increased accessibility for maintenance and construction are noted. Some components, including pumps and valves, are not yet included in the current assembly design due to their lack of influence on space requirements and minimal impact on the total weight of the system.

8.1 PRIMARY BUILDING BARGE CHARACTERISTICS

The primary building barge contains the reactor inside the containment structure, fuel handling equipment and facilities, a shield that surrounds the containment structure, and typical auxiliary building features. The auxiliary building features include the main control room, safe shutdown panel, steam and feedwater piping and isolation valve room, and all safety related equipment such as batteries for electrical power and equipment associated with monitoring reactor operation and initiating required safety functions [Westinghouse, 2003]. **Figure 8.1** shows an elevation view of the primary building barge. **Table 8.1** lists the main components and their estimated weights.

The draft of the primary building barge is calculated using Equation 8.1

$$\text{Draft} = \frac{m_{barge}}{\rho_{water} L_{barge} W_{barge}} = \frac{4.99\text{E}6\,\text{kg}}{(996.48\,\text{kg/m}^3)(70\text{m})(30\text{m})} = 2.39\text{m} = 7.83\text{ft} \qquad (8.1)$$

Using a freshwater density at 80 °F of 996.48 kg/m^3, the barge draft is calculated to be 2.39 meters (7.83 feet). Since the minimum water level for all of the considered river systems is 2.74 meters, the assumed barge is capable of successful delivery to its destination.

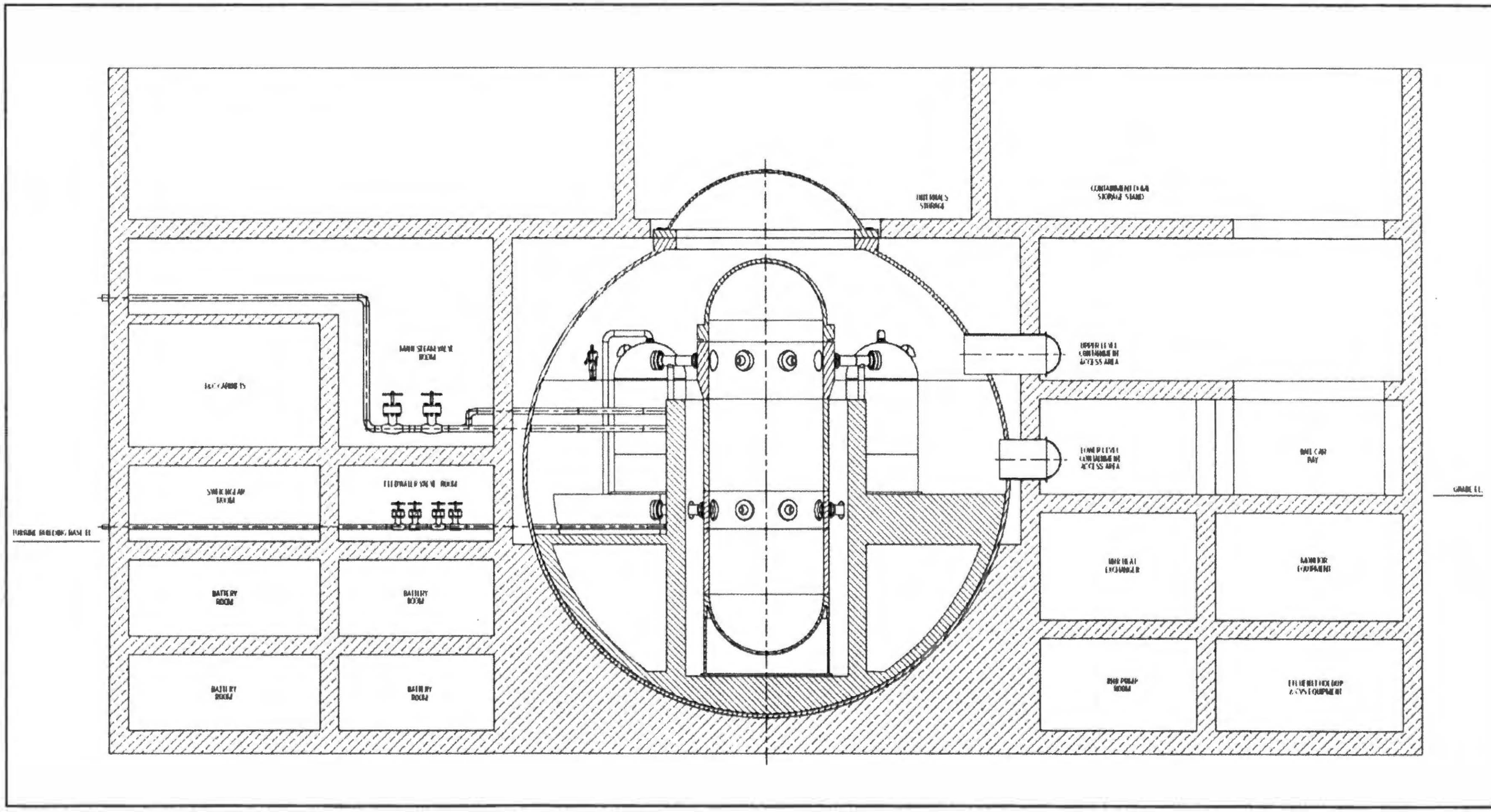

Figure 8-1. Elevation view of the primary building barge

[Source: Westinghouse, 2003]

Table 8-1. Primary Building Barge Component Weights

Component / Structure	Estimated Weight in Metric Tons (kg)
Reactor Vessel Shell	950 (9.50E5)
Reactor Vessel Internal Components	
RV Bottom Shield Plates	51 (5.10E4)
Lower Core Plate	14 (1.40E4)
Radial Reflector	50 (5.00E4)
Core Barrel	52 (5.20E4)
Upper Internals	33 (3.30E4)
Steam Generators (8)	280 (2.80E5)
Reactor Coolant Pumps (8)	32 (3.20E4)
Containment Vessel (w/o head)	750 (7.50E5)
In-side CV Concrete/steel (Estimated Min.)	1000 (1.00E6)
CV Pedestal Concrete/steel (Estimated Min.)	1500 (1.50E6)
Barge	280 (2.80E5)
Total Weight	**4992 (4.99E6)**

8.2 TURBINE GENERATOR BUILDING BARGE CHARACTERISTICS

The turbine generator building barge contains the power conversion equipment for the power plant and other auxiliary and support equipment. **Figure 8.2** shows an isometric view of the turbine generator building barge including major components for the turbine generator building barge, with the feedwater heaters (shown in blue), the turbo-generator unit (shown in bright green), the dual reheat (shown in brown). **Figure 8.3** shows a side view of the turbine generator building barge with the condenser shown in dull green.

The main components of the turbine generator building barge and their estimated weights are shown in **Table 8.2**.

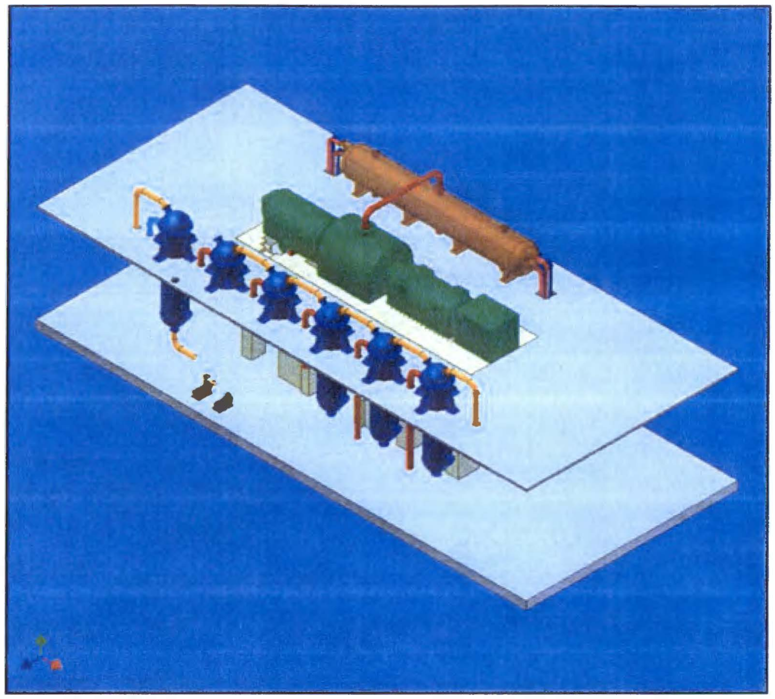

Figure 8-2. Isometric view of the turbine generator building barge
[Source: Westinghouse, 2003]

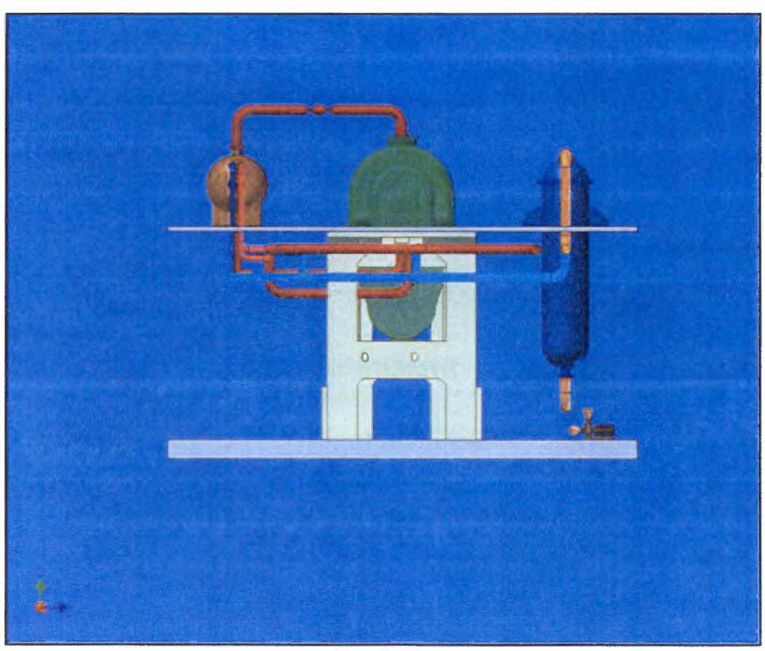

Figure 8-3. Side view of the turbine generator building barge
[Source: Westinghouse, 2003]

Table 8-2. Turbine Generator Building Barge Component Weights

Component / Structure	Estimated Weight in Metric Tons (kg)
Turbo-Generator Unit	1451 (1.45E6)
Feedwater Heater #1	37.6 (3.76E4)
Feedwater Heater #2	9.1 (9.06E3)
Feedwater Heater #3	16.1 (1.61E4)
Feedwater Heater #4	32.0 (3.20E4)
Feedwater Heater #5	33.0 (3.30E4)
Feedwater Heater #6	40.7 (4.07E4)
Reheat Stage #1	3.64 (3.64E3)
Reheat Stage #2	5.72 (5.72E3)
Condenser	187.8 (1.88E5)
Piping	281 (2.81E5)
Barge	280 (2.80E5)
Total Weight	**2378 (2.38E6)**

The draft of the turbine generator building barge is calculated using Equation 8.1

$$\text{Draft} = \frac{m_{barge}}{\rho_{water} L_{barge} W_{barge}} = \frac{2.38\text{E6 kg}}{(996.48\text{ kg/m3})(70\text{m})(30\text{m})} = 1.14\text{ m} = 3.73\text{ ft}$$

Using a freshwater density at 80 °F of 996.48 kg/m^3, the barge draft is calculated to be 1.14 meters (3.73 feet). Since the minimum water level for all of the considered river systems is 2.74 meters, the assumed barge is capable of successful delivery to its destination.

9. BOSCO SENSITIVITY STUDIES

In order to demonstrate BOSCO's ability to calculate the BOP component sizes for various initial conditions, this chapter presents two sensitivity studies. These studies show how component sizes and masses vary with changes in several important input parameters including cooling water inlet temperature and steam generator outlet flow rate.

9.1 COOLING WATER INLET TEMPERATURE STUDY

Depending on the location of a power plant, the average inlet temperature of the circulating water varies significantly. **Figure 9-1** shows the average temperatures of circulating water, °F, for the United States.

The Base Case BOSCO calculations used a conservative 90°F for the condenser cooling water inlet temperature. However, as shown in Figure 9-1, temperatures below 90°F are common in most parts of the United States. The circulating water inlet temperature plays an important role in the sizing of the condenser. In order to demonstrate this, BOSCO was used to calculate the BOP sizes and parameters using a cooling water inlet temperature of 70°F, while all of the other parameters used in the Base Case remained the same. The BOSCO input for this sensitivity study is shown in **Table 9-1**.

The results of the BOSCO calculations for Sensitivity Study 1 are shown in **Table 9-2**.

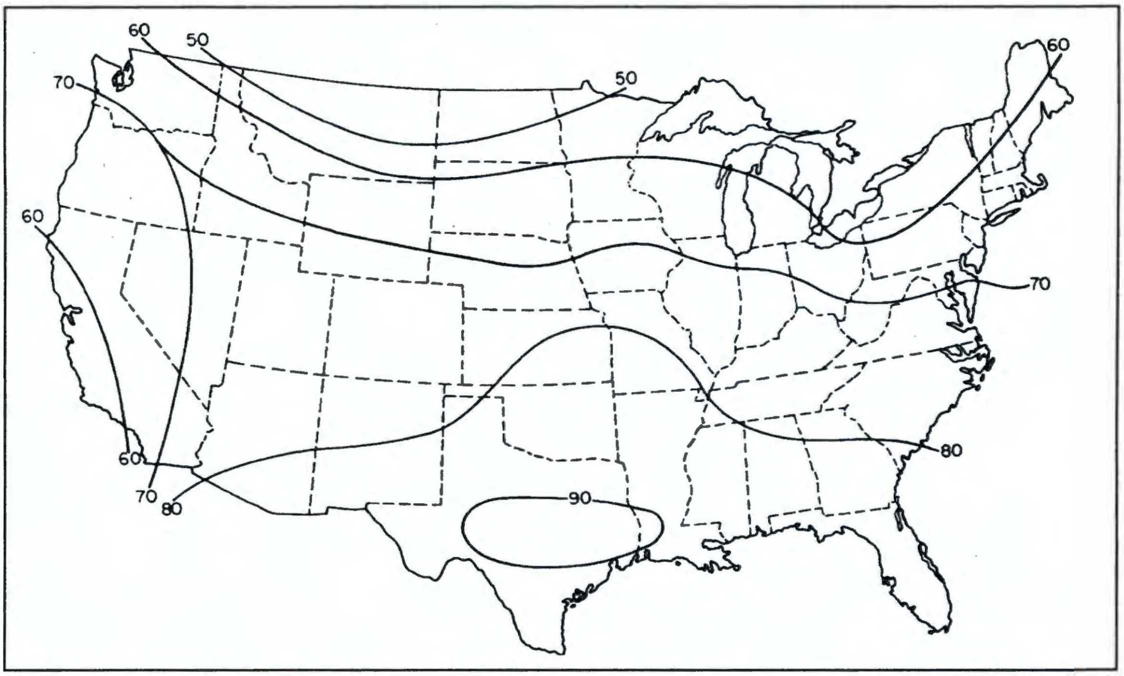

Figure 9-1. Average inlet temperature of circulating water, °F, United States
[Source: Avallone and Baumeister, 1996]

Table 9-1. BOSCO Input Conditions for Sensitivity Study 1

Parameter	Value
Steam Generator Outlet Steam Temperature (°F)	602.6
Steam Generator Outlet Steam Pressure (psia)	841.0
Total Steam Generator Outlet Steam Flow (lb/hr)	3990543.3
Electrical Output (MWe)	335.0
Condenser Circulating Water Inlet Temperature (°F)	70.0

Table 9-2. Balance of Plant Parameters for Sensitivity Study 1

	FW#1	FW#2	FW#3	FW#4	FW#5	FW#6	RH#1	RH#2	Condenser
T_{HI} (°C)	2.27E+02	1.83E+02	1.61E+02	1.44E+02	1.06E+02	7.47E+01	3.17E+02	3.17E+02	4.61E+01
T_{HO} (°C)	1.87E+02	1.83E+02	1.47E+02	1.09E+02	7.75E+01	5.24E+01	2.29E+02	2.72E+02	4.61E+01
T_{CI} (°C)	1.82E+02	1.58E+02	1.41E+02	1.04E+02	7.19E+01	4.68E+01	1.85E+02	2.15E+02	2.11E+01
T_{CO} (°C)	2.24E+02	1.80E+02	1.58E+02	1.41E+02	1.04E+02	7.19E+01	2.15E+02	2.59E+02	2.67E+01
m_{hot} (kg/s)	7.89E+01	1.19E+02	1.24E+01	3.81E+01	5.96E+01	8.37E+01	1.58E+01	2.22E+01	3.84E+02
m_{cold} (kg/s)	5.03E+02	3.84E+02	3.84E+02	3.84E+02	3.84E+02	3.84E+02	3.82E+02	3.82E+02	2.82E+04
v_{hot} (m/s)	4.57E+00	4.99E+01	5.83E+00	1.57E+01	7.03E+01	1.50E+02	9.40E-01	8.00E-01	1.55E+02
v_{cold} (m/s)	2.13E+00	2.13E+00	2.13E+00	2.13E+00	2.13E+00	2.13E+00	2.36E+01	1.41E+01	2.13E+00
q (Watts)	9.50E+07	3.70E+07	2.80E+07	6.20E+07	5.10E+07	4.00E+07	2.90E+07	3.90E+07	6.60E+08
# of Tubes	2.93E+03	9.57E+02	1.42E+03	2.46E+03	2.54E+03	5.17E+03	6.00E+02	1.00E+03	1.50E+04
Diameter of component (m)	2.33E+00	1.34E+00	1.63E+00	2.14E+00	2.18E+00	3.10E+00	1.06E+00	1.37E+00	8.00E+00
Length of Component (m)	1.00E+01	6.02E+00	8.02E+00	1.00E+01	1.00E+01	6.01E+00	3.13E+00	3.35E+00	5.30E+00
HT Area (m^2)	4.69E+03	9.19E+02	1.81E+03	3.93E+03	4.07E+03	4.96E+03	3.00E+02	5.35E+02	1.27E+04
Total Weight (tons)	4.15E+01	9.99E+00	1.78E+01	3.53E+01	3.64E+01	4.49E+01	4.03E+00	6.33E+00	1.38E+02

As shown in Table 9-2, the heat transfer area for the condenser is 1.27E+04 m^2. This heat transfer area is 42% less than the area that was required for the condenser in the Base Case. The decrease in the cooling water inlet temperature caused an increase in the LMTD. As shown in Equation 5.8, the increase in the LMTD causes a decrease in the required heat transfer area.

9.2 STEAM GENERATOR OUTLET FLOW RATE STUDY

For the Base Case BOSCO calculations, where the IRIS primary system was used, there were eight steam generators whose steam combined for a total mass flow rate of 3,990,543.3 lbm/hr. The total mass flow rate of the steam coming out of the steam generator(s) determines how much electrical output will be generated. The user-input electrical output is used as a starting point for the iterative procedure used to calculate the true electrical output within ORCENT2. This sensitivity study confirms BOSCO's ability to calculate the BOP sizes and parameters for a total steam mass flow rate of 5,000,000.0 lbm/hr (a ~25 % increase from the Base Case). All other parameters from the Base Case remained the same. **Table 9-3** shows the BOSCO input conditions for this sensitivity study.

Table 9-3. BOSCO Input Conditions for Sensitivity Study 2

Parameter	Value
Steam Generator Outlet Steam Temperature (°F)	602.6
Steam Generator Outlet Steam Pressure (psia)	841.0
Total Steam Generator Outlet Steam Flow (lb/hr)	5000000.0
Electrical Output (MWe)	335.0
Condenser Circulating Water Inlet Temperature (°F)	90.0

The results of the BOSCO calculation for Sensitivity Study 2 are shown in **Table 9-4.**

As expected, due to the ~25% increase in steam flow, the generator output increased from 343.7 MWe to 428.9 MWe (~25%). Also, as shown in Table 9-4, the average increase in heat transfer area for the feedwater heaters was ~23%, for the reheaters ~17%, and for the condenser ~20%. Equation 5.5 indicates that an increase in $\dot{m}$, or steam flow rate, causes an increase in q, the heat transfer rate. Equation 5.8 shows that the increase in q causes the increase in the heat transfer area required for the component.

Table 9-4. Balance of Plant Parameters for Sensitivity Study 2

	FW#1	FW#2	FW#3	FW#4	FW#5	FW#6	RH#1	RH#2	Condenser
T_{HI} (°C)	2.27E+02	1.83E+02	1.61E+02	1.44E+02	1.06E+02	7.47E+01	3.17E+02	3.17E+02	4.61E+01
T_{HO} (°C)	1.87E+02	1.83E+02	1.47E+02	1.09E+02	7.75E+01	5.22E+01	2.29E+02	2.72E+02	4.61E+01
T_{CI} (°C)	1.82E+02	1.58E+02	1.41E+02	1.04E+02	7.19E+01	4.67E+01	1.85E+02	2.15E+02	3.22E+01
T_{CO} (°C)	2.24E+02	1.80E+02	1.58E+02	1.41E+02	1.04E+02	7.19E+01	2.15E+02	2.59E+02	3.78E+01
m_{hot} (kg/s)	9.88E+01	1.49E+02	1.56E+01	4.77E+01	7.46E+01	1.05E+02	1.98E+01	2.79E+01	4.81E+02
m_{cold} (kg/s)	6.30E+02	4.81E+02	4.81E+02	4.81E+02	4.81E+02	4.81E+02	4.79E+02	4.79E+02	3.55E+04
v_{hot} (m/s)	4.58E+00	5.01E+01	5.84E+00	1.57E+01	7.04E+01	1.49E+02	1.18E+00	1.00E+00	1.94E+02
v_{cold} (m/s)	2.13E+00	2.13E+00	2.13E+00	2.13E+00	2.13E+00	2.13E+00	2.95E+01	1.77E+01	2.13E+00
q (Watts)	1.20E+08	4.60E+07	3.50E+07	7.70E+07	6.40E+07	5.10E+07	3.60E+07	4.90E+07	8.20E+08
# of Tubes	3.67E+03	1.20E+03	1.78E+03	3.08E+03	3.19E+03	6.52E+03	6.00E+02	1.00E+03	1.50E+04
Diameter of component (m)	2.61E+00	1.49E+00	1.82E+00	2.39E+00	2.43E+00	3.48E+00	1.06E+00	1.37E+00	8.00E+00
Length of Component (m)	1.00E+01	6.02E+00	8.02E+00	1.00E+01	1.00E+01	6.01E+00	3.83E+00	4.06E+00	1.15E+01
HT Area (m^2)	5.87E+03	1.15E+03	2.27E+03	4.92E+03	5.09E+03	6.25E+03	3.66E+02	6.48E+02	2.75E+04
Total Weight (tons)	5.11E+01	1.20E+01	2.16E+01	4.34E+01	4.47E+01	5.61E+01	4.75E+00	7.40E+00	2.49E+02

10. CONCLUSIONS AND FUTURE WORK

10.1 CONCLUSIONS

A preliminary balance of plant design and layout and, suitable for use in modularity and barge transportation studies, has been presented. A Matlab® script file has been created which automates the process of calculating the component sizes for different initial conditions, enabling the use of different primary systems and/or initial conditions without difficulty. The components have been assembled on primary and turbine generator building barges. These components and barge assemblies have been modeled into a CAD environment. The sizes and weights of the barges have been calculated, and it has been shown that these barges are capable of traveling from the Gulf of Mexico to Chattanooga, Tennessee.

10.2 FUTURE WORK

Future work includes completion of the piping runs so that the plant layout can be completed. Mechanical loads due to the effects of contraction and on seismic loads also need to be evaluated. Analysis will be required to assure that the structural steel and concrete used in the as-fabricated barge provides the necessary stiffness needed to prevent buckling of the barge during transportation. The structural steel and concrete must also be constructed so that the center of gravity is sufficiently low such that the barge will not capsize. Auxiliary building barges could also be built and shipped.

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APPENDICES

APPENDIX A – BOSCO SOURCE CODE

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%   Martin R. Williamson                          -  Project funded by TVA                    %
%   December 20, 2003                                                                         %
%   This m-file (named BOSCO) does the following:                                             %
%       - Reads input from the user pertaining to the system conditions,                      %
%       - Creates an input file for the Orcent_2 Heat Balance Program,                        %
%       - Compiles ORCENT2 using the created input file,                                      %
%       - Extracts pertinent data from the resulting output file                              %
%       - Uses the extracted data to calculate the BOP sizes, weights, etc., and              %
%       - Prints the results.                                                                 %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clear all;clc;
% Water Properties taken from Table E-1 Nuclear Systems 1 - Todreas
%   oC    P(bar)     rho_f(kg/m^3)    Cp_f(J/kg-oC)  mu_f(kg/m-s)   neu_f(m^2/s)  k_f(W/m-oC)   Pr_f    h_f(J/kg)
prop_f = [
  0.01   0.006112    1/1.0002e-3       4218          1786e-6        1.786e-6       0.569         13.2    0.000611e3
    10   0.012271    1/1.0004e-3       4194          1304e-6        1.305e-6       0.587         9.32    41.99e3
    20   0.023368    1/1.0018e-3       4182          1002e-6        1.004e-6       0.603         6.95    83.86e3
    30   0.042418    1/1.0044e-3       4179          798.3e-6       0.802e-6       0.618         5.40    125.66e3
    40   0.073750    1/1.0079e-3       4179          653.9e-6       0.659e-6       0.631         4.33    167.47e3
    50   0.12335     1/1.0121e-3       4181          547.8e-6       0.554e-6       0.643         3.56    209.3e3
    60   0.19919     1/1.0171e-3       4185          467.3e-6       0.473e-6       0.653         2.99    251.1e3
    70   0.31161     1/1.0228e-3       4191          404.8e-6       0.414e-6       0.662         2.56    293.0e3
    80   0.47358     1/1.0290e-3       4198          355.4e-6       0.366e-6       0.670         2.23    334.9e3
    90   0.70109     1/1.0359e-3       4207          315.6e-6       0.327e-6       0.676         1.96    376.9e3
   100   1.01325     1/1.0435e-3       4218          283.1e-6       0.295e-6       0.681         1.75    419.1e3
   110   1.4327      1/1.0515e-3       4230          254.8e-6       0.268e-6       0.684         1.58    461.3e3
   120   1.9854      1/1.0603e-3       4244          231.0e-6       0.245e-6       0.687         1.43    503.7e3
   130   2.7011      1/1.0697e-3       4262          210.9e-6       0.226e-6       0.688         1.31    546.3e3
   140   3.6136      1/1.0798e-3       4282          194.1e-6       0.210e-6       0.688         1.21    589.1e3
   150   4.7597      1/1.0906e-3       4306          179.8e-6       0.196e-6       0.687         1.13    632.2e3
   160   6.1804      1/1.1021e-3       4334          167.7e-6       0.185e-6       0.684         1.06    675.5e3
   170   7.9202      1/1.1144e-3       4366          157.4e-6       0.175e-6       0.681         1.01    719.1e3
   180   10.027      1/1.1275e-3       4403          148.5e-6       0.167e-6       0.677         0.967   763.1e3
   190   12.553      1/1.1415e-3       4446          140.7e-6       0.161e-6       0.671         0.932   807.5e3
   200   15.550      1/1.1565e-3       4494          133.9e-6       0.155e-6       0.664         0.906   852.4e3
   210   19.080      1/1.1726e-3       4550          127.9e-6       0.150e-6       0.657         0.886   897.7e3
   220   23.202      1/1.1900e-3       4613          122.4e-6       0.146e-6       0.648         0.871   943.7e3
   230   27.979      1/1.2087e-3       4685          117.5e-6       0.142e-6       0.639         0.861   990.3e3
   240   33.480      1/1.2291e-3       4769          112.9e-6       0.139e-6       0.628         0.850   1037.6e3
```

```
  250  39.776     1/1.2512e-3    4866    108.7e-6    0.136e-6    0.616       0.859  1085.8e3
  260  46.941     1/1.2755e-3    4985    104.8e-6    0.134e-6    0.603       0.866  1135.0e3
  270  55.052     1/1.3023e-3    5134    101.1e-6    0.132e-6    0.589       0.882  1185.2e3
  280  64.191     1/1.3321e-3    5307    97.5e-6     0.130e-6    0.574       0.902  1236.8e3
  290  74.449     1/1.3655e-3    5520    94.1e-6     0.128e-6    0.558       0.932  1290e3
  300  85.917     1/1.4036e-3    5794    90.7e-6     0.127e-6    0.541       0.970  1345e3
  310  98.694     1/1.4475e-3    6143    87.2e-6     0.126e-6    0.523       1.024  1402e3
  320  112.89     1/1.4992e-3    6604    83.5e-6     0.125e-6    0.503       1.11   1462e3
  330  128.64     1/1.562e-3     7241    79.5e-6     0.124e-6    0.482       1.20   1526e3
  340  146.08     1/1.639e-3     8225    75.4e-6     0.123e-6    0.460       1.35   1596e3
  350  165.37     1/1.741e-3    10070    69.4e-6     0.121e-6    0.434       1.61   1672e3
  360  186.74     1/1.894e-3    15000    62.1e-6     0.118e-6    0.397       2.34   1762e3
  370  210.53     1/2.22e-3     55000    51.8e-6     0.116e-6    0.340       8.37   1892e3];

% Steam Properties taken from Table E-1 Nuclear Systems 1 - Todreas
%   oC    P(bar)     rho_g(kg/m^3)   Cp_g(J/kg-oC)  mu_g(kg/m-s)   neu_g(m^2/s)  k_g(W/m-oC)    Pr_g     h_g(J/kg)
prop_g = [
  0.01  0.006112   1/206.146      1863    8.105e-6    1672e-6     17.6e-3     0.858    2501e3
   10   0.012271   1/106.422      1870    8.504e-6    905e-6      18.2e-3     0.873    2519e3
   20   0.023368   1/57.836       1880    8.903e-6    515e-6      18.8e-3     0.888    2538e3
   30   0.042418   1/32.929       1890    9.305e-6    306e-6      19.5e-3     0.901    2556e3
   40   0.073750   1/19.546       1900    9.701e-6    190e-6      20.2e-3     0.912    2574e3
   50   0.12335    1/12.045       1912    10.10e-6    121e-6      20.9e-3     0.924    2592e3
   60   0.19919    1/7.6776       1924    10.50e-6    80.6e-6     21.6e-3     0.934    2609e3
   70   0.31161    1/5.0453       1946    10.89e-6    59.4e-6     22.4e-3     0.946    2626e3
   80   0.47358    1/3.4083       1970    11.29e-6    38.5e-6     23.2e-3     0.959    2643e3
   90   0.70109    1/2.3609       1999    11.67e-6    27.6e-6     24.0e-3     0.973    2660e3
  100   1.01325    1/1.6730       2034    12.06e-6    20.2e-6     24.9e-3     0.987    2676e3
  110   1.4327     1/1.2101       2076    12.45e-6    15.1e-6     25.8e-3     1.00     2691e3
  120   1.9854     1/0.89171      2125    12.83e-6    11.4e-6     26.7e-3     1.02     2706e3
  130   2.7011     1/0.66832      2180    13.20e-6    8.82e-6     27.8e-3     1.03     2720e3
  140   3.6136     1/0.50866      2245    13.57e-6    6.90e-6     28.9e-3     1.05     2734e3
  150   4.7597     1/0.39257      2320    13.94e-6    5.47e-6     30.0e-3     1.08     2747e3
  160   6.1804     1/0.30685      2406    14.30e-6    4.39e-6     31.3e-3     1.10     2758e3
  170   7.9202     1/0.24262      2504    14.66e-6    3.55e-6     32.6e-3     1.13     2769e3
  180   10.027     1/0.19385      2615    15.02e-6    2.91e-6     34.1e-3     1.15     2778e3
  190   12.553     1/0.15635      2741    15.37e-6    2.40e-6     35.7e-3     1.18     2786e3
  200   15.550     1/0.12719      2883    15.72e-6    2.00e-6     37.4e-3     1.21     2793e3
  210   19.080     1/0.104265     3043    16.07e-6    1.68e-6     39.4e-3     1.24     2798e3
  220   23.202     1/0.086062     3223    16.42e-6    1.41e-6     41.5e-3     1.28     2802e3
  230   27.979     1/0.071472     3426    16.78e-6    1.20e-6     43.9e-3     1.31     2803e3
  240   33.480     1/0.059674     3656    17.14e-6    1.02e-6     46.5e-3     1.35     2803e3
  250   39.776     1/0.050056     3918    17.51e-6    0.876e-6    49.5e-3     1.39     2801e3
  260   46.941     1/0.042149     4221    17.90e-6    0.755e-6    52.8e-3     1.43     2796e3
  270   55.052     1/0.035599     4575    18.31e-6    0.652e-6    56.6e-3     1.48     2790e3
  280   64.191     1/0.030133     4996    18.74e-6    0.565e-6    60.9e-3     1.54     2780e3
  290   74.449     1/0.025537     5509    19.21e-6    0.491e-6    66.0e-3     1.61     2766e3
```

```
    300  85.917    1/0.021643     6148     19.73e-6    0.427e-6    71.9e-3    1.69    2749e3
    310  98.694    1/0.018316     6968     20.30e-6    0.372e-6    79.1e-3    1.79    2727e3
    320  112.89    1/0.015451     8060     20.95e-6    0.324e-6    87.8e-3    1.92    2700e3
    330  128.64    1/0.012967     9580     21.70e-6    0.281e-6    99.0e-3    2.10    2666e3
    340  146.08    1/0.010779    11870     22.70e-6    0.245e-6   114.0e-3    2.36    2623e3
    350  165.37    1/0.008805    15800     24.15e-6    0.213e-6   134.0e-3    2.84    2565e3
    360  186.74    1/0.006943    27000     26.45e-6    0.184e-6   162.0e-3    4.40    2481e3
    370  210.53    1/0.00317    107000     30.60e-6    0.150e-6   199.0e-3   16.4     2331e3];

% Table taken from Marks' Standard Handbook for MEs (10th Ed)
%   T(°F)    P(inHG abs)
prop_cond = [
    55       1.0
    70       1.5
    80       2.0
    85       2.5
    90       3.0
    95       3.5];

% Read input from the user to use in Orcent_2 input file
fprintf('Base Case (BC) / IRIS input parameters are shown in parenthesis. \n')
fprintf('Please input the following numbers with one number past the decimal point (as shown in the IRIS data). \n');
stmtmp = input('\n\nPlease input the SG outlet steam temperature in F (IRIS = 602.6):  ','s');
stmprs = input('Please input the SG outlet steam pressure in psia (IRIS = 841.0):  ','s');
stmmdot = input('Please input the total SG outlet steam flow rate in lb/hr (IRIS = 3990543.3): ','s');
mwe = input('Please input the desired plant output in MWe (IRIS = 335.0):  ','s');
% Convert back and forth from string to integer to appease matlab
mwe_int = str2num(mwe);
stmthrtlmdot_int = 10000*mwe_int;
stmthrtlmdot = int2str(stmthrtlmdot_int);
T_cold_in_F_cond_s = input('Please input the desired condenser inlet temperature from the heat sink in degrees F (BC = 90.0):
','s');
% Convert to a number for calculations
T_cold_in_F_cond = str2num(T_cold_in_F_cond_s);
% Convert this cold-inlet condenser temperature into celsius
T_cold_in_cond = (5/9)*(T_cold_in_F_cond-32);
% Interpolates to find the new condenser pressure from the temperature
% in units of (inHg)
cond_press_hg = interp1(prop_cond(:,1),prop_cond(:,2),T_cold_in_F_cond);
% Convert this pressure to psi (for ORCENT2)
cond_press_num = cond_press_hg*0.4911542205185763;
% Convert this pressure to a string for replacement in ORCENT2
cond_press = num2str(cond_press_num,3);
% Convert this cold-inlet condenser temperature into celsius for our calcs
T_cold_in_cond = (5/9)*(T_cold_in_F_cond-32);

% Open our created file
```

```
fid = fopen('UTBOP','r');
% Copy existing UTBOP file to a file that Matlab will work with and run
fid2 = fopen('matlabUTBOP','w+');
s1 = 'start';
% This loop Search for "602.6" which will be replaced with the new steam temperature
while s1 ~= -1
    % s1 = -1 when EOF is reached - loop runs until EOF
    % Gets the first line
    s1 = fgets(fid);
    % Scans for string "602.6"
    while isempty(findstr(s1,'602.6')) & s1 ~= -1
        % Echos (copies) the sample file to the new one
        fprintf(fid2,'%s',s1);
        % Gets the next line
        s1 = fgets(fid);
    end
    % Loop terminates when "602.6" is found

    % Flag is raised when "602.6" is found
    if ~isempty(findstr(s1,'602.6'));
        % strrep replaces "602.6" with new steam temperature
        s1 = strrep(s1,'602.6',stmtmp);
        % New line with new power output is written to file
        fprintf(fid2,'%s',s1);
    end
    % The while loop continues until it reaches EOF
end
% Close the files
fclose(fid);fclose(fid2);

% Open our created file
fid = fopen('matlabUTBOP','r');
% Copy existing UTBOP file to a file that Matlab will work with and run
fid2 = fopen('matlabUTBOPi2','w+');
s1 = 'start';
% This loop Search for "841.0" which will be replaced with the new steam pressure
while s1 ~= -1
    % s1 = -1 when EOF is reached - loop runs until EOF
    % Gets the first line
    s1 = fgets(fid);
    % Scans for string "841.0"
    while isempty(findstr(s1,'841.0')) & s1 ~= -1
        % Echos (copies) the sample file to the new one
        fprintf(fid2,'%s',s1);
        % Gets the next line
        s1 = fgets(fid);
    end
```

```
    % Loop terminates when "841.0" is found

    % Flag is raised when "841.0" is found
    if ~isempty(findstr(s1,'841.0'));
        % strrep replaces "602.6" with new steam pressure
        s1 = strrep(s1,'841.0',stmprs);
        % New line with new power output is written to file
        fprintf(fid2,'%s',s1);
    end
    % The while loop continues until it reaches EOF
end
% Close the files
fclose(fid);fclose(fid2);


% Open our created file
fid = fopen('matlabUTBOPi2','r');
% Copy existing UTBOP file to a file that Matlab will work with and run
fid2 = fopen('matlabUTBOPi3','w+');
s1 = 'start';
% This loop Search for "3990543.3" which will be replaced with the new steam flow rate
while s1 ~= -1
    % s1 = -1 when EOF is reached - loop runs until EOF
    % Gets the first line
    s1 = fgets(fid);
    % Scans for string "3990543.3"
    while isempty(findstr(s1,'3990543.3')) & s1 ~= -1
        % Echos (copies) the sample file to the new one
        fprintf(fid2,'%s',s1);
        % Gets the next line
        s1 = fgets(fid);
    end
    % Loop terminates when "3990543.3" is found

    % Flag is raised when "3990543.3" is found
    if ~isempty(findstr(s1,'3990543.3'));
        % strrep replaces "3990543.3" with new steam flow rate
        s1 = strrep(s1,'3990543.3',stmmdot);
        % New line with new power output is written to file
        fprintf(fid2,'%s',s1);
    end
    % The while loop continues until it reaches EOF
end
% Close the files
fclose(fid);fclose(fid2);
```

```
% Open our created file
fid = fopen('matlabUTBOPi3','r');
% Copy existing UTBOP file to a file that Matlab will work with and run
fid2 = fopen('matlabUTBOPi4','w+');
s1 = 'start';
% This loop Search for "335." which will be replaced with the new power output
while s1 ~= -1
    % s1 = -1 when EOF is reached - loop runs until EOF
    % Gets the first line
    s1 = fgets(fid);
    % Scans for string "335."
    while isempty(findstr(s1,'335.')) & s1 ~= -1
        % Echos (copies) the sample file to the new one
        fprintf(fid2,'%s',s1);
        % Gets the next line
        s1 = fgets(fid);
    end
    % Loop terminates when "335." is found

    % Flag is raised when "335." is found
    if ~isempty(findstr(s1,'335.'));
        % strrep replaces "335." with new power output
        s1 = strrep(s1,'335.',mwe);
        % New line with new power output is written to file
        fprintf(fid2,'%s',s1);
    end
    % The while loop continues until it reaches EOF
end
% Close our opened files
fclose(fid);fclose(fid2);


% Open our created file
fid = fopen('matlabUTBOPi4','r');
% Copy existing UTBOP file to a file that Matlab will work with and run
fid2 = fopen('matlabUTBOPi5','w+');
s1 = 'start';
% This loop Search for "1.36" which will be replaced with the new condenser
% pressure
while s1 ~= -1
    % s1 = -1 when EOF is reached - loop runs until EOF
    % Gets the first line
    s1 = fgets(fid);
    % Scans for string "1.36"
    while isempty(findstr(s1,'1.36')) & s1 ~= -1
        % Echos (copies) the sample file to the new one
        fprintf(fid2,'%s',s1);
```

```
        % Gets the next line
        s1 = fgets(fid);
    end
    % Loop terminates when "1.36" is found

    % Flag is raised when "1.36" is found
    if ~isempty(findstr(s1,'1.36'));
        % strrep replaces "3800000" with new throttle steam flow rate
        s1 = strrep(s1,'1.36',cond_press);
        % New line with new power output is written to file
        fprintf(fid2,'%s',s1);
    end
    % The while loop continues until it reaches EOF
end
% Close the files
fclose(fid);fclose(fid2);


% Open our created file
fid = fopen('matlabUTBOPi5','r');
% Copy existing UTBOP file to a file that Matlab will work with and run
fid2 = fopen('matlabUTBOP','w+');
s1 = 'start';
% This loop Search for "3800000" which will be replaced with the new throttle steam flow rate
while s1 ~= -1
    % s1 = -1 when EOF is reached - loop runs until EOF
    % Gets the first line
    s1 = fgets(fid);
    % Scans for string "3800000"
    while isempty(findstr(s1,'3800000')) & s1 ~= -1
        % Echos (copies) the sample file to the new one
        fprintf(fid2,'%s',s1);
        % Gets the next line
        s1 = fgets(fid);
    end
    % Loop terminates when "3800000" is found

    % Flag is raised when "3800000" is found
    if ~isempty(findstr(s1,'3800000'));
        % strrep replaces "3800000" with new throttle steam flow rate
        s1 = strrep(s1,'3800000',stmthrtlmdot);
        % New line with new power output is written to file
        fprintf(fid2,'%s',s1);
    end
    % The while loop continues until it reaches EOF
end
% Close the files
```

```
fclose(fid);fclose(fid2);

% Create a batch file which will execute Orcent2 with the desired output
% file name
fid = fopen('Batchfile.bat','w+');
fwrite(fid,'echo matlabUTBOP|orcent2 > matlabUTBOP_out');
fclose(fid);
% Now run the batch file which calls out Orcent2 with our newly created input file
!Batchfile.bat

% Now scan the output file for the parameters needed to calculate BOP component sizes
% Open the output file
fid3 = fopen('matlabUTBOP_out','r');

% Remove the unnecessary files we created.
delete Batchfile.bat;
delete matlabUTBOP;
delete matlabUTBOPi2;
delete matlabUTBOPi3;
delete matlabUTBOPi4;
delete matlabUTBOPi5;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                BEGIN DATA EXTRACTION                                       %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                Table 1 data extraction                                     %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s1 = 'start';
i = 0;
t1_eff = [];
while ~(strcmp(s1,'EFFICIENCY,')) & ~isempty(s1)
    s1 = fscanf(fid,'%s',1);
    if strcmp(s1,'EFFICIENCY,')
        while ~strcmp(s1,'CENT')
            s1 = fscanf(fid,'%s',1);
        end
        if strcmp(s1,'CENT') & i<2
            s1 = fscanf(fid,'%s',1);
            t1_eff = [t1_eff str2num(s1)];
            i = i+1;
```

```
        end
    end
end
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s2 = 'start';
i = 0;
t1_power_output = [];
while ~(strcmp(s2,'MWE')) & ~isempty(s2)
    s2 = fscanf(fid,'%s',1);
    if strcmp(s2,'MWE') & i<2
        s2 = fscanf(fid,'%s',1);
        t1_power_output = [t1_power_output str2num(s2)];
        i = i+1;
    end
end
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s3 = 'start';
i = 0;
t1_losses = [];
while ~(strcmp(s3,'KW')) & ~isempty(s3)
    s3 = fscanf(fid,'%s',1);
    if strcmp(s3,'KW') & i<2
        s3 = fscanf(fid,'%s',1);
        t1_losses = [t1_losses str2num(s3)];
        i = i+1;
    end
end
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
t1_output = t1_power_output / (t1_eff(1)/100);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fprintf('\n\n   ORCENT2 OUTPUT PARAMETERS (SHOWN BY TABLE)');
fprintf('\n\n\nTable 1          Properties:   Net Efficiency   OutPut (MWe)  Output (MWt)  Losses in kW (Mechanical / Generator)');
fprintf('\n                 Values:        %0.2f           %0.2f         %0.2f             %0.1f  /  %0.1f',...
    t1_eff(1),t1_power_output(1),t1_output,t1_losses(1),t1_losses(2));
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                Table 2 data extraction                                     %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s4 = 'start';s5 = 'start';s6 = 'start';
t2_turb_throttle = [];
while ~strcmp(s6,'TURBINE THROTTLE')
    while ~(strcmp(s4,'TURBINE')) & ~isempty(s4)
        s4 = fscanf(fid,'%s',1);
    end
    s5 = fscanf(fid,'%s',1);
    s6 = sprintf('%s %s',s4,s5);
    s4 = fscanf(fid,'%c',59);
    t2_turb_throttle = [t2_turb_throttle str2num(s4)];
end
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s7 = 'start';s8 = 'start';s9 = 'start';
t2_first_stg_rh_in = [];
while ~strcmp(s9,'REHEATER INLET')
    while ~(strcmp(s7,'REHEATER')) & ~isempty(s7)
        s7 = fscanf(fid,'%s',1);
    end
    s8 = fscanf(fid,'%s',1);
    s9 = sprintf('%s %s',s7,s8);
    s7 = fscanf(fid,'%c',76);
    t2_first_stg_rh_in = [t2_first_stg_rh_in str2num(s7)];
end
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s10 = 'start';s11 = 'start';s12 = 'start';
t2_first_stg_rh_in_temp = [];
while ~strcmp(s12,'SEPARATOR OUTLET')
    while ~(strcmp(s10,'SEPARATOR')) & ~isempty(s10)
        s10 = fscanf(fid,'%s',1);
    end
    s11 = fscanf(fid,'%s',1);
```

```
    s12 = sprintf('%s %s',s10,s11);
    s10 = fscanf(fid,'%c',40);
    t2_first_stg_rh_in_temp = [str2num(s10)];
end
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fprintf('\n\n\nTable 2        Properties:      mdot(lb/hr)    P(psia)     Temp(F)     Enthalpy(BTU/lb)     Q(BTU/hr)');
fprintf('\n          Turbine Throttle:                                %0.2f',t2_turb_throttle(3));
fprintf('\n 1st Stage RH Inlet Values:      %0.2f      %0.2f     %0.2f        %0.2f',...
    t2_first_stg_rh_in(1),t2_first_stg_rh_in(2),t2_first_stg_rh_in_temp(3),t2_first_stg_rh_in(3));
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s13 = 'start';s14 = 'start';s15 = 'start';
t2_first_stg_rh_out = [];
while ~strcmp(s15,'REHEATER OUTLET')
    while ~(strcmp(s13,'REHEATER')) & ~isempty(s13)
        s13 = fscanf(fid,'%s',1);
    end
    s14 = fscanf(fid,'%s',1);
    s15 = sprintf('%s %s',s13,s14);
    s13 = fscanf(fid,'%c',76);
    t2_first_stg_rh_out = [str2num(s13)];
end
% Close the output file
fclose(fid);
t2_first_stg_rh_q = (t2_first_stg_rh_out(4) - t2_first_stg_rh_in(3)) * t2_first_stg_rh_in(1);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fprintf('\n1st Stage RH Outlet Values:      %0.2f      %0.2f     %0.2f        %0.2f           %0.2e',...
    t2_first_stg_rh_out(1),t2_first_stg_rh_out(2),t2_first_stg_rh_out(3),t2_first_stg_rh_out(4),t2_first_stg_rh_q);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s16 = 'start';s17 = 'start';s18 = 'start';
t2_scnd_stg_rh_in = [];
while ~(strcmp(s18,'REHEATER INLET')) & ~isempty(s16)
    while ~(strcmp(s16,'REHEATER')) & ~isempty(s16);
        s16 = fscanf(fid,'%s',1);
    end
    s17 = fscanf(fid,'%s',1);
    s18 = sprintf('%s %s',s16,s17);
    if strcmp(s18,'REHEATER INLET')
```

```
        while ~strcmp(s16,'2ND')
            s16 = fscanf(fid,'%s',1);
        end
        while ~strcmp(s16,'REHEATER')
            s16 = fscanf(fid,'%s',1);
        end
        s17 = fscanf(fid,'%s',1);
        s18 = sprintf('%s %s',s16,s17);
        s16 = fscanf(fid,'%c',76);
        t2_scnd_stg_rh_in = [str2num(s16)];
    end
end
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fprintf('\n 2nd Stage RH Inlet Values:      %0.2f      %0.2f     %0.2f        %0.2f',...
    t2_scnd_stg_rh_in(1),t2_scnd_stg_rh_in(2),t2_first_stg_rh_out(3),t2_scnd_stg_rh_in(3));
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s19 = 'start';s20 = 'start';s21 = 'start';
dummy = 'start';
t2_scnd_stg_rh_out = [];
i = 0;
while ~strcmp(s21,'REHEATER OUTLET')
    while ~(strcmp(s19,'REHEATER')) & ~isempty(s19)
        s19 = fscanf(fid,'%s',1);
    end
    s20 = fscanf(fid,'%s',1);
    s21 = sprintf('%s %s',s19,s20);
end
while i < 31
    dummy = fscanf(fid,'%s',1);
    i = i +1;
end
s19 = fscanf(fid,'%c',76);
t2_scnd_stg_rh_out = [str2num(s19)];
% Close the output file
fclose(fid);
t2_scnd_stg_rh_q = (t2_scnd_stg_rh_out(4) - t2_scnd_stg_rh_in(3)) * t2_scnd_stg_rh_in(1);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fprintf('\n2nd Stage RH Outlet Values:      %0.2f      %0.2f     %0.2f        %0.2f            %0.2e',...
    t2_scnd_stg_rh_out(1),t2_scnd_stg_rh_out(2),t2_scnd_stg_rh_out(3),t2_scnd_stg_rh_out(4),t2_scnd_stg_rh_q);
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                               Table 5 data extraction                                        %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s22 = 'start';s23 = 'start';s24 = 'start';
t5_first_stg_stm_mdot = [];
while ~strcmp(s24,'TABLE V')
    while ~(strcmp(s22,'TABLE')) & ~isempty(s22)
        s22 = fscanf(fid,'%s',1);
    end
    s23 = fscanf(fid,'%s',1);
    s24 = sprintf('%s %s',s22,s23);
    s22 = fscanf(fid,'%c',25);
end
while ~strcmp(s24,'FLOW, LB/HR')
    while ~(strcmp(s22,'FLOW,')) & ~isempty(s22)
        s22 = fscanf(fid,'%s',1);
    end
    s23 = fscanf(fid,'%s',1);
    s24 = sprintf('%s %s',s22,s23);
    s22 = fscanf(fid,'%c',25);
    t5_first_stg_stm_mdot = [str2num(s22)];
end
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s25 = 'start';s26 = 'start';s27 = 'start';
t5_first_stg_stm_h = [];
while ~strcmp(s27,'TABLE V')
    while ~(strcmp(s25,'TABLE')) & ~isempty(s25)
        s25 = fscanf(fid,'%s',1);
    end
    s26 = fscanf(fid,'%s',1);
    s27 = sprintf('%s %s',s25,s26);
    s25 = fscanf(fid,'%c',25);
end
while ~strcmp(s27,'ENTHALPY, BTU/LB')
    while ~(strcmp(s25,'ENTHALPY,')) & ~isempty(s25)
        s25 = fscanf(fid,'%s',1);
    end
    s26 = fscanf(fid,'%s',1);
    s27 = sprintf('%s %s',s25,s26);
```

```
    s25 = fscanf(fid,'%c',13);
    t5_first_stg_stm_h = [str2num(s25)];
end
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s28 = 'start';s29 = 'start';s30 = 'start';
t5_first_stg_stm_p = [];
while ~strcmp(s30,'TABLE V')
    while ~(strcmp(s28,'TABLE')) & ~isempty(s28)
        s28 = fscanf(fid,'%s',1);
    end
    s29 = fscanf(fid,'%s',1);
    s30 = sprintf('%s %s',s28,s29);
    s28 = fscanf(fid,'%c',25);
end
while ~strcmp(s30,'PRESSURE, PSIA')
    while ~(strcmp(s28,'PRESSURE,')) & ~isempty(s28)
        s28 = fscanf(fid,'%s',1);
    end
    s29 = fscanf(fid,'%s',1);
    s30 = sprintf('%s %s',s28,s29);
    s28 = fscanf(fid,'%c',21);
    t5_first_stg_stm_p = [str2num(s28)];
end
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s31 = 'start';s32 = 'start';s33 = 'start';
t5_first_stg_stm_t = [];
while ~strcmp(s33,'TABLE V')
    while ~(strcmp(s31,'TABLE')) & ~isempty(s31)
        s31 = fscanf(fid,'%s',1);
    end
    s32 = fscanf(fid,'%s',1);
    s33 = sprintf('%s %s',s31,s32);
    s31 = fscanf(fid,'%c',25);
end
while ~strcmp(s33,'TEMPERATURE, F')
    while ~(strcmp(s31,'TEMPERATURE,')) & ~isempty(s31)
        s31 = fscanf(fid,'%s',1);
```

```
    end
    s32 = fscanf(fid,'%s',1);
    s33 = sprintf('%s %s',s31,s32);
    s31 = fscanf(fid,'%c',15);
    t5_first_stg_stm_t = [str2num(s31)];
end
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s34 = 'start';s35 = 'start';s36 = 'start';i = 0;
dummy = 'start';
t5_first_stg_drn_h = [];
while ~strcmp(s36,'TABLE V')
    while ~(strcmp(s34,'TABLE')) & ~isempty(s34)
        s34 = fscanf(fid,'%s',1);
    end
    s35 = fscanf(fid,'%s',1);
    s36 = sprintf('%s %s',s34,s35);
end
while i < 39
    dummy = fscanf(fid,'%s',1);
    i = i +1;
end
s34 = fscanf(fid,'%c',12);
t5_first_stg_drn_h = [str2num(s34)];
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fprintf('\n\n\nTable 5         Properties:      mdot(lb/hr)    Steam h(BTU/lb)     P(psia)     Temp(F)       Drain h(BTU/lb)');
fprintf('\n 1sr Stage RH Drain Values:      %0.2f          %0.2f          %0.2f      %0.2f          %0.2f',...
    t5_first_stg_stm_mdot,t5_first_stg_stm_h,t5_first_stg_stm_p,t5_first_stg_stm_t,t5_first_stg_drn_h);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s37 = 'start';s38 = 'start';s39 = 'start';i=0;
t5_scnd_stg_stm_mdot = [];
while ~strcmp(s39,'TABLE V')
    while ~(strcmp(s37,'TABLE')) & ~isempty(s37)
        s37 = fscanf(fid,'%s',1);
    end
    s38 = fscanf(fid,'%s',1);
    s39 = sprintf('%s %s',s37,s38);
end
```

```
while i < 53
    dummy = fscanf(fid,'%s',1);
    i = i +1;
end
s37 = fscanf(fid,'%c',15);
t5_scnd_stg_stm_mdot = [str2num(s37)];
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s40 = 'start';s41 = 'start';s42 = 'start';i=0;
t5_scnd_stg_stm_h = [];
while ~strcmp(s42,'TABLE V')
    while ~(strcmp(s40,'TABLE')) & ~isempty(s40)
        s40 = fscanf(fid,'%s',1);
    end
    s41 = fscanf(fid,'%s',1);
    s42 = sprintf('%s %s',s40,s41);
end
while i < 59
    dummy = fscanf(fid,'%s',1);
    i = i +1;
end
s40 = fscanf(fid,'%c',12);
t5_scnd_stg_stm_h = [str2num(s40)];
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s43 = 'start';s44 = 'start';s45 = 'start';i=0;
t5_scnd_stg_stm_p = [];
while ~strcmp(s45,'TABLE V')
    while ~(strcmp(s43,'TABLE')) & ~isempty(s43)
        s43 = fscanf(fid,'%s',1);
    end
    s44 = fscanf(fid,'%s',1);
    s45 = sprintf('%s %s',s43,s44);
end
while i < 64
    dummy = fscanf(fid,'%s',1);
    i = i +1;
end
s43 = fscanf(fid,'%c',20);
```

```
t5_scnd_stg_stm_p = [str2num(s43)];
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s46 = 'start';s47 = 'start';s48 = 'start';i=0;
t5_scnd_stg_stm_t = [];
while ~strcmp(s48,'TABLE V')
    while ~(strcmp(s46,'TABLE')) & ~isempty(s46)
        s46 = fscanf(fid,'%s',1);
    end
    s47 = fscanf(fid,'%s',1);
    s48 = sprintf('%s %s',s46,s47);
end
while i < 70
    dummy = fscanf(fid,'%s',1);
    i = i +1;
end
s46 = fscanf(fid,'%c',14);
t5_scnd_stg_stm_t = [str2num(s46)];
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s49 = 'start';s50 = 'start';s51 = 'start';i=0;
t5_scnd_stg_drn_h = [];
while ~strcmp(s51,'TABLE V')
    while ~(strcmp(s49,'TABLE')) & ~isempty(s49)
        s49 = fscanf(fid,'%s',1);
    end
    s50 = fscanf(fid,'%s',1);
    s51 = sprintf('%s %s',s49,s50);
end
while i < 76
    dummy = fscanf(fid,'%s',1);
    i = i +1;
end
s49 = fscanf(fid,'%c',12);
t5_scnd_stg_drn_h = [str2num(s49)];
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fprintf('\n 2nd Stage RH Drain Values:     %0.2f          %0.2f         %0.2f      %0.2f          %0.2f',...
```

```
    t5_scnd_stg_stm_mdot,t5_scnd_stg_stm_h,t5_scnd_stg_stm_p,t5_scnd_stg_stm_t,t5_scnd_stg_drn_h);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                Table 7 data extraction                                     %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s52 = 'start';s53 = 'start';s54 = 'start';
t7_fwh_mdot = [];
while ~strcmp(s54,'TABLE VII')
    while ~(strcmp(s52,'TABLE')) & ~isempty(s52)
        s52 = fscanf(fid,'%s',1);
    end
    s53 = fscanf(fid,'%s',1);
    s54 = sprintf('%s %s',s52,s53);
    s52 = fscanf(fid,'%c',25);
end
while ~strcmp(s54,'FLOW, LB/HR')
    while ~(strcmp(s52,'FLOW,')) & ~isempty(s52)
        s52 = fscanf(fid,'%s',1);
    end
    s53 = fscanf(fid,'%s',1);
    s54 = sprintf('%s %s',s52,s53);
    s52 = fscanf(fid,'%c',104);
    t7_fwh_mdot = [str2num(s52)];
end
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s55 = 'start';s56 = 'start';s57 = 'start';
t7_fwh_t_out = [];
while ~strcmp(s57,'TABLE VII')
    while ~(strcmp(s55,'TABLE')) & ~isempty(s55)
        s55 = fscanf(fid,'%s',1);
    end
    s56 = fscanf(fid,'%s',1);
    s57 = sprintf('%s %s',s55,s56);
    s55 = fscanf(fid,'%c',25);
end
while ~strcmp(s57,'OUT, F')
    while ~(strcmp(s55,'OUT,')) & ~isempty(s55)
        s55 = fscanf(fid,'%s',1);
    end
    s56 = fscanf(fid,'%s',1);
```

```
    s57 = sprintf('%s %s',s55,s56);
    s55 = fscanf(fid,'%c',99);
    t7_fwh_t_out = [str2num(s55)];
end
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s58 = 'start';s59 = 'start';s60 = 'start';
t7_fwh_h_out = [];
while ~strcmp(s60,'TABLE VII')
    while ~(strcmp(s58,'TABLE')) & ~isempty(s58)
        s58 = fscanf(fid,'%s',1);
    end
    s59 = fscanf(fid,'%s',1);
    s60 = sprintf('%s %s',s58,s59);
    s58 = fscanf(fid,'%c',25);
end
while ~strcmp(s60,'OUT, BTU/LB')
    while ~(strcmp(s58,'OUT,')) & ~isempty(s58)
        s58 = fscanf(fid,'%s',1);
    end
    s59 = fscanf(fid,'%s',1);
    s60 = sprintf('%s %s',s58,s59);
    s58 = fscanf(fid,'%c',97);
    t7_fwh_h_out = [str2num(s58)];
end
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s61 = 'start';s62 = 'start';s63 = 'start';
t7_fwh_t_in = [];
while ~strcmp(s63,'TABLE VII')
    while ~(strcmp(s61,'TABLE')) & ~isempty(s61)
        s61 = fscanf(fid,'%s',1);
    end
    s62 = fscanf(fid,'%s',1);
    s63 = sprintf('%s %s',s61,s62);
    s61 = fscanf(fid,'%c',25);
end
while ~strcmp(s63,'IN, F')
    while ~(strcmp(s61,'IN,')) & ~isempty(s61)
```

```
        s61 = fscanf(fid,'%s',1);
    end
    s62 = fscanf(fid,'%s',1);
    s63 = sprintf('%s %s',s61,s62);
    s61 = fscanf(fid,'%c',102);
    t7_fwh_t_in = [str2num(s61)];
end
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s64 = 'start';s65 = 'start';s66 = 'start';
t7_fwh_h_in = [];
while ~strcmp(s66,'TABLE VII')
    while ~(strcmp(s64,'TABLE')) & ~isempty(s64)
        s64 = fscanf(fid,'%s',1);
    end
    s65 = fscanf(fid,'%s',1);
    s66 = sprintf('%s %s',s64,s65);
    s64 = fscanf(fid,'%c',25);
end
while ~strcmp(s66,'IN, BTU/LB')
    while ~(strcmp(s64,'IN,')) & ~isempty(s64)
        s64 = fscanf(fid,'%s',1);
    end
    s65 = fscanf(fid,'%s',1);
    s66 = sprintf('%s %s',s64,s65);
    s64 = fscanf(fid,'%c',100);
    t7_fwh_h_in = [str2num(s64)];
end
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s67 = 'start';s68 = 'start';s69 = 'start';
t7_extrn_p = [];
while ~strcmp(s69,'TABLE VII')
    while ~(strcmp(s67,'TABLE')) & ~isempty(s67)
        s67 = fscanf(fid,'%s',1);
    end
    s68 = fscanf(fid,'%s',1);
    s69 = sprintf('%s %s',s67,s68);
    s67 = fscanf(fid,'%c',25);
```

```
end
while ~strcmp(s69,'PRESSURE, PSIA')
    while ~(strcmp(s67,'PRESSURE,')) & ~isempty(s67)
        s67 = fscanf(fid,'%s',1);
    end
    s68 = fscanf(fid,'%s',1);
    s69 = sprintf('%s %s',s67,s68);
    s67 = fscanf(fid,'%c',91);
    t7_extrn_p = [str2num(s67)];
end
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s70 = 'start';s71 = 'start';s72 = 'start';i=0;
t7_extrn_mdot = [];
while ~strcmp(s72,'TABLE VII')
    while ~(strcmp(s70,'TABLE')) & ~isempty(s70)
        s70 = fscanf(fid,'%s',1);
    end
    s71 = fscanf(fid,'%s',1);
    s72 = sprintf('%s %s',s70,s71);
end
while i < 74
    dummy = fscanf(fid,'%s',1);
    i = i +1;
end
s70 = fscanf(fid,'%c',94);
t7_extrn_mdot = [str2num(s70)];
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s73 = 'start';s74 = 'start';s75 = 'start';i=0;
t7_extrn_h = [];
while ~strcmp(s75,'TABLE VII')
    while ~(strcmp(s73,'TABLE')) & ~isempty(s73)
        s73 = fscanf(fid,'%s',1);
    end
    s74 = fscanf(fid,'%s',1);
    s75 = sprintf('%s %s',s73,s74);
end
while i < 84
```

```
    dummy = fscanf(fid,'%s',1);
    i = i +1;
end
s73 = fscanf(fid,'%c',89);
t7_extrn_h = [str2num(s73)];
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s76 = 'start';s77 = 'start';s78 = 'start';i=0;
t7_shell_p = [];
while ~strcmp(s78,'TABLE VII')
    while ~(strcmp(s76,'TABLE')) & ~isempty(s76)
        s76 = fscanf(fid,'%s',1);
    end
    s77 = fscanf(fid,'%s',1);
    s78 = sprintf('%s %s',s76,s77);
end
while i < 93
    dummy = fscanf(fid,'%s',1);
    i = i +1;
end
s76 = fscanf(fid,'%c',104);
t7_shell_p = [str2num(s76)];
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s79 = 'start';s80 = 'start';s81 = 'start';i=0;
t7_shell_t = [];
while ~strcmp(s81,'TABLE VII')
    while ~(strcmp(s79,'TABLE')) & ~isempty(s79)
        s79 = fscanf(fid,'%s',1);
    end
    s80 = fscanf(fid,'%s',1);
    s81 = sprintf('%s %s',s79,s80);
end
while i < 102
    dummy = fscanf(fid,'%s',1);
    i = i +1;
end
s79 = fscanf(fid,'%c',104);
t7_shell_t = [str2num(s79)];
```

```
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s82 = 'start';s83 = 'start';s84 = 'start';i=0;
t7_shell_drn_mdot = [];
while ~strcmp(s84,'TABLE VII')
    while ~(strcmp(s82,'TABLE')) & ~isempty(s82)
        s82 = fscanf(fid,'%s',1);
    end
    s83 = fscanf(fid,'%s',1);
    s84 = sprintf('%s %s',s82,s83);
end
while i < 112
    dummy = fscanf(fid,'%s',1);
    i = i +1;
end
s82 = fscanf(fid,'%c',101);
t7_shell_drn_mdot = [str2num(s82)];
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s85 = 'start';s86 = 'start';s87 = 'start';i=0;
t7_shell_drn_t = [];
while ~strcmp(s87,'TABLE VII')
    while ~(strcmp(s85,'TABLE')) & ~isempty(s85)
        s85 = fscanf(fid,'%s',1);
    end
    s86 = fscanf(fid,'%s',1);
    s87 = sprintf('%s %s',s85,s86);
end
while i < 122
    dummy = fscanf(fid,'%s',1);
    i = i +1;
end
s85 = fscanf(fid,'%c',98);
t7_shell_drn_t = [str2num(s85)];
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
```

```
% Initialize
s88 = 'start';s89 = 'start';s90 = 'start';i=0;
t7_shell_drn_h = [];
while ~strcmp(s90,'TABLE VII')
    while ~(strcmp(s88,'TABLE')) & ~isempty(s88)
        s88 = fscanf(fid,'%s',1);
    end
    s89 = fscanf(fid,'%s',1);
    s90 = sprintf('%s %s',s88,s89);
end
while i < 132
    dummy = fscanf(fid,'%s',1);
    i = i +1;
end
s88 = fscanf(fid,'%c',96);
t7_shell_drn_h = [str2num(s88)];
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fprintf('\n\n\nTable 7 Feed Water Heater#:        1             2             3             4             5             6');
fprintf('\n   Feed Water Flow (lb/hr):     %0.1f     %0.1f     %0.1f     %0.1f     %0.1f     %0.1f',...
    t7_fwh_mdot(1),t7_fwh_mdot(2),t7_fwh_mdot(3),t7_fwh_mdot(4),t7_fwh_mdot(5),t7_fwh_mdot(6));
fprintf('\nFeed Water Outlet Temp (F):       %0.2f         %0.2f         %0.2f         %0.2f         %0.2f         %0.2f',...
    t7_fwh_t_out(1),t7_fwh_t_out(2),t7_fwh_t_out(3),t7_fwh_t_out(4),t7_fwh_t_out(5),t7_fwh_t_out(6));
fprintf('\nFW Outlet Enthalpy(BTU/lb):       %0.2f         %0.2f         %0.2f         %0.2f         %0.2f         %0.2f',...
    t7_fwh_h_out(1),t7_fwh_h_out(2),t7_fwh_h_out(3),t7_fwh_h_out(4),t7_fwh_h_out(5),t7_fwh_h_out(6));
fprintf('\n Feed Water Inlet Temp (F):       %0.2f         %0.2f         %0.2f         %0.2f         %0.2f         %0.2f',...
    t7_fwh_t_in(1),t7_fwh_t_in(2),t7_fwh_t_in(3),t7_fwh_t_in(4),t7_fwh_t_in(5),t7_fwh_t_in(6));
fprintf('\nFW Inlet Enthalpy (BTU/lb):       %0.2f         %0.2f         %0.2f         %0.2f         %0.2f          %0.2f',...
    t7_fwh_h_in(1),t7_fwh_h_in(2),t7_fwh_h_in(3),t7_fwh_h_in(4),t7_fwh_h_in(5),t7_fwh_h_in(6));
fprintf('\nExtrn Stage Pressure(psia):       %0.2f         %0.2f         %0.2f          %0.2f          %0.2f           %0.2f',...
    t7_extrn_p(1),t7_extrn_p(2),t7_extrn_p(3),t7_extrn_p(4),t7_extrn_p(5),t7_extrn_p(6));
fprintf('\n  Extrn Steam Flow (lb/hr):      %0.1f      %0.1f       %0.1f       %0.1f      %0.1f       %0.1f',...
    t7_extrn_mdot(1),t7_extrn_mdot(2),t7_extrn_mdot(3),t7_extrn_mdot(4),t7_extrn_mdot(5),t7_extrn_mdot(6));
fprintf('\nExtrn Stm Enthalpy(BTU/lb):      %0.2f       %0.2f       %0.2f       %0.2f       %0.2f       %0.2f',...
    t7_extrn_h(1),t7_extrn_h(2),t7_extrn_h(3),t7_extrn_h(4),t7_extrn_h(5),t7_extrn_h(6));
fprintf('\n     Shell Pressure (psia):       %0.2f         %0.2f          %0.2f          %0.2f          %0.2f           %0.2f',...
    t7_shell_p(1),t7_shell_p(2),t7_shell_p(3),t7_shell_p(4),t7_shell_p(5),t7_shell_p(6));
fprintf('\n     Shell Temperature (F):       %0.2f         %0.2f         %0.2f         %0.2f         %0.2f         %0.2f',...
    t7_shell_t(1),t7_shell_t(2),t7_shell_t(3),t7_shell_t(4),t7_shell_t(5),t7_shell_t(6));
fprintf('\n  Shell Drain Flow (lb/hr):    %0.1f      %0.1f      %0.1f      %0.1f      %0.1f      %0.1f',...

t7_shell_drn_mdot(1),t7_shell_drn_mdot(2),t7_shell_drn_mdot(3),t7_shell_drn_mdot(4),t7_shell_drn_mdot(5),t7_shell_drn_mdot(6));
fprintf('\nShell Drain Temperature(F):       %0.2f         %0.2f         %0.2f         %0.2f         %0.2f         %0.2f',...
    t7_shell_drn_t(1),t7_shell_drn_t(2),t7_shell_drn_t(3),t7_shell_drn_t(4),t7_shell_drn_t(5),t7_shell_drn_t(6));
fprintf('\nShell Drn Enthalpy(BTU/lb):       %0.2f         %0.2f         %0.2f         %0.2f         %0.2f          %0.2f',...
    t7_shell_drn_h(1),t7_shell_drn_h(2),t7_shell_drn_h(3),t7_shell_drn_h(4),t7_shell_drn_h(5),t7_shell_drn_h(6));
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                Table 8 data extraction                                     %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s91 = 'start';s92 = 'start';s93 = 'start';
t8_cond_p = [];
while ~strcmp(s93,'TABLE VIII')
    while ~(strcmp(s91,'TABLE')) & ~isempty(s91)
        s91 = fscanf(fid,'%s',1);
    end
    s92 = fscanf(fid,'%s',1);
    s93 = sprintf('%s %s',s91,s92);
    s91 = fscanf(fid,'%c',25);
end
while ~strcmp(s93,'PRESSURE, PSIA')
    while ~(strcmp(s91,'PRESSURE,')) & ~isempty(s91)
        s91 = fscanf(fid,'%s',1);
    end
    s92 = fscanf(fid,'%s',1);
    s93 = sprintf('%s %s',s91,s92);
    s91 = fscanf(fid,'%c',27);
    t8_cond_p = [str2num(s91)];
end
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s94 = 'start';s95 = 'start';s96 = 'start';
t8_cond_mdot = [];
while ~strcmp(s96,'TABLE VIII')
    while ~(strcmp(s94,'TABLE')) & ~isempty(s94)
        s94 = fscanf(fid,'%s',1);
    end
    s95 = fscanf(fid,'%s',1);
    s96 = sprintf('%s %s',s94,s95);
    s94 = fscanf(fid,'%c',25);
end
while ~strcmp(s96,'FLOW, LB/HR')
    while ~(strcmp(s94,'FLOW,')) & ~isempty(s94)
        s94 = fscanf(fid,'%s',1);
    end
    s95 = fscanf(fid,'%s',1);
    s96 = sprintf('%s %s',s94,s95);
```

```
    s94 = fscanf(fid,'%c',22);
    t8_cond_mdot = [str2num(s94)];
end
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s97 = 'start';s98 = 'start';s99 = 'start';
t8_cond_t = [];
while ~strcmp(s99,'TABLE VIII')
    while ~(strcmp(s97,'TABLE')) & ~isempty(s97)
        s97 = fscanf(fid,'%s',1);
    end
    s98 = fscanf(fid,'%s',1);
    s99 = sprintf('%s %s',s97,s98);
    s97 = fscanf(fid,'%c',25);
end
while ~strcmp(s99,'TEMPERATURE, F')
    while ~(strcmp(s97,'TEMPERATURE,')) & ~isempty(s97)
        s97 = fscanf(fid,'%s',1);
    end
    s98 = fscanf(fid,'%s',1);
    s99 = sprintf('%s %s',s97,s98);
    s97 = fscanf(fid,'%c',21);
    t8_cond_t = [str2num(s97)];
end
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%Open the output file
fid = fopen('matlabUTBOP_out','rt');
% Initialize
s100 = 'start';s101 = 'start';s102 = 'start';
t8_cond_h = [];
while ~strcmp(s102,'TABLE VIII')
    while ~(strcmp(s100,'TABLE')) & ~isempty(s100)
        s100 = fscanf(fid,'%s',1);
    end
    s101 = fscanf(fid,'%s',1);
    s102 = sprintf('%s %s',s100,s101);
    s100 = fscanf(fid,'%c',25);
end
while ~strcmp(s102,'ENTHALPY, BTU/LB')
    while ~(strcmp(s100,'ENTHALPY,')) & ~isempty(s100)
        s100 = fscanf(fid,'%s',1);
```

```
    end
    s101 = fscanf(fid,'%s',1);
    s102 = sprintf('%s %s',s100,s101);
    s100 = fscanf(fid,'%c',19);
    t8_cond_h = [str2num(s100)];
end
% Close the output file
fclose(fid);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fprintf('\n\n\nTable 8         Properties:     Pressure(psia)         mdot(lb/hr)         Temp(F)         Enthalpy(BTU/lb)');
fprintf('\n    Condenser / Condensate:         %0.2f              %0.2f         %0.2f              %0.2f',...
    t8_cond_p,t8_cond_mdot,t8_cond_t,t8_cond_h);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                END OF DATA EXTRACTION                                               %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                BEGIN COMPONENT SIZING CALCULATIONS                                  %
%                                        - tube in shell  -                                           %
%  As a general rule, to ensure good steam distribution, is that the Length (in ft)                  %
%     should not exceed the Shell Diameter (in inches) plus two                                       %
%     - Marks' Standards for ME - pg 9-86, 10th ed.                                                   %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Conversion factors to go from English to SI
conv_mdot = 1/7936.6;                % Mass Flow Rate (lb/hr) -> (kg/s)
conv_h = 1/0.00042992;               % Enthalpy (BTU/lb) -> (J/kg)
conv_p = 1/14.50378;                 % Pressure (psia) -> (bar)
conv_q = 1/3.41214;                  % Power
conv_w = 0.0011023;                  % kg to ton conversion
% Properties used for all components
gravity = 9.81;              % (m/s^2)
OD = 0.0254;                 % 20 BWG 1" Pipes
ID = 0.02362;                % 20 BWG 1" Pipes
ss316d = 7737.25;            % SS316 Density (kg/m3)
shell_thick = 0.0508;        % Shell Thickness (m)
T_start = 21.11;             % (C) Start temp for HX tubes (70 F)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                         Condenser                                                   %
%            20BWG 1" Diameter tubes - Horizontal Configuration - Calculate Tube Length               %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fprintf('\n\n');
```

```
% Properties for condenser taken from ORCENT2 output
q_cond = 1000000*t1_output*(1-(t1_eff(1)/100));  % Watts
T_hot_in_cond = (5/9)*(t8_cond_t-32);            % C
T_hot_out_cond = T_hot_in_cond;                  % C
mdot_h_cond = t8_cond_mdot*conv_mdot;            % kg/s
press_cond = t8_cond_p*conv_p;                   % bars

% Condenser Properties
CCW_inlet_pipe_OD = 1.524;          % (m) = 60 in.
CCW_inlet_pipe_ID = 1.4732;         % (m) = 58 in.
OD_cond = 8.0;                      % m
no_passes_cond = 1;
no_tubes_cond = 15000;              % per shell
no_shells_cond = 2;
v_water_cond = 2.1336;              % Mark's Standard Handbook for Mech. Eng. (8th ed) suggests this velocity (m/s) = 7 ft/s
% Using "Marks' Standard Handbook for Mech. Eng. (8th Ed.) pg. 9-62, "Water temp rise is about 10F for a single pass
% Condenser with a minimum of 5F terminal temp difference ==> (delta 10F = delta 5.56C, delta 5F = delta 2.78C)
T_cold_out_cond = T_cold_in_cond + 5.56;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%   CONDENSER - COLD SIDE   %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Interpolations from the tables at the top (cold side)
rho_t_cond = interp1(prop_f(:,1),prop_f(:,3),T_cold_in_cond);
Cp_t_cond = interp1(prop_f(:,1),prop_f(:,4),T_cold_in_cond);
mu_t_cond = interp1(prop_f(:,1),prop_f(:,5),T_cold_in_cond);
k_t_cond = interp1(prop_f(:,1),prop_f(:,7),T_cold_in_cond);
Pr_t_cond = interp1(prop_f(:,1),prop_f(:,8),T_cold_in_cond);

mdot_c_cond = rho_t_cond * v_water_cond * pi * (ID/2)^2;
mdot_c_total_cond = q_cond/(Cp_t_cond*(T_cold_out_cond - T_cold_in_cond));
Re_t_cond = (4*mdot_c_cond)/(pi*ID*mu_t_cond);
% DB Correlation
Nu_t_cond = 0.023*Re_t_cond^0.8 * Pr_t_cond^0.4;
h_i_cond = (Nu_t_cond * k_t_cond)/ID;    % W/(m^2 C)

% Guess wall and film temperatures (cold side)
T_inner_pipe_surf_cond = (0.25)*(T_hot_in_cond-T_cold_in_cond) + T_cold_in_cond;
T_c_film_cond = (0.25)*(T_hot_in_cond-T_inner_pipe_surf_cond)/2 + T_inner_pipe_surf_cond;
Cp_t_f_cond = interp1(prop_f(:,1),prop_f(:,4),T_cold_in_cond);
neu_t_f_cond = interp1(prop_f(:,1),prop_f(:,6),T_cold_in_cond);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%   CONDENSER - HOT SIDE   %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Interpolations from the tables above (hot side)
mu_l_cond = (3*interp1(prop_f(:,1),prop_f(:,5),T_inner_pipe_surf_cond)+interp1(prop_f(:,1),prop_f(:,5),T_hot_in_cond))/4;
k_f_cond = interp1(prop_f(:,1),prop_f(:,7),T_c_film_cond);
rho_g_cond = interp1(prop_g(:,1),prop_g(:,3),T_hot_in_cond);                  % rho_g(kg/m^3)
rho_f_cond = interp1(prop_f(:,1),prop_f(:,3),T_c_film_cond);
```

```
h_f_g_cond = interp1(prop_f(:,1),prop_f(:,9),T_hot_in_cond);
h_g_g_cond = interp1(prop_g(:,1),prop_g(:,9),T_hot_in_cond);
h_fg_before_cond = h_g_g_cond - h_f_g_cond;                    % h_fg(J/kg)
h_fg_prime_cond = h_fg_before_cond + 0.68*Cp_t_f_cond*(T_hot_in_cond-T_inner_pipe_surf_cond);    % (Thome - Convective Boiling &
Condensation)

v_steam_cond = mdot_h_cond/(rho_g_cond*((pi*(OD_cond/2)^2)-(pi*no_tubes_cond*no_shells_cond*((OD/2)^2))));
% The h_o equation come from Fund. of Heat & Mass Transfer (Dewitt) pg 565, Eqn 10.40 and 10.41
h_o_bar_tube_cond = 0.729*(((gravity*rho_f_cond*(rho_f_cond-rho_g_cond)*(k_f_cond^3)*h_fg_prime_cond) / (mu_l_cond*(T_hot_in_cond-
T_inner_pipe_surf_cond)*OD))^0.25);
% The h_o_total equation comes from Buttweworth - Hemisphere Handbook of Heat Exchanger Design
h_o_bar_total_cond = h_o_bar_tube_cond*((sqrt(no_tubes_cond*no_shells_cond))^(-1/6));

% Calculate the overall H.T. coefficient using (pg. 595 Fund. of Heat & Mass Transfer by Dewitt)
U_cond = 1/((1/h_i_cond)+(1/h_o_bar_total_cond));
DTLM_cond    =    ((T_hot_in_cond-T_cold_out_cond)-(T_hot_in_cond-T_cold_in_cond))    /    (log((T_hot_in_cond-
T_cold_out_cond)/(T_hot_in_cond-T_cold_in_cond)));
% Begin thermal expansion calculations for SS316 - expansion coefficients from
% www.aksteel.com
delta_T_cond = T_hot_in_cond - T_start;
if delta_T_cond < 871
    C_cond = 19.9E-6;
    if delta_T_cond < 649
        C_cond = 18.5E-6;
        if delta_T_cond < 538
            C_cond = 17.5E-6;
            if delta_T_cond < 315
                C_cond = 16.2E-6;
                if delta_T_cond < 100
                    C_cond = 16.0E-6;
                end
            end
        end
    end
end
Length_tubes_cond_init = q_cond/(U_cond*no_tubes_cond*no_shells_cond*pi*OD*DTLM_cond);
delta_Length_cond = Length_tubes_cond_init*C_cond*delta_T_cond;
Length_tubes_cond = Length_tubes_cond_init+delta_Length_cond;
HT_area_cond = no_tubes_cond*no_shells_cond*Length_tubes_cond*pi*OD;

hollow_tube_vol_cond = (pi/4)*Length_tubes_cond*((OD^2)-(ID^2))*no_tubes_cond*no_passes_cond*no_shells_cond;
tube_w_cond = hollow_tube_vol_cond*ss316d*conv_w;
shell_vol_cond = (pi/4)*Length_tubes_cond*(((OD_cond^2)+shell_thick)-(OD_cond^2));
shell_w_cond = shell_vol_cond*ss316d*conv_w;
end_caps_vol_cond = 2*(pi/4)*(OD_cond^2)*shell_thick;
end_caps_w_cond = end_caps_vol_cond*ss316d*conv_w;
total_w_cond = tube_w_cond+shell_w_cond+end_caps_w_cond;
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                       Feed Water Heater #1 (Closest to Steam Generator)                    %
% 20BWG 1" Diameter tubes -  vertical FWH's - max length 12 meters - calcs req. # of tubes   %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Properties for fwh#1 taken from ORCENT2 output
q_fwh1 = conv_q*(t7_fwh_mdot(1)*(t7_fwh_h_out(1)-t7_fwh_h_in(1)));  % Watts
T_hot_in_fwh1 = (5/9)*(t7_shell_t(1)-32);                           % C
T_hot_out_fwh1 = (5/9)*(t7_shell_drn_t(1)-32);                      % C
T_cold_in_fwh1 = (5/9)*(t7_fwh_t_in(1)-32);                         % C
T_cold_out_fwh1 = (5/9)*(t7_fwh_t_out(1)-32);                       % C
press_fwh1 = t7_shell_p(1)*conv_p;                                  % bars
mdot_h_fwh1 = t7_shell_drn_mdot(1)*conv_mdot;                       % kg/s
mdot_c_fwh1 = t7_fwh_mdot(1)*conv_mdot;                             % kg/s

% fwh#1 Properties
Length_tubes_fwh1_init = 10.00;    % m
no_passes_fwh1 = 2;
v_water_fwh1 = 2.1336;             % Mark's Standard Handbook for Mech. Eng. (8th ed) suggests this velocity (m/s) = 7 ft/s
F = 0.69;                          % Correction Factor - Chart 11.10

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%     FWH#1 - COLD SIDE     %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Begin thermal expansion calculations for SS316 - expansion coefficients from
% www.aksteel.com
delta_T_fwh1 = T_hot_in_fwh1 - T_start;
if delta_T_fwh1 < 871
    C1_fwh1 = 19.9E-6;
    if delta_T_fwh1 < 649
        C1_fwh1 = 18.5E-6;
        if delta_T_fwh1 < 538
            C1_fwh1 = 17.5E-6;
            if delta_T_fwh1 < 315
                C1_fwh1 = 16.2E-6;
                if delta_T_fwh1 < 100
                    C1_fwh1 = 16.0E-6;
                end
            end
        end
    end
end
delta_Length_fwh1 = Length_tubes_fwh1_init*C1_fwh1*delta_T_fwh1;
Length_tubes_fwh1 = Length_tubes_fwh1_init+delta_Length_fwh1;

% Interpolations from the tables at the top (cold side)
rho_t_fwh1 = interp1(prop_f(:,1),prop_f(:,3),T_cold_in_fwh1);
Cp_t_fwh1 = interp1(prop_f(:,1),prop_f(:,4),T_cold_in_fwh1);
mu_t_fwh1 = interp1(prop_f(:,1),prop_f(:,5),T_cold_in_fwh1);
```

```
k_t_fwh1 = interp1(prop_f(:,1),prop_f(:,7),T_cold_in_fwh1);
Pr_t_fwh1 = interp1(prop_f(:,1),prop_f(:,8),T_cold_in_fwh1);

mdot_c_fwh1 = rho_t_fwh1 * v_water_fwh1 * pi * (ID/2)^2;
mdot_c_total_fwh1 = q_fwh1/(Cp_t_fwh1*(T_cold_out_fwh1 - T_cold_in_fwh1));
Re_t_fwh1 = (4*mdot_c_fwh1)/(pi*ID*mu_t_fwh1);
% DB Correlation
Nu_t_fwh1 = 0.023*Re_t_fwh1^0.8 * Pr_t_fwh1^0.4;
h_i_fwh1 = (Nu_t_fwh1 * k_t_fwh1)/ID;    % W/(m^2 C)

% Guess wall and film temperatures (cold side)
T_inner_pipe_surf_fwh1 = (0.25)*(T_hot_in_fwh1-T_cold_in_fwh1) + T_cold_in_fwh1;
T_c_film_fwh1 = (0.25)*(T_hot_in_fwh1-T_inner_pipe_surf_fwh1)/2 + T_inner_pipe_surf_fwh1;
Cp_t_f_fwh1 = interp1(prop_f(:,1),prop_f(:,4),T_cold_in_fwh1);
neu_t_f_fwh1 = interp1(prop_f(:,1),prop_f(:,6),T_cold_in_fwh1);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%      FWH#1 - HOT SIDE     %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Interpolations from the tables above (hot side)
mu_l_fwh1 = (3*interp1(prop_f(:,1),prop_f(:,5),T_inner_pipe_surf_fwh1)+interp1(prop_f(:,1),prop_f(:,5),T_hot_in_fwh1))/4;
k_f_fwh1 = interp1(prop_f(:,1),prop_f(:,7),T_c_film_fwh1);
rho_g_fwh1 = interp1(prop_g(:,1),prop_g(:,3),T_hot_in_fwh1);                    % rho_g(kg/m^3)
rho_f_fwh1 = interp1(prop_f(:,1),prop_f(:,3),T_c_film_fwh1);
h_f_g_fwh1 = interp1(prop_f(:,1),prop_f(:,9),T_hot_in_fwh1);
h_g_g_fwh1 = interp1(prop_g(:,1),prop_g(:,9),T_hot_in_fwh1);
h_fg_before_fwh1 = h_g_g_fwh1 - h_f_g_fwh1;                                       % h_fg(J/kg)
h_fg_prime_fwh1 = h_fg_before_fwh1 + 0.68*Cp_t_f_fwh1*(T_hot_in_fwh1-T_inner_pipe_surf_fwh1);    % (Thome - Convective Boiling &
fwh1ensation)
Pr_l_fwh1 = interp1(prop_f(:,1),prop_f(:,8),T_c_film_fwh1);

C_fwh1 = (mu_l_fwh1^(2/3)) / (k_f_fwh1*(rho_f_fwh1*(rho_f_fwh1-rho_g_fwh1)*gravity)^(1/3));
% I need to take the Tube length dependence out of Rec2 equation so that L can be recalculated (manip eqns)
Rec2_fwh1 = 4*(T_hot_in_fwh1-T_inner_pipe_surf_fwh1)*Length_tubes_fwh1 / (mu_l_fwh1*h_fg_prime_fwh1);
h_o_fwh1 = (((Rec2_fwh1/C_fwh1)+253*58*Pr_l_fwh1^(-0.5)-8750)/(Rec2_fwh1^(0.75)*58*Pr_l_fwh1^(-0.5)))^(4/3);

% Calculate the overall H.T. coefficient using (pg. 595 Fund. of Heat & Mass Transfer by Dewitt)
U_fwh1 = 1/((1/h_i_fwh1)+(1/h_o_fwh1));
DTLM_fwh1        =        ((T_hot_in_fwh1-T_cold_out_fwh1)-(T_hot_out_fwh1-T_cold_in_fwh1))        /        (log((T_hot_in_fwh1-
T_cold_out_fwh1)/(T_hot_out_fwh1-T_cold_in_fwh1)));
no_tubes_fwh1 = round(q_fwh1/(U_fwh1*Length_tubes_fwh1*no_passes_fwh1*pi*OD*DTLM_fwh1*F));
OD_fwh1 = (1.7161*(no_tubes_fwh1^0.4986)/12)/3.28;
HT_area_fwh1 = no_tubes_fwh1*no_passes_fwh1*Length_tubes_fwh1*pi*OD;
v_steam_fwh1 = mdot_h_fwh1/(rho_g_fwh1*((pi*(OD_fwh1/2)^2)-(pi*no_tubes_fwh1*no_passes_fwh1*((OD/2)^2))));

hollow_tube_vol_fwh1 = (pi/4)*Length_tubes_fwh1*((OD^2)-(ID^2))*no_tubes_fwh1*no_passes_fwh1;
tube_w_fwh1 = hollow_tube_vol_fwh1*ss316d*conv_w;
shell_vol_fwh1 = (pi/4)*Length_tubes_fwh1*(((OD_fwh1^2)+shell_thick)-(OD_fwh1^2));
shell_w_fwh1 = shell_vol_fwh1*ss316d*conv_w;
```

```
end_caps_vol_fwh1 = 2*(pi/4)*(OD_fwh1^2)*shell_thick;
end_caps_w_fwh1 = end_caps_vol_fwh1*ss316d*conv_w;
total_w_fwh1 = tube_w_fwh1+shell_w_fwh1+end_caps_w_fwh1;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                Feed Water Heater #2                                         %
% 20BWG 1" Diameter tubes -  vertical FWH's - max length 12 meters - calcs req. # of tubes   %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Properties for fwh#2 taken from ORCENT2 output
q_fwh2 = conv_q*(t7_fwh_mdot(2)*(t7_fwh_h_out(2)-t7_fwh_h_in(2)));  % Watts
T_hot_in_fwh2 = (5/9)*(t7_shell_t(2)-32);                           % C
T_hot_out_fwh2 = (5/9)*(t7_shell_drn_t(2)-32);                      % C
T_cold_in_fwh2 = (5/9)*(t7_fwh_t_in(2)-32);                         % C
T_cold_out_fwh2 = (5/9)*(t7_fwh_t_out(2)-32);                       % C
press_fwh2 = t7_shell_p(2)*conv_p;                                  % bars
mdot_h_fwh2 = t7_shell_drn_mdot(2)*conv_mdot;                       % kg/s
mdot_c_fwh2 = t7_fwh_mdot(2)*conv_mdot;                             % kg/s

% fwh#1 Properties
Length_tubes_fwh2_init = 6.00;      % m
no_passes_fwh2 = 2;
v_water_fwh2 = 2.1336;              % Mark's Standard Handbook for Mech. Eng. (8th ed) suggests this velocity (m/s) = 7 ft/s

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%     FWH#2 - COLD SIDE     %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Begin thermal expansion calculations for SS316 - expansion coefficients from
% www.aksteel.com
delta_T_fwh2 = T_hot_in_fwh2 - T_start;
if delta_T_fwh2 < 871
    C1_fwh2 = 19.9E-6;
    if delta_T_fwh2 < 649
        C1_fwh2 = 18.5E-6;
        if delta_T_fwh2 < 538
            C1_fwh2 = 17.5E-6;
            if delta_T_fwh2 < 315
                C1_fwh2 = 16.2E-6;
                if delta_T_fwh2 < 100
                    C1_fwh2 = 16.0E-6;
                end
            end
        end
    end
end
delta_Length_fwh2 = Length_tubes_fwh2_init*C1_fwh2*delta_T_fwh2;
Length_tubes_fwh2 = Length_tubes_fwh2_init+delta_Length_fwh2;

% Interpolations from the tables at the top (cold side)
rho_t_fwh2 = interp1(prop_f(:,1),prop_f(:,3),T_cold_in_fwh2);
```

```
Cp_t_fwh2 = interp1(prop_f(:,1),prop_f(:,4),T_cold_in_fwh2);
mu_t_fwh2 = interp1(prop_f(:,1),prop_f(:,5),T_cold_in_fwh2);
k_t_fwh2 = interp1(prop_f(:,1),prop_f(:,7),T_cold_in_fwh2);
Pr_t_fwh2 = interp1(prop_f(:,1),prop_f(:,8),T_cold_in_fwh2);

mdot_c_fwh2 = rho_t_fwh2 * v_water_fwh2 * pi * (ID/2)^2;
mdot_c_total_fwh2 = q_fwh2/(Cp_t_fwh2*(T_cold_out_fwh2 - T_cold_in_fwh2));
Re_t_fwh2 = (4*mdot_c_fwh2)/(pi*ID*mu_t_fwh2);
% DB Correlation
Nu_t_fwh2 = 0.023*Re_t_fwh2^0.8 * Pr_t_fwh2^0.4;
h_i_fwh2 = (Nu_t_fwh2 * k_t_fwh2)/ID;    % W/(m^2 C)

% Guess wall and film temperatures (cold side)
T_inner_pipe_surf_fwh2 = (0.25)*(T_hot_in_fwh2-T_cold_in_fwh2) + T_cold_in_fwh2;
T_c_film_fwh2 = (0.25)*(T_hot_in_fwh2-T_inner_pipe_surf_fwh2)/2 + T_inner_pipe_surf_fwh2;
Cp_t_f_fwh2 = interp1(prop_f(:,1),prop_f(:,4),T_cold_in_fwh2);
neu_t_f_fwh2 = interp1(prop_f(:,1),prop_f(:,6),T_cold_in_fwh2);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%      FWH#2 - HOT SIDE     %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Interpolations from the tables above (hot side)
mu_l_fwh2 = (3*interp1(prop_f(:,1),prop_f(:,5),T_inner_pipe_surf_fwh2)+interp1(prop_f(:,1),prop_f(:,5),T_hot_in_fwh2))/4;
k_f_fwh2 = interp1(prop_f(:,1),prop_f(:,7),T_c_film_fwh2);
rho_g_fwh2 = interp1(prop_g(:,1),prop_g(:,3),T_hot_in_fwh2);                    %  rho_g(kg/m^3)
rho_f_fwh2 = interp1(prop_f(:,1),prop_f(:,3),T_c_film_fwh2);
h_f_g_fwh2 = interp1(prop_f(:,1),prop_f(:,9),T_hot_in_fwh2);
h_g_g_fwh2 = interp1(prop_g(:,1),prop_g(:,9),T_hot_in_fwh2);
h_fg_before_fwh2 = h_g_g_fwh2 - h_f_g_fwh2;                                       %  h_fg(J/kg)
h_fg_prime_fwh2 = h_fg_before_fwh2 + 0.68*Cp_t_f_fwh2*(T_hot_in_fwh2-T_inner_pipe_surf_fwh2);     % (Thome - Convective Boiling &
fwh1ensation)
Pr_l_fwh2 = interp1(prop_f(:,1),prop_f(:,8),T_c_film_fwh2);

C_fwh2 = (mu_l_fwh2^(2/3)) / (k_f_fwh2*(rho_f_fwh2*(rho_f_fwh2-rho_g_fwh2)*gravity)^(1/3));
% I need to take the Tube length dependence out of Rec2 equation so that L can be recalculated (manip eqns)
Rec2_fwh2 = 4*(T_hot_in_fwh2-T_inner_pipe_surf_fwh2)*Length_tubes_fwh2 / (mu_l_fwh2*h_fg_prime_fwh2);
h_o_fwh2 = (((Rec2_fwh2/C_fwh2)+253*58*Pr_l_fwh2^(-0.5)-8750)/(Rec2_fwh2^(0.75)*58*Pr_l_fwh2^(-0.5)))^(4/3);

% Calculate the overall H.T. coefficient using (pg. 595 Fund. of Heat & Mass Transfer by Dewitt)
U_fwh2 = 1/((1/h_i_fwh2)+(1/h_o_fwh2));
DTLM_fwh2        =        ((T_hot_in_fwh2-T_cold_out_fwh2)-(T_hot_out_fwh2-T_cold_in_fwh2))        /        (log((T_hot_in_fwh2-
T_cold_out_fwh2)/(T_hot_out_fwh2-T_cold_in_fwh2)));
no_tubes_fwh2 = round(q_fwh2/(U_fwh2*Length_tubes_fwh2*no_passes_fwh2*pi*OD*DTLM_fwh2*F));
OD_fwh2 = (1.7161*(no_tubes_fwh2^0.4986)/12)/3.28;
HT_area_fwh2 = no_tubes_fwh2*no_passes_fwh2*Length_tubes_fwh2*pi*OD;
v_steam_fwh2 = mdot_h_fwh2/(rho_g_fwh2*((pi*(OD_fwh2/2)^2)-(pi*no_tubes_fwh2*no_passes_fwh2*((OD/2)^2))));

hollow_tube_vol_fwh2 = (pi/4)*Length_tubes_fwh2*((OD^2)-(ID^2))*no_tubes_fwh2*no_passes_fwh2;
tube_w_fwh2 = hollow_tube_vol_fwh2*ss316d*conv_w;
```

```
shell_vol_fwh2 = (pi/4)*Length_tubes_fwh2*(((OD_fwh2^2)+shell_thick)-(OD_fwh2^2));
shell_w_fwh2 = shell_vol_fwh2*ss316d*conv_w;
end_caps_vol_fwh2 = 2*(pi/4)*(OD_fwh2^2)*shell_thick;
end_caps_w_fwh2 = end_caps_vol_fwh2*ss316d*conv_w;
total_w_fwh2 = tube_w_fwh2+shell_w_fwh2+end_caps_w_fwh2;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                Feed Water Heater #3                                         %
% 20BWG 1" Diameter tubes -  vertical FWH's - max length 12 meters - calcs req. # of tubes   %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Properties for fwh#3 taken from ORCENT2 output
q_fwh3 = conv_q*(t7_fwh_mdot(3)*(t7_fwh_h_out(3)-t7_fwh_h_in(3)));  % Watts
T_hot_in_fwh3 = (5/9)*(t7_shell_t(3)-32);                          % C
T_hot_out_fwh3 = (5/9)*(t7_shell_drn_t(3)-32);                     % C
T_cold_in_fwh3 = (5/9)*(t7_fwh_t_in(3)-32);                        % C
T_cold_out_fwh3 = (5/9)*(t7_fwh_t_out(3)-32);                      % C
press_fwh3 = t7_shell_p(3)*conv_p;                                 % bars
mdot_h_fwh3 = t7_shell_drn_mdot(3)*conv_mdot;                      % kg/s
mdot_c_fwh3 = t7_fwh_mdot(3)*conv_mdot;                            % kg/s

% fwh#1 Properties
Length_tubes_fwh3_init = 8.00;     % m
no_passes_fwh3 = 2;
v_water_fwh3 = 2.1336;             % Mark's Standard Handbook for Mech. Eng. (8th ed) suggests this velocity (m/s) = 7 ft/s

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%     FWH#3 - COLD SIDE     %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Begin thermal expansion calculations for SS316 - expansion coefficients from
% www.aksteel.com
delta_T_fwh3 = T_hot_in_fwh3 - T_start;
if delta_T_fwh3 < 871
    C1_fwh3 = 19.9E-6;
    if delta_T_fwh3 < 649
        C1_fwh3 = 18.5E-6;
        if delta_T_fwh3 < 538
            C1_fwh3 = 17.5E-6;
            if delta_T_fwh3 < 315
                C1_fwh3 = 16.2E-6;
                if delta_T_fwh3 < 100
                    C1_fwh3 = 16.0E-6;
                end
            end
        end
    end
end
delta_Length_fwh3 = Length_tubes_fwh3_init*C1_fwh3*delta_T_fwh3;
Length_tubes_fwh3 = Length_tubes_fwh3_init+delta_Length_fwh3;
```

```
% Interpolations from the tables at the top (cold side)
rho_t_fwh3 = interp1(prop_f(:,1),prop_f(:,3),T_cold_in_fwh3);
Cp_t_fwh3 = interp1(prop_f(:,1),prop_f(:,4),T_cold_in_fwh3);
mu_t_fwh3 = interp1(prop_f(:,1),prop_f(:,5),T_cold_in_fwh3);
k_t_fwh3 = interp1(prop_f(:,1),prop_f(:,7),T_cold_in_fwh3);
Pr_t_fwh3 = interp1(prop_f(:,1),prop_f(:,8),T_cold_in_fwh3);

mdot_c_fwh3 = rho_t_fwh3 * v_water_fwh3 * pi * (ID/2)^2;
mdot_c_total_fwh3 = q_fwh3/(Cp_t_fwh3*(T_cold_out_fwh3 - T_cold_in_fwh3));
Re_t_fwh3 = (4*mdot_c_fwh3)/(pi*ID*mu_t_fwh3);
% DB Correlation
Nu_t_fwh3 = 0.023*Re_t_fwh3^0.8 * Pr_t_fwh3^0.4;
h_i_fwh3 = (Nu_t_fwh3 * k_t_fwh3)/ID;    % W/(m^2 C)

% Guess wall and film temperatures (cold side)
T_inner_pipe_surf_fwh3 = (0.25)*(T_hot_in_fwh3-T_cold_in_fwh3) + T_cold_in_fwh3;
T_c_film_fwh3 = (0.25)*(T_hot_in_fwh3-T_inner_pipe_surf_fwh3)/2 + T_inner_pipe_surf_fwh3;
Cp_t_f_fwh3 = interp1(prop_f(:,1),prop_f(:,4),T_cold_in_fwh3);
neu_t_f_fwh3 = interp1(prop_f(:,1),prop_f(:,6),T_cold_in_fwh3);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%     FWH#3 - HOT SIDE     %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Interpolations from the tables above (hot side)
mu_l_fwh3 = (3*interp1(prop_f(:,1),prop_f(:,5),T_inner_pipe_surf_fwh3)+interp1(prop_f(:,1),prop_f(:,5),T_hot_in_fwh3))/4;
k_f_fwh3 = interp1(prop_f(:,1),prop_f(:,7),T_c_film_fwh3);
rho_g_fwh3 = interp1(prop_g(:,1),prop_g(:,3),T_hot_in_fwh3);                    %  rho_g(kg/m^3)
rho_f_fwh3 = interp1(prop_f(:,1),prop_f(:,3),T_c_film_fwh3);
h_f_g_fwh3 = interp1(prop_f(:,1),prop_f(:,9),T_hot_in_fwh3);
h_g_g_fwh3 = interp1(prop_g(:,1),prop_g(:,9),T_hot_in_fwh3);
h_fg_before_fwh3 = h_g_g_fwh3 - h_f_g_fwh3;                                       %  h_fg(J/kg)
h_fg_prime_fwh3 = h_fg_before_fwh3 + 0.68*Cp_t_f_fwh3*(T_hot_in_fwh3-T_inner_pipe_surf_fwh3);     % (Thome - Convective Boiling &
fwh1ensation)
Pr_l_fwh3 = interp1(prop_f(:,1),prop_f(:,8),T_c_film_fwh3);

C_fwh3 = (mu_l_fwh3^(2/3)) / (k_f_fwh3*(rho_f_fwh3*(rho_f_fwh3-rho_g_fwh3)*gravity)^(1/3));
% I need to take the Tube length dependence out of Rec2 equation so that L can be recalculated (manip eqns)
Rec2_fwh3 = 4*(T_hot_in_fwh3-T_inner_pipe_surf_fwh3)*Length_tubes_fwh3 / (mu_l_fwh3*h_fg_prime_fwh3);
h_o_fwh3 = (((Rec2_fwh3/C_fwh3)+253*58*Pr_l_fwh3^(-0.5)-8750)/(Rec2_fwh3^(0.75)*58*Pr_l_fwh3^(-0.5)))^(4/3);

% Calculate the overall H.T. coefficient using (pg. 595 Fund. of Heat & Mass Transfer by Dewitt)
U_fwh3 = 1/((1/h_i_fwh3)+(1/h_o_fwh3));
DTLM_fwh3        =        ((T_hot_in_fwh3-T_cold_out_fwh3)-(T_hot_out_fwh3-T_cold_in_fwh3))        /        (log((T_hot_in_fwh3-
T_cold_out_fwh3)/(T_hot_out_fwh3-T_cold_in_fwh3)));
no_tubes_fwh3 = round(q_fwh3/(U_fwh3*Length_tubes_fwh3*no_passes_fwh3*pi*OD*DTLM_fwh3*F));
OD_fwh3 = (1.7161*(no_tubes_fwh3^0.4986)/12)/3.28;
HT_area_fwh3 = no_tubes_fwh3*no_passes_fwh3*Length_tubes_fwh3*pi*OD;
v_steam_fwh3 = mdot_h_fwh3/(rho_g_fwh3*((pi*(OD_fwh3/2)^2)-(pi*no_tubes_fwh3*no_passes_fwh3*((OD/2)^2))));
```

```
hollow_tube_vol_fwh3 = (pi/4)*Length_tubes_fwh3*((OD^2)-(ID^2))*no_tubes_fwh3*no_passes_fwh3;
tube_w_fwh3 = hollow_tube_vol_fwh3*ss316d*conv_w;
shell_vol_fwh3 = (pi/4)*Length_tubes_fwh3*(((OD_fwh3^2)+shell_thick)-(OD_fwh3^2));
shell_w_fwh3 = shell_vol_fwh3*ss316d*conv_w;
end_caps_vol_fwh3 = 2*(pi/4)*(OD_fwh3^2)*shell_thick;
end_caps_w_fwh3 = end_caps_vol_fwh3*ss316d*conv_w;
total_w_fwh3 = tube_w_fwh3+shell_w_fwh3+end_caps_w_fwh3;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                Feed Water Heater #4                                          %
% 20BWG 1" Diameter tubes -  vertical FWH's - max length 12 meters - calcs req. # of tubes   %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Properties for fwh#4 taken from ORCENT2 output
q_fwh4 = conv_q*(t7_fwh_mdot(4)*(t7_fwh_h_out(4)-t7_fwh_h_in(4)));  % Watts
T_hot_in_fwh4 = (5/9)*(t7_shell_t(4)-32);                           % C
T_hot_out_fwh4 = (5/9)*(t7_shell_drn_t(4)-32);                      % C
T_cold_in_fwh4 = (5/9)*(t7_fwh_t_in(4)-32);                         % C
T_cold_out_fwh4 = (5/9)*(t7_fwh_t_out(4)-32);                       % C
press_fwh4 = t7_shell_p(4)*conv_p;                                  % bars
mdot_h_fwh4 = t7_shell_drn_mdot(4)*conv_mdot;                       % kg/s
mdot_c_fwh4 = t7_fwh_mdot(4)*conv_mdot;                             % kg/s

% fwh#1 Properties
Length_tubes_fwh4_init = 10.00;    % m
no_passes_fwh4 = 2;
v_water_fwh4 = 2.1336;             % Mark's Standard Handbook for Mech. Eng. (8th ed) suggests this velocity (m/s) = 7 ft/s

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%     FWH#4 - COLD SIDE     %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Begin thermal expansion calculations for SS316 - expansion coefficients from
% www.aksteel.com
delta_T_fwh4 = T_hot_in_fwh4 - T_start;
if delta_T_fwh4 < 871
    C1_fwh4 = 19.9E-6;
    if delta_T_fwh4 < 649
        C1_fwh4 = 18.5E-6;
        if delta_T_fwh4 < 538
            C1_fwh4 = 17.5E-6;
            if delta_T_fwh4 < 315
                C1_fwh4 = 16.2E-6;
                if delta_T_fwh4 < 100
                    C1_fwh4 = 16.0E-6;
                end
            end
        end
    end
end
delta_Length_fwh4 = Length_tubes_fwh4_init*C1_fwh4*delta_T_fwh4;
```

```
Length_tubes_fwh4 = Length_tubes_fwh4_init+delta_Length_fwh4;

% Interpolations from the tables at the top (cold side)
rho_t_fwh4 = interp1(prop_f(:,1),prop_f(:,3),T_cold_in_fwh4);
Cp_t_fwh4 = interp1(prop_f(:,1),prop_f(:,4),T_cold_in_fwh4);
mu_t_fwh4 = interp1(prop_f(:,1),prop_f(:,5),T_cold_in_fwh4);
k_t_fwh4 = interp1(prop_f(:,1),prop_f(:,7),T_cold_in_fwh4);
Pr_t_fwh4 = interp1(prop_f(:,1),prop_f(:,8),T_cold_in_fwh4);

mdot_c_fwh4 = rho_t_fwh4 * v_water_fwh4 * pi * (ID/2)^2;
mdot_c_total_fwh4 = q_fwh4/(Cp_t_fwh4*(T_cold_out_fwh4 - T_cold_in_fwh4));
Re_t_fwh4 = (4*mdot_c_fwh4)/(pi*ID*mu_t_fwh4);
% DB Correlation
Nu_t_fwh4 = 0.023*Re_t_fwh4^0.8 * Pr_t_fwh4^0.4;
h_i_fwh4 = (Nu_t_fwh4 * k_t_fwh4)/ID;    % W/(m^2 C)

% Guess wall and film temperatures (cold side)
T_inner_pipe_surf_fwh4 = (0.25)*(T_hot_in_fwh4-T_cold_in_fwh4) + T_cold_in_fwh4;
T_c_film_fwh4 = (0.25)*(T_hot_in_fwh4-T_inner_pipe_surf_fwh4)/2 + T_inner_pipe_surf_fwh4;
Cp_t_f_fwh4 = interp1(prop_f(:,1),prop_f(:,4),T_cold_in_fwh4);
neu_t_f_fwh4 = interp1(prop_f(:,1),prop_f(:,6),T_cold_in_fwh4);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%      FWH#4 - HOT SIDE     %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Interpolations from the tables above (hot side)
mu_l_fwh4 = (3*interp1(prop_f(:,1),prop_f(:,5),T_inner_pipe_surf_fwh4)+interp1(prop_f(:,1),prop_f(:,5),T_hot_in_fwh4))/4;
k_f_fwh4 = interp1(prop_f(:,1),prop_f(:,7),T_c_film_fwh4);
rho_g_fwh4 = interp1(prop_g(:,1),prop_g(:,3),T_hot_in_fwh4);                          %  rho_g(kg/m^3)
rho_f_fwh4 = interp1(prop_f(:,1),prop_f(:,3),T_c_film_fwh4);
h_f_g_fwh4 = interp1(prop_f(:,1),prop_f(:,9),T_hot_in_fwh4);
h_g_g_fwh4 = interp1(prop_g(:,1),prop_g(:,9),T_hot_in_fwh4);
h_fg_before_fwh4 = h_g_g_fwh4 - h_f_g_fwh4;                                             %  h_fg(J/kg)
h_fg_prime_fwh4 = h_fg_before_fwh4 + 0.68*Cp_t_f_fwh4*(T_hot_in_fwh4-T_inner_pipe_surf_fwh4);     % (Thome - Convective Boiling & fwh1ensation)
Pr_l_fwh4 = interp1(prop_f(:,1),prop_f(:,8),T_c_film_fwh4);

C_fwh4 = (mu_l_fwh4^(2/3)) / (k_f_fwh4*(rho_f_fwh4*(rho_f_fwh4-rho_g_fwh4)*gravity)^(1/3));
% I need to take the Tube length dependence out of Rec2 equation so that L can be recalculated (manip eqns)
Rec2_fwh4 = 4*(T_hot_in_fwh4-T_inner_pipe_surf_fwh4)*Length_tubes_fwh4 / (mu_l_fwh4*h_fg_prime_fwh4);
h_o_fwh4 = (((Rec2_fwh4/C_fwh4)+253*58*Pr_l_fwh4^(-0.5)-8750)/(Rec2_fwh4^(0.75)*58*Pr_l_fwh4^(-0.5)))^(4/3);

% Calculate the overall H.T. coefficient using (pg. 595 Fund. of Heat & Mass Transfer by Dewitt)
U_fwh4 = 1/((1/h_i_fwh4)+(1/h_o_fwh4));
DTLM_fwh4       =       ((T_hot_in_fwh4-T_cold_out_fwh4)-(T_hot_out_fwh4-T_cold_in_fwh4))       /       (log((T_hot_in_fwh4-T_cold_out_fwh4)/(T_hot_out_fwh4-T_cold_in_fwh4)));
no_tubes_fwh4 = round(q_fwh4/(U_fwh4*Length_tubes_fwh4*no_passes_fwh4*pi*OD*DTLM_fwh4*F));
OD_fwh4 = (1.7161*(no_tubes_fwh4^0.4986)/12)/3.28;
HT_area_fwh4 = no_tubes_fwh4*no_passes_fwh4*Length_tubes_fwh4*pi*OD;
```

```
v_steam_fwh4 = mdot_h_fwh4/(rho_g_fwh4*((pi*(OD_fwh4/2)^2)-(pi*no_tubes_fwh4*no_passes_fwh4*((OD/2)^2))));

hollow_tube_vol_fwh4 = (pi/4)*Length_tubes_fwh4*((OD^2)-(ID^2))*no_tubes_fwh4*no_passes_fwh4;
tube_w_fwh4 = hollow_tube_vol_fwh4*ss316d*conv_w;
shell_vol_fwh4 = (pi/4)*Length_tubes_fwh4*(((OD_fwh4^2)+shell_thick)-(OD_fwh4^2));
shell_w_fwh4 = shell_vol_fwh4*ss316d*conv_w;
end_caps_vol_fwh4 = 2*(pi/4)*(OD_fwh4^2)*shell_thick;
end_caps_w_fwh4 = end_caps_vol_fwh4*ss316d*conv_w;
total_w_fwh4 = tube_w_fwh4+shell_w_fwh4+end_caps_w_fwh4;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                Feed Water Heater #5                                         %
% 20BWG 1" Diameter tubes -  vertical FWH's - max length 12 meters - calcs req. # of tubes    %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Properties for fwh#5 taken from ORCENT2 output
q_fwh5 = conv_q*(t7_fwh_mdot(5)*(t7_fwh_h_out(5)-t7_fwh_h_in(5)));  % Watts
T_hot_in_fwh5 = (5/9)*(t7_shell_t(5)-32);                           % C
T_hot_out_fwh5 = (5/9)*(t7_shell_drn_t(5)-32);                      % C
T_cold_in_fwh5 = (5/9)*(t7_fwh_t_in(5)-32);                         % C
T_cold_out_fwh5 = (5/9)*(t7_fwh_t_out(5)-32);                       % C
press_fwh5 = t7_shell_p(5)*conv_p;                                  % bars
mdot_h_fwh5 = t7_shell_drn_mdot(5)*conv_mdot;                       % kg/s
mdot_c_fwh5 = t7_fwh_mdot(5)*conv_mdot;                             % kg/s

% fwh#1 Properties
Length_tubes_fwh5_init = 10.00;    % m
no_passes_fwh5 = 2;
v_water_fwh5 = 2.1336;             % Mark's Standard Handbook for Mech. Eng. (8th ed) suggests this velocity (m/s) = 7 ft/s

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%     FWH#5 - COLD SIDE     %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Begin thermal expansion calculations for SS316 - expansion coefficients from
% www.aksteel.com
delta_T_fwh5 = T_hot_in_fwh5 - T_start;
if delta_T_fwh5 < 871
    C1_fwh5 = 19.9E-6;
    if delta_T_fwh5 < 649
        C1_fwh5 = 18.5E-6;
        if delta_T_fwh5 < 538
            C1_fwh5 = 17.5E-6;
            if delta_T_fwh5 < 315
                C1_fwh5 = 16.2E-6;
                if delta_T_fwh5 < 100
                    C1_fwh5 = 16.0E-6;
                end
            end
        end
    end
```

```
end
delta_Length_fwh5 = Length_tubes_fwh5_init*C1_fwh5*delta_T_fwh5;
Length_tubes_fwh5 = Length_tubes_fwh5_init+delta_Length_fwh5;

% Interpolations from the tables at the top (cold side)
rho_t_fwh5 = interp1(prop_f(:,1),prop_f(:,3),T_cold_in_fwh5);
Cp_t_fwh5 = interp1(prop_f(:,1),prop_f(:,4),T_cold_in_fwh5);
mu_t_fwh5 = interp1(prop_f(:,1),prop_f(:,5),T_cold_in_fwh5);
k_t_fwh5 = interp1(prop_f(:,1),prop_f(:,7),T_cold_in_fwh5);
Pr_t_fwh5 = interp1(prop_f(:,1),prop_f(:,8),T_cold_in_fwh5);

mdot_c_fwh5 = rho_t_fwh5 * v_water_fwh5 * pi * (ID/2)^2;
mdot_c_total_fwh5 = q_fwh5/(Cp_t_fwh5*(T_cold_out_fwh5 - T_cold_in_fwh5));
Re_t_fwh5 = (4*mdot_c_fwh5)/(pi*ID*mu_t_fwh5);
% DB Correlation
Nu_t_fwh5 = 0.023*Re_t_fwh5^0.8 * Pr_t_fwh5^0.4;
h_i_fwh5 = (Nu_t_fwh5 * k_t_fwh5)/ID;    % W/(m^2 C)

% Guess wall and film temperatures (cold side)
T_inner_pipe_surf_fwh5 = (0.25)*(T_hot_in_fwh5-T_cold_in_fwh5) + T_cold_in_fwh5;
T_c_film_fwh5 = (0.25)*(T_hot_in_fwh5-T_inner_pipe_surf_fwh5)/2 + T_inner_pipe_surf_fwh5;
Cp_t_f_fwh5 = interp1(prop_f(:,1),prop_f(:,4),T_cold_in_fwh5);
neu_t_f_fwh5 = interp1(prop_f(:,1),prop_f(:,6),T_cold_in_fwh5);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%      FWH#5 - HOT SIDE     %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Interpolations from the tables above (hot side)
mu_l_fwh5 = (3*interp1(prop_f(:,1),prop_f(:,5),T_inner_pipe_surf_fwh5)+interp1(prop_f(:,1),prop_f(:,5),T_hot_in_fwh5))/4;
k_f_fwh5 = interp1(prop_f(:,1),prop_f(:,7),T_c_film_fwh5);
rho_g_fwh5 = interp1(prop_g(:,1),prop_g(:,3),T_hot_in_fwh5);                    %  rho_g(kg/m^3)
rho_f_fwh5 = interp1(prop_f(:,1),prop_f(:,3),T_c_film_fwh5);
h_f_g_fwh5 = interp1(prop_f(:,1),prop_f(:,9),T_hot_in_fwh5);
h_g_g_fwh5 = interp1(prop_g(:,1),prop_g(:,9),T_hot_in_fwh5);
h_fg_before_fwh5 = h_g_g_fwh5 - h_f_g_fwh5;                                     %  h_fg(J/kg)
h_fg_prime_fwh5 = h_fg_before_fwh5 + 0.68*Cp_t_f_fwh5*(T_hot_in_fwh5-T_inner_pipe_surf_fwh5);     % (Thome - Convective Boiling &
fwh1ensation)
Pr_l_fwh5 = interp1(prop_f(:,1),prop_f(:,8),T_c_film_fwh5);

C_fwh5 = (mu_l_fwh5^(2/3)) / (k_f_fwh5*(rho_f_fwh5*(rho_f_fwh5-rho_g_fwh5)*gravity)^(1/3));
% I need to take the Tube length dependence out of Rec2 equation so that L can be recalculated (manip eqns)
Rec2_fwh5 = 4*(T_hot_in_fwh5-T_inner_pipe_surf_fwh5)*Length_tubes_fwh5 / (mu_l_fwh5*h_fg_prime_fwh5);
h_o_fwh5 = (((Rec2_fwh5/C_fwh5)+253*58*Pr_l_fwh5^(-0.5)-8750)/(Rec2_fwh5^(0.75)*58*Pr_l_fwh5^(-0.5)))^(4/3);

% Calculate the overall H.T. coefficient using (pg. 595 Fund. of Heat & Mass Transfer by Dewitt)
U_fwh5 = 1/((1/h_i_fwh5)+(1/h_o_fwh5));
DTLM_fwh5        =        ((T_hot_in_fwh5-T_cold_out_fwh5)-(T_hot_out_fwh5-T_cold_in_fwh5))        /        (log((T_hot_in_fwh5-
T_cold_out_fwh5)/(T_hot_out_fwh5-T_cold_in_fwh5)));
no_tubes_fwh5 = round(q_fwh5/(U_fwh5*Length_tubes_fwh5*no_passes_fwh5*pi*OD*DTLM_fwh5*F));
```

```
OD_fwh5 = (1.7161*(no_tubes_fwh5^0.4986)/12)/3.28;
HT_area_fwh5 = no_tubes_fwh5*no_passes_fwh5*Length_tubes_fwh5*pi*OD;
v_steam_fwh5 = mdot_h_fwh5/(rho_g_fwh5*((pi*(OD_fwh5/2)^2)-(pi*no_tubes_fwh5*no_passes_fwh5*((OD/2)^2))));

hollow_tube_vol_fwh5 = (pi/4)*Length_tubes_fwh5*((OD^2)-(ID^2))*no_tubes_fwh5*no_passes_fwh5;
tube_w_fwh5 = hollow_tube_vol_fwh5*ss316d*conv_w;
shell_vol_fwh5 = (pi/4)*Length_tubes_fwh5*(((OD_fwh5^2)+shell_thick)-(OD_fwh5^2));
shell_w_fwh5 = shell_vol_fwh5*ss316d*conv_w;
end_caps_vol_fwh5 = 2*(pi/4)*(OD_fwh5^2)*shell_thick;
end_caps_w_fwh5 = end_caps_vol_fwh5*ss316d*conv_w;
total_w_fwh5 = tube_w_fwh5+shell_w_fwh5+end_caps_w_fwh5;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                              Feed Water Heater #6                                         %
% 20BWG 1" Diameter tubes -  vertical FWH's - max length 12 meters - calcs req. # of tubes   %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Properties for fwh#6 taken from ORCENT2 output
q_fwh6 = conv_q*(t7_fwh_mdot(6)*(t7_fwh_h_out(6)-t7_fwh_h_in(6)));  % Watts
T_hot_in_fwh6 = (5/9)*(t7_shell_t(6)-32);                           % C
T_hot_out_fwh6 = (5/9)*(t7_shell_drn_t(6)-32);                      % C
T_cold_in_fwh6 = (5/9)*(t7_fwh_t_in(6)-32);                         % C
T_cold_out_fwh6 = (5/9)*(t7_fwh_t_out(6)-32);                       % C
press_fwh6 = t7_shell_p(6)*conv_p;                                  % bars
mdot_h_fwh6 = t7_shell_drn_mdot(6)*conv_mdot;                       % kg/s
mdot_c_fwh6 = t7_fwh_mdot(6)*conv_mdot;                             % kg/s

% fwh#1 Properties
Length_tubes_fwh6_init = 6.00;     % m
no_passes_fwh6 = 2;
v_water_fwh6 = 2.1336;             % Mark's Standard Handbook for Mech. Eng. (8th ed) suggests this velocity (m/s) = 7 ft/s

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%     FWH#6 - COLD SIDE     %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Begin thermal expansion calculations for SS316 - expansion coefficients from
% www.aksteel.com
delta_T_fwh6 = T_hot_in_fwh6 - T_start;
if delta_T_fwh6 < 871
    C1_fwh6 = 19.9E-6;
    if delta_T_fwh6 < 649
        C1_fwh6 = 18.5E-6;
        if delta_T_fwh6 < 538
            C1_fwh6 = 17.5E-6;
            if delta_T_fwh6 < 315
                C1_fwh6 = 16.2E-6;
                if delta_T_fwh6 < 100
                    C1_fwh6 = 16.0E-6;
                end
            end
```

```
        end
    end
end
delta_Length_fwh6 = Length_tubes_fwh6_init*C1_fwh6*delta_T_fwh6;
Length_tubes_fwh6 = Length_tubes_fwh6_init+delta_Length_fwh6;

% Interpolations from the tables at the top (cold side)
rho_t_fwh6 = interp1(prop_f(:,1),prop_f(:,3),T_cold_in_fwh6);
Cp_t_fwh6 = interp1(prop_f(:,1),prop_f(:,4),T_cold_in_fwh6);
mu_t_fwh6 = interp1(prop_f(:,1),prop_f(:,5),T_cold_in_fwh6);
k_t_fwh6 = interp1(prop_f(:,1),prop_f(:,7),T_cold_in_fwh6);
Pr_t_fwh6 = interp1(prop_f(:,1),prop_f(:,8),T_cold_in_fwh6);

mdot_c_fwh6 = rho_t_fwh6 * v_water_fwh6 * pi * (ID/2)^2;
mdot_c_total_fwh6 = q_fwh6/(Cp_t_fwh6*(T_cold_out_fwh6 - T_cold_in_fwh6));
Re_t_fwh6 = (4*mdot_c_fwh6)/(pi*ID*mu_t_fwh6);
% DB Correlation
Nu_t_fwh6 = 0.023*Re_t_fwh6^0.8 * Pr_t_fwh6^0.4;
h_i_fwh6 = (Nu_t_fwh6 * k_t_fwh6)/ID;    % W/(m^2 C)

% Guess wall and film temperatures (cold side)
T_inner_pipe_surf_fwh6 = (0.25)*(T_hot_in_fwh6-T_cold_in_fwh6) + T_cold_in_fwh6;
T_c_film_fwh6 = (0.25)*(T_hot_in_fwh6-T_inner_pipe_surf_fwh6)/2 + T_inner_pipe_surf_fwh6;
Cp_t_f_fwh6 = interp1(prop_f(:,1),prop_f(:,4),T_cold_in_fwh6);
neu_t_f_fwh6 = interp1(prop_f(:,1),prop_f(:,6),T_cold_in_fwh6);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%      FWH#6 - HOT SIDE     %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Interpolations from the tables above (hot side)
mu_l_fwh6 = (3*interp1(prop_f(:,1),prop_f(:,5),T_inner_pipe_surf_fwh6)+interp1(prop_f(:,1),prop_f(:,5),T_hot_in_fwh6))/4;
k_f_fwh6 = interp1(prop_f(:,1),prop_f(:,7),T_c_film_fwh6);
rho_g_fwh6 = interp1(prop_g(:,1),prop_g(:,3),T_hot_in_fwh6);                         %  rho_g(kg/m^3)
rho_f_fwh6 = interp1(prop_f(:,1),prop_f(:,3),T_c_film_fwh6);
h_f_g_fwh6 = interp1(prop_f(:,1),prop_f(:,9),T_hot_in_fwh6);
h_g_g_fwh6 = interp1(prop_g(:,1),prop_g(:,9),T_hot_in_fwh6);
h_fg_before_fwh6 = h_g_g_fwh6 - h_f_g_fwh6;                                            %  h_fg(J/kg)
h_fg_prime_fwh6 = h_fg_before_fwh6 + 0.68*Cp_t_f_fwh6*(T_hot_in_fwh6-T_inner_pipe_surf_fwh6);     % (Thome - Convective Boiling &
fwh1ensation)
Pr_l_fwh6 = interp1(prop_f(:,1),prop_f(:,8),T_c_film_fwh6);

C_fwh6 = (mu_l_fwh6^(2/3)) / (k_f_fwh6*(rho_f_fwh6*(rho_f_fwh6-rho_g_fwh6)*gravity)^(1/3));
% I need to take the Tube length dependence out of Rec2 equation so that L can be recalculated (manip eqns)
Rec2_fwh6 = 4*(T_hot_in_fwh6-T_inner_pipe_surf_fwh6)*Length_tubes_fwh6 / (mu_l_fwh6*h_fg_prime_fwh6);
h_o_fwh6 = (((Rec2_fwh6/C_fwh6)+253*58*Pr_l_fwh6^(-0.5)-8750)/(Rec2_fwh6^(0.75)*58*Pr_l_fwh6^(-0.5)))^(4/3);

% Calculate the overall H.T. coefficient using (pg. 595 Fund. of Heat & Mass Transfer by Dewitt)
U_fwh6 = 1/((1/h_i_fwh6)+(1/h_o_fwh6));
```

```
DTLM_fwh6          =          ((T_hot_in_fwh6-T_cold_out_fwh6)-(T_hot_out_fwh6-T_cold_in_fwh6))          /          (log((T_hot_in_fwh6-
T_cold_out_fwh6)/(T_hot_out_fwh6-T_cold_in_fwh6)));
no_tubes_fwh6 = round(q_fwh6/(U_fwh6*Length_tubes_fwh6*no_passes_fwh6*pi*OD*DTLM_fwh6*F));
OD_fwh6 = (1.7161*(no_tubes_fwh6^0.4986)/12)/3.28;
HT_area_fwh6 = no_tubes_fwh6*no_passes_fwh6*Length_tubes_fwh6*pi*OD;
v_steam_fwh6 = mdot_h_fwh6/(rho_g_fwh6*((pi*(OD_fwh6/2)^2)-(pi*no_tubes_fwh6*no_passes_fwh6*((OD/2)^2))));

hollow_tube_vol_fwh6 = (pi/4)*Length_tubes_fwh6*((OD^2)-(ID^2))*no_tubes_fwh6*no_passes_fwh6;
tube_w_fwh6 = hollow_tube_vol_fwh6*ss316d*conv_w;
shell_vol_fwh6 = (pi/4)*Length_tubes_fwh6*(((OD_fwh6^2)+shell_thick)-(OD_fwh6^2));
shell_w_fwh6 = shell_vol_fwh6*ss316d*conv_w;
end_caps_vol_fwh6 = 2*(pi/4)*(OD_fwh6^2)*shell_thick;
end_caps_w_fwh6 = end_caps_vol_fwh6*ss316d*conv_w;
total_w_fwh6 = tube_w_fwh6+shell_w_fwh6+end_caps_w_fwh6;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                    Reheater #1                                              %
%             20BWG 1" Diameter tubes - Horizontal Configuration - Calculate Tube Length      %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% RH#1 Properties
no_tubes_rh1 = 600;
no_passes_rh1 = 2;

% Properties for RH#1 taken from ORCENT2 output
q_rh1 = conv_q*(t2_first_stg_rh_in(1)*(t2_first_stg_rh_out(4)-t2_first_stg_rh_in(3)));  % Watts
T_hot_in_rh1 = (5/9)*(t2_turb_throttle(3)-32);                    % C
T_hot_out_rh1 = (5/9)*(t5_first_stg_stm_t-32);                    % C
T_cold_in_rh1 = (5/9)*(t2_first_stg_rh_in_temp(3)-32);            % C
T_cold_out_rh1 = (5/9)*(t2_first_stg_rh_out(3)-32);               % C
press_rh1 = t5_first_stg_stm_p*conv_p;                            % bars
mdot_h_rh1 = t5_first_stg_stm_mdot*conv_mdot;                     % kg/s
mdot_c_rh1 = (t2_first_stg_rh_in(1)*conv_mdot)/no_tubes_rh1;     % kg/s

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%   RH#1 - COLD SIDE   %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Interpolations from the tables at the top (cold side)
rho_t_rh1 = interp1(prop_f(:,1),prop_f(:,3),T_cold_in_rh1);
Cp_t_rh1 = interp1(prop_f(:,1),prop_f(:,4),T_cold_in_rh1);
mu_t_rh1 = interp1(prop_f(:,1),prop_f(:,5),T_cold_in_rh1);
k_t_rh1 = interp1(prop_f(:,1),prop_f(:,7),T_cold_in_rh1);
Pr_t_rh1 = interp1(prop_f(:,1),prop_f(:,8),T_cold_in_rh1);

Re_t_rh1 = (4*mdot_c_rh1)/(pi*ID*mu_t_rh1);
% DB Correlation
Nu_t_rh1 = 0.023*Re_t_rh1^0.8 * Pr_t_rh1^0.4;
h_i_rh1 = (Nu_t_rh1 * k_t_rh1)/ID;    % W/(m^2 C)

% Guess wall and film temperatures (cold side)
```

```
T_inner_pipe_surf_rh1 = (0.25)*(T_hot_in_rh1-T_cold_in_rh1) + T_cold_in_rh1;
T_c_film_rh1 = (0.25)*(T_hot_in_rh1-T_inner_pipe_surf_rh1)/2 + T_inner_pipe_surf_rh1;
Cp_t_f_rh1 = interp1(prop_f(:,1),prop_f(:,4),T_cold_in_rh1);
neu_t_f_rh1 = interp1(prop_f(:,1),prop_f(:,6),T_cold_in_rh1);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%   RH#1 - HOT SIDE   %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Interpolations from the tables above (hot side)
mu_l_rh1 = (3*interp1(prop_f(:,1),prop_f(:,5),T_inner_pipe_surf_rh1)+interp1(prop_f(:,1),prop_f(:,5),T_hot_in_rh1))/4;
k_f_rh1 = interp1(prop_f(:,1),prop_f(:,7),T_c_film_rh1);
rho_g_rh1 = interp1(prop_g(:,1),prop_g(:,3),T_hot_in_rh1);                     %  rho_g(kg/m^3)
rho_f_rh1 = interp1(prop_f(:,1),prop_f(:,3),T_c_film_rh1);
h_f_g_rh1 = interp1(prop_f(:,1),prop_f(:,9),T_hot_in_rh1);
h_g_g_rh1 = interp1(prop_g(:,1),prop_g(:,9),T_hot_in_rh1);
h_fg_before_rh1 = h_g_g_rh1 - h_f_g_rh1;                                       %  h_fg(J/kg)
h_fg_prime_rh1  =  h_fg_before_rh1  +  0.68*Cp_t_f_rh1*(T_hot_in_rh1-T_inner_pipe_surf_rh1);      %  (Thome  -  Convective  Boiling  &
rh1ensation)

OD_rh1 = (1.7161*(no_tubes_rh1^0.4986)/12)/3.28;
v_steam_rh1 = mdot_h_rh1/(rho_g_rh1*((pi*(OD_rh1/2)^2)-(pi*no_tubes_rh1*no_passes_rh1*((OD/2)^2))));
v_cold_rh1 = mdot_c_rh1/(rho_g_rh1*pi*((ID/2)^2));
% The h_o equation come from Fund. of Heat & Mass Transfer (Dewitt) pg 565, Eqn 10.40 and 10.41
h_o_bar_tube_rh1   =   0.729*(((gravity*rho_f_rh1*(rho_f_rh1-rho_g_rh1)*(k_f_rh1^3)*h_fg_prime_rh1)   /   (mu_l_rh1*(T_hot_in_rh1-
T_inner_pipe_surf_rh1)*OD))^0.25);
% The h_o_total equation comes from Buttweworth - Hemisphere Handbook of Heat Exchanger Design
h_o_bar_total_rh1 = h_o_bar_tube_rh1*(no_tubes_rh1^(-1/6));

% Calculate the overall H.T. coefficient using (pg. 595 Fund. of Heat & Mass Transfer by Dewitt)
U_rh1 = 1/((1/h_i_rh1)+(1/h_o_bar_total_rh1));
DTLM_rh1  =  ((T_hot_in_rh1-T_cold_out_rh1)-(T_hot_out_rh1-T_cold_in_rh1))  /  (log((T_hot_in_rh1-T_cold_out_rh1)/(T_hot_out_rh1-
T_cold_in_rh1)));
% Begin thermal expansion calculations for SS316 - expansion coefficients from
% www.aksteel.com
delta_T_rh1 = T_hot_in_rh1 - T_start;
if delta_T_rh1 < 871
    C_rh1 = 19.9E-6;
    if delta_T_rh1 < 649
        C_rh1 = 18.5E-6;
        if delta_T_rh1 < 538
            C_rh1 = 17.5E-6;
            if delta_T_rh1 < 315
                C_rh1 = 16.2E-6;
                if delta_T_rh1 < 100
                    C_rh1 = 16.0E-6;
                end
            end
        end
    end
```

```
end
Length_tubes_rh1_init = q_rh1/(U_rh1*no_tubes_rh1*no_passes_rh1*pi*OD*DTLM_rh1*F);
delta_Length_rh1 = Length_tubes_rh1_init*C_rh1*delta_T_rh1;
Length_tubes_rh1 = Length_tubes_rh1_init+delta_Length_rh1;
HT_area_rh1 = no_tubes_rh1*no_passes_rh1*Length_tubes_rh1*pi*OD;

hollow_tube_vol_rh1 = (pi/4)*Length_tubes_rh1*((OD^2)-(ID^2))*no_tubes_rh1*no_passes_rh1;
tube_w_rh1 = hollow_tube_vol_rh1*ss316d*conv_w;
shell_vol_rh1 = (pi/4)*Length_tubes_rh1*(((OD_rh1^2)+shell_thick)-(OD_rh1^2));
shell_w_rh1 = shell_vol_rh1*ss316d*conv_w;
end_caps_vol_rh1 = 2*(pi/4)*(OD_rh1^2)*shell_thick;
end_caps_w_rh1 = end_caps_vol_rh1*ss316d*conv_w;
total_w_rh1 = tube_w_rh1+shell_w_rh1+end_caps_w_rh1;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                    Reheater #2                                               %
%            20BWG 1" Diameter tubes - Horizontal Configuration - Calculate Tube Length       %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% RH#2 Properties
no_tubes_rh2 = 1000;
no_passes_rh2 = 2;

% Properties for RH#2 taken from ORCENT2 output
q_rh2 = conv_q*(t2_scnd_stg_rh_in(1)*(t2_scnd_stg_rh_out(4)-t2_scnd_stg_rh_in(3)));  % Watts
T_hot_in_rh2 = (5/9)*(t2_turb_throttle(3)-32);                 % C
T_hot_out_rh2 = (5/9)*(t5_scnd_stg_stm_t-32);                  % C
T_cold_in_rh2 = (5/9)*(t2_first_stg_rh_out(3)-32);             % C
T_cold_out_rh2 = (5/9)*(t2_scnd_stg_rh_out(3)-32);             % C
press_rh2 = t5_scnd_stg_stm_p*conv_p;                          % bars
mdot_h_rh2 = t5_scnd_stg_stm_mdot*conv_mdot;                   % kg/s
mdot_c_rh2 = (t2_scnd_stg_rh_in(1)*conv_mdot)/no_tubes_rh2;    % kg/s

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%   RH#2 - COLD SIDE   %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Interpolations from the tables at the top (cold side)
rho_t_rh2 = interp1(prop_f(:,1),prop_f(:,3),T_cold_in_rh2);
Cp_t_rh2 = interp1(prop_f(:,1),prop_f(:,4),T_cold_in_rh2);
mu_t_rh2 = interp1(prop_f(:,1),prop_f(:,5),T_cold_in_rh2);
k_t_rh2 = interp1(prop_f(:,1),prop_f(:,7),T_cold_in_rh2);
Pr_t_rh2 = interp1(prop_f(:,1),prop_f(:,8),T_cold_in_rh2);

Re_t_rh2 = (4*mdot_c_rh2)/(pi*ID*mu_t_rh2);
% DB Correlation
Nu_t_rh2 = 0.023*Re_t_rh2^0.8 * Pr_t_rh2^0.4;
h_i_rh2 = (Nu_t_rh2 * k_t_rh2)/ID;    % W/(m^2 C)

% Guess wall and film temperatures (cold side)
T_inner_pipe_surf_rh2 = (0.25)*(T_hot_in_rh2-T_cold_in_rh2) + T_cold_in_rh2;
```

```
T_c_film_rh2 = (0.25)*(T_hot_in_rh2-T_inner_pipe_surf_rh2)/2 + T_inner_pipe_surf_rh2;
Cp_t_f_rh2 = interp1(prop_f(:,1),prop_f(:,4),T_cold_in_rh2);
neu_t_f_rh2 = interp1(prop_f(:,1),prop_f(:,6),T_cold_in_rh2);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%   RH#2 - HOT SIDE   %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Interpolations from the tables above (hot side)
mu_l_rh2 = (3*interp1(prop_f(:,1),prop_f(:,5),T_inner_pipe_surf_rh2)+interp1(prop_f(:,1),prop_f(:,5),T_hot_in_rh2))/4;
k_f_rh2 = interp1(prop_f(:,1),prop_f(:,7),T_c_film_rh2);
rho_g_rh2 = interp1(prop_g(:,1),prop_g(:,3),T_hot_in_rh2);                    % rho_g(kg/m^3)
rho_f_rh2 = interp1(prop_f(:,1),prop_f(:,3),T_c_film_rh2);
h_f_g_rh2 = interp1(prop_f(:,1),prop_f(:,9),T_hot_in_rh2);
h_g_g_rh2 = interp1(prop_g(:,1),prop_g(:,9),T_hot_in_rh2);
h_fg_before_rh2 = h_g_g_rh2 - h_f_g_rh2;                                       % h_fg(J/kg)
h_fg_prime_rh2  =  h_fg_before_rh2  +  0.68*Cp_t_f_rh2*(T_hot_in_rh2-T_inner_pipe_surf_rh2);      %  (Thome  -  Convective  Boiling  &
rh2ensation)

OD_rh2 = (1.7161*(no_tubes_rh2^0.4986)/12)/3.28;
v_steam_rh2 = mdot_h_rh2/(rho_g_rh2*((pi*(OD_rh2/2)^2)-(pi*no_tubes_rh2*no_passes_rh2*((OD/2)^2))));
v_cold_rh2 = mdot_c_rh2/(rho_g_rh2*pi*((ID/2)^2));
% The h_o equation come from Fund. of Heat & Mass Transfer (Dewitt) pg 565, Eqn 10.40 and 10.41
h_o_bar_tube_rh2   =   0.729*(((gravity*rho_f_rh2*(rho_f_rh2-rho_g_rh2)*(k_f_rh2^3)*h_fg_prime_rh2)   /   (mu_l_rh2*(T_hot_in_rh2-
T_inner_pipe_surf_rh2)*OD))^0.25);
% The h_o_total equation comes from Buttweworth - Hemisphere Handbook of Heat Exchanger Design
h_o_bar_total_rh2 = h_o_bar_tube_rh2*(no_tubes_rh2^(-1/6));

% Calculate the overall H.T. coefficient using (pg. 595 Fund. of Heat & Mass Transfer by Dewitt)
U_rh2 = 1/((1/h_i_rh2)+(1/h_o_bar_total_rh2));
DTLM_rh2  =  ((T_hot_in_rh2-T_cold_out_rh2)-(T_hot_out_rh2-T_cold_in_rh2))  /  (log((T_hot_in_rh2-T_cold_out_rh2)/(T_hot_out_rh2-
T_cold_in_rh2)));
% Begin thermal expansion calculations for SS316 - expansion coefficients from
% www.aksteel.com
delta_T_rh2 = T_hot_in_rh2 - T_start;
if delta_T_rh2 < 871
    C_rh2 = 19.9E-6;
    if delta_T_rh2 < 649
        C_rh2 = 18.5E-6;
        if delta_T_rh2 < 538
            C_rh2 = 17.5E-6;
            if delta_T_rh2 < 315
                C_rh2 = 16.2E-6;
                if delta_T_rh2 < 100
                    C_rh2 = 16.0E-6;
                end
            end
        end
    end
end
```

```
Length_tubes_rh2_init = q_rh2/(U_rh2*no_tubes_rh2*no_passes_rh2*pi*OD*DTLM_rh2*F);
delta_Length_rh2 = Length_tubes_rh2_init*C_rh2*delta_T_rh2;
Length_tubes_rh2 = Length_tubes_rh2_init+delta_Length_rh2;
HT_area_rh2 = no_tubes_rh2*no_passes_rh2*Length_tubes_rh2*pi*OD;

hollow_tube_vol_rh2 = (pi/4)*Length_tubes_rh2*((OD^2)-(ID^2))*no_tubes_rh2*no_passes_rh2;
tube_w_rh2 = hollow_tube_vol_rh2*ss316d*conv_w;
shell_vol_rh2 = (pi/4)*Length_tubes_rh2*(((OD_rh2^2)+shell_thick)-(OD_rh2^2));
shell_w_rh2 = shell_vol_rh2*ss316d*conv_w;
end_caps_vol_rh2 = 2*(pi/4)*(OD_rh2^2)*shell_thick;
end_caps_w_rh2 = end_caps_vol_rh2*ss316d*conv_w;
total_w_rh2 = tube_w_rh2+shell_w_rh2+end_caps_w_rh2;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%                                    Print Out Results                                        %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fprintf(' \n\n  TABLE SHOWING SYSTEM PARAMETERS AND RESULTS OF CALCULATIONS');
fprintf('\n\n\n\n                                    :      FW#1       FW#2       FW#3       FW#4       FW#5      FW#6       RH#1       RH#2
Condenser');
fprintf('\n     Temperature Hot In (C):     %0.2f     %0.2f     %0.2f     %0.2f     %0.2f     %0.2f     %0.2f     %0.2f       %0.2f',...
    T_hot_in_fwh1,T_hot_in_fwh2,T_hot_in_fwh3,T_hot_in_fwh4,T_hot_in_fwh5,T_hot_in_fwh6,T_hot_in_rh1,T_hot_in_rh2,T_hot_in_cond)
fprintf('\n    Temperature Hot Out (C):     %0.2f     %0.2f     %0.2f     %0.2f     %0.2f      %0.2f     %0.2f     %0.2f       %0.2f',...

T_hot_out_fwh1,T_hot_out_fwh2,T_hot_out_fwh3,T_hot_out_fwh4,T_hot_out_fwh5,T_hot_out_fwh6,T_hot_out_rh1,T_hot_out_rh2,T_hot_out_co
nd)
fprintf('\n    Temperature Cold In (C):     %0.2f     %0.2f     %0.2f     %0.2f     %0.2f      %0.2f     %0.2f     %0.2f       %0.2f',...

T_cold_in_fwh1,T_cold_in_fwh2,T_cold_in_fwh3,T_cold_in_fwh4,T_cold_in_fwh5,T_cold_in_fwh6,T_cold_in_rh1,T_cold_in_rh2,T_cold_in_co
nd)
fprintf('\n   Temperature Cold Out (C):     %0.2f     %0.2f     %0.2f     %0.2f     %0.2f     %0.2f     %0.2f     %0.2f       %0.2f',...

T_cold_out_fwh1,T_cold_out_fwh2,T_cold_out_fwh3,T_cold_out_fwh4,T_cold_out_fwh5,T_cold_out_fwh6,T_cold_out_rh1,T_cold_out_rh2,T_co
ld_out_cond)
fprintf('\n  Mass Flow Rate Hot (kg/s):       %0.2f      %0.2f       %0.2f       %0.2f       %0.2f      %0.2f       %0.2f       %0.2f
%0.2f',...
    mdot_h_fwh1,mdot_h_fwh2,mdot_h_fwh3,mdot_h_fwh4,mdot_h_fwh5,mdot_h_fwh6,mdot_h_rh1,mdot_h_rh2,mdot_h_cond)
fprintf('\n Mass Flow Rate Cold (kg/s):     %0.2f     %0.2f     %0.2f     %0.2f     %0.2f   %0.2f     %0.2f     %0.2f   %0.2f',...

t7_fwh_mdot(1)*conv_mdot,t7_fwh_mdot(2)*conv_mdot,t7_fwh_mdot(3)*conv_mdot,t7_fwh_mdot(4)*conv_mdot,t7_fwh_mdot(5)*conv_mdot...
    ,t7_fwh_mdot(6)*conv_mdot,(t2_first_stg_rh_in(1)*conv_mdot),(t2_scnd_stg_rh_in(1)*conv_mdot),mdot_c_total_cond)
fprintf('\n           Velocity Hot (m/s):       %0.2f      %0.2f       %0.2f      %0.2f      %0.2f   %0.2f       %0.2f       %0.2f
%0.2f',...
    v_steam_fwh1,v_steam_fwh2,v_steam_fwh3,v_steam_fwh4,v_steam_fwh5,v_steam_fwh6,v_steam_rh1,v_steam_rh2,v_steam_cond)
fprintf('\n         Velocity Cold (m/s):       %0.2f       %0.2f       %0.2f       %0.2f       %0.2f      %0.2f      %0.2f      %0.2f
%0.2f',...
    v_water_fwh1,v_water_fwh2,v_water_fwh3,v_water_fwh4,v_water_fwh5,v_water_fwh6,v_cold_rh1,v_cold_rh2,v_water_cond)
fprintf('\n                  Q (Watts):  %0.1e  %0.1e  %0.1e  %0.1e  %0.1e %0.1e  %0.1e  %0.1e   %0.1e',...
```

```
    q_fwh1,q_fwh2,q_fwh3,q_fwh4,q_fwh5,q_fwh6,q_rh1,q_rh2,q_cond)
fprintf('\n           Number of Tubes:      %0.0f       %0.0f      %0.0f      %0.0f      %0.0f     %0.0f      %0.0f      %0.0f
%0.0f',...
    no_tubes_fwh1,no_tubes_fwh2,no_tubes_fwh3,no_tubes_fwh4,no_tubes_fwh5,no_tubes_fwh6,no_tubes_rh1,no_tubes_rh2,no_tubes_cond)
fprintf('\n  Diameter of Component (m):      %0.2f       %0.2f      %0.2f      %0.2f      %0.2f     %0.2f      %0.2f      %0.2f
%0.2f',...
    OD_fwh1,OD_fwh2,OD_fwh3,OD_fwh4,OD_fwh5,OD_fwh6,OD_rh1,OD_rh2,OD_cond)
fprintf('\n    Length of Component (m):      %0.2f       %0.2f      %0.2f      %0.2f      %0.2f     %0.2f      %0.2f      %0.2f
%0.2f',...

Length_tubes_fwh1,Length_tubes_fwh2,Length_tubes_fwh3,Length_tubes_fwh4,Length_tubes_fwh5,Length_tubes_fwh6,Length_tubes_rh1...
    ,Length_tubes_rh2,Length_tubes_cond)
fprintf('\n   Heat Transfer Area (m^2):   %0.2f    %0.2f   %0.2f   %0.2f   %0.2f  %0.2f    %0.2f    %0.2f   %0.2f',...
    HT_area_fwh1,HT_area_fwh2,HT_area_fwh3,HT_area_fwh4,HT_area_fwh5,HT_area_fwh6,HT_area_rh1,HT_area_rh2,HT_area_cond)
fprintf('\n          Total Weight (Tons):      %0.2f      %0.2f      %0.2f      %0.2f      %0.2f     %0.2f      %0.2f      %0.2f
%0.2f',...
    total_w_fwh1,total_w_fwh2,total_w_fwh3,total_w_fwh4,total_w_fwh5,total_w_fwh6,total_w_rh1,total_w_rh2,total_w_cond)
```

APPENDIX B – BOSCO DIARY (BASE CASE)

The following output is from a diary created using MATLAB while the Base Case calculation was performed.

```
bosco
Base Case (BC) / IRIS input parameters are shown in parenthesis.
Please input the following numbers with one number past the decimal point (as shown in the IRIS data).

Please input the SG outlet steam temperature in F (IRIS = 602.6):  602.6
Please input the SG outlet steam pressure in psia (IRIS = 841.0):  841.0
Please input the total SG outlet steam flow rate in lb/hr (IRIS = 3990543.3): 3990543.3
Please input the desired plant output in MWe (IRIS = 335.0):  335.0
Please input the desired condenser inlet temperature from the heat sink in degrees F (BC = 90.0):  90.0

C:\MATLAB6p5\work>echo matlabUTBOP  | orcent2  1>matlabUTBOP_out


   ORCENT2 OUTPUT PARAMETERS (SHOWN BY TABLE)


Table 1          Properties:   Net Efficiency   OutPut (MWe)  Output (MWt)  Losses in kW (Mechanical / Generator)
                     Values:       34.38           343.73        999.78            1507.0  /  4507.0


Table 2          Properties:      mdot(lb/hr)     P(psia)      Temp(F)      Enthalpy(BTU/lb)      Q(BTU/hr)
          Turbine Throttle:                                    602.60
 1st Stage RH Inlet Values:       3032724.00       163.80      365.40         1195.40
1st Stage RH Outlet Values:       3032724.00       161.70      418.70         1228.00             9.89e+007
 2nd Stage RH Inlet Values:       3032724.00       161.70      418.70         1228.00
2nd Stage RH Outlet Values:       3032724.00       159.20      497.30         1271.90             1.33e+008


Table 5          Properties:      mdot(lb/hr)     Steam h(BTU/lb)     P(psia)     Temp(F)       Drain h(BTU/lb)
 1sr Stage RH Drain Values:       125106.00           1212.80         396.20      443.70            423.10
 2nd Stage RH Drain Values:       176447.00           1268.90         828.40      522.30            514.80
```

Table 7 Feed Water Heater#:	1	2	3	4	5	6
Feed Water Flow (lb/hr):	3990543.0	3047034.0	3047034.0	3047034.0	3047034.0	3047034.0
Feed Water Outlet Temp (F):	435.00	356.30	316.80	286.50	218.60	161.50
FW Outlet Enthalpy(BTU/lb):	414.00	328.40	287.10	255.80	186.80	129.40
Feed Water Inlet Temp (F):	359.40	316.80	286.50	218.60	161.50	116.30
FW Inlet Enthalpy (BTU/lb):	333.10	287.10	255.80	186.80	129.40	84.30
Extrn Stage Pressure(psia):	414.70	163.80	100.00	64.00	20.00	6.00
Extrn Steam Flow (lb/hr):	324259.0	135597.0	96392.0	203282.0	159728.0	97680.0
Extrn Stm Enthalpy(BTU/lb):	1212.80	1195.40	1234.10	1198.10	1121.20	1069.60
Shell Pressure (psia):	381.50	155.60	92.00	58.90	18.40	5.50
Shell Temperature (F):	440.00	361.30	321.80	291.50	223.60	166.50
Shell Drain Flow (lb/hr):	625811.0	943509.0	98751.0	302034.0	472805.0	664344.0
Shell Drain Temperature(F):	369.40	361.30	296.50	228.60	171.50	126.30
Shell Drn Enthalpy(BTU/lb):	342.30	333.70	266.10	196.90	139.40	94.20

Table 8 Properties:	Pressure(psia)	mdot(lb/hr)	Temp(F)	Enthalpy(BTU/lb)
Condenser / Condensate:	1.47	3047034.00	115.00	82.90

TABLE SHOWING SYSTEM PARAMETERS AND RESULTS OF CALCULATIONS

:	FW#1	FW#2	FW#3	FW#4	FW#5	FW#6	RH#1	RH#2	Condenser
Temperature Hot In (C):	226.67	182.94	161.00	144.17	106.44	74.72	317.00	317.00	46.11
Temperature Hot Out (C):	187.44	182.94	146.94	109.22	77.50	52.39	228.72	272.39	46.11
Temperature Cold In (C):	181.89	158.22	141.39	103.67	71.94	46.83	185.22	214.83	32.22
Temperature Cold Out (C):	223.89	180.17	158.22	141.39	103.67	71.94	214.83	258.50	37.78
Mass Flow Rate Hot (kg/s):	78.85	118.88	12.44	38.06	59.57	83.71	15.76	22.23	383.92
Mass Flow Rate Cold (kg/s):	502.80	383.92	383.92	383.92	383.92	383.92	382.12	382.12	28235.42
Velocity Hot (m/s):	4.57	49.85	5.83	15.67	70.28	149.81	0.94	0.80	155.02

Velocity Cold (m/s):	2.13	2.13	2.13	2.13	2.13	2.13	23.56	14.14	2.13
Q (Watts):	9.5e+007	3.7e+007	2.8e+007	6.2e+007	5.1e+007	4.0e+007	2.9e+007	3.9e+007	6.6e+008
Number of Tubes:	2928	957	1418	2458	2544	5172	600	1000	15000
Diameter of Component (m):	2.33	1.34	1.63	2.14	2.18	3.10	1.06	1.37	8.00
Length of Component (m):	10.03	6.02	8.02	10.02	10.01	6.01	3.13	3.35	9.15
Heat Transfer Area (m^2):	4688.44	918.78	1814.52	3930.61	4065.59	4956.74	300.19	535.05	21896.22
Total Weight (Tons):	41.46	9.99	17.82	35.31	36.41	44.88	4.03	6.33	207.05

diary off

APPENDIX C – ORCENT2 INPUT DECK (BASE CASE)

```
MRW's IRIS Optimized - new SG parameters
 1 602.6     841.0
 2 3800000.                          1.0         3990543.3
 3 335.                  0.9
 4 .878      .77         220.        1.31
 5 65
 9 2.        152.3       -1.36       43.
10 3.        20.         10.         5.
11 2.        100.
12 2.        30.         25.         81.         25.         1.
13 6.        2.          4.
14 1.        414.7                   0.          1.
14 2.                    5.          1.          0.
14 3.        100.                    0.          1.
14 4.        64.                     0.          1.
14 5.        20.                     0.          1.
14 6.        6.                      0.          1.
15 1.        1.
16 1500.
17 1.
 0
```

APPENDIX D – ORCENT2 OUTPUT DECK (BASE CASE)

```
Common blocks set
 Name of input file?

        MRW's IRIS Optimized - new SG parameters
        STEAM TURBINE CYCLE HEAT BALANCE
        ORCENT, VERSION 11-1-78

        INPUT DATA

             THROTTLE STEAM TEMPERATURE                              602.6      F

             THROTTLE STEAM PRESSURE                                 841.0      PSIA

             THROTTLE STEAM MOISTURE                                   .00      PER CENT

             ESTIMATED THROTTLE STEAM FLOW                       3800000.       LB/HR

             FW MAKE-UP RATE (TO CONDENSER HOTWELL)                    .0       PER CENT

             CONDENSATE BY-PASSED TO STEAM GENERATOR                  0.        LB/HR

             THROTTLE FLOW RATIO                                      1.00000

             REQUIRED STEAM GENERATOR OUTLET FLOW                3990543.       LB/HR

             REQUIRED ELECTRICAL OUTPUT                             335.000     MWE

             GENERATOR RATED CAPABILITY                             372.222     MVA

             GENERATOR POWER FACTOR                                    .90

             GENERATOR OPERATION AT RATED HYDROGEN PRESSURE, IH2= 0

             ROTATIONAL SPEED OF TURBINE-GENERATOR                  1800        RPM

             FEEDWATER PUMP ISENTROPIC EFFICIENCY                      .8780
```

FEEDWATER PUMP TURBINE EFFICIENCY	.7700				
PRESSURE OF FWP INLET ABOVE COND. PRESSURE	220.00	PSIA			
RATIO OF FWP DISCH. PRESS. TO H-P THROTTLE	1.31				
PITCH DIAMETER OF GOVERNING STAGE	65.00	IN.			
NUMBER OF PARALLEL H-P SECTIONS	2				
NUMBER OF PARALLEL L-P SECTIONS	2				
BOWL PRESSURE L-P SECTION	152.3	PSIA			
EXHAUST PRESSURE L-P SECTION	1.36000	PSIA	=	2.77	IN. HGA
CONDENSER PRESSURE	1.36000	PSIA	=	2.77	IN. HGA
PITCH DIAMETER OF LAST STAGE L-P SECTION	132.00	IN.			
LENGTH OF LAST STAGE BUCKETS L-P SECTION	43.00	IN.			
NO. OF MOISTURE REMOVAL STAGES LP SECTION	3				
MOISTURE REMOVAL STAGE NO. 1					
MOISTURE REMOVAL STAGE PRESSURE	20.0	PSIA			
MOISTURE REMOVAL STAGE NO. 2					
MOISTURE REMOVAL STAGE PRESSURE	10.0	PSIA			
MOISTURE REMOVAL STAGE NO. 3					
MOISTURE REMOVAL STAGE PRESSURE	5.0	PSIA			
EXTERNAL MOISTURE SEPARATOR DRAINS TO FW HEATER NO. 2, MS=	2				
MOISTURE SEPARATOR EFFECTIVENESS	100.	PER CENT			
NUMBER OF STAGES OF REHEAT	2				

```
ESTIMATED STEAM FLOW TO 1ST STAGE REHEATER                   30.      LB/HR

TERMINAL TEMPERATURE DIFFERENCE 1ST STAGE REHEATER           25.0     F

1ST STAGE REHEATER DRAINS TO FW HEATER NO. 1, NDRH= 1

ESTIMATED STEAM FLOW TO 2ND STAGE REHEATER                   81.      LB/HR

TERMINAL TEMPERATURE DIFFERENCE 2ND STAGE REHEATER           25.0     F

2ND STAGE REHEATER DRAINS TO FW HEATER NO. 1

TOTAL NO. OF FW HEATERS                                       6

NO. OF FW HEATERS HP SECTION                                  2

NO. OF FW HEATERS LP SECTION                                  4

FW HEATER NO.  1

  EXTRACTION STAGE PRESSURE                                 414.7     PSIA

  TERMINAL TEMPERATURE DIFFERENCE                             5.0     F

  DRAIN IS FLASHED, ND( 1)= 0

  THERE IS A DRAIN COOLER SECTION, NDC( 1)= 1

  DRAIN COOLER APPROACH TEMPERATURE DIFFERENCE               10.0     F

FW HEATER NO.  2

  EXTRACTION STEAM FROM MOISTURE SEPARATOR VESSEL

  TERMINAL TEMPERATURE DIFFERENCE                             5.0     F

  DRAIN IS PUMPED, ND( 2)= 1

  THERE IS NO DRAIN COOLER SECTION, NDC( 2)= 0

FW HEATER NO.  3
```

```
  EXTRACTION STAGE PRESSURE                                100.0     PSIA
  TERMINAL TEMPERATURE DIFFERENCE                            5.0     F
  DRAIN IS FLASHED, ND( 3)= 0
  THERE IS A DRAIN COOLER SECTION, NDC( 3)= 1
  DRAIN COOLER APPROACH TEMPERATURE DIFFERENCE              10.0     F
FW HEATER NO.  4
  EXTRACTION STAGE PRESSURE                                 64.0     PSIA
  TERMINAL TEMPERATURE DIFFERENCE                            5.0     F
  DRAIN IS FLASHED, ND( 4)= 0
  THERE IS A DRAIN COOLER SECTION, NDC( 4)= 1
  DRAIN COOLER APPROACH TEMPERATURE DIFFERENCE              10.0     F
FW HEATER NO.  5
  EXTRACTION STAGE PRESSURE                                 20.0     PSIA
  TERMINAL TEMPERATURE DIFFERENCE                            5.0     F
  DRAIN IS FLASHED, ND( 5)= 0
  THERE IS A DRAIN COOLER SECTION, NDC( 5)= 1
  DRAIN COOLER APPROACH TEMPERATURE DIFFERENCE              10.0     F
FW HEATER NO.  6
  EXTRACTION STAGE PRESSURE                                  6.0     PSIA
  TERMINAL TEMPERATURE DIFFERENCE                            5.0     F
  DRAIN IS FLASHED, ND( 6)= 0
```

```
   THERE IS A DRAIN COOLER SECTION, NDC( 6)= 1

   DRAIN COOLER APPROACH TEMPERATURE DIFFERENCE          10.0     F

  FW PUMP IS LOCATED BEFORE FW HEATER NO.  1, IP=  1

  FW PUMP IS TURBINE DRIVEN, IFPT=  1

  STEAM FLOW TO FW PUMP TURBINE WILL BE CALCULATED

  STEAM FLOW TO STEAM JET AIR EJECTOR                  1500.      LB/HR

  VALVE STEM AND PACKING LEAKAGES WILL BE CALCULATED, LK= 1
```

```
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STEAM TURBINE CYCLE HEAT BALANCE
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TABLE I OVERALL PERFORMANCE

NET TURBINE CYCLE HEAT RATE, BTU/KW-HR	9864.
NET TURBINE CYCLE EFFICIENCY, PER CENT	34.59
GROSS TURBINE CYCLE HEAT RATE, BTU/KW-HR	9751.
GROSS TURBINE CYCLE EFFICIENCY, PER CENT	34.99
GENERATOR OUTPUT, MWE	345.849
POWER REQUIRED BY TURBINE-DRIVEN FW PUMP, MW	4.015
GENERATOR OUTPUT PLUS FW PUMP POWER, MW	349.864
MECHANICAL LOSSES, KW	1507.
GENERATOR LOSSES, KW	4550.

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TABLE II TURBINE EXPANSION LINE

	STEAM FLOW LB/HR	PRESSURE PSIA	TEMPERATURE F	MOISTURE PER CENT	ENTHALPY BTU/LB	ENTROPY BTU/LB-F
TURBINE THROTTLE	3812593.	841.0	602.6	.00	1268.9	
GOVERNING STAGE BOWL	3808780.	807.4	598.1	.00	1268.8	1.4839
GOVERNING STAGE SHELL	3808780.	652.1	552.0	.00	1250.9	1.4867
HP SECTION ELEP	3359467.	166.8	366.9	5.56	1148.1	1.5030
HP SECTION UEEP		166.8			1149.6	
EXTERNAL MOISTURE SEPARATOR INLET	3347400.	165.6			1149.6	
EXTERNAL MOISTURE SEPARATOR OUTLET	3168366.	163.8	365.4	.00	1195.4	
1ST STAGE REHEATER INLET	3032776.	163.8			1195.4	
1ST STAGE REHEATER OUTLET	3032776.	161.7	418.7		1228.0	
2ND STAGE REHEATER INLET	3032776.	161.7			1228.0	
2ND STAGE REHEATER OUTLET	3032776.	159.2	497.3		1271.9	
LP SECTION BOWL	2977486.	152.3	495.9	.00	1271.9	1.6560
BEFORE MOISTURE REMOVAL NO. 1		20.0	228.0	4.06	1117.4	1.6754
AFTER MOISTURE REMOVAL NO. 1		20.0	228.0	3.66	1121.2	1.6809
BEFORE MOISTURE REMOVAL NO. 2		10.0	193.2	6.52	1079.3	1.6898

```
     AFTER MOISTURE REMOVAL NO. 2                                10.0     193.2           5.35      1090.8
1.7074
     BEFORE MOISTURE REMOVAL NO. 3                                5.0     162.2           7.89      1052.1
1.7173
     AFTER MOISTURE REMOVAL NO. 3                                 5.0     162.2           6.14      1069.6
1.7454
     LP SECTION ELEP                            2313291.      1.36000     112.2          10.44      1002.8
1.7643
     LP SECTION UEEP                                      1.36000                          1008.1


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     TABLE III   STEAM JET AIR EJECTOR

     STEAM FLOW, LB/HR                  1500.
     STEAM ENTHALPY IN, BTU/LB          1268.9
     STEAM ENTHALPY OUT, BTU/LB          180.2

     TABLE IV  EXTERNAL MOISTURE SEPARATOR DRAINS TO FW HEATER NO. 2

     DRAIN FLOW, LB/HR         179034.
     DRAIN PRESSURE, PSIA         163.8
     DRAIN TEMPERATURE, F         365.4
     DRAIN ENTHALPY, BTU/LB       338.1

     TABLE V  LIVE STEAM REHEATER

     1ST STAGE DRAINS TO FW HEATER NO. 1
     1ST STAGE STEAM FLOW, LB/HR         125108.
     1ST STAGE STEAM ENTHALPY, BTU/LB      1212.8
     1ST STAGE PRESSURE, PSIA               396.2
     1ST STAGE DRAIN TEMPERATURE, F         443.7
```

1ST STAGE DRAIN ENTHALPY, BTU/LB	423.1
2ND STAGE DRAINS TO FW HEATER NO. 1	
2ND STAGE STEAM FLOW, LB/HR	176450.
2ND STAGE STEAM ENTHALPY, BTU/LB	1268.9
2ND STAGE PRESSURE, PSIA	828.4
2ND STAGE DRAIN TEMPERATURE, F	522.3
2ND STAGE DRAIN ENTHALPY, BTU/LB	514.8

TABLE VI MOISTURE REMOVAL STAGES

MOISTURE REMOVAL STAGE NO.	1	2	3
DRAINS TO FW HEATER NO.	5	6	6
STAGE PRESSURE, PSIA	20.0	10.0	5.0
TEMPERATURE, F	228.0	193.2	162.2
WATER REMOVED, LB/HR	11045.	31100.	45798.
WATER ENTHALPY, BTU/LB	196.3	161.3	130.2
STEAM REMOVED, LB/HR	0.	12535.	0.
STEAM ENTHALPY, BTU/LB	.0	1090.8	.0

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TABLE VII FW HEATERS

FW HEATER NO.	1	2	3	4	5	6
FW FLOW, LB/HR	3990543.	3047086.	3047086.	3047086.	3047086.	3047086.
FW TEMPERATURE OUT, F	435.0	356.3	316.8	286.5	218.6	161.5
FW ENTHALPY OUT, BTU/LB	414.0	328.4	287.1	255.8	186.8	129.4
FW TEMPERATURE IN, F	359.4	316.8	286.5	218.6	161.5	113.6
FW ENTHALPY IN, BTU/LB	333.1	287.1	255.8	186.8	129.4	81.5
EXTRACTION STAGE PRESSURE, PSIA	414.7	163.8	100.0	64.0	20.0	6.0
EXTRACTION STEAM FLOW, LB/HR	324206.	135590.	96394.	203286.	159731.	104306.
EXTRACTION STEAM ENTHALPY, BTU/LB	1212.8	1195.4	1234.1	1198.1	1121.2	1069.6
SHELL PRESSURE, PSIA	381.5	155.6	92.0	58.9	18.4	5.5
SHELL TEMPERATURE, F	440.0	361.3	321.8	291.5	223.6	166.5
SHELL DRAIN FLOW, LB/HR	625764.	943458.	98753.	302039.	472815.	671004.
SHELL DRAIN TEMPERATURE, F	369.4	361.3	296.5	228.6	171.5	123.6
SHELL DRAIN ENTHALPY, BTU/LB	342.3	333.7	266.1	196.9	139.4	91.5

TABLE VIII CONDENSER

CONDENSER PRESSURE, PSIA	1.36000	=	2.77	IN. HGA
CONDENSATE FLOW, LB/HR	3047086.			
CONDENSATE TEMPERATURE, F	112.2			
CONDENSATE ENTHALPY, BTU/LB	80.2			

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TABLE IX CONDENSATE AND FEEDWATER

FW FLOW TO FW PUMP, LB/HR	3990543.			
FW TEMPERATURE TO FW PUMP, F	357.5			
FW ENTHALPY TO FW PUMP, BTU/LB	329.7			
FW ENTHALPY RISE ACROSS FW PUMP, BTU/LB	3.4			
FW PRESSURE INCREASE ACROSS FW PUMP, PSI	880.			
FW FLOW TO STEAM GENERATOR, LB/HR	3990543.			
FW TEMPERATURE TO STEAM GENERATOR, F	435.0			
FW ENTHALPY TO STEAM GENERATOR, BTU/LB	414.0			
MAKE-UP TO CONDENSER HOTWELL, LB/HR	0.			
STEAM FLOW FROM STEAM GENERATOR, LB/HR	3990543.			
STEAM ENTHALPY FROM STEAM GENERATOR, BTU/LB	1268.9			
THROTTLE STEAM FLOW FW PUMP TURBINE, LB/HR	55290.			
THROTTLE PRESSURE FW PUMP TURBINE, PSIA	151.2			
THROTTLE ENTHALPY FW PUMP TURBINE, BTU/LB	1271.9			
EXHAUST PRESSURE FW PUMP TURBINE, PSIA	1.60558	=	3.27	IN. HGA
EXHAUST ENTHALPY FW PUMP TURBINE, BTU/LB	1024.1			

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TABLE X   VALVE STEM AND SHAFT LEAKAGES

STEAM SEAL REGULATOR
  FLOW TO SSR, LB/HR                                        10450.
  ENTHALPY AT SSR, BTU/LB                                    1158.1
  FLOW FROM SSR TO MAIN CONDENSER, LB/HR                     3600.
  FLOW FROM SSR TO STEAM PACKING EXHAUSTER, LB/HR            2400.
  FLOW FROM SSR TO FW HEATER NO.  6, LB/HR                   4450.
  MAKE-UP FROM THROTTLE STEAM, LB/HR                            0.
  ENTHALPY OF MAKE-UP STEAM, BTU/LB                              .0

THROTTLE VALVE STEM
  LEAK NO. 1 (DRAINS TO FW HEATER NO.  2), LB/HR             3070.
  ENTHALPY LEAK NO. 1, BTU/LB                                1268.9
  LEAK NO. 2 (DRAINS TO SSR), LB/HR                           743.
  ENTHALPY LEAK NO. 2, BTU/LB                                1268.9

GOVERNING STAGE SECTION
  LEAK NO. 3 (DRAINS TO FW HEATER NO.  0), LB/HR                0.
  ENTHALPY LEAK NO. 3, BTU/LB                                    .0
  LEAK NO. 4 (DRAINS TO SSR), LB/HR                             0.
  ENTHALPY LEAK NO. 4, BTU/LB                                    .0

HP TURBINE SECTION
  TOTAL LEAK NO. 5 (DRAINS TO FW HEATER NO.  3), LB/HR       2359.
  ENTHALPY LEAK NO. 5, BTU/LB                                1149.6
  TOTAL LEAK NO. 6 (DRAINS TO SSR), LB/HR                    9708.
  ENTHALPY LEAK NO. 6, BTU/LB                                1149.6
Return code 999
```

APPENDIX E – MISSISSIPPI RIVER OBSTRUCTIONS

Table E-1 shows the obstructions encountered on the Mississippi River, traveling upstream from the Gulf of Mexico (Map #139) and ending in Cairo, IL (Map #29). These data were taken from the US Army Corps of Engineers (1998).

Table E-1. Mississippi River Obstructions

Mile #	Closest Town/City/County	Structure Type	Vertical Clearance (minus Gage for Bridges) - (ft)	Horizontal Clearance (ft)	Additional Comments
Gulf of Mexico					
24.5	Ostrica, LA	Ostrica Lock	-9.2		Lock Size = 40' X 247' - see Map #137 - possibly not on main route
89.2	Chalmette, LA	Aerial Power Crossing	191	N/A	
95.7	Orleans Parish, LA	Crescent City Connection Hwy. Bridge	170	750	
95.8	Orleans Parish, LA	Crescent City Connection Hwy. Bridge	170	750	
103.8	Southport, LA	Aerial Power Crossing	175	N/A	
106.1	Jefferson Heights, LA	Huey P. Long R.R. and Hwy. Bridge	153	750	
107.3	Harahan, LA	Aerial Power Crossing	171	N/A	
121.6	Destrehan, LA	Hale Boggs Bridge	155.4	1200	Interstate Route 310
129	Waterford, LA	Aerial Power Crossing	192	N/A	
129.6	Waterford, LA	Aerial Power Crossing	160	N/A	
145.9	Wallace, LA	Gramercy Bridge	165	750	
167.4	Salsburg, LA	Ascension - St. James Hwy. Bridge	170	750	
201.5	St. Gabriel, LA	Aerial Power Crossing	205	N/A	

Table E-1. Continued.

Mile #	Closest Town/City/County	Structure Type	Vertical Clearance (minus Gage for Bridges) - (ft)	Horizontal Clearance (ft)	Additional Comments
224.2	Lukeville, LA	Aerial Power Crossing	194	N/A	
229.3	Baton Rouge, LA	Baton Rouge Hwy. Bridge	175	500	Interstate Route 10
233.9	Scotlandville, LA	Baton Rouge R.R. and Hwy. 190 Bridge	113	748	
261.5	West Feliciana Parish, LA	Aerial Power Crossing	152	N/A	
262.6	West Feliciana Parish, LA	Aerial Power Crossing	160	N/A	
361.2	Adams County, MS	Aerial Power Crossing	93.5	N/A	
363.3	Vidalia, MS	Natchez - Vidalia Eastbound Bridge Hwy. 84	126	848	
363.3	Vidalia, MS	Natchez - Vidalia Westbound Bridge Hwy. 84	125.5	848	
369.1	Adams County, MS	Aerial Power Crossing	84	N/A	
434.7	Madison Parish, LA	Aerial Power Crossing	93.5	N/A	
437.7	Madison Parish, LA	Vicksburg Bridge Interstate 20	116.2	846	
437.8	Madison Parish, LA	Vicksburg Bridge Hwy. 80	116.3	800	
531.3	Chicot County, AR	Greenville Bridge Hwy. 82	130	800	
659.6	Coahoma County, MS	Aerial Power Crossing	?	N/A	? See Map #67
661.8	Helena, AR	Helena Hwy. Bridge	119.4	800	Lowest Steel = 261.1' N.G.V.D.
662.6	Helena, AR	Aerial Power Crossing	?	N/A	? See Map #66
727.5	Shelby County, TN	Aerial Power Crossing	331	N/A	

Table E-1. Continued.

Mile #	Closest Town/City/County	Structure Type	Vertical Clearance (minus Gage for Bridges) - (ft)	Horizontal Clearance (ft)	Additional Comments
734.4	Crittenden County, AR	Memphis Hwy. Bridge	112.8	770	Lowest Steel = 296.71' N.G.V.D.
734.7	Crittenden County, AR	Harahan Railroad Bridge	108.3	770	Lowest Steel = 292.21' N.G.V.D.
734.7	Crittenden County, AR	Burlington Northern R.R. Bridge	109	770	Lowest Steel = 292.91' N.G.V.D.
736.6	Crittenden County, AR	Hernando Desoto Bridge	108.7	870	Lowest Steel = 292.61' N.G.V.D.
769	Mississippi County, AR	Aerial Power Crossing	340	N/A	
838.7	Dyer County, TN	Interstate 55 Bridge	99.2	900	Lowest Steel = 334.69' N.G.V.D.
977.7	Cairo, IL	Illinois Central R.R. Bridge	104.6	503	Lowest Steel = 375.07' N.G.V.D. *Seems like should be mile #957.5
980.4	Alexander County, IL / Ballard County, KY	Cairo Hwy. Bridge	105.3	800	Lowest Steel = 375.77' N.G.V.D. *Seems like should be mile #954.9
Ohio River joins here					

APPENDIX F – OHIO RIVER OBSTRUCTIONS

Table F-1 shows the obstructions encountered on the 48 mile stretch of the Ohio River between the Mississippi River and the Tennessee River. These data were taken from the US Army Corps of Engineers (2003).

Table F-1. Ohio River Obstructions

Mile #	Closest Town/City/County	Structure Type	Vertical Clearance at High Water / Zero Gage (ft)	Horizontal Clearance (ft)	Additional Comments
To the Mississippi River					
980.4	Alexander County, IL / Ballard County, KY	Cairo Hwy. Bridge (U.S. 60)	57.4 / 116.4	780	
977.7	Ballard County, KY	Illinois Central Railroad Bridge	44.1 / 104.6	500.5	
962.6	Ballard County, KY	Locks and Dam #53	?	**110**	Lock Size 600' X 110' See Chart #5
952.4	McCracken County, KY	Aerial Power Crossing	121.2	>	
952.5	McCracken County, KY	Aerial Power Crossing	121.2	>	
951.8	McCracken County, KY	Aerial Power Crossing	121.2	>	
945.6	McCracken County, KY	Aerial Power Crossing	130	>	
944.1	McCracken County, KY	P. & I. Railroad Bridge	44.8 / 98	530	
940.9	McCracken County, KY	I-24 Hwy. Bridge	40.7 / 95.2	700	
939	McCracken County, KY	Lock and Dam #52	280	**110**	Lock Size 600' X 110' See Chart #10
937.3	McCracken County, KY	Irvin S. Cobb Bridge	**46.7 / 91**	700	
From the Tennessee River					

APPENDIX G – TENNESSEE RIVER OBSTRUCTIONS

Table G-1 shows the obstructions encountered on the Tennessee River, from Paducah, Kentucky to Knoxville, Tennessee. These data were taken from the US Army Corps of Engineers (2000).

Table G-1. Tennessee River Obstructions

Mile #	Closest Town/City/County	Structure Type	Vertical Clearance at High Water / Pool Stage (ft)	Horizontal Clearance (ft)	Additional Comments
To the Ohio River					
5.3	McCracken County, KY	George Rogers Clark Mem. Hwy. Bridge	47.5 / 84.8	387	U.S. Hwy #60
5.4	McCracken County, KY	Aerial Power Crossing	61 / 105	N/A	
8.6	Livingston County, KY	Aerial Power Crossing	93 / 128	N/A	
10.6	Marshall County, KY	Aerial Power Crossing	77 / 112	N/A	
20.1	Gilbertsville, KY	Aerial Power Crossing	80 / 116	N/A	
20.2	Gilbertsville, KY	Aerial Power Crossing	96 / 132	N/A	
20.3	Gilbertsville, KY	Aerial Power Crossing	93 / 128	N/A	
20.8	Gilbertsville, KY	Aerial Power Crossing	79 / 123	N/A	
20.9	Gilbertsville, KY	Aerial Power Crossing	83 / 127	N/A	
21.1	Gilbertsville, KY	I - 24 Highway Bridge	45 / 87.3	500	
21.6	Gilbertsville, KY	Aerial Power Crossing	57 / 93	N/A	
21.7	Gilbertsville, KY	Aerial Power Crossing	63 / 107	N/A	
22.4	Gilbertsville, KY	Illinois Central Railroad Bridge	48.3 / 85.6	*110	* Between Lock Walls

Table G-1. Continued.

Mile #	Closest Town/City/County	Structure Type	Vertical Clearance at High Water / Pool Stage (ft)	Horizontal Clearance (ft)	Additional Comments
22.5	Gilbertsville, KY	Kentucky Lock and Dam Highway Bridge	49.8 / 87	*110	Lock Size = 600' X 110' - U.S. Hwy. #62 - *Between Lock Walls - see chart #4
41.7	Marshall County, KY	Eggners Ferry Hwy. Bridge	41 / 57.2	357	U.S. Hwy #68
66.3	Henry County, TN	Gov. Ned R. McWherter Hwy. Bridge	51 / 58	400	U.S. Hwy. #79
72.4	Stewart County, TN	Aerial Power Crossing	85 / 102	N/A	
78.2	Benton County, TN	Old Louisville and Nashville Railroad Bridge	N/A	900+	Retired bridge with sailing line portion removed
100.5	Benton County, TN	CSX Railroad Bridge	*44.8 / *62.6	352	*These values are for if the bridge is raised
100.5	Benton County, TN	Hickman-Lockhard Hwy. Bridge	49 / 60	389	U.S. Hwy. #70
101.6	Benton County, TN	Aerial Power Crossing	97 / 114	N/A	
101.9	Benton County, TN	Aerial Power Crossing	92 / 109	N/A	
116.1	Benton County, TN	Cuba Landing Hwy. Bridge	47 / 64	350	I-40
134.9	Perryville, TN	Alvin C. York Hwy. Bridge	48.9 / 68.9	428	U.S. Hwy. #412
161.9	Hardin County, TN	Clifton Hwy. Bridge	?	?	No description (chart no. 25) - State Rt. 69
189.9	Hardin County, TN	Harrison-McGarity Memorial Hwy. Bridge	45.2 / 83.7	500	U.S. Hwy. #64
190	Hardin County, TN	Aerial Power Crossing	71 / 110	N/A	
203.9	Hardin County, TN	Aerial Power Crossing	81 / 123	N/A	
204	Hardin County, TN	Aerial Power Crossing	76 / 118	N/A	
206.1	Hardin County, TN	Aerial Power Crossing	50 / 120	N/A	
206.2	Hardin County, TN	Aerial Power Crossing	80 / 120	N/A	

Table G-1. Continued.

Mile #	Closest Town/City/County	Structure Type	Vertical Clearance at High Water / Pool Stage (ft)	Horizontal Clearance (ft)	Additional Comments
206.7	Hardin County, TN	Pickwell Landing Lock and Dam Hwy. Bridge	53 / 57	*110	Aux. Lock Size = 600' X 110' - State Hwy. #128 *Between Lock Walls - see chart #30
236.6	Lauderdale County, AL	Natchez Trace Parkway Bridge	*58.7 / *63.7	350	*Data taken at center
244.3	Colbert County, AL	Aerial Power Crossing	92 / 101	N/A	
244.4	Colbert County, AL	Aerial Power Crossing	89 / 98	N/A	
256.4	Florence, AL	O'Neal Hwy. Bridge	45.1 / 61.4	350	U.S. Hwy. #72
256.5	Florence, AL	Old Southern Railway Bridge	?	?	No description (chart no. 38)
256.6	Florence, AL	Aerial Power Crossing	70 / 84	N/A	
256.7	Florence, AL	Aerial Power Crossing	60 / 74	N/A	
257.6	Florence, AL	Aerial Power Crossing	64 / 79	N/A	
258.1	Florence, AL	Patton Island Bridge (Construction)	?	?	Under Consruction
258.3	Florence, AL	Aerial Power Crossing	65 / 80	N/A	
259.4	East Florence, AL	Wilson Dam Hwy. Bridge	57 / 57	*110	*Between Lock Walls
259.5	East Florence, AL	*Wilson Lock Access Bridge	67 / 67	**110	*Alternate Route? - Main Lock Size = 600' X 110' see chart # 38 **Between Lock Walls
274.5	Lawrence County, AL	Aerial Power Crossing	90 / 92	N/A	
274.6	Lawrence County, AL	Aerial Power Crossing	74 / 76	N/A	
274.8	Lawrence County, AL	Wheeler Lock and Dam Hwy. Bridge	59.2 / 59.5	*110	Main Lock Size = 600' X 110' - State Hwy. #101 *Between Lock Walls - see chart #41

Table G-1. Continued.

Mile #	Closest Town/City/County	Structure Type	Vertical Clearance at High Water / Pool Stage (ft)	Horizontal Clearance (ft)	Additional Comments
292.6	Lawrence County, AL	Aerial Power Crossing	98 / 99	N/A	
292.6	Lawrence County, AL	Aerial Power Crossing	92 / 93	N/A	
297.5	Lawrence County, AL	Aerial Power Crossing	97 / 100	N/A	
297.6	Lawrence County, AL	Aerial Power Crossing	58 / 60	N/A	
304.4	Morgan County, AL	Southern Railway Bridge	*53.8 / *57.8	388	*If bridge is raised
305	Morgan County, AL	Capt. William J. Hudson Bridge (Steamboat Bill)	49.3 / 57	350	
305	Morgan County, AL	Keller Memorial Hwy. Bridge (Under Construction)	*18.8 / *24	210	*If bridge is closed (no info available if raised) U.S. Hwy. #31 & Alt. #72 - see chart #45
307.6	Morgan County, AL	Aerial Power Crossing	66 / 72	N/A	
309.6	Morgan County, AL	Interstate 65 Hwy. Bridge	50 / 57	350	
333.2	Morgan County, AL	Arab to Huntsville Hwy. Bridge	47 / 66	350	U.S. Hwy. #231
333.3	Morgan County, AL	Clement C. Clay Hwy. Bridge	48 / 67	301	U.S. Hwy. #231
344.9	Marshall County, AL	Aerial Power Crossing	87 / 112	N/A	
348.7	Marshall County, AL	Aerial Power Crossing	77 / 104	N/A	
349	Marshall County, AL	Guntersville Lock, Dam, and Hydro P. Plant	?	110	Lock Size = 600' X 110' - see chart #51
358	Guntersville, AL	George S. Houston Hwy. Bridge	56.9 / 58.4	350	
358	Guntersville, AL	Veterans Memorial Hwy. Bridge	55 / 56	350	

Table G-1. Continued.

Mile #	Closest Town/City/County	Structure Type	Vertical Clearance at High Water / Pool Stage (ft)	Horizontal Clearance (ft)	Additional Comments
364.5	Marshall County, AL	Aerial Power Crossing	87 / 85	N/A	
385.8	Jackson County, AL	B.B. Comer Hwy. Bridge	51 / 54.4	301	
390.6	Jackson County, AL	Aerial Power Crossing	121 / 129	N/A	
403.1	Jackson County, AL	Capt. John Snodgrass Hwy. Bridge	51.1 / 64.1	480	
405.7	Jackson County, AL	Aerial Power Crossing	85 / 100	N/A	
408.1	Jackson County, AL	Aerial Power Crossing	78 / 93	N/A	
411	Jackson County, AL	Aerial Power Crossing	81 / 98	N/A	
414.4	Bridgeport, AL	CSX Railroad Bridge	*59.7 / *77.7	280	*If bridge is raised
416.5	Marion County, TN	Aerial Power Crossing	77 / 99	N/A	
418.5	Marion County, TN	Shelby A. Rhinehart Hwy. Bridge	55 / 73	730	
420.4	Marion County, TN	Aerial Power Crossing	73 / 95	N/A	
424.2	Marion County, TN	Aerial Power Crossing	69 / 94	N/A	
424.7	Marion County, TN	Nickajack Lock			Lock Size = 600' X 110'
429.3	Marion County, TN	Holman J. Walker Hwy. Bridge	57 / 58	400	
429.7	Marion County, TN	Marion County Mem. Hwy. Bridge	57 / 58	358	
431.3	Marion County, TN	Aerial Power Crossing	103 / 104	N/A	
433.9	Marion County, TN	Aerial Power Crossing	89 / 91	N/A	
457	Hamilton County, TN	Aerial Power Crossing	81 / 105	N/A	
459.5	Hamilton County, TN	Aerial Power Crossing	83 / 108	N/A	
462.1	Hamilton County, TN	Aerial Power Crossing	78 / 103	N/A	
463.7	Hamilton County, TN	P.R. Olgiati Hwy. Bridge	46 / 73	350	

Table G-1. Continued.

Mile #	Closest Town/City/County	Structure Type	Vertical Clearance at High Water / Pool Stage (ft)	Horizontal Clearance (ft)	Additional Comments
464.1	Hamilton County, TN	Chief John Ross Drawbridge	*32.9 / 59.6	295	*With bridge closed
464.2	Hamilton County, TN	Walnut Street Bridge	57.7 / 84.5	305	
464.5	Hamilton County, TN	Veterans Memorial Bridge	49.3 / 75.8	400	
465.3	Hamilton County, TN	Aerial Power Crossing	61 / 89	N/A	
469.5	Hamilton County, TN	C.B. Robinson Bridge	48 / 77	455	
469.8	Hamilton County, TN	Aerial Power Crossing	93 / 117	N/A	
470.7	Hamilton County, TN	Southern Railway Bridge	*70.5 / *101	307	*With Bridge Raised
471	Chattanooga, TN	Chickamauga Lock			Lock Size = 360' X 60' See Chart # 68
471	Chattanooga, TN	Wilkes T. Thrasher Hwy. Bridge	60.8 / 63.7	*60	*Between Lock Walls
483.5	Hamilton County, TN	Aerial Power Crossing	86 / 90	N/A	
485.3	Hamilton County, TN	Aerial Power Crossing	91 / 95	N/A	
498.9	Hamilton County, TN	State Route 60 Hwy. Bridge	52 / 57	517	
516.5	Meigs County, TN	Aerial Power Crossing	74 / 84	N/A	
518	Meigs County, TN	State Route 30 Hwy. Bridge	47 / 57.9	495	
527.7	Meigs County, TN	Aerial Power Crossing	101 / 119	N/A	
529.8	Meigs County, TN	Aerial Power Crossing	93 / 109	N/A	
529.9	Rhea County, TN	Watts Bar Lock		60	Lock Size = 360' X 60' *Lock on Chart #76, Details oppisit Chart #72
530.1	Rhea County, TN	Aerial Power Crossing	77 / 81	N/A	
568.2	Roane County, TN	Decatur-Kingston Hwy. Bridge	55.8 / 61.1	358	
569.3	Roane County, TN	Aerial Power Crossing	98 / 103	N/A	
573	Roane County, TN	Aerial Power Crossing	95 / 101	N/A	

Table G-1. Continued.

Mile #	Closest Town/City/County	Structure Type	Vertical Clearance at High Water / Pool Stage (ft)	Horizontal Clearance (ft)	Additional Comments
581.5	Loundon County, TN	Aerial Power Crossing	71 / 81	N/A	
584.8	Loundon County, TN	Interstate 75 Hwy. Bridge	47 / 57	388	
591.1	Loundon County, TN	Aerial Power Crossing	106 / 119	N/A	
591.3	Loundon County, TN	Southern Railway Bridge	47.8 / 62.1	267	
591.6	Loundon County, TN	Louden County Mem. Hwy. Bridge	51.1 / 66.1	257	
592.2	Loundon County, TN	Aerial Power Crossing	70 / 84	N/A	
593.1	Loundon County, TN	Aerial Power Crossing	79 / 95	N/A	
595.2	Loundon County, TN	Aerial Power Crossing	83 / 99	N/A	
602.3	Lenoir City, TN	Fort Loudoun Lock and Dam Hwy. Bridge	55.1 / 57.1	***60**	Lock Size = 360' X 60' *Between Lock Walls - See Chart #84
627.9	Blount County, TN	Aerial Power Crossing	81 / 84	N/A	
630.1	Blount County, TN	Pellissippi Parkway Bridge	70 / 77	450	
644.9	Knox County, TN	Aerial Power Crossing	80 / 89	N/A	
645.1	Knox County, TN	James E. Karnes Hwy. Bridge	50 / 57	308	
646.6	Knox County, TN	CSX Railroad Bridge	48.2 / 58	261	
646.7	Knox County, TN	Aerial Power Crossing	79 / 89	N/A	
647.3	Knox County, TN	Southern Railway Bridge	**39.7 / 50**	130	
647.4	Knox County, TN	Henley Street Bridge (U.S. Hwy. 441)	78.7 / 89	297	
647.7	Knox County, TN	Gay Street Bridge	54.3 / 65	252	

VITA

Martin Rodney Williamson was born in Knoxville, Tennessee on April 14, 1980. He has one older brother, James Andrew "Andy" Williamson. He grew up in Cosby, Tennessee, and graduated from Gatlinburg Pittman High School in May 1998. The following August he entered Walters State Community College in Morristown, Tennessee, and studied engineering for one year. While attending Walters State, he met his future wife, whom he would later marry in May of 2000. Starting in August of 1999, he entered The University of Tennessee where he received a Bachelor of Science in Nuclear Engineering in May 2002. During his undergraduate years, he worked as a lifeguard at the Gatlinburg Community Center, a server at TGI Friday's in Gatlinburg, and as a criticality safety intern at Westinghouse Safety Management Solutions in Aiken, South Carolina.

Immediately after graduating, he entered graduate school at UTK. He was awarded the National Academy for Nuclear Training (NANT) fellowship and received a Master of Science degree in Nuclear Engineering in May 2004.