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OCEAN THERMAL ENERGY CONVERSION POWER SYSTEM DEVELOPMENT

Phase 1: Preliminary Design
Final Report

December 4, 1978

Work Performed Under Contract No. EG-77-C-03-1569

Westinghouse Electric Corporation
Power Generation Divisions
Lester, Pennsylvania

U.S. Department of Energy

Solar Energy

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PART II

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ODSP3 Dynamic Simulation Program

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DYNAMIC MODEL (ODSP3) OF THE PROPOSED WESTINGHOUSE OTEC DESIGN

1. Introduction

This report outlines the basic features of the dynamic model developed to simulate the performance of the proposed Westinghouse OTEC module. Much of the information herein contained was previously submitted to Westinghouse during the model development phase. There have, however, been some important modifications made to the model (in consultation with Westinghouse) since that time. This report includes all such modifications and documents the model currently in use.

The goal of this modeling work has been to provide Westinghouse with a design tool to be used for ascertaining system control reliability and for tradeoff studies on system design variables. Pressure drop considerations may preclude the use of turbine inlet control and stop valves; for this reason, a design involving a turbine bypass valve has been proposed as a solution to the problem of turbine speed control during a loss of load condition. In order to evaluate the adequacy of the proposed control scheme, the presently proposed Westinghouse OTEC conceptual design was modularized (as shown in Figure 1) and modeled.

The above model is applicable to a number of particular cases of interest, predicting system response to various control actions. The control actions included as options in the model are:

- Opening of the bypass valve in response to a loss of load condition;
- Closing of control valve CV-1 and opening of CV-2 in response to a loss of load;
- A combination of the above two actions;

- Control of turbine speed and load by manipulation of valves CV-1 and the bypass valve in various ways.

Section 2 of this report describes the development of system component models. The following section (3) shows how, in an overall sense, these components are integrated into the final model. The sequence of calculations for the initial (steady-state) condition and those for the transient case are presented in some detail.

Section 4 is the ODSP3 user's manual, sections of which were previously submitted to Westinghouse as the ODSP1 user's manual. This section outlines program input requirements and general program operation.

Section 5 presents the detailed flow charts for the ODSP3 package. Appendix 6.1-B presents the results of a sample problem.

2.0 Component Models

2.1 Conventions Regarding Naming of Variables

In the sections which follow, all process components will be modeled. To as great an extent as possible, the equations presented will employ the same nomenclature as that found in the ODSP-3 code. For the purposes of this report, however, the use of ODSP-3 variable names could make a few derivations long and awkward to follow; therefore, a few sections will be written using standard engineering nomenclature, with only the final result converted to ODSP-3 nomenclature.

All program variables (not including constants) are identified by a 3 character prefix and a 3 character suffix. The following is a list of prefixes, indicating what type of variable is being measured:

TMP	Temperature (^oF)
PRS	Pressure (psia)
VFR	Vapor flow rate (lbs/sec)
LFR	Liquid flow rate (lbs/sec)
TWA	Average water temperature (^oF)
TTB	Average tube temperature (^oF)
TAV	Average ammonia vapor temperature (^oF)
MAV	Mass of ammonia vapor (lbs)
MAL	Mass of ammonia liquid (lbs)
RPM	Revolutions per minute

The 3 character suffix indicates the device to which the variable relates, and is keyed to the flowsheet shown in Figure 1. The following is a list of suffixes:

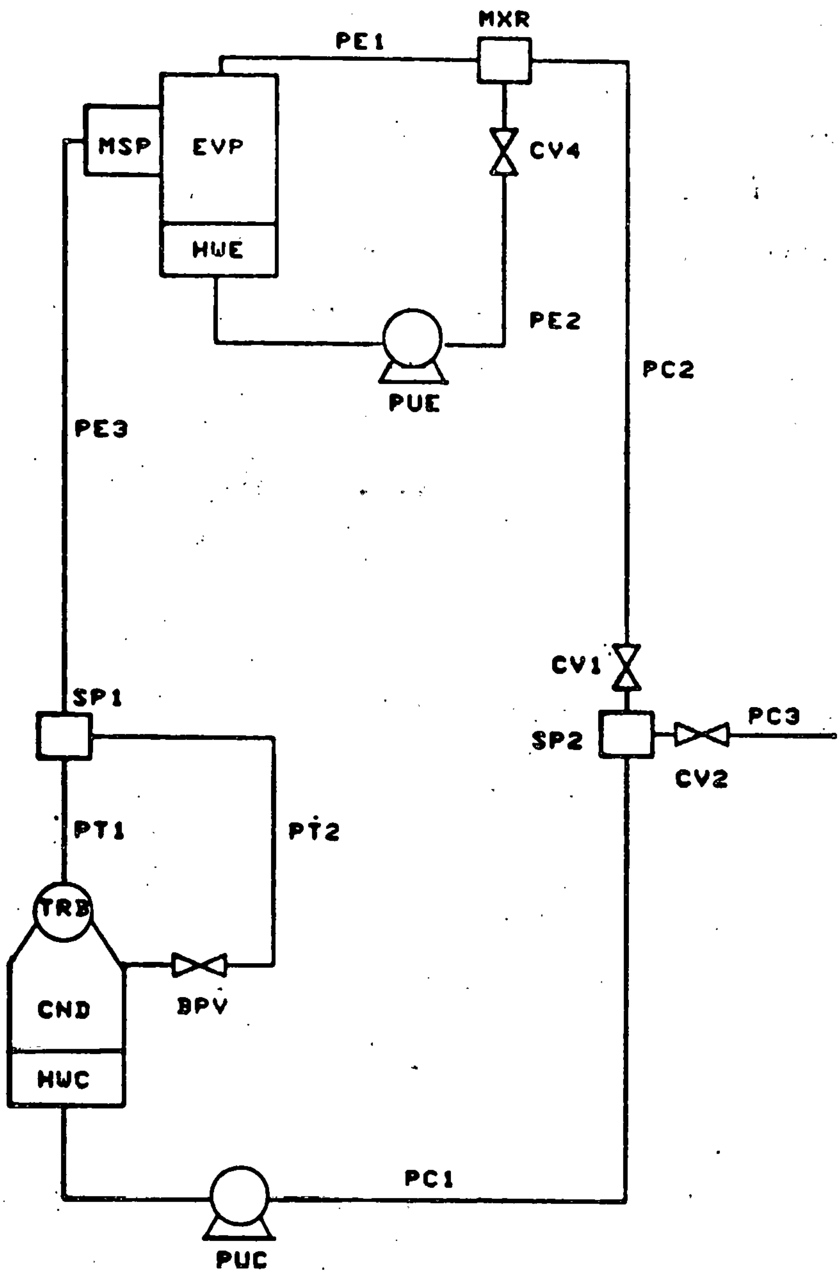

Figure 1

FLOWSHEET FOR OTEC PLANT

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CV1 to CV4	Control Valves
BPV	Bypass Valve
EVP	Evaporator
CND	Condenser
HWE	Evaporator Hotwell
HWC	Condenser Hotwell
MSP	Moisture Separator
TRB	Turbine
PUE	Ammonia Recirculation Pump, Evaporator Loop
PUC	Main Ammonia Condensate Pump
SP1, SP2	Splitters
MXR	Mixer
PC1-PC3 PE1-PE3 PT1, PT2	Pipelines

Stream variables are named for the unit through which the fluid last passed. For example, the temperature of the vapor leaving the turbine is called TMPTRB.

2.2 Splitters

At two points in the system, the flow of ammonia can be split in two (at SP1 and SP2). The governing equations for the splitters are simple mass balances:

Flow into Splitter = Flow (1) out + Flow (2) out

For the splitter SP1, this condition requires that:

VFRPE3 = VFRPT2 + VFRPT1 (splitter SP1 handles vapor) (SPL-1)

For the splitter SP2, the equation is:

LFRPC1 = LFRPC2 + LFRPC3 (splitter SP2 handles liquid) (SPL-2)

Since physically SP1 and SP2 are nothing more than pipe "tees", the thermodynamic properties of the fluid are unchanged by splitting, i.e.

TMPSP2 = TMPPC1 (SPL-3)

PRSSP2 = PRSPC1 (SPL-4)

TMPSP1 = TMPPE3 (SPL-5)

PRSSP1 = PRSPE3 (SPL-6)

2.3 Mixer

There is one mixing tee in the system (MXR). The governing equations for the mixer are:

Mass Balance LFRMXR = LFRPE2 + LFRPC2 (MXR-1)

Enthalpy Balance $$\text{TMPMXR} = \frac{m_1 C_{P_1} T_1 + m_2 C_{P_2} T_2}{m_1 C_{P_1} + m_2 CP_2} \quad \text{(MXR-2)}$$

where: m_1 = LFRPE2

m_2 = LFRPC2

T_1 = TMPPE2

T_2 = TMPPC2

C_{P_1} = CPAL (TMPPE2) = heat capacity at T_1

C_{P_2} = CPAL (TMPPC2) = heat capacity at T_2

"Pressure Balance" PRSMXR = PRSCV4 = PRSPC2 (MXR-3)

It is assumed that the mixer operates adiabatically and offers no resistance to flow. The resistance of the pipeline between CV4 and MXR can be included in PE2.

The function CPAL(T) is user supplied, and gives the heat capacity of ammonia liquid (at constant P) as a function of temperature.

2.4 Pipelines

The model considers flow resistance and transport lags in eight sections of pipeline indicated in Figure 1. Of these eight sections, five normally carry liquid ammonia (PE1, PE2, PC1, PC2, PC3) while three are vapor lines (PE3, PT1, PT2). While there are certainly more than eight physically distinct sections of pipe in the actual design, it was felt that these eight resistances would be sufficient for dynamic simulation purposes.

The cross sectional area for flow through a pipeline assumed to be running full is of course $A = \pi D^2/4$, where D is the pipeline diameter. These quantities receive variable names in accord with the previously developed procedure, e.g. APC1 and DPC1. The fluid velocity is given by the relationship:

VEL = VFRXXX/(DAV · AXXX) For vapor line XXX (P-1)

or VEL = LFRXXX/(DAL · AXXX) For liquid line XXX (P-2)

DAV (or DAL) is the vapor (or liquid) density in pipeline XXX. The Reynolds number for pipeline XXX can then be calculated as

REN = (DAV)(VEL)(DXXX)/(VIS) For vapor line XXX (P-3)

or REN = (DAL)(VEL)(DXXX)/(VIS) For liquid line XXX (P-4)

The quantity VIS is the viscosity of the ammonia vapor (or liquid), determined from user supplied input data. The friction factor for the pipeline is calculated from the following:

$$FRF = \begin{cases} 16/REN, & \text{If } REN < 2100 \quad \text{(P-5)} \\ 1.4\times10^{-3} + 0.125(REN)^{-0.32} & \text{If } REN \geq 2100 \quad \text{(P-6)} \end{cases}$$

The pressure drop in a pipeline is calculated based on Darcy's Law, with a correction for head change due to an elevation difference between the inlet and exit of the pipeline (ZXXX). When the fluid density is given in lbs/ft^3, length (LXXX), diameter and elevation change in feet, and velocity in ft/sec, the pressure drop in the pipeline is given by:

$$\Delta P = 4.31\times10^{-4} \frac{(FRF)(DAV)(LXXX)(VEL)^2}{(DXXX)} (1 + KXXX) + \frac{(DAV)(ZXXX)}{144} \quad \text{(P-7)}$$

The above is for pipeline XXX carrying vapor; changing DAV to DAL makes the relation applicable to liquid lines. Implicit in this formula is the assumption that flow in the pipeline is isothermal and incompressible. The assumption of incompressibility is applicable even to the ammonia vapor case because of the small pressure drops encountered. Pressure variations are assumed to be transmitted instantaneously. KXXX is an "equivalent length" factor included to account for the additional frictional losses due to "bends" and other fittings (except valves) in the pipeline.

The delay time of a pipeline is calculated from the integral equation:

$$\int_{Time-TAUXXX}^{Time} (VFRXXX)\, dt = (DAV)(LXXX)(AXXX) \qquad \text{For vapor line XXX} \quad \text{(P-8)}$$

or

$$\int_{Time-TAUXXX}^{Time} (LFRXXX)\, dt = (DAL)(LXXX)(AXXX) \qquad \text{For liquid line XXX} \quad \text{(P-9)}$$

The value TAUXXX represents the time required for a parcel of fluid to transit the pipeline.

The quantities DAV, DAL, AND VIS are calculated from fluid inlet properties. The following table matches pipelines (XXX) with the source of their inlet.

Pipeline	Inlet from Unit
PE1	MXR
PE2	PUE
PC1	PUC
PC2	CV1
PC3	CV2
PE3	MSP
PT1	SP1
PT2	SP1

2.5 Valves

There are four valves included in the model, 3 liquid control valves (CV1, CV2, CV4), and the turbine bypass valve (BPV). The governing pressure drop equation is:

$$\Delta P = \frac{(KXXX)(LFRYYY)^2}{(9276.43)(ASQXXX)(DAL)} \qquad \text{(Liquids)} \qquad \text{(V-1)}$$

or

$$\Delta P = \frac{(KXXX)(VFRYYY)^2}{(9276.43)(ASQXXX)(DAV)} \qquad \text{(Vapor)} \qquad \text{(V-2)}$$

KXXX is the dimensionless valve coefficient for valve XXX, which also has a throat area (in inches^2) of ASQXXX. The suffix YYY on the vapor and liquid flow rates refers to the inlet to or outlet from valve XXX. These valves and their inlets and outlets are matched in the following table:

Valve	Outlet to Unit	Inlet From Unit
CV1	PC2	SP2
CV2	PC3	SP2
CV4	MXR	PE2
BPV	CND	PT2

A valve is "closed" by assigning it a very large value of the valve coefficient KXXX.

2.6 Pumps

The pump models include simple mass balances (LFRHWE = LFRPUE = LFRPE2; LFRHWC = LFRPUC = LFRPC1) and energy balances. The energy balance on the fluid in the pump is modeled as:

$$PHD = \frac{550}{144}\left(\frac{DAL}{LFRXXX}\right) W_U \text{ or } PHDE = \frac{550}{144}\left(\frac{DAV}{VFRXXX}\right) WU \qquad \text{(PU-1)}$$

where the symbols have the same meanings as before, W_U = pump brake (useful) horsepower, and PHD = total increase in pressure head (psia).

The adiabatic temperature rise in the pump has a frictional heating component (pump inefficiency) and a flow work component:

$$Q - W_U = \Delta H = C_p \Delta T$$

Thus:

$$TMPPUC = \frac{(.1848)(PHD)}{(DAL)(CPA)} + TAVCND \qquad \text{(PU-2)}$$

and

$$TMPPUE = \frac{(.1848)(PHD)}{(DAL)(CPA)} + TALHWE \qquad \text{(PU-3)}$$

The pump is assumed to operate at constant speed; the relationship between increase in head and flow rate is a function of the pump itself. These data are supplied by Westinghouse:

$$PHD = PHD(LFRXXX) \qquad \text{(PU-4)}$$

2.7 Turbine

An energy balance on the turbine at steady state (design) conditions requires that the power produced in the turbine (TPWRD) either go into generation of electrical power (NPWRD) or into losses (TLOSSD, generally frictional). Thus the energy balance at design conditions (subscripted D) is:

$$TPWRD = NPWRD + TLOSSD \quad \text{(all quantities in KW)} \qquad (T\text{-}1)$$

NPWRD is input and TLOSSD is calculated from input quantities. This power is provided by the change in enthalpy of the working fluid on passage through the turbine (DHD in Btu/lb) at design conditions (vapor flow rate FRD):

$$DHD = (TPWRD/FRD)\left(\frac{3414\ \text{Btu/KWH}}{3600\ \text{sec/hr}}\right) \qquad (T\text{-}2)$$

The losses at design conditions are assumed to include a thrust bearing loss (TBLD), a turbine journal bearing loss (TJBLD), a generator journal bearing loss (GJBLD), a generator electrical loss (GELD), and coupling losses (CLD), all in kilowatts. Thus

$$TLOSSD = TBLD + TJBLD + GJBLD + CLD + GELD \qquad (T\text{-}3)$$

The pressure ratio for the turbine is given by the ratio of inlet to outlet pressures at design conditions:

$$PRD = PRSPT1/PRSCND \qquad (T\text{-}4)$$

During a change of load, NPWR, the energy balance on the turbine is modified to include the kinetic energy going into speeding up the turbine itself:

$$\frac{dRPMTRB}{dt} = 2.163\text{x}10^{6}(TPWR-NPWR-TLOSS)/(RPMTRB \cdot ITRB) \qquad (T\text{-}5)$$

where: ITRB = moment of inertia of the turbine input (lb_m-ft^2)

RPMTRB = rotational rate of the turbine (revs per minute)

RPMD = 1800

t = time (seconds)

$$TLOSS = TBL + TJBL + GJBL + CL + GEL + WL \qquad (T\text{-}6)$$

$$TBL = TBLD\ (RPMTRB/RPMD)^{2}$$

$$TJBL = TJBLD\ (RPMTRB/RPMD)^{1.7}$$

$$GJBL = GJBLD\ (RPMTRB/RPMD)^{1.7}$$

$$CL = CLD\ (RPMTRB/RPMD)^{3}$$

The dependence of the various turbine losses on turbine rotational rate was provided by Ed Graf of Westinghouse (Sunnyvale) who also suggested the use of the Stodola Ellipse Law for turbine performance:

Defining T2 = RPMTRB/RPMD

$$TPWR = TPWRD \cdot T2[KAY^1 - KAY^2 \cdot T2 + KAY3 \cdot T2^2] \left[-.3092 + 1.897\frac{PR-1}{PRD-1} - .5899 \left(\frac{PR-1}{PRD-1}\right)^2 \right] \left[\frac{PRSPT1}{PID} \right] \left[\left(\frac{TFD}{TMPPT1} \right) \left(\frac{1 - [PR]^{-j}}{1 - [PRD]^{-j}} \right) \right]^{1/2} \quad \text{(T-7)}$$

(If $\left(\frac{PR-1}{PRD-1}\right) > 1.1$ then $\left(\frac{PR-1}{PRD-1}\right) = 1.1$ is used.)

where symbols have their previously defined meanings and

$$j = 2 + \left(\frac{1-\gamma}{\gamma}\right) \eta_p \quad \text{(T-8)}$$

$$\left(\frac{1-\gamma}{\gamma}\right) \eta_p = \frac{\ln [1 - EFFD(1 - PRD^{(1-\gamma)/\gamma})]}{\ln PRD} \quad \text{(T-9)}$$

$$\gamma = C_p/C_v \text{ (calcualted at } T_{PLT1}) \quad \text{(T-10)}$$

EFFD = turbine efficiency at design, input

η_p = polytropic efficiency

C_p = constant pressure mass heat capacity of NH_3 (Btu/lb °K)

C_v = constant volume mass heat capacity of NH_3 (Btu/lb °F)

TID,PID = temperature and pressure at turbine inlet, input, design condition

The mass rate through the turbine is given by:

$$LFRPT1 = \sqrt{\frac{TID}{TMP}} \left[\frac{PRSPT1}{PID} \right] \left[\frac{1 - (PR)^{-j}}{1 - (PRD)^{-j}} \right]^{1/2} \quad \text{(T-11)}$$

At less than 1% turbine design flow conditions, windage losses of turbine, WL, are non-zero, and are given by:

$$W_L = 8.25 \times 10^{-4} \text{ (HBLADE)(DAV)} \left(\frac{\text{RPMTRB}}{100} \right)^3 \text{(DBLADE)}^4 \qquad \text{(T-12)}$$

where HBLADE is the blade height and DBLADE the blade diameter, both in feet. At the zero flow condition of course TPWR = 0.

GEL = the greater of:

GEL = GELD (RPMTRB/RPMD)

or

$$\text{GEL} = \text{GELD} \left[\exp \left(2.8658 \log_e(\text{RPMTRB/RPMD}) - .10748 \right] \right.$$

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2.8 MOISTURE SEPARATOR

The volume of the moisture separator is included in the vapor volume of the evaporator. Conceptually, the separator is considered as a flow resistance component with inlet pressure, the same as the saturated vapor pressure in the evaporator. That is,

$$P_{exit} = P_{sat}(T_{\ell v}) \; K \frac{\rho_v}{2} \left[\frac{\dot{m}_v}{\rho_v A} \right]^2$$

or

$$P_{exit} = P_{sat}(T_{\ell v}) - K \frac{\dot{m}_v^2}{2\rho_v A^2}$$

In terms of the nomenclature used in the computer, it is

PRSMSP = PRSEVP - (KMSP*VFRPE3*VFRPE3)/(9276.43*DAV*APE3*APE3)

2.9 CONDENSER

A lumped system is considered in the dynamic modeling of the condenser. Essentially, only one horizontal tube will be considered in the modeling as indicated in Figure 2. Where the state variables are: M_v, M_ℓ, M_ℓ', T_w, T_t, and $T_{\ell v}$. All the nomenclatures in modeling the condenser and evaporator are summarized in Table 1.

Due to the specific design, the following parameters can be evaluated

$$D_o = D_i + 2\delta$$

$$A_i = \pi D_i L_c N_c$$

$$A_o = A_i D_o / D_i$$

$$M_t = [(A_i + A_o)/2] \delta \rho_t$$

$$M_w = (\pi D_i^2/4) L_c N_c \rho_w$$

Then the transient heat balance of water, tube and ammonia can be formulated.

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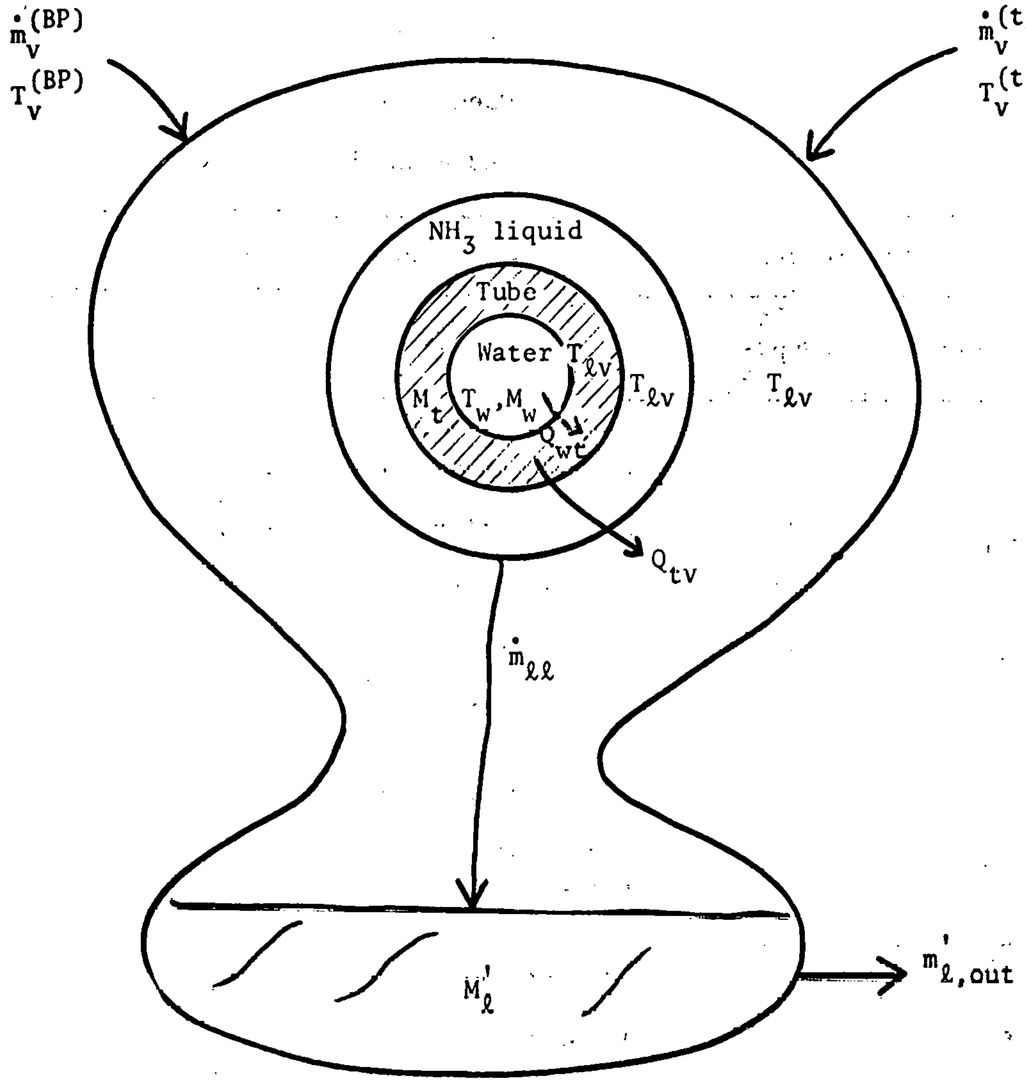

Figure 2

Condenser Model

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TABLE 1

Nomenclature Used in the Derivations of

Condenser and Evaporator Models

Nomenclature In Derivation	Nomenclature In computer code	Interpretation	Units
A_i	-	Heat transfer area based on D_i (ft)	
A_o	OTA	Heat transfer area based on D_o (ft)	
C	CP	Heat capacity	$BTU/lb_m{}^{\circ}F$
D_i	ITD	Inside tube diameter	ft
D_o	OTD	Outside tube diameter	ft
h	-	Heat transfer coefficient	
h_{wt}	HWT	Heat transfer coefficient, water to tube	$BTU/hr\ ft^2\ {}^{\circ}F$
h_{tv}	HTV	Heat transfer coefficient, tube to ammonia vapor	$BTU/hr\ ft^2\ {}^{\circ}F$
H	H	Enthalpy	BTU/lb_m
k	-	Thermal conductivity	$BTU/hr\ ft\ {}^{\circ}F$
L_e	LEN	Length of evaporator tube	ft
L_c	LEN	Length of condenser tube	ft
$\dot{m}_w$	WFR	Water flow rate	lb_m/s
$\dot{m}_v$	VFR	NH_3 vapor leaving system	lb_m/s
$\dot{m}_{\ell v}$	FFV	NH_3 going from liquid to vapor phase	lb_m/s
$\dot{m}'_{\ell,out}$	LFR	NH_3 liquid leaving hotwell	lb_m/s
$\dot{m}_{\ell\ell}$	DRN	Excess NH_3 liquid leaving evaporator and going to hotwell	lb_m/s
$\dot{m}_{Hv}$	FWV	Mass evaporation rate from hot well to vapor	lb_m/s
$\dot{m}_{v\ell}$	FFV	$= -\dot{m}_{v\ell}$	

TABLE 1 (continued)

Nomenclature In Derivation	Nomenclature In computer code	Interpretation	Units
$\underline{M}$	MLCRWT	Molecular weight	lb_m/lb_{mole}
M_w	MW	Mass of water in tubes	lb_m
M_t	MT	Mass of metals in tubes	lb_m
M_ℓ	MAL	Mass of NH_3 in liquid on tubes	lb_m
M_ℓ^*	MMX	Maximum mass of NH_3 liquid on tubes	lb_m
M_ℓ'	MAL	Mass of NH_3 in hot well	lb_m
M_v	MAV	Vapor in evaporator, hotwell, and moisture separator	lb_m
N_e	NTB	Number of tubes in evaporator	
N_c	NTB	Number of tubes in condenser	
P	PRS	Pressure of vapor v in the vessel	psia
P_{sat}		Saturation pressure	psia
Q_{wt}	QWT	Heat transferred from tubes to water	BTU/s
Q_{tv}	QTV	Heat transferred from tubes to ammonia vapor	BTU/s
R	GASR	Gas Constant, 1545.3	ft lb_f/lb_{mole} °R
t	TIME	Time	s
T_t	TTB	Average temperature of tube metal	°F
T_w	TWA	Average temperature of water	°F
$T_{\ell v}$	TAV	Average temperature of both liquid and vapor NH_3 in system	°F
V	VAV	Volume of vapor in evaporator,hotwell and moisture separator	ft^3
$V_{shellside}$	VOL	Volume of shell side space in evaporator and hotwell and moisture separator	ft^3
z		Length,measured from water inlet	ft

TABLE 1 (continued)

Nomenclature: In Derivation	Nomenclature: In computer code	Interpretation	Units
<u>Greek Letters</u>			
ρ	DEN	Density	lb_m/ft^3
γ	GMA	Transit time	s
ζ	ZTA	Length constant	ft
λ	LMDA	Latent heat of vaporization	BTU/lb_m
δ	DTB	Tube wall thickness	ft
<u>Subscripts</u>			
v		Vapor	
ℓ		Liquid NH_3	
w		Water	
t		Tube	
HW		Hot well	
in		Inlet	
HV		Vaporization from hot well	

2.9.1 HEAT BALANCE FOR WATER

$$M_w C_w \frac{dT_w}{dt} = - Q_{wt} + \dot{m}_w C_w (T_w(0,t) - T_w(L_e,t)) \qquad \text{(CND-1)}$$

where Q_{tw} is the heat transferred from tube to water. In compatible units, it is

$$Q_{wt} = h_{tw} A_i (T_w - T_t)/3600 \qquad \text{(CND-2)}$$

The second term at right hand sido of the heat balance equation considers the incoming and outgoing enthalpies of water of the condenser tube. The outlet water temperature $T(L_e,t)$ is related to the inlet water temperature $T_w(0,t)$ and the vapor temperature $T_{\ell v}(t)$.

This relationship is accomplished by writing the steady state water and tube heat balances. These balances are, respectively:

Water heat balance

$$\left(\frac{\dot{m}_w C_w}{\pi D_i h_{wt}}\right) \frac{dT_w(z)}{dz} = T_w(z) + T_t(z) = 0$$

Tube heat balance

$$h_{wt}(T_w(z) - T_t(z)) = h_{tv}(T_t(z) - T_{\ell v})$$

Eliminate $T_t(z)$ to get

$$\zeta \frac{dT_w(z)}{dz} + T_w(z) - T_{\ell v}$$

where $\zeta \equiv$ length constant $\equiv \left[\frac{1}{h_{wt}} + \frac{1}{h_{tv}}\right]\left(\frac{\dot{m}_w C_w}{\pi D_i}\right)$. (CND-3)

The solution of this equation evaluated at $z = L_e$ is

$$T_w(L_e) = T_w(0) e^{-L_e/\zeta} + \left[1 - e^{-L_e/\zeta}\right] T_{\ell v}.$$

This is the outlet water temperature at steady state. To approximate the dynamic behavior, the transit times of water and vapor are introduced as time delays. The transit time of water through the condenser tube from $z = 0$ to $z = L_e$ is

$$\gamma = \frac{M_w}{\dot{m}_w} . \qquad \text{(CND-4)}$$

The averaged time delay is half of γ. As a result, the outlet water temperature can be presented as

$$T_w(L_e,t) = T_w(0,t-\gamma)e^{-L_e/\zeta} + (1 - e^{-L_e/\zeta})T_{\ell v}(t - \frac{\gamma}{2}) \qquad \text{(CND-5)}$$

In summary, the water temperature is

$$\frac{dT_w}{dt} = \frac{1}{M_w C_w}\left[- Q_{wt} + \dot{m}_w C_w (T_w(0,t)-T_w(L_e,t))\right] \qquad \text{(CND-6)}$$

where Q_{wt} is stated in equation (CND-2), $T_w(L_e,t)$ is in equation (CND-5), ζ and γ are defined in (CND-3) and (CND-4), respectively.

2.9.2 HEAT BALANCE OF TUBE

The heat balance of tube at transient condition is

$$\frac{dT_t}{dt} = \frac{1}{M_t C_t}\left[Q_{wt} - Q_{tv}\right] \qquad \text{(CND-7)}$$

where $Q_{tv} = h_{tv}A_o(T_t - T_{\ell v})/3600$ (CND-8)

Q_{wt} is stated in equation (CND-2).

2.9.3 HEAT BALANCE OF AMMONIA

The enthalpy balance of ammonia vapor, liquid on tube and liquid in hot well can be stated as

$$H_v \frac{dM_v}{dt} + H_\ell \frac{d(M_\ell + M_\ell')}{dt} + \left[M_v C_v + (M_\ell + M_\ell')C_\ell\right] \frac{dT_{\ell v}}{dt}$$

$$= Q_{tv} + \dot{m}_v^{(t)} H_v^{(t)} + \dot{m}_v^{(BP)} H_v^{(BP)} - \dot{m}_{\ell,out}' H_\ell \qquad \text{(CND-9)}$$

where superscript t is for turbine, BP for bypass valve discharges to the condenser.

To do the calculations, the state equations for the vapor mass, liquid mass on tube and liquid mass in hot well have to be presented.

2.9.4 MASS BALANCES

The vapor mass balance is

$$\frac{dM_v}{dt} = -\dot{m}_{v\ell} + \dot{m}_v^{(t)} + \dot{m}_v^{(BP)} . \qquad \text{(CND-10)}$$

Mass balance of liquid ammonia on tube is

$$\frac{dM_\ell}{dt} = \dot{m}_{v\ell} - \dot{m}_{\ell\ell} \quad \text{, and} \qquad \text{(CND-11)}$$

mass balance of liquid in the hot well is

$$\frac{dM_\ell'}{dt} = \dot{m}_{\ell\ell} - \dot{m}_{\ell,out}' . \qquad \text{(CND-12)}$$

2.9.5 DERIVATION OF THE STATE EQUATION FOR VAPOR TEMPERATURE

The state equation for $T_{\ell v}$ can be derived from equation (CND-9) with the assumption that the vapor in the condenser is in the saturated state and that it also follows the ideal gas law. That is,

$$P = P_{sat}(T_{\ell v}) = \frac{M_v}{\underline{M}} \frac{RT_{\ell v}}{V}$$

Therefore,

$$\frac{dM_v}{dt} = \frac{\underline{M}V}{R} \left[\frac{1}{T_{\ell v}} \left(\frac{\partial P_{sat}}{\partial T} \right)_{T_{\ell v}} - \frac{P_{sat}(T_{\ell v})}{T_{\ell v}^2} \right] \frac{dT_{\ell v}}{dt} . \qquad \text{(CND-13)}$$

Additionally, equations (CND-11) and (CND-12) can be combined as (CND-13)

$$\frac{d(M_\ell + M_\ell')}{dt} = \dot{m}_{v\ell} - \dot{m}'_{\ell,out} .$$

Equation (CND-9) becomes

$$H_v(-\dot{m}_{v\ell} + \dot{m}_v^{(t)} + \dot{m}_v^{(BP)}) + H_\ell(\dot{m}_{v\ell} - \dot{m}'_{\ell,out}) + \hat{C}\frac{dT_{\ell v}}{dt}$$

$$= Q_{tv} + \dot{m}_v^{(t)}H_v^{(t)} + \dot{m}_v^{(BP)}H_v^{(BP)} - \dot{m}'_{\ell,out}H_\ell$$

where $$\hat{C} \equiv M_vC_v + (M_\ell + M_\ell')C_\ell \qquad \text{(CND-14)}$$

or $$-(H_v-H_\ell)\dot{m}_{v\ell} + \hat{C}\frac{dT_{\ell v}}{dt} = +Q_{tv} + (H_v^{(t)}-H_v)\dot{m}_v^{(t)} + (H_v^{(BP)}-H_v)\dot{m}_v^{(BP)} .$$

Using equations (CND-10) and (CND-13), $\dot{m}_{v\ell}$ can be expressed as

$$\dot{m}_{v\ell} = \dot{m}_v^{(t)} + \dot{m}_v^{(BP)} - \frac{dM_v}{dt}$$

$$= \dot{m}_v^{(t)} + \dot{m}_v^{(BP)} - \hat{B}\frac{dT_{\ell v}}{dt}$$

where $$\hat{B} \equiv \frac{MV}{R}\frac{1}{T_{\ell v}}\left(\frac{\partial P_{sat}}{\partial T}\right)_{T_{\ell v}} - \frac{P_{sat}(T_{\ell v})}{T_{\ell v}^2} . \qquad \text{(CND-15)}$$

In addition, the latent heat of vaporization λ can be used. That is,

$$\lambda = H_v - H_\ell \qquad \text{(CND-16)}$$

and $$H_v^{(t)} - H_v = C_v(T_v^{(t)} - T_{\ell v})$$

$$H_v^{(BP)} - H_v = C_v(T_v^{(BP)} - T_{\ell v})$$

Finally, the state equation of vapor temperature is

$$\frac{dT_{\ell v}}{dt} = \frac{1}{(\lambda\hat{B}+\hat{C})}\left[+Q_{tv} + C_v(T_v^{(t)} - T_{\ell v})\dot{m}_v^{(t)} + C_v(T_v^{(BP)} - T_{\ell v})\dot{m}_v^{(BP)} + \lambda(\dot{m}_v^{(t)} + \dot{m}_v^{(BP)})\right]$$

where λ is stated in equation (CND-16), $\hat{B}$ is in equation (CND-15), $\hat{C}$ is in equation (CND-14) and Q_{tv} is in equation (CND-8).

2.10 EVAPORATOR MODELING

The modeling of evaporator is similar to that of condenser. The difference between them will be presented here. In modeling the performance of the evaporator, the possible flashing of liquid from the tube and from the hot well will be considered (which is likely to occur when the vapor bypass valve opens rapidly). However, when vapor pressure increases, the condensation of vapor on liquid is assumed to occur at a very slow rate and is neglected. Therefore, there is one new state variable, T_{HW} for the temperature of liquid in hot well, in addition to the six state variables used in condenser modeling (e.g., T_w, T_t, $T_{\ell v}$, M_v, M_ℓ and M_{HW}). The schematization of the evaporator model is shown in Fig. 3.

The same state equations for T_w and T_t in condenser modeling can be used in evaporator modeling. Similar state equations for M_v, M_ℓ, M_{HW} can be constructed as those for condenser.

2.10.1 MASS BALANCES

$$\frac{dM_v}{dt} = \dot{m}_{\ell v} + \dot{m}_{Hv} - \dot{m}_v \quad \text{(EVP-1)}$$

$$\frac{dM_\ell}{dt} = \dot{m}_{\ell,in} - \dot{m}_{\ell v} - \dot{m}_{\ell\ell} \quad \text{(EVP-2)}$$

$$\frac{dM_{HW}}{dt} = \dot{m}_{\ell\ell} - \dot{m}_{Hv} - \dot{m}_{\ell,out} \quad \text{(EVP-3)}$$

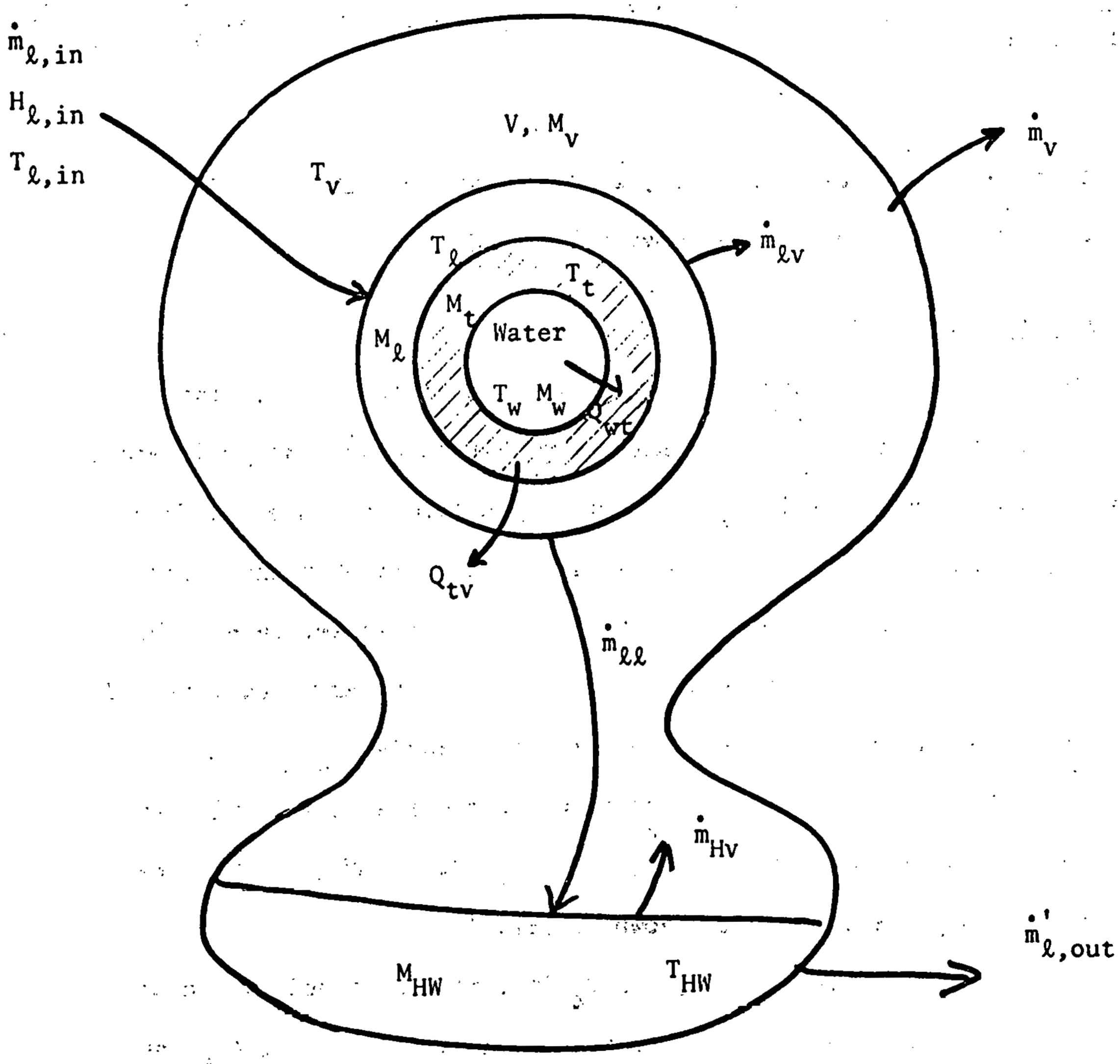

Figure 3

Evaporator Model

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2.10.2 HEAT BALANCE OF LIQUID ON TUBE AND VAPOR IN VESSEL

The enthalpy balance is

$$H_\ell \frac{dM_\ell}{dt} + H_v \frac{dM_v}{dt} + (M_\ell C_\ell + M_v C_v) \frac{dT_{\ell v}}{dt}$$

$$= Q_{tv} + H_{\ell,in}\dot{m}_{\ell,in} + H_{HW}\dot{m}_{Hv} - H_\ell \dot{m}_{\ell\ell} - H_v \dot{m}_v \quad \text{(EVP-4)}$$

or

$$\frac{dT_{\ell v}}{dt} = \frac{1}{M_\ell C_\ell + M_v C_v}\left[Q_{tv} + C_{\ell,in}(T_{\ell,in} - T_{\ell v})\dot{m}_{\ell,in} + C_{v,HW}(T_{HW} - T_{\ell v})\dot{m}_{Hv} - \lambda(T_{\ell v})\dot{m}_{\ell v}\right] \quad \text{(EVP-5)}$$

2.10.3 HEAT BALANCE OF LIQUID IN HOTWELL

$$M_{HW}C_{HW}\frac{dT_{HW}}{dt} = C_\ell(T_{\ell v} - T_{HW})\dot{m}_{\ell\ell} - \lambda(T_{HW})\dot{m}_{Hv}$$

or

$$\frac{dT_{HW}}{dt} = \frac{1}{M_{HW}C_{HW}}\left[C_\ell(T_{\ell v} - T_{HW})\dot{m}_{\ell\ell} - \lambda(T_{HW})\dot{m}_{Hv}\right] \quad \text{(EVP-6)}$$

2.10.4 CONSIDERATIONS OF FLASHING OF LIQUID

During the operation it is necessary to know about the instantaneous vapor pressure in the evaporator such that the occurrence of flashing from liquid which is on the tube or in the hot well can be monitored. This is accomplished by assuming that ideal gas behavior for the vapor and the derivations are as follows:

Using $P = (M_v R T_{\ell v})/(\underline{M}V)$ (ideal gas law), then the time rate of change is

$$\frac{dP}{dt} = P\left[\frac{1}{M_v}\frac{dM_v}{dt} + \frac{1}{T_{\ell v}}\frac{dT_{\ell v}}{dt} - \frac{1}{V}\frac{dV}{dt}\right]$$

where the vapor volume in the evaporator is

$$V = V_{shell\ side} - M_\ell/\rho_\ell - M_{HW}/\rho_{HW}$$

or

$$\frac{dV}{dt} = -\frac{1}{\rho_\ell}\frac{dM_\ell}{dt} - \frac{1}{\rho_{HW}}\frac{dM_{HW}}{dt}$$

Using the appropriate mass and energy balance equations (EVP-1, EVP-5, EVP-2, EVP-3), the equation for P becomes

$$\frac{dP}{dt} = P\left\{\frac{1}{M_v}(\dot{m}_{\ell v} + \dot{m}_{Hv} - \dot{m}_v) + \frac{1}{T_{\ell v}(M_\ell C_\ell + M_v C_v)}(Q_{tv} + C_{\ell,in}(T_{\ell,in} - T_{\ell v})\dot{m}_{\ell,in} + C_{v,HW}(T_{HW} - T_{\ell v})\dot{m}_{HV} - \lambda(T_{\ell v})\dot{m}_{\ell v}) + \frac{1}{V}\left[\frac{1}{\rho_\ell}(-\dot{m}_{\ell\ell} - \dot{m}_{\ell v} + \dot{m}_{\ell,in}) + \frac{1}{\rho_{HW}}(\dot{m}_{\ell\ell} - \dot{m}_{Hv} - \dot{m}_{\ell,out})\right]\right\} \quad \text{(EVP-7)}$$

By comparing the calculated vapor pressure in the evaporator with the saturation pressure of the liquid on the tubes or in the hot well, the conditions for flashing, evaporation or condensation can be justified. As stated before, the condensation of vapor in the evaporator is neglected for the present treatment. Therefore

(1) If $P > P_{sat}(T_{\ell v})$ then $\dot{m}_{v\ell} = 0$ (EVP-8)

(2) If $P > P_{sat}(T_{HW})$ then $\dot{m}_{Hv} = 0$ (EVP-9)

When flashing occurs the liquid ammonia evaporates rapidly while its temperature decreases. The rate of pressure reduction in the evaporator will be less than the rate expected by considering that the vapor and liquid are in thermodynamic equilibrium. According to this, the rate of pressure reduction can be written as

(3) If $p \le p_{sat}(T_\ell)$, flashing will occur and

$$\frac{dP}{dt} = \left(\frac{\partial P_{sat}}{\partial T}\right)_{T_{\ell v}} \frac{dT_{\ell v}}{dt} + \sigma_1 , \qquad \sigma_1 \geq 0$$

where σ_1 is a "slack" variable whose value must be greater than or equal to zero. Using the equation (EVP-7) for $\frac{dP}{dt}$, get the condition

For $p \leq p_{sat}(T_{\ell v})$

$$\left[\frac{P}{M_v} - \left[\frac{\frac{P}{T_{\ell v}} - \left(\frac{\partial P_{sat}}{\partial T}\right)_{T_{\ell v}}}{M_\ell C_\ell + M_v C_v}\right] \lambda(T_{\ell v}) - \frac{P}{V\rho_\ell}\right] \dot{m}_{\ell v}$$

$$+ \left[\frac{P}{M_v} + \frac{\frac{P}{T_{\ell v}} - \left(\frac{\partial P_{sat}}{\partial T}\right)_{T_{\ell v}}}{M_\ell C_\ell + M_v C_v} (C_{v,HW}(T_{HW} - T_{\ell v})) - \frac{P}{V\rho_{HW}}\right] \dot{m}_{Hv}$$

$$+ \left[\frac{P}{V\rho_{HW}} - \frac{P}{V\rho_\ell}\right] \dot{m}_{\ell\ell} + \left[\frac{\frac{P}{T_{\ell v}} - \left(\frac{\partial P_{sat}}{\partial T}\right)_{T_{\ell v}}}{M_\ell C_\ell + M_v C_v}\right] Q_{tv}$$

$$- \sigma_1 + \left[\left[\frac{\frac{P}{T_{\ell v}} - \left(\frac{\partial P_{sat}}{\partial T}\right)_{T_{\ell v}}}{M_\ell C_\ell + M_v C_v}\right] C_{\ell,in}(T_{\ell,in} - T_{\ell v}) + \frac{P}{V\rho_\ell}\right] \dot{m}_{\ell,in}$$

$$- \left[\frac{P}{V\rho_{HW}}\right] \dot{m}_{\ell,out} - \left[\frac{P}{M_v}\right] \dot{m}_v = 0 . \qquad \text{(EVP-10)}$$

Similarly for the hot well of evaporator,

(4) If $p \leq p_{sat}(T_{HW})$, then flashing will also occur and

$$\frac{dP}{dt} = \left(\frac{\partial P_{sat}}{\partial T}\right)_{T_{HW}} \frac{dT_{HW}}{dt} + \sigma_2 , \qquad \sigma_2 \geq 0 .$$

Using $\frac{dP}{dt}$ from equation (EVP-7), get

$$\left[\frac{P}{M_v} - \left[\frac{\left(\frac{P}{T_{\ell v}}\right)}{M_\ell C_\ell + M_v C_v}\right] \lambda(T_{\ell v}) - \frac{P}{V\rho_\ell}\right]\dot{m}_{\ell v}$$

$$+\left[\frac{P}{M_v} + \frac{\left(\frac{P}{T_{\ell v}}\right)}{M_\ell C_\ell + M_v C_v} C_{v,HW}(T_{HW}-T_{\ell v}) - \frac{P}{V\rho_{HW}} + \frac{\left(\frac{\partial P_{sat}}{\partial T}\right)_{T_{HW}}}{M_{HW}C_{HW}} \lambda T_{HW}\right]\dot{m}_{Hv}$$

$$+\left[\frac{P}{V\rho_{HW}} - \frac{P}{V\rho_\ell} - \frac{\left(\frac{\partial P_{sat}}{\partial T}\right)_{T_{HW}}}{M_{HW}C_{HW}} C_\ell(T_{\ell v}-T_{HW})\right]\dot{m}_{\ell\ell}$$

$$+\left[\frac{\left(\frac{P}{T_{\ell v}}\right)}{M_\ell C_\ell + M_v C_v}\right]Q_{tv} - \sigma_2 + \left[\frac{\left(\frac{P}{T_{\ell v}}\right)}{M_\ell C_\ell + M_v C_v} (C_{\ell,in}(T_{\ell,in}-T_{\ell v}))\right.$$

$$\left. + \frac{P}{V\rho_\ell}\right] - \frac{P}{V\rho_{HW}} \dot{m}_{\ell,out} - \frac{P}{M_v}\dot{m}_v = 0 \qquad \text{(EVP-11)}$$

(5) Both $\sigma_1 \geq 0$, $\sigma_2 \geq 0$ are slack variables. (EVP-12)

In addition, we have

(6) $\dot{m}_{\ell v} \geq 0$, $\dot{m}_{Hv} \geq 0$, $\dot{m}_{\ell\ell} \geq 0$ (EVP-13)

2.10.5 CONSIDERATION OF LIQUID DRYOUT ON TUBES

The evaporator may operate at low recirculation rate, and the tube may experience partial or complete dryout during transients.

The heat transfer across the liquid films is mainly controlled by the heat conduction through the film. Therefore the heat transfer coefficient of the film can be related to the liquid film thickness f by

$$h = \frac{k}{f} .$$

According to this, the total liquid mass staying on the tubes will have a maximum amount equal to

$$M_{\ell}^{*} = \left[\frac{k}{h} A_o \rho_{\ell}\right]_{T_{\ell v}} \qquad \text{(EVP-14)}$$

Following the lumped model of the evaporator, when liquid feeding rate is higher than that required for maintaining the maximum load M_{ℓ}^{*}, the extra liquid will drain to the hot well instantaneously. That means

(7) If $M_{\ell} \geq M_{\ell}^{*}$, then $\frac{dM_{\ell}}{dt} \leq 0$. (EVP-15)

The other extreme condition is the complete dryout of the film. That is,

(8) If $M_{\ell} \leq 0$, then $\dot{m}_{\ell\ell} = 0$

and $\dot{m}_{\ell v} \leq \dot{m}_{\ell,in}$. (EVP-16)

The heat transfer coefficient may decrease as the dryout starts to occur on the tube. However, since we do not know exactly the specific h and Re relationship during dryout on a horizontal type bundle, it is suggested here to use a constant heat transfer coefficient when tubes are not completely dried. Thus

(9) $Q_{tv} \leq h_{tv} A_o (T_t - T_{\ell v})/3600$ (EVP-17)

When the tube is completely dried the heat transfer is assumed as zero.

(10) If $\dot{m}_{\ell,in} = 0$ and $M_{\ell} \leq 0$, then $Q_{tv} = 0$. (EVP-18)

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2.10.6 METHOD OF SOLUTIONS

With all the above constraints available, the calculation can be performed with various IF statements in the computer program to select the appropriate operation conditions. However, a general scheme is developed to simplify the selection procedure. Considering the linear property of the above constraints (linear in variables $\dot{m}_{\ell\ell}$, $\dot{m}_{\ell v}$, $\dot{m}_{Hv}$, Q_{tv}, σ_1 and σ_2), these ten constraints can be included in the overall calculations by solving a simple linear programming problem.

Tested with various operation conditions, the objective function of the linear programming is formulated as

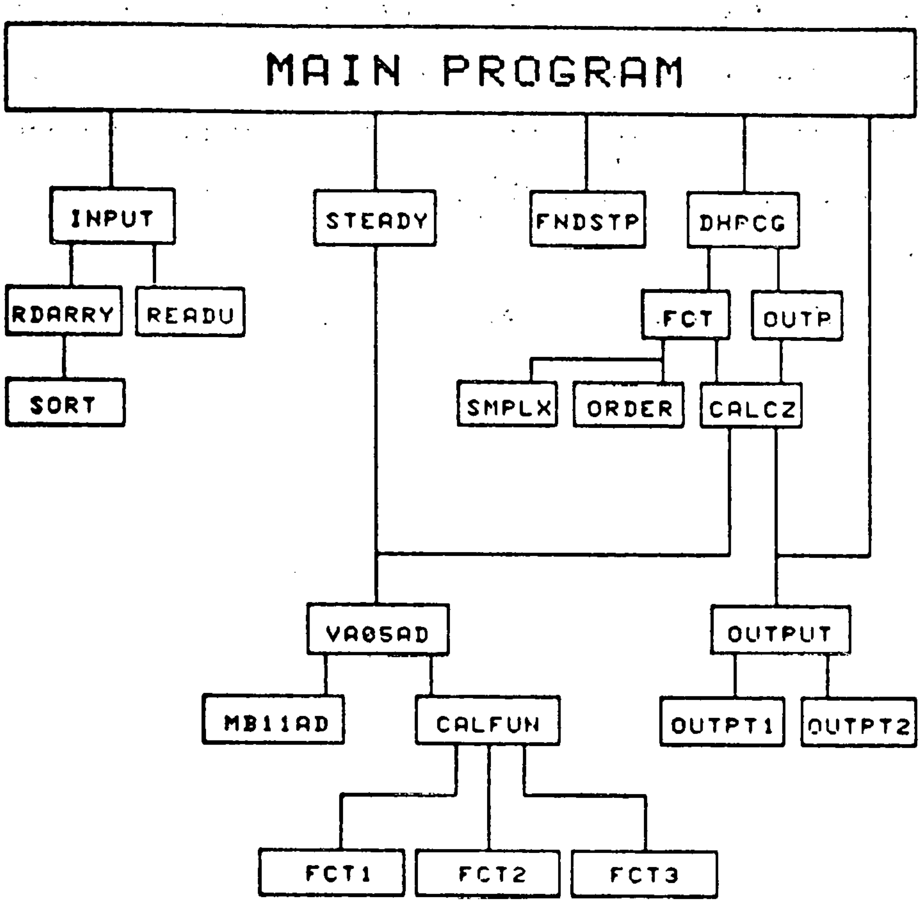
$$\text{Maximize } (Q_{tv} - \mu\sigma_1 - \mu\sigma_2 - \dot{m}_{\ell\ell}) \qquad \text{(EVP-19)}$$

where μ is a large positive number. Thus one, at least, of the slack variables σ's will be set to zero during the calculations if either or both of the corresponding constraints (EVP-10) or (EVP-11) are binding.

3. THE PROGRAM ODSP3

Figure 4 gives an overview of the program structure for ODSP3. At the upper level is the main program which directs the overall activity needed to produce a simulation. Four major tasks comprise a simulation: (1) Input of data, (2) Calculation of the original steady-state values for all variables, (3) Simulation of the dynamic behavior of the system and (4) Output of simulation results.

Flow charts for all the routines are given in Part 5.



MAIN STRUCTURE

OF

ODSP3

Figure 4

3.1 DATA INPUT

Data input to set up a simulation occurs using subroutines INPUT, RDARRY, SORT and READU. The user's manual for ODSP3 appears as Appendix A. This manual indicates what data are needed and the order and format in which to enter it. The data entered are the following:

1. Print control flags.
2. Pipeline data, giving geometry of all segments of pipe which connect the equipment together.
3. Valve data, giving throat areas.
4. Pressure drop constant for moisture separator.
5. Pump head vs. flow rate tables, both pumps.
6. Condenser and evaporator geometric data, water side data, heat transfer coefficients.
7. Turbine geometric data, model coefficient data.
8. Initial steady state data.
9. Initial dynamic simulation data.
10. Physical property data tables.
11. Input of independent variables versus time for control (valve K values and electrical load)
12. Simulation time data.

The data input is accomplished principally in subroutine INPUT, with physical property tabular data read in and sorted (if necessary) using RDARRY and SORT. Subroutine READU is used to input the independent variables versus time, items 11 above.

3.2 STEADY STATE CALCULATIONS

The steady state calculations performed for the OTEC model assume all equipment geometry is input by the user. Also given are the ammonia vapor flow rate through the turbine and the flow of liquid ammonia recirculating around the evaporator (through pipeline PE2).

The calculations for obtaining a steady state use subroutines STEADY, VAØ5AD, MB11AD, CALFUN and FCT3. STEADY directs the calculations. The equations are nonlinear and require iteration to solve some of them. The AERE Harwell subroutines VAØ5AD and MB11AD are used to effect this solution by iteration. The routine VAØ5AD is a sophisticated numerical routine which can solve the problem

$$\min_{x_1,x_2\ldots x_n} \sum_{j=1}^{m} f_j^2(x_1,x_2,\ldots,x_n) \ .$$

When $n = m$, the routine will adjust n x_i variable values to drive n functions f_j to zero (as that would be the minimum of $\sum_{j=1}^{n} f_j^2(x_1,\ldots x_n)$). To use VAØ5AD, the user supplies initial guesses for the variables $x_1,x_2,\ldots,x_n$. VAØ5AD will call repeatedly a user supplied subroutine named CALFUN to evaluate all the functions $f_j(x_1,x_2,\ldots,x_n)$, $j = 1,2,..,n$, for each call. VAØ5AD adjusts the values of $x_1,x_2,\ldots,x_n$ before each call, searching over these values to find the correct ones to drive all functions $f_j(x_1,x_2,\ldots x_n)$ to zero (by driving Σf_j^2 to zero). Routine MB11AD is used by VAØ5AD and need not be described in any detail here. User supplied routine CALFUN however is of interst. A three way switch occurs in CALFUN to cause the appropriate routine FCT1, FCT2 or FCT3 to be called. During steady state calculations, the correct routine to be called is FCT3; the other two are used during the dynamic simulation part of ODSP3. FCT3 receives guesses for

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"tear" variables $x_1, x_2, .., x_n$ and evaluates a set of tear functions (error functions) $f_1, f_2, .., f_n$ appropriate to solve the steady state nonlinear equations.

The steady state calculations proceed, briefly, as follows. First, because the mass flows are input data, the steady state mass flows in all the pipelines can be established. The flows are zero in the bypass line PT2 and in the line PC3. With flows established, the next task is to set the pressure levels in both the evaporator and condenser so the heat transferred in each will produce exactly these flows. For example the evaporator pressure must be set so that, via the heat transfer mechanism modeled in it (which involves ΔT driving forces), the exact amount of heat transfers as is needed to vaporize the ammonia flow through the turbine. Pressure affects the vapor temperature, which must be the saturation temperature corresponding to the pressure, and the higher it is, the smaller the ΔT driving force in the evaporator, and thus the smaller the heat transferred. The vapor flow out is user specified so the pressure must be set to cause exactly this flow. Similarly the pressure in the condenser affects the temperature level of the vapor in the condenser. The lower it is assumed, the lower the saturation temperature and the smaller the ΔT driving force to cause heat to flow from the condensing vapor into the cold sea water. Thus, lowering PRSCND (P in the condenser) lowers the heat transferred. With the flows set, the pressure must be adjusted to condense all the incoming vapor.

After pressures are established, one must adjust something in each flow path ((1) the pipeline from the condenser to the evaporator, (2) the recirculation line around the evaporator, (3) the flow from the evaporator through the turbine to the condenser) to cause exactly the right pressure drops in each for the flows required.

The pressure losses for the given flows are calculated everywhere except in valves CV1, CV4 and through the turbine. The losses in each of these devices are required to be those just established and for CV1 and CV4 the throat areas of the valves are adjusted. The design pressure ratio of the turbine is computed and set as the adjustable parameter in its line.

Because of secondary but not negligible temperature effects of the pumps and turbine, the above calculations are actually imbedded in a computational loop. The order of the entire steady state calculations proceeds as follows.

(1) All flows are established.

(2) Values are guessed for the tube temperature in the evaporator, TTBEVP, the temperature of the ammonia vapor in the condenser, TAVCND and the temperature of the inlet liquid to the evaporator, TMPPE1. These are rescaled by dividing by nominal values so the variables seen by VAØ5AD are "nominally" 1.Ø in value.

VAØ5AD calls CALFUN which calls FCT3 repeatedly to solve basically for the pressure levels in both the condenser and evaporator. Calculation starts with the evaporator and moves counterclockwise around the system. The error functions (equal in number to the number of guessed variables) are

(1) difference between given and calculated flow of vapor out of the evaporator (calculated vapor flow reflects heat transferred in evaporator)

(2) difference between given and calculated liquid flow out of condenser

(3) difference between guessed and calculated temperature of liquid stream entering evaporator.

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VAØ5AD adjusts the guessed variables (TTBEVP, TAVCND and TMPPE1) to drive these errors to zero.

After the pressure levels are established, control returns from VAØ5AD to STEADY, where the remaining noniterative calculations occur. These include setting internal variables for evaporator and condenser, calculating pressure losses so the throat areas of CV1 and CV4 can be set and establishing the calculated design pressure ratio of the turbine.

Values for all the variables are saved at this point, at a large negative time (-1ØØØØ secs). Upon starting the dynamic simulation they are resaved at time equal zero. Thus for very early times in the dynamic simulation, variable values needed, because of time delays, are readily found even before time equals zero by linear interpolation.

3.3 TRANSIENT CALCULATIONS

After the steady state calculations are completed, control returns to the main program. Before initiating the dynamic simulation, the times are found at which any one of the independent variables (K's for valves and also the electrical load on the turbine) has a step change in its value versus time. At these times one can be assured of discontinuities appearing in the derivatives to be evaluated for the state variables. Thus the simulation will be stopped and restarted at these points in time because the restart procedure of the integration routine can tolerate these discontinuities, whereas the "predictor" "corrector" procedure used after starting will have numerical problems. The subroutine FNDSTP locates the times for each of these steps and records them in the table TIMSTP.

The dynamic simulation uses subroutines DHPCG, FCT, SMPLX, ORDER, CALCZ, VAØ5AD, MB11AD, FCT1, FCT2 and OUTPUT.

DHPCG is a routine from the IBM SSP package of subroutines, and it is a Hamming-Predictor/Corrector integration package for numerically integrating first order ordinary differential equations. A copy of IBM's documentation for it is in Part 3.

DHPCG, once started, will integrate forward in time a system of ordinary first order differential equations (state equations) from an initial state; the equations are of the form

$$\frac{dx_i}{dt} = f_i(x_1,x_2,..,x_n,t)$$

$$x_i(0) = x_i^0, \text{ given}$$

$$i = 1,2,...,n$$

A user written routine called FCT is called by DHPCG, repeatedly to evaluate $f_i(x_1,x_2,...,x_n,t)$ for values of $x_1,x_2,...,t$ supplied by DHPCG. Because it is a predictor/corrector scheme, the values of t supplied may repeat or even decrease as the routine iterates and/or reduces or increases the integration step size.

Subroutine FCT has the overall task of supplying the RHS's (Right Hand Sides) $f_i(x_1,x_2,...,x_n,t)$ to the state equations. However to do this really requires solving a moderately large set of nonlinear algebraic equations at each request as the form of the real simulation problem is

Solve

$$\frac{dx_i}{dt} = f(x_1,x_2,..,x_n,z_1,z_2,..,z_m,u_1u_2,..,u_r,t)$$

subject to $g_j(x_1,..,x_n,z_1,..,z_m,u_1,..,u_r) = 0$

where $i = 1,2,..,n, \quad j = 1,2,..,m$.

The variables z_1 to z_m are algebraic variables whose values are determined by solving the algebraic equations $g_j = 0$, $j = 1,2,..,m$. They are thus functions of the state variables x_i and the variables u_k. The u_k variables are the user supplied independent variables whose values must be specified versus time by the user. An example is the user specifying the valve constant K_{CV1} versus time. Thus the u_k variables are strictly functions of time and act as parameters to the problem, giving the problem the desired form:

Solve

$$\frac{dx_i}{dt} = f(x_\ell, z_j(x_i, u_k(t)), t, \qquad \ell = 1,..,n,\ j = 1,..,m,\ k = 1,..,r)$$

$$= f(x_\ell, t,\ \ell=1,2,...,n)\ .$$

The routines SMPLX, ORDER, CALCZ, VAØ5AD, MB11AD, FCT1 and FCT2 are used to solve for the variables z_j in terms of all x_i and u_k by solving the algebraic equations g_j.

On entry into FCT, the algebraic z variables are found which are associated with the two major flow paths ((1) vapor NH_3 from the evaporator through the turbine and bypass lines to the condenser and (2) liquid NH_3 from the condenser to the evaporator plus the recirculation flow of liquid NH_3 from the evaporator hotwell back to the evaporator). The flows, intermediate pressures and temperatures can be solved along each path separately. Iteration in both cases guesses flows and adjusts these to get the correct total pressure drops. Thus CALCZ uses VAØ5AD once with FCT1 to solve for the conditions in flow path (1) and FCT2 for flow path (2). With all flows into and out of the condenser and evaporator known, then control returns from CALCZ to FCT. FCT then solves in turn for the internal flows of heat and material for the evaporator (using routine ORDER and SMPLX) and for the condenser. The modeling equations for the evaporator are in Section 2.10 where a number of different operating modes are stated, such as: (1) the tubes are dry, (2) the tubes are fully loaded with NH_3, (3) the tubes are partially loaded with NH_3, (4) no liquid is entering the evaporator, (5) liquid is entering but insufficient in amount to match the vaporization rate or (6) liquid is entering in excess of the evaporation rate, etc. By checking (in routine OUTP) various conditions at the start of each complete integration step taken by subroutine DHPCG, a number of flags are set which indicate which inequality and equality constraints are to hold during that step. Thus if the tubes are fully loaded with NH_3 liquid, then the flag is set requiring the $\frac{dM_\ell}{dt} \leq 0$ for the evaporator, i.e., that the amount of liquid on the tubes cannot increase. Using these flags the correct inequalities and equalities are set up, all of them linear in the internal heat and material flows within the evaporator. To decide on internal flows, these constraints are reordered in subroutine order to put them into the order: (1) all greater than or equal constraints, (2) all equalities, (3) all less than or equal constraints. Also any of the inequalities are reversed if their right hand side is negative by multiplying through by -1. Equalities are also multiplied through by -1 if their RHS's are negative. The routine SMPLX, an available debugged but not very elegant Linear Programming routine, requires the above order for constraints and also requires positive right hand sides.

The return from SMPLX gives all internal flows ($\dot{m}_{\ell\ell}$, $\dot{m}_{\ell v}$, $\dot{m}_{Hv}$) as well as the heat flux ($Q_{t\ell}$) within the evaporator. The RHS's of the evaporator state variable equations are then calculated.

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The routine FCT continues by solving for the internal heat and mass flows within the condenser. Also the RHS's are calculated for the condenser. The last step is to calculate the RHS for the turbine state variable equation for d(RPM)/dt; return is then made to DHPCG.

After completion of an integration step (which usually requires two calls but may have involved several calls to FCT to adjust the time step taken), DHPCG calls user supplied routine OUTP. In this routine the user can write out results and/or save them. In the ODSP3 system, results are saved. However routine DHPCG supplies values for only the state variables so OUTP must call CALCZ to evaluate the z variables for the two flow lines. It is here that the decisions are made as to whether the tubes are dry or full or partially full, etc., for the evaporator for the next time step. All variables are saved if the time equals or exceeds the time at which the next saving of values is requested via the user input (Variable DTSNP).

The last phase of ODSP3 is the printing out of the simulation results, which is accomplished by the MAIN program calling OUTPUT. OUTPUT simply decides whether to call OUTPT1 and/or OUTPT2 based on the value of user input variable PCKOUT. (See first card, Appendix A.) OUTPT2 outputs all of the variables and is executed first if requested. The format is inelegant, as this option is an aid for debugging. OUTPT2 outputs a selected subset of variables with English headings.

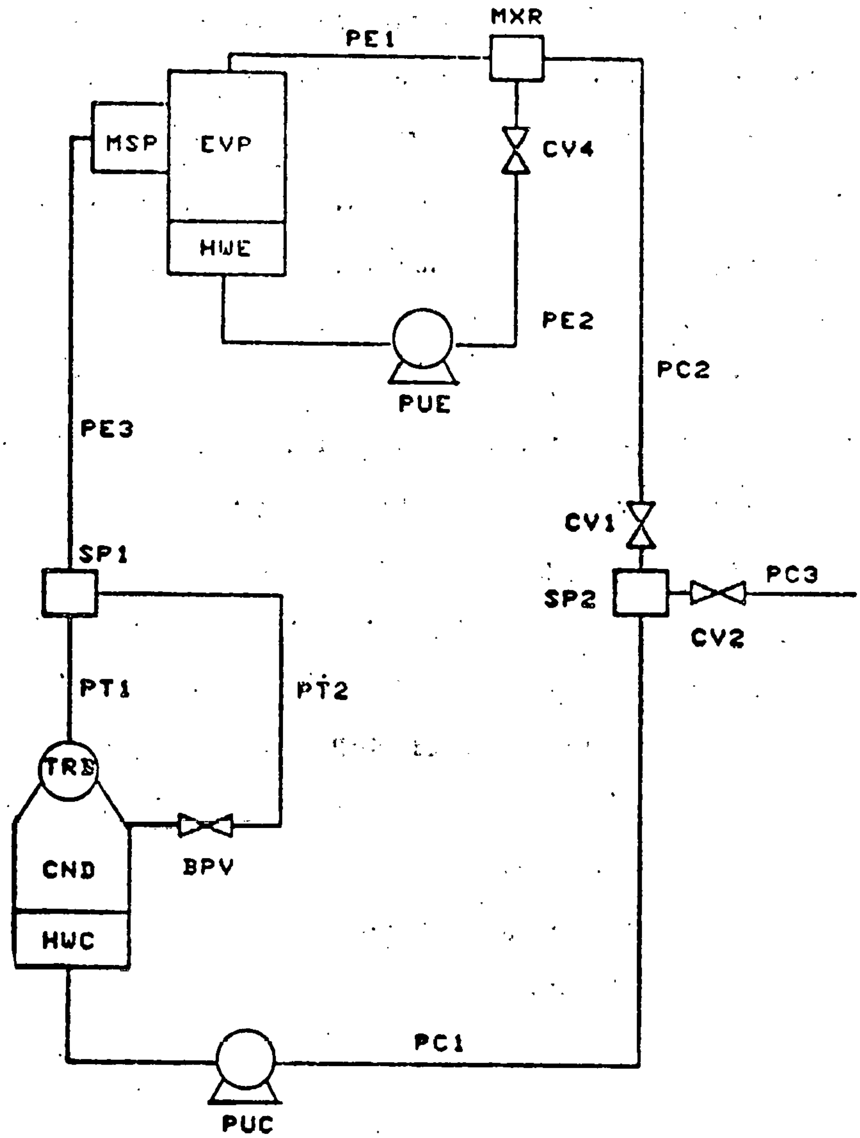

Figure 5
FLOWSHEET FOR
OTEC PLANT

All program variables (not including constants) are named in following manner:

1- Each name comprises a 3-character prefix and a 3-character suffix.

2- The prefix is one of the following:

TMP	Temperature
PRS	Pressure
VFR	Vapor flow rate
LFR	Liquid flow rate
TWA	Average water temperature
TTB	Average tube temperature
TAV	Average ammonia vapor temperature
MAV	Mass of ammonia vapor
MAL	Mass of ammonia liquid
RPM	RPM

3- The suffix is the 3-character code for the device to which the variable relates (see Figure 5).

CV1 to 4	Control Valves
BPV	Bypass Valve
EVP	Evaporator
CND	Condenser
HWE	Hot well, evaporator
HWC	Hot well, condenser
MSP	Moisture separator
TRB	Turbine
PUE	Pump for recirculating NH_3, evaporator

PUC	Pump for transferring NH_3 out of condenser
SP1	Splitter for flow through turbine and bypass valve
SP2	Splitter to allow liquid NH_3 to leave system
MXR	Miser
PC1-3	Pipelines following condenser
PE1-3	Pipelines around evaporator
PT1-2	Pipelines around turbine

4- The variables are named for either the unit in which they occur or the units from which they exit, e.g., the temperature of the stream leaving PC1 is called TMP PC1.

Data Input Cards for ODSPI (OTEC Dynamic Simulation Package, Version 1)

The content and format for the data input cards follow. Many of these data are entered in tabular form, with the table always entered in the following format. Ea ch card for the table has two entries, the first being the value of the independent variable and the second being the value of the dependent variable. Up to 19 pairs of values may be entered. The input of a table is terminated by entering a card containing the number 1.ØD2Ø. The card formats are -

Table entry (2D1Ø.4)

Termination card (D1Ø.4).

Data input cards for ODSP1, OTEC Dynamic Simulation Package, Version 1.

First card ECHO FLAG

=0 do not ECHO print the input cards

>0 do ECHO print all input cards

<0 do ECHO print all input cards, except those entered as tables

PCKOUT FLAG

=0 execite pit½it rpitome PIT½T;

(outputs a selected set of variables)

=/= 0 execute output routine OUTPT2

(outputs all variables)

FORMAT (215)

Next Cards One card for each pipeline. Each contains the following 4 data items:

L Length of pipe, ft.

K K for fittings, entrance and exit effects, etc., dimensionless.

D Diameter, in.

Z Vertical rise in pipe from entrance to exit (negative valve says pipeline falls in elevation, ft.

Format (4D1Ø.4)

Enter one card for each of the following pipelines:

1. PC1
2. PC2
3. FC3
4. PE1
5. PE2
6. PE3
7. PT1
8. PT2

Next card ACV1 Throat area of CV1, in^2

ACV2 " " " CV2, "

ACV4 " " " CV4, "

ABPV " " " BPV, "

Format (4D1Ø.4)

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Next card KMSP The equivalent of a valve constant to calculate pressure drop for the moisture separator, MSP.

Format (D1Ø.4)

Next cards Enter in "Table Format" (See page 1)

mass flow rate (lbm/sec) vs pressure head produced (psia) for the two pumps, PUC and PUE.

Table

1 in vs Head for PUC

2 in vs Head for PUE

Next cards Condenser and Evaporator Data Input

Enter two cards for the condenser and then two for the evaporator, each containing the following data items.

Card 1

ITD Inside tube diameter, in.

OTD Outside tube diameter, in.

LEN Length of a tube, ft.

NTB Number of tubes

CTB Heat capacity of tube material, Btu/lbm ^oF

DTB Density of tube material, lbm/ft^3

Format (6D1Ø.4)

Card 2

VOL Total vapor volume for unit (including vapor volume of moisture separator (if appropriate) and hot wells), ft^3

WFR Fixed water flow rate through unit, lbm/sec

TWI Inlet water temperature, ^oF

HWT Water/Tube heat transfer coefficient, Btu/ft^2 hr ^oF

HTV Tube/Ammonia heat transfer coefficient, Btu/ft^2 hr ^oF

Format (5D1Ø.4)

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Next cards Turbine Input Data (2 cards)

Card 1

ITRB Moment of inertia for turbine plus

DBLADE Blade diameter, ft.

HBLADE Blade height, ft.

Format (3D1Ø.4)

Card 2

KAY1, KAY2, KAY3 KAY1-KAY2*T1+KAY3*T1*T1

Next cards Two cards to define initial steady state

Card 1

FRD Design flow rate of NH_3 through turbine, lbm/sec

LFRPE2 Flow of liquid NH_3 recirculating around evaporator through PUE and PE2, lbm/sec

RPMD Design RPM for turbine

Format (3D1Ø.4)

Card 2

NPWRD Design net power for turbine, kW

TBLD

TJBLD

GJBLD

GLD

Losses in turbine, kW

EFFD η at design for turbine, dimensionless.

Format (6D1Ø.4)

Next card Input to Initialize Transient Calculations

MALHWE Mass of ammonia liquid initially in evaporator hot well, HWE, lb

MALHWC Ditto for condenser hot well, HWC, lb

PRSPC3 Pressure of exit of PC3, the pressure of the external NH_3 storage vessel, psia.

Format (3D1Ø.4)

Next Cards Physical Property Data Tables. Each physical property data table is entered in "Table Format" (See page 1). Enter data for following physical properties.

Table	Independent Variable	Dependent Variable
1.	T, °F	Viscosity of Ammonia Vapor, lbm ft/sec
2.	T, °F	Cp of NH_3 vapor, Btu/lbm °F
3.	T, °F	$\gamma \equiv Cp/Cv$ of NH_3 vapor, dimensionless
4.	T, °F	Density of NH_3 liquid, lbm/ft^3
5.	T, °F	Cp of NH_3 liquid, lbm/ft^3
6.	T, °F	Viscosity of NH_3 liquid, lbm ft/sec
7.	T, °F	Thermal conductivity NH_3 liquid, Btu/ft hr °F
8.	Saturation T, °F	Saturation P for NH_3, psia
9.	Saturation T, °F	dP_{sat}/dT_{sat} for NH_3, psia/°F
10.	Saturation t, °F	Heat of vaporization for NH_3, Btu/lbm

Next cards Control Variable Input

Control variable input is given in "Table Format" (See page 1). The independent variable is always "time" (seconds). To represent a step change in the value of the control variable, simply repeat the time at which the step occurs, giving, as the first control variable value, the value just before the step and, as the second, the value just after the step. an esample is:

time	Base Value, BV	Amplitude, $\hat{A}$	Frequency, f
Ø.Ø	2.7	0.1	2
Ø.5	2.7	0.1	2
Ø.5	Ø.Ø	0.1	2
2ØØØ.	Ø.Ø	0.1	2

The control variable starts at time t=0 around the value 2.7, following the equation: value = BV + A cos (ft); +, sec, continuing in this manner until time t=0.5 seconds. At that time, the base value switches to Ø.Ø and remains there until t=2ØØØ.Ø , a time exceeding any expected simulation to be run.

Tables must be entered for the following control variables.

1. KCV1   K for value CV1, unitless
2. KCV2   " " " CV2, "
3. KCV4   " " " CV4, "
4. KBPV   " " " BPV, "
5. NPWR   Net power output of turbine (P), kW

If BV for NPWR is 1.021 at time t=0, then the simulation will hold RPM at design and calculate resulting load needed.

Last Card   Simulatime Time Data

DTINTG   Initial and also largest time step to be used when integrating using IBM's SSP routine DHPCG (Double precision Hamming Predictor Corrector Routine). Recommended value is Ø.5 seconds.

DTSNP   Increment in time for program to save values of important simulator variables. Should be an integer multiple of DTINTG. Recommended value is Ø.5 sec.

DTPRNT   Increment in time for program to print out values of important simulation variables. Should be an integer multiple of DTSNP.

SIMTIM   Total length of dynamic simulation, seconds.

IDBLL   Number of times initial time step can be doubled.

Format (4D1Ø.4,IS)

Section 5

Detailed Flow Charts/Algorithms

for

ODSP3

On the following pages are sample input data prepared as described above.

Note - the termination card for table input is included as the last entry in table for the control variable input. Therefore, the KCV1 data was listed as:

Time	BV for KCV1	DKCV1	FCV1
Ø.Ø	Ø.4	0.	0.
1.ØD2Ø	Ø.4	0.	0.

terminates input

The last card will terminate KCV1 data input as well as give a time for which the value Ø.4 holds. (This value is always open with KCV1=Ø.4 with this data input.)

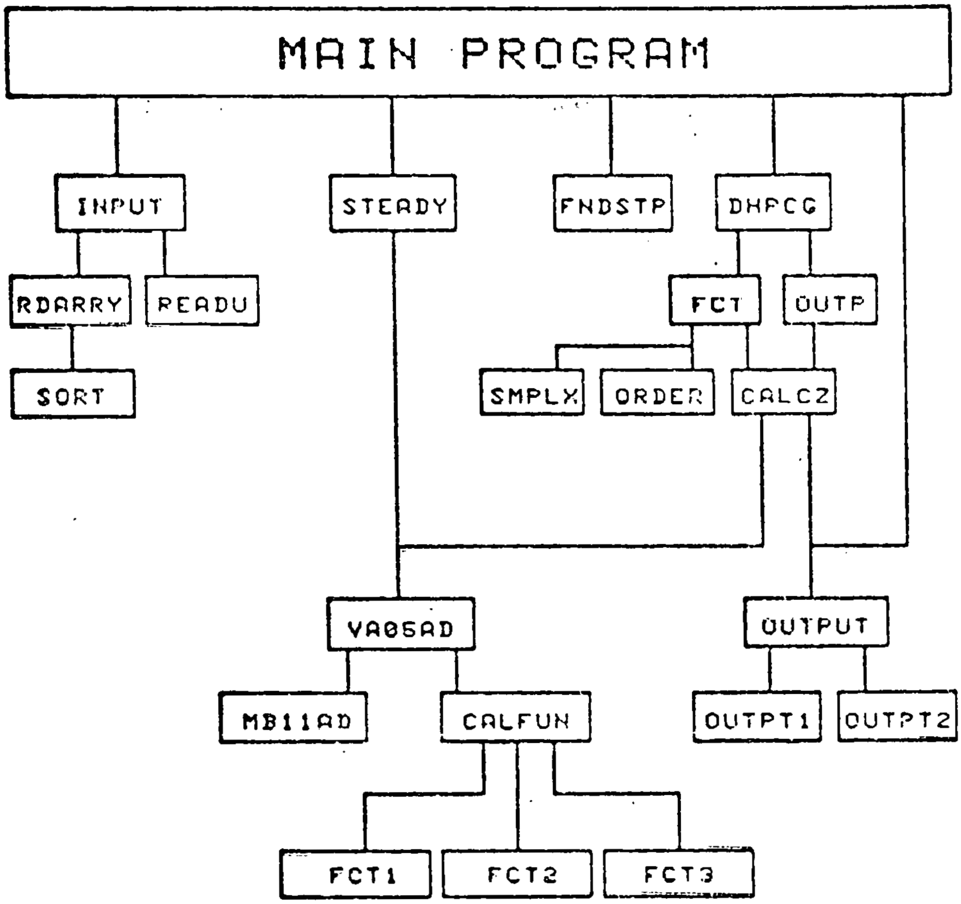


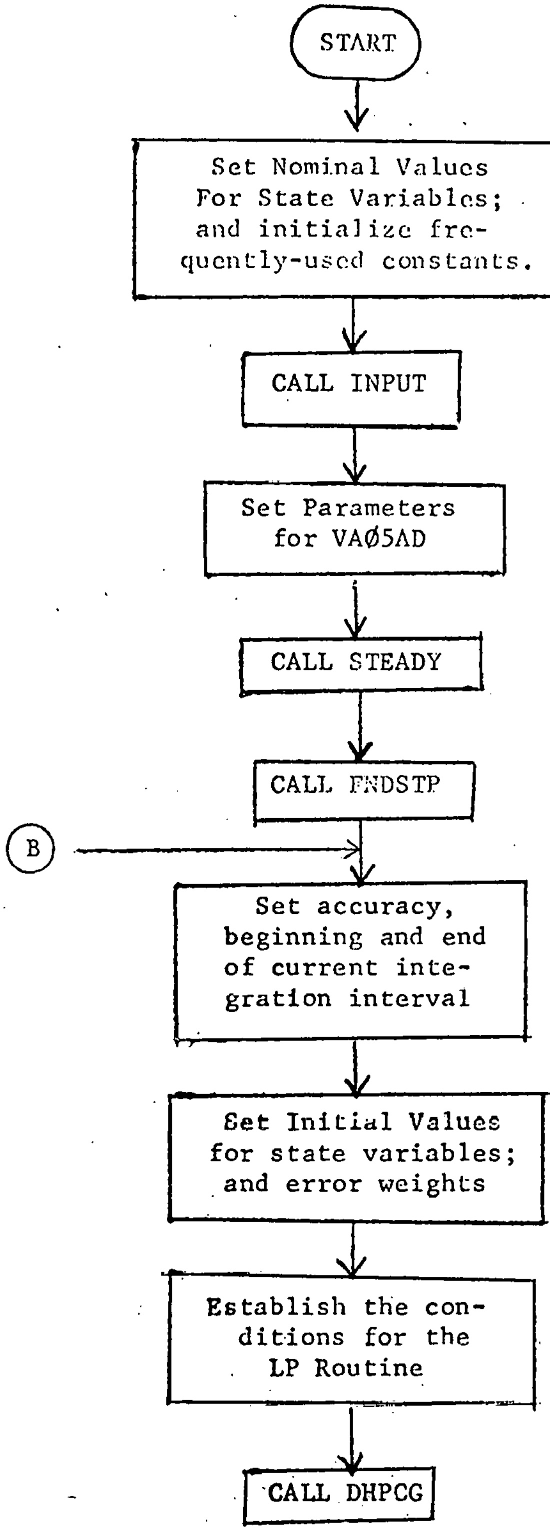
Figure 6.

MAIN STRUCTURE

OF

ODSP3

Main Program:



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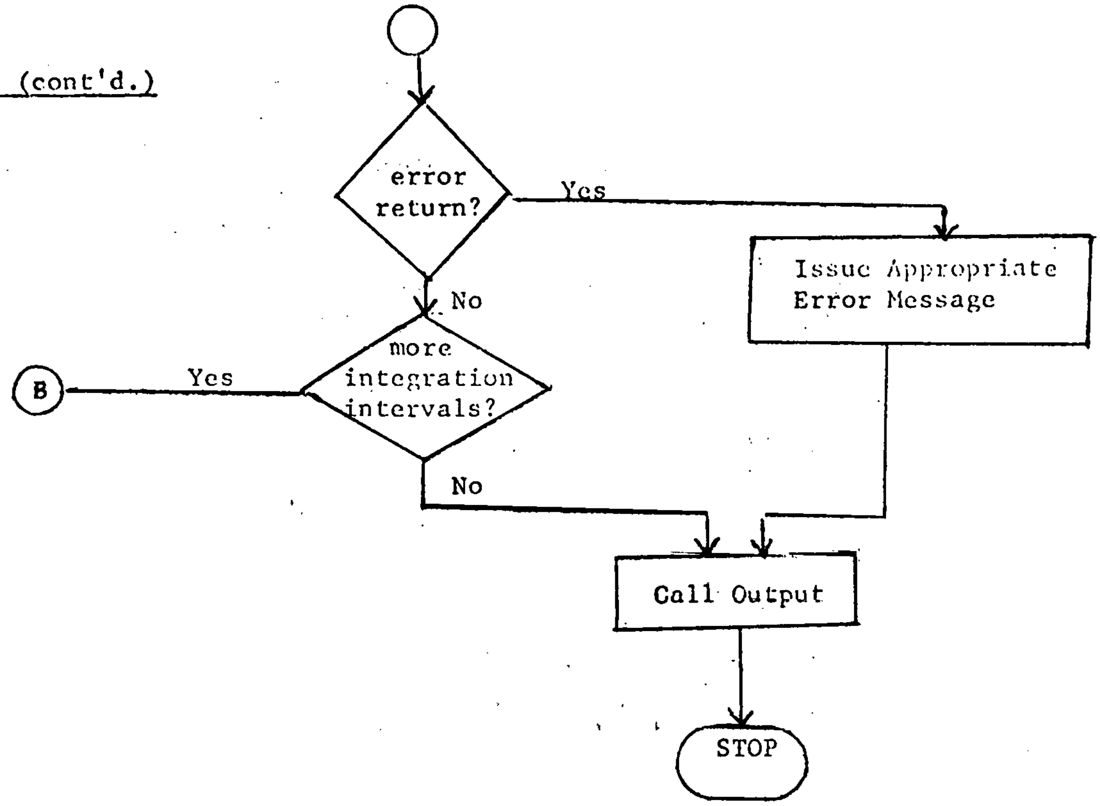
Main Program (cont'd.)



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Subroutine Input

1. Read in pipeline data for complete system and control valves area.
2. Read in flow rate vs. pressure head for each pump.
3. Read data for condenser's components and calculate the geometric and heat transfer parameter (Equ. CND 1 to Equ. CND 9).
4. Read data for evaporator's components and calculate the parameter.
5. Read turbine geometric data.
6. Read in steady state FRD, LFRPE 2, RPMD.
7. Read turbine characteristic parameter and calculate total turbine power and total loss.
8. Read in the data required for the transient simulation.
9. Read in physical properties of NH_3 vs. Temp.
10. Read in control input.
11. Read in simulation time data.

Subroutines called by INPUT:

SUBROUTINE RDARRY (A,NA):

Reads a table from the input device and stores it in the two-D array A. Input is terminated when a large number (∞) is encountered in the first field of an input record. The size of the table is returned in NA.

SUBROUTINE READU (J):

Reads the input data associated with the control input whose index is J. The data for each control input consists of a table with four columns as shown below:

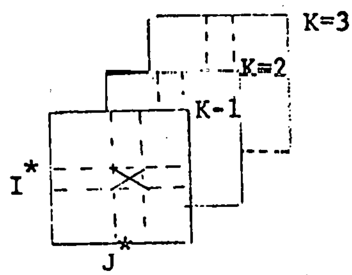
time, t	ΔA	A	F

The value of the control input takes the form:

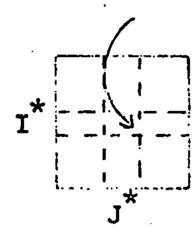
$$A + \Delta A \cos (2\pi F t)$$

The table is terminated with a large number in the first field that also serves as $t = \infty$. The control input data is stored in two arrays; a 3-D array SAVU (I,J,K), and a 2-D array TIMU (I,J) having the following format:

K=1 → A
K=2 → ΔA
K=3 → F



SAVU(I,J,K)



TIMU (I,J)

SUBROUTINE SORT (A,NA):

Sort's a table according to its "key" (input variable) into ascending order.

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Subroutine FNDSTP

To avoid the severe numerical problems that arise if integration of a function that goes through a step change is attempted, it was decided that the total simulation length be broken down into a number of intervals during which the functions to be integrated are "well-behaved". Step changes can occur in either the algebraic (z) or control (u) variables (the state variables have to be continuous functions of time). Upon close examination of the problem, we came to the conclusion that the exact times at which the z-variables take step changes cannot be known a-priori (i.e. before the integration starts). Steps in the control variables, however, are easily found since the control variables are known functions of time. If the times at which step changes occur in the u-variables are determined, the integration can be carried through over several time intervals that are bounded by the steps in the u-variables.

Subroutine FNDSTP scans all the control inputs, and assembles a vector called TIMSTP that has as its elements (in ascending order) the points on the time axis at which steps occur in the u-inputs. The last element of TIMSTP is set to hold the total simulated time (SIMTIM), so that the last integration interval ends after SIMTIM seconds from the start of the simulation. The size of TIMSTP is NSTP. A flow chart of FNDSTP follows.

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FNDSTP

1. Scan array T and record steptime in S.
2. Steps are detected if two consecutive entries are equal and store this message.
3. Sort S into ascending order and eliminate redundant entries.
4. If two elements are equal, "compress".
5. If TIMSTP (I) > TIMSTP (I+1), interchange them and set "switch flag" SW to 1.

Solution of a set of n non-linear eqns. in n unknowns:

Two Harwell-Library subroutines (VAØ5AD and MB11AD) are employed in the solution of systems of non-linear eqns. They are documented elsewhere. VAØ5AD basically attempts to minimize $\sum_{i=1} (F_i(\underline{x}))^2$, and requires, therefore, the evaluation of the function $\underline{F}$ for given values of the indept. variables $\underline{x}$. It assumes the existence of a subroutine called CALFUN that will evaluate those functions.

Since VAØ5AS is used to solve different sets of Eqns. in the course of the simulation, a flag is needed to select the correc set of equations to evaluate. This flag is called FCTID and can assume the values 1, 2, and 3. CALFUN will call one of three subroutines depending on the value of FCTID. These subroutines are called FCT1, FCT2, and FCT3, and are related to the value of FCTID in an obvious manner. FCT1 contains the Eqns. for the vapor branch between the evaporator and the condenser (including the turbine). FCT2 has the model Eqns. for the liquid branch from the condenser to the evaporator (including the recirculator line). FCT3 has the describing Eqns. for the whole system in the steady state.

In the steady-state calculation, subroutine STEADY calls VAØ5AD after setting FCTID to 3. This selects FCT3 for the evaluation of the functions that VAØ5AD is trying to minimize.

In the transient calculation, subroutine CALCZ calls VAØ5AD twice, as the solution for the z-variables proceeds from the evaporator to the condenser in the vapor branch, and then from the condenser to the evaporator in the liquid branch. In the first half of the calculation CALCZ sets FCTID to 1 and FCT1 is selected, and in the second half it sets FCTID to 2 whereby FCT2 is chosen. Separate flow charts for STEADY, CALCZ, FCT1, FCT2, and FCT3 are given later showing the computational sequence adopted. The flow chart for CALFUN is given below:

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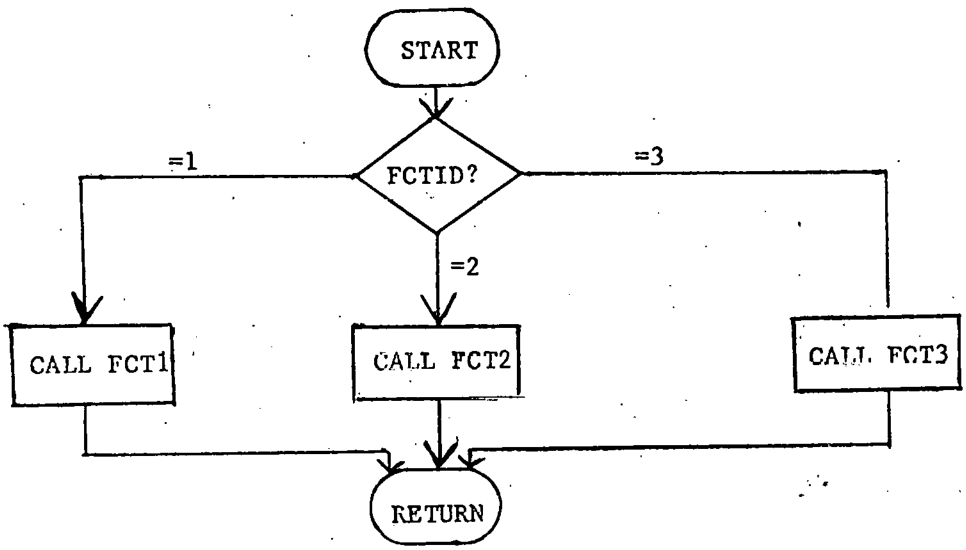
Subroutine CALFUN:



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Subroutine Steady

1. Given flow through turbine and in recirculation line, calculate the flows in the rest of the pipelines.

2. Guess and scale TTDEVP, TAVCND, TMPPE1.

3. CALL Subroutine VAØ5AD
   A. If error message return, STOP

4. Calculate the following quantities in evaporator:
   A. NH_3 vapor temp. (heat balance)
   B. Avg. water temp.
   C. Hot well temp.
   D. Vol. and mass of NH_3 liquid in film
   E. Vol. of NH_3 liquid in hot well, (Equation of state)
   F. Mass of NH_3 vapor.

5. Solve for turbine design conditions:
   A. Design inlet pressure
   B. Design outlet pressure
   C. Design pressure ratio
   D. Design inlet temp.
   E. Design enthalpy change (Equation T-2)
   F. Turbine speed

6. Solve for condenser variables:
   A. Tube Temperature (heat balance)
   B. Average water temp. (heat balance)
   C. Liquid ammonia drain rate
   D. Calculate volume and mass of ammonia liquid in film
   E. Calculate volume of ammonia liquid in hot well
   F. Calculate mass of ammonia vapor in condenser.

7. Solve for pressure at outlet of PC2. (mixer pressure)

8. A. Calculate the required throat area for CV4, and adjust the input valve according.
   B. If PUE is too small, issue error message and exit.

9. Solve for pressure at outlet from CV1.

10. A. Calculate the required throat area for CV1, and adjust the input valve accordingly.
    B. If PUC is too small, issue error message and exit.

11. Store the steady-state values.

Subroutine FCT

1. Calculate the z-variables call subroutine CALCZ

2. Calculate the internal flows and net heat transfer in the evaporator using the linear - Programming Routine SMPLX
   A. Calculate densities, heat capacities and heats of vaporization
   B. Calculate the volume of the ammonia vapor in the evaporator
   C. Zero the simuless tableaux
   D. Set the suitplex constraint to the equations
   E. Set up the objective functions
   F. Call subroutine SMPLX

3. Retrieve the output values from the result vector

4. Calculate the derivatives

5. Calculate B (Eqn. CND-13)

6. Calculate overall heat capacity of vapor + liquid NH_3 (Eqn. CND-14)

7. Calculate the drain rate into HWC

8. Calculate the net power output and mass of liquid NH_3 in evaporator.

Subroutine FCT1

1. Calculate the density of vapor NH_3 and pressure at moisture separater

2. Calculate the following quantities in Pipeline PE3
   A. Density of NH3 vapor
   B. Viscosity
   C. Velocity
   D. Reynolds
   E. Friction factor and pressure at exit from PE3
   F. Calculate delay time in PE3
   G. Calculate temperature at exit from PE3

3. Check the bypass valve; closed? If yes, go to 4
   A. Do the calculation for pipeline PT2 (Reference procedure 1)

4. Do the calculation for pipeline PT1 (Reference procedure 2)

5. Do the turbine calculation
   A. Losses (Eqn. T-3)
   B. Total power output (Eqn. T-7)

Subroutine FCT2

1. If CV1 and CV2 are closed; return

2. Calculate the following quantities in pressurizing pump PUC
   - A. Density of liquid NH_3
   - B. Heat capacity of NH_3 at constant pressure
   - C. Pressure at exit from PUC
   - D. Temperature at exit from PUC

3. Calculate the following quantities in pipeline PC1
   - A. Density of liquid NH_3
   - B. Viscosity
   - C. Velocity
   - D. Reynolds Numbers
   - E. Pressure at exit from PC1
   - F. Temperature at exit from PC1

4. If CV2 is closed; go to 5
   - A. Calculate liquid flow rate in PC2
   - B. Calculate pressure at exit from CV2
   - C. Do the calculations for pipeline PC3 (reference procedure 3)
   - D. Go to 5-B

5.
   - A. Liquid flow rate PC2 = Liquid flow rate PC1
   - B. If CV1 closed; go to 6-A
   - C. Calculate pressure at exit from CV1
   - D. Do the calculation for pipeline PC2 (reference procedure 3)
   - E. Go to 6-B

6.
   - A. Liquid flow rate at PC2 = 0
   - B. If CV4 is closed; go to 7-A
   - C. Mass balance in mixer
   - D. Do the calculation for recirculation pump PUE (reference procedure 2)
   - E. Do the calculation for PE2 (reference procedure 3)
   - F. Calculate the pressure drop across CV4
   - G. Go to 7-B

7.
   - A. Liquid flow rate at PE2 = 0
   - B. Heat balance in mixer
   - C. Determine the flow in each line by changing the control valves CV1, CV2 and CV4, open or close state

Subroutine FCT3

1. Calculate the following quantities in Evaporator
   A. Outlet water temperature
   B. Heat transferred from water to tube
   C. Heat transferred from tube to liquid and vapor ammonia
   D. Ammonia vapor temperature
   E. Liquid ammonia temperature in HWE
   F. Vapor pressure
   G. The flows internal to the evaporator

2. A. Calculate the vapor density in moisture separator
   B. Calculate pressure at exit from moisture separator

3. Calculate the following quantities in PE3
   A. Vapor density
   B. Viscosity
   C. Velosity (Eq. P-1)
   D. Reynolds (Eq. P-3)
   E. Friction factor (Eq. P-5 or P-6)
   F. Pressure (Eq. P-7)
   G. Temperature at exit from PE3

4. Do the same calculation for PT1

5. A. Calculate the enthalpy change across the turbine
   B. Calculate temperature of "subcooled vapor" exiting the turbine

6. Calculate the following quantities in Condenser
   A. Pressure
   B. Outlet water temperature
   C. Heat transferred from water to tube
   D. Heat transferred from tube to liquid and vapor ammonia
   E. The vapor flow rate out of the condenser

7. Calculate the following quantities in Pressurizing pump PUC
   A. Liquid density
   B. Heat capacity of ammonia
   C. Total increase in pressure head (PU-1)
   D. Pressure
   E. Temperature at exit from PUC

8. Do the same calculation as in procedure 3 for pipeline PC1

9. Calculate the temperature at exit from PC2

10. Do the calculation for PUE (Reference procedure 7)

11. Do the calculation for PE2 (Reference procedure 3)

12. Do the heat balance in mixer

Subroutine CALCZ

1. Update the state variables of the system.

2. Solve for z-variables in Evaporator - Hot well:
   A. Volume of NH_3 vapor
   B. Pressure in evaporator
   C. Heat transferred from water to tube
   D. Water outlet temperature

3. Solve for z-variables in Condenser:
   A. Pressure in condenser
   B. Heat transferred from water to tube
   C. Water outlet temperature
   D. Heat transferred from tube to liquid and vapor ammonia

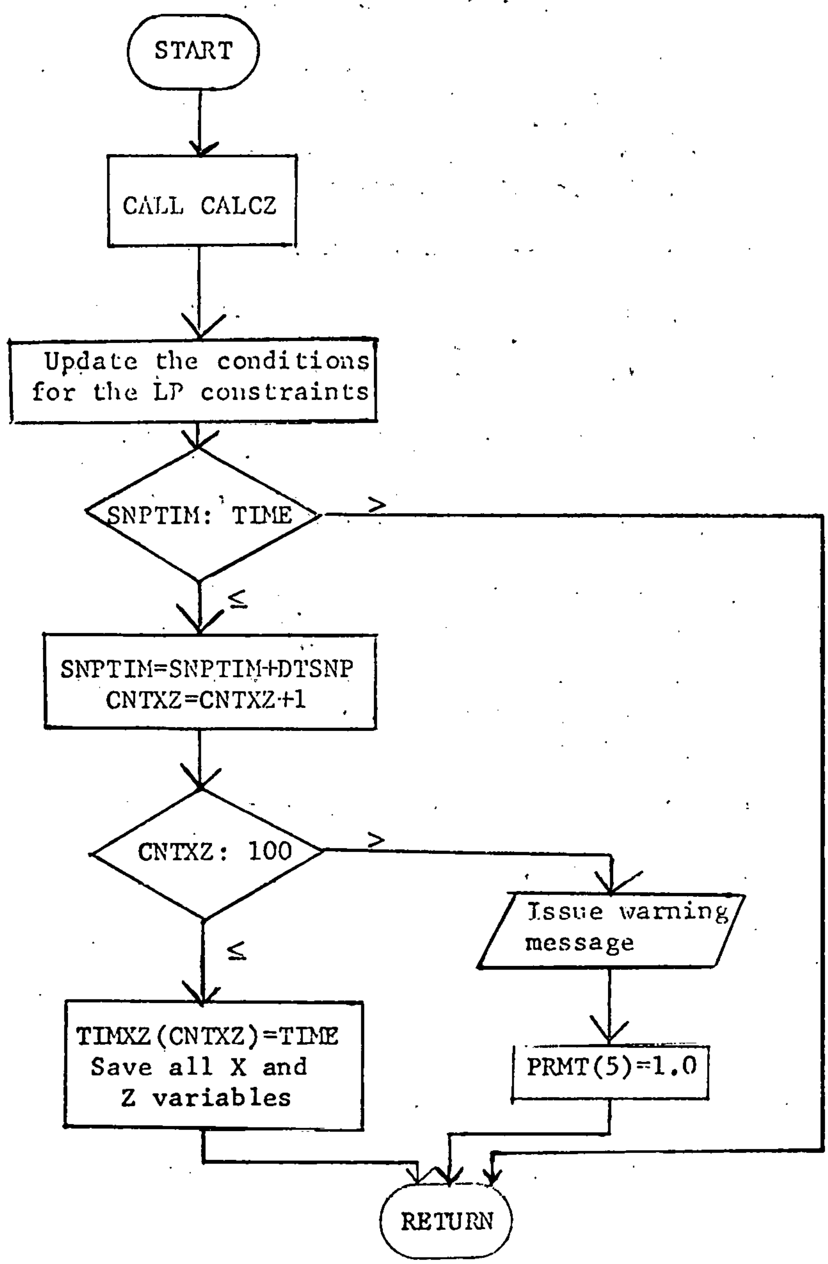
4. Solve for z-variables in "Vapor Branch"
   A. If bypass valve is closed, the vapor flow rate at PT2 equals zero
   B. Guess vapor flow rates in PE3 and PT1
   C. CALL subroutine VAØ5AD

5. Solve for z-variables in Liquid Branch
   A. If CV1 closed LFRPC2 = 0
   B. If CV2 closed LFRPC2 = LFRPC1
   C. If no circulation in Evaporator LFRPE2 = 0
   D. Guess liquid flow rates in PE1, PC3 and PC1 then call subroutine VAØ5AD.

6. If subroutine CALFUN called more than 17, give error message

7. Write Time, FCTID, INDEX, TMP.

Subroutine OUTP



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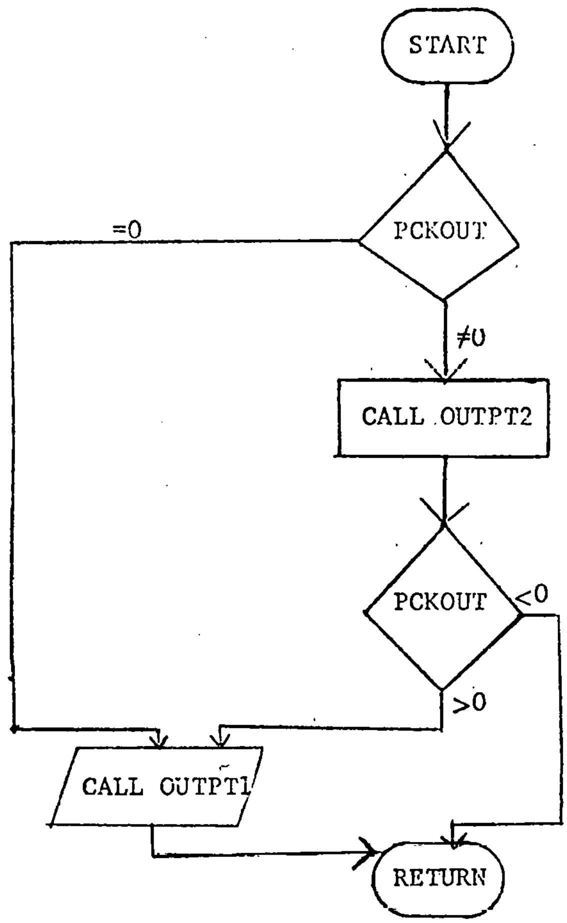
Subroutine OUTPUT



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Subroutine Output 1

1. Print the adjusted throat area of control valves CV1 and CV4
2. Print turbine rpm, mass flow rate in turbine, mass flow rate out of CDNHW, Liquid mass in CNDHW, Liquid mass in evaporator. With respect to time
3. Print pressure drop, temp. in evaporator, pressure in evaporator, Temp. at inlet to evaporator, temp. at CND, temp. at inlet to CND. All these with respect to time.

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Subroutine Output 2

1. Print the adjusted throat area of CV1 and CV4
2. Print TWAEVP, TTBEVP, TAVEVP, MAVEVP, VALEVP and MALHWE with respect to time.
3. Print the TWACND, TTBCND, TAVCND, MAVCND, MALCND and MALHWC with respect to time.
4. Print RPMTRB, TMPPE3, TMPPT1, TMPPT2, TMPPUC and TMPPC1 with respect to time.
5. Print TMPPC3, TMPPC2, TMPMXR, TMPPT1, TMPPUE and TMPPE2 with respect to time.
6. Print PRSEVP, PRSMSP, PRSPE3, PRSPT1, PRSPT2, PRSCND and PRSPUC with respect to time.
7. Print PRSPC1, PRSCV2, PRSPC3, PRSCV1, PRSPC2, PRSPUE and PRSPE2 with respect to time.
8. Print VFRPE#, VFRPT1, VFRPT2, LFRPC1, LFRPC3, LFRPC2, LFRPE1 and LFRPE2 with respect to time.
9. Print TWAEVP, TTBEVP, TAVEVP, TALEVP, TALHWE, ZTVEVP, SIGMA1 and SIGMA2 with respect to time.
10. Print VFRPE3, LFRPE1, LFRPE2, DRNEVP, FFVEVP, FWVZVP, DRNCND and FFVCND with respect to time.

Table Lookup:

There are 12 tables that are provided as input data by the user. Each table consists of a set of (X,Y) pairs where X is the independent variable, and Y is the dependent variable. It can, therefore, be thought of as a function Y = F(x), which is specified at a discrete set of points Xi, i=1...n. When the value of the function is required at a certain X^y (that is not one of the X's), linear interpolation is used to find a value Y^x $f(X^y)$

To increase the flexibility of the cone, and allow for future additions each of the 12 tables has been assigned a unique index which is used to access it. The table names their indices and a brief description of them is given below:

INDEX	NAME	SIZE	DESCRIPTION
1	VISAV	NVISAV	Viscosity of NH_3 vapor vs. temperature
2	CPAV	NCPAV	Heat capacity of NH_3 vapor vs. temperatur
3	GMAV	NGMAV	Cp/Cv of NH_3 vapor vs. temperature
4	DENAL	NDENAL	Density of NH_3 liquid vs. temperature
5	CPAL	NCPAL	Heat Capacity of NH_3 Liquid vs. temperature
6	VISAL	NVISAL	Viscosity of NH_3 liquid vs. temperature
7	PSATA	NPSATA	Psat vs. Tsat for NH_3
8	DPDTA	NDPDTA	(2Psat/2Tsat) vs. Tsat for NH_3
9	LMDA	NLMDA	Heat of vaporization vs. temperature NH_3
10	PFRPC	NPTRPC	Pressure heat vs. flow rate for PUC
11	PFRPE	NPFRPE	Pressure heat vs. flow rate for PUE
12	TCONL	NTCONL	Thermal conductivity for NH_3 liquid vs. temp.

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Two function subprograms are involved in table lookup:

a) FUNCTION INTRPZ (T, A, NA, ERR)

Interpolates in array A (size NA) to find the value of the function at T (the indept variable). ERR is an integer flag that is set as follows:

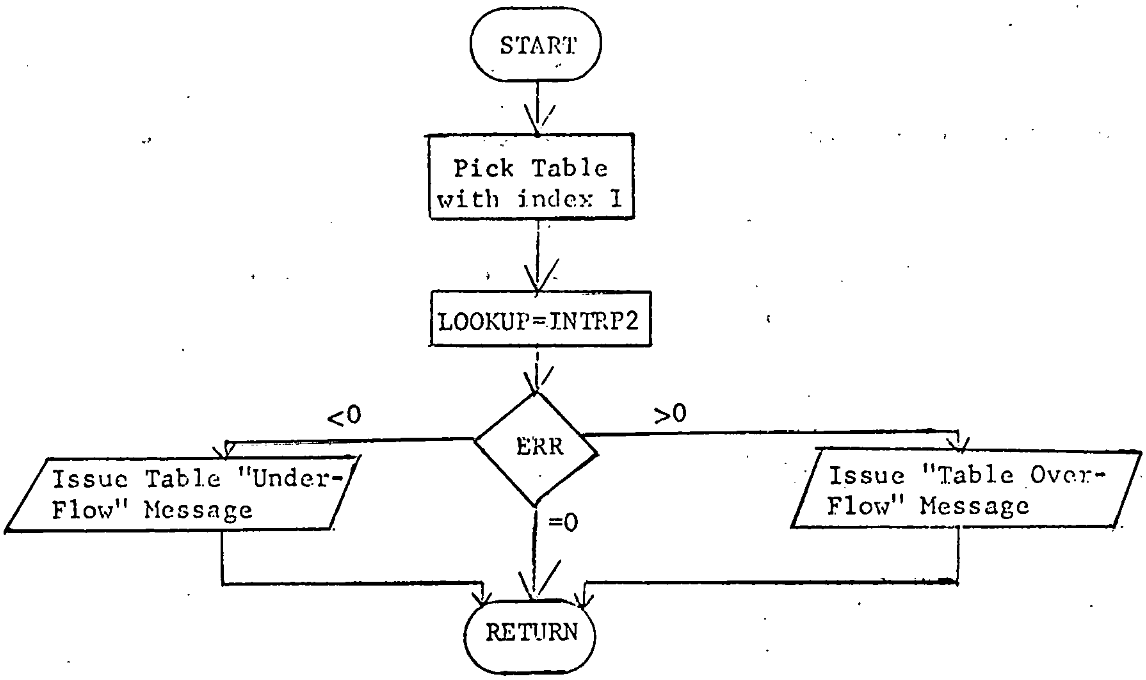
If T < A(1,) ⇒ ERR = -1 and INTRP2 = A(1,2)
If T > A(NA,1) ⇒ ERR = +1 and INTRP2 = A(NA,2)
IF A(1,1) ≤ T ≤ A(NA,1) · ERR = 0 and INTRP2 is found by linear interpolation

b) FUNCTION LOOKUP (I,T)

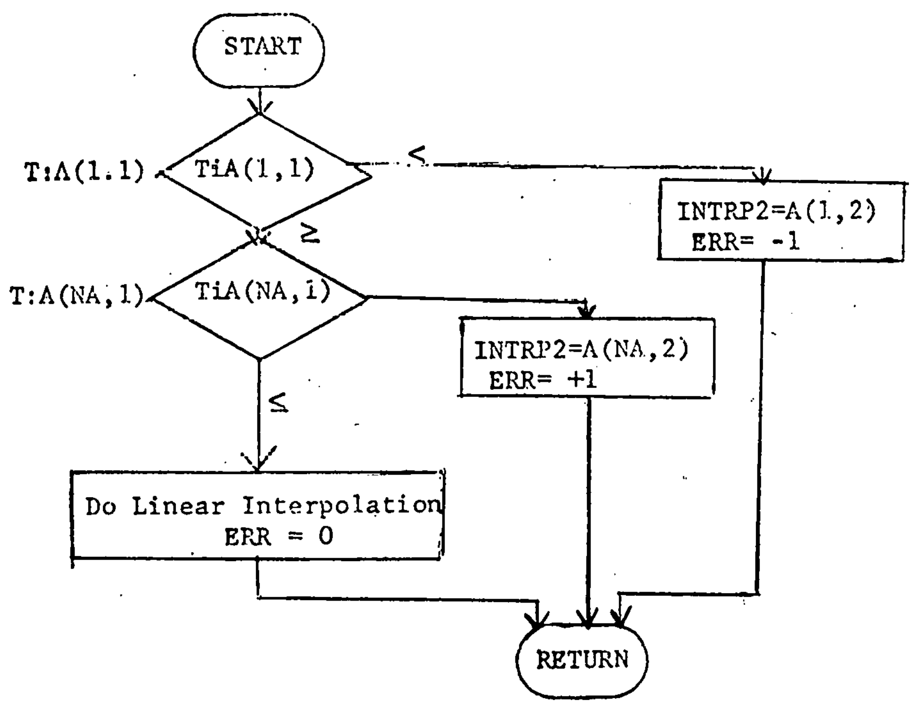
Selects the table whose index is I, and passes it along with T (the indept variable) to INTRP2. When INTRP2 returns, it examines ERR and issues an appropriate ascerning message if ERR = ±1, and finally it returns the value in INTRP2.

The following charts illustrate the table lookup procedure.

FUNCTION LOOKUP (I,T)



FUNCTION INTRP2 (T,A,NA,ERR)



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Evaluation of X,Z, and U variables vs. time:

The system variables are stored versus time in save vectors.

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Computation of time delays in pipelines

Function subprogram DELAY solve by Forward Euler the following eqn. for τ:

$$\int_{t-\tau}^{\tau} \dot{m} \, dx = \rho A L$$

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Miscellaneous Routines:

FUNCTION DMX (A, NA, INDEX)

Finds the largest element in the 1-D array A (size NA) and returns its value (double-precision) in DMX, and its index in the array INDEX.

LOGICAL FUNCTION EQUAL (X,Y)

Tests for equality between two double-precision numbers X and Y. Returns TRUE, if X and Y are withing E * |X| from each other, FALSE. Otherwise, $\epsilon = 1 \times 10^{-8}$.

LOGICAL FUNCTION LSSEOL (X,Y)

Returns TRUE if $x \leq Y$, equality being assumed if EQUAL (X,Y) returns TRUE, FALSE, otherwise.

Subroutine GETVAR will get the variables value from the appropriate array for specific time.

Subroutine INTRP1 will interpolate the variables value from the appropriate array.

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Subroutines HPCG and DHPCG

These subroutines use Hamming's modified predictor-corrector method for the solution of general initial-value problems.

The purpose of Hamming's modified predictor-corrector method is to obtain an approximate solution of a general system of first-order ordinary differential equations with given initial values. It is a stable fourth-order integration procedure that requires the evaluation of the right-hand side of the system only two times per step. This is a great advantage compared with other methods of the same order of accuracy, especially the Runge-Kutta method, which requires the evaluation of the right-hand side four times per step. Another advantage is that at each step the calculation procedure gives an estimate for the local truncation error; thus the procedure is able, without a significant amount of calculation time, to choose and change the step size h. On the other hand, Hamming's predictor-corrector method itself is not self-starting; that is, the functional values at a single previous point are not enough to get the functional values ahead. Therefore, to obtain the starting values, a special Runge-Kutta procedure followed by one iteration step is added to the predictor-corrector method.

Given the general system of first-order ordinary differential equations:

$$y_1' = \frac{dy_1}{dx} = f_1(x, y_1, y_2, \ldots, y_n)$$

$$y_2' = \frac{dy_2}{dx} = f_2(x, y_1, y_2, \ldots, y_n)$$

$$\cdots\cdots\cdots\cdots$$

$$y_n' = \frac{dy_n}{dx} = f_n(x, y_1, y_2, \ldots, y_n)$$

and the initial values:

$$y_1(x_0) = y_{1,0},\ y_2(x_0) = y_{2,0},\ \ldots,\ y_n(x_0) = y_{n,0}$$

and using the following vector notations:

$$Y(x) = \begin{pmatrix} y_1(x) \\ y_2(x) \\ \vdots \\ y_n(x) \end{pmatrix},\quad F(x,Y) = \begin{pmatrix} f_1(x,Y) \\ f_2(x,Y) \\ \vdots \\ f_n(x,Y) \end{pmatrix},\quad Y_0 = \begin{pmatrix} y_{1,0} \\ y_{2,0} \\ \vdots \\ y_{n,0} \end{pmatrix}$$

where Y, F, and Y_0 are column vectors, the given problem appears as follows:

$$Y' = \frac{dY}{dx} = F(x, Y) \text{ with } Y(x_0) = Y_0$$

For stability purposes, the modification by Hamming of Milne's classical modified predictor-corrector method is preferred. Thus, knowing the results at the equidistant points x_{j-3}, x_{j-2}, x_{j-1} and x_j, the results at point $x_{j+1} = x_j + h$ are computed by the formulas below.

Predictor: $$P_{j+1} = Y_{j-3} + \frac{4h}{3}(2Y_j' - Y_{j-1}' + 2Y_{j-2}') \quad (1)$$

Modifier: $$M_{j+1} = P_{j+1} - \frac{112}{121}(P_j - C_j);$$

$$M_{j+1}' = F(x_{j+1}, M_{j+1}) \quad (2),(3)$$

Corrector: $$C_{j+1} = \frac{1}{8}\left[9Y_j - Y_{j-2} + 3h(M_{j+1}' + 2Y_j' - Y_{j-1}')\right] \quad (4)$$

Final value: $$Y_{j+1} = C_{j+1} + \frac{9}{121}(P_{j+1} - C_{j+1}) \quad (5)$$

where Y, Y', P, M, M', F and C are column vectors with n components. Formulas (1) and (4) have local truncation errors:

$$T_1 = \frac{14}{45} h^5 Y^{(5)}(\xi_1) \text{ with } \xi_1 \in (x_{j-3}, x_{j+1})$$

and

$$T_2 = -\frac{1}{40} h^5 Y^{(5)}(\xi_2) \text{ with } \xi_2 \in (x_{j-2}, x_{j+1})$$

respectively, such that

$$C_{j+1} - P_{j+1} = \frac{121}{360} h^5 Y^{(5)}(\xi) \quad \left[\xi \in (x_{j-3}, x_{j+1})\right]$$

Assuming that $Y^{(5)}(x)$ does not vary to any great extent in the interval (x_{j-3}, x_{j+1}), it follows that:

$$T_2 \approx \frac{9}{121}(P_{j+1} - C_{j+1})$$

This formula shows that the components of column vector $P_{j+1} - C_{j+1}$ are measures for the local truncation errors in the components of column vector Y_{j+1}, and therefore control of accuracy and adjustment of step size h can be done by generating the following test value:

$$\delta = \sum_{i=1}^{n} a_i \cdot |p_{j+1,i} - c_{j+1,i}| \qquad (6)$$

where the coefficients a_i ($i = 1, 2, \ldots, n$) are error-weights specified in the input of the procedure.

If δ is greater than a given tolerance ϵ†, increment h is halved and the procedure computes $Y_{j+1/2}$ -- that is, $Y(x_j + \frac{h}{2})$ -- after having interpolated $Y_{j-1/2} = Y(x_j - \frac{h}{2})$ and $Y_{j-3/2} = Y(x_j - \frac{3}{2}h)$, with previous increment h, using the following sixth-order interpolation formulas):

$$Y_{j-1/2} = \frac{1}{256}(80Y_j + 135Y_{j-1} + 40Y_{j-2} + Y_{j-3}) + \frac{h}{2} \cdot \frac{15}{128}(-Y'_j + 6Y'_{j-1} + Y'_{j-2}) \qquad (7)$$

$$Y_{j-3/2} = \frac{1}{256}(12Y_j + 135Y_{j-1} + 108Y_{j-2} + Y_{j-3}) + \frac{h}{2} \cdot \frac{3}{128}(-Y'_j - 18Y'_{j-1} + 9Y'_{j-2}) \qquad (8)$$

If δ is less than ϵ, the result Y_{j+1} is assumed to be correct and is handed, together with x_{j+1} and the vector of derivatives $Y'_{j+1} = F(x_{j+1}, Y_{j+1})$, to a user-supplied output subroutine.

If δ is less than $\epsilon/50$, the next step is carried out with the doubled increment; however, care is taken in the procedure that the increment never gets greater than the increment h specified as an input parameter, and further, that among the output are all points $x_0 + j \cdot h$ (where $j = 0, 1, 2, \ldots$, and h is the input step size) which are situated between the lower and the upper bound of the integration interval.

Changing the step size by halving or doubling requires changing of $P_j - C_j$ or $P_{j+1} - C_{j+1}$, respectively. Using the following interpolation formula:

$$Y_j = Y_{j-3} + \frac{3}{8}h(Y'_{j-3} + 3Y'_{j-2} + 3Y'_{j-1} + Y'_j) - \frac{3}{80}h^5 Y^{(5)}(\xi_3) \quad \left[\xi_3 \epsilon (x_{j-3}, x_j)\right]$$

and assuming that $Y^{(5)}(x)$ does not vary to any great extent in this interval, $P_j - C_j$ can be written as:

$$P_j - C_j \approx \frac{242}{27}(Y_j - Y_{j-3}) - \frac{121}{36}h(Y'_j + 3Y'_{j-1} + 3Y'_{j-2} + Y'_{j-3})$$

When halving increment h, this formula becomes:

$$P_j - C_j \approx \frac{242}{27}(Y_j - Y_{j-3/2}) - \frac{121}{36} \cdot \frac{h}{2}(Y'_j + 3Y'_{j-1/2} + 3Y'_{j-1} + Y'_{j-3/2}) \qquad (9)$$

and when doubling:

$$P_{j+1} - C_{j+1} \approx \frac{242}{27}(Y_{j+1} - Y_{j-5}) - \frac{121}{36} \cdot 2h(Y'_{j+1} + 3Y'_{j-1} + 3Y'_{j-3} + Y'_{j-5}) \qquad (10)$$

---

†Numerical experience seems to show that the procedure does not exceed a global relative error approximately equal to ϵ.

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Starting Hamming's modified predictor-corrector method requires the functional and derivative values at four preceding equidistant points; that is, x_0, x_1, x_2 and x_3. The values Y_0 and $Y'_0 = F(x_0, Y_0)$ are specified by input. For computation of Y_1, Y'_1, Y_2, Y'_2, Y_3 and Y'_3 and for adjustment of the step size h to accuracy requirements, a special Runge-Kutta procedure suggested by Ralston is used. Starting at x_j, result values at point $x_{j+1} = x_j + h$ are computed using the following formulas:

$$K_1 = h \cdot Y'_j \tag{11}$$

$$K_2 = h \cdot F(x_j + 0.4h,\ Y_j + 0.4K_1) \tag{12}$$

$$\begin{aligned} K_3 = h \cdot F(x_j &+ 0.45573725421878943\,h,\ Y_j \\ &+ 0.29697760924775360\ K_1 \\ &+ 0.15875964497103583\ K_2) \end{aligned} \tag{13}$$

$$\begin{aligned} K_4 = h \cdot F(x_j + h,\ Y_j &+ 0.21810038822592047\,K_1 \\ &- 3.05096514869293080\ K_2 \\ &+ 3.83286476046701030\ K_3) \end{aligned} \tag{14}$$

$$\begin{aligned} Y_{j+1} = Y_j &+ 0.17476028226269037\ K_1 \\ &- 0.55148066287873294\ K_2 \\ &+ 1.20553559939652350\ K_3 \\ &+ 0.17118478121951903\ K_4 \end{aligned} \tag{15}$$

where Y_j, Y_{j+1}, K_1, K_2, K_3 and K_4 are all column vectors with n components.

These formulas are not very stable, but this does not matter because they are used only in three successive steps (j = 0, 1, 2). On the other hand, they have the smallest bound of truncation error of all fourth-order Runge-Kutta procedures. Therefore they are best suited to start other integration methods which are not self-starting.

For initial control of accuracy and adjustment of step size h, in starting the procedure an approximation for $Y_2 = Y(x_0 + h)$, named $Y_2^{(1)}$, is computed using the step size h, and then an approximation named $Y_2^{(2)}$, using the step size h/2 twice. From these two approximations a test value for accuracy is generated in the following way:

$$\delta = \frac{1}{15} \sum_{i=1}^{n} a_i \cdot \left| y_{2,i}^{(1)} - y_{2,i}^{(2)} \right| \tag{16}$$

If δ is greater than ϵ, increment h is halved, and the procedure starts again at point x_0.

If δ is less than ϵ, the results $Y_1^{(2)} = Y(x_0 + \frac{h}{2})$ and $Y_2^{(2)} = Y(x_0 + h)$ are assumed to be corre and a third step follows, which computes the results at point $x_0 + \frac{3}{2}h$ -- that is, $Y_3 = Y(x_0 + \frac{3}{2}h)$. The step size h/2 of these three steps is handed as initial step size h to the predictor-corrector method.

It is very important that the starting values be as accurate as possible, because errors in these starting values may increase during the following predictor-corrector procedure. Therefore the starting values computed by the Runge-Kutta method are refined by one iteration step using the following fourth-order interpolation formulas:

$$Y_1 = Y_0 + \frac{h}{24}(9\,Y'_0 + 19\,Y'_1 - 5\,Y'_2 + Y'_3) \tag{17}$$

$$Y_2 = Y_0 + \frac{h}{3}(Y'_0 + 4\,Y'_1 + Y'_2) \tag{18}$$

$$Y_3 = Y_0 + \frac{3h}{8}(Y'_0 + 3\,Y'_1 + 3\,Y'_2 + Y'_3) \tag{19}$$

Use of these must be considered an iteration procedure; that is, first the result values of the Runge-Kutta method are used in the right-hand side of formula (17) to compute a refined Y_1. After computing the refined $Y'_1 = F(x_1, Y_1)$, the refined vector Y_2 is generated using formula (18). Finally, the refined $Y'_2 = F(x_2, Y_2)$ is used, together with the other values, in the right-hand side of formula (19) to compute the refined vector Y_3. During this iteration, the refined data sets x_j, Y_j, Y'_j are handed, together with the number of bisections of the initial step size (specified by input), to the output subroutine.

It can be shown that, using this iterative procedure, the initial column vector $P_3 - C_3$ used in formula (2) for j=3 is equal to zero.

The entire input of the procedure is:

1. Lower and upper bound of the integration interval, initial step size h of the independent variable, and upper bound ε of the local truncation error
2. Initial values Y_0 of the dependent variables and weights a_i (i = 1, 2, ..., n) for the local truncation errors in each component of the dependent variables
3. The number n of differential equations in the system
4. As external subroutine subprograms, the computation of the right-hand side of the system of differential equations; for flexibility in output, an output subroutine
5. An auxiliary storage array named AUX with 16 rows and n columns

Output is done in the following way. If a set of approximations to the dependent variables Y(x) is found to be of sufficient accuracy, it is handed -- together with x, the derivative Y' (x), the number of bisections of the initial increment, the number of differential equations, the lower and upper bound of the interval, the initial step size, error bound ε, and a parameter for terminating subroutine HPCG or DHPCG -- to the output subroutine. By means of this output subroutine, the user has the opportunity to choose his own output format, to handle the output values as he wants, to change the upper error bound, and to terminate subroutine HPCG or DHPCG at any output point. In particular, the user is able to drop the output of some intermediate points, printing only the result values at the special points $x_0 + j \cdot h$ (where j = 0, 1, 2, ..., and h is the initial step size specified by input). The user may also perform intermediate computations using the integration results before continuing the process.

For reference see:

(1) A. Ralston/ H.S. Wilf, Mathematical Methods for Digital Computers, Wiley, New York/London, 1960, pp. 95 - 109.

(2) A. Ralston, "Runge-Kutta Methods with Minimum Error Bounds", MTAC, vol. 16, no. 80 (1962), pp. 431 - 437.

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SOLUTION OF SYSTEM OF EQUATIONS

The nonlinear system equations are linearized in ODSP-3. The resulting system of linear equations is then solved by the following method, using a least squares technique.

To minimise the sum of squares of M given functions, f_j, j=1,2,...M, each of N variables, $\underline{x} = (x_1\ x_2\ \ldots\ x_N)$ $M \geq N$, without the use of any partial derivatives. i.e. to find $\underline{x}$ to minimise

$$F(\underline{x}) = \sum_{k-1}^{M} [f_k(x_1,x_2,\ldots x_N)]^2 \qquad M > N$$

The user must supply an initial approximation to the required minimum position $\underline{x}$, and a subroutine CALFUN, to calculate values of the functions f_j, j=1,2,...M, for any values of the variables $\underline{x}$.

ARGUMENT LIST

SUBROUTINE VA05A (M,N,F,X,H,DMAX,ACC,MAXFUN,IPRINT,W)

All variables except F are input arguments and their values must be set before VA05A is called.

F,X,W, are 1-dimensional arrays, which must be declared in the user's program.

M the number of functions f_j occuring in the sum of squares

N the number of variables $x_1,x_2,\ldots x_N$

X an array, of length at least N, whose elements are set to the user's estimate of the required variables $\underline{x} = (x_1\ x_2\ \ldots x_N)$, where

$$X(K) = x_K \quad K=1,2,\ldots N$$

These values are changed by subroutine VA05A so that on return X(K) will contain an estimate of the required value of X_k, K=1,2,...N.

H a scalar parameter set by the user's program to allow VA05A to estimate the partial derivatives of each of the functions from different approximations. In fact the approximation used is

$$\frac{\partial f_i}{\partial x_j} \approx [f_i(x_1,x_2,\ldots x_j + H,\ldots x_N) - f_i(x_1,x_2\ldots x_j\ldots x_N)]/H$$

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important that the variables x_1 x_2 ... x_N are scaled to be similar in magnitude (See §4).

DMAX a scalar parameter which must be set to a generous estimate of the "distance" between the users initial estimate, and the required value of $\underline{x}$ (see §4 for definition of "distance").

ACC a scalar parameter specifying the accuracy required in the calculated value of the sum of squares $F(\underline{x})$
A normal return is made to the calling program when it is predicted that the best calculated value of $F(\underline{x})$ is not more than ACC greater than the minimum value. See §6.

MAXFUN an integer variable, to ensure that the subroutine finishes. There will be an error return if more than MAXFUN calls of the subroutine CALFUN are required, with the exception that at least N+1 such calls are always made.

IPRINT as an input parameter, this integer specifies the printing that will be obtained from VA05A.
IPRINT=0 No printing. In this case IPRINT will be used as an output argument if an error return occurs.

IPRINT>0 Values of the functions and variables are printed every IPRINT iterations.

IPRINT<0 Values of the variables only are printed every |IPRINT| iterations.

This parameter will be used as an output parameter only if the input value is zero and an error return occurs. For details of the errors that may occur see §5, the output values of IPRINT are

IPRINT=1 the sum of squares $F(\underline{x})$ fails to decrease
IPRINT=2 MAXFUN calls of CALFUN have been made

W an array of length at least $2MN+2N^2+2M+5N$, used by VA05A as working space. On return from VA05A the approximations to the partial derivatives are held in the first MN locations of W, so that

$$\frac{\partial f_i}{\partial x_j} \approx W(N(i-1)+j).$$

The output arguments are F,X,W and possibly IPRINT. For X,W,IPRINT see above.

F a 1-dimensional array, of length M at least, which will be set to the values of the functions at the vector of variables returned by the subroutine.

$$F(K) = f_K(X(1),X(2),\ldots X(N)) \quad K=1,2,\ldots M.$$

USER SUPPLIED SUBROUTINE CALFUN

SUBROUTINE CALFUN (M,N,F,X)

The arguments for this subroutine have the same significance as for VA05A, so that F,X are 1-dimensional arrays. This subroutine must be provided by the user and must calculate the values of the functions $f_j(x_1,x_2,\ldots x_N)$, $j=1,2,\ldots M$ for the given variables $\underline{x}=(x_1\ x_2\ \ldots x_N)$. These function values must be planted in the array F so that

$$F(K) = f_K.$$

Note that this subroutine must not change the values of M,N or X.
Apart from Calfum, Harwell Library subroutine MB11A is called.

CHOICE OF SCALING

The method used requires some step-length control, for which the "distance" between two estimates $(a_1,a_2,\ldots a_N)$ and $(b_1\ b_2\ \ldots b_N)$ of the vector $(x_1,x_2,\ldots x_N)$ is

$$\left\{\sum_{i=1}^{N} (a_i-b_i)^2\right\}^{\frac{1}{2}}$$

Therefore it is important that the user shall scale the variables, perhaps by multiplying them by appropriate constants, so that their magnitudes are similar.

ERROR RETURNS

Two conditions will cause VA05A to produce an error return to the calling program:-

(a) More than MAXFUN calls of CALFUN have been made and the required minimum value has not been found.

(b) A number of consecutive iterations have failed to reduce the sum of squares $F(\underline{x})$. This may happen if ACC has been chosen too small, or if $\overline{H}$ has been poorly chosen.

A diagnostic will be printed only if IPRINT≠0, otherwise the error return is signalled by changing this parameter (see §2 above). In either case, control is returned to the calling program.

ACCURACY

Note that a normal return from the subroutine occurs when it is predicted that the required accuracy has been obtained. Sometimes this prediction may be wrong, which has been shown by an example with M=50, N=30, having the property that the correct final value of the sum of squares, $F(\underline{x})$, is large. Here the subroutine finishes too soon, but the final answer was very close to the required one. Experience with the subroutine on about thirty other examples has shown that the convergence criterion is usually adequate.

METHOD

The method is a compromise between three different algorithms for minimising a sum of squares, namely Newton-Raphson, Steepest Descent, and Marquardt. Moreover it automatically obtains and improves an approximation to the first derivative matrix following the ideas of Broyden.

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APPENDIX 6.1-B

SAMPLE RESULTS OF ODSP3-DYNAMIC SIMULATION PROGRAM

A dynamic computer simulation of the Primary Power System shown in Figure 1 was developed. This dynamic performance model is discussed in Appendix 6.1-A in detail. This computer program analyzes the static and transient response of this power system to control operations and plots the resulting characteristic curves. Sample computer print-outs of characteristic curves for two significant transient control operations are presented here to illustrate program capability. These are typical characteristics for a 10 MWe module, based on preliminary input data.

CASE A - MODIFIED, ALL VALVES FIXED. (See Figure 2).

This figure shows the turbine generator overspeed transient following sudden loss of electrical load at full rated turbine flow conditions, in which none of the valving provided acts to limit the overspeed. The turbine By-pass valves remain closed, while the liquid NH_3 feed valve (CV-1) and the circulating flow valve (CV-4) to the evaporator remain wide open.

This trip situation illustrates the potential overspeed reached for the worst condition. The computer print-out shows that the turbine generator would accelerate from 3600 RPM to slightly less than 7200 RPM (100% overspeed) in approximately 30 seconds, after the electrical load is disconnected. Calculation gives final overspeed of 7500 RPM (109%).

CASE C-BPV AND CV2 OPEN, CV1 AND CV4 CLOSE AT 0.5 SEC.
(See Figures 3A through 3N).

These figures show the system transients following sudden loss of electrical load at full rated turbine flow conditions, in which four valves in the power loop act simultaneously to limit the overspeed.

A half second after the electrical load is interrupted, the turbine By-pass valves go to the wide open position, the evaporator liquid feed valves CV1 and CV4 to the closed position and valves CV2 to liquid storage go to a partial PV1 open position.

This valving operation sequence illustrates the best provision for limiting turbine generator overspeed. Figure 3A shows that the turbine generator would accelerate from 3600 RPM to 4974 RPM (approximately 38% overspeed) in 7 seconds. After 7 seconds, speed would start to decay. In addition to overspeed protection, this is the trip operation that would be used for rapid system shutdown, in the event of any major system component malfunction.

Figures 3B through 3N show the static valves prior to this trip situation and transient characteristics following the trip for local flow, pressure, temperature, vapor inventories and liquid inventories through out the power loop.

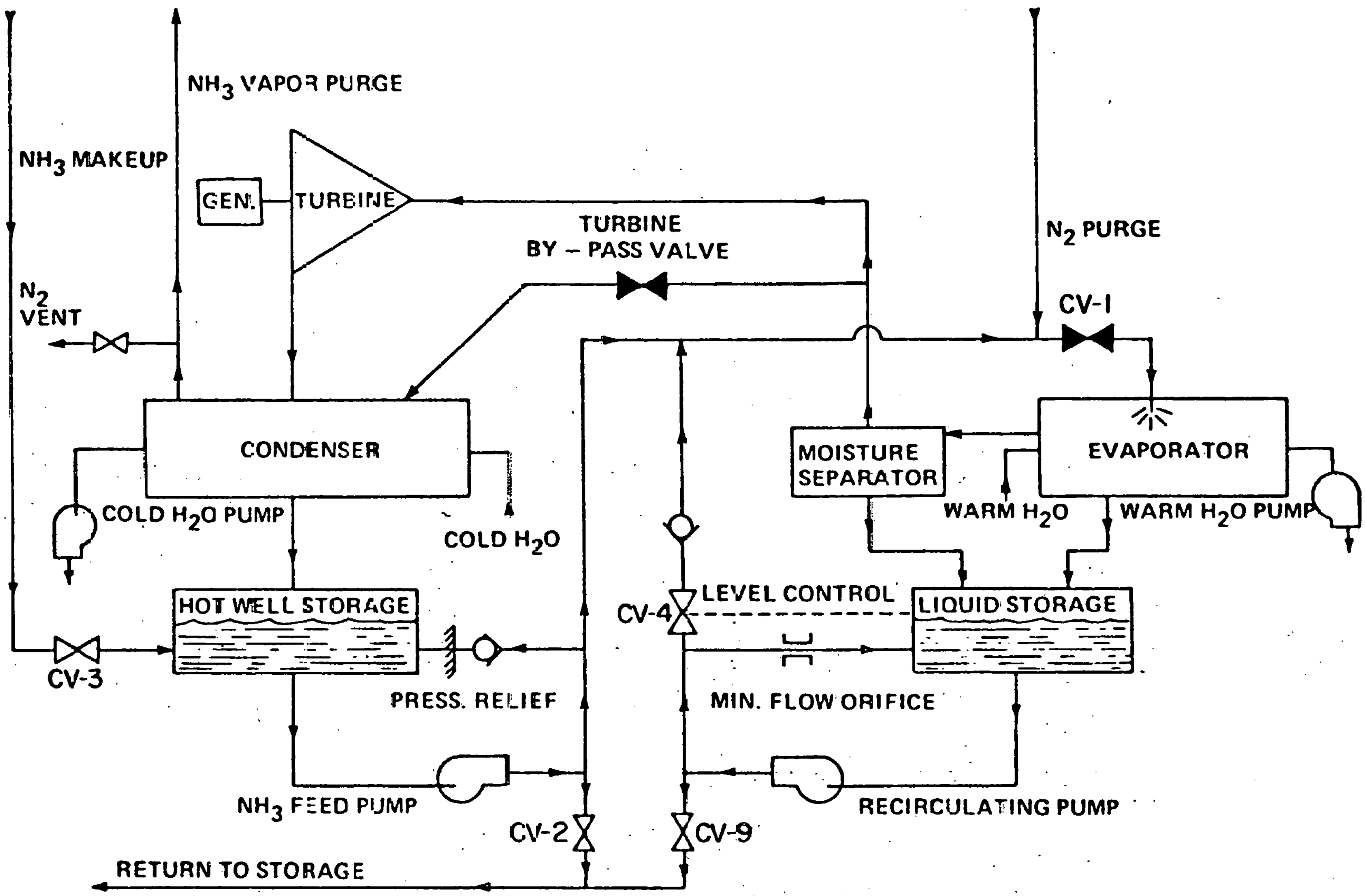

FIGURE 1. PRIMARY POWER SYSTEM

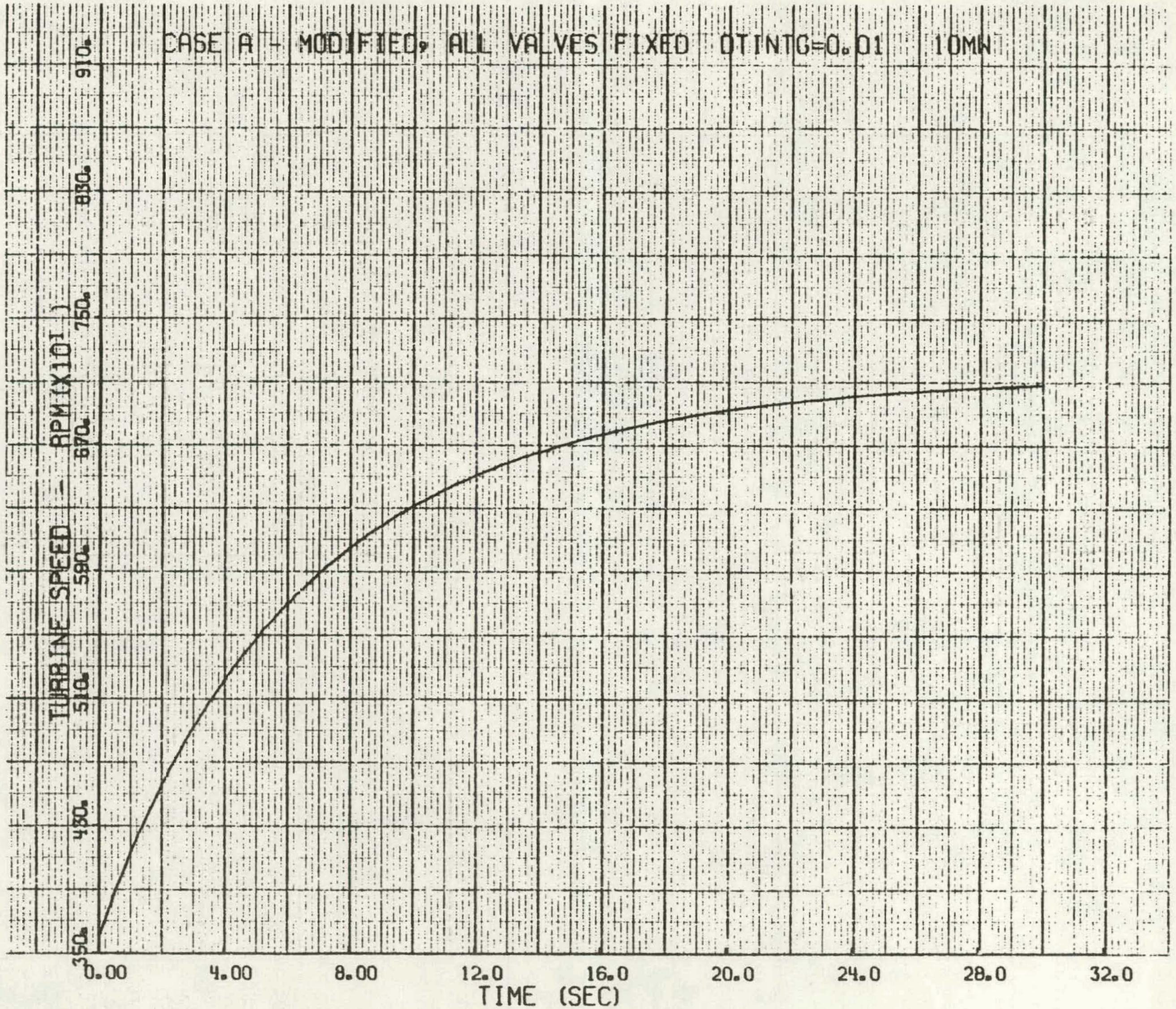

FIGURE 2. 10MWe CASE A - MODIFIED, ALL VALVES FIXED DTINTG=0.01

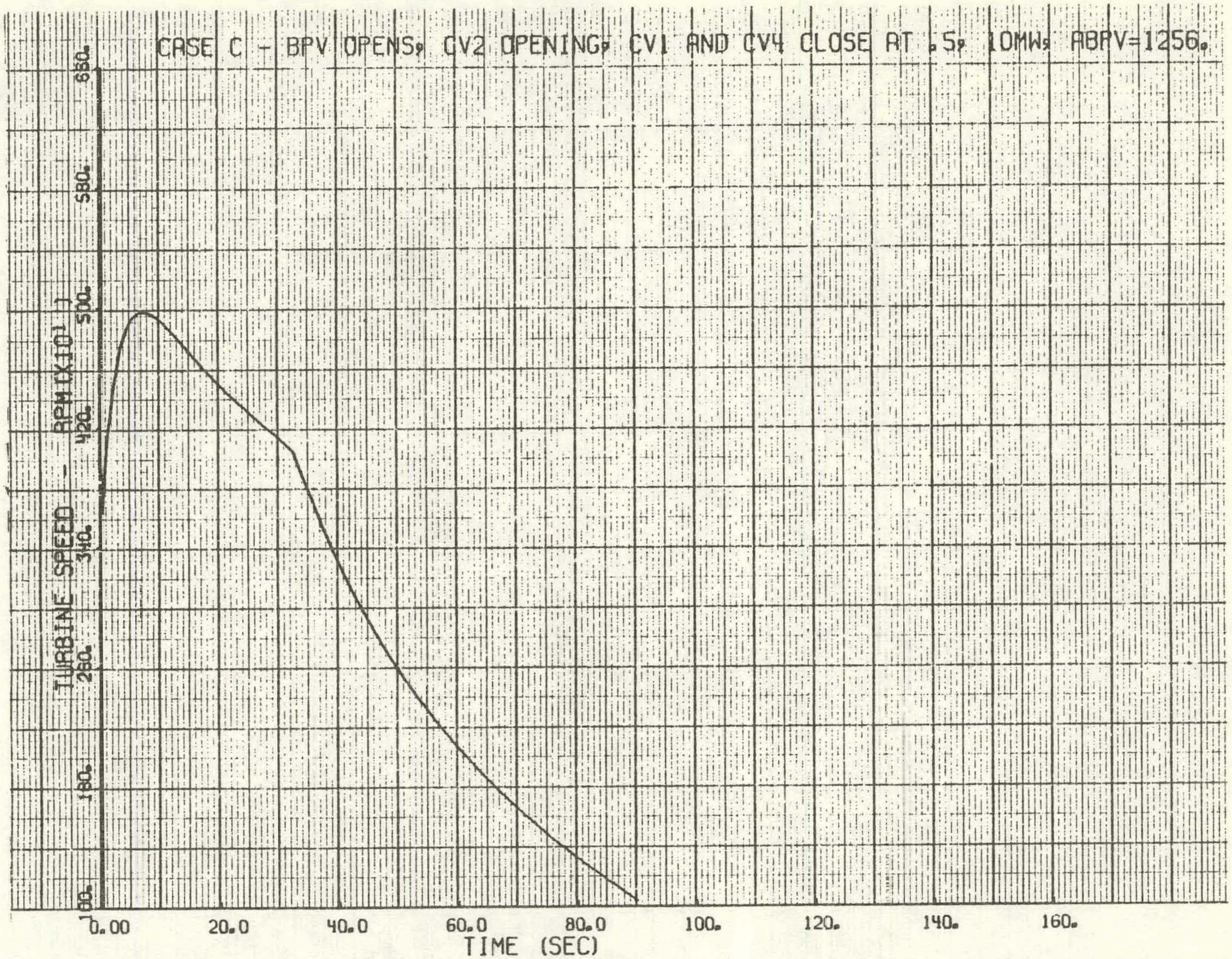

FIGURE 3A. CASE C - BPV OPENS, CV2 OPENING, CV1 AND CV4 CLOSE AT .5, 10 MW, ABPV=1256

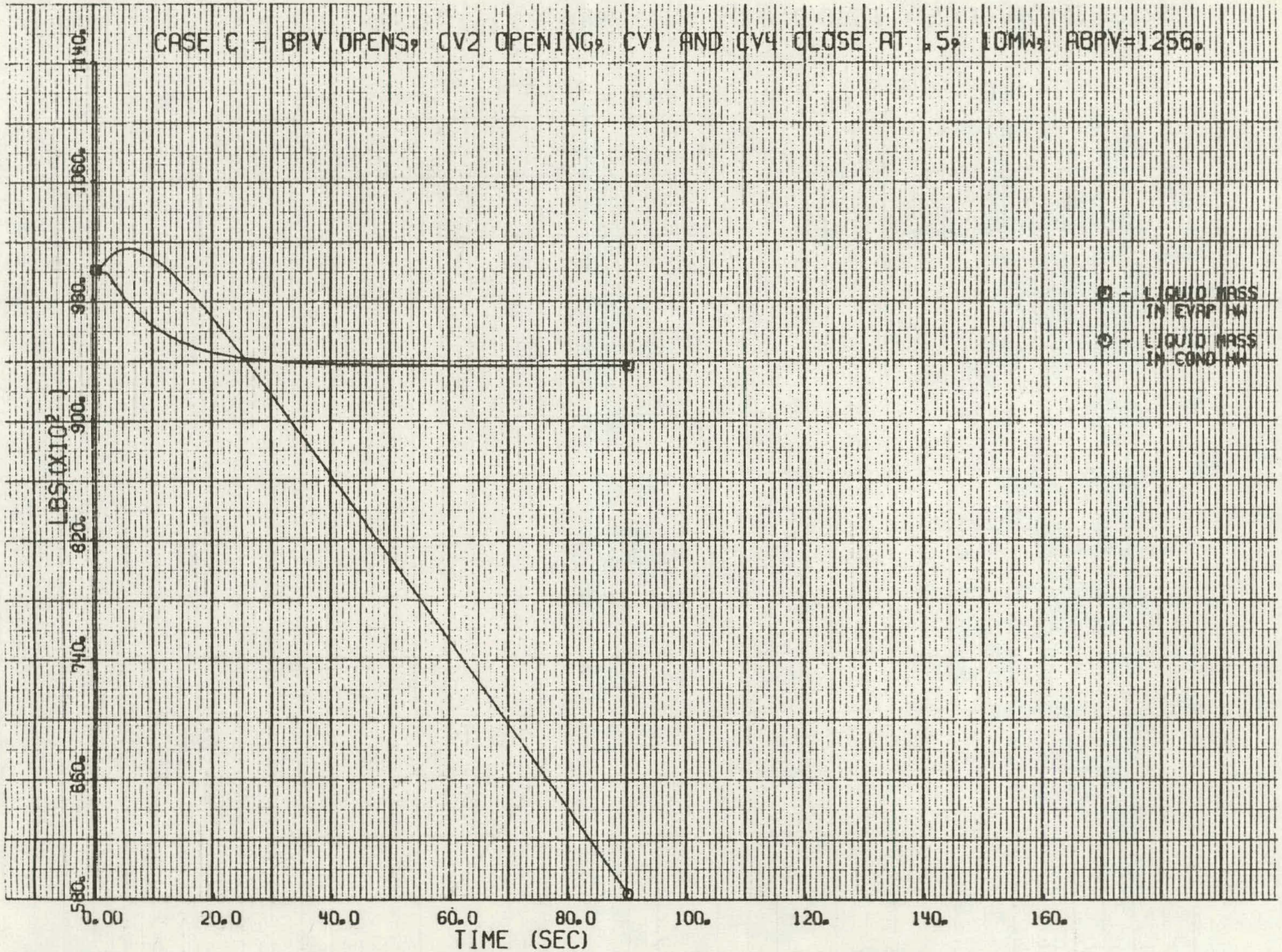

FIGURE 3B. CASE C - BPV OPENS, CV2 OPENING, CV1 AND CV4 CLOSE AT .5, 10 MW, ABPV=1256

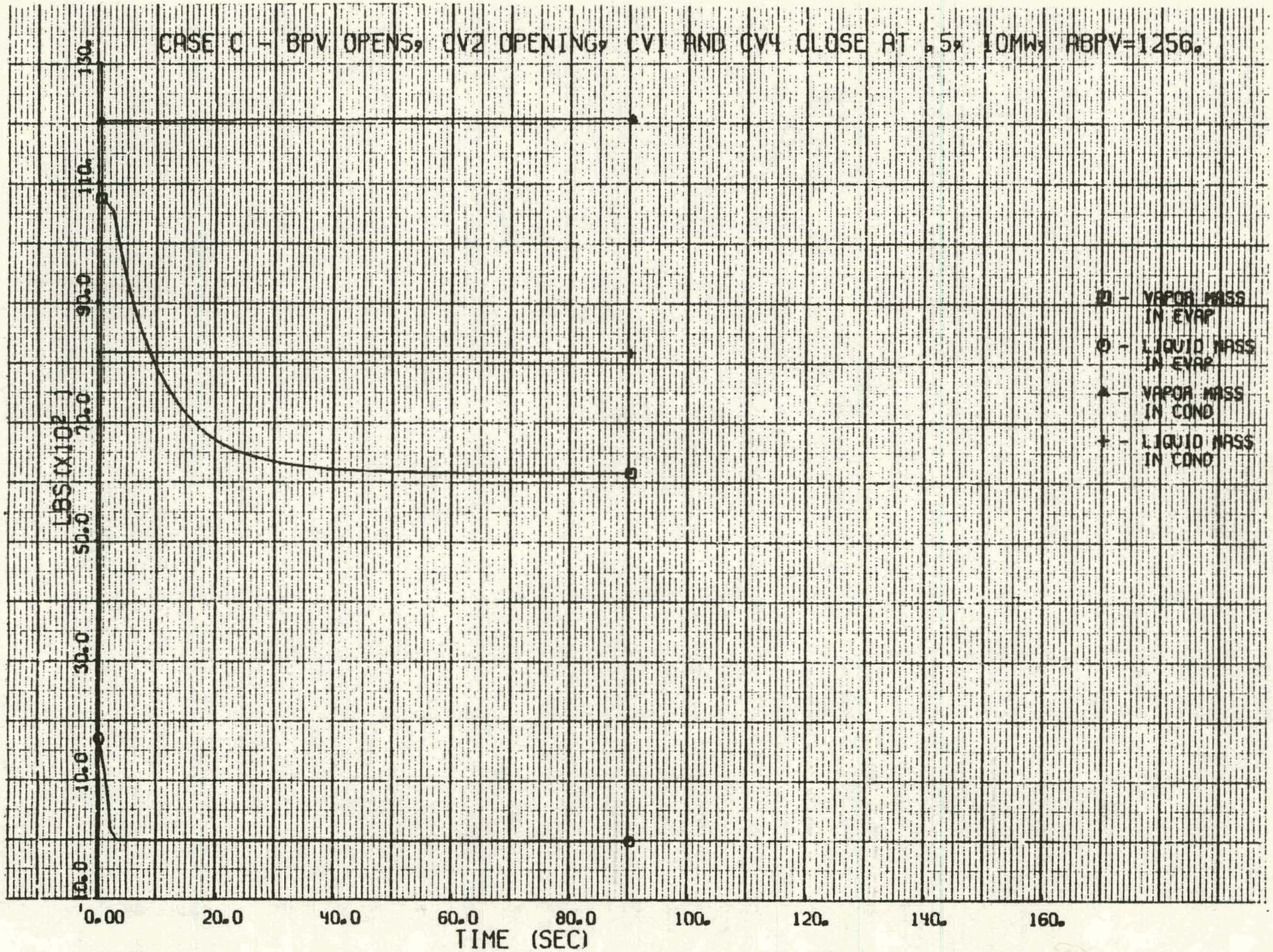

FIGURE 3C. CASE C - BPV OPENS, CV2 OPENING, CV1 AND CV4 CLOSE AT .5, 10 MW, ABPV=1256

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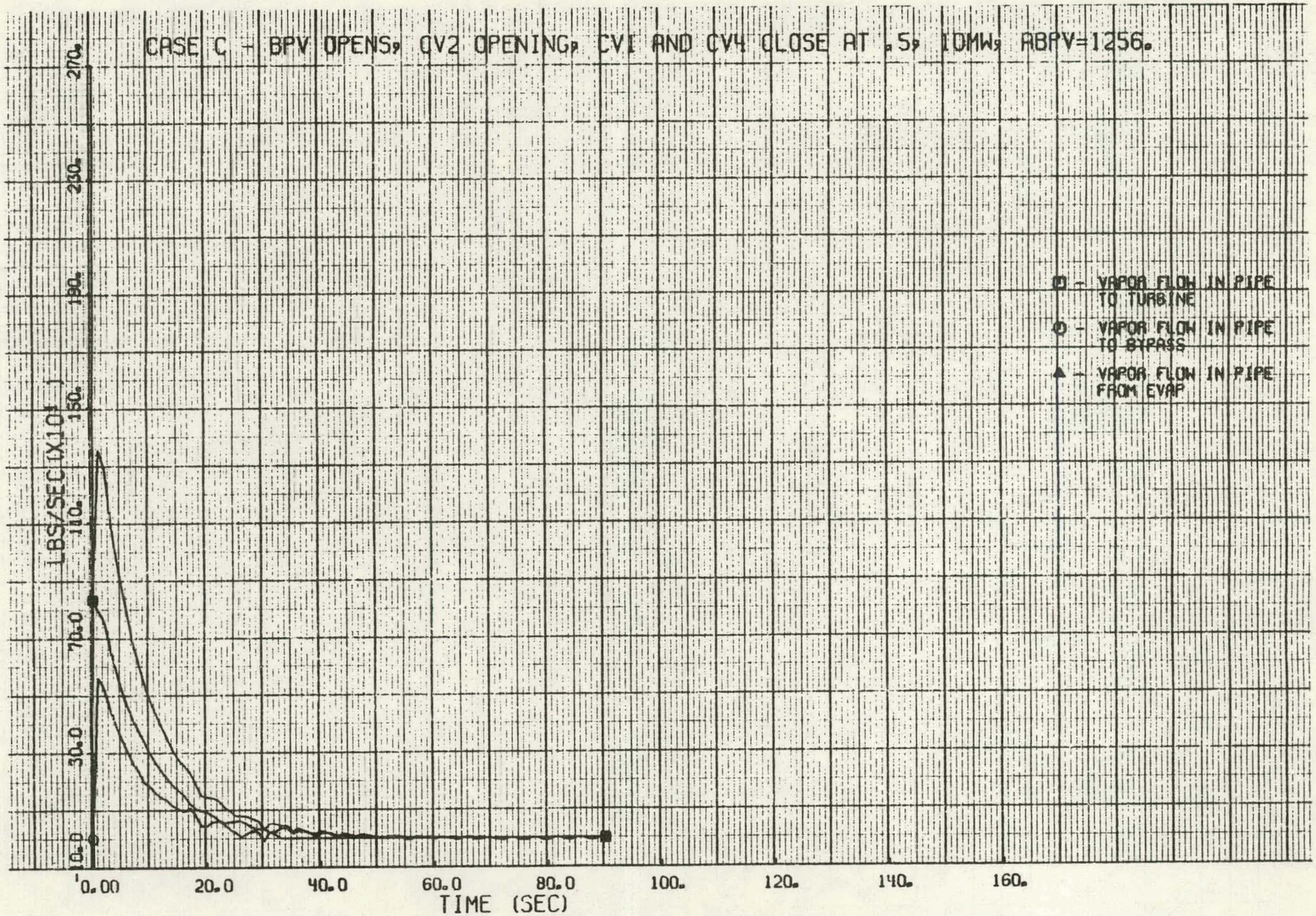

FIGURE 3D. CASE C - BPV OPENS, CV2 OPENING, CV1 AND CV4 CLOSE AT .5, 10 MW, ABPV=1256

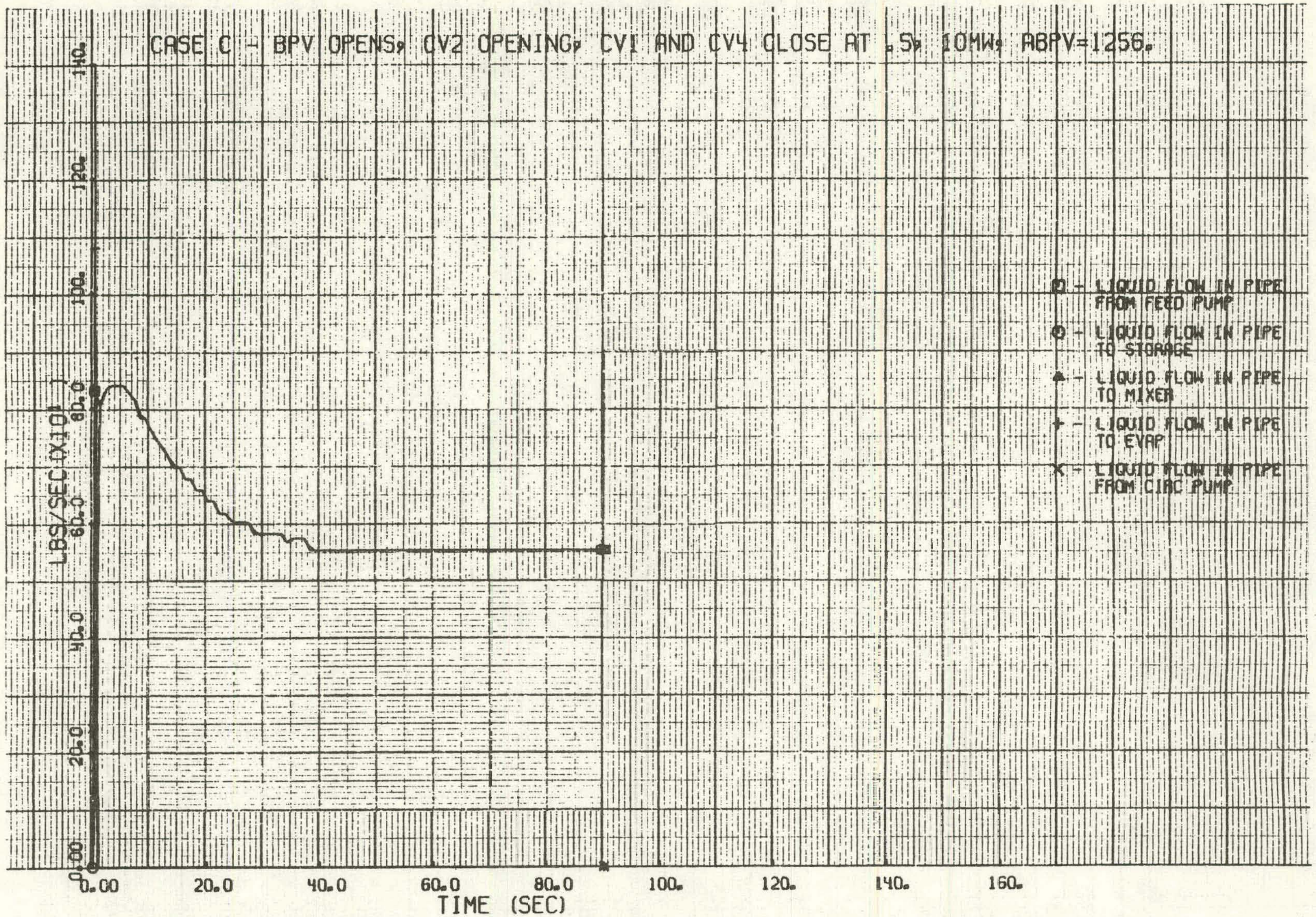

FIGURE 3E. CASE C - BPV OPENS, CV2 OPENING, CV1 AND CV4 CLOSE AT .5, 10 MW, ABPV-1256

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6.1-B

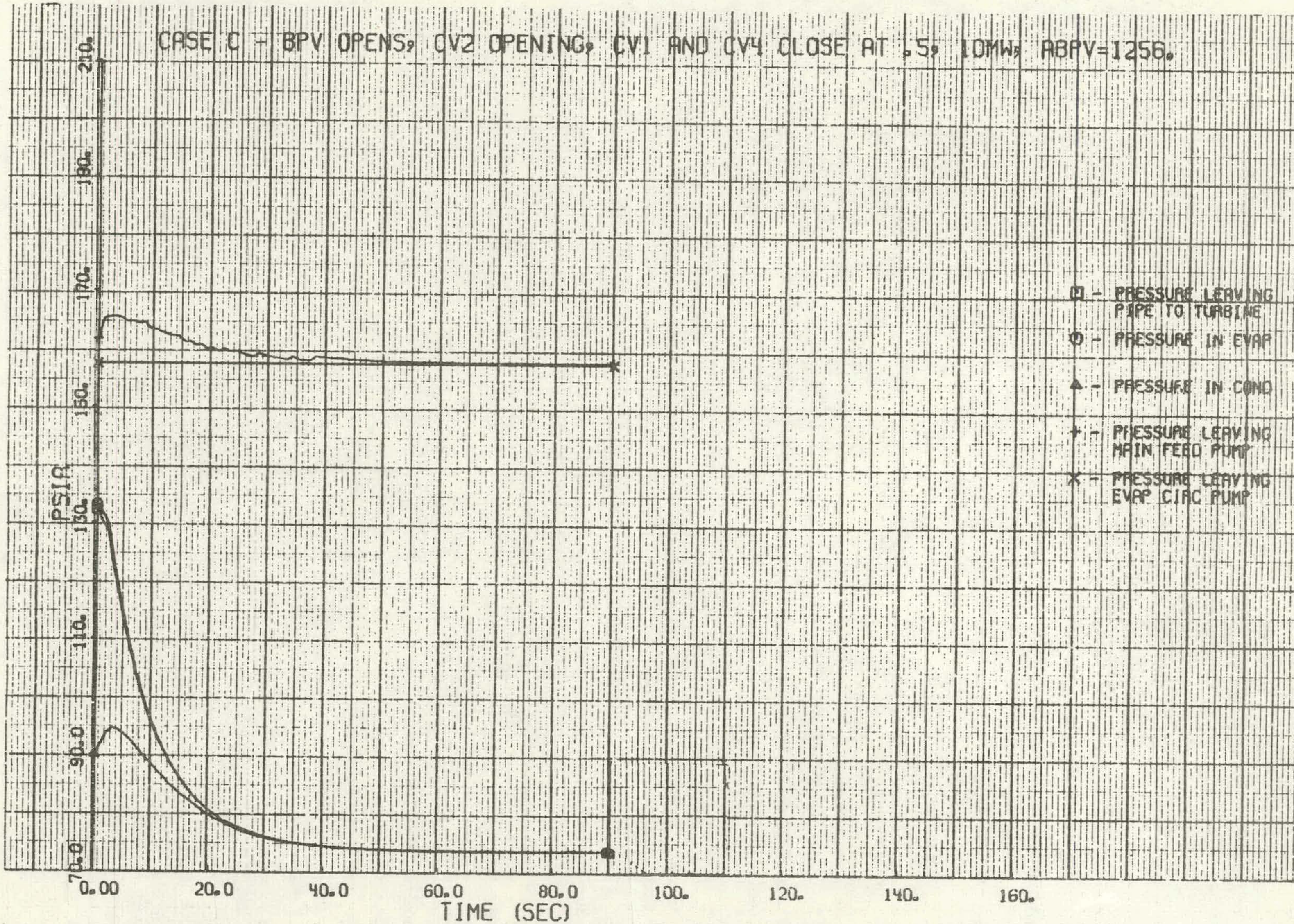

FIGURE 3F. CASE C - BPV OPENS, CV2 OPENING, CV1 AND CV4 CLOSE AT .5, 10 MW, ABPV=1256

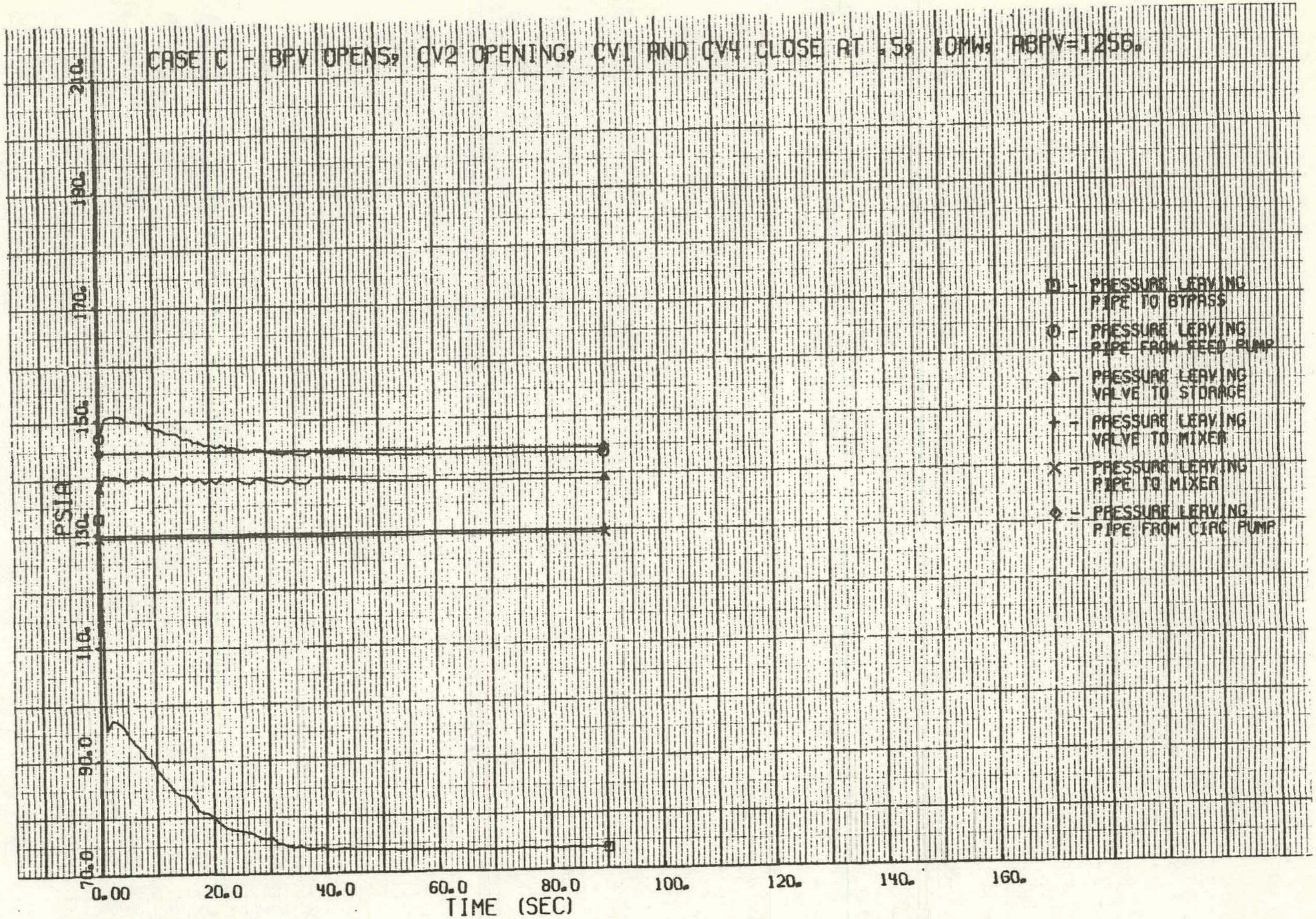

FIGURE 3G. CASE C - BPV OPENS, CV2 OPENING, CV1 AND CV4 CLOSE AT .5, 10 MW, ABPV=1256

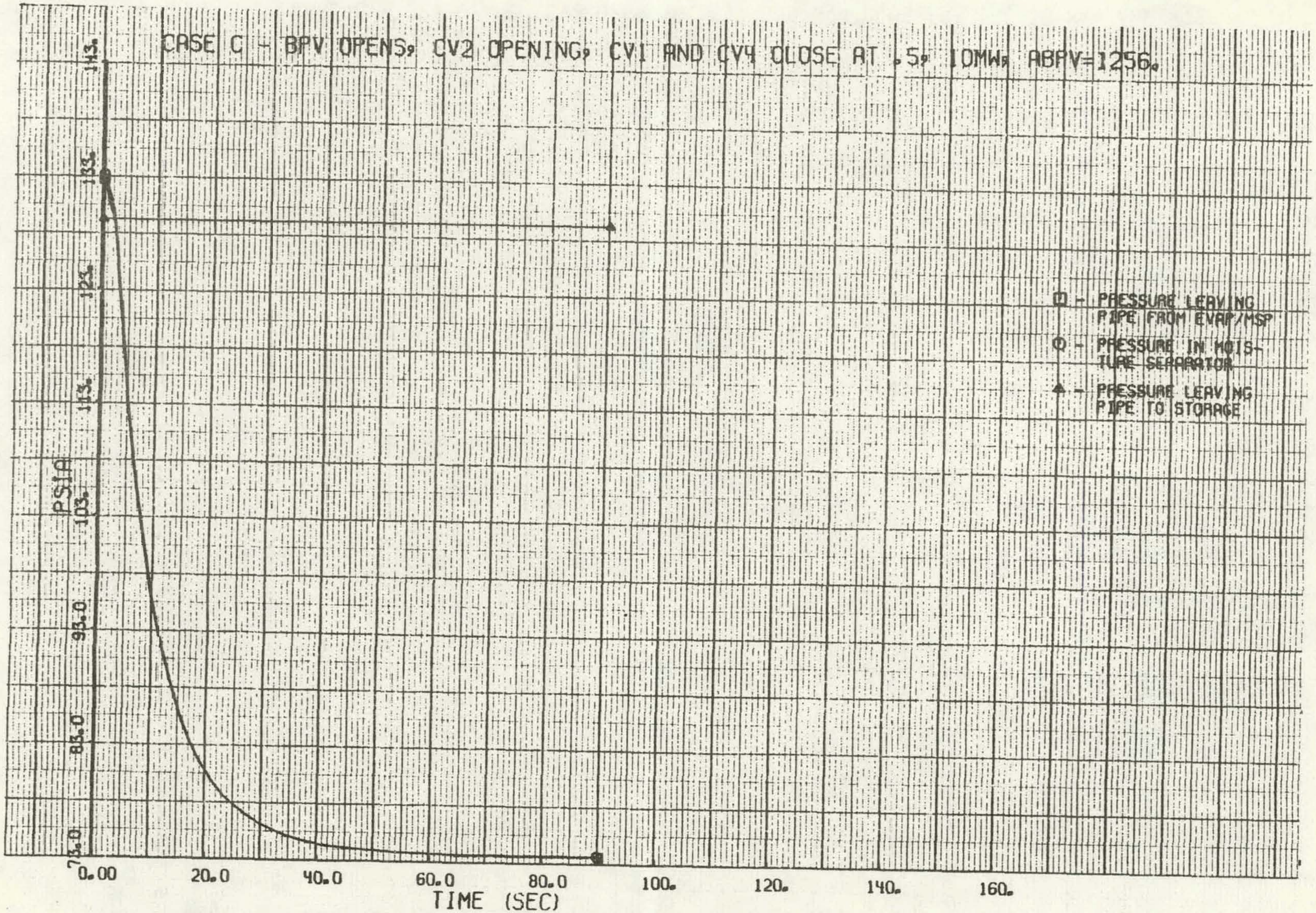

FIGURE 3H. CASE C - BPV OPENS, CV2 OPENING, CV1 AND CV4 CLOSE AT .5, 10 MW; ABPV=1256

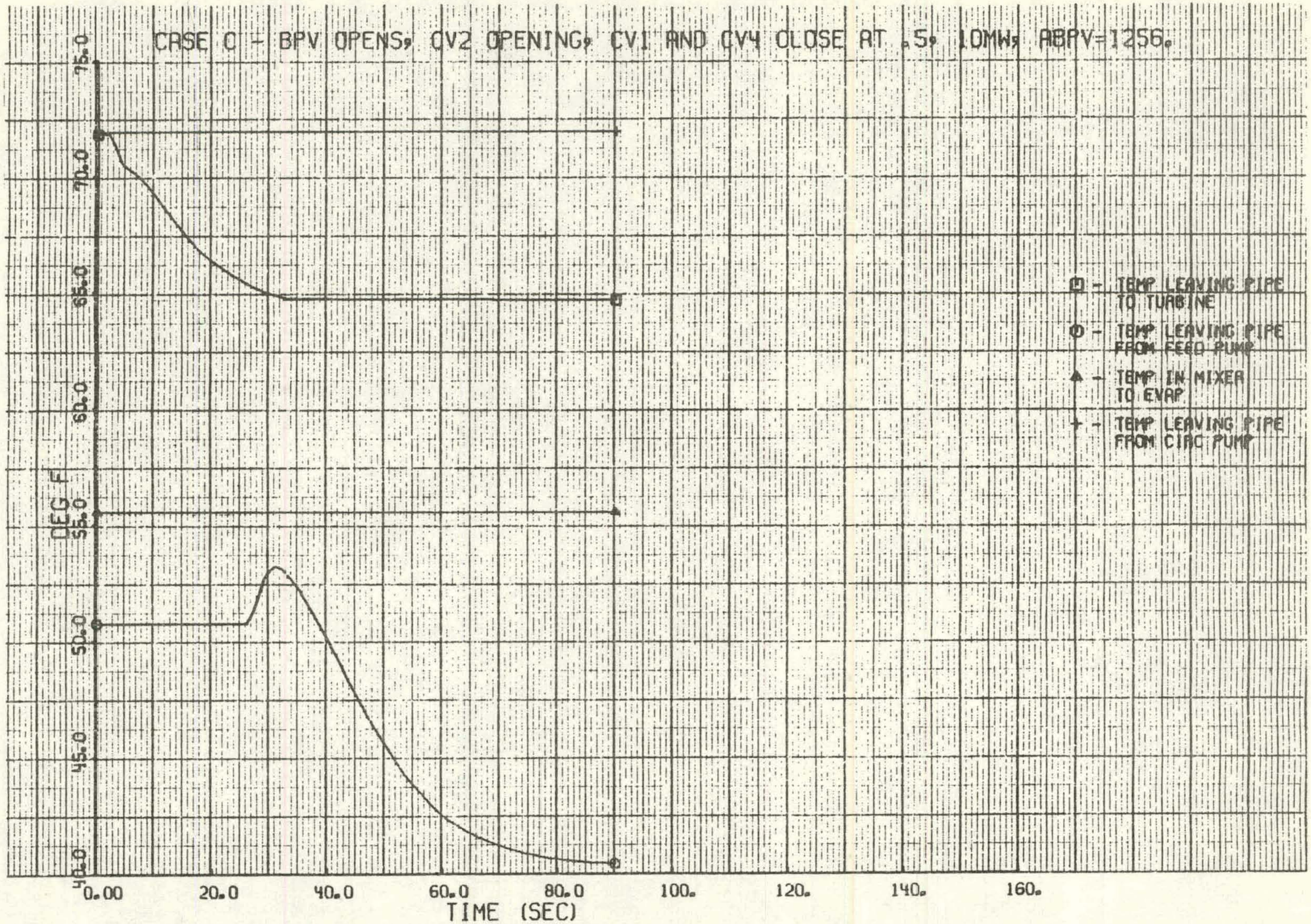

FIGURE 3I. CASE C - BPV OPENS, CV2 OPENING, CV1 AND CV4 CLOSE AT .5, 10 MW; ABPV=1256

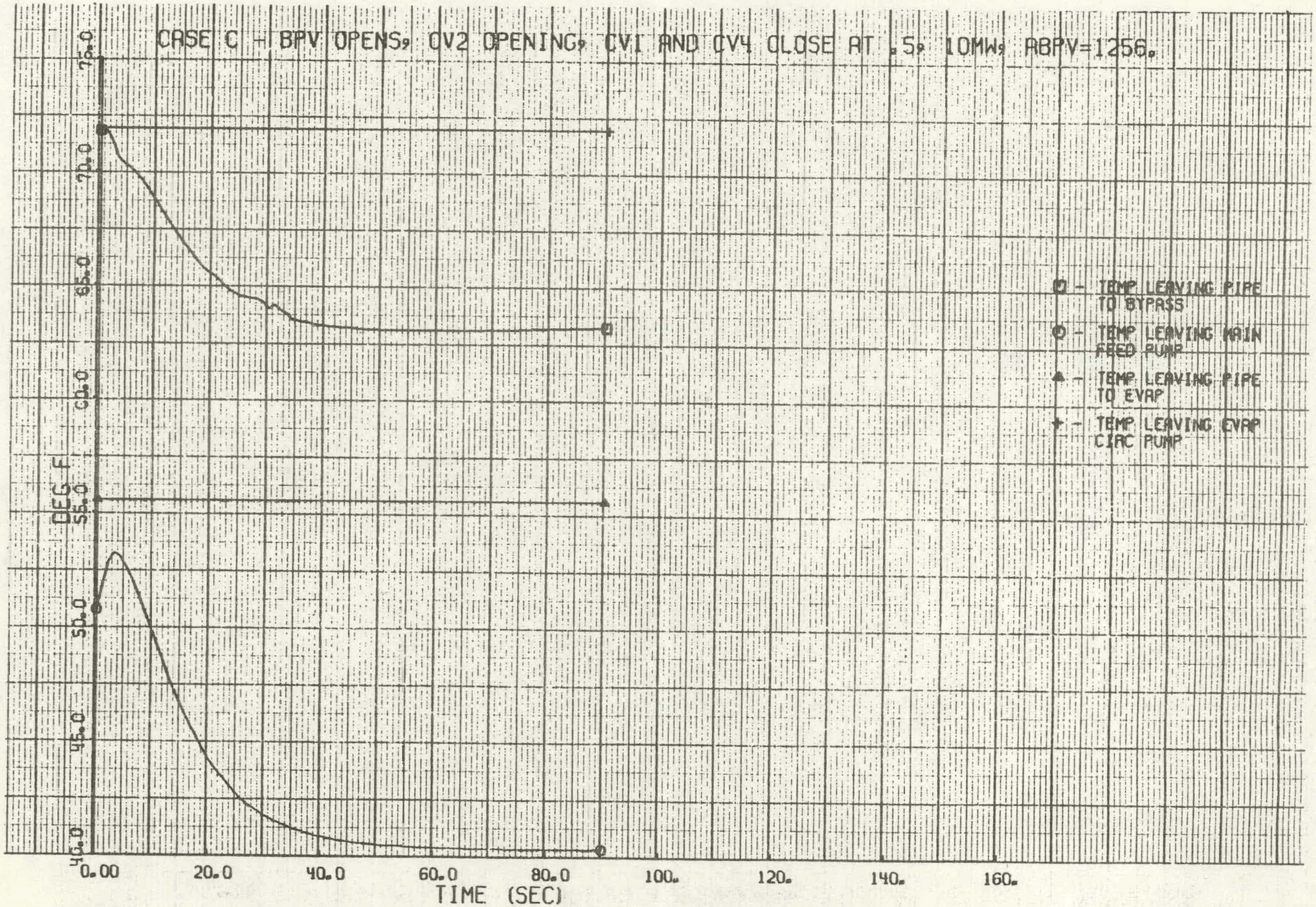

FIGURE 3J. CASE C - BPV OPENS, CV2 OPENING, CV1 AND CV4 CLOSE AT .5, 10 MW; ABPV=1256

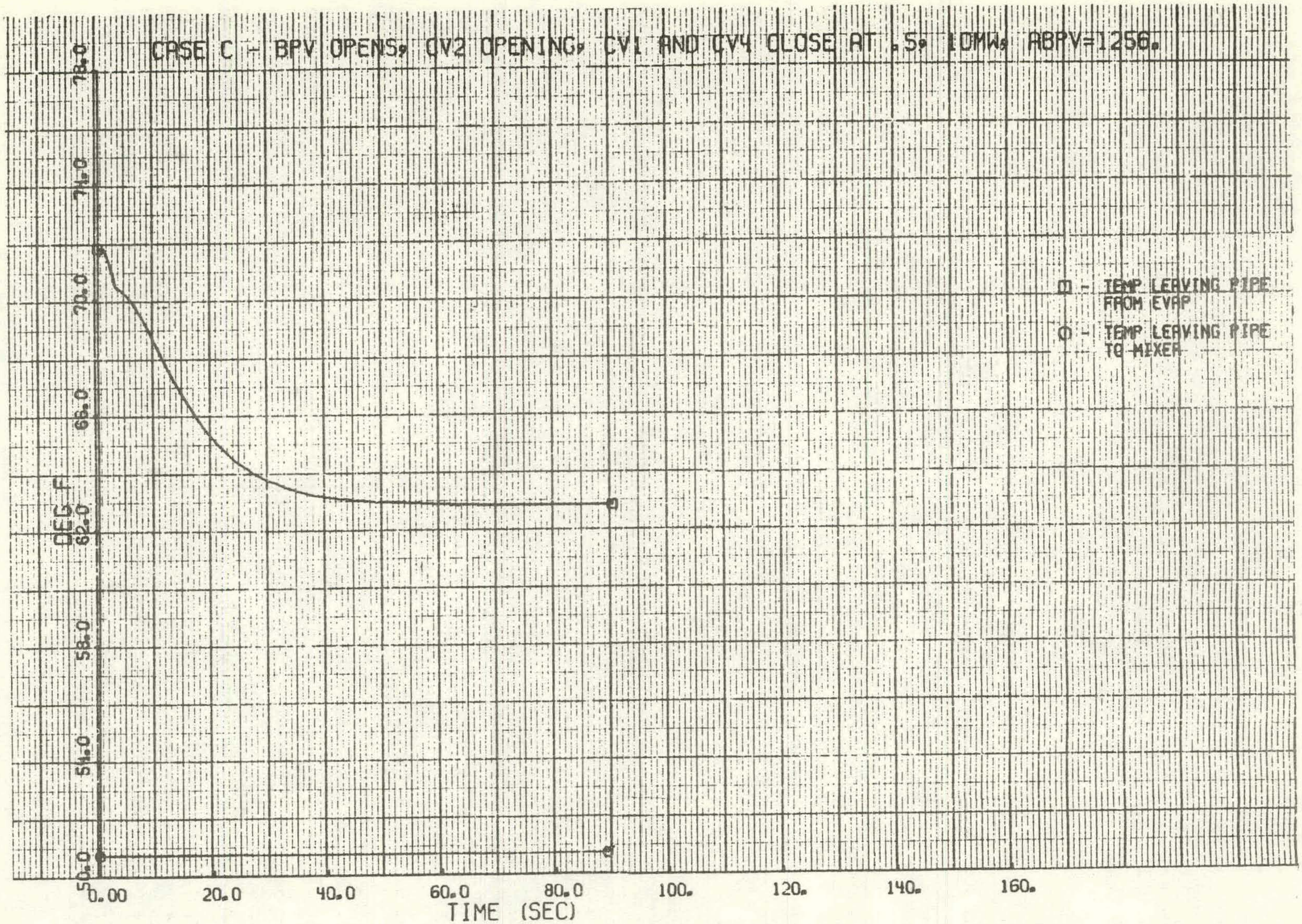

FIGURE 3K. CASE C - BPV OPENS, CV2 OPENING, CV1 AND CV4 CLOSE AT .5, 10 MW; ABPV=1256

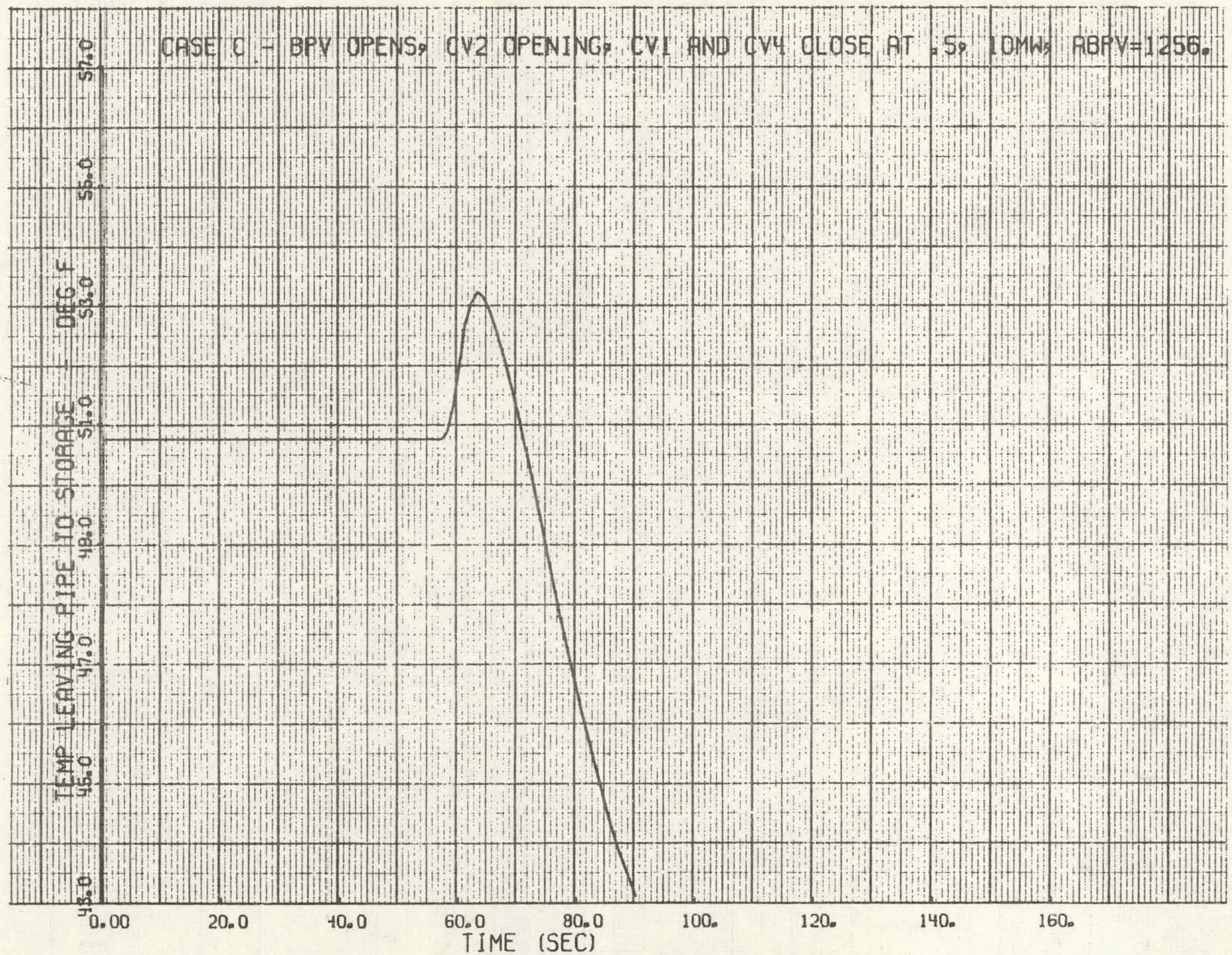

FIGURE 3L. CASE C - BPV OPENS, CV2 OPENING, CV1 AND CV4 CLOSE AT .5, 10 MW; ABPV=1256

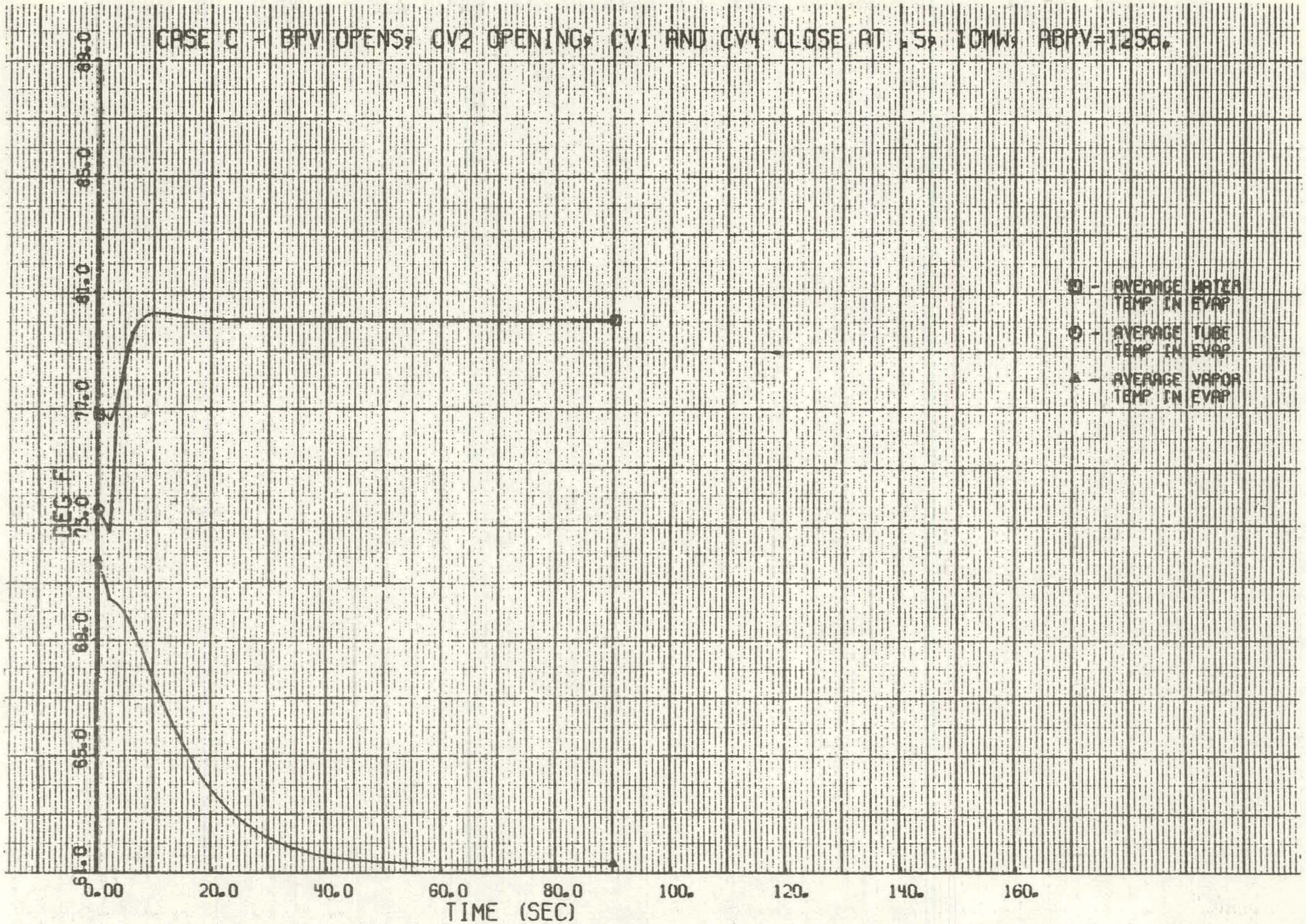

FIGURE 3M. CASE C - BPV OPENS, CV2 OPENING, CV1 AND CV4 CLOSE AT .5, 10 MW; ABPV=1256

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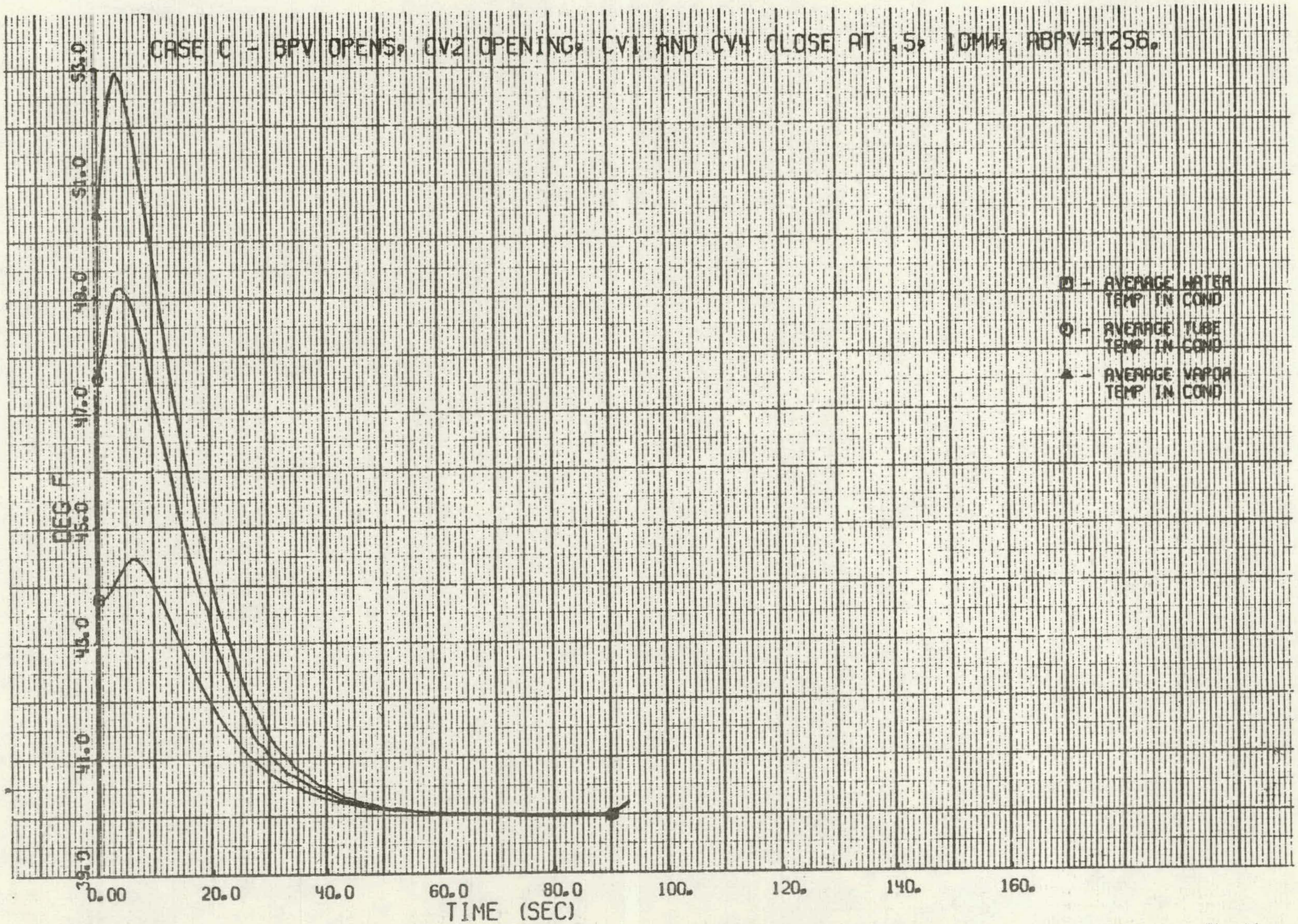

FIGURE 3N. CASE C - BPV OPENS, CV2 OPENING, CV1 AND CV4 CLOSE AT .5, 10 MW; ABPV=1256

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APPENDIX 6.4-A

TRIP REPORT - NH_3 SAFETY PRECAUTIONS/ACCIDENT RECORDS

Place Visited: The Fertilizer Institute (TFI)

Location: Washington, D.C.

Persons Contacted: James D. Massie, Director of Safety Programs

Date of Visit: August 18, 1978

Report of Visit: The purpose of my visit was to review the known potential hazards of handling, transporting and using anhydrous ammonia. Since 85% of the NH_3 consumed in this country is for agricultural purposes, the Institute is a logical source of safety data. Mr. Massie is Director of Safety Programs. He has also replaced Mr. Benjamin F. Day, also of TFI, as Secretary of the American National Standards Committee on Storage and Handling of Anhydrous Ammonia and Ammonia Solutions, K61.

The first area I reviewed was the hazards of filling operations. To prevent fires, did the air need to be purged from storage tanks being filled for the first time, and were the fill hoses required to be conductive? The answer was no to both questions. Years ago, the systems were grounded during fill operations, but this is no longer required. No records exist of fires started by a static electric discharge during a transfer operation. The main hazard is from an accidental spill.

Most of the NH_3 used in this country comes in from overseas plants. It is shipped into gulf ports; next spring, an offloading facility will be available in Charleston, South Carolina. Since ammonia is shipped by sea, large quantities of ammonia may be safely transported to the OTEC platform without having to be transported by railroad through populated communities.

Mr. Massie said that other than a fish kill, he could see no problem with a large dump of NH_3 into salt water. I mentioned that a California report concluded that it was actually beneficial. If such a dump is made purposely, it should be discharged at a depth of at least 5 feet below the surface of the water to allow for complete absorption and to prevent any vapor clouds from forming.

Mr. Massie also thought that salt water in lieu of fresh water in the first aid deluge showers would be acceptable--perhaps even better than fresh, if burns were involved.

When asked about continuous leak detectors for monitoring for NH_3 vapors in unmanned spaces, Mr. Massie said they were available and that he would get me information on them.

He also stated that he was traveling to the Navy installation at China Lake, California, where they were going to conduct tests on massive spills of ammonia. He said he would keep me informed of the results.

In a discussion on massive spills, it was noted that there are different opinions on the method to use to combat it. Toxic vapors are produced by flash-off from the initial spill. If water is then used on the remaining spill, the relatively warm water will cause quicker vaporization and result in larger quantities of toxic vapor clouds. Some people advocate using a foam-producing system to cover the liquid and control the vaporization rate. Then water can be applied slowly to cause the liquid to go into solution without producing additional vapor clouds. If water alone is used, it must be in sufficient quantities, which is at least 100 parts of water to one part of ammonia.

I concluded the visit with a review of accident records, which were mainly concerned with storage tank failures or railroad car accidents. In no case was fire the cause or result of an accident. Although newspapers have reported resulting explosions of car derailments, these were not "explosions" in the true sense of the word. The tanks failed "violently" due to overpressurization. Water was sprayed on the tanks to contain the ammonia, but it heated the liquid in the tanks, causing it to increase in pressure and vaporize at faster rates than the relief valves could handle. Some tank failures were also traced to stress corrosion cracking and poor welds.

Finally, Mr. Massie reported that most foreign countries were going to double wall tanks for the storage and transporting of ammonia.

Frederick Eliot
System Safety Director

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APPENDIX 6.4-B

TRIP REPORT - U.S. COAST GUARD HEADQUARTERS

Place Visited: United States Coast Guard Headquarters

Location: Washington, D.C.

Date of Visit: July 28, 1978

Report of Visit: I had originally contacted Mary Williams of the United States Coast Guard, Office of Hazardous Materials, relative to safety requirements of NH_3. When I visited her office she had also invited Captain Gears, Chief, Merchant Marine Technical Division; Captain Spence, Chief, Cargo and Hazardous Materials Division, and Fred Adamchek. The discussions ended up being more general than specific, but the following points were made:

- The main concern with the Coast Guard will be with the Federal Code of Regulations, Title 33 on Polution Prevention, and Title 46, Shipping, mainly sections F,I,J, and O.

- For Coast Guard approval, plans and calculations must be submitted for review.

- If there were a need to resolve certain conflicts, a "letter of understanding" could be used to reach an accord between the Coast Guard and the Department of Energy.

- A similar agreement exists between the Coast Guard and OSHA, where an "understanding" in lieu of a letter of understanding exists. Here, OSHA does not involve itself with safety aboard vessels under the cognizance of the Coast Guard, but leaves the safety of personnel to them.

- The Coast Guard is not concerned with the underwater transmission of electric power.

- Studies are pending on the dumping of large quantities of NH_3 into the ocean.

In addition to the above, a proposed standard was obtained that would revise certain sections of Title 46. This revision, entitled "Self-Propelled Vessels Carrying Bulk Liquified Gases", has several sections that pertain to NH_3 and will pertain to the design requirements of an OTEC system. While the OTEC platform will not be self-propelled, it was given to me because many of the requirements are of a safety concern and would be applicable to platforms -- stationary or self-propelled.

Frederick Eliot
System Safety Director

APPENDIX 7 - A

OTEC POWER SYSTEM DEVELOPMENT

PRELIMINARY DESIGN

TEST PROGRAM REPORT

28 August 1978

M. A. Paul
A. S. Jeung
C. A. Cascio
G. Bawroski
J. T. Malone

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CONTENTS

Page No.

1. INTRODUCTION

The purpose of the Test Program is to demonstrate OTEC Power System and operational performance in situ and to obtain data for future OTEC designs. This will be achieved by development of overall system and individual element research plans for operational data measurement, recording, playback and analysis.

The hardware includes a 0.18 MWe Evaporator and Condenser Test Articles, and a 10.1 MWe Modular Experiment Power System Application. Specific objectives achievable from hardware testing include verification of:

- Thermodynamic Performance
- Dynamic Stability and Operational Controls
- Mechanical Design
- Reliability/Availability/Maintainability and Safety

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2. SUMMARY CONCLUSIONS

2.1 System Elements and Test Objectives

The following system elements will be evaluated in both overall system and individual element performance testing:

- Heat Exchangers and Moisture Separator
- Turbine/Generator
- Ammonia Feed and Recirculating Pumps
- Warm and Cold Seawater Pumps
- Control and Storage Systems
- Ammonia and Seawater Piping

All of the above will be tested in the Modular Experiment while only the Heat Exchangers and Moisture Separator will be tested with the Test Articles.

The scope of the testing program is outlined by the development of specific test objectives for the following key areas:

- Heat Exchanger Characteristics
- Overall System and Individual Element Thermodynamic Performance
- Fouling Characteristics
- Effect of Ammonia/Seawater on Materials
- Steady State Operating Characteristics
- System Transient Dynamics
- Off-Design Conditions Performance
- R/A/M and Safety Performance

2.2 Program Development

By applying objectives to overall system and individual element operations a series of test questions was developed by the individual component designers and systems designers. Next, research plans outlining an approach for the resolution of the questions were developed. They specific test procedures, data requirements, instrument locations, and data sampling requirements. Finally, test hardware consisting of data acquisition, data playback, test instrumentation and data analysis equipment were developed to implement the research plans and fulfill test objectives to support design schedules.

This approach to program development is illustrated in Figure 2-1. Detailed results of this process are presented in subsequent sections of this report. A general overview of data requirements was obtained by an analysis of test objectives versus system elements and is presented in matrix form in Figure 2-2.

Measurement accuracies (Appendix A) and data sample frequencies (3.6 and 4.9) given herein are considered to be typical values, subject to revision following additional analysis (2.3). They were developed here to facilitate the test instrumentation and data acquisition efforts.

The instrumentation effort is a survey of hardware and technologies applicable to the OTEC program, and considers parameters such as:

- Measurement Range
- Measurement Accuracy
- Compatability With OTEC Environment
- Cost
- Commercially Available Versus Developmental Items

The data acquisition and analysis effort develops a design to meet the OTEC test requirements, but provides flexibility to adapt to changes in number of sensors, sample frequency rates, etc. The systems' real time analysis capability provides the operator with performance values, data tabulations and graphic displays. Another system feature is simplicity of installation, operation and maintenance. The system is designed for compatibility with modular power system design concept.

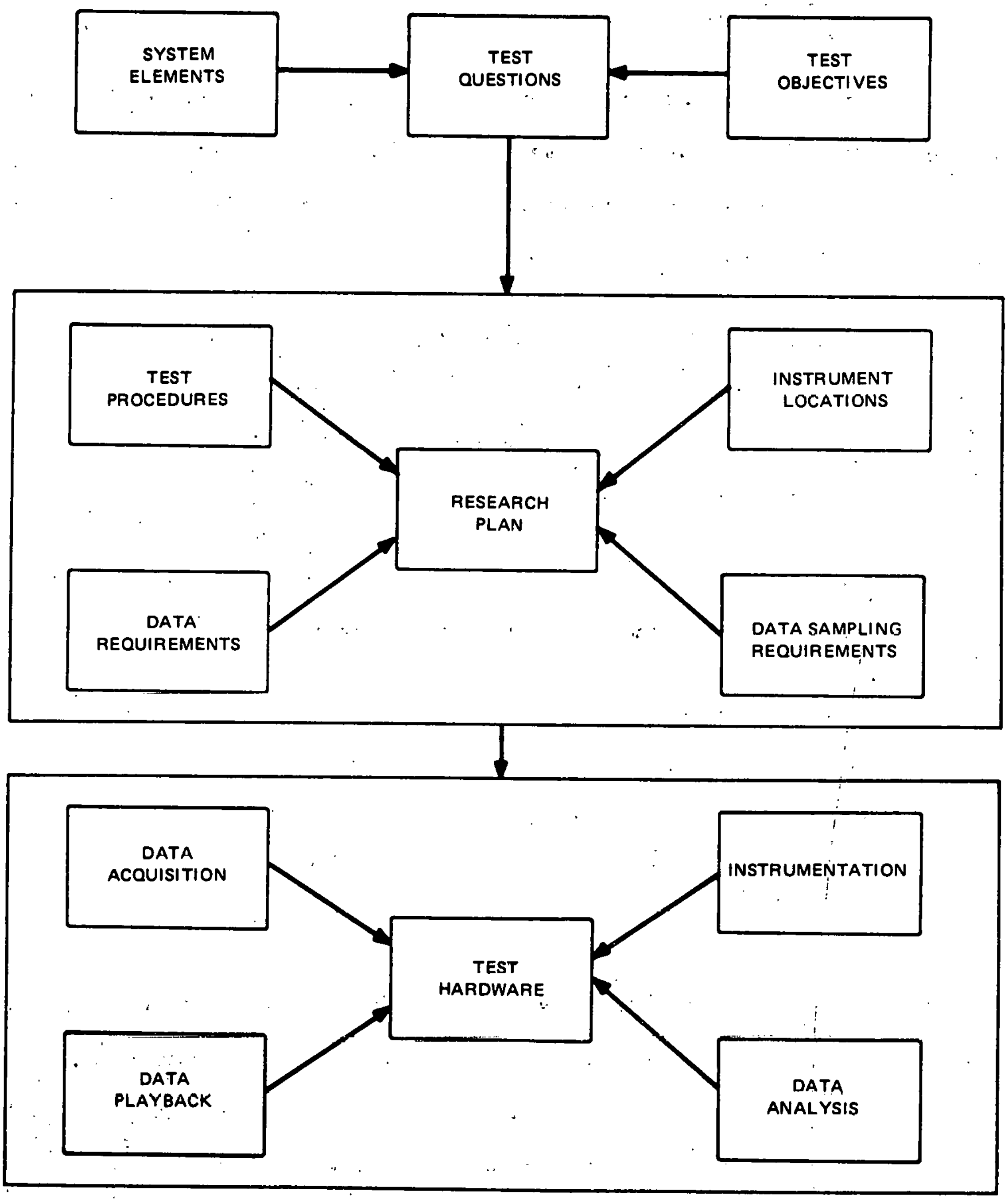

FIGURE 2-1

TEST PROGRAM DEVELOPMENT

KEY:

P – PRESSURE
T – TEMPERATURE
F – FLOW
A – ACCELERATION
C – CHEMICAL
B – BIOLOGICAL
E – POWER

TEST OBJECTIVES \ SYSTEM ELEMENT	HX'S AND MOISTURE SEP.	TURBINE/GENERATOR	NH_3 FEED AND RECIRC PUMPS	WARM AND COLD SW PUMPS	CONTROL AND STORAGE SYSTEM	NH_3 AND SW PIPING
Overall System and Individual Element Themodynamic Performance	PTF	PTF E	PTF	PFE	PFE	PTF
Individual Element Vibration and Rotating Element Balancing	A	A	A	A		
Fouling Characteristics	BT	E		B		
Effect of Ammonia/Seawater on Materials	C	C	C	C	C	C
Steady State Operating Characteristics	PTF	PTF E	PTF E	PTF E	PFE	PTF
System Transient Dynamics	PTF	PTF E	PTF E	PTF E	PFE	PTF
Off-Design Conditions Performance	PTF	PTF E	PTF E	PTF E	PFE	PTF
Heat Exchanger Characteristics	PTF	E	F	F		
R/A/M and Safety Performance	All Measurements for all Elements					

78160A02

Figure 2-2. Test Objectives Vs System Element – Data Requirements Matrix

Satellite data modules are packaged within an envelope of a few cubic feet. The central processor, data storage, man-machine interfaces and system peripherials are design to be installed in a mobile 40 foot long trailer/laboratory.

2.3 Conclusions

This report provides the conceptual development of a plan whose implementation will achieve OTEC Test Program objectives and goals. In the next phase of the OTEC-PSD program efforts should be directed to further develop the work contained in this report as follows:

- Prepare a detail Test and Evaluation Plan.
- Provide specifications for instrumentation and data acquisition system in detail sufficient for procurement.
- Define in detail all interfaces between system testing hardware and platforms, system elements and control system.

In addition to the above efforts the tasks described below should also be initiated in supported of the Test Program.

2.3.1 Accuracy Analysis

This analysis will define acceptable levels of performance calculation uncertainty for the system and individual elements. These accuracy requirements will be used to determine individual sensor accuracies. An accuracy versus cost and feasibility analysis of these requirements may, in some cases, require the employment of statistical techniques to improve measurement accuracies. These techniques include increasing the number of sensors, varying sensor locations, increasing data sample frequency, and increasing test duration. In addition, system geometry and dynamics may also require statistical techniques to reduce data measurement uncertainty.

2.3.2 Design of Experiment

This technique determines the parameters of interest for a particular experiment and which parameters will be allowed to vary during the experiment. Predictions regarding parametric interactions are also developed.

2.3.3 Instrumentation Development

Certain measurement techniques discussed in section 5 require instrumentation development. If any of these techniques are selected as OTEC test instrumentation, a program should be started during the next OTEC phase to develop the hardware required for testing.

3. TEST ARTICLES' - RESEARCH PLANS

3.1 Introduction

The Test Articles' consist of a 0.18 MWe evaporator with integral moisture separator and hotwell, and a condenser with integral hotwell. Their impact on the power system in terms of both cost and performance is sufficient to make separate testing prior to deployment of the Modular Experiment very desirable.

The Test Articles' research plans are devoted entirely to heat exchanger performance and phenomena. Heat exchanger and external parameters are varied to determine full range performance characteristics.

Unlike the Modular Experiment where a total system is being developed, the Test Articles' program will include:

- Recommended data measurements
- Suggested instrumentation
- Installation of sensors supplied or specified by the Test Director in areas not easily accessable after manufacture.

This section is concluded (3.8) with a discussion of the impact of Aluminum as the tube material in the Test Article.

3.2 Test Questions

The Test Articles' Research Plans will answer questions as to overall heat exchanger performance. Specifically the heat transfer algorithms will be verified. Pressure drops of both seawater and ammonia across the heat exchangers will be measured. Seawater distribution from the plenum through the waterbox and to the tube bundle will be recorded. The distribution of ammonia liquid and vapor in the heat exchangers will be verified.

The unique design of the Test Articles and their proposed test loop facilitates testing specific heat exchanger characteristics. Test will determine the relationship between evaporator vapor output and the magnitude of ammonia feed and recirculation.

Within the evaporator, the tube bundle ammonia exit velocity distribution will be determined. Vapor-liquid entrainment as a function of skimming velocity will be noted, as well as separator exit quality.

Other questions regarding specific evaporator phenomena include:

- Liquid Distribution
- Tube Wetting
- Film Stripping and Deflection
- Minimum Film Thickness

Tube vibration characteristics will be measured over the entire design range and at overload values.

Heat exchanger performance under off-design conditions will include:

- Changes in ΔT
- Various feed/recirculation conditions
- Load changes and loss of load
- Changes in vapor velocity
- Changes in seawater velocity

The effect of fouling and fouling control techniques on heat exchanger performance will be measured. The test will also determine the effect of ammonia/ seawater on selected candidate materials.

3.3 Measurements

3.3.1 Heat Exchanger Performance and Characteristics

The measurements recommended for the Test Articles' are shown in Figure 3-1 and listed in Appendix A. Data will be obtained by direct measurement and/or calculations. The Test Articles are of a size and configuration to facilitate the acquisition of data. The results are a key to the success of the Modular Experiment and Prototype Plants.

On the seawater side; pressure, temperature and flow measurements will be taken at the inlet and outlet of each heat exchanger. On the ammonia side pressure drops in the evaporator, separator, and condeser will be measured. Elsewhere in the ammonia system, temperatures and pressures will be measured for both liquid and vapor phases. Techniques for obtaining reliable data, for the heat exchangers, tube bundles, and individual tubes, are developed and presented in this section.

Both system operation and performance analysis require vapor flow measurements through the vapor recirculation loop. Measurements will be made at the evaporator outlet, throttle inlet, and evaporator vapor recirculation inlet. Vapor flow rate and velocity will be recorded and also presented in real time to facilitate test operation.

All ammonia liquid flows will be measured directly including; (1) feed, (2) recirculation, (3) evaporator liquid drain, and (4) separator liquid drain. Liquid distribution in the evaporator will be observed by taking individual flow measurements at nine distribution chamber inlets and at nine collection chamber outlets.

Individual tube vibration measurements will be taken in 6 tubes on the seawater side of the evaporator and condenser. Instrumentation will consist of two inductive displacement sensors per tube (horizontal and vertical). The

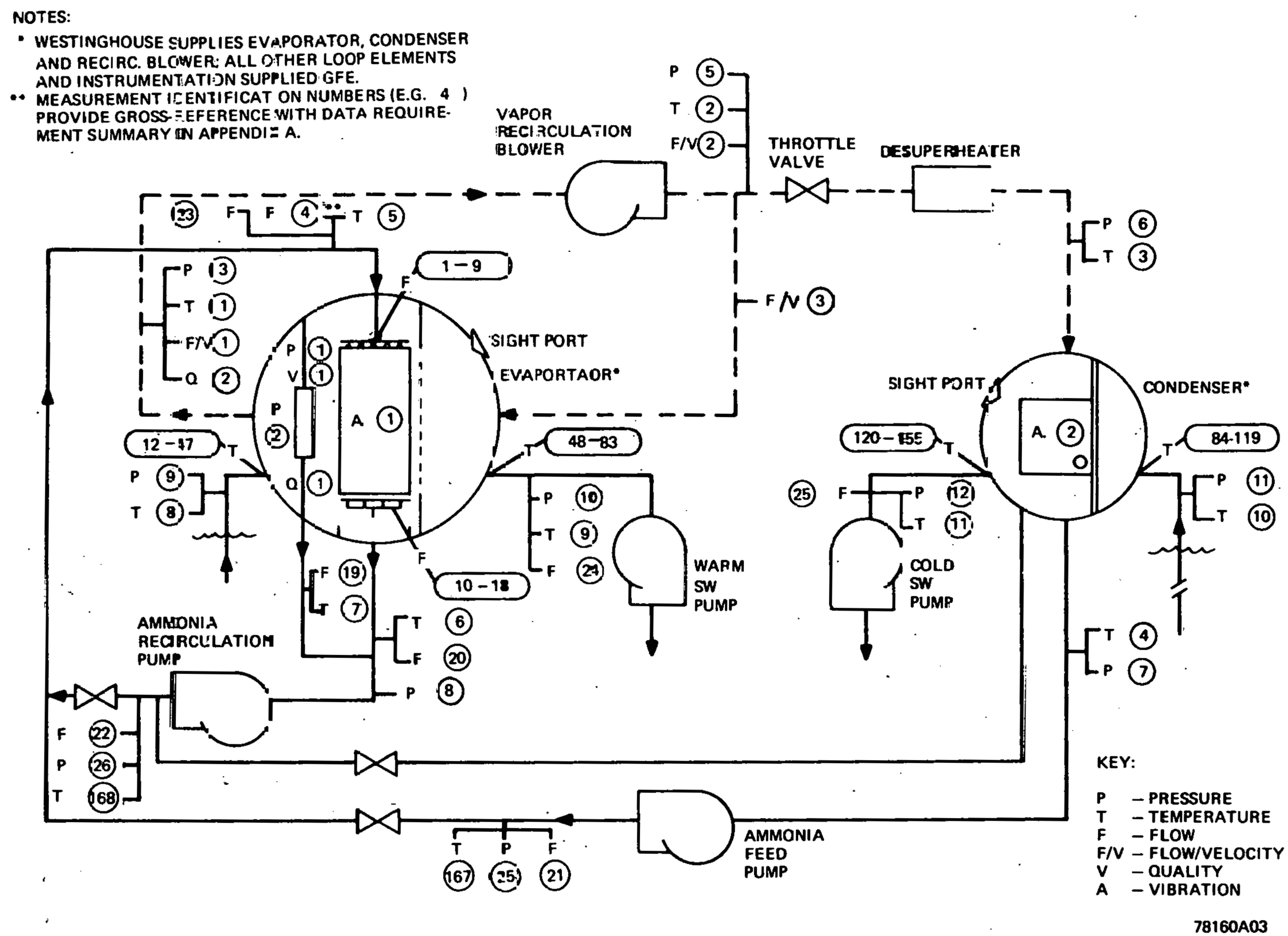

FIGURE 3-1

.18 MWe TEST ARTICLES-

TEST DATA REQUIREMENTS

measurement output, the tube's orbital displacement, will be presented on an oscilloscope.

Sea water temperature traverses will be made near individual tube entrances and exits to ascertain any variation in tube loadings. This measurement will be made on clusters of six tubes each, in six locations in the evaporator and condenser. These measurements are especially important in the evaporator to verify complete wetting of tube surface during all modes of operation.

Ammonia quality measurements will be made in the evaporator between the tube bundle and separator, and at the separator exit. Velocity traverses of the evaporator tube bundle will indicate the distribution of ammonia vapor exit velocities.

Sight ports will be located on the shell of both the evaporator and condenser. These will be of particular help on the evaporator where they will be used for visual observation and photographic records of evaporator phenomena (listed in 3.2). This technique is common practice, with applications in industry in fresh water distillation and chemical processing.

3.3.2 Fouling and Material Considerations

Measurement techniques will be similar to those used on the Modular Experiments, and will be discussed in 4.8 and 4.9. Coupon racks will be located on the seawater side in the inlet/outlet of the evaporator/condenser and within the evaporator and condenser shells. Each coupon rack will be instrumented to provide local temperature, pressure, and flow measurements.

3.4 Heat Transfer Performance Calculations

The technique used to verify the heat transfer algorithms is presented in this section. Calculated outside heat transfer coefficient is the key design parameter used in each case to verify design. Test data requirements, for these calculations, include: (1) seawater inlet and outlet temperatures; (2) saturated ammonia temperature; and (3) volume rate of flow for both seawater and ammonia.

3.4.1 Evaporator Outside Heat Transfer Coefficient

The form of the equation used to evaluate evaporator heat flux is as follows:

(1)

$$\frac{Q}{A_o} = 5723 \; (\Delta T_f)^{1.86} \quad \text{OR} = K \; (\Delta T_f)^{m+1}$$

K and m are to be validated or changed.

The form outside of the heat transfer coefficient, h_o , is calculated as follows:

(2)

$$h_o = 5723 \; (\Delta T_f)^{.86} \quad \text{OR} = K \; (\Delta T_f)^{m} \tag{2a}$$

The nomenclature is presented in Section 3.4.6.

First, using test data measurements, the log mean temperature difference is calculated:

$$\theta = \frac{(Tin - Tsat) - (Tout - Tsat)}{\ln\left(\frac{Tin - Tsat}{T_{out} - T_{sat}}\right)} \tag{3}$$

$$Q = W_{sw} * Cp_{SW} * (T_{in} - T_{out}) \tag{4}$$

$$Q = W_{NH_3} * \lambda \tag{5}$$

Equation 5 assumes that the ammonia is a saturated liquid. If this is not the case, equation 6 accounts for the preheat required prior to evaporation.

$$Q = W_{NH_3} * \lambda + \left[W_{NH_3} * Cp_{NH_3} * \Delta T_{PREHEAT} \right] \tag{6}$$

Then the overall heat transfer coefficient is calculated:

$$U = \frac{Q}{\theta A_o}$$

The overall resistance is then calculated: (8)

$$\sum R = \frac{1}{U}$$

Finally, outside heat transfer coefficient, h_o, is calculated using the value of outside resistance obtained from equation 10 below:

$$h_o = \frac{1}{R_o} \tag{9}$$

Outside resistance is calculated:

$$R_o = \sum R - (R_i + R_f + R_m) \tag{10}$$

The equations used to calculate the individual resistance terms in equation 10 are presented below:

3.4.1.1 Seawater Resistance (R_i)

The Dittus Boelter equation is used to calculate the Nusselt Number:

$$Nu = .023\ Re^{.8}\ P_r^{.4} \tag{11}$$

The inside heat transfer coefficient is then calculated:

$$h_i = \frac{Nu\ k}{d_i} \tag{12}$$

Seawater resistance is finally calculated:

$$R_i = \frac{1}{hi} * \frac{Ao}{Ai} \tag{13}$$

3.4.1.2 Tube Metal Resistance (R_m)

The following algorithms are used to obtain values for the thermal conductivity of aluminum and titanium.

Aluminum $k_m = 119.5 + .0168\ T_m$ (14)

Titanium $k_m = 11.7 - .0033\ T_m$ (15)

The resistance is corrected to the appropriate surface by use of the ratio of outside diameter to log mean diameter.

$$d_m = \frac{do - di}{\ln\left(\frac{do}{di}\right)} \tag{16}$$

The tube metal heat transfer coefficient is calculated:

$$h_m = \frac{t}{12\ k_m} \quad \frac{do}{dm} \tag{17}$$

The tube metal resistance is calculated:

$$R_m = \frac{1}{h_m} \tag{18}$$

3.4.1.3 Fouling Resistance (R_f)

Fouling resistance is assumed to be equal to zero for this test.

For this to be a valid assumption the tubes must be as clean as possible when heat transfer testing begins and maintained in this condition during this entire phase of the test.

3.4.2 Outside Heat Transfer Coefficient Evaluation

The value of outside heat transfer coefficient calculated in equation 9 is compared with the value obtained using equation 2.* Concurrence of these two values validates the heat transfer algorithms.

In the event of nonconcurrence, equations 1 and 2 may be revised to a form that is in better agreement with the heat exchanger configuration. This will be accomplished using a technique such as the Wilson Plot to evaluate better K and m values. Off-design values of overall and outside resistance are obtained by performing the above test and varying the seawater volume rate of flow. Seawater pump flow capability will have the following off-design capabilities:

- Test Articles - ± 50%
- Modular Experiment - ± 5%

3.4.3 Condenser Outside Heat Transfer Coefficient

With one exception verification of the heat transfer algorithms for the condenser is accomplished using the technique and calculations described above in 3.4.1 and 3.4.2. The only exceptions are the equations used to evaluate outside heat transfer coefficient. The single tube Nusselt condensing equation is:

$$h_o = .725 \left[\frac{3600\, g\, \rho^2\, k^3\, \lambda}{\mu\, d_o\, T_f} \right]^{.25} \tag{19}$$

And when corrected for the tube bundle factor this value becomes:

$$h_{o_{BUNDLE}} = h_{o_{SINGLE\ TUBE}} \left(\frac{1}{N_t} \right)^n \tag{20}$$

3.4.4. Liquid and Vapor Distribution Testing.

*NOTE: Use $\Delta T_f = \theta \left(\frac{R_o}{\Sigma R} \right)$ in equation (2) to obtain a value for h_o.

The ammonia liquid and vapor distribution tests are to be performed under the same conditions (of clean heat exchanger tubes) as the heat transfer performance tests. This will clearly establish the relationship between liquid and vapor distribution and heat transfer performance.

3.4.5. Fouling

When the tests described above in 3.4.1 through 3.4.4 have been completed, and heat transfer performance can be confidently predicted, system fouling tests (as described in 4.7) will be started. The equations described above are used to determine fouling resistance (R_f). By repeating the experiments periodically values of fouling resistance and their rates of buildup can be determined under different operating conditions and levels of fouling control (i.e. dosages of chlorine).

3.4.6 Nomenclature

A_o	Total outside surface area
C_p	Specific heat, BTU/(lb.$_m$-F)
d_i	Tube inside diameter, ft.
d_m	Tube mean diameter, ft.
d_o	Tube outside diameter, ft.
g	Acceleration of gravity, ft./sec.^{2}
h_i	Inside heat transfer coefficient BTU/(hr. - ^oF -ft.^{2})
h_m	Metal heat transfer coefficient BTU/ (hr. - ^oF - ft.^{2})
h_o	Outside heat transfer coefficient BTU/ (hr. - ^oF - ft.
k	Constant in (1) and (2)
k	Fluid conductivity, BTU/ (hr. - ^oF - ft.)
k_m	Tube metal conductivity, BTU/(Hr. - ^oF - ft.)
m	Exponent in (1) and (2)
N_t	Number of tubes in a vertical row
N_u	Nusselt No., $Nu = h_i\ d_i/K$
n	Condensate loading exponent
P_r	Prandtl No., $P_r = C_p\ u/K$
Q	Heat Load, BTU/hr.
Q/A_o	Heat Flux, BTU/ (Hr. - ft.^{2})
R_e	Reynolds No., Re - $d_i V/\nu$
R_f	Fouling resistance
R_i	Seawater resistance $(1/h_i)$ corrected to outside surface
R_m	Tube metal resistance $(1/h_m)$ corrected to outside surface
R_o	Ammonia resistance $(1/h_o)$

T_m	Metal temperature, ^oF.
T_{IN}	Seawater inlet temperature, ^oF.
T_{OUT}	Seawater outlet temperature, ^oF.
T_{SAT}	Saturation temperature
U	Overall heat transfer coefficient, BTU/ (hr. - ^oF - $ft.^2$)
V	Velocity, ft./sec.
W_{NH3}	Ammonia volume rate of flow, lb./sec.
W_{SW}	Seawater volume rate of flow, lb/sec.
ΔT_f	Temperature drop across outside film, ^oF.
$\Delta T_{PREHEAT}$	Temperature difference between evaporator liquid ammonia inlet temperature and $T_{SAT,}$ ^oF.
θ	Log mean temperature difference, ^oF
λ	Latent heat, BTU/$lb._m$
u	Dynamic viscosity, $lb._m$/ ($ft.^2$ - sec.)
ν	Kinematic viscosity, $ft.^2$ /sec.
ρ	Density, $lb._m/ft.^3$

3.5 Procedures

The heat exchangers will be tested by starting the test loop and running it at normal steady state design conditions. During this operation measurements will provide date for tabulations, plots, and input for the performance calculations previously discussed. It is planned to employ "real time" data reduction to facilitate graphic presentation of intermediate results during testing. In addition to steady state operation testing, other tests will require specific procedures as discussed below.

3.5.1 Ammonia vapor velocity tests.

Verification of the evaporator perforated plate design should be performed early in the test series. To accomplish this test the test loop will be run with the vapor recirculation line blanked and the vapor recirculation blower stopped. The ammonia vapor exit velocity distribution will be measured as it leaves the evaporator tube bundle. This data will be used to modify the perforated plate as necessary, before it is replaced in the evaporator. After the blank is removed from the vapor recirculation line the loop will be ready for subsequent testing to begin.

During testing, vapor recirculation flow and velocity will be determined by the throttle valve and blower controls. It is expected that flow will be split approximately nine to one between recirculation and throttle control respectively. The vapor velocity will be varied through the normal expected range and also into overload regions and the following characteristics recorded and/or observed:

- Film stripping and deflection
- Vapor - liquid entrainment resulting from exit velocity skimming
- Tube vibration

3.5.2. Evaporator Ammonia Flow Distribution

Flow distribution of ammonia in the heat exchanger will be measured by temperature traverses of individual tubes on the seawater side. In addition to this measurement liquid distribution in the evaporator will be checked using t e flow instrumentation in the distribution/collection chambers.

The liquid ammonia will be recirculated through the evaporator with the warm seawater pump stopped, to verify balance of flows between respective distribution/collection chambers. These flows will again be monitored during normal test loop steady state operation to verify balanced distribution. After the above distribution balances have been verified there will no longer be a need to maintain or record all 18 flow measurements in the distribution/collection chambers.

3.5.3 Reflux Rates

This test will establish the relationship between evaporator vapor flow out, total liquid flow in, and the ratio of recirculated ammonia to total ammonia flow into the evaporator. This test will be performed by a process of varying evaporator feed and recording all flows. First ammonia feed flow will be slowly increased until the ammonia level begins to rise in the evaporator drain tank. Then the ammonia recirculation pump will be started and controls activated to maintain constant level in the evaporator drain tank. Finally the ammonia feed flow will be slowly increased again until the ammonia vapor flow out of the evaporator no longer is increasing. The actual ammonia vapor flow out of the evaporator will be equal to evaporator vapor outlet flow less vapor recirculation flow. Several runs of the above test will document the ammonia reflux ratio.

3.5.4 Off-Design and Transient Performance

Off-design performance tests will include varying warm and cold seawater temperatures and/or flow rates and observing heat exchanger performance, and changing throttle valve settings to simulate changes in test loop loads. A sudden full opening of the throttle valve will approximate the turbine by-pass valve during a loss of load situation. As the throttle valve is opened the liquid ammonia flow to the evaporator will be shut-off to further simulate the loss of load situation. The flashing and increase in ammonia vapor flow effects will be observed and recorded.

3.6 Data Measurement Frequency

The measurements required to verify the heat exchanger algorithms will be read every five minutes during steady state operation. These include the seawater flows, seawater inlet and outlet temperatures, ammonia flow and ammonia saturation temperature. In general all other temperatures, pressures and flows will be read every ten minutes. Ammonia vapor velocity will be checked and reset at this frequency, except during off-design testing when it will be read and set every minute. Ammonia flows will be read at one minute intervals during the tests to determine reflux ratio. Ammonia flows through the distribution and collection chambers will be read at one minute intervals during flow distribution testing. Tube vibration, temperature traverses and ammonia quality will be read every five minutes.

The measurement frequencies presented above represent typical values. Specific case sampling frequency and test duration will be determined by an accuracy analysis in detail design as discussed in 2.3.1. The early segments of the test schedule will be concerned with special purpose testing and will require relatively higher measurement frequency rates. Following this specified period of special purpose testing the test articles will be scheduled to run at steady state design conditions for long periods of time with relatively lower measurement rates.

3.7 Environmental Data

A certain correlation exists between Test Articles and local environmental conditions. The following data will be recorded during testing and their impact will be considered during performance analysis:

- Water column temperature distribution
- Water column currents
- Sea State
- Local biological data
- Weather conditions

3.8 Test Article Tube Material

Aluminum is the tube material to be used in the Test Article. Its use has modified the Test Article design configuration as originally developed for titanium tubes. However, the changes will not preclude the application of design data obtained to the 10 MWe Modular Experiment and the commercial 50 MWe/40 MWe modules built with titanium tubes. The Test Articles will prove the technical feasibility of the Westinghouse OTEC heat exchanger designs. It also will verify the ability to predict performance parameters, thus providing the confidence required for the larger design effort.

Aluminum tube design requires a wall thickness that is greater than titanium. The revised design decreases the tube inside diameter while maintaining the same outside diameter and tube spacing configuration. Thus the Test Article still accurately models important shell side phenomena including: (1) film heat transfer coefficient; (2) liquid distribution; (3) tube wetting/dry out; and (4) film deflection. Inside characteristics are more predictable, thus exact modeling is less critical. The seawater volume flow rate will be reduced to maintain design velocity through the heat exchanger tubes. Thus the inside heat exchanger coefficient remains unchanged, but its effect on unit performance is also a function of the ratio of tube I.D. to O.D., since all coefficients are corrected to total outside surface area. Design seawater velocity will model its effect on material erosion and fouling; however the material will be different.

Aluminum tubes require a revised support configuration as a result of different strength and damping characteristics. Therefore, titanium tube support design will not be tested. However the tests will verify the techniques used to predict tube vibration characteristics in OTEC applications.

Although the use of different tube material will prevent the collection of other valuable material performance data such as the fatique characteristics of the Linde surface bond, corrosion, and thermal conductivity of titanium tubes, coupon racks will help supply some of the material data of interest.

4. MODULAR EXPERIMENT RESEARCH PLANS

The research plans for the Modular Experiment are presented in this section. The test questions developed concern the overall system, individual system elements and specific subjects. For each question a plan has been devised to obtain the answer. The plans include data reqirements, instrument locations and test procedures. A summary of the test data requirements is shown on the system schematic, Figure 4-1 and listed in Appendix A.

4.1 Heat Exchangers and Moisture Separator

The heat exchanger tests will be similar to those recommended for the Test Articles. However, less emphasis will be placed on specific heat exchanger phenomena. The performance tests will verify the Test Articles' results, and verify that the heat exchangers are contributing to total system performance as predicted.

4.1.1 Test Questions

The Modular Experiment will confirm the findings of the Test Articles at actual plant operating conditions. Thus providing further confidence in the answers to the following:

- Verification of the heat transfer algorithms
- Establishment of ammonia reflux ratio
- Tube vibration characteristics
- Seawater and ammonia pressure drops across the heat exchangers and moisture separator.
- Seawater temperature distribution in the evaporator and condenser.
- Ammonia liquid and vapor distribution in the condenser and evaporator shell side.

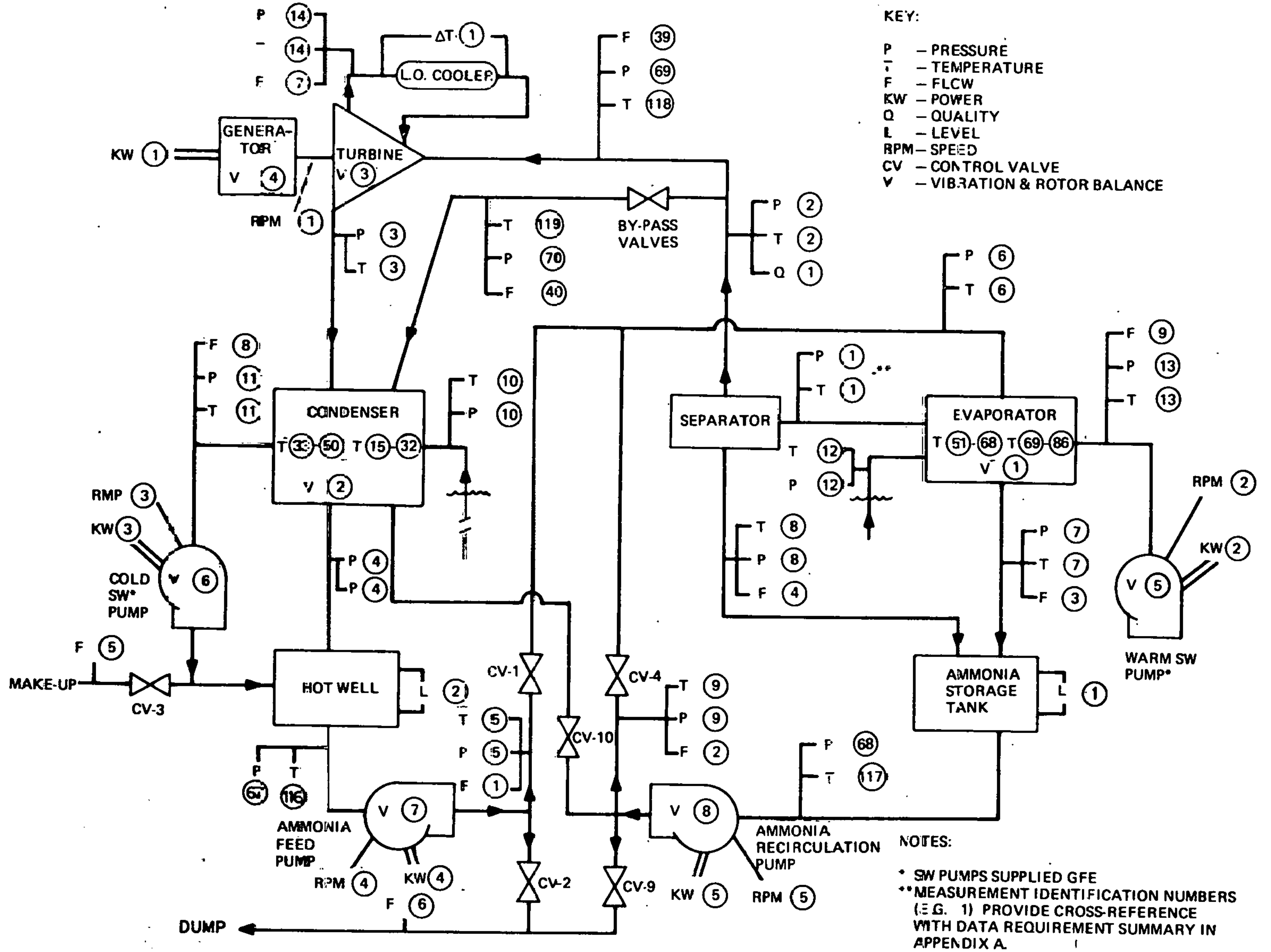

FIGURE 4-1

10 MWe MODULAR EXPERIMENT-

TEST DATA REQUIREMENTS

4.1.2 Measurements

The measurements are similar to those to be made on the Test Articles. Seawater inlet and outlet temperature, pressure and flow will be measured on both the condenser and evaporator. Inlet and outlet ammonia temperatures and pressures will be measured at the evaporator, separator, and condenser. Liquid ammonia flows will be measured at the outlet of the evaporator and separator and at the evaporator inlet.

Tube vibration characteristics will be measured in six individual tubes. In each tube, displacements in the horizontal and vertical planes will be measured by two inductive displacement sensors. Recorded data will be presented in orbital format on an oscilloscope.

Temperature traverses will be made near tube entrance and exit to ascertain any variation of individual tube loading. They will be located at the inlet and outlet of the evaporator and condenser. Measurements will consist of clusters of six tubes in three locations. This measurement is to verify the Test Articles' results on the Modular Experiment sized heat exchangers.

4.1.3 Calculations

Calculations for verification of the heat exchanger design algorithms are the same as those used with the Test Articles in 3.4.

4.1.4 Procedures

Heat exchanger performance data will be measured during all the Modular Experiment tests. These tests are discussed in the following sections. They include steady state tests over long time intervals, off-design condition testing, and system transient dynamic response performance.

4.2 Thermodynamic Performance

Thermodynamic performance testing will consist of performing complete heat balance calculations of the OTEC plant while operating at an ocean site. Overall system and individual element performances will be analyzed. The test will be performed at designed steady state conditions; but additional tests, measuring the same performance parameters, will be performed at off-design conditions. Test questions to be answered are overall and individual element efficiencies, and evaporator reflux rate.

4.2.1 Overall System and Individual Element Thermodynamic Performance

The thermodynamic performance calculations for the OTEC system are presented below. All measurements referenced have been previously identified as data requirements on Figure 4-1 and listed in Appendix A.

4.2.1.1 Net and Gross Power System Efficiency

Power system efficiency is a measure of the effectiveness with which the system uses the total available energy which is a function of the temperature differential between the warm and cold seawater. Net and gross power system efficiencies are calculated as follows:

$$\eta_{NET} = \frac{KW_{NET} * 3412.14}{G_{WSW} * H_{WSW} - G_{CSW} H_{CSW}} \qquad (21)$$

$$\eta_{GROSS} = \frac{GROSS \quad 3412.14}{G_{WSW} * H_{WSW} - G_{CSW} * H_{CSW}} \qquad (22)$$

where;

KW_{NET} = Measured system net terminal output power, KW

KW_{GROSS} = Measured generator output power, KW

G_{WSW} = Measured warm seawater flow, lb./hr.

G_{CSW} = Measured cold seawater flow, lb./hr.

H_{WSW} = Enthalpy warm seawater, Btu/lb. -determined from temperature and pressure measurements of the warm seawater.

H_{CSW} = Enthalpy cold seawater, Btu/lb. - determined from temperature and pressure measurements of the cold seawater.

4.2.1.2 Turbine/Generator Efficiencies

Using the data available three different efficiencies will be calculated.

Turbine Cycle Efficiency

Turbine cycle efficiency is a measure of the effectiveness with which the system uses the available energy which crosses a boundary surrounding the turbine/generator and condenser. It is calculated by the equation:

$$\text{TURB CYC} = \frac{KW_{GROSS} * 3412.14}{G_{THT} * H_{THT} - G_{FEED} * H_{FEED}} \qquad (23)$$

where:

KW_{GROSS} = Defined in Eq. (22)

G_{FEED} = Measured ammonia feed flow, lb./hr.

H_{THT} = Enthalpy ammonia vapor at turbine inlet, Btu/lb. - determined from pressure and quality measurements at turbine inlet.

H_{FEED} = Enthalpy ammonia feed, Btu/lb. - determined from temperature and pressure measurements.

G_{THT} = Ammonia vapor flow at turbine inlet, lb./hr. - Equal to G_{FEED} minus hotwell increase plus hotwell decrease.

Turbine Efficiency

Turbine efficiency is a measure of the effectiveness with which the turbine uses the total energy available under ideal conditions. It is calculated by the equation:

$$\eta_{TURBINE} = \frac{H\ WORK}{\Delta H_{IS}} = \frac{H_{THT} - H_{TOT\ EXIT}}{H_{THT} - H_{IS}} \qquad (24)$$

where:

H_{THT} - Defined in Eq. (23)

ΔH_{IS} - Assumes an isometric process where entropy at turbine inlet equals exit entropy. Since inlet pressure and quality are given it is possible to determine inlet and exit entropy. Then exit quality is calculated and exit enthalpy is determined.

and:

$$H_{TOT\ EXIT} = \frac{G_{THT} * H_{THT} - KW_{GROSS} - (ML + WL)}{G_{THT}} \quad (25)$$

Where:

G_{THT}, H_{THT} - Defined in Eq. (23)

KW_{GROSS} - Measured generator output power (at a specified power factor), KW.

ML = Turbine mechanical loss determined by measurements of lube oil flow to cooler and Δ T of lube oil across cooler.

WL = Windage loss determined from generator hydrogen pressure and purity.

Generator Efficiency

The effectiveness with which the generator uses the energy available to it is a function of generator losses. It is calculated by the equation:

$$GEN = \frac{KW_{GROSS} - WL}{KW_{GROSS}} \quad (26)$$

where:

KW_{GROSS} - Defined in Eq. (22).

WL - Defined in Eq. (25)

4.2.1.3 Evaporator Enthalpy

Evaporator enthalpy is calculated as a measure of evaporator and separator performance. It will be compared with predicted values in performance evaluation. It is calculated by the equation:

$$H_{EVAP} = \frac{G_{THT} * H_{THT} + G_{SEP} * H_{SEP}}{G_{EVAP\ VAP}}$$

where:

G_{THT} & H_{THT} = Defined in Eq. (23)

G_{SEP} = Measured value of liquid ammonia out of separator, lb./hr.

H_{SEP} = Enthalpy of ammonia at separator outlet determined from temperature and pressure measurements, Btu/lb.

The vapor flow at the evaporator outlet is calculated as follows:

$$G_{EVAP\ VAP} = (G_{FEED} + G_{RECIRC}) - G_{EVAP\ LIQ.}$$

where:

G_{FEED} = Defined in Eq. (23)

G_{RECIRC} = Measured value of recirculated ammonia, lb./hr.

$G_{EVAP\ LIQ.}$ = Measured value of liquid ammonia out of evaporator, lb./hr.

4.2.1.4 Evaporator Reflux Rate

During the thermodynamic performance steady state testing evaporator reflux rate will be calculated as follows:

$$\text{RECIRCULATION RATIO} = \frac{G_{\text{EVAP LIQ}}}{G_{\text{FEED}} + G_{\text{RECIRC}}} \tag{29}$$

where:

$G_{\text{EVAP LIQ}}$ G_{FEED} & G_{RECIRC} - Defined in Eq. (28)

Furthermore the relationship between evaporator vapor flow out, and total liquid flow into the evaporator will be measured during plant start-ups. The procedure is the same as that described for the Test Articles in 3.5.3. Ammonia feed and recirculation flow rates will be measured directly. Ammonia vapor flow out of the evaporator is calculated in equation (28).

Vapor flow rate out of the separator is calculated as follows:

$$G_{\text{THT VAP}} = G_{\text{EVAP VAP}} - G_{\text{SEP LIQ}} \tag{30}$$

where:

$G_{\text{EVAP VAP}}$ - Defined in Eq. (28).

$G_{\text{SEP LIQ}}$ - Measured value of liquid ammonia out of separator lb./hr.

4.2.2 Steady State Operating Characteristics

The heat balance calculations will be performed during steady state plant operating conditions. During each test the plant will be run at design load for a period of two hours. Additional time will be allowed to enable the power system to stabilize before testing begins. Data readings will be taken over the entire test period and calculations will be performed using data averaged over the collection period.

During testing the system will be totally isolated. The make-up and dump control valves will remain in the closed position. Isolation blocking valves located on the storage system side of these control valves will also be shut. The no leakage condition will be verified, during the test, by monitoring the flow meters in the make-up and dump lines, and by temperature probes between the control valve and blocking valve.

Pre-tests are planned to checkout and verify test instrumentation. For example, the acoustic flow meter, measuring the ammonia feed, will be calibrated with a throat-tap flow nozzle in parallel with the ammonia piping. Another pre-test will be a comparison of readings taken by a thermocouple traverse of the seawater pipe versus therocouples placed around the pipe's inside diameter.

4.2.3 Off Design Conditions Performance

A series of tests, similar to the one described above, will be performed for off=design conditions. Off-design seawater temperature testing is achievable as such conditions become available on site or by mixing the seawater in the plenums before the heat exchangers. A variability of $\pm 5\%$ in seawater pump flow capability provides additional potential off-design testing combinations.

4.3 Operational Performance

The control system has been designed to maintain system stability during start-up, steady state with design load, and normal and emergency transients. A dynamic computer model has been designed to simulate control system response characteristics. One of the first test objectives will be the verification of the control system dynamic model's predictions.

4.3.1 Test Questions

Test questions are specifically concerned with the system operational performance characteristics. These include the following:

- System start-up and coming up to full load.
- Ability to maintain stabilized operation at full load.
- Ability to handle step load changes or changes in operating parameters such as seawater temperature.
- Loss of load performance.
- Emergency shut down.
- Verify that speed and load control are satisfactory for utility type service.

4.3.2 Measurements

Many of the measurements required for Control System testing have already been identified in previous test descriptions. These include pressure and flow measurements in the ammonia loop. Others are unique to control system operation. They include control valve position and control signals, and make-up and dump line flow rates.

Of special interest is the flow and pressure drop in the ammonia vapor lines. It is especially important that vapor flow be measured in the lines that split between the turbine and bypass valves. The flow and change in pressure across the ammonia pumps will be measured. All temperatures associated with ammonia flow will also be measured.

Recorded data will provide the material for performance curves that will be used to analyze system responses and evaluate computer predictions. These plots include:

- Turbine Vapor Flow vs Lift/Diameter of Control and By Pass Valves.
- Turbine Vapor Flow vs Small Changes in Control Valve Position.
- Ammonia Vapor Flow Vs. Time
- Turbine Speed vs. Time
- Ammonia Vapor Flow vs. the Sum of Ammonia Feed and Recirculation Flow.

- Pump Discharge Flow vs. Pressure
- Valve Position vs. Time
- Error Signals vs. Time

4.3.3 Procedures

The control system includes its own system operation simulation program. It will be used dockside following the installation of the control system to verify control logic and valve responses to system operating conditions.

On site the control system tests will be the first performed since control system verification is prerequisite to other tests. During the first system start-up the value of vacuum obtainable will be an indication of the integrity of system seals. Furthermore, during the first start-up a vacuum hold test will be performed. After system stabilization measure air flow rate through air ejector system. A criteria will be established for verification of a tight system.

Following start-up turbine overspeed protection will be the first phase of the control system tested. Drop the load at a level of load or flow such that conditions are safe, with respect to overspeed, but high enough to be able to verify characteristics of overspeed protection. Analysis of the system characteristics plots will provide verification of the system's overspeed protection and the computer dynamic model predictions.

The system will be operated with full rated load in a steady state condition to test the ability to maintain stabilized operation. This ability will then be further tested with step load changes and off-design changes in available temperature differential and seawater flow rates. In addition to performing normal operating sequence shutdowns a number of emergency shutdowns will be performed. During the emergency shutdowns time requirements will be established for: (1) pumping out liquid ammonia; and (2) drawing out vapor ammonia.

4.4 Turbine/Generator

The turbine and generator will be tested on site under actural operating conditions. As previously discussed in 4.2, performance testing includes turbine, generator and turbine cycle efficiencies.

The turbine, generator and their rotors are instrumented to measure vibration and rotor balance. Individual turbine blades are fitted with blade stress instrumentation; and this data is relayed to the recording station using an FM transmitter or high speed slip rings.

The turbine will be factory tested to verify performance, using steam as the working fluid. Prior to manufacture turbine design will be verified using the following model tests:

- Gland Seal
- Aerodynamic
- Exhaust Hood
- Blade Section Cascade

A model with the same gland geometry as the 10 MWe turbine will be tested using ammonia as the working fluid. It will be run at speeds of from 3600 to 7200 rpm to verify predicted leakage, "O" ring reliability, and corrosion resistance of materials. A scaled model of the inlet configuration will be used to verify predicted inlet loss, eliminate adverse blade vibration effects and maximize efficiency.

A three-dimensional model of the exhaust hood will be tested with the objective to increase design efficiency. Sections of the rotating blade, such as the hub, mean and tip, will be cascade tested to verify profile losses.

The turbine and generator will be factory tested by first running each rotor in a heaterbox and secondly by performance testing using steam as the working fluid. During the heaterbox testing mechanical vibration will be measured while each rotor is run through the design speed range and up to the required value of overspeed.

A facility such as the one presently available at the Westinghouse Lester Site is required for performance testing the turbine and generator using steam as the working fluid. Under these conditions the turbine output will be approximately 2,000 kw. The first test will be to measure the efficiency of the turbine only using a waterbrake load. Then the turbine and generator will be run together to determine generator efficiency. The latter test will require the development of a water rheostat device. During these tests strain gauges on the blading will measure blade stress. These measured values will then be used to predict blade stress at full load in the OTEC power system.

4.5 Seawater Pumps

The Modular Experiment is the first opportunity to test the seawater pumps in operation with the total OTEC power system. Pump parameters, such as power requirements, flow rates, and speed will also be measured during all tests. Power requirements are a key measurement, since the seawater pumps are the systems greatest parasitic loss. These parameters will be used to develop pump performance curves for comparison with predicted pump characteristics. Other pump test questions include the following:

- Pressure profile across the pumps
- Pump vibration and balance characteristics
- Pump seal leakage
- Pump characteristics at off-design flow rates

Pump flow rates, pressures, temperatures and power requirements are being measured for other system tests and will provide some of the pump data requirements. The pumps will be instrumented to measure vibration and rotor balance.

A pressure profile across each pump will be obtained by stationing pressure instrumentation at approximately five foot intervals across the pump as follows: (1) 2-before the pump section; (2) 6-along the impeller, stator, pod and casing; and (3) 4-along the diffuser. Seal leakage will be observed by monitoring the pressurized air line to the pod and recording make-up air requirements. During periods of off-design flow rate testing all pump parameters will be will be recorded for development of off-design characteristics.

4.6 Ammonia Feed and Recirculating Pumps

Ammonia pump test data will be collected during all the system and element testing. Pump power requirements and speed, ammonia flow rates, pressures and temperatures will be recorded during all tests. These parameters will be used to develop pump characteristic curves for comparison with predicted. The pumps will be instrumented to measure vibration and rotor balance.

4.7 Fouling Characteristics

4.7.1 Test Questions

Fouling characteristics considerations are presented here but are also applicable to the Test Articles in section three. The OTEC heat exchanger feasibility and cost are significantly dependent upon fouling characteristics. A test period of six months to one year in situ should provide answers to the following key issues:

- What are the rates of fouling on heat transfer surfaces? (Seawater and ammonia side).
- Can fouling be controlled?
- Can heat transfer surfaces be cleaned to provide economic plant operation? What is the best method of cleaning?
- Is the rate of fouling dependent upon external conditions, e.g. seasonal, weather, etc.

- Does fouling reach an asymptote or is periodic cleaning required?

Secondary questions include the fouling rate of cold water and the the effect of mixing nutrient rich cold water with warmer near surface water. Alternate techniques of fouling control should be evaluated during the test period. These include turbulence inducers such as twisted tapes or air injectors. The environmental impact of fouling control should also be determined.

4.7.2 <u>Data Measurements</u>

Fouling data measurements will be taken over the duration of the test program. Fouling characteristics will be determined directly by measurement and observation, and indirectly by calculation.

However, this reading may also be effected by other factors such as pollution in the seawater.

The plant's chlorination system plans to use an analyzer to determine the amount of chlorine to be distributed to the seawater intake. Monitoring the analyzer readings and chlorine distribution values may provide an indication of fouling trends. However, this reading may also be effected by other factors such as pollution in the seawater. Another direct measurement uses an instrument that determines fouling resistance as a function of tube metal temperature. This technique is new and may require some developmental effort.

A television system will provide a means for direct observation of fouling during periods of plant operation. A system of TV camera and lights will be periodically inserted into the waterboxes of the heat exchangers for visual inspection of fouling buildup on the tubes. Periodically water samples will be removed from system test points for bacteriaological studies and growth counts will be recorded. During periods of shutdown for cleaning the conditions of the heat exchanger tubes will be observed directly from the waterbox before and after cleaning. Periodically fouling coupons will be removed from various coupon racks throughout the system. Coupon samples will consist of various tube and system element materials provided with fouling prevention coatings and a corresponding unprotected control group. Instrumentation in the vicinity of these racks will measure local temperatures, pressures, and flows. The coupon racks will be located as follows:

Number of Racks	Location
3	Cold Water Pipe
2	Evaporator Plenum
2	Condenser Plenum
4	Condenser Inlet & Outlet Waterboxes
4	Evaporator Inlet & Outlet Waterboxes.
2	Cold Seawater Pump Suction & Discharge
2	Warm Seawater Pump Suction & Discharge.

Fouling resistance will also be calculated using the heat exchanger performance calculations as described in section 3.4. Fouling resistance will also impact turbine net and gross output.

Data output will include typically presentations of waterside fouling resistance versus time, and fouling control techniques.

4.7.3 Procedures

Testing will include an uncontrolled fouling buildup situation. After establishing a condition of clean heat transfer surfaces(either when plant is first started or after shutdown for tube cleaning), the plant will be run with no fouling control and fouling buildup will be monitored with respect to time. Then fouling control will be introduced and heat transfer performance will be observed.

4.8 Effect of Ammonia and Seawater on Materials

Material considerations presented here are also applicable to the Test Articles in section three.

One source of materials data will be performing destructive testing; upon test conclusion; consisting of metallographic tests. Of special interest is the condition of the Linde Surface.

During periods of maintenance shutdowns all system materials will be examined for corrosion and galvanic effects. The following effects are of special interest:

- Tube inlet - end erosion
- Tube ID pitting
- Other tube corrosion problems
- Pump erosion and corrosion problems

Some tubes will be partially blocked during operation to evaluate this effect on the tubing.

Intermediate test data will be obtained by examination of specimens located on coupon racks throughout the system. Sufficient specimens will be provided for removal and examination for different periods of operation. Specimens for the coupon racks will include:

- Several types of aluminum, including the Linde surface
- Carbon steel and coated carbon steel
- 31LSS pump alloys
- Ni - Cr-Mo-V and other turbine alloys in ammonia
- Titanium
- Stressed specimens of many alloys including carbon steel

Whenever possible the material racks will be located in the vicinity of fouling racks, thus sharing local measurements of temperature, pressure, and flow. Coupon racks will be located as follows:

Number of Racks	Location
3	Cold Water Pipe
2	Evaporator Plenum
2	Condenser Plenum
4	Condenser Inlet & Outlet Waterboxes
4	Evaporator Inlet & Outlet Waterboxes
2	Warm Seawater Pump Suction & Discharge
2	Cold Seawater Pump Suction & Discharge

(NOTE: The following racks are located on the ammonia side).

2	Evaporator
2	Separator
2	Condenser
2	Hotwell
2	Ammonia Storage Tank

System performance is degraded by the presence of water in the ammonia. However, a small amount of water is necessary to prevent stress corrosion cracking of steel. Both Test Article and Modular Experiment Testing will include procedures for monitoring and controlling the water content in ammonia throughout the system. Analysis of the data will contribute to a greater understanding of this pehenomena.

4.9 Data Measurement Frequency

In general, all temperatures, pressures and flows will be read every ten minutes. Measurements required for the heat exchanger algorithm verification will be read every five minutes. These include seawater flow rates and inlet/outlet temperatures, and ammonia flow rates and saturation temperature.

The plant heat balance test will be two hours in duration. During this test interval measurements used directly in the heat balance calculations will be read every five minutes. These include:

- Generator Net and Gross Power
- Pump Power Requirements
- Seawater and Ammonia Flow Rates
- Seawater and Ammonia Temperatures and Pressures
- Ammonia Quality

Operational performance testing will require short duration high frequency data measurements. Typically during a loss of load test measurements will be read five times a second for a period of 60 seconds. These measurements include:

- Ammonia Flows
- Ammonia Liquid and Vapor Pressure
- Valve Position and Control Data
- Turbine Speed

Heat exchanger tube and rotating element vibration, tank levels, temperature traverses, and coupon rack location conditions will all be read at ten minute intervals.

The measurement frequencies presented above represent typical values. Specific case sampling frequency and test duration will be determined by an accuracy analysis in detail design as discussed in 2.3.1. The early segments of the test schdule will be concerned with special purpose testing and will require relatively higher measurement frequency rates. Following this specified period of special purpose testing the Modular Experiment will be scheduled to run at steady state design conditions for long periods of time with relatevely lower measurement rates.

4.10 Reliability/Availability/Maintainability and Safety Performance

R/A/M and Safety considerations will be determined for the Test Article and Modular Experiment by a technique of recordkeeping and post-test evaluation. Detail maintenance and safety logs will be recorded during all on site tests. They will contain reports of the causes and effects of all failures, times to repair, and logged hours of plant operation.

Post-test analyses will use these records to determine plant performance criteria such as:

- Availability
- Mean Time Between Failure
- Mean Time to Repair
- Verification of Failure Modes and Effects Analysis
- Safety Record

4.11 Environmental-Considerations

A certain correlation exists between the Modular Experiment performance and local environmental conditions. The following data will be recorded during testing and their impact will be considered during performance analysis:

- Water column temperature distribution
- Water column currents
- Sea State
- Local biological data
- Weather conditions

In addition the local chemical and biological baseline of the site will be determined before testing is started. Periodically the baseline will be updated to determine the effect of the OTEC plant on the local environment.

5.0 INSTRUMENTATION AND DATA ACQUISITION SYSTEM

The instrumentation and data acquisition system presented herein is a general outline of current practices in testing, availability, capabilities, and problems which can be encountered by using certain types os instrumentation. The instrumentation and data acquisition system was determined according to the test requirements in Appendix A.

5.1 INSTRUMENTATION

5.1.1 TEMPERATURE MEASUREMENT

Introduction

Measurement of fluid temperature is required at 168 locations in the Test Article and 119 locations in the 10 MWe Modular Experiment. The large number of locations requires a fully automatic measurement system for continuous recording of temperature values. The following section describes an approach to providing such a system for both the Test Article and 10 MWe Modular Experiment.

Requirements

For the test article, all 168 locations will be exposed to a possible 10°F temperature variation somewhere in the 35°F to 85°F range. For the 10 MWe Modular Experiments, 114 of the locations will be exposed to similar 10°F variations in the 35°F to 85°F temperature range while three locations in the Lube Oil system will see a possible 20°F variation in the 130°F to 150°F range. The vast majority of all the temperature measurements are required to have an accuracy of ± 0.5°F. A small number, 6 in the Test Article and 8 in the 10 MWe Modular Experiment, require a higher accuracy of ± 0.1°F. In addition to the three lube oil locations, the temperature measurements will be made in sea water and also in ammonia. It is anticipated that the temperature measurement capability will be required for the duration of the Test Article program and at least the first year of the 10 MWe Modular Experiment. Electronics for signal processing and calibration will be expected to operate in the typical OTEC environment without substantial (costly) protection. Reliability and maintainability of the temperature sensors must be high to avoid plant shutdowns to repair sensors, most of which are normally inaccessible.

The large number of measurement locations implies that the per sensor cost is an important consideration in minimizing the total price of the temperature measurement system.

The large size of the components and piping in both systems will require spatial averaging for some of the temperature measurements to ensure that an accurate bulk fluid temperature is determined. As a result, multiple temperature measurements will probably be required at 11 of the Test Article locations and 16 of the 10 MWe Modular Experiment locations. A detailed analysis will be required to determine the exact number, but it is anticipated that at least three temperature sensors will be required at each of the 27 locations. The remaining locations are either coupon rack or individual heat exchanger tube locations, and it is anticipated that a single point temperature measurement will be sufficient for these locations.

Available Temperature Sensors

Acceptable temperature measurement devices are described in the ASME Temperature Measurement Code.[1] The automation and accuracy requirements for the OTEC system limit the available devices to thermocouples and resistance temperature devices. Analysis of the capabilities of thermocouples, thermistors, platinum resistors and other noble metal resistance devices indicate that the thermocouple is probably the best choise for the $\pm$ 0.5°F temperature measurements. Its basic advantage is the long term stability of the temperature-voltage characteristics of the thermocouple junction. Experience with the thermocouple has shown it to be much less prone to drifting over long periods of time as compared to the resistance temperature devices. Its basic disadvantages are the requirement for a reference temp-

1 ASME PTC 19.3-1974 The American Society of Mechanical Engineers, Performance Test Codes, Part 3, Temperature Measurement, 1974.

erature junction and the relatively low level voltage output of the sensor. Since commerifally available thermocouples are quoted to accuracies of approximately ± 0.75°F, individual calibration of each thermocouple will be required. The relatively narrow range of temperatures to be measured will allow the selection of the type of thermocouple to be limited to one of four standard types. These are Copper-Constantan (T), Iron-Constantan (J), Chromel-Constantan (E) and Chromel-Alumel (K). The emfs produced by exposing these thermocouples to an 85°F temperature and referencing to 32°F are nominally 1.173, 1.507, 1.767 and 1.181 millevolts, respectively. Although there is some variation in the magnitude of the sensitivity of the different types, the selection of the particular type sould be strongly influenced by long-term stability considerations. In the interest of standardization of the signal conditioning and computer processing, it is recommended that only one type of thermocouple be chosen. Suitable thermocouples encased in stainless steel tubes are available for less than $100 each. The tubes can be purchased with a threaded connection for insertion in a pipe and without for installation inside a pressurized system. Typically, the tube diameter is on the order of 1/8 inch and the tube length is 4 to 5 inches. The stainless steel housing should be appropriate for the sea water, ammonia and lube oil environments.

The measurement of temperature to an accuracy of ± 0.1°F in a select number of locations (14) presents a more substantial challenge. These accuracies are not generally achieved in field measurements with commercially available equipment. Special care will have to be taken in the design, construction and operation of this portion of the temperature measurement system to ensure these accuracies for extended periods of time. Several approaches to handling these accuracy requirements are available. To obtain ± 0.1°F accuracy in temperature measurement, specific thermocouples could be hand picked to be within the $\pm$ 0.1°F requirement over a narrow 10°F operating temperature range. Additional calibration at the OTEC site would probably be required to verify this accuracy at suitable time intervals. Instead of thermocouples, platinum resistance thermometers could be utilized. Again, the sensors would have to be hand picked since industrial platinum resistance thermometers are usually specified with an accuracy of $\pm$ 0.5°F. It would be feasible to calibrate them to an accuracy of $\pm$ 0.1°F over a limited range in much the same manner as the thermocouples. Another option could be the use of a quartz thermometer marketed by Hewlett-Packard. It operates on the shift of the resonance frequency of a quartz crystal as a function of temperature and is claimed to have an absolute accuracy of $\pm$ 0.09°F over the -112°F to +480°F temperature range. The chief disadvantage of this approach is cost since two temperature probes and signal conditioning would require at least $5,000. It is also possible to use thermistors in conjunction with a resistance to temperature table to obtain $\pm$ 0.1°F accuracy. The thermistors would have to be recalibrated at frequent intervals and this disadvantage would have to be weighed against the higher sensitivity this type of sensor offers.

Since the $\pm$ 0.1°F temperature accuracy is required for bulk flow measurements, a better approach to improving the temperature accuracy is to increase the number of measurement points and average their result. Not only does the accuracy improve by the square root of the number of measurements, but a better spatial average is obtained. If sensors with an accuracy of $\pm$ 0.4°F were used, a total of 16 would be required to provide an accuray of $\pm$ 0.1°F. However, if a small number of sensors were hand picked to provide an individual accuracy of $\pm$ 0.3°F over the limited temperature range, then only 9 sensors would have to be averaged to provide a $\pm$ 0.1°F temperature accuracy. If the individual sensor accuracy could be improved to $\pm$ 0.2°F, then 4 sensors would be required. It will be left to the detailed design to decide exactly how many sensors will be used. This will depend on the expected temperature uniformity of the bulk flow as well as the available accuracy of an individual temperature sensor. Although this approach could be applied to any of the different types of temperature sensors, it will be assumed that the thermocouple will be chosen for the reasons described above. This allows the signal conditioning to remain simple and provides a temperature measurement system with considerable field experience. It is anticipated that at least 6 thermocouples would be required at each measurement location. This implies that the individual accuracy of each sensor must be on the order of ± 0.25°F.

Recommended Approach

Temperature measurements will be made by installing one or more thermocouples at all the required locations. For measurements to an accuracy of ± 0.5°F one sensor will be used for point measurements while at least three sensors will be used for bulk flow measurements. For an accuracy of ± 0.1°F, at least six sensors will be used and they will be chosen to have an individual accuracy of approximately ± 0.25°F. The requirements for the sensors are shown on the temperature specification sheet in the appendix. The temperature will be monitored by attaching the thermocuople to an electronic ice point reference junction. The electronic ice point will compensate for the ambient temperature at the reference junction and then supply the correct emf to the signal conditioning and analog to digital conversion required for the computer. The computer cna apply any necessary constants and convert the voltage to a temperature value by using the known sensitivity of the thermocouple material. The inaccuracies due to signal processing will be kept to a small fraction of the sensor inaccuracy so that the overall system accuracy will be predominantly the accuracy of the thermocouple. Calibration will be accomplished automatically by inserting a voltage staircase at the input to the ice point reference junction to check the ambient temperature compensation and to verify the linearity of the signal conditioning. Sampling rate and sample averaging will be controlled by the computer to provide the required frequency of temperature measurements.

In certain locations the measurement of temperature difference is probably more important than the value of the absolute temperature at the two locations. For these cases the use of thermopiles is recommended. Since the thermopile is basically a thermocouple with a measuring junction at each of the two locations, the problem of a reference junction is avoided and the thermopile measurement can be made with considerable accuracy. The emf's generated at each location interact and the result is a voltage proportional to the temperature difference between the two locations.

Signal Conditioning

The type of signal conditioning is determined by the selection of the temperature sensor. For a thermocouple, high gain, drift free amplifiers are required to boost the microvolt signals that are available. For platinum and other noble metal resistance devices, as well as thermistors, the available signals are in the millevolt range and the amplifier requirements are not as severe. Typically, the temperature sensor is placed in series with a known voltage source and a fixed precision resistor whose value is similar to the thermistor. The voltage drop across the precision resistor is then used to determine the resitance of the thermistor. For platinum and noble metal resistors there is about a 0.2 percent change in resistance for every ^{o}F change in temperature. For thermistors, the sensitivity is ten times higher with a 2 to 3 percent change in resistance for every ^{o}F change in temperature. For the four thermocouples mentioned above there is a change in emf of from 23 to 42 microvolts for every ^{o}F change in temperature. The $\pm$ 0.5^{o}F temperature measurement will require measuring the emf to an accuracy of 10 to 20 microvolts while the $\pm$ 0.1^{o}F bulk measurements could require an accuracy of 5 to 10 microvolts. This capability is certainly state-of-the-art and has been successfully demonstrated in extensive field testing.

In order to minimize cable length and electrical interference, it is anticipated that several satellite stations will be located at convenient sites in both the Test Article and 10 MWe Modular Experiment. These sites will contain the analog to digital converters so that long cable runs to the computer can be made in digital format. Depending on the length of the cable runs and the required sensor accuracy, it may prove necessary to install the signal conditioning as close to the temperature sensors as possible. These considerations as well as the numbers and locations of the satellite stations will be addressed in the detailed design of the temperature measurement system.

Calibration

The establishment and maintenance of a $\pm$ 0.1^{o}F temperature measurement system will require an automated calibration system. It is anticipated that the computer will be programmed to conduct these periodic calibrations. In addition, it may be necessary to remove some of the sensors from their locations and place them in an ice point reference. Hopefully, this type of calibration will occur infrequently. The automatic calibration accomplished by the computer will consist of a staircase voltage input to the ice point reference junction. The known voltage levels will correspond to selected temperature values in the range to be measured by the thermocouple. The temperature values computed from these known inputs will indicate the accuracy of the reference junction, the signal conditioning and the computer calculations. The values calculated may then be used to recalibrate the electronic elements of the system producing a precise temperature-voltage relationship. The actual calibration of the thermocouple will not be automatic since insertion in a known temperature bath is required. This will be done prior to installation and at whatever intervals during the test that are necessary to maintain the specified accuracy of the temperature measurements.

5.1.2.1 STATIC PRESSURE MEASUREMENT

Introduction

The large number of static pressure measurement locations required for the Test Article and the 10 MWe Modular Experiment suggest the use of electrical pressure transducers for automatic and continuous recording. A system of pressure transducers will be described for both the Test Article and the Modular Experiment.

Test Requirements

The range of expected pressure values extend from a low of 7.5-9.5 psia to a high of 118-136 psia and 126-144 psia. The lower range of values have a required accuracy of ± .1 psia; while the upper ranges have a required accuracy of ± .5 psia. The accuracy requirements for the measurements made near the coupon rack locations are ± .5 psia for all ranges of expected pressure values.

The working environment is sea water, ammonia and one lube oil location. The temperatures anticipated in these areas fall within a range of 35°F to 150°F and do not pose any concern. The measurement capability of the pressure transducers is required for the duration of the Test Article testing and at least one or two years of the Modular Experiment program. Transducer mounting should be designed for ease of removal and installation of sensors without disrupting plant performance. The electronics for signal conditioning and processing and calibration will be expected to operate in the normal OTEC environment without costly protection. Reliability and maintainability should be high for these instruments to prevent shut down and repairs.

The flow may be non-uniform in the large components and large piping in both systems and, therefore, may required the use of multiple sensors in any location. The measurements can be averaged to obtain a more accurate static pressure in these areas. A detailed analysis of the flow in these areas will be required to determine the number of transducers necessary to obtain the required accuracy. A rough estimate would be 3 to 4 sensors in the sea water plenums and any piping over 48" DIA. The smaller piping (< 48" DIA) and coupon rack locations will require one transducer.

Available Pressure Transducers

Acceptable pressure measurement devices are described in the ASME Pressure Measurement Instruments and Apparatus Code.[1] Due to the nature of the automatic data recording and the high accuracies required, the types of pressure measurement devices are narrowed to electrical pressure transducers. The essential component of a pressure transducer is an elastic element which converts energy from the pressure system into a mechanical displacement. This displacement, in turn, is converted into an electrical signal, then amplified, transmitted and measured by a data acquisition system (See Sec. 5.2). The pressure transducers described herein are passive transducers which require an electrical excitation to modify and the resulting change in impedance is proportional to the displacement of the elastic element.

The elastic elements of the pressure transducer may be a bourbon tube, bellows or diaphragm. The displacement mechanisms are similar in all three. One

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1 ASME PTC 19.2-1964 The American Society of Mechanical Engineering Performance Test Codes, Part 2, Pressure Measurements, 1964

side or end of the element is exposed to the fluid and the other side or end is allowed to deflect move. This displacement caused a change in electrical impedance in the electrical element. Various types of electrical elements are used. They consist of variable resistance types (i.e., strain gage, potentiometric, and capacitance) and variable inductance types (i.e., linear variable differential transformer (LVDT) and variable reluctance).

Combinations of various elastic elements and electrical elements are available to obtain the desired accuracies within the relatively small range of pressures to be measured. The choice of pressure transducer is dependent on cost, accuracy, and degree of sensitivity to temperature effects and vibration, ruggedness, and durability. The transducers can be calibrated by the manufacturer to be accurate within $\pm$ .25-1.0% full scale within the range of values expected. This can easily provide the $\pm$ .1 psia for the 7.5-9.5 psia range and the $\pm$ .5 psia for the 118-136 psia and 126-144 psia range.

Stainless steel should be the material used for the transducer housing and the area in contact with the sea water, ammonia, and lube oil should be 17-4PH stainless steel. Operating temperatures range for most available transducers are $-65^{o}F$ to $+250^{o}F$ with a sensitivity to temperature change of 1% per $100^{o}F$, in the safe temperature ranges.

Pressure transducers are available to measure absolute, gage and differential pressures, and are also available with self-contained amplifiers. Some transducers have built in shunt resistors to enable calibration to 50% of full scale. Cost of pressure transducers are approximately $250 to $350.

Recommended Approach

Static pressure measurement will be made by installing one or more passive pressure transducers (i.e., strain gage, capacitive or LVDT) in each of the required locations. Pressure measurement in small piping ($<$ 48 in.), around coupon rack locations, and the lube oil location will be made with one transducer. Measurement in larger components and large piping may require 3 to 4 transducers to obtain representative pressures if the flow is suspected to be non-uniform. Approximate number of sensors required at 22 transducers with $\pm$ .5 psia accuracy and 12 transducers with $\pm$ .1 psia accuracy for the Test Article and 50 transducers with $\pm$ .5 psia accuracy and 36 transducers with $\pm$ .1 psia accuracy for the 10 MWe Modular Experiment. The requirements for the transducers are shown on a sample specification sheet in Appendix B. To monitor pressure, input a known voltage and measure the change in electrical impedance. The resulting millivolt signal, which is proportional to the pressure, is then amplified, conditioned, and converted into a usable form for computation in the computer.

The pressure transducers may be mounted in the wall of the pipes or mounted externally with flexible or rigid tubing connecting the pipe and the transducer. Vibration may affect the sensitivity of the transducer and therefore isolation mounts may be required. The dynamic response of the transducer is affected by the length of the connecting tubing and any trapped air or liquid pockets. Careful consideration is required during detail design to account for water leg corrections in pressure and the effects of vibration, temperature (ambient and test), and dynamic response.

The measurements may be made through static holes in the wall or by using static pressure probes of appropriate aerodynamic shapes. i.e., cylinders, spherical tips, wedges.

Pressure profile may be made by traversing the static pressure probe across the section of pipe or component. The probe may be driven electrically and controlled from the computer in the data acquisition system.

The transducers will be calibrated from the factory and may require calibration at regular intervals to reset zero and span caused by drift. The on-site calibration may be done manually using a portable deadweight tester.

The signal conditioning required would be determined by the data acquisition system. The low level millivolt output signal may be amplified to 0-5 V or $\pm$ 5V and then converted to BDC for computational use. The vase size of the Modular Application would require transducers located very long distances from the main data acquisition center. The use of satellite stations to amplify and condition the signals are described in Sec. 5.2. Calibration of the signal conditioning electronics is preformed automatically by the computer.

5.1.2.2 VELOCITY MEASUREMENT

Introduction

Velocity of ammonia vapor is required in the Test Article at the Evaporator Outlet, Throttle Inlet and Vapor Recirculation Pump. The velocity at the Throttle Inlet and Vapor Recirculation Pump may be deduced from the flow, temperature and pressure measured, using the measurement techniques described in Sections 5.1.1, 5.1.2.1, and 5.1.3. The following is a description of a system of measuring dynamic or velocity pressure for the Evaporator Outlet.

Requirements

The range of expected values for the velocity is 0 to 10 ft/sec with a required accuracy of ± .05 ft/sec. Since the velocity measurement is obtained indirectly, the accuracy requirement is dependent on the accuracies of the instrumentation measuring the total pressure or stagnation pressure, static pressure, and temperature. The accuracy requirements of these sensors should be at least ± .25% or better to obtain an accuracy of velocity pressure of 2 to 3%.

Recommended Approach

The operating temperatures are 32°F - 90°F and are safe operating ranges for most instrumentation. All electronics and sensors are anticipated to function properly in the normal OTEC environment and should be reliable and and virtually maintenance free.

The velocity is proportional to the square root of the difference between the total pressure and the static pressure

$$V \propto \sqrt{P_T - P}$$

where V = velocity

P_T = total pressure

P = static pressure

This computation is made by the computer using pressure measurements obtained from pressure transducers and applying appropriate conversion constants. The density or specific weight of the vapor is necessary and can be obtained by storing a table of physical properties in the computer. The computer will look up the density as a function of temperature and pressure. If the density is uniform over the operating temperatures and pressures, only a constant is required.

To measure the velocity distribution across the Evaporator Outlet, a series of pitot tubes or holes located at stagnation points on aerodynamic bodies may be used to transverse the length and breadth of the Evaporator Outlet. The number and spacing of pitot tubes would be determined by estimation of the velocity profile. The extent of pitot tube arrays should be determined in detailed design and cost should be an important factor. Measurements may also be made individually if conditions permit.

The alignment of the probe in the flow may cause errors in the measurements since flow direction is not always known. The problem is tripled in the Evaporator Outlet where three dimensional flow will be encountered. In two dimensional flow, cylindrical shaped tubes are found to be less sensitive to alignment and the insensitivity may be achieved by increasing the size of the stagnation hole and by providing a smooth entrance at the hole.[1] Development is needed to design a probe that is fairly insensitive to flow direction. The probe would be tested and calibrated prior to installation.

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[1] Robert P. Benedict, Fundamentals of Temperature, Pressure and Flow Measurement, John Wiley, New York, 1969. pp. 247

The total pressure may be measured using the pressure transducers described in Section 5.1.2.1. It is estimated that the pressure different, $P = P_T - P$, is so small that commercial differential pressure transducers may not be available to measure this difference to a high degree of accuracy.

Velocity measurements in the Throttle Inlet and Vapor Recirculation Pump may also use total pressure probe technique.

5.1.3 Flow Measurement

Introduction

Flow measurements are required for seawater and liquid and gaseous ammonia in the Test Article and 10 MeW Modular Experiment. Three methods of measuring flow will be described.

Test Requirements

The anticipated flow values in various areas of the test facility range from lows of 0-4.50 x 10^4 lb/hr to 2.9 x 10^8 - 3.21 x 10^8 lb/hr. The required accuracies of flow measurements are $\pm$1% of minimum flow. Due to the nature of the automated data acquisition system, it would be desirable for flow measurement parameters to be an electrical output which can be conditioned and converted into compatible language for computation. The fluids to be measured will be seawater, liquid and gaseous ammonia. The operating temperatures range from 40°F to 150°F and the operating pressure range from 7.5 psia to 140 psia.

Measurement capabilities of the sensors required to function the duration of the Test Article testing and at least one to two years of the Modular Application program. The electronics for signal conditioning, processing and calibration will be expected to operate in the normal OTEC environment without costly protection. The sensors should have a high reliability and be virtually maintenance free due to size of components and inaccessibility of many locations.

Available Flow Measuring Sensors and Techniques

Flow nozzles and orifice plates are obstruction flow metering devices which may be used to a high degree of confidence and are recognized by ASME as approved instruments for measuring flow.[1] These instruments

1. ASME, Application Part II of Fluid Meters, 1971.

are well documented for pipe sizes less than 16 in. diameter. The majority of piping used in the OTEC program are well over 16 in., with the largest diameter at 204 in., and therefore, other methods will have to be considered.

The flow metering devices are sized for the anticipated flow and for the pipe diameter test section. Static pressure is measured upstream and downstream of the metering device using pipe taps, flange taps or vera contracta taps. The pressure can be measured using the pressure transducers described in Sec. 5.1.2.1. Discharge coefficients are available for various types of metering devices. The constants necessary to determine ideal flow rate are dependent on ratios of the downstream and upstream pressures. The tables for the constants in the ideal flow rate equation[2] can be stored in the computer and the computer can be programmed to look up and compute flow rate whenever the flow sample is required.

Several disadvantages are inherent in using the ASME approved flow metering devices. A large pressure drop is experienced across the meter for any measurement to be accomplished. Careful consideration in the detail design phase is necessary and trade-offs made between known accuracies and reliability and non-recoverable pressure drop. The placement, design and construction of each flow metering device is very critical. The recommended installation and design is delineated in the ASME Application Part II of Fluid Meters, 1971. Another disadvantage is the limitation of pipe sizes in which the meters have been used in the past. Documentation exists for pipes 16 in., in diameter and under, but information on flow metering devices in pipes greater than 16 in. diameter are virtually unknown. STD will be performing a flow test on a 48 in. diameter plenum to verify theoretical data. This, so far, will be the largest

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2. Robert P. Benedict, Fundamentals of Temperature, Pressure and Flow Measurement, John Wiley, New York, 1969, Chap. 20-21.

pipe test section available. Further investigation is necessary for pipe sections greater than 16 in. diameter. Each flow metering device will require calibration prior to installation.

Westinghouse Oceanic Division has used a Leading Edge acoustic flow meter and have been able to obtain accuracies of ±1% or better in liquids. The LEFM system consists of a dedicated electronics console, a pipe section containing 8 ulstrasonic transducers (senders/receivers) and interconnecting cable. The transducers create 4 parallel acoustic paths at an angle to the flow direction. Ultrasonic pulses are sent simultaneously from transducers on both sides of the pipe. The transit time of each pulse is measured electronically. The time is proportional to flow velocity. A numerical integration is performed using this relationship to result in a rate or volume flow. Temperature and pressure compensations are then made.

Another type of acoustic flow meter does not require special sections for the flow meter as in the LEFM system. The ultrasonic transducers are strapped in line on the sides of the pipe test section. Ultrasonic pulses are sent perpendicularly into the stream and received in transducers downstream at a known distance. Again, the transit time is proportional to the fluid velocity and flow rate can be determined. Canadian GE has been able to obtain accuracies of ±2% using this type of acoustic flow meter. Further development and testing is necessary for both types of acoustic flow meters in liquids and gas.

The measurement of gas using the LEFM system is still in a developmental stage. The techniques are the same as in a liquid acoustic flow meter although a higher transmission frequency is required. A system developed by Panametrics, Inc. of Massachusetts can be used in pipe sizes less than one foot in diameter to pipes larger than three feet.

The Panametrics system requires a dedicated microcomputer to provide various outputs such as flow rate, supercompressibility, volumetric flow rate, Reynolds number, etc. Again, further development is necessary to obtain a system of gaseous flow meters for OTEC use.

Chemical and radioactive tracers have been used to determine flow rates in nuclear power plants, in rivers, and in hydroelectric machinery. The tracer is injected into the flow at some distance from the sampling point either at a continuous, constant rate or instantaneous rate. Samples are drawn off into containers and the activity or concentration is measured. The flow rate is calculated by performing a tracer mass balance between the injection point and the sampling point. Many samples are taken over the test period to assure accurate and consistent readings.

The use of any tracer for test purposes must be carefully designed and planned for the type of system and system constraints, the kind of measurements, and the accuracies required. The tracer must be injected at a point far enough upstream of the sampling point to allow for complete miaxing and flows to reach steady state. Samples are taken manually and prepared for analysis. The criteria for choosing a tracer is as follows:[3]

1) The absorption properties of the tracer
2) Stability and solubility in the item of interest
3) Radioactive half-life
4) Types and energy of emitted radiation
5) Maximum permissible level in the environment

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3. T. Dincer, "Application of Radiotracer Methods in Streamflow Measurements," IAEA, Vienna, SM-83/8, pg. 97.

6) Maximum specific activity available

7) Cost of the tracer

8) Its availability

Although obtaining each sample is done manually, the results of the analysis can be fed to the data acquisition system for computation and correlation to other system parameters.

<u>Recommended Approach</u>

Flow metering devices such as nozzles and orifice plates should be used in pipe diameters 16 inches or less and probably in pipes up to 24 inchco. Further investigation and development for use in larger pipe sizes would be necessary. The static pressures would be measured using the pressure transducers described in the Pressure Measurement section.

Flow measurement in pipe over 24 in. in diameter should be made using acoustic flow meters. The acoustic flow meters may either be the Leading Edge Flow Meter System developed by Westinghouse Oceanic or the acoustic flow metering technique used by Canadian GE. In both cases, developmental work is necessary to assure accuracies of flow measurements of $\pm1\%$ or better. The LEFM system has a dedicated electronic console which can be patched into the main data acquisition computer for computation of heat balance, etc.

Either the flow nozzle or acoustic flow meter technique would require calibration prior to installation. It is anticipated that calibration would not be required for at least one year, at which time, sensors and transducers should be calibrated using NBS standards.

The use of chemical or radioactive tracers for flow measurement can be used if cost trade-offs for its research and development and practicality proves feasible with respect to the other methods.

5.1.4 QUALITY MEASUREMENT

INTRODUCTION

The quality of ammonia vapor is required at two locations in the Test Article and one location in the 10 MeW Modular Experiment. Several innovative techniques are in the development stage and may be used with further development and investigation, for measuring ammonia vapor. These techniques and current methods are described here.

TEST REQUIREMENTS

The expected range of quality values range from .93 - .97 to .99 - .999. The required accuracy is ± .0097. The working fluid is ammonia vapor with operating temperatures between 60 - 70°F and operating pressures at 118 - 136 psia. The measured output should be an electric signal or a series of electric signals that can be processed by the data acquisition system to provide the necessary result. Any instrumentation used to measure quality must be capable of withstanding the environment of the OTEC I program. The sensors should have a high reliability and be virtually maintenance free.

PRESENT TECHNIQUES

Current methods used to determine steam quality are variations of a calorimeter, such as the throttling calorimeter and the separating calorimeter or combination of both. These methods have been used mainly in steam power plants. The quality is determined by measuring the weight of liquid separated or from the enthalpies of the superheated vapor.

Error is introduced through the sampling technique. The samples are usually drawn at the point in the flow, but the distribution of liquid droplets may not be uniform. Depending on the flow rate and the amount of liquid entrained in the vapor, a layer of liquid may adhere to the pipe walls. A false reading would be obtained if the sample was taken near the center or near the wall of the pipe.

Low activity radioactive isotopes such as sodium-24, used for quality determinations in steam power plants and cooling towers. The tracers are injected into the flow and the concentrations of the specific element is determined in the entrained liquid. The measurements are determined using a multichannel analyzer, the energy spectrum and half-life of the specific nuclide. The use of radioactive tracers require special design and safety precautions due to the hazardous nature of the tracer. A study of available tracers and their compatability with ammonia liquid is necessary to develop a safe and accurate system to handle, test and measure ammonia vapor quality. Careful design of the test plan is required since special handling procedures and Federal codes dictate the transportation and storage of radioactive tracers.

INNOVATIVE TECHNIQUES

Two innovative techniques have been developed in the past few years to cope with measurement of steam quality with better accuracy and measurement methods. Both techniques described herein have not been used to measure quality of ammonia vapor and, therefore, further research and development is required to determine feasibility, effectiveness and operating characteristics.

The first technique addresses the droplet distribution problem presented earlier. R. P. Benedict of Westinghouse Electric Corporation, STD, proposed to disperse large droplets of water in wet steam using acoustic energy and therefore the quality can be determined on the premise that the amount of liquid in saturated vapor affects the acoustic velocity of the vapor.[1] Tests have been concucted by Westinghouse R & D Center and the Oceanic Division to investigate the feasibility of this idea. A 20 kHz standing wave was set up in air using an acoustic horn and reflector. Water droplets entering the sound field were instantly dispersed. The tests proved the feasibility of the basic theory and recommended further study to obtain information on the mechanism involved in obtaining atomization, the required intensity and frequency of acoustic energy, and the initial and final sizes and spatial distribution of the water droplets.[2] By using an acoustic flow meter, such as those described in Section 5.1.3, the acoustic velocity of the saturated vapor can be provided. The quality of the vapor can then be deduced. Testing is necessary to determine the acoustic velocity in various degrees of saturated ammonia vapor.

The present status of the atomization technique is proof of the basic theory only. Quality measurements have not been conducted using an acoustic flowmeter.

The second technique uses a laser light scattering probe to determine the quality of steam at the low pressure end of steam turbines. A parallel beam of light is passed through a fiber optic bundle and is incident on transparent particles of a certain refractive index with respect to the surrounding medium. The light is partially scattered by the particles and causes an attenuation of the emerging light beam. The transmittance,

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[1]Robert P. Benedict, "Device for Continuously Monitoring the Quality of a Two-Phase, Single Component Fluid," Westinghouse Disclosure July 6, 1976.

[2]J. L. McShane and P. G. Spink, Acoustic Dispensing of Droplets in Wet Steam, Westinghouse Report 77-1G6-UDWIS-R1, March 21, 1978.

versus the steam wetness is determined using an average particle diameter.[3] The initial tests were conducted using a single wavelength and a predetermined average particle size. The probe was calibrated in a known wet steam environment and various ranges of flow conditions. Further work is being done using a multiple wavelength laser. This will increase the effectiveness of the probe since it will be able to scan different sizes of droplets, and provide information on the size distribution of droplets in the vapor. A better determination on steam quality can be made.

RECOMMENDED APPROACH

There is no clear cut approach to be taken. Many factors must be considered at the detailed design phase; and trade-off studies should be made since the approaches presented here require some degree of developmental work for use in the OTEC I Program. The factors which enter into the consideration are as follows:

1. Time necessary to develop and prove feasibility in staurated ammonia vapor.
2. Time necessary to procure the instrumentation for installation.
3. Cost of developmental work and production.
4. Automation of measurements and recording of data.
5. Accuracy, repeatability and sensitivity obtainable.

[3] J. S. Wyler and K. J. Desai, Laser Light Scattering Probe, Industrial Research/Development, June 1978, pg. 111-115.

5.1.5 VIBRATION MEASUREMENT

Introduction

In the Test Article measurement of heat exchanger tube vibration is required for each of six tubes in both the Evaporator and Condenser. In the 10 MWe Modular Experiment, these same measurements will be made for the Evaporator and Condenser. In addition, the vibration of the six major rotating components will be monitored. The purpose of the vibration measurements is to provide warning of excessive vibration levels in the heat exchanger tubes and rotating equipment. It will also be possible to monitor the state of balance in the rotating equipment and determine when overhaul and/or rebalancing is required.

Requirements

The measurement of heat exchanger tube vibration will require the attachment of a small vibration sensor to six tubes in each heat exchanger. Typically, this has been accomplished by inserting a short spring-loaded sensor in the tube. The cylindrical sensor contains two miniature accelerometers that provide the acceleration level in mutually orthogonal directions both of which are perpendicualr to the longitudinal axis of the tube. The wire from the sensor is routed out of the tube into the water box and then through a penetrator in the heat exchanger outer wall. It is also possible to attach accelerometers to the exterior tube walls in the ammonia section of the heat exchanger. In this case, the mounting of the sensor is more difficult and the clearance between tubes will be reduced. Since this type of mounting would be inconvenient for any but the edge tubes, the sensors should be chosen to be installed inside the heat exchanger tubes.

Depending on the flow rates in the heat exchanger, it is anticipated that the tubes will have a peak to peak displacement that ranges from 0 to 10 mils. During normal operation, an average value of 2 mils is expected. It is conceivable that tubes with excessive vibration problems will show displacement levels of 100 mils and higher. The sensor installed in the tube will be required to measure these vibration levels with an accuracy of $\pm$ 0.1 mils. Since the vibration of the tubes results from flow excitation of the flexural resonances of the tubes, the sensor must have a high enough frequency response to cover at least the first five flexural resonances. Assuming a 3-foot span between attachemnts, the first five frequencies are approximately 185, 510, 1000, 1650, and 2460 Hertz. The sensor should have flat response from 10 Hertz to at least 3000 Hertz. This will require the natural frequency of the sensor mounted in the pipe to be in the 15 to 20 kiloHertz frequency range.

The vibration levels of the Turbine, Generator, Warm Sea Water Pump, Cold Sea Water Pump, NH_3 Feed Pump and NH_3 Recirculation Pump are also required. For the Turbine and Generator, the vibration measurements will be made by using non-contacting proximity sensors to monitor rotor vibration at each of the journal bearings. For the Sea Water and HN_3 Pumps the vibration levels will be monitored by attaching vibration sensors to the bearing housings of the pumps. It is anticipated that the peak to peak displacements on this equipment will also be in the 0 to 10 mil range with an average value of 2 mils. The actual displacements are to be determined to an accuracy of $\pm$ 0.1 mils. Monitoring of the rotational imbalance of the equipment will be made at the frequency corresponding to the operating rpm of the equipment. This will be 60 Hertz for the Turbine and Generator, 1.1 Hertz for the Warm Sea Pump, 1.7 Hertz for the Cold Sea Water Pump, and similar values for the two HN_3 pumps. Monitoring of bearing wear will occur over a broad range of higher frequencies, probably in the 1 to 10 kiloHertz range. Sensors used for monitoring the response of the Turbine and Generator rotors will be required to have a flat freequency response from DC to 10 kiloHertz while the sensors attached to the various pumps will have a flat response from 1 Hertz to 10 kiloHertz.

Available Vibration Sensors

Acceptable vibration sensors for installation in the heat exchanger tubes have been marketed by several companies for the power industry. These sensors contain two mututally perpendicular piezo-electric accelerometers that are mounted in a cylindrical water and pressure-tight stainless steel case. Designed especially for measuring tube vibration in heat exchangers, the sensor has spring-loaded arms that allow it to be rigidly fixed inside the tube. The available units generally are high in price because of the requirement to withstand the high temperatures in heat exchangers for nuclear power plants. It is anticipated that the low temperature requirements for the OTEC application will substantially reduce the cost to a value in the vicinity of $100 per sensor.

Acceptable vibration sensors for monitoring the levels on the rotating equipment are available from a large number of companies. The requirement for low frequency rotational vibration and high frequency bearing vibration limits the selection of possible devices to eddy current proximity devices (Turbine and Generator) and piezoresistive or piezoelectric accelerometers (Pumps). Proximity devices and accelerometers are produced by several manufacturers. Since the available sensors cover the required amplitude, frequency and accuracy ranges required for the OTEC installation, choice of the sensor will be quite flexible. One consideration will be whether to select an accelerometer with an integral preamplifier or to use an external preamplifier. Because of the possibility of long cable runs and electrical interference, it is recommended that an accelerometer be chosen with an integral preamplifier. Since there is no requirement to measure zero frequency acceleration, a piezoelectric accelerometer will most adequately meet the requirements for measuring the vibration levels of the pumps.

Recommended Approach

Vibration measurements in the six tubes of each heat exchanger will be made by installing a two axis piezoelectric accelerometer in each tube. Twelve sensors will be required for both the Test Article and 10 MWe Modular Experiment. The signals from the sensor will be routed to a signal conditioning box where they will be suitable amplified, filtered, level detached and then relayed to the computer for interpretation. The vibration measurements for the rotating equipment will be made by installing eddy current proximity devices at the journal bearings of the Turbine and Generator. A two axis system at each bearing will be used to make journal orbit measurements and monitor the actual rotor vibration levels. Six sensors will be required for the 10 MWe Modular Experiment. Measurement of pump vibration levels will be accomplished by installing piezoelectric accelerometers on the bearing housing of the four pumps. The number of accelerometers used will depend on the complexity of the equipment item and the required precision of the rotational balancing to be performed on the item. The precise number and location of accelerometers will be determined in the detailed design. It is anticipated that approximately 12 accelerometers will be required. The preamplified signals from these sensors will be routed to a signal conditioning box where they will be suitably amplified, filtered, level detected and relayed to the computer for interpretation.

The purpose of the filtering and level detecting in the signal conditioning box is to avoid the necessity of having the computer sample the vibration data at a high enough rate to maintain the 10 kiloHertz frequency response. Instead, an average value of the vibration level in the appropriate frequency band is determined at the signal conditioner to represent the vibration state at the measurement location. This average value is then sampled by the computer at the appropriate time intervals and compared with preset levels stored in the computer's memory. This approach allows for an automatic monitoring of the vibrational condition of the heat exchanger tubes and the rotating equipment. Diagnostic investigation of the frequency response of the vibration at any of the sensors will be accomplished on an individual non-automatic basis by sampling the unfiltered amplifier output with a narrow band spectrum analyzer. This operation will be conducted by an OTEC plant technician on a much less frequent basis than the automatic computer sampling. It is anticipated that a spectral analysis of each sensor will be accomplished on a weekly interval to document the vibration history of all the equipment. When balancing or rebalancing of the rotational equipment becomes necessary, this operation will be conducted using the sensors mounted at the appropriate places on the rotating equipment. Due to the requirements of the balancing operation, the amplified sensor output will be fed to the balancing instrumentation independent of the computer.

The sensitivity of the piezoelectric crystals used in the accelerometers and the eddy current probes is generally taken to be accurate for a period of one year after which recalibration is required. The remainder of the signal conditioning and computer sampling electronics will be automatically calibrated by the computer at regular intervals. This will be accomplished by inserting a voltage staircase at the appropriate location in the signal conditioning box.

Signal Conditioning

There are several approaches that can be taken in the design of the signal conditioning for the vibration sensors. The first and simplest is to buy one of the off-the-shelf vibration monitoring systems presently on the market. These systems will accomplish the entire signal conditioning function including a relay contact to shut the machine down if the vibration exceeds a present limit. The only additional instrumentation needed would be an analog to digital converter to relay the vibration level to the computer. A second approach is to buy the individual components that make up the vibration monitoring system and assemble them in a system tailored to the OTEC requirements. The necessary components would include the eddy current probe or accelerometer, preamplifier, amplifier, filter, level detector and analog to digital converter. This approach offers additional flexibility in the selection of components and in establishing the overall capability of the system. A third approach would be to design the entire vibration monitoring system specifically for the OTEC mission. This would take the selection of components one step further, to the piece part level, and in effect, would have the contractor designing and building the complete vibration monitoring system to the specific requirements of the OTEC mission.

The selection of the approach to use will be part of the detailed design task. It must trade-off the parameters to cost, flexibility, reliability, availability, schedule, etc. before a final choice can be made. Although each of the approaches can be successfully applied, the last approach is most flexible and offers the easiest way to meeting any and all of the specific requirements that will be developed. This will probably be the deciding factor since components such as the filters have to be selected for the appropriate frequency range of a particular machine. On the rotating equipment, more than one frequency range will probably be desired, and as a result, the different equipment items would have different numbers of filters acting over different frequency ranges.

Since the sensor output signals are in the millivolt range, the difficulty in transmitting, amplifying and measuring the vibration level is manageable. Some consideration will have to be made to determine the upper and lower limits of the vibration levels that are to be recorded. Although the sensor and amplifiers can process signals over a much larger dynamic range, the actual computer recorded values will be limited by the 8 bit analog to digital conversion. This implies that if the minimum acceleration level to be recorded is 0.1 mil, the maximum acceleration level will be approximately 40 mils. If this range is not sufficient, then a second A to D channel with a different range will be required.

In order to minimize cable length and electrical interference, it is anticipated that several satellite stations will be located at convenient sites in both the Test Article and 10 MWe Modular Experiment. These sites will contain the analog to digital converters and probably most of the signal conditioning. Depending on the length of the cable run, it may be necessary to put the preamplifiers for the tube vibration sensors near the penetrators in the heat exchangers. The rotating equipment sensors should have integral or near by preamplifiers so that the remainder of the signal conditioning can be located at the satellite station. These considerations, as well as the number and location of the satellite stations, will be addressed in the detailed design of the vibraion measurement system.

<u>Calibration</u>

The accuracy of the vibration measurements will be sustained by an automatic calibration system. It is anticipated that the computer will be programmed to conduct these periodic checks. The automatic calibration will be accomplished by inserting both a voltage staircase and a square waveform at the input of the signal conditioning. The voltage staircase will be used to automatically verify the linearity of the signal conditioning and computer display while the square wave will be available to check the frequency response since the computer does not sample at a rate fast enough to provide enough frequency bandwidth for the square wave calibration. Calibration of the eddy current probes and accelerometers will be obtained from the manufacturer and verified by operating the sensors on an electromechanical shaker at the OTEC site. Recalibration of the sensors will be required at least on a yearly basis. The convenience of having an electromechanical shaker on site should allow quarterly calibration of the external accelerometers on the rotating equipment. Investigation of previous experience with the heat exchanger tube accelerometers should be made in the detailed design stage to determine if more than yearly calibration is required.

5.1.6 Speed Measurements

Introduction

Speed measurements are required for the four pumps and the turbine/generator in the 10 MeW Modular Experiment. These measurements will be used to monitor performance and efficiency of the power plant.

Test Requirements

The expected range of speed for the seawater pumps are 60-74 rpm and 94-108 rpm, and 1140-1260 rpm for the ammonia pumps and 3060-4140 rpm for the Turbine/Generator. The required accuracy for the four pumps is ±5% of rated output and ±.5% of rated output for the Turbine/Generator. The operating temperatures range from 32°F to 150°F and the operating pressures from atmospheric to 144 psia. The working environment will be seawater, liquid ammonia and salt air. The sensors will be non-contacting proximity probes and will be mounted on brackets for exposed shafts or mounted in pump housings for totally enclosed shafts or blades.

Available Speed Sensors

Typical sensors used for speed measurement are non-contacting ferrous metal sensing devices or non-contacting proximity probes. The mounting of both types of sensors are the same. Acceptable sensors of both types are available from a large number of companies.

Recommended Approach

To maintain commonality of sensors, the use of eddy current proximity probes may be desirable since they will be used to monitor rotor balance. See the discussion on calibration and signal conditioning in Sec. 5.1.5.

5.1.7 POWER MEASUREMENT

Introduction

Power measurement is required at all pump inputs and the generator output is required for the 10 Me W Modular Experiment. The large wattage values expected will require the use of current and potential transformers to bring the wattage down to measureable quantities. The power will be measured using watt transducers.

Test Requirements

The expected wattage values range from 50 Kw to 14,420 Kw. It is anticipated that the watt transducers and associated instrument transformers will be mounted near the component being monitored. The instrumentation must be capable of withstanding exposure to the normal OTEC environment. The required accuracy of the measurements are ± .5% of rated output. This would require any instrument transformers to have a finer accuracy. The test output signal will be DC millivolt output compatible with the data acquisition system. Any recalibration of the watt transducer should be done on site. The reliability and maintainability should be high to avoid frequent and costly plant shutdown.

Available Watt Transducers

Watt transducers are available with accuracies of 1% and .5%. The associated instrument transformers will have to be designed for each component being monitored and for compatible interface with the input requirements of the data acquisition system. The watt transducer may be recalibrated on-site using a precision instrument calibrator (a regulated source of current and voltage in phase) or commercial power and a single phase portable instrument of .5% accuracy class. Totalization for gross power output or consumed is also available.

5.2 DATA ACQUISITION SYSTEM

5.2.1 SYSTEM OBJECTIVES

The data acquisition system should be a modularized system easily adaptable both physically and electrically to any ultimate system configuration. The basic subsystems should consist or be made up of readily available commercial grade components. It is to be used as both a diagnostic and evaluation tool during the system tests of the demonstration power plant and as such should be configured to allow ease of operation and maintenance with a minimum of instructions. More specific design objectives are listed below:

- Provide a means of continuously monitoring and storing for permanent record up to 350 test parameters.
- Provide on-line monitor, analysis and computation of all recorded parameters.
- Provide graphic display of monitored, stored and analyzed data
- System accuracy must be at least 1% of dynamic range
- System bandwidth is to be sufficient to faithfully reproduce the various measurement response curves as predicted by the system computer model for the transient test conditions.
- Simplicity
  - a) Installation should be modular in concept with sensor signal conditioning configured for installation within the test article if that becomes necessary.
  - b) Operation is to be controlled entirely from a keyboard or control panel with no access to remote locations.
  - c) Maintainability should be minimal with replacement of failures done on a modular or component basis.

- Flexibility should be incorporated to increase the measured parameters and change the analytical software.
- Noise immunity to both electrically and magnetically coupled interferrence signals must be provided.
- Operate from an uninterruptable power source impervious to demonstration power plant output fluctuations.

5.2.2 CONCEPT

A conceptual data acquisition system that meets the above objectives is presented in terms of a functional diagram in Figure 5-1. The system utilizes a general purpose digital computer together with the necessary peripherials to provide the data storage and man-machine interfaces. Transducer outputs are signal conditioned, digitized and inputted to the computer for logging, monitoring and analysis by appropriate subsystems. The unique feature of the concept is the modular nature of the various elements of the system and the simplicity of interconnections derived from their relative independency.

The diagram illustrates that the various sensors are powered and monitored by a number of Satellite Stations. Each satellite is a self-contained data multiplexing module, powered by internal power supplies operating off of the uninterruptable source and providing all the hardware necessary to tend the sensors which it services. So configured, the satellite module may be placed in close proximity to the sensors located on a single or number of test articles. The number of satellites in the total system will be determined by detail design of the physical layout of the demonstration system and nature of the electrical interfaces between the transducers and their signal conditioning.

Each of the satellite modules output data upon command to the central processor. The processor and peripherials are also modularized within a small trailer or van that may be located anywhere on the test platform. The data and calibration instructions are transferred between the Processing Center and each satellite in serial form. Since each module is an independent element, the information transfer is asynchronous. The relatively low sampling rates required of the Data Acquisition System allows the central processor to serially receive complete frames of N data channels from all satellites between sample time. While satellites are not reporting they continue to update their output buffers with new data.

The Processing Center provides the power plant operators with a continuous real time monitoring, analysis, control, and data storage capability. The entire data acquisition system is controlled from the system's keyboard. A monitor provides on-line computation and analysis of long term and transient test data. Continuously monitored data is stored on IBM format tape.

A 365-day time code generator provides a digital time resolution to milliseconds and serves to correlate all recorded data.

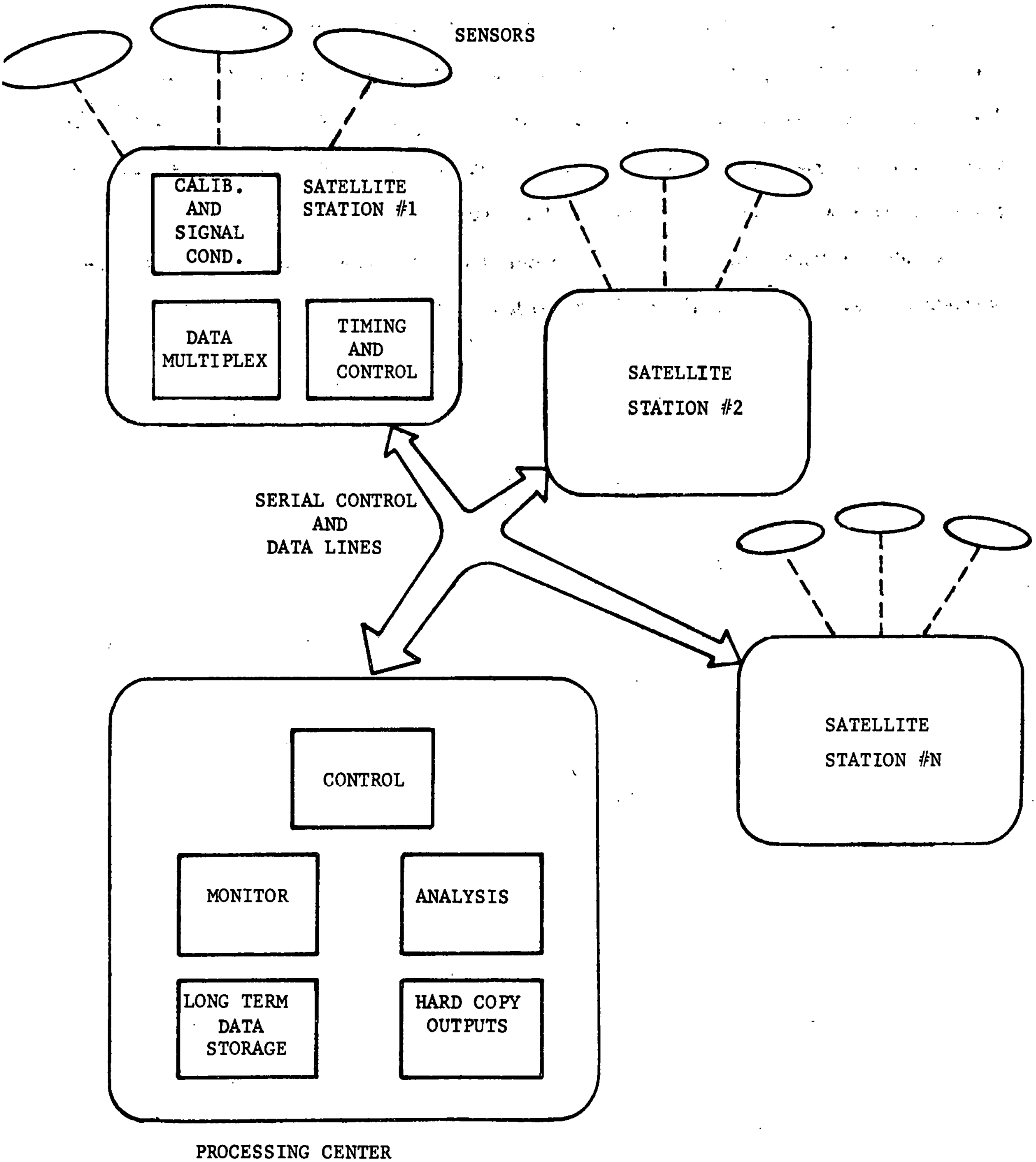

FIGURE 5-1

DATA ACQUISITION SYSTEM FUNCTIONAL BLOCK DIAGRAM

5-41

5.2.3 SATELLITE SYSTEMS

The satellite station performs virtually as an independent sensor sampler. It serves as a collection point for a number of sensor outputs providing localized signal conditioning, transducer excitation, and digitizing of the analog data. Upon request from the processing computer, the data is multiplexed and transmitted in serial digital format to the Processing Center. The particular data format generated by each satellite is a function of the number and type of sensors to be monitored. Special sensors such as flow transducers that may have digital outputs will be accommodated as well as the conventional high and low level analog temperature and pressure sensors. Vibration sensor outputs will be frequency band limited, and amplitude detected with an RMS meter. The low frequency DC output from the RMS reading may then be inputted to the satellite for multiplexing. Data sampling rates will be at least 10 times that required during the worst case transient system testing making the sampled data available for serial transmission to the processor at a slower rate. In this manner, time uncertainties between data points within a satellite data frame or from station-to-station may be kept to a minimum. The number of channels to be monitored by a satellite station will vary according to the physical proximity of the transducers and the satellite module.

The volume required to house sufficient electronics for as many as 50 signals will be approximately 1 cu. ft. Its small size will enable incorporation of the satellite station into the test articles or on the platform in a manner to minimize signal conditioning cable lengths, thereby minimizing noise pick-up. The digitizing of the data at the source further reduces the vulnerability of the data to the electrical and magnetic interferrence prevalent in such an installation.

Figure 5-2 illustrates the hardware to be used in the satellite module. The unit will contain printed circuit card locations to accommodate the desired number of channels of signal conditioning. The individual channels of signal conditioning will be fixed gain amplifiers with provisions for automatic calibration using precision voltage staircases. Bridge type sensors will be excited from individual gage excitation circuits and in addition will be automatically calibrated with shunt resistors. The calibration process will be under control of a single PC board processor commanded by the computer at the processing center.

All sampled data is subject to allaising errors introduced by sampling non-band limited data at too low a sampling frequency. Multiple order low pass filters are utilized for each channel prior to sampling in order to eliminate such errors. Existing Westinghouse electronics providing the above functions in a volume of 5 cu. inches per channel serve to illustrate the potential for locating the signal conditioning as close to the sensor as possible if extremely low signal levels and excessive wire runs preclude its installation in the satellite module.

After low pass filtering, the data signals are sampled by a multi-channel solid state switch and routed to an amplifier, sample and hold circuit, and 8 bit analog to digital converter. The multiplex and conversion process is controlled by a single PC Board computer utilizing a Programmable Read Only Memory for the stored program. The processor determines output data format as well as timing and control for the satellite electronics.

The actual transmission of the data to the processing center is accomplished via a multiple twisted pair cable upon request by the computer. The single board microprocessor retains satellite data until required, whereupon it transmits a frame of N channels via a high rate Universal Asynchronous Receiver/Transmitter. Interface busses of this nature allows serial transmission keeping the number of interface wires to a minimum. The available bandwidth on the hardwire transmission link will allow the use of NRZ coding of the digital data.

Each of 3 interface lines between the satellite and the processing center consists of a twisted pair of shielded wires providing protection against magnetic and electrical interface. The wire is terminated by either a dual line driver or balanced receiver which provides subsystem isolation of ground currents and high noise immunity.

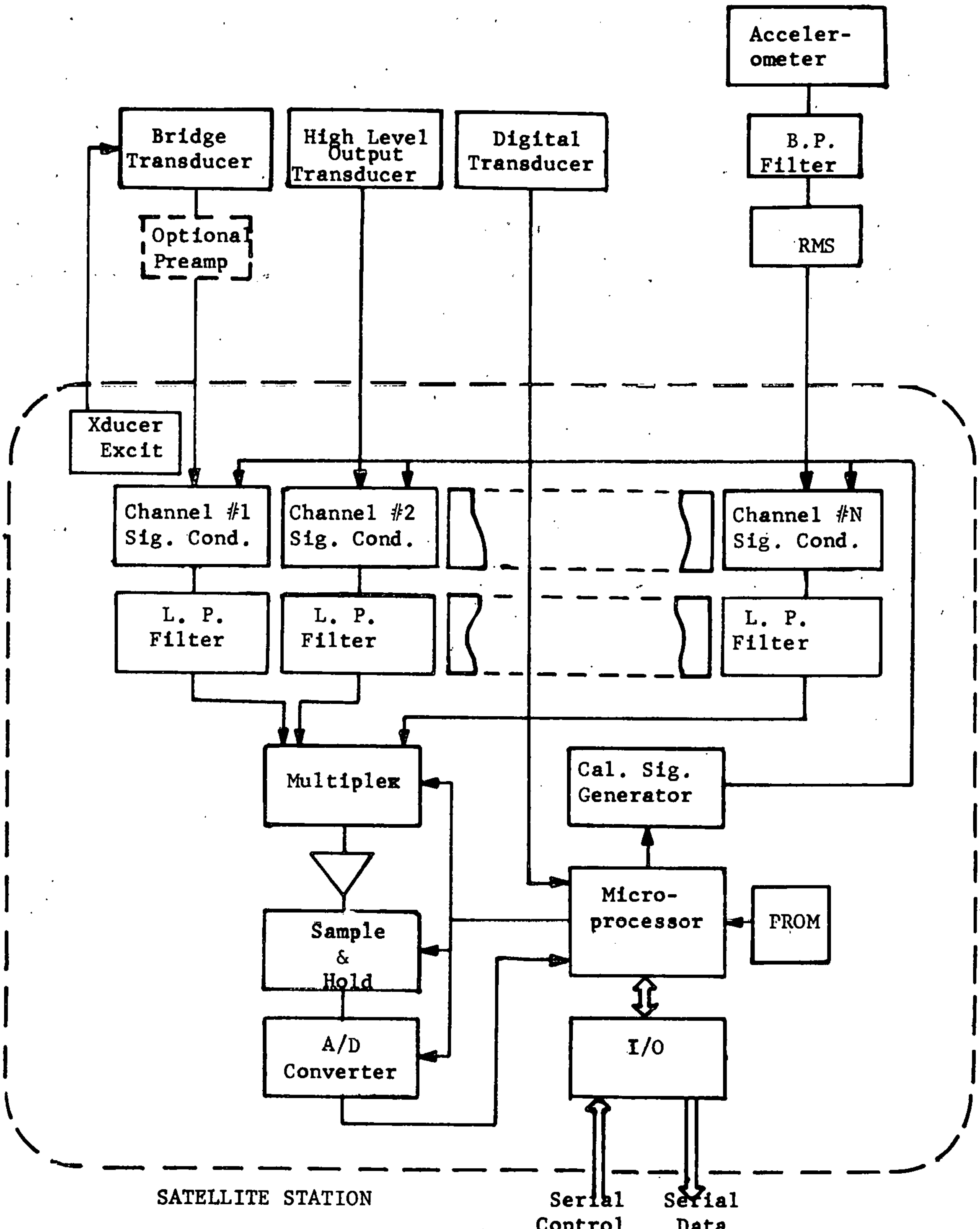

FIGURE 5-2

SATELLITE HARDWARE BLOCK DIAGRAM

5.2.4 PROCESSING CENTER

A. System Description

The data taken by the Satellite Stations is collected, analyzed and stored at the Processing Center. The operator controls the DAS from this center through the use of a general purpose digital computer. The computer will have a library of programs to perform various collection and analysis functions. Figure 5-3 shows a functional block diagram of the Processing Center. Following paragraphs will describe the operation of the system and the function of each block.

B. System Operation

As described in Section III, the Satellite Stations are continuously sampling all the sensors in the system at a relatively high rate and while retaining only the most recent value of each signal. It is the function of the Processing Center (directed by the operator) to control the effective sampling rate of the DAS according to the objectives of tests being conducted. The system is designed to collect this data at rates from 10 samples per second for short term transient tests to once every hour or day for monitoring long term steady state operation. When the data is being collected at less than the maximum 10 samples per second, multiple samples will be taken at each interval to maximize the probability of getting valid data. Data collection is accomplished by commanding the Satellite Stations to halt its sampling function. Each station, in turn, is then asked to report the most recent value for each of its sensors. After completing its report, it is released to continue its sampling function.

Once the data from all Satellite Stations has been received, it is time tagged and recorded on both the Data Disk and the Data Tape Recorder. In addition to being stored, the outputs of sensors selected by the operator can be directed to the Data Display for monitoring in either tabular or graphic form. A limited amount of on-line processing, depending on the system sampling rate, can also be accomplished with the results being displayed. A Data Printer will provide a permanent copy of any tables or graphs put on the Data Display. In the type of test where the sample rate is slow, minutes between samples, the computer can be used between samples to perform analysis on any the data previously collected and stored on the Data Disk. After completion of the test, the computer can be dedicated to data analysis which is limited only by the software library. The digital tape provides a convenient medium for permanent storage of the data and for transferring the data to any other computer facility for further analysis. In addition it its data acquisition and analysis functions, the Processing Center computer can be used to develop and modify the software library.

C. Satellite Station Interface

As their name implies, the Satellite Stations operate under control of the Processing Center. The I/O interface is essentially a parallel to serial to parallel conversion. The interface to both the Processing Center's Digital Computer and the Satellite's Stations Timing and Control Logic appears to be a parallel bus. However, the actual transmission method is serial and designed to minimize the number of wires between the Processing Center and each Satellite Station while maintaining a sufficiently high data rate.

D. Time Code Generator

The Time Code Generator develops a digital representation of the time of day which is used by the system to time tag the data which is collected and to provide a time base for establishing the sampling rate. The code also includes a 365 day calendar to provide complete identification of the data.

E. Data Tape Recorder

This recorder provides a permanent record of all data collected by the DAS. The data is recorded in a standard IBM tape format so that it can be transferred to another data processing facility. Data from previous tests can also be reloaded into the Processing Center computer for further analysis. This feature can be used to trace the history of a problem which had gone unnoticed when the data was origionally taken. Assuming the DAS is monitoring 350 parameters, the tape will store over 1 hour of data taken at the 10 sample per second rate and over 2 days of data taken at a rate of 1 second of data (10 samples) every minute.

F. Data Disk

This disk is used for temporary storage of data for use by the Digital Computer. Use of a disk allows the computer rapid access to the data compared to the digital tape. The fast access time increases the amount of on-line processing that can be done between data samples. Dual double-density diskettes will store about 5 minutes of data taken at the 10 samples per second rate (350 parameters).

G. Data Display

The Data Display is a high resolution CRT which is the primary display of the DAS. Data can be displayed in either tabular (character) format or graphic plots as the computer directs. The system may include multiple displays.

H. Data Printer

The Data Printer will provide a permanent hard copy of data taken by the DAS or the results of any analysis, including graphics, done by the computer.

I. Program Disk

This disk is used to store program for the Digital Computer. These programs include data acquisition and analysis programs and utility programs used by the computer to create new programs or modify existing programs. The use of some of the utility programs may be restricted to knowledgeable programmers. Depending on the type of computer selected, it may be possible to write many of the programs relating to data acquisition and analysis programs in a higher level language such as FORTRAN. In this case, the programmer would only be required to learn the computer's operating system to create and modify programs.

J. Operators Terminal

The Operators Terminal is a keyboard and CRT display. The terminal is used by the operator to control operation of the DAS via the Digital Computer. Multiple terminals may be interfaced to the computer on a time-sharing basis.

K. Digital Computer

The computer is the central element of the Processing Center, yet it is almost transparent to the operator since he sees only the results of its operation. Through it, the operator controls the action of the entire DAS. The computational load on the computer is minimal as its primary function is to move data from one peripheral to another. There are numerous micro and mini computers capable of performing this function.

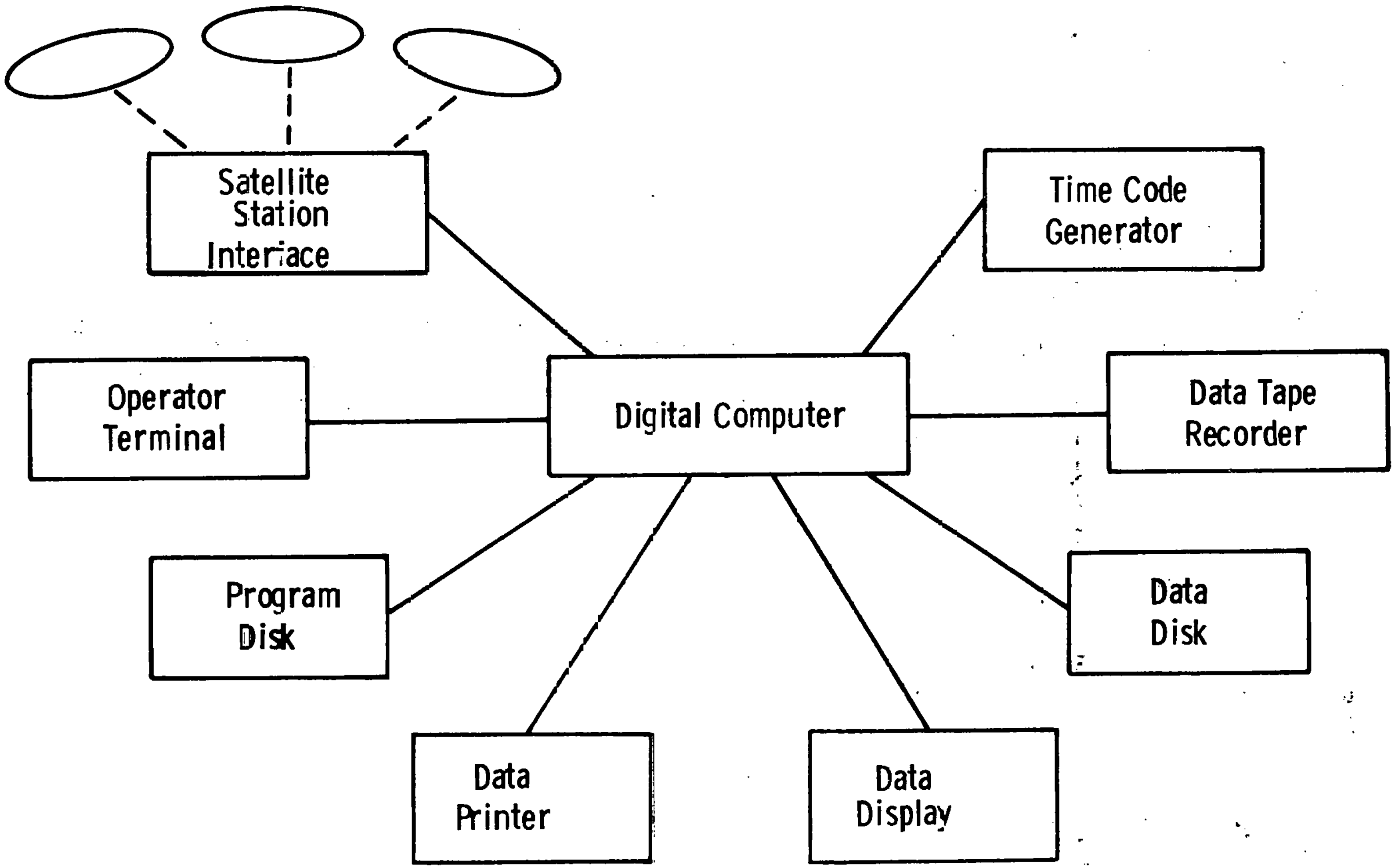

FIGURE 5-3

PROCESSING CENTER BLOCK DIAGRAM

5.3 Summary

The instrumentation requirements of the Test Articles and especially the 10 MeW Modular Experiment require careful design, planning, and coordination for effective and meaningful tests. The instrumentation and data acquisition system cannot be separate entities but are closely tied together. Since there are a large number of measurements and a good variety of test sensors and apparatus, the use of an instrumentation consultant may prove to be prudent to obtain the best compatible and most cost efficient system. The specific types of instrumentation will be left to the detail design phase but certain areas of development have been recognized. They include the area of ammonia vapor quality and flow measurement.

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6.0 COST

The Instumentation and Data Acquisition System hardware costs are shown summarized in Table 6-1. These costs represent a first look rough order of magnitude estimate, and are based on best available design parameters. These cost estimates will be further refined during the detail design phase of power system development.

TABLE 6-1

TEST PROGRAM HARDWARE COST SUMMARY

HARDWARE	COST ($1,000) TEST ARTICLES	MODULAR EXPERIMENT
TEMPERATURE SENSORS	44	36
PRESSURE SENSORS	32	60
FLOW METERS	435	1,000
VIBRATION SENSORS	44	62
SPEED SENSORS	-	8
WATT TRANSDUCERS	-	38
QUALITY SENSORS	(1)	(1)
DATA ACQUISITION SYSTEM		350
DAS LABORATORY/TRAILER		25
TOTAL	555	1,579

NOTE: (1) Quality sensors are developmental instrumentation and should be quoted separately. Each alternative technique should be costed out and a trade off analysis performed.

APPENDIX A

TEST DATA REQUIREMENTS

The test data requirements for the Test Article and Modular Experiment are summarized in Tables 1 and 2 respectively. Measurement identification numbers (i.e. 1,2,3....) provide cross-reference with data requirement schematics, Figures 3-1 and 4-1.

The accuracies contained herein are considered to be typical of those that will be required for an OTEC test plant operation. These values were developed to facilitate the test instrumentation and data acquisition system efforts. It is recommended that overall test and individual instrumentation accuracy requirements be analyzed in greater detail during the next phase of the OTEC test program.

.18 MWe . . Article TABLE -1 - TES. ..TA REQUIREMENTS

MEASUREMENT	LOCATION	EXPECTED VALUE °F	RANGE °F	REQUIRED ACCURACY °F
1. Temperature				
Sensor Number:				
1	Evaporator Outlet (NH_3)	70	65-73	± .5
2	Throttle Valve Inlet	70	65-73	± .5
3	Condenser Inlet (NH_3)	49	46-54	± .5
4	Condenser Outlet (NH_3)	49	46-54	± .1
5	Evaporator Inlet (NH_3)	60	56-63	± .5
6	Evaporator Liquid Drain (NH_3)	71	66-74	± .1
7	Separator Liquid Drain (NH_3)	70	65-73	± .5
8	Evaporator SW Inlet	80	75-85	± .1
9	Evaporator SW Outlet	75	70-80	± .1
10	Condenser SW Inlet	40	35-45	± .1
11	Condenser SW Outlet	46	41-51	± .1
12 through 47	Evaporator SW Inlet	80	75-85	± .5
(INDIVIDUAL TUBE MEASUREMENTS - CLUSTERS OF 6 IN 6 LOCATIONS)				

MEASUREMENT	LOCATION	EXPECTED VALUE °F	RANGE °F	REQUIRED ACCURACY °F
1. Temperature (Cont.)				
48 through 83 (Same as 12-47)	Evaporator SW Outlet	75	70-80	± .5
84 through 119 (Same as 12-47)	Condenser SW Inlet	40	35-45	± .5
120 through 155 (Same as 12-47)	Condenser SW Outlet	46	41-51	± .5
(NOTE: SENSORS 156-167 ARE COUPON RACK INSTRUMENTATION AND ARE NOT SHOWN)				
155, 156	Evaporator SW Inlet	80	75-85	± .5
157, 158	Evaporator SW Outlet	75	70-80	± .5
159, 160	Condenser SW Inlet	40	35-45	± .5
161, 162	Condenser SW Outlet	46	41-51	± .5
163, 164	Evaporator NH_3 Side	70	65-73	± .5
165, 166	Condenser NH_3 Side	49	46-54	± .5
167	Ammonia Feed Pump Discharge	49	46-54	± .5
168	Ammonia Recirculation Pump Discharge	71	66-74	± .5

.18 MWe Article TABLE -1 - TES. .TA REQUIREMENTS

MEASUREMENT	LOCATION	EXPECTED VALUE PSIA	RANGE PSIA	REQUIRED ACCURACY PSIA
2. Pressure Sensor Number				
1	Inside Evaporator (NH_3)	130	118-136	± .5
2	Inside Separator (NH_3)	130	118-136	± .5
3	Evaporator Outlet (NH_3)	130	188-136	± .5
4	Evaporator Inlet (NH_3)	138	126-144	± .5
5	Throttle Valve Inlet	129	117-135	± .5
6	Condenser Inlet (NH_3)	88	83-96	± .5
7	Condenser Outlet (NH_3)	88	83-96	± .5
8	Recirculation Pump Inlet	130	118-136	± .5
9	Evaporator SW Inlet	15	13-15	± .1
10	Evaporator SW Outlet	11	9.5-12.5	± .1
11	Condenser SW Inlet	13	11-15	± .1
12	Condenser SW Outlet	8	7.5-9.5	± .1

TABLE -1 - TEST DATA REQUIREMENTS

MEASUREMENT	LOCATION	EXPECTED VALUE PSIA	RANGE PSIA	REQUIRED ACCURACY PSIA
2. Pressure (Cont.)				
(NOTE: SENSORS 13-24 ARE COUPON RACK INSTRUMENTATION AND ARE NOT SHOWN.)				
13,14	Evaporator SW Inlet	15	13-15	± .1
15, 16	Evaporator SW Outlet	11	9.5-12.5	± .1
17, 18	Condenser SW Inlet	13	11-15	± .1
19, 20	Condenser SW Outlet	8	7.5-9.5	± .1
21, 22	Evaporator NH_3 Side	130	118-136	± .5
23, 24	Condenser NH_3 Side	88	83-96	± .5
25	Ammonia Feed Pump Discharge	139	127-145	± .5
26	Ammonia Recirculation Pump Discharge	138	126-144	± .5

.18 MWe . . Article   TABLE -1 - TES. ..TA REQUIREMENTS

MEASUREMENT	LOCATION	EXPECTED VALUE LB/HR	RANGE LB/HR	REQUIRED ACCURACY LB/HR
3. Flow Sensor Number:				
1-9	Nine Nozzles to Evaporator Distribution Chambers	1.19×10^{4}	$5.95 \times 10^{3} - 1.25 \times 10^{4}$	$\pm 1.19 \times 10^{2}$
10-18	Nine Nozzles from Evaporator Collection Chambers	5.27×10^{3}	$2.64 \times 10^{3} - 5.53 \times 10^{3}$	$\pm 5.28 \times 10^{1}$
19	Seperator Liquid Drain	5.92×10^{3}	$2.97 \times 10^{3} - 6.23 \times 10^{3}$	$\pm 2.97 \times 10^{1}$
20	Evaporator Liquid Drain	4.74×10^{4}	$2.37 \times 10^{4} - 4.98 \times 10^{4}$	$\pm 2.37 \times 10^{2}$
21	Feed Pump Discharge	5.33×10^{4}	$5.06 \times 10^{4} - 5.60 \times 10^{4}$	$\pm 5.06 \times 10^{2}$
22	Recirculation Pump Discharge	5.33×10^{4}	$0 - 5.60 \times 10^{4}$	$\pm 5.06 \times 10^{2}$
23	Evaporator Inlet	1.07×10^{5}	$5.35 \times 10^{4} - 1.12 \times 10^{5}$	$\pm 5.35 \times 10^{2}$
24	Warm SW Pump Suction	5.44×10^{6}	$5.17 \times 10^{6} - 5.7 \times 10^{6}$	$\pm 5.17 \times 10^{4}$
25	Cold SW Pump Suction	4.69×10^{6}	$4.46 \times 10^{6} - 4.92 \times 10^{6}$	$\pm 4.46 \times 10^{4}$

MEASUREMENT	LOCATION	EXPECTED VALUE LB/HR	RANGE LB/HR	REQUIRED ACCURACY LB/HR
3. FLOW (Cont.)				
(NOTE: SENSORS 26-37 ARE COUPON RACK INSTRUMENTATION AND ARE NOT SHOWN).				
26, 27	Evaporator SW Inlet	5.44×10^{6}	$5.17 \times 10^{6} - 5.71 \times 10^{6}$	$\pm 1.55 \times 10^{5}$
28, 29	Condenser SW Inlet	4.69×10^{6}	$4.46 \times 10^{6} - 4.92 \times 10^{6}$	$\pm 1.34 \times 10^{5}$
30, 31	Evaporator NH_3 Side	5.92×10^{4}	$5.62 \times 10^{4} - 6.21 \times 10^{4}$	$\pm 1.69 \times 10^{3}$
32, 33	Condenser NH_3 Side	5.33×10^{4}	$5.06 \times 10^{4} - 5.60 \times 10^{4}$	$\pm 1.52 \times 10^{3}$

.18 MWe . . Article TABLE -1 - TES' ..TA REQUIREMENTS

MEASUREMENT	LOCATION	EXPECTED VALUE FT/SEC	RANGE FT/SEC	REQUIRED ACCURACY FT/SEC
4. Flow/Velocity Sensor Number:				
(NOTE: THESE SENSORS REQUIRED TO DISPLAY NH_3 VAPOR FLOW AND VELOCITY IN REAL TIME FOR TEST OPERATION).				
1	Evaporator Outlet	5	0-10	± .25
2	Throttle Inlet	5	0-10	± .25
3	Vapor Recirculation	5	0-10	± .25

TABLE -1 - TES. .A REQUIREMENTS

MEASUREMENT	LOCATION	EXPECTED VALUE FT/SEC	RANGE FT/SEC	REQUIRED ACCURACY FT/SEC
5. Velocity Sensor Number				
1-7	Evaporator Tube Bundle Outlet (TO OBTAIN VAPOR BUNDLE EXIT VELOCITY DISTRIBUTION)	5	0-10	±.25

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.18 MWe ... Article TABLE -1 - TEST DATA REQUIREMENTS

MEASUREMENT	LOCATION	EXPECTED VALUE	RANGE	REQUIRED ACCURACY
6. Quality Sensor Number:				
1	Between Tube Bundle and Separator	.95	.93 - .97	± .01
2	Evaporator Outlet	.9975	.99 - .999	± .01

MEASUREMENT	LOCATION	EXPECTED VALUE	RANGE	REQUIRED ACCURACY
		MILS - PEAK TO PEAK		
7. Vibration Sensor Number				
1	Evaporator	2	0-10	± .1
(NOTE: TWO INDUCTIVE DISPLACEMENT SENSORS (HORIZONTAL & VERTICAL) WILL BE PLACED IN 6 TUBES ON THE SEAWATER SIDE.)				
2 (Same as 1)	Condenser	2	0-10	± .1

10 MWe MODULAR APPLICATION — TABLE 2 - TEST DATA REQUIREMENTS

MEASUREMENT	LOCATION	EXPECTED VALUE PSIA	RANGE PSIA	REQUIRED ACCURACY PSIA
1. Pressure Sensor Number:				
1	Evaporator Outlet (NH_3)	130	118-136	± .5
2	Separator Outlet (NH_3)	129	117-135	± .5
3	Turbine Exhaust	88	83-96	± .5
4	Condenser Hotwell	88	83-96	± .5
5	NH_3 Feed Pump Discharge	138	126-144	± .5
6	Evaporator Inlet (NH_3)	138	126-144	± .5
7	Evaporator Liquid Drain	130	118-136	± .5
8	Separator Liquid Drain	130	118-136	± .5
9	NH_3 Recirculation Pump Discharge	138	126-144	± .5
10	Condenser SW Inlet	12	11-15	± .1
11	Condenser SW Outlet	8	7.5 - 9.5	± .1
12	Evaporator SW Inlet	15	13-15	± .1

TABLE 2 - TEST ...A REQUIREMENTS

MEASUREMENT	LOCATION	EXPECTED VALUE PSIA	RANGE PSIA	REQUIRED ACCURACY PSIA
1. Pressure (Cont.)				
13	Evaporator SW Outlet	11	9.5-12.5	± .1
14	Lube Oil Cooler Inlet	55	50-60	± .5
15-26	Warm SW Pump	11-15	11-15	± .1
(NOT SHOWN: STATIC PRESSURE SENSORS TO MEASURE PROFILE ACROSS THE PUMP AT APPROXIMATELY 5 FT. INTERVALS LOCATED AS FOLLOWS: (1) 2 - Pump Inlet (2) 6 - Impeller/Stator/Pod/Casing (3) 4 - Diffuser				
26-38	Cold SW Pump	8-15	8-15	± .1
(NOT SHOWN SAME AS 15-26)				
(NOTE: SENSORS 39-66 ARE COUPON RACK INSTRUMENTATION AND ARE NOT SHOWN).				

10 MWe [illegible] AR APPLICATION TABLE 2 - TES[illegible] A REQUIREMENTS

MEASUREMENT	LOCATION	EXPECTED VALUE PSIA	RANGE PSIA	REQUIRED ACCURACY PSIA
1. Pressure (Cont.)				
39-41	Cold Water Pipe	14.7	13-15	± .5
41, 42	Cold Water Plenum	14.7	13-15	± .5
43, 44	Warm Water Plenum	14.7	13-15	± .5
45, 46	Evaporator SW Inlet	14.7	13-15	± .5
47, 48	Evaporator SW Outlet	10.8	9.5 - 12.5	± .5
49, 50	Condenser SW Inlet	12.5	11-15	± .5
51, 52	Condenser SW Outlet	7.8	7.5-9.5	± .5
53	Warm SW Pump Suction	10.8	9.5-12.5	± .5
54	Warm SW Pump Discharge	14.7	13-15	± .5
55	Cold Sw Pump Suction	7.8	7.5 - 9.5	± .5
56	Cold SW Pump Discharge	14.7	13-15	± .5
Sensors 57-66	Are Ammonia Side			
57, 58	Evaporator	130	118-136	± .5

10 MWe MODULAR APPLICATION TABLE - TEST DATA REQUIREMENTS

MEASUREMENT	LOCATION	EXPECTED VALUE PSIA	RANGE PSIA	REQUIRED ACCURACY PSIA
1. Pressure (Cont.)				
59, 60	Separator	129	117-135	± .5
61, 62	Condenser	88	83-96	± .5
63,64	Hotwell	88	83-96	± .5
65,66	Ammonia Storage Tank	130	118-136	± .5
67	Ammonia Feed Pump Suction	88	83-96	± .5
68	Ammonia Recirculating Pump Suction	130	118-136	± .5
69	Turbine Ammonia Vapor Inlet	129	117-135	± .5
70	By-Pass Valve Outlet to Condenser	90	75-135	± .5

10 MWe MODULAR APPLICATION TABLE 2 - TEST DATA REQUIREMENTS

MEASUREMENT	LOCATION	EXPECTED VALUE °F	RANGE °F	REQUIRED ACCURACY °F
2. Temperature Sensor Number				
1	Evaporator Outlet (NH_3)	71	66-74	± .5
2	Separator Outlet (NH_3)	70	65-73	± .5
3	Turbine Exhaust	49	46-54	± .5
4	Condenser Hotwell	49	46-54	± .1
5	NH_3 Feed Pump Discharge	49	46-54	± .5
6	Evaporator Inlet (NH_3)	60	56-63	± .5
7	Evaporator Liquid Drain	71	66-74	± .1
8	Separator Liquid Drain	70	65-73	± .5
9	NH_3 Recirculation Pump Discharge	71	66-74	± .5
10	Condenser SW Inlet	40	35-45	± .1
11	Condenser SW Outlet	46	41-51	± .1
12	Evaporator SW Inlet	80	75-85	± .1

10 MWe MODULAR APPLICATION TABLE - TEST DATA REQUIREMENTS

MEASUREMENT	LOCATION	EXPECTED VALUE °F	RANGE °F	REQUIRED ACCURACY °F
2. Temperature (Cont'd)				
13	Evaporator SW outlet	75	70-80	± .1
14	Lube Oil Cooler Inlet	140	130-150	± .5
15 through 32	Condenser SW Inlet	40	35-45	± .5
Individual Tube Measurements - Clusters of 6 In 3 Locations				
33 through 50 (Same as 15-32)	Condenser SW Cutlet	46	41-51	± .5
51 through 68 (Same as 15-32)	Evaporator SW Inlet	80	75-85	± .5
69 through 86 (Same as 15-32)	Evaporator SW Outlet	75	70-80	± .5

10 MWe .ODULAR APPLICATION. TABLE 2 - TES1 ..tA REQUIREMENTS

MEASUREMENT	LOCATION	EXPECTED VALUE °F	RANGE °F	REQUIRED ACCURACY °F
2. Temp. (Cont.)				
(NOTE: Sensors 87-115 are coupon rack instrumentation and are not shown).				
87-89	Cold Water Pipe			
90, 91	Cold Water Plenum	40	35-45	± .5
92, 93	Warm Water Plenum	80	75-85	± .5
94, 95	Evaporator SW Inlet	80	75-85	± .5
96, 97	Evaporator SW Outlet	75	70-80	± .5
98, 9'	Condenser SW Inlet	40	35-45	± .5
100, 1	Condenser SW Outlet	46	41-51	± .5
102	Warm SW Pump Suction	75	70-80	± .5
103	Warm SW Pump Discharge	75	70-80	± .5
104	Cold SW Pump Suction	46	41-51	± .5
105	Cold SW Pump Discharge	46	41-51	± .5
Sensors 106-115 are Ammonia Side.				

10 MWe MODULAR APPLICATION TABLE 2 - TEST DATA REQUIREMENTS

MEASUREMENT	LOCATION	EXPECTED VALUE °F	RANGE °F	REQUIRED ACCURACY °F
2. TEMP. (Cont.)				
106,107	Evaporator	70	65-73	± .5
108, 109	Separator	70	65-73	± .5
110,111	Condenser	49	46-54	± .5
112, 113	Hotwell	49	46-54	± .5
114, 115	Ammonia Storage Tank	70	65-73	± .5
116	Ammonia Feed Pump Suction	49	46-54	± .5
117	Ammonia Recirculation Pump Suction	71	66-74	± .5
118	Turbine Ammonia Vapor Inlet	70	65-73	± .5
119	By-Pass Valve Outlet to Condenser	60	45-75	± .5

10 MWe MODULAR APPLICATION TABLE - TEST DATA REQUIREMENTS

MEASUREMENT	LOCATION	EXPECTED VALUE °F	RANGE °F	REQUIRED ACCURACY °F
3. Temperature Differential Sensor Number:				
1	Lube Oil Cooler	30	20-40	± .1

MEASUREMENT	LOCATION	EXPECTED VALUE LB/HR.	RANGE LB/HR	REQUIRED ACCURACY LB/HR
4. Flow Sensor Number				
1	NH_3 Feed	2.987×10^6	$2.83 \times 10^6 - 3.14 \times 10^6$	$\pm 2.83 \times 10^4$
2	NH_3 Recirculation	2.987×10^6	$0 - 3.14 \times 10^6$	$\pm 2.83 \times 10^4$
3	Evaporator Liquid Drain	2.655×10^6	$1.33 \times 10^6 - 2.79 \times 10^6$	$\pm 1.33 \times 10^4$
4	Separator Liquid Drain	3.319×10^5	$1.66 \times 10^5 - 3.48 \times 10^5$	$\pm 1.66 \times 10^3$
5	Make-Up	VAR	$0 - 2.987 \times 10^6$	$\pm 2.987 \times 10^4$
6	Dump	VAR	$0 - 2.987 \times 10^6$	$\pm 2.987 \times 10^4$
7	Lube Oil Cooler	TBD		
8	Cold SW Pump Suction	2.63×10^8	$2.5 \times 10^8 - 2.76 \times 10^8$	$\pm 2.5 \times 10^6$
9	Warm SW Pump Suction	3.054×10^8	$2.9 \times 10^8 - 3.21 \times 10^8$	$\pm 2.9 \times 10^6$

(NOTE: Sensors 10-38 are coupon rack instrumentation and are not shown).

10 MWe ODULAR APPLICATION — TABLE 2 - TEST A REQUIREMENTS

MEASUREMENT	LOCATION	EXPECTED VALUE LB/HR	RANGE LB/HR	REQUIRED ACCURACY LB/HR
4. Flow (Cont.)				
10-12	Cold Water Pipe	2.63×10^8	$2.5 \times 10^8 - 2.76 \times 10^8$	$\pm 7.5 \times 10^6$
13, 14	Cold Water Plenum	2.63×10^8	$2.5 \times 10^8 - 2.76 \times 10^8$	$\pm 7.5 \times 10^6$
15, 16	Warm Water Plenum	3.05×10^8	$2.9 \times 10^8 - 3.21 \times 10^8$	$\pm 8.7 \times 10^6$
17, 18	Evaporator SW Inlet	3.05×10^8	$2.9 \times 10^8 - 3.21 \times 10^8$	$\pm 8.7 \times 10^6$
19, 20	Evaporator SW Outlet	3.05×10^8	$2.9 \times 10^8 - 3.21 \times 10^8$	$\pm 8.7 \times 10^6$
21, 22	Condenser SW Inlet	2.63×10^8	$2.5 \times 10^8 - 2.76 \times 10^8$	$\pm 7.5 \times 10^6$
23, 24	Condenser SW Outlet	2.63×10^8	$2.5 \times 10^8 - 2.76 \times 10^8$	$\pm 7.5 \times 10^6$
25	Warm SW Pump Suction	3.05×10^8	$2.9 \times 10^8 - 3.21 \times 10^8$	$\pm 8.7 \times 10^6$
26	Warm SW Pump Discharge	3.05×10^8	$2.9 \times 10^8 - 3.21 \times 10^8$	$\pm 8.7 \times 10^6$
27	Cold SW Pump Suction	2.63×10^8	$2.5 \times 10^8 - 2.76 \times 10^8$	$\pm 2.5 \times 10^6$
28	Cold SW Pump Discharge	2.63×10^8	$2.5 \times 10^8 - 2.76 \times 10^8$	$\pm 2.5 \times 10^6$
Sensors 29-38 Are Ammonia Side.				
29, 30	Evaporator	3.32×10^6	$3.15 \times 10^6 - 3.49 \times 10^6$	$\pm 9.45 \times 10^4$
31, 32	Separator	2.29×10^6	$2.17 \times 10^6 - 2.41 \times 10^6$	$\pm 6.51 \times 10^4$

MEASUREMENT	LOCATION	EXPECTED VALUE LB/HR	RANGE	REQUIRED ACCURACY
4. Flow (Cont.)				
33, 34	Condenser	2.99×10^6	$2.84 \times 10^6 - 3.14 \times 10^6$	$\pm 8.52 \times 10^4$
35, 36	Hotwell	2.99×10^6	$2.84 \times 10^6 - 3.14 \times 10^6$	$\pm 8.52 \times 10^4$
37, 38	Ammonia Storage Tank	2.99×10^6	$2.84 \times 10^6 - 3.14 \times 10^6$	$\pm 8.52 \times 10^4$
39	Turbine Ammonia Vapor Inlet	2.99×10^6	$2.83 \times 10^6 - 3.14 \times 10^6$	$\pm 2.83 \times 10^4$
40	By-Pass Valve Outlet to Condenser	2.99×10^4	$2.99 \times 10^4 - 1.79 \times 10^6$	$\pm 2.99 \times 10^2$

10 MWe MODULAR APPLICATION — TABLE 2 - TEST DATA REQUIREMENTS

MEASUREMENT	LOCATION	EXPECTED VALUE KW	RANGE KW	REQUIRED ACCURACY KW
5. Power Sensor Number:				
1-1	Generator Gross Out	14, 420	13,700 - 14,420	± 14
1-2	Generator Net Out	10, 100	9,595 - 10,605	± 10
2	Warm SW Pump In	1, 522	1,446 - 1,598	± 2
3	Cold SW Pump In	2, 297	2,182 - 2,412	± 2
4	NH_3 Feed Pump In	781	742 - 820	± 1
5	NH_3 Recirculation Pump In	50	47.5 - 52.5	± .1

TABLE 2 - TEST DATA REQUIREMENTS

MEASUREMENT	LOCATION	EXPECTED VALUE	RANGE	REQUIRED ACCURACY
6. Quality Sensor Number				
1	Separator Outlet	.995	.99 - .999	± .01

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10 MWe MODULAR APPLICATION

TABLE 2 - TEST DATA REQUIREMENTS

MEASUREMENT	LOCATION	EXPECTED VALUE	RANGE	REQUIRED ACCURACY
7. Level Sensor Number				
1	Hot Well	Level Signal from Control System		
2	NH_3 Storage Tank			

MEASUREMENT	LOCATION	EXPECTED VALUE RPM	RANGE RPM	REQUIRED ACCURACY RPM
8. Speed Sensor Number:				
1	Turbine	3600	3060 - 4140	± 15
2	Warm SW Pump	67	60-74	± 3
3	Cold SW Pump	101	94 - 108	± 5
4	NH_3 Feed Pump	TBD		
5	NH_3 Recirculation Pump	TBD		

10 MWe MODULAR APPLICATION — TABLE 2 - TEST DATA REQUIREMENTS

MEASUREMENT	LOCATION	EXPECTED VALUE	RANGE	REQUIRED ACCURACY
9. Control Valve Measurements				
(NOTE: Three measurements for each valve will include:)				
(1) Valve Position				
(2) Control Reference Signal				
(3) Control Error Signal				
4 By-Pass Valves Separator Outlet				
CV-1	NH_3 Feed			
CV-2	NH_3 Dump			
CV-3	NH_3 Make-Up From Storage			
CV-4	NH_3 Recirculation			
CV-9	NH_3 Dump To Storage			
CV-10	NH_3 Dump to Condenser from Evaporator			

MEASUREMENT	LOCATION	EXPECTED VALUE	RANGE	REQUIRED ACCURACY
			MILS - PEAK TO PEAK	
10. Vibration and Rotor Balance				
1	Evaporator	2	0-10	± .1
(NOTE: Two inductive displacement sensors (horizontal & vertical) will be placed in 6 tubes on the seawater side).				
2 (Same as 1)	Condenser	2	0-10	± .1
3	Turbine	2	0-10	± .1
(NOTE: Two inductive displacement sensors are mounted at each bearing and a fifth is used as a reference for the orbit (Lissajous) method of balancing).				
4 (Same as 3)	Generator	2	0-10	± .1
5 (Same as 3)	Warm SW Pump	2	0-10	± .1

10 MWe ODULAR APPLICATION TABLE 2 - TEST DATA REQUIREMENTS

MEASUREMENT	LOCATION	EXPECTED VALUE	RANGE	REQUIRED ACCURACY
			MILS - PEAK TO PEAK	
10. Vibration/ Balance (Cont.)				
6 (Same as 3)	Cold SW Pump	2	0-10	± .1
7 (Same as 3)	NH_3 Feed Pump	2	0-10	± .1
8 (Same as 3)	NH_3 Recirculation Pump	2	0-10	± .1

APPENDIX B

INSTRUMENTATION SPECIFICATIONS FOR TEMPERATURE, PRESSURE, VIBRATION, SPEED, AND POWER

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TEMPERATURE MEASUREMENT SPECIFICATION

Type: Thermocouple

Range: 32°F - 150°F (0°C - 65°C)

Accuracy: ± 0.5°F (310 required; 180 TA, 130-10MWe)

± 0.25°F (90 required; 40-TA, 50-10 MWe)

Material: Choose from

1. Copper-Constantan (T)
2. Iron-Constantan (J)
3. Chromel-Constantan (E)
4. Chromel-Alumel (K)

Time Constant: 5 seconds maximum

Interchangeability: ± 0.5°F (310); ± 0.25°F (90)

Long Term Stability: ± 0.5°F (310); ± 0.25°F (90)

Maximum Change in sensitivity ± 0.5% due to thermal shock, high and low temperature storage, vibration, shock, immersion, life test, and moisture.

Estimated Cost @ $200/sensor

Test Article	$44,000
10 MWe Modular Experiment	$36,000

Pressure Measurement Specification

Type: Electrical pressure transducer, passive type

Kind: Strain gage, potentiometric, capacitive, LVDT

Range: 0-20 psia

0-200 psia

Accuracy: ±.1 psia (low range)

±.5 psia (high range)

Operating Temperature: 32°F-150°F

Sensitivity Change with Temperature in Operation Range: 1% of Full Scale

Non-Linearity: .25% rated output

Repeatability: .03% rated output

Hysteresis: .25% rated output

Excitation: 15-18V, AC or DC

Estimated cost

Test Article	$ 32,000
10 MWe Modular Experiment	$ 60,000

VIBRATION MEASUREMENT SPECIFICATION

	Heat Exchanger Tube	Pumps	Turbine/Generator
Type:	Piezoelectric Acceler.		Eddy Current Probe
Sensitivity:	1 mv/g	5 mv/g	50 mv/mil
Frequency Response (± 5%):	10-3000 Hz	1-10000 Hz	DC - 10,000 Hz
Mounted Resonance Frequency:	_ 15,000 Hz	_ 50,000 Hz	
Transverse Sensitivity:	5%	5%	5%
Amplitude Linearity:	± 1%	±1%	± 5%
Operating Temperature Range:	32°F-90°F	32°F-150°F	32°F-90°F
Shock Resistance:	50 g	500 g	500 g
Noise Floor (overall):	_ 10^{-3} g rms	_ 10^{-3} g rms	_ 10^{-3} g rms
Sensitivity Change with Temp. in Operating Range:	_ 1%	_ 2%	_ 3%
Calibration Accuracy:	± 1%	± 1%	± 1%

Estimated Cost:

Test Article	$24,000
10 MWe Modular Experiment	42,000
Narrow Band Specrum Analyzer	20,000

Speed Measurement Specification

Type:	Eddy Current Probe
Sensitivity:	50 mV/mil
Frequency Response (±5%):	DC - 10,000 Hz
Mounted Resonance Frequency:	------
Transverse Sensitivity:	5%
Amplitude Linearity:	±5%
Operating Temperature Range:	32°F - 150°F
Shock Resistance:	500g
Noise Floor (overall):	10^{-3} g rms
Sensitvity Change with Temp. in Operating Range:	3%
Calibration Accuracy:	±1%

POWER MEASUREMENT SPECIFICATION

Type:	Watt Transducer
Input Watts:	1500 Watts, 3-Phase, 4 Wire
Input Voltage:	120 VAC
Input Current:	5A
Frequency:	60 Hz
Output:	0-50 mv (1 ma)
Output Load Resistance:	0-10,000 ohms
Accuracy:	± .5%
Temperature Sensitivity:	± .5% max.
	-20 to 65°C
Response Time (To 99% of Rated Output)	400 msec

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MEDIUM TURBINE GENERATOR
Inspection Point Program

Table of Contents

Westinghouse Electric Corporation
Steam Turbine Division, Philadelphia, Pa. 19113
Printed in USA

June, 1976
New Information

A. Rotor Forgings

The generator forgings are ordered rough-machined with approximately one-eighth (⅛) of an inch material left on all surfaces.

1. At Supplier

The following are approved and/or witnessed by Large Rotating Apparatus Department, Quality Control when performed.

	W	A	R
a. Ladle analysis of chemical properties			X
b. Ultrasonic test (U.T.) for mill information.		X	
c. *Preliminary mechanical properties test after heat treatment.*			X
d. Ultrasonic test in the solid after heat treatment.			X
e. Official tests for mechanical properties – samples are taken from the rotor for:			
1. Tensile test			X
2. Charpy impact test			X
f. Ultrasonic (U.T.) test after boring.			X
g. Dry bore examination.			X
h. Borescopic examination of wet magnetized bore surface.			X
i. *Bore concentricity reading in relation to journal outside diameter.*			X
j. Dimensional checks.			X

2. At Westinghouse

	W	A	R
a. Layout forging for machining. Inspect forging bore and check layout for metal sufficiency.		X	
b. Finish-machined in lathe prior to slotting. The inspections are as follows:			
1. Truth check (Concentricity)			X
2. Surface finish.			X
3. *Dimensional charting at the completion of the lathe operation.*			X
c. Coil slots and additional machining are done at this point. The inspections are as follows:			
1. Set up prior to machining.		X	
2. Surface finish		X	
3. Dimensional charting.			X
d. Rotor shaft end surfaces are subjected to wet magnetic particle test after slotting.			X
e. Rotor body is subjected to ultrasonic testing (U.T.) thru crescent grooves machined in pole *faces where applicable.*			X
f. Final machining quality assurance chart completed.			X

B. Retaining Ring Forgings

The rotor retaining forgings are ordered rough-machined with approximately one-eigth (⅛) of an inch material left on all surfaces.

1. At Supplier

Westinghouse approves test reports for the following operations.

	W	A	R
a. *Ladle analysis for chemical composition.*			X
b. Mechanical properties test.			X
c. Ultrasonic test (U.T.)		X	
d. Dimensional checks.		X	

2. At Westinghouse

	W	A	R
a. Machining operation to suit test tools for hydrostatic test.			
1. Ultrasonic test (U.T.)			X
2. Liquid penetrant (Zyglo) (Where applicable)			X
3. Magnetic particle test (Where applicable)			X
4. Hydrostatic test (Where applicable)			X
5. Final finish machining operation		X	
6. Truth check (concentricity)		X	
7. Surface finish			X
8. Dimensional charting at the completion of boring mill operation			X
9. Liquid penetrant test (Zyglo) (Where applicable)			X
10. Magnetic particle test (Where applicable)			X

C. Blowers

1. Blower Hub and Keeper Forging

	W	A	R
a. At Supplier			
1. Ladle analysis of chemical properties			X
2. Mechanical properties test			X
3. Surface finish		X	
4. Dimensional checks		X	
b. At Westinghouse			
1. Ultrasonic examination			X
2. Dimensional check after finish machining			X
3. Surface finish		X	
4. Magnetic particle test			X

2. Blower Blade Castings

	W	A	R
a. Ladle analysis of chemical properties		X	
b. Mechanical properties test		X	
c. Dimensional check		X	
d. Zyglo examination		X	

D. Rotor Coil Processing

1. At Westinghouse Copper Mill

	W	A	R
a. Chemical properties		X	
b. Mechanical properties		X	
c. Surface finish and visual defects		X	
d. Dimensional check		X	

2. At Westinghouse East Pittsburgh

	W	A	R
a. Raw Material. All incoming copper straps brazing alloys, and insulation are randomly inspected for proper identification, size, shape and surface defects.		X	
b. End Turns. During the manufacture of the end turns, the following inspections are performed:			
1. Dimensions – check on template after edge bending		X	
2. Visual check of taper after milling operation		X	
3. Dimensional check of inner straights		X	
4. Visual inspection of brazed joints			
5. Check shape of end turns on template		X	
6. Check location of vent holes		X	
7. Absence of burrs and nicks		X	
c. Straight Parts		X	
1. Inspection for proper length		X	
2. Inspection for quality of punched holes		X	
3. Proper position and quantity of punched holes		X	

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	W	A	R
4. Absence of burrs and nicks		X	
5. Visual inspection after insulating and baking for insulation adhesion and alignment		X	
6. Proper stenciling of straps to insure correct stacking sequence is maintained		X	
7. Electrical test to locate and eliminate potential shorts between turns		X	
8. After the straight bars and the end turns are brazed together to form "C" sections, a visual inspection is performed on the brazed joints and the completion of the insulating process		X	
E. Generator Details			
There are numerous component parts such as: Wedges, Radial Conductors, Axial Leads, Coupling, Main Lead Cleats, Oil Seals that are fabricated and welded, made from bar stock or cast. Listed are general inspection operations for manufacture of generator components:			
1. Material specification compliance		X	
2. Welding processes and procedures compliances		X	
3. Cleanliness of details		X	
4. Dimensional and detail item checks		X	
5. Non-Destructive tests		X	
6. Stress relief		X	
7. Abrasive cleaning		X	
8. Painting and preservation		X	
F. Rotor Processing			
1. While in the rotor winding section, the following inspections and tests are performed:			
a. Check for proper identification of components		X	
b. Cleanliness of slots and cells		X	
c. Ground test of J-straps			X
d. Check proper support of cells			X
e. Ground test of cells			X
f. Inspect coils for nicks, burrs, etc.		X	
g. Alignment of coils and vent holes			X
h. Dimensional check of each coil to pole face			X
i. Inspection of brazed joints			X
j. Pole balance test			X
k. High potential test			X
2. Rotor assembly			
a. Final machining of shaft ends			
1. Dimensional charting			X
2. Surface finish		X	
3. Truth check (concentricity)			X
b. Assembly of retaining rings, blower hubs and coupling inspections are as follows:			
1. Dimensional checks			X
2. Temperature checks (expansion for assembly)			X
3. Location checks after assembly			X
4. Truth check for concentricity			X
5. Final reaming of coupling holes, spacers, adapters and jack shafts are assembled and charted for size, finish and truth			X
6. Specify gland seal ring size from finished journal diameter			X
7. Pressure test for leaks at radial conductors			X
c. Balance and overspeed			
1. Assemble rotor in rig			X
2. Record slow-roll out at vibration measuring points			X
3. Balance rotor at normal speed, cold and hot			X
4. Overspeed rotor to specified RPM			X
5. Ultrasonic test (U.T.) thru crescent grooves in pole faces where applicable			X
6. Check insulation resistance			X
7. Hi-potential test			X
G. Stator Frames			
1. Fabrication			
a. Ultrasonic inspection of frame ring material before flame cutting where applicable		X	
b. Inspect detail parts for cleanliness prior to welding		X	
c. Check layout			X
d. Visual inspection of all welds		X	
e. Non-Destructive examination of welds where applicable			X
f. Continuous audit of the various operations for conformance to Process Specification.		X	
g. Dimensional check			X
h. Inspect gas tight welds where applicable			X
i. Approve final abrasive cleaning operation			X
j. Inspect frame cleanliness and approve prime painting operation for conformance to specification			X
2. Stator Frame Machining			
Stator frame is machined complete on special N/C machines. Inspection operations are as follows:			
a. Verify correct set up on machine			X
b. Complete dimensional check (charted)			X
c. Check for cleanliness			X
H. Cores			
1. Punchings			
a. Incoming raw material			
1. Dimensional checks		X	
2. Check of suppliers material reports for conformance to specification		X	
3. Electrical checks (core loss and permeability) – one out of every three coils of raw material		X	
b. Surface coating of core material			
1. Check for acidity		X	
c. Inspection prior to production blanking			
1. Complete dimensional check of inspection gage		X	
2. Complete dimensional check of punchings individually and on checking gage		X	
d. Inspection during production run			
1. Check first pieces to drawing requirements and to gage, and sign for approval of run		X	
2. Regular patrol inspections are made during production runs		X	
e. Coating punchings			
1. Inspection by sampling and visual inspection for conformance to Finish and Process Specifications. Results are recorded.		X	

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Item	W	A	R
a. Resistivity		X	
b. Flatness		X	
c. Acidity		X	
d. Coating thickness		X	
2. Fingerplates			
a. Ladle analysis for chemical properties		X	
b. Check for correct pouring temperatures		X	
c. Check for proper heat treating methods		X	
d. Radiographic examination (if applicable)		X	
e. Visual examination for cracks and porosity		X	
f. Ductility test		X	
g. Dimensional check		X	
h. Visual check of welds		X	
3. Stator Core Assembly			
a. Assure cleanliness of frame			X
b. Inspect internal piping			X
c. Assure correct set up on parallels			X
d. Check centerpost setting			X
e. Assure setting of building bolts			X
f. Check welding of building bolts			X
g. Assure cleanliness prior to painting			X
h. Check for proper fingerplate setting			X
i. Check at every press			
1. Level and length			X
2. Tightness			X
3. For damaged iron, vent plates, etc.			X
4. Slot clearance			X
j. Ground test all thermocouples			X
k. Inspect insulated thru bolts			
1. Length			X
2. Insulation			X
3. Threads			X
4. Non-magnetic properties			X
5. Assembly			X
6. Proper Torque			X
l. Check total length of core			X
m. Mic bore for proper dimensions			X
n. Ground test insulated thru bolts			X
I. Stator Coils			
During the manufacture of these coils, the following inspections and tests are done:			
1. Copper Wire – Inspect for the following properties:			
a. Insulated and bare wire size		X	
b. Proper insulating material		X	
c. Degree of cure on insulation		X	
2. Coil Assembly – Inspect as follows:			
a. Cut lengths of wire dimensionally		X	
b. Check for proper cure of insulation		X	
3. Coil Former Set Up			
a. Inspect for shape and dimensions		X	
4. Formed Coils			
a. Inspect all coils for width and depth dimensions and surface defects		X	
5. Insulated Coils			
a. Inspect for proper application of groundwall insulation		X	
b. Check width and depth dimensions		X	

Item	W	A	R
6. Resin Impregnated Coils			
a. Inspect all gages and process charts on ovens and tanks to insure proper processing		X	
7. Coil Press			
a. Inspect all press set ups for dimensions		X	
8. Pressed Coil			
a. Inspect first coil of each item for shape and dimensions		X	
9. Finished Coil			
Inspect each finished coil as follows			
a. Surface defects		X	
b. Proper application of varnish		X	
c. Tinned leads		X	
d. Width and depth dimensions		X	
e. Approve final short circuit and high-potential tests		X	
J. Stator Processing			
1. Stator Winding			
a. Check core for damaged iron prior to winding		X	
b. Check winding layout and layout of RTD's			X
c. Check assembly of coil supports and braces			X
d. Check bottom coil assembly			X
e. Ground test bottom coils			X
f. Check fitting of strain blocks			X
g. Assembly of top coils			X
h. Wedge assembly			X
i. Ground test all windings after wedging operations			X
j. Test of RTD's			X
k. Inspect soldered series joints			X
l. Short circuit test between groups of coils prior to phase connections			X
m. Inspect soldered cross-overs and parallel rings			X
n. Insulation of series connections			X
o. Phase to Phase hi-pot			X
p. Phase Balance test			X
q. Final check for cleanliness			X
2. Machine Assembly			
Since the following is meant to apply to both air cooled and hydrogen cooled generators, several of the inspections may not be applicable.			
a. Check insulation of piping in frame base			X
b. Check doweling of bearing brackets			X
c. Check assembly of air baffles			X
d. Meggar rotor before assembly			X
e. Measure insulation resistance of bearing seats			X
f. Check assembly of bearings and alignment of piping			X
g. Check rotor endplay			X
h. Check air gap			X
i. Check assembly of gland seal brackets and rings			X
j. Check assembly of oil seals			X
k. Check assembly of blower shrouds			X
l. Oil flush and inspection of oil system and bottom half of bearings			X
m. Check assembly and cleanliness at air coolers			X
n. Check neutral ground lead fit			X
o. Check assembly of coupling to exciter			X
p. Test per customer specifications			X

Item	W	A	R
K. Bearing Brackets			
1. Fabrication			
Quality Control performs the following inspections during fabrication of bearing brackets.			
a. Inspect detail parts for cleanliness prior to welding		X	
b. Layout		X	
c. Dimensional checks		X	
d. Continuous audit of the various operations for conformance to Process Specifications		X	
e. Inspect gas tight welds		X	
f. Approve final abrasive cleaning, inspect for cleanliness and approve prime painting operation		X	
2. Machining			
a. Horizontal joint machining – Quality Control checks joint flatness and surface finish		X	
b. Drilling Operation – Quality Control checks and records hole location and size		X	
c. Boring Mill Operation – Quality Control checks and records diameters, surface finish, and finished axial dimensions.		X	
d. Drilling Operation – Quality Control inspects proper use of fixtures and threads of tapped holes		X	
e. Final Inspection – Quality Control checks and records finish dimensions		X	
f. Gas Leakage Test – Quality Control witnesses and verifies compliance of air tests to engineering specifications		X	
3. Bearing Processing			
a. Bearing babbitt is analyzed by lot number for proper chemical composition by the Westinghouse non-ferrous foundry where it is produced, prior to shipment to the bearing manufacturing department. Quality Control personnel perform the analysis and maintain records of the results			X
b. Weekly babbitt pot samples from the bearing manufacturing department are analyzed for proper chemical composition by the Westinghouse Material & Process Laboratory. A record of these test results are maintained by the Quality Control Department.			X
c. Turbine Generator bearings are ultrasonically inspected to assure complete bonding of babbitt to bearing shell.		X	
d. Before and during machining, bearing castings are inspected for flaws. Non-destructive test methods are employed as required.		X	
e. Final dimensional check after machining		X	
f. After final machining and cleaning, the finished bearing is inspected to determine that it is clean and adequately protected for future handling.		X	
L. Raw Materials			
1. The following materials are released to manufacturing with acceptance based on the supplier's certified test report. Periodic checks are made by Westinghouse to verify these test reports on some items.			

Item	W	A	R
a. All plates (ferrous and non-ferrous)		X	
b. Bar products		X	
c. Miscellaneous forgings		X	
d. Pipe and pipe fittings		X	
e. Hardware		X	
f. Components		X	
g. Tubing		X	
M. Generator Cooling and Lubrication			
There are several major components which are manufactured to aid in the cooling of the generator. Inspections and tests are categorized as follows.			
1. Seal Oil System			
a. The fabrication of seal oil systems is subcontracted			X
b. Prior to shipping to the jobsite, each unit is given a visual inspection and a quality assurance data sheet is completed.			X
2. Hydrogen Control System			
a. Quality Control inspects the assembled unit for conformance to wiring and piping diagrams and specifications.			X
b. Quality Control approves the results of the following items.			
1. Dielectric test of insulation			X
2. Wiring continuity tests			X
3. Leak tests of piping			X
4. Function of the alarm system			X
3. Air Coolers			
The following Q.A. requirements are applicable to all cooler types.			
a. Verification of proper material for cooler tubes		X	
b. Hydrostatic test		X	
c. Dimension check to drawing requirements.		X	
4. Gland Seal and Brackets			
The following tests and inspections are performed during the manufacture of gland seal assemblies:			
a. Ultrasonic test of plates after burnout		X	
b. Custom machining instructions to actual shaft journal size		X	
c. Dimensional check		X	
d. Leak test of welds		X	
e. Final check for identification, burrs, cleanliness		X	
5. Piping			
During the manufacture and assembly of piping for medium turbine generators, the following tests and inspections are performed.			
a. Inspection during fabrication for shape and dimensions		X	
b. Inspection of weld integrities		X	
c. Verification of pickling operation prior to assembly		X	
d. Inspection of fit up during assembly		X	
e. Oil flush during assembly (Oil piping only)		X	
6. Baffles			
a. Pour analysis (If applicable)		X	
b. Dimensional check at completion of machining		X	
c. Zyglo examination (If applicable)		X	

	W	A	R
N. Welder Qualification			
The East Pittsburgh Divisions operate a welding school to train new welders and to provide additional training for experienced welders as required. Before performing any production welding, a welder must first be qualified at the East Pittsburgh welding school for the welding process to be used.			
Qualification of welders is done in accordance with requirements and tests set forth in MIL-STD-248A (Ships). These requirements and tests are considered minimum for any welding whether military or commercial. The welding school maintains and circulates a current record of all qualified welders. The Quality Control Department performs a continuous audit of this record for assurance that only qualified welders perform production welding. The Quality Control Department also maintains records which are used to verify a welder's continuing proficiency in the processes for which he is qualified.		X	
O. NDT Qualification			
1. The LRA Division of Westinghouse maintains a group of technicians who are assigned to perform non-destructive testing.		X	
2. These technicians have been trained in Westinghouse-sponsored schools or in schools sponsored by equipment suppliers. Initial qualification is to the Society of Non-destructive Testing Specifications SNT-TC-1-A.		X	
P. Inspection Gage Control Program			
All critical gages and measuring devices assigned to Quality Control Inspection Stations, as well as any personal gages used for inspection purposes, are checked periodically for accuracy by comparison with standards whose calibration is traceable to the Bureau of Standards. The checking is performed by highly qualified personnel in the W-5 Gage Laboratory, a temperature and humidity-controlled room. The maintenance of the system is assisted through the use of a computer to assure timely tool recall as well as an accurate tool status inventory.		X	

APPENDIX 9.1-A

NET ENERGY ANALYSIS

A. INTRODUCTION

This section presents the calculations for net energy balance of an Ocean Thermal Energy conversion (OTEC) power plant, based on Westinghouse's design.

The concept of net energy analysis is motivated by a growing concern that an energy supply system based on new energy technologies should be evaluated not only in terms of their dollar economics but also in terms of actual energy economics. Recent congressional action has mandated that net energy criteria be utilized as one of the criteria in evaluating proposed energy technologies. Specifically, the federal non-nuclear Energy Research and Development Act of 1974, PL 93-577 5(a)(5) stipulates that "Potential for production of net energy by the proposed technology at the state of commercial application shall be analyzed and considered in evaluating proposals."

The PL 93-577 however, does not define net energy but the following definition is most commonly used by researchers in this field. "Net energy is the amount of energy that remains for consumer use after the energy costs of finding, producing, upgrading, and delivering the energy have been accounted for."

B. PREVIOUS STUDIES IN OTEC

The Oregon Energy Office [1] report is apparently the first published work for net energy analysis of an OTEC system. The Lockheed Missiles and Space Company (LMSC) [2] applied the oregon approach to assess the net energy of its OTEC power system. The Institute for Energy Analysis (IEA) [3] performed a comprehensive net energy analysis of an OTEC system designed by LMSC. The IEA approach was based on the use of energy coefficients in Btu per ton for various materials and components used in an OTEC power system.

C. THE W-OTEC SYSTEM

A net energy analysis was performed on a 50 MWe power module of the W-OTEC system. This system was segregated into the following major components.

1. A surface platform/ship designated as the basic hull (concrete or steel), and anchor system.
2. A power module consisting of heat exchangers, turbine/generators, pumps, ammonia piping and other miscellaneous components.
3. Cold water piping system
4. Other components

Table 1 shows the mass in short tons for the above components. The mass of the platform/ship was prorated down from a 400 MWe plant ship while the masses of the other components were obtained from the corresponding masses of a 10 MWe module, by multiplying by 5 (except ammonia which was calculated separately).

It is observed that the total weight of the OTEC plant with steel hull amounts to 29,990 short tons, out of which fabricated steel accounts for 23,623 short tons (about 78.8 percent). If the hull were that of concrete, the plant weight amounts to 79,933 short tons. Reinforced concrete constitutes 63,427 short tons (79.35 percent) and fabricated steel accounts for 10,139 short tons (12.7 percent).

D. THE METHODOLOGY

The method employed for energy computations uses primary* energy coefficients (Btu/ton) and the masses of the OTEC power plant components. These energy intensity coefficients were obtained from the published reports of IEA [3] Battelle Columbus Laboratories [4], [5] and Bullard et. al. [6]. These energy coefficients were computed from the input-out analysis of U.S. economy consisting of 357 production sectors in 1967 and process analysis of specific materials or components.

E. THE ENERGY INPUT CALCULATIONS

The OTEC power system under study consists essentially of the following distinct materials and components (from Table 1)

1. Reinforced concrete (optional)
2. Fabricated Steel Products
3. Stainless Steel Products
4. Fabricated Titanium Products
5. Manufactured equipment
6. Ammonia
7. Nitrogen

The energy intensity coefficients of all the above products were taken from the published sources described earlier with the exception of nitrogen. The energy coefficient of nitrogen was estimated from the process and cost data supplied by Linde Air Products (Division of Union Carbide Corp.) and Research Corp.

Table 2 shows the energy coefficients, total energy, and annualized input energy from the components considered in the Westinghouse OTEC 50 MWe power plant system. Annualized energy inputs were obtained from the total input energy of each major component by dividing the latter by the expected service life of the individual components.

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*Primary energy is defined as the sum of coal, crude oil plus the fossil energy equivalent of the hydro and nuclear energy (used to produce electricity in 1967) for electrical energy used in the product.

The expected service life of the OTEC system components were assumed as follows: Concrete products 100 years, fabricated steel products 50 years, and manufactured equipment 40 years. It was assumed* that ammonia leak would be less than 3 percent per year and that the nitrogen used for purging the system would have to be 100 percent replaced after each purge. A total of six purges were assumed per year.

The IEA [3] report used a 20 percent markup for the facility construction for the platform, power system and cold water pipe fabrication. The same markup was used in the present study.

The economic analysis issued separately estimates, the annual operating and maintenance (O&M) costs at $550,000 per year (1978 dollars). These costs include the personnel, fringes, material, supplies and contingency. These costs were deflated to 1967 and energy coefficients Btu per dollar from Bullard et. al. [6] were used to estimate the energy equivalents of O&M dollar costs. This was found to be, 30,000 million Btu per year.

The energy required for towing the ship to the anchoring site, as well as the energy required in moving the parts to and from the shore both during construction and for maintenance over the service life of the plant are believed to be relatively small and hence not included in the computation of the input energy.

The total primary energy input in millions of Btu was found to be 110,026 per year based on concrete hull and 143,863 based on a steel hull. Table 2 also shows a breakdown of the total primary energy into electrical energy and thermal energy. The electrical energy component was obtained by using a conversion factor of 13,850** Btu per net kWh. The total electrical input was found to be 40 percent for the concrete hull and 37 percent for the steel hull based system.

F. Net Energy Output

The OTEC system gross output is bus bar electrical estimated at 70 MWe. The following are the auxiliary power requirements (from Westinghouse Electric Corp.).

1. Cold Water Pump	10 MWe
2. Warm Water Pump	6.6 MWe
3. Cycle Feed Pump	1.5 MWe
4. Recycle Pump	0.1 MWe
5. Chlorination	1.2 MWe
6. Hotel Loads	0.5 MWe
Total auxiliary power required	19.9 MWe

*These assumptions were supplied by Westinghouse.
**From Bullard et al. [6], average of all fossil plants operating in U.S. in 1967, 13850 Btu represents the total direct and indirect energy required to deliver 1 kWh to customers.

The net bus bar output available is hence 79 MWe, less 19.9 MWe or 50.1 MWe. The Westinghouse report [7] estimates the OTEC system availability at 90 percent. This high availability is considered possible because of moderate temperature and pressure, and use of proven materials and design techniques.

A 90 percent availability would generate 395 million kWh per year. This is equivalent to 1,348,000 million Btus per year.

G. Summary and Conclusions

The annualized electrical energy inputs are 53,121 x 10^6 Btu and thermal energy inputs are 90.742 x 10^6 Btu (for steel hull). The total inputs are thus 143,863 x 10^6 Btu. The bus bar output of electrical energy is estimated to be 1,348,000 x 10^6 Btu. Hence, it is observed that the net annual electrical energy output of the OTEC power plant is 9.37 times (for steel hull) the annualized energy inputs during the construction and operation period (over the service life of the components). The net energy ratio for concrete hull is 12-25. The overall heat rate measured by the ratio of thermal energy inputs (Btu) to the net electrical energy output (kWh)amounts to 232 Btu/kWh for steel hull (168 Btu/kWh for concrete hull).

The accuracy of energy intensity coefficients has been judged as ± 20 percent to ± 30 percent. This is because of inherent difficulty with the input-output method referred to before. There are a finite number of productions sectors (e.g. 357) and the problem is to locate an appropriate sector to represent a particular product in question. This product may not be adequately represented by the average product of the selected sector. Other limitations of the input-output method are discussed in a paper by Bullard and Herendeen [8].

Hence, if the total input energy is increased by 30 percent to allow for any estimating error the net energy output to input ratio decreases to 7.20 for steel hull and 9.4 for concrete hull based system.

It is concluded that the OTEC system represents a highly favorable net energy balance. Even after allowing for a reasonably large error margin, the energy delivered is more than seven times the total direct and indirect input energy.

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TABLE 1

50 MWe OTEC POWER PLANT - MASS OF MATERIALS

SHORT TONS

COMPONENT	FABRICATED STEEL	FABRICATED TITANIUM	TURBINE/ PUMP	MHE (1)	MOTOR/ GENERATOR	TRANSFORMER	SWITCHGEAR	OTHER
1. Platform/Ship								
a. Concrete, or								63,427 (2)
b. Steel	13,484							
c. Deck House and Anchor	3,087							
2. Power Module								
a. Condenser	1,363	787						
b. Evaporator	944	509						
c. Turbine/Generator			82		290			
d. Lube Oil System	35							
e. Ammonia Pumps			155					
f. Ammonia Pipes and Tanks	1,185							
g. Ammonia Valves	595							
h. Sea Pumps			675			50		
i. Sea Screens								460 (3)
j. Amertap								220 (3)
k. Diesel System	5				505			
l. Nitrogen Tank	75							
m. Gantry				600				
n. Cooling Water	5							
o. Power Conditions							665	
p. Wiring								65 (4)
3. Cold Water Pipe								
Pipe	2,845							
4. Other Components								
a. Ammonia								1,156
b. Nitrogen								148
5. TOTAL	23,623	1,296	912	600	795	50	665	65,476

(1) Mechanical heavy equipment

(2) Reinforced concrete

(3) Stainless steel

(4) Naval wiring material

Source: Westinghouse Electric Corporation
Power Generation Division

9.1-A

TABLE 2

WESTINGHOUSE OTEC POWER SYSTEM ENERGY ANALYSIS

A: INPUT ENERGY PLANT COMPONENTS	MASS SHORT TONS	PRIMARY ENERGY COEFFICIENT 10^6 Btu/ton	TOTAL PRIMARY ENERGY 10^6 Btu	SERVICE LIFE (YEARS)	ANNUALIZED ENERGY INPUTS ELECTRICAL 10^6 Btu	THERMAL 10^6 Btu	TOTAL PRIMARY 10^6 Btu
1. Platform							
a. Concrete Hull	63,427	2.74	173,790	100	360	1,378	1,738
or							
Steel Hull	13,484	111	1,496,724	50	7,880	22,055	29,935
b. Deck House and Anchor	3,087	111	342,657	50	1,804	5,049	6,853
c. Construction	(20% of sub-total)						
Concrete Hull			171,821	100	433	1,285	1,718
Steel Hull			367,876	50	1,937	5,421	7,358
Subtotal							
Concrete Hull			688,268		2,597	7,712	10,309
Steel Hull			2,207,257		11,621	32,525	44,146
2. Power System							
a. Steel Components	4,207	111	466,977	40	3,074	8,600	11,674
b. Titanium Components	1,296	626	811,296	40	16,915	3,367	20,282
c. Equipment							
Pumps/Compressors	912	110	100,320	40	842	1,666	2,508
Gantry	600	114	68,400	40	542	1,168	1,710
Transformers	50	85	4,250	40	38	68	106
Switchgear	665	252	167,580	40	1,660	2,530	4,190
Motor/Generators	795	131	104,145	40	944	1,660	2,604
Wiring Devices	65	113	7,345	40	85	99	184
Sea Screens and Amertap	680	111	75,480	40	497	1,390	1,887
d. Construction	(20% of steel & equipment)		198,900	40	1,094	3,879	4,973
Subtotal			2,004,693		25,691	24,427	50,118
3. Cold Water Pipe							
a. Steel	2,845	111	315,795	50	1,663	4,653	6,316
b. Fabrication	(20% of steel)		63,160	50	227	1,036	1,263
Subtotal			378,955		1,890	5,689	7,579
4. Other Components							
a. Ammonia	1,156	39	45,084	33	-	1,366	1,366
b. Nitrogen	148	12	1,776	0.17	7,319	3,335	10,654
Subtotal			46,860		7,319	4,701	12,020
5. Operation & Maintenance							
O&M Staff, Materials and Supplies					6,600	23,400	30,000
Total Input Energy							
a. Concrete Hull System					44,097	65,929	110,026
b. Steel Hull System					53,121	90,742	143,863
B: OUTPUT ENERGY							
1. Gross Output Power	70 MWe						
Less Auxiliaries	19.9 MWe						
Net Output Power	50.1 MWe						

2. Output energy per year (90%) availability = 395 x 10^6 kWh
= 1,348,000 x 10^6 Btu

3. Output energy to input energy ratio

Concrete Hull System = 12.25

Steel Hull System = 9.37

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APPENDIX 9.1-B

BUS BAR COST OF ELECTRICITY

A. Introduction

This section presents the economic calculations based on a set of financial assumptions and determines the bus bar costs of electricity generated from the 50 MWe Ocean Thermal Energy Conversion Power System. The financial assumptions are representative of the current market conditions.

B. The Method

The bus bar cost of electricity was calculated using utility oriented book return-on-equity method. In this method the total project equity is determined for each year of the plant's assumed useful life by deducting cumulative depreciation of plant and equipment, outstanding long-term debt, and preferred stock from the gross capital investment in the project. Using an assumed required rate of return, the required return on equity was then calculated. Annual revenue requirements were then obtained by adding operating, maintenance and overhead expenses; capital charges; and taxes to the required return on equity and dividend on preferred stock. The annual production volume of electricity was calculated using the rated output of the plant, less auxiliary and hotel loads, and an assumed capacity factor. Finally, the bus bar cost was found by dividing the required revenues by the production volume. The detailed procedure is shown in Figure A.

C. **The Assumptions**

The bus bar cost for the first and last year, as well as the arithmetic average of the annual bus bar cost over the 30-year life were calculated using the following parameters:

1. Direct Capital Cost Per 50 MWe Module (1978 $):

Power Module	$68,136,000
Start-Up Power Equipment	1,876,000
Hull	15,735,000
Cold Water Pipe	2,600,000
Plant Erection	2,800,000
Total	$91,147,000*

2. Contingency (10%): $ 9,115,000
3. Escalation (8%/ year): $11,452,000
4. Interest During Construction (10%/ year): 16,222,000
5. Working Capital (20 percent of annual fixed charges**): 366,000
6. Financial Parameters: 50-percent debt at 10-1/2 percent for 20 years, 15 percent preferred stock at 13-percent dividend rate, 35-percent common stock at 15 percent return on equity after taxes

* Per Westinghouse estimate dated August 18, 1978

** O&M and insurance charges

7. Annual Operating and Maintenance Costs: $550,000**

8. Startup Costs (four months of annual operating and maintenance): $183,000

9. Insurance Costs (1 percent of capital costs): $1,281,000

10. Depreciation: 15-percent salvage value, straight line over 30-year life cycle: $3,630,000

11. Income Taxes: 48 percent of equity return and preferred stock dividends.

12. Investment Tax Credit (10 percent of Capital Expenditures, amortized over plant life and converted to pretax equivalent): $716,000

13. Annual Power Generation (50,000 kW x 8760 hrs x .9 capacity factor): 390,000,000 kWh

** Wages for 5 men team (prorated from 40 men team for 400 MWe Module): $125,000

Fringes (33 1/3 percent of Wages):	42,000	
Materials and Supplies (40 percent of wages):	50,000	
Major Maintenance (Westinghouse Estimate):	165,000	
Subtotal O&M:	$382,000	
Escalation at 8 percent per year over three years:		$ 99,000
Subtotal Escalated O&M:		$481,000
Contingency at 15 percent of Escalated Subtotal		$ 69,000
Total O&M Costs:		$550,000

D. Results

Figure A shows that, for the first year of operation, annual revenue requirements are $28,573,000 or 73.3 mills per kilowatt-hour. Similar calculations result in a kilowatt-hour cost of 24.8 mills in the last year. The arithmetic average over the assumed 30-year life is 51.6 mills per kilowatt-hour.

E. Discussion

The after tax return on common equity of 15% and the preferred stock dividend of 13% were assumed as probable returns in mid eighties. However, the present returns allowed by the public utility commissioners range as low as 13% for common equity.

The current dividend on preferred stock is around 11% for utility companies. If these lower rates are used, the first year mill rate reduces to 67 mills per KWH while the life cycle average rate becomes 47 mills.

Figure A

Annual Revenue Requirement - 1st Year (1981 $)

Direct Capital Cost	$ 91,147,000
Contingency	9,115,000
Escalation	11,452,000
Capital Expenditures	111,714,000
Interest During Construction	16,222,000
Startup Costs	183,000
Total Capital Cost	128,119,000
Working Capital	366,000
Gross Capital Investment	128,485,000
Less: Cumulative Depreciation	3,630,000
Outstanding Long-Term Debt	63,003,000
Preferred Stock	19,218,000
Total Project Equity	$ 42,634,000

Operating & Maintenance	$ 550,000
Insurance	1,281,000
Depreciation	3,630,000
Interest	6,726,000
Preferred Stock Dividends	2,498,000
Return on Equity	6,395,000
Income Tax	8,209,000
Investment Tax Credit	(716,000)
Required Revenue	28,573,000
Unit Price (mills/kilowatt-hour)	73.3

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APPENDIX 10-A

TECHNICAL SPECIFICATIONS

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OTEC TECHNICAL SPECIFICATION

Ammonia Feed Pump and Ammonia Recirculation Pump

Introduction

The object of this specification is to define the design parameters material selections and the various constraints of the ammonia feed and ammonia recirculation pumps. The ammonia feed pump will transfer liquid ammonia from the condenser to the evaporator via NH^3 manifold and to storage tanks. The ammonia recirculation pump is capable of transferring ammonia from the evaporator and discharging it either back to the evaporator or to the storage tanks.

Component Description

Both the feed and recirculation pumps will be standard industrial vertical turbine type pumps. These pumps will be furnished with vertical motor drives mounted on a fabricated steel discharge head/base plate which is fastened to the hull structure. The motor is contained in a totally enclosed fan cooled (TEFC) enclosure. The ammonia feed pump will require a 600 hp motor supplied by a three (3) phase, 60 cycle, 6900 volt power source. The recirculation pump will require a 70 hp motor supplied by a 3 phase, 60 cycle, 480 volt power source. Each motor is coupled to a vertical line shaft which extends down to the impeller/bowl assembly. The line shafts are located within sections of steel flanged column pipe which serves both as the pump discharge line and the shaft housing. Carbon steel will be used for the lineshaft and couplings. Cast iron or steel will be employed for the bearing retainers and graphalloy will be used for the lineshaft bearings. The column pipe will be connected to a barrel section. The barrel extends from the bottom of the platform vessel in order to satisfy the net positive suction head requirements of the pumps. Pumps suction lines will also extend from the respective heat exchangers and will be connected to the barrel suction nozzle. The bowl assembly is housed in the barrel and consists of cast iron bowls, impellers and stainless steel wear rings and bowl shaft. Both pumps will be fitted with mechanical seals to ensure zero leakage.

Codes and Standards

The design, materials, fabrication, inspection and testing of the ammonia pumps described herein will be governed by the following applicable codes and standards.

a. American National Standards Institute (ANSI)

b. American Society for Testing and Materials (ASTM)

c. American Society of Mechanical Engineers (ASME)

d. American Welding Society (AWS)

e. Hydraulic Institute (HI)

f. Code of Federal Regulations (CFR)

g. Occupational Safety and Health Administration (OSHA)

h. National Electrical Manfacturers Association (NEMA)

i. Institute of Electrical and Electronics Engineers (IEEE)

DESIGN AND OPERATING CONDITIONS

AMMONIA FEED PUMP	10 MWe
Liquid Pumped	Anhydrous Ammonia
Capacity (gpm)	10,494
Temperature (F)	50
Specific Gravity	0.70
Suction Pressure Approx. (psia)	89
Discharge Pressure Approx. (psia)	130
Total Dynamic Head (ft)	239
Number of Pumps Required	1
Brake Horsepower @ Design Point	533
Pump Efficiency @ Design Point	83%
Motor Required (hp)	600
Power Supplied to Motor	3-phase, 60 cycle, 6900 volts
Required NPSH (ft)	20

MATERIALS

Lineshaft and Couplings	Carbon Steel
Bearing Retainers	Cast Iron or Steel
Lineshaft Bearings	Graphalloy

<u>AMMONIA RECIRCULATION PUMP</u>	<u>10 MWe</u>
Liquid Pumped	Anhydrous Ammonia
Capacity (gpm)	3,954
Temperature (F)	70
Specific Gravity	0.70
Suction Pressure Approx. (psia)	128
Discharge Pressure Approx. (psia)	130
Total Dynamic Head (ft)	42
Number of Pumps Required	1
Brake Horsepower at Design Point	61.3
Pump Efficiency at Design Point	82%
Speed (rpm)	1180
Motor Required (hp)	70
Power Supplied to Motor	3-phase, 60 cycle, 480 volt
Required NPSH (ft)	16
<u>Materials</u>	
Lineshaft and Couplings	Carbon Steel
Bearings Retainers	Cast Iron or Steel
Lineshaft Bearings	Graphalloy

OTEC TECHNICAL SPECIFICATION

Ammonia Piping

Introduction

This specification addresses the design requirements and other related details of the OTEC power module ammonia piping system. A network of large diameter pipe is utilized to connect the various components in the power cycle. The pipe routing between components along with the orientation of components was studied in order to minimize losses in the ammonia piping and also in the seawater systems. The piping system is designed to contain the working substance, anhydrous ammonia, in both the gaseous and liquid phase. The piping system will also be designed to withstand all internal normal operating temperatures and pressures.

System Description

The ammonia power cycle piping will be similar to the class of pipe used in the ammonia refrigeration industry. It will be welded steel piping such as ASTM A-63 or A-106. The piping will be extremely important as contamination will be a source of system trouble. Contamination may reduce heat transfer in the evaporator and condenser, cause excessive system pressure drop and increase horsepower requirements. Overall, this will effect the OTEC System efficiency and net generating capacity. To ensure the cleanliness of the ammonia piping system, standard pipe such as A-63 or A-106 must be pickled in an acid solution to remove all foreign matter, especially the coating of varnish applied at the steel mills for protection in storage. After pickling, the piping must be rinsed and a light coat of oil applied to prevent rusting. During welding (fabrication/installation) of the ammonia piping, nitrogen gas will be utilized to displace the surrounding air and prevent oxidation and scale formation.

The following is an estimated Ammonia Piping Bill of materials which will be required for a 10 MWe OTEC power cycle:

QTY	LINE DESIGNATION	APPROX. DIAMETER (IN.)	APPROX. THICKNESS (IN.)	APPROX. LENGTH (FT)	FITTINGS
2	Evaporator Outlet to Turbine	62	.750	16	2-45° Elbow
		62	.750	95	2-90° Elbow
		62	.750	3	
1	Condenser Hot Well to Feed Pump	50	.750	39	1-90° Elbow
		30	.500	2	1-Reducer 50"-30"
1	Evaporator Drain Well to Ammonia Recirc. Pump	50	.750	27	1-90° Elbow
		30	.500	4	1-50"x30" Reducer
2	Turbine Bypass	30	.500	26	2-90° Elbows
		30	.500	3	2-45° Elbows
		(Two) 20	.375	5	1-Tee
		(Two) 20	.375	8	2-Gate Valves
					2-30"x20" Reducers
1	Feed Pump to Storage Tank	28	.500	10	5 Tees
		28	.500	16	1-90° Elbow
		(Two) 28	.500	1.5	2-Angle Plug Valves
		(Two) 28	.500	9	1-Check Valve
		(Two) 28	.500	3	
1	Recirc. Pump to Storage Tanks	28	.500	10	5 Tees
		28	.500	16	1-90° Elbow
		(Two) 28	.500	1.5	2-Angle Plug Valves
		(Two) 28	.500	9	1-Check Valve
		(Two) 28	.500	3	
1	Feed Pump Disch. to NH3 Manifold	28	.500	33	1-28"x20" reducer
		28	.500	7	2-45° Elbows
		28	.500	16	1-Tee
		(Four) 14	.375	1.5	4-Angle Plug Valves
		(Four) 14	.375	6	
1	Feed Pump Disch. to Condenser	(Two) 10	.307	2	1-Angle Plug Valve
		10	.307	1	4-90° Elbows
		10	.307	5	1-45° Elbows
		10	.307	29	
		10	.307	16	
		10	.307	8	

QTY	LINE DESIGNATION	APPROX. DIAMETER (IN.)	APPROX. THICKNESS (IN.)	APPROX. LENGTH (FT)	FITTINGS
1	Recirc. Pump Disch. to Condenser	10	.307	3	4-90° Elbows
		10	.307	1	1-Orifice
		10	.307	19	1-45° Elbow
		10	.307	10	
		10	.307	2	
		10	.307	8	
1	Recirc. Pump Disch. to Evaporator	(Four) 14	.375	1	2-90° Elbow
		14	.375	58	1-Tee
		(Two) 10	.307	6	2-14"x"10" Reducers
		(Two) 10	.307	8	2-Angle Plug Valves 2-45° Elbows
1	Recirc. Pump Disch. Line to NH3 Manifold	28	.500	9	1-28"x20 reducer
		28	.500	7	2-45° Elbow
		28	.500	16	4-Check Valves
		(Four) 10	.307	1.5	4-Angle Plug Valves
		(Eight) 10	.307	2	1-Tee
1	From NH3 Manifold to Evaporator	(Three) 24	.375	10	3-Orifice Flanges
1	From Storage Tanks to Condenser	28	.500	39	1-Angle Plug Valve
		28	.500	50	4-90° Elbow
		28	.500	9	1-Gate Valve
		28	.500	4	1-Tee
		28	.500	11	
		28	.500	7	
		28	.500	3	
1	From Storage Tanks to Pressure Tank	28	.500	2	1-Gate Valve 1-90° Elbow
1	From Compressor to Pressure Tank	NOT SHOWN ON PIPING COMPOSITES Approx. 34' x 3" diameter			1-Gate Valve 1-90° Elbow
1	Storage Tank(s) Liquid NH 3 Manifold	(Three) 28	.500	19	10-90° Elbows
		(Two) 28	.500	8	4-Tees
		(Two) 28	.500	3	4-Gate Valves
		(Two) 28	.500	6	

Codes and Standards

The fabrication, materials, certification and testing requirements of the OTEC power system ammonia piping will be in accordance with the following applicable codes, legislations, regulations and standards:

a. American Society of Mechanical Engineers (ASME)

b. American National Standards Institute (ANSI)

c. American Society for Testing and Materials (ASTM)

d. American Petroleum Institute (API)

e. American Welding Society (AWS)

f. Pipe Fabrication Institute (PFI)

g. Code of Federal Regulations (CFR)

h. Occupational Safety and Health Act (OSHA)

Design and Operating Conditions

Design Pressure (psia)
Design Temperature (F)
Operating Pressure (psia)
Operating Temperature (F)

Materials

Pipe - ASTM A-53 or A-106

ASTM A-587 is also acceptable. This class of pipe is furnished with a blue annealed finish which retards oxidation. A rust inhibitor and capped ends are also available with A-587.

10-A

OTEC TECHNICAL SPECIFICATION

Ammonia Storage Tanks, Pressure Tank and Ammonia Compressor

Introduction

This specification covers design requirements and related details of the Ammonia Storage Tanks, Pressure Tank and the ammonia compressor. The tanks are used for storage, makeup and purification of the cycle fluid, ammonia. The ammonia compressor is used to transfer ammonia vapor from storage or the power loop to the Pressure Tank for Purification.

System Description

The Ammonia Storage System will consist of pressure vessels containing sufficient capacity for storage of the total volume requirements of ammonia for a 10 MWe module. The total liquid requirement of ammonia, including makeup, is estimated at 500,000 lbs. Based on the assumption that the filling density of the storage tanks is approximately 56 percent, the corresponding total volume requirement is 15,000 cu ft.

This total storage volume will be satisfied by using four (4) horizontal 30,000 gallon vessels to suit requirements of the plant layout. The Ammonia Storage Tanks will be provided with a cooling capability in order to control vapor pressure within design limits. The cooling will be accomplished by means of internal cooling coils using component cooling water. Each vessel will have individual inlet, outlet, vent, drain and relief connections. 16 gpm of CCW will circulate through approximately 140 ft of coil per tank and will maintain a fluid temperature of 75 F.

The Ammonia Pressure Tank will be used to separate noncondensibles and nitrogen from the nitrogen-ammonia gas mixture during the on-line purging operations and to accumulate a charge of pressurized liquid ammonia for controlled injection into the cycle. A single pressure vessel equipped with a diaphragm separator will be used. The tank will also have a connection with a ball float to allow venting of noncondensibles and nitrogen from under the diaphragm separator. Capacity of the tank will be approximately 10,000 gallons, and will condense 500 ft^3 of gas per minute performing one full purge in 3.5 hours. A cooling coil/condenser will be required and provided by the component cooling water system. The length of the coil will be 1,300 ft and will need 1,660 gpm to condense the volume of gas described above.

Codes and Standards

The tanks will conform to the latest applicable requirements of the following:

(a) American Society of Mechanical Engineers (ASME)

(b) American National Standards Institute (ANSI)

(c) American Society for Testing and Materials (ASTM)

(d) American Welding Society (AWS)

(e) Occupational Safety and Health Administration (OSHA)

(f) Heat Exchange Institute (HEI)

(g) Code of Federal Regulations (CFR)

DESIGN AND OPERATING CONDITIONS

Ammonia Storage Tanks	10 MWe
Design pressure (psi)	250
Ambient design temperature (F)	130
Storage pressure (psia)	114
Valve relief pressure (psi)	225
Storage temperature (F)	75
Storage design temperature (F)	100
Orientation of tanks	Horizontal
Number of Tanks	4
Total Power System volume requirements, ft^3	< 100,000
gpm of cooling water per tank	16
Approx. heat to be removed by CCW $(\frac{btu}{hr})$	78,000
Dimensions of Tanks (Each)	
Overall length (ft)	47
Diameter (ID) (ft)	10.9
Shell thickness (in.)	.8125
Head thickness (in.)	.46875
Shell & head specs	ASTM SA-612, A-516 Gr 70, A-516 Gr F or A-202 Gr B
Weight (dry) (lbs)	48,848
Capacity (gallons)	30,000
Fittings per tank	1 - manhole 3 - Couplings for instrumentation
Material : Carbon Steel	2 - inlet nozzles 1 - outlet nozzle 2 - relief valves
Approximate length of cooling coil (ft)	140

Ammonia Pressure Tank

	10 MWe
Design pressure (psi)	300
Design temperature (F)	150
Flow rate of condensing gas (cfm)	500
Orientation of Tank	Horizontal
Number of Tanks	1
Volume requirements (ft^3)	1336
Capacity (gallons)	10,000
Approx. length (ft) (overall)	30
Approx. diameter (ft) (ID)	7.8
Approx. shell thickness (in.)	.75
Approx. length of cooling coil (ft)	1,300
Fluid condensed (gpm)	61
Approx. heat removed by CCW (btu/hr)	9,933,750
Rate of cooling water needed (gpm)	1660
Material : Carbon Steel	ASTM SA-612
Approximate time for one full purge using a 300 hp compressor	3.5 hrs
Approximate time for one full purge using a 24 hp compressor	42 hrs

OTEC TECHNICAL SPECIFICATION

Nitrogen Supply and Storage System

Introduction

This specification addresses the design requirements and other related details of the Nitrogen Supply and Storage System. During evacuation, prior to initial system startup, all components exposed to anhydrous ammonia will be filled with nitrogen gas to displace any air present, thus avoiding direct contact between air and the ammonia. Prior to performing maintenance on the ammonia side of the system, nitrogen gas will be utilized to displace residual ammonia gas present in the system.

System Description

Dry nitrogen gas is used during the initial evacuation of air, moisture and other noncondensible gases from the OTEC power system and also after completion of repairs or maintenance prior to the introduction of the ammonia. The system is purged with nitrogen in order to displace any remaining traces of air within the system. This minimizes the possibility an ammonia-air mixture which may pose a potential hazard, causes loss of efficiency and prevents oxidation of the piping and components. Nitrogen gas is also used prior to performing maintenance or inspections on the system. Prior to scheduled or unscheduled maintenance or an inspection, the ammonia contained within the system is pumped back to storage and nitrogen gas is then used to purge the system. Once this is accomplished, multiple purges may be required until the system is safe for disassembly and/or maintenance.

The nitrogen supply and storage system is capable of supplying nitrogen at 5 psig for purging and at 225 psig for the ammonia pressure tank. The cryogenic nitrogen system includes a liquid nitrogen storage vessel, nitrogen vaporizer, piping, associated valves, instrumentation and miscellaneous accessories. In addition, a two stage high vacuum pump is furnished for evacuation of the system.

During system evacuation and purging procedures, nitrogen is supplied from the storage tank through the vaporizer to all major components of the OTEC Power System. At this time the nitrogen gas supply system will be manually lined up and started. An adequate supply of liquid nitrogen will be maintained on board the platform vessel to ensure four system purges.

The nitrogen storage tank is constructed of stainless steel or 9 percent nickel steel. The N_2 vaporizer is a conventional shell and tube type heat exchanger.

During normal operation of the OTEC power cycle, the dry nitrogen gas lines supplying the system components are secured and valved closed.

Safety valves are furnished on the liquid nitrogen storage tank as well as downstream of the nitrogen vaporizer. The safety valves will be set approximately 10 percent above operating pressure.

During system evacuation the nitrogen gas contained within the system will be vented directly to atmosphere. This will be accomplished by the system vacuum pump. During purging, the nitrogen-ammonia gas mixture is passed through a compressor and pressure tank where the ammonia is condensed and the nitrogen is vented to atmosphere.

Provisions are made for furnishing makeup liquid nitrogen when needed.

Standard and Codes

All nitrogen storage and supply equipment including all accessories, will conform to all national standards, regulations and safety codes and with the applicable requirements and test procedures of the following organizations:

a. American Society of Mechanical Engineers (ASME)

b. American National Standards Institute (ANSI)

c. American Standards Association (ASA)

d. American Society for Testing and Materials (ASTM)

e. American Institute of Steel Construction (AISC)

f. American Welding Society (AWS)

g. Steel Structures Painting Council (SSPC)

h. National Board of Fire Underwriters (NBFU)

i. Underwriters' Laboratories (UL)

j. Code of Federal Regulations (CFP)

k. Occupational Safety and Health Act (OSHA)

Design and Operating Conditions

Nitrogen Storage Tank	10 MWe
Design Pressure (psig)	250
Approximate storage temperature	-320
Capacity (gallons)	6000
Storage pressure	225
Approximate length (ft)	40
Approximate diameter (ft)	8
Tank type	Double walled tank with Perlite insulation in evacuated annular space
Quantity	1
Approximate weight (dry)	31,000 lbs

Materials	
Inner shell	Aluminum
Outer shell	stainless, carbon, or nickel steel

Nitrogen Vaporizer	
CCW Temperature Difference (inlet-outlet), F	20
Water flow rate needed (gpm)	300
High gas supply pressure (psig)	225
Low gas supply pressure (psig)	5
Gas supply temperature	Ambient
Type	Shell & Tube
Number of vaporizers	1
Available number of purges	4

Approximate Gas Impurities

Maximum purity	99.99 percent
Maximum impurities	100 ppm oxygen 1 ppm CO & CO2

OTEC System Vacuum Pump
(for system evacuation)

Type/Model	Worthington/19/19x7 type Y CU-2 Dry Vacuum Pump
Piston displacement (cfm)	1148
Actual capacity (acfm)	895
Suction Pressure (in. Hg abs)	1.0
Discharge Pressure (psig)	14.7
Full load speed (rpm)	500
Volumetric efficiency (%)	78.0
Required shaft horsepower (bhp)	21.9
Peak brake horsepower (on starting only)	
@ approximately 14.0 in. Hg abs (bhp)	51.0
Motor rated horsepower (hp)	25
Service Factor	1.15
Pump and Motor Weight (lbs)	11,200
Suction connection (in.)	10,125 lb ASA
Discharge connection (in.)	6125 lb ASA
Cooling water requirements (gpm)	20 - 30
Service voltage	480V, 3Ø, 60Hz.

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OTEC TECHNICAL SPECIFICATION

Startup and Standby Power System

Introduction

In order to avoid the complications involved with using shore-based power for startup and for standby, a startup and standby power system is provided on board. The system consists of a Diesel-Generator set furnishing in aggregate sufficient power at 6900V, 3Ø, 60Hz. to startup the OTEC power module. A secondary function of this system is that it can furnish power instantaneously (i.e. within 10 seconds) to enable pumping of the ammonia from the power system loop into the ammonia storage system. A single D-G set supplies sufficient power for this operation.

Component Description

The startup and standby power system for the test article consists of one D-G set of the quick starting type, complete with skid-mounted piped auxiliaries and is capable of providing continuous electric power of not less than that shown in the attached table for the 10 MWe module size considered. The diesel-generator set will consist of a turbocharged, four-stroke engine designed for automatic start on receipt of a remote signal and can be fully loaded within 10 seconds. The engine is furnished with exhaust turbocharger, air intercoolers, engine-driven lube pump and engine driven jacket water and intercooler water pump. Starting is by a compressed air system giving 100 percent redundancy of starting components. The engine has a motor-driven barring gear with safety interlocks to prevent starting when the barring gear is engaged. Speed control is by an electric governor and there is an independent automatic overspeed trip device which also actuates a microswitch for the control panel annunciator. Engine shutdown controls include an emergency shutdown pneumatic cylinder for operation by remote signal. The engine-driven accessories also include the pump for the separate rocker lube system and the fuel supply pump. The fuel system has an engine-mounted duplex fuel filter. Sensors are furnished with the engine and include exhaust gas thermocouples and speed pickups for engine and turbochargers.

The generator is of the low reactance type and is designed for rapid starting of large motors with minimum voltage dip and rapid voltage recovery characteristics. The generator is a self-ventilated, air cooled machine. The stator assembly consists of the frame, stator core, and the stator coils. The stator frame is fabricated from structural steel plate. It provides support for the stator core, coil guards, and space heaters. Two fabricated feet are built into the lower half of the frame for securing the generator to the skid or foundation sole plate. Lifting lugs are provided for handling the stator frame.

Ventilating ducts are provided throughout the length of the stator core for the passage of ventilating air. Clearance is also provided between the stator frame and the stator core to permit a free flow of air around the outside of the stator core. The stator coils shall be carefully insulated with Class "F" insulating material and thoroughly treated with a Class "F" insulating varnish, before being placed in the stator core. After the coils have been assembled and connected in the stator, the complete assembly shall be given additional treatments of baked varnish to produce a sealed insulation system.

The generator rotor consists of shaft, cast modular iron spider, laminated poles, field coils, circulating fans, and a collector assembly. The spider is secured to the shaft by means of mating flanges on shaft and spider. The poles and field coils are secured to the spider by means of "dove-tailed" projections on the poles with corresponding slots, machined in the spider rim. The field coils are wound directly on the poles using Class "F" insulating materials and wire. The completed coils are impregnated with a Class "F" epoxy compound to form a firm, trouble-free coil. Individual fan blades are bolted to each spider pole at both ends of the rotor assembly.

The collector assembly consists of two copper alloy collector rings which are carefully insulated from each other and the supporting steel ring by mica insulation.

The rotor may be supported at the engine end, through the engine coupling, by the engine bearing. The rotor is supported at the free end of the generator by means of a Babbitt-lined sleeve bearing in a pedestal assembly. The bearing may be water cooled as required by loading. On some applications, a two-bearing alternator may be used.

Space heaters are provided in the bottom of the frame to guard against condensation within the machine when idle.

Excitation of the alternator field is provided through a static excitation and voltage regulation system.

The generator neutral is connected to ground through the primary winding of a dry-type distribution transformer with a grounding resistor connected across the transformer secondary winding designed to limit the generator ground-fault current to approximately 2 amperes.

Codes and Standards

The equipment described in this specification will conform to the latest applicable requirements of the following:

a. American Welding Society (AWS)

b. American National Standards Institute (ANSI)

c. American Society for Testing and Materials (ASTM)

d. Institute of Electrical and Electronics Engineers (IEEE)

e. National Electrical Manufacturers Association (NEMA)

f. National Electrical Code (NEC)

g. Occupational Safety and Health Administration (OSHA)

h. Code of Federal Regulations (CFR)

i. Diesel Engine Manufacturers Association (DEMA)

j. Insulated Power Cable Engineers Association (IPCEA)

k. Tubular Exchanger Manufacturers Association (TEMA)

l. Hydraulic Institute (HI)

m. Anti-Friction Bearing Manufacturers Association (AFBMA)

n. Underwriters' Laboratories, Inc. (UL)

o. American Petroleum Institute (API)

p. National Fire Protection Association (NFPA)

q. Instrument Society of America (ISA)

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GENERAL DATA

	10 MWe
Rating-kW (7-day set rating)	4500-5089
Kilovolt-ampere @ .8 p.f.	5625-6361
Generated voltage	6900V, 3Ø, 60Hz
Maximum No. Sec. to Rated Voltage and Speed	10
Minimum Starting Air Pressure, psi	200
Maximum Air Pressure, psig	250
Jacket Cooling Water, Lube Oil Cooler and Intercooler Flow Rate Required	850 gpm
Fuel Oil Day Tank Capacity (gallons)	1300
Skid Assembly with Auxiliaries, Maximum Length	36 ft
Skid Assembly with Auxiliaries, Maximum Width	13 ft
Skid Assembly with Auxiliaries, Maximum Height*	14 ft
Starting Air Package	48"x213"x82"
Fuel Oil Day Tank Dimensions	4'dia.x13.7'
Wt. D-G Skid Assembly	225,000 lbs
Wt. of Air Skid	8900 lbs
Wt. of Muffler	10,550 lbs
Starting Air Requirements	150 cfm
Wt. of Air Silencer	2250 lbs
Number of hours that D-G Set can operate using Day Tank	4 hours
Fuel Oil Storage Tank Dimensions	Depends on tank location: Double Bottom, Deep or Cylindrical Tank
Fuel Oil Storage Tank Capacity (gallons)	54,000
Number of days that D-G Set can operate	

*16'2" Required for Piston Rod Removal with Air Manifold in Place.

GENERAL DATA

	10 MWe
utilizing fuel oil from the Storage Tank	7 days
Transfer Pump Capacity (gpm)	35-40
Time required to fill Day Tank from Storage Tank (minutes)	30
Number of cylinders of diesel	12

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OTEC TECHNICAL SPECIFICATICN

Circulating Seawater and Component Cooling Water System

INTRODUCTION

There is a need for cooling water to be supplied to components of various auxiliary systems such as ammonia storage and pressure tank, nitrogen vaporizer, air compressors, intercoolers and aftercoolers, lube oil and seal oil coolers and to the electric hydraulic heat exchangers and HVAC equipment.

SYSTEM DESCRIPTION

The system consists of two cooling loops. In one of the loops, demineralized water flows through a cold water heat exchanger where the water is chilled to approximately 45 F and is used in the HVAC cooling coils, lube oil and seal oil cooler. The second loop warms the demineralized water by passing it through the warm water heat exchanger furnished with 80 F seawater. The temperature of the water exiting the heat exchanger will be approximately 75 F and will be used mainly in the nitrogen vaporizer. Since there will be a need to vary the water temperature of the ammonia pressure and storage tanks, the warm CCW and the cold CCW will be mixed. Cold seawater, supplied at 40 F, is used for extracting the heat in the cold seawater heat exchanger.

The component cooling water system will be provided with two pumps, one per loop. These pumps are utilized to circulate the water within the system. In addition, a head tank is furnished to help maintain a positive suction head on the pumps. As previously mentioned, the seawater is either the sink or source for the cooling or warming the CCW. Two (2) seawater pumps are provided. The cold seawater pump capacity is approximately 10,700 gpm, of which 8700 gpm is used in the cold water heat exchanger. The remaining 2000 gpm will be utilized for the chlorination system, D-G-intercooler, jacket water, lube oil heat exchangers and one of the two screen wash booster pumps provided. After passing through the heat exchangers and other auxiliary components, the seawater is discharged to the ocean. The warm seawater pump will circulate approximately 4,000 gpm of water to the warm heat exchanger and to the second screen wash booster pump.

CODES AND STANDARS

The equipment specified herein shall conform to the intent of the following codes and standards.

a) American Welding Society (AWS)

b) American National Standards Institute (ANSI)

c) American Society for Testing and Materials (ASTM)

d) American Society of Mechanical Engineers (ASME)

e) Tubular Exchanger Manufacturers Association (TEMA)

f) Hydraulic Institute (HI)

g) Code of Federal Regulations (CFR)

h) National Electrical Manufacturers Association (NEMA)

i) National Electrical Code (NEC)

j) Institute of Electrical and Electronics Engineers (IEEE)

k) Underwriters' Laboratories, Inc. (UL)

l) Instrument Society of America (ISA)

m) Occupational Safety and Health Act (OSHA)

DESIGN AND OPERATING CONDITIONS

CCW SYSTEM	10 MWe
Number of pumps required	2
Water temperature (approx. F) trough pumps	68
Warm water pump capacity (gpm)	1200
Cold water pump capacity (gpm)	1100
Type of pumps	Centrifugal
Warm CCW heat exchanger inlet temperature (F)	68.1
Warm CCW heat exchanger outlet temperature (F)	75
Cold CCW heat exchanger inlet temperature (F)	68.7
Cold CCW heat exchanger outlet temperature (F)	45
CIRCULATING SEAWATER	
Number of pumps required	2
Warm seawater pump capacity (gpm)	5000
Cold seawater pump capacity (gpm)	9700
Warm seawater temperature (F)	80
Cold seawater temperature (F)	40
GPM through warm CCW heat exchanger	3000
GPM through cold CCW heat exchanger	8700
Seawater outlet temperature through warm CCW H/X	77 F
Seawater outlet temperature through cold CCW H/X	43 F
Heat removed by cold seawater through H/X $\frac{btu}{hr}$	12,581,700
Heat lost by warm seawater through CCW H/X $\frac{btu}{hr}$	4,350,000

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OTEC TECHNICAL SPECIFICATION

COMPRESSED AIR SYSTEM

INTRODUCTION

A compressed air system is provided to furnish starting air for the diesel-generator package; seal air for the warm and cold seawater pumps to avoid a differential pressure across the seals; and to provide service and instrument air at various locations on the OTEC platform vessel.

DESCRIPTION

During normal operation, service, diesel generating start-up and pod pressurization air is supplied by a train of equipment consisting of air compressors, after-coolers, air receivers and air dryers. This air is filtered and dried before it is delivered to the distribution network.

The compressed air system contains two compressors. One furnishes service, compressed air to the pods and the various locations on the platform vessel. The second compressor furnishes dried air to the diesel starting air system. These compressors are of the double-stage water-cooled centrifugal type. Each compressor is provided with an air intake silencer in the intake line, and their cylinder jackets are cooled by water from the component cooling water system.

The aftercoolers are of identical design and are provided with a moisture separator and a moisture trap for automatic removal of the separated water. In addition, the air receivers are also provided with a moisture trap.

Two air driers covering the supply air to the diesel generator start-up system are provided. These driers are of the heatless type, and one unit is capable of drying the full compressed air flow requirements of one compressor to -40 F dew point at a line pressure of 250 psi. The second air drier will be kept on standby. In addition, the compressors are interchangeable in order to provide a degree of redundancy. Pressure reducers are installed where auxilliary equipment requires less than 250 psia air. Overall this system will provide compressed air to the warm and cold seawater pumps, potable water tank, service air controls, sanitary system (if required) and the diesel generator starting system. During start-up the compressor drive motor shall be supplied from a 480 V, 3Ø, 60 Hz source, via the platform power distribution center, originating at a small emergency diesel engine generator. (Both by the hull contractor.)

During normal operation the drive motor will be fed from OTEC System 480 V MCC, 1C1M-1. Motor terminal box shall be large enough to accept two incoming feeds.

CODES AND STANDARDS

The Compressed Air System meets the requirements of the following Codes and Standards.

a. Code of Federal Regulations (CFR)

b. American Society of Mechanical Engineers (ASME)

c. American National Standards Institute (ANSI)

d. American Society for Testing and Materials (ASTM)

e. Hydraulic Institute (HI)

f. Institute of Electrical and Electronics Engineers (IEEE)

g. National Electrical Manufacturers Association (NEMA)

h. American Water Works Association (AWWA)

i. Occupational Safety and Health Act (OSHA)

j. American Welding Society (AWS)

k. Heat Exchange Institute

TECHNICAL SPECIFICATIONS

Air Compressors

Quantity	2 (two)
Type	two stage base mounted water cooled motor
Features	air intake filter, silencer and loadless starting
Start compressor pressure (psi)	210
Stop compressor pressure (psi)	240
Nominal working pressure (psi)	250
Relief valve set pressure (psi)	255
Minimum compressor output to recharge from 180 to 250 psi in one hour	7 SCFM
Service voltage	480 V, 3Ø, 60 Hz

Prefilter

No. of Units Required	2, aerolescer type

Operating Mode	100 percent capacity
Design Pressure, psia	250
Hydrostatic Test Pressure, psia	325
Design Temperature, F	650

Air Receivers

Type	cylindrical steel with dished heads and base support ring for vertical mounting.
Design working pressure	250 psi
Relief valve set pressure	250 psi
Air required per start (scf)	110
Minimum air tank pressure (psi)	180
Full air tank pressure (psi)	250
Number of receivers required	2
Approximate diameter (in.)	48
Approximate length (in.)	96

Air Dryers

Features	filter/moisture separator metal bowl and sight glass and manual drain
Design temperature (F)	450
Design working pressure	250 PSI
Temperature (maximum F)	175
Filter element	50 microns
Connections	1/2 in. NPT
Desiccant used	alumina and molecular sleeves

MATERIALS

Shells and heads	ASTM-A-285C
Nozzle necks	ASTM-A-53d
Flanges	ASTM-A-182 Type 304 or 306
Studs	ASTM-A-307
Nuts	ASTM-A-307d
Pipe	ASTM-SA-312 Type 304 or 316
Gaskets	asbestos

OTEC TECHNICAL SPECIFICATION
6900 VOLT METALCLAD SWITCHGEAR

1.0 Introduction

This specification details the standard features and requirements of metalclad switchgear for 6900v, 3ø, 60Hz, low resistance grounded auxiliary power service at the OTEC pilot plant. The switchgear, consisting of drawout type air circuit breakers, will be energized directly from the turbine generator (normal source) as well as the diesel engine generator (standby source) during start-up or shutdown conditions.

2.0 Codes and Standards

Except as otherwise stated herein, all equipment furnished in accordance with this specification shall comply with the latest applicable codes and standards of American National Standards Institute (ANSI), Institute of Electrical and Electronics Engineers (IEEE), National Electrical Manufacturers Association (NEMA), American Society for Testing & Materials (ASTM), National Electric Code (NEC), Occupational Safety and Health Administration (OSHA) and the U.S. Coast Guard Electrical Engineering Regulations (U.S.C.G.). As a minimum, the following individual standards shall apply:

a. ANSI-C37.06 - Schedules of Preferred Ratings and Related Required Capabilities for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis

b. ANSI-C37.09 - Test Procedure for AC High-Voltage Circuit Breakers

c. ANSI-C37.010 - Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis

d. ANSI-C37.20 - Switchgear Assemblies Including Metal-Enclosed Bus

e. ANSI-C57.13 - Requirements for Instrument Transformers

3.0 **Design and Operating Conditions**

3.1 Metalclad Switchgear Sections — One

3.2 Bus Insulation

a.	Normal Voltage (KV)	6.9
b.	BIL (KV)	95.0

3.3 Main Bus Current Ratings

		Incoming	Feeder
a.	Continuous (A)	2000	1200
b.	Momentary (KA)	66	66

3.4 Breaker Current Ratings

		Feeder	Main
a.	Continuous (A)	1200	2000
b.	Short Circuit (KA)	33	33
c.	Max. Symm. I. C. (KA)	41	41
d.	Close & Latch Capability (KA)	66	66

4.0 Service Conditions

The Metal Clad Switchgear shall be capable of maintaining normal operations during the conditions of a "sea state 6"; and survive, in a secured status, the conditions of a "sea state 9"

The Switchgear will be installed indoors with a design ambient air temperature of 40C maximum.

5.0 Component Description

5.1 Enclosure

5.1.1 The bus and breaker compartments shall be completely enclosed and shall be separated from each other by tightly fitting barriers. The breaker compartments shall have hinged doors with provision for mounting of controls, relays and instruments. Removal covers shall be provided at the rear for access.

5.1.2 Main bus and bus taps shall be fully insulated copper or aluminum bar. Bus-bar joints shall have silver-to-silver contact surfaces securely bolted to provide low-resistance contact. Aluminum joints shall be welded wherever possible. Each switchgear section shall be provided with a copper ground bus continuous through and connected to all units. Ground bus shall be furnished with clamp-type terminals at each end for connection of 500-kcmil copper ground cable.

5.1.3 The mechanical strength of all equipment, such as current transformers, bus structures, and similar equipment, shall be coordinated with the air circuit breakers.

5.1.4 Maximum bus conductor hot-spot temperature shall be 105C

5.2 Circuit Breakers

5.2.1 Circuit breakers shall be capable of being racked from the fully-disconnected position through the test position to the fully-connected position with the breaker compartment door closed. Guides and racking mechanisms shall be adequate to perform this function without the application of undue force and with complete safety. When a breaker is withdrawn from the connected position, it shall be isolated from the main bus by a positive-action insulated shutter.

5.2.2 Breaker auxiliary contacts on the drawout element and mechanism-operated auxiliary switch shall be furnished and wired to terminal blocks. A minimum of four normally open and four normally closed spare auxiliary contacts shall be available in addition to the auxiliary contacts required for breaker operation. Normally closed auxiliary contacts shall break before the normally open auxiliary contacts make. The circuit breaker mechanism devices shall be wired to terminal blocks for remote control, indication and alarm.

5.2.3 Remotely controlled circuit breakers shall be provided with a permissive control switch with red and green indicating lights on the breaker front panel for closing and tripping the breaker in the test position only. The remote closing or tripping shall be inoperative when the breaker is in the test position. Remote closing of the breaker shall be possible only after the permissive control switch has been operated to the close position. This operation shall be indicated by the lighting of the green lamp at the remote control point. Automatic tripping of the breaker shall cause the remote white indicating light to come on, indicating disagreement between the remote control-switch position and breaker position.

5.2.5 Control switches and indicating lights shall be mounted on the front door of each breaker compartment.

5.2.6 Circuit breakers of the same rating shall be interchangeable with identical wiring and auxiliary contact arrangement for each breaker even if all the auxiliary contacts may not be used for a breaker in the particular unit to which it is assigned.

5.2.7 The breakers shall be electrically operated. Breaker operating mechanisms shall be stored-energy type. Each breaker compartment shall have a fused disconnect switch for isolating the breaker dc control circuits. Closing and tripping circuits shall be individually fused in both legs. Fuses shall be located in the control compartment and shall be readily accessible.

5.3 Painting

To ensure compatibility with the environment with the intent of limiting or eliminating contamination or corrosion the switchgear steel shall be thoroughly cleaned after fabrication. All surfaces shall be phosphate treated and given a prime coat of rust-inhibiting paint. A finish coat of lacquer or enamel, light gray ANSI 61 shall be applied overall. Paints such as alkyd enamels having a fungus resistant property shall be used on all inside surfaces and shall be sprayed with a fungicidal varnish.

All insulations that are not fungus resistant shall have a fungus resisting coating applied. Where such coatings would interfere with proper operation of the apparatus, the coating shall not be applied. In such cases, the part shall be inherently fungus resistant.

5.4 Tests

5.4.1 The completed switchgear and individual air circuit breakers shall be tested in accordance with American National Standards Institute (ANSI) and National Electrical Manufacturers Association (NEMA) standards.

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OTEC TECHNICAL SPECIFICATION
480 VOLT SECONDARY UNIT SUBSTATION

1.0 Introduction

This specification details the standard features and general requirements of the Secondary Unit Substations and their associated Lighting Load Center Power Transformers. Each substation consists of a dry type transformer close coupled to low voltage switchgear. The switchgear is the dividing point for loads directly associated with OTEC power generation operations and miscellaneous auxiliary loads not directly associated with power generation operations.

2.0 Codes and Standards

Except as otherwise stated herein, all equipment furnished in accordance with this specification shall comply with the latest applicable codes and standards of American National Standards Institute (ANSI), Institute of Electrical and Electronics Engineers (IEEE), National Electrical Manufacturers Association (NEMA), American Society for Testing & Materials (ASTM), National Electric Code (NEC), Occupational Safety and Health Administration (OSHA) and the U.S. Coast Guard Electrical Engineering Regulations (U.S.C.G.). As a minimum, the following individual standards shall apply:

a. ANSI C37.20 - Switchgear Assemblies, including Metal-Enclosed Bus

b. ANSI C57.12.00 - General Requirements for Distribution, Power and Regulating Transformers

c. ANSI C57.12.90 - Test Code for Distribution, Power, and Regulating Transformers

d. ANSI C57.12.90a - Distribution and Power Transformer Short-Circuit Test Code.

3.0 Design and Operating Conditions

	Unit Substation		LTG. LOAD CTR.
Transformer			
Rating:			
Dry Type (150c)			
Self Cooled (KVA)	1000		75
force cooled (KVA)	1333		-
Windings			
Primary			
Rated Volts, V	6900		480
Insulation Class, KV	5.0		1.2
Insulation BIL, KV	75		10
Connection	Delta		Delta
Secondary			
Rated Volts, V	480		120/208
Insulation Class, KV	1.2		1.2
Insulation BIL, KV	10		10
Connection	Delta		Delta
Transformer Phsical Conns.			
Primary	Cable		Cable
Secondary	Bus(close-coupled)		Cable
Switchgear			
Bus Nominal Rating (A)	1600		-
Bus Fault Current (KA)	35		-
Withstand (KA RMS SYM)	35		-
Nominal Voltage	600		-
Circuit Breakers			
Frame Size (A)	1600	600	
Interrupting Rating (KA)	35	35	
Control Voltage, (dc)	125V	125V	

4.0 Service Conditions

The substations and Lighting Load Center transformers shall be capable of maintaining normal operations during the conditions of a "sea state" 6; and survive, in a secured status, the conditions of a "sea state 9". The eouipment will be installed indoors with a de sign ambient air temperature of 40c maximum and a 24 hour average 30c

5.0 Component Description

5.1 Construction & Arrangement

Each 480 volt secondary unit substation shall consist of factory-assembled metal-enclosed equipment consisting of a high-voltage incoming-line section, a transformer section, and a low-voltage switchgear section. The sections shall be bolted and connected together side by side to form a rigid, free-standing, totally-enclosed assembly and to provide a neat in-line appearance. Each section shall be fabricated of steel sheet, reinforced to form a rigid, free-standing structure.

5.1.1 The incoming section shall be an air-filled cubicle of adequate size to accommodate and terminate the 6900 volt, incoming power supply conductors. As shielded cable is employed for the incoming power supply, the air-filled terminal box shall be adequately sized to make up the required stress cones.

5.1.2 The secondary-unit-substation transformer shall be close-coupled to the respective switchgear. Low-voltage bushings shall be directly connected to the transformer secondary breaker in the switchgear section.

5.1.3 The switchgear section shall consist of an assembly of free-standing enclosed steel structures. Each structure shall contain individual drawout-type air circuit breakers or instrument compartments in the front and a full-height rear compartment for buses, incoming bus connections, and feeder-cable connections. The individual circuit breaker compartments shall be completely enclosed with sheet steel barriers to segregate the breakers from adjacent compartments and buses.

5_.2 Transformers

5.2.1 Secondary-unit-substation transformers shall be ventilated dry type 3 phase, 60 hertz and shall have electrical ratings as listed in the design section of this specification.

5.2.2 Ventilated dry type transformers shall be provided with Class H insulation, 150 C temperature rise above a 30 C average daily ambient (40 C maximum ambient). The transformer shall have a self-cooled capacity as specified in the design section of this specification and a capacity of 133 percent of the self-cooled rating when provided with cooling fans.

Transformer cooling fans shall be suitable for operation on a 480 -V, 3 -phase, 60 -Hz, power source. Control of transformer cooling fans shall be automatic, responsive to the transformer winding temperature. All controls, including temperature detector with contacts, control relays, circuit protective devices, and wiring, shall be provided. The transformer and secondary bus connections shall be mounted on a fabricated steel framework and enclosed with steel panels and a cover. Side panels shall be removable to permit access to transformer core and coils. Ventilation shall be provided by means of louvered openings near the top and bottom to provide adequate free ventilation. Louvers shall be screened and provided with removable filters.

5_.2.3 Ventilated dry type transformers shall be provided with four 2-1/2-percent full-capacity taps. Tap ratings shall be 2 above and 2 below normal voltage.

Taps shall be accessible for changing through a removable panel on the transformer enclosure. Tap locations shall be accessible to personnel standing on the floor.

5.2.6 Construction of and accessories for separate low-voltage transformers shall meet all the requirements herein specified for secondary unit substation transformers, with the exception that secondary bushings shall contain lugs suitable for purchaser's cables as shown on the specification drawings. A suitable air-filled terminal chamber shall be provided for the secondary bushings of low-voltage transformers.

5.2.7 Two ground pads with bolted-type connectors for purchaser's 500 kcmil stranded copper ground cable shall be provided located diagonally opposite each other on the transformer tank base.

5.3 Switchgear Bus & Breaker Compartments

5.3.1 Continuous current rating of main buses shall be coordinated with the transformer and breaker ratings.

5.3.2 The switchgear main bus shall be three-phase, four-wire for operation on 480-v, and shall be supported and braced to with stand a fault current of not less than 35000A rms symmetrical. The power feeder and control conductors for each circuit breaker will enter the enclosure from top or bottom. The feeder cable size will be as indicated on the one-line drawings.

5.3.2 A copper ground bus shall extend the entire length near the bottom of the switchgear. A two-bolt ground lug sized for 500 - kcmil copper ground cable shall be provided at each end of the ground bus.

5.3.4 Circuit breaker compartments shall be equipped with primary and secondary contacts, drawout rails, and a mechanical interlock to prevent insertion or withdrawal of the breaker when the breaker is in the closed position.

5.3.5 Each breaker compartment shall have a hinged steel door arranged so that the door will open a minimum of 90 degrees, with a mechanical interlock to prevent the door from being opened when the breaker is in the closed position. Each breaker compartment shall be provided with a breaker drawout mechanism which will permit a tripped breaker to be moved from the connected position to the test and disconnect positions with the door closed.

5.3.6 Rear compartments shall be enclosed with removable covers, and the end sheets of each switchgear section shall be removable to allow for future extensions.

5.3.7 Each vertical section of the switchgear shall be equipped with blank steel removable plates, top and bottom, to permit drilling of the plates in the future for conduit entrance.

5.3.8 Buses shall be copper or aluminum suitably supported and braced to withstand the fault current specified in the design section of this specification. Buses shall be silver-plated at bolted connection points. Aluminum joints shall be welded wherever possible. Bus connections to the line-side terminals of the incoming supply breaker shall be segregated from the main switchgear bus by means of isolating barriers completely enclosing the buses. Buses shall be held rigidly within the structure by bus supports fabricated from materials which will maintain their physical and dielectric properties under the service conditions.

5.4 <u>Air Circuit Breakers</u>

5.4.1 Air circuit breakers shall be three-pole drawout type, either manually or electrically operated as indicated on the one-line drawings. Breakers shall have a stored-energy-type operating mechanism and shall be provided with three solid-state or electromechanical trip devices.

5.4.2 The trip devices shall have the following characteristics:

a. <u>Solid-State</u>

1) <u>Long time delay</u>: The long-time-delay trip element shall be adjustable from 50 percent to 125 percent of the trip coil current rating (sensor rating).

2) <u>Short time delay</u>: The short-time-delay trip element shall be adjustable from 400 percent to 1000 percent of the sensor rating.

3) <u>Instantaneous</u>: The instantaneous trip element shall be adjustable from 500 percent to 1200 percent of the sensor current rating.

5.5 Painting

To ensure compatibility with the environment with the intent of limiting or eliminating contamination or corrosion the equipment steel shall be thoroughly cleaned after fabrication. All surfaces shall be phosphate treated and given a prime coat of rust-inhibiting paint. A finish coat of lacquer or enamel, light gray ANSI 61 shall be applied overall. Paints such as alkyd enamels having a fungus resistant property shall be used on all inside surfaces and shall be sprayed with a fungicidal varnish.

All insulations that are not fungus resistant shall have a fungus resisting coating applied. Where such coatings would interfere with proper operation of the apparatus, the coating shall not be applied. In such cases, the part shall be inherently fungus resistant.

5.6 Tests

5.6.1 Each completed secondary unit substation and individual transformer shall be tested in accordance with IEEE, NEMA and ANSI standards. Tests shall consist of the standard production, design, conformance, and functional tests.

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OTEC TECHNICAL SPECIFICATION
480 VOLT MOTOR CONTROL CENTERS

1.0 Introduction

This specification details the standard features and requirements of the Motor Control Centers and their function within the OTEC electrical system. Each motor control center shall consist of the required number of combination starters and feeder breakers, each of which will act as the controller and protective device, for the OTEC auxiliary operating loads.

2.0 Codes and Standards

Except as otherwise stated herein, all equipment furnished in accordance with this specification shall comply with the latest applicable codes and standards of American National Standards Institute (ANSI), Institute of Electrical and Electronics Engineers (IEEE), National Electrical Manufacturers Association (NEMA).

National Electric CODE (NEC)
Occupational Safety and Health Administration (OSHA) and
U. S. Coast Guard, Electrical Engineering Regulations (CG)

As a minimum the latest revision of the following individual codes and standards shall apply:

a. ANSI C 1 National Electrical Code
b. NEMA ICS Industrial Controls and Systems
c. NEMA FU 1 Low-Voltage Cartridge Fuses
d. NEMA AB 1 Molded Case Circuit Breakers

3.0 Design and Operating Conditions

Number of Motor Control Centers	TWO
Bus	
Insulation Class (V)	600
Amperes	
Continuous (A)	600
Max. Momentary Symmetrical (A)	
Circuit Breakers	
Interrupting rating Symmetrical at 480V. (A)	25,000
Continuous (A)	100

4.0 Service Conditions

The motor control centers shall be capable of maintaining normal operations during the conditions of a "sea state 6"; and survive, in a secured status, the conditions of a "sea state 9" The equipment will be installed indoors with a design ambient air temperature of 40C maximum.

5.0 Component Description

5.1 Enclosure & Bus

Each motor control center shall have enclosed dead-front construction, arranged in a group consisting of vertical sections, each an independent structural unit. The vertical sections shall be joined together side by side to form a rigid free-standing assembly. Each vertical section shall be fabricated of steel sheet, reinforced to form a rigid free-standing structure. Structural details of each section shall be the same as those of all other sections and shall be so arranged that additional sections may be added to either end. Vertical sections shall be divided by sheet steel barriers into individual compartments for each starter or feeder circuit.

Each vertical section shall be provided with a main three-phase horizontal bus at the top, and with a three-phase vertical bus to distribute power to the starters and feeder units in the vertical section. The main bus and bus taps shall be copper or aluminum bar. Bus-bar joints shall have silver-to-silver contact surfaces securely bolted to provide low-resistance contact. Aluminum joints shall be welded wherever possible.

Buses shall be rated at 480 V for operation on a 480 V solidly-grounded system. Bus assemblies shall be supported and braced to withstand bolted fault conditions of not less than 25000 rms symmetrical amperes. Minimum continuous current rating of control center buses shall be 600A for main bus & 300A for vertical bus.

5.2 Combination Starter and Feeder Units

Each motor control center shall contain full-voltage, combination type starters with molded case, 100A frame minimum, 3 pole air circuit breakers for 480v, 3 phase 60Hz induction motors and similar feeder circuit breakers for miscellaneous loads.

The feeder and combination starter circuit breaker shall have a current rating based on load requirements as well as the 40 C ambient temperature. Circuit breakers shall have an interrupting capacity of not less than 25000rms symmetrical amperes at 480 V.

Circuit breakers shall have a toggle-operated mechanism which shall provide positive trip-free operation on overcurrent, and shall provide quick-make and quick-break contact movement under both manual and automatic operation. Combination starter circuit breakers shall be equipped with instantaneous magnetic adjustable tripping element only. Feeder unit circuit breakers shall be equipped with both thermal and instantaneous magnetic tripping elements. Feeder circuit breakers for groups of motors, transformers, or miscellaneous loads shall be manually or electrically operated as indicated on the drawings. Circuit breakers, fuses and overload heater elements shall be temperature compensated for the environment in which they will be installed.

The contactor and the thermal overload device for each combination starter shall be based on the motor current and the 40 C ambient temperature. Thermal overload heater ratings shall be sized to protect the motors.

Each starter shall be provided with a 120 V operating coil and a suitable single-phase 480/120 V control transformer. Control transformer continuous rating shall be ample for starter operation, remote and local position indicating lights, auxiliary relays, and any other devices that may be required. Required additional capacities will be furnished to the successful bidder when these data are known.

A size 1 starter shall be the minimum size used for motor control.

Motor starters shall have three manually-reset thermal overload devices, and shall be wired for single-speed, nonreversing, reversing, or multispeed motors as indicated on the drawings.

Magnetic contactors shall be single-throw; shall disconnect all leads to the motor; shall be provided with magnetic blowouts and arc shields; and shall be capable of interrupting 10 times the full-load current corresponding to the maximum horsepower for which they are rated at the service voltage. Some contactors will be reversing type. Each starter shall be furnished with two extra auxiliary contacts in addition to the seal-in and motor space heater contacts. Extra contacts shall be suitable for either normally open or normally closed use and shall be wired to terminal blocks.

A control transformer primary at each starter shall be connected to the load side of the combination-starter circuit breaker or fuse using phases 1 and 2 for all starters. The control transformer secondary shall have one side fused and the other side grounded.

As indicated on the drawings, each motor-control center shall be provided with a 7.5 kVA, 480-120/208 V, 3 phase, 60 Hz, dry-type transformer, and a 24 circuit distribution panel equipped with two- pole 20 A breakers for motor and control-center space heaters, and for other miscellaneous loads. The transformer primary shall be connected to the control center power bus through a 3 - pole, 100 A breaker.

Painting
To ensure compatibility with the environment with the intent of limiting or eliminating contamination or corrosion the switchgear steel shall be thoroughly cleaned after fabrication. All surfaces shall be phosphate treated and given a prime coat of rust-inhibiting paint. A finish coat of lacquer or enamel, light gray ANSI 61 shall be applied overall. Paints such as alkyd enamels having a fungus resistant property shall be used on all inside surfaces and shall be sprayed with a fungicidal varnish.

All insulations that are not fungus resistant shall have a fungus resisting coating applied. Where such coatings would interfere with proper operation of the apparatus, the coating shall not be applied. In such cases, the part shall be inleventlу fungus resistant.

Tests
The completed switchgear and individual air circuit breakers shall be tested in accordance with American National Standards Institute (ANSI) and National Electrical Manufacturers Association (NEMA) standards.

OTEC TECHNICAL SPECIFICATION
2 KV and 8 KV POWER CABLE

1.0 Introduction

This specification is concerned with the detail and general requirements of the 2 kV and 8 kV cable. This cable is used on the medium voltage system connections, both for connection to individual loads and as cable requirements of interconnecting cable bus duct.

2.0 Codes and Standards

Except as otherwise stated herein, the power cables furnished in accordance with this specification shall comply with the latest applicable codes and standards of U.S.Coast Guard, Electrical Engineering Regulations (CG) the American National Standards Institute (ANSI), the Institute of Electrical and Electronics Engineers (IEEE), the National Electrical Manufacturers Association (NEMA), the American Society for Testing and Materials (ASTM), and the Insulated Power Cable Engineers Association (IPCEA). As a minimum, the following individual codes and standards shall apply:

a. IPCEA S-19-81 - Rubber-Insulated Wire and Cable

b. IPCEA S-68-516, Interim No. 1-Ethylene-Propylene-Rubber-Insulated, Ozone-Resistant Wires and Cables, Rated 0-35,000 Volts

c. ASTM B8 - Specification for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft

d. ASTM B33 - Specification for Tinned Soft or Annealed Copper Wire for Electrical Purposes

e. ASTM B189 - Specification for Lead-Coated and Lead-Alloy-Coated Soft Copper Wire for Electrical Purposes

f. ASTM B231 - Specification for Aluminum Conductors, Concentric-Lay-Stranded

g. ASTM D752 - Specification for Heavy-Duty Black Neoprene Sheath for Wire and Cable

3.0 Design and Operating Conditions

Conductor material	
8kv	copper
2 kv	copper
Design Ambient	
8 kv & 2 kv cable	
Maximum	40C
Rated conductor operating temp.	
8kv & 2kv cable	90C
Rated Voltage	
Class/BIL (KV)	8/95
Class/BIL (KV)	2/45

The following table indicates cable size and configurations to be furnished in accordance with this specification.

8KV	2KV
1/c 750 Kcmil	1/c 750 Kcmil
1/c 4/0 AWG	1/c 500 Kcmil

4.0 Service Conditions

The 8kv&2 -kV insulated power cable shall be suitable for use on a 3 phase 60 -Hertz (Hz), low resistance grounded) system. The installation will be in conduits or ducts above ground, and exposed installation in cable tray runs. Manufacturer's information will be requested, including but not limited to: recommended installation lubricant, maximum pulling tension and minimum bending radius.

5.0 Component Description

The cablc specified is part of the OTEC electric system interconnections. Each cable shall be of the following general construction - single conductor, 2 kV and 8 kV class insulation, shielded with overall jacket. Cable construction shall be suitable for use with prefabricated cable terminations or field fabricated stress cones. The cable manufacturer shall provide any information required to terminate the cable by either means including recommended materials and installation techniques, for applying protective materials to prevent termination deterioration due to hostile factors in the environment. configuration shall be as follows;

Conductors

The copper Conductors shall be Class B concentric-stranded, in accordance with IPCEA S-19-81 (NEMA WC-3), Part 2. Copper conductors shall be annealed-coated wire, in accordance with ASTM B33 for tin-coated conductors or ASTM B189 for lead- or lead-alloy-coated conductors. Concentric-stranded copper conductors shall conform to ASTM B8.

Conductor Shielding

Shielding applied over the surface of the conductor shall be at least 2.5 mils thick and firmly bonded to the cable insulation. It may be conducting nonmetallic tape, conducting compound, or conducting cement. The conductor shielding shall meet the requirements of IPCEA S-19-81.

Insulation

Insulation shall be heat-, oil-, moisture-, and ozone-resisting EPR compound suitable for 90 C maximum conductor temperature under normal operating conditions, 130 C under emergency operating conditions, and 250 C under short-circuit conditions. The insulation shall be applied directly to the surface of the conductor or conductor covering, and shall fit tightly to that surface.

The average insulation thickness shall not be less than that specified in IPCEA S-68-516, Interim No. 1, based on the rated circuit voltage, phase-to-phase, cable insulation level, and grounded or ungrounded operation. The minimum thickness at any point shall not be less than 90 percent of the average thickness.

Physical and electrical properties of the insulation shall be in accordance with IPCEA S-68-516 Interim No. 1.

Insulation Shielding

Insulation shielding shall meet the requirements of IPCEA S-19-81, Part 4. A suitable nonmagnetic metallic tape (tinned, annealed-copper shielding tape) which is protected against chemical action from cable components, and at least 2.5 mils thick, shall be applied over the insulation, in accordance with IPCEA S-19-81, Part 4.1.1.1.

Jacket

The jacket compound shall be neoprene and shall be thermosetting, fire-retardant, and heat-, oil-, ozone-, moisture-, and corona-resistant.

The average jacket wall thickness shall not be less than that specified in IPCEA S-19-81, Part 4. The minimum thickness shall not be less than 80 percent average thickness.

The properties shall be as indicated in IPCEA S-19-81, Part 4 and ASTM D752.

A cable Insulation or jacket material of polyvinyl chloride (PVC), cross-linked polyethylene (XLPE) or other thermoplastic compounds is unacceptable.

Tests

Cable shall be tested in accordance with the latest requirements of IPCEA S-19-81 and S-68-516.

All cables shall pass the IEEE fire test as defined in IEE standard 383.

OTEC TECHNICAL SPECIFICATION

600 VOLT POWER AND CONTROL CABLES

1.0 Introduction

This specification is concerned with the detail and general requirements of the 600V class power and control cables. These cables will be used in the 480V power distribution system and the various control, alarm and indication systems required by the OTEC electrical system

2.0 Codes and Standards

Except as otherwise stated herein, the control cables furnished in accordance with this specification shall comply with the latest applicable codes and standards of the American National Standards Institute (ANSI), the National Electric Code (NEC)
Occupational Safety and Health Administration (OSHA)
U.S. Coast Guard, Electrical Engineering Regulations (CG)
Underwriters Laboratories, Inc. (UL)
Institute of Electrical and Electronics Engineers (IEEE), the National Electrical Manufacturers Association (NEMA), the American Society for Testing and Materials (ASTM), and the Insulated Power Cable Engineers Association (IPCEA). As a minimum the latest revisions of the following individual codes and standards shall apply:

a. IPCEA S-19-81 - Rubber-Insulated Wire and Cable

b. IPCEA S-68-516, Interim No. 1 - Ethylene-Propylene-Rubber-Insulated, Ozone-Resistant Wires and Cables, Rated 0-35,000 Volts.

c. ASTM B8 - Specification for Concentric-Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft

d. ASTM B33 - Specification for Tinned Soft or Annealed Copper Wire for Electrical Purposes

e. ASTM D752 - Specification for Heavy-Duty Black Neoprene Sheath for Wire and Cable

f. IEEE 383 - Standard for Type Test of Class IE Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations

g. ASTM B189 - Specification for lead-coated and lead-alloy-coated soft copper wire for electrical purposes.

3.0 Design and Operating Conditions

Conductor and Coating, power and control	Tinned copper
Conductor Stranding,	
power	Class B
control	Class B
Temperature	
Ambient	40c
Conductor operating max.	90c

The following table indicates sizes & configurations selected for OTEC:

Power	Control
1/c 500Kcmil	12/c #12 AWG
1/c 4/0 AWG	7/c #12 AWG
1/c 1/0 AWG	3/c #12 AWG
1/c #2 AWG	2/c #12 AWG
3/c #6 AWG	4/c #10 AWG
# 3/c #10 AWG	2/c # 10 AWG
	1/c # 10 AWG

4.0 Service Conditions

Power cable shall be insulated for 600V and be suitable for use on a 480V, 60-Hertz, low resistance grounded system, on 208Y/120-Volt alternating current (Vac) and 125-Volt direct current (Vdc)

The 600-V control cable shall be suitable for use on 120/208-V alternating current (Vac) and 125 volt direct-current (Vdc) control system.

Cable shall be suitable for direct burial, installation in conduits or ducts above and below ground, and exposed installation in cable trays. Cables shall be suitable for operation in wet or dry locations with alternatively wet and dry conditions.

Manufacturers information will be requested, including but not limited to: recommended installation techniques and materials maximum pulling tension and minimum bending radius.

5.0 COMPONENT DESCRIPTION

Cable shall have copper conductor, ethylene propylene rubber (EPR) insulation with an overall jacket of neoprene or Hypalon. Insulation or jackets of polyvinyl chloride or cross-linked polyethylene will not be acceptable.

Power cables may be required to be single-conductor or three conductor configuration construction Specific requirements as to cable configuration are indicated. Three conductor cable shall be color coded.

Control cables shall be single or multiconductor, color coded, with round configuration and overall shealth of neoprene or Hypalon. Filler material shall be nonhygroscopic, fire-retardant and shall not adhere to the conductors.

Conductors

Conductor shall be Class B (7 strand) concentric-stranded copper, in accordance with IPCEA S-19-81 (NEMA WC-3), Part 2. Conductor wire shall be annealed tin-coated wire, in accordance with ASTM B33 for tin-coated conductors. Concentric-stranded copper conductors shall conform to ASTM B8.

Insulation

Insulation shall be heat-, oil-, ozone-, and moisture-resistant thermosetting compound rated for 90 C maximum conductor temperature under normal operating conditions, 130 C under emergency operating conditions, and 250 C under short-circuit conditions. The insulation shall be applied directly to the surface of the conductor and shall fit tightly to that surface.

The average insulation thickness shall be not less than that specified in IPCEA S-19-81, Part 3 and 7, IPCEA S-68-516, interim #1 or IPCEA S-66-524 based on the rated circuit voltage, phase-to-phase, cable insulation level, and conductor size. The minimum thickness at any point shall be not less than 90 percent of the average thickness.

Special fire-retardant construction incorporating fire-resistant tapes will be considered.

Conductor Identification

Each conductor shall be color coded in accordance with Method 1 of IPCEA S-19-81, Section 5.6.3.1.

Cable Assembly

The proper number of insulated conductors shall be cabled together in sequence, in accordance with IPCEA S-19-81, Part 5.

Fillers shall be used where necessary to assure a round cable. Filler material shall be nonhygroscopic, fire-retardant, and shall not adhere to the conductors. A nonhygroscopic, fire-retardant binding tape shall be applied over the cable assembly.

Outer Jacket

Overall jacketing shall be a thermosetting, fire-retardant, heat-, oil-, ozone-, and moisture-resistant material such as neoprene or Hypalon compound.

The average jacket wall thickness shall be not less than that specified in IPCEA S-19-81, Part 7. The minimum thickness shall be not less than 80 percent of average thickness.

The properties of the jacket shall be as indicated in IPCEA S-19-81, Part 4, and ASTM D752.

Tests

Cable shall be tested in accordance with the latest requirements of IPCEA S-19-81 and S-68-516.

Cable shall be tested to determine its capability of preventing the propagation of fire, and to determine that it has self-extinguishing characteristics.

a. The flame-retardant capability of the cable shall be demonstrated by subjecting samples of the cable to be furnished to the vertical cable tray flame test as described in IEEE 383, paragraph 2.5. The sizes of the test samples shall be in accordance with IEEE 383, paragraph 2.2, Table 1.

b. Individual insulated conductors of the multiconductor cable shall satisfactorily pass the Underwriters' Laboratories, Inc. (UL) vertical flame test as described in UL 83, and the flame test as described in IPCEA S-19-81, section 6.19.6.

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OTEC TECHNICAL SPECIFICATION
ELECTRIC MOTORS

1.0 Introduction

This specification addresses the detail and general design requirements of motors required within the OTEC systems. These motors may be furnished as part of some item of driven equipment, furnished separately or even furnished as part of an auxiliary associated with a major item of equipment.

2.0 Codes and Standards

Except as otherwise stated herein, the equipment furnished in accordance with this specification shall comply with the latest applicable codes and standards of the American National Standards Institute (ANSI), the National Electrical Code (NEC)
Occupational Safety and Health Administration (OSHA)
U.S. Coast Guard, Electrical Engineering Regulations (CG)
Institute of Electrical and Electronics Engineers (IEEE), and the National Electrical Manufacturers Association (NEMA). As a minimum the latest revision of the following individual codes and standards shall apply:

a. ANSI C50.41 Polyphase Induction Motors for Power Generating Stations

b. ANSI C52.1 (NEMA MG1) Motors and Generators

c. ANSI C51.1-Safety Standards for Construction and Guide for Selection, Installation and Use of Electric Motors and Generators

d. IEEE Standards Publication No. 112A-Test Procedure for Polyphase Induction Motors and Generators

e. IEEE 85-Test Procedure for Airborne Sound Measurements on Rotating Electric Machinery

f. ANSI C1 (NFPA 70) National Electrical Code

3.0 Design and Operating Conditions

	Both test articles & module
Design Ambient	
Maximum	40C
24 hrs. avg.	30C
Environment:	Ammonia (NH_3) Hydrogen (H_2) Chlorine (Cl_2) Sea Salt saturated moisture laden air

Electrical Characteristics

Electric power services at the plant will be:

System voltages (Nominal)	120/208 wye, grounded neutral 480, 3 phase 6900, 3 phase
System frequency	60 Hz ± 2 Hz

Motor Horsepower	Motor Rated Volts
Below 1/2-nonreversing	115-single phase
Below 1/2-reversing	200-3 phase
1/2 thru 250	460-3 phase
300 and larger	6600-3 phase

The system short-circuit ratings are 33 kA at 6900 volts and 22 kA at 480 volts.

Motors for operation under emergency conditions shall be rated 125V, dc. All motors shall have NEMA "Class B" insulation.

4.0 Service Conditions

Motors shall be capable of normal operation during conditions of a "Sea State 6" and shall survive, in a secured status, the conditions of a "Sea State 9".

The design ambient air temperature for motors shall be considered as 40 C maximum. Where motors are specified for outdoor locations, consideration shall be given to the effects of exposure to direct solar radiation.

5.0 Component Description

The motors shall be designed to operate successfully and to develop the capabilities in the driven equipment specifications under the operating conditions described therein.

Motors shall have enclosures suitable for the rigorous and hostile environments in which they will operate.

As a minimum motors shall be totally enclosed, suitable for marine service. In specific locations motors shall be explosion proof for Class 1, Division 1, Group B or D atmospheres.

Unless otherwise specified, motors shall be three-phase, squirrel-cage induction type. Motors larger than NEMA frame size 440 shall be Design NT or HT per ANSI C50.41 as required. NEMA frame size 440 and smaller motors shall be NEMA design B unless the speed-torque requirements of the driven equipment dictate otherwise.

The horsepower rating of each motor shall permit the driven equipment to develop its required capacity continuously without exceeding the standard motor temperature rise limits for Class B insulation measured by embedded detector over an ambient air temperature of 40 C at 1.0 service factor. Motors shall be furnished with Class B sealed insulation. The insulation shall be resistant to damage from lubricating oil.

A motor terminal housing shall be supplied for terminating the motor power supply cables. The terminal housing shall be of substantial construction, metal fabricated and totally supported by the motor enclosure.

Motors shall be provided with locations for equipment-grounding terminals. Location of the grounding pads shall be shown on the outline drawing.

Motors shall be the manufacturer's premium line with accessories as required to implement extended continuous service and necessary monitoring of winding temperature and bearing temperature as specified for each motor.

Motors 100 horsepower and larger for nonhazardous areas shall have space heaters arranged for automatic energization when the motor is idle. Motors smaller than 100 hp may require space heaters. Where the motor frame is too small to accommodate a space heater, the windings shall be encapsulated.

Painting

To ensure compatibility with the environment with the intent of limiting or eliminating contamination or corrosion the exposed metal shall be thoroughly cleaned after fabrication. All surfaces shall be phosphate treated and given a prime coat of rust-inhibiting paint. A finish coat of lacquer or enamel, light gray ANSI 61 shall be applied overall. Paints such as alkyd enamels having a fungus resistant property shall be used on all inside surfaces and shall be sprayed with a fungicidal varnish.

All insulations that are not fungus resistant shall have a fungus resisting coating applied. Where such coatings would interfere with proper operation of the apparatus, the coating shall not be applied. In such cases, the part shall be inlevently fungus resistant.

Tests

The manufacturer shall make tests on each motor in accordance with the referenced standards.

For motors larger than NEMA frame size 440, the manufacturer shall make the following tests in addition to the tests specified in ANSI C50.41-25.2:

a. Determination of locked rotor (zero speed) torque and current

b. Temperature test

c. Airborne sound power level unless otherwise specified, when duplicate motors are provided, the above tests shall be conducted on one motor only.

OTEC TECHNICAL SPECIFICATION
STATION BATTERY & BATTERY CHARGERS

1.0 Introduction

This specification is concerned with the detail and general requirements of station batteries and battery chargers. Requirements of this section shall be incorporated into the design, fabrication, and testing of the subject equipment as required in conjunction with the OTEC power generating system.

2.0 Codes and Standards

Except as otherwise stated herein, all equipment furnished in accordance with this specification shall comply with the applicable codes and standards of the American National Standards Institute (ANSI), the National Electric Code (NEC)
Occupational Safety and Health Administration (OSHA)
U.S. Coast Guard Electrical Engineering Regulations (U.S.CG)
Institute of Electrical and Electronics Engineers (IEEE), and the National Electrical Manufacturers Association (NEMA). As a minimum, the following individual codes and standards shall apply:

a. IEEE 450-1975 - Recommended Practice for Maintenance, Testing, and Replacement of Large Stationary Type Power Plant and Substation Lead Storage Batteries

b. IEEE 485-1978 - Recommended Practice for Sizing Lead Storage Batteries for Generating Stations and Substations

c. NEMA RI 2-1966 - General-Purpose and Communication Battery Chargers

3.0 Design and Operating Conditions

Battery Requirements.

The calculated capacity of each battery shall be based on the following load duty cycle with the battery cells initially fully charged to a specific gravity of 1.210 at 25 C and discharged to a final cell voltage of 1.81 V per cell. The ambient air temperature throughout the load duty cycle shall be taken to be the minimum ambient temperature of 20c.

The load duty cycle for each battery is as follows:

Item No. one Service OTEC dc supply
125 V 58 cells

Under emergency conditions the battery will be subject to a 3 -hour duty cycle.

Time Period	Load (Amperes)
first one minute	212
next one minute	465
next 28 minutes	300
next 149 minutes	190
last one minute	194

For the purpose of battery capacity calculations, the above loads shall be considered constant power loads.

Charger Requirements

Each charger will operate from a 480 V 3 phase, 60 hertz (Hz) alternating-current (ac) source.

Chargers shall have the following nominal continuous output rating:

Item No.	Service	Rating	Continuous Amps
2A (Normal)	OTEC dc system	125 volt	200
2B (Standby)	OTEC dc system	125 volt	200

4.0 Service Conditions

The battery and chargers will be installed indoors at elevation 71.0' and shall be capable of maintaining normal operations during the conditions of a "sea state 6"; and survive, in a secured status, the conditions of a "sea state 9".

The ambient air temperature for the battery and charger installation will vary from 20 C minimum to 40 C maximum. Normal operating ambient temperature will be maintained at 40 C. Each battery and charger shall be capable of supplying the specified direct-current (dc) loads through the complete range of ambient air temperatures.

5.0 Component Description

Battery Requirements

Each battery will operate in conjunction with constant-voltage chargers to provide 125 volts dc (Vdc) power supply for circuit breaker operation, control equipment, (instrumentation, electric motors, static inverters) and emergency lighting.

Each battery shall meet 100 percent of its required capacity at the inception of service.

The rated capacity of each battery shall be the calculated capacity based on paragraph 3.0 increased as required to compensate for loss of capacity due to 20-year operation and sized in accordance with IEEE P485-1975.

Each battery shall consist of 58 cells with a nominal battery voltage of 125 V.

Cells shall be lead-calcium, pasted-plate, type suitable for a float charge of 2.25 V per cell and an equalizing charge of 2.33 V per cell.

All plates shall be reinforced and adequately supported to prevent plate distortion under all operating conditions, including short circuit at the cell terminals.

The cells shall be mounted in shock-absorbing clear plastic containers permanently marked on all four sides with high and low electrolyte levels. The cell jars shall be of uniform thickness and shall be designed to withstand without breakage the conditions of battery operation on the OTEC module.

Cell covers shall be cemented in place to form a permanent leakproof seal. Removable sprayproof vent plugs shall be firmly inserted into vent wells of cover to preclude the escape of electrolytic spray but allow the escape of gases. Ample sediment space shall be provided to eliminate the necessity for cleaning during the life of the battery.

Each battery shall be provided with compression-type terminations for purchaser's copper 600 volt, cables as follows:

Item No.	Conductor Size	Number Per Post
one	500 Kcmil	Four

Terminal posts shall be lead-plated, copper or lead with copper inserts and permanently marked "Pos"/"Neg" or with plus/minus symbols.

Each battery shall be provided with steel racks properly painted with acid-resistant paint. All joints shall be welded and ground smooth to remove any sharp edges. Racks shall be complete with all necessary frames, rails, and braces, and all necessary bolts, nuts, and washers. Cell support rails shall be steel stringers covered with insulation strips.

Chargers

Each charger, which shall be a 3-phase constant-voltage static type, will be required for charging the associated battery and supplying the unit with continuous dc loads.

Float and equalizing voltage regulation shall be ± 0.5 percent from no load to full load, with ± 10 percent normal input voltage variation and ± 5 percent variation in frequency.

The charger shall operate automatically with no voltage adjustment required during operation. The equipment shall be provided with separate front-of-panel-mounted manual-adjusting devices for setting the operating levels of the float and equalizing charging systems.

The charger output float voltage shall be adjustable over a range of not less than ± 15 V, and the equalizing voltage shall be adjustable over a range of not less than ± 20 V.

The output shall be filtered. The ripple content of the output shall be not greater than (30 mVrms filtered)

Each charger shall be capable of recharging the battery in a minimum of 12 hours when the battery has been discharged to 1.75 volts per cell.

Each charger shall be provided with compression-type terminations for purchaser's copper cables as follows:

Item No.	Conductor Size
1A	250Kcmil
1B	250Kcmil

The minimum interrupting rating of the ac incoming circuit breaker shall be 22,000 amps symmetrical at 480 volts. The air circuit breaker shall be manually operated with thermal magnetic overload short circuit protection. The breaker shall be rated for 75 amps continuous load.

The minimum interrupting rating of the two pole dc output circuit breaker shall be 20000 amps at 250 Vdc. The 225 A frame breaker shall be provided with thermomagnetic trip.

Control wiring shall be copper conductor, No. 14 AWG minimum. Wire insulation shall be 600-V class, thermosetting, moisture-, heat-, oil-, and flame-resistant. Wires shall be terminated with ring-type, insulated, crimp-on connectors. Grouped

for parallel operation with other constant-voltage battery chargers vendor shall provide control circuit cross wiring between chargers.

The chargers shall be suitable for floor-mounting with all components readily accessible from the front.

Each charger shall be convection-cooled and housed in a NEMA 1 ventilated steel enclosure.

Painting

To ensure compatibility with the environment with the intent of limiting or eliminating contamination or corrosion the exposed steel shall be thoroughly cleaned after fabrication. All surfaces shall be phosphate treated and given a prime coat of rust-inhibiting paint. A finish coat of lacquer or enamel, light gray ANSI 61 shall be applied overall. Paints such as alkyd enamels having a fungus resistant property shall be used on all inside surfaces and shall be sprayed with a fungicidal varnish.

All insulations that are not fungus resistant shall have a fungus resisting coating applied. Where such coatings would interfere with proper operation of the apparatus, the coating shall not be applied. In such cases, the part shall be inherently fungus resistant.

Tests

Batteries shall be tested in accordance with ANSI, IEEE, and NEMA standards.

The seller shall perform the battery-capacity acceptance test on each battery in accordance with IEEE 450-1975, paragraph 5.4 per battery duty cycle to determine whether the battery meets its special rating.

The seller shall perform charger maximum-output-current tests on each charger in accordance with NEMA RI 2-1966, Section 6.05, together with conversion-efficiency tests in accordance with NEMA RI 2-1966, Section 6.09, to prove the guaranteed efficiencies stated.

10-A

OTEC TECHNICAL SPECIFICATION

UNINTERRUPTABLE POWER SUPPLY (UPS) SYSTEM

1.0 INTRODUCTION

This specification covers general requirements of the UPS to be furnished for the subject project. The power system (UPS), completely assembled and wired shall supply loads consisting of computers, electronic equipment, controls and emergency lighting. It also defines the requirements for a solid-state UPS designed to supply a critical load with reliable and precise one- or three-phase ac power output regardless of transients on the incoming ac and dc power buses, including total power failures. Power for the critical load shall be taken from the UPS at all times except during time intervals when the UPS may be shut down for maintenance. During such time intervals, the critical load shall be operated from the incoming ac power line through a bypass circuit. Transfer of the critical load to the bypass circuit and its return shall be made without interruption of power to the critical load.

2.0 Codes and Standards

Except as otherwise stated herein, all equipment furnished in accordance with this specification shall comply with the latest applicable codes and standards of American National Standards Institute (ANSI), Institute of Electrical and Electronics Engineers (IEEE), and National Electrical Manufacturers Association (NEMA)
National Electric Code (NEC)
Occupational Safety and Health Administration (OSHA)
U.S. Coast Guard Electrical Engineering Regulations (CG)

minimum, the latest revisions of the following individual codes and standards shall apply:

a. ANSI C1 National Electrical Code

b. IEEE 59 Semiconductor Rectifier Components

c. IEEE 299 Recommended Practice for Measurement of Shielding Effectiveness of High-Performance Shielding Enclosures

d. NEMA SK 60 Silicon Rectifier Diodes Stacks

e. NEMA SK 56 Temperatures for Electrical Measurement and Rating Specification

f. ANSIS 1.2 Method for Physical Method of Sound

g. ANSI S1.13 Method of Measurement of Sound Pressure levels

3.0 Design and Operating Conditions

Ratings

The UPS shall have the following output ratings:

Item No.	kVA	kW	V	Phase	Wire	Hz
1.	7.5		118±	One	2	60 ±
2.	7.5		118±	One	2	60 ±
3.	15		118±	One	3	60 ±

The UPS shall use battery stored electrical energy and a solid-state inverter to convert dc battery power to one -phase ac power when incoming ac power is out of limits or has failed.

4.0 Service Conditions

The UPS will be installed indoors at elevation 71.0'

The UPS equipment when required shall meet the seismic standards of IEEE 344-1975 Guide for Seismic Qualification of Class 1E Electrical Equipment for Nuclear Power Generating Stations.

The design ambient air temperature for each UPS shall be 40 C maximum.

The UPS shall be capable of normal operation during conditions of a "Sea State 6" and shall survive, in a secured status, the conditions of a "Sea State 9".

5.0 Component Description

Arrangement, Construction, and Performance

Each UPS shall be a coordinated, factory-assembled unit, completely, wired, and ready for connection to purchaser's power and load connections.

Equipment furnished in accordance with this specification shall be assembled in a freestanding, indoor NEMA I enclosure with lifting eyes and adequate bracing to permit lifting, skidding, or rolling without damage to the enclosure.

Each UPS should be normally designed and rated for natural air cooling. If designed for fan cooling, 100-percent-redundant fans should be furnished. One additional set shall be sufficient for full cooling of the UPS.

Each UPS shall be as shown on the attached specification drawings and shall consist of the following major components:

a. Alternate Sypply Transformer

b. ac supply disconnect switch

c. dc supply breaker and fuses

d. Automatic transfer switch

e. Manually operated ac bypass switch

f. Inverter unit

A circuit breaker and separate, visible break disconnect switch shall be provided for the rectifier ac input. The breaker shall open all conductors of the ac input power supply for protection against an internal malfunction in the UPS. The circuit breaker shall be closed only by manual operation and shall not trip open when the UPS is supplying full ac output short-circuit current. The disconnect switch is used as a manual disconnecting device.

For protection against an internal UPS malfunction and for use as a manual disconnecting device, a dc circuit breaker shall be provided in the output of the dc supply circuit to open all conductors of the dc input power. The circuit breaker shall be closed only by manual operation and shall not trip open when the UPS is supplying full ac output short-circuit current.

All circuit breakers and fuses furnished with UPS shall be coordinated with the supply and output circuit breakers and fuses to which it is connected.

Static Transfer Switch

Each UPS control power shall include a solid-state automatic transfer switch. Under normal operating conditions, the transfer switch shall connect the inverter to the load. If inverter voltage or frequency exceeds preset limits of 110 to 125 V or 58 to 62 Hz, or both, or when the inverter is driven to current limit, the transfer switch shall disconnect the inverter from the load and connect the load to the alternate supply line from the constant voltage transformer. The switch operation shall preferably be of the make-before-break type.

Upon restoration of the inverter output voltage to within preset limits, the load shall be transferred back to the inverter. The return to normal voltage monitoring circuit shall be independently and continuously adjustable from 60 to 100 percent of normal source voltage. Transfer back to the inverter shall be time delayed to insure inverter output voltage stability and to allow automatic synchronizing equipment to operate prior to transfer. The time delay shall be continuously adjustable from 1 to 10 seconds.

Each solid-state, automatic transfer switch shall have an associated manual bypass switch. The manual bypass switch shall have the following three positions:

Position 1, load fed from inverter bypassing static switch

Position 2, load fed through static switch

Position 3, load fed from alternate source bypassing static switch

The bypass switch shall be mounted and connected so that the inverter and solid-state automatic transfer switch components can be removed or replaced without making the system inoperative.

Circuit Interrupter Switches

The power supply inverter shall include a solid-state interrupter switch connected in the inverter output.

The interrupter switch shall disconnect the inverter from the load if the inverter output exceeds the following preset voltage, frequency, phase-angle, and rate-of-change-of-frequency limits:

a. Voltage, 105 to 130 V (or as required by project)

b. Frequency, 58 to 62 Hz

c. Phase angle, ±5 electrical degrees

d. dHz/dt, 0.035 Hz/sec

Upon restoration of the inverter output voltage to within preset limits, the inverter shall be automatically reconnected to the load. The reconnection monitoring circuit shall include a time delay to insure inverter output voltage stability and to allow automatic synchronizing equipment to operate prior to reconnection. The time delay shall be continuously adjustable from 1 to 10 seconds.

The current-carrying capacity and voltage rating shall be in accordance with the inverter unit rating.

The total operating time of the interrupter switch shall not exceed 0.25 Hz (60 Hz base).

Each solid-state interrupter switch shall have a manually operated bypass switch which permits isolation of the interrupter switch without power interruption to the load.

Inverter Performance

The power supply to each static inverter will be taken from a 125-Vdc bus which will be supplied by a battery and a voltage battery charger. The bus will also supply additional loads including motors, circuit breaker operating solenoid, and other static inverters. The inverters shall be capable of operating with an input voltage range of 98 V to 135 V.

The inverter shall be capable of accepting a dc input transient with a maximum of 4000 V for 10 microseconds, 40 ohms source impedance.

a. The UPS shall conform to the radio frequency interference requirements of the Federal Communications Commission Rules and Regulations Volume 2, Part 18, Subparts E & H dated 8/69

b. The ac and dc input lines shall be filtered to provide EMI/RFI transient suppression

c. The audio noise level of the UPS defined as weighted sound level shall not exceed 70 dB when meausred at a distance of 5 feet from the enclosure. Measurement is to be made in accordance with ANSI standard S-12 Transformers and other noise sources should be isolated from the cabinet if necessary to meet the sound level requirements

The inverter efficiency shall not be less than 80 percent under all loading conditions, from 25-percent load to full load and a power factor of 80 percent and higher. Efficiency shall be defined as rms watts output divided by dc watts input.

The inverter shall be capable of operating from unity to 0.5 power factor lagging at rated kVA.

The output voltage shall remain with ±1 percent of rated output voltage for any one of the following conditions:

a. No load to full load at 1.0 to 0.5 power factor lagging

b. 98- to 135-Vdc input

c. 0 to 40C ambient

For any combination of previously mentioned items a., b., or c., the output voltage shall be maintained within ±4 percent.

Transient response of voltage (instantaneous deviation from a pure sine wave of nominal amplitude) shall not exceed ±5 percent within 0.5 cycle after a 50 percent load application or removal; maximum transient, and excursion of output voltage shall not exceed ±10 percent.

The output frequency shall remain within ±0.5 Hz of 60 Hz under all conditions of load and dc voltage when operating without synchronization at an ambient temperature of 0 to 40 C. Output frequency shall not be affected by sudden or gradual changes in load.

The output frequency control of the inverter shall be capable of being synchronized to another alternating frequency compatible with the designed output frequency of the inverter. This synchronizing circuit shall be capable of

The inverter shall have built-in protection against undervoltage and overcurrent operation in conjunction with the dc input circuit breaker. The inverter shall also be self-protected against damage when energized with any connected load from no load to short circuit.

Alternate Supply Transformers

The alternate power supply transformer for each UPS shall be mounted in a separate cubicle located near to the associated inverter equipment cubicle.

The transformer shall be self-cooled, Type AA, and shall have Class B insulation.

Each transformer shall have a continuous output rating at least equal to that of the associated static inverter. The output voltage shall be 118 Vac, 60 Hz, single phase, or three phase as required and shall be filtered to reduce the harmonic content to a maximum of 5 percent under all specified operating conditions.

The transformer primary winding will be connected to a 480-V or 120/208V (with neutral) three-phase, three-wire, 60 Hz system, and a prospective short-circuit fault rating of 22,000 A symmetrical.

The transformer output voltage shall remain within ±4 percent of rated output voltage for any one of the following operating conditions:

a. No load to full load at 1.0 to 0.5 power factor lagging

b. 375- to 528-Vac or 160- to 230-Vac input

c. 58 to 62 Hz input

d. 0 to 40 C ambient

For any combination of previously mentioned items a., b., c., and d., the output voltage shall be maintained within ±6 percent.

Wiring and Terminals

Control wiring shall be tinned copper, stranded, with insulation to withstand the maximum attainable unit temperatures. There shall be no splices in the wire, and connections shall be made at terminal blocks with preinsulated, crimp-on, ring-type connectors.

Wiring shall be fire-resistant in any position and shall satisfactorily pass the vertical flame test specified in Underwriters' Laboratories, Inc. Publication UL-83. Thermoplastic insulation will not be accepted.

Grounding

Each UPS shall be provided with a copper ground bus running near the bottom of the length of the enclosure. The ground bus shall be provided with a compression-type lug at one end that is capable of accepting purchaser's No. 4/0 copper ground cable.

Painting

To ensure compatibility with the environment with the intent of limiting or eliminating contamination or corrosion the exposed metal shall be thoroughly cleaned after fabrication. All surfaces shall be phosphate treated and given a prime coat of rust-inhibiting paint. A finish coat of lacquer or enamel, light gray ANSI 61 shall be applied overall. Paints such as alkyd enamels having a fungus resistant property shall be used on all inside surfaces and shall be sprayed with a fungicidal varnish.

All insulations that are not fungus resistant shall have a fungus resisting coating applied. Where such coatings would interfere with proper operation of the apparatus, the coating shall not be applied. In such cases, the part shall be inherently fungus resistant.

Tests

Static inverter equipment components shall be tested, in accordance with IEEE 59-1962 and IEEE 472-1974, America National Standards Institute (ANSI) C34.2-1968, and NEMA standards, and with the manufacturers' own commercial standards.

In addition, each completed uninterruptible supply system shall be tested as required by the owner to verify the specified performance requirements.

Tests shall be performed by the seller prior to shipment from the factory at no cost to the owners.

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REINFORCED CONCRETE
FOR
POWER PLANT EQUIPMENT SUPPORTS

INTRODUCTION

This outline specification covers the more significant requirements for design and construction of Reinforced Concrete Foundations for the turbine generator, heat exchangers seawater pumps and miscellaneous tanks placed on a floating concrete hull.

DESCRIPTION

Major equipment requiring foundations are located at various levels of a concrete hull. The 10Mwe ammonia turbine generator is located over an intermediate level of the hull. Pedestal for the turbine generator approximately 10'0 above an intermediate level of hull will be tied to hull walls and floor by reinforcing bar dowels from the hull. It is expected that all foundations shall be constructed at the site of hull construction. Small foundations may be constructed as integral part of the hull. See drawings AA1-S-1, AA1-S-2 and AA1-S-3.

CODES AND STANDARDS

Concrete design shall conform to the provisions of building code requirements for reinforced concrete ACI 318 of the American Concrete Institute. Concrete construction shall comply with requirements of ACI 301.

MATERIALS

Cement for all concrete work shall be Type II, conforming to ASTM C150. Aggregate shall conform to the requirements of ASTM C-33. The proportioning shall be for the compressive strength (f'c) of concrete equal to 4000 psi based on 28 day test age. Reinforcing Steel shall be defromed bars of intermediate grade conforming to the requirements of "specifications for billet steel for concrete reinforcement" ASTM A615 Grade 60.

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OTEC TECHNICAL SPECIFICATION
STRUCTURAL STEEL
FOR
POWER PLANT EQUIPMENT SUPPORTS

INTRODUCTION

This outline specification covers the significant requirements for design and construction of structural steel supports for the turbine generator, heat exchangers, seawater pumps and miscellaneous tank placed on a floating steel hull.

DESCRIPTION

Major equipment requiring supports are located at various levels of a steel hull. The 10Mwe ammonia tubine generator is located over an intermediate level of the hull. The pedestal approximately 10'0" in height consists primarily of girders, columns and bracing. Girders and columns comprising of two or more members are to be filled in with concrete after installation in order to achieve necessary mass. Supports for heat exchanger, seawater pumps and tanks are blocks made up by welding plates of sufficient size to distribute loads to the hull. See drawings AA1-S-1, AA1-S-2 and AA1-S-3.

CODES & STANDARDS

All steel design and construction shall comply with the requirements of the "rules for building and classing steel vessels - american Bureau of shipping (ABS) specification for materials".

MATERIALS

Structural steel shall comply with the requirements of American Society for Testing and Materials, ASTM A 131, "Structural Steel for Ships". Steel shapes and plates shall be furnished either in ordinary strength grades with a minimum yield point of 34,000 psi or in higher strength grades with a minimum yield point of 45,500 psi.

All connections and joints shall be welded and shall comply with the requirements of the ABS, "Specification for Materials".

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ENGINEERING DRAWINGS

(VOLUME 3)

These drawings are referenced in Volume 2 and 3 of this report.

The drawings listed in the left column appear in Section 5, Volume 2, under the figure numbers indicated in the right column.

Drawing Number	Westinghouse Figure Number
AAI-M-30	5-6
AAI-M-28	5-7
AAI-M-27	5-8
AAI-M-26	5-9
AAI-M-29	5-10
AAI-M-37	5-11
AAI-M-35	5-12
AAI-M-34	5-13
AAI-M-33	5-14
AAI-M-36	5-15

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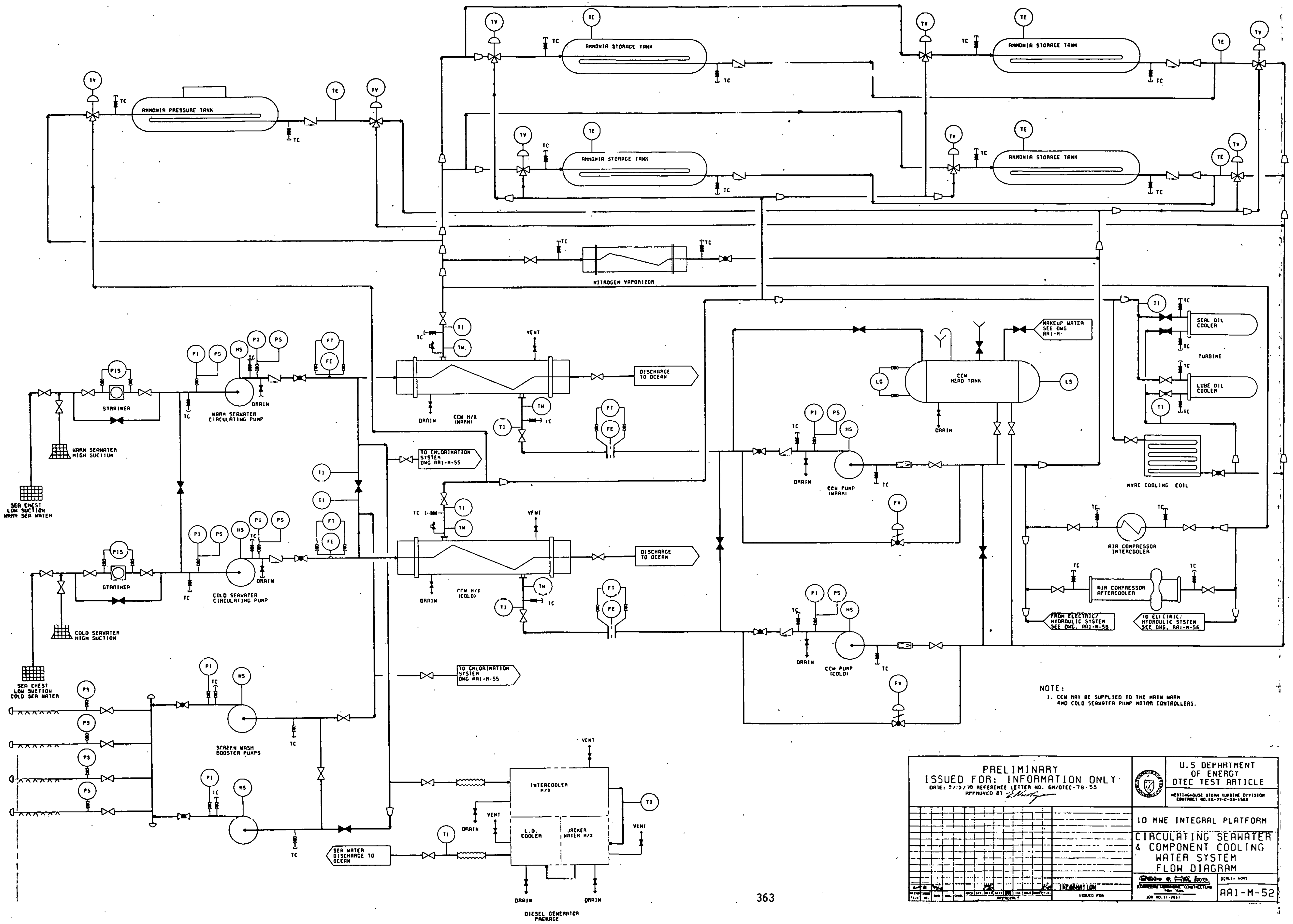

AMMONIA PRESSURE TANK
AMMONIA STORAGE TANK
AMMONIA STORAGE TANK
AMMONIA STORAGE TANK
AMMONIA STORAGE TANK
NITROGEN VAPORIZOR
STRAINER
WARM SEAWATER HIGH SUCTION
SEA CHEST LOW SUCTION WARM SEA WATER
WARM SEAWATER CIRCULATING PUMP
DRAIN
CCW H/X (WARM)
DISCHARGE TO OCEAN
TO CHLORINATION SYSTEM DWG AA1-M-55
STRAINER
COLD SEAWATER HIGH SUCTION
SEA CHEST LOW SUCTION COLD SEA WATER
COLD SEAWATER CIRCULATING PUMP
CCW H/X (COLD)
DISCHARGE TO OCEAN
TO CHLORINATION SYSTEM DWG AA1-M-55
SCREEN WASH BOOSTER PUMPS
INTERCOOLER H/X
L.O. COOLER
JACKET WATER H/X
SEA WATER DISCHARGE TO OCEAN
DIESEL GENERATOR PACKAGE
CCW HEAD TANK
MAKEUP WATER SEE DWG AA1-M-
CCW PUMP (WARM)
CCW PUMP (COLD)
SEAL OIL COOLER
TURBINE
LUBE OIL COOLER
HVAC COOLING COIL
AIR COMPRESSOR INTERCOOLER
AIR COMPRESSOR AFTERCOOLER
FROM ELECTRIC/ HYDRAULIC SYSTEM SEE DWG. AA1-M-56
TO ELECTRIC/ HYDRAULIC SYSTEM SEE DWG. AA1-M-56
NOTE:
1. CCW MAY BE SUPPLIED TO THE MAIN WARM AND COLD SEAWATER PUMP MOTOR CONTROLLERS.
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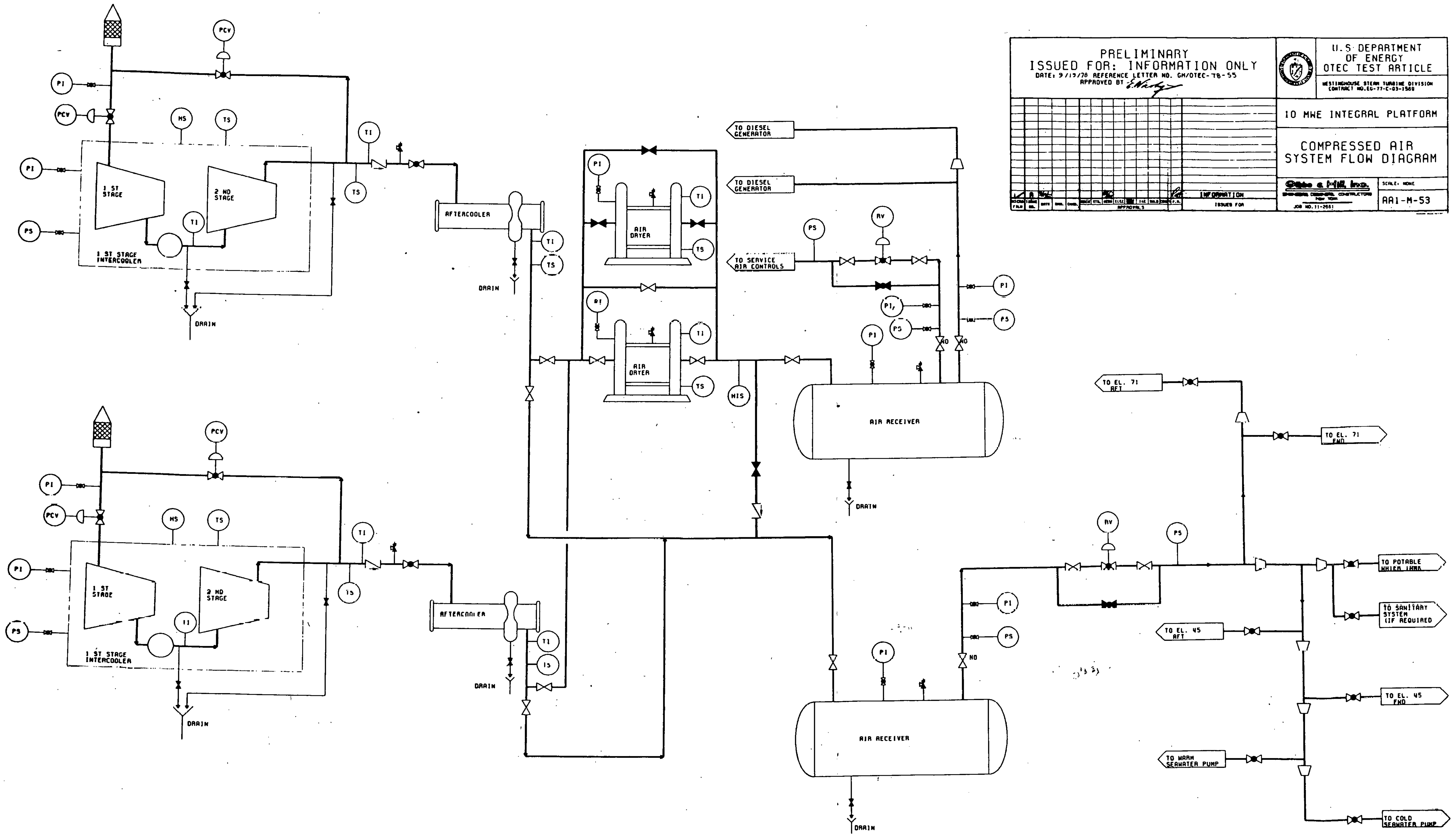
OTEC TEST ARTICLE
WESTINGHOUSE STEAM TURBINE DIVISION CONTRACT NO.EG-77-C-03-1569
10 MWE INTEGRAL PLATFORM
CIRCULATING SEAWATER & COMPONENT COOLING WATER SYSTEM FLOW DIAGRAM
Gibbs & Hill, Inc.
JOB NO.11-2651
SCALE: NONE
AA1-M-52
INFORMATION
ISSUED FOR
APPROVALS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CONTRACT NO.EG-77-C-03-1569
10 MWE INTEGRAL PLATFORM
COMPRESSED AIR SYSTEM FLOW DIAGRAM
INFORMATION
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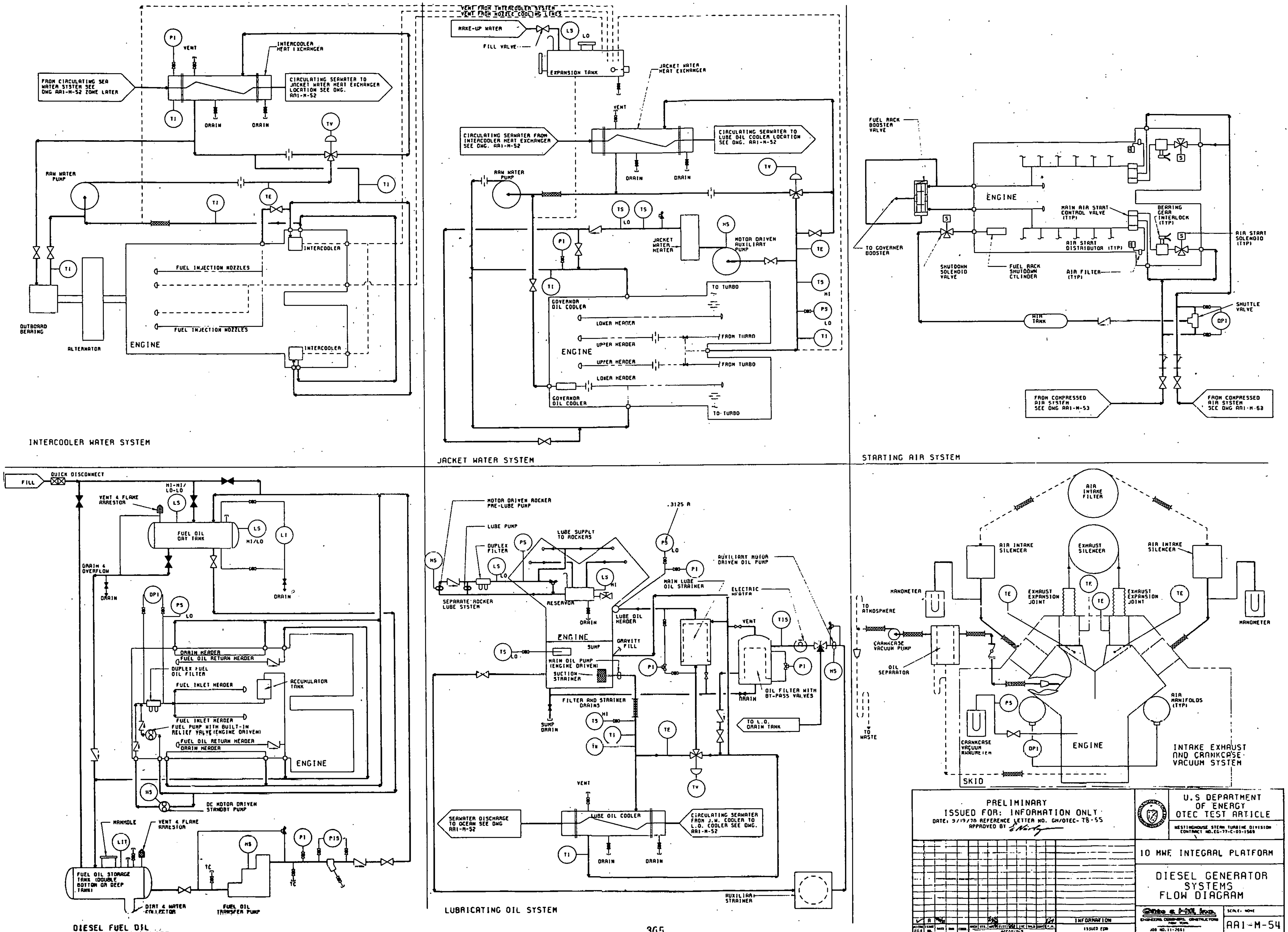
SCALE: NONE
AA1-M-53
PCV
PI
HS
TS
TI
PS
RV
MIS
1 ST STAGE
2 ND STAGE
1 ST STAGE INTERCOOLER
AFTERCOOLER
DRAIN
AIR DRYER
AIR RECEIVER
TO DIESEL GENERATOR
TO SERVICE AIR CONTROLS
TO EL. 71 AFT
TO EL. 71 FWD
TO POTABLE WATER TANK
TO SANITARY SYSTEM (IF REQUIRED
TO EL. 45 AFT
TO EL. 45 FWD
TO WARM SEAWATER PUMP
TO COLD SEAWATER PUMP
NO



INTERCOOLER WATER SYSTEM
JACKET WATER SYSTEM
STARTING AIR SYSTEM
DIESEL FUEL OIL STORAGE & TRANSFER SYSTEM
LUBRICATING OIL SYSTEM
INTAKE EXHAUST AND CRANKCASE VACUUM SYSTEM
ENGINE
ALTERNATOR
OUTBOARD BEARING
RAW WATER PUMP
INTERCOOLER HEAT EXCHANGER
FUEL INJECTION NOZZLES
INTERCOOLER
EXPANSION TANK
MAKE-UP WATER
FILL VALVE
JACKET WATER HEAT EXCHANGER
JACKET WATER HEATER
MOTOR DRIVEN AUXILIARY PUMP
GOVERNOR OIL COOLER
UPPER HEADER
LOWER HEADER
TO TURBO
FROM TURBO
AIR TANK
SHUTTLE VALVE
AIR START SOLENOID
MAIN AIR START CONTROL VALVE
AIR START DISTRIBUTOR (TYP)
FUEL RACK BOOSTER VALVE
FUEL RACK SHUTDOWN CYLINDER
SHUTDOWN SOLENOID VALVE
TO GOVERNOR BOOSTER
FILL
QUICK DISCONNECT
FUEL OIL DAY TANK
DRAIN HEADER
FUEL OIL RETURN HEADER
DUPLEX FUEL OIL FILTER
FUEL INLET HEADER
ACCUMULATOR TANK
DC MOTOR DRIVEN STANDBY PUMP
FUEL OIL TRANSFER PUMP
FUEL OIL STORAGE TANK (DOUBLE BOTTOM OR DEEP TANK)
DIRT & WATER COLLECTOR
MOTOR DRIVEN ROCKER PRE-LUBE PUMP
LUBE PUMP
DUPLEX FILTER
LUBE SUPPLY TO ROCKERS
RESERVOIR
SEPARATE ROCKER LUBE SYSTEM
MAIN OIL PUMP (ENGINE DRIVEN)
SUCTION STRAINER
SUMP
GRAVITY FILL
MAIN LUBE OIL STRAINER
AUXILIARY MOTOR DRIVEN OIL PUMP
ELECTRIC HEATER
OIL FILTER WITH BY-PASS VALVES
TO L.O. DRAIN TANK
LUBE OIL COOLER
AUXILIARY STRAINER
AIR INTAKE FILTER
AIR INTAKE SILENCER
EXHAUST SILENCER
EXHAUST EXPANSION JOINT
MANOMETER
CRANKCASE VACUUM PUMP
OIL SEPARATOR
AIR MANIFOLDS (TYP)
CRANKCASE VACUUM MANOMETER
SKID
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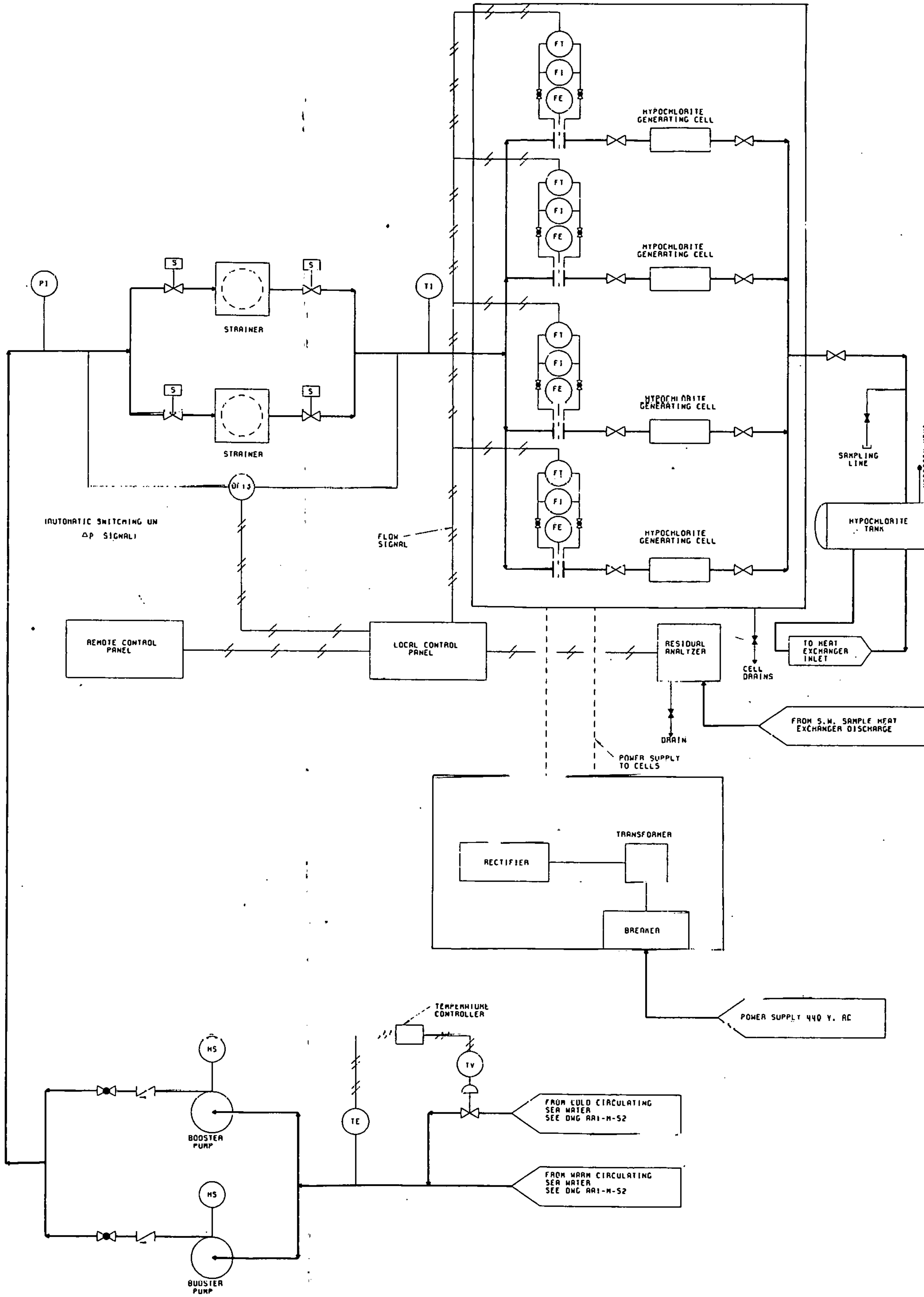
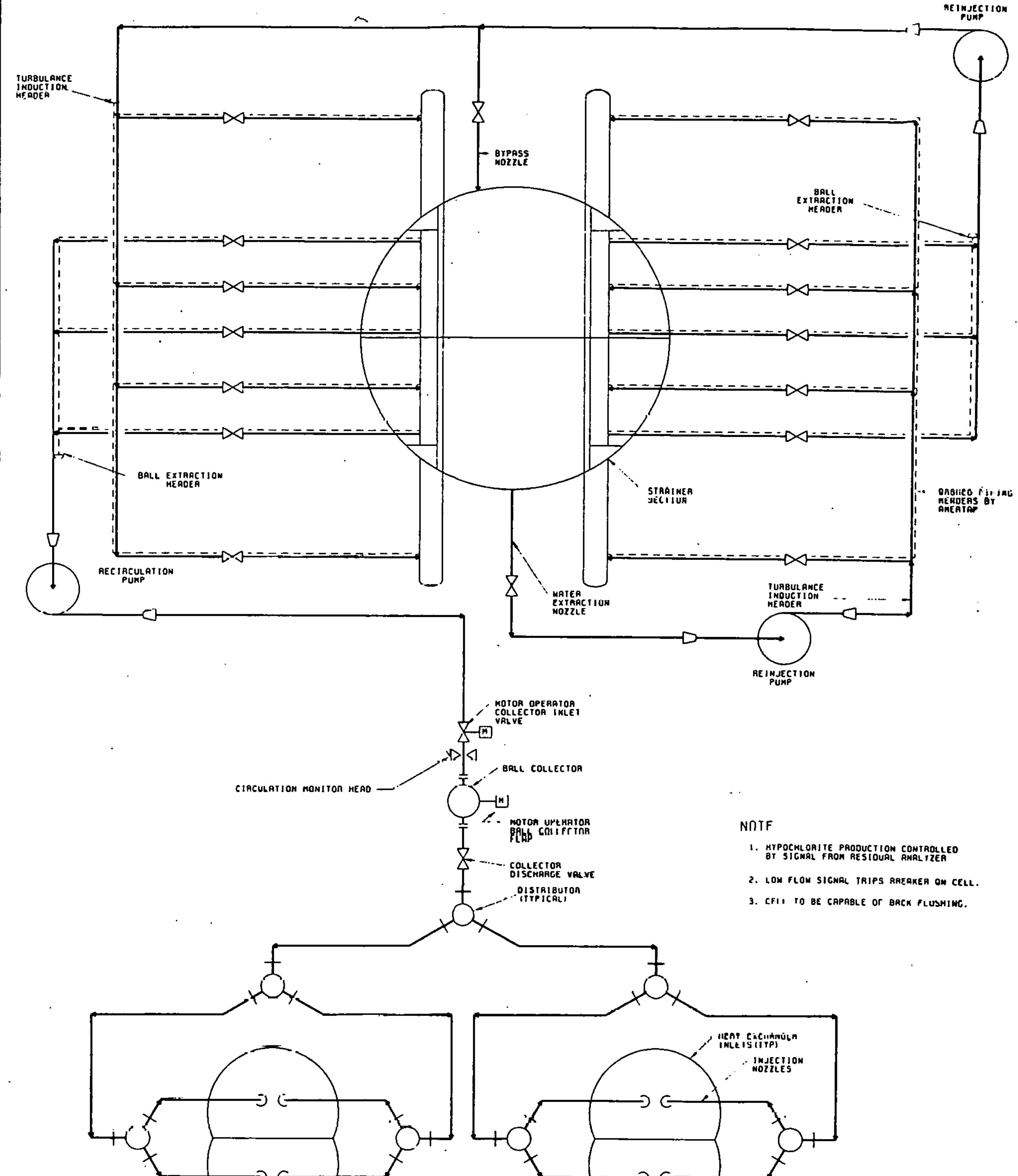
10 MWE INTEGRAL PLATFORM
DIESEL GENERATOR SYSTEMS FLOW DIAGRAM
RA1-M-54



CHLORINATION SYSTEM



MECHANICAL TUBE CLEANING SYSTEM

(CONVENTIONAL AMERTAP SYSTEM)

NOTE

1. HYPOCHLORITE PRODUCTION CONTROLLED BY SIGNAL FROM RESIDUAL ANALYZER
2. LOW FLOW SIGNAL TRIPS BREAKER ON CELL.
3. CELL TO BE CAPABLE OF BACK FLUSHING.

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CONTRACT NO. EG-77-C-03-1560

10 MWE INTEGRAL PLATFORM

BIOFOULING SYSTEM FLOW DIAGRAM

CHLORINATION SYSTEM, MECHANICAL TUBE CLEANING (AMERTAP) SYSTEM

INFORMATION

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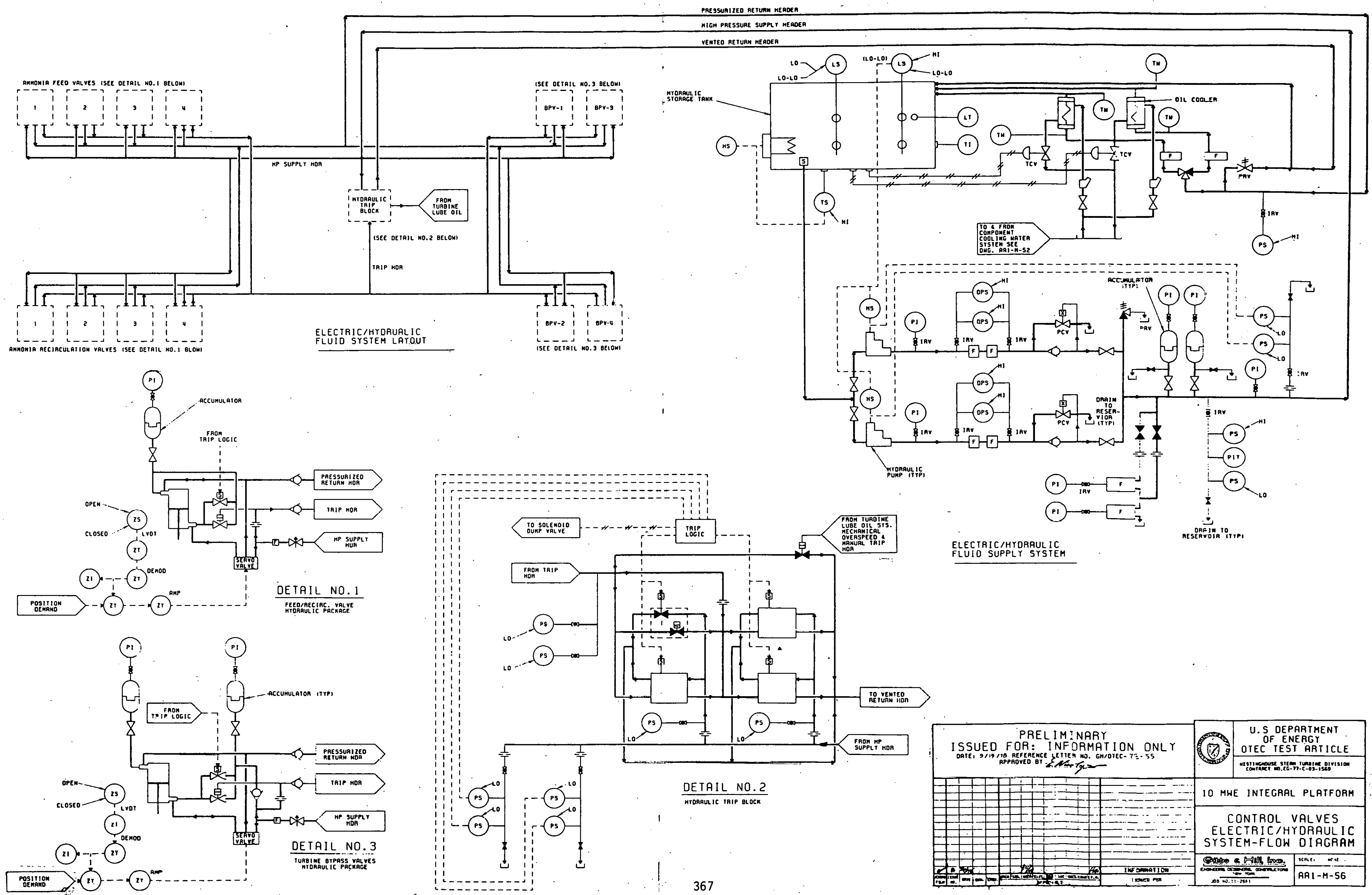
Gibbs & Hill, Inc.
ENGINEERS, DESIGNERS, CONSTRUCTORS
NEW YORK
JOB NO. 11-2661

SCALE: NONE

AA1-M-55



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WESTINGHOUSE STEAM TURBINE DIVISION CONTRACT NO. EG-77-C-03-1569

10 MWE INTEGRAL PLATFORM

CONTROL VALVES
ELECTRIC/HYDRAULIC
SYSTEM-FLOW DIAGRAM

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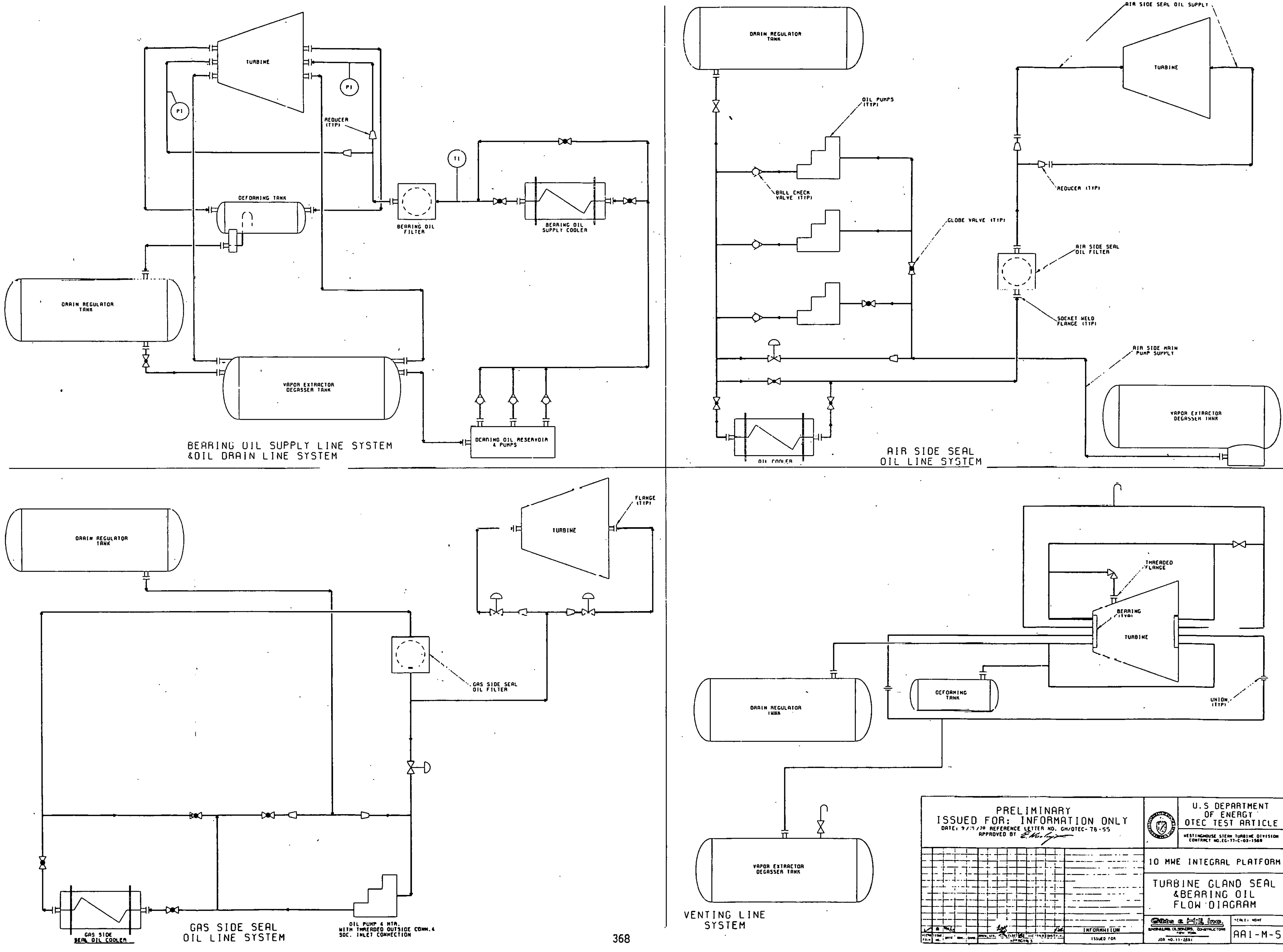
AA1-M-56



TURBINE
PI
REDUCER (TYP)
TI
DEFOAMING TANK
BEARING OIL FILTER
BEARING OIL SUPPLY COOLER
DRAIN REGULATOR TANK
VAPOR EXTRACTOR DEGASSER TANK
BEARING OIL RESERVOIR & PUMPS
BEARING OIL SUPPLY LINE SYSTEM
&OIL DRAIN LINE SYSTEM
AIR SIDE SEAL OIL SUPPLY
OIL PUMPS (TYP)
BALL CHECK VALVE (TYP)
GLOBE VALVE (TYP)
AIR SIDE SEAL OIL FILTER
SOCKET WELD FLANGE (TYP)
AIR SIDE MAIN PUMP SUPPLY
OIL COOLER
AIR SIDE SEAL
OIL LINE SYSTEM
FLANGE (TYP)
GAS SIDE SEAL OIL FILTER
GAS SIDE SEAL OIL COOLER
GAS SIDE SEAL
OIL LINE SYSTEM
OIL PUMP & MTR. WITH THREADED OUTSIDE CONN. & SOC. INLET CONNECTION
THREADED FLANGE
BEARING (TYP)
UNION (TYP)
VENTING LINE
SYSTEM
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WESTINGHOUSE STEAM TURBINE DIVISION
CONTRACT NO.EG-77-C-03-1569
10 MWE INTEGRAL PLATFORM
TURBINE GLAND SEAL
&BEARING OIL
FLOW DIAGRAM
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ENGINEERS DESIGNERS CONSTRUCTORS
NEW YORK
JOB NO. 11-2661
SCALE: NONE
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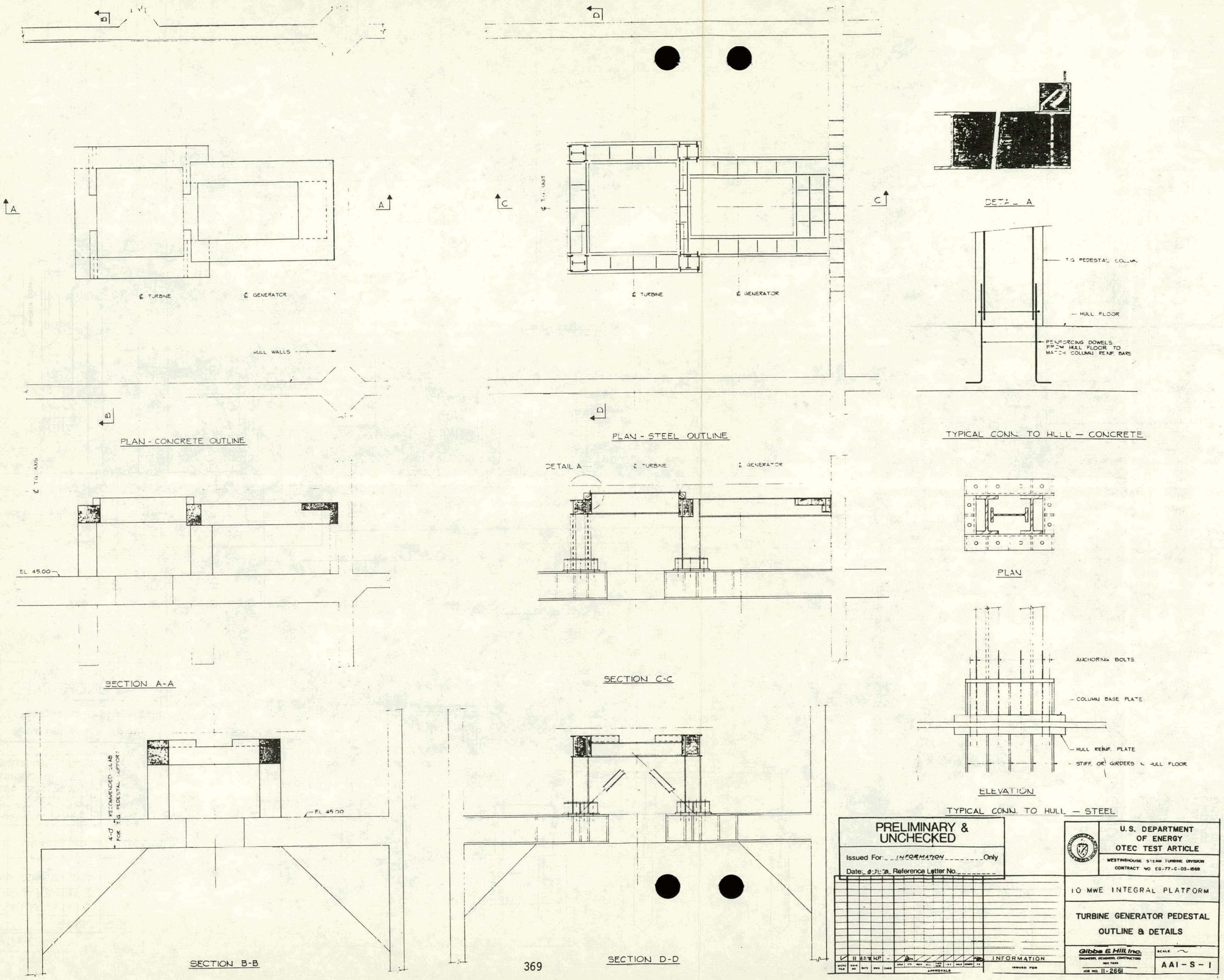
PLAN - CONCRETE OUTLINE
℄ TURBINE
℄ GENERATOR
HULL WALLS
PLAN - STEEL OUTLINE
DETAIL A
T.G. PEDESTAL COLUMN
HULL FLOOR
REINFORCING DOWELS FROM HULL FLOOR TO MATCH COLUMN REINF. BARS
TYPICAL CONN. TO HULL — CONCRETE
SECTION A-A
EL 45.00
SECTION C-C
PLAN
ANCHORING BOLTS
COLUMN BASE PLATE
HULL REINF. PLATE
STIFF. OR GIRDERS & HULL FLOOR
ELEVATION
TYPICAL CONN. TO HULL — STEEL
SECTION B-B
SECTION D-D
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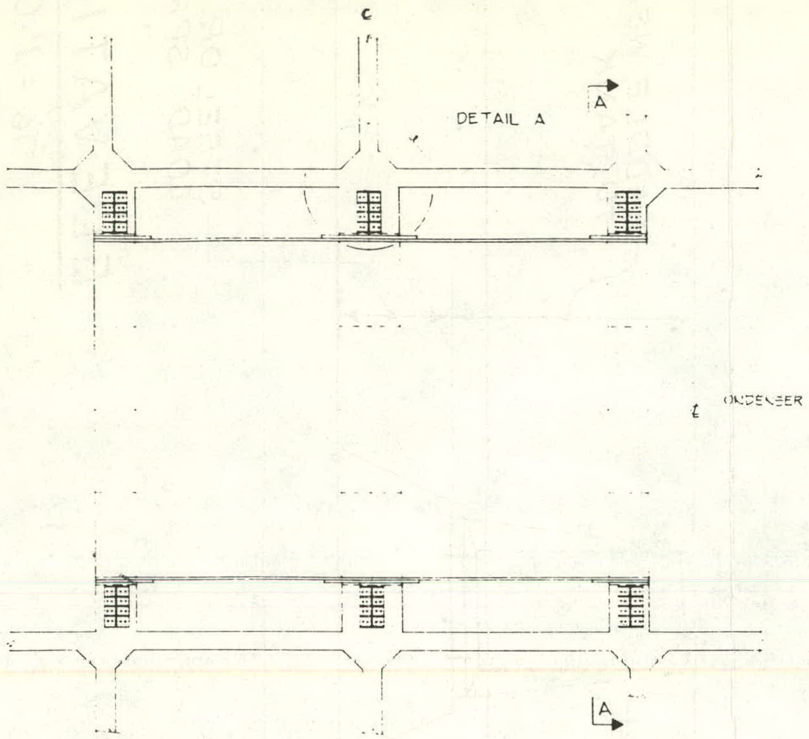
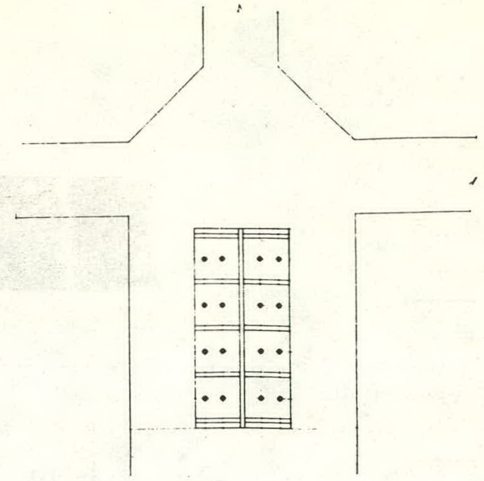
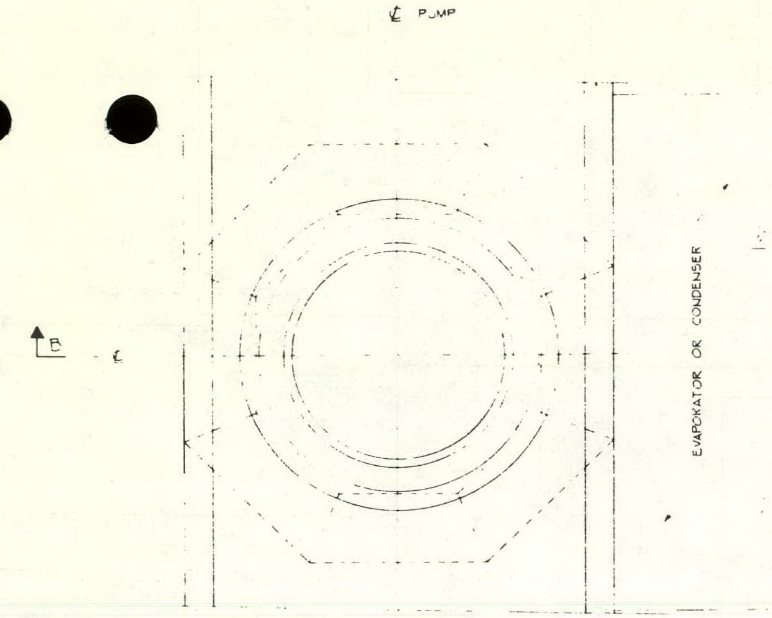
WESTINGHOUSE STEAM TURBINE DIVISION
CONTRACT NO EG-77-C-03-1569
10 MWE INTEGRAL PLATFORM
TURBINE GENERATOR PEDESTAL
OUTLINE & DETAILS
Gibbs & Hill Inc.
ENGINEERS, DESIGNERS, CONSTRUCTORS
NEW YORK
JOB NO. 11-2661
SCALE
AAI-S-1



CONDENSER SUPPORT - PLAN LOOKING UP

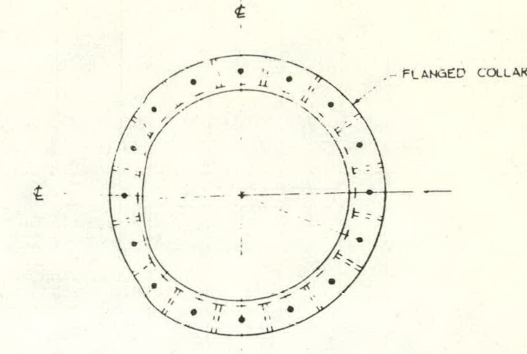


DETAIL A

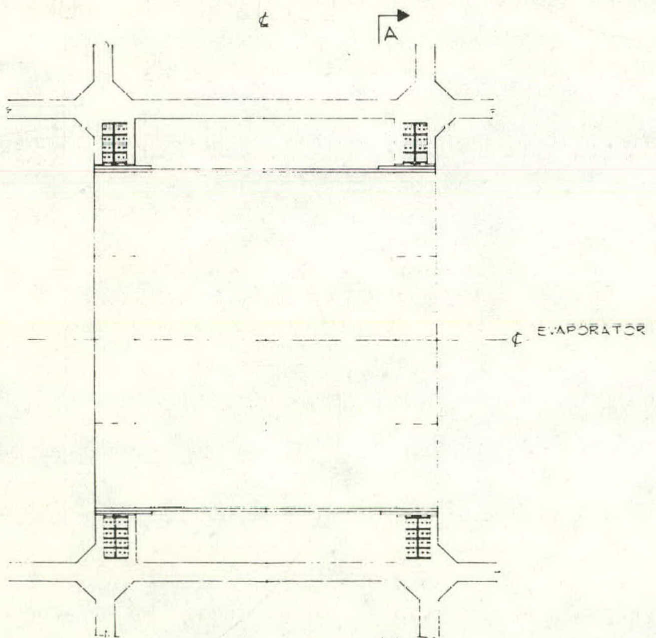


SEAWATER PUMP SUPPORT PLAN

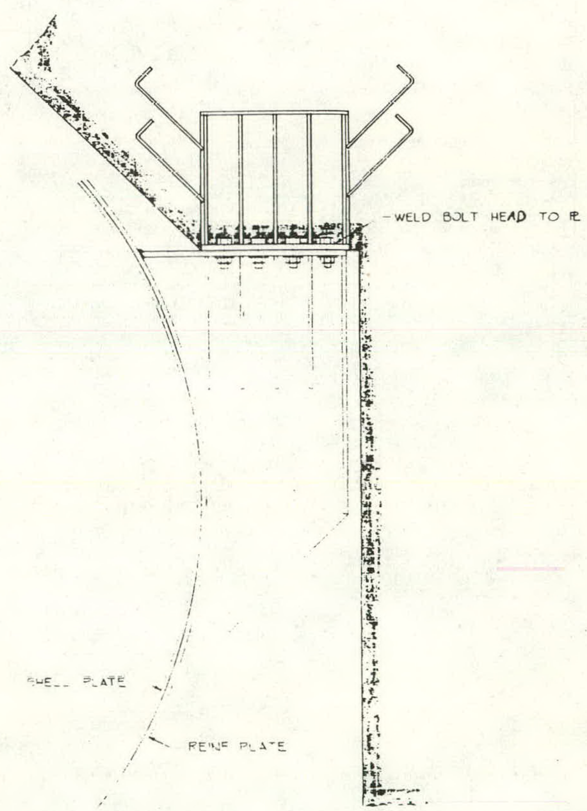
FOR WARM WATER AS SHOWN. FOR COLD WATER OPP HAND



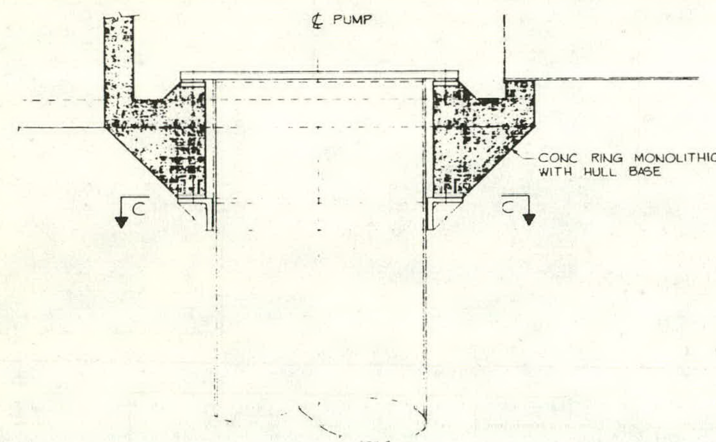
SECTION C-C



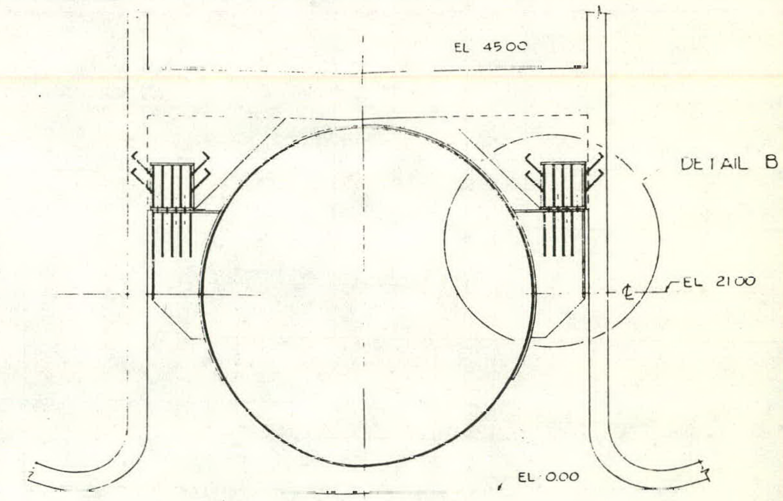
EVAPORATOR SUPPORT - PLAN LOOKING UP



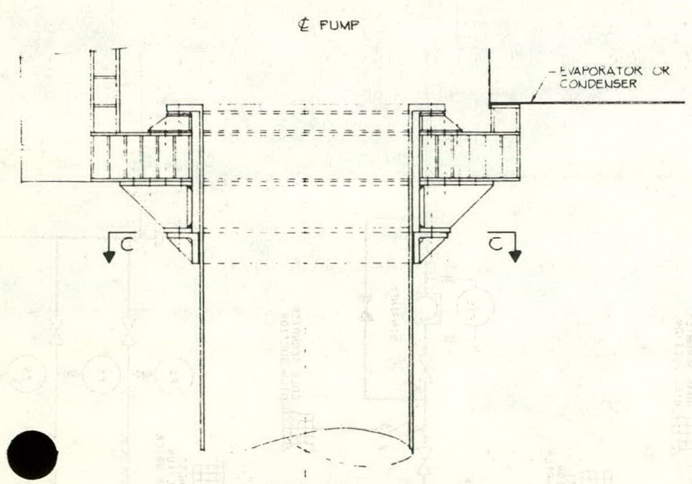
DETAIL B



SECTION B-B -CONCRETE



SECTION A-A



SECTION B-B -STEEL

PRELIMINARY & UNCHECKED

Issued For: INFORMATION Only

Date: 8-21-78 Reference Letter No.

U.S. DEPARTMENT OF ENERGY
OTEC TEST ARTICLE

WESTINGHOUSE STEAM TURBINE DIVISION
CONTRACT NO. EG 77 C 03 1569

10 MWE INTEGRAL PLATFORM

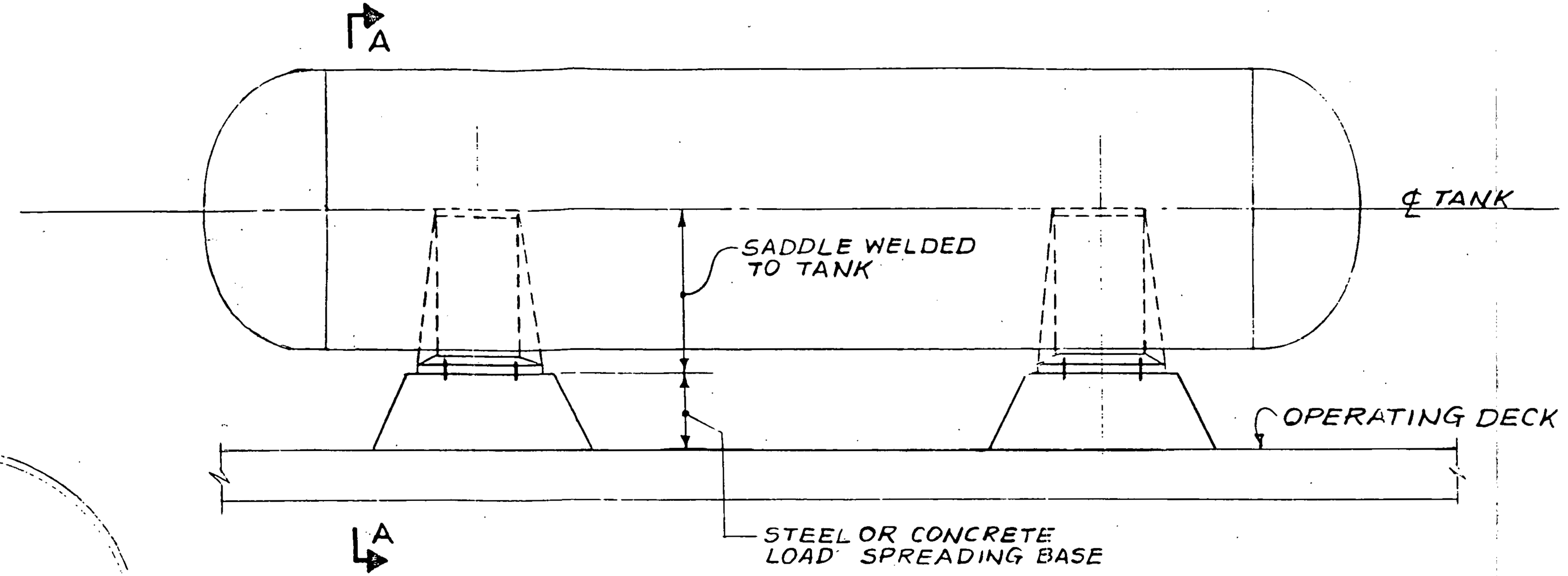
HEAT EXCHANGERS & SEAWATER PUMPS SUPPORT DETAILS

Gibbs & Hill, Inc.
ENGINEERS, DESIGNERS, CONSTRUCTORS

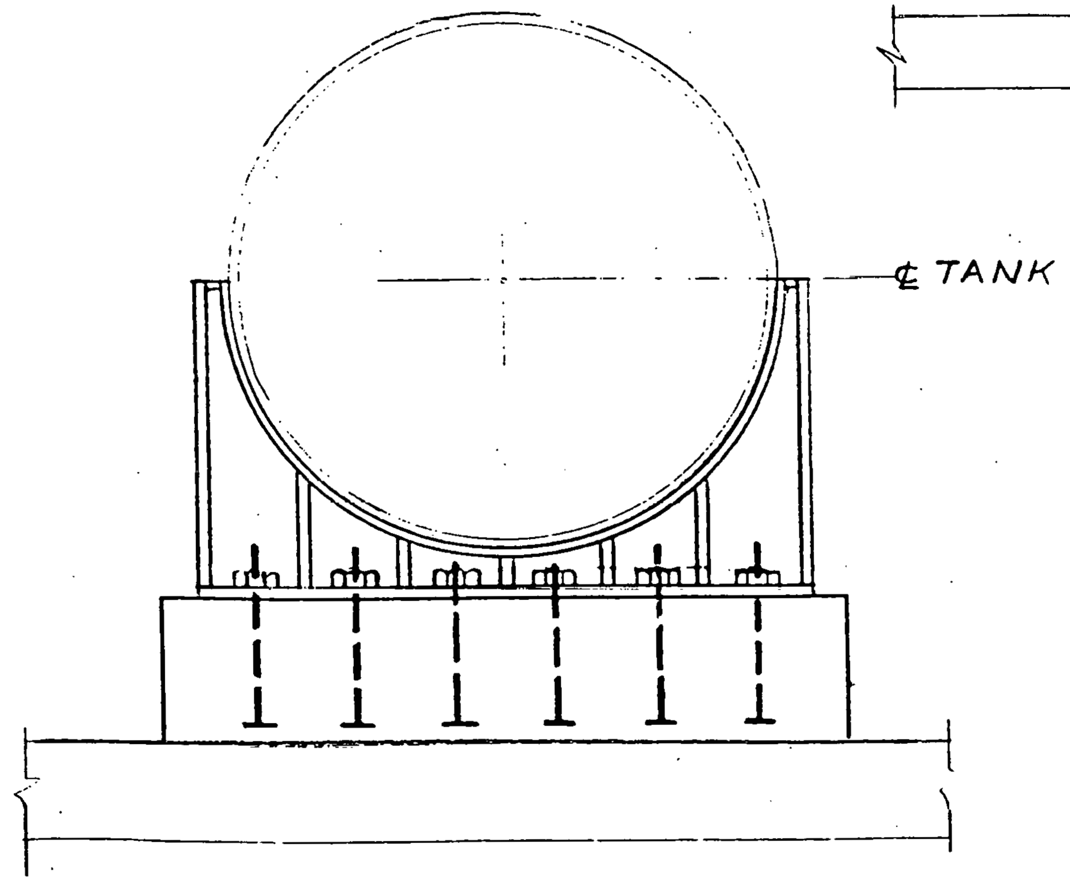
SCALE: ~

JOB NO. 11-2661

AAI - S - 2



ELEVATION
3/16" = 1'-0"



SECTION A-A
1/4" = 1'-0"

PRELIMINARY &
UNCHECKED

Issued For: INFORMATION Only

Date: 8-21-78 Reference Letter No. ________

MK. NO. FKM	ISSUE NO	DATE	DWN	CHKD	APPROVALS	ISSUED FOR
✓	R	8-21-78	M.H	–		INFORMATION

U.S. DEPARTMENT OF ENERGY
OTEC TEST ARTICLE
WESTINGHOUSE STEAM TURBINE DEVISION
CONTRACT NO. EG-77-C-03-1569

10 MWE INTEGRAL PLATFORM

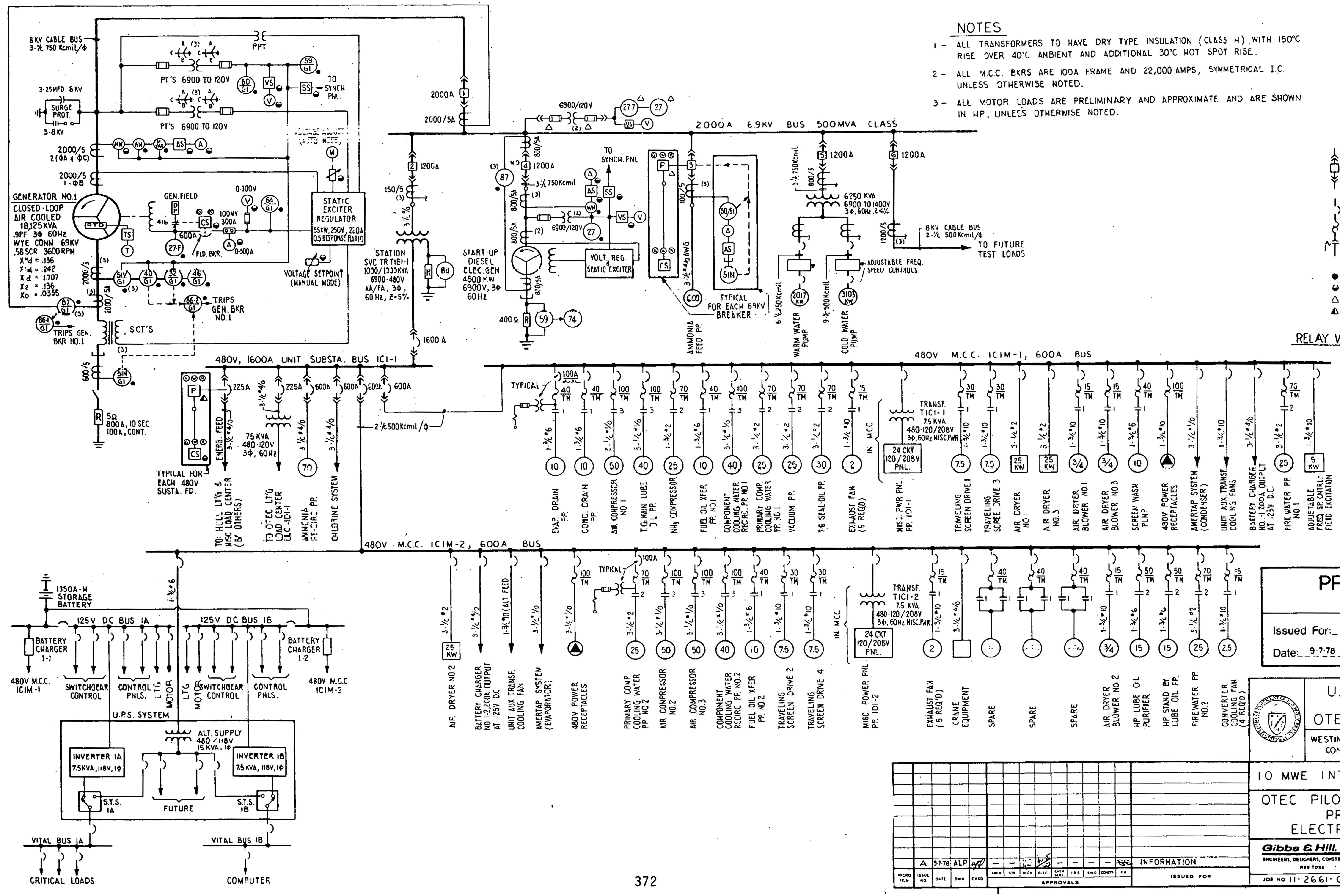
MISCELLANEOUS TANK SUPPORTS

Gibbs & Hill, Inc.
ENGINEERS DESIGNERS CONSTRUCTORS
NEW YORK

JOB NO. 11-2661

SCALE.- AS NOTED

AAI - S - 3



NOTES

1 - ALL TRANSFORMERS TO HAVE DRY TYPE INSULATION (CLASS H), WITH 150°C RISE OVER 40°C AMBIENT AND ADDITIONAL 30°C HOT SPOT RISE.

2 - ALL M.C.C. BKRS ARE 100A FRAME AND 22,000 AMPS, SYMMETRICAL I.C. UNLESS OTHERWISE NOTED.

3 - ALL MOTOR LOADS ARE PRELIMINARY AND APPROXIMATE AND ARE SHOWN IN HP, UNLESS OTHERWISE NOTED.

LEGEND

OR	BREAKER (WITHDRAWABLE TYPE)
100 / 50 TM / 2	NEMA SIZE 2 MAGNETIC CONTACTOR WITH 100A FIXED FRAME BREAKER HAVING THERMAL MAGNETIC (TM) TRIP SET AT 50A AND CONTINUOUS SETTING TO BE ADDED LATER.
● —	MAIN CONTROL PANEL (REAR)
◒ —	MAIN CONTROL PANEL (FRONT)
△ —	6.9KV SWITCHGEAR
▲ —	480V SWITCHGEAR

RELAY WITH DEVICE FUNCTION NUMBER

40	LOSS OF FIELD
60	VOLTAGE BALANCE
59	OVEREXCITATION
32	REVERSE POWER
87	DIFFERENTIAL CURRENT
51N	GROUND OVERCURRENT TIME DELAY
51V	PHASE OVERCURRENT TIME DELAY
50	PHASE OVERCURRENT-INSTANTANEOUS
64	GROUND VOLTAGE
27	UNDERVOLTAGE
86	TRIP & LOCKOUT
46	NEGATIVE SEQUENCE
74	ALARM RELAY

PRELIMINARY

Issued For: INFORMATION Only

Date: 9-7-78 Reference Letter No.

U. S. DEPARTMENT OF ENERGY OTEC TEST ARTICLE

WESTINGHOUSE STEAM TURBINE DIVISION CONTRACT NO. EG-77-C-03-1569

10 MWE INTEGRAL PLATFORM

OTEC PILOT PLANT MODULE PRELIMINARY ELECTRICAL ONE LINE

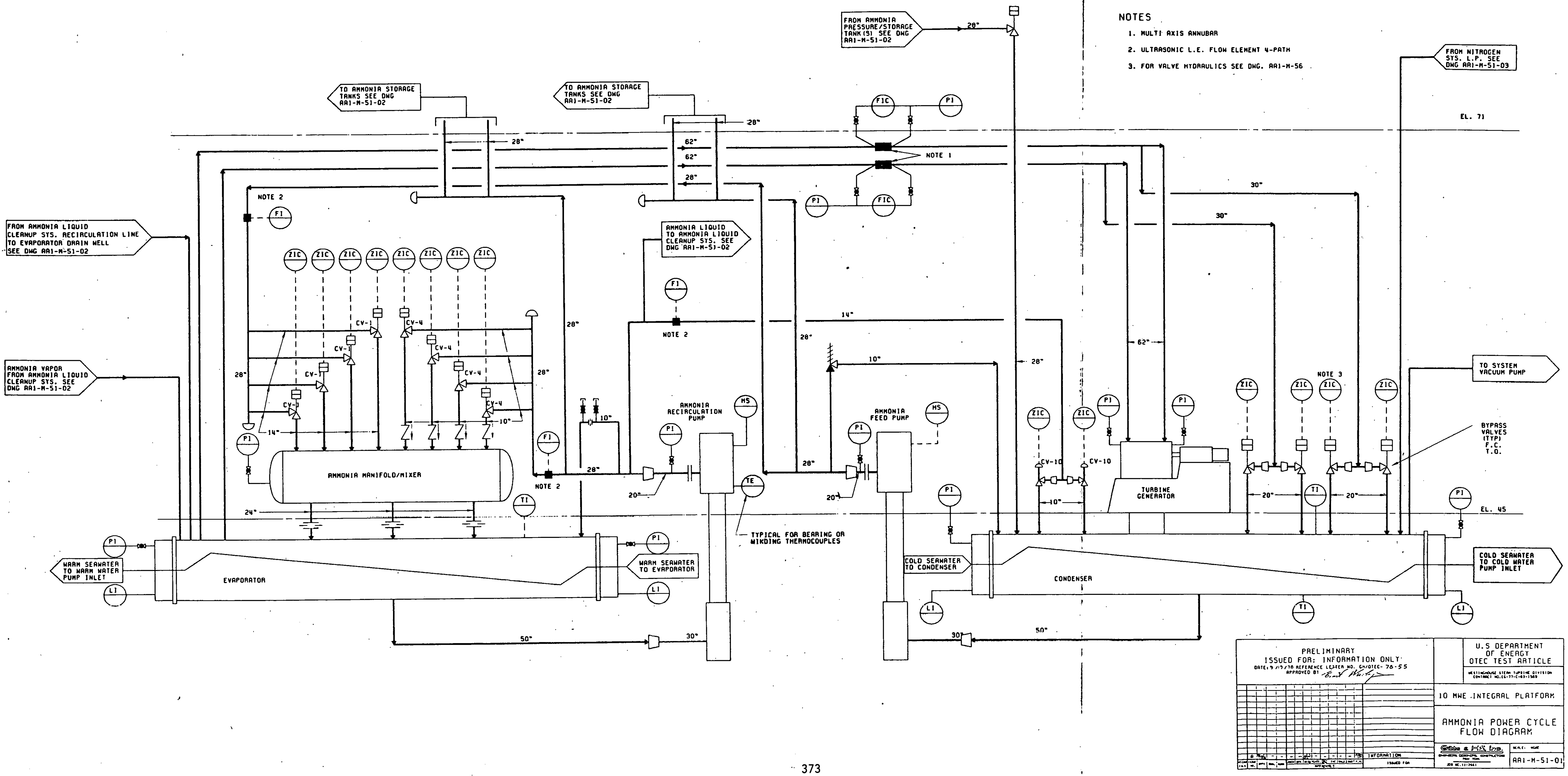
ISSUE NO	DATE	DWN	CHKD		ISSUED FOR
A	9-7-78	ALP			INFORMATION

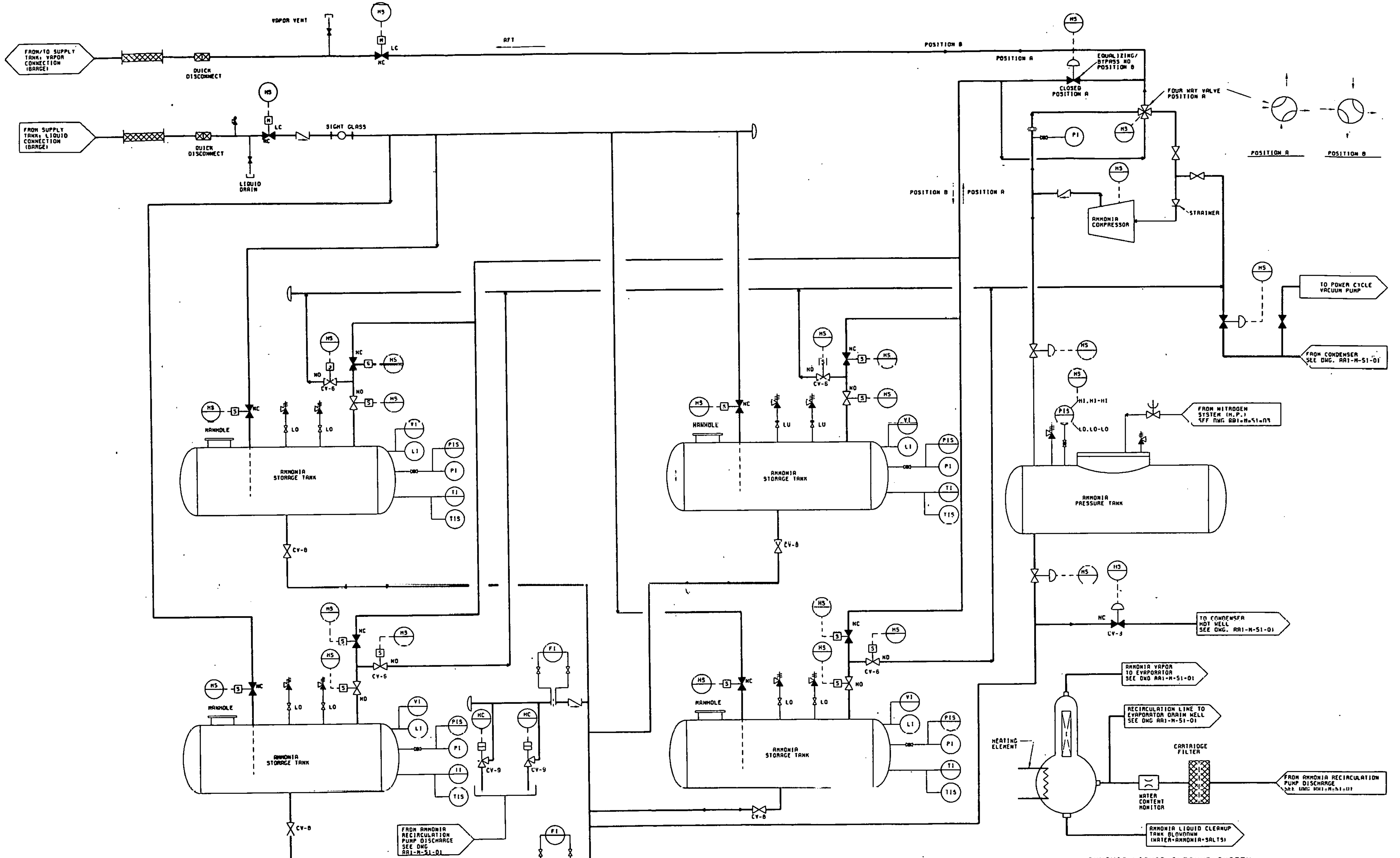
Gibbs & Hill, Inc. ENGINEERS, DESIGNERS, CONSTRUCTORS NEW YORK

SCALE: NONE

JOB NO 11-2661-004

AAI-E-10


NOTES
1. MULTI AXIS ANNUBAR
2. ULTRASONIC L.E. FLOW ELEMENT 4-PATH
3. FOR VALVE HYDRAULICS SEE DWG. AA1-M-56
FROM AMMONIA PRESSURE/STORAGE TANK(S) SEE DWG AA1-M-51-02
TO AMMONIA STORAGE TANKS SEE DWG AA1-M-51-02
TO AMMONIA STORAGE TANKS SEE DWG AA1-M-51-02
FROM NITROGEN SYS. L.P. SEE DWG AA1-M-51-03
EL. 71
NOTE 1
NOTE 2
FROM AMMONIA LIQUID CLEANUP SYS. RECIRCULATION LINE TO EVAPORATOR DRAIN WELL SEE DWG AA1-M-51-02
AMMONIA LIQUID TO AMMONIA LIQUID CLEANUP SYS. SEE DWG AA1-M-51-02
AMMONIA VAPOR FROM AMMONIA LIQUID CLEANUP SYS. SEE DWG AA1-M-51-02
ZIC
CV-1
CV-4
CV-10
FI
FIC
PI
TI
LI
MS
TE
AMMONIA MANIFOLD/MIXER
AMMONIA RECIRCULATION PUMP
AMMONIA FEED PUMP
TURBINE GENERATOR
TO SYSTEM VACUUM PUMP
NOTE 3
BYPASS VALVES (TYP) F.C. T.O.
EL. 45
TYPICAL FOR BEARING OR WINDING THERMOCOUPLES
WARM SEAWATER TO WARM WATER PUMP INLET
WARM SEAWATER TO EVAPORATOR
EVAPORATOR
COLD SEAWATER TO CONDENSER
CONDENSER
COLD SEAWATER TO COLD WATER PUMP INLET
28"
62"
30"
14"
10"
20"
24"
50"
PRELIMINARY
ISSUED FOR: INFORMATION ONLY
U.S DEPARTMENT OF ENERGY OTEC TEST ARTICLE
10 MWE INTEGRAL PLATFORM
AMMONIA POWER CYCLE FLOW DIAGRAM
Gibbs & Hill Inc.
AA1-M-51-01



NOTE

1. RELIEF VALVES WILL BE MANIFOLDED.

PRELIMINARY
ISSUED FOR: INFORMATION ONLY
DATE: 9/19/78 REFERENCE LETTER NO. GH/OTEC- 78-55
APPROVED BY

U.S DEPARTMENT OF ENERGY
OTEC TEST ARTICLE

WESTINGHOUSE STEAM TURBINE DIVISION
CONTRACT NO.EG-77-C-03-1589

10 MWE INTEGRAL PLATFORM

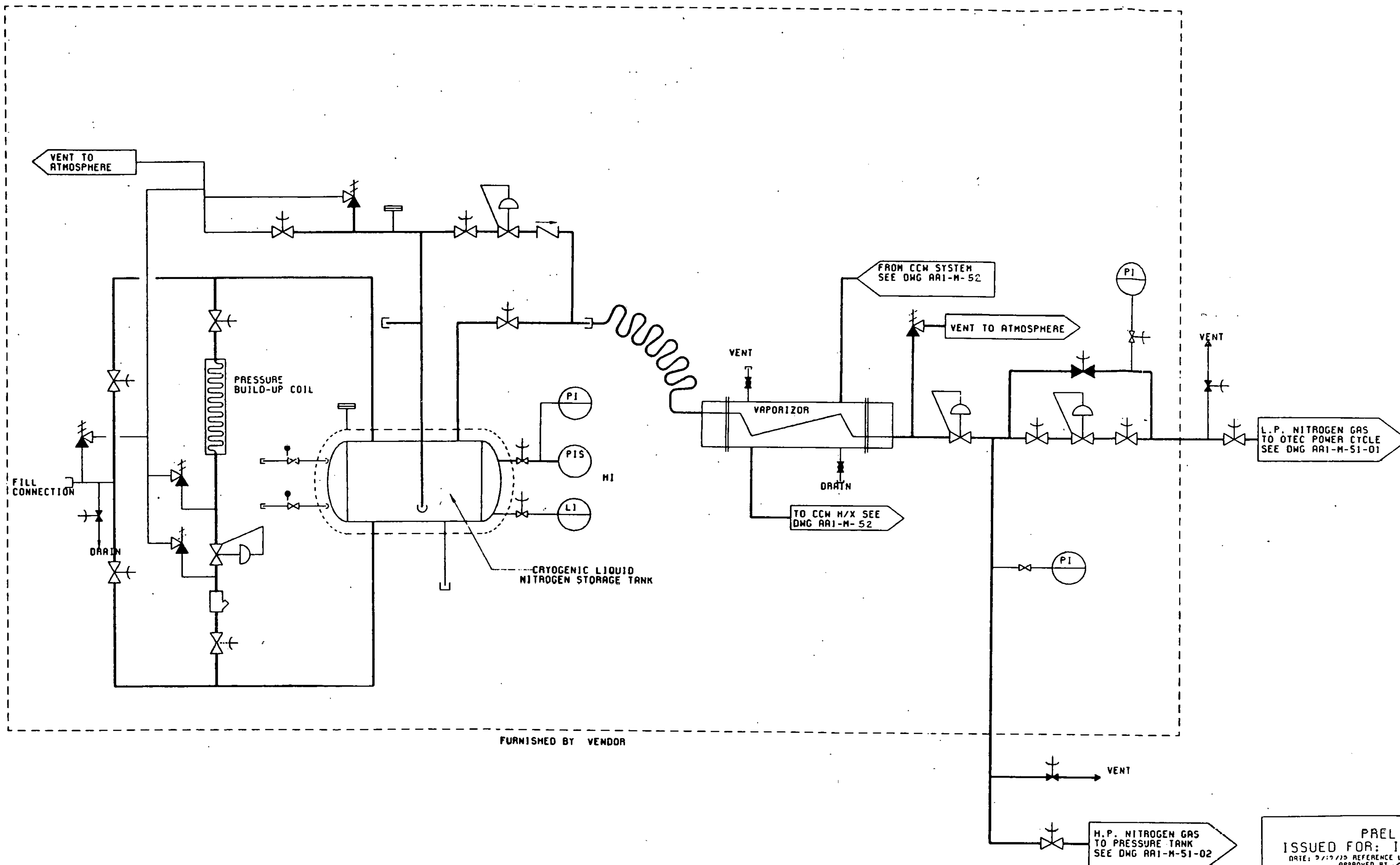
AMMONIA STORAGE, HANDLING AND PURIFICATION SYSTEM FLOW DIAGRAM

INFORMATION
ISSUED FOR

Gibbs & Hill, Inc.
ENGINEERS DESIGNERS CONSTRUCTORS
NEW YORK
JOB NO. 11-2681

SCALE: NONE

AA1-M-51-02



PRELIMINARY
ISSUED FOR: INFORMATION ONLY
DATE: 9/19/79 REFERENCE LETTER NO. GM/OTEC-78-55
APPROVED BY

U.S DEPARTMENT OF ENERGY
OTEC TEST ARTICLE
WESTINGHOUSE STEAM TURBINE DIVISION
CONTRACT NO. EG-77-C-03-1569

10 MWE INTEGRAL PLATFORM

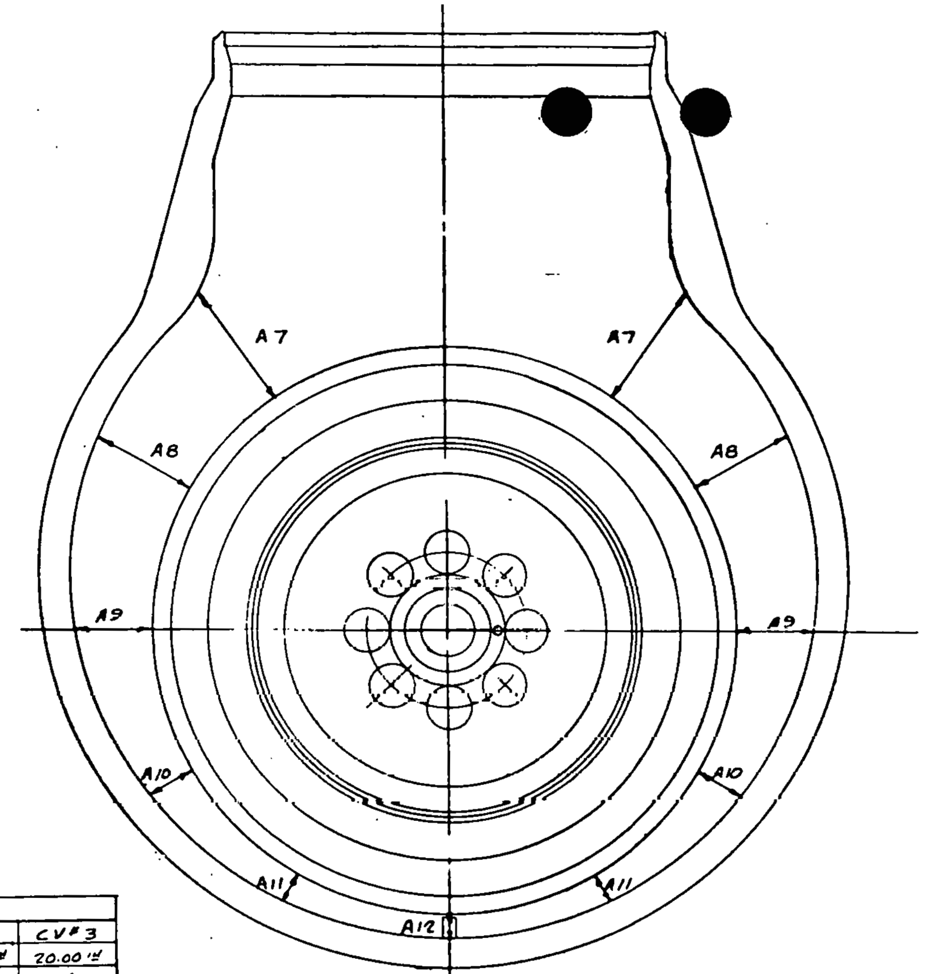
NITROGEN SYSTEM FLOW DIAGRAM

Gibbs & Hill, Inc.
ENGINEERS, DESIGNERS, CONSTRUCTORS
NEW YORK
JOB NO. 11-2661
SCALE: NONE
AA1-M-51-C3

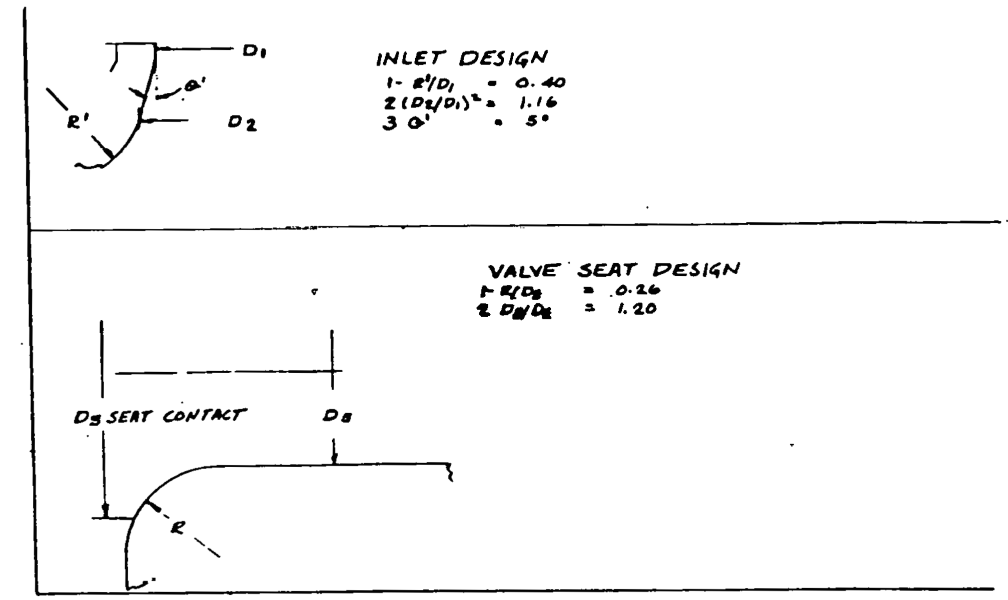
INFORMATION
ISSUED FOR

AREA/RATIO PRESSURE DROP - VOLUTE VALVE

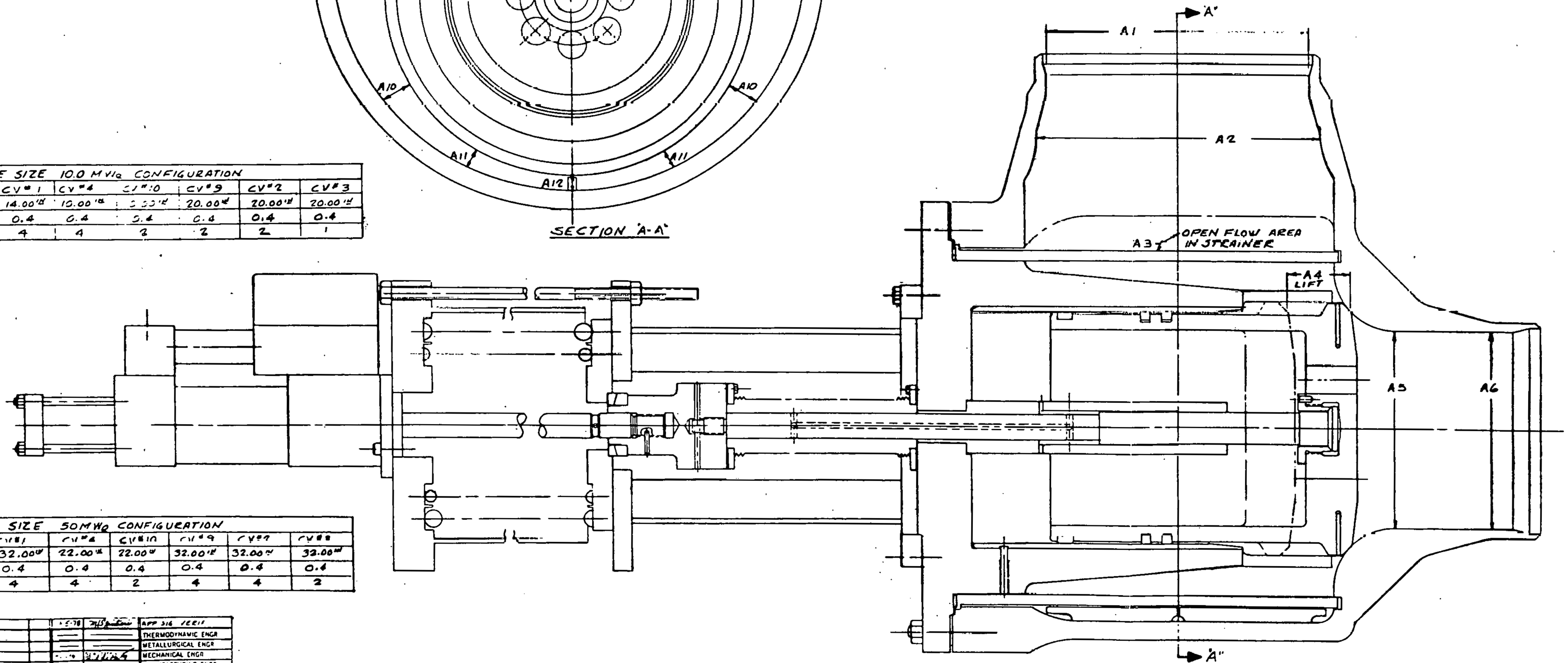
AREA	RATIO
A1/A6	1.45
A2/A6	1.60
A3/A6	4.10
A4/A6	1.90
A5/A6	1.00
A6/A5	1.00
A7/A1	.56
A8/A1	.44
A9/A1	.33
A10/A1	.21
A11/A1	.14
A12/A1	.00



SECTION 'A-A'



VALVE SIZE 10.0 MWe CONFIGURATION						
VALVE LOCATIONS	CV#1	CV#4	CV#10	CV#9	CV#2	CV#3
Ds, THROAT DIAMETER	14.00"Ø	10.00"Ø	[illegible]	20.00"Ø	20.00"Ø	20.00"Ø
MAX LIFT/THROAT DIA.	0.4	0.4	0.4	0.4	0.4	0.4
NO OF VALVES	4	4	2	2	2	1



VALVE SIZE 50MWe CONFIGURATION						
VALVE LOCATIONS	CV#1	CV#4	CV#10	CV#9	CV#7	CV#8
Ds, THROAT DIAMETER	32.00"Ø	22.00"Ø	22.00"Ø	32.00"Ø	32.00"Ø	32.00"Ø
MAX LIFT/THROAT DIA.	0.4	0.4	0.4	0.4	0.4	0.4
NO OF VALVES	4	4	2	4	4	2

APP SIG VERIF	
THERMODYNAMIC ENGR	
METALLURGICAL ENGR	
MECHANICAL ENGR	
MANUFACTURING ENGR	
CONTROL ENGR	
PROJECT ENGR	
DRAFTING MGR	
LAYOUT DRAFTSMAN	
SUB 5 DATE / INIT. / SUB 4 DATE / INIT. / SUB 3 DATE / INIT / SUB 2 DATE / INIT. / SUB 1 DATE / SIGNATURE	APPROVED BY:

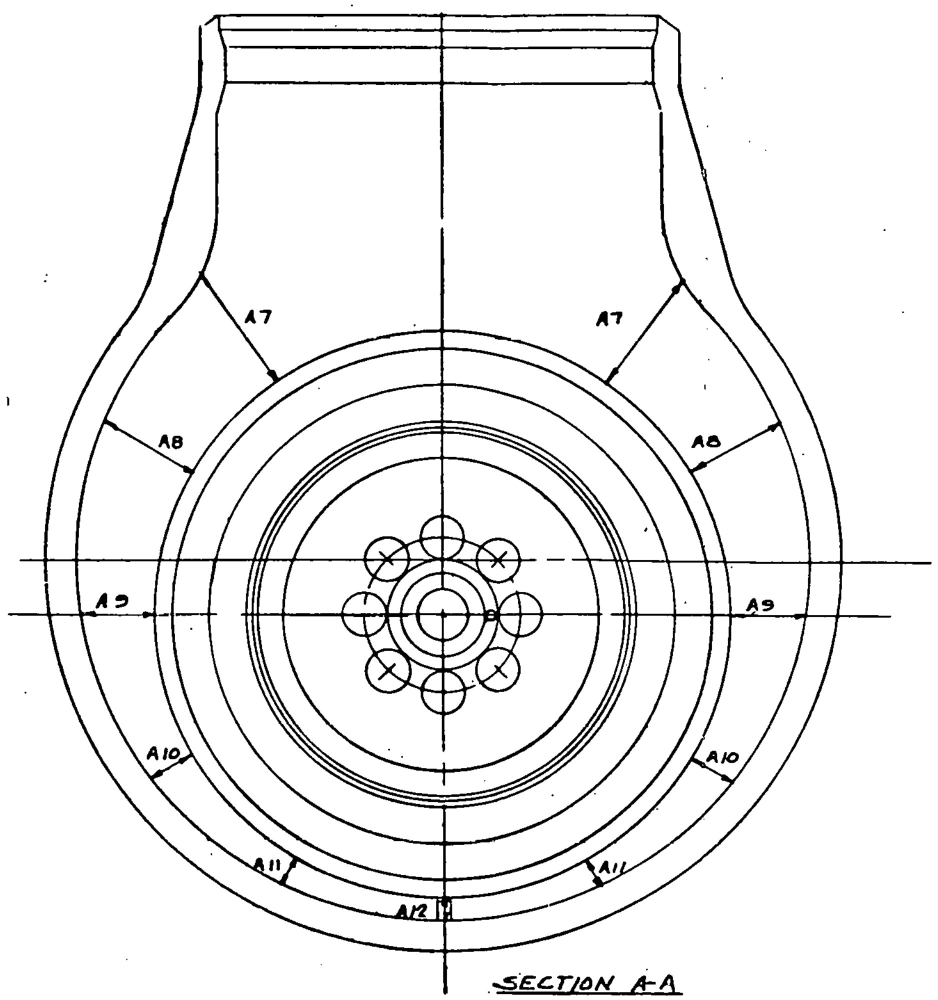
Westinghouse Electric Corporation
STEAM TURBINE DIVISION, LESTER, PA. U.S.A. — ISSUE DATE

APPLICATION OTEC #1 — TITLE LIQUID AMMONIA CONTROL VALVES — LAYOUT NO. 746J479

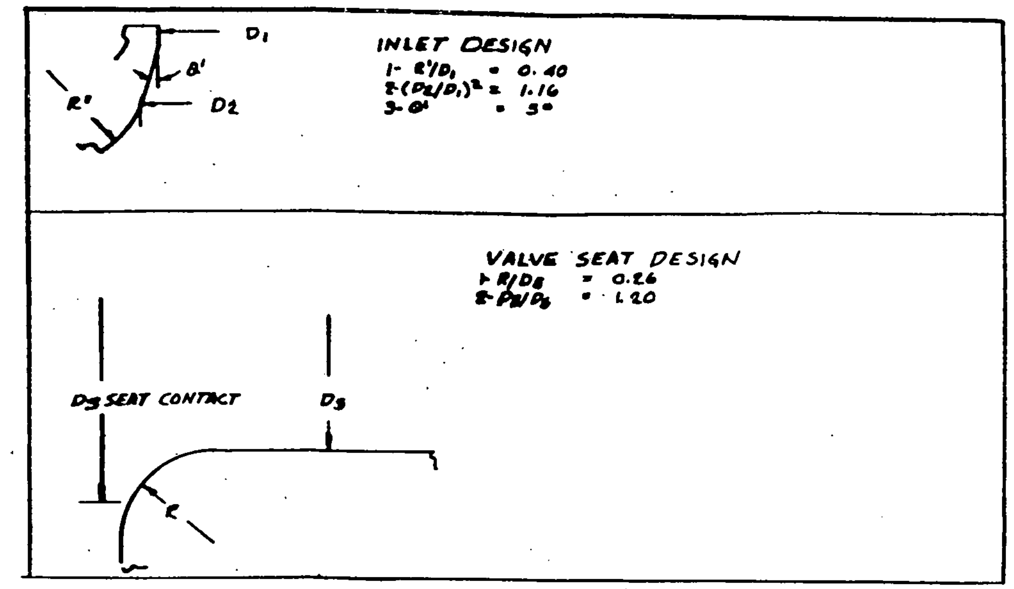
S.O. AA123100 | ORIG. L.O. SCALE =12.00 | CODE NO. | DISTR. CODE 397 LA8 000 | SHEET 1 OF

AREA/RATIO PRESSURE DROP-VOLUTE VALVE

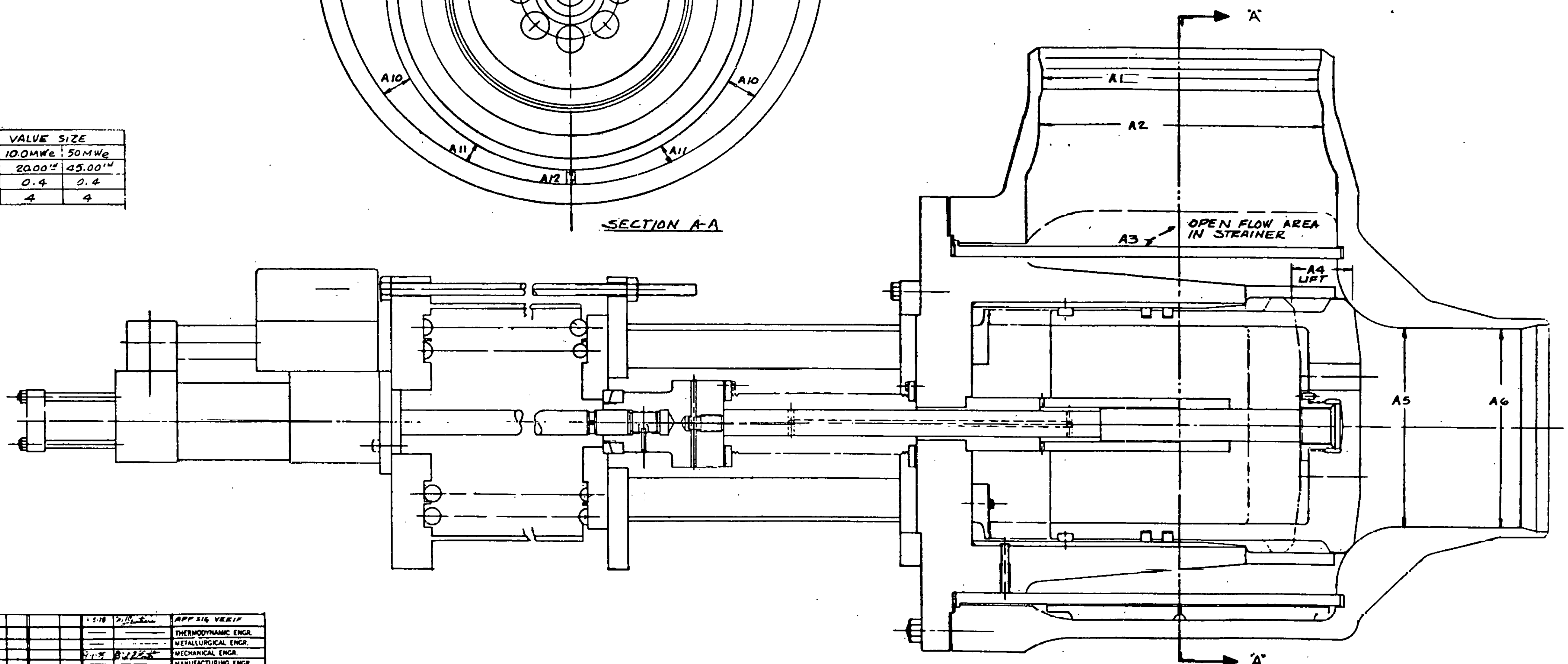
AREA	RATIO
A1/A6	1.45
A2/A6	1.60
A3/A6	4.10
A4/A6	1.90
A5/A6	1.00
A6/A5	1.00
A7/A1	.56
A8/A1	.44
A9/A1	.33
A10/A1	.21
A11/A1	.14
A12/A1	.0



SECTION A-A



TURBINE BYPASS VALVE SIZE		
CONFIGURATION	10.0MWe	50MWe
DS, THROAT DIAMETER	20.00"	45.00"
MAX LIFT/THROAT DIA	0.4	0.4
NO. OF VALVES	4	4



APP SIG VERIF	
THERMODYNAMIC ENGR.	
METALLURGICAL ENGR.	
MECHANICAL ENGR.	
MANUFACTURING ENGR.	
CONTROL ENGR.	
PROJECT ENGR.	
DRAFTING MGR.	
LAYOUT DRAFTSMAN	
APPROVED BY:	

SUB 5 DATE | INIT. | SUB 4 DATE | INIT. | SUB 3 DATE | INIT. | SUB 2 DATE | INIT | SUB 1 DATE | SIGNATURE

Westinghouse Electric Corporation
STEAM TURBINE DIVISION, LESTER, PA. U.S.A.

ISSUE DATE 7/ /78

APPLICATION: OTEC-1

TITLE: TURBINE BYPASS VALVES AMMONIA VAPOR

LAYOUT NO. 746J480

S.O.AA123100 | ORIG. L.O. SCALE —12.00 | CODE NO. | DISTR. CODE | SHEET OF