DOE/SF/11109--T15

M+R F-11098-2

ERDA CONTRACT NO. E (C4-3)-1109

SOLAR PILOT PLANT

Phase I

MASTER

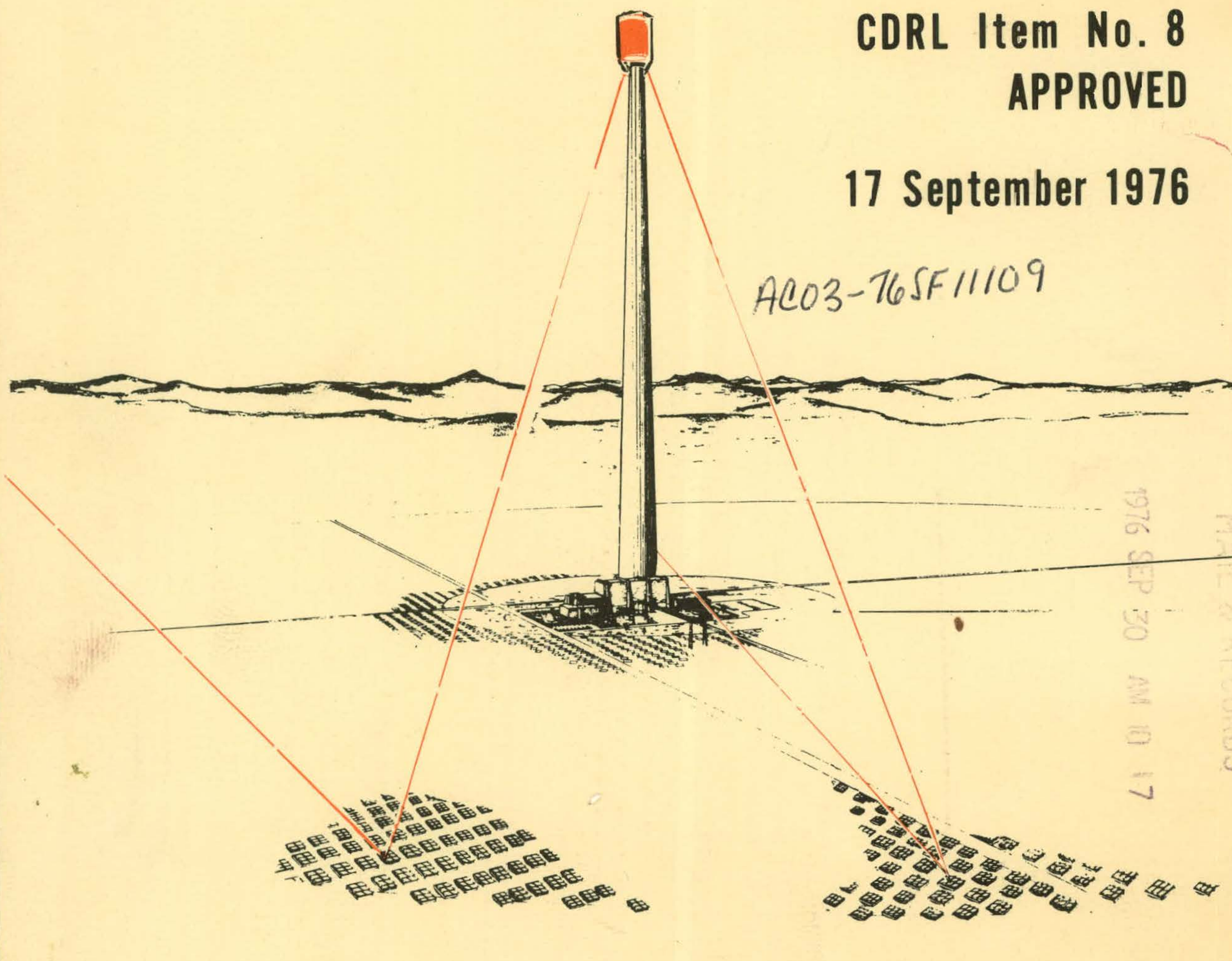
DETAILED DESIGN REPORT

Thermal Storage Subsystem Research Experiment

CDRL Item No. 8
APPROVED

17 September 1976

AC03-76SF11109



RECEIVED MAIL & RECORDS 1976 SEP 30 AM 10 17

HONEYWELL INC. **BLACK & VEATCH**

F3419-DR-204A

NOTICE

THIS REPORT IS ILLEGIBLE TO A DEGREE THAT PRECLUDES SATISFACTORY REPRODUCTION

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DOE/SF/11109--T15

Honeywell

ERDA Contract No. E(04-3)-1109

17 September 1976

DOE/SF/11109--T15

DE82 011800

SOLAR PILOT PLANT

PHASE I

NOTICE

THIS REPORT IS ILLEGIBLE TO A DEGREE THAT PRECLUDES SATISFACTORY REPRODUCTION

DETAILED DESIGN REPORT

Thermal Storage Subsystem Research Experiment

CDRL Item No. 8

APPROVED

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Systems & Research Center

2600 RIDGWAY PARKWAY,

MINNEAPOLIS, MINNESOTA 55413

40454 Printed in U.S.A. F3419-DR-204A

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

FOREWORD

This is the final submittal of the Solar Pilot Plant Thermal Storage Subsystem Research Experiment Detailed Design Report (DDR) per CDRL Item 8 under ERDA Contract E(04-3)-1109.

The technical contents of this document have been approved by ERDA. Corrections and additions to the original document (submitted 22 June 1976) are indicated by a vertical line in the margin adjacent to the change.

SECTION I

SECTION I
INTRODUCTION

Introduction

PURPOSE AND CONTENT

This report presents the Thermal Storage Test Item and associated test facilities and equipment at the level of detail required to show the ability of the design to meet the program objectives and to demonstrate that satisfactory interfaces have been determined to ensure testability.

The Thermal Storage Subsystem Research Experiment has been classified into three categories: Test Item, Test Facility and Test Equipment. Although the latter two have been covered and approved in CDRL #7, they have been included here because additional detailed design effort was required to support the test item. The test item contains all of the major hardware elements for the storage subsystem, including component installation packages. The test facility provides the services, housing, sources/sinks and valves/piping to tie the major storage elements into an operating system. The test equipment provides the operating system with control and safety features, exercises the system during test, and provides the necessary data reduction capability.

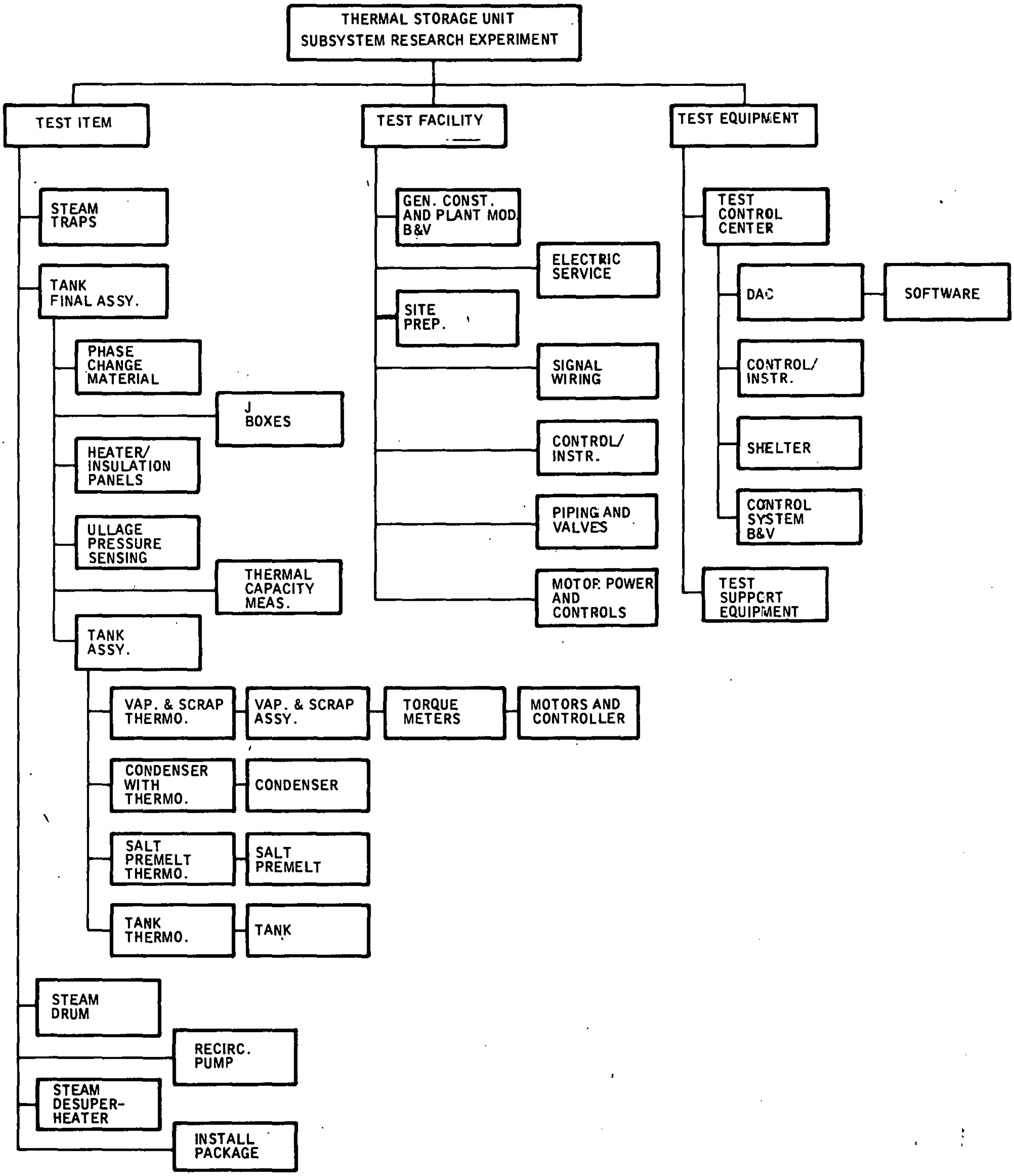


Figure 1-1. Thermal Storage Unit Subsystem Research Experiment

PILOT PLANT BASELINE DESIGN PERFORMANCE REVIEW

The Thermal Storage Detail Design activity implemented the design concept presented at the Conceptual Design Review for the subsystem research experiment. The Pilot Plant Updated Design was used as the basis for establishing requirements for the subsystem research experiment.

The basic features of the Pilot Plant Thermal Storage Subsystem include Pilot Plant Design and Performance Features:

- Design Features
  - 345 MWH(t) storage capacity main/superheater tankage
  - Salt phase change materials: $NaNO_3$-NaOH
  - Array of five insulated cylindrical tanks/two cylindrical tanks
  - Ground-level storage
  - Modular heat exchangers
  - Self-regulating control system
  - 40-year storage life
  - One reserve storage tank
- Performance Features
  - Deliver 7 MW(e) net - 6 hours
  - Provide 28°C (50.4°F) superheat
  - 6.5 MPa/307°C (942.7 psia/584.6°F) discharge cycle
  - 12.0 MPa/510°C (1740 psia/950°F) charge cycle
  - Handle 31.5 MW(t) charge rate
  - Heat loss <0.34 percent per hour

The selection of 12.0 MPa/510°C (1740 psia/950°F) charge cycle was predicated on the phase material solidification characteristics. During the freezing process, only $NaNO_3$ is precipitated from solution and it settles to the bottom of the tank. Consequently, to achieve the design heat rate the charging steam must, at least be supplied at 327°C (620.6°F). The saturation pressure corresponding to this temperature is approximately 12.0 MPa (1740 psia). The superheater storage unit will require a drop from 510°C (950°F) to 371°C (700°F). The condenser is capable of handling superheated steam at 12.0 MPa/371°C (1740 psia/700°F). Based on this constraint from the storage subsystem a performance/cost tradeoff was made to determine the "best" discharge conditions to the turbine based on the overall plant design. This resulted in the main storage discharge conditions of 6.5 MPa/279°C (942.7 psia/534°F).

basic main storage concept proposed at the preliminary design baseline review, 'irmed at the conceptual design review, and presented herein for the basis for procurement of hardware consists of the following:

- Thermal Energy Storage Material -- Mixture of $NaNO_3$, NaOH phase change material.
- Thermal Storage Charging -- Transfer of latent heat of condensing steam inside circular tubes to the salt outside the tubes as latent heat of fusion. Use of convection and thermo-syphon effects for bulk heat transfer.

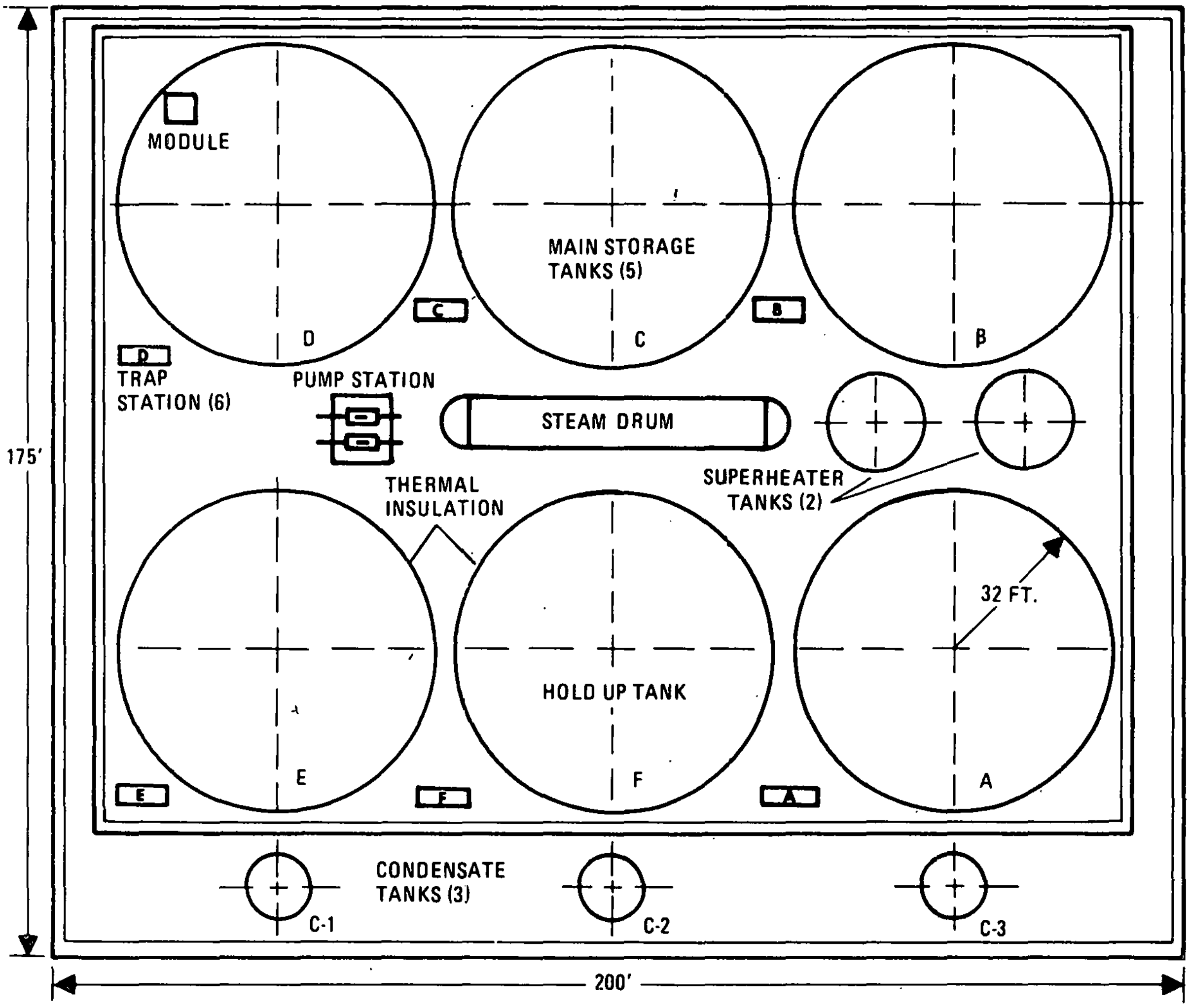


Figure 1-2. Pilot Plant Arrangement - Thermal Storage

- Thermal Storage Discharging -- Transfer of heat from the freezing salts surrounding circular tubes to water forced-circulated through these tubes. The water, receiving heat of vaporization, generates steam vapor and is supplied to a steam drum separator where saturated steam is withdrawn. The crystallized salt is removed from the outside of the tubes by mechanical means.

The basic objective of conducting the Thermal Storage Subsystem Research Experiment Program is to confirm and/or extend the Pilot Plant Preliminary Design mechanization to permit preliminary design specifications to be prepared.

With this objective in mind, and based on the foregoing baseline design, the components and operating elements are detailed on the succeeding pages.

SECTION—II

SECTION II
SUMMARY

Summary

THERMAL STORAGE SUBSYSTEM RESEARCH EXPERIMENT KEY FEATURES

The Thermal Storage Subsystem Research Experiment (TSS/RE) is designed to give maximum information for evaluating the design, performance and operating parameters of the proposed pilot plant configuration.

The baseline pilot plant configuration makes it possible to design, construct and test a full-size heat exchange SRE module. The SRE will contain the same salt mixture as the pilot plant module and will exchange heat with identical vaporizer and condenser heat exchangers. The same control system technique will be used and will operate on the same basic charge and discharge cycle conditions. The performance of the SRE can be evaluated and the operating characteristics defined and directly applied to the pilot plant design. The operating experience gained during the testing phases will permit a realistic assessment of equipment reliability and maintenance.

The key design and test features of the SRE include:

- An instrumented forced circulation steam generating system that can be used in a number of different operating and engineering modes to characterize the rangeability of the design and performance parameters.
- An instrumented steam condensing system capable of supplying steam at variable rates and state conditions to a serpentine condenser to evaluate the design and performance from trickle charge to full charge.
- A steam drum warming sequence to ensure a controlled experiment with quick safe starts.
- A vaporizer thaw steam capability to free "frozen" scrapers to reduce test turnaround time.
- An instrumented storage tank with a variable heat loss control system to evaluate the effects of heat loss on system design/performance.
- An instrumented dual steam trap station to evaluate the performance of a mechanical versus thermodynamic type trap for pilot plant application.
- A centralized mobile SRE control center for remote integrated experiment operations.
- A data acquisition system to collect, store and display the test conditions, alarms and provide real-time computational results.
- Use of the operating electric utility facility at NSP for the experiment testing.

Table 2-1. Pilot Plant/SRE Requirements

	Pilot Plant	SRE Characteristics
DESIGN	• 320 MWH(t) main storage capacity	• 1.34 MWH(t) storage capacity
	• Salt PCM-$NaNO_3$-NaOH	• Same salt PCM-$NaNO_3$-NaOH
	• 235 modular exchangers housed in 5 cylindrical storage tanks	• Single PP modular exchanger in a square tank
	• Self-regulating control system	• Same control system
	• Ground level storage	• Above-ground storage with insulation/ variable heat loss control system
PERFORMANCE	• Deliver 7 MW(e) net or 31.5 MW(t) discharge rate - 6 hours	• 134.4 KW(t) discharge rate - 6 hours
	• 6.5 MPa/307°C discharge cycle	• Same discharge cycle
	• 12.4 MPa/510°C charge cycle	• Same charge cycle
	• 31.5 MW(t) charge rate	• 134.4 KW(t) charge rate - 6 hours
	• Heat Loss <0.35%/hr	• Variable heat loss

Summary

EXPERIMENT LAYOUT AND SCHEMATIC

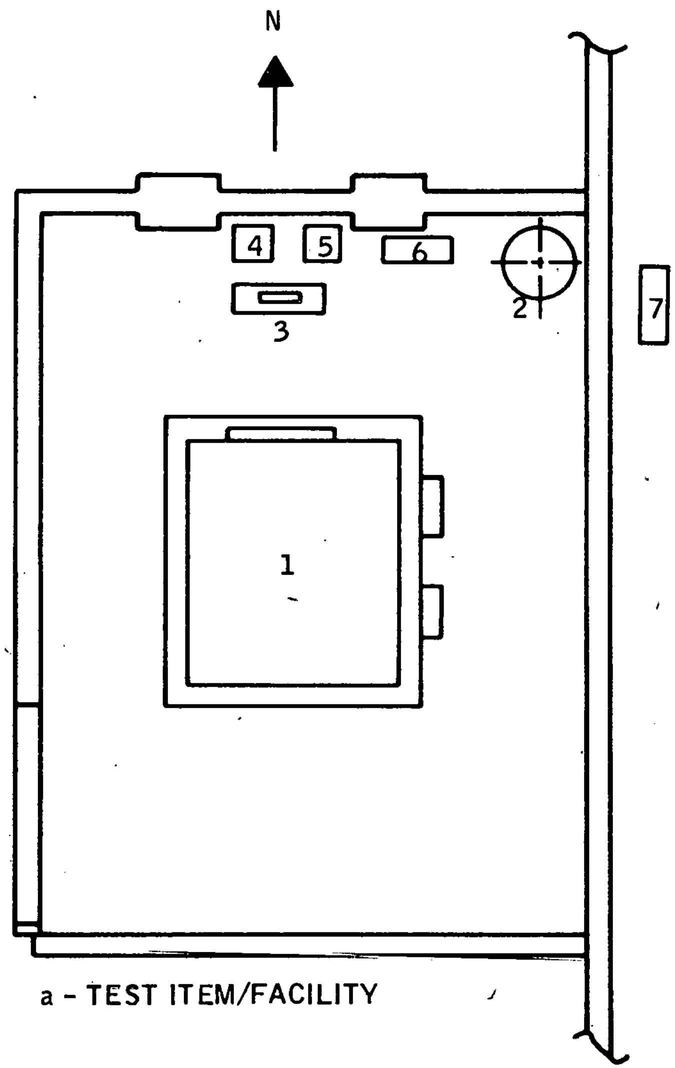
The SRE consists of a Thermal Storage Unit, a Steam-Generating System, Steam-Condensing System, Instrumentation, controls with data reduction, support equipment and facility items.

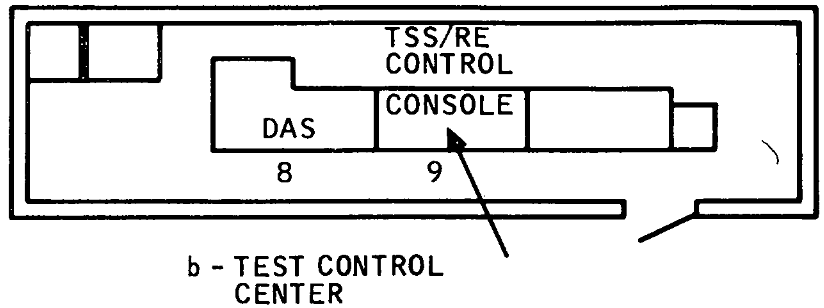
The research experiment will be located at the NSP Riverside Power Plant in Minneapolis, Minnesota. The Storage Test Item will be located as shown-installed in a refurbished transformer vault (a) adjacent to the main building. Elements 1 through 7 are located as shown. The Test Control Center is located in the main building on the turbine floor. Elements 8 and 9 make up the Data Acquisition and Control Systems.

The Simplified SRE schematic shows the Thermal Storage Unit as an insulated square tank containing the salt phase change material. The tank supports the vaporizer and condenser modules, as well as the mechanisms and instrumentation.

The Steam Generating System consists of the vaporizer, steam drum, pump, controls, valves, instrumentation and piping. Feedwater is pumped through the vaporizer and saturated steam is withdrawn from the steam drum. The steam throttle valve will place the same type of demand on the system as the turbine throttle valve.

The Steam Condensing System consists of a condenser module, desuperheater, steam traps, with control valves and piping. The desuperheater provides saturated steam to the condenser module and the condensed steam is discharged from the steam traps. The steam throttle valve will load the system in the same way as the Receiver Steam Generator supply valve.





ELEMENTS

1. SALT STORAGE TANK ASSY (WITH HEAT EXCHANGER)
2. STEAM DRUM STATION
3. RECIRCULATION PUMP/MOTOR STATION
4. #1 VAPORIZER-SCRAPER DRIVE MOTOR ASSY.
5. #2 VAPORIZER-SCRAPER DRIVE MOTOR ASSY.
6. STEAM TRAP STATION
7. DESUPERHEATER STATION
8. DATA ACQUISITION SYSTEM
9. STORAGE CONTROL CONSOLE

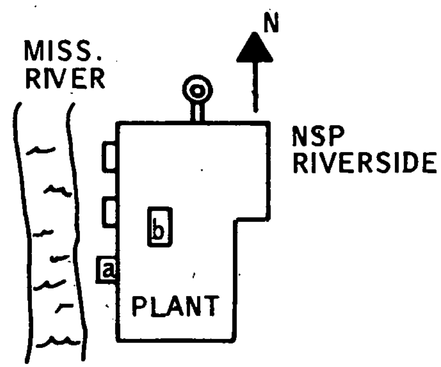


Figure 2-1. Thermal Storage Research Experiment Layout at NSP

40454

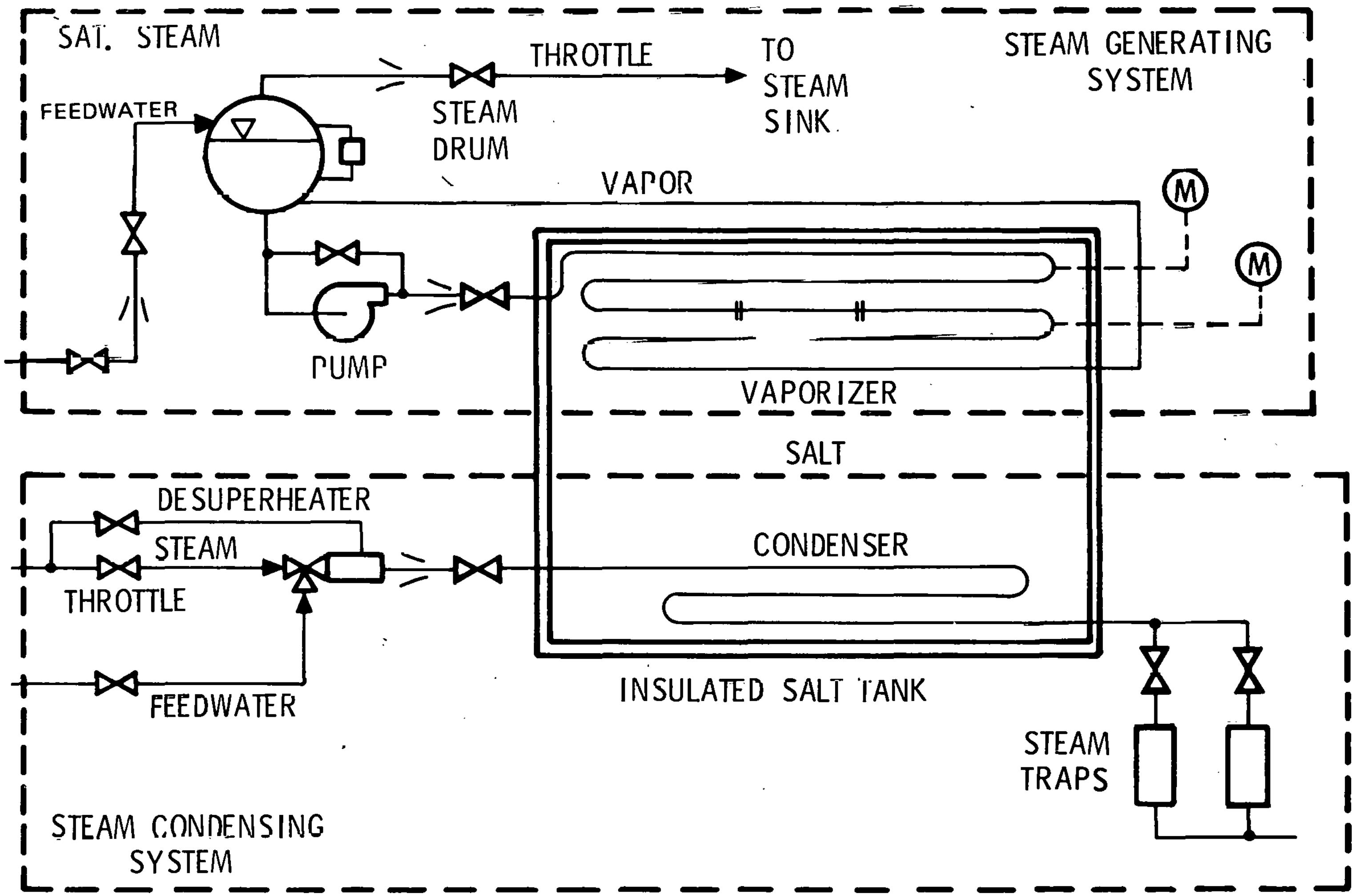


Figure 2-2. Simplified SRE Schematic

This page intentionally left blank.

Summary

DESIGN REQUIREMENTS

The design requirements are predicated on the selected Pilot Plant performance and specified charge and discharge cycle conditions, the characteristics of the selected phase change material, the engineering model test program, and the applicable codes and standards.

The SRE must store 1.34 MWH(t) heat energy 99% (wt) $NaNO_3$-1% (wt) NaOH PCM. The discharge or steam generation system must be capable of operating steady-state salt temperature of 307°C (584°F). Using a 10 percent margin for good design practice results in a design pressure of 10.4 MPa (1505 psia). The charging or steam condensation system must be capable of operating at 12.27 MPa (1790 pisa). Using a 10 percent margin gives a design pressure of 13.5 MPa (1958 psia). The salt storage structure must be capable of operating safely at a temperature of 335°C (635°F) and handle up to 71.0 kPa (10.3 psig) hydrostatic loads during its lifetime.

The SRE design requirements and related codes and standards are shown in Tables 2-2 and 2-3, respectively.

Table 2-2. SRE Design Requirements

DESIGN REQUIREMENTS

Item	Temperature	Pressure
Steam Generation System		
Melting point of salt at start of discharge ($NaNO_3$ 99% net, 1% NaOH)	303°C (578°F)	9 MPa (1306 psia)
Maximum operating steady-state temperature limit for salt (1% control margin on melt temperature)	306.7°C (584°F) →	9.43 MPa (1368 psia)
Design pressure for steam generation system (10 percent margin on maximum operating pressure)	314.4°C (598°F) ←	10.38 MPa (1505 psia)
Hydrostatic test pressure (1.5x)	---	15.57 MPa (2257 psia)
Steam Condensation System		
Maximum working saturation steam temperature at condenser module inlet	326.7°C (620°F) →	12.28 MPa (1780 psia) ↓
Design pressure for steam condensing system (10 percent margin)	335.0°C (635°F)	13.51 MPa (1958 psia)
Hydrostatic test pressure	---	20.27 MPa (2937 psia)
Storage Tank Assembly		
Maximum operating salt temperature	326.7°C (620°F)	
Design temperature (corresponding to steam condensing system design) pressure of 1958 psia	335.0°C (635°F)	
Design pressure for hydrostatic and handling loads		0.07 MPa (10.3 psig)
Phase Change Material		
99 percent wt $NaNO_3$-1% NaOH maximum safe temperature for negligible decomposition	371.1°C (700°F)	21.39 MPa (3100 psia)

Table 2-3. SRE Codes and Standards

CODES AND STANDARDS	
Pressure Vessels	
ASME Boiler and Pressure Vessel Code	
Section II	- Material Specifications
Section VIII	- Pressure Vessels
Section IX	- Welding Qualifications
Power Piping (Beyond Scope of ASME Code)	
ANSI B1.1	- bolt and threads
B2.1	- threaded connections
B16.5	- for flange valves, flange fittings, bolts and gaskets
B16.9	- for butt welded connections
B16.11	- for socket welded connections
B16.25	- for butt welded grooves and back up rings
B16.34	- for butt welded valves
B18.2	- bolting (nuts)
B31.1	- for material design and fabrication
TEMA Standards	- for heat exchangers
Storage Tank	
API Standard 620	- Recommended rules for design and construction of low pressure storage tanks
API Standard 650	- Welded steel tanks for oil storage
AWS	- Structural Welding Code
AISC	- Manual of steel construction
AISC	- Quality criteria and inspections
ANSI A58.1	- Building code requirements for minimum design loads in buildup and other structures
ASTM	- Material Specifications
A283	- for steel plates
A570	- for steel sheet
A233	- for mild steel arc welding electrodes
A36	- for structural steel
A131	- for structural steel for ships
A20	- for general requirements for delivery of steel plates pressure vessels
Electrical	
ANSI CI, NFPA70	- National Electric Code
NEMA Standards	
Circulating Pumps	
API-610	- centrifugal pumps for general refinery service
Feedwater Standards	
ABMA Standard 1958	- minimum acceptable water quality for design pH - 8.5 to 9.5
Conductivity (μmhos)	- 5-10
Total Solids (ppm)	- .03 max
SiO_2 (ppm)	- 0.25 max
O_2 (ppm)	- 0.005
Fe (ppm)	- 0.01
Cu (ppm)	- 0.005
Total hardness (ppm)	- 0
Organics (ppm)	- 0

This page intentionally left blank.

Summary

SRE DESIGN POINT SELECTION

The design point selected for the SRE phase change material, steam generation and condensation systems are based on experimental data for the critical parameters which account for the physical realities of the system. This provides a high degree of design confidence in the SRE.

Engineering model test results indicate that an average discharge salt heat flux of 20.5 kW/m^2 (6500 Btu/hr-ft^2) (Figure 2-3) and pipe heat flux based on outside area of 59.85 kW/m^2 (19,000 Btu/hr-ft^2) can readily be achieved when using a dilute eutectic composition of 99 percent (wt) of $NaNO_3$ and 1 percent (wt) NaOH (Figure 2-4) for recovery of 60 percent of the latent heat energy with a 12.2°C (10°F) freezing point depression in the phase change material (Figure 2-5). A value of 4.828 kW/m^2-°K (850 Btu/hr-ft^2-°F) for the outside film coefficient (Figure 2-6) is used for vaporizer design.

The phenomena associated with the steam side of the heat exchanger were not experimentally evaluated in the engineering model test program. For a good flow distribution, a mass velocity in excess of 3.9 x 10^6 Kg/hr-m^2 (0.8 x 10^6 lb/hr-ft^2) and a recirculation ratio of 5 to 1 is chosen for vaporiser tube design. Heat transfer correlations with two-phase flow inside horizontal tubes predict an average coefficient of about 17.03 kW/m^2-k (3000 Btu/hr-ft^2)°F. Using these values, an overall coefficient, based on outside area of 2.8675 kW/m^2-k (505 Btu/hr-ft^2-°F) is selected.

The systems tradeoff analysis on the solar pilot plant indicates an optimum discharge cycle pressure of 6.48 MPa (940 psia). To meet the code requirements, a pipe size of 2.540 cm O. D. /1.986 cm I. D., (1 in O. D. /0.782 in I. D.) is selected. One-inch O. D. tubing has been used in all engineering model testing. Thus using these parameters, the SRE vaporizer having a tube length of 34.14 m (112 ft) and capable of a heat rate of 134.4 kW(t) (4.59 x 10^5 Btu/hr) at 1360 Kg/hr (3000 lb/hr) recirculation rate (X_c = 0.2) is required (Figure 2-7).

The engineering model tests results for the charge cycle indicate that a salt side coefficient of about 511 W/m^2-k (90 Btu/hr-ft^2-°F) can be achieved (Figure 2-8). Theoretical calculations also predict about the same value for the coefficient. Systems tradeoff studies indicate a charge cycle pressure of 12.4 MPa (1800 psia), which results in a pipe size of 2.540 cm O. D. /1.935 cm I. D. (1 in O. D. /0.762 in I. D.). Using an inside coefficient of 13.75 kW/m^2-k (2421 Btu/hr-ft^2-°F) predicted from theory, an overall coefficient of 433 W/m^2-k (76.3 Btu/hr-ft^2-°F) is arrived at. The charge heat rate was set to be the same as discharge heat rate. Thus using these parameters and total steam condensation a bare tube exchanger of length 166.7 m (547 ft) is obtained.

The Thermal Storage SRE Design/Performance Summary is shown in Table 2-4).

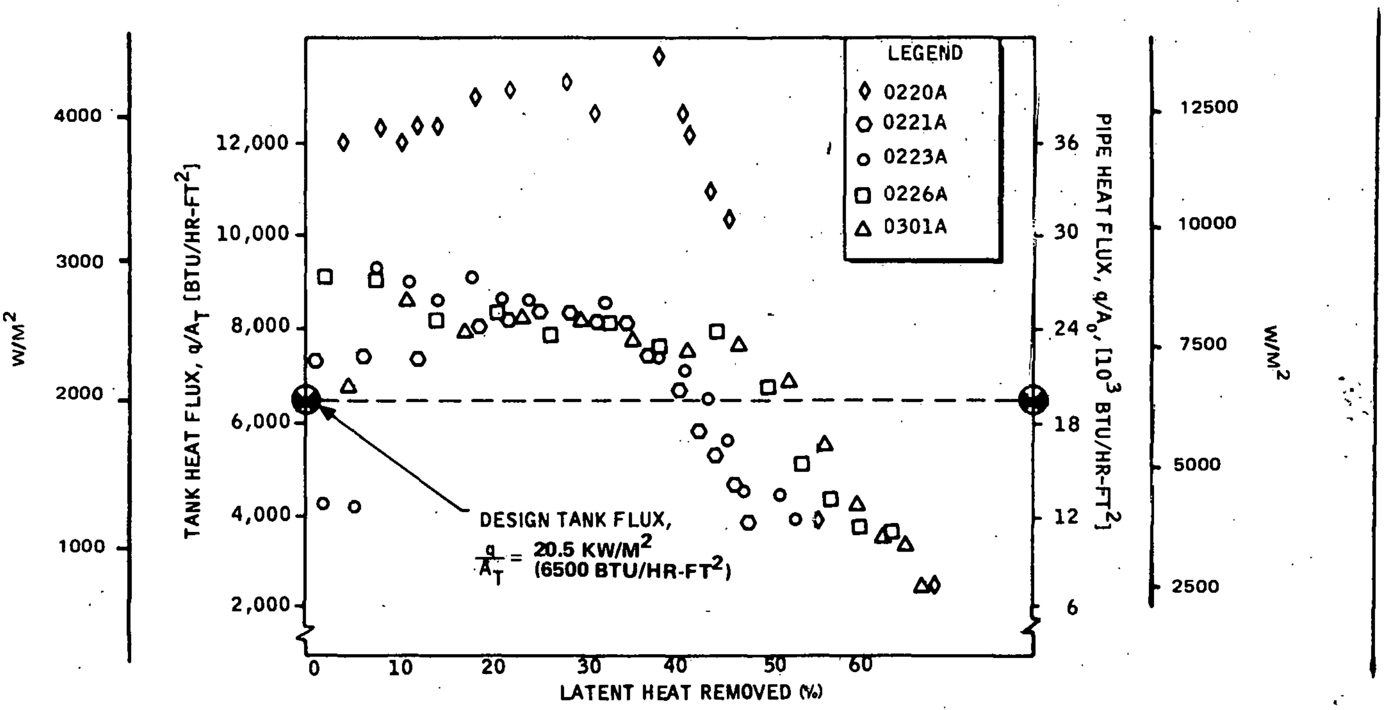


Figure 2-3. Average Discharge Salt Heat Flux Based on Engineering Model Test Results

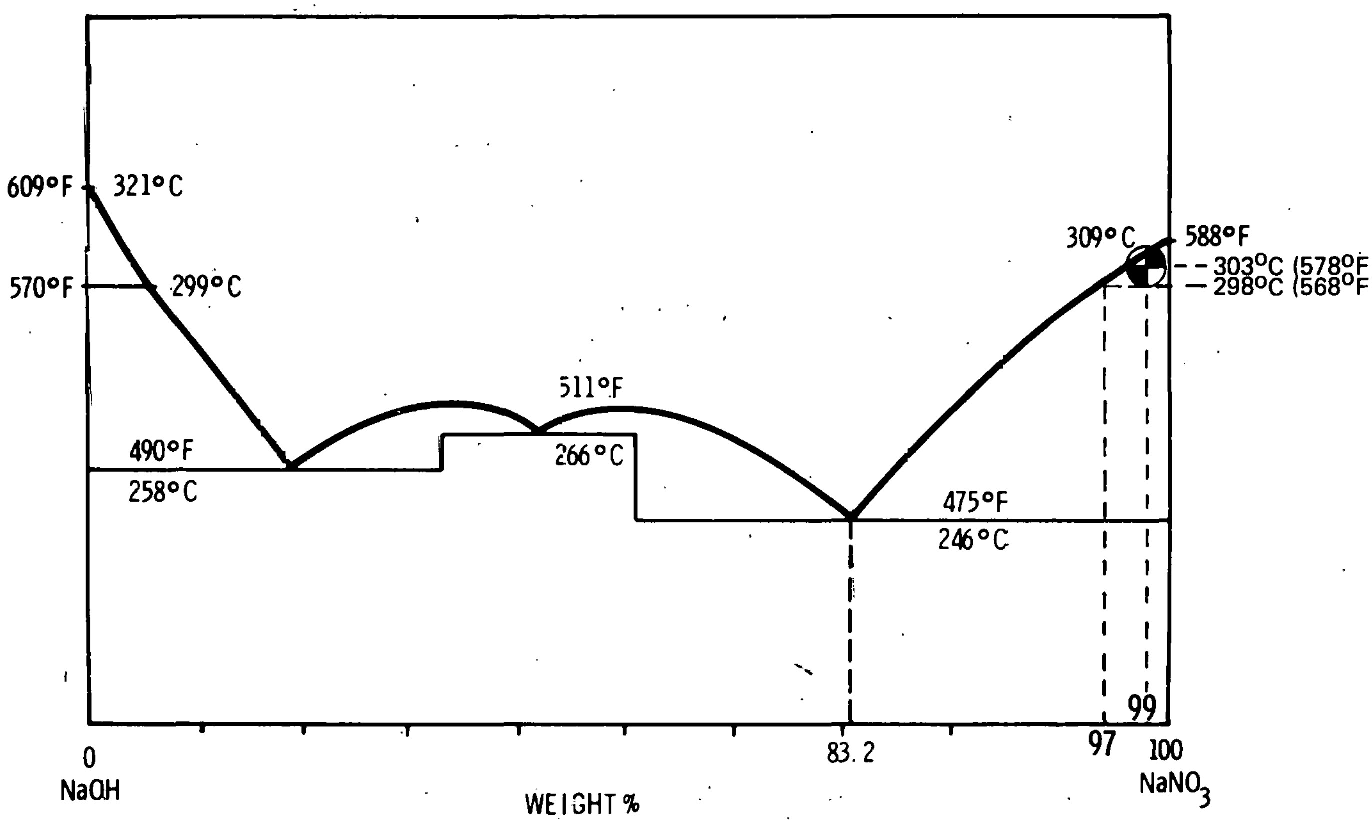


Figure 2-4. $NaNO_3$-NaOH Phase Diagram

$t_{M.pt}$ (MIXTURE) = $t_{M.pt}(NaNO_3) - \Delta T_f$

ΔT_f = MELTING POINT DEPRESSION DUE TO ADDITION OF NaOH, (°C)

$\Delta T_f = K_f m (1 - \rho)\, \nu$

WHERE,

- $t_{M.pt}$ = MELTING POINT TEMPERATURE
- m = CONCENTRATIONS, (MOLS NaOH/1000g $NaNO_3$)
- ρ = EXPERIMENTAL FACTOR, MEASURES SOLID SOLUTION TENDENCY
- ν = NUMBER OF "CRYOSCOPICALLY ACTIVE" PARTICLES
- K_f = M. PT. DEPRESSION CONSTANT (CALCULATED FROM ΔH_f AND T_f)

ASSUMPTIONS:

1. NO SOLID SOLUTIONS, $\rho = 0$
2. $K_f = 15.0$ (for $NaNO_3$ AS SOLVENT)
3. $\nu = 1.0$

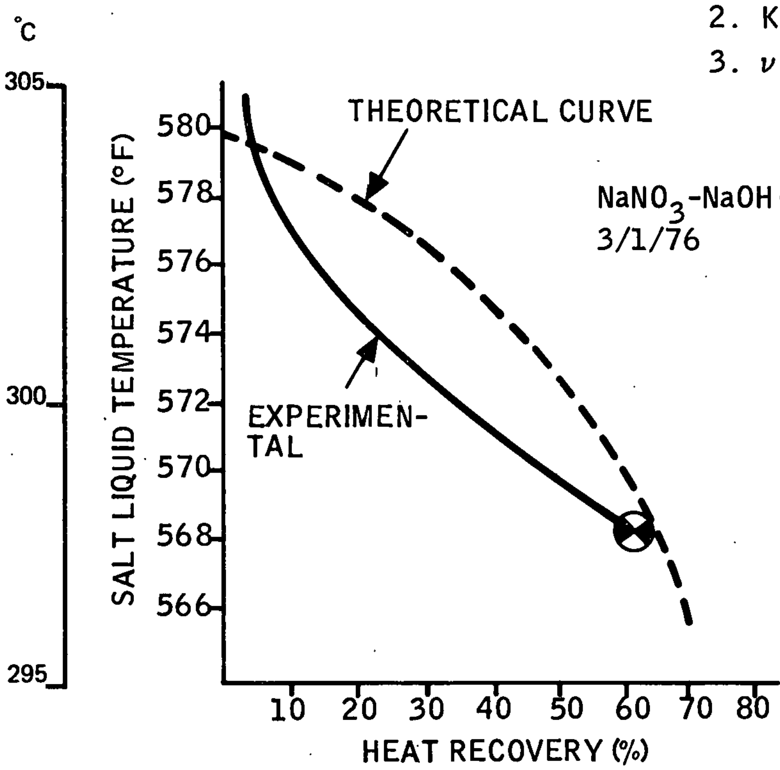


Figure 2-5. Theoretical Estimation of Salt Temperature (From Melting Point Depression)

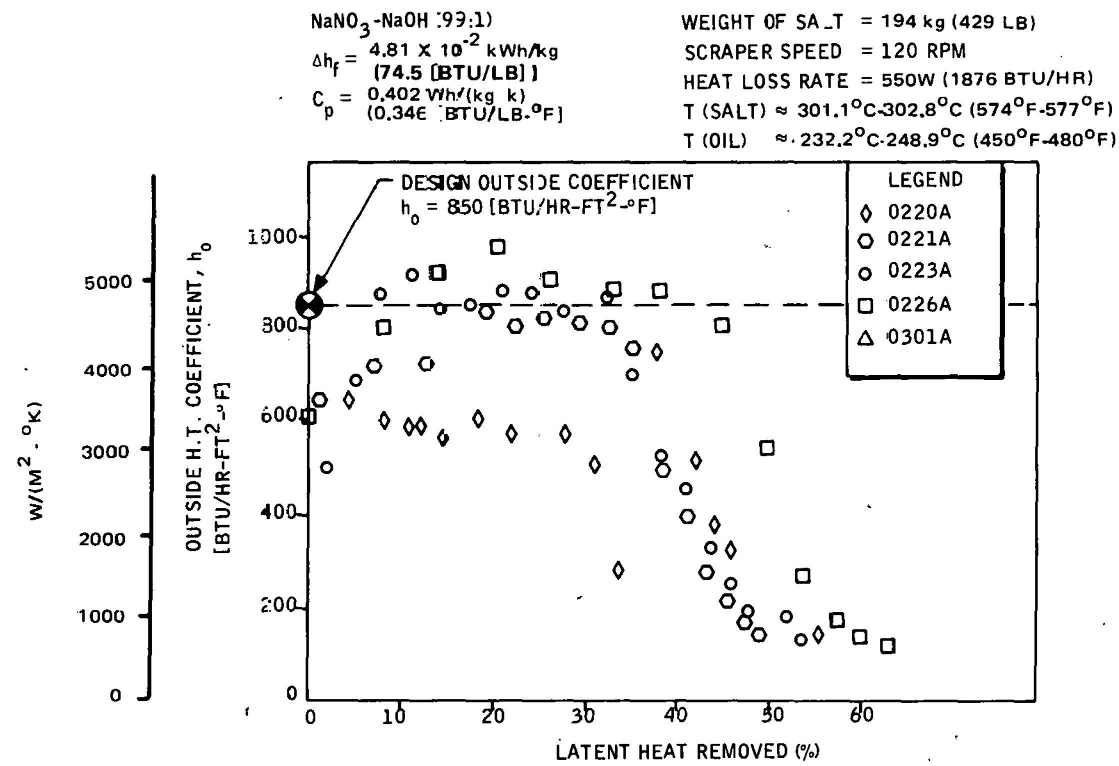


Figure 2-6. Engineering Model Test Results

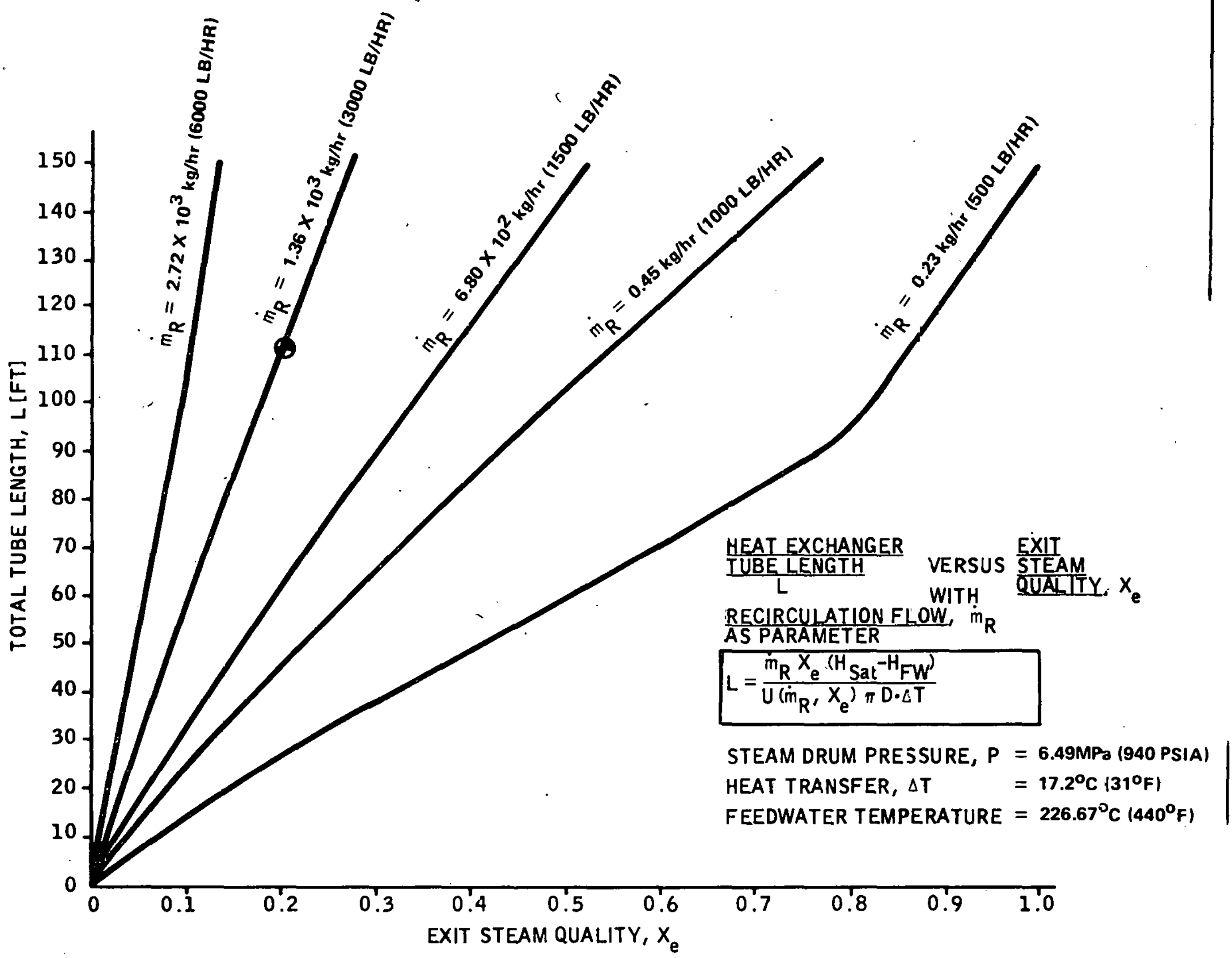


Figure 2-7. SRE Vaporizer

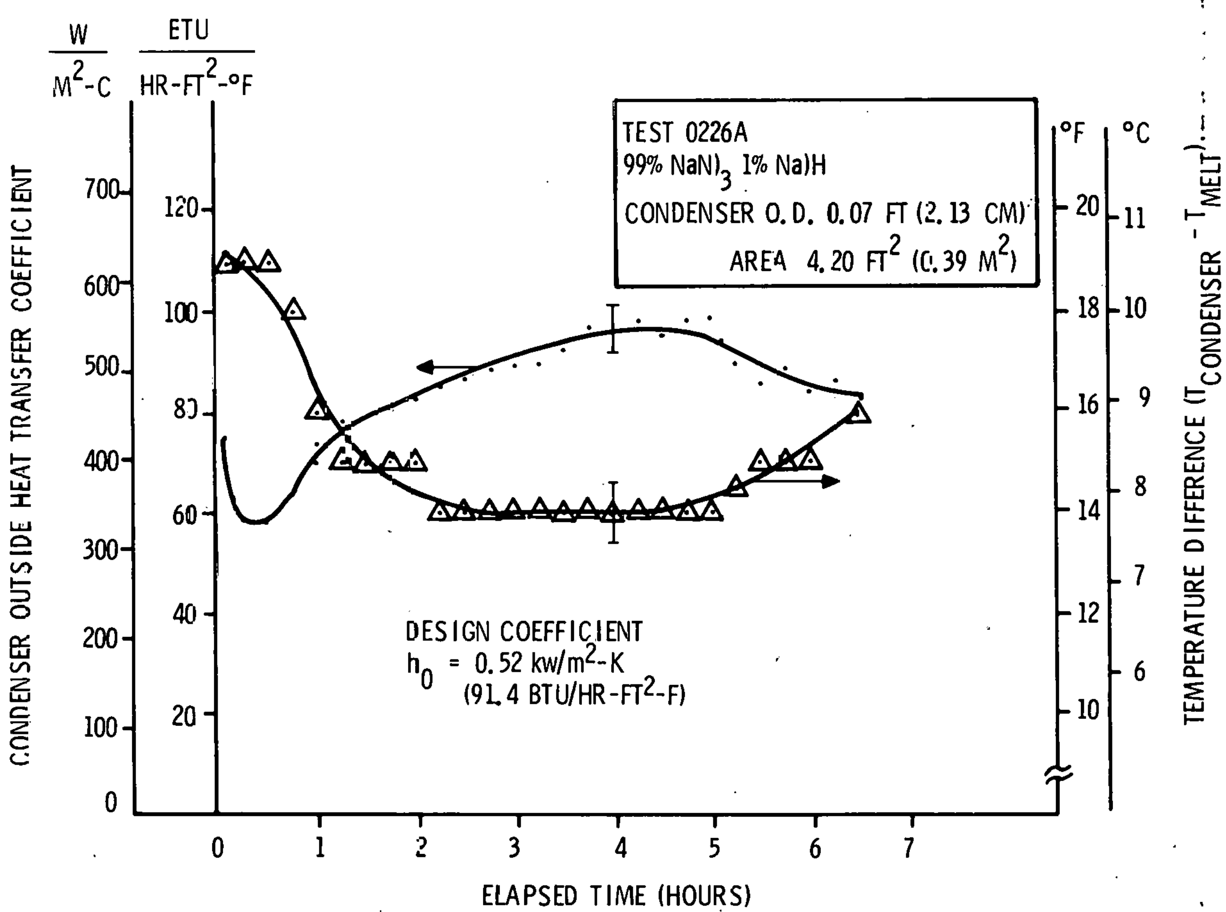


Figure 2-8. Test 0226A Results

Table 2-4. Thermal Storage SRE Design Performance Summary

Parameter	SI Units	English Engineering
Tank Size (Nominal)	2.56m x 2.56m x 2.53m	8.4 ft x 8.4 ft x 8.3 ft
Tank Weight	7260 (kgs)	16,000 (lb)
Vaporizer Weight	2720 (kgs)	6000 (lb)
Condenser Weight	1360 (kgs)	3000 (lb)
Salt Weight $NaNO_3$-NaOH	29,710 (kgs)	65,500 (lb)
Tank Weight - Gross	41,050 (kgs)	90,500 (lb)
Thermal Storage Capacity	1.34 MWH(t)	4.60×10^6 (Btu)
Nominal Charge Rate	134.4 KW(t)	4.60×10^5 (Btu/hr)
Mean Discharge Rate	134.4 KW(t)	4.60×10^5 (Btu/hr)
Discharge Heat Recovery	60%	60%
Charge Time	6 (hr)	6 (hr)
Discharge Time	6 (hr)	6 (hr)
Steam Condensation System		
Charge Steam Rate	412 (kg/hr)	908 (lb/hr)
Charge Conditions	12,270 KPa/327°C	1780 psia/620°F
Condensate Loading	2.46 (kg/hr-m)	1.65 (lb/hr-ft)
Condensation Coefficient:		
Outside, h_o	519 W/m^2-K	91.4 (Btu/hr-ft^2-°F)
Overall, U_o	433 W/m^2-K	76.3 (Btu/hr-ft^2-°F)
Pipe Size, O.D./I.D.	2.54 cm/2 cm	1 in./0.732 in.
Pipe Length	168 (m)	544 (ft)
Configuration	1-71 leg serpentine 2.35 m/leg	1-71 leg serpentine 7.7 ft/leg
Steam Generation System		
*Discharge Steam Rate	272 (kg/hr)	600 (lb/hr)
Discharge Steam Conditions	6535 KPa/280°C	948 psia/538°F
Recirculation Rate	5/1	5/1
Vaporizer Coefficient:		
Outside, h_o	4826 W/m^2-K	850 (Btu/hr-ft^2-°F)
Overall, U_o	2868 W/m^2-K	505 (Btu/hr-ft^2-°F)
Pipe Size, O.D./I.D.	2.54 cm/1.986 cm	1 in./0.782 in.
Pipe Length Configuration	34.1 (m)	112 (ft)
	1-16 leg serpentine with scrapers on 2.13 m/leg	1-16 leg serpentine with scrapers on 7 ft/leg

STEAM GENERATOR PERFORMANCE

The mean operating heat rate at the design point over the complete discharge cycle is expected to be 134.81 KW(t) (4.60 x 10^5 Btu/hr) with a mean LMTD of 17.2C° (31 F°) and overall coefficient of 2.867 kW/m^{2}k (505 Btu/hr-ft^2-F°).

The maximum heat rate will occur at the initial point of discharge when the salt temperature is 303.3°C (578°F) and is expected to be 153.28 KW(t) (5.23 x 10^5 Btu/hr) based on a LMTD of 20.2°C (36.4°F) and initial overall coefficient, U_{oi} of 2.782 kW/m^{2}k (490 Btu/hr-ft^2-°F), assuming a pressure drop of 344.7 kPa (50 psi).

The minimum heat rate will occur at the end of the discharge cycle when the salt temperature is 297.8°C (568°F), and is expected to be 117.22 KW(t) (4.00 x 10^5 Btu/hr) based on LMTD of 14.7°C (26.4°F) and an overall coefficient U_{of} of 2.924 kW/m^2-k (515 Btu/hr-ft^2-°F).

The mean heat rate integrated over the discharge cycle time of 6 hours is expected to be 134.8 KW(t) (4.60 x 10^5 Btu/hr) based on a mean LMTD of 17.3°C (31.1°F) and an overall coefficient of 2.867 kW/m^2-k (505 Btu/hr-ft^2-°F). The mean or time averaged LMTD is calculated from the change in salt bath temperature with percent heat recovered obtained from the engineering model experiments. Figure 2-9) shows the experimental and theoretical curve for salt bath temperature with percent recovery and the LMTD versus discharge time. The mean P_{sat} = 6.69 MPa (970 psia), T_{sat} = 283.3°C (542°F) and T_{salt} = 300.5°C (573°F).

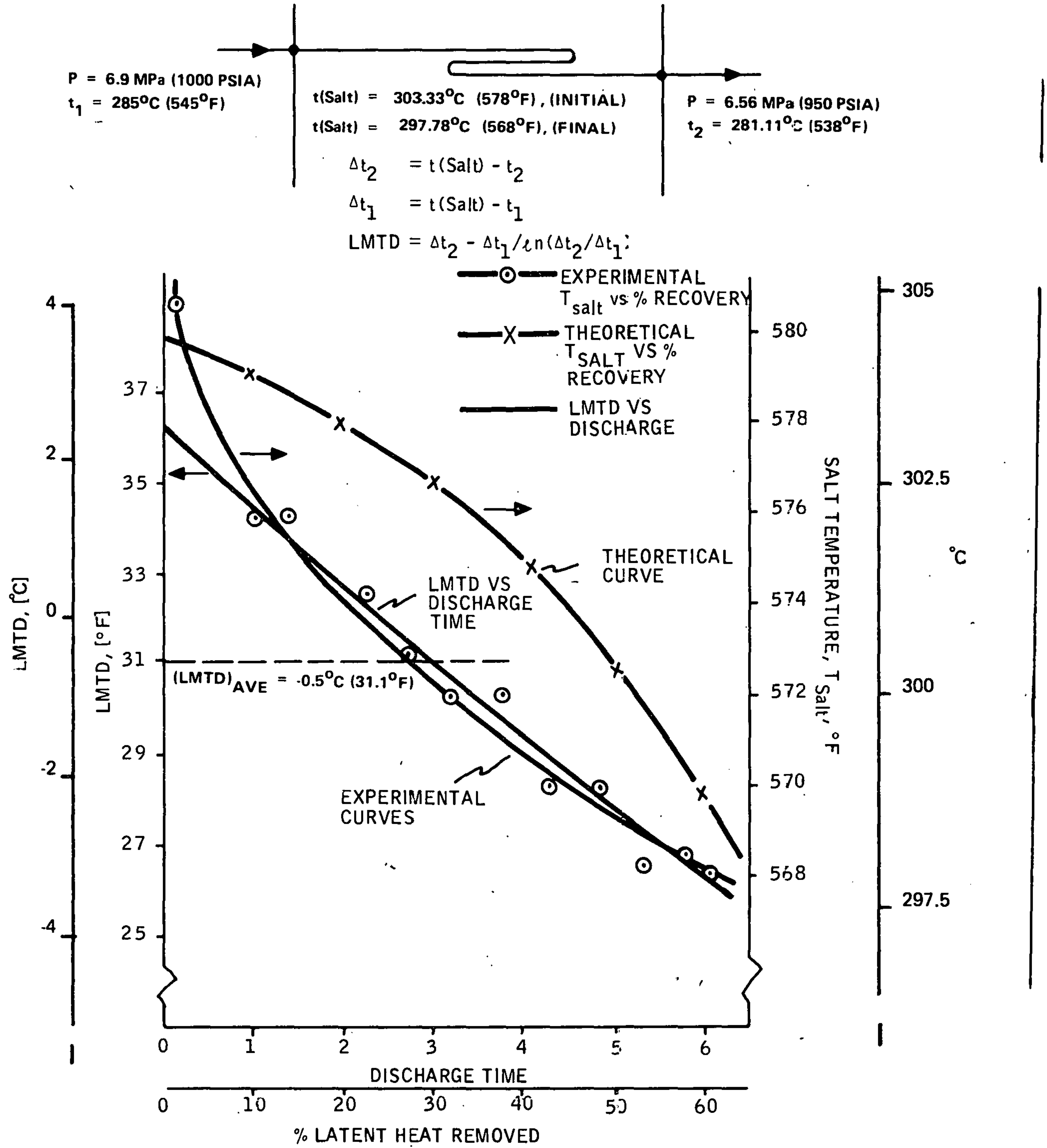


Figure 2-9. SRE Vaporizer

Summary

SRE Performance Sensitivity

DISCHARGE HEAT RATE VERSUS DRUM PRESSURE

Steam drum pressure is the primary control variable for setting the discharge heat rate. Recirculation rate and/or scraper speed are alternate nodes for evaluation.

The design mean heat rate from the vaporizer will be 134.7 kW ($4.6 \cdot 10^5$ Btu/hr) at 6.49 MPa (940 psia) steam drum pressure and 1.36×10^3 kg/hr (3000 lb/hr) recirculation rate. A 20 percent reduction in drum pressure is expected to produce a 60 percent increase in output heat rate at the same recirculation flow condition if design mechanization limits are not exceeded.

Varying the recirculation flow over a range of 6 to 1 produces a 13 percent change in the output heat rate at constant steam drum pressure (Figure 2-10).

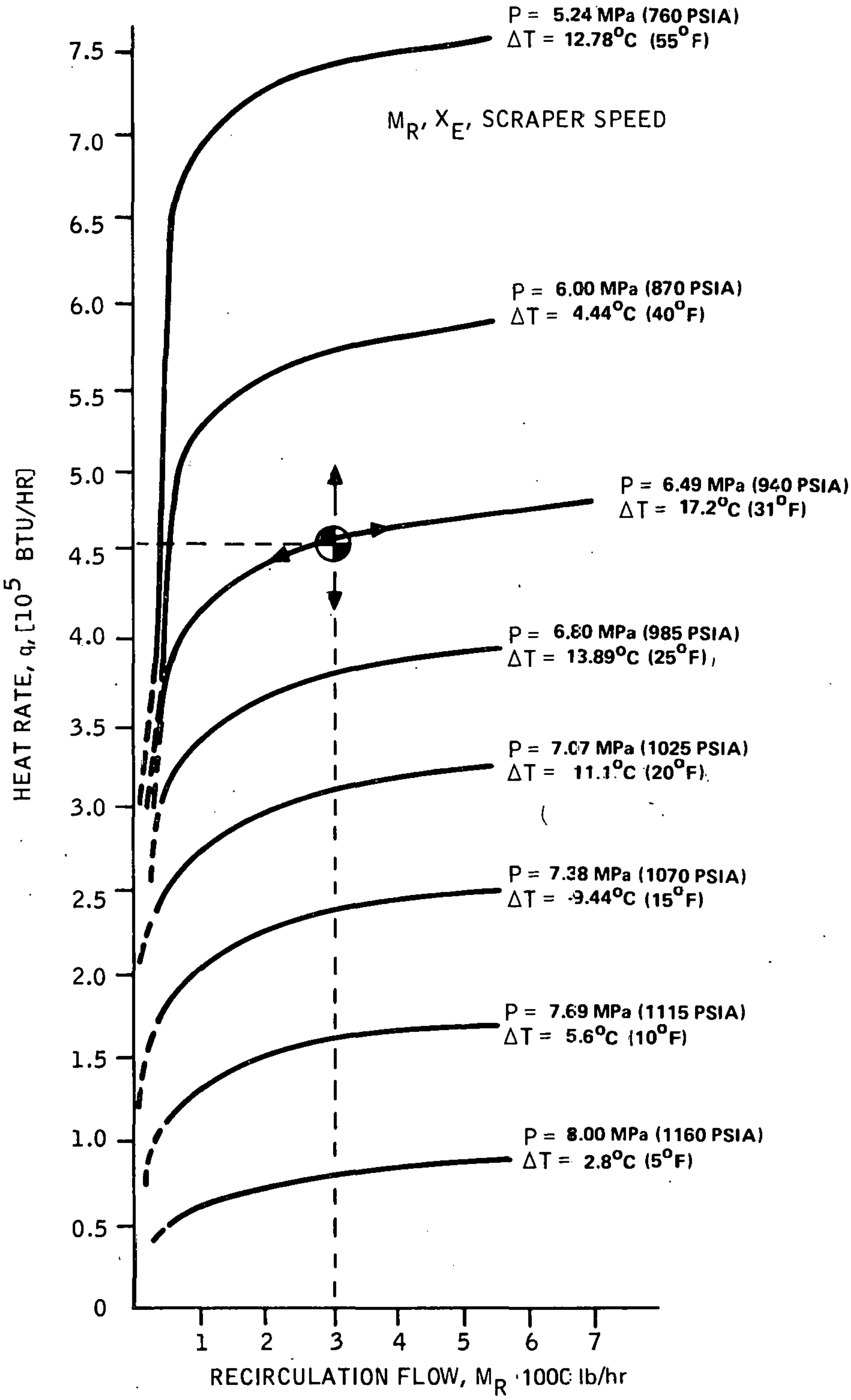


Figure 2-10. Discharge Heat Rate versus Recirculation Flows and Drum Pressures

Summary

SRE Performance Sensitivity

FEEDWATER TEMPERATURE VERSUS DISCHARGE HEAT RATE

The feedwater temperature to the steam drum will affect the discharge heat rate and steam rate delivered by the SRE.

The feedwater temperature to the steam drum is expected to vary during the test operations at NSP. Figure 2-11 shows that heat rate and steam rate increases with increase in feedwater temperature. Writing the energy equation,

$$q = U(X_e) \cdot A \cdot \Delta T = M_R X_e (H_{sat} - H_{FW}) \qquad (1)$$

$$x_e = \frac{U(X_e) \cdot A \cdot \Delta T}{M_R(H_{sat} - H_{FW})} \qquad (2)$$

$$M_s = M_R \cdot X_e \qquad (3)$$

it can be seen from Equation (2) that increasing the feedwater temperature increases the exit steam quality, since the ΔH term in the denominator decreases. Since the inside, and hence the overall coefficient increases with steam quality, the heat rate will increase with feedwater temperature. The steam rate is calculated from Equation (3). Computer calculations were done to obtain the exit quality from Equation (2) for a given tube length.

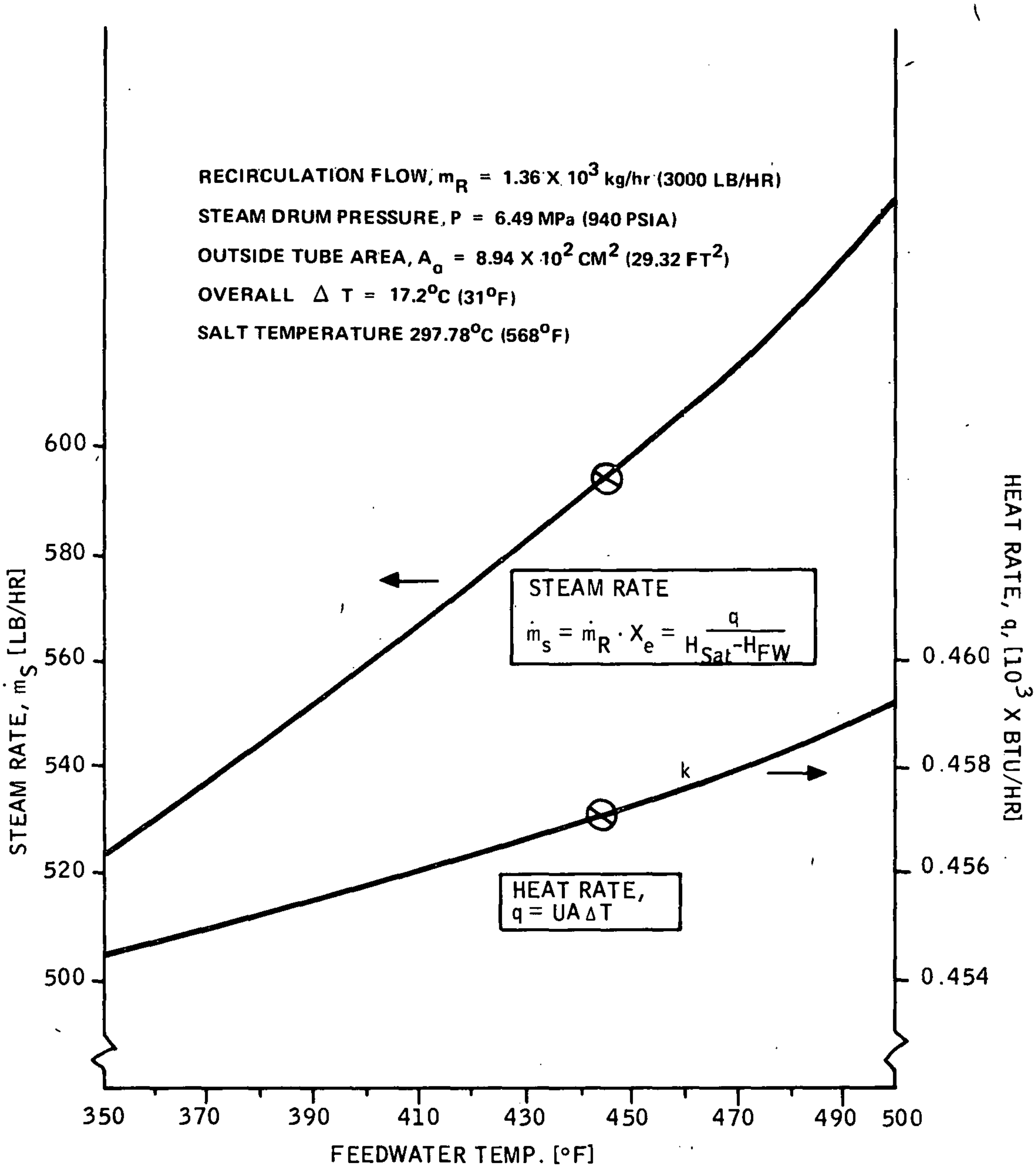


Figure 2-11. Effect of Feedwater Temperature on Design Parameters

Summary

SRE Performance Sensitivity

RECIRCULATION FLOW VERSUS DISCHARGE HEAT RATE

The recirculation flow rate in the steam generator loop will affect the discharge heat rate due to variation of steam side film coefficient.

The recirculation flow through the vaporizer tubes will be varied over a range of 4.54×10^2 - 2.72×10^3 kg/hr (1000 - 6000 lb/hr) to determine the influence of the inside heat transfer coefficient on the discharge heat rate. Figure 2-12 shows the expected heat rates for SRE vaporizer, as a function of recirculation flow with feedwater temperature as parameter. At flow rates lower than about 9.07×10^2 kg/hr (2000 lb/hr) the curve shows a sharp decrease because the effective inside coefficient controls. At flow rates higher than about 1.36×10^3 - 1.81×10^3 kg/hr (3000-4000 lb/hr) the curve begins to flatten because the outside coefficient becomes controlling.

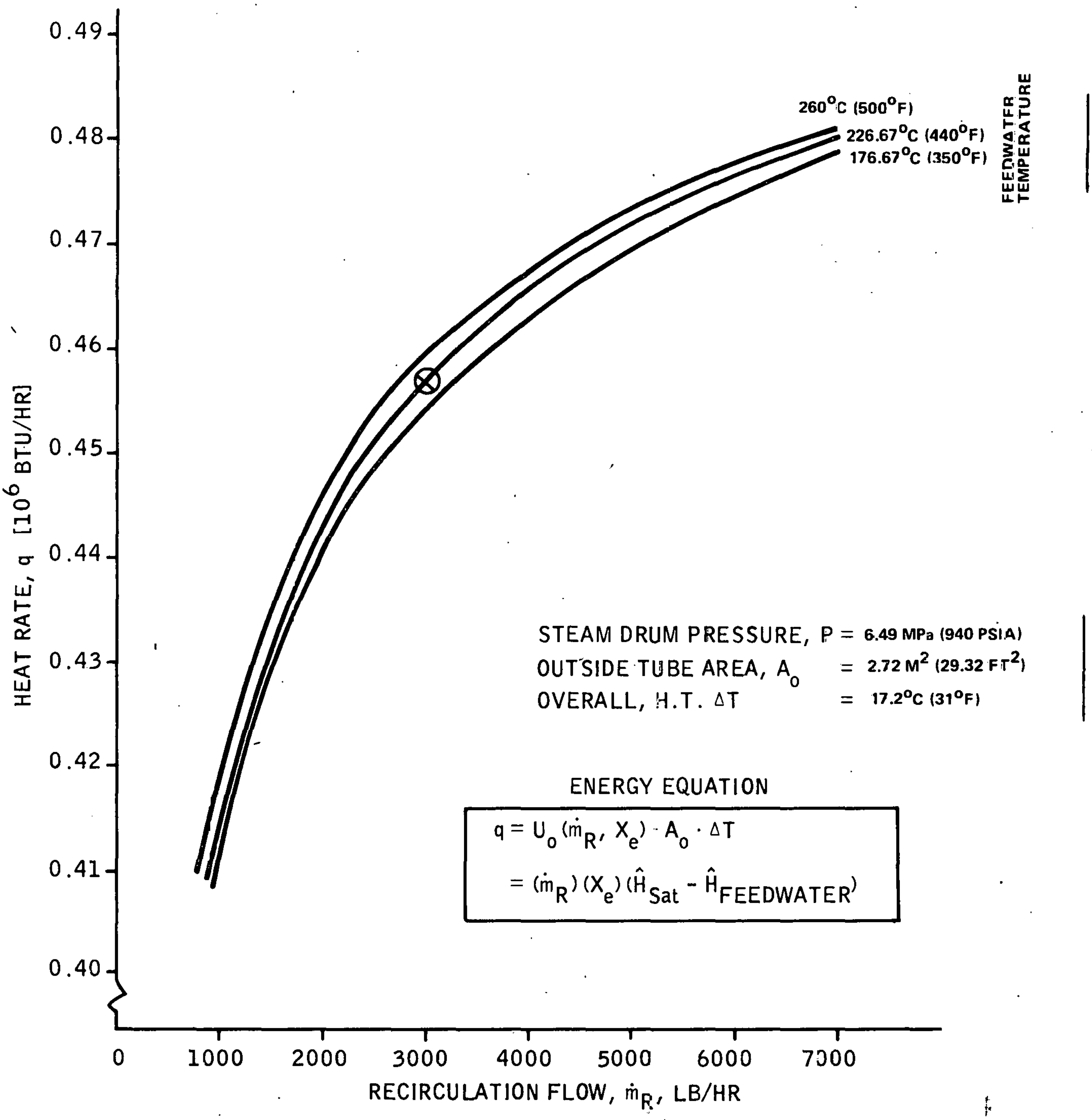


Figure 2-12. Heat Rate versus Recirculation Flow with Feedwater Temperature as Parameter

VAPORISER SCRAPER SPEED VERSUS OVERALL H. T. COEFFICIENT

The scraper speed changes the discharge heat rate by modifying thé outside coefficient.

The overall heat transfer coefficient varies along the tube length and is a function of the steam quality and mass velocity, the scraper speed, the overall ΔT, the scraper clearance and the salt properties. All these parameters have been lumped into a dimensionless variable θ in the scraping model described in Appendix H. The outside coefficient increases as the square root of the scraping speed but decreases as the square root of ΔT. Figure 2-13 shows the effect of scraper speed and mass velocity on the overall-overall coefficient for the SRE vaporiser, based on the scraping model. The overall-overall coefficient is the overall coefficient integrated over the tube length. For a given flow rate, the coefficient, and hence the heat rate, continually increases with scraper speed. The effect of change in the scraper speed is noticeable at scraper speeds lower than about 120 rpm, because at lower rpms the outside coefficient controls. At higher scraper speeds, the curves tend to flatten out as the outside coefficient approaches the inside coefficient.

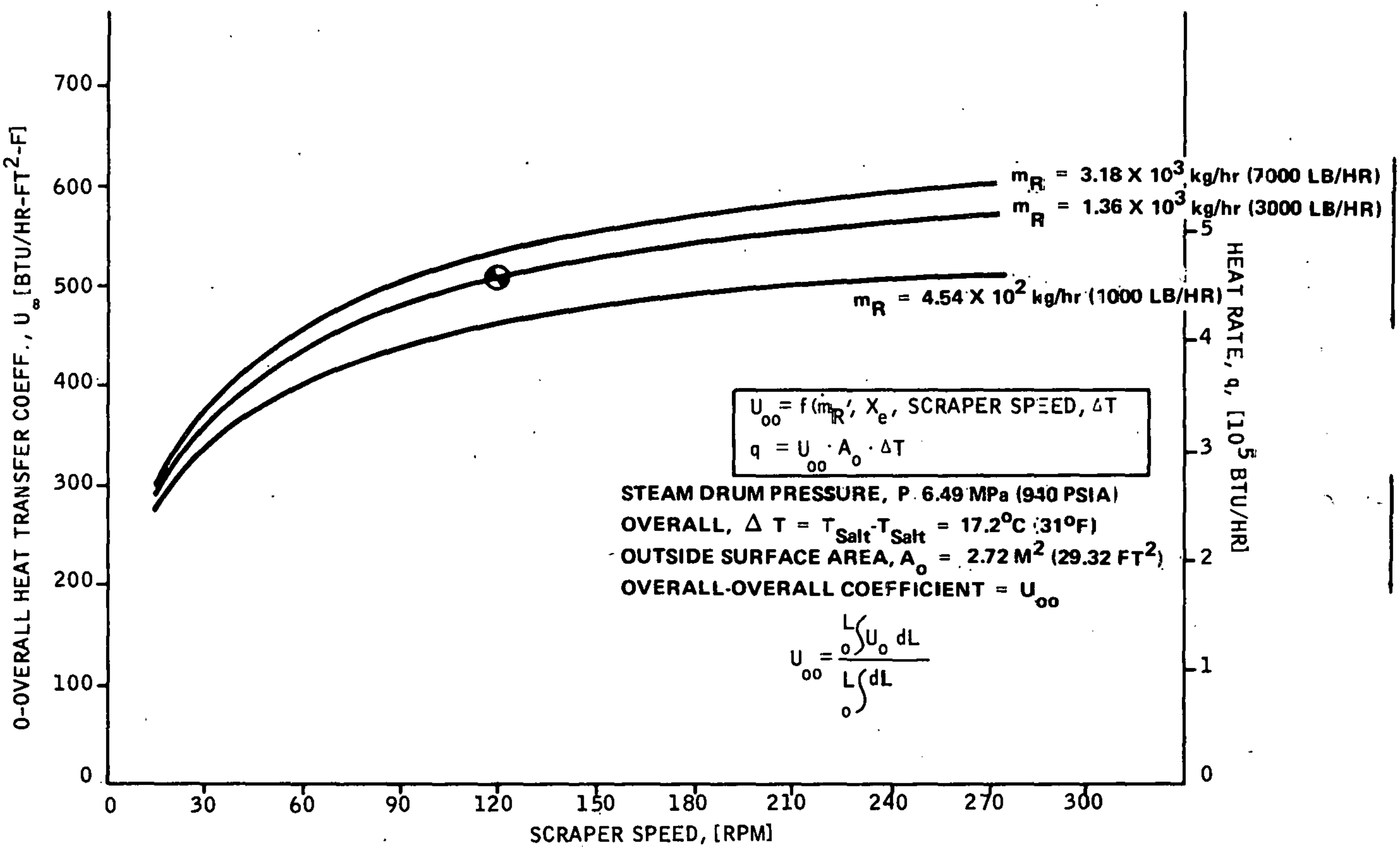


Figure 2-13. Overall H. T. Coefficient, U_o versus Scraper Speed

SECTION III

SECTION III

EXPERIMENT COMPONENTS DETAIL DESIGN AND INTEGRATION

Experiment Components Detail Design and Integration

Experiment Detail Design

SPECIFICATION AND DRAWING SUMMARY

The specifications and drawings for the complete project are all included in Appendix A. The only exceptions are the General Construction Specification, Black & Veatch Specification 7021-D-2A and the NSP Plant Modification Bill of Materials Package. These documents are available for reference.

This page is intentionally left blank

STORAGE TANK AND FOUNDATION SUPPORT

The SRE Thermal Storage Tank will be an insulated reinforced cube-shaped steel, container, mounted on an insulating base. A steam vaporizer and steam condenser will be mounted inside the tank. The condenser supplies heat to melt salt and the vaporizer removes the heat from the salt to generate vapor.

A cube-shaped tank is readily manufactured and presents a simple shape for design, insulation, handling and transport. The shape appears to be a logical choice from a standpoint of both vaporizer and condenser design.

The thermo-syphon and convection currents appear the most straight-forward in a rectangular pattern and the deposits of solidified salt from the vaporizer on the condenser would be more uniform than other shapes.

The tank measures 2.53 m high x 2.56 m wide x 2.56 m long (8.3 ft high x 8.4 ft wide x 8.4 ft long) and will hold sufficient molten salt 14.99 m^3 (511.6 ft^3) or 23,200 kg (61,540 lb) to provide 1.61 MWH(t) of stored latent heat of fusion. An ullage space of 0.3 m (1.0 ft) is provided for above the liquid level in which the mechanical vaporizer tube scrapers can be suspended.

The tank will be equipped with external I-beam reinforcements, insulated sectional covers and viewing ports above a double sectional vaporizer and a bottom-mounted condenser. The tank will be mounted on double grid of 20 cm (8 in.) beams to provide both support and thermal isolation from the lower concrete base. Insulation between five upper cross beams and three longitudinal lower beams will serve to reduce bottom heat loss. The upper I-beams will be welded to the tank to form a rigid base easily able to withstand static, dynamic and seismic loads. The lower I-beams will be fastened to the concrete base to provide firm footing. Anchoring will be arranged to permit the base frame to expand and contract without stress build-up. The base unit loading will be less than 618 gms/cm^2 (8.8 lb/in^2). The primary foundation consists of a large 3.35 m x 2.74 m (11 ft x 9 ft) concrete pad.

The concrete mounting pad protrudes 59 cm (1.83 ft above grade). A recessed area around the foundation is adequate in volume to contain the entire molten salt volume in the event of serious leakage.

Mild steel-type A285 GrC has been selected for the tank since the salts do not appear to attack it. It is also an easily weldable, readily available standard material sold in a wide variety of shapes. Building the SRE of mild steel will permit substantiating the use of this material on the full-scale Pilot Plant. The application of block insulation and also the thermal heat loss studies will be facilitated by this tank design. Figure 3-1 shows the tank construction.

The vaporizer units will be mounted on channel sections which will be bolted to the upper tank I beam.

40454

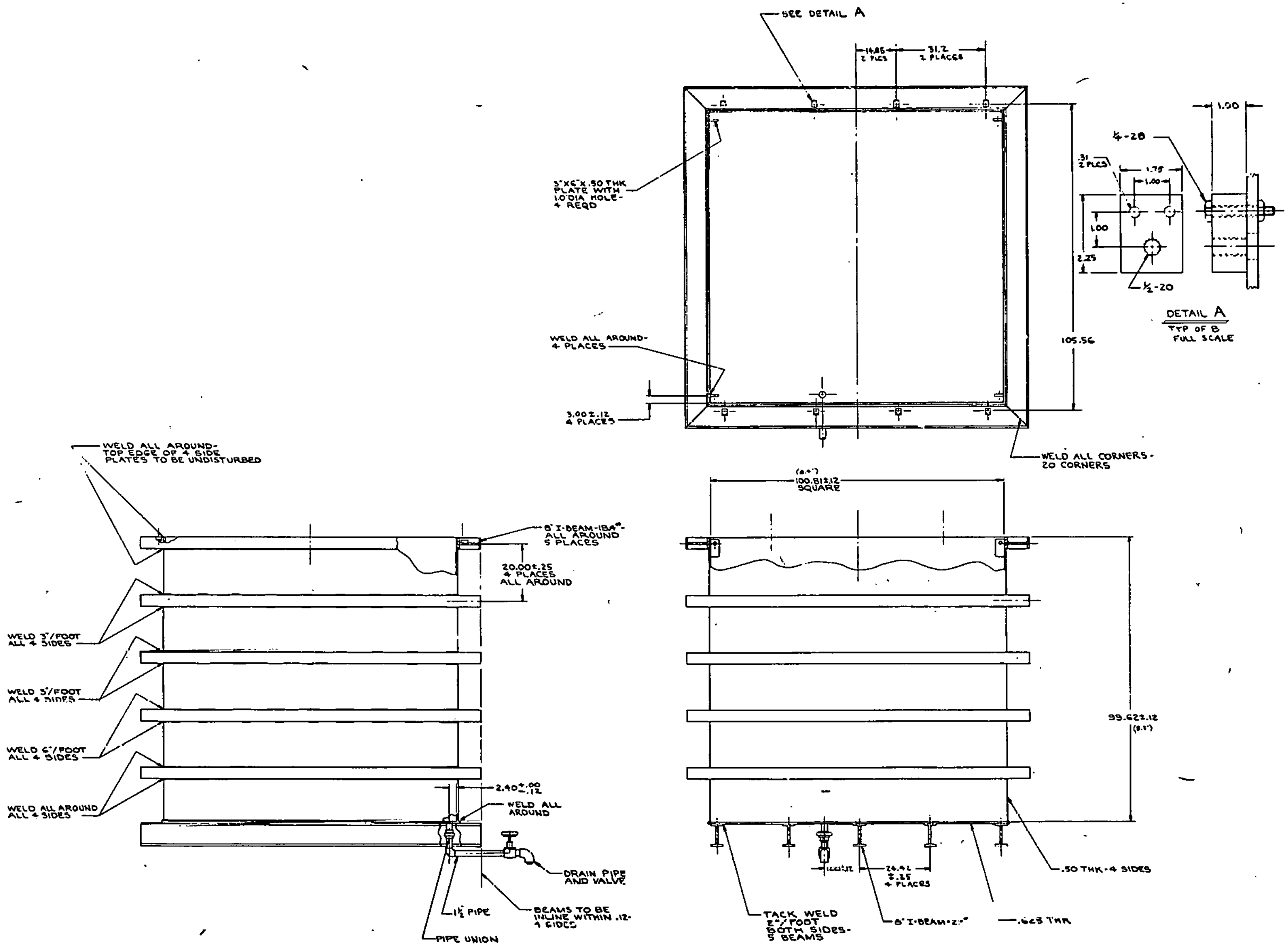


Figure 3-1. Tank Construction

Tank Drainage

A controlled drain line will be installed for removal of the molten salt. A heatab quick-opening valve on an adequately sized drain line is planned to permit controlled drainage of the tank. This feature will be installed in the bottom of the tank.

Tank Corrosion

Corrosion of the mild steel is expected to be minimal. At the temperature levels expected, corrosion rates of less than 0.02 mm (0.8 mil) per year under operating conditions will assure adequate system life. External surfaces not protected by insulation will require special paints or other coatings. The high external temperatures of the tank will eliminate the normal operating problems encountered by mild steel in rusting due to condensation.

Samples of ASTM A 285-74A Grade C Pressure Vessel Plate being used for the SRE tank structure have been cut and ground to a convenient shape and measured for thickness.

The samples have been immersed in the engineering test tank facility and have been exposed to the liquid salt for a period of 2350 hours.

The samples remained during heat rejection tests and were periodically examined qualitatively and also measured with a micrometer. The oxidizing nature of the salts provided a thin protective oxide coating in the steel samples within three days. Measurements show that after 98 days of immersion in the molten salt mixture any change was immeasurable using ordinary techniques. The original grinding marks were visible on the samples through the thin oxide coating.

Tank Temperatures

After charging, the thermal storage system will be exposed to only a limited range of temperatures. The salt freezing temperature of 298-300°C (568-578°F) will be a strong leveling function. Salt temperatures approximately 310°C (590°F) may be reached only on prolonged charging since most of the energy will be absorbed in the latent heat of fusion of the material. Higher temperatures due to sensible heat charging can only approach the steam charging temperature 327°C (621°F). Minimum temperatures will be represented by the partly solidified salt as exposed to external heat losses. The walls and bottom of the tank will be cooled by heat loss to the outside through the insulation. The temperature of the walls will be at some level below the solidification temperature 298°C (568°F), depending on tank charging state and heat loss status.

Generally, the tank walls and bottom will be restricted to temperatures near the freezing point.

Storage Tank Heat Exchangers

The operation of the thermal cycle of the storage systems utilizes the charging steam to melt the salts surrounding the condenser located on the tank bottom. The high-temperature steam melts the salt immediately around the heat exchanger. If the salts are completely solid, a liquid relief path to the upper surface of the salt "l be necessary to avoid pressures from building up since the frozen salt is ıser than the liquid. The steam supply lines will be brought into the tank down through the salt to provide such a path. In addition, a special heating coil, installed just below the condenser, will provide an emergency source of heat and additional liquid paths to the salt surface.

With the salts completely molten, the volume increase will bring the salt level well above the vaporizer tube structure.

The vaporizer will consist of two clusters of 8 tubes each. The tubes will be connected in series to form a single serpentine path. To maintain heat transfer rates during generation of steam, a scraper system driven by external motors on each cluster will be provided. The scrapers surrounding the tubes will be driven through chain drive systems. Each cluster will have its own motor drive independently mounted on the wall of the enclosure. This will permit removal of either of the sections of the vaporizer for servicing and experimental work.

The entire structure will be insulated with a suitable high-temperature insulation. The cover will consist of a sheet of 12-gauge steel which is hinged on the side opposite where the tubing for the heat exchangers enter the tank. The cover will have six 2-ft-square access holes with removable panels. This entire cover will be insulated by three heater/insulation panels.

The area where the tubing for the heat exchangers enters the tank will be stuffed with appropriate insulation to prevent heat loss. However, this is not a pressure vessel and if the pressure in the ullage space increases it will blow this insulation out. If the pressure even reached 0.20 psi, the entire cover will start to lift and the excess pressure will be relieved. If any salt should come out of the tank, it will be directed towards the north wall.

Barriers will be erected on the east and west sides of the tank to prevent entry into the north side of the tank when any of the heat exchangers is pressurized. The theory is that if a heat exchanger is going to fail, failure will occur while the heat exchanger is pressurized.

One of the tasks required of the tank vendor is a stress analysis of the tank.

If a heat exchanger fails and the pressure in the ullage portion of the tank increases, redundant pressure sensors will sense this pressure rise and a signal will be sent to the control room, closing all of the valves, stopping all of the motors, sounding an alarm, and causing a red light on the control panel to flash. The operator can silence the alarm by pushing the acknowledge push button. This will also cause the light to stay on steady red.

TANK AND FOUNDATION: TANK STRUCTURE DESIGN

The molten salt storage tank for the SRE was designed with adequate size and strength for all anticipated operating conditions.

A structural design was chosen which permits easy construction with reasonable total weight, cost and thermal losses.

For ease of construction the tank could consist of heavy plate walls with no external reinforcing. This would be the easiest to insulate but would be very heavy. The other extreme would be a thin-skinned structure with many reinforcements which increases the cost of construction and makes the apparent outside surface larger and more difficult to thermally insulate. The compromise was to use five horizontal I-beams as stiffeners for 1.27 cm (0.5 in.)-thick side walls and five transverse I-beams supporting a 1.59 cm (5/8 in.)-thick bottom (Figure 3-2).

With five equally spaced horizontal I-beams on the tank walls and five equally spaced transverse I-beams under the bottom of the tank, the side and bottom plate thickness was obtained using ASME code data and allowing for corrosion, taking the nearest thicker standard thickness plate steel (see Figure 3-3).

The horizontal stiffeners are I-beams 0.203 m by kg/m (8 in. x 18.4 lb/ft) which will be welded together at the corners and welded to the outside of the tank. With tie rods across the middle of the tank, these beams will pass a hydrostatic test pressure of 71 kPa (10.2 psi).

Another way of calculating the bottom plate thickness required is given by

$$T = \frac{\ell}{1.254\sqrt{\frac{S}{0.036\,GH}}} \qquad \text{(Ref. 1)}$$

where

ℓ = Maximum distance between support in inches

S = Stress value of plate, psi, as tabulated in code

G = Specific gravity of the liquid

H = Liquid height

1. Megyesy, Eugene F., PRESSURE VESSEL HANDBOOK, Pressure Vessel Handbook Publishing, Inc., 3920 E. 53rd St., Tulsa, OK 74135, 1975.

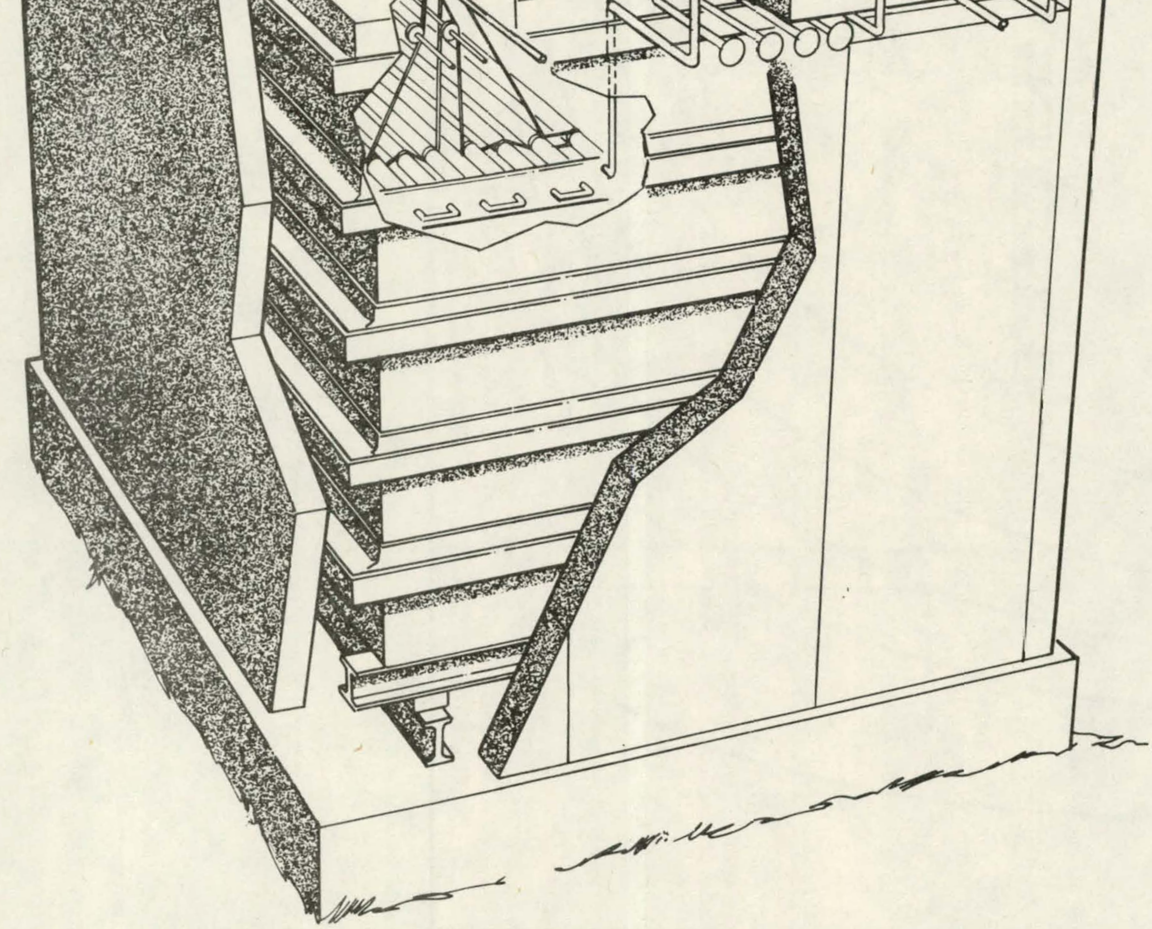


Figure 3-2. Thermal Storage Tank

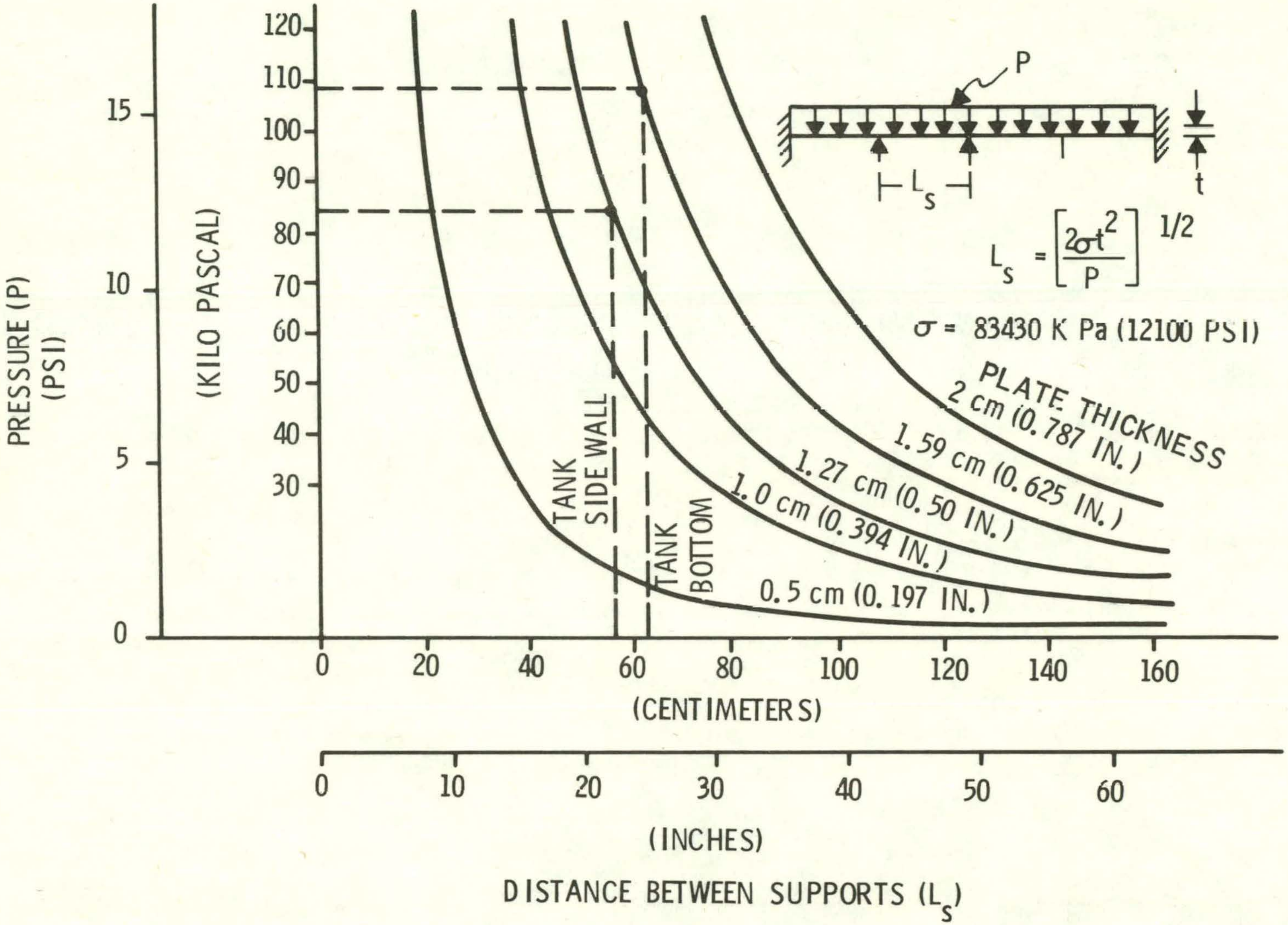


Figure 3-3. Tank Wall Design Point

40454

For this application 5 beams,

ℓ = 0.61 meter (24 in.)
S = 94.8 MPa (13,750 psi) for SA 285 Grade C Steel
G = 1.913
H = 7.35 ft = 2.24 meters (88.2 in.)

Substituting

$$T = \frac{24}{1.254\sqrt{\frac{13,750}{0.036\ (1.913)\ (88.2)}}} = 1.02 \text{ cm } (0.402 \text{ in.})$$

Corrosion allowance = 0.08 cm (0.032 in.)

$$T = 0.402 + 0.032 = 1.10 \text{ cm } (0.434 \text{ in.})$$

The minimum thickness for the total bottom plate is 1.10 cm (0.434 in.).

The side plate thickness required is given by

$$t = 2.45L\sqrt{\alpha n\ \frac{Pn}{S}}$$

where

L = length of the tank in inches = 256 cm (100.8 in.)

n = 0.0005 for $\frac{HS}{L} = \frac{16.8}{100.8} = 0.17$

$Pn = 0.036\ G\ \frac{hn-1+hn}{2}$

S = 94.8 MPa (13,750 psi) for SA 285 Grade C Steel

The pressure is greatest at the bottom of the tank. At a point half way between the bottom and the lowest stiffener

$$Pn = 0.036\ (1.913)\ \frac{(7.25 + 5.85)}{2}\ 12\ (1.5) = 56.0 \text{ kPa } (8.12 \text{ PSI})$$

Note: A 1.5 factor is used as a safety factor.

$$T = 2.45\ (100.8)\sqrt{0.0005\ \frac{8.12}{13,750}} = 0.34 \text{ cm } (0.134 \text{ in.})$$

The minimum moment of inertia of the stiffener is

$$I = 500\ R\ \frac{L^3}{E}$$

where

R = the reaction at the beam in psi

E = modulus of elasticity = 30×10^6 for carbon steel

$$R = 0.707\ W = 0.707\ \frac{0.036\ GH}{2} = \frac{0.707\ (0.036)\ (1.913)\ (5.85)\ 12}{2}$$

$$R = 1.709 \times 1.5 = 2.564$$

$$I = 500 \left[2.56\ \frac{(100.8)^3}{30 \times 10^6}\right] = 1821\ cm^4\ (43.76\ in.^4)$$

For 20.32 cm (8 in.), 8.35 Kg (18.4 lb) I Beam

$$I = 2368\ cm^4\ (56.9\ in.^4)$$

If the tank was filled completely with molten salt

$$R = \frac{0.707\ (0.033)\ (1.913)\ (8.3 - 1.4)^{12}}{2}$$

$$R = 2.016 \times 1.5 = 3.024$$

$$I = 500 \left[3.637\ \frac{(100.8)^3}{30 \times 10^6}\right] = 2148\ cm^4\ (51.6\ in.^4)$$

Therefore, the stiffener would still hold, even if the tank was completely filled with salt with a safety margin of 50 percent.

Calculations indicate that seismic loading on the tank will not pose any problem. At the Twin Cities the probable maximum horizontal acceleration is under 0.04 g. In Alburquerque this rises to 0.08 g (Ref. 2). This would cause the salt to slosh in the tank and the pressure would rise as much as 3.86 kPa (0.56 psi). The tank would not move with respect to the base because the coefficient of friction between the tank and the support at least 0.3. Figure 3-4 is a reprint of Figure 4, Preliminary Map of Horizontal Acceleration (Expressed As Percent of Gravity) In Rock with 90% Probability Of Not Being Exceeded in 50 Years from Reference 2.

---

2. Algermissen, S.T. and Perkins, D.M., "A Probabilistic Estimate of Maximum Acceleration in Rock in the Contiguous United States," United States Department of the Interior Geological Survey, Open File Report 76-416, 1976, 45 pages.

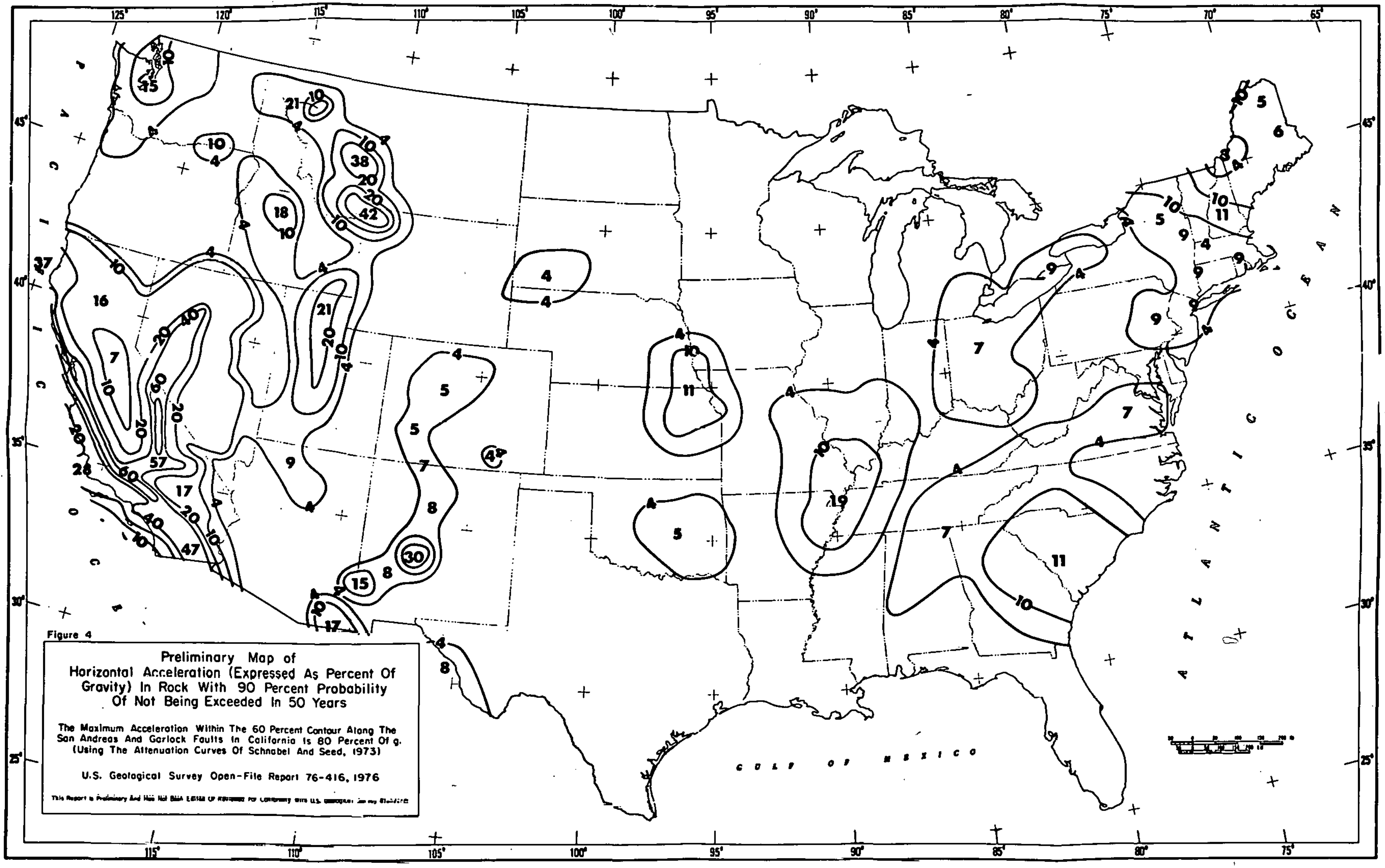


Figure 3-4. Preliminary Map of Horizontal Acceleration

40454

TANK AND FOUNDATION: TANK DESIGN PRESSURE

The maximum tank pressure is determined by the hydrostatic test requirements.

The tank will be designed to meet the ASME hydrostatic test requirements. The hydrostatic test pressure (HTP) is given by the equation:

$$HTP = 1.5\,(1.1 \times W.P.) \times \frac{\left(S_{T_{ambient}}\right)}{\left(S_{T_{operating}}\right)}$$

where:

W. P.	=	the working hydrostatic pressure
1.1	=	a design working allowance
$S_{T_{ambient}}$	=	working stress of steel at test conditions
$S_{T_{operating}}$	=	working stress of steel at the actual operating conditions

Figure 3-5 is a plot of the working design and the hydrostatic test pressures.

The hydrostatic test will be performed by filling the tank and a special stand pipe with water and pressurizing the unit. This gives a higher pressure distribution at the tank top than will be observed with the tank filled with molten salt. Consequently, the reinforcing of the tank was designed with a spacing of stiffeners to meet the hydrostatic test rather than to meet the load requirements imposed by the molten salt.

The SRE storage tank will be designed in accordance with ASME Sections I and VIII. Construction and certification will be in accordance with API 6-20 and traceability will be maintained on all pertinent materials via mill stamps.

40454

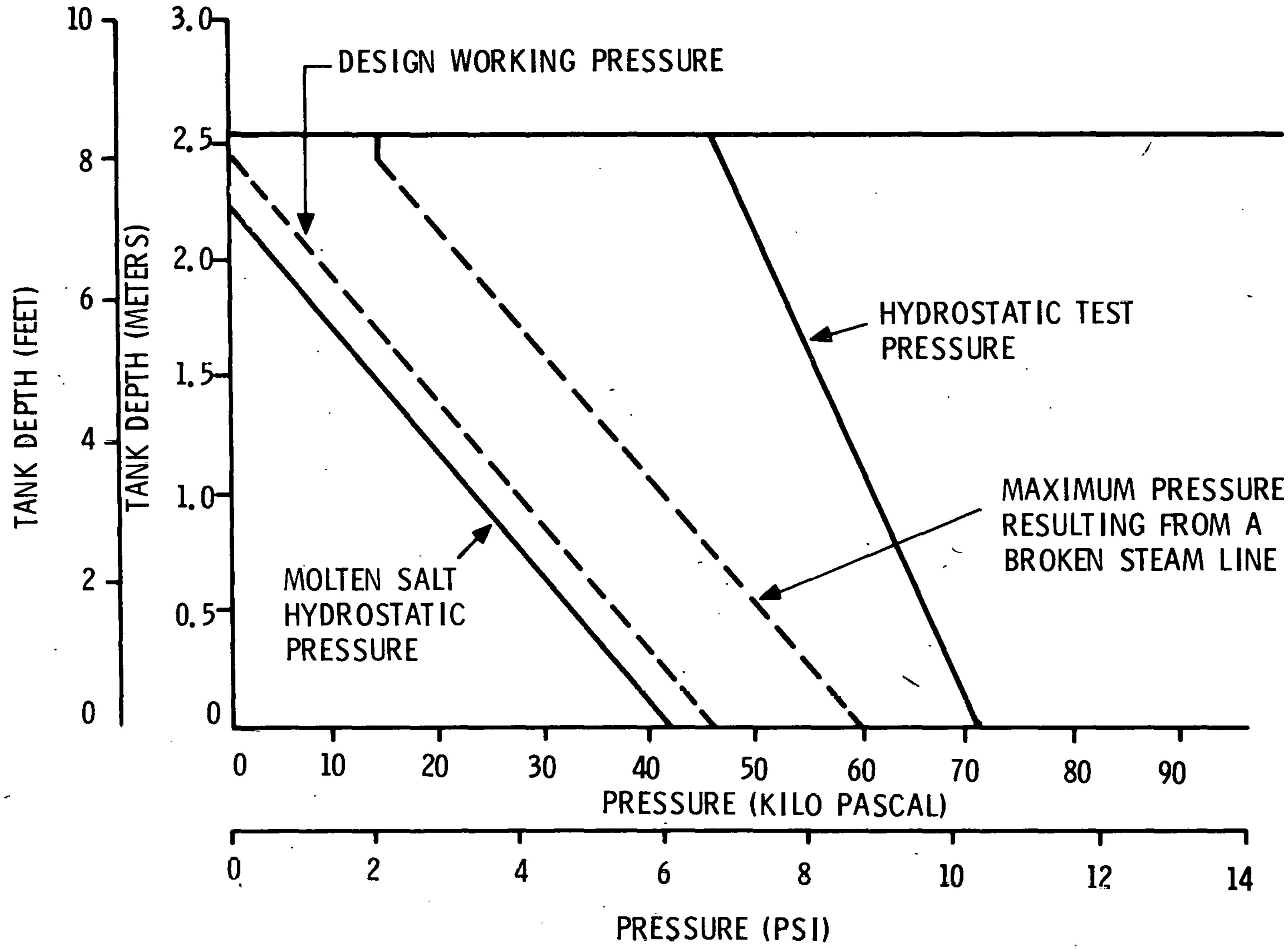


Figure 3-5. Thermal Storage Tank Design Pressure

VAPORIZER MODULE

Heat energy can be extracted from the thermal storage salt to generate steam by using forced-circulation scheme inside pipes and mechanical salt removal on outside of pipes.

The vaporizer consists of a horizontal parallel array of high-pressure steam pressure tubing using forced circulation inside the tubes and mechanical scraping on the outside to extract heat from the freezing salt.

Utilization of the latent heat of fusion of salts for the generation of high-temperature, high-pressure steam requires that low-cost salts with the correct freezing temperature range be permitted to release their heat by freezing to the exterior surface of proper heat exchangers. The use of high-pressure steel tubing permits considerable flexibility in the generator or vaporizer design but requires that the freezing salt be continuously removed from the tubes to maintain desirable heat transfer rates. The present SRE design uses a parallel array of tubes supported on two frames and immersed below the salt surface. The tubes are connected in series at the ends and may be removed as units with their frames from the salt bath. The straight sections of the tubes are surrounded by a special design of the external scraper which is capable of removing the salt and also agitating the molten salt to increase the heat transfer rates.

The scrapers are turned by roller chain drives from a shaft system above the molten salt. Two variable-speed electric motors are used to drive the two systems.

The vaporizer unit of the SRE is one of the 235 pilot plant heat exchanger modules, thus the SRE will be a full size unit which will be used directly in the pilot plant. This heat exchanger will experience the identical operating conditions as in the pilot plant and have 1/235 of the pilot plant output. The vaporizer design parameters are summarized in Table 3-1.

The vaporizer design details are summarized in Table 3-2 . Note that the scrapers are ganged together and driven with two drive motors. The scraper drive will consist of SCR controlled, permanent magnet D.C. motors with helical spur gear speed reducers. The SCR will accurately control speed and torque limit.

The piping design is compatible with the ASME and ANSI code. The tube wall thickness is calculated from the empirical formulae and tables given in the code book using a corrosion allowance. A standard carbon steel pipe size was selected.

Small-scale experiments have been successfully conducted with the proposed scrapers. Design changes which occur during the detail design of the SRE will be reflected back to the pilot plant to assure that similarity is being maintained.

Table 3-1. Vaporizer Design Parameters

	Parameters	Engineering Units		SI Units	
		Pilot Plant	SRE	Pilot Plant	SRE
Performance Requirements	Discharge Heat Rate	1.078×10^8 Btu/hr	4.59×10^5 Btu/hr	31.59 MW(t)	134.4 kW(t)
	Overall Temperature Difference	31 F°		17.2 C°	
	Operating Pressure	1000 psia		6.9 MPA	
	Pipe Size, O.D./I.D.	1.0 (in.)/0.782 (in.)		2.54 (cm)/1.986 (cm)	
	Steam Quality	0.2		0.2	
	Water Entrance Velocity	6.2 ft/sec		1.52 M/sec	
Overall Limitations	Salt Energy Density	9000 Btu/ft^3		93.15 kWh/M^3	
	Heat Recovery Factor*	0.6		0.6	
	Salt Heat Flux**	6500 Btu/hr-ft^2		20.5 kW/M^2	
	Overall Heat Transfer Coeff. (U)	505 Btu/hr-ft^2-F°		2.87 kW/M^2-K	
Design	Number of Modules	235	1	235	1
	Salt Surface Area (Tank Top Area)	16,590 ft^2	70.60 ft^2	1540 M^2	6.56 M^2
	Salt Depth	7.25 ft	7.25 ft	2.21 M	2.21 M
	Heat Exchanger Tube Length	26,300 ft	112 ft	8016 M	34.1 M

*Heat recovery factor = fraction of latent heat of fusion utilized.

**Salt heat flux = heat rate per unit area below heat exchangers.

Table 3-2. Vaporizer Design Details for SRE

Parameter	Value	Remarks
Number of Modules	2	Separate units, combined into single vaporizer
Number of Serpentines	1	Single-pass series, 180-deg reverse bends
Number of Tubes	16	8 tubes per module
Length of Tubes	2.13 cm (7 ft)	Scraped length
Center-Center Tube Spacing	14 cm (5.5 in.)	
Tubing Type	2.5 cm O.D. (1.0 in.) ASTM A192	Standard carbon steel steam boiler tubing
Corrosion Allowance	0.03 cm (0.012 in.)	
Scraper Unit Length	53 cm (21 in.) (64 units)	Inclined blade split
Drive Motors	2	5 hp variable-speed 1750 rpm totally enclosed fan cooled permanent magnet d-c motors
Scraper Drive	1.27 cm (1/2 in.) roller chain	Tensioned chain drive to sprocketed scrapers. Groups of four separate scrapers power from one primary chain.
Scraper Sprockets	22 tooth (72 units)	Atlas
Idler Sprockets	27 tooth (8 units)	Atlas
Main Shaft Sprockets	15 tooth (8 units)	Atlas
Bearings, Main Shaft	3	Graphalloy self-aligning split pillow block -- material designed to operate without lubrication.
Idler, Bearing	15	Graphalloy bushing -- material designed to operate without lubrication up to 750°F
Frame	Steel angle iron-bars	Angle iron -- welded. Tube bundle clamped under frame.
Controller	240V 60 Hz unit 180Vdc max 24 amp output	
Gear Speed Reducer	2	Approximately 5 to 1 speed reduction

Corrosion allowances do not include removal of oxide during scraping. The oxide med on the surface of standard steel appears to be Fe_3O_4 which forms a strong, it coating on the steel. The freezing process forms a film between the scrapers and the vaporizer tubes. Examination of the tubes after extended scraping periods shows a coating of oxide on all scraped areas. Rotation of scrapers in the molten salt without extraction of heat would occasionally produce squeaking noises, indicating abrasive metallic contact. This would immediately cease upon extraction of heat and the formation of films of freezing salt.

To determine the possibility of accelerated corrosion, a program involving weighing and mechanically measuring a steel specimen section is being developed. Techniques involving use of radioactive materials may be useful in such a study.

The abrasion losses are in a similar category to the scraped corrosion but involve the mechanical interaction of tubing and scrapers. The drag force between the scrapers and the tubes has two components, friction and scraping force. Tests have shown that the total force during operation may exceed 13.3 Nm/m (3 ft-lbf) of torque per foot of scraper. However, a 5595 Watt (7-1/2 H.P.) motor will only produce a torque of about 7.38 Nm/m (1.66 ft-lbf/ft) of scraper. Each motor has to drive 17.1 m (56 ft) of scrapers. Power to drive these scrapers is transferred via 8 sprockets and 8 drive chains. If one of the scrapers were to lock to the pipe due to scraper failure or some other failure all of the excess torque could be applied to that particular scraper and possibly damage the tube. To prevent this from occurring, each sprocket has a shear pin designed to shear at 207.3 N (46.6 lb) or 103.6 N (23.3 lb)/shear plane. That particular scraper will be lost but the other 7 scrapers will continue to work properly and damage to the vaporizer will be minimized. In the engineering model, tests have operated with a torque as high as 32.1 Nm/m (7.2 ft-lbf/ft) of scraper length with no damage to the device.

Studies will be made of the mechanical-fit scraping phenomena to understand more clearly the conditions of an abrasion process. In some pressure lubrication systems, additives are used with oils which form acids under high pressure and temperature. These acids in turn attack the metal parts forming film which prevent the metals from welding together and subsequently tearing each other apart, forming rough surfaces. Either additive or techniques to achieve long service should be sought.

Discussions concerning the possibility of a program to run extended performance tests have been made. The existing engineering model equipment may be modified to both charge and discharge the storage tank simultaneously. Oil could be circulated through both vaporizer and condenser with proper trimming of heat exchangers to maintain needed temperature gradients. Such a system could be operated for a lengthy time period to test longer range effects of corrosion, abrasion wear on drives, etc.

Heat Transfer Tubing

The heat transfer system consists of sixteen (16) 223.42 cm (7.33 ft) lengths in 2.54 cm (1 in.) O.D. A192 steel tubing. The tubing will be bent or welded to 180 deg bends to form two groups or modules of eight parallel tubes on 12.70 cm (5-in.) centers. Support plates on approximately 55.88 cm (22-in.) centers will provide spacing and support for the tube. Figure 3-6 shows the assembly drawir With an even number of tubes in the two modules, supply and outlet tubes of the same material will be brought out at one end of the module and brought up and over the upper surface of the tank structure. A horizontal run of about 45.72 cm (18 in.) will bring the lines beyond the insulated portion of the tank. A second vertical bend and rise of 30.48 cm (12.0 in.) will be terminated in a standard bolted flange for both inlet and outlet. A special coupling section (not drawn) will be fabricated to permit assembling the two modules into a single series loop.

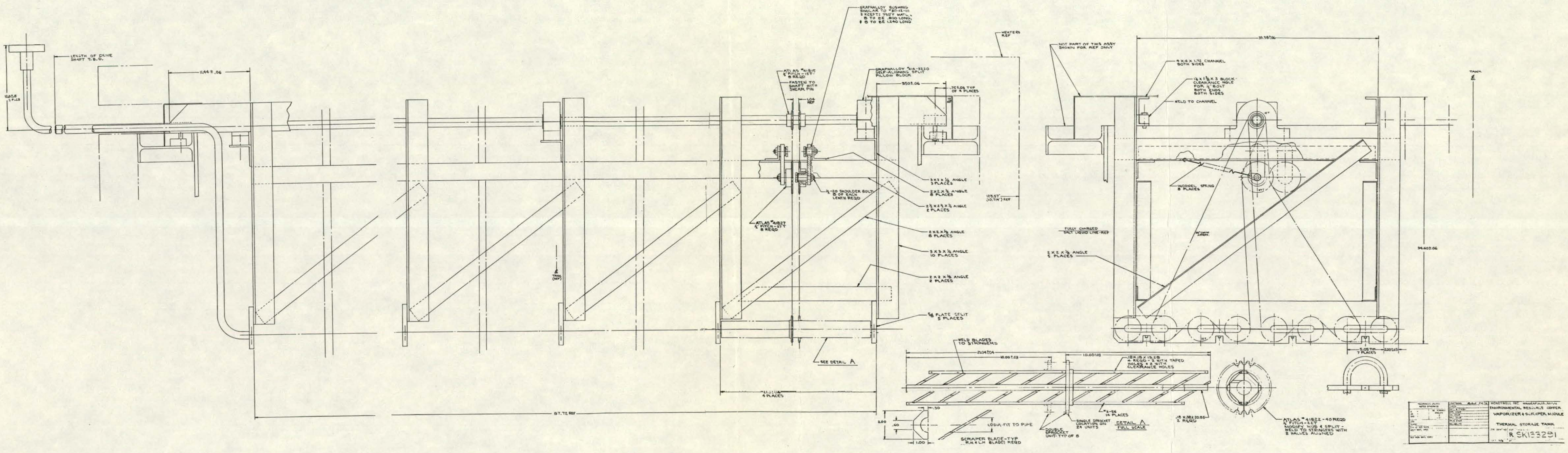


Figure 3-6. Heat Transfer Tubing Assembly Drawing

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

This page intentionally left blank.

MECHANISMS

Mechanical scraping devices and drives are required for operation of the thermal storage subsystem.

Vaporizer Tube Scrapers

Tests of the vaporizer tube salt buildup during heat removal show that continuous removal of the freezing salt is necessary to maintain adequate heat transfer rates. A special external scraper design has been developed and is shown in Figure 3-7. The scraper elements consist of steel blades with elliptical half sections which fit closely over the vaporizer tube. A series of these plates are welded into a retaining frame structure such that they fit closely over the vaporizer tubes at an angle with the tubes. Two of these frames with half sections of a roller chain sprocket are fastened together over a tube, and when rotated, scrape the covered length of the tube each rotation. The design avoids bearings and other closed non-scrapable surfaces since these have a tendency to freeze up the scrapers.

The design for the SRE requires 34.1 m (112 ft) of vaporizer tubing, 2.54 cm (1 in) O.D. and 1.986 cm (0.704 in) I.D. The tubing will be arrayed in two modules of eight 2.13 m (7 ft) tubes each. Each vaporizer tube will be scraped by four independently driven scrapers 53 cm (21 in) long. The design of the scrapers permits removal and replacement of each scraper without disturbing the basic boiler tube structure. Each module will carry one reduction motor drive which rotates a shaft carrying chain and sprockets to transmit the power to the scrapers.

The motor and reduction systems are mounted on the wall adjacent to the tank and power the mechanism via a drive shaft. The SRE drives will be approximately 5-hp variable-speed, limited-torque units to facilitate test work.

The scrapers consist of a series of inclined offset steel blades machined to form elliptical surfaces which fit over the heat transfer tubes. The blades are fixture welded to a backing bar and two side bars. Two units are fastened together with Allen screws to form a torsionally stiff cage with closely fitting half sections over the tube. When rotated, the entire section of the tube covered by the scraper is cleaned by the inclined blades. A split chain sprocket is welded near the center of each cage. The scrapers may be removed by unbolting the two halves. This allows servicing and replacement of the scraper elements without disturbing the high pressure boiler tubing.

A special characteristic of the scraper is the lack of normal bearings. The entire tube is scraped and the scraper blades act as bearings as well as scrapers. A relatively close fit, approximately 0.0127 cm (0.005 inch) clearance assures good heat transfer. An interesting characteristic appears to be the formation of a thin film of salt under the scrapers which prevents rapid wear of the assembly. Preliminary tests seem to confirm that the bearing material is being formed by salt. The scraper blades themselves are sharp edged to reduce scraping power.

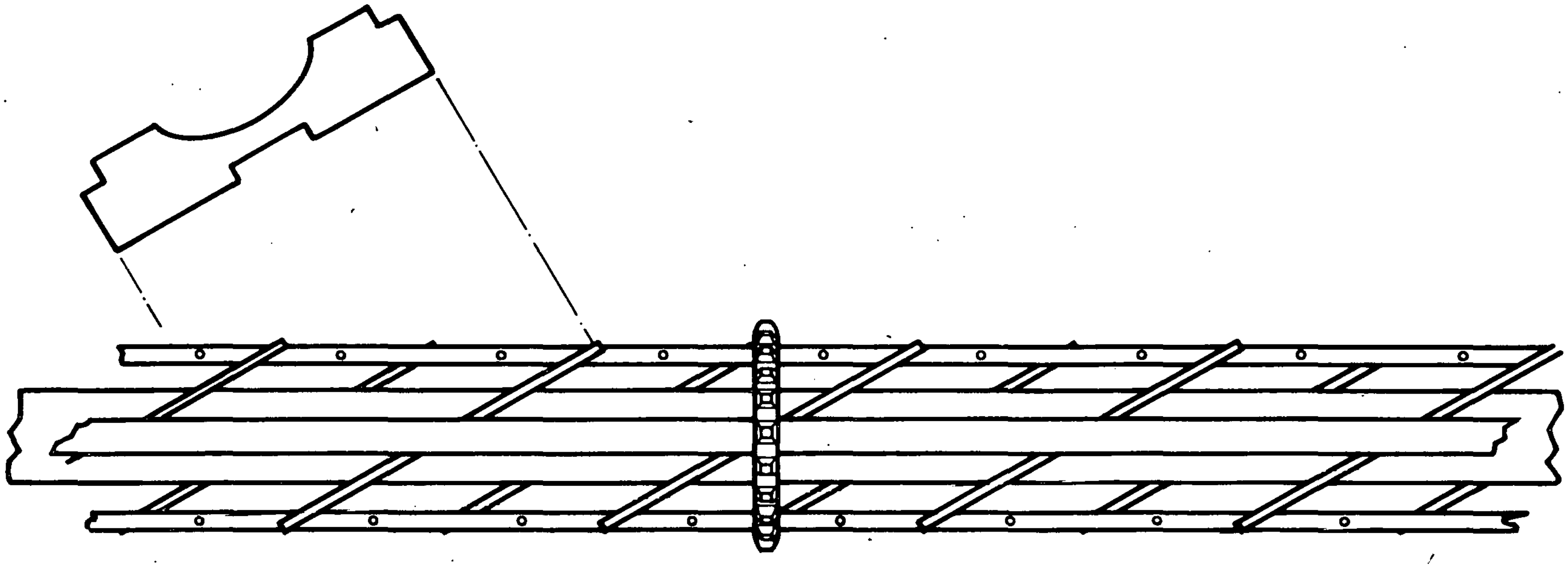


Figure 3-7. Split Design Inclined Plate Rotary Scraper

40454

Rotation of the scraper blades around the tubes increases turbulence and heat transfer due to agitation of the salt. Together with the thin films, this acts to provide relatively high heat transfer coefficients.

Chain-sprocket drives were selected since problems with bearings, gears and shafts are minimized. Chains are positive drives and when lightly loaded, serve well under hostile environments. Chains of stainless or carbon steel are available for this application.

Rotation of the scrapers without removal of heat often has been accompanied by squeaking, grating sounds indicating metal-to-metal contact. The liquid salt appears to have little lubricity and does a poor job of providing a lubricating film. During extraction of heat, the scrapers work very smoothly, indicating the presence of a separating film of freezing salt between scraper and heat transfer tube. Examination of the tubes during scraping shows a smooth white coating on the exterior of the tubes under the rotating scrapers. Calculations of the effect of the salt layer on the tubes using an approximate thickness equivalent to the clearance show heat transfer rates that correspond to the actual measured data.

The drive system for the scrapers consists of 22 tooth steel sprockets split in halves and welded to the scraper shells. The sprockets are somewhat offset from the scraper centers to allow one primary drive shaft drive two groups of scrapers with separate drive roller chains. The assembly includes an overhead drive shaft for each module. The drive shaft carries two 15 tooth adjacent sprockets for each parallel set of four scrapers. A roller chain from each sprocket passes down into the melt and over three adjacent scrapers interleaving to give a maximum sprocket-chain contact. A spring-loaded 27-tooth sprocket above themelt takes up the slack on each chain. Since four parallel scrapers are required, an additional sprocket and a short connecting chain drive one adjacent unit.

The torque required to rotate the scrapers at input shaft speeds of 200 rpm has been measured at 0.69 kg-m (5 foot pounds).

Figure 3-7 shows the scraper unit.

This page intentionally left blank.

CONDENSER MODULE

Heat energy from condensing steam can be charged into thermal storage salt by using a bare tube serpentine heat exchanger located at bottom of the tank, with natural convection heat transfer to molten salt, with steam condensing on the inside of condenser tubing.

The condenser unit of SRE is a one-to-one scale model of a pilot plant condenser module. The physical dimensions of, and the input parameters to, the SRE condenser unit will be same as the pilot plant condenser module and are given in Table 3-3 . Figure 3-8 shows the condenser module.

The use of receiver steam for melting the frozen salt has been tested in the engineering test module by substituting hot oil for steam. During discharge (removal) of heat by the vaporizer section, the frozen salt settles to the tank bottom. The solid salt slowly becomes denser at the bottom as the less dense liquid works its way upward in the slurry generated. With a time period of several hours the material at the tank bottom becomes sufficiently dense to require considerable force to penetrate it with a 0.95 cm (3/8 in.) steel rod.

Remelting the charge, normally occurring at approximately 310°C (590°F), may be done by circulating a suitable high-temperature fluid through a bare tube heat exchanger at the bottom of the tank. The salt surrounding the tube absorbs heat and forms a molten sleeve around the tubing. As the volume of molten salt increases, the free convection currents increase the heat transfer and soon generate a relatively large volume of molten salt. The supply line to the heat exchanger is brought down through the frozen salt and serves to provide a tracing function or "leak" path to the surface. The salt moves up through this path and the large mass of still frozen salt settles downward to rest on the heat exchanger. A continual flow of melted salt thus works its way to the upper surface of the bath. This is desirable since it permits partial charging and discharging. With extended charging, the salt completely melts, providing a maximum charging condition.

From a functional standpoint, the ideal heat exchanger for melting the solidified salt would consist of an integral tank bottom - heater with additional heating paths or zones on the vertical walls of the tank. This would supply the heat to the very lowest part of the charge, avoiding unheated volumes below heat exchangers. The heated wall areas would free the salt from the tank. Such a design employing boiler-type membrane wall heat exchanger tubing, would be strong, durable and maximize the quantity of salt in the tank. During meltdown the entire charge could smoothly settle to the tank bottom as the liquid generated could flow up the walls to the surface.

The heat exchanger or condenser planned for the SRE is shown in Figure 3-8. The design consists of a single serpentine series of boiler tubes arrayed in two

40454

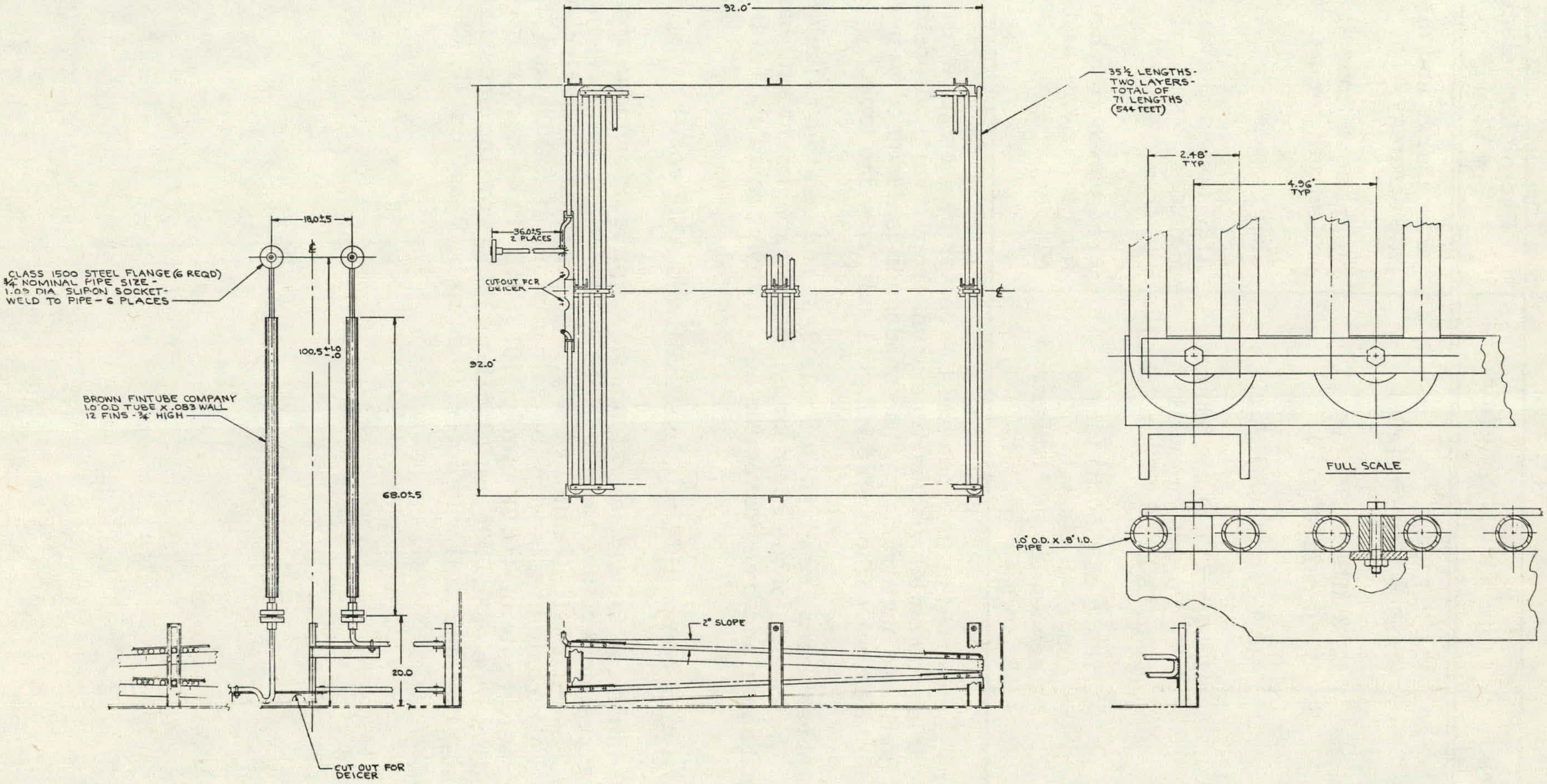


Figure 3-8. Thermal Storage Condenser Module

Table 3-3. Condenser Design Parameters

Parameters	Value for Module	Factor for Selection of Value
Heat Rate	134.4 KW(t) (4.59 x 10^5 Btu/hr)	Same charge and discharge rate strategy
Steam Conditions	12.3 MPa/327°C (1780 psia/620°F)	Steam conditions at receiver and salt temperature
Steam Rate	412 Kg/hr (908 lb/hr)	Charge rate
Pipe Size	2.54 cm O.D./1.860 cm I.D., 0.340 cm wall (1 in O.D./0.732 in I.D.)	ANSI code and available sizes
Module Size	167.6 m (550 ft) tube length in a single serpentine of 71 legs and 2 rows	Free convection heat transfer coefficients and overall ΔT

inclined layers, supported at the ends and the center by a suitable frame work of steel. The inlet and outlet tubes are adjacent from a vertical positioning standpoint to facilitate heat tracing. The condenser is designed to permit removal from the SRE tank without emptying the salt from the tank.

Detail design parameters are given in Table 3-3 and detailed calculations in Appendix E. The results of the engineering model experiment with bare tube serpentine exchanger and free convection heat transfer are detailed in Appendix E.

The piping design is compatible with the ASME and ANSI codes.

The pipe wall thickness is calculated from the empirical formulas and the table of pressure-temperature ratings (Ref. ASME Boiler and Pressure Vessels Code, Section VIII, Table ACS-1). The pipe material selected was carbon steel. Corrosion tests with the salt mixture of $NaNO_3$ and NaOH showed a corrosion rate of <0.02 mm/yr (0.8 mil/yr) on carbon steel. Using a corrosion allowance of 0.0305 cm (0.012 in.) and working pressure of 12.3 MPa (1780 psia) the pipe wall was determined to be 0.340 cm (0.134 in.) (9 gage tubing).

This page intentionally left blank.

SALT PREMELT SYSTEM

An independent high-pressure high-temperature heat exchanger is planned which is able to provide a clear melt path from the salt surface to the condenser and also provide heat below the condenser for melt down and emergency heating.

The heat exchanger consists of a hairpin-type steel circular finned tube heat exchanger which lies on the tank bottom below the regular condenser. Figure 3-9 shows the device. The inlet and outlet tubing is formed up into a 90 deg bend and terminates in class 1500 steel flanges. Additional vertical parallel finned tubes with corresponding flanges connect with the bottom heat exchanger and are designed to fit close to the main condenser supply and return lines. The upper ends of the tubes are unfinned and bent at 90 deg to pass over the upper edge of the tank and insulation. An appropriate flange permits connecting to a steam source.

This heat exchanger will be installed before other equipment is placed above it. The vertical finned inlet and outlet tubes are in close proximity to the primary condenser supply and return lines. The premelter makes possible the assurance of a liquid zone around the condenser tubing and thus a relief path from the condenser to the upper surface of the salt. During charging, the melting salt expands, and if trapped, would generate considerable pressure. A liquid relief path to the upper surface of the salt prevents damage. Normally, this would be automatically done by the inlet steam line. However, under some special circumstances, the additional liquid volume provided by the premelter would assure that rapid melt-down would not generate high pressure in the spaces above the condenser.

The unit is also expected to be of considerable assistance in the primary melt-down. Powdered salt will be poured into the tank after the premelter and condenser are installed and functioning.

Addition of heat from the premelter will assist in providing a molten pool of salt to start a larger scale melt-down. Experience has shown that pouring large quantities of powder into the molten salt results in a large mass of powder surrounded by a shell of solid salt. Because of trapped air, the mass floats on the salt surface. The limited heat transfer area and poor conductivity make this a slow process. The starting of a melted pool and steady additions of smaller quantities of salt improves the rate of melt-down. The premelter permits melting the powdered salt which would normally accumulate below the regular condenser.

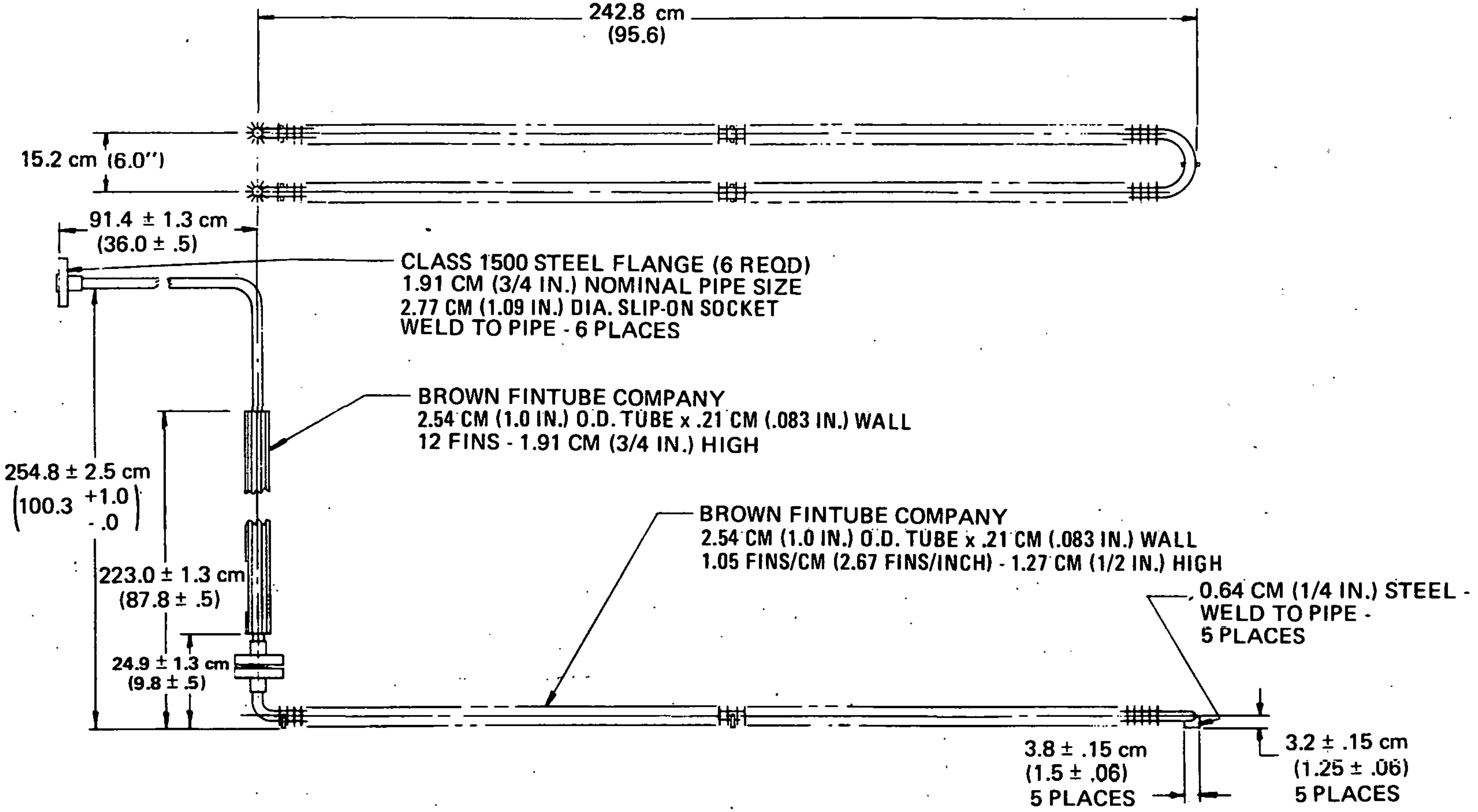


Figure 3-9. Salt Premelt - Storage Tank

40454

INSULATION AND HEAT LOSS

By using properly designed guard heaters, heat loss from the tank exterior surfaces can be minimized.

In any installation, heat will always transfer from an object at a high temperature to any area at a lower temperature. To eliminate heat loss through the external surfaces, guard heaters will be installed in all external panels. These heaters will each have a controller that senses the temperature outside of the heater and turns the heaters on and off to give a temperature within the panel equal to the setpoint. The controller is set at tank temperature. If the guard heater works properly, the panel will be at the same temperature as the wall and no heat transfer will occur.

Figure 3-10 shows that the insulation required to achieve the heat loss rate of 0.35 percent per hour for the SRE-size tank becomes excessive both in size and cost.

To provide the heat and insulation needed, panels will be constructed. A typical panel is shown in Figure 3-11. All of the panels are the same size and shape and three fit on each side and three on top. The panels contain integral heaters which are controlled by a thermostatic controller. On any one side only one of the three panels will have a temperature controller and it will control all three panels.

The temperature controller senses the temperature just outside of the heater panel by means of a bulb and capillary. The bulb on the controller selected is 0.48 cm (3/16 in.) in diameter and 33.01 cm (13 in.) long and is at the end of a 121.92 cm (48 in.) capillary. The controllers have a range of from 140°C to 371°C (300 to 700°F) and can handle heaters using up to 35 amp of electricity at 125 Vac.

The heaters will be constructed using 26-gauge nichrome wire which has a resistance of 0.09 ohms/cm (2.61 ohms per foot). A typical panel will have four heaters connected in parallel. Each heater will be constructed of approximately 774.19 cm (25.4 ft) of the wire mounted in a serpentine with 10.16 cm (4 in.) spacing between wires. The maximum heat released at 120-Volt input will be 216 Watts per heater or 864 Watts per panel. This will give about 2600 Watts per side or 12,950 Watts for the whole tank excluding the bottom.

Guard heater panel insulation used will range from high temperature asbestos and cement board next to the tank to 10.16 cm (4 in.) fiberglass insulation outside of the guard heater.

Heater/insulation panels of a similar design will be also constructed for insertion between the I beams under the tank.

The total bottom heat loss from the guard heaters will be approximately 500 Watts (1700 Btu/hr) and surface temperature of the concrete pad could reach 105°C (221°F). Because of the concrete pad depth, no serious heating of the surrounding floor is expected. The total heat loss is expected to be approximately 9000 Watts (30,000 Btu/hr).

To simulate a variable conductivity insulation approximately 15,000 Watts of guard heater power will be installed. Provision will be made to vary the heating rate over different zones of the tank and to vary the total power input. To determine

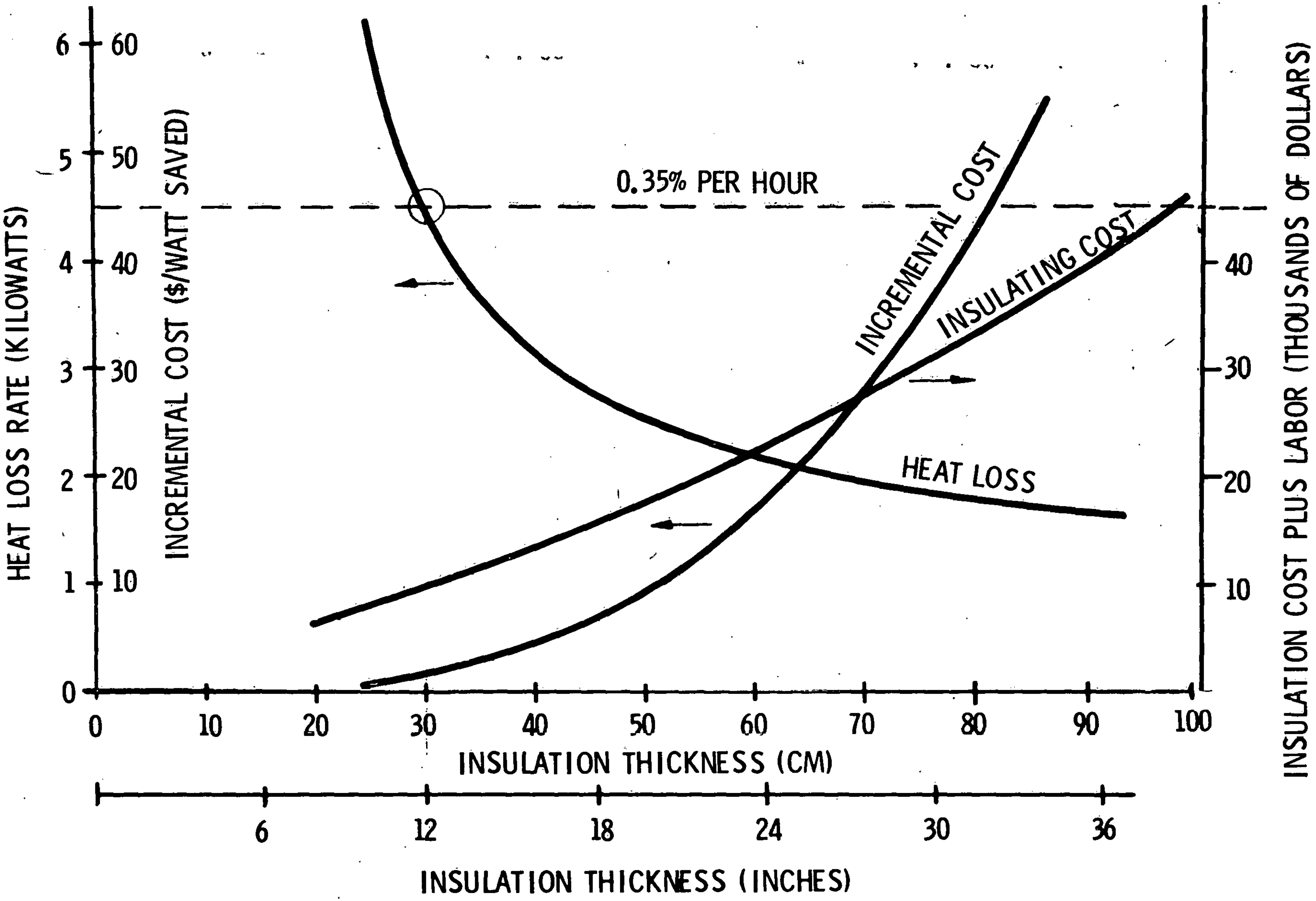
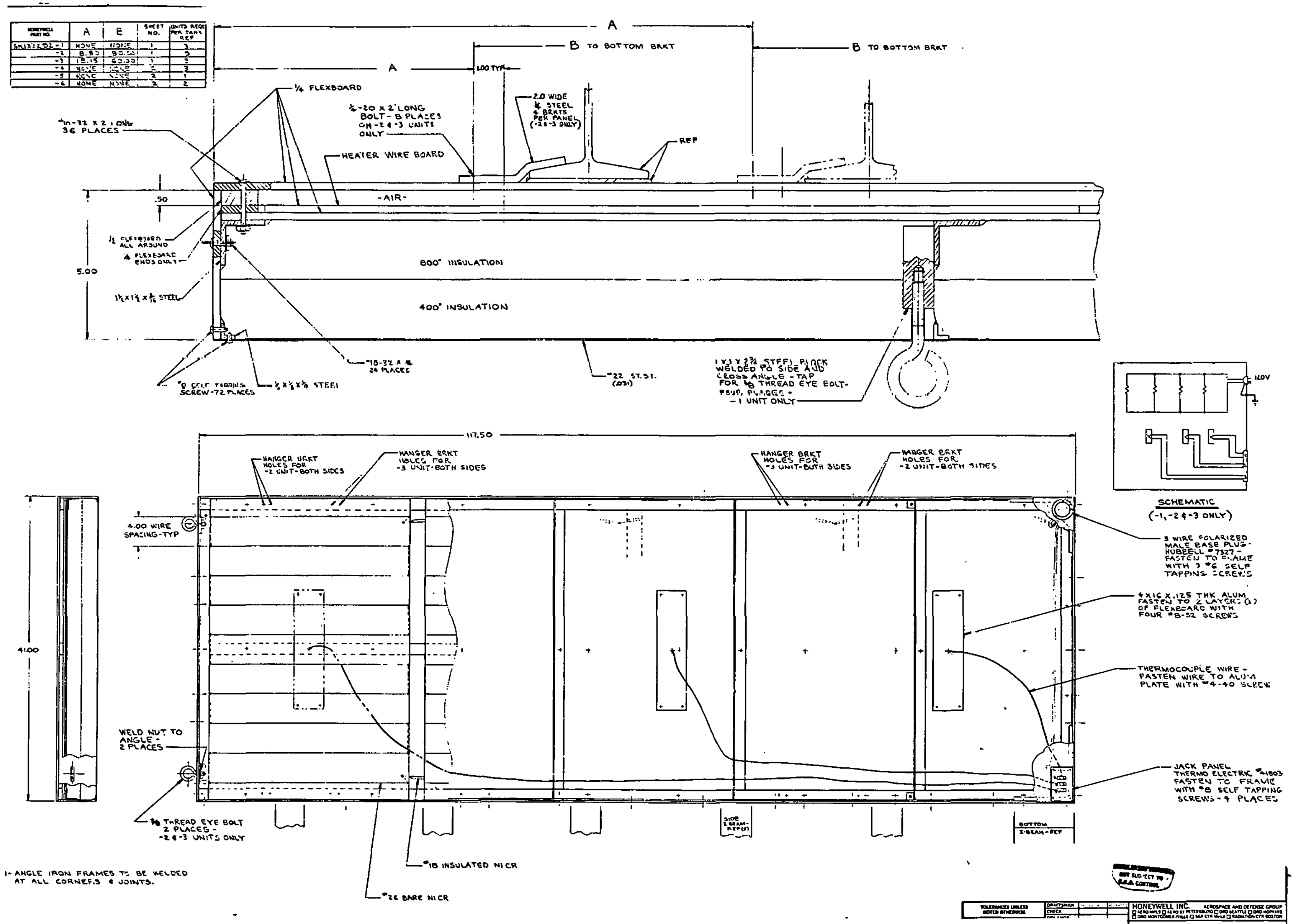


Figure 3-10. Heat Loss and Tank Insulation

40454

40454



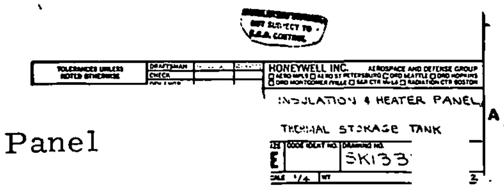


Figure 3-11. Thermal Storage Tank Guard and Heater Panel

40454

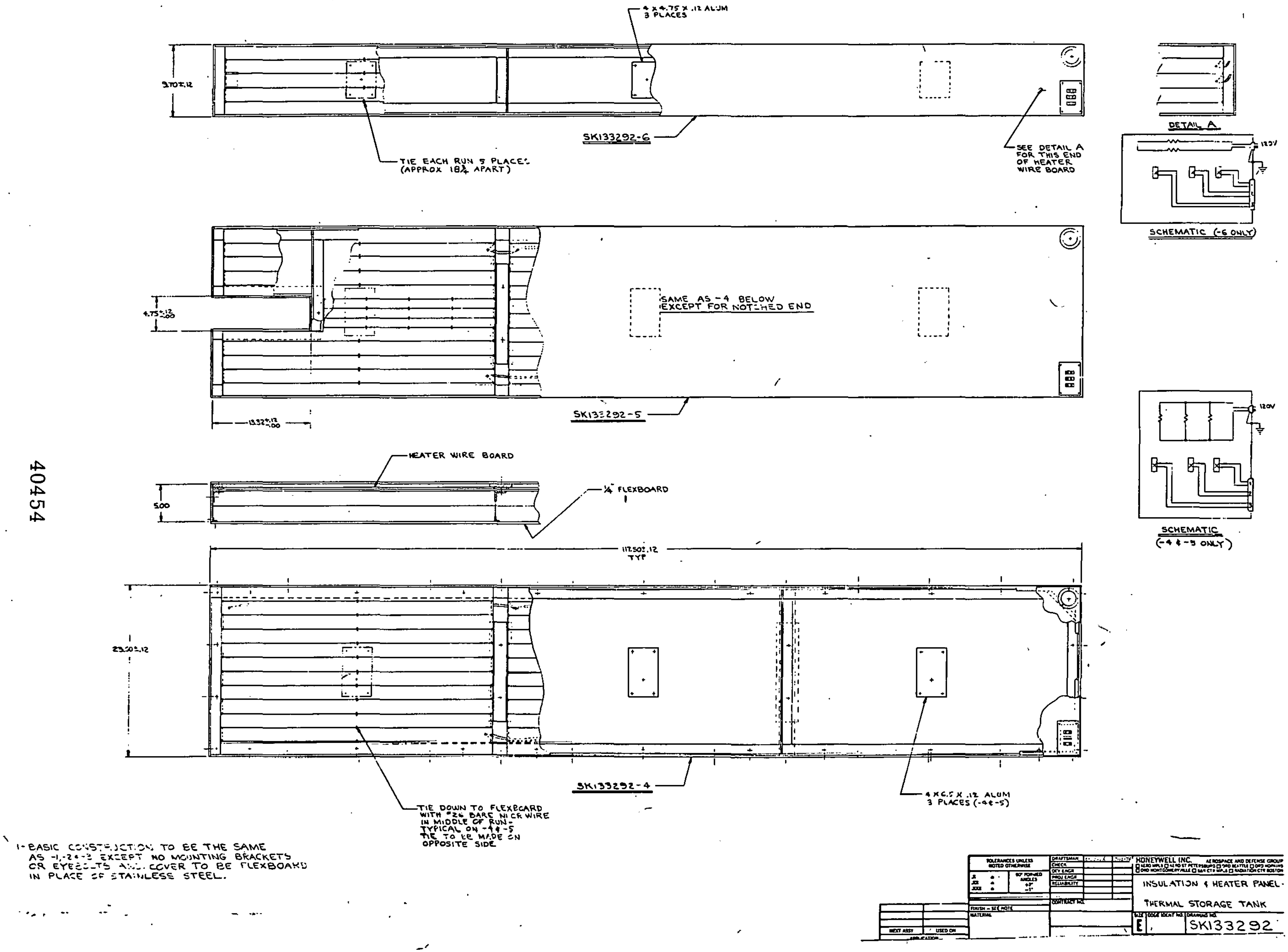


Figure 3-11. Guard and Heater Panel - Concluded

the correct power input, thermocouples will be attached to the tank walls and guard heater plates to measure temperature differences.

The side panels will hook onto the I beam stiffener that surrounds the tank. Pads of insulation will be attached to each of the outside faces of the I beams between the I beams and the panels to prevent a chimney effect from developing. As each panel is set in place a strip of insulation will be attached to the side adjacent to the next panel. The next panel will compress the insulation, effectively sealing the gap and preventing heat loss between panels. The outside of the gap will also be sealed by a strip of sealing material.

This page intentionally left blank.

PHASE CHANGE MATERIAL

A mixture of 99 wt% $NaNO_3$ and 1% NaOH has been selected as the best storage media because of its solid plus liquid phase in the operating temperature range.

Laboratory experiments have shown that it is necessary to have a salt composition that forms a slurry during the freezing process. The salt mixture must allow a large percentage of the material to freeze over a narrow temperature range and yet not form a complete solid at or above the surface temperature of the heat exchanger. A slurry or slush must be formed which retains a small amount of liquid to prevent the formation of a strong rigid material that cannot be scraped.

The composition phase diagram is shown in Figure 3-12. The operating temperature is shown for 70% heat recovery. Note that the composition of the liquid changes as the $NaNO_3$ solidifies. Note also that the solidus temperature is well below the steam boiling temperature. Thus, the liquid portion of the slurry will not solidify.

The DSC scan of the material in Figure 3-13 also shows that the bulk of the energy is transferred over a small temperature range while a small portion of energy is held in the liquid until a much lower temperature. The dashed lines compare the large scale experimental results with the DSC scan. The DSC scan temperatures are shifted because of the high speed of the heat transfer in the test tube and subcooling effects of small quantities of material.

The $NaNO_3$ - NaOH storage media is very stable in air at temperatures considerably above the operating temperature of the storage unit. Appendix C includes experimental data that show slight decomposition at 475°C (887°F).

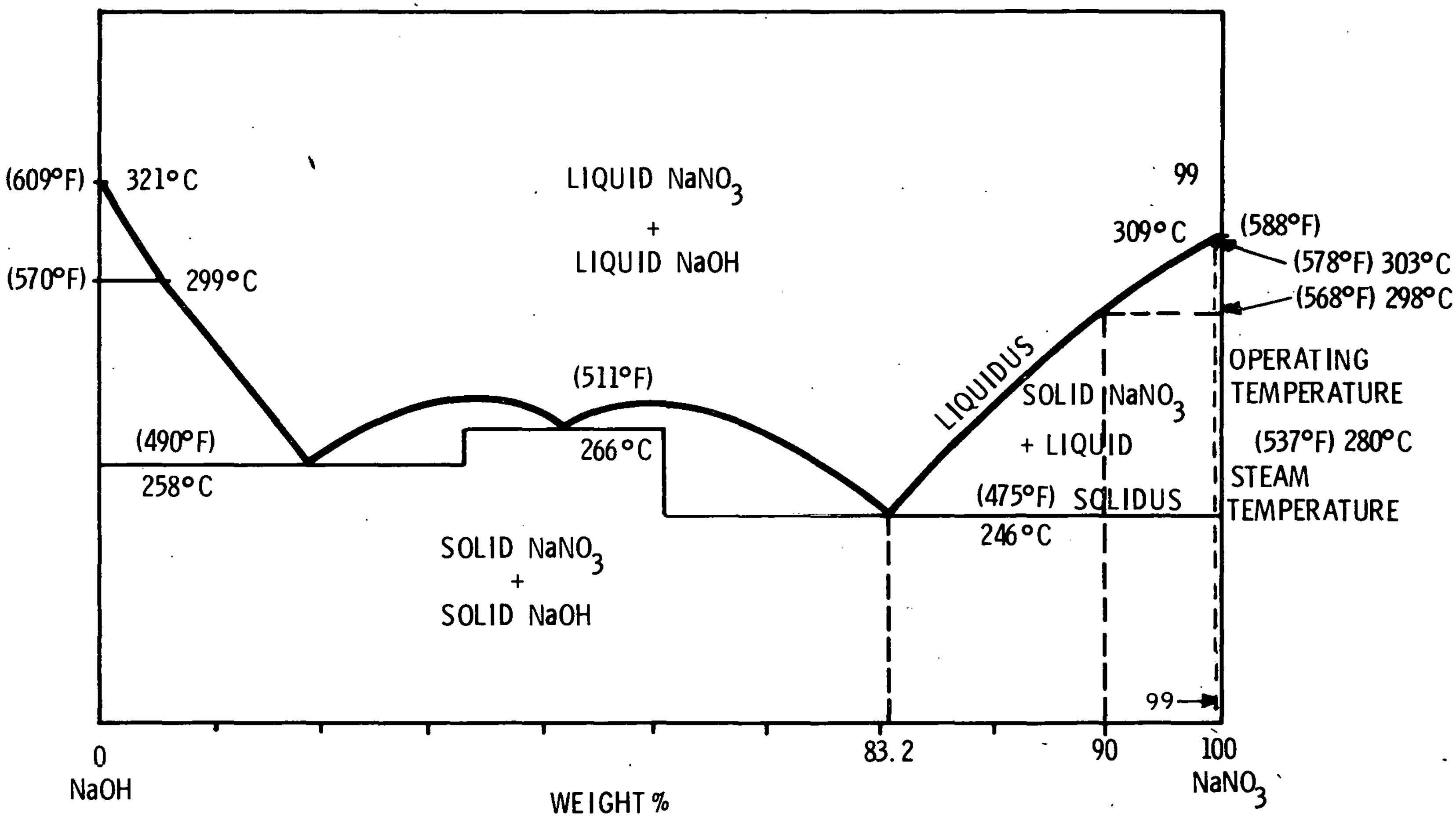


Figure 3-12. $NaNO_3$ - NaOH Phase Diagram

40454

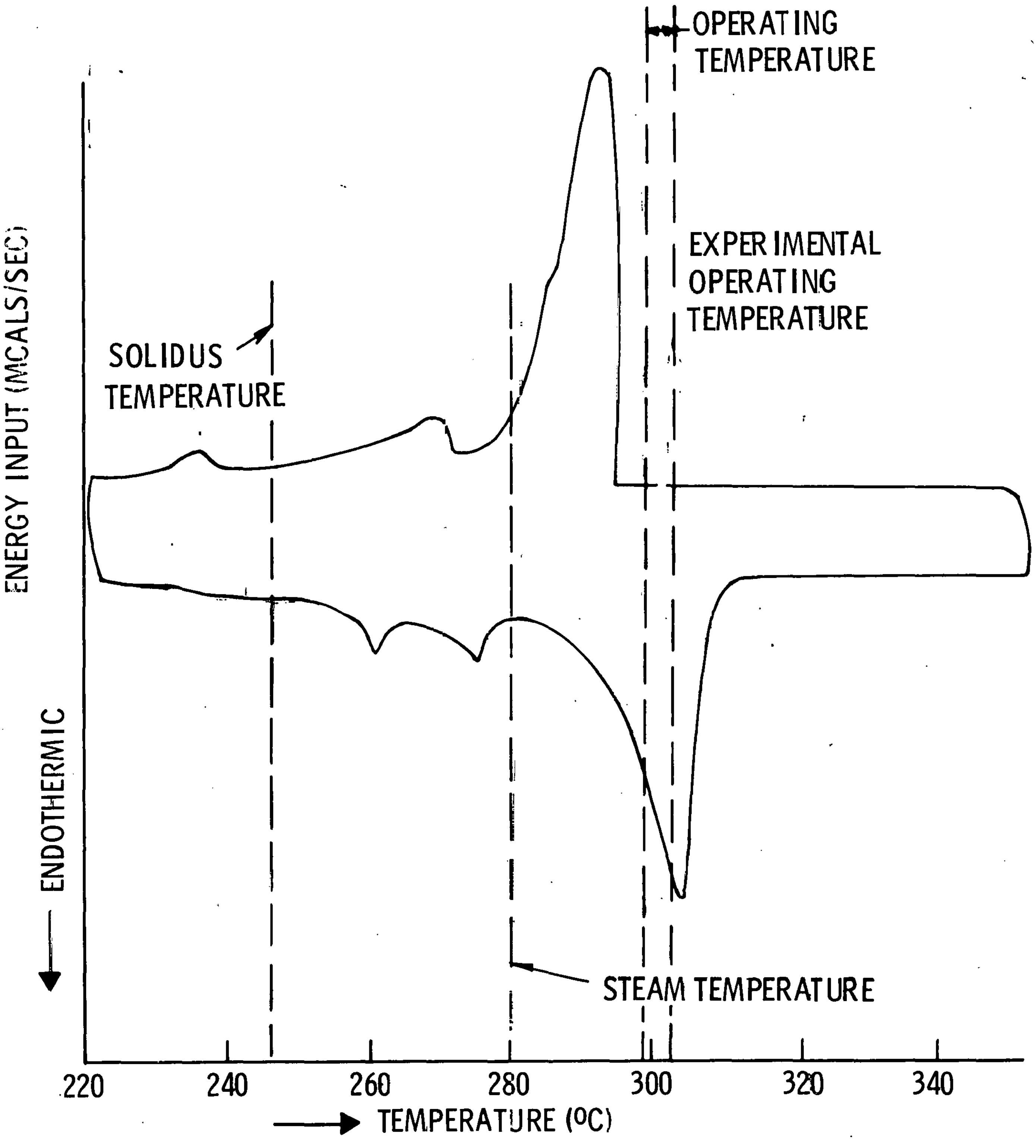


Figure 3-13. $NaNO_3$ + NaOH (1% By Weight)

This page intentionally left blank.

Experiment Components Detail Design and Integration

Experiment Detail Design

RECEIVER-TYPE STEAM DRUM

The steam drum design is based on the proper separation of the entrained water in the two-phase flow to provide high-quality steam, the liquid hold-up capacity desired, and the fluid flow and state parameters.

The preliminary design of the receiver-type steam drum is shown in Figure 3-14. Since the date of Figure 3-14, the design has been changed to utilize welded lugs to permit mounting of the steam drum on a vertical wall. Minor drum penetrations are not shown on this preliminary drawing, but will appear on the detailed drum design drawing. The drum is a vertical drum to obtain sufficient sensitivity to water hold-up changes. Some initial design specifications are:

- Dyna-Therm separator, Model #CC-900-.11-2-1, in accordance with the attached Dyna-Therm Drawing No. A-P-76-0135-1-1, herein Figure 3-14
- Shell and Head Material: SA-53-B
- Design Pressure: Int. 10.35 MPa (1500 psig) @ 315.56°C (600°F)
- Corrosion Allowance: 1.59 mm (0.0625 in.)
- Paint: 1 s/c red lead primer
- ASME Sect. VIII, Div. 1 construction, stamp included
- Estimated Empty Weight: 1247 kg (2750 lb)
- Shipment: 18-20 weeks after receipt of purchase order
- Exit steam purity guarantee is 0.5 ppm total dissolved solids, when boiler water is maintained within ABMA units.
- This unit designed to handle 315 kg/hr (694 lb/hr) of steam @ 6.64 MPa (947 psig) @ 281.1°C (538°F) with a maximum pressure drop of 635 mm (25 in.) in water.

Two-phase flow enters on the side at the left where most of the water is separated by the primary separator, a centrifugal separator, illustrated in Figure 3-15. The steam then passes through chevron purifiers illustrated in Figure 3-16 and to the steam outlet at the top in Figure 3-14. The water from each of these internals falls to the bottom of the drum.

The steam quality is guaranteed and will be certified to be very high quality as indicated by less than 0.5 total dissolved solids (TDS) using the sodium tracer technique. A steam drum providing such high-quality steam will permit analysts to consider the steam quality to be unity to simplify thermodynamic analyses and will give the experimenters experience with internals which will be necessary for the

NOTE:

DESIGN & STAMP ASME SEC. VIII DIV. 1

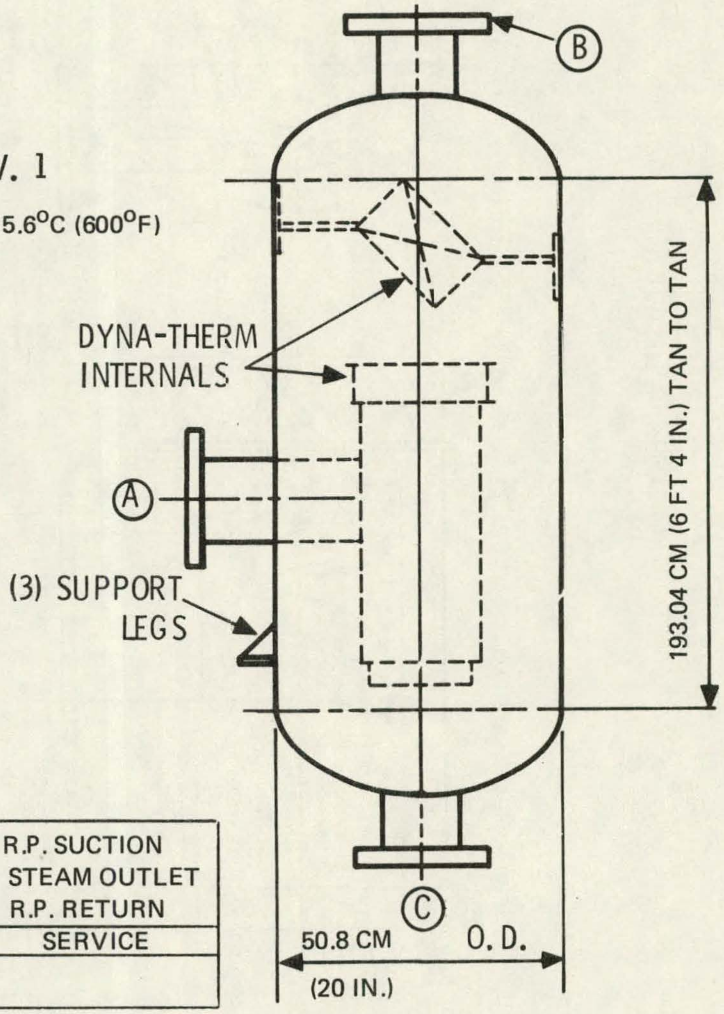
DESIGN PRESS. 10.35 MPA (1500 PSIG), 315.6°C (600°F)

CORP. ALLOW: 1.59 MM (0.0625 IN.)

MATERIAL : SA-53-B

PAINT: (1) S/C REDLEAD PRIMER

DYNA-THERM
CENTRIFUGAL & CHEVRON
SEPARATOR
MODEL No. CC-900-.11-2-1



CONN	SIZE	RATING & TYPE	SERVICE
C	5.08 CM (2 IN.)	ANSI 900 # RF	R.P. SUCTION
B	2.54 CM (1 IN.)		STEAM OUTLET
A	3.81 CM (1-1/2 IN.)		R.P. RETURN
NOZZLE SCHEDULE			

Figure 3-14. Preliminary Design of the Steam Drum

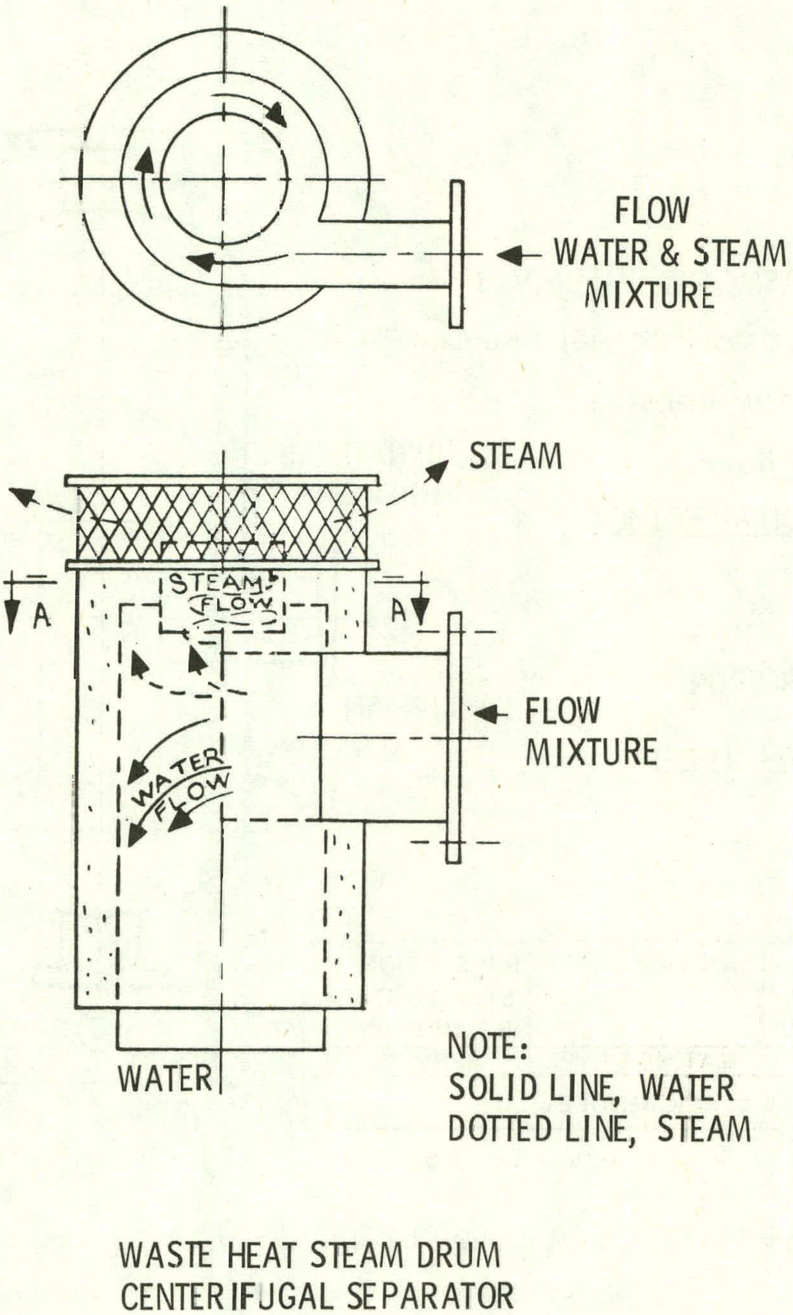


Figure 3-15. The Primary Separator in the Steam Drum, a Centrifugal Separator

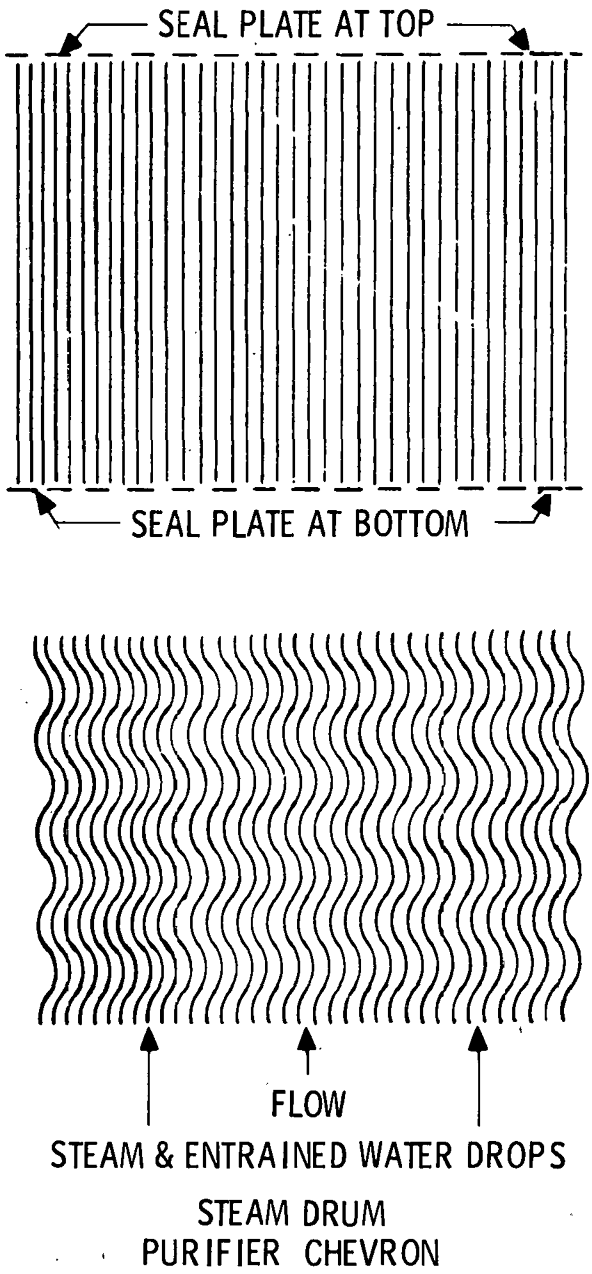


Figure 3-16. Steam Purifier in the Steam Drum, a Chevron Purifier

steam drum in the pilot plant. In Figure 3-17 a steam drum is schematically illustrated in operation producing high-purity steam and compared with it is a simpler separator producing lower quality steam.

The internals will be designed to separate 1574 kg/hr (3470 lb/hr) of a two-phase, steam-water mixture with a steam quality of 20 percent corresponding to a recirculation ratio of five-to-one. The hold-up capacity will be 132 liters (35 gallons) to permit approximately nine minutes of hold-up capacity at the maximum steam flow rate of 590 kg/hr (1300 lb/hr) should the feedwater be lost. Off-design capabilities will permit the separation of up to 2740 kg/hr (6040 lb/hr) of a two-phase, steam-water mixture with a steam quality from 4 to 30 percent.

Blowdown will be employed to keep the solids concentration sufficiently low; however, blowdown will occur only during periods when tests are not in progress. This means that varying heat losses due to blowdown will not have to be measured, thereby permitting better control of the thermodynamics of the experiments.

The design temperature and pressure are 316°C (600°F) and 10.4 MPa (1500 psig), respectively, each with a small design margin. The normal operating temperature will be 281°C (538°F) with off-design temperatures ranging from 270 to 292°C (518 to 558°F). The normal operating pressure will be 6.5 MPa (947 psia) with off-design pressures ranging from 5.5 to 7.7 MPa (800 to 1120 psia). The steam drum will be hydrostatically tested to 15.6 MPa (2250 psig).

The steam drum separator will be built according to ASME Code, Section VIII, Division 1, Unfired Pressure Vessels. Agreement that this code is proper was received verbally from Northern States Power Company, the owner of the site of the experiment. Their feedwater heaters are designed under the same code, which serves as a precedent.

The steam drum will be fitted with a pressure relief valve set to 10.4 MPa (1500 psig), a pressure gauge and transmitter, high water and low water level alarms, a water level transmitter, a water level indicator and a simple sight gage as shown on the P and ID Drawing No. M1004. Each of these instruments will pass the design and hydrostatic test conditions.

The requirement specification (HRS SK-133288) governing procurement of the steam drum is attached as Appendix A.

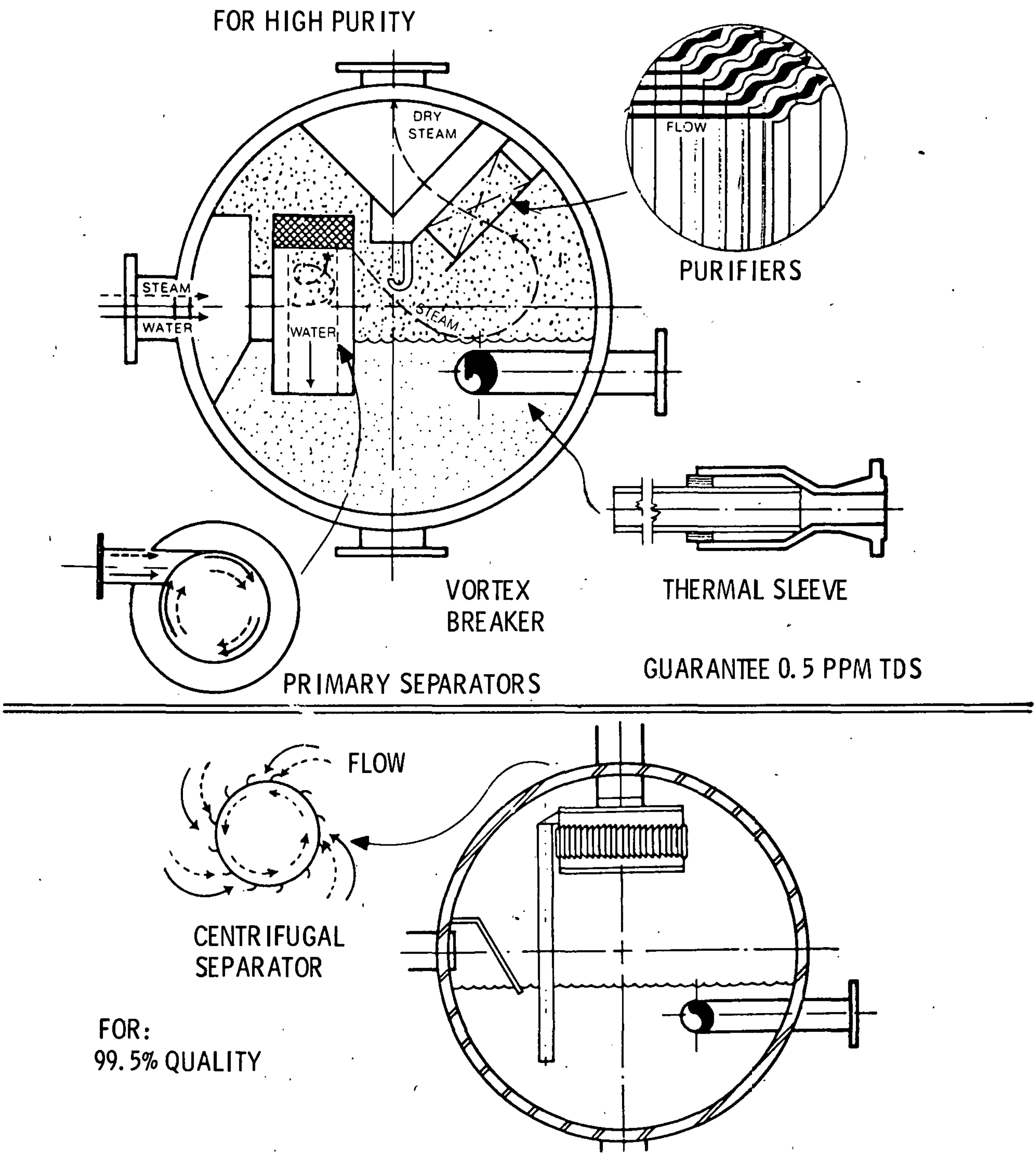


Figure 3-17. An Illustration of a Steam Drum for Separating High Purity Steam and of a Simpler Separator for a Lower Quality Steam

STEAM TRAPS

The steam traps will provide the necessary extraction of steam from the condenser with a minimum loss of live steam.

The steam trap system will consist of a water seal at the bottom of the condenser, a vertical siphon leg to carry the condensate from the bottom of the salt storage tank to the top, the shutoff and isolation valves steam traps and the discharge lines. Steam traps are off-the-shelf commercial traps designed to pass liquid with a minimal loss of live steam.

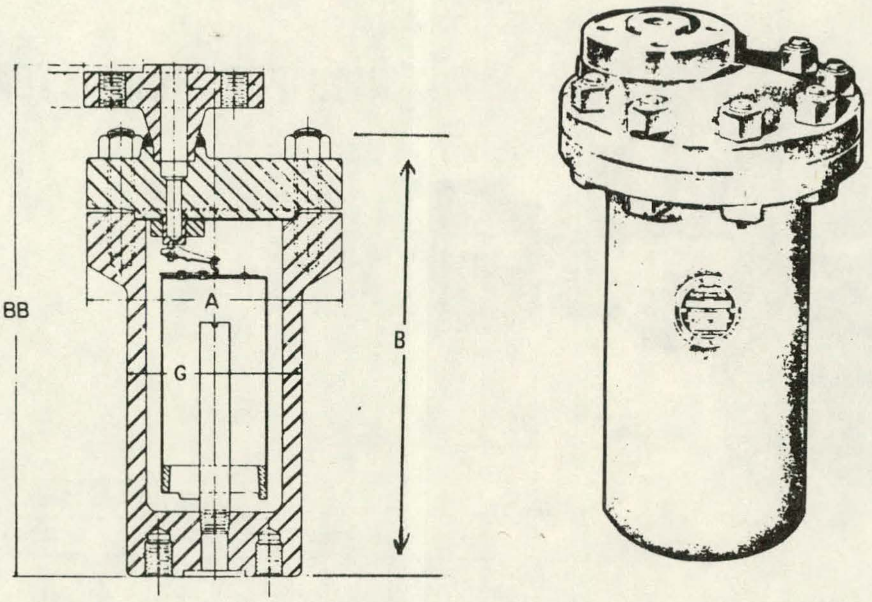
An inverted bucket trap operates on the difference in density between vapor and condensate. Figure 3-18 is a cross section view of an inverted bucket trap.* When vapor fills the inverted bucket, it floats on the residual condensate in the trap to close the discharge port. Because of the small continuous heat loss from the trap, the vapor in the bucket will condense, allowing the bucket to sink and open the discharge valve. Condensate and/or steam again enters the bucket to reinitiate the cycle. A small bypass port is provided in the bucket to allow noncondensible gas to escape. Live steam will also pass through the vent, but it is usually less than the steam flow required to keep the trap warm.

The second steam trap which will be tried is a thermodynamic trap (Figure 3-19). (Note that Figure 3-20 is not a cross section of the trap which will be used, but is used to illustrate the principle of operation of the thermodynamic trap.) This trap uses a flat disk to seal the discharge port. If condensate is flowing, the port remains open. When steam passes through the space between the disk and the port face the higher vapor velocity reduces the pressure and the port is forced closed by the high pressure in the control chamber. The area of the control chamber is greater than the area of the port, allowing the slightly lower pressure in the control chamber to hold the disk closed against the higher supply pressure. Small vent passages are provided to allow the control chamber pressure to decrease slowly and a new cycle to be initiated.

The inverted bucket trap is larger and more expensive but should have a longer life between servicing than the thermodynamic trap. The thermodynamic trap is operated on a relatively continuous time cycle determined by the size of vent passages and control volume; the inverted bucket trap opens only when condensate fills the bucket, but a small flow of condensate through the bucket vent occurs continuously. Assuming the entering condensate is at saturation condition at 12.28 MPa (1780 psia), and the discharge pressure is 1.73 MPa (250 psia), the condensate will flash when leaving the steam trap and will have an exit quality of 32.7 percent. This will give the appearance that the trap is operating efficiently, but the steam in the discharge line is flashed condensate and not live steam being leaked through the trap.

---

*Catalog L-4A, Armstrong Machine Works, Three Rivers, Michigan 49093.



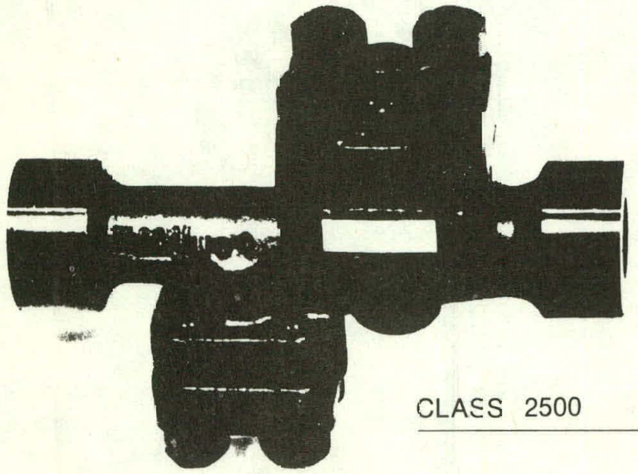
A. FLANGE DIAMETER = 26.3 cm (10 3/8 in)

B. HEIGHT = 41.9 cm (16 1/2 in)

BB. FLANGED HEIGHT = 50.8 cm (20 in)

G. BODY O.D. = 17.8 cm (7 in)

Figure 3-18. 5155F Flanged Inverted Bucket Type Steam Trap



HIGH-PRESSURE STEAM TRAP

CLASS 2500

PART	C-500 (CLASS 2500)	
	MATERIAL	SPECIFICATION
BODY	CAST CHROME MOLY	ASTM A-217 GR. WC-9
TRAP BONNET		
STRAINER BONNET		
STUD	ALLOY STEEL	ASTM A-453 GR. 660
NUT		ASTM A-194 GR. 4
SEAT	STAINLESS STEEL	AISI SERIES 400 HEAT TREATED
CONTROL CYLINDER		17-4 PH HEAT TREATED
CYLINDER ADAPTER		AISI SERIES 400
VALVE		AISI SERIES 400 HEAT TREATED
BONNET GASKET		SPIRAL WOUND MIL-G-21032
SEAT GASKET		
LOCK PIN	MONEL	—
LOCK NUT	STAINLESS STEEL	AISI SERIES 400
SCREEN		AISI SERIES 300 0.020" PERF.

Figure 3-19. Yarway Thermodynamic Steam Trap

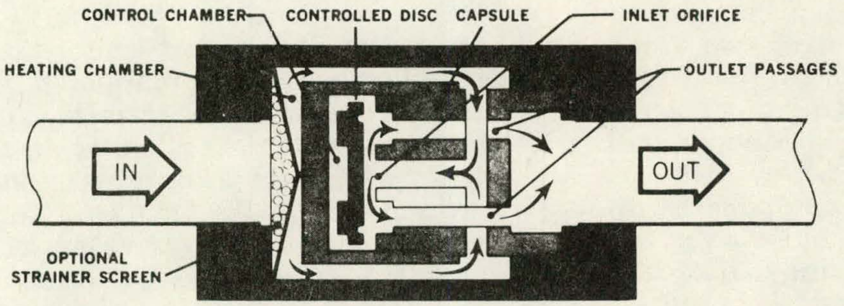


Figure 3-20. Thermodynamic Trap Schematic

In the SRE design the condenser is at the bottom of the salt storage tank, with all steam lines entering from the top. To bring the condensate out of the storage tank, a syphon leg is used. A water seal is formed by a "U" bend at the bottom of the condenser and a vertical leg carries the condensate out of the tank to the steam trap. In the condenser the condensate and steam are at the same pressure. The water seal allows the condensate to completely fill the discharge line. When the pressure at the steam trap is reduced due to cooling or venting, the liquid is forced up the vertical leg by the steam.

There is a reduction in the pressure in the vertical syphon leg due to the reduction in hydrostatic head. In low-pressure systems this can cause flashing and water hammer, but should not be a problem in the high-pressure system where a small reduction in temperature of the liquid causes a large reduction in the pressure. Heat will be lost by the vertical syphon leg to the salt, thus no flashing in the syphon leg is expected. A rough calculation shows that the heat transfer coefficient from the vertical syphon leg need only be 1/15 of the horizontal tube to prevent flashing. The steam trap orifice is sized to provide condensate flow rates two to four times the expected flow rate. This allows extra capacity for start up transients and allows the steam trap to cycle between full open and full closed condition.

The purpose of testing two steam traps is to determine what effect the different operating cycles of the two traps have on condenser performance. The inverted bucket trap operating on a demand cycle may cause the essentially horizontal condenser to load up with condensate then purge the entire condenser in a long continuous discharge after which the condensate will start to build up again. The thermodynamic trap operates on a cycle which allows the trap to remain open when condensate flows, but closes for a relatively fixed time after vapor reaches the trap. This type of cycle may tend to purge the condenser in short bursts or if the flow rates are low enough it could allow the condensate to trickle on down the lower half of the condenser with a small amount of vapor flowing in the top half of the tube. This will greatly reduce the inside heat transfer coefficient. Each of the scenarios may be dependent upon the condensing pressure and the salt melting temperature.

The steam traps only discharge condensate with a very small amount of live steam being lost by the thermodynamic trap during each cycle. The inverted bucket trap loses a small amount essentially equivalent to heat required to keep the trap warm.

For energy balance purposes, the enthalpy of the discharge from the condenser can be considered to be that of saturated water at the discharge temperature and pressure conditions.

This page intentionally left blank.

Experiment Components Detail Design and Integration

Experiment Detail Design

RECIRCULATION PUMP

The recirculation pump for the TSS/RE is based on the requirement to force-circulate water through the vaporizer to produce steam over a range of experimental conditions.

The recirculation pump specifications are chiefly dependent upon the design of the vaporizer and the operating conditions of the thermal storage unit. Appendix B presents a calculation of pressure drop through the TSS/RE vaporizer for several experimental conditions. From these calculations, Figure 3-21 is plotted to show the head loss in feet of water against capacity in gallons per minute for a number of system pressures and heat transfer rates. The normal design point is shown to be 45.7 meters (150 feet) of head loss at a water pumping rate of 30.3 liters per minute (eight gallons per minute), at a system pressure of 6.48 MPa (940 psia), corresponding to a temperature of 281°C (537°F), and at heat transfer rate of 134.8 kW (0.46 x 10^6 Btu/hr).

Figure 3-21 also contains a dashed curve to illustrate the approximate pump characteristic necessary to meet minimum acceptable TSS/RE test objectives. This curve was adjusted upward to compensate for the 20 percent uncertainty in the calculated values of pressure drop through the TSS/RE vaporizer.

A version of the Kontro pump is illustrated in Figure 3-22. Two pumps similar to this will be used in series as a rigid assembly to generate the head requirement shown on Figure 3-21.

The pump assembly will be supplied with two motors with a total of 20 horsepower. They will be industrial quality motors suitable for the environment at NSP's Riverside Plant.

Figure 3-23 shows the full characteristics of the Kontro pump.

Figure 3-24 is a drawing of the Kontro pump.

The requirement specification (HRS SK-140010) governing procurement of the recirculation pump is attached as Appendix A.

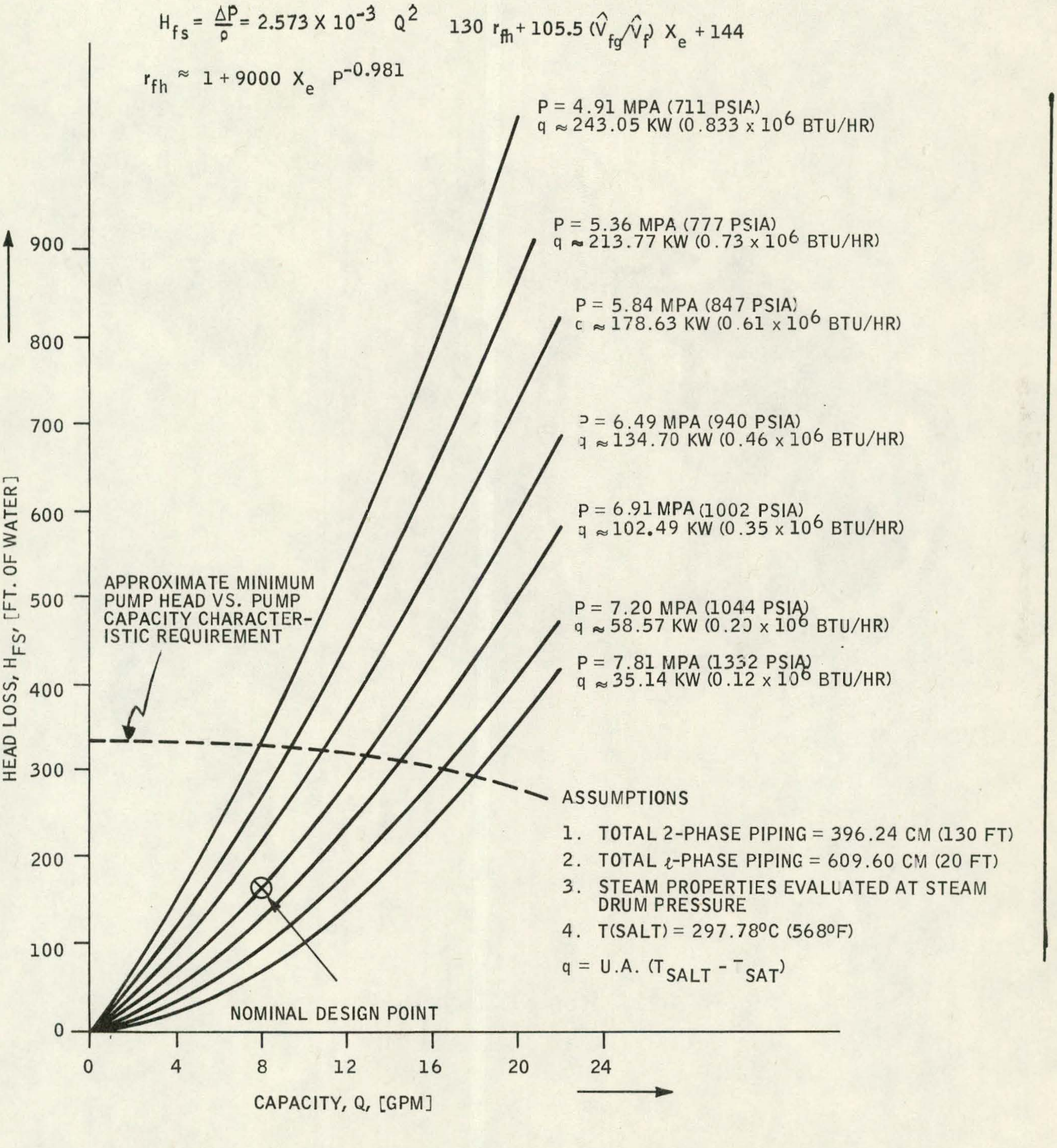


Figure 3-21, Head Loss versus Capacity for the TSS/RE Steam Generation System at Several Conditions of Pressure and Heat Flux

MAGNET DRIVE PUMP

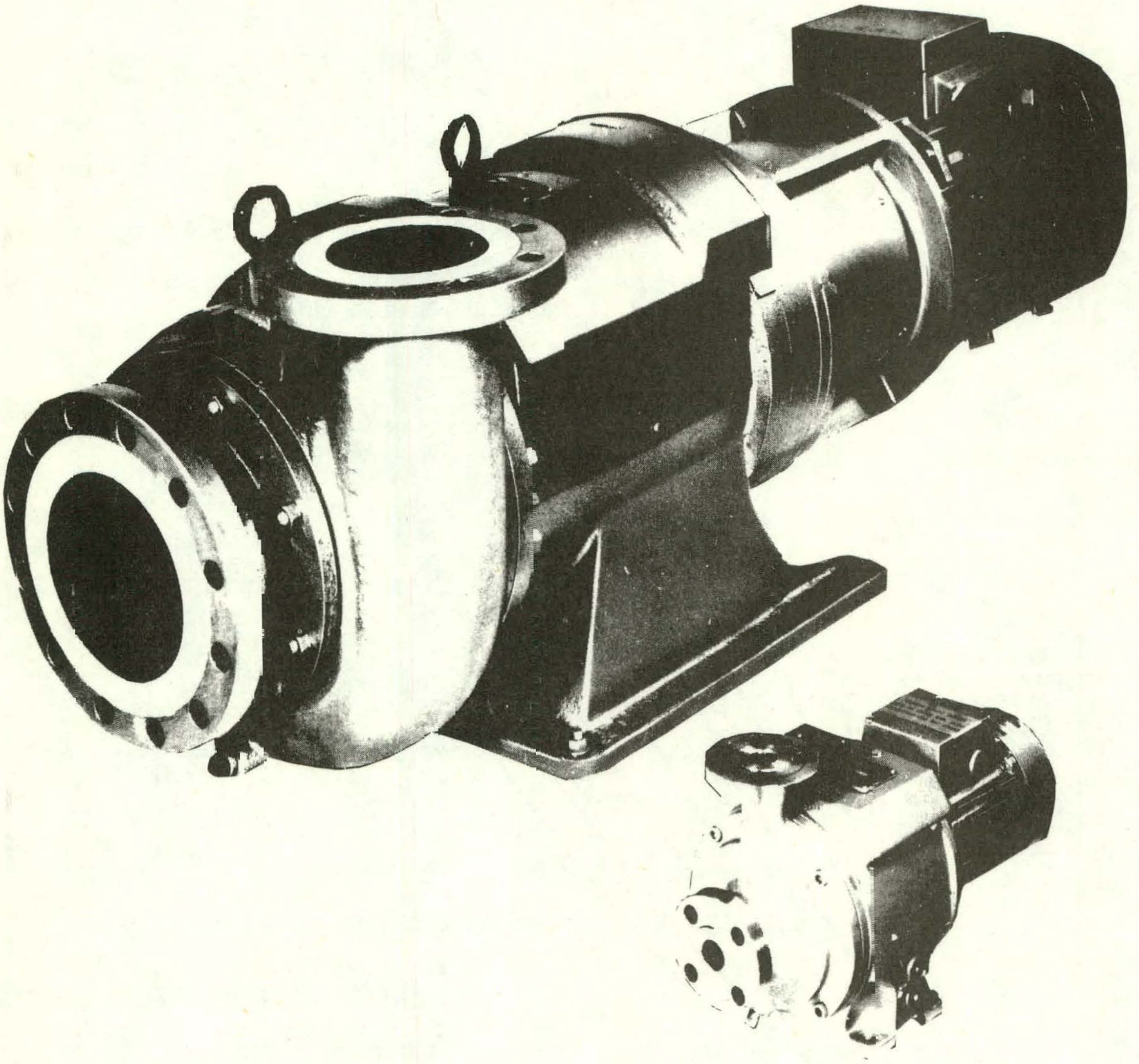


Figure 3-22. Kontro Magnetic Drive Pump

PUMP SIZE: **HS2M HSP 2.54 CM X 2.54 CM (1" X 1")**
SPEED: 3450 RPM
LIQUID: WATER
SG: 0.678
IMPELLER

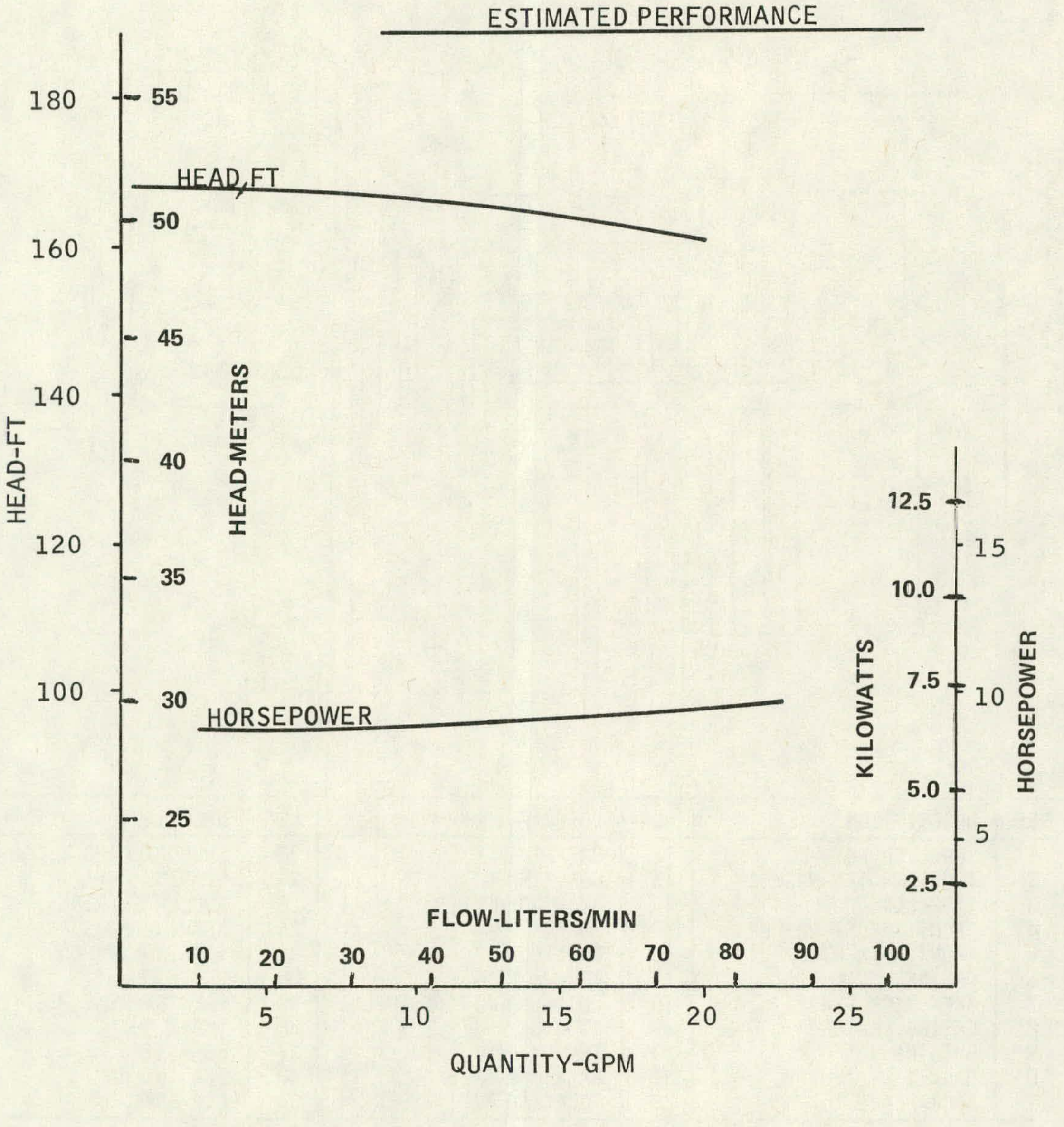
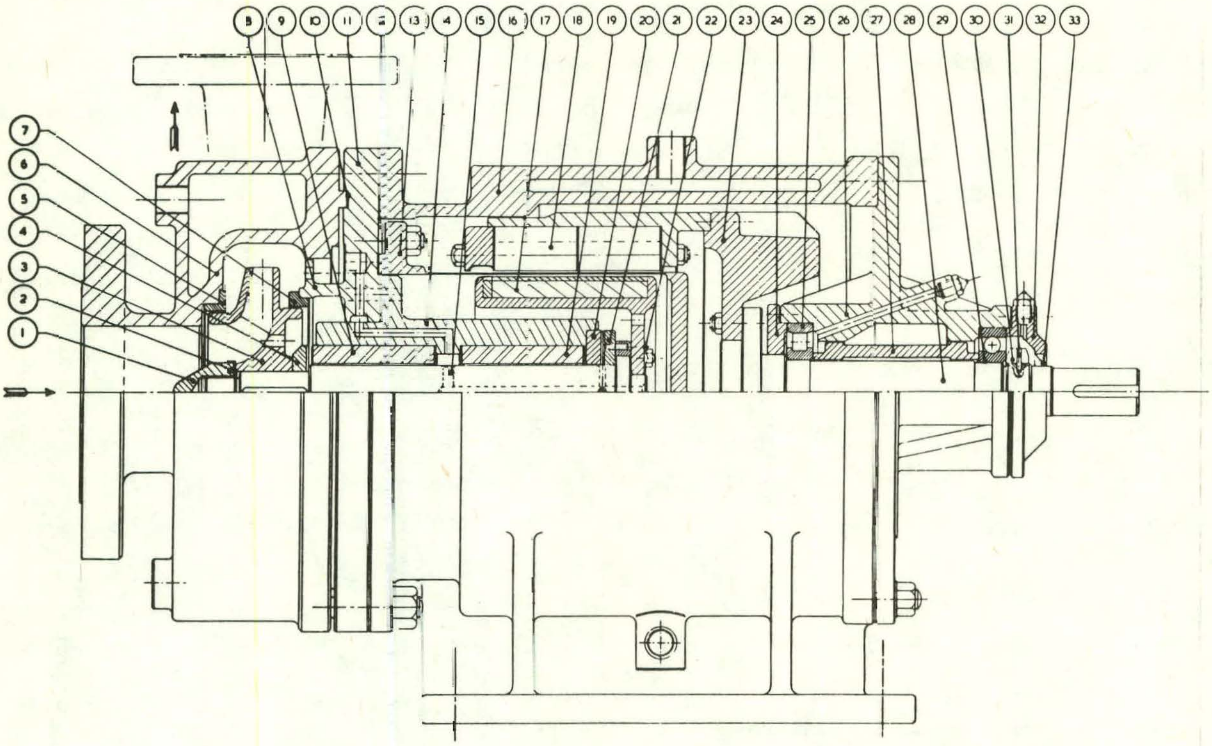


Figure 3-23. Kontro Pump Characteristics

PARTS LIST
FOR
SEPARATE MOTOR TYPE



REF	DESCRIPTION	REF	DESCRIPTION	REF	DESCRIPTION
1	IMPELLER NUT	12	GASKET	23	SUPPORT RING / FAN
2	IMPELLER TAB WASHER	13	CONTAINMENT SHELL	24	BEARING CAP
3	IMPELLER	14	BUSHING HOLDER	25	ROLLER BEARING
4	FRONT THRUST WASHER	15	SHAFT	26	BEARING HOUSING
5	FRONT NECK RING	16	HOUSING	27	BEARING SPACER
6	CASING	17	TORQUE RING	28	DRIVE SHAFT
7	BACK NECK RING	18	OUTER MAGNET ASSEMBLY	29	BALL BEARING
8	CASING PLATE	19	BUSHING	30	SHAFT NUT
9	BUSHING	20	THRUST PAD	31	SNAP RING
10	GASKET	21	BACK THRUST WASHER	32	BEARING CAP
11	BACK PLATE	22	COUPLING TAB WASHER	33	LIP SEAL

Figure 3-24. Kontro Pump Drawing

This page intentionally left blank.

Experiment Components Detail Design and Integration

Experiment Detail Design

DESUPERHEATER

A desuperheater will produce steam with conditions covering the spectrum of conditions necessary for experimental evaluation of the TSS/RE.

The source of steam for the TSS/RE is the No. 8 unit of NSP's Riverside Plant as indicated on Figure 3-25. This steam has a pressure of 16.5 MPa (2400 psig) and a temperature of 538°C (1000°F). As a minimum, the TSS/RE experiments will cover a pressure range at the condenser of 9.7 MPa (1400 psia) to 12.4 MPa (1800 psia) and a temperature range of 309°C (588°F) to 328°C (622°F). A device to change the conditions of the No. 8 service steam to steam with the desired conditions is called a desuperheater.

The desuperheater selected for the TSS/RE is a Schutte and Koerting type 6970 illustrated by Figures 3-26 through 3-28. The type 6970 is useful when a combined pressure-reducing and desuperheating station is required when flows vary widely. One can obtain the desired steam conditions simply by dialing them into the pressure and temperature controllers associated with CV-3 and CV-6, respectively, as indicated on Figures 3-28 and 3-25.

In a combined pressure reducing, desuperheating station where flow rates vary widely, this unit, with adequate controls (Figure 3-27), provides dependable operation with turndown ratios of 50 to 1 and higher approaching to within 5.6°C (10°F) of the saturated temperature of desuperheated steam. This is the widest range available from a desuperheater.

Type 6970 desuperheaters are recommended for use where sufficient high-pressure steam is available to provide the atomizing steam supply. The most frequent application would be in combination reducing-desuperheating stations. The minimum atomizing steam pressure required is 1.4 times the steam pressure through the desuperheater, and the amount required is constant.

In the Type 6970, the water preheating and distributing device is installed in a short pipe section with R. F. weld neck flanged connections. This unit can also be supplied with a flange for mounting through a nozzle connection on the pipe or supplied in a section of pipe suitable for welding into the pipeline. Various mounting arrangements are possible.

This desuperheater uses a steam atomizing device, operating on the jet principle, to entrain cooling water, preheat, and discharge the atomized water into the superheated steam flow.

Ejector-type steam atomizing desuperheaters (Figure 3-26) utilize steam at higher than line pressure to atomize water. In the Type 6970, the ejector action is used to entrain condensate from the pipeline. This is an important feature of this type unit.

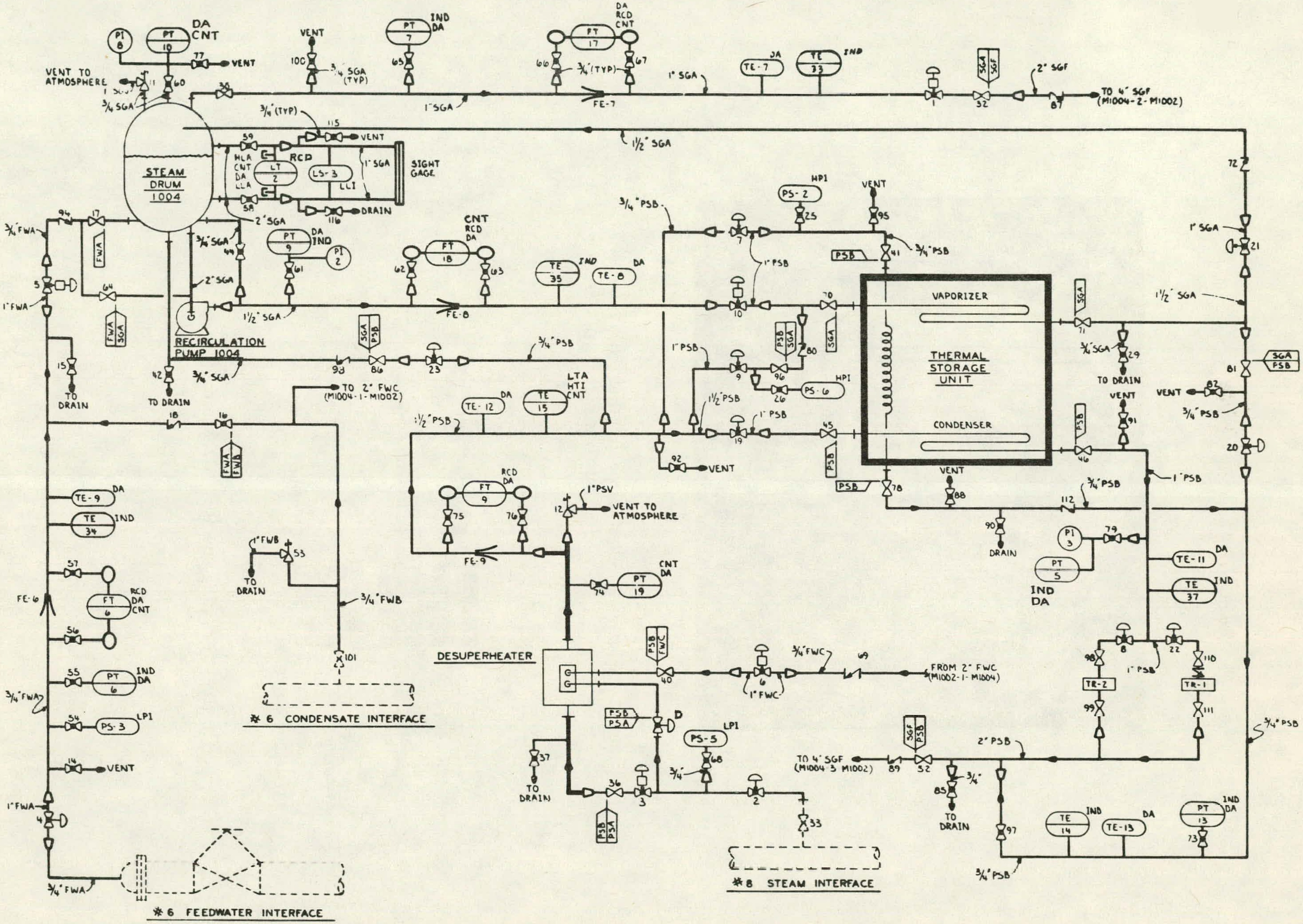


Figure 3-25. Piping and Instrument Diagram M1004 for the TSS/RE.

40454

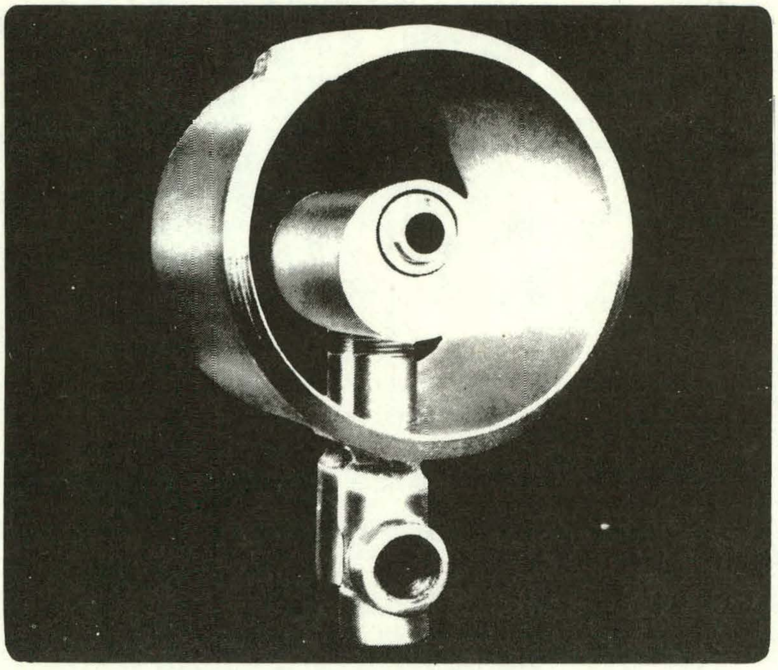


Figure 3-26. Type 6970 Steam Ejector, Atomizing Desuperheater

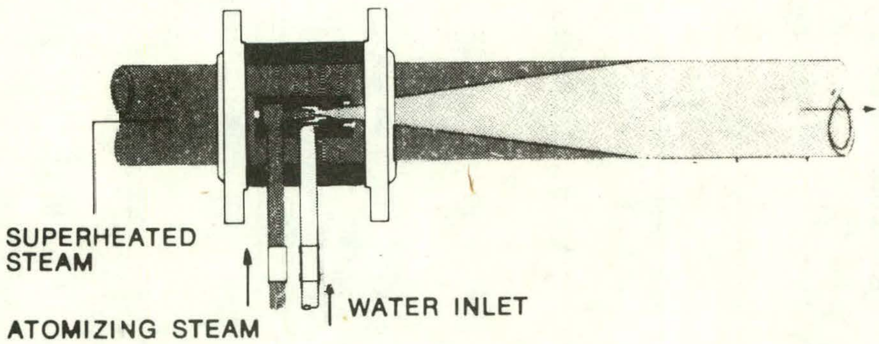


Figure 3-27. Type 6970 Desuperheater

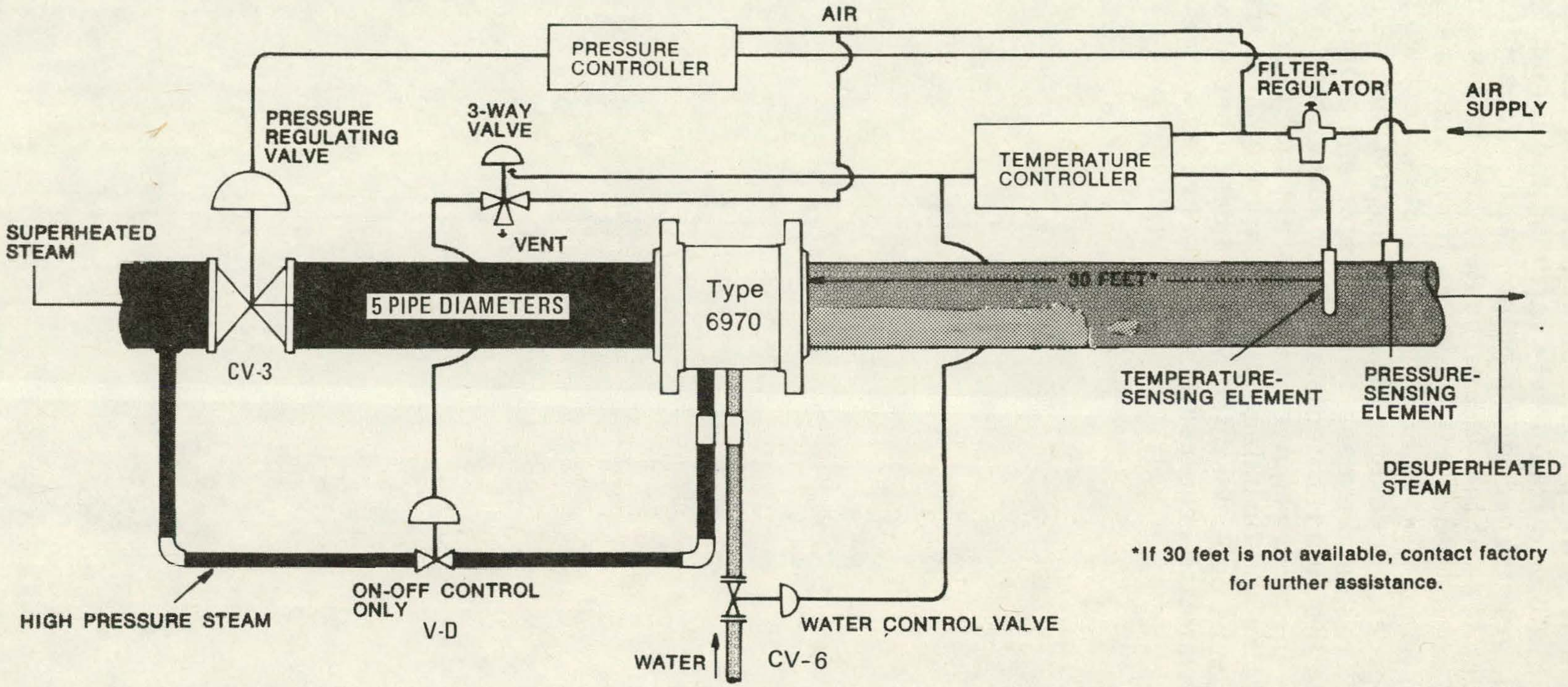


Figure 3-28. Typical Control Arrangement for a Steam Ejector, Atomizing Desuperheater

40454

Few problems are encountered in operating desuperheaters at normal pipeline velocities. When it is desired to approach saturation temperature within 5.6°C (10°F), it becomes impossible to completely vaporize the liquid. Thus, while superheated steam is flowing through the pipeline, water accumulates on the walls of the pipe and flows back toward the desuperheater. As it flows back it is exposed to superheated steam which will vaporize it and also desuperheat the steam. As indicated in Figure 3-27, high pressure steam enters the ejector steam nozzle which is precisely designed for each application. This steam entrains the mixture of fresh and excess cooling water and atomizes this water, which is discharged into the superheated steam line at saturation temperature. The preheating reduces the time required to evaporate the liquid, and the consequent small particular size and turbulent stream improves heat transfer. At low flows the excess water runs back down the walls as described above. At high flows, when no excess water is required, the unit operates as a steam-atomizing desuperheater.

This page intentionally left blank

Experiment Components Detail Design and Integration

Experiment Detail Design

INSTRUMENTATION: THERMAL STORAGE MEASUREMENT AND CONTROL

The TSS/RE facility is designed to permit nine modes of operation (one mode is actually comprised of three submodes) through the use of measurement instrumentation, on-off valves, and control valves with their associated controllers and to permit monitoring its performance through indicators, recordings, and data acquisition.

Each of Figures 3-29 through 3-32 is the piping and instrument diagram (M1004) for the TSS/RE with emphasis by outlining with hexagons on valves, controllers, indicators and recording channels, and data acquisition, respectively. Local instruments such as pressure gauges are not outlined. Table 3-4 is a legend for interpreting symbols on these figures.

The 11 on-off valves are outlined on Figure 3-29 by the use of solid hexagons:

- V-7 Tank premelt steam
- V-21 Vaporizer outlet (drum isolation)
- V-23 Drum warming steam
- V-9 Scraper thaw steam
- V-19 Condenser steam (condenser isolation)
- V-20 Thaw steam discharge (vaporizer isolation)
- V-8 Trap select (thermodynamic trap)
- V-22 Trap select (inverted bucket trap)
- V-D Atomizer steam (to be furnished with desuperheater)
- V-2 No. 8 service steam
- V-4 No. 6 feedwater

As an example, the system logic permits only one of V-7, V-9, V-19, and V-23 to be open at once. See Appendix G for the total logic of the TSS/RE.

The five control valves are outlined on Figure 3-29 by the use of dashed hexagons:

- CV-1 Main steam (drum-purified steam) discharge control
- CV-5 Feedwater control (drum level control)
- CV-10 Recirculation flow control
- CV-6 Desuperheater feedwater flow control (in)
- CV-3 Desuperheater service steam flow control (in)

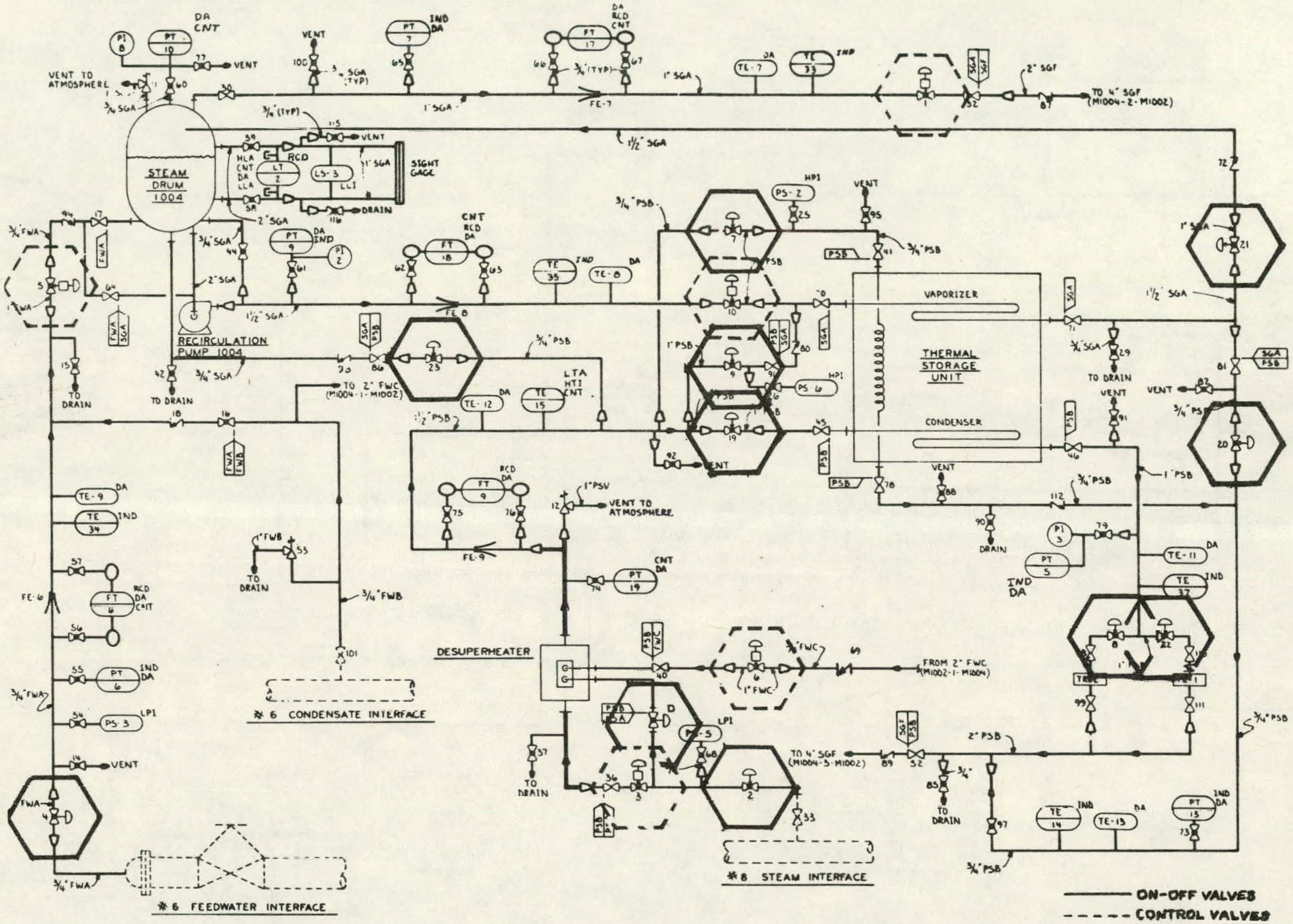


Figure 3-29. The Eleven On-Off Valves and Five Control Valves of the TS SRE

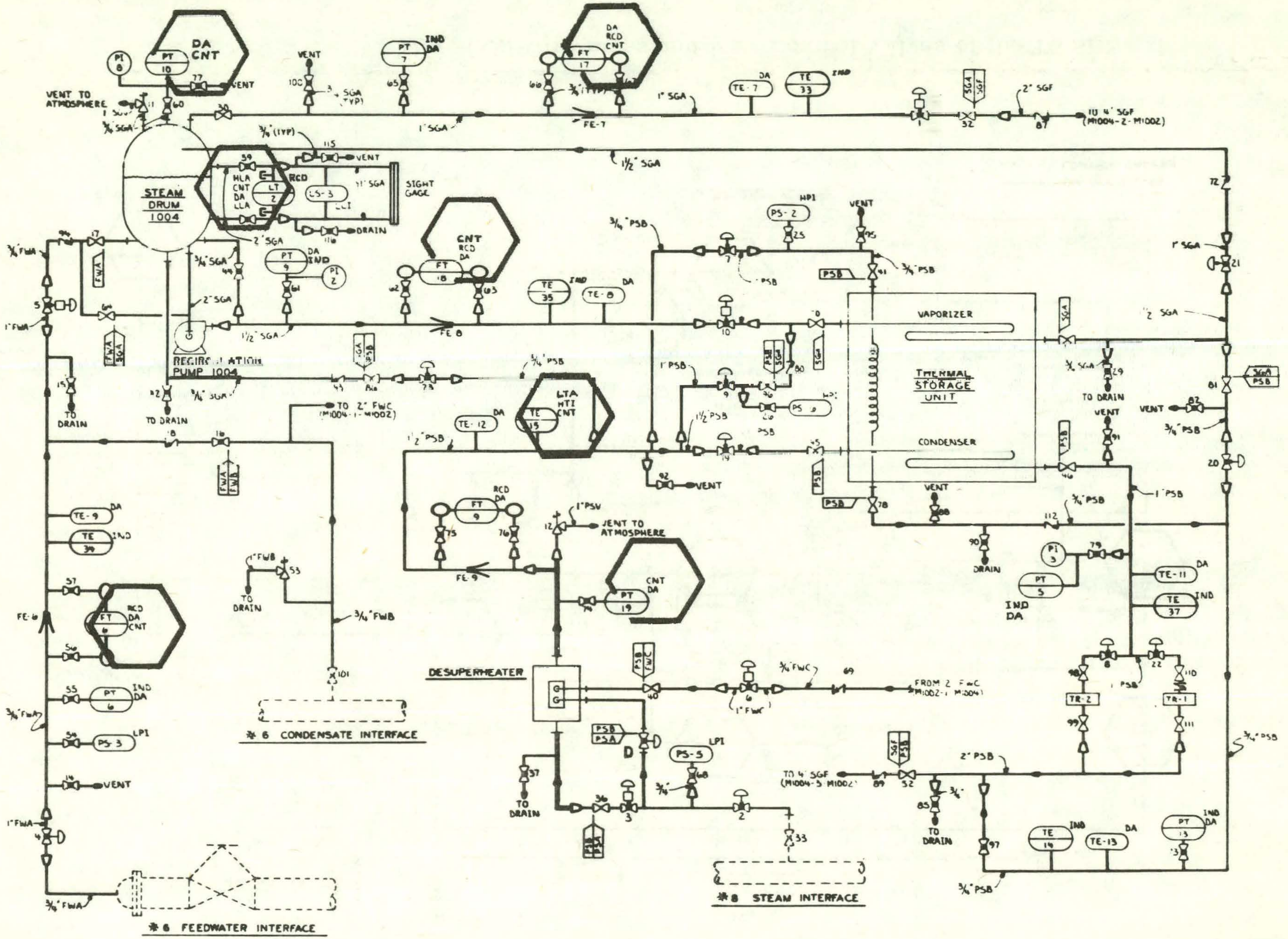


Figure 3-30. The Seven Controllers of the TSS/RE

40454

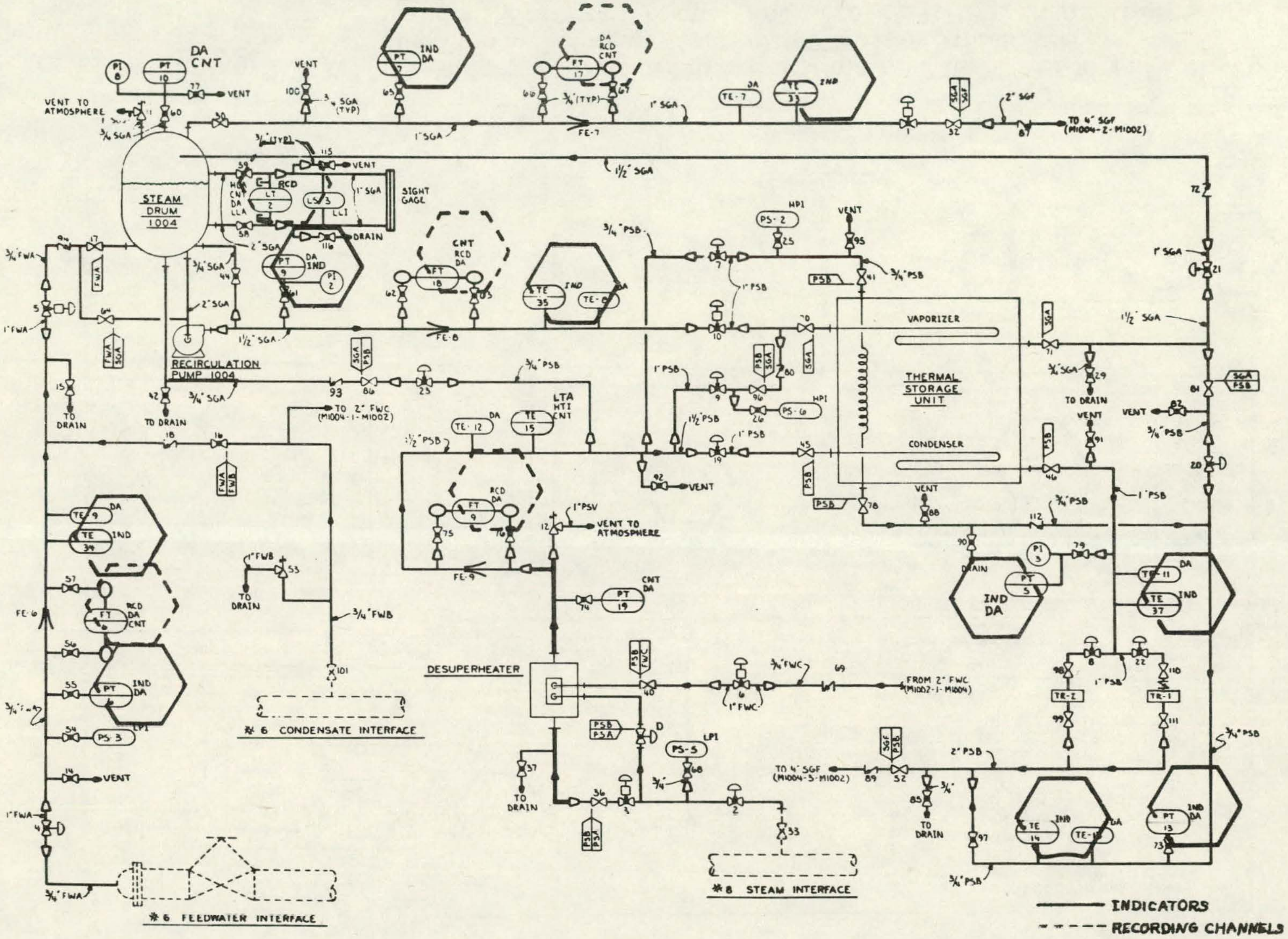


Figure 3-31. The Ten Indicators and Five Recording Channels of the TS SRE (Seven Additional Built-In Indicators are Associated with the Controllers, Figure 3-29)

40454

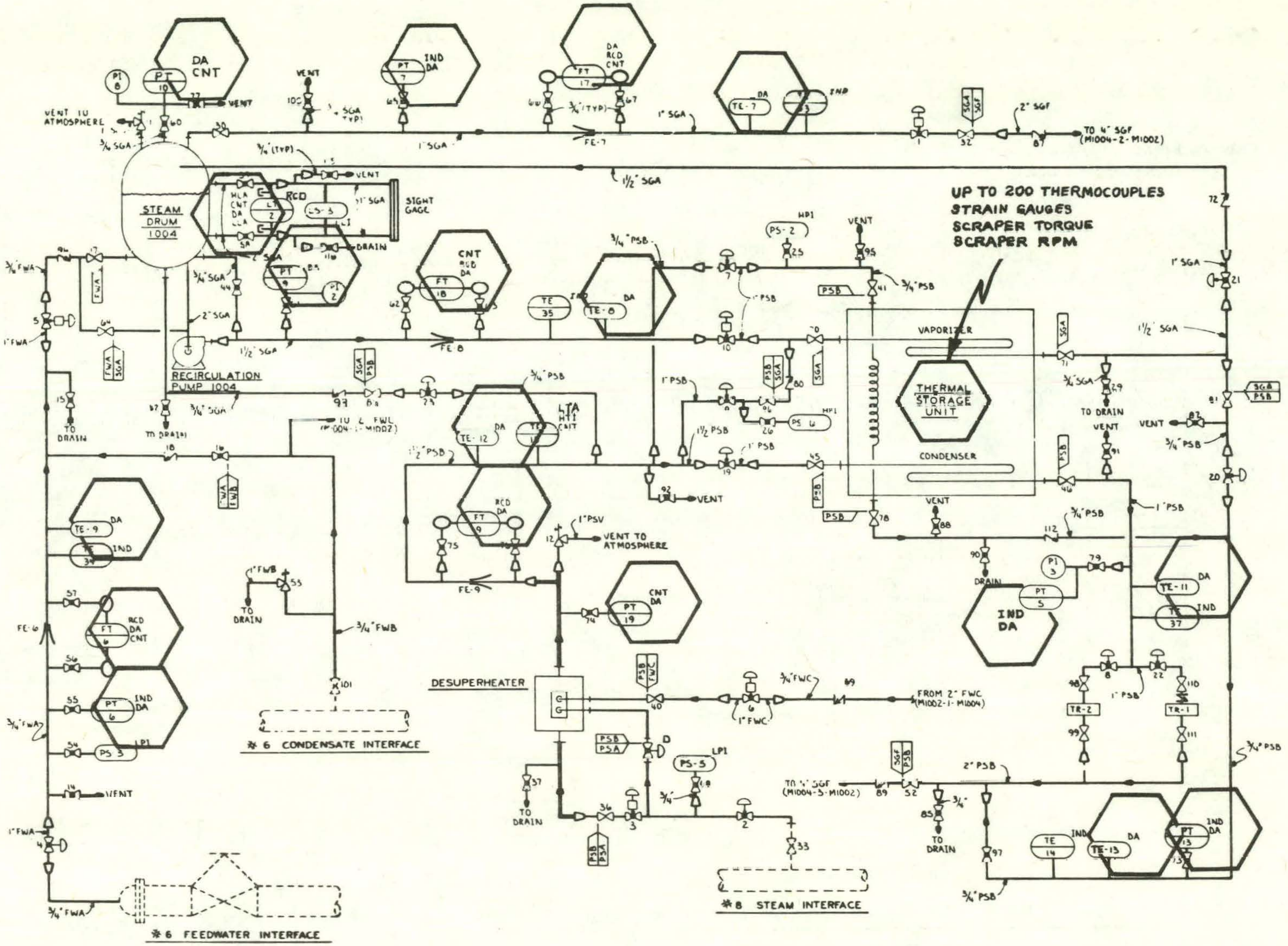


Figure 3-32. The Eighteen Data Acquisition Points of the TS SRE and the Thermal Storage Unit with Thermocouples, Strain Gauges, Scraper Torque, and Scraper RPM. In Addition, Each On-Off Valve Position is Fed into Data Acquisition

Table 3-4. List of Symbols Used on the Piping and Instrument Diagram M1004

CNT	Controller (at control console)
DA	Data acquisition (to computer)
FE	Flow element
FT	Flow transmitter
HLA	High level alarm
HPI	High pressure interlock
HTI	High temperature interlock
IND	Indicator (to control console)
LLA	Low level alarm
LLI	Low level interlock
LPI	Low pressure interlock
LT	Level transmitter
LTA	Low temperature alarm
LTG	Light (valve status light, on control console)
LS	Level switch
PI	Pressure indication, a pressure gauge (local)
PS	Pressure switch
PT	Pressure transmitter
RCD	Recorder (strip chart)
TE	Temperature element (thermocouple) and transmitter
TR	Trap
SGA, . . . , FWA, . . .	Pipe run designation

The seven controllers are outlined on Figure 3-30 by the use of solid hexagons:

- PT-10 Drum pressure control
- FT-17 Main steam (drum-purified steam) throttling control
- LT-2 Drum level control
- FT-18 Recirculation flow control
- TE-15 Desuperheater outlet temperature control
- PT-19 Desuperheater outlet pressure control
- FT-6 Feedwater flow control

Each of the seven controllers has a built-in indicator plus a manual control feature. In addition, there are 10 indicators as outlined on Figure 3-31 by the use of solid hexagons:

- PT-7 Main steam pressure (drum-purified steam pressure)
- TE-33 Main steam temperature (drum-purified steam temperature)
- PT-9 Recirculation water pressure
- TE-35 Recirculation water temperature
- TE-34 Feedwater temperature
- PT-6 Feedwater pressure
- PT-5 Condensate pressure (condenser discharge pressure)
- TE-37 Condensate temperature (condenser discharge temperature)
- TE-14 Premelt discharge temperature (also thaw)
- PT-13 Premelt discharge pressure (also thaw)

Excluding the feasibility of recording the signals to each of the seven controllers, there are five recording channels, as outlined on Figure 3-31 by the use of dashed hexagons which will appear on two three-channel strip chart recorders:

- FT-17 Main steam flow (drum-purified steam flow)
- FT-18 Recirculation flow
- FT-9 Desuperheater flow (out)
- FT-6 Feedwater flow
- LT-2 Steam drum liquid level

By use of solid hexagons on Figure 3-32, 18 data acquisition points of the TSS/RE and other data acquisition for the thermal storage unit are outlined. In addition, the status of each of the 11 on-off valves is fed into the data acquisition system as is that of each of the five control valves.

- PT-10 Steam drum pressure
- LT-2 Steam drum liquid level
- FT-7 Main steam pressure (drum-purified steam pressure)

- FT-17 Main steam flow (drum-purified steam flow)
- TE-7 Main steam temperature (drum-purified steam temperature)
- PT-9 Recirculation pressure
- FT-18 Recirculation flow
- TE-8 Recirculation temperature
- PT-6 Feedwater pressure
- FT-6 Feedwater flow
- TE-9 Feedwater temperature
- PT-19 Desuperheater outlet pressure
- FT-9 Desuperheater outlet flow
- TE-12 Desuperheater outlet temperature
- PT-5 Condensate pressure (condenser discharge pressure)
- TE-11 Condensate temperature (condenser discharge temperature)
- TE-13 Premelt discharge temperature (also thaw)
- PT-13 Premelt discharge pressure (also thaw)
- Up to 200 thermocouples, strain gauges, scraper torque, and scraper rpm data from the thermal storage unit
- Status of each valve

For safety purposes, there are numerous alarms and interlocks. Refer to Table 3-4 and Figure 3-29.

The steam drum control is a three-element control:

- Liquid-level control by LT-2
- Steam flow control by FT-17
- Feedwater flow control by FT-6

See Figure 3-30.

There are two submodes of the discharge mode for controlling steam drum pressure.

- PT-10 controlling CV-10, CV-1 in manual, and FT-18 not used
- PT-10 controlling CV-1 and FT-18 controlling CV-10.

See Figures 3-29 and 3-30.

There is one submode of the discharge mode for controlling the recirculation rate:

- FT-18 controlling CV-10, CV-1 in manual, and PT-10 not used

See Figures 3-29 and 3-30.

. discussion of each control mode and submode appears elsewhere.

INSTRUMENTATION: THERMAL STORAGE UNIT MEASUREMENT

Temperature measurements will be made in the thermal storage to determine the performance characteristics of the vaporizer, condenser and the salt flow patterns.

The vaporizer tube surface temperature will be measured to determine the effectiveness of the scrapers in augmenting heat transfer.

Heat transfer at the vaporizer consists of three mechanisms convection from salt to tube wall, conductor through the tube wall, and convection and boiling on the inside of the tube. Conduction through the tube wall is well understood, but the two convection mechanisms are not. To determine heat transfer coefficients for each mechanism, the tube wall temperature must be known and the fluid temperatures must be known. Figure 3-33 is a cutaway section of the scraped tube showing how thermocouples will be embedded in the tube wall. It is necessary to embed the thermocouple in the pipe wall to avoid disturbing the local fluid flow and obtaining false temperature indications. Figure 3-34 is an enlarged view of how the thermocouples are installed. The tube wall has approximately 0.6 mm (0.025 in.) of extra thickness to allow for necking down when the tube is bent into a serpentine. A flat will be removed 0.6 mm (0.025 in.) in depth and 0.5 mm (0.020 in.) diameter sheathed thermocouple placed on the pipe. The pipe will be welded or braze filled and filed back to a round profile. Because there are no sharp transitions in the wall thickness and the total length of the flat is less than 63 mm (2.5 in.) the tube strength should easily meet the pressure test requirements.

Figure 3-35 shows the location of thermocouples on each scraper module. Each location "B" will have two thermocouples embedded in the tube wall--one at the top and one at the bottom--to detect the difference in the heat transfer in two phase flows where separation of phases may occur. At location "A",which is outside of the scraped area, the thermocouples will be welded to the outside of the tubes.

In addition to the thermocouples welded to the tubes, thermocouples will be located in the salt between the scrapers at locations "B". Thermocouples will be located on the condenser tube to determine the condenser performance.

Figure 3-36 shows the local condensing vapor quality as a function of length along the condenser tube. This assumes that the condenser is operating at maximum capacity with a uniform heat transfer rate along its length. If full condensation occurs before the end of the condenser is reached, the condensate will be sub-cooled and the condenser will be operating at less than full capacity. To measure the performance of the condenser, thermocouples will be welded to the condenser surface at the locations "A", "B", and "C" in Figure 3-37. The thermocouple location patterns "A", "B", and "C" are illustrated in Figure 3-38. The thermocouples at each location are staggered axially along the tube to reduce the effect of the wake of one thermocouple on the reading of the thermocouple above it. Thermocouples will be placed in the salt near the tube surface to measure the salt temperature and flow pattern.

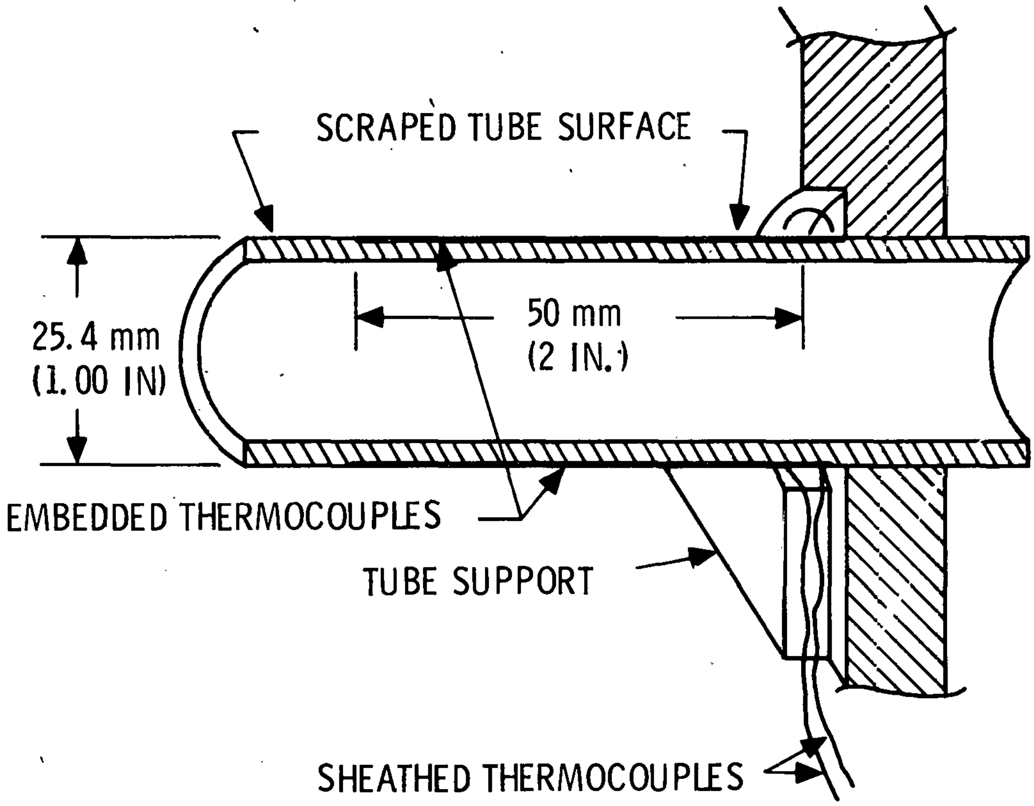


Figure 3-33. Placement of Thermocouples Under Scraped Tube Surface

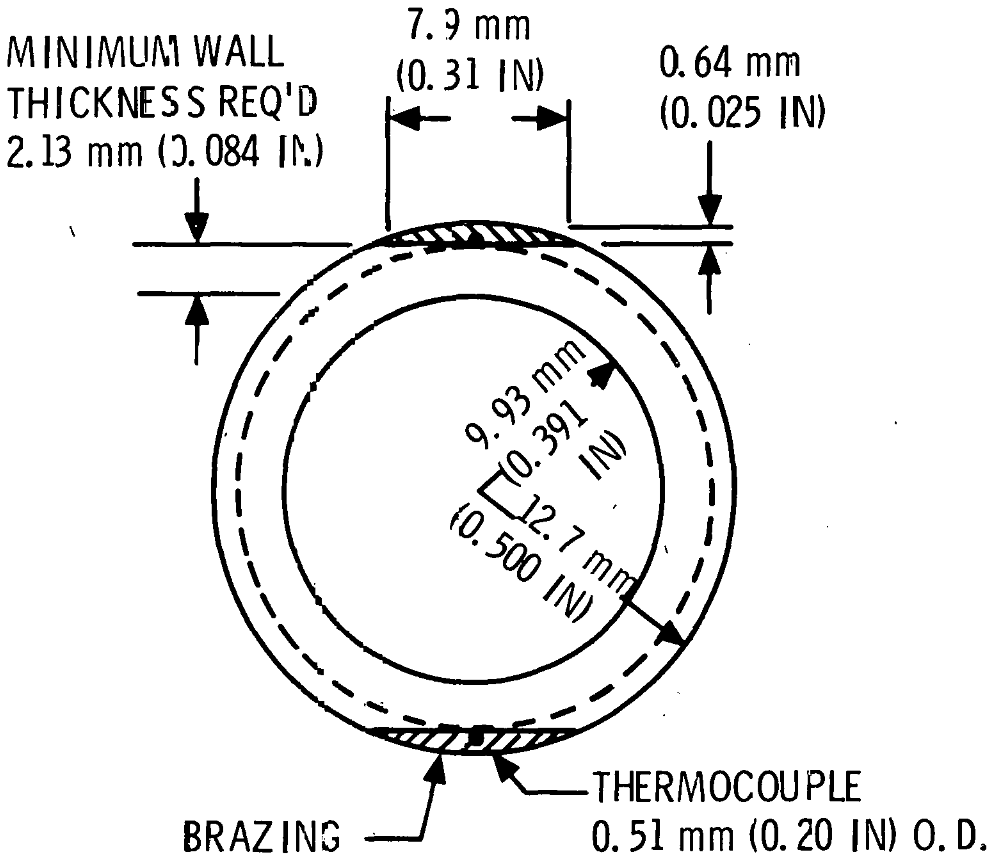


Figure 3-34. Embedment of Thermocouples in Vaporizer Tube Surface

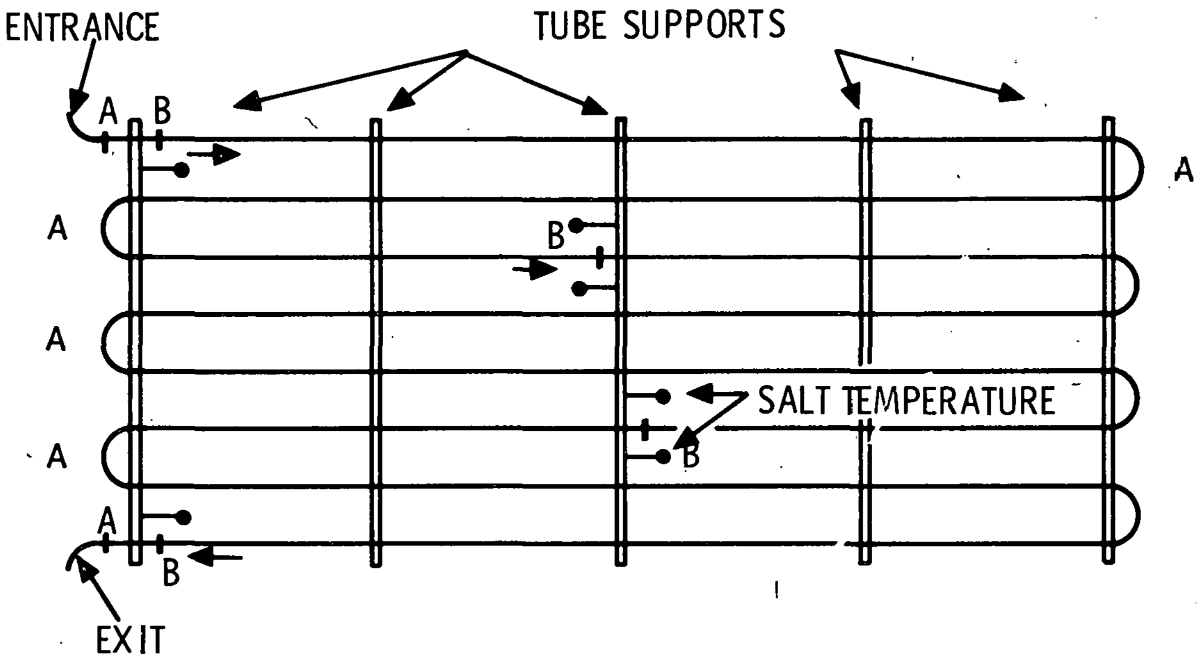


Figure 3-35. Thermocouple Locations on Vaporizer Module

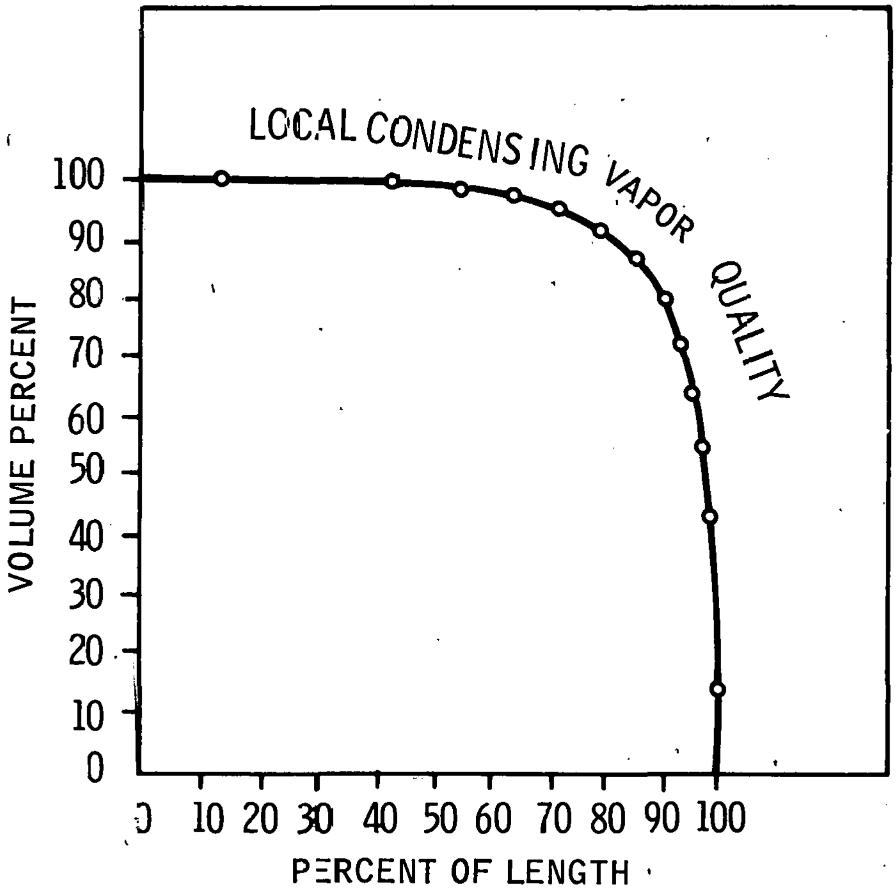


Figure 3-36. Course of Condensation or Evaporation

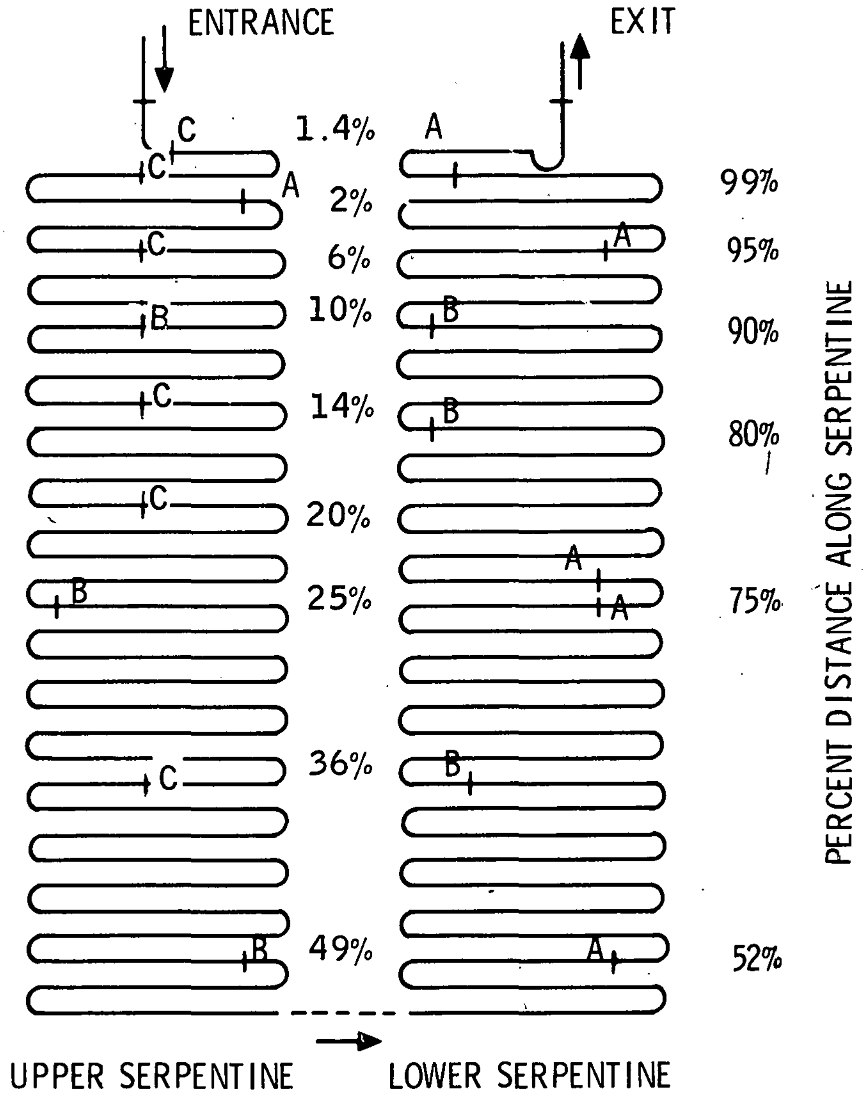


Figure 3-37. Condenser Thermocouple Array Locations

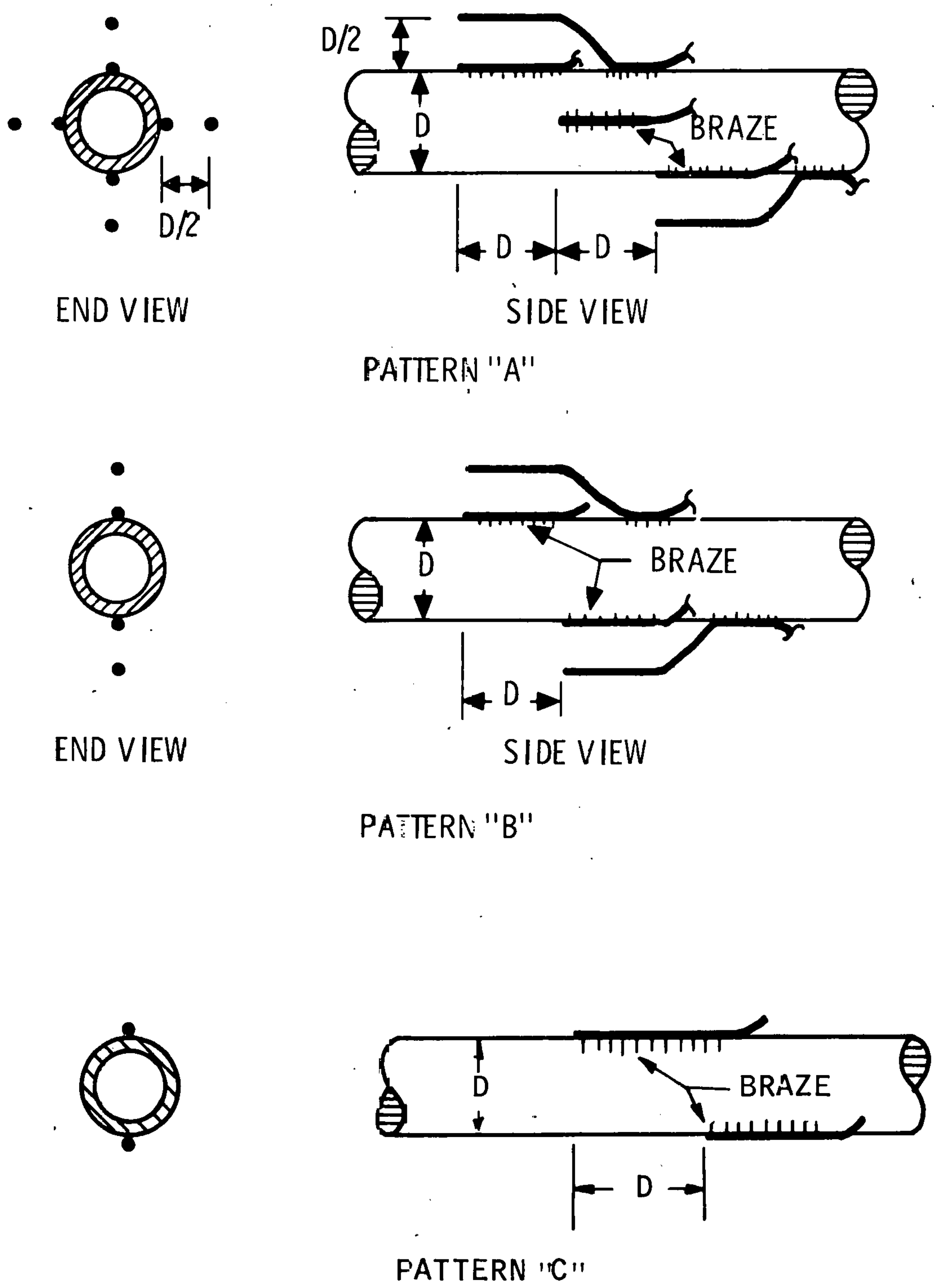


Figure 3-38. Thermocouple Placement Patterns

gure 3-36 shows that the greatest percentage of condensate accumulates in the last 25 percent of the condenser. It is therefore most important to concentrate the thermocouples more heavily on the last 25 percent of the condenser. To study the effect of introducing superheated steam into the condenser, additional thermocouples will be concentrated at the beginning of the condenser.

Eight pairs of thermocouples will be attached to the condenser downcomers and the premelt tubes. A pair will consist of one thermocouple attached to the tube fin and a second one located in the adjacent salt 2.5 cm (1 in.) away. These will be used to monitor the development of a liquid relief path when charging is started with the storage system initially frozen solid.

To measure the bulk salt temperature profiles, thermocouple probes will be inserted into the salt.

The bulk salt temperature changes significantly during the charge and discharge cycle. By measuring the temperature at several locations in the bulk of the salt an indication of the bulk movement of the salt can be plotted. This will aid in determining the best way to obtain the maximum heat recovery, the maximum vaporizer heat rate, and the optimum charging rate.

Five vertical probes will be inserted into the tank, each containing nine thermocouples on the tip of 10 cm (4 in.) horizontal extensions. This will provide a temperature reading at 30 cm (12 in.) spacings from the bottom to top of the tank, with the topmost thermocouple being located in the ullage space.

All of the probes will be concentrated around one module such that symmetry of flow conditions can be checked very well without using an excessive number of thermocouples. Figure 3-39 shows the plan view and profile view locations of the thermocouple probes. Should salt flow anomalies be detected, the probes may be moved to a new location when the salt is fully melted, which will provide further data.

Each wall of the salt storage tank will have four thermocouples on it as illustrated in Figure 3-39.

The total complement of thermocouples in the storage system will be:

26	per scraper module
84	on the condenser
15	downcomers
27	premelt and downcomers
45	bulk salt temperature
24	tank walls
38	guard heaters
285	Total

Scraper speed and torque will be measured to obtain relationships between scraper power requirements and heat transfer rates.

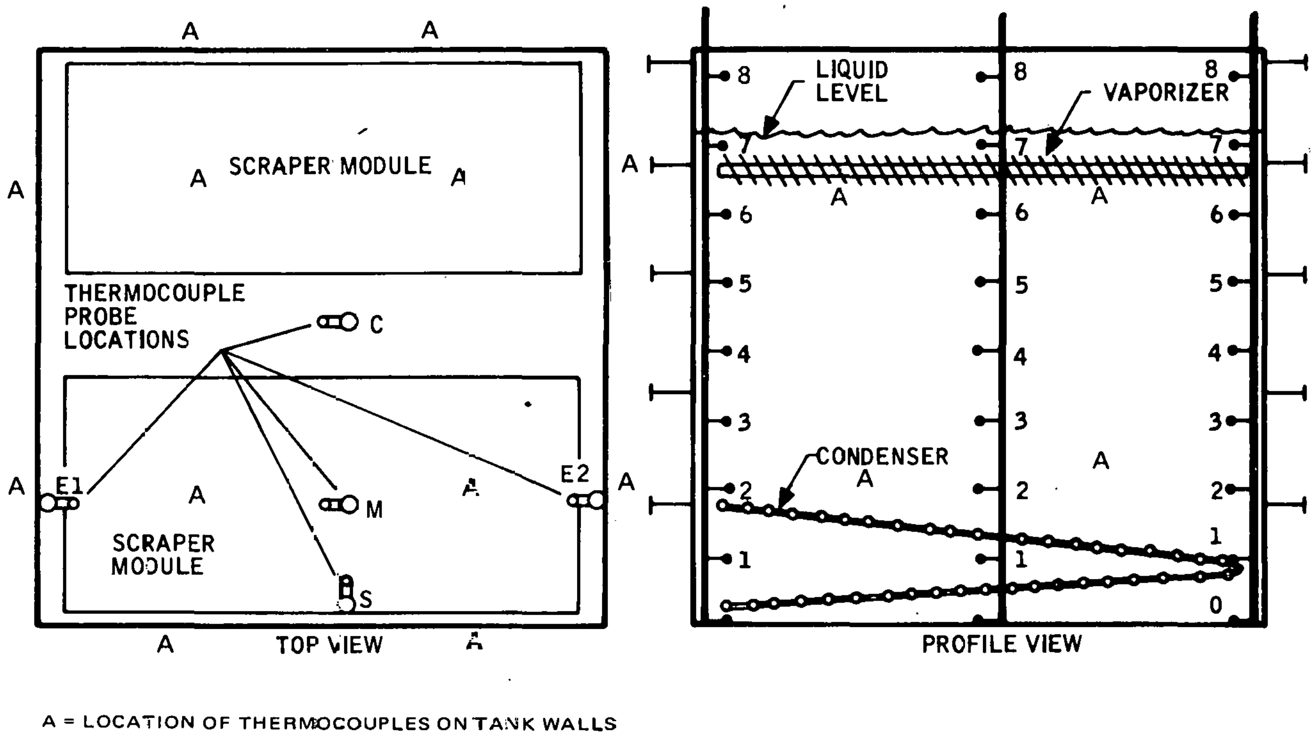


Figure 3-39. Thermocouple Locations for Bulk Salt Temperature Measurement

›rque meters with speed pickups will be installed in the scraper drive shafts to monitor scraper power requirements. Panel meters on the instrument control panel will display torque and speed for each vaporizer scraper unit. Analog signals will be fed to the computer where a continuous record of torque speed and power will be made. This will permit correlations to be made between scraper speed and heat transfer coefficient, speed and torque, and between torque and slurry.

Experiment Components Detail Design and Integration

Experiment Detail Design

DATA ACQUISITION SYSTEM CONFIGURATION

A DAC system has been configured to provide engineering data and alarm functions for the SRE testing.

The data acquisition system configuration is shown in Figure 3-40. The major components of this configuration are the Hewlett Packard 9611 A/R industrial (computer) measurement system with a Tektronix 4012-6 CRT/console and a Versatec 1110A printer/plotter.

All data acquisition system input and output electrical signals are connected through the 9611R. The data acquisition system 9611R will have 19 analog input multiplexer modules with 16 differential inputs each. The ranges of the analog modules are: 2 - 0 to ±10 Vdc, 2 - 4 to 20 MaDC and 15 low level (e.g., programmable 0 to ±10 MV through 0 to ±800 MV). Two digital I/O modules are also included in the 9611R. Each has 12 inputs. The digital input module is an event sense module. The digital output module is a set of 12 individual relay contacts. All electrical I/O signals are routed through a set of connectors so the thermal storage SRE test connections may be easily replaced by the steam generator SRE test connections.

The 9611A consists of a 2112A controller with 64K memory and RTE III disk based software, a remote analog/digital communication system, a 2.5 MW disk, a paper tape reader, and a nine-track NRZI magnetic tape unit.

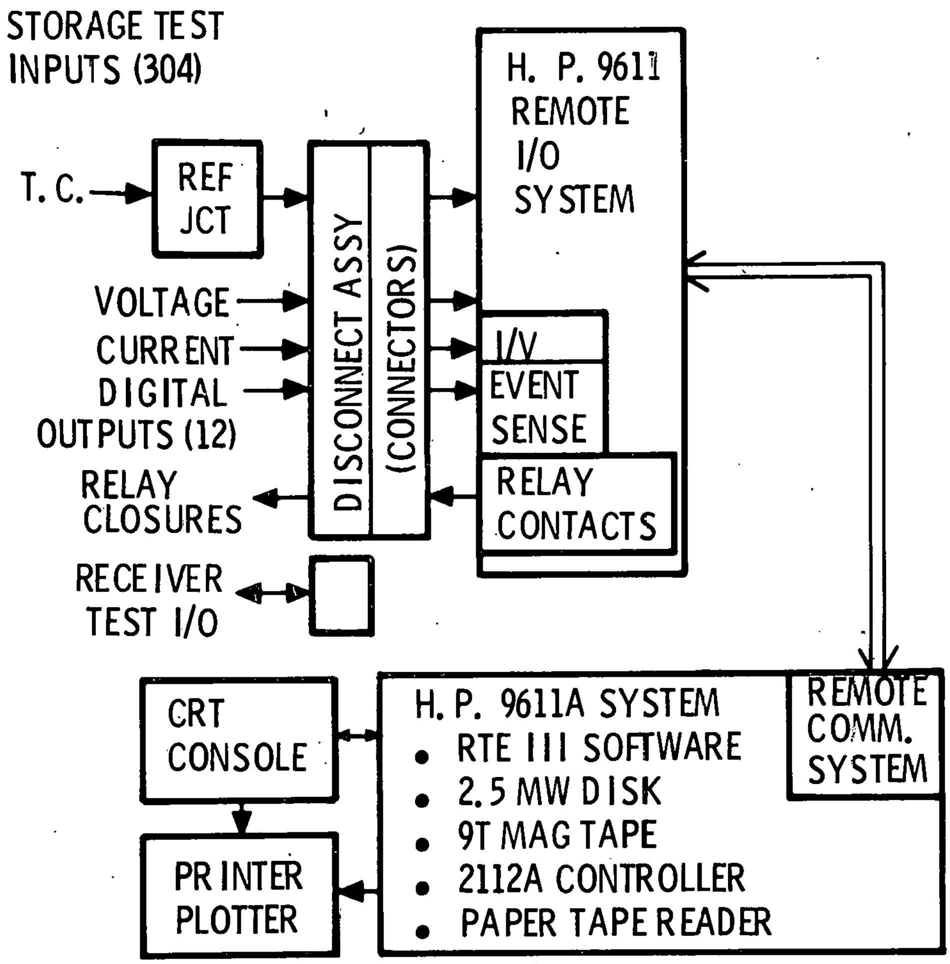


Figure 3-40. SRE Data Acquisition System Configuration

Experiment Components Detail Design and Integration

Experiment Detail Design

DATA ACQUISITION SYSTEM SOFTWARE

Flow charts for the data acquisition system software to be used during SRE thermal storage testing have been generated.

Data acquisition system software for the thermal storage SRE testing consists of an executive program and nine subprograms with supporting subroutines. A listing of the driver and its nine subprograms is shown in Table 3-5 and the flow charts are in Appendix D.

The executive program executes a bootstrap load of itself and loads the subprograms, subroutines, initial conditions, and warning/alarm level data tables. During operation the executive program drives the subprograms on a priority basis. It will suspend a lower priority subprogram, execute a high-priority subprogram and then resume the lower subprogram.

The alarm subprogram is enabled by a parameter at design limit as measured in the P4 subprogram. The data acquisition system relays will close, energize a light and audio alarm on the thermal storage SRE control console, and print out the variable which caused the alarm, its value, and the time the alarm occurred.

A sample cycle timer (SCT) count down to zero from a preset time interval enables the P3 subprogram. The operational status of seven valves is read and a logical determination of the thermal storage operating mode is made.

The P4 subprogram is enabled by the P3 subprogram. It measures and converts all the analog data inputs and checks for alarm and warning levels. An alarm condition will generate a P1 enable and warning levels generate a P5 enable. Measured data will be stored as it is taken if the respective "store data" switch is equal to one.

The P5 subprogram causes a printout of the warning messages generated in the data measurement subprogram. The switch in this section determines if only the new warning messages generated in the last P4 pass will be printed or if a new list of all the last pass messages will be printed.

Keyboard requests for data analysis/reductions are initiated through the P6 subprogram.

Display output requests on the CRT or printer/plotter are processed by the P7 subprogram.

After a test sequence the test data dump subprogram (P8) transfers the disk stored data to mag tape and/or prints selected data on the printer/plotter.

Background program development of almost any nature can be performed in the P9 subprogram. A typical P9 task would be inputting an additional display (P7) or analysis (P6) subprogram. All background program activity will be restricted suc that the occupied memory and disk areas may be read but not written into.

Table 3-5. Data Acquisition System Software - SRE Thermal Storage

EXEC. DRIVER – LOAD PROGRAM AND INITIAL CONDITIONS
– DRIVE SUBPROGRAMS (PRIORITY)

SUBPROGRAMS

P1 – ALARMS

P2 – CHANGE INITIAL CONDITIONS

P3 – OPERATING MODE DETERMINATION

P4 – DATA MEASUREMENT AND CONVERSIONS

P5 – WARNING MESSAGES

P6 – ANALYSIS/REDUCTION REQUESTS

P7 – DISPLAY OUTPUT REQUESTS

P8 – TEST DATA DUMP

P9 – BACKGROUND PROGRAMS

CONTROL CONSOLE

Controls and displays for operation of the thermal storage unit are housed in two instrument racks together with auxiliary devices and power supply.

The control console of the thermal storage unit, Figure 3-41, has been designed for "stand-up" operation using standard mounting racks and instrument panel cases. Since the thermal storage operations at Riverside are of an engineering nature, the control console design allows for flexibility in operation and arrangement; i.e., a spare recorder channel for both thermocouple and 4 to 20 ma inputs is available, controller and indicators can be mounted interchangeably, and spare mounting space is provided for instruments and auxiliary devices. The valve control console is positioned on top of the right-hand panel. This console, shown in detail in Figure 3-42, has a schematic showing the location of the valves. Each valve has a three-position switch. To the left is closed, center is automatic, and right is open. Above the switch is a set of lights that indicate whether the valve is open or closed. The switches are spring returned to the center position.

In addition, there are indicator lights to indicate such faults as high steam drum level, etc. If one of these faults occurs, an audible signal is heard and the core-sponding red panel light will flash on and off. Pushing the "Acknowledge" button will silence the alarm and the light will be on steady red.

The mode selection push buttons are all in a row in the panel below this one. All of these are of the type that light up when depressed except the acknowledge button. Figure 3-43 is a more detailed view of this section. Nine of the 10 indicators are mounted in the next rack down. The 10 indicators (Figure 3-43a) are:

- Feedwater Pressure
- Feedwater Temperature
- Recirculation Water Pressure
- Recirculation Water Temperature
- Main Steam Discharge Pressure
- Main Steam Discharge Temperature
- Condensate Pressure
- Condensate Temperature
- Premelt Discharge Pressure
- Premelt Discharge Temperature

The Premelt Discharge Temperature indicator would not fit in the panel and is mounted in the rack with the controllers.

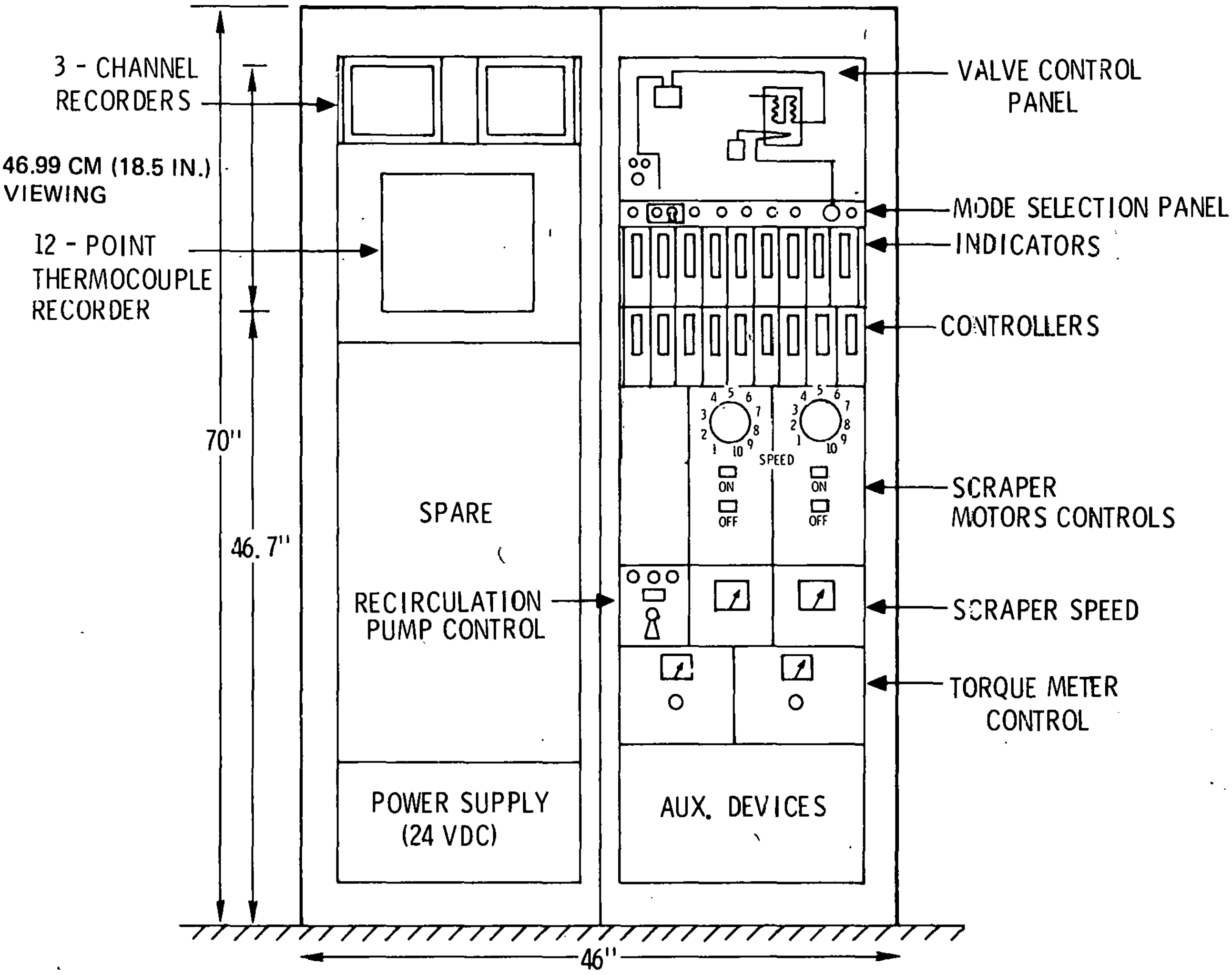


Figure 3-41. Thermal Storage Control Console

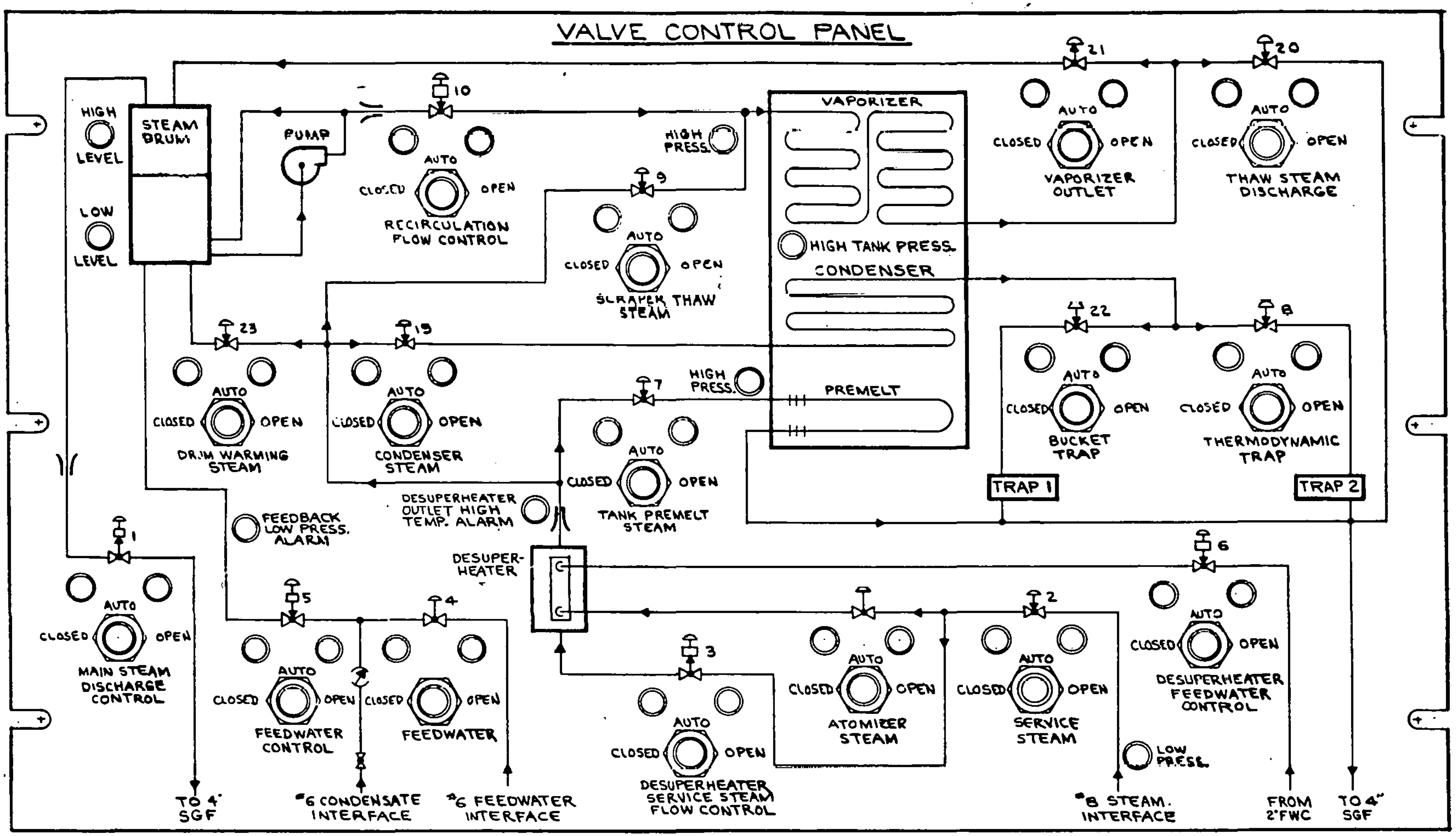
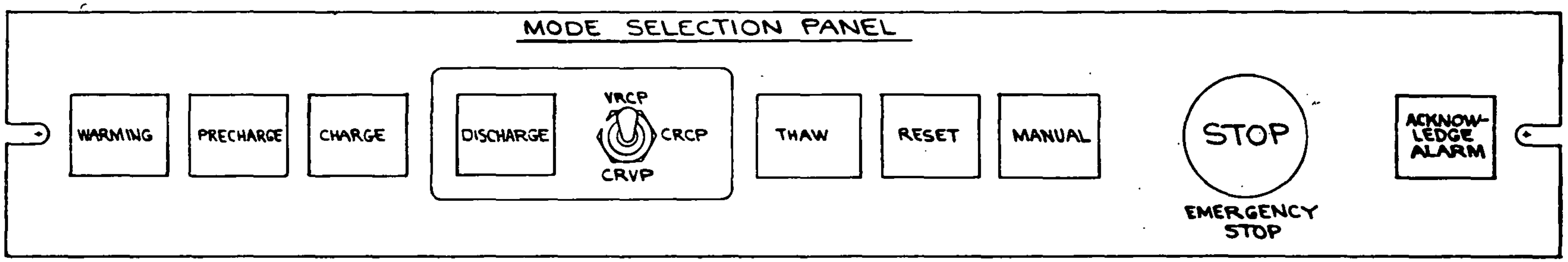


Figure 3-42. Valve Control Panel



40454

Figure 3-43. Mode Selection Panel

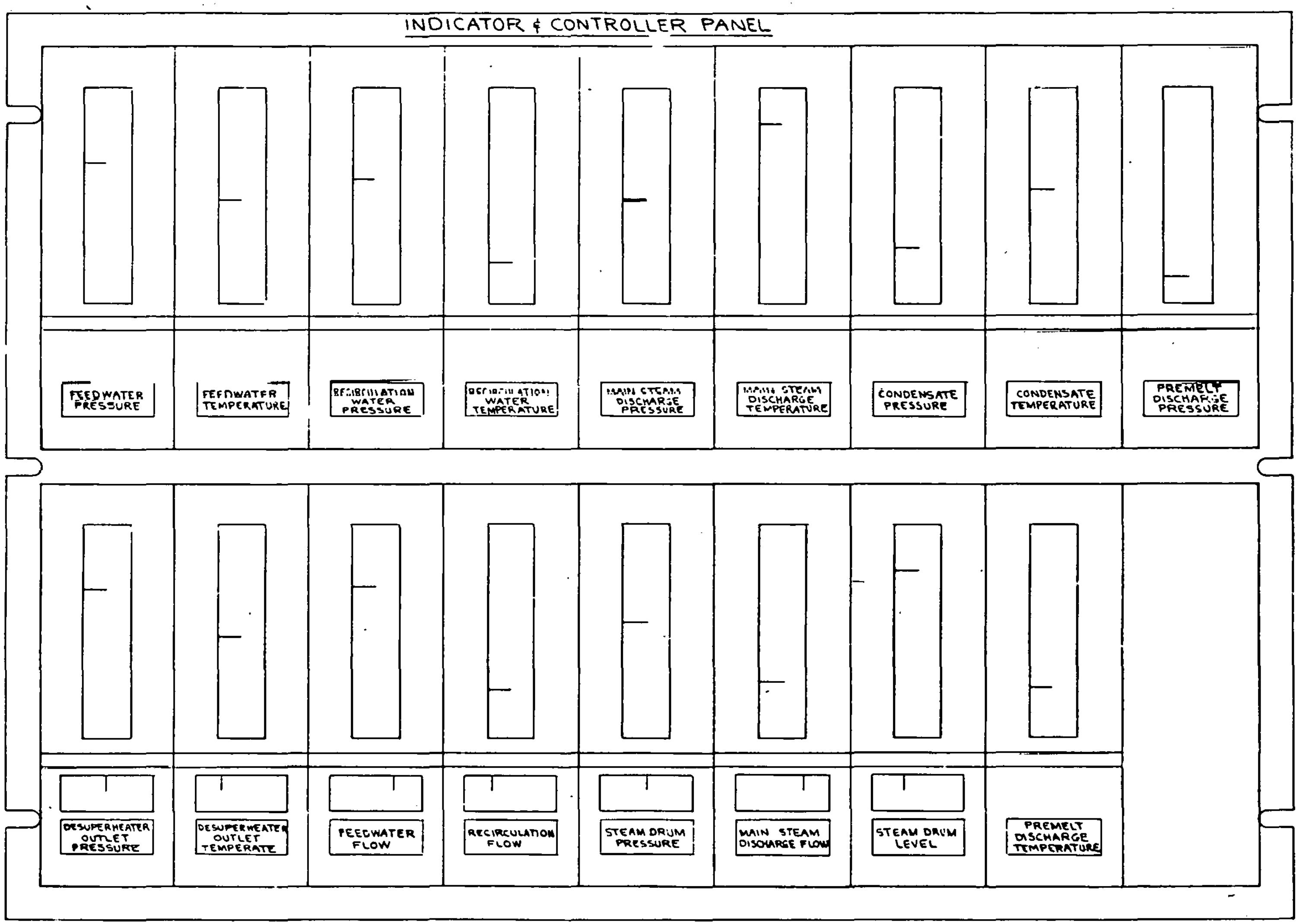


Figure 3-43a. Indicator and Controller Panel

The seven controllers are in the next panel down. Reading from left to right there are:

- Desuperheater Outlet Pressure
- Desuperheater Outlet Temperature
- Feedwater Flow
- Recirculation Flow
- Steam Drum Pressure
- Mail Steam Discharge Flow
- Steam Drum Level

The next panel down contains the controls and readouts for the recirculation pump, the scraper motor controls and speed indicator, and the torque meter output. Figure 3-44 shows this installation.

The rest of the panel is reserved for auxiliary devices.

Three recorders are located in one instrument rack and operate with 4 to 20 ma and thermocouple inputs. Two of these are 15.24 cm-by-15.24 cm (6-inch-by-6-inch) recorders which may be used for trend recording. Up to 12 inputs may be "patched" into either of these recorders. A multipoint recorder (Figure 3-44) is used for recording temperatures. Up to 12 temperatures may be recorded from thermocouples with reference junction compensation built into the recorder.

The two recorders will record the following data:

- Feedwater Flow
- Drum Level
- Receiver Flow
- Mainsteam Flow
- Desuperheater Discharge Flow
- Steam Drum Pressure

The other pressures are being recorded every 5 seconds by the data acquisition system.

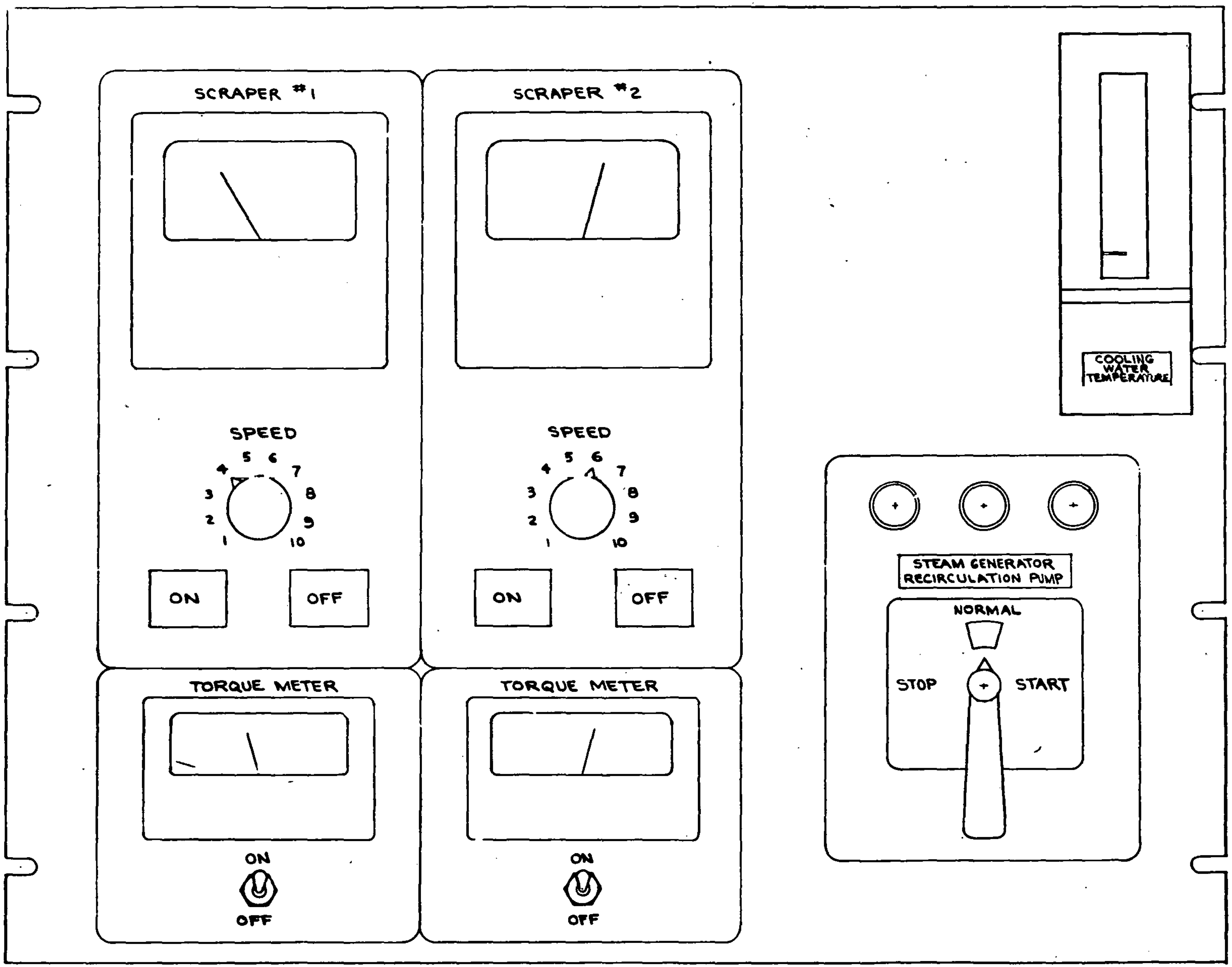


Figure 3-44. Scraper Motor Speed and Torque Motor Panel

40454

This page intentionally left blank

TRAILER CONTROL CENTER

The trailer control center provides a central location for the control of the steam generator and thermal storage experiments.

A 3.05 m-by-10.97 m (10-ft by 36-ft) trailer will provide air conditioned space for housing the control consoles and data acquisition system. The trailer will be located on the turbine room floor at Riverside adjacent to the 6.71 m-by-12.50 m (22-ft by 41-ft) opening in which the steam generator is located. Valves which control steam and water loops in the experiments are centrally operated from the trailer, and all control/instrument signals to and from the trailer are electric. Trailer communications include: (1) intercom stations at the steam generator floor, thermal storage area, and the existing NSP intercommunication system; (2) a line to the existing Riverside Bell Telephone system.

The various control consoles are aligned centrally in the trailer (Figure 3-45) providing operator access on the steam generator side, and access to terminals and auxiliary devices on the other. Functionally related equipment is placed adjacent (e.g., data acquisition display and keyboard near storage and steam generator control consoles, steam generator and radiant array controls are adjacent). The steam generator and thermal storage tests will not be carried out simultaneously, however, there are controls common to both (i.e., No. 8 feedwater supply and bypass, discharge header pressure control) and the control consoles have been placed side by side.

Walls, floor and ceiling of the trailer will be metal covered and grounded for electric field shielding.

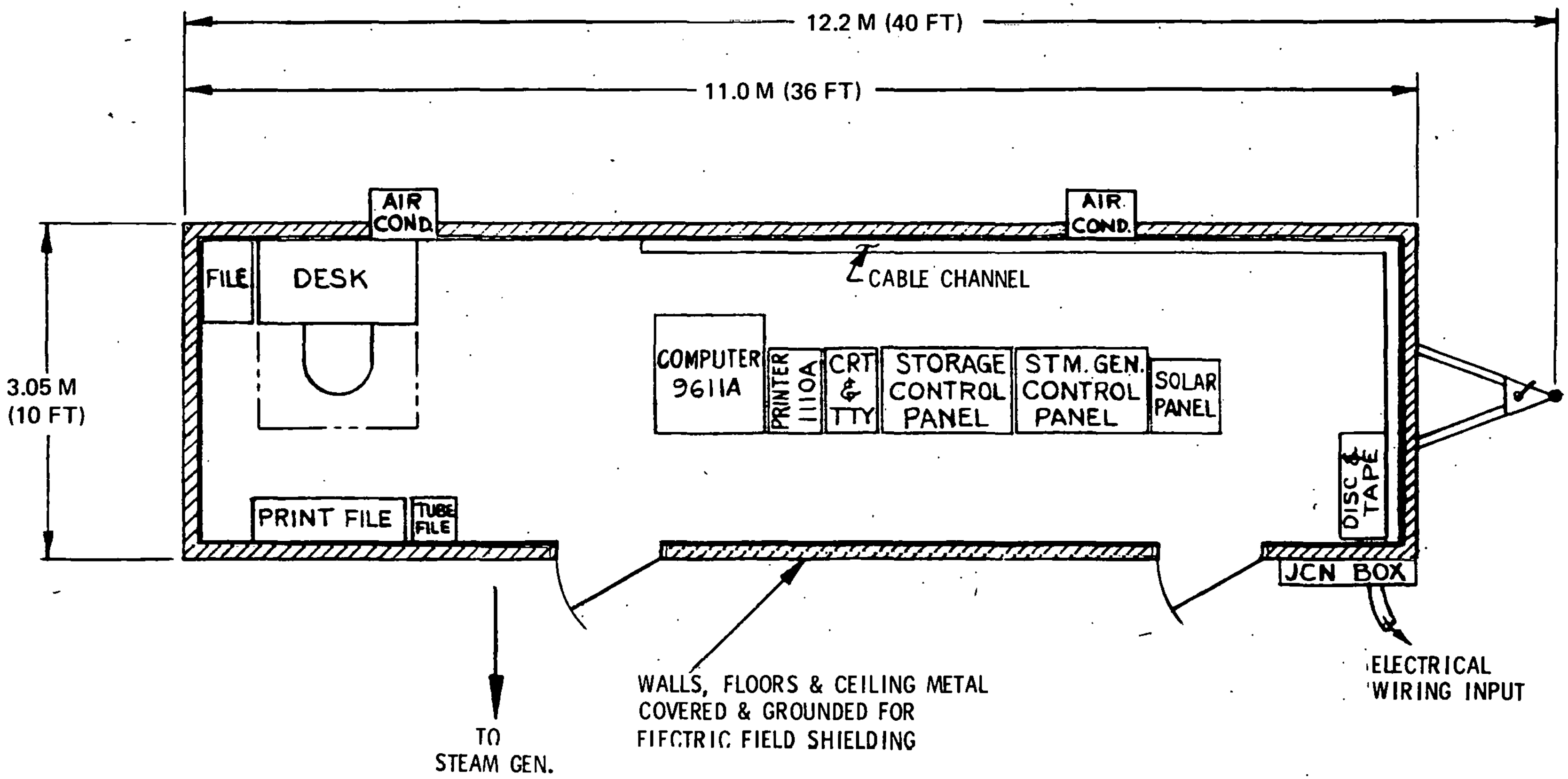


Figure 3-45. Trailer Layout

Experiment Components Detail Design and Integration

Experiment Integration

ACTIVATION AND TEST SCHEDULE

An SRE delivery and activation plan has been developed to permit storage experiment testing by January 1977.

The schedule (Figure 3-46) shows the hardware procurement, software development and integration activities necessary for efficient coordination of site construction and SRE buildup.

The storage tank will be delivered by the supplier to Honeywell's New Brighton Facility NB105 (government owned) where the heat exchangers, mechanisms, heat loss control system, electrical, instrumentation and wiring will be installed by skilled technicians. It will then be transported to NSP for installation and hook up.

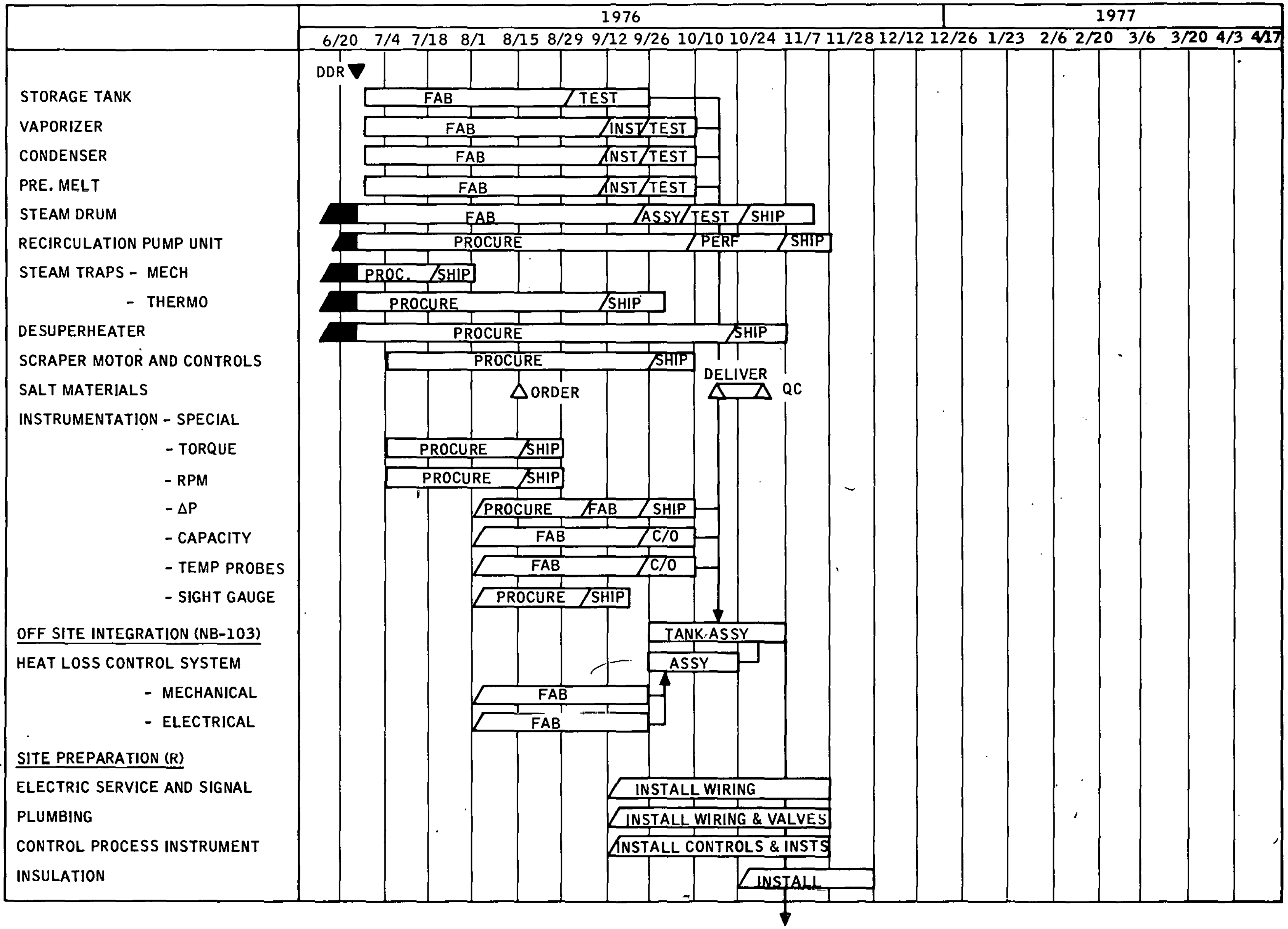
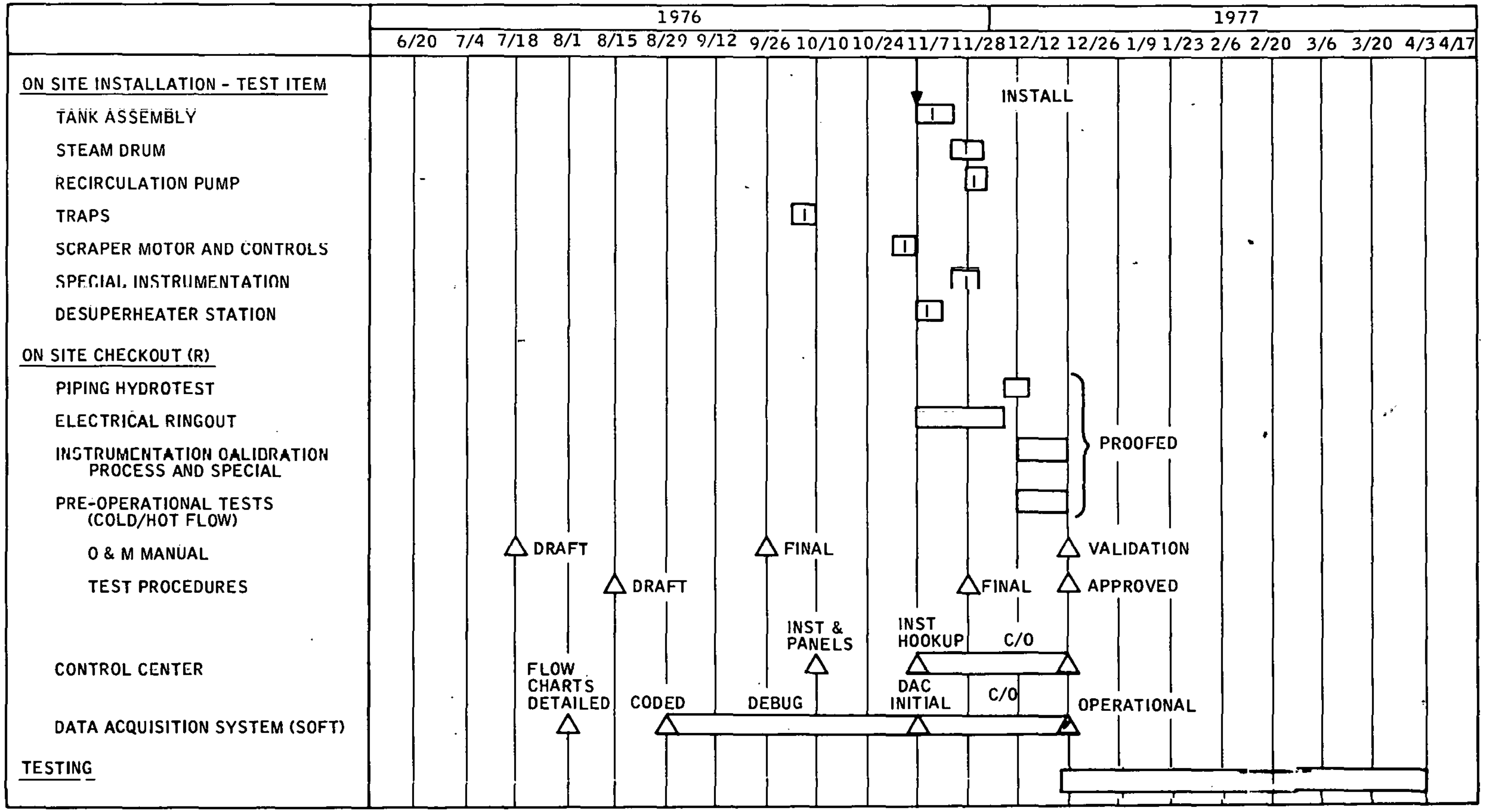


Figure 3-46. Thermal Storage SRE Activation and Test Schedule

40454



R = REFER INSTALLATION AND TEST SEQUENCE
FIGURE 9-1 CDRL NO. 7

Figure 3-47. Thermal Storage SRE Activation and Test Schedule (Concluded)

This page intentionally left blank

Experiment Components Detail Design and Integration

Experiment Integration

STORAGE TANK ASSEMBLY AND INTEGRATION

The storage tank, salt pre-melt, condenser and vaporizer detail design is complete and out for bids.

The storage tank went out for bid on May 14. One bid has been received to date. It came from:

Brown-Minneapolis Tank
P. O. Box 3670
St. Paul, MN 55165

Their price is $9,114.00 with delivery on or before September 15, 1976.

Other companies that are expected to bid on this item are:

Moorhead Machinery and Boiler Company
3477 University Avenue N. E.
Minneapolis, MN 50418

Kenny Boiler & Manufacturing Company
344 University Avenue
St. Paul, MN

The salt pre-melt went out for bid on June 5. No responses have been received.

The condenser went out for bid on May 24, 1976. No bids have been received to date.

The vaporizer went out for bid on June 1, 1976. So far we have received three no bids. However, two other companies have asked for more detail and are expected to bid. These companies are:

Midway Machine Company
2324 University Avenue
St. Paul, MN 55114

Dale Design Inc.
6820 Shingle Creek Parkway
Minneapolis, MN

Dale Design plans to subcontract the tube bending and welding to

Deltak Corporation
7401 Walker Street
Minneapolis, MN 55426

Honeywell plans to use a portion of Bldg. 103 at the Twin Cities Army Ammunition Plant in New Brighton, MN. for the final assembly of the pre-melt, condenser, a[nd] vaporizer into the tank.

Experiment Components Detail Design and Integration

Experiment Integration

STORAGE TANK ASSEMBLY AND INTEGRATION - MECHANICAL AND ELECTRICAL

The drawings and specifications for the mechanical and electrical installation at the NSP Riverside plant are complete. A bidder's conference is scheduled for 8 July, 1976.

The drawings and specifications for the mechanical and electrical installation at the NSP Riverside Plant are complete. These are listed and included in Appendix A . The NSP Plant Modification Bill of Materials and the General Construction Specification were not included, but are available.

A bidder's conference is scheduled for 8 July. At this time, the complete program will be outlined and drawings and specifications will be available for those who wish to bid on them. The bids are due in by 1 August with contract award date of 15 August. Work should start by 15 September, with completion due by 1 December.

Experiment Components Detail Design and Integration

Experiment Integration

SCHEDULE OF SOURCES/SINKS (NSP TEST SITE)

The schedule of sources and sinks for testing at NSP Riverside Station remains essentially the same as at Concept Design Review.

The schedule of sources and sinks is given in Figure 3-48.

Drum fill modes at start-up have been added for both the steam generator and thermal storage tests using condensate from the No. 6 unit at Riverside. The temperature of the condensate water is considerably lower than that of feedwater 38°C (100°F) versus 204°C (400°F) thereby imposing less thermal shock if condensate is used for drum filling rather than feedwater.

Scraper thaw and drum warming capabilities have been added to the thermal storage discharge mode. Desuperheated steam from the No. 8 Unit will be used to supply thaw and warming steam as well as the charge steam.

REQUIREMENT	SOURCE					SINK	
	NO. 8 UNIT FEEDWATER 17.60 ±0.35 MPA (2550 ±50 PSI) 204.44 ±4.44°C (400 ±40°F)	NO. 6 UNIT FEEDWATER 9.32 ±1.04 MPA (1350 ±150 PSI) 187.78°/215.56°C (370°/420°F)	NO. 8 UNIT MAIN STEAM 16.56 MPA (2400 PSI) 537.78°C (1000°F)	LOW-SERVICE WATER 0.55/0.69 MPA (80/100 PSI) 1.67°/29.44°C (35°/85°F)	NO. 6 UNIT CONDENSATE WATER 0.69 MPA (100 PSI) 37.78°C (100°F)	NO. 6 UNIT CONDENSER DISCHARGE	NO. 7 UNIT CONDENSER DISCHARGE
STEAM GENERATOR TEST							
FEEDWATER SUPPLY	X						
ATTEMPERATOR WATER SUPPLY	X						
*DRUM FILL (START-UP)					X		
STEAM DISPOSAL						X	
BLOW-DOWN DISPOSAL						X	
*FEEDWATER BY-PASS DISPOSAL						X	
COOLING WATER SUPPLY				X			
COOLING WATER DISPOSAL							X
THERMAL STORAGE TEST							
CHARGE MODE:							
STEAM SUPPLY (CHARGE AND TANK THAW)			X				
ATTEMPERATOR WATER SUPPLY	X						
WATER DISPOSAL						X	
TANK THAW STEAM DISPOSAL						X	
DISCHARGE MODE:							
FEEDWATER SUPPLY		X					
STEAM DISPOSAL						X	
*STEAM SUPPLY (SCRAPPER THAW, DRUM WARMING)			X				
*ATTEMPERATOR WATER SUPPLY	X						
*SCRAPPER THAW STEAM DISPOSAL						X	
*DRUM FILL (START-UP)					X		

*CHANGED SINCE CDR.

Figure 3-48. Schedule of Sources/Sinks (NSP Test Site)

40454

Experiment Components Detail Design and Integration

Experiment Integration

STORAGE TANK ASSEMBLY AND INTEGRATION - STEAM DRUM STATION

One responsive quote for the steam drum has been received and a second is expected.

The two leading contenders for the steam drum are:

- Dyna-Therm Corporation
  P.O. Box 6629
  701 Richmond Avenue
  Houston, Texas 77001

- Wright-Austin Company
  3245 White Street
  Detroit, Michigan 48207

The Dyna-Therm Corporation has offered to manufacture a steam drum to HI specification for $9830 with delivery around 15 October 1975.

HI is waiting for a response from Wright-Austin Company.

The Dyna-Therm Corporation steam drum would be supplied with the ANSI 900-pound RF flanges.

Description	Quantity	Size (cm)	Size (in.)
Steam outlet	1	2.54	1
Level control	2	5.08	2
Recirculation pump bypass	1	1.91	3/4
Recirculation pump suction	1	5.08	2
Recirculation pump return	1	3.81	1-1/2
Prewarming and blowdown (drain), combined	1	1.91	3/4
Feedwater	1	1.91	3/4
Relief valve	1	1.91	3/4
Pressure transmitter and indicator, combined	1	1.91	3/4
Sight gauge	2	2.54	1

The Wright-Austin steam drum would probably be similarly equipped.

The steam drum will be mounted on the north wall of the thermal storage room. It will be in the northeast corner as high as possible and will be insulated to minimize heat loss. The sight gauge and level transmitter will be mounted on it. There will be liquid level and pressure indication and recording capability in the control room.

Experiment Components Detail Design and Integration

Experiment Integration

STORAGE TANK ASSEMBLY AND INTEGRATION - STEAM TRAP STATION

Two steam traps have been ordered to determine whether a mechanical trap or a thermodynamic trap is better for this application. Either one can be selected from the control console by operating either valve 22 to select the mechanical trap on valve 8 for the thermodynamic trap.

The mechanical trap selected is an inverted bucket trap model 5155 CV which is manufactured by Armstrong Machine Works. Delivery of this trap is expected mid-August. This trap is sometimes supplied with an internal check valve. However, at this operating pressure the check valve tends to have a short life so the steam trap was ordered without it and an external check valve was substituted.

The thermodynamic trap ordered is a 1.91 cm (3/4 in.) C-500 BSWR YARWAY with "B" internals. In case the loads are lighter than those calculated, "A" internals can be field changed without removing the trap from the line. Delivery of this trap is expected on 1 October 1976.

Both traps will have 1.91 cm (3/4 in.) 6.80 x 10^2 kg (1500-lb) F.S. weld neck flanges with raised faces. They will be selected by activating either valve 22 for the inverted bucket trap or valve 8 for the thermodynamic trap. This is done at the console.

STORAGE TANK ASSEMBLY AND INTEGRATION - RECIRCULATION PUMP STATION

A recirculation pump has been ordered from the Kontro Co. Inc.

The following bids for the recirculation pump were received

- The Kontro Co. Inc.
  465 Main Street
  Athol, Massachusetts 01331
  2 pumps in series
  $25,379
  Delivery -- 30 Nov. 1976
- Chem Pump Division of Crane Co.
  Warrington Industrial Park
  Warrington, Pennsylvania 18976
  $24,790
  Delivery -- 49-50 weeks after drawing acceptance

A number of companies were nonresponsive.

The Kontro pump was selected primarily because it could be delivered on time. The original quote called for Mid January 1977 delivery. A premium of $3,227 is being paid to insure early delivery.

The recirculation pump will be mounted between the thermal storage tank and the north wall of the room. The ground in the area of the NSP plant is very soft. However, there is a pad on pilings just 76.20 cm (2-1/2 feet) below the surface in this area, so it will be excavated and a new pad poured on top to support the pump and motor. A new floor section will be poured around the pad.

The recirculation pump will be supplied with these ANSI 900-pound RF flanges:

Description	Quantity	Size (cm)	Size (in)
Suction	1	2.54	1
Discharge	1	2.54	1

The installation will actually consist of two pumps in series. Each pump will be driven by a 7.46 kilowatt (10 H.P.) electric motor. The pump motors will be controlled by a switch on the console of the thermal storage system in the control room. The motor starters will be interconnected so that both will always operate simultaneously.

Experiment Components Detail Design and Integration

Experiment Integration

STORAGE TANK ASSEMBLY AND INTEGRATION -
VALVES, PIPING AND CONTROLS

Orders for all of the noncontrol valves have been placed, the control valves and the piping have been specified by Black & Veatch, and the control systems are being finalized.

All of the noncontrol valves were ordered, and delivery should be completed by 25 August 1976.

The control valves specifications, as determined by Black & Veatch, were sent out for bid in May. One quote has been received.

The piping has been specified by Black & Veatch and will be part of the bid package for the equipment installation with the contractor furnishing it.

The control system logic was designed by Black & Veatch, and the hardware is now being specified by Honeywell.

SECTION IV

SECTION IV
EXPERIMENT TEST AND OPERATION

Experiment Test and Operation

Test Objective and Goals

EVALUATION

The objective of the TSS/RE testing is to collect a quantitative set of engineering data to allow the SRE design, performance and operational characteristics to be specified for the Pilot Plant Configuration.

To achieve the test objective, the following goals are set:

a) Successfully complete a block of eight charge/discharge cycles to evaluate the best operating range for the design.

b) Successfully complete a block of two charge/discharge cycles to evaluate the performance over the "selected" best operating range for the design.

c) Successfully complete a block of five charge/discharge cycles to evaluate the design and performance under operational conditions.

See Figure 4-1.

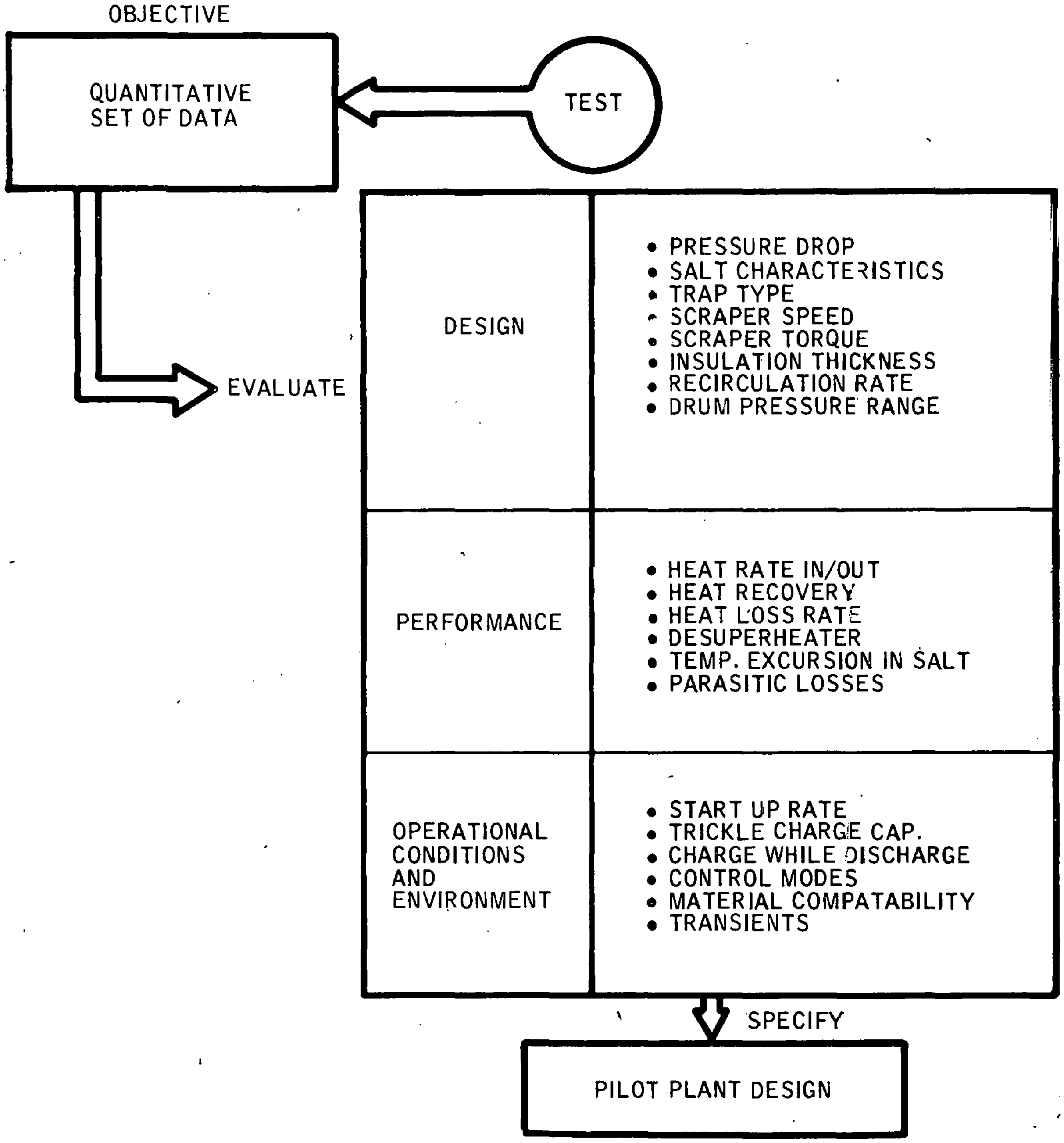


Figure 4-1. Test Goals

Experiment Test and Operation

Test Plan and Schedule

SRE SCHEDULE

A test plan has been formulated that utilizes the program resources to the maximum extent possible to achieve the test objective.

Thermal storage testing must be completed by the first week in April, 1977 in order to provide an updated pilot plant thermal storage design by June 1, 1977. The activation schedule for thermal storage reflects an expected test start on January 3, 1977. This gives 95 calendar days or 70 test days. These test days must be shared between the steam generator and the thermal storage experiments. Allocating 30 test days to thermal storage and assuming that it will take two test days to produce one successful test with a full set of data, results in 15 test completions.

These tests are defined as a charge and discharge cycle. This number of tests, as shown on the schedule, is adequate to quantify the design and specify the performance of the Pilot Plant Thermal Storage.

See Figure 4-2.

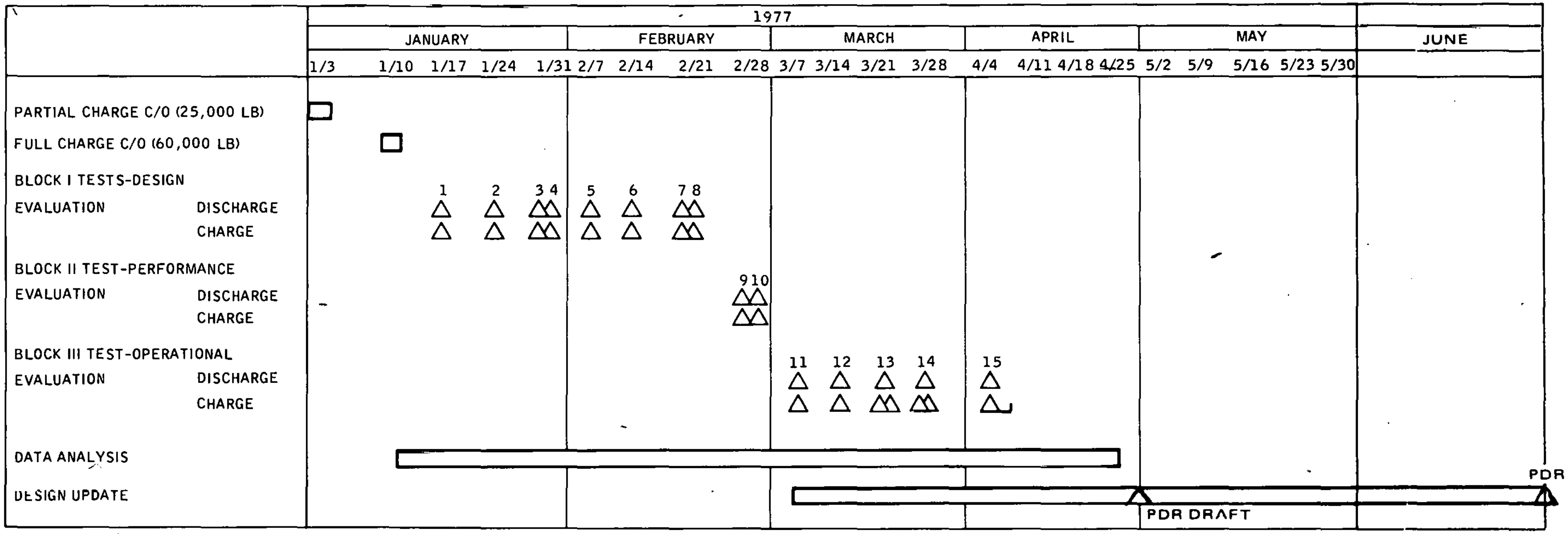


Figure 4-2. Test Schedule

40454

Experiment Test and Operation

Parameters and Variables for Test

SRE TEST

The SRE/TS tests contain a very limited number of variables - four for the vaporizer, and four for the condenser - but the system requires many measurements to quantify the effects of each of the variables.

The operator-determined independent variables are listed below, followed by a list of parameters which must be measured to fully define the effects each variable has on the storage system performance.

INDEPENDENT VARIABLES

Vaporizer Performance Variables

a) Saturation pressure
b) Water inlet temperature at vaporizer
c) Scraper speed
d) Water flow rate

Condenser Performance Variables

a) Saturation pressure
b) Selection of steam trap
c) Previous history of frozen or partially solidified bath
d) Degrees superheat of entering steam

MEASURED QUANTITIES

Vaporizer Performance

1) Inlet water to vaporizer
   a) Temperature
   b) Pressure
   c) Flow rate
2) Discharge temperature from vaporizer
3) Discharge steam flow from steam drum
4) Steam drum pressure
5) Scraper speed
6) Scraper torque

7) Salt liquid level
8) Salt temperature profiles
9) Density versus depth and time

Condenser Performance

1) Steam temperature
2) Steam pressure
3) Steam flow rate
4) Condenser outside wall temperature
5) Condensate exit temperature
6) Trap cycling rate
7) Salt temperature profiles
8) Salt liquid level

THERMAL STORAGE CONTROL, MODES OF OPERATION

The TSS/RE facility can be operated in nine different modes.

This section covers the requirements for, and description of, the various modes of operation and control. Steady-state analyses have been applied to determine the functional characteristic of the defined modes. A transient analysis of the discharge and charge while discharge modes will be performed prior to test operations to ensure adequate response and stability. The plan is to model the steam drum and vaporizer and analyze response of these elements to rapid changes of the drum pressure, simulating a charge in the demand heat rate. Secondly, under this simulated demand heat rate the feedwater, drum level sensing and output steam controllers will be modelled and analyzed as part of the entire control loop.

Figure 4-3 is a matrix of the nine different modes of operation of the TSS/RE and the associated status of the valves. (See Figure 3-29 for outlined valves.) The discharge mode is actually three submodes. The symbol "M" in the matrix indicates the valve will be modulating in the related mode; "O" means the valve will be open; no entry means the status of the valve remains in the reset (closed) position.

Figure 4-4 is a matrix of the valve interlock requirements during operation of the TSS/RE. When a valve in the left column is either open or modulating as indicated on the diagonal of the matrix, each of the other valves must assume its status as shown. When there are no entries in the matrix, the valve remains in the reset (closed) position.

Consider, for example, warming the drum. Referring to Figures 3-29 and 4-4, when the warming mode buttons are pushed at the control console, valve No. V-23 will open (O) to permit steam from the No. 8 steam interface to flow into the drum valve Nos. CV-1, V-2, CV-3, CV-6, and the desuperheater atomizer steam valve (automatic, valve "D") open as shown in Figure 4-3. Steam losses to the thermal storage unit are avoided with the closure of valve Nos. V-7, V-9, and V-19 as shown by "C" in Figure 4-4.

A discussion of each mode follows.

VALVE (i) NUMBERS	VALVE DESCRIPTION	WARMING	DISCHARGE (iv) (3 SUBMODES)	PRECHARGE	CHARGE	CHARGE WHILE DISCHARGE	THAW	MANUAL	RESET (iii)	EMERGENCY STOP
1	MAIN STEAM DISCHARGE	M		["O"pen]		M		ALL CONTROL VALVES MANUALLY OPERABLE	ALL VALVES CLOSED	ALL VALVES CLOSED, ALL MOTCRS STOPPED FLASHING LIGHT AND HORN SOUNDED AT CONTROL CONSOLE AND IN TSS/RE FACILITY
2	SERVICE STEAM	0		0	0	0	0			
3	SERVICE STEAM MODULATOR	M		M	M	M	M			
4	FEEDWATER									
5	FEEDWATER CONTROL									
6	DESUPERHEATER FEEDWATER	M		M	M	M	M			
7	PREMELT STEAM			0						
8	TRAP NO. 2				0^{ii}	0^{ii}				
9	THAW STEAM						0			
10	RECIRCULATION CONTROL		M			M				
19	CONDENSER STEAM				0	0				
20	THAW STEAM DISCHARGE						0			
21	VAPORIZER OUTLET		0			0				
22	TRAP NO. 1				0^{ii}	0^{ii}				
23	WARMING STEAM	0								
–	RECIRCULATION PUMP									
–	PUMP COOLING WATER									

M : MODULATING

0 : OPEN

i VALVE NUMBERS CORRESPOND TO P&ID M1004 VALVE NUMBERS.

ii EITHER VALVE 8 OR 22 OPEN.

iii RESET BUTTON MUST BE ACTIVATED TO CHANGE MODES.

iv DISCHARGE MODE VALVE MODULATION SIGNAL SOURCE DETERMINED BY SEPARATE SWITCH FOR THREE SUBMODES OF OPERATION.

Figure 4-3. The Nine Modes, One with Three Submodes, of Operation of the TS SRE and the Status of Each Pertinent Associated Valve

ACTIVE VALVE

VALVE ** NUMBERS		1	2	3	4	5	6	7	8	9	10	19	20	21	22	23	RECIRC. PUMP	PUMP COOLING WATER
1	MAIN STEAM DISCHARGE	O*								C								
2	SERVICE STEAM		O	(i)			(i)											
3	SERVICE STEAM MODULATION			M			(i)											
4	FEEDWATER				O													
5	FEEDWATER CONTROL					M												
6	DESUPERHEATER FEEDWATER			(i)			M											
7	PREMELT STEAM							O		C		C	C			C		
8	TRAP NO. 2								O									
9	THAW STEAM							C		O	C	C	O	C		C		
10	RECIRCULATION CONTROL									C	M		C	O		C		
19	CONDENSER STEAM							C		C		O	C			C		
20	THAW STEAM DISCHARGE										C		O	C				
21	VAPORIZER OUTLET												C	O				
22	TRAP NO. 1														O			
23	WARMING STEAM							C		C		C				O		
–	RECIRCULATION PUMP																ON	O
–	PUMP COOLING WATER																	O

O = OPEN

C = CLOSED

M = MODULATING

* VALVE POSITION

** VALVE NUMBERS CORRESPOND TO P&ID M1004 VALVE NUMBERS

(i) VALVES 3 AND 6 ARE INTERLOCKED IN DESUPERHEATER LOGIC.

Figure 4-4. Valve Position Interlock Requirements During Operation of the TS SRE Interlocked Valve Numbers

40454

This page is intentionally left blank

THERMAL STORAGE CONTROL, RESET MODE

A reset mode is desirable to simply place all valves into a known status.

The reset mode places all valves into their normal positions. A new mode, other than the emergency mode, cannot be instituted without first employing the reset mode. Associated valve states are given in Figures 4-3 and 4-4 .

Related logic diagrams are presented in Appendix G.

THERMAL STORAGE CONTROL, EMERGENCY MODE

For safety of personnel and protection of property, an emergency mode is required which will automatically place the system in a safe condition.

The emergency mode may be actuated by pressing a button on a cord, either worn on the operator's belt, or carried by the operator in the thermal storage facility. The operator at the control console can also actuate the emergency mode. Actuating the emergency mode will institute the reset mode, and in addition, will shut off all motors. An audible alarm will sound in the thermal storage area and at the console. A light will also flash at the control console. The control console operator can acknowledge the alarm which will turn off the audible portion and will change the stacking light to steady. Correcting the problem will turn off the steady light. See EMERGENCY STATES which follows.

Associated valve states are given in Figures 4-3 and 4-4 . Related logic diagrams appear in Appendix G.

THERMAL STORAGE CONTROL, EMERGENCY STATES

Emergency states during operation of the thermal storage system will be indicated first as alarms to the operators, followed by automatic intervention if corrective action is not brought about.

Table 4-1 summarizes the alarm/interlock actions for the fluid circuits of the thermal storage system. Simultaneous audible/visible alarm is given to the operator prior to automatic intervention. If corrective action is not taken, or is inadequate, automatic intervention (interlock) takes place bringing about another simultaneous audible/visible alarm indicating the actual interlock event. The audible alarms can be turned off by the operator in acknowledgement of the alarm state. However, the visible alarm will persist until the process variable has been restored within normal limits.

From Table 4-1 it is seen that interlock action is of three kinds: trip of the recirculation pump, shutdown of the steam supply (from No. 8 Unit), and shutdown of the feedwater supply (from No. 6 Unit). Tripping of the pump occurs to protect it in the event of low suction or cooling water failure. Abnormally high pressures and temperatures of the charge and thaw steam will stop the supply of steam to the desuperheater. Loss of feedwater or steam to the desuperheater due to pipeline break will cause the isolation valves CV-4 and CV-6 to close.

Table 4-1. Thermal Storage Alarm/Interlock Schedule (Fluids)

PARAMETER	ALARM	INTERLOCK	INTERLOCK ACTION
DRUM LEVEL	HIGH & LOW LEVEL		
DRUM LEVEL		LOW LEVEL	TRIP RECIRCULATION PUMP
DESUPERHEATER OUTLET STEAM TEMPERATURE	LOW TEMPERATURE	HIGH TEMPERATURE	SHUT STEAM SUPPLY VALVE (CV-2)
THAW (TANK) STEAM PRESSURE		HIGH PRESSURE	SHUT STEAM SUPPLY VALVE (CV-2)
THAW (VAPORIZER) STEAM PRESSURE		HIGH PRESSURE	SHUT STEAM SUPPLY VALVE (CV-2)
NO. 6 FEEDWATER PRESSURE		LOW PRESSURE	SHUT FEEDWATER SUPPLY VALVE (CV-4)
No. 8 MAIN STEAM PRESSURE		LOW PRESSURE	SHUT STEAM SUPPLY VALVE (CV-2)
RECIRCULATION PUMP C/W FLOW	LOW FLOW	LOW FLOW	TRIP RECIRCULATION PUMP
RECIRCULATION PUMP C/W DISCHARGE TEMPERATURE	HIGH TEMPERATURE	HIGH TEMPERATURE	TRIP RECIRCULATION PUMP

THERMAL STORAGE CONTROL, PRECHARGE MODE

The precharge mode will melt vertical and horizontal channels in the solid salt of the thermal storage unit to establish a liquid path to the surface for stress relief of the expanding salt.

The precharge mode, illustrated in Figure 4-5 , is an auxiliary mode to forestall the possibility of damage to the thermal storage unit during the charge mode. When salt melts, it expands. If salt were to melt in the interior of a large block of solid salt due to the flow of steam in the condenser coil, the pressure in the molten salt could increase to the point where the condenser tubes might collapse, the tank wall might bulge or rupture, or the salt might break to relieve the stress. Once melted, the salt would solidify with fissures, but there would be no certainty of stress relief by this mechanism. The precharge mode dispenses with the need to rely on such natural fissures.

Although all downcomers and risers in the thermal storage unit will be finned longitudinally, a sufficient body of experience in thermal storage has not yet been accumulated to be certain that they will adequately form liquid channels for stress relief of the expanding salts in the thermal storage unit. For this reason, the precharge mode was included and will be employed until proof exists that the condenser downcomers and risers properly relieve the thermal storage unit of these expansive stresses.

In operation, steam of any temperature and pressure within the design limits can be selected simply by dialing the desired conditions on the desuperheater controllers for valve Nos. CV-3 and CV-6, as discussed elsewhere. The steam will pass through the precharge tubing in the thermal storage unit from the top to the bottom, horizontally and back, then up to create liquid channels. Additional liquid channels formed by the condenser will connect with these. Passage of the incoming steam from top to bottom instead of from bottom to top is an essential design feature of the precharge mode.

The associated valve states are given in Figures 4-3 and 4-4 . See Appendix G for logic diagrams associated with the precharge mode.

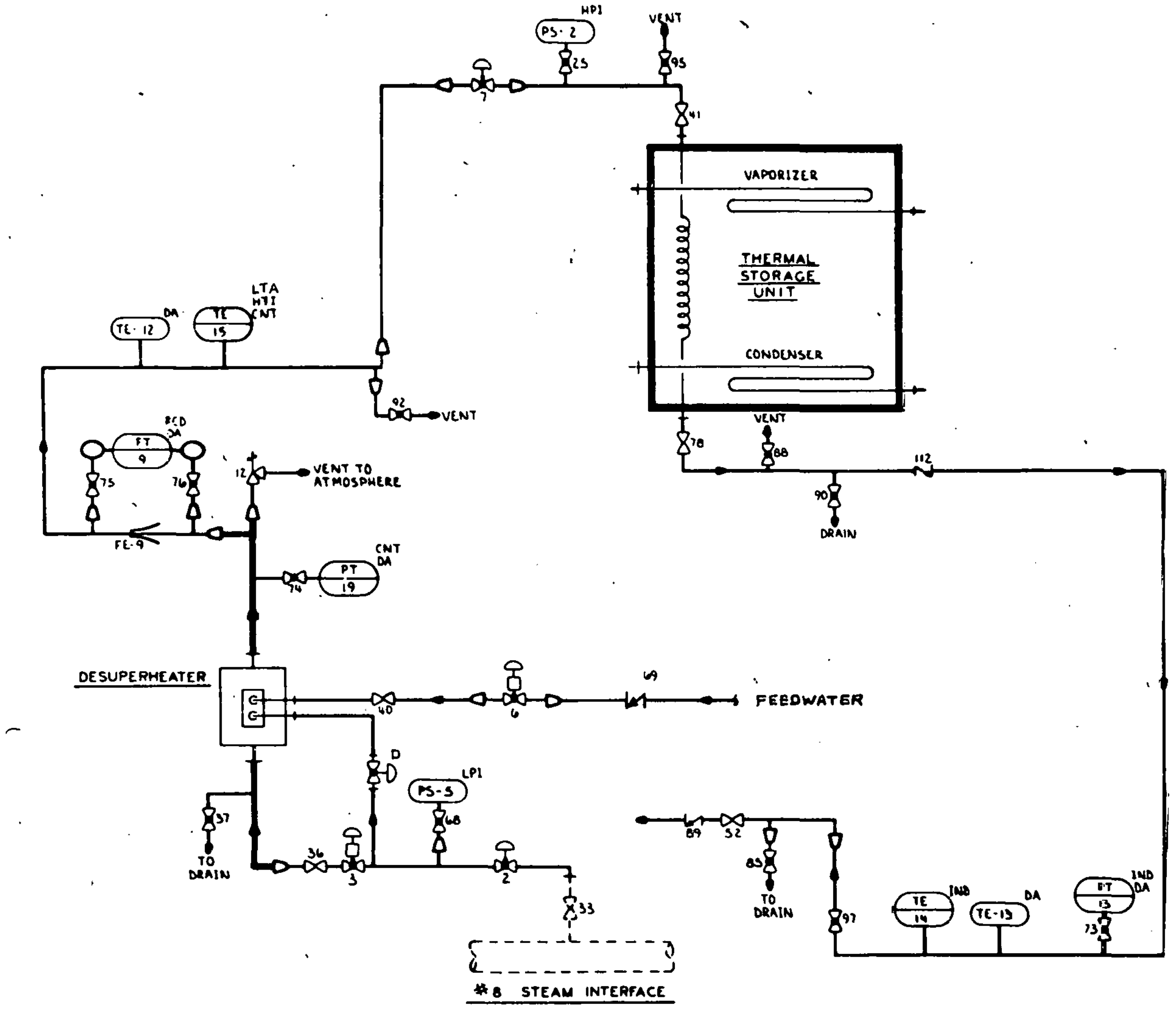


Figure 4-5. Precharge Mode

THERMAL STORAGE CONTROL, CHARGE MODE

The charge mode is used to store energy in the thermal storage unit as latent heat by melting the salt.

In the charge mode the thermal storage unit will receive steam from the No. 8 unit of NSP's Riverside Plant as indicated in Figure 4-6 . The steam of the No. 8 unit has a pressure of 16.5 MPa (2400 psig) and a temperature of 538°C (1000°F). The saturated steam design conditions for the charge mode are 13.5 MPa (1958 psia) and 334°C (633°F). Saturated steam with these conditions or lower, or superheated steam at temperatures up to 371°C (700°F) and pressures up to 13.5 MPa (1958 psia) may be dialed into the controllers for valve Nos. CV-3 and CV-6 associated with the desuperheater to deliver steam consistent with safe operation of the thermal storage facility. These steam conditions will be ample to melt the sodium nitrate salt which has a melting point of 309°C (588°F).

Completion of the charging cycle will be indicated by salt temperature and/or liquid salt level in the thermal storage tank.

Associated valve states are given in Figures 4-3 and 4-4. See Appendix G for logic diagrams associated with the charge mode.

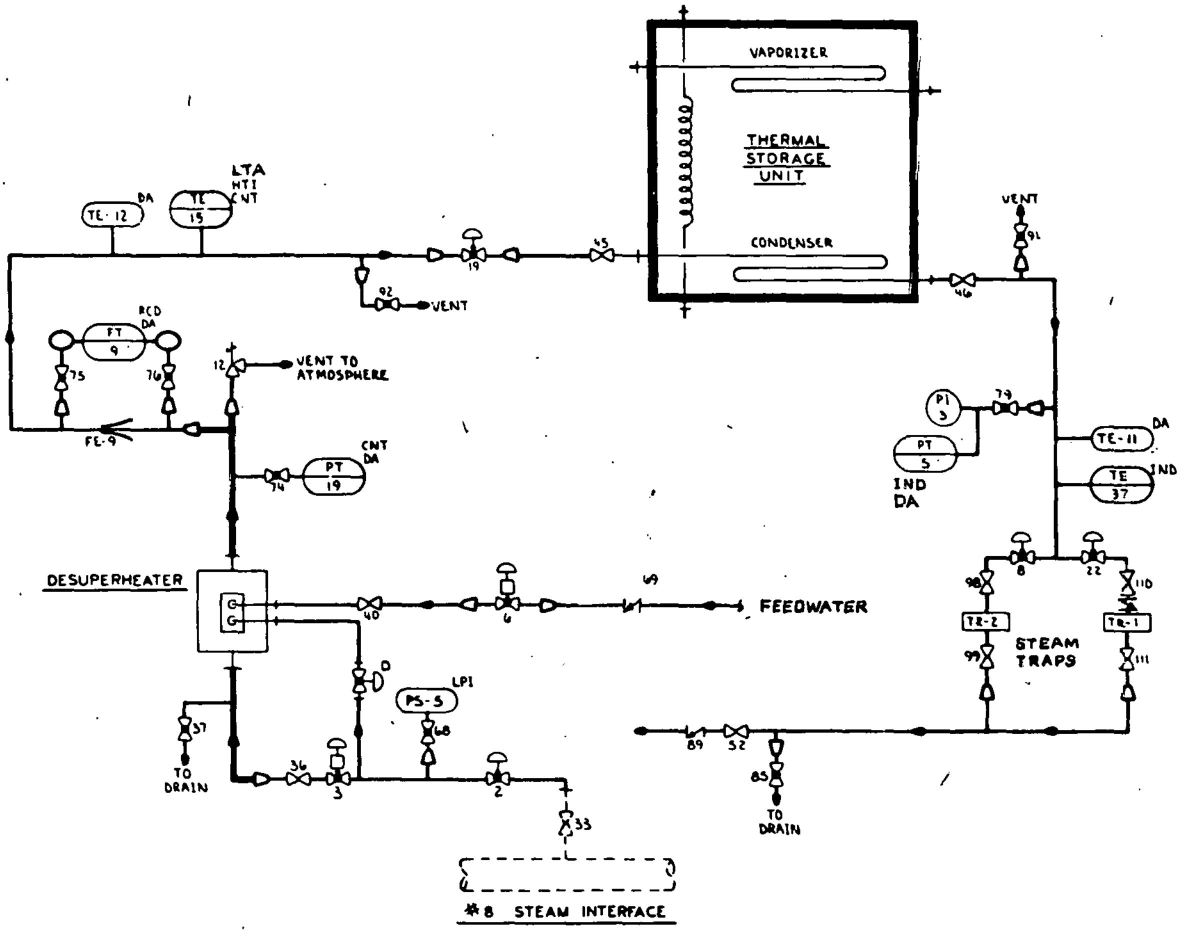


Figure 4-6. Charge Mode

THERMAL STORAGE CONTROL, THAW MODE

The thaw mode is to release frozen scraper blades on the vaporizer.

Since the TSS/RE is an experiment, the boundaries of its operability will be probed in off-design experiments to determine the dynamic range of operability of the thermal storage unit. Under these conditions the scraper blades may stall due to excessively rapid solid salt formation.

The thaw mode will be used to free the scrapers if they freeze up during these off-design operations by passing steam directly through the vaporizer tubes. This will permit rapid return of the system to test operations. See Figure 4-7.

Associated valve states are given in Figures 4-3 and 4-4 . See Appendix G for logic diagrams associated with the thaw mode.

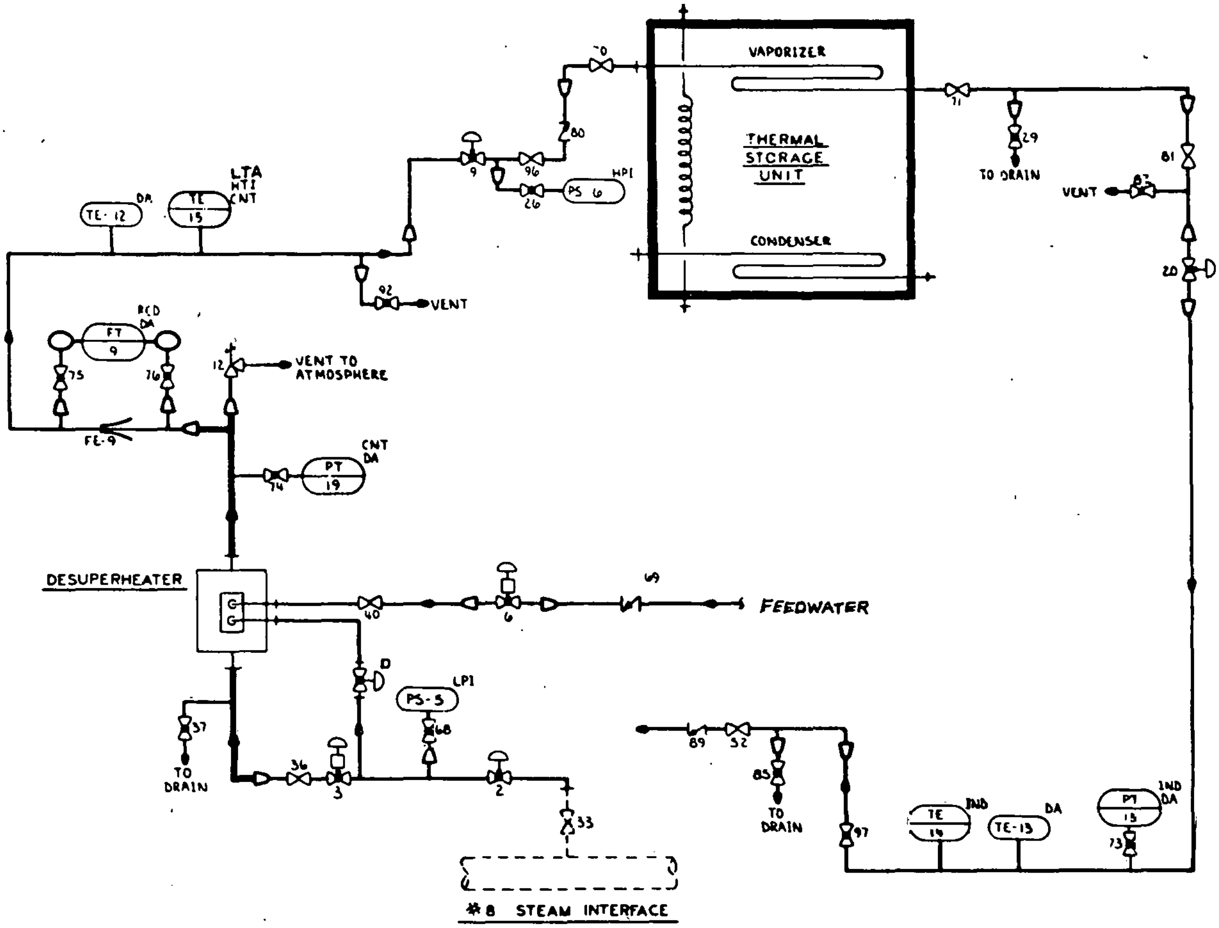


Figure 4-7. Thaw Mode

THERMAL STORAGE CONTROL, WARMING MODE

A warming mode is required for safe and repeated start-up procedures for the TSS/RE facility.

The warming mode will be used to bring the system up to near thermal equilibrium to simplify start-up and thermodynamic analyses.

If water and steam at a temperature below 246°C (475°F) is supplied to the vaporizer in the discharge mode, the temperature gradient at the vaporizer coils may be sufficiently large to freeze salt so rapidly that the scraper blades will stall. A simple method to avoid scraper blade stall at start-up is to warm the facility using the warming mode illustrated in Figure 4-8 . The warming mode utilizes steam from the No. 8 unit with the conditions dialed on the controllers of the desuperheater discussed elsewhere.

See Figures 4-3 and 4-4 for associated valve states and Appendix G for logic diagrams associated with the warming mode.

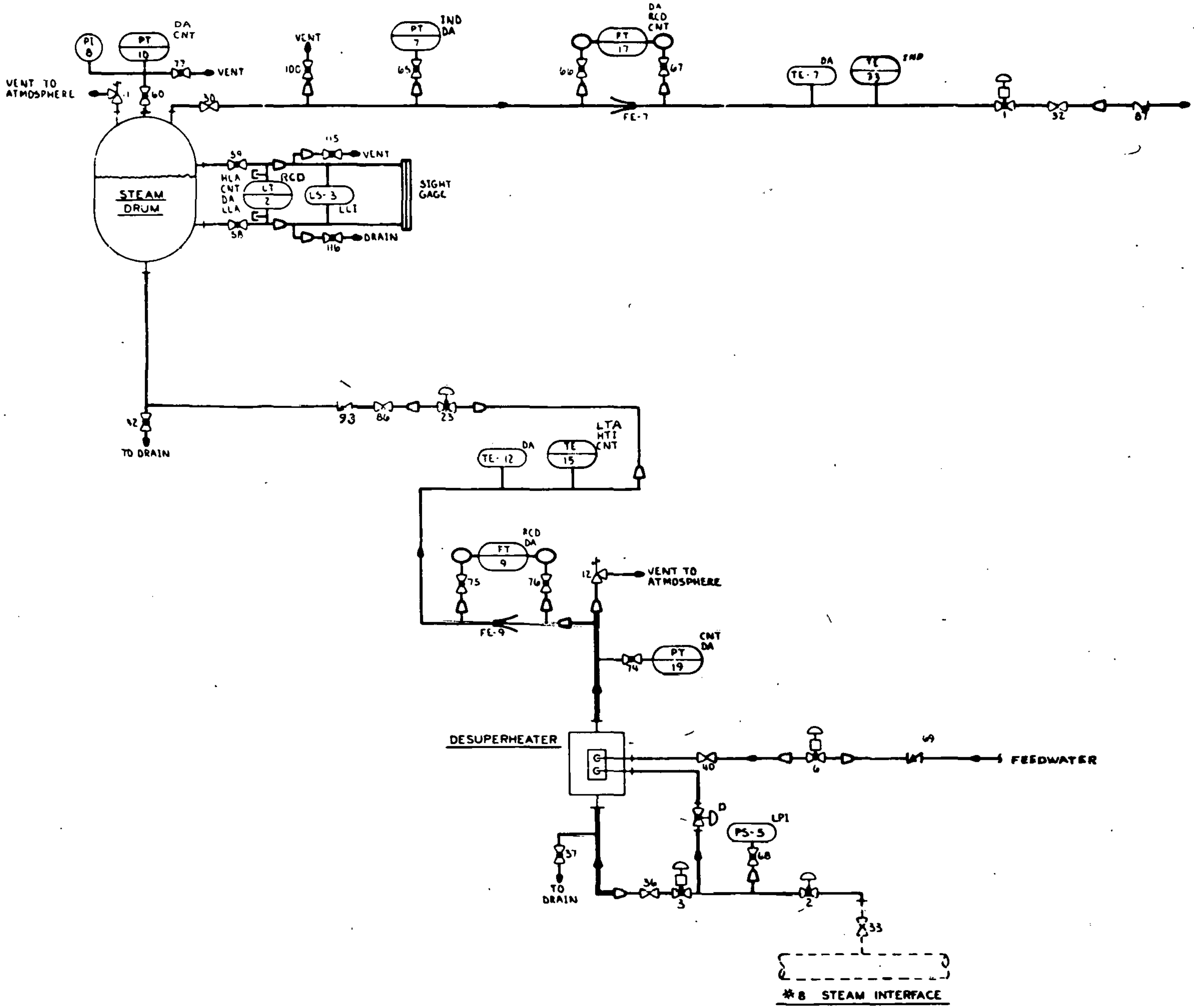


Figure 4-8. Warming Mode

THERMAL STORAGE CONTROL, DISCHARGE MODE ANALYSIS

Two basic modes of control will be used to evaluate the operating characteristics of the TSS/RE in the discharge mode.

Referring to Figure 4-9 the steam drum pressure can be allowed to vary from below the design point to the saturation pressure corresponding to the salt temperature or it can be controlled by using recirculation rate as a controlled variable.

If the recirculation rate is held constant and CV-1 is throttled, the steam drum pressure will seek an equilibrium value proportional to the heat rate delivered. The equilibrium is described by the energy balance

$$q = U(\dot{m}_R, X_e) \cdot A \cdot \Delta T \qquad (1)$$

and

$$q = \dot{m}_R X_e \, \Delta H \qquad (2)$$

where

q = heat rate

U = overall coefficient

ΔT = T(salt) - T(steam)

A = tube surface area

$\dot{m}_R$ = recirculation rate

X_e = exit steam quality

ΔH = $H_{sat} - H_{fw}$

H_{sat} = saturated vapor enthalpy

H_{fw} = feedwater enthalpy

Solving for X_e, from Equation (2):

$$X_e = \frac{q}{\dot{m}_R \cdot \Delta H}$$

Substituting into Equation (1), we get

$$q = U(\dot{m}_R, q/\dot{m}_R, \Delta H) \cdot A \cdot \Delta T$$

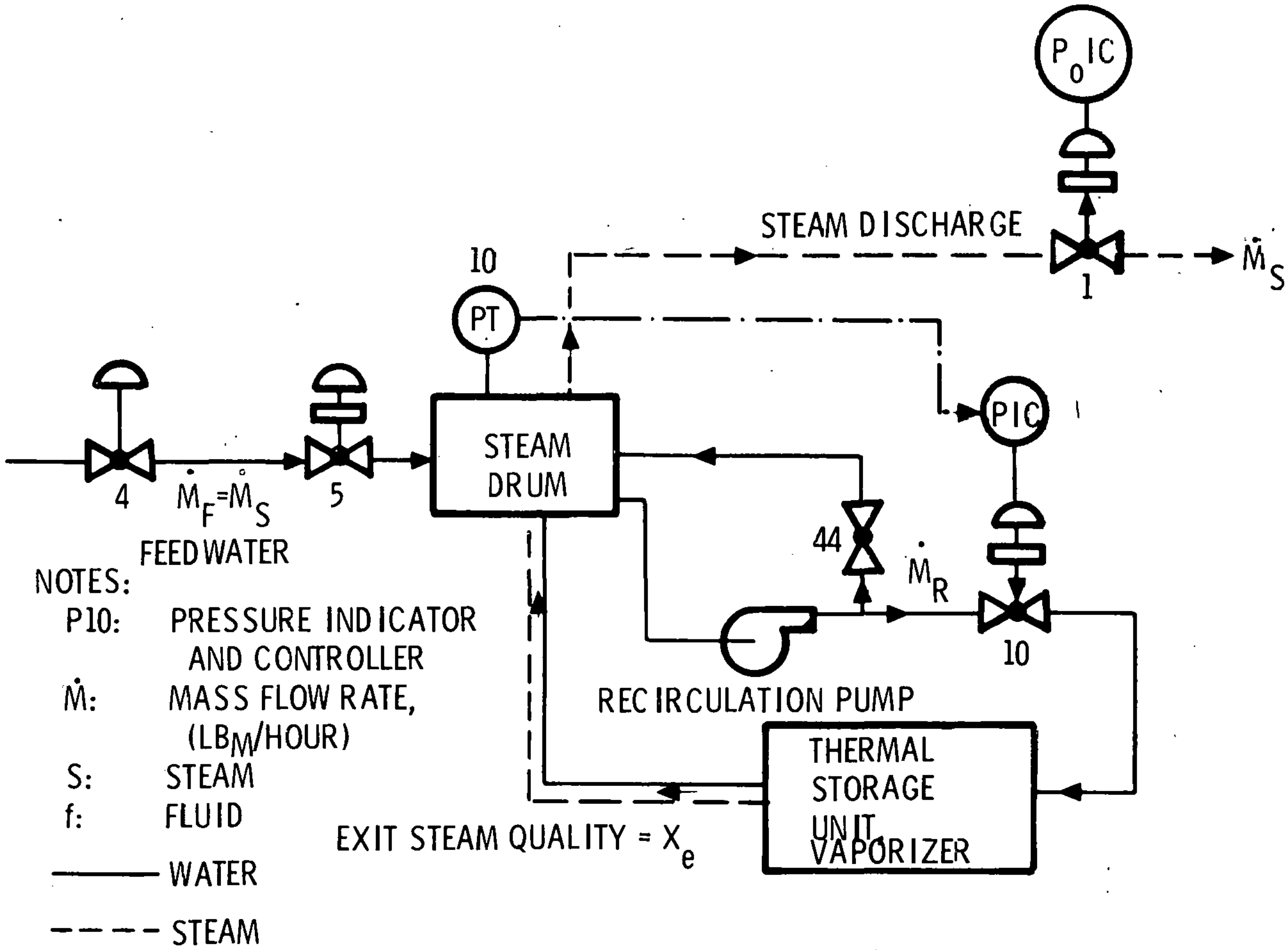


Figure 4-9. Schematic of the TSS/RE Control Loop

For given tube area

$$q = \oint (\dot{m}_R, \ \Delta T, \ \text{steam properties}) \tag{3}$$

With $\dot{m}_R$ held constant, q will vary as ΔT or vice versa. The drum pressure is directly related to ΔT. At low discharge rate, ΔT will go to zero. In that condition, the steam temperature will approach the salt temperature and the saturation pressure will vary accordingly. Figure 4-10 shows the variation of steam drum pressure with heat extraction rate with recirculation flow as the parameter. Figure is based on a salt temperature of 298°C (568°F). The drum pressure is very sensitive to the heat rate.

If drum pressure is held constant, ΔT will be constant and from Equation (3) heat rate will vary as recirculation flow, $\dot{m}_R$. Figures 4-11 and 4-12 show the variation of heat rate with recirculation flow with drum pressure as the parameter. At recirculation flows greater than 454 kg/hr (1000 lb/hr) the curve is flat and heat rate is very insensitive to the recirculation flow rate. While at recirculation flows below 454 kg/hr (1000 lb/hr), the heat rate decreases almost asymtotically. This is because at higher flow rates the outside coefficient controls and the overall coefficient is insensitive to changes in inside coefficient. But at low flows the inside coefficient becomes controlling and the overall coefficient depends on the recirculation flow and quality.

Computer calculations were done to calculate the heat rates, using the program whose flow chart is presented in Appendix I. The outside coefficient was evaluated using the scraping model described in Appendix H, and the inside coefficient was calculated using Rohsenow's equation, Chen's correlation and Dittus Boelter equation for different quality ranges.

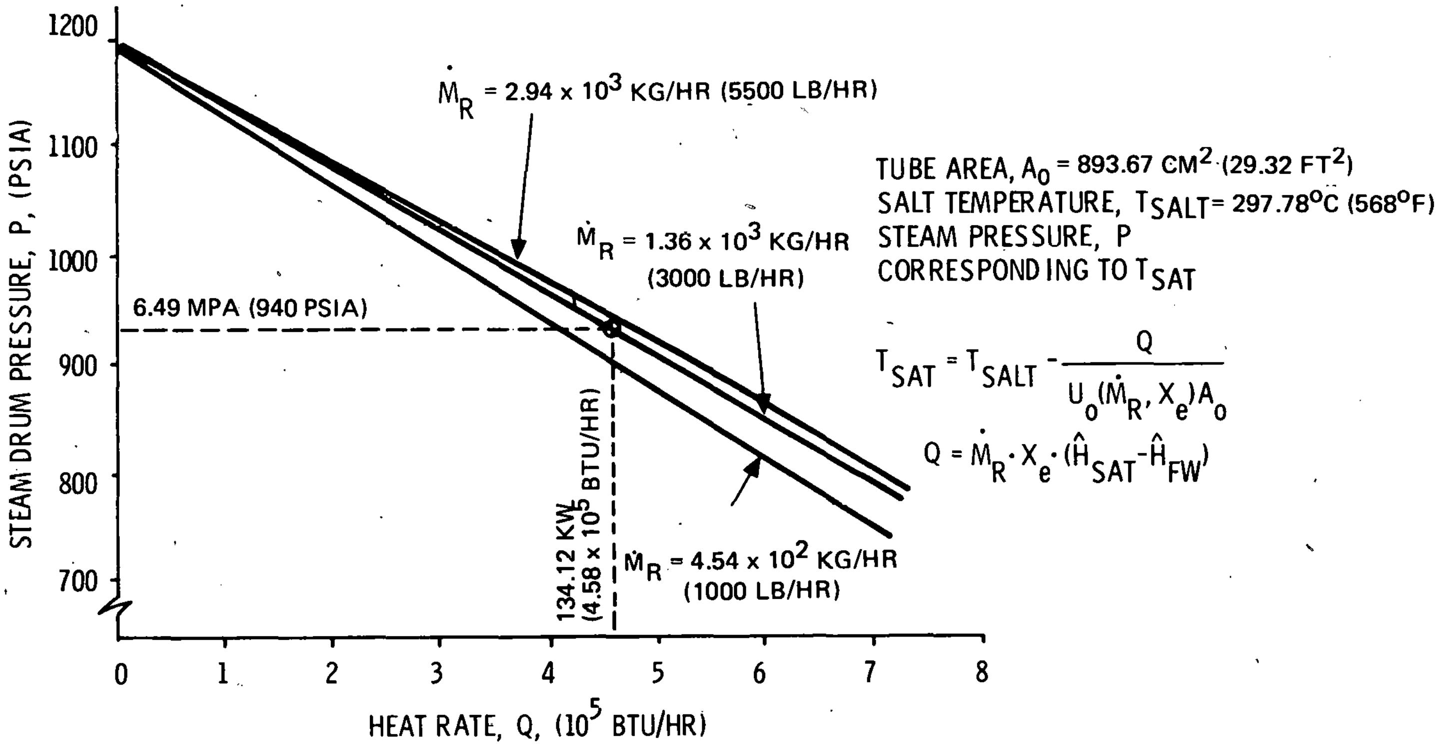


Figure 4-10. Steam Drum Pressure versus Heat Rate at Constant Recirculation Flow Rate

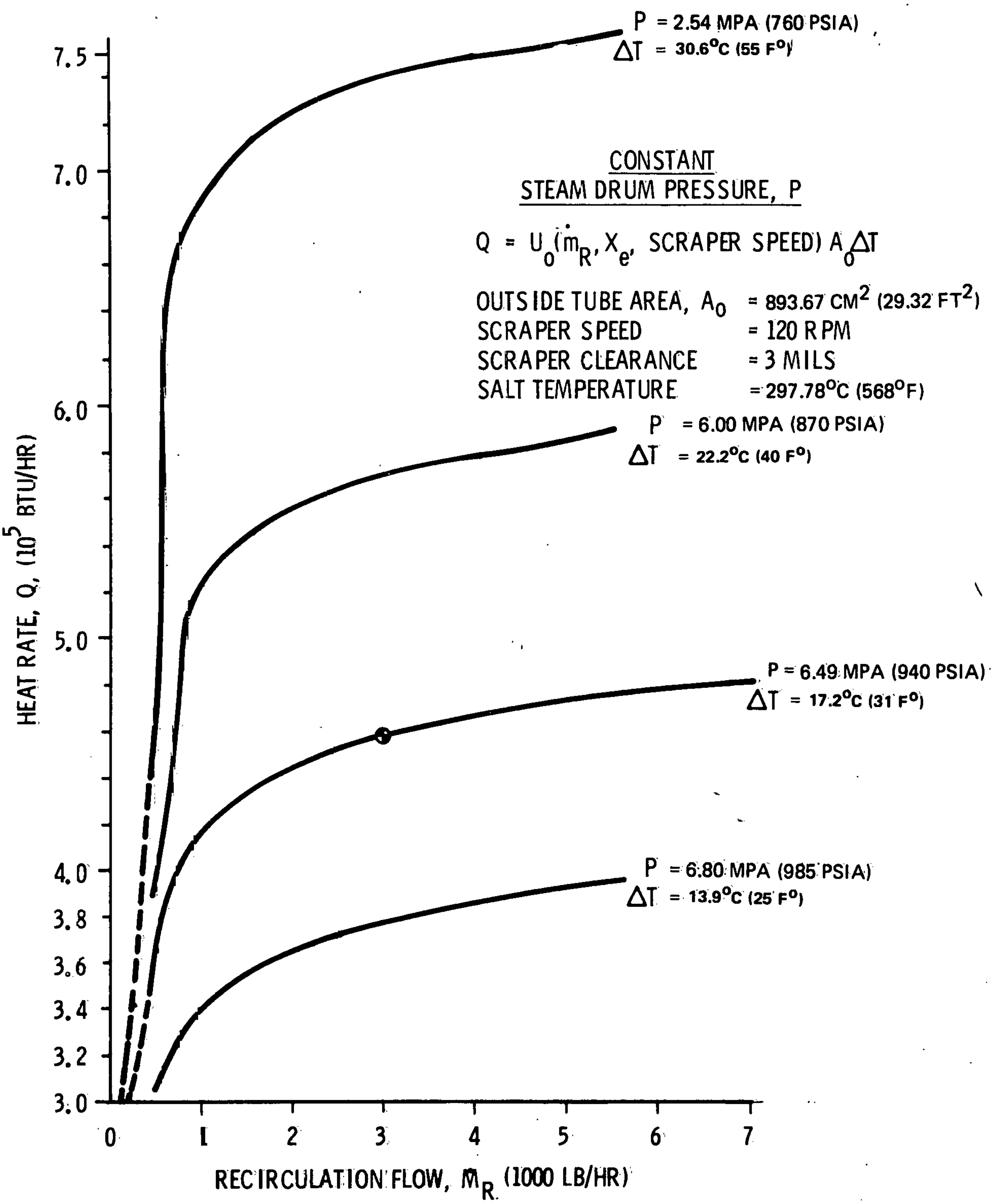


Figure 4-11. Heat Rate versus Recirculation Flow Rate at Higher Constant Steam Drum Pressures

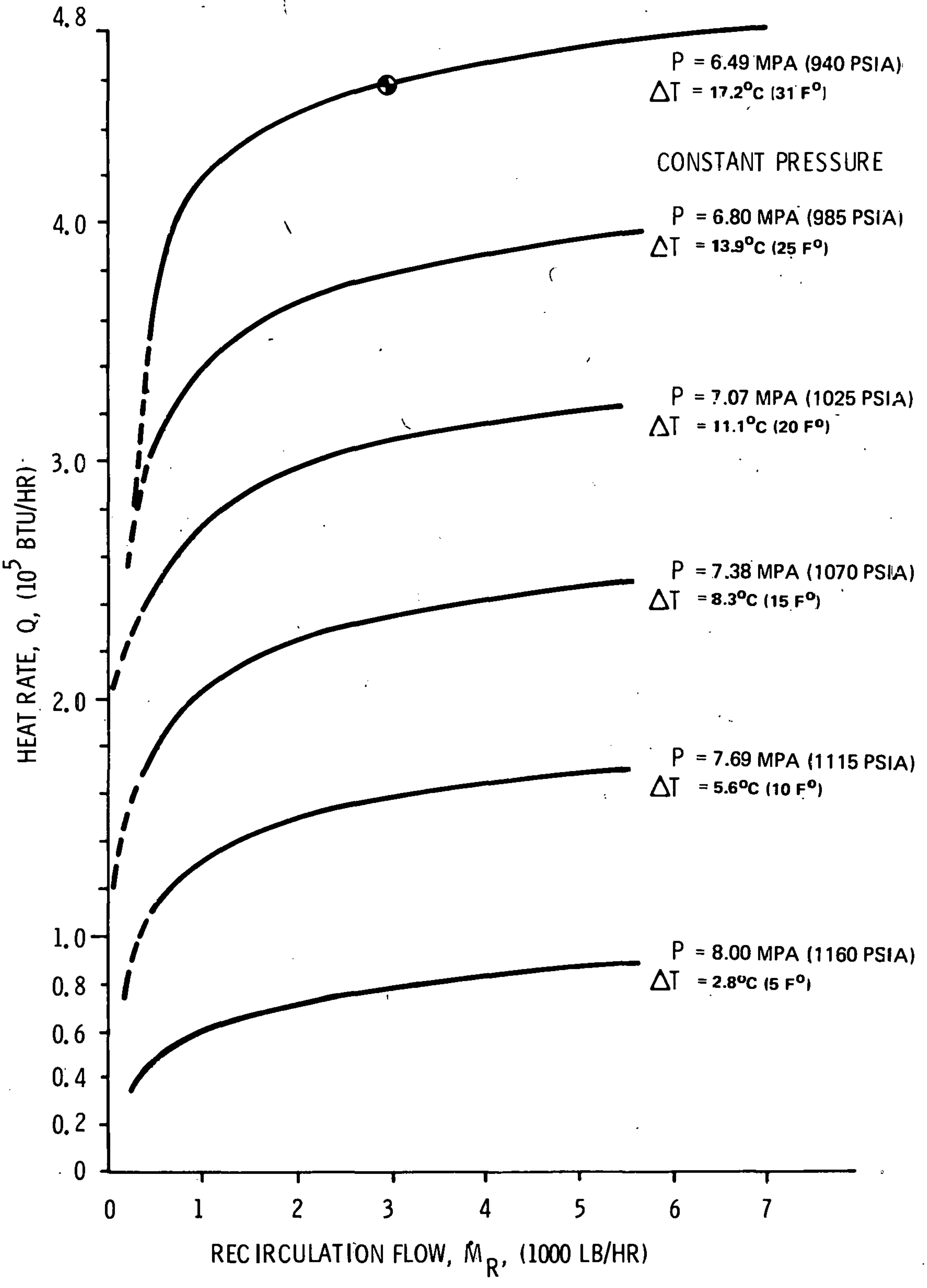


Figure 4-12. Heat Rate versus Recirculation Flow Rate at Constant Steam Drum Pressures

THERMAL STORAGE CONTROL, DISCHARGE MODE

There are three submodes required for the discharge mode to evaluate the discharge, design, and performance capability: one submode is required for operational evaluation and two submodes are required for design evaluation.

Figure 4-13 is that part of the PI&D No. M1004 which constitutes the discharge mode of the TSS/RE.

- Operational Evaluation Submode - Constant Recirculation Rate, Variable Pressure (CRVP). In this submode FT-18 controls CV-10, CV-1 is in manual, and PT-10 is not used. This allows CV-1 to set a demand in the vaporizer loop similar to that which would be imposed by a turbine-throttling valve in the pilot plant.

- Design Evaluation Submode - Constant Recirculation Rate, Constant Pressure (CRCP). In this submode PT-10 controls CV-1 and FT-18 controls CV-10. The purpose of this submode is to evaluate the heat rate capability from the thermal storage unit under controlled conditions of temperature, pressure, and flow.

- Design Evaluation Submode - Variable Recirculation Rate, Constant Pressure (VRCP). In this submode PT-10 controls CV-10, CV-1 is in manual, and FT-18 is not used. This submode will be used to determine the capability of controlling the heat rate with variable recirculation flow rate.

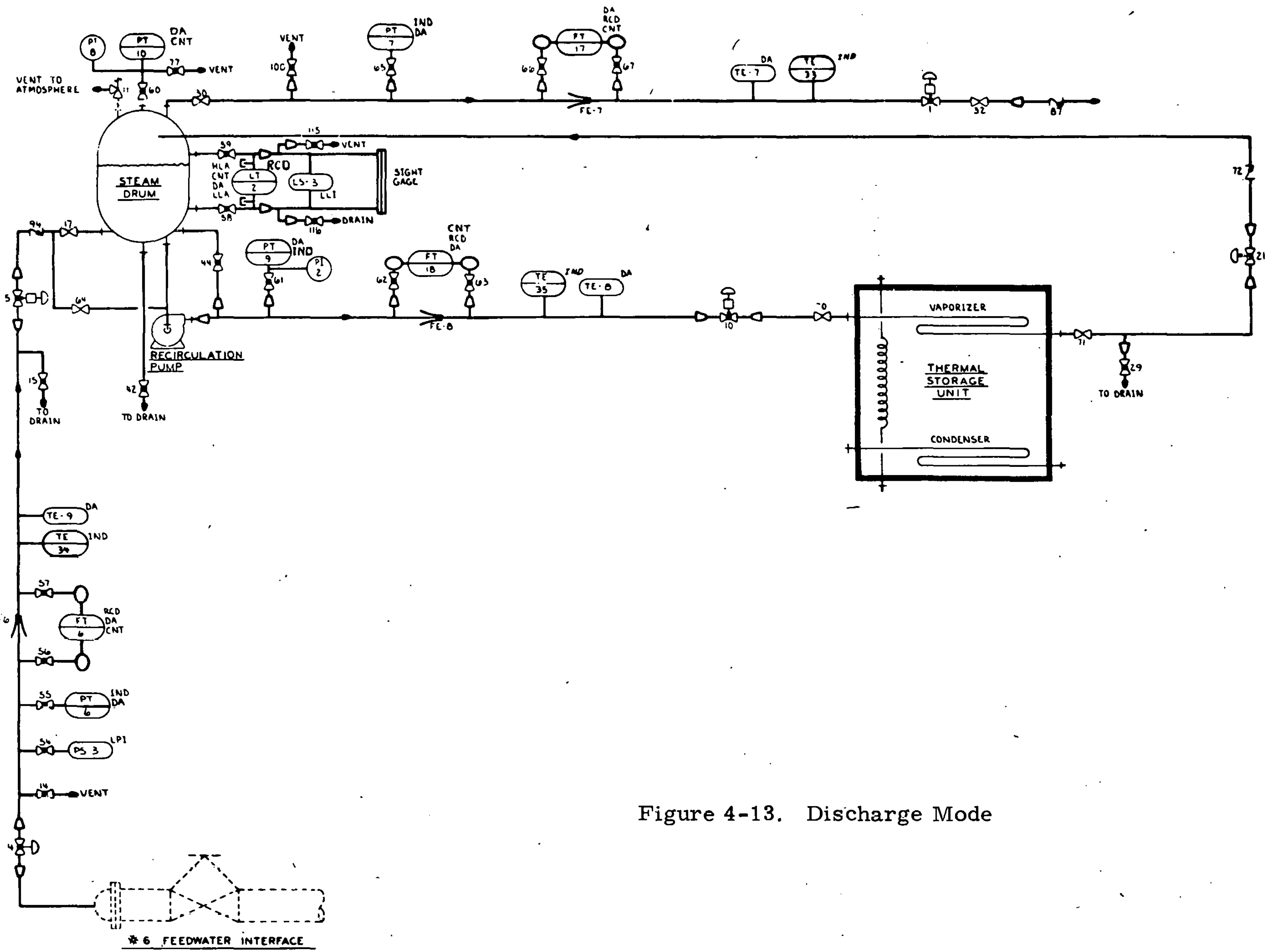


Figure 4-13. Discharge Mode

40454

Experiment Test and Operation

Test Operations and Controls

THERMAL STORAGE CONTROL, CHARGE-WHILE-DISCHARGE MODE

The operational thermal storage facility will function in a mode of charging while simultaneously discharging the thermal storage unit.

The TSS/RE will be tested in a charge-while-discharge mode, a combination of Figures 4-6 and 4-13, since this mode will be an operational feature of the thermal storage facility of the solar pilot plant. Due to the existence of large thermal time constants, switching from charge to discharge at a cloud passage cannot be performed instantaneously. Therefore the two modes will necessarily be in operation simultaneously. Furthermore, the best method of operating the thermal storage facility to accomplish most rapid transfer from the steam generator to the thermal storage facility may be shown to be a continuous but low-power discharge while in the charge mode. This combined mode will be evaluated with the TSS/RE.

Associated valve states are given in Figures 4-3 and 4-4 . See Appendix G for logic diagrams associated with the charge-while-discharge mode.

Experiment Test and Operation

Test Operations and Controls

THERMAL STORAGE CONTROL, MANUAL MODE

For maximum flexibility in this experimental project, a manual mode is desirable to permit an experienced operator to manually control the TSS/RE.

In the manual mode each on-off and each control valve can be independently activated except as restricted by the intrinsic logic of the control system. Referring to Figure 3-24, examples of such restrictions are that of CV-7, CV-9, CV-19, and CV-23, only one can be open at any one time; V-20 and V-21 cannot be open at the same time; CV-10 cannot open unless V-21 is open.

See Appendix G for the total logic diagrams for the TSS/RE.

THERMAL STORAGE CONTROL, CONTROL IMPLEMENTATION IN THE DISCHARGE MODE

Controls are provided for maintaining drum level, drum pressure, and recirculation flow in the discharge mode.

The control scheme for the discharge mode is shown in Figure 4-14. Five control stations are used to effect the control of water level in the drum, drum pressure, and recirculation flow. Drum level is controlled using three-element control. Drum pressure is controlled by throttling either main steam discharge or recirculation flow. Recirculation flow throttling can also be effected in response to a flow controller. These control submodes are explained further in the following.

Conventional three-element drum level control uses three measurements: steam flow, feedwater flow and drum levels. Steam flow and feedwater flow measurements are linearized by square root extractors. The linearized steam flow measurement (generated by FT-17) and the drum level measurement (generated by LT-2) are combined electrically in a summer whose output sets the control point of the feedwater flow controller (FIC-9) in cascade fashion. Output of this controller modulates the feedwater control valve, CV-5. Three-element control is used to stabilize drum level during load transients by endeavoring to maintain the relationship of feedwater and main steam flows; i. e., steam flow is used as a feed forward signal. The drum level controller (LIC-10) acts to restore a set drum level after a load change. Both the drum level and feedwater flow controllers use gain-plus-integral control action, and both can be manually operated (as during start-up of the system).

Drum pressure, measured by PT-10, is controlled in one of two submodes as selected by the operator: viz, main steam throttling using controller PIC-13 to modulate the main steam valve, CV-1; or, recirculation flow throttling using controller PIC-6 to modulate the recirculation flow valve, CV-10. But CV-10 can also be controlled in yet another submode by recirculation flow controller, FIC-14. In this submode, PIC-6 is not in use, and the thermal storage system can be set up to simulate a "turbine-following" situation. In this case CV-1 simulates a turbine throttle valve. Throttle (or drum) pressure is maintained at the set point of controller PIC-13 acting on CV-1. A system load demand is imposed by manipulation of the set point of controller FIC-14 to set up a desired recirculation flow rate (via control valve CV-10), hence to maintain a desired evaporation or main steam flow rate.

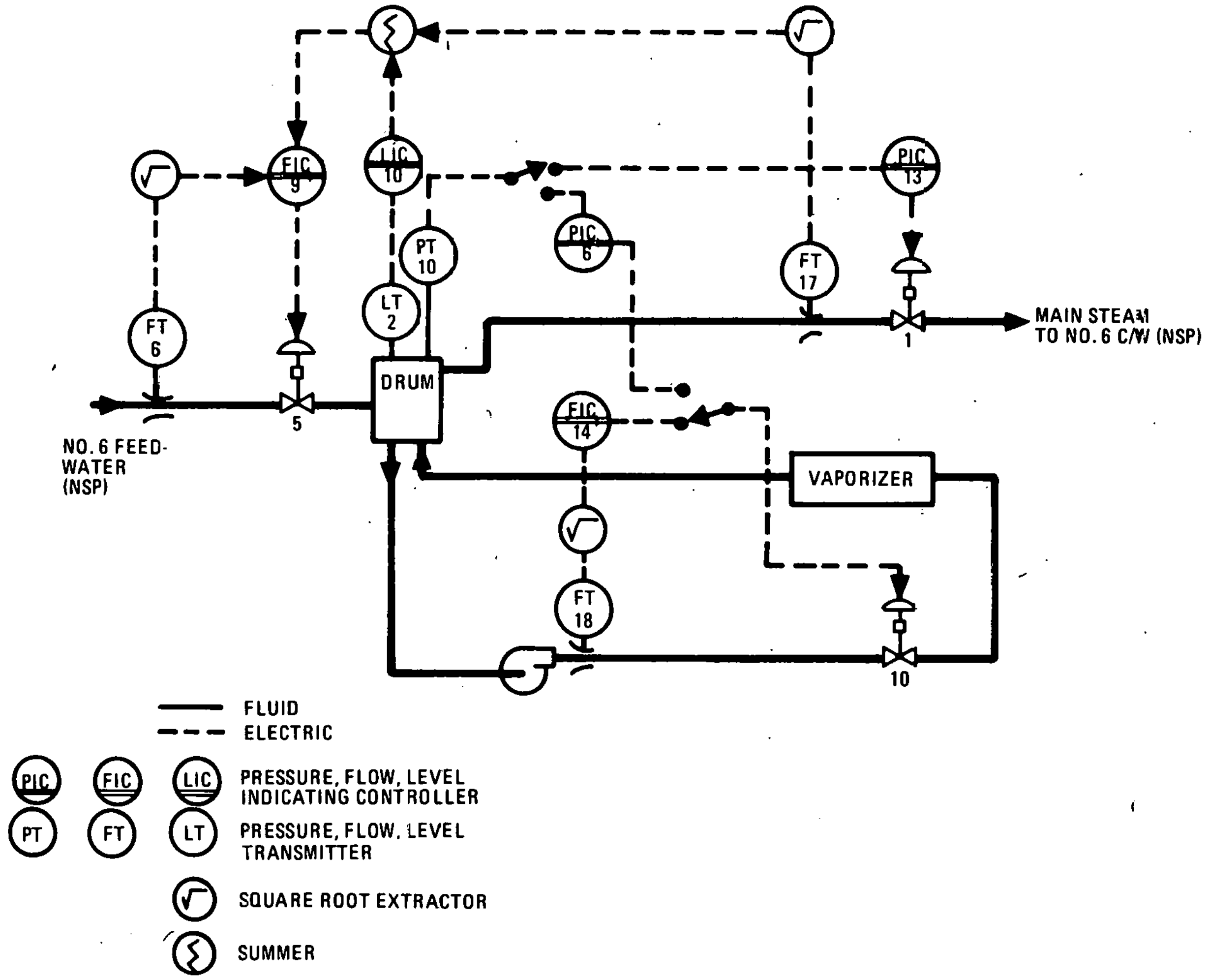


Figure 4-14. Thermal Storage Controllers (Discharge Mode)

THERMAL STORAGE CONTROL, CONTROL IMPLEMENTATION IN THE CHARGE MODE

In the charge mode, steam is delivered at the required pressure and temperature by controlling the desuperheat of main steam from No. 8 Unit at Riverside.

The control scheme for the charge mode is shown in Figure 4-15. Two controllers are used to effect desuperheating. Sufficient rangeability of desuperheater performance is available so that thaw and warming steam, as well as charge steam, can be provided by the desuperheater.

Main steam and feedwater from No. 8 Unit, the only unit at Riverside operating at sufficiently high pressure, are used for supplying the desuperheater. Pressure control of the desuperheater discharge steam is done using controller PIC-11 operating from transmitter PT-19 to modulate control valve CV-3. No. 8 main steam is pressure reduced from 16.56 MPa (2400 psi) to 12.21 MPa (1770 psi) and 6.90 MPa (1000 psi) for charge and thaw/warming modes, respectively. No. 8 feedwater is used to cool No. 8 main steam from 537.78°C (1000°F) to 326.67°C (620°F) and 357.22°C (675°F) for charge and thaw/warming modes, respectively, using controller TIC-12 to modulate feedwater flow via control valve CV-6.

Both controllers PIC-11 and TIC-12 use gain plus integral control action, and both are capable of manual or automatic operation.

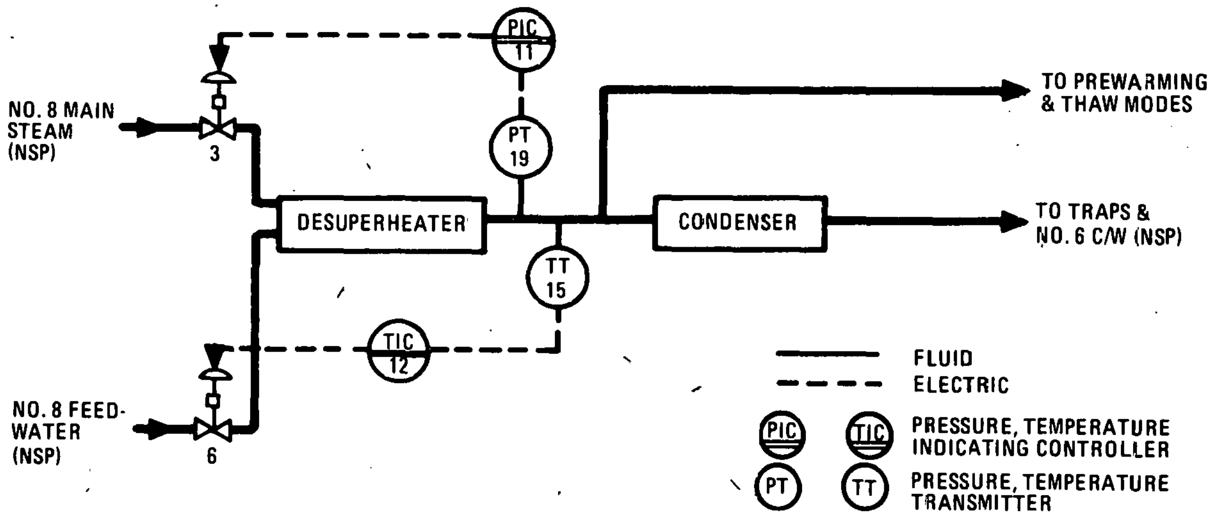


Figure 4-15. Thermal Storage Controllers (Charge Mode)

THERMAL STORAGE CONTROL, CONTROLLERS

Controllers for the thermal storage system feature manual - automatic control selection, adjustable set-point, process variable and valve position displays, and two-mode control action.

The front and side view of the controllers proposed for the thermal storage system are shown in Figures 4-16 and 4-17, respectively. The controllers have vertical-scale indication of the process variable (e.g., pressure, temperature, flow, level) and horizontal-scale indication of the control station output (valve position). Process variable scales are in engineering units while the output scale indicates percent (of valve travel). Setting of the controller is made by thumb-wheel adjustment of the 19.05 cm (7-1/2-inch) movable tape scale so that the set point, as indicated on the scale, is opposite a fixed mark midway on the vertical display window of the instrument. The pointer of a deviation meter moves above and below this center position to indicate "off-control" levels of the process variable, but is centered midway on the vertical scale when "on-control."

The input to the controllers from the transmitter (or square root extractor in the case of flow) is a 4-20 milliampere (ma) signal. The controller output, which is fed to the respective valve positioner, is likewise 4-20 ma signal generated by the error signal caused by a process variable - set point difference. When in the "manual" mode of operation, the operator can manually generate this 4-20 ma signal by means of "open" and "close" pushbutton switches on the face of the controller. "Bumpless" transfer between automatic and manual operation is achieved using a memory circuit in the controller.

Infrequent adjustments to the controller are made at the side of the instrument (ref. Figure 4-17). These include "zero," "span," "gain," "integral," and "control algorithm select." The latter can be used to accommodate large set point changes by modifying internal circuitry (making "gain" action responsive to process variable input rather than error signal). Gain range is continuously adjustable from 0.1 to 100; integral range is adjustable from "off" to 0.02 to 100 repeats per minute.

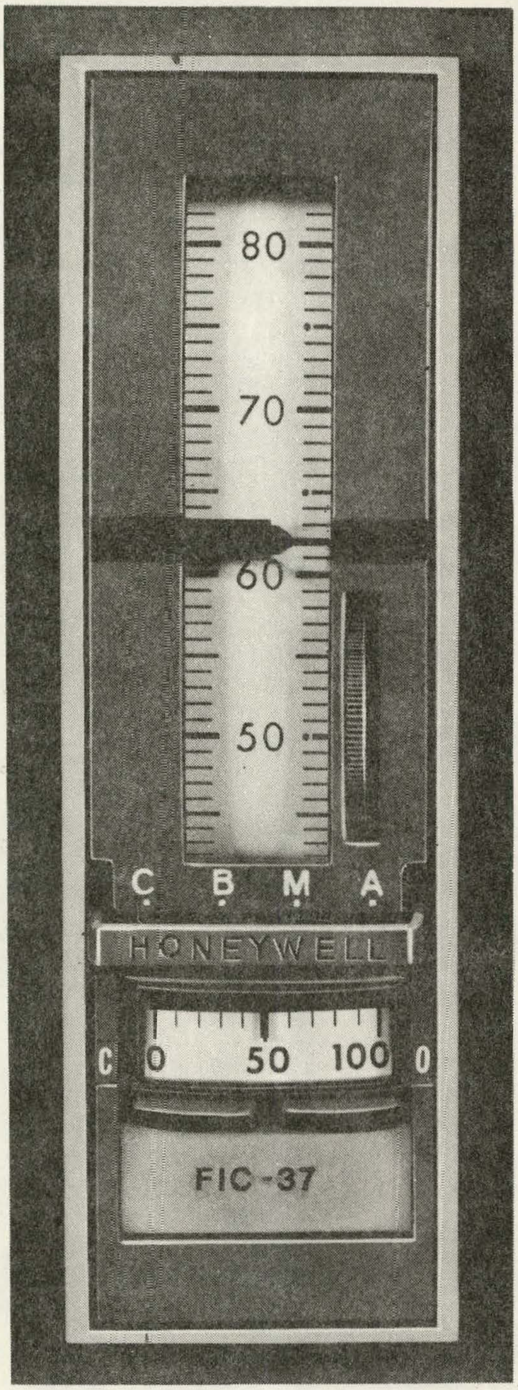


Figure 4-16. Controller (Front View)

40454

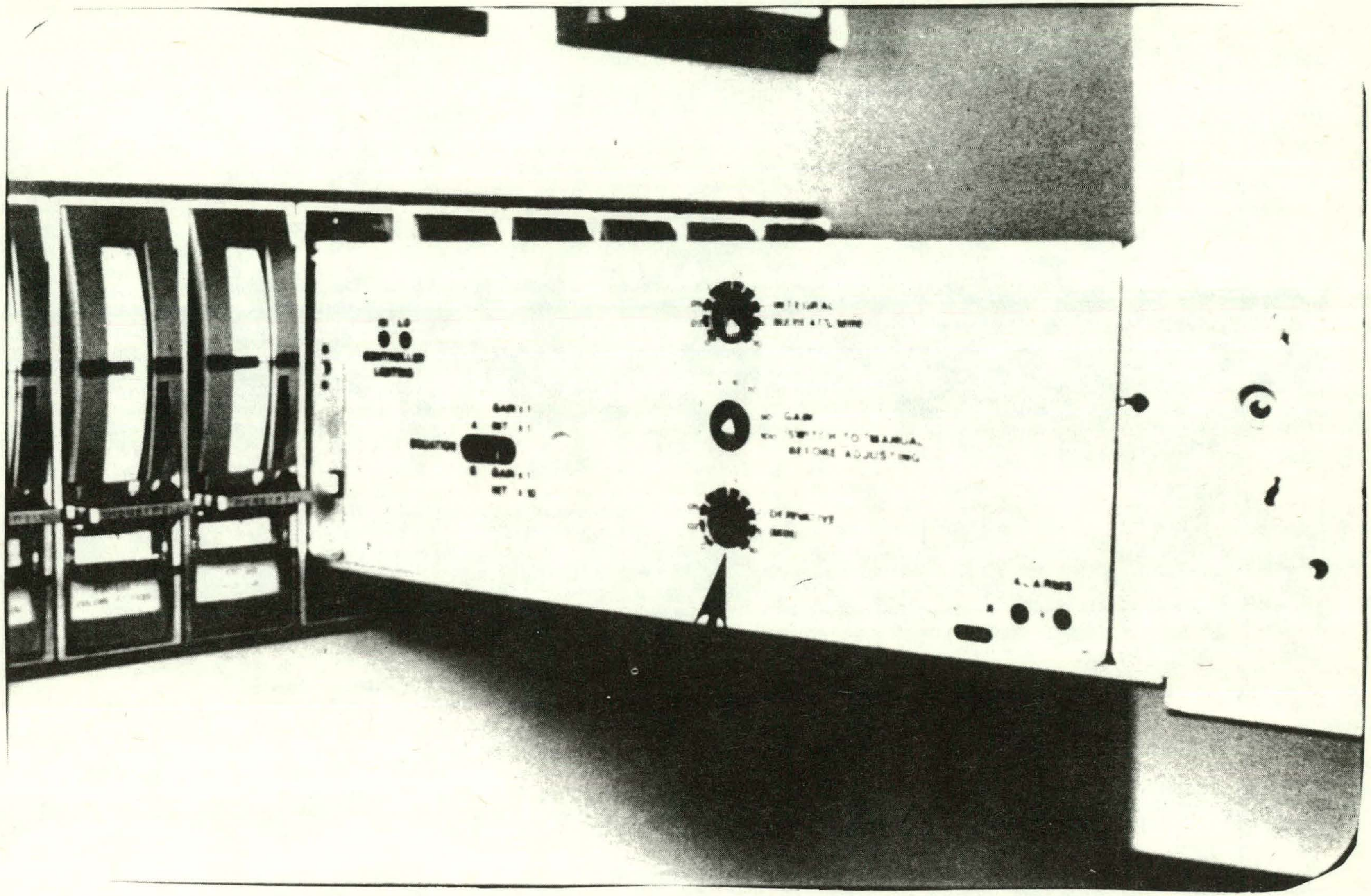


Figure 4-17. Controller (Side View)

This page intentionally left blank

THERMAL STORAGE CONTROL, READOUTS

Key fluid measurements in operating the thermal storage system are indicated and recorded on the control console.

The readout rationale is predicated on two-man control of the thermal storage system using conventional supervisory displays operating continuously, together with those which may be printed out upon operator interrogation of the data acquisition system. The printout and CRT-display information available from the data acquisition system will complement that which appears on the control console. Readout versatility is afforded on the control console by having spare recorder channels, patch panels, and the capability for parallel operation of controllers and recorders.

Key fluid parameters will be displayed on the control console by indicators, indicating controllers, and recorders. Figure 4-18 shows the measurements and readouts for the discharge mode. The measurements are:

- Feedwater: pressure, temperature, flow
- Main steam: pressure, temperature, flow
- Recirculation loop: pressure, temperature, flow
- Drum pressure and level

In addition to these measurements, the flow and discharge temperatures of the cooling water to the recirculation pump are also indicated on the control console.

Figure 4-19 shows the measurements and readouts for the charge mode. The measurements are:

- Desuperheater discharge: pressure, temperature, flow
- Thaw discharge: pressure, temperature
- Condenser discharge: pressure, temperature

Figure 4-20 shows a front view of an indicator. Indication is on a 7.62 cm (3-inch) vertical scale with servo-driven pointer driven by the 4-20 ma transmitter output signal. The indicator has built in level switches for activating process alarms. Figure 4-21 shows a recorder front view. This instrument is also servo driven from the 4-20 ma transmitter signal. Up to three channels may be recorded simultaneously; the recorder can also be "patched" accepting up to 12 inputs. It has built-in level alarm switches and can be parallel operated with controllers.

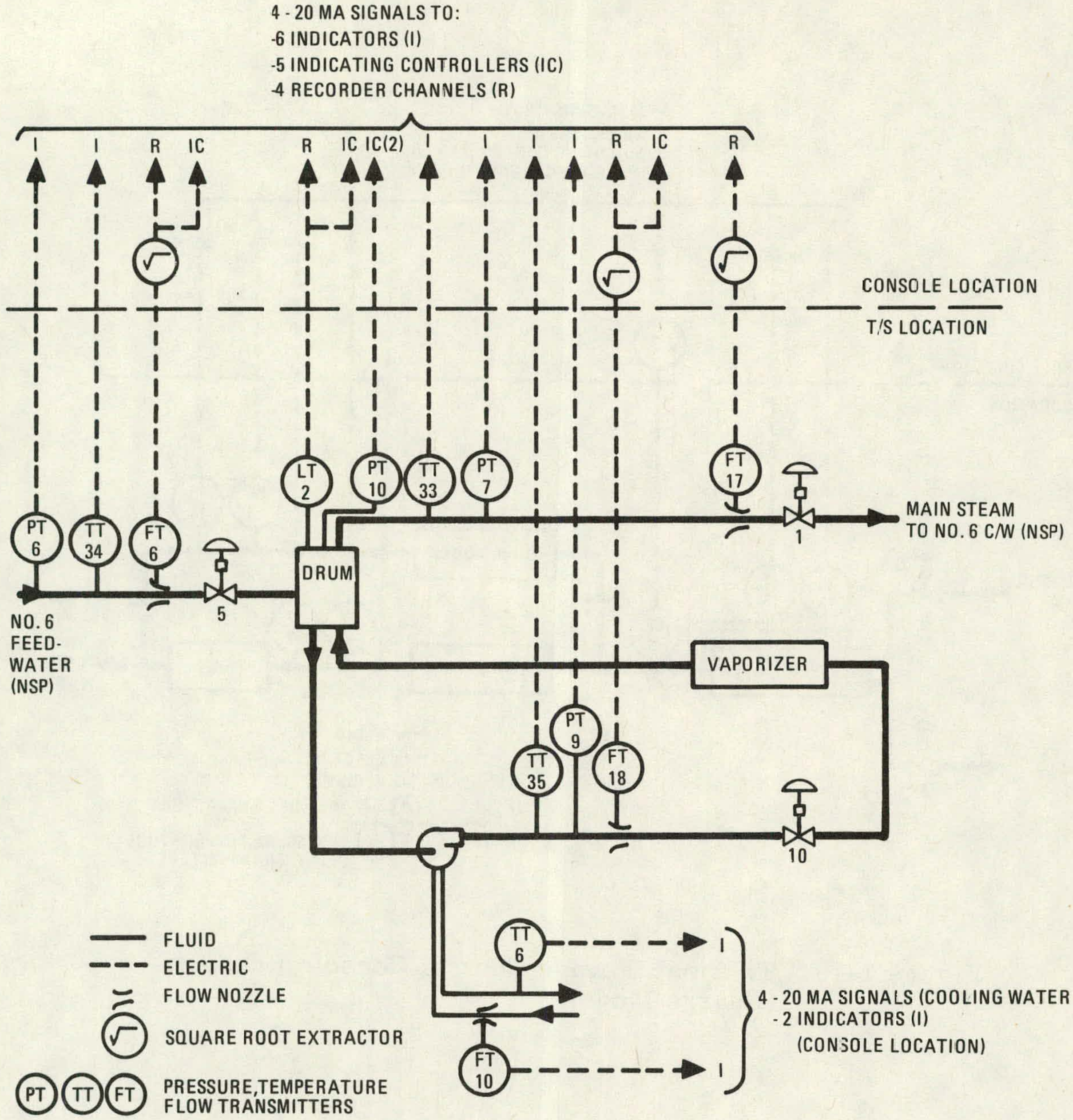


Figure 4-18. Thermal Storage Control Console Readouts (Discharge Mode)

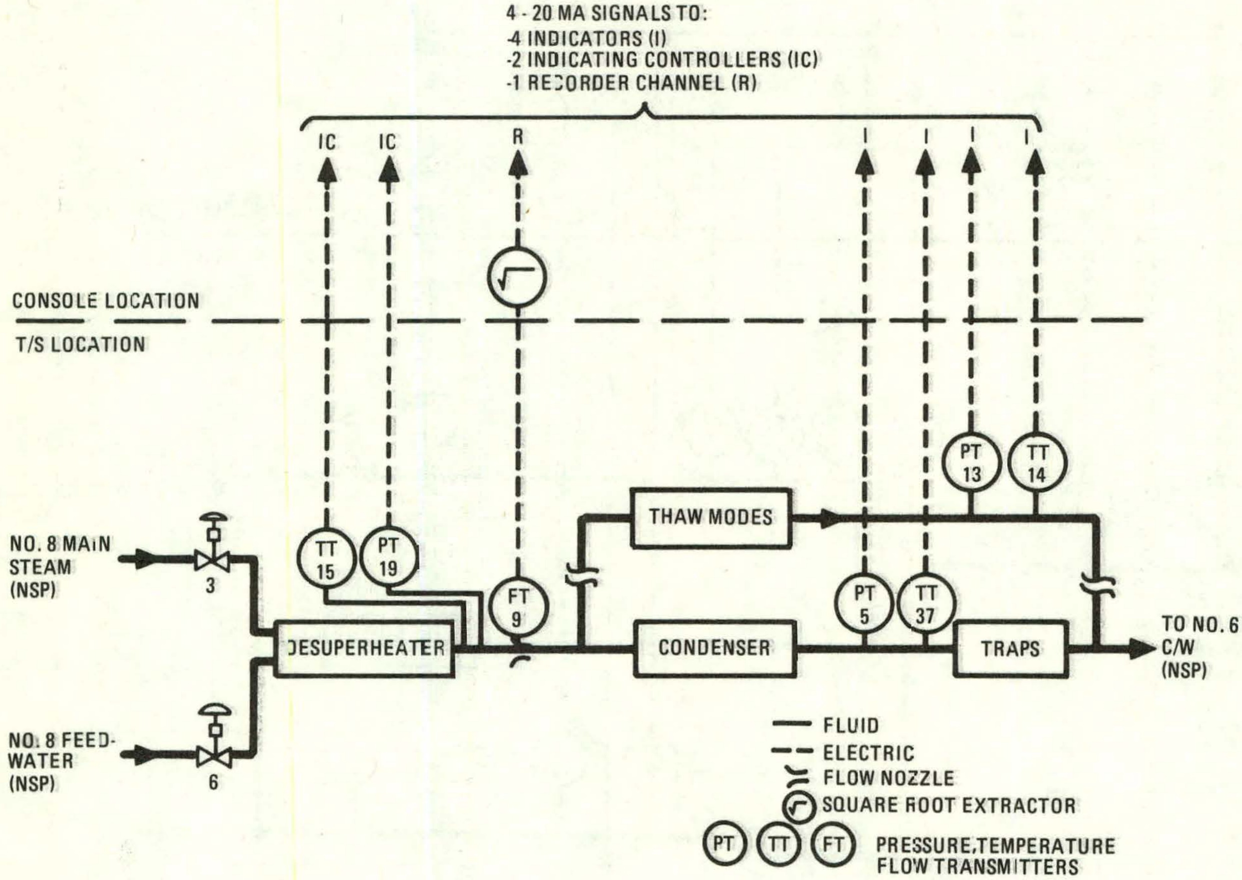


Figure 4-19. Thermal Storage Control Console Readouts (Charge Mode)

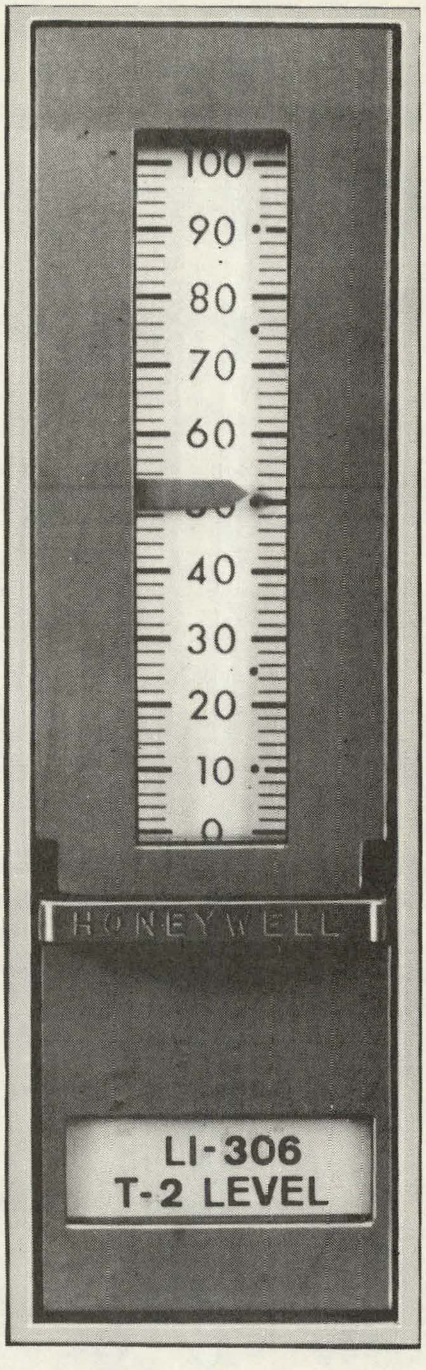


Figure 4-20. Servoed Indicator

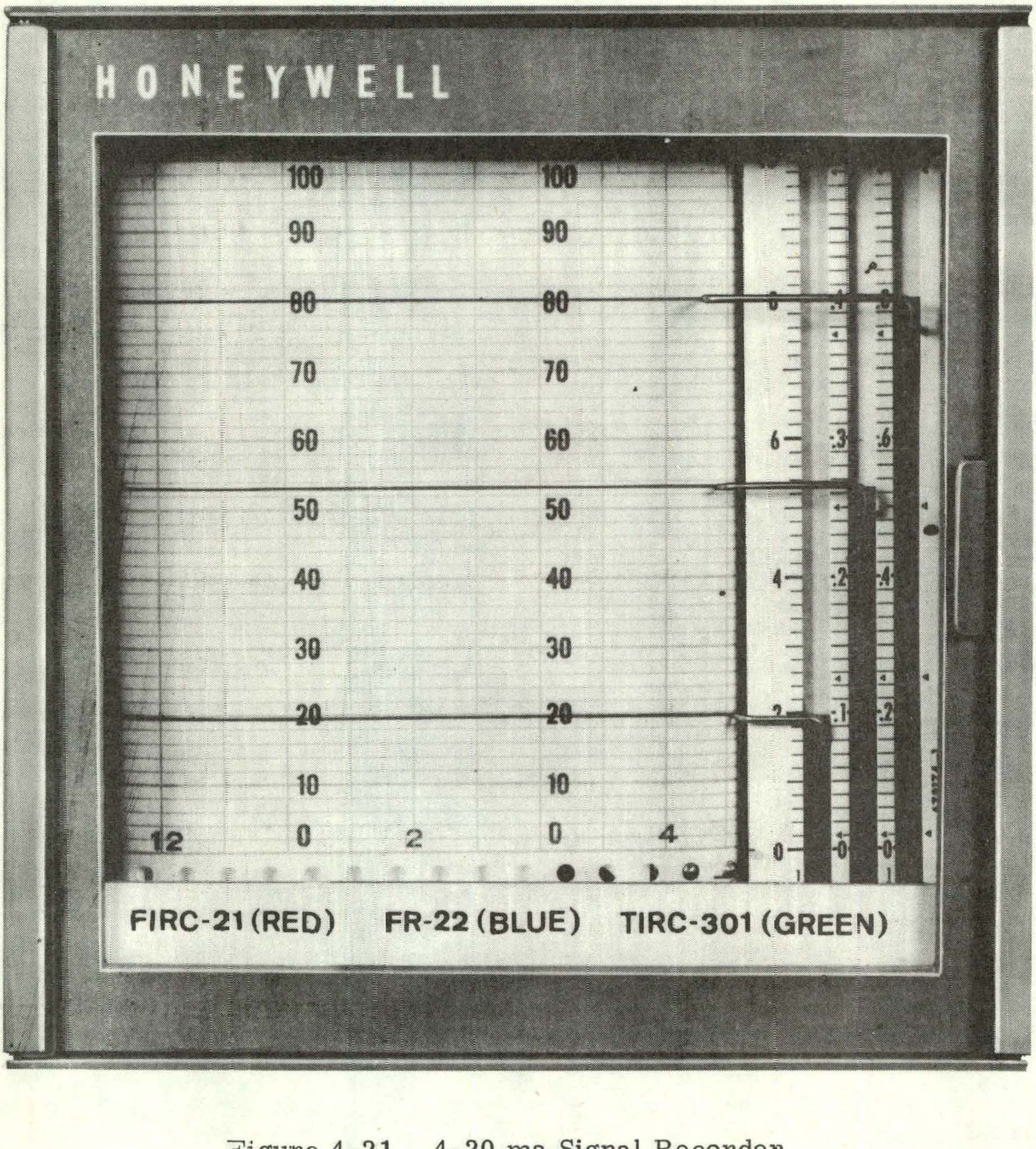


Figure 4-21. 4-20 ma Signal Recorder

This page intentionally left blank

Experiment Test and Operation

Test Program

BLOCK I TESTS-DESIGN POINT EVALUATION

Storage system operation and system repeatability will be demonstrated with a series of eight charge and discharge runs made at and around the design point.

Four complete charge/discharge cycles will be completed at the design conditions to demonstrate system reliability and repeatability. Heat transfer rates, steam pressures and temperature will be checked and scraper torque versus percent of storage charge will be compared in consecutive runs to detect changes in salt properties of scraper wear. An attempt will be made to evaluate the accuracy of the data recording and data reduction system at the same time.

The condenser will have been used previously to melt down the initial charge in the system. Its performance characteristics will have been quantified during the partial charge runs. The four charge mode runs will be used to evaluate the differences in the two types of steam traps, the inverted bucket trap and the thermodynamic trap. It is expected that the difference in trap operation will have an effect upon the temperature distribution along the condenser and upon the amount of steam condensed.

The next four test runs will be made to determine the thermal storage system performance when operating at off-design conditions.

Assuming that the previous four design heat flux rate tests do not produce latent heat recovery factors of 60 percent, the vaporizer heat flux will be adjusted to determine that heat flux that can be attained and still maintain a 60 percent recovery factor. From the engineering model test results presented in conceptual Design Report (CDRL Item No. 5) the plot of Salt Heat Flux versus Percentage of Heat Recovered shows that the heat recovery factor R can be described by the equation:

$$R(\%) = 80 - 4 \times 10^{-3} Qs$$

where Qs = the salt heat flux in Btu/hr-ft^2.

This equation is an experimental result from tests on a much smaller scale which may not be valid in the larger system. Unitl the higher heat flux tests are conducted, it remains the only way of predicting a recovery factor as a function of heat rate. Information about higher than design heat rate is of more interest than lower heat rates and will be the first nondesign point data sought.

Recovery factors for lower than design heat fluxes will be determined in two following tests. It is desirable to have data at heat recovery rates above and below the design point to establish the slope of the system performance curves around the design point. This data can then be used to make the system study tradeoffs to optimize the pilot plant configuration.

— ıch of the four off-design vaporizer tests will be preceded by a condenser test. ıe condenser tests will also be off-design performance tests each utilizing the steam trap determined to be the most effective by the previous four condenser tests. Information sought in these tests will be condenser effectiveness versus length, total heat transfer rates and variation of heat rate with condenser temperature and percentage of charge.

BLOCK III TESTS-OPERATIONAL EVALUATION

Five successful operational tests are required to evaluate the SRE performance under operational conditions.

The results from the Block II - Performance Evaluation tests will consist of a set of optimum conditions for best performance. This will include such things as the condenser inlet pressure and temperature range, vaporizer recirculation rate, vaporizer scraper speed and torque level, etc. This optimum set of conditions and parameters will be exercised under various operating scenarios. This will include:

a) A charging pressure/temperature/flow profile similar to that of the Receiver Subsystem during early morning and later afternoon hours

b) A turbine throttle position profile similar to that expected from a central dispatcher designated load profile

c) A charge while discharge sequence typical of the pilot plant

d) Start up, shut down and hold conditions typical of the pilot plant

e) Simulated emergency conditions and associated response times for safe control

An example of item (a) above is shown in Figure 4-22. Receiver steam could be supplied to storage 35 minutes from cold start. The conditions would be 315.56°C (600°F), 3.447 MPa (500 psia) and 10 percent of full flow. This minimum time is based on the fact that no heat will be transferred into the salt until the steam temperature is greater than the salt temperature - 310°C (590°F). The pressure could rise to 12.42 MPa (1800 psia) and maintain 26.67°C (80°F) of superheat. This charging scenario would be the type of test conducted during operational evaluation of the SRE.

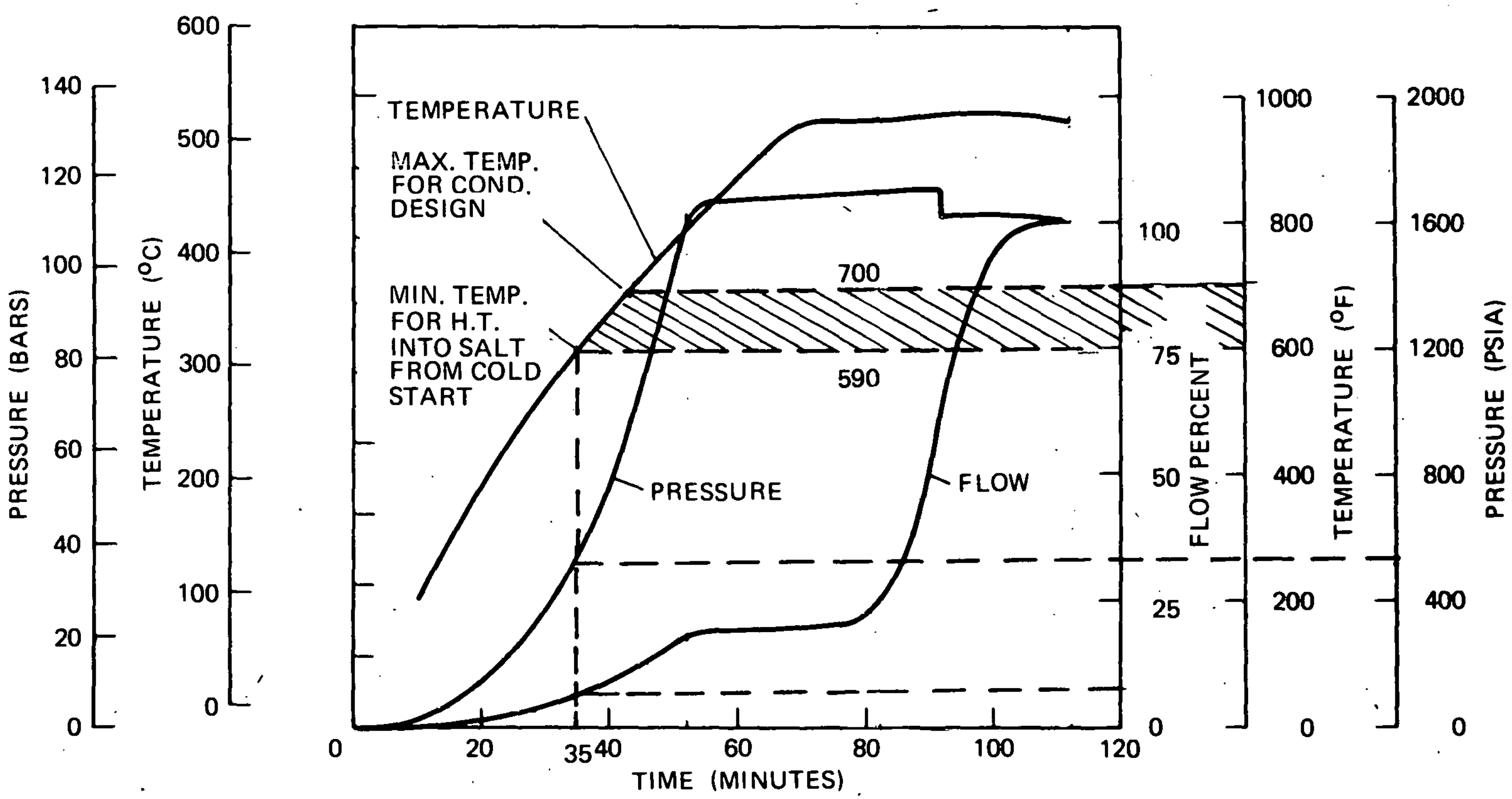


Figure 4-22. Typical Receiver Start Up

40454

Experiment Test and Operation

Expected Test Results

DATA ANALYSIS

The data analysis will be largely done by computer working from data stored on magnetic tape.

The Hewlett Packard 9611 computer system will store all of the data on magnetic disks or tape for future data reduction. The computer system will be programmed with all necessary conversion factors to convert all electronic sensor signals into physical units and to supply real-time data in the form of pressures, temperatures, mass flow rates, enthalpies, heat fluxes, charge status, etc. The system has a real-time plotting capability to permit continuous plotting of the most important variables under test. At the completion of a test, further analysis may be performed at the site or the magnetic tape data can be processed further by another computer system. An error analysis for the system is presented in Appendix F.

The operator will also have some data available from a multipoint recorder which will be used to monitor such functions as salt temperature charge level, steam discharge rate and drum level. These signals will also go to the data recording system for integration into the data package and the overall test results.

DATA PRESENTATION

The experimental data will be presented graphically whenever possible for ease of understanding.

The outline that follows contains a list of the different types of data that is expected to be obtained during the experiment. Some of the graphs are compilations of the results from several experiments, such as the Maximum Percent Discharge versus Discharge Rate.

A. Calculated quantities

1. Vaporizer data

a) Evaporator exit quality
b) Overall heat transfer coefficient
c) Scraper power
d) Percent discharge
e) Salt settling rate
f) Salt build-up thickness per revolution of scrapers

2. Condenser data

a) Heat flux from condenser
b) Percent charged
c) Degrees superheat of entering steam
d) Salt flow rates

B. Graphical Presentation

1. Vaporizer data plots

a) Heat flux versus saturation pressure
b) Heat flux versus scraper speed
c) Heat flux versus percent discharge
d) Heat flux versus exit quality
e) Heat flux versus entrance temperature
f) Scraper torque versus heat flux
g) Scraper torque versus speed
h) Scraper torque versus percent discharge
i) Maximum percent discharge versus discharge rate
j) Scraper power versus heat flux
k) Pressure drop versus recirculation rate
l) Heat rate versus recirculation rate

2. Condenser data plots

a) Heat flux versus saturation pressure
b) Heat flux versus percent charge

c) Heat flux versus type of steam trap
d) Heat flux versus salt freezing history
e) Heat flux versus percent charge while discharging
f) Heat flux versus percent charge after extended settling time
g) Condenser effectiveness versus distance along condenser

3. Salt temperature movement data α discharge

a) Discharge

i) Temperature profiles versus time during discharge

ii) Temperature profiles versus time after a complete discharge

iii) Temperature profiles versus time after a partial discharge

b) Charging

i) Temperature profile versus time while charging immediately following a full discharge

ii) Temperature profiles versus time while charging after an extended settling time

iii) Temperature profiles versus time for various charging rates

c) Charging while discharging

i) Temperature profiles for charge while discharge as a function of charge rate

ii) Temperature profile for charge while discharge as a function of percent charged

Figure 4-23 is sketches of the graphical results that are expected. Each group is numbered corresponding to the outline line number. These graphs illustrate the trends that have been observed in the engineering model tests, predicted by theory or in the case of the steam trap operation represent an educated guess. The scales were intentionally left off from the graphs to ensure that they will not be confused with actual data.

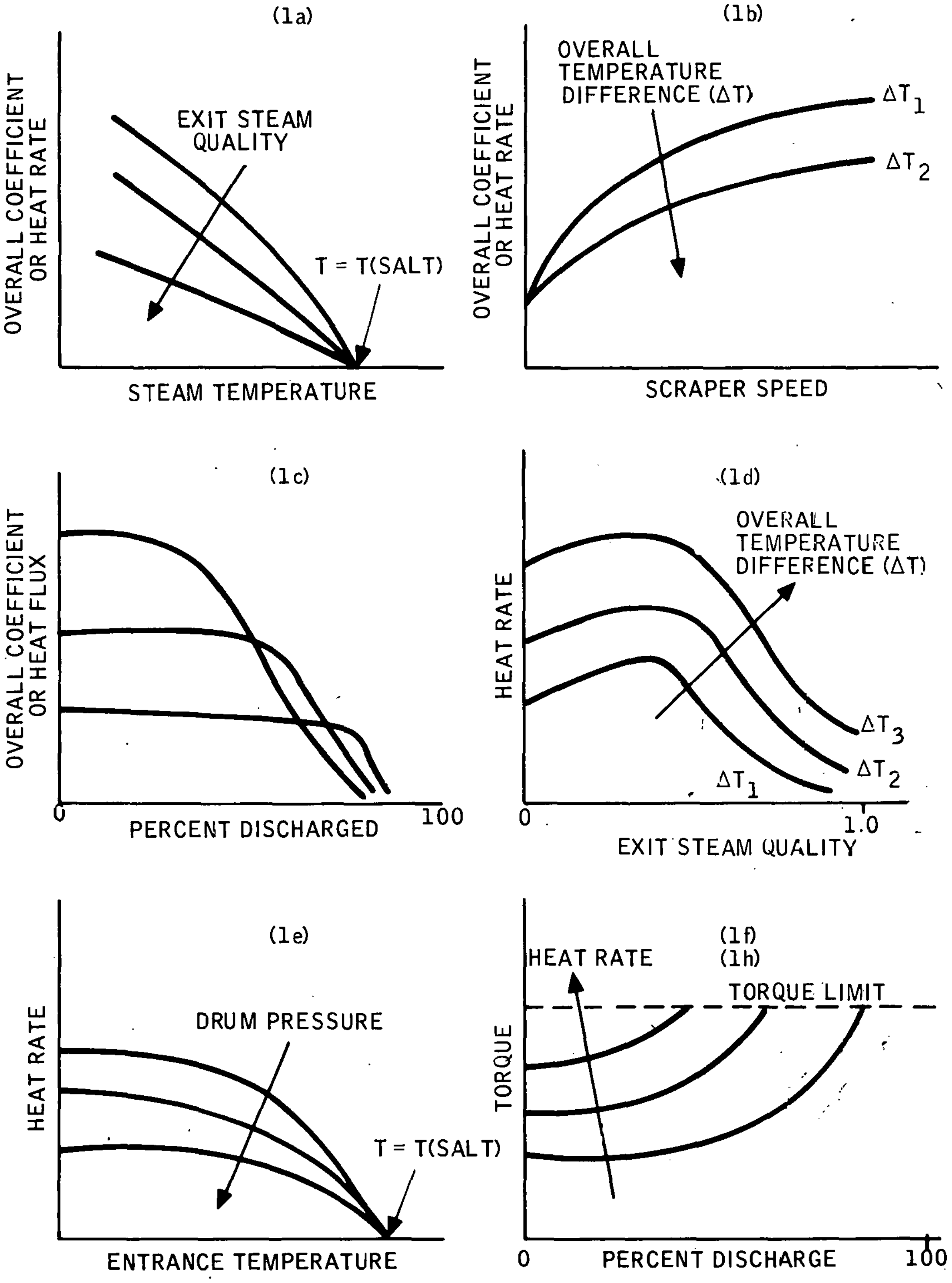


Figure 4-23. Expected Test Results

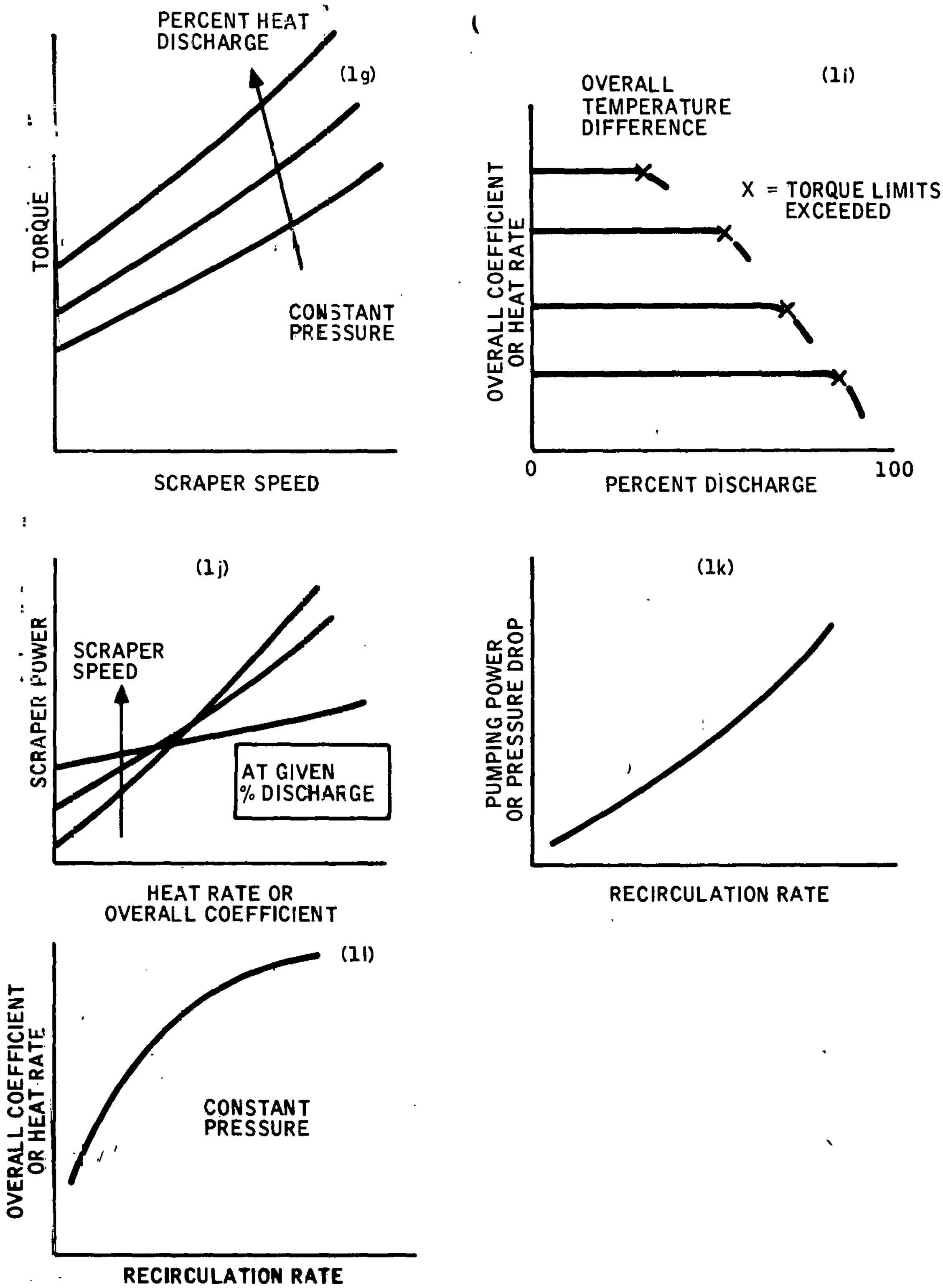


Figure 4-23. Expected Test Results (Continued)

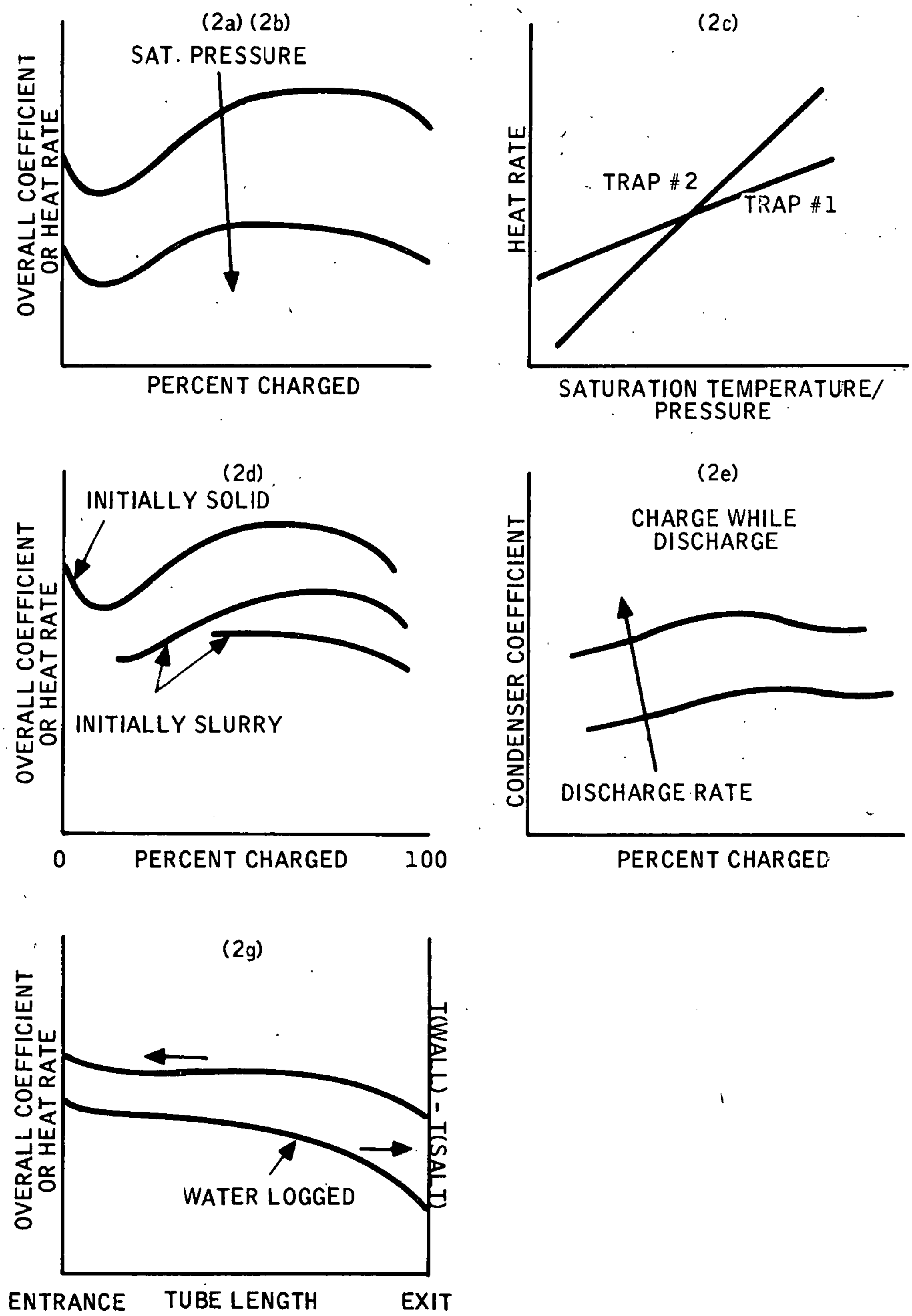


Figure 4-23. Expected Test Results (Concluded)

APPENDIX A

APPENDIX A
DESIGN DOCUMENTATION

Documents used in support of the oral presentation of the Detail Design or otherwise available are listed below:

Specifications

SPEC. NO.	DATE	TITLE	ORGANIZATION
SK 133242	12/12/75	TES/SRE Design Specification	Honeywell
SK 133248	12/12/75	TES/SRE Test Specification	"
SK 140001		Steam Traps	"
SK 133289	5/04/76	TSS/RE Storage Tank	"
SK 140009		TSS/RE Salt Pre-melt	"
SK 133500	5/12/76	TSS/RE Condenser Submodule	"
SK 133291	5/24/76	TSS/RE Vaporizer	"
SK 133288	5/05/76	TSS/RE Steam Drum	"
SK 140010	5/20/76	TSS/RE Recirculation Pump	"
SK 140002	4/26/76	TSS/RE Torque Meters	"
SK 140011	5/27/76	TSS/RE Electric Motors, Speed Controllers and Gear Reducers	"
SK 140012	5/28/76	Procurement Spec. for Phase Change Material	"

THERMAL ENERGY STORAGE (TES)
SUBSYSTEMS RESEARCH EXPERIMENT (SRE)
DESIGN SPECIFICATION

Honeywell

SYSTEMS & RESEARCH CENTER Code Ident No. 27327

SPECIFICATION NO. SK 133242

TYPE: ☐ SYSTEM ☒ DEVELOPMENT ☐ PRODUCT ☐ OTHER

TITLE: THERMAL ENERGY STORAGE (TES) SUBSYSTEMS RESEARCH EXPERIMENT (SRE) DESIGN SPECIFICATION

SIGNATURES		DATE
PREPARED BY		
APPROVED BY PROJECT ENGR.	R. T. LeFrois *R.T. LeFrois*	12/12/75

REVISIONS

LTR	DESCRIPTION	DATE	APPROVAL	LTR	DESCRIPTION	DATE	APPROVAL
A	General Update due to Pilot Plant Design Change	3/9/76	RTL				

PAGE																											
REVISION																											
PAGE																						PAGE OF					
REVISION																											

H5-256

1.0 SCOPE

This specification establishes the design, performance, and test requirements for a Thermal Energy Storage (TES) Subsystem Research Experiment (SRE).

2.0 APPLICABLE DOCUMENTS

The following documents, of the latest issue, form a part of this specification to the extent specified herein. In the event of a conflict between the documents referenced herein and the contents of this specification, then the contents of this specification shall be considered a superseding requirement.

a. Preliminary Design Baseline Report, CDRL No 1., 30 Sept. 1975

b. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code:

SECTION I	Rules for construction of Power Boilers
SECTION II	Material Specifications
SECTION V	Nondestructive Examination
SECTION VIII	Unfired Pressure Vessels
SECTION IX	Welding and Brazing Qualifications

c. American National Standards Institute

B31.1 Power Piping

d. Standards of the American Institute of Steel Construction and American Concrete Institute

e. Interstate Commerce Commission Shipping Standards Regulations

f. Uniform Building Codes

g. Standards for Tubular Exchanger Manufacturers Association, Class R

h. American Petroleum Institute Code 620,650

3.0 REQUIREMENTS

3.1 Thermal Energy Storage Subsystem Research Experiment TES/SRE Definition

The aim of the TES/SRE is to provide the necessary experimental test data

3.1 (Continued)

and operating experience to specify the design of an efficient, economical thermal storage subsystem for the Pilot Plant.

The Thermal Storage Subsystem Research Experiment shall provide a means of transferring thermal energy from a working fluid to a thermal energy storage medium and, subsequently, transferring stored thermal energy to a working fluid in a form suitable for generating electrical power with a conventional turbine/generator. The working fluids in the subsystem research experiment shall be the same as that in Solar Thermal Power System (Pilot Plant). The TES/SRE may consist of:

a) the inlet heat exchanger containing tubing, valves, and fittings required to transfer the thermal energy from the heat transfer fluid into the storage material.

b) the thermal storage tank, including the structure, insulation piping, foundation required for the containment of the phase change material and heat exchange surfaces.

c) the outlet heat exchanger, tanks, drums, pumps, valves, fittings, and tubing required to transfer the stored thermal energy to the working fluid.

d) the pumps, controls, required to safely regulate and direct the fluid flows and instrumentation to measure state and other parameters as necessary to quantify the required test parameters and variables.

The Thermal Storage Subsystem Reasearch Experiment test hardware shall have a thermal storage capacity of not less than 1 MW hours thermal and be capable of scaling to a capacity to provide thermal energy for at least 7 MW(e) net for 6 hours for the Central Receiver Pilot Plant and larger for the commercial power generating system if possible.

3.1.1 Thermal Storage Subsystem Research Experiment Diagram

Figure 1 shows a schematic of the Thermal Storage Subsystem Research Experiment and its interfaces.

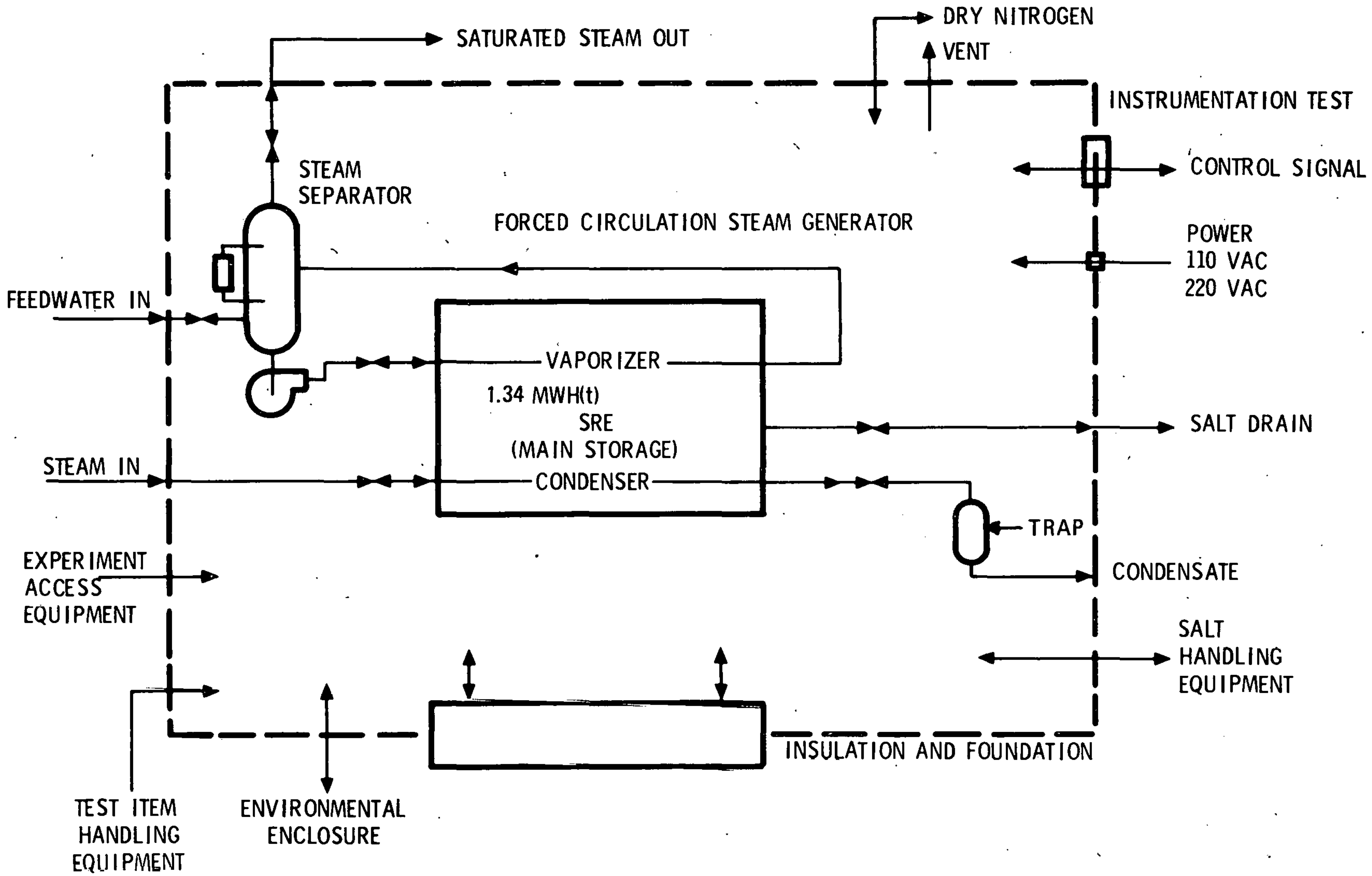
3.1.2 Interface Definition

The physical and functional interface between the Thermal Storage Subsystem Research Experiment and facility or elements thereof are as follows:

3.1.2.1 Fluid

Piping, connections and mounting fixtures shall be provided at the facility at the following fluid interfaces:

STORAGE SRE INTERFACES



40454

3.1.2.1 Fluids (Continued)

a) Entrance and exit of the charging working fluid

b) Entrance and exit of the discharging working fluid

c) Salt drainage

d) Gases used in the operation, including instrument air and gaseous nitrogen.

3.1.2.2 Electrical Power

Electrical power to the test item shall be provided at a junction box within the test enclosure. It shall contain 120 VAC and 240 VAC at TBD and TBD KVA, respectively. This power shall be used to drive test item motors and auxiliary equipments. The auxiliary equipment includes heaters used to melt the phase change materials which require 55 KW power.

3.1.2.3 Instrumentation - Test Data

All test data instrumentation output shall terminate at a patch panel located within the test item enclosure. The instrumentation shall make it possible to measure and record temperatures, pressures, mass flows, heat loss, thermal capacity and other special parameters taken during the test. The instrument accuracies shall permit an overall heat balance to be determined to within ±3%.

3.1.2.4 Instrumentation - Process Data

All process data instrumentation shall terminate at a patch panel located within the test item enclosure. This instrumentation shall insure that the process is properly functioning and shall provide appropriate signals for automatic shutdown of the operation when necessary. This shall include monitoring the inlet and outlet fluid conditions, the ullage pressure, tank drain status, feedwater recirculation rate, and fluid levels.

3.1.2.5 Facility Foundation

A raised pad shall be provided to support a rectangular storage tank with a dead weight load not to exceed 45500 kg and a cold face temperature not to exceed 316°C for its operating life. The tank/foundation interface shall withstand seismic loads corresponding to zone 2 intensity.

3.1.2.6 Environmental Enclosure

An enclosure shall be provided to insure protection from the elements, i.e., snow, wind and rain and provide space conditioning to the storage unit to 18°C ± 8°C during winter operations. The enclosure shall allow for installation and removal of the test unit as well as draining and filling the tank with the phase change material.

3.1.2.7 Support Equipment

Equipment to install, remove or repair the test unit or its components, shall be provided. Equipment shall be provided to insure the safe handling and preparation of the phase change material at the test site. Electric heaters shall be provided to permit the melting of the phase change material in the event of a malfunction. Containers or receivers shall be supplied to permit the tank to be drained in an efficient manner. Special tools and test equipment shall be provided to install, maintain, repair or replace critical storage components and to provide access where required.

3.1.2.8 Thermal Storage Subsystem Experiment Controls/Master Controls

The Thermal Storage Subsystem Research Experiment controls shall be responsive to standard control signals from the master control center or may be remotely manual or manual if adequate safety requirements are met.

3.2 Characteristics

3.2.1 Performance

The Thermal Subsystem Research Experiment test hardware shall have a thermal storage capacity of not less than one Megawatt hour operating and be capable of scaling to a capacity to provide thermal energy for at least 7 MW(3) for 6 hours for the Central Receiver Pilot Plant and larger for the commercial generating system. The working fluid conditions shall be 12.5 MPa saturated steam for charge cycle and the output steam from subsystem experiment shall be saturated steam at 6.7 MPa.

Specific design characteristics of the Thermal Storage Subsystem Research Experiment shall be provided as follows:

a. The Thermal Storage SRE shall be a one to one scale model of the Pilot plant module described in Preliminary Design Baseline (Second Revision), CDRL No. 2. The output from the SRE unit shall be the same as in the Pilot Plant module and be equivalent to 134 KW(t) (179 boiler hp) and coil represent 1/235 of the total power generated by the Pilot Plant Storage Subsystem.

b. The design shall maximize the recovery of useful thermal energy from storage consistent with cost and performance considerations.

3.2.1 Performance (Continued)

c. The design shall provide for the control of the conductive, convective and radiative thermal losses. The allowable losses are 35% of the total storage capacity over a period of 4 days.

d. Instrumentation and controls shall respond to transient conditions rapidly enough to prevent any adverse effects with regard to the safety and operation of the research experiment and the facility interfaces thereof.

e. The design shall provide for the removal of crystallized salt from the outside of the vaporizer tubes. Primary consideration should be given to mechanical techniques. In addition, it may be necessary to "de-ice" the vaporizer tubes during the course of an experiment in an attempt to evaluate various salt removal techniques. Consequently, the design should be capable of supplying facility steam to the vaporizer tubes at a temperature above the eutectic salt temperature.

f. The design shall provide for the salt input of plant steam heat to melt the salt in the storage tank. The salt may be in a granular or crystallized state. When in either of these states a liquid vent, protruding throughout the solid bulk must be insured prior to transferring steam heat at rated conditions.

3.2.2 Physical Characteristics

The Thermal Storage Tank shall be rectangular in shape. The weight of the tank with salt heat exchangers, insulation, cover and attached base support shall not exceed 46,000 kg (101,200 lb.). The outside envelope dimensions, of the insulated tank shall not exceed (3.5 meter) in height, (3.5 meter) in width and (3.5 meter) in length. The base of the tank shall be located sufficiently above local grade to allow gravity drain of the salt. The tank shall be filled with salt from the top. The tank closure must allow for accessibility for salt loading, handling, equipment installation's removal.

3.2.3 Reliability

Consideration shall be given in the data gathering system and operating procedure in the Thermal Storage Subsystem Research Experiment to permit extrapolation of useful reliability data for Pilot Plant Design.

3.2.4 Maintainability

Consideration shall be given in the data gathering system and operating procedures on Thermal Storage Subsystem Research Experiment design to permit extrapolation of useful maintainability for Pilot Plant Design.

3.2.5 Environmental Conditions

The Thermal Storage Subsystem Research Experiment shall be designed to withstand natural environmental conditions expected to be encountered during installation within an environmental enclosure and operation at NSP Riverside plantsite in seismic zone 2. Electrical components shall be protected from electrical disturbances and stray currents.

3,2.6 Transportability

Transportation of all elements of the Thermal Storage Subsystem Research Experiment to the test site shall be subject to all pertinent federal and state transportation regulations. The storage subsystem may be shipped disassembled as required.

3.3 <u>Design and Construction</u>

The Thermal Storage Subsystem Research Experiment shall be designed and constructed in accordance with the applicable ASME and API Codes. Piping shall meet applicable ANSI codes. Structures, facilities and enclosures shall be designed and constructed in accordance with the best engineering practices and the Standards of the American Institute of Steel Construction, American Concrete Institute, Uniform Building Code, and special state codes where applicable.

3.3.1 Materials

The Thermal Storage Subsystem Research Experiment components shall be fabricated from materials as specified in the applicable specifications or codes.

3.3.2 Phase Change Materials

The thermal energy storage medium shall be phase change material, single salt or a mixture of inorganic salts of a particular composition. The material of fabrication shall be compatible to the storage medium with regard corrosion to containment.

3.3.3 Electrical Transients & Grounding

The electrical components of the Thermal Storage Subsystem Research Experiment shall be protected against normal power line and sudden power outages transients and all required elements grounded.

3.3.4 Nameplates

All components, instruments, and controls shall have identifying markings on nameplates which shall be permanently attached to the respective items.

3.3.5 Workmanship

The Thermal Storage Subsystem Research Experiment and all associated items shall be constructed, fabricated and assembled in accordance with the best modern engineering, shop, and field practices, consistent with cost and performance requirements.

3.3.6 Interchangeability

Components, with standard tolerances where available, shall be used to permit interchangeability for servicing. Consideration shall be given to components to permit extrapolation of useful part selection function data to the Pilot Plant Design.

3.3.7 Safety

The Thermal Storage Subsystem Research Experiment shall be designed to minimize safety hazards to operating and service personnel and the public. Electrical components shall be grounded. All parts or components with elevated temperatures shall be insulated against contact with or exposure to personnel. Any moving elements shall be shielded to avoid entanglements and safety override controls shall be provided for servicing. Safe salt handling and mixing equipment shall be used to prevent any direct contact to personnel. All pertinent OSHA rules and regulations shall be observed. Design of the storage tank shall accommodate a rupture causing spillage of the maximum tank salt contents of 27,000 kg (60,000 lb.). The spillage must be contained with a designate area. Design of the storage tank shall also consider rupture of the high pressure water and/or steam tubing causing ullage pressure increase with possible tank failure.

3.3.8 Public Display

It is anticipated that the thermal storage SRE will stimulate considerable public interest and the test facility will be inspected from time to time by the public, public officials and other dignitaries. The test item, facility and immediate area should be designed to meet this scrutiny.

3.4 Documentation

3.4.1 Instructions

Instructions shall cover assembly, installation, alignment, adjustment, checking, lubrication, salt handling and mixing, and maintenance. Operating instructions shall be included for startup, routine and normal operation, regulation and control, shutdown, salt draining, and emergency conditions.

3.4.2 Characteristics and Performance

Equipment functions, normal operating characteristics, limiting conditions, test data, and performance curves, where applicable, shall be provided.

3.4.3 Construction

Engineering and assembly drawings shall be provided to show the equipment construction, including assembly and disassembly procedures. Engineering data, wiring diagrams, and parts list shall be provided.

4.0 QUALITY ASSURANCE PROVISIONS

Verification of conformance to designs and drawings as approved by ERDA at the DDR is required prior to initiation of the subsystem tests.

4.1 Test Program

All tests will be directed by Honeywell Incorporated. These tests may be witnessed by ERDA or its representatives or the witnessing may be waived. In either case, substantive evidence of hardware compliance with all test requirments is required. All tests will be conducted per a formalized test plan and procedure.

4.1.1 Engineering Test and Evaluation

The performance of the instrumentation and control system shall be measured to verify compliance with power level control requirements, cooling requirments, emergency responses, and ability to maintain total system control under variable test conditions.

4.1.1.1 Thermal storage performance shall be tested to demonstrate the effective transfer of heat energy to the storage medium using the working fluid same as that available from the Receiver Subsystem in the Central Receiver Solar Thermal Power System Pilot Plant, to verify the storage of heat energy, and also to demonstrate the generation of steam vapor same as in Pilot Plant.

4.1.1.2 Mechanical integrity shall be verified by subjecting the Thermal Storage Subsystem Research Experiment to simulated operating conditions for various environmental situations.

4.1.1.3 Thermal storage controls will be tested to verify that they respond to standard control signals and function over the full range of operating conditions.

4.1.1.4 Thermal Storage Cycling and Off Design

Capability will be tested to determine the useful life of the phase change material and to insure that the system is capable of responding to the full range of conditions anticipated in the pilot plant operations.

4.1.1.5 Thermal Storage Phase Change Material Safety

It shall be verified that the use of inorganic salts as storage medium is not hazardous.

4.1.2 Preliminary Qualification Tests

Hydrostatic tests of the vessels and tanks shall be accomplished per the applicable code at the manufactures facility or prior delivery to the NSP test facility. Pressure piping tests can be conducted on site. Subsequent to assembly on the test pad pre-operational, tests shall conducted prior to starting the operational testing.

4.1.3 Life tests and Analysis

Results from the tests will be reviewed and conponents requiring life test data and analysis be recommended to ERDA for a specific test program.

4.1.4 Engineering Critical Component Qualification

Components for which reliability data are not available nor estimatible from the test program shall be identified to ERDA for consideration of additional testing.

TEST SPECIFICATION, THERMAL ENERGY STORAGE (TES), SUBSYSTEMS RESEARCH EXPERIMENT (SRE)

Honeywell

SYSTEMS & RESEARCH CENTER Code Ident No. 27327

SPECIFICATION NO. SK 133248

TYPE: ☐ SYSTEM ☒ DEVELOPMENT ☐ PRODUCT ☐ OTHER

TITLE: TEST SPECIFICATION,
THERMAL ENERGY STORAGE (TES)
SUBSYSTEMS RESEARCH EXPERIMENT (SRE)

SIGNATURES	DATE
PREPARED BY	
APPROVED BY PROJECT ENGR. R. T. LeFrois *R. T. LeFrois*	12-12-75

REVISIONS

LTR	DESCRIPTION	DATE	APPROVAL	LTR	DESCRIPTION	DATE	APPROVAL
A	General Update due to Pilot Plant Design Change	3/9/76	RTL				

PAGE																											
REVISION																											
PAGE																							PAGE OF				
REVISION																											

HS-256

Honeywell

SYSTEMS & RESEARCH CENTER Code Ident No. 27327

SPECIFICATION NO. SK 133248

TABLE OF CONTENTS

1.0 PURPOSE

The purpose of this specification is to provide standard test and evaluation procedures for determining the design and performance characteristics of a Thermal Energy Storage (TES) Subsystem Research Experiment (SRE).

2.0 SCOPE

This specification applies in general to thermal energy subsystems and in particular to the latent-heat type storage system described in the reference documents.

This specification is subordinate to the DESIGN SPECIFICATION for the TES/SRE in case of conflicts.

The constraints on this specification are subject to the interface requirements at the test site.

3.0 REFERENCE DOCUMENTS & DEFINITIONS

1. Preliminary Design Baseline Report, CDRL No. 1, 30 September 1975.
2. Thermal Energy Storage (TES) Subsystem Research Experiment (SRE) Design Specification.
3. Method of Testing for Rating Thermal Storage Devices Based on Thermal Performance, NBSIR-74-634, May 1975.
4. ASHRAE Standard 41-66.
5. ANSI Standard C95.1-1964.
6. ASME Performance Test Codes:

Pressure Measurement	PTC 19.2	1964
Temperature Measurement	PTC 19.3	1974
Water & Steam in Power Cycle	PTC 19.11	1970

7. ASME Power Test Codes:

Steam Generating Units	PTC 4.1	1964
	(ANSI PTC 4.1	1974)

3.1 Ambient Air

Ambient air is the air in the space surrounding the thermal energy storage system.

3.2 Cycling

Cycling of a latent-heat type storage device is a process in which the temperature of the system is raised and lowered in a cyclic manner and the phase of the storage medium is changed twice in each temperature cycle.

3.3 Effective Capacity for Heat Removal

The effective capacity for heat removal is the amount of heat that can be removed from the storage system during a period of time.

3.4 Effective Capacity for Heat Storage

The effective capacity for heat storage is the amount of heat that can be stored in the storage system during a period of time.

3.5 Charge/Discharge Time

The fill time is the duration of a single transient test in which energy is either added or extracted from the storage system.

3.6 Heat Loss Coefficient

The heat loss coefficient is the rate that heat is lost from the storage system per degree temperature between the storage medium temperature and the average ambient air temperature.

3.7 Total Storage Capacity

The storage capacity of a thermal energy storage system is defined as the heat that can be stored in a system including the sensible and latent portions.

3.8 Performance Coefficient for Heat Removal

The performance coefficient for heat removal is the ratio of the effective capacity for heat removal to the amount of heat that could be removed from an equal volume of water in an ideal water tank under the same conditions.

3.9 Performance Coefficient for Heat Storage

The performance coefficient for heat storage is the ratio of the effective capacity for heat storage to the amount of heat that could be stored in an equal volume of water in an ideal water tank under the same conditions.

3.10 Standard Air

Standard air is weighing 1.2 kg/m^3 (0.075 lb/ft^3), and is equivalent in density to dry air at a temperature of 21.1°C (70°F) and a barometric pressure of 1.01×10^5 N/M^2 (29.92 in. of Hg.).

3.11 Standard Barometric Pressure

1.01×10^5 N/m^2 (29.92 in. of Hg.).

3.12 Storage Medium

The storage medium is the material in the storage system in which the heat energy is stored.

3.13 Storage System

The storage system is defined as the container(s) plus all contents of the container(s) used for storing thermal energy in a system. The transfer fluid and other accessories such as heat exchangers within the thermal storage container(s) are considered as part of the storage system.

3.14 Specific Heat

The specific heat of a substance is the quantity of energy necessary to produce a unit change in temperature of a unit mass.

3.15 Transfer Fluid

The transfer fluid is the fluid that carries energy in and out of the storage system.

4.0 CLASSIFICATION

In this specification storage systems are classified according to the method they use to store energy and the transfer fluid employed.

Latent-heat storage system are those involving a change of phase of the storage medium. In this type of system, most of the heat added to or removed from the system goes into changing the enthalpy of the storage medium during a change of phase process. Some heat is also stored as sensible heat, since charging and discharging of the storage device usually involves a finite change in the temperature of the system.

Sensible heat storage systems are those in which the heat absorbed by or removed from the system results in an increase or decrease in the temperature of the storage medium and there is no change of phase of any portion of the storage medium. Typical systems employ pressurized water, unpressurized water, rock, brick or concrete as the storage medium.

A storage system will use either a liquid or a gas as the transfer fluid. The most common liquids are water or a water-ethylene glycol solution. The most common gas is air.

The TES/SRE baseline subsystem is a latent-heat system which employs steam as the transfer fluid and an eutectic salt as the storage medium.

5.0 REQUIREMENTS

5.1 Latent-heat type storage systems evaluated under this specification shall have been cycled (see definition of cycling) through their change of phase at least 30 times during testing.

5.2 The transfer fluid used in evaluating the performance of a thermal energy storage system shall have a known property over the temperature range encountered during a test.

5.3 The area where the testing of the storage system is performed shall have its temperature controlled to the extent to be specified.

5.4 Manually recorded data shall be logged in "controlled" data books (Honeywell or equivalent). Control of these records shall be by name and book number.

5.5 Tests shall be logged as to date, run time, objective, etc., and shall be in accordance with a predetermined, detail test plan.

5.6 Data accuracies are subject to the overall accuracy of the TES/SRE DESIGN SPECIFICATION. Accuracy budgets can be adjusted accordingly.

6.0 INSTRUMENTATION

6.1 Temperature Measurements

6.1.1 Temperature measurements shall be made in accordance with ASHRAE Standard 41-66, Part 1 (1) and ASME PTC 19.3 1974.

6.1.2 The temperature difference of the transfer fluid across the thermal storage system shall be measured with:

a. Thermopile (air or liquid as the transfer fluid)

b. Calibrated resistance thermometers connected in two arms of a bridge circuit (only when a liquid is the transfer fluid)

6.1.3 The accuracy and precision of the instruments and their associated readout devices shall be within the limits TBD.

6.1.4 The instruments shall be configured and used in accordance with Section 7.

6.1.5 When thermopiles are used, they shall be constructed in accordance with ANSI Standard C96.1-1964 (R 1969) 2.

6.2 Liquid Flow Measurements

6.2.1 The accuracy of the meter including a calibration, if furnished, shall be equal to or better than ±1.0% of the measured value.

6.3 Recorders and Integrators

6.3.1 Strip chart recorders used shall have an accuracy equal to or better than ±0.5% of the temperature difference and/or voltage measured for each test with the exception of the heat loss rate test. In the test to determine the heat loss rate, the accuracy of the strip chart recorder shall be equal to or better than ±2.0%.

6.3.2 Electronic integrators used shall have an accuracy equal to or better than ±1.0% of the measured value ofr each test with the exception of the heat loss rate test. In the test to determine the heat loss rate, the accuracy of the electronic integrator shall be equal to or better than ±4.0%.

6.4 Pressure Measurements

6.4.1 The pressure measurement shall be made with instruments that shall permit measurements of pressure to within ±2.0% absolute and whose smallest scale division shall not exceed 2 1/2 times the specified accuracy.

6.4.2 The static pressure drop across the thermal storage system shall be measured with an accuracy of 25 N/m^2 (0.1 in. of water).

6.5 Time and Mass Measurements

Time measurements and mass measurements shall be made to an accuracy of ±0.20%.

7.0 TEST PROGRAM

All tests will be directed by Honeywell Incorporated. These tests may be witnessed by ERDA or its representatives or the witnessing may be waived. In either case, substantive evidence of hardware compliance with all test requirements is required. All tests will be conducted per a formalized test plan and procedure to be established under a separate cover.

Thermal storage performance shall be tested to demonstrate the effective transfer of heat energy to the storage medium using a working fluid the same as that available from the Receiver Subsystem in the Central Receiver Solar Thermal Power System Pilot Plant, to verify the storage of heat energy, and also to demonstrate the generation of steam vapor comparable as in Pilot Plant, Unit Cell. For this purpose the test program shall include the tests indicated below.

7.1 Performance Tests

7.1.1 Charge Mode

The storage subsystem shall be configured so that no discharge steam flow occurs. In this configurations, by design, only heat is transferred into storage. Transmit response data will be obtained for this mode of operation.

7.1.2 Discharge Mode

The storage subsystem shall be configured so that no charge flow occurs. In this configuration, by design, only heat is transferred out of storage. Transient response data will be obtained for this mode of operation.

7.1.3 Storage Mode

The storage subsystem shall be configured so that neither charge or discharge flows occur. In this configuration only heat is lost through the walls of the subsystem.

7.1.4 Charge/Discharge Mode

The storage subsystem shall be configured so that charge and discharge flows occur simultaneously. In this configuration heat flows into and out of storage. The net heat flux is a controlled test variable and independent upon pilot plant duty cycle simulations.

7.2 <u>Critical Function Tests</u>

The subsystem shall be subjected to test conditions which simulate a malfunctioning subsystem. These tests shall include, but not be limited to the following:

7.2.1 Over Temperature

7.2.2 Over Pressure

7.2.3 Ruptured Components

7.2.4 Adverse Liquid/Solid Levels

7.2.5 Component Hazards

- o Chemical
- o Mechanical
- o Pneumatic

7.3 <u>Preliminary Qualification Tests</u>

It is desirable that preliminary tests be conducted as soon as practical to confirm, or better define, any characteristics of the thermal storage subsystem experiment which involve unusual materials or unconventional applications.

8.0 TEST PROCEDURE AND CALCULATIONS

8.1 Procedures

Alternate procedures are available for evaluating thermal storage devices. The following are listed as alternatives to be considered in establishing a detail test plan for the TES/SRE. Subsequent tests shall be in accordance with the Detail Test Plan to be established under a separate cover.

The method that has been commonly employed in testing of water storage tanks is to cause the transfer fluid entering the storage device to undergo a step change in temperature and to measure the temperature of the transfer fluid leaving the storage unit. By integrating the difference in temperature between the inlet and outlet over the testing period and multiplying the result by the transfer fluids' mass flow rate and specific heat, one can determine the amount of heat added or removed during this time period. The area under the curve represents the energy absorbed during the time period shown. If the time period chosen for the test were some characteristic time depending upon the size of the storage device chosen, the heat storage capability of different devices could be compared.

A second method that could be employed would be to subject the transfer fluid entering the storage unit to a constant influx of heat, Q. This would result in raising the temperature of the entering transfer fluid (assuming the specific heat of the transfer fluid is constant) by a fixed number of degrees above the outlet temperature. By measuring the time dependent outlet temperature one could obtain information that would be useful in designing collector-storage systems. While this method simulates more closely the real interaction between a collector and a storage device, it has the disadvantage that one cannot measure the energy storage and removal capability of the unit. This is due to the fact that if one measured the heat absorbed by the storage unit over a period of time, it would just be equal to $\dot{Q}$ x the test period of the amount of energy added to the system. Thus the only way of comparing different storage devices would be to compare plots of outlet temperature versus time for different values of Q chosen so as to take into account the different sizes of the storage units being compared. The storage device with the lowest average outlet temperature would probably be considered best because this would tend to maximize the efficiency of a collector.

A third method would be to use a time varying Q and to measure the outlet temperature as a function of time during the testing period. This would allow one to simulate the output of a collector over one or more days and to determine the response of the storage device. If the time dependence of Q resulted in an oscillating inlet temperature, one would also be able to look at the degree of stratification attained in the storage unit. This method has the same disadvantage as the second method in that it would be very difficult to compare the performance of different storage

8.1 Procedures (Continued)

devices. In addition, one has the problem of deciding on what is the typical cycle for $\dot{Q}$; not an easy task when one considers that the output of the collector depends not only on the weather but on the particular storage unit employed. The major advantage of this method would be that by inserting an array of thermocouples in the storage medium, the experimenter could measure the temperature stratification in the unit.

Of the three types the first method is the most advantageous because:

a) it permits the determination of effective storage capacity and thus allows an easy comparison of different types of storage units,

b) it appears to be the most fundamental approach since linear theory shows that the outlet temperature response to a constant or variable heat flux $\dot{Q}$ can be predicted if one knows how the outlet temperature changes with a step change in inlet temperature.

The procedure selected for this application shall be based upon the heat and mass balance equations established for the test subsystem, and shall be tailored to the final subsystem mechanizations.

Detailed procedures for conducting the various tests described in SECTION 7 shall be established in conjunction with the Detail Test Plan.

8.2 Test Specs

The SRE tests shall include evaluation of the following items:

a) Vaporiser Scraping technique and start up performance.

b) Procedures for evaluation of the performance of condensation inside horizontal pipes, by measurements of pressure drops and heat transfers coefficients under design and off-design conditions.

c) To determine the validity of salt liquid level measurement to determine energy stored.

d) Off-design performance of the Storage System.

8.3 Calculations

The calculations will include those necessary to establish the static and dynamic performance characteristic of the storage subsystem. These are determined by the heat and mass balance equations of the system. The desired performance characteristics include but are not limited to storage capacity, effective capacities for heat storage and heat removal, charge and discharge time constants.

8.3 Calculations (Continued)

The data reduction techniques will be established with the appropriate design personnel to minimize test turn around time. The approach of Reference 3 will be considered as a baseline.

9.0 DATA & TEST REPORT

Test data to be obtained shall be in accordance with a predetermined data list. The data shall include test date, relative ambient air conditions, observer names, temperatures, pressures, flow rates, etc., as required for determining the performance characteristics of the test item, as well as the identification necessary to identify test components such as manufacturer's name, serial number, and model number.

10.0 NOMENCLATURE - TBD

11.1 REFERENCES - TBD

Honeywell Interoffice Correspondence

Date: May 3, 1976

To: R. Larson, MS H2610
Phone 542-6971

From: R. T. LeFrois,MS R2301
Energy Resources Center, 2700 Ridgway Parkway. Phone 378-5083

Location: SRC/UES (ERC)

Subject: PROCUREMENT SPECIFICATION - REQUEST FOR QUOTATION

Attached is a procurement specification, SPP No. SK 140001, for two steam traps to be used on the Solar Pilot Plant (SPP) Thermal Storage Research Experiment (SRE). Two vendors who should be given requests for bids are:

1) Mark Evans
Blesi-Evans Company
2533 24th Avenue So.
Minneapolis, MN 55406
Representative for Armstrong Machine Works

2) Al Funes
R.B. Whitacre & Co. Inc.
105 State Street
St. Paul, MN 55101
Representative for Yarway Corporation.

R. Le Frois
GK:cd
Enclosure.

81-3388-128

SPP No SK 140001
Date April 26, 1976

Honeywell
Procurement Specification
For
Steam Traps

Prepared By | Thermal Storage Subsystem | Solar Pilot Program Manager

Honeywell Inc
ERC
2700 Ridgway Parkway
Minneapolis, Minnesota 55413

Revision Page

Date	Revision	Date	Revision

SPP NO SK 140001
Date April 26, 1976

STEAM TRAPS

TECHNICAL REQUIREMENTS. Two high pressure steam traps as specified herein shall be supplied.

Code Requirements. The steam traps shall be designed and constructed in accordance with the latest applicable requirements of the Power Piping Code, ANSI B31.1.

Type. One trap will be of the mechanical bucket type. The second trap shall be of the thermodynamic type.

Design Criteria. Each steam trap must meet the following steam inlet and outlet steam conditions.

(a) Condensate Inlet

Maximum	1800 psia	(621 $^{\circ}$F)
Design (1)	1780 psia	(620 $^{\circ}$F)
Minimum	1200 psia	(567 $^{\circ}$F)

(b) Condensate Flow Rate

Maximum (1)	1800 lb/hr
Design	908 lb/hr
Minimum	90 lb/hr

(c) Discharge Pressure

Maximum	300 psi
Design	200 psi

(1) NOTE: The traps will be required to pass the maximum flow rate at the maximum pressure, but not necessarily at the minimum pressure.

The steam traps should have a capacity factor of safety of three over the design conditions.

Construction. The trap shall be provided as a complete working unit with 3/4 inch nominal pipe size, class 1500, raised face flange fittings attached or provisions made for welding flanges to the trap. The bucket trap should be provided with a check valve on the inlet line.

Pricing. A lump sum price should be quoted for each trap individually. The price shall include delivery to Honeywell Inc. Energy Resource Center, 2700 Ridgway Parkway, Minneapolis, Minnesota 55413.

Delivery Date. The trap or traps must be delivered to Honeywell no later than September 30, 1976.

Honeywell

SYSTEMS & RESEARCH CENTER Code Ident No. 27327

HONEYWELL REQUIREMENTS SPECIFICATION NO. **HRS** SK 133289

THIS HONEYWELL REQUIREMENTS SPECIFICATION IS FOR:

Thermal Storage Subsystem Research Experiment; Storage Tank

	SIGNATURES	DATE
PREPARED BY John A. Kallevig	[signature]	4-26-76
APPROVED BY PROJECT ENGR. Richard LeFrois	[signature]	4-28-76
J.C. Powell	[signature]	5/4/76

REVISIONS

LTR	DESCRIPTION	DATE	APPROVAL	LTR	DESCRIPTION	DATE	APPROVAL

PAGE																											
REVISION																											
PAGE																											
REVISION																											

1.0 SCOPE

1.1 General

a) This specification covers material, design, fabrication and testing requirements for the Thermal Energy Storage (TES) Subsystems Research Experiment (SRE) storage tank. This will consist of a non-sealed top welded steel storage tank. The internal pressure in this tank shall be approximately atmospheric with the only pressure occurring due to the static head of the material in the tank and pressure buildup due to steamline failure. This should not exceed 2 PSIG.

b) The purpose of this specification is to provide a storage tank of adequate safety and reasonable economy for the storage of heated salts.

1.2 Compliance

The manufacturer is responsible for complying with all of the provisions of this specification. The purchaser may make any investigation necessary to satisfy himself or compliance of the manufacturer, and he may reject any material that does not comply with this specification.

2.0 APPLICABLE DOCUMENTS

The following documents of the latest issue form a part of this specification to the extent specified herein. In the event of a conflict between the documents referenced herein and the content of this specification, then the contents of this specification shall be considered a superceeding requirement:

ASTM A283 Specification for steel plates

ASTM A570 Specification for steel sheet

ASTM A233 Specification for mild steel arc welding electrodes

ASTM A36 Specification for structural steel

ASTM A131 Specification for structural steel for ships

API 620 and 650

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

ASTM A20 Standard Specification for General Requirements for Delivery of Steel Plates for Pressure Vessels.

ASME Boiler and pressure vessel code SECT IX welding qualifications

All applicable Local, State, Federal and Insurance Rules, Regulations and Codes

Any other documents normally necessary for the assurance of device adequacy, safety of personnel and property

Drawing SK 133289 Thermal Storage Tank

3.0 REQUIREMENTS

3.1.1 Function Characteristics

The thermal storage tank shall have the following functional characteristics:

Inside Dimensions: 8.4 ft x 8.4 ft x 8.3 ft high

Material: Sides ½" thick CS-SA 283B Steel or equivalent
Bottom 5/8" thick CS-SA 283B Steel or equivalent

Supports: 5-8" x 23 lb./ft I Beams equally spaced

Tank Wall Stiffeners: 5-8" x 18.4 lb./ft I beams welded together at the corners and welded to the side of the tank. The top one will be flush with the top of the side plates and the other four equally spaced 20" apart center line to center line.

Pressure: 10.3 PSIG at the bottom

Temperature: 650°F

The inside shall be smooth and free of bumps, holes and crevices. The tank shall have a 1½" drain out of the bottom as shown in drawing SK 133289. It shall include a 1½" gate valve capable of operating continuously at 600°F.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

3.1.2.1 Engineering Documentation

Drawing SK 133289

3.1.3 Operability

3.1.3.1 Environment

The thermal storage tank shall operate with 7.25 ft of molten salt at an average temperature of approximately 600°F.

3.1.3.2 Safety

The thermal storage tank shall be designed to contain molten salts at 600°F without leaking or bulging so as to cause permanent deformation.

3.2 Design and Construction Standards

3.2.1 Material

3.2.1.1 Plates

a) Plates purchased shall conform to the latest edition of one of the following specifications, subject to the modifications and limitations indicated in this standard. Material produced to specifications other than those listed in this paragraph may be employed provided the material is certified to meet all the requirements of a material specification listed herein and its use is approved by the purchaser.

ASTM* Standards

A283: Low and Intermediate Tensile Strength Carbon Steel Plates of Structural Quality - grades C and D only (Maximum plate thickness: grade C = 1½in.; grade D = 3/4in.)

b) The manufacturer shall state in his proposal the plate specification which he intends to use. The plate used shall be inspected for surface imperfections per ASTM A20-68 Section 7. Quality. If the supplier prefers he may substitute A285 steel which is also covered by this standard.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

c) All plates shall be manufactured by the open-hearth, electric-furnace, or basic oxygen processes only. Copper-bearing steel shall be used if specified by the purchaser.

d) Plate specification on an edge-thickness basis is required for all shell plates, the thicknesses of which are determined by design computations. Shell plates for which minimum thicknesses have been computed may be purchased on a weight basis, provided they are ordered sufficiently heavier than the nominal weight corresponding to the specified minimum thickness to insure that plates furnished by the mill will not underrun the computed thickness by more than 0.01 in. Shell plates for which minimum thicknesses have been fixed for practical reasons (greater than required by computation) and which will not underrun the required computed thickness by more than 0.01 in., as well as all roof and bottom plates, may be purchased on a weight basis. The plate thicknesses or weights, as stipulated herein, are minimum; thicker or heavier material may be required on the order at the option of the purchaser.

3.2.1.2 Sheets

Sheets shall conform to the latest revision of ASTM A570, grade C, open-hearth process and basic oxygen process. Copper-bearing steel shall be used if so specified on the purchase order. Sheets may be ordered on a weight or thickness basis, at the option of the tank manufacturer.

3.2.1.3 Welding Electrodes

Manual arc-welding electrodes shall conform to the E60 and E70 series of Classification (suitable for the electric current characteristics, the position of welding, and other conditions of intended use) in the latest edition of ASTM A233: Specification for Mild Steel Arc-Welding Electrodes.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

3.2.1.4 Structural Shapes

Structural shapes shall be of open-hearth, electric-furnace, or basic oxygen process and shall conform to the latest edition of one of the following specifications:

ASTM Standards

A36: Structural Steel

A131: Structural Steel for ships

3.2.2 Design

3.2.2.1 Joint Design

3.2.2.1.1 Definitions

The following definitions shall apply to tank joint designs:

1. Double-welded butt joint: A joint between two abutting parts lying in approximately the same plane and welded from both sides.

2. Double-welded lap joint: A joint between two overlapping members in which the overlapped edges of both members are welded with fillet welds.

3. Butt weld: A weld placed in a groove between two abutting members. Grooves may be square, V (single or double), or U (single or double), and may be either single or double-beveled.

4. Fillet weld: A weld of approximately triangular cross-section joining two surfaces approximately at right angles to each other, as in a lap joint, tee joint or corner joint.

5. Full-fillet weld: A fillet weld whose size is equal to the thickness of the thinner member joined.

6. Tack weld: A weld made to hold parts of a weld-ment in proper alignment until the final welds are made.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

3.2.2.2 Size of Weld

The size of a weld shall be based on the following dimensions:

a) Groove weld: The joint penetration (depth of chamfering plus the root penetration when specified).

b) Fillet weld: For equal-leg fillet welds, the leg length of the largest isosceles right triangle which can be inscribed within the fillet weld cross-section. For unequal-leg fillet welds, the leg lengths of the largest right triangle which can be inscribed within the fillet weld cross-section.

3.2.2.3 Joint Restrictions

The following restrictions on type and size of joints or welds shall apply:

a) Tack welds may not be considered as having any strength value in the finished structure.

b) The minimum size of fillet welds shall be as follows: plates 3/16 in. thick, full-fillet welds; plates over 3/16 in. thick, not less than one-third the thickness of the thinner plate at the joint, with a minimum of 3/16 in.

c) Single-welded lap joints are not permissible.

d) Lap-welded joints, as tack-welded, shall be lapped not less than five times the nominal thickness of the thinner plate joined; but in case of double-welded lap joints the lap need not exceed 2 in.

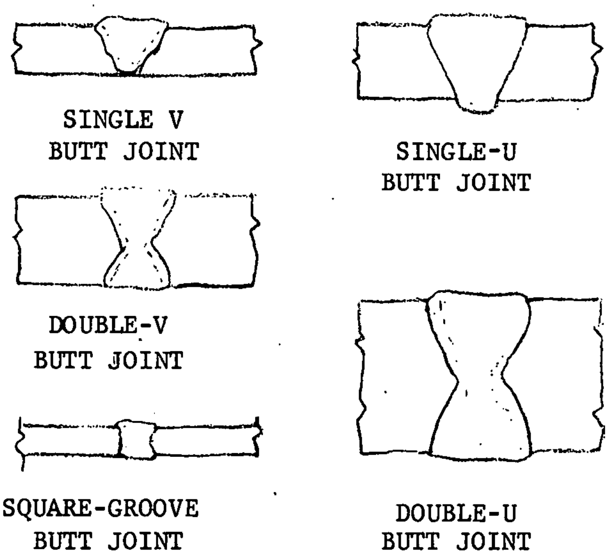
3.2.2.4 Welding Symbols

Welding symbols used on drawings shall be those of the American Welding Society.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

3.2.2.5 Typical Joints

Typical tank joints are shown in Fig. 3-1, 3-2, and 3-3.



Note: See Par. 3.3.5 for specific requirements on vertical shell joints

Fig. 3.1 Typical Joints in Tank

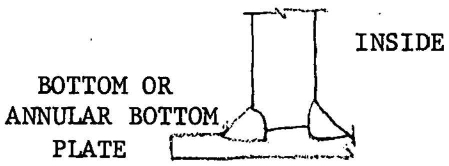


Fig. 3.3 BOTTOM-TO-SHELL JOINT

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

3.2.3 Plate Sizes

Bottom plates shall be ordered of sufficient size so that when trimmed, at least a 1-in. width will project beyond the outside edge of the weld attaching the bottom to the shell plate.

3.2.4 Methods of Construction

The corner of the tank may be formed by either bending a large sheet to form two or more sides or by welding two (2) sheets together at the corner. Care should be taken to make the inside of the corner smooth so that salt deposits will not build up in them and to facilitate thorough cleaning of the tank.

When splicing two plates butt-welding joints are preferred. Butt-welded plates shall have the paralell edges prepared for butt welding with either square on V-grooves. If square grooves are employed, the root opening shall be not less than ¼ in.

3.2.5 Side to Bottom Attachment

The attachment between the bottom edges of the lowest course shell plate shall be a continuous fillet weld laid on each side of the shell plate. The size of each weld shall be not greater than ½ in. and not less than the nominal thickness of the thinner of the two plates joined (i.e. the shell plate or the bottom plate immediately under the shell), nor less than the following values:

Max. Thickness of Shell Plate (Inches)	Min. Size of Fillet Weld (Inches)
3/16	3/16
Over 3/16 to 3/4	¼
Over 3/4 to 1¼	5/16
Over 1¼ to 1½	3/8

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

Note: Refer to Sect. 3.2.2.1 "Joint Design", for description of, and information and certain restrictions on, the foregoing types of joints. Refer to Sect. 3.4.1 for details of welding.

3.2.6 Joints

Joints between two plates in the same plane shall be butt joints with complete penetration and complete fusion as obtained by double welding on by other means which will obtain the same quality of depositor weld metal on the inside and outside weld surfaced to agree with the requirements of Par. 3.4.1 and 3.4.1.3. The remainder of the joints shall conform to the applicable requirements as follows:

a) Joints between two plates at a corner shall be corner welds with complete fusion with the base metal over the required depth of weld. The suitability of plate preparation and welding procedure shall be determined in accordance with Section 4.2.1.2.

b) Single-beveled butt joints, including the stiffness-to-shell joints, shall have complete penetration and complete fusion.

c) Square-groove and double-beveled joints, if the thickness of either plate is 3/8 in. or less, shall have complete penetration and complete fusion.

d) Square-groove and double-beveled joints, if the thicknesses of both plates are greater than 3/8 in., shall have at least two-thirds penetration. Any lack of penetration or fusion plus any undercutting (see Par.3.4.1.1(d) regarding undercutting) shall not exceed one-third of the thickness of the thinner plate, and the zone lacking penetration or fusion shall be located substantially at the center of the thinner plate.

3.2.7 Stiffener Attachment

The stiffeners around the sides of the tank shall be welded to the tank as follows: The top and bottom stiffeners shall be continuously welded to the tank sides, both top and bottom. The second stiffener from the bottom shall be welded 6" out of every foot both top and bottom. The other two stiffeners shall be welded 3" out of every foot, both top and bottom. At the corners all stiffeners shall be beveled 45° and welded to each other so that each stiffener forms a rigid frame. All welds

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

shall have complete penetration and complete fusion.

3.2.8 Cross Support Beam Attachment

The cross support beams shall be welded to the bottom of the tank by fillet welds on either side of the beam. These welds shall be at least 2" long per side per foot. The beams shall extend at least 8" beyond each side of the tank.

3.2.9 Weld Requirements

Continuous welds shall be used for all joints which because of their location, may be subjected to corrosion from entrapped moisture or which may cause rust markings on the tank shell.

3.3 Fabrication

3.3.1 General

3.3.1.1 Workmanship

a) All work of fabricating this thermal storage tank shall be done in accordance with the permissible alternatives specified in the inquiry or order form. The workmanship and finish shall be first class in every respect and subject to the closest inspection by the manufacturer's inspector whether or not the purchaser waives any part of the inspection.

b) When material requires straightening, the work shall be done by pressing or other noninjurious method prior to any layout or shaping. Heating or hammering is not permissible unless the material is heated to a forging temperature.

3.3.1.2 Finish of Plate Edges

The edges of plates may be sheared, machined, chipped, or machine oxygen cut. Shearing shall be limited to 3/8-in. thickness of plates for butt-welded joints and to 5/8-in. thickness for lap-welded joints. When edges of plates are oxygen cut, the resulting surface shall be uniform and smooth and shall be freed of scale and slag accumulations before welding. After wire-brushing cut or sheared edges, the fine

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

film of rust which adheres to the edges need not be removed before welding. Circumferential edges of roof and bottom plates may be manually oxygen cut.

3.3.2 Shop Inspection

a) The purchaser's inspector shall be permitted free entry to all parts of the manufacturer's plant concerned with the contract whenever any work under the contract is being performed. The manufacturer shall afford the purchaser's inspector, free of cost to the purchaser, all reasonable facilities to assure him that the material is being furnished in accordance with this specification. The manufacturer also shall furnish, free of cost to the purchaser, any samples or specimens of materials for the purpose of wualifying welders in accordance with Sect. 7.3. Inspection shall be made at the place of manufacture prior to shipment, unless otherwise specified. The manufacturer shall give the purchaser ample notice as to when fabrication will begin so that the purchaser's inspector may be present when required. The usual mill test of plates shall be deemed sufficient to prove the quality of the steel furnished (except as noted in the following paragraph). Mill test reports shall be furnished to the purchaser when requested.

b) Mill and shop inspection shall not release the manufacturer from responsibility for replacing any defective material and for repairing any defective workmanship that may be discovered in the field.

c) Any material or workmanship which in any way fails to meet the requirements of this specification will be rejected by the purchaser's inspector, and the material involved shall not be used under the contract. Material which shows injurious defects subsequent to its acceptance at the mill, subsequent to its acceptance at the manufacturer's works, or during erection and test of the tank will be rejected. The manufacturer will be notified to this effect in writing and will be required to furnish new material promptly and make the necessary replacements or make suitable repairs.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

3.4 Erection

3.4.1 Details of Welding

3.4.1.1 General

a) Tanks and their structural attachments shall be welded by the shielded metal-arc, the gas metal-arc, the flux-cored-arc, or the submerged-arc process, using suitable equipment. Welding may be performed manually, automatically, or semiautomatically according to procedures described in, and by welders and welding operators qualified under, Part 4.2 "Welding Procedure and Welder Qualifications." Welding shall be performed in such a manner as to insure complete fusion with the base metal within the limits required by the applicable paragraphs and illustrations.

b) Welding shall not be performed when the surfaces of the parts to be welded are wet from rain, snow, or ice; when rain or snow is falling on such surfaces; nor during periods of high winds unless the welder and the work are properly shielded. Welding shall not be performed when the base metal temperature is less than 0 F. When the base metal temperature is within the range of 0 F to 32 F, inclusive, or the thickness is in excess of 1¼ in., the base metal within 3 in. of the place where welding is to be started shall be heated to a temperature warm to the hand.

c) Each layer of weld metal or multilayer welding shall be cleaned of slag and other deposits before applying the next layer.

d) The edges of all welds shall merge with the surface of the plate without a sharp angle. There shall be no undercutting of the base metal, except that on horizontal butt joints undercutting not to exceed 1/32 in. in depth is permissible, subject to the restrictions of Par. 3.3.5.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

e) The weld metal on both sides of all butt joints, except the offset faces of horizontal joints, shall be built up in the form of a reinforcement so that all of the finished face in the area of fusion shall extend above the surface of the adjoining plates, preferably not more than 1/16 in.

f) During the welding operation, plates shall be held in close contact at all lap joints.

g) The method proposed by the manufacturer to hold the plates in position for welding shall be submitted for approval to the purchaser's inspector, if such approval has not already been given in writing by the purchaser.

h) Tack welds used in the assembly of vertical joints of tank shells shall be removed and shall not remain in the finished joint when the joints are welded manually. When such joints are welded by the submerged-arc process, the tack welds shall be thoroughly cleaned of all welding slag but need not be removed provided they are sound and are thoroughly fused into the subsequently deposited weld metal. Tack welds in the bottom, roof, and circumferential joints of the tank shell need not be removed provided they are sound and the subsequently applied weld beads are thoroughly fused into the tack welds.

i) If protective coatings are to be used on surfaces to be welded, they shall be included in welding procedure qualification tests for the brand formulation and maximum thickness of coating to be applied.

3.4.1.2 Bottoms

a) After being laid out and tacked, the bottom plates, unless otherwise specified, shall be joined by welding the joints in a sequence that the manufacturer has found to result in the least distortion from shrinkage and to thus provide, as nearly as possible, a plane surface.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

b) It is recommended that the sequence or order of welding the seams joining the bottom plates be specified by the manufacturer on approval plans so that the purchaser may object if he so desires. However, the manufacturer should follow a practice that will produce the minimum inequalities in the bottom-plate surface when the tank is completed.

c) The welding of shell to bottom shall be practically completed before starting the completion of welding of bottom joints which may have been left open to compensate for shrinkage of any welds previously made.

d) Shell plates may be aligned by metal clips attached to the bottom plates, and the shell may tackwelded to the bottom before continuous welding is started between the bottom edge of the shell plate and the bottom plates.

3.4.1.3 Tank Shells

a) Plates to be joined by butt welding shall be matched accurately and retained in position during the welding operation. Misalignment in completed vertical joints shall not exceed 10 percent of the plate thickness, or 1/16 in., whichever is larger.

b) In completed horizontal butt joints, the upper plate shall not project beyond the face of the lower plate at any point by more than 20 percent of the thickness of the upper plate, with a maximum of 1/8 in., except that a projection of 1/16 in. is permissible for upper plates less than 5/16 in. thick.

c) The reverse side of double-welded butt joints, as well as portions of horizontal joints specified to have complete penetration and fusion, shall be thoroughly cleaned in a manner that will leave the exposed surface satisfactory for fusion of the weld metal to be added, prior to the application of the first bead to the second side. This cleaning may be done by chipping, grinding, melting out, or, where the back of the initial bead is smooth and free from crevices which might entrap slag, by other methods which may upon field inspection be acceptable to the purchaser. In the case

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

of submerged-arc welds, the cleaning shall conform to the requirements established in Welding Qualifications Sect. IX of ASME Boiler and Pressure Vessel Code.

4.0 Quality Assurance

4.1 Inspection, Testing, and Repairs

4.1.1 Weld Inspection

Inspections of all welds shall be made by visual examination. Where visual inspection by the purchaser's inspector indicates unsatisfactory welds, acceptance or rejection shall be based on sectioning such areas by chipping with a mechanical round nose chipping tool.

4.1.2 Testing Tank

Upon completion of the entire tank and before acceptance by the purchaser, the tank shall be tested as follows:

a) A cover shall be fabricated out of ½ in. steel plate with an overhang of 5" all around the top of the tank.

b) Connect a pipe to the tank drain outlet and pipe it vertically to a point 24 ft. above the bottom of the tank.

c) Fill the tank with water.

d) Install a ¼" thick rubber gasket on the top surface of the tank.

e) Place the cover over the top of the tank, use care to ensure that that the gasket is properly placed between the tank and the cover.

f) Place 5-8" 23 lb/ft I beams on the cover. The two outside I beams should be placed 1" from the inside of the tank, the other 3 should be equally spaced across the top of the tank.

g) Weld the ends of the rods for 10-3/4" turnbuckles to the ends of the 5 upper I beams and the five lower I beams.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

h) Use "C" clamps between the cover and the web of the I beam to clamp the cover down. The "C" clamp should be installed at least one per foot on the side parallel to the I beams and at least one in between each pair of I beams on the other two sides as needed to tightly seal the cover.

i) Fill the 24 ft. standpipe with water.

j) Inspect the tank for leaks or damage due to excessive bulging or any permanent deformation.

k) The supplier shall keep permanent record of the mill stamp on each steel sheet and stiffener used in constructing the tank. A copy of this information shall be forwarded to the engineer upon delivery of the tank.

4.1.3 Repairs

a) All defects found in welds shall be called to the attention of the purchaser's inspector and his approval shall be obtained before they are repaired. All completed repairs shall be subject to the approval of the purchaser's inspector.

b) Pinhole leaks or porosity in tank-bottom joints may be repaired by applying an additional weld bead over the defective area. Other defects or cracks in tank-bottom joints shall be repaired as required in Par. 4.1.4.

c) All defects, cracks, or leaks in shell joints or in the shell-to-bottom joint shall be repaired in accordance with Par. 4.1.4.

4.1.4 Repair of Defective Welds

a) Defects in welds shall be repaired by chipping or melting out from one or from both sides of the joint, as required, and rewelding. Only sufficient cutting out of defective joints necessary to correct the defects is required.

b) All repaired welds in joints shall be checked by repeating the original test procedure.

4.2 Welding Procedure and Welder Qualifications

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

4.2.1 General

4.2.1.1 Definitions

The following definitions shall apply to welders and welding procedures:

1. Welder: One who is capable of performing a manual or semiautomatic welding operation.

2. Welding Operator: One who operates machine welding equipment or automatic welding equipment.

3. Manual welding: Welding wherein the entire welding operation is performed and controlled by hand.

4. Automatic Welding (Machine Welding): Welding with equipment which performs the welding operation under the observation and control of an operator.

5. Semiautomatic arc Welding: Arc welding with equipment which controls only the filler-metal feed. The advance of the welding is manually controlled.

6. Shielded Metal-Arc Welding (SMAW): An arc-welding process wherein coalescence is produced by heating with an arc between a covered metal electrode and the work. Shielding is obtained from decomposition of the electrode covering. Pressure is not used and filler metal is obtained from the electrode.

7. Gas Metal-Arc Welding (GMAW): An arcwelding process wherein coalescence is produced by heating with an arc between a continuous filler-metal (consumable) electrode and the work. Shielding is obtained entirely from an externally supplied gas or gas mixture. Some methods of this process are called MIG or CO_2 welding.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

8. Flux-Cored-Arc Welding (FCAW): An arc-welding process wherein coalescence is produced by heating with an arc between a continuous filler-metal (consumable) electrode and the work. Shielding is obtained from a flux contained within the electrode. Additional shielding may or may not be obtained from an externally supplied gas or gas mixture.

9. Electrogas Welding: A method of gas metal-arc welding or flux-cored-arc welding wherein molding shoes confine the molten weld metal for vertical position welding.

10. Submerged Arc Welding (SAW): An arc welding process wherein coalescence is produced by heating with an arc or arcs between a bare metal electrode or electrodes and the work. The arc is shielded by a blanket of granular fusible material on the work. Pressure is not used and filler metal is obtained from the electrode and sometimes from a supplementary welding rod.

4.2.1.2 Welding Procedure Qualification

a) The manufacturer shall conduct tests of his procedures to demonstrate their suitability in making welds which conform to the specified requirements.

b) The specification for each welding procedure shall be qualified in accordance with the latest practice as given in the applicable rules in Welding Qualifications, Sect. IX, ASME Boiler and Pressure Vessel Code, except as stated in the following Par. (c) for horizontal joints, and Par. (d) for material not listed in Sect. IX see Par. 3.4.1.1 (i) for plate surfaces having protective coatings.

4.2.1.3 Welder Qualification

a) The manufacturer shall conduct tests for all welders assigned to manual and semiautomatic welding and all operators assigned to automatic welding to demonstrate their ability to make acceptable welds.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

b) Tests shall be as prescribed for welder qualification in Sect. IX of the ASME code.

c) The records of such tests shall be as follows:

1. Each welder or welding operator shall be assigned an identifying number, letter or symbol by the manufacturer. Except for all roof seams and all flange-to-neck joints, this identifying mark shall be stamped, either by hand or machine, on all tanks adjacent to and at intervals of not more than 3 ft. along the welds made by a welder or welding operator--or the manufacturer may keep, until after test, a record of welders or welding operators employed on each joint and shell opening joint and omit the stamping. If such a record is kept, it shall be available to the inspector.

2. The manufacturer shall maintain a record of the welders or welding operators employed by him, showing the date and result of tests and the identifying mark assigned to each. These records shall be certified by the manufacturer and shall be accessible to the inspector.

5.0 Preparation for Delivery

5.1 Marking

5.1.1 Name Plates

The thermal storage tank must have a permanently stamped metal tag in accordance with the applicable code. In addition, the tank must have a permanently stamped metal tag which lists the following:

a. Name of Manufacturer

b. Address of Manufacturer

c. Honeywell name and address

d. Purchase order number

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

e. Project number

5.1.3 Rust Prevention

The thermal storage tank shall be coated with an approved type of rust preventative that can be easily washed off by use of a solvent that will not leave a residue when it evaporates. The solvent must also be safe and approved by Local, State, Federal and Insurance Codes.

Prior to shipment of the tank and prior to coating with the rust inhibition, the turnbuckles shall be removed from the ends of the I beams by some method such as burning them off.

5.2 The turnbuckles, I beams and cover used for leak testing shall be coated with an approved type of rust preventative coating and shipped to Honeywell with the thermal storage tank.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

Honeywell

SYSTEMS & RESEARCH CENTER Code Ident No. 27327

HONEYWELL REQUIREMENTS SPECIFICATION NO. **HRS** SK 140009

THIS HONEYWELL REQUIREMENTS SPECIFICATION IS FOR:

Thermal Storage Subsystem Research Experiment, Salt Pre-melt Module

	SIGNATURES		DATE
PREPARED BY	John A. Kallevig	*John A. Kallevig*	5/12/76
APPROVED BY PROJECT ENGR.	Richard T. LeFrois	*R. T. LeFrois*	5/12/76
	Jerry C. Powell	*Powell*	5/13/76

REVISIONS

LTR	DESCRIPTION	DATE	APPROVAL	LTR	DESCRIPTION	DATE	APPROVAL

PAGE																										
REVISION																										

PAGE		PAGE 1 OF
REVISION		HRS SK 140009

1.0 SCOPE

This specification establishes the performance and baseline design requirements for the salt pre-melt module portion of the subsystem research experiment thermal storage system and the performance, design, and acceptance requirements for the salt pre-melt module for the research experiment.

2.0 APPLICABLE DOCUMENTS

The following documents of the latest issue form a part of this specification to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered a superceding requirement.

- American Society of Mechanical Engineers, Unfired Pressure Vessel Code
- American National Standard Code for Pressure Piping ANSI B 31.1 Power Piping
- Honeywell Drawing SK 140009
- American National Standard Code for Steel Pipe Flanges, Flanged Valves and Fittings ANSI B16.5.

3.0 REQUIREMENTS

The salt pre-melt module shall be installed into the bottom of the thermal storage tank. Salt will cover the salt pre-melt module completely except for the pipes entering and leaving the tank. Steam at 1780 PSIA and 620°F will be pumped into the salt pre-melt module to melt the salt around it. The salt melts at 584°F.

3.1 PERFORMANCE

The salt pre-melt module is used to add heat to the salt in the thermal storage tank. The heat will be stored as heat energy in the form of heat of fusion of the salt.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

3.1.1 ENGINEERING DOCUMENTATION

Honeywell drawing No. SK 140009 shows the salt pre-melt.

3.1.2 OPERABILITY

3.1.2.1 Reliability

Consideration will begiven to achieving high reliability in the salt pre-melt module design by allowing operating margins, using conservative design practices and standard parts where available.

3.1.2.1 Maintainability

Consideration will be given in the sale pre-melt module design to assure that required service can be accomplished by personnel of normal skills, with a minimum of non-standard tooling or special equipment.

3.1.2.3 Useful Life

Consideration will be given in the sale pre-melt module design to assure that the useful life will be 40 years.

3.1.2.4 Environment

The salt pre-melt module will operate in molten salt at about 600°F. A corrosion allowance of 0.8 mil/yr. is included for a 40-year life cycle.

3.1.2.5 Transportability

To allow for ease in transporting the sale pre-melt module, the downcomers can be disconnected from the loop at the flange connections.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

3.1.2.6 Safety

The salt pre-melt module shall be designed and constructed in accordance with good engineering practice to assure its safe operation under the conditions specified.

3.2 DESIGN AND CONSTRUCTION STANDARDS

3.2.1 GENERAL DESIGN AND CONSTRUCTION STANDARDS

3.2.1.1 Code Requirements

The salt pre-melt module shall be designed and constructed in accordance with the latest applicable requirements of the American Society of Mechanical Engineers and the American Standard Code for pressure piping as specified and any other applicable codes.

3.2.1.2 Materials

The salt pre-melt module shall be fabricated from materials as dictated by good engineering practice.

3.2.1.3 Workmanship

The salt pre-melt module and all associated items will be constructed, fabricated and assembled in accordance with the best modern engineering, shop and field practices, consistent with cost and performance requirements.

3.2.1.4 Design Criteria

The salt pre-melt module will operate immersed in molten salts. It is important that any welds or seams be smooth to minimize corrosion paths.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

The salt pre-melt will operate under the following conditions:

Salt Temperature	584 °F
External Pressure	10 PSIG
Steam Temperature	700 °F
Design Temperature	750 °F
Steam Pressure	1000 PSIA
Design Pressure	1100 PSIA
Steam Rate	300 lb/hr.

To meet those conditions with the proper free convection heat transfer coefficients and overall temperature difference, the module was sized as follows:

Module Size:

Tube Length	39 ft. overall
Tube Arrangement	Single loop of finned tubing
Tube Size	1 in. O.D.
	0.834 in I.D.
Material	A106A carbon steel or equivalent

This includes a corrosion allowance of 0.8 mil/yr. for a 40-year life cycle.

3.3 FABRICATION

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

3.3.1 General

The salt pre-melt module shall be constructed in accordance with the requirements of Chapter V of the latest issue of ANSI B 31.1 Power Piping. All materials used shall have been manufactured in accordance with the requirements of Chapter VI of the latest issue of ANSI B31.1 Power Piping. These requirements apply to all fabrication, assembly, and erection operations, whether performed in the shop or at the construction site.

The welding processes that may be used in constructing the condenser module shall meet all the test requirements of Section IX of the ASME boiler and pressure vessel code.

3.3.2 Bending and Forming

Pipe may be bent by any hot or cold method and to any radius which will result in a bent surface free of cracks, and substantially free of buckles.

3.3.3 Supports

No supports are required.

4.0 QUALITY ASSURANCE

4.1 EXAMINATION AND INSPECTION

Prior to delivery of the salt pre-melt module, the module shall be inspected as necessary to assure compliance with the engineering design and with the material, fabrication, assembly and test requirements or the latest issue of the B 31.1 code.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

Compliance with the requirements of this code shall be verified by an Authorized Code Inspector when a Code Stamp is required by Section I or the ASME Boiler and Pressure Vessel Code. The rules of this code shall apply, and the duty of the Inspector shall be defined as in Para PG 90, Section I, or the ASME Boiler and Pressure Vessel Code. The Inspector shall assure himself that the piping has been constructed in accordance with the applicable requirements of this code.

4.2 QUALIFICATION AND ACCEPTANCE TESTING

The salt pre-melt module shall be hydrostatically tested to 1650 PSIG in accordance with the leak test requirements as specified in Section 137 LEAK TEST of the latest issue of ANSI B31.1.

5.0 PREPARATION FOR DELIVERY

Prior to packing for shipment, the salt pre-melt module shall be thoroughly cleaned and protected inside and out by a light film of approved corrosion preventative material. The ends shall be sealed to prevent any dirt or debris from entering into the salt pre-melt module. The corrosion preventative material shall be a type easily removed using a solvent or a type that leaves no residue and is approved by OSHA and other Local, State, Federal and Insurance codes.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

Honeywell

SYSTEMS & RESEARCH CENTER Code Ident No. 27327

HONEYWELL REQUIREMENTS SPECIFICATION NO. HRS SK 133500

THIS HONEYWELL REQUIREMENTS SPECIFICATION IS FOR:

Thermal Storage Subsystem Research Experiment, Condenser Submodule

SIGNATURES			DATE
PREPARED BY	John A. Kallevig	[signature]	10 May, 1976
APPROVED BY PROJECT ENGR.	R.T. LeFrois	[signature]	5-10-76
	J.C. Powell	[signature]	5/12/76

REVISIONS

LTR	DESCRIPTION	DATE	APPROVAL	LTR	DESCRIPTION	DATE	APPROVAL

PAGE	
REVISION	
PAGE	
REVISION	

PAGE 1 OF

HRS SK 133500

1.0 SCOPE

This specification establishes the performance and baseline design requirements for the condenser module portion of the subsystem research experiment thermal storage system and the performance, design, and acceptance requirements for the condenser module for the research experiment.

2.0 APPLICABLE DOCUMENTS

The following documents of the latest issue form a part of this specification to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered a superceding requirement.

- American Society of Mechanical Engineers, Unfired Pressure Vessel Code
- American National Standard code for Pressure Piping ANSI B 31.1 Power Piping
- Honeywell Drawing SK 133500

3.0 REQUIREMENTS

The condenser module shall be installed into the bottom of the thermal storage tank. Salt will cover the condenser module completely except for the pipes entering and leaving the tank. Steam at 1780 PSIA and 620°F will be pumped into the condenser module to melt the salt around it. The salt melts at 584°F.

3.1 PERFORMANCE

The condenser module is used to add heat to the salt in the thermal storage tank. The heat will be stored as heat energy in the form of heat of fusion of the salt.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

3.1.1 ENGINEERING DOCUMENTATION

Honeywell drawing No. SK 133500 shows the condenser.

3.1.2 OPERABILITY

3.1.2.1 Relability

Consideration will be given to achieving high reliability in the condenser module design by allowing operating margins, using conservative design practices and standard parts where available.

3.1.2.1 Maintainability

Consideration will be given in the condenser module design to assure that required service can be accomplished by personnel of normal skills, with a minimum of nonstandard tooling or special equipment.

3.1.2.3 Useful Life

Consideration will be given in the condenser module design to assure that the useful life will be 40 years.

3.1.2.4 Environment

The condenser module will operate in molten salt at about 600°F. A corrosion allowance of 0.8 mil/yr. is included for a 40-year life cycle.

3.1.2.5 Transportability

To allow for ease in transporting the condenser module, the downcomers can be disconnected from the coil at the flange connections.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

3.1.2.6 Safety

The condenser module shall be designed and constructed in accordance with good engineering practice to assure its safe operation under the conditions specified.

3.2 DESIGN AND CONSTRUCTION STANDARDS

3.2.1 GENERAL DESIGN AND CONSTRUCTION STANDARDS

3.2.1.1 Code Requirements

The condenser module shall be designed and constructed in accordance with the latest applicable requirements of the American Society of Mechanical Engineers and the American Standard Code for pressure piping as specified and any other applicable codes.

3.2.1.2 Materials

The condenser module shall be fabricated from materials as dictated by good engineering practice.

3.2.1.3 Workmanship

The condenser module and all associated items will be constructed, fabricated and assembled in accordance with the best modern engineering, shop and field practices, consistent with cost and performance requirements.

3.2.1.4 Design Criteria

The condenser module will operate immersed in molten salts. It is important that any welds or seams be smooth to minimize corrosion paths.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

The condenser will operate under the following conditions:

Salt temperature	584 ^{o}F
External pressure	10 PSIG
Steam Temperature	620 ^{o}F
Design Temperature	635 ^{o}F
Steam pressure	1780 PSIA
Design pressure	1958 PSIA
Steam rate	908 lb/hr.

To meet those conditions with the proper free convection heat transfer coefficients and overall temperature difference, the module was sized as follows:

Module Size:

Tube length	544 ft. overall
Tube Arrangement	Single serpentine of 71 legs in two rows
Tube size	1 in O.D. 10 gauge
	0.732 in I.D.
Material	A106A carbon steel

This includes a corrosion allowance of 0.8 MIL/yr for a 40-year life cycle.

3.3 FABRICATION

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

3.3.1 General

The condenser module shall be constructed in accordance with the requirements of Chapter V of the latest issue of ANSI B31.1 Power Piping. All materials used shall have been manufactured in accordance with the requirements of Chapter VI of the latest issue of ANSI B31.1 Power Piping. These requirements apply to all fabrication, assembly, and erection operations, whether performed in the shop or at the construction site.

The welding processes that may be used in constructing the condenser module shall meet all the test requirements of Section IX OF THE ASME boiler and pressure vessel code.

3.3.2 Bending and Forming

Pipe may be bent by any hot or cold method and to any radius which will result in a bent surface free of cracks, and substantially free of buckles.

3.3.3 Supports

The tubing shall be supported by supports that provide the required supporting effort and allow pipe line movement with thermal changes without causing overstress. The design shall also prevent complete release of the piping load in the event of spring failure or misalignment and all parts of the supportive equipment shall be fabricated and assembled so that they will not be disengaged by movement of the supporting piping.

4.0 QUALITY ASSURANCE

4.1 EXAMINATION AND INSPECTION

Prior to delivery of the condenser module, the module shall be inspected as necessary to assure compliance with the engineering design and with the material, fabrication, assembly and test requirements or the latest issue of the B31.1 code.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

Compliance with the requirements of this code shall be verified by an Authorized Code Inspector when a Code stamp is required by Section I or the ASME Boiler and Pressure Vessel Code. The rules of this code shall apply, and the duty of the Inspector shall be defined as in Para PG90, Section I, or the ASME Boiler and Pressure Vessel Code. The inspector shall assure himself that the piping has been constructed in accordance with the applicable requirements of this code.

4.2 QUALIFICATION AND ACCEPTANCE TESTING

The condenser module shall be hydrostatically tested to 2937 PSIG in accordance with the leak test requirements as specified in Section 137 LEAK TEST of the latest issue of ANSI B31.1.

5.0 PREPARATION FOR DELIVERY

Prior to packing for shipment, the condenser module shall be thoroughly cleaned and protected inside and out by a light film of corrosion preventative material. The ends shall be sealed to prevent any dirt or debris from entering into the corrosion module. The corrosion preventative material shall be a type easily removed using a solvent or a type that leaves no residue and is approved by OSHA and other Local, State, Federal and Insurance codes.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

Honeywell

SYSTEMS & RESEARCH CENTER Code Ident No. 27327

HONEYWELL REQUIREMENTS SPECIFICATION NO. HRS SK 133291

THIS HONEYWELL REQUIREMENTS SPECIFICATION IS FOR:

Thermal Storage Subsystem Research Experiment, Vaporizer Submodule

SIGNATURES		DATE
PREPARED BY	John A. Kallevig	
APPROVED BY PROJECT ENGR.	Richard T. LeFrois	5/21/76
	Jerry C. Powell	5/24/76

REVISIONS

LTR	DESCRIPTION	DATE	APPROVAL	LTR	DESCRIPTION	DATE	APPROVAL

PAGE																											
REVISION																											

PAGE																PAGE 1 OF 10
REVISION																HRS SK 133291

1.0 SCOPE

This specification establishes the performance and baseline design requirements for the vaporizer module portion of the subsystem research experiment thermal storage system and the performance, design and acceptance requirements for the vaporizer module for the research experiment.

2.0 APPLICABLE DOCUMENTS

The following documents of the latest issue form a part of this specification to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered a superceding requirement.

- American Society of Mechanical Engineers, Unfired Pressure Vessel Code
- American Society of Mechanical Engineers, Pressure Vessel Code, Section VIII and Welder Qualifications, Section IX.
- American National Standard Code for Pressure Piping ANSI B31.1 Power Piping.
- Honeywell Drawing SK 133291
- American National Standard Code for Steel Pipe Flanges, Flanged Valves, and Fittings ANSI B16.5
- OSHA

3.0 REQUIREMENTS

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

3.1.1 FUNCTIONAL CHARACTERISTICS

The vaporizer module shall be used to change hot water into steam by extracting the necessary heat from molten salt at 584°F. As the salt gives up its heat, it solidifies on the vaporizer tubes. The scrapers scrape the hardened salt off of the tube and the hardened salt settles to the bottom of the tank. The salt acts as a lubricant between the scrapers and the tubes.

The salt is at 584°F at ambient pressure. The resulting steam is at 584°F at 1368 PSIA. For design purposes use a 10% safety factor or 597°F at 1505 PSIA.

3.1.2 ENGINEERING DOCUMENTATION

Honeywell drawing SK 133291 is a layout of the vaporizer/scraper assembly.

3.1.3 ENVIRONMENT

The vaporizer module shall operate in an environment of molten salt at 584°F.

3.1.4 RELIABILITY

Consideration will be given to achieving high reliability in the vaporizer/scraper module design by allowing operating margins, using conservative design practices and standard parts where available.

3.1.5 MAINTAINABILITY

Consideration will be given in the vaporizer/scraper module design to assure that required service can be accomplished by personnel of normal skills, with a minimum of nonstandard tooling or special equipment.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

3.1.6 TRANSPORTABILITY

Transportation of all elements of the vaporizer/scraper module to Honeywell and to the SRE test site will be subject to all pertinent federal and state transportation regulations. The vaporizer/scraper module may be shipped partially assembled as required.

3.2 DESIGN AND CONSTRUCTION

The vaporizer/scraper module shall be designed and constructed in accordance with the latest applicable requirements of the American Society of Mechanical Engineers and the American Standard Code for pressure piping as specified above and any other applicable code.

TYPE

The vaporizer module shall be of the type that heats water to steam at the condition shown, extracting the heat from molten salt.

3.2.1 Materials

The vaporizer/scraper module will be fabricated from materials as dictated by good engineering practice.

3.2.2 Nameplates

All components, instruments and controls unless defined by Module drawings will have identifying markings or nameplates which will be permanently attached to the respective items.

3.2.3 Workmanship

The vaporizer/scraper module and all associated items will be constructed, fabricated and assembled in accordance with the best modern engineering, shop and field practices, consistent with cost and performance requirements.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

3.2.4 Interchangeability

Components, with standard tolerances where available, will be used to permit interchangeability for servicing. Satisfactory replacement parts will be available for the period of the SRE tests.

3.2.5 Safety

The vaporizer/scraper module will be designed to minimize safety hazards to operating and service personnel and the public. Electrical components will be insulated and grounded. All pertinent OSHA rules and regulations will be observed.

Precedence

The order of precedence of requirements of the Solar Simulator system characteristics is as follows:

a) Performance

b) Safety

c) Cost

3.3 DESIGN CRITERIA

The vaporizer module will operate immersed in molten salts. As the heat is extracted from the salt, the salt solidified on the tubes of the module. The scrapers scrape the salt from the tubes. The vaporizer must be capable of performance under the following conditions:

a) Salt -

Temperature	584 $^{\circ}$F
Pressure	Ambient

b) Steam Inside of the Tubing

Temperature	584 $^{\circ}$F
Pressure	1367.7 PSIA

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

3.3.1 CONSTRUCTION

The tubing will be arrayed in a module of 8-7ft. tubes. Each vaporizer tube will be scraped by 4 independently driven scrapers each 21" long. The scrapers are designed to permit their removal and replacement without disturbing the basic boiler tube structure. A shear pin shall be installed in each sprocket on the main drive shaft. It shall be sized to shear whenever the torque of the scrapers exceeds 10 ft./lb.

The scraper does not have bearings as such. The scrapers fit to within .0025 in. of the tube and the scrapers act as bearings as well as scrapers with the salt film acting as a lubricant. The scraper blades are sharp edged to reduce scraping power requirements. A chain-sprocket drive system is utilized to drive the scrapers. The chains can be of stainless or carbon steel.

The tubing used shall be as follows:

Material	ASTM 192 Steel Tubing
Outside Dia.	1.00 in.
Inside Dia.	0.782 (12 gauge)
No. of tubes in array	8 tubes
Each Tube	7 ft. straight section
Total Tube Length	56 ft.

The scrapers are shown in Drawing SK 133291

No. of Scrapers	32 (4 per tube)
Scraper Length	21 in.
Scraper Material	A283 or equivalent

Clearance between scraper and pipe - .0025

REVISIONS

LTR	DESCRIPTION	DATE	APPROVAL

The scraper blade where it contacts the tube shall be sharp to reduce scraping force required.

Chain Drive - ASA 41½" pitch ¼" roller width

Sprocket on Shaft - 15 teeth

Sprocket on Scraper - 22 teeth

Sprocket on Idler - 21 teeth

The scrapers are designed to overlap during operation so that except for the support areas, the entire length of pipe is scraped clean.

The tubing supports shall provide the required supporting effort and allow pipe line movement with thermal changes without causing overstress. The design shall also prevent complete release of the piping load in the event of spring failure or misalignment, and all parts of the supporting equipment shall be fabricated and assembled so that they will not be disengaged by movement of the supporting piping.

The design shall conform with the standards specified in the latest issue of ANSI B31.1 power piping section 121 and other applicable codes and standards.

3.3.2 FABRICATION

3.3.3 GENERAL

The vaporizer module shall be considered in accordance with the requirements of Chapter V of the latest issue of ANSI B31.1 power piping. All materials used shall have been manufactured in accordance with the requirements of Chapter VI of the latest issue of ANSI B31.1 Power Piping. These requirements apply to all fabrication, assembly, and erection operations, whether performed in the shop or at the construction site.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

The welding processes that may be used in constructing the condenser module shall meet all the test requirements of Section IX of the ASME Boiler and Pressure Vessel Code.

3.3.4 BENDING & FORMING

Pipe to be bent shall be heated to a temperature between 1700°F and 2000°F using electric resistance heating on fuel fired burners. The bent surface shall be free of cracks and substantially free of buckles. Oxyacetylene flame heating will not be permitted. Suitable provisions shall be made for maintaining uniform wall thickness and cross-sectional areas by sandfilling, dies or other means.

3.3.5 SUPPORTS

The tubing supports shall provide the required supporting effort and allow pipe line movement with thermal changes without causing overstress. The design shall also prevent complete release of the piping load in the event of spring failure cr misalignment and all parts of the supporting equipment shall be fabricated and assembled so that they will not be disengaged by movement or the supportive piping.

4.0 QUALITY ASSURANCE

Examination and Inspection

General

Prior to delivery of the vaporizer module, the module shall be inspected to the extent necessary to assure compliance with the engineering design, and with the material, fabrication, assembly and test requirements of this code.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

Compliance with the requirements of this code shall be verified by an Authorized Code Inspector when a code stamp is required by Section I, of the ASME Boiler and Pressure Vessel Code. The rules of this code shall apply, and the duty of the Inspector shall be as defined in Para. pg. 90, Section I, of the ASME Boiler and Pressure Vessel Code. Data report forms are included in Appendix X (Section I, ASME Boiler and Pressure Vessel Code) for use in developing the necessary inspection records. The Inspector shall assure himself that the piping has been constructed in accordance with the applicable requirements of this code.

4.1 TEST PROGRAM

All tests will be approved by Honeywell, Inc. These tests may be witnessed by ERDA or its representatives or the witnessing may be waived. In either case, substantive evidence of hardware compliance with all test requirements is required.

4.2 PRESSURE TESTING OF VAPORIZER MODULE

The vaporizer module shall be hydrostatically tested to 2250 PSIG in accordance with the leak test requirements as specified in Section 137, Leak Test of the latest issue of ANSI B31.1.

While the module is under pressure, the scraper mechanism shall be turned to insure that it operates freely.

4.3 TESTING OF SCRAPERS AND DRIVE MECHANISM

The scrapers shall be tested to insure that they turn freely on the tubing. No binding or sticking shall occur. Insure that all sprockets are properly aligned and all chains operate freely.

5.0 PREPARATION FOR DELIVERY

Prior to packing for shipment, all unpainted parts of the vaporizer/scraper module shall thoroughly cleaned and protected inside and out by a light film of corrosion preventative material. The ends shall be sealed to prevent any dirt or debris from entering the condenser module.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

Honeywell

SYSTEMS & RESEARCH CENTER Code Ident No. 27327

HONEYWELL REQUIREMENTS SPECIFICATION NO. | **HRS** SK 133291

The corrosion preventative material shall be a type easily removed using a solvent or a type that leaves no residue and is approved by OSHA and other Local, State, Federal and Insurance codes.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVAL

Honeywell

SYSTEMS & RESEARCH CENTER Code Ident No. 27327

HONEYWELL REQUIREMENTS SPECIFICATION NO. **HRS** SK-133288

THIS HONEYWELL REQUIREMENTS SPECIFICATION IS FOR:

STEAM DRUM,
THERMAL STORAGE SUBSYSTEM RESEARCH EXPERIMENT,
SOLAR PILOT PLANT

SIGNATURES		DATE
PREPARED BY	W. E. Anderson	4-2?-76
APPROVED BY PROJECT ENGR.	R. T. LeFrois	5-3-76
	J. C. Powell	5/5/76

REVISIONS

LTR	DESCRIPTION	DATE	APPROVAL	LTR	DESCRIPTION	DATE	APPROVAL
A	On page 4, add 6040. lb/hr; update sheet 1 REV BLK; make enclosure (Figure 2) sheet 14	May 19,'76	RTL				
B	On page 4, add 4.-30.%, change 681 to 800.-1120., change 500 to 518.-558., update sheet 1 REV BLK.	May 21,'76	RTL				

PAGE	1	2	3	4	5	6	7	8	9	10	11	12	13	14
REVISION	B			B										

40454

1.0 SCOPE

This specification relates to services and materials to be furnished to Honeywell Inc., Energy Resources Center, hereinafter referred to as buyer, by the vendor, hereinafter referred to as seller.

This specification establishes the design, test, performance, stamp, certification, and delivery requirements for a wall-mountable steam drum and associated items for the Thermal Storage Subsystem Research Experiment (TSS/RE). This experiment is part of the 10-MWe solar pilot plant contract from the buyer's customer, the Energy Research and Development Administration (ERDA).

Background information is presented below under "6.0 NOTES."

2.0 APPLICABLE DOCUMENTS

The following documents of exact issue shown form a part of this specification to the extent specified herein:

- ASME Code, Section I (latest issue)
- ASME Code, Section VIII, Division 1 (latest issue)
- Standards, such as ANSI B16.5, referred to in the ASME Code
- All applicable local, state, federal and insurance rules, regulations, and codes
- Any other documents normally necessary for the assurance of acceptable device performance, safety of personnel and property, and insurability of personnel and property
- Figure 1 (herein) -- Sketch of Approximate Amount of Space Available for the Steam Drum
- Figure 2 (enclosure) -- Piping and Instrument Diagram, Storage Unit SRE, ERDA - 10 MWe Solar Pilot Plant, Subsystem Research Experiments, Black & Veatch Drawing No. M1004.

3.0 REQUIREMENTS

3.1 Description and Performance

The steam drum for the TSS/RE shall extract steam of high quality from a two-phase, steam-water mixture of approximately 20.% quality. The steam drum may be either a vertical or a horizontal unit. Since the steam drum for the TSS/RE will be small, adequate water level sensitivity may exist only for a vertical steam drum. We anticipate, however, that the subsequent larger steam drum for the TSS of the 10-MWe solar pilot plant will be a horizontal unit. The steam drum shall provide steam of a very high quality, a quality in excess of that which the buyer believes to be obtainable with simple 180° open turns for the steam. The steam drum shall be capable of operating satisfactorily over the range of experimental conditions presented below and of interfacing to the extent presented below.

The steam drum shall produce steam with a quality specified as having either less than 0.6 ppm TDS for feedwater superior to the ABMA Standard of 1958 or a quality in excess of 99.5% for all TSS/RE test conditions, equilibrium or transient. The transient condition of greatest concern is that involving a change in load from 0% to 100% from a hot standby condition at design temperature and pressure.

3.2 Design

3.2.1 Design Data Base -- The temperature and pressures to be used in designs relative to the TSS/RE are those presented in the table below. These numbers are included to give the seller more understanding of the design factors which follow the table below.

Item	Temperature	Corresponding Saturated Steam Pressure
Melting point of salt (99% $NaNO_3$, 1% NaOH)	578.°F	1306. psia
Temperature limit for salt (1% margin on °F) and design temperature	584.°F	1368. psia
Maximum allowable working pressure and design pressure (10% margin)		1505. psia
Hydrostatic test pressure (50% margin)		2257. psia

The numbers above constitute the basis set. For working purposes, round off the design temperature (584.^{o}F) to 600.^{o}F, the design pressure (1505. psia) to 1500. psig, and the hydrostatic test pressure (2257. psia) to 2250. psig.

3.2.2 Design Factors and Connections -- Tables of design factors and connections follow. The descriptive information elsewhere also relates to design factors and connections.

Design Factor	Design	Off-Design Tests
ASME Code, Section VIII, Division 1		
Flow of steam (two-phase, steam-water mixture), recirculation loop, inlet	3470.* lb/hr	6040. lb/hr
Quality of steam, recirculation loop, inlet	20.%	4.-30.%
Flow of feedwater, inlet	594.* lb/hr	1300.
Flow of saturated steam, outlet	594.* lb/hr	1300.
Quality of steam, outlet	Less than 0.6 ppm TDS or greater than a quality of 99.5%	
Quality of feedwater, inlet	Superior to ABMA Standard of 1958 (See subsection 3.2.2)	
Normal operating pressure	947. psia	800.-1120.
Normal operating temperature	538.^{o}F	518.-558.
Design pressure	1500. psig	
Design temperature	600.^{o}F	
Hydrostatic test pressure (factor 1.5)	2250. psig	

*5:1 recirculation ratio

Design Factor	Design	Off-Design Tests
Holdup capacity	35. gallons	
Sight gage to be included; water level control point will be approximately eight inches or more below vapor inlet (recirculation pump return) which presumes a vertical drum		
Provision for mounting steam drum on a vertical surface		
Certified performance during equilibrium operation and during transient response from 0% to 100% load from hot standby condition		

Connections Assuming ASME Code, Section VIII, Division 1

Steam outlet (1)	1 inch	
Level control (2)	2 inches	
Recirculation pump bypass (1)	3/4 inch	
Recirculation pump suction (1)	2 inches	
Recirculation pump return (1)	1-1/2 inches	
Prewarming and blowdown (drain), combined (1)	3/4 inch	
Feedwater (1)	3/4 inch	
Sight gage (2) (sight gage to be included)	1 inch	
Relief valve (1)	3/4 inch	
Pressure transmitter and indicator, combined (1)	3/4 inch	

The conditions of possible off-design research experiments are shown in the right-most column. For these conditions, the recirculation ratio will be decreased from 5:1 to accommodate the tests.

Since the steam drum will be used in an experimental facility, a range of operating conditions departing from nominal will be examined. One such set of conditions representing that producing the greatest mass flow of steam is included in the table above as "Off-Design Tests."

3.2.3 Feedwater Specifications -- NSP personnel gave the buyer the following information on their #6 feedwater at their Riverside Plant:

Consideration	Unit #6 Feedwater
pH	8.5 - 9.5
Conductivity (μmhos)	5-10, estimate 50, max., if condenser leaks
Total Solids (ppm)	100, max., if condenser leaks
SiO_2 (ppm)	0.25, max.
O_2 (ppm)	0.005
Fe (ppm)	0.01
Cu (ppm)	0.005
Total Hardness (ppm)	0
Organics (ppm)	0

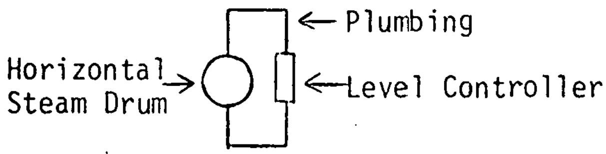
3.3 Mechanical Characteristics Including Interface Considerations

The steam drum shall have suitable hardware attached by welding to permit mounting the steam drum above the floor without floor supports on a sturdy brick wall. Adequate space for insulating the drum shall be allowed between the drum and the plane of attachment representing the wall. All fittings shall meet all applicable codes. The steam drum shall be supplied with sight gage(s) meeting all applicable codes.

The holdup capacity of the drum shall be a minimum of five minutes at the maximum steam production rate (1300. lbm/hour). The buyer is requesting a 10-minute holdup capacity of 35 gallons as presented in the design factors below.

In the case of a vertical steam drum, the flanges to accept the level control shall be separated by 32 inches on a vertical line and be placed symmetrically 16 inches above and below the normal liquid level. Flanges for two-inch pipes are requested so that the piping shall be adequate to support the level control instrumentation. The seller shall consider the possibility of mounting the sight gage(s) on this piping. The liquid level will be controlled to the design level ±1 inch except for transients when it will be controlled to the design level ±7 inches.

The equivalent in a horizontal drum will be satisfactory. In the use of a horizontal drum, the level control flanges need not be 32 inches apart but shall have vertical axes (i.e., one flange shall face up, the other down) to permit plumbing to accommodate a rectangular array of pipes to connect to the level controller:



To obtain sufficiently high-quality steam, the steam drum shall include centrifugal separators and other purifiers. The steam drum shall also include internal deflectors or devices to minimize turbulence and vortices associated with introduction of the feedwater and the bypass water from the recirculation pump. To illustrate, the buyer requires that the water level in the sight gage(s) shall indicate the water level in the drum; also that a vortex tip shall not enter the recirculation pump suction flange.

Additionally, the feedwater shall enter the drum below the water level as far from the steam discharge point as possible to minimize condensation of steam and warming of the feedwater. The liquid level shall be several inches below the vapor inlet (recirculation pump return), such as eight inches or more for a vertical drum, to permit fluctuation of the liquid level during transients by up to plus and minus seven inches. The equivalent in a horizontal drum will be satisfactory.

The pipe routing (a buyer responsibility) for the TSS/RE will depend upon the details of the design of the steam drum. Some general considerations follow for locations of penetrations of the drum:

- Steam outlet: can vary; above high water level; depends on drum design
- Level controller and sight gage(s): see above
- Recirculation pump bypass return line: below water level -- no higher than low level of water

- Recirculation pump suction line: at or very near bottom of drum

- Recirculation pump return line: as far from the steam outlet as possible, as the steam flies; dependent upon drum design; approximately eight inches or more above the water level control point, i.e., eight or more inches above the level of 35 gallons of holdup capacity; minimize heat exchange, maximize isolation between steam and holdup water.

- Prewarming and blowdown: at or very near bottom of drum

- Feedwater inlet: below low-level interlock; place as far away from steam outlet as possible to minimize heat exchange, i.e., to maximize their relative isolation.

- Relief valve: dead center at top, usually

- Pressure transmitter and indicator: near top of drum.

3.4 Steam Quality

The steam drum shall yield steam of very high quality; for example, it shall contain less than 0.6 ppm TDS (total dissolved solids) for feedwater superior to the ABMA (American Boiler Manufacturer's Association) Standard of 1958. The steam from the TSS/RE steam drum will not be superheated nor will it pass on to a turbine at this time. Thus, the buyer's immediate concern for the steam quality from the TSS/RE steam drum is not one of deposits in a superheater or on turbine blades, but the buyer's concern is that the steam quality will always be sufficiently high that analysts can treat it as 100% quality without continual experimental confirmation of this quality.

The direct method of specifying steam quality is 0 to 100%. The buyer anticipates that a steam drum which delivers steam with a quality greater than 99.5% under all operating conditions, equilibrium and transient, during the experiment will be satisfactory.

3.5 Drawings and Documentation

All drawings and documents shall be prepared according to good commercial practice.

3.6 Space Provisions

A sketch, Figure 1, shows the approximate amount of space available for the steam drum.

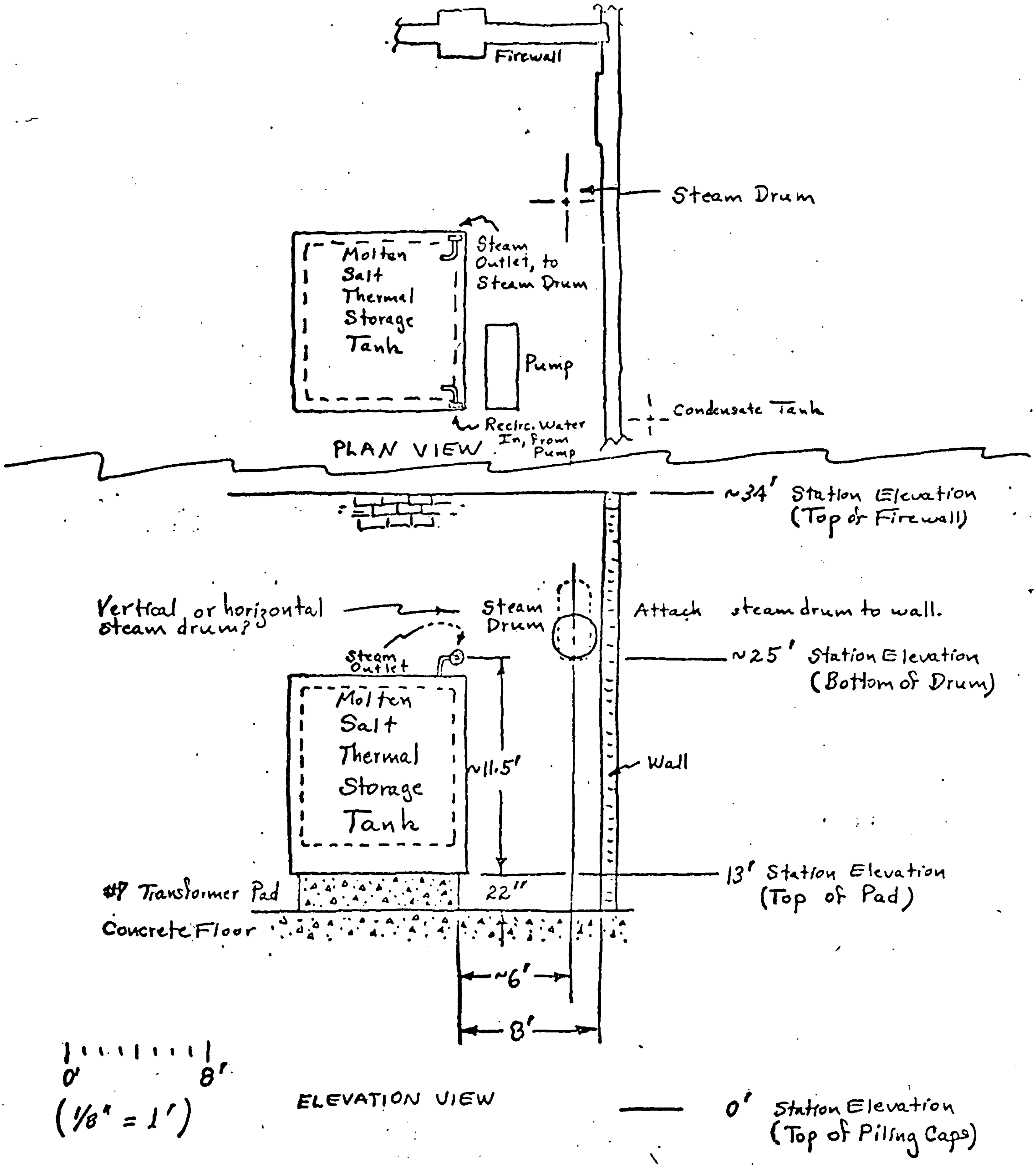


Figure 1. Sketch of Approximate Space Available for Steam Drum

3.7 Piping and Instrument Diagram

Figure 2 (enclosure) is a drawing by Black & Veatch showing the piping and instrumentation diagram (P&ID) M1004 at the latest revision. The figure illustrates the relationship of the steam drum to the subsystem.

4.0 QUALITY ASSURANCE

The steam drum and sight gage(s) shall be constructed under all applicable codes. The buyer believes one applicable code to be ASME Code, Section VIII, Division 1. If the seller prefers to fabricate the steam drum under ASME Code, Section I, the buyer shall be convinced by the seller of the necessity to use this code; or if not essential, the buyer shall be convinced that the cost shall be the same or less than if the ASME Code, Section VIII, Division 1, were used.

The seller shall present, by way of analyses and test results on the seller's letterhead to the buyer, evidence that the assembly will pass all applicable codes and underwriter's tests for safety and insurance purposes.

The assembly shall be subjected to all applicable processes such as post-heat treatment, radiographs and hydrostatic tests as required to ensure safety, insurability and acceptance.

The assembly shall be fabricated and assembled in such a manner as to permit its easy inspection for acceptance.

The assembly shall include National Board and ASME stamps and a plate stating the name and address of the manufacturer and of the buyer, an identification number, and the date of manufacture.

The steam drum shall be warranted and certified to produce steam with a quality specified as having either less than 0.6 ppm TDS for feedwater superior to the ABMA Standard of 1958 or a quality in exc[illegible] of 99.5% for all TSS/RE test conditions, equilibrium or transient. [illegible]e transient condition of greatest concern is that involving a change [illegible] load from 0% to 100% from a hot standby condition at design temperature and pressure.

The final acceptance of the assembly shall be contingent upon approval by our customer, ERDA, and Northern States Power Company (NSP), the utility which is owner of the site where the assembly will be operated.

5.0 DELIVERY

5.1 Preliminary Documentation

The buyer requires preliminary documentation of interface specifications such as flanges, comments relative to scaling the drum to a larger drum for the 10-MWe solar pilot plant, and all information necessary to assure the buyer's customer, ERDA, that the drum will be acceptable with respect to steam quality, safety and insurability. This information shall arrive at the buyer's facility per the schedule to provide time to permit assimilation of the material for use at the Detailed Design Review (DDR) with the buyer's customer, ERDA. Since changes in the TSS/RE may be made by ERDA during the DDR, detailed design drawings of the steam drum will not be required for this delivery date for economic reasons.

5.2 Steam Drum Design Review

Subsequent to the DDR with ERDA, the seller shall be supplied with any required change information. The seller shall then supply the buyer's Engineer (see the Statement of Work) with fabrication drawings and other documentation for review and approval prior to construction of the steam drum assembly.

5.3 Steam Drum and Final Documentation

The steam drum; sight gage(s); full drawings; analyses and test results on the seller's letterhead; comprehensive preparation, start-up, operating and maintenance instructions; warranty and certification of performance shall be shipped to arrive at the buyer's facility as scheduled in the Statement of Work.

The steam drum and sight gage(s) shall be shipped closed to protect the interior. Closure shall be such as to protect flanges, fittings and other hardware in shipment.

6.0 NOTES

6.1 Letter of Inquiry

Willard E. Anderson, employed by but not an agent of the buyer, mailed a letter of inquiry dated April 1, 1976, to the seller. The letter contained the essential design details of this specification to speed the process of procurement.

6.2 Background Information

The initial phase of an important part of the U.S. solar energy program began in June 1975 when the Energy Research and Development Administration (ERDA) contracted with the buyer to be a prime contractor (Contract No. E(04-3)-1109) for the preliminary design of a 10-MWe solar pilot plant to be built by 1980. Subcontractors to the buyer are Black & Veatch, Babcock & Wilcox, Northern States Power (NSP), and Research Inc. NSP is the utility which is owner of the site where design experiments will be run.

Energy must be stored for use during periods when insolation is not available. The energy storage concept under investigation by the buyer is that of latent heat storage employing the phase change from solid to liquid of inexpensive salts. The salts will be melted by passing steam through a condenser in the storage tanks during periods of insolation. The energy can be removed when insolation is not available by simply reversing the process; i.e., by passing water through a vaporizer in the storage tank to produce steam. This steam will then pass through a steam purifying drum, through a superheater, and on to the turbine. Equilibrium and transient conditions due to clouds must be considered.

But first, since latent heat storage is not well developed but has the potential for cost savings, the buyer must demonstrate its feasibility. Feasibility demonstrations have been performed in the laboratory on a smaller scale. On a larger scale, the present program to further demonstrate feasibility is an experiment called the Thermal Storage Subsystem Research Experiment (TSS/RE). Due to the use of latent heat technology for storage, the system will normally operate at a nearly constant temperature. However, for experimental purposes, tests will be conducted over a range of conditions including temperature, pressure, and flow rate, both at equilibrium and at transient conditions.

6.3 Use of Seller's Expertise

Since the buyer does not design and fabricate steam drums, the buyer desires to utilize the seller's expertise. The buyer's goal is to obtain a steam drum which will work in the TSS/RE. The buyer will appreciate the seller's working with the buyer in a candid manner to accomplish this goal.

This being an experiment, the buyer desires a close working relationship with and flexibility on the part of the seller to ensure successful development of the latent heat storage technology.

The steam purifying drum for the TSS/RE referred to above is the subject of this specification; however, the buyer desires also to work with the seller to estimate the steam purifying drum required for the thermal storage system for the 10-MWe solar pilot plant.

The seller's general and specific comments will be appreciated on any point including those relative to the code suggested and additional holes if ASME Section I is recommended, vertical vs. horizontal drum, mounting of drum on wall, post-heat treatment, radiographs, and National Board and ASME stamps.

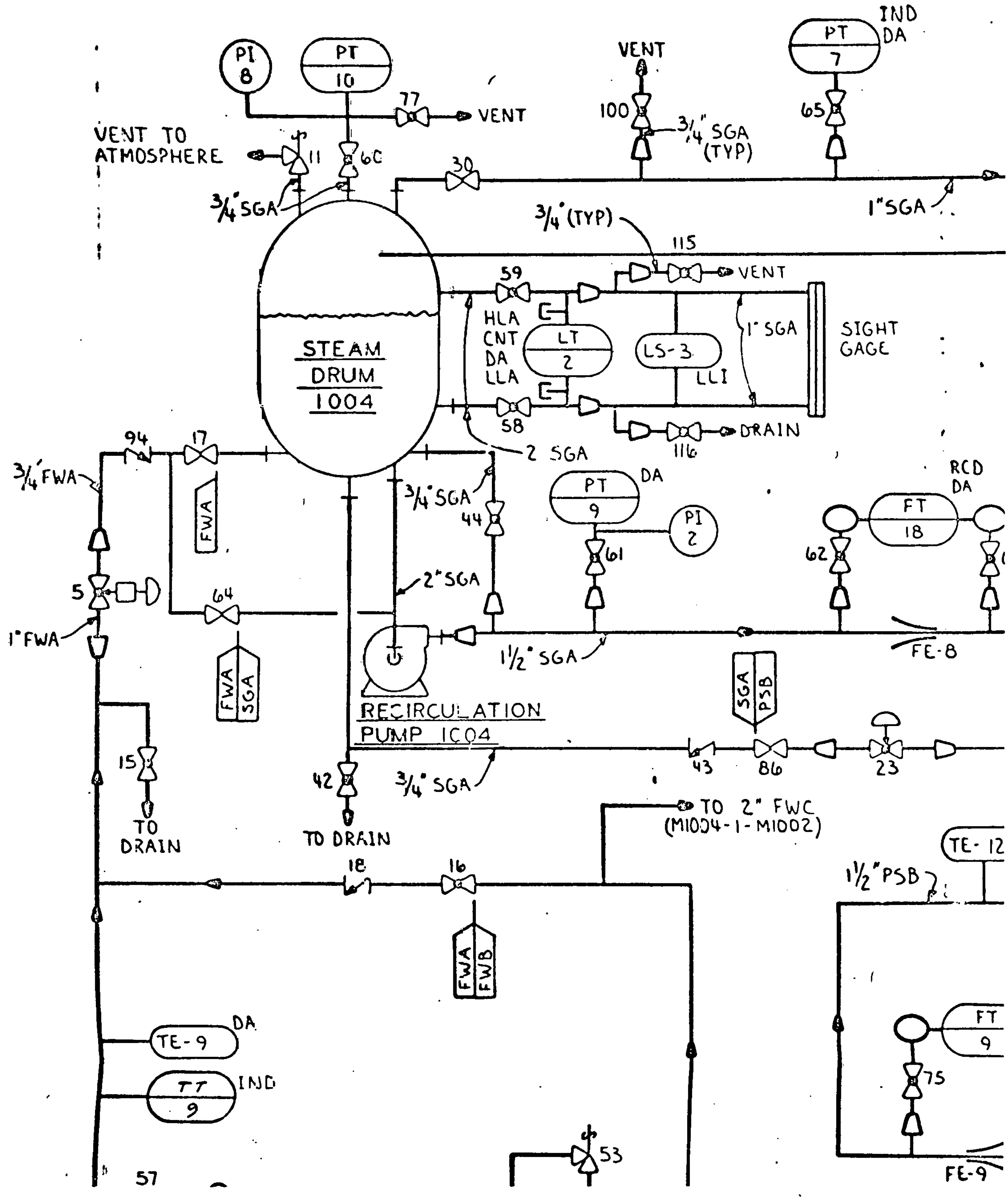


Figure 2. Piping and Instrument Diagram, TSS/RE. (Part of Black & Veatch Drawing No. M1004 to become an enclosure)

Honeywell

SYSTEMS & RESEARCH CENTER Code Ident No. 27327

HONEYWELL REQUIREMENTS SPECIFICATION NO. **HRS** SK-140010

THIS HONEYWELL REQUIREMENTS SPECIFICATION IS FOR:

Recirculation Pump,
Thermal Storage Subsystem Research Experiment,
Solar Pilot Plant

SIGNATURES		DATE
PREPARED BY W. E. Anderson	Willard E. Anderson	5-14-76
APPROVED BY PROJECT ENGR. R. T. LeFrois	R. T. LeFrois	5-19-76
J. C. Powell	J. C. Powell	5/20/76

REVISIONS

LTR	DESCRIPTION	DATE	APPROVAL	LTR	DESCRIPTION	DATE	APPROVAL
A	On p. 4, add ", minimum acceptable", On p. 5, delete "Seal-less" and "Uncooled", add "Continuous, pulsation-free flow", change 510. to 513., change 600. to 558., Update sheet 1, REV BLK.	5/21/76	RTL				

PAGE	1	2	3	4	5	6	7	8	9
REVISION	A			A	A				

PAGE 1 OF 9

HRS SK-140010

1.0 SCOPE

This specification relates to services and materials to be furnished to Honeywell Inc., Energy Resources Center, hereinafter referred to as buyer, by the vendor, hereinafter referred to as seller.

This specification establishes the design, test, performance, stamp and delivery requirements for a recirculation pump and associated items for the Thermal Storage Subsystem Research Experiment (TSS/RE). This experiment is part of the 10-MWe solar pilot plant contract from the buyer's customer, the Energy Research and Development Administration (ERDA).

Background information is presented below under "6.0 NOTES."

2.0 APPLICABLE DOCUMENTS

The following documents of exact issue shown form a part of this specification to the extent specified herein:

- ASME, ANSI, and API Codes as applicable
- All applicable local, state, federal and insurance rules, regulations and codes
- Any other documents normally necessary for the assurance of acceptable device performance, safety of personnel and property, and insurability of personnel and property
- Figure 1 -- Piping and Instrument Diagram, Storage Unit SRE, ERDA - 10 MWe Solar Pilot Plant, Subsystem Research Experiments, Part of Black & Veatch Drawing No. M1004.

3.0 REQUIREMENTS

3.1 Description and Performance

The recirculation pump for the TSS/RE shall pump water essentially at its boiling point through a vaporizer to produce a two-phase steam-water mixture of approximately 20.% quality. The recirculation pump shall be capable of operating satisfactorily over the range of experimental conditions presented below and of interfacing to the extent presented below.

The recirculation pump shall operate for all TSS/RE test conditions, equilibrium or transient. The transient condition of greatest concern is that involving a change in load from 0% to 100% from a hot standby condition at design temperature and pressure.

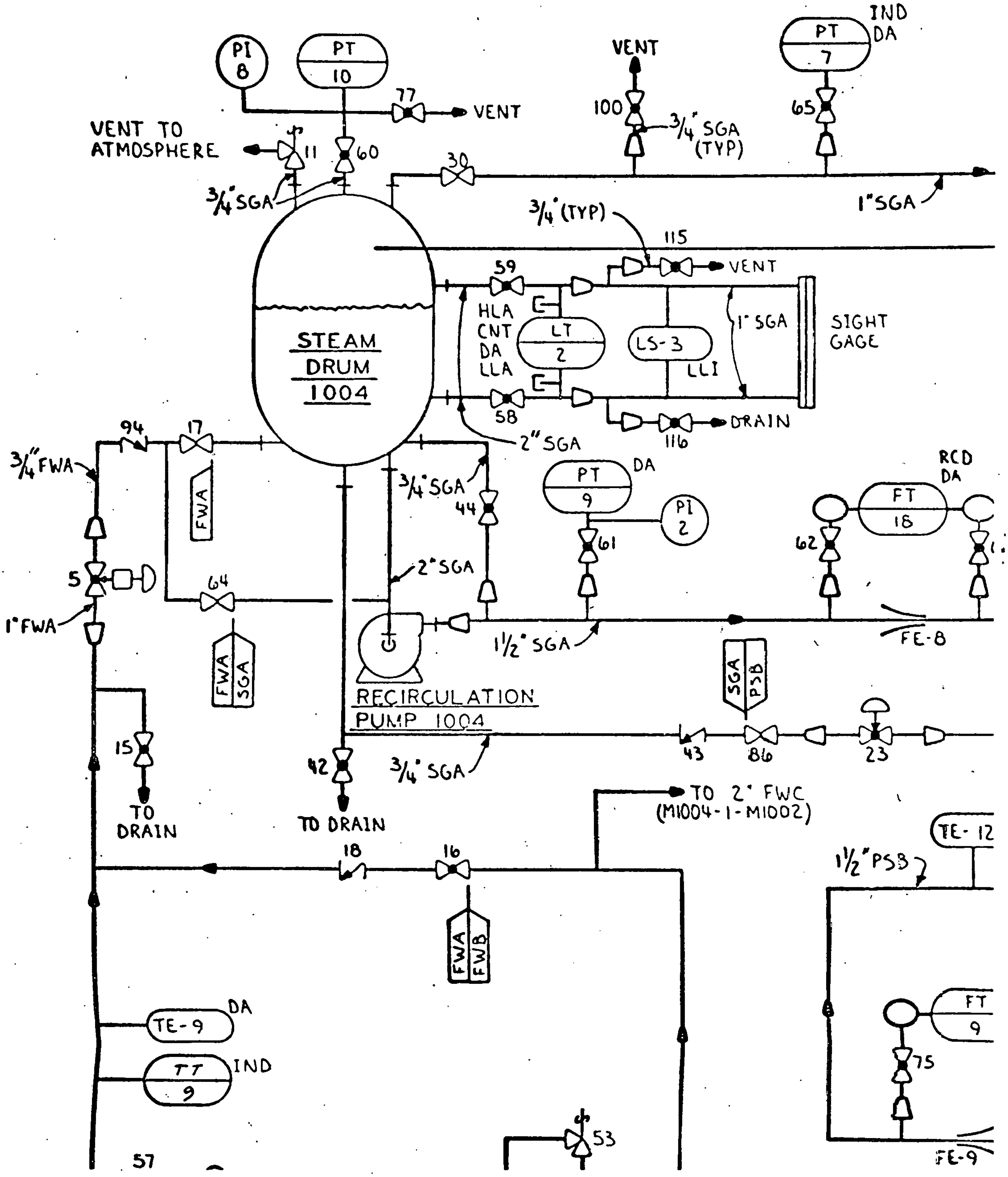


Figure 1. Piping and Instrument Diagram, TSS/RE.
(Part of Black & Veatch Drawing No. M1004)

HRS SK-140010

The pump assembly shall meet reliability specifications common to the commercial practice. The pump assembly shall be easily maintained. The useful life of the pump assembly shall exceed one year for the worst water and operating conditions in this specification.

3.2 Design

3.2.1 Design Data Base -- The temperature and pressures to be used in the designs relative to the TSS/RE are those presented in the table below. These numbers are included to give the seller more understanding of the design factors which follow the table below.

Item	Temperature	Corresponding Saturated Steam Pressure
Melting point of salt (99% $NaNO_3$, 1% NaOH)	578.°F	1306. psia
Temperature limit for salt (1% margin on °F) and design temperature	584.°F	1368. psia
Maximum allowable working pressure and design pressure (10% margin)		1505. psia
Hydrostatic test pressure (50% margin)		2257. psia

The numbers above constitute the basis set. For working purposes, round off the design temperature (584.°F) to 600.°F, the design pressure (1505. psia) to 1500. psig, and the hydrostatic test pressure (2257. psia) to 2250. psig.

3.2.2 Design Factors and Connections -- The table below presents basic requirements for the recirculation pump for the TSS/RE:

Flow Condition	Minimum Design Condition	Maximum Design Condition
Suction pressure, psig	750.	1100.
Discharge pressure, psig	850.	1196.
Head, psi, at operating temperature	100.	96.
Head, feet H_2O, minimum acceptable	298.	327.
NPSH, feet	<12.	<12.

Flow Condition	Minimum Design Condition	Maximum Design Condition
Operating Temperature, ^oF	513.	558.
Flow, gallons/minute, at operating temperature	8. (Note 1)	16. (Note 1)

Design Factor

ASME Code: Section II; Section VIII, Division 1

ANSI and API Codes

All other applicable pump codes

Continuous, pulsation-free flow		
Suction connection, inches	-----2. (Note 2)-----	
Discharge connection, inches	----1.5 (Note 2)-----	
Material to be pumped is water. See Subsection 3.2.3.		
pH	8.5	9.5
Conductivity, μmhos	5. - 10.	50.
Solids	------Negligible------	
Motor power	--480 volts, 3 phase, 60. HZ---	
Design temperature, ^oF	-----600.------------	
Design discharge pressure, psig	-----1500.-----------	
Hydrostatic test, psig	-----2250.-----------	

Continuous duty but off/on for experimental purposes

Calibrated performance curves

Pump/motor assembly to be complete, ready to connect to recirculation system and power.

Note 1: Excess flow may be by-passed. The by-pass flow shall be selectable based on pressure and the use of the calibrated performance curves to be supplied.

Note 2: Smaller connections may be supplied if they adapt to 2 and 1.5 inch pipes and are designed to preclude cavitation.

Since the recirculation pump will be used in an experimental facility, a range of operating conditions departing from nominal will be examined.

3.2.3 Feedwater Specifications -- NSP personnel gave the buyer the following information on their #6 feedwater at their Riverside Plant:

Consideration	Unit #6 Feedwater
pH	8.5 - 9.5
Conductivity (μmhos)	5-10, estimate 50, max., if condenser leaks
Total solids (ppm)	100, max., if condenser leaks
SiO_2 (ppm)	0.25, max.
O_2 (ppm)	0.005
Fe (ppm)	0.01
Cu (ppm)	0.005
Total hardness (ppm)	0
Organics (ppm)	0

3.2.4 Corrosion of Metal Parts -- The materials of the pump assembly shall be compatible with the worst water and operating conditions and the useful life in this specification.

3.3 Mechanical Characteristics Including Interface Considerations

The recirculation pump shall have suitable hardware attached to permit mounting the pump to a horizontal concrete slab. All fittings shall meet all applicable codes.

3.4 Drawings and Documentation

All drawings and documents shall be prepared according to good commercial practice.

3.5 Piping and Instrument Diagram

Figure 1 is part of a drawing by Black & Veatch showing the piping and instrumentation diagram (P&ID) M1004 at the latest revision. The figure illustrates the relationship of the recirculation pump to the subsystem.

4.0 QUALITY ASSURANCE

The recirculation pump and motor assembly shall be constructed under all applicable codes.

The seller shall present, by way of analyses and test results on the seller's letterhead to the buyer, evidence that the assembly will pass all applicable codes and underwriter's tests for safety and insurance purposes.

The assembly shall be subjected to all applicable processes such as post-heat treatment, radiographs and hydrostatic tests as required to ensure safety, insurability and acceptance.

The assembly shall be fabricated and assembled in such a manner as to permit its easy inspection for acceptance.

The assembly shall include applicable stamps and a plate stating the name and address of the manufacturer and of the buyer, an identification number and the date of manufacture.

The assembly shall be warranted and certified to operate for all TSS/RE test conditions, equilibrium or transient. The transient condition of greatest concern is that involving a change in load from 0% to 100% from a hot standby condition at design temperature and pressure.

The casing of the pump must be formed by casting, forging, rolling or die forming.

The pressure parts shall be made of materials permitted under Section II of the ASME Boiler and Pressure Vessel Code or in an accepted standard covering the particular type of pressure part. A published company standard of the pump manufacturer or written certification from the manufacturer that it meets the material requirements of an accepted standard (such as ANSI or API) will be acceptable.

The pressure parts shall be marked with the name or trademark of the manufacturer and such other markings as are required by the above standards. These markings will be accepted as the manufacturer's certification that these parts comply with the above standards and are suitable for service at the specified ratings.

If the casing of the pump is formed by welding, paragraphs PG 11.3.2, 11.3.3 and 11.3.4 of Section I - ASME Boiler and Pressure Vessel Code - will also be mandatory.

The final acceptance of the assembly shall be contingent upon approval by our customer, ERDA, and Northern States Power Company (NSP), the utility which is owner of the site where the assembly will be operated.

5.0 DELIVERY

5.1 Preliminary Documentation

The buyer requires preliminary documentation of interface specifications such as flanges and all information necessary to assure the buyer's customer, ERDA, that the assembly will be acceptable with respect to quality, safety, and insurability. This information shall arrive at the buyer's facility per the schedule to provide time to permit assimilation of the material for use at the Detailed Design Review (DDR) with the buyer's customer, ERDA.

5.2 Recirculation Pump Assembly and Final Documentation

The assembly; full drawings; analyses and test results including calibrated performance characteristics on the seller's letterhead; comprehensive preparation, start-up, operating and maintenance instructions; warranty and certification of performance shall be shipped to arrive at the buyer's facility per the schedule.

The assembly shall be shipped closed to protect the interior. Closure shall be such as to protect flanges, fittings and other hardware in shipment.

6.0 NOTES

6.1 Background Information

The initial phase of an important part of the U.S. solar energy program began in June 1975 when the Energy Research and Development Administration (ERDA) contracted with the buyer to be a prime contractor (Contract No. E(04-3)-1109) for the preliminary design of a 10-MWe solar pilot plant to be built by 1980. Subcontractors to the buyer are Black & Veatch, Babcock & Wilcox, Northern States Power (NSP), and Research Inc. NSP is the utility which is owner of the site where design experiments will be run.

Energy must be stored for use during periods when insolation is not available. The energy storage concept under investigation by the buyer is that of latent heat storage employing the phase change from solid to liquid of inexpensive salts. The salts will be melted by passing steam through a condenser in the storage tanks during periods of insolation. The energy can be removed when insolation is not available by simply reversing the process; i.e., by passing water through a vaporizer in the storage tank to produce steam. This steam will then pass through a steam purifying drum, through a superheater, and on to the turbine. Equilibrium and transient conditions due to clouds must be considered.

But first, since latent heat storage is not well developed but has the potential for cost savings, the buyer must demonstrate its feasibility. Feasibility demonstrations have been performed in the laboratory on a smaller scale. On a larger scale, the present program to further demonstrate feasibility is an experiment called the Thermal Storage Subsystem Research Experiment (TSS/RE). Due to the use of latent heat technology for storage, the system will normally operate at a nearly constant temperature. However, for experimental purposes, tests will be conducted over a range of conditions including temperature, pressure, and flow rate, both at equilibrium and at transient conditions.

6.2 Use of Seller's Expertise

Since the buyer does not design and fabricate recirculation pumps, the buyer desires to utilize the seller's expertise. The buyer's goal is to obtain a recirculation pump assembly which will work in the TSS/RE. The buyer will appreciate the seller's working with the buyer in a candid manner to accomplish this goal.

This being an experiment, the buyer desires a close working relationship with and flexibility on the part of the seller to ensure successful development of the latent heat storage technology.

The recirculation pump assembly for the TSS/RE referred to above is the subject of this specification.

SPP No SK 140002
Date April 26, 1976

Honeywell
Procurement Specification
For
Torque Meters

Prepared By | Thermal Storage Subsystem | Solar Pilot Program Manager

Honeywell Inc
ERC
2700 Ridgway Parkway
Minneapolis, Minnesota 55413

Revision Page

Date	Revision	Date	Revision

SPP NO SK 140002
Date April 26, 1976

TORQUE METER REQUIREMENTS

TECHNICAL REQUIREMENTS. Two torque meters are required to continuously measure torque on two low speed scraper drive units.

DESIGN REQUIREMENTS.

(a) Torque:

Minimum	15 ft-lbf
Maximum	300 ft-lbf

Minimum overload (without damage) 450 ft-lbf.

(b) Speed:

Speed indication requirements:

Minimum	60 RPM
Maximum	400 RPM

(c) Accuracy:

Torque	±1% @ 300 ft-lbf ±5% @ 15 ft-lbf
Speed	±2% @ 60 to 400 RPM

(d) Signal Pickup:

Brushless

(e) Metering:

Display: Analog or digital with a precision of ± 3ft-lbf at 300 ft-lbf and ±0.5 ft-lbf at 15 ft-lbf.

Output: Analog voltage output voltage, impedence less than 1000Ω.

(f) Construction:

Overall length less than 12 inches, with self contained support bearings. Torque and speed pickups should be brushless.

PRICING. A lump sum price should be quoted for the torque meters. Thr price shall include delivery to Honeywell Inc. Energy Resources Center, 2700 Ridgway Parkway, Minneapolis, MN 55413

DELIVERY DATE. The torque meter must be delivered to Honeywell no later than September 30, 1976.

SPP NO. SK 140011
Date May 27, 1976

HONEYWELL

PROCUREMENT SPECIFICATION

FOR

ELECTRIC MOTORS, SPEED CONTROLLERS AND GEAR REDUCERS

Energy Resources Center

Honeywell Inc.

2600 Ridgway Parkway

Minneapolis, Minnesota 55413

Prepared by:	Approved by:	Approved by:
John A. Kallevig	Richard T. LeFrois	Jerry C. Powell

SPP NO. SK 140011
Date May 27, 1976

REVISION PAGE

Date of Revision	Page	Task	Changes Made
5/27/76			Original Issue

SPP NO. SK 140011
Date May 27, 1976

ELECTRIC MOTOR, CONTROLLER AND SPEED REDUCER REQUIREMENTS

TECHNICAL REQUIREMENTS

Two electric motors, controllers, and speed controllers are required to drive the two vaporizer scraper units.

DESIGN REQUIREMENTS

Motor -

(a) Power Output - 5 horsepower

(b) Type - Totally enclosed fan cooled permanent magnet D.C. motor

(c) Speed - 1750 rpm maximum

(d) Frame - 256 U

(e) Armature Voltage - 180 VDC

(f) Armature Current - 24 Amps

CONTROLLER

(a) Model SV 200 Randtronics with Toggle on/off switch.

(b) Input voltage - 240V 60 Hertz single phase

GEAR REDUCER

(a) Input Speed - 1750 rpm maximum

The overall system shall be operable over an output shaft speed range of 50 to 300 rpm and be continuously adjustable.

PRICING

A lump sum price shall be provided for all of the equipment specified as well as individual prices for each item listed. The price shall include delivery to Honeywell Inc., Energy Resources Center, 2600 Ridgway Parkway, Minneapolis, Minnesota 55413.

DELIVERY DATE

The equipment specified must be delivered to Honeywell no later than September 15, 1976.

SPP No. SK 140012

Date: May 28, 1976

HONEYWELL
PROCUREMENT SPECIFICATION
FOR
PHASE CHANGE MATERIALS

J. A. Kallevig
Prepared By

R. T. LeFrois
Thermal Storage Subsystem

J. C. Powell
Solar Power Program Mgr.

Honeywell Inc.
Energy Resources Center
2600 Ridgway Parkway
Minneapolis, Minnesota 55413

SPP No. SK 140012
Date: 28 May 1976

REVISION PAGE

Date of Revision	Page	Task	Change Made
5/28/76			Original Issue

SPP No. SK140012
Date: 28 May 1976

TECHNICAL REQUIREMENTS

The materials sodium nitrate $NaNO_3$ and sodium Hydroxide NaOH are required for use as the phase change material for the storage of heat for the Thermal Storage Subsystem Research Experiment (TSS/RE).

Requirements	Amount Required	Analysis	Comments
$NaNO_3$	34 tons	99.4% $NaNO_3$	Pellets
NaOH Flake Form	800 lbs.	98% NaOH	Flake form industrial grade

Packaging

$NaNO_3$ - 100 lb. 4-ply polyethylene lined paper bags
NaOH - 100 lb drums

Pricing

A lump sum price shall be provided for the entire shipment as well as a quantity breakdown. The price shall include delivery to NSP, Riverside Plant, 2800 Marshall Avenue N. E., Minneapolis, Minnesota 55418

Delivery Date

The materials specified must be delivered to NSP on or before November 1, 1976.

SPP No. SK 140012

Date: May 28, 1976

HONEYWELL PROCUREMENT SPECIFICATION FOR PHASE CHANGE MATERIALS

J. A. Kallevig
Prepared By

R. T. LeFrois
Thermal Storage Subsystem

J. C. Powell
Solar Power Program Mgr.

Honeywell Inc.
Energy Resources Center
2600 Ridgway Parkway
Minneapolis, Minnesota 55413

SPP No. SK 140012
Date: 28 May 1976

REVISION PAGE

Date of Revision	Page	Task	Change Made
5/28/76			Original Issue

SPP No. SK140012

Date: 28 May 1976

TECHNICAL REQUIREMENTS

The materials sodium nitrate $NaNO_3$ and sodium Hydroxide NaOH are required for use as the phase change material for the storage of heat for the Thermal Storage Subsystem Research Experiment (TSS/RE).

Requirements	Amount Required	Analysis	Comments
$NaNO_3$	34 tons	99.4% $NaNO_3$	Pellets
NaOH Flake Form	800 lbs.	98% NaOH	Flake form industrial grade

Packaging

$NaNO_3$ - 100 lb. 4-ply polyethylene lined paper bags

NaOH - 100 lb drums

Pricing

A lump sum price shall be provided for the entire shipment as well as a quantity breakdown. The price shall include delivery to NSP, Riverside Plant, 2800 Marshall Avenue N. E., Minneapolis, Minnesota 55418

Delivery Date

The materials specified must be delivered to NSP on or before November 1, 1976.

Specification Continued

The following General Construction Specifications are not included in this document but are available.

Spec. No.	Date	Title	Organization
7021-D-2A	4/14/76	General Construction Specifications	Black & Veatch
7021-M-22A	4/16/76	Steam Desuperheater	"
7021-M-22B	"	Fluid Discharge Diffuser	"
7021-M-28A	"	Duplex Strainer	"
7021-M-28B	"	Pressure Reducing Orifice	"
7021-M-42A	"	Large Steel Valves	"
7021-M-42B	"	Small Steel Valves	"
7021-M-42C	"	Bronze Valves	"
7021-M-44A	"	Safety & Relief Valves	"
7021-M-44B	"	Control Valves	"

STATEMENTS OF WORK

SOW NO.	DATE	TITLE	ORGANIZATION
F3419-PM-108	4/26/76	Design and Fabrication of Storage Tank for TSS/RE	Honeywell
F3419-PM-112		Design and Fabrication of Salt Pre-melt for TSS/RE	"
F3419-PM-109	4/27/76	Design and Fabrication of Condenser Module for TSS/RE	"
F3419-PM-110	4/29/76	Design and Fabrication of Vaporizer Submodule for TSS/RE	"
F3419-PM-111	4/23/76	Steam Drum, TSS/RE	"

SOW No. F3419-PM-108
Dated: 26 April 1976

SOLAR PILOT PLANT

Statement of Work
For
Design and Fabrication of Storage Tank
For
Thermal Storage Subsystem Research Experiment

Systems and Research Center
(Energy Resources Center)
Honeywell, Inc.
Minneapolis, Minnesota

J. A. Kallevig   R. T. LeFrois   J. C. Powell

STATEMENT OF WORK

NO. F3419-PM-108

REVISION SHEET

Date of Revision	Page	Task	Change Made
26 April 1976	---	---	Original Issue

GENERAL:

This Statement of Work covers the furnishing of subject equipment and material as described in the paragraphs "TECHNICAL REQUIREMENTS" complete with manufacturer's drawings, and services as specified.

TERMS AND CONDITIONS:

The company "ADDITIONAL TERMS AND CONDITIONS APPLICABLE TO ERDA FIXED PRICE SUBCONTRACTS" FORM PTC-30 (10/75) shall apply except Article 7, "WARRANTIES" is deleted.

SPECIAL CONDITIONS:

Warranty -- The Supplier shall warrant that the equipment and materials will be as specified and will be free from defects in design, workmanship and materials. If within the warranty period the material or equipment fails to meet the provisions of this warranty, the Supplier shall promptly correct any defects, including non-conformance with the documents by adjustment, repair or replacement of all defective parts or materials.

Unless otherwise specified, the warranty period shall begin on the date of initial operation and shall end 12 months later or twenty-four (24) months following the date of shipment, whichever occurs first.

The Supplier shall pay all costs for correction of defects, including transportation, materials, parts, supplies and special tools; provided upon notification and substantiation that equipment has been maintained and operated in accordance with the Supplier's recommendations and usual industry practice.

Shipment -- Ship cheapest way unless specified otherwise in the purchase order.

Payment Terms -- Shall be net 30 days in accordance with Terms and Conditions Article 5, "INVOICING".

Definitions -- The following definitions shall apply to this purchase:

a. "Documents" shall include the following:

   1. This Statement of Work including Terms and Conditions, General Requirements, Technical Requirements, and all revisions thereto.

   2. The Company's purchase order and purchase order revision notices.

   3. All data submitted by the Supplier, provided such are acceptable to the Engineer and in accordance with this Bill of Material. These documents collectively shall form the purchase agreement between the Company and Supplier.

b. "Company shall mean Honeywell Inc, 2600 Ridgway Parkway, Minneapolis, Minnesota 55413, and its duly authorized agents.

c. "Supplier" shall mean the corporation, company, partnership, firm or individual, named and designated in the Company's purchase order, who has entered into this purchase agreement with the Company.

d. "Engineer" shall mean Richard LeFrois, Honeywell, Inc., 2600 Ridgway Parkway, Minneapolis, Minnesota 55413.

GENERAL REQUIREMENTS:

The following general requirements are applicable to the purchase of this equipment.

Delivery -- Complete delivery for all items shall be made FOB point of shipment to Honeywell Inc., 1433 Stinson Blvd, N. E. Minneapolis, Minnesota, 55413. Date of shipment shall be on or before 15 September 1976.

Identification -- All drawings, correspondence, shipping papers and other documents shall be identified with the Purchase Order Number and Project and Bill of Material numbers.

Drawings -- Six prints of all drawings shall be submitted to the Company for review. One copy of the drawings will be returned to the supplier.

Drawings reviewed by the Engineer will be returned to the Supplier marked RETURNED FOR CORRECTION, EXCEPTIONS NOTED, NO EXCEPTIONS NOTED, or RECEIVED FOR DISTRIBUTION.

When drawings and data re returned marked EXCEPTIONS NOTED, the changes shall be made as noted thereon and 20 corrected copies shall be submitted to the Company.

When the drawings and data are returned marked RETURNED FOR CORRECTION, the corrections shall be made as noted thereon and as instructed by the Company and six corrected copies shall be submitted to the Company.

When drawings are returned marked NO EXCEPTIONS NOTED or RECEIVED FOR DISTRIBUTION, the Supplier shall submit 14 drawings for final distribution.

The Company shall have the right to reproduce all data provided in order to satisfy U. S. Government contractual requirements.

TECHNICAL REQUIREMENTS:

One thermal energy storage (TES) subsystems research experiment (SRE) storage tank as specified herein shall be supplied.

CODE REQUIREMENTS:

The storage tank shall be designed and constructed in accordance with the latest applicable requirements of all Federal, State and Local codes.

Type -- The storage tank shall have a removable top with access holes as shown in the attached drawing.

Design Criteria -- The storage tank must meet the following conditions:
Size: 8. 4 ft long x 3. 4 ft wide x 8. 3 ft high, inside dimensions
Construction: CS-SA-283B Steel or equivalent
Pressure: 10. 3 PSIG at the bottom
Temperature: 650°F
The inside must be smooth and free of bumps, holes and crevices that could corrode easily and/or make removal of the salt difficult.
4 lifting eyes must be provided on the inside for lifting the tank.

Identification -- The storage tank must have a permanently stamped model tag in accordance with the applicable code.

Pricing -- The price of this contract shall be divided into two parts:

Part 1: Price for Task 1.0, Thermal Tank Design and Analysis

Part 2: Price to fabricate, test and deliver the thermal storage tank.

STATEMENT OF WORK

1.0 INTRODUCTION

This Statement of Work defines the tasks which are to be performed by the vendor (herein referred to as vendor) for Honeywell, Inc., Energy Resources Center (hereinafter referred to as Honeywell) during the period of contract performance.

2.0 SCOPE

The vendor shall provide the necessary service, material, and personnel required to design, fabricate, test, and deliver, one (1) storage tank which will meet the requirements of specification SK 133289 dated 23 April 1976.

3.0 TASKS

The following tasks shall be conducted by the vendor:

Task 1

Design one (1) thermal storage tank and provide necessary drawings and detailed documentation to show that the design meets or exceeds all requirements or the applicable codes in accordance with Exhibit A.

Task 2

Fabricate, test and deliver one (1) thermal storage tank which meets the requirements of specification SK 140008. Delivery shall be in accordance with Exhibit B, Schedules.

EXHIBIT A: CONTRACT DATA REQUIREMENTS LIST

1. Sequence Number	2. Title or Description of Data		3. Contract Reference	4. Frequency
5. Date of First Submission	6. Date of Subsequent Submission	7. Distribution and Addresses		
Remarks				
1.	2. Thermal Storage Tank Conceptual Design		3. SOW	4. One Time
5. TBD	6. TBD	7. Honeywell For Item 5 - 1 reproducible + 6 copies For Item 6 - 1 reproducible + 6 copies		

8\.

The subcontractor shall prepare and submit a Thermal Storage Tank Conceptual Design for Honeywell and NSP approval. Design data shall be prepared and delivered in written form and also presented orally by the Principal Investigator. The subcontractors format may be used.

The data shall include all drawings, specifications, analyses, etc., as specified in the subcontract and covering the subject contents as indicated by Item 3 above. The drawings shall be formatted according to good commercial practice.

The data shall be delivered for review as stipulated in Items 5 and 7 above.

Honeywell will provide a copy of its analysis and design. The vendor may review it, use it as is or modify it. However, the vendor shall provide a copy of his analysis and design to Honeywell per above. Even if vendor's analysis agrees completely with Honeywell's this shall not relieve vendor of full and complete responsibility for the delivery or a safe and acceptance tank to Honeywell.

The oral presentation shall be made following the delivery of the data and at suchplace as directed by the Honeywell Program Manager. The technical review will be completed and notice of approval or non-approval delivered to the subcontractor within 40 days from receipt of original data. The subcontractor shall then make the corrections and revisions delineated in the review notice and submit final copies as stipulated in Items 6 and 7 above. Acceptance of the final version as satisfying this CDRL line item is dependent upon Honeywell approval of the data.

EXHIBIT B

SCHEDULES

The subcontractor shall accomplish the effort called for in the Statement of Work F3419-PM-108 and shall provide the following deliverables and comply with the following schedule.

Item Number		Quantity	Delivery/ Acceptance Date
1	Thermal Storage Tank	1	
2	Documents per Exhibit A, Statement of Work	*	**

* In accordance with Block 7 of Exhibit A

** In accordance with Blocks 5 and 6 of Exhibit A

Date May 12, 1976

SOW NO. F3419-PM-112

SOLAR PILOT PLANT

STATEMENT OF WORK

FOR

DESIGN AND FABRICATION OF SALT PRE-MELT MODULE

FOR

THERMAL STORAGE SUBSYSTEMS RESEARCH EXPERIMENT

Energy Resources Center

Honeywell Inc.

2600 Ridgway Parkway

Minneapolis, Minnesota 55413

John A. Kallevig   Richard LeFrois   Jerry C. Powell

STATEMENT OF WORK

NO. F3419-PM-112

REVISION SHEET

Date of Revision	Page	Task	Change Made
5/12/76			Criginal Issue

GENERAL

This statement of work covers the furnishing of subject equipment and material as described in the paragraphs "TECHNICAL REQUIREMENTS" complete with manufacturer's drawings, and services as specified.

TERMS AND CONDITIONS

The company "ADDITIONAL TERMS AND CONDITIONS APPLICABLE TO ERDA FIXED PRICE SUBCONTRACTS" FORM PTC-30 (10/75) shall apply except Article 7, "WARRANTIES" is deleted.

SPECIAL CONDITIONS

Warranty. The Supplier shall warrant that the equipment and materials will be as specified and will be free from defects in design, workmanship and materials. If within the warranty period the material or equipment fails to meet the provisions of this warranty, the Supplier shall promptly correct any defects, including non-conformance with the documents by adjustment, repair or replacement of all defective parts or materials.

Unless otherwise specified, the warranty period shall begin on the date of initial operation and shall end 12 months later or twenty-four (24) months following the date of shipment, whichever occurs first.

The supplier shall pay all costs for correction of defects, including transportation, materials, parts, supplies and special tools; provided upon notification and substantiation that the equipment has been maintained and operated in accordance with the Supplier's recommendations and usual industry practice.

Shipment. Ship cheapest way unless specified otherwise in the purchase order.

Payment Terms. Shall be net 30 days in accordance with Terms and Conditions Article 5, "INVOICING".

Definitions. The following definitions shall apply to this purchase:

a. "Documents" shall include the following:

1. This statement of work including Terms and Conditions, General Requirements, Technical Requirements, and all revisions thereto.

2. The Company's purchase order revision notices.

3. All data submitted by the Supplier, provided such are acceptable to the Engineer and in accordance with this statement of work. These documents collectively shall form the purchase agreement between the Company and Supplier.

b. "Company" shall mean Honeywell Incorporated, 2600 Ridgway Parkway, Minneapolis, Minnesota 55413, and its duly authorized agents.

c. "Supplier" shall mean the corporation, company, partnership, firm or individual, named and designated in the Company's purchase order, who has entered into this purchase agreement with the Company.

d. "Engineer" shall mean Richard LeFrois, Honeywell Incorporated, 2600 Ridgway Parkway, Minneapolis, Minnesota 55413.

GENERAL REQUIREMENTS

The following general requirements are applicable to the purchase of this equipment.

Delivery. Complete delivery for all items shall be made FOB point of shipment to Honeywell Inc., 1433 Stinson Blvd., NE Minneapolis, MN 55413. Date of shipment shall be on or before 1st September, 1976.

Identification. All drawings, correspondence, shipping papers and other documents shall be identified with the Purchase Order Number and Project and Statement of Work numbers.

Drawings. Six prints of all drawings shall be submitted to the Company for review. One copy of the drawings will be returned to the Supplier.

Drawings reviewed by the Engineer will be returned to the Supplier marked RETURNED FOR CORRECTION, EXCEPTIONS NOTED, NO EXCEPTIONS NOTED, OR RECEIVED FOR DISTRIBUTION.

When drawings and data are returned marked EXCEPTIONS NOTED, the changes shall be made as noted thereon and 20 corrected copies shall be submitted to the Company.

When the drawings and data are returned marked RETURNED FOR CORRECTION, the corrections shall be made as noted thereon and as instructed by the Company and six corrected copies shall be submitted to the Company.

When drawings are returned marked NO EXCEPTIONS NOTED or RECEIVED FOR DISTRIBUTION, the Supplier shall submit 14 drawings for final distribution.

The Company shall have the right to reproduce all data provided in order to satisfy U.S. Government contractual requirements.

TECHNICAL REQUIREMENTS

One thermal energy storage (TES) subsystems research experiment (SRE) salt pre-melt module as specified herein shall be supplied.

CODE REQUIREMENTS

The salt pre-melt module shall be designed and constructed in accordance with the latest applicable requirements of all Federal, State, and Local codes.

TYPE

The salt pre-melt module shall consist of a finned tube single loop heat exchanger. This salt pre-melt module shall be immersed in salt in the thermal storage tank. Steam condensing in the salt pre-melt module will heat the salt.

DESIGN CRITERIA

The following salt pre-melt design parameters shall be met:

Steam Conditions	-	1000 PSIA/700 ^{o}F
Pipe Size	-	1.0 in. O.D. 0.834 in. I.D.
Pipe Material	-	A106A Steel
Module Size	-	39 ft. tube length in a single loop of finned tubing

CONSTRUCTION

The salt pre-melt module shall be constructed of Fintube as shown on the Honeywell drawing SK 140009 or equivalent. The downcomers shall have 1.0 O.D. tube with .083 wall with longitudinal fins, 12 fins 3/4 in. high. This section shall be bolted to the lower section by Class 1500 Steel Flanges, 3/4 in. nominal pipe size using 1.09 diameter socket welded flanges. The bottom section shall be made up of finned tubing 1.0 in. O.D. tube x .083 wall with 2.67 fins/inch ½" high.

IDENTIFICATION

The salt pre-melt module shall have a permanently stamped tag which is in accordance with the applicable code permanently attached to it.

PRICING

The price of this contract shall be divided into two parts:

Part 1 - Price for Task 1, Salt Pre-melt Design and Analysis

Part 2 - Price to Fabricate, Test and Deliver the Salt Pre-melt Module.

SALT PRE-MELT MODULE

STATEMENT OF WORK

This statement of work defines the tasks which are to be performed by the subcontractor for Honeywell Inc. Energy Resources Center (Hereinafter referred to as Honeywell) during the period of contract performance.

SCOPE

The supplier shall provide the necessary services, material, and personnel required to design, fabricate, test, and deliver one (1) salt pre-melt module which will meet the requirements of specification SK 140009 dated May 12, 1976. The salt pre-melt module shall include the supporting structure to attach it inside of the thermal storage tank.

TASKS

The following specific tasks shall be conducted by the subcontractor:

Task 1 Design one (1) salt pre-melt module which meets the requirements of specification SK 140009. This shall include documentation to show that the design meets or exceeds all requirements of the applicable codes in accordance with Exhibit A. Delivery shall be in accordance with Exhibit B, Schedules.

Task 2 Fabricate, test and deliver one (1) salt pre-melt module which meets the requirements of specification SK 140009. Delivery shall be in accordance with Exhibit B, Schedules.

EXHIBIT A: CONTRACT DATA REQUIREMENTS LIST

1. Sequence Number	2. Title or Description of Data	3. Contract Reference	4. Frequency
5. Date of First Submission	6. Date of Subsequent Submission	7. Distribution and Addresses	
Remarks			
1. RI 1-4	2. Salt Pre-melt module Conceptual Design	3. SOW 1.3	4. One Time
5. TBD	6. TBD	7. Honeywell For Item 5 - 1 reproducible + 6 copies For Item 6 - 1 reproducible + 6 copies	

8.

The Subcontractor shall prepare and submit a salt pre-melt module design for Honeywell and NSP approval. Design data shall be prepared and delivered in written form. The subcontractors format may be used.

The data shall include all drawings, specifications, analyses, etc. as specified in the subcontract and covering the subject contents as indicated by Item 3 above. The drawings shall be formatted according to good commercial practice.

Honeywell will provide a copy of its analysis and design. The vendor may review it, use it as is or modify it. However, the vendor shall provide a copy of his analysis and design to Honeywell per above. Even if vendor's analysis agrees completely with Honeywell's, this shall not relieve vendor of full and complete responsibility for the delivery of a safe and acceptable salt pre-melt module to Honeywell.

The data shall be delivered for review as stipulated in Items 5 and 7 above.

The technical review will be completed and notice of approval or non-approval delivered to the subcontractor within 40 days from receipt of original data. The subcontractor shall then make the corrections and revisions delineated in the review notice and submit final copies as stipulated in Items 6 and 7 above. Acceptance of the final version as satisfying this CDRL line item is dependent upon Honeywell approval of the data.

EXHIBIT B

SCHEDULES

The subcontractor shall accomplish the effort called for in the statement of work F3419-PM-112 and shall provide the following deliverables and comply with the following schedule.

ITEM NUMBER		QUANTITY	DELIVERY/ ACCEPTANCE DATE
1	Salt Pre-melt module including Supports	1	1 Sept., 1976
2	Document per Exhibit A, Statement of Work	*	**

* In accordance with Block 7 of Exhibit A

** In accordance with Blocks 5 & 6 of Exhibit A

Date April 28, 1976

SOW No. F3419-PM-109

SOLAR PILOT PLANT
STATEMENT OF WORK
FOR
DESIGN AND FABRICATION OF CONDENSER MODULE
FOR
THERMAL STORAGE SUBSYSTEMS RESEARCH EXPERIMENT

Energy Resources Center

Honeywell Inc.

2600 Ridgway Parkway

Minneapolis, Minnesota 55413

John A. Kallevig | Richard LeFrois | Jerry C. Powell

STATEMENT OF WORK

NO. F3419-PM-109

REVISION SHEET

Date of Revision	Page	Task	Change Made
4/27/76			Original Issue

GENERAL

This statement of work covers the furnishing of subject equipment and material as described in the paragraphs "TECHNICAL REQUIREMENTS" complete with manufacturer's drawings, and services as specified.

TERMS AND CONDITIONS

The company "ADDITIONAL TERMS AND CONDITIONS APPLICABLE TO ERDA FIXED PRICE SUBCONTRACTS" FORM PTC-30 (10/75) shall apply except Article 7, "WARRANTIES" is deleted.

SPECIAL CONDITIONS

Warranty. The Supplier shall warrant that the equipment and materials will be as specified and will be free from defects in design, workmanship and materials. If within the warranty period the material or equipment fails to meet the provisions of this warranty, the Supplier shall promptly correct any defects, including non-conformance with the documents by adjustment, repair or replacement of all defective parts or materials.

Unless otherwise specified, the warranty period shall begin on the date of initial operation and shall end 12 months later or twenty-four (24) months following the date of shipment, whichever occurs first.

The Supplier shall pay all costs for correction of defects, including transportation, materials, parts, supplies and special tools; provided upon notification and substantiation that the equipment has been maintained and operated in accordance with the Supplier's recommendations and usual industry practice.

Shipment. Ship cheapest way unless specified otherwise in the purchase order.

Payment Terms. Shall be net 30 days in accordance with Terms and Conditions Article 5, "INVOICING".

Definitions. The following definitions shall apply to this purchase:

a. "Documents" shall include the following:

1. This statement of work including Terms and Conditions, General Requirements, Technical Requirements, and all revisions thereto.

2. The Company's purchase order revision notices.

3. All data submitted by the Supplier, provided such are acceptable to the Engineer and in accordance with this statement of work. These documents collectively shall form the purchase agreement between the Company and Supplier.

b. "Company" shall mean Honeywell Incorporated, 2600 Ridgway Parkway, Minneapolis, Minnesota 55413, and its duly authorized agents.

c. "Supplier" shall mean the corporation, company, partnership, firm or individual, named and designated in the Company's purchase order, who has entered into this purchase agreement with the Company.

d. "Engineer" shall mean Richard LeFrois, Honeywell Incorporated, 2600 Ridgway Parkway, Minneapolis, Minnesota 55413.

GENERAL REQUIREMENTS

The following general requirements are applicable to the purchase of this equipment.

Delivery. Complete delivery for all items shall be made FOB point of shipment to Honeywell Inc., 1433 Stinson Blvd. NE Minneapolis, MN 55413. Date of shipment shall be on or before 1st September, 1976.

Identification. All drawings, correspondence, shipping papers and other documents shall be identified with the Purchase Order Number and Project and Statement of Work numbers.

Drawings. Six prints of all drawings shall be submitted to the Company for review. One copy of the drawings will be returned to the supplier.

Drawings reviewed by the Engineer will be returned to the Supplier marked RETURNED FOR CORRECTION, EXCEPTIONS NOTED, NO EXCEPTIONS NOTED, OR RECEIVED FOR DISTRIBUTION.

When drawings and data are returned marked EXCEPTIONS NOTED, the changes shall be made as noted thereon and 20 corrected copies shall be submitted to the Company.

When the drawings and data are returned marked RETURNED FOR CORRECTION, the corrections shall be made as noted thereon and as instructed by the Company and six corrected copies shall be submitted to the Company.

When drawings are returned marked NO EXCEPTIONS NOTED or RECEIVED FOR DISTRIBUTION, the Supplier shall submit 14 drawings for final distribution.

The Company shall have the right to reproduce all data provided in order to satisfy U.S. Government contractual requirements.

TECHNICAL REQUIREMENTS

One thermal energy storage (TES) subsystems research experiment (SRE) condenser module as specified herein shall be supplied.

CODE REQUIREMENTS

The condenser module shall be designed and constructed in accordance with the latest applicable requirements of all Federal, State and Local codes.

TYPE

The condenser module shall consist of a bare tube serpentine heat exchanger with supporting structure. This condenser module shall be immersed in salt in the thermal storage tank. Steam condensing in the condenser module will heat the salt.

DESIGN CRITERIA

The following condenser design parameters shall be met:

Steam Conditions - 1962 PSIA/635°F

Pipe Size - 1.0 in. O.D. 0.732 in. I.D.

Pipe Material - A106A Steel

Module Size - 544 ft. tube length in a single serpentine of 71 legs in 2 rows.

CONSTRUCTION

The condenser module shall be bent up of 1" O.D. A106A steel tubing into a single serpentine of 71 legs in 2 rows or equivalent. The ends of the tubing shall have flanged fittings for connection to the downcomers. The downcomers shall be of 1 in. O.D. longitudinally finned tubing with a mating flange to match the flange on the serpentine.

IDENTIFICATION

The condenser module shall have a permanently stamped tag which is in accordance with the applicable code permanently attached to it.

PRICING

The price of this contract shall be divided into two parts:

Part 1 - Price for Task 1, Thermal Tank Design and Analysis

Part 2 - Price to Fabricate, Test and Deliver the Condenser Module.

CONDENSER MODULE

STATEMENT OF WORK

This statement of work defines the tasks which are to be performed by the subcontractor for Honeywell Inc. Energy Resources Center (Hereinafter referred to as Honeywell) during the period of contract performance.

SCOPE

The supplier shall provide the necessary services, material, and personnel required to design, fabricate, test, and deliver one (1) condenser module which will meet the requirements of specification SK 133500 dated 4/27/76. The condenser module shall include the supporting structure to attach it inside of the thermal storage tank.

TASKS

The following specific tasks shall be conducted by the subcontractor:

Task 1 Design one (1) condenser module which meets the requirements of specification SK 133500. This shall include documentation to show that the design meets or exceeds all requirements of the applicable codes in accordance with Exhibit A. Delivery shall be in accordance with Exhibit B, Schedules.

Task 2 Fabricate, test and deliver one (1) condenser module which meets the requirements of specification SK 133500. Delivery shall be in accordance with Exhibit B, Schedules.

EXHIBIT A: CONTRACT DATA REQUIREMENTS LIST

1. Sequence Number	2. Title or Description of Data	3. Contract Reference	4. Frequency
5. Date of First Submission	6. Date of Subsequent Submission	7. Distribution and Addresses	
Remarks			
1. RI 1-4	2. Condenser Module Conceptual Design	3. SOW 1.3	4. One Time
5. TBD	6. TBD	7. Honeywell For Item 5 - 1 reproducible + 6 copies For Item 6 - 1 reproducible + 6 copies	

8.

The Subcontractor shall prepare and submit a condenser module design for Honeywell and NSP approval. Design data shall be prepared and delivered in written form. The subcontractors format may be used.

The data shall include all drawings, specifications, analyses, etc. as specified in the subcontract and covering the subject contents as indicated by Item 3 above. The drawings shall be formatted according to good commercial practice.

Honeywell will provide a copy of its analysis and design. The vendor may review it, use it as is or modify it. However, the vendor shall provide a copy of his analysis and design to Honeywell per above. Even if vendor's analysis agrees completely with Honeywell's, this shall not relieve vendor of full and complete responsibility for the delivery of a safe and acceptable condenser module to Honeywell.

The data shall be delivered for review as stipulated in Items 5 and 7 above.

The technical review will be completed and notice of approval or non-approval delivered to the subcontractor within 40 days from receipt of original data. The subcontractor shall then make the corrections and revisions delineated in the review notice and submit final copies as stipulated in Items 6 and 7 above. Acceptance of the final version as satisfying this CDRL line item is dependent upon Honeywell approval of the data.

EXHIBIT B

SCHEDULES

The subcontractor shall accomplish the effort called for in the statement of work F3419-PM-109 and shall provide the following deliverables and comply with the following schedule.

ITEM NUMBER		QUANTITY	DELIVERY/ ACCEPTANCE DATE
1	Condenser module including Supports	1	1 Sept., 1976
2	Document per Exhibit A, Statement of Work	*	**

* In accordance with Block 7 of Exhibit A

** In accordance with Blocks 5 & 6 of Exhibit A

SOW No. F3419 PM-110

Date April 28, 1976

SOLAR PILOT PLANT

Statement of Work

For

Design and Fabrication of Vaporizer Module

For

Thermal Storage Subsystems Research Experiment

Honeywell Inc.

Energy Resources Center

2600 Ridgway Parkway

Minneapolis, Minnesota 55413

Prepared by:	Approved by:	Approved by:
John A. Kallevig	R. LeFrois	J.C. Powell

STATEMENT OF WORK

No. F3419 PM-110

REVISION SHEET

Date of Revision	Page	Task	Change Made
4/29/76			Original Issue

GENERAL: This statement of work covers the furnishing of subject equipment and material as described in the paragraphs "TECHNICAL REQUIREMENTS" complete with manufacturer's drawings, and services as specified.

TERMS AND CONDITIONS: The company "ADDITIONAL TERMS AND CONDITIONS - APPLICABLE TO ERDA FIXED PRICE SUBCONTRACTS" FORM PTC-30 (10/75) shall apply except Article 7, "WARRANTIES" is deleted.

SPECIAL CONDITIONS:

Warranty. The Supplier shall warrant that the equipment and materials will be as specified and will be free from defects in design, workmanship and materials. If within the warranty period the material or equipment fails to meet the provisions of this warranty, the Supplier shall promptly correct any defects, including non-conformance with the documents by adjustment, repair or replacement of all defective parts or materials.

Unless otherwise specified, the warranty period shall begin on the date of initial operation and shall end 12 months later or twenty-four (24) months following the date of shipment, whichever occurs first.

The Supplier shall pay all costs for correction of defects, including transportation, materials, parts, supplies and special tools; provided upon notification and substantiation that equipment has been maintained and operated in accordance with the Supplier's recommendations and usual industry practice.

Shipment. Ship cheapest way unless specified otherwise in the purchase order.

Payment Terms. Shall be net 30 days in accordance with Terms and Conditions Article 5, "INVOICING".

Definitions. The following definitions shall apply to this purchase:

a. "Documents" shall include the following:

    1. This Statement of Work including Terms and Conditions, General Requirements, Technical Requirements, and all revisions thereto.

    2. The Company's purchase order and purchase order revision notices.

    3. All data submitted by the Supplier, provided such are acceptable to the Engineer and in accordance with this Statement of Work. These documents collectively shall form the purchase agreement between the Company and Supplier.

b. "Company" shall mean Honeywell Incorporated, 2600 Ridgway Parkway, Minneapolis, Minnesota 55413, and its duly authorized agents.

c. "Supplier" shall mean the corporation, company, partnership, firm or individual, named and designated in the Company's purchase order, who has entered into this purchase agreement with the Company.

d. "Engineer" shall mean Richard LeFrois, Honeywell Incorporated, 2600 Ridgway Parkway, Minneapolis, Minnesota 55413.

GENERAL REQUIREMENTS. The following general requirements are applicable to the purchase of this equipment.

Delivery. Complete delivery for all items shall be made FOB point of shipment to Honeywell Inc., 1433 Stinson Blvd. NE Minneapolis, MN 55413. Date of shipment shall be on or before September 15, 1976.

Identification. All drawings, correspondence, shipping papers and other documents shall be identified with the Purchase Order Number and Project and statement of work numbers.

Drawings. Six prints of all drawings shall be submitted to the Company for review. One copy of the drawings will be returned to the Supplier.

Drawings reviewed by the Engineer will be returned to the Supplier marked RETURNED FOR CORRECTION, EXCEPTIONS NOTED, NO EXCEPTIONS NOTED, or RECEIVED FOR DISTRIBUTION.

When drawings and data are returned marked EXCEPTIONS NOTED, the changes shall be made as noted thereon and 20 corrected copies shall be submitted to the Company.

When the drawings and data are returned marked RETURNED FOR CORRECTION, the corrections shall be made as noted thereon and as instructed by the Company and six corrected copies shall be submitted to the Company.

When drawings are returned marked NO EXCEPTIONS NOTED or RECEIVED FOR DISTRIBUTION, the Supplier shall submit 14 drawings for final distribution.

The Company shall have the right to reproduce all data provided in order to satisfy U.S. Government contractual requirements.

TECHNICAL REQUIREMENTS. One thermal energy storage (TES) subsystems research experiment (SRE) vaporizer complete with scrapers and drive mechanism and tank cover as specified herein shall be supplied.

CODE REQUIREMENTS. The vaporizer module shall be constructed in accordance with the latest applicable requirements of all Federal, State, Local and Insurance codes.

TYPE. The vaporizer module shall consist of a pair of bare tube serpentine heat exchangers with supporting structures. All of this will be supported by channels that are bolted at the ends to the tank sides. The vaporizer and scraper mechanism will be suspended in molten salts at about 600°F. As water is pumped through the serpentine, it is vaporized (becomes steam). As the heat is removed from the molten salt, it solidifies on the heat exchanger tubing, causing a reduction in heat transfer. The scrapers scrape off this solid salt.

DESIGN CRITERIA. The following vaporizer/scraper design parameters shall be met:

Operating Pressure	1368 PSIA
Operating Temperature	584°F
Design Pressure	1505 PSIA
Design Temperature	600°F
Hydrostatic Test Pressure	2250 PSIG
Tubing Size	1.0" O.D./.782 I.D.
Material ASTM A192 Tubing	
Tubing Tolerance - Out of Round - ±.006	Max.
Water Velocity through Tubing	6 ft./sec.
No. of Modules to be supplied	3
No. of Serpentines	1 per module
No. of Legs	8 per module
Length of Legs	7 ft.
Length of Tubing	56 ft. each module
Scraper Length	21 in.
No. of Scrapers	36 per module
Scraper Speed	40 to 200 rpm
Scraper Clearance of Tubing	.0025 in. max.
No. of Drive Motors (Not included in this specification)	1 per module

The portion of the scrapers that interface with the tubing shall be sharp so that the scraping force required is minimized.

The scrapers shall be driven by a variable speed 5 H.P. D.C. motor with a speed reducer of 6.4 to 1. The motor, controls, and speed reducer shall be provided and installed by Honeywell.

EXHIBIT B

SCHEDULES

The subcontractor shall accomplish the effort called for in this statement of work F3419 PM-110 and shall provide the following deliverables and comply with the following schedule.

ITEM NUMBER		QUANTITY	DELIVERY/ ACCEPTANCE DATE
1	Vaporizer module including Scraper Mechanism	3	15 Sept., 1976
2	Document per Exhibit A, Statement of Work	*	**

* In accordance with Block 7 of Exhibit A

** In accordance with Blocks 5 & 6 of Exhibit A

CONSTRUCTION. The vaporizer module shall be constructed cf tubing bent into a serpentine as shown in drawing No. SK 133291. Scrapers shall be bolted onto the tubing to remove the salt that hardens on the tubing. The tubing is supported by channels that are bolted at the ends to the tank sides. The scrapers are chain driven from a shaft that is turned by a variable speed reduction drive motor.

IDENTIFICATION. The vaporizer shall have a permanently stamped tag which is in accordance with the applicable code permanently attached to it.

PRICING. A lump sum price shall be provided for this equipment.

VAPORIZER MODULE

STATEMENT OF WORK

This Statement of Work defines the tasks which are to be performed by the Supplier for Honeywell, Inc. Energy Resources Center (Hereinafter referred to as Honeywell) during the period of contract performance.

SCOPE

The Supplier shall provide the necessary services, material, and personnel required to design, fabricate, test and deliver three (3) vaporizer modules which will meet the requirements of specification SK 133291 dated 4/28/76.

TASKS: The following specific task shall be conducted by the Supplier:

1.0 Design, fabricate, test and deliver three (3) vaporizer modules which meets the requirements of specification SK 133291. Delivery shall be in accordance with Exhibit B, Schedules.

2.0 Provide detailed documentation to show that the design meets or exceeds all requirements of the applicable codes in accordance with Exhibit A.

EXHIBIT A: CONTRACT DATA REQUIREMENTS LIST

1. Sequence Number	2. Title or Description of Data	3. Contract Reference	4. Frequency
5. Date of First Submission	6. Date of Subsequent Submission	7. Distribution and Addresses	
Remarks			
1. RI 1-4	2. Vaporizer Module Conceptual Design	3. SOW 1.3	4. One time
5. TBD	6. TBD	7. Honeywell For Item 5 - 1 reproducible + 6 copies For Item 6 - 1 reproducible + 6 copies	

8\.

The subcontractor shall prepare and submit a Vaporizer Module Conceptual Design for Honeywell and NSP approval. Design data shall be prepared and delivered in written form and also presented orally by the Principal Investigator. The subcontractor's format may be used.

The data shall include all drawings, specifications, analyses, etc., as specified in the subcontract and covering the subject contents as indicated by Item 3 above. The drawings shall be formatted according to good commercial practice.

Honeywell will provide a copy of its analysis and design. The vendor may review it, use it as is or modify it. However, the vendor shall provide a copy of his analysis and design to Honeywell per above. Even if vendor's analysis agrees completely with Honeywell's, this shall not relieve vendor of full and complete responsibility for the delivery of a safe and acceptable tank to Honeywell.

The data shall be delivered for review as stipulated in Items 5 and 7 above.

The oral presentation shall be made following the delivery of the data and at such place as directed by the Honeywell Program Manager. The technical review will be completed and notice of approval or non-approval delivered to the subcontractor within 40 days from receipt of original data. The subcontractor shall then make the corrections and revisions delineated in the review notice and submit final copies as stipulated in Items 6 and 7 above. Acceptance of the final version as satisfying this CDRL line item is dependent upon Honeywell approval of the data.

SOW No. F3419-PM-111
Dated 23 April 1976

SOLAR PILOT PLANT

Statement of Work
for
Steam Drum,
Thermal Storage Subsystem Research Experiment

Honeywell Inc.
Energy Resources Center
2600 Ridgway Parkway N. E.
Minneapolis, Minnesota 55413

W. E. Anderson   R. T. LeFrois   J. C. Powell

STATEMENT OF WORK

No. F3419-PM-111

REVISION SHEET

Date of Revision	Page	Task	Change Made
4-23-76	--	--	Original Issue

INTRODUCTION

Intent

This statement of work (SOW) and its exhibits are intended to define the services and materials to be furnished to Honeywell Inc., Energy Resources Center, hereinafter referred to as buyer, by the vendor, hereinafter referred to as seller.

Background Information

The initial phase of an important part of the U.S. solar energy program began in June 1975 when the Energy Research and Development Administration (ERDA) contracted with the buyer to be a prime contractor (Contract No. E(04-3)-1109) for the preliminary design of a 10-MWe solar pilot plant to be built by 1980. Subcontractors to the buyer are Black & Veatch, Babcock & Wilcox, Northern States Power (NSP) and Research Inc. NSP is the utility whose site (NSP Riverside Plant, Minneapolis, Minnesota) will be used for feasibility demonstrations.

Energy must be stored for use during periods when insolation is not available. The energy storage concept under investigation by the buyer is that of latent heat storage employing the phase change from solid to liquid of inexpensive salts. The salts will be melted by passing steam through a condenser in the storage tanks during periods of insolation. The energy can be removed when insolation is not available by simply reversing the process, i.e., by passing water through a vaporizer in the storage tank to produce steam. This steam will then pass through a steam purifying drum, through a superheater, and on to the turbine. Equilibrium and transient conditions due to clouds must be considered.

But first, since latent heat storage is not well developed but has the potential for cost savings, the buyer must demonstrate its feasibility. Feasibility demonstrations have been performed in the laboratory on a smaller scale. On a larger scale, the present program to further demonstrate feasibility is an experiment called the Thermal Storage Subsystem Research Experiment (TSS/RE). Due to the use of latent heat technology for storage, the system will normally operate at a nearly constant temperature. However, for experimental purposes, tests will be conducted over a range of conditions including temperature, pressure, and flow rate, both at equilibrium and at transient conditions.

Since the buyer does not design and fabricate steam drums, he desires to utilize the seller's expertise. The buyer's goal is to obtain a steam drum which will work in the TSS/RE. The buyer will appreciate the seller's working with him in a candid manner to accomplish this goal.

This being an experiment, the buyer desires a close working relationship with and flexibility on the part of each seller to ensure successful development of the latent heat storage technology.

The steam purifying drum for the TSS/RE referred to above is the subject of this statement of work; however, the buyer desires also to work with the seller to estimate the steam purifying drum required for the thermal storage system for the 10-MWe solar pilot plant.

The seller's general and specific comments will be appreciated on any point including those relative to the code suggested and additional holes if ASME Section I is recommended, vertical vs. horizontal drum, mounting of drum on wall, post-heat treatment, radiographs, and National Board and ASME stamps.

SCOPE

The seller shall provide the necessary services and materials required to design, fabricate, certify and warrant a wall-hangable steam drum with sight gage(s); to provide prior to drum fabrication, support to the buyer for the detailed design review with the buyer's customer, ERDA, and Northern States Power Company (NSP), the utility which owns the site where the steam drum assembly will be operated; and to deliver one (1) steam drum with sight gage(s) with all associated drawings and operating manuals each acceptable to the buyer, NSP, ERDA, and to all inspectors, as applicable, as defined in the Honeywell Requirements Specification.

APPLICABLE DOCUMENTS

Honeywell Requirements Specification No. HRS SK-133288, dated April 21, 1976.

TASKS

Task 1: Steam Drum Design

The seller shall provide the buyer with sufficient design information in accordance with HRS SK-133288 for the buyer to be able to assure its customer, ERDA, and NSP that the steam drum design, sight gage(s) and associated material will satisfy all requirements of the TSS/RE with respect to performance, safety, and insurability. The information shall be provided to the buyer per the delivery schedule for use at the Detailed Design Review (DDR) with ERDA.

Task 2: Steam Drum Design Update, Fabrication and Delivery

Subsequent to approval of Task 1, the design shall be detailed and fabrication drawings shall be prepared for the buyer's approval. The seller shall fabricate, test, certify the performance of, and warrant the steam drum and sight gage(s) assembly as defined in HRS SK-133288. The deliverables shall be in the buyer's facility per the delivery schedule.

DELIVERABLE ITEMS AND SCHEDULE

Delivery shall mean that an item is in the buyer's facility on the scheduled date.

The following table presents deliverable items and the delivery schedule:

Item	Quantity	Schedule
Design Analyses, Data, and Preliminary Drawings	1 Reproducible Set 2 Sets of Copies	June 1, 1976
Fabrication Drawings	1 Reproducible Set 2 Sets of Copies	September 2, 1976
Instruction Manuals	1 Reproducible Set 2 Sets of Copies	September 2, 1976
Warranty, Certification, and Data	1 Reproducible Set 2 Sets of Copies	September 2, 1976
Steam Drum and Sight Gage(s) Assembly	1	September 2, 1976

GENERAL REQUIREMENTS

The following general requirements are applicable to the purchase of this equipment.

Identification

All drawings, correspondence, shipping papers, and other documents shall be identified with the buyer's purchase order number.

Analyses, Data, Drawings, Manuals, Warranty and Certification

These shall be submitted to the Engineer (see name and address below) for review. After review by the Engineer, one set will be returned to the seller marked: EXCEPTIONS NOTED, RETURNED FOR CORRECTION, NO EXCEPTIONS NOTED, or RECEIVED FOR DISTRIBUTION.

When these items are returned marked EXCEPTIONS NOTED, the changes shall be made as noted thereon and the specified number and type of corrected copies shall be submitted to the Engineer.

When they are returned marked RETURNED FOR CORRECTION, the corrections shall be made as noted thereon and as instructed by the Engineer and the specified number and type of copies shall be submitted to the Engineer.

When they are returned marked NO EXCEPTIONS NOTED or RECEIVED FOR DISTRIBUTION, the seller shall submit the specified number and type of copies for final distribution.

Analyses and Data -- The seller shall present, by way of analyses and test results on the seller's letterhead to the Engineer, evidence that the assembly will pass all applicable codes and underwriter's tests for safety and insurance purposes and that the steam quality will pass the specifications given in HRS SK-133288.

Drawings -- Fabrication drawings shall be "as shipped" assembly drawings, subassembly drawings, and parts lists.

Instruction Manuals -- The seller shall furnish the specified number and type of completed and final copies of instruction manuals.

The instruction manuals shall cover complete installation, preparation, operating and maintenance instructions, drawings, and parts lists for each item of equipment furnished.

The instruction manuals shall be bound in the seller's standard heavy-duty binders, suitable for rough usage. The front covers shall be stamped with lettering indicating the buyer's name, unit number, name of power plant, location of power plant, name of equipment, basic capacity rating of equipment, name of seller, and purchase order number.

Where applicable, a list of recommended spare parts with the price of each such item and a schedule of required lubricants, as recommended by the seller of each item of equipment, shall be included in the instruction manuals.

The instruction manuals shall indicate all nameplate information and shop order numbers of each item of equipment and component part thereof.

The buyer shall have the right to reproduce all data provided in order to satisfy U.S. Government contractual requirements.

Warranty and Certification -- The seller shall warrant and certify on the seller's letterhead, with attachments if desired, to the Engineer that the steam drum assembly will output steam meeting the quality specified in HRS SK-133288.

Delivery

Complete delivery for all hardware items shall be made FOB point of shipment to the address below:

Honeywell Inc.
1433 Stinson Boulevard N.E.
Minneapolis, Minnesota 55413

Complete delivery for all software items shall be made to the Engineer to the address below:

Honeywell Inc.
2600 Ridgway Parkway N.E.
Minneapolis, Minnesota 55413

Attn: Mr. Richard T. LeFrois
Mail Station R2540

General Construction Drawings

Drawing No.	Pages	Title	Organization
A1002	1	Plant Arrangement - Riverside Station Mexxanine Floor EL 19'-0" & 24' 0"	Black & Veatch
A1003	1	Plant Arrangement - Riverside Station Operating Floor EL 38' 0"	"
M1001	1	Piping & Instrument Diagram Legend	"
M1004	1	Piping & Instrument Diagram Storage Unit SRE	"
M5001	1	One line Piping Routing - All Elevations	"
M5002	1	Piping - Section and Details	"
M5003	1	Piping - Sections and Details	"
E0001	1	Electrical Graphic Symbols	"
E1001	1	Electrical One-Line Diagram	"
E3002	1	Raceway - Conduit Riverside Station Basement EL 4' 0"	"
E4001	1	Lighting - Communications - Raceway Riverside Station Basement EL 4' 0"	"
E5001	1	Grounding - Equipment and Instrument Riverside Station EL 4'0" and 38' 0"	"

These drawings are not included but are available.

Drawings (Contd.)

DRAWING NO.	PAGES	TITLE	ORGANIZATION
		Schematics, Raceway List, Circuit List	Black & Veatch
A-000	1	Electrical Schematic Legend	"
A-004	1	Thermal Storage Recirculation Water Pump	"
A-005	1	Thermal Storage Inlet Steam Shutoff Valve	"
A-006	1	Thermal Storage Feedwater Shutoff Valve	"
A-007	1	Thermal Storage Systems Mode Selector	"
A-008	1	Thermal Storage De-Icer Steam Shutoff Valve	"
A-009	1	Thermal Storage Systems Thaw System Shutoff Valve	"
A-010	1	Thermal Storage Systems Charge Steam Shutoff Valve	"
A-011	1	Thermal Storage Systems Thaw Steam Discharge Valve	"
A-012	1	Thermal Storage Systems Discharge Mode Shutoff Valve	"
A-013	1	Thermal Storage Systems Drum Prewarming Shutoff Valve	"
A-300	1	Thermal Storage Instrumentation	"
A-301	1	Thermal Storage Instrumentation	"
R1	1	Raceway List	"
R2	1	Raceway List	"
C1	1	Circuit List	"
C2	1	Circuit List	"
C3	1	Circuit List	"
C4	1	Circuit List	"
C5	1	Circuit List	"

Drawings (Contd)

DRAWING NO.	PAGES	TITLE	ORGANIZATION
C6	1	Circuit List	Black & Veatch
P1	1	Circuit List	"

A162

40454

INDICATING LIGHT
- R-RED
- W-WHITE
- G-GREEN

IND-B (IND) INDICATOR B

(ET) ET-ELECTRONIC TRANSMITTER
- PT- PRESSURE TRANSMITTER
- FT- FLOW TRANSMITTER
- LT- LEVEL TRANSMITTER

COIL OF STARTER, SOLENOID VALVE, OR RELAY
- SV - SOLENOID VALVE COIL
- 6 - MOTOR STARTER COIL
- AR AUXILIARY RELAY COIL

NO NORMALLY OPEN CONTACT

NC NORMALLY CLOSED CONTACT

CONTACT IDENTIFICATION
- ZS - LIMIT SWITCH
- LS - LEVEL SWITCH
- PS - PRESSURE SWITCH
- MS - MOTOR STARTER
- CS - CONTROL SWITCH
- OL - MOTOR OVERLOAD
- TSS- TOGGLE SELECTOR SWITCH

CS C CLOSED IN CLOSE

CS T CLOSED IN TRIP

CS SCC CLOSED IN CLOSE AND NORMAL AFTER CLOSE

CS O CLOSED IN NORMAL AFTER CLOSE AND NORMAL AFTER TRIP

CS PO CLOSED IN PULLOUT POSITION

CS SCT CLOSED IN TRIP AND NORMAL AFTER TRIP

CS C CONTACT CLOSED IN CLOSE

CONTACT NUMBER. THE POSITION OF THE NUMBER REPRESENTS THE INCOMING BINDING POST. THE CENTER BINDING POST IS NOT IDENTIFIED HERE BUT IN THIS CASE WOULD BE IC

FUSE

CIRCUIT BREAKER

EXTERNAL CONNECTION

INTERNAL CONNECTION

A/W — INDICATES CIRCUIT / WIRE COLOR

RCD-A RECORDER #A

A(16) ← CIRCUIT NUMBER

DAC DATA ACQUISITION COMPUTER INPUT

FL FLOW LINEARIZER

EE-D ELECTRICAL TRANSDUCER #D
- MV/MA - MILLIVOLT TO MILLIAMP TRANSDUCER
- MV/D - MILLIVOLT TO DIGITAL TRANSDUCER

E/P EP-D ELECTRICAL TO PNUEMATIC POSITIONER #D

LOCATION CODES & NOMENCLATURE

- A INSTRUMENT TRAILER
- B DATA ACQUISITION CABINET
- C STEAM GENERATOR INTERFACE CABINET
- D STEAM GENERATOR
- E RADIANT ARRAY
- F RADIANT ARRAY POWER CONTROLLER
- G RADIANT ARRAY ZONE TRANSFORMERS
- H FLUX MEASUREMENT BOOM
- J TRANSDUCER CABINET
- L LOCATED LOCALLY
- R INSTRUMENT RACK
- ZS VALVE LIMIT SWITCH

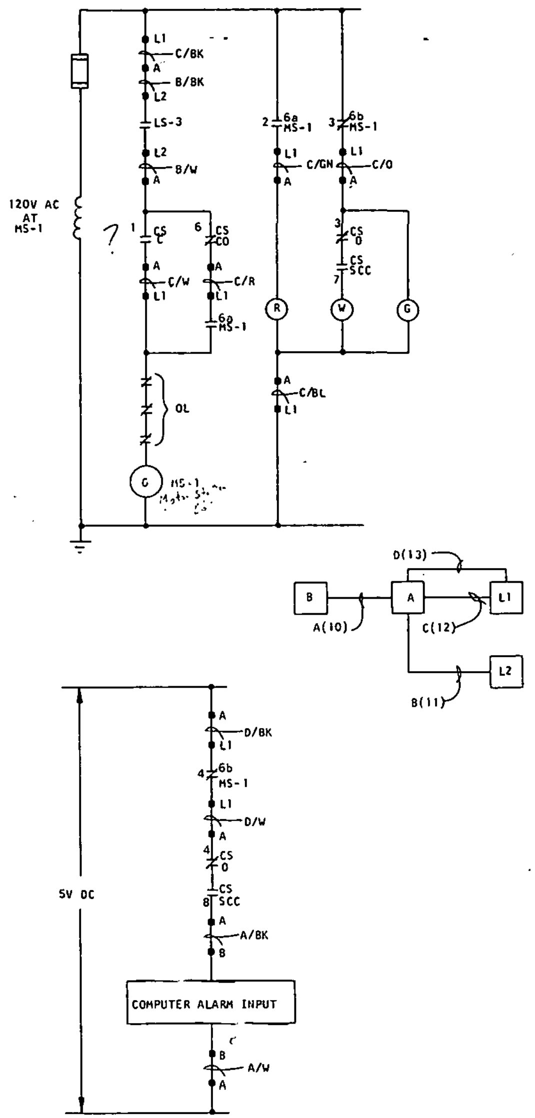
NOT TO BE USED FOR CONSTRUCTION

DATE OF ISSUE 5-14-76

DATE	REVISIONS AND RECORD OF ISSUE	NO.	BY	CK	APP	DEPT HEAD / DES ENGR / CHECKED / DRAWN S.W.T.	I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY REGISTERED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF. SIGNED ___ DATE ___ REG. NO. ___	BLACK & VEATCH CONSULTING ENGINEERS PROJECT 7021	ERDA — 10MWe SOLAR PILOT PLANT SUBSYSTEM RESEARCH EXPERIMENTS ELECTRICAL SCHEMATIC LEGEND	B & V DWG NO. A-000

MS-1 THERMAL STORAGE RECIRCULATION WATER PUMP STARTER

LS-3 THERMAL STORAGE DRUM LEVEL SWITCH.CONTACT OPENS ON LOW LEVEL



MS-1 AUXILIARY CONTACTS

1 THIS DRAWING

2 THIS DRAWING

3 THIS DRAWING

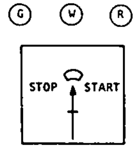
4 THIS DRAWING

CS

CONTACTS HANDLE END		POSITION				REFERENCE DRAWING
		START	NORMAL		STOP	
			AFTER START	AFTER STOP		
1 — 2	1	X				☆
	2				X	
3 — 4	3		X	X		☆
	4		X	X		☆
5 — 6	5		X	X		
	6	X	X	X		☆
7 — 8	7	X	X			☆
	8	X	X			☆
9 — 10	9	X	X			
	10	X	X			

GE SB-1 LOCATED IN TRAILER SPRING RETURN TO NORMAL FROM START AND STOP

☆ SEE THIS DWG



ITEM SW-1

LOGIC DIAGRAM LD 1004-S

NOT TO BE USED FOR CONSTRUCTION

DATE OF ISSUE 5-14-76

DATE	REVISIONS AND RECORD OF ISSUE	NO.	BY	CK	APP

DEPT HEAD / DES ENGR / CHECKED / DRAWN

I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY REGISTERED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF.

SIGNED ____

DATE ____ REG. NO. ____

BLACK & VEATCH CONSULTING ENGINEERS

PROJECT 7021

ERDA — 10MWe SOLAR PILOT PLANT

SUBSYSTEM RESEARCH EXPERIMENTS

THERMAL STORAGE RECIRCULATION WATER PUMP

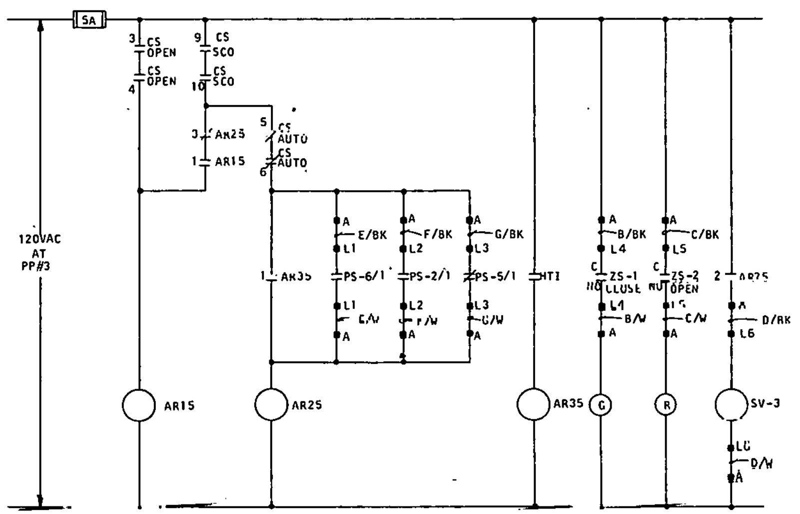
B & V DWG NO. A-004

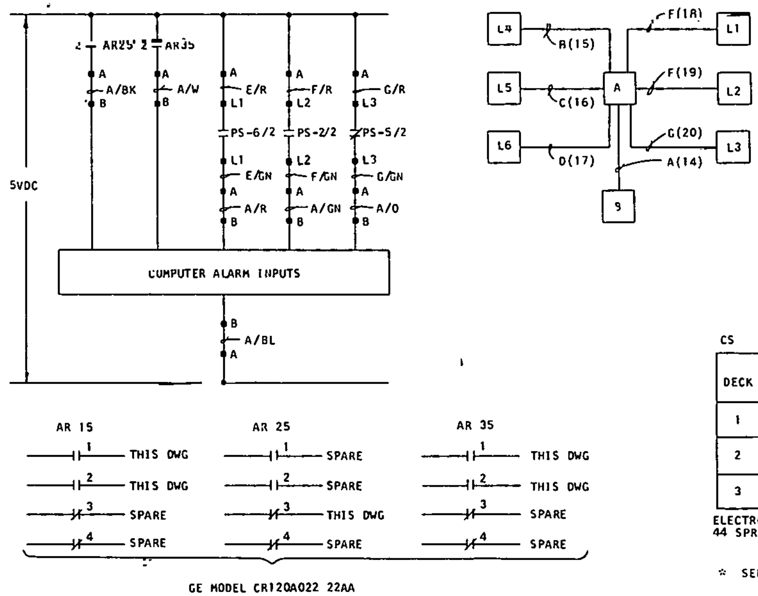
40454

A163

A164

40454





SV-3-SOLENOID LOCATED ON VALVE M1004-2 ENERGIZE TO OPEN

ZS-1-VALVE M1004-2 OPEN LIMIT SWITCH

ZS-2-VALVE M1004-2 CLOSED LIMIT SWITCH

HTI - HIGH TEMP INTERLOCK IS PART OF CONTROL STATION 12-CONTACT CLOSES ON DESUPER HEATER OUTLET TEMPERATURE HIGH

PS-6-THAW STEAM PRESSURE CLOSES ON HIGH PRESSURE

PS-2-DE-ICER STEAM PRESSURE CLOSES ON HIGH PRESSURE

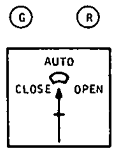
PS-5-SYSTEM INLET PRESSURE CLOSES ON LOW PRESSURE

CS

DECK	CONTROLS	POSITION CLOSE	AUTO NAC	AUTO NAO	OPEN	REFERENCE DRAWING
1	1 2	X				
	3 4				X	☆
2	5 6		X	X		☆
	7 8		X	X		
3	9 10			X	X	☆
	11 12			X	X	☆

ELECTRO SWITCH SERIES 10K UNIVERSAL CIRCUIT
44 SPRING RETURN TO AUTO FROM CLOSE OR OPEN

☆ SEE THIS DWG



ITEM SW-4

LOGIC DIAGRAM 1004-12

NOT TO BE USED FOR CONSTRUCTION

DATE OF ISSUE 5-14-76

DATE	REVISIONS AND RECORD OF ISSUE	NO.	BY	CK	APP

DEPT HEAD / DES ENGR / CHECKED / DRAWN

I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY REGISTERED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF
SIGNED
DATE REG. NO.

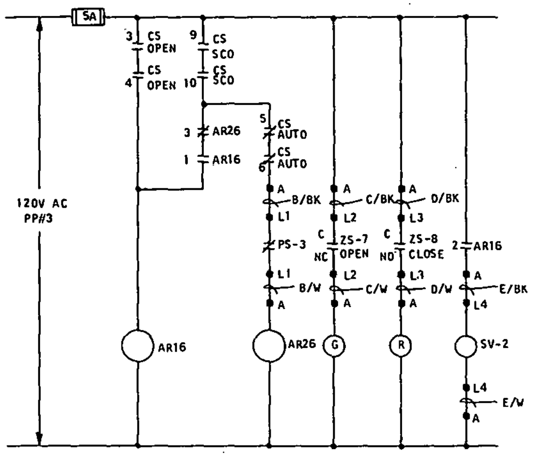
BLACK & VEATCH CONSULTING ENGINEERS
PROJECT 7021

ERDA — 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENTS

THERMAL STORAGE INLET STEAM SHUTOFF VALVE

B & V DWG NO. A-005

40454

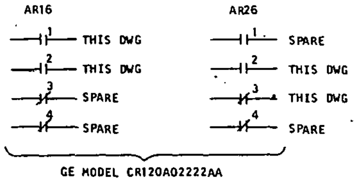


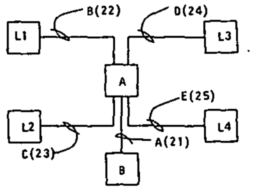
SV-2 SOLENOID LOCATED ON VALVE M1004-4. ENERGIZE TO OPEN.

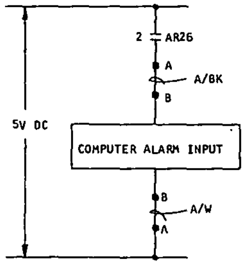
ZS-7 VALVE M1004-4 OPEN LIMIT SWITCH.

ZS-8 VALVE M1004-4 CLOSED LIMIT SWITCH

PS-3 SYSTEM INLET PRESSURE. CLOSES ON LOW PRESSURE.





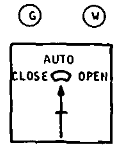


CS

DECK	CONTACTS	POSITION CLOSE	AUTO NAC	AUTO NAO	OPEN	REFERENCE DRAWING
1	1 – 2	X				
	3 – 4				X	*
2	5 – 6		X	X		*
	7 – 8		X	X		
3	9 – 10			X	X	*
	11 – 12			X	X	

ELECTRO SWITCH SERIES 10K-
UNIVERSAL CIRCUIT 44. SPRING RETURN TO AUTO
FROM CLOSE OR OPEN.

* SEE THIS DWG



ITEM SW-5

NOT TO BE USED FOR CONSTRUCTION

DATE OF ISSUE 5-14-76

LOGIC DIAGRAM LD 1004-13

DATE	REVISIONS AND RECORD OF ISSUE	NO.	BY	CK	APP

DEPT HEAD / DES ENGR / CHECKED / DRAWN

I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY REGISTERED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF.

SIGNED ______ DATE ______ REG. NO. ______

BLACK & VEATCH CONSULTING ENGINEERS

PROJECT 7021

ERDA – 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENTS

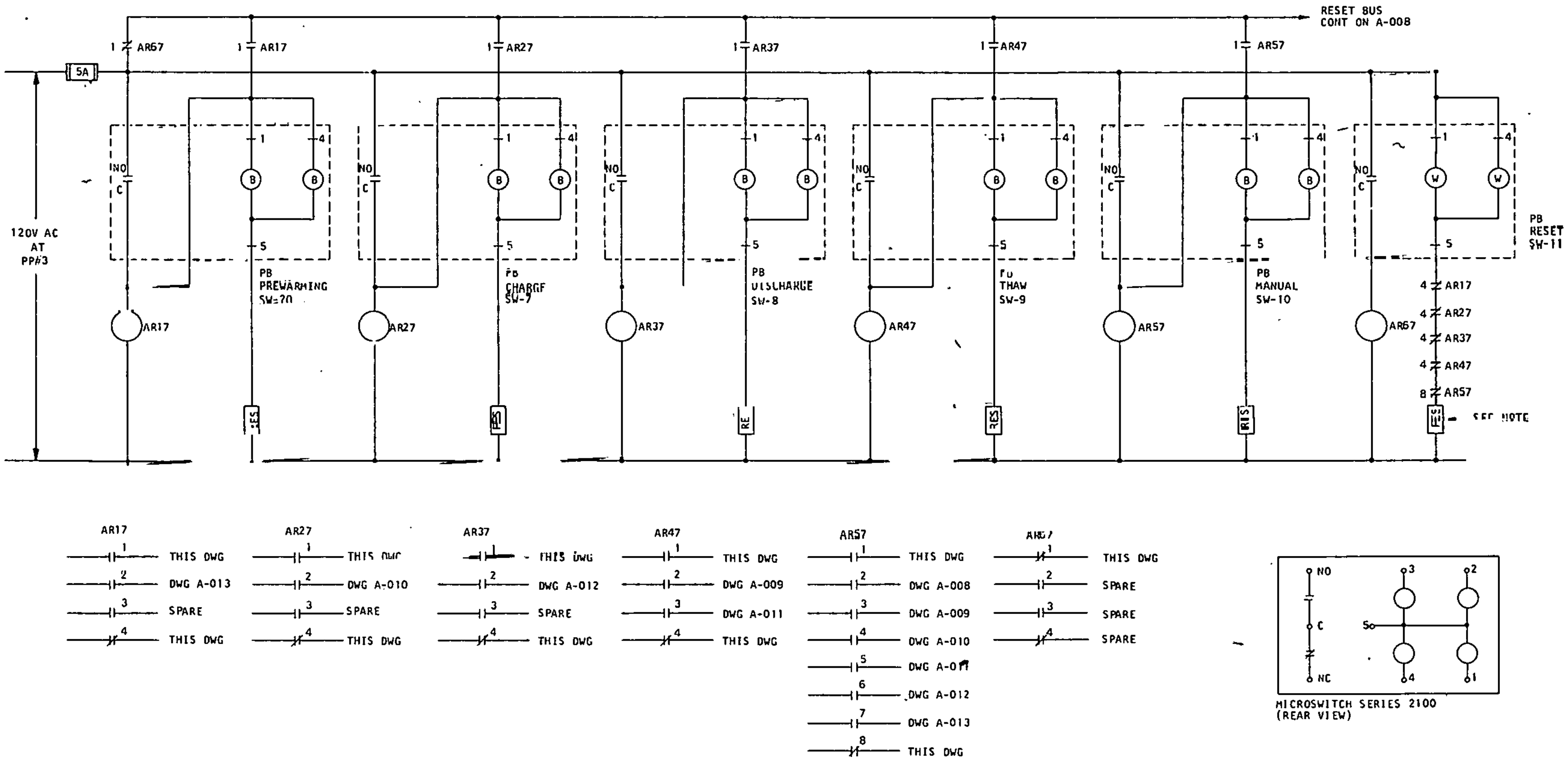
THERMAL STORAGE FEEDWATER SHUTOFF VALVE

B & V DWG NO. A-006

A165

A166

40454



GE MODEL CR120A03122AA
RELAYS AR17, AR27, AR37, AR47, AR67

GE MODEL CR120A07122AA
RELAY AR57

NOTE:

ALL RESISTORS 1200Ω
25W.

NOT TO BE USED FOR CONSTRUCTION

LOGIC DIAGRAM LD-1004-14

DATE OF ISSUE 5-14-76

DATE	REVISIONS AND RECORD OF ISSUE	NO.	BY	CK	APP

DEPT HEAD / DES ENGR / CHECKED / DRAWN

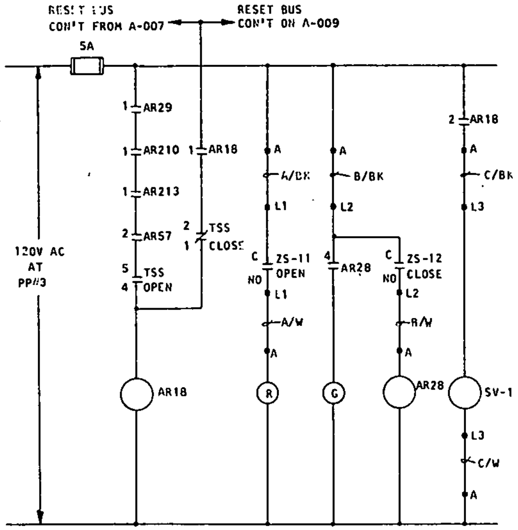
I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY REGISTERED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF
SIGNED
DATE REG. NO.

BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT 7021

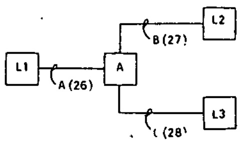
ERDA — 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENTS

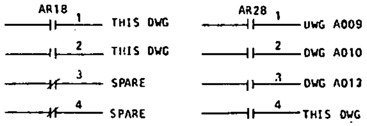
THERMAL STORAGE SYSTEMS
MODE SELECTION

B & V DWG NO. A-007



SV-1	SOLENOID LOCATED ON VALVE M1004 TO OPEN
ZS-11	VALVE M1004-7 OPEN LIMIT SWITCH
ZS-12	VALVE M1004-7 CLOSE LIMIT SWITCH
AR-57	MANUAL MODE SELECTION RELAY-SEE DWG A-007
AR29	CONTACT CLOSES WHEN VALVE M1004-9 IS FULLY CLOSED. SEE DWG A-009
AR210	CONTACT CLOSES WHEN VALVE M1004-19 IS FULLY CLOSED. SEE DWG A-010
AR213	CONTACT CLOSES WHEN VALVE M1004-23 IS FULLY CLOSED. SEE DWG A-013





GE MODEL
CR120 A022 22AA

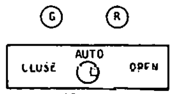
GE MODEL
CR 120 A031 22AA

TSS (2TL1-50K)

CONTACTS	POSITION CLOSE	AUTO	OPEN	REFERENCE DRAWING
2-1		X	X	*
2-3	X			
5-4			X	*
5-6	X	-- X		

MICROSWITCH TYPE TL SPRING RETURN TO AUTO FROM OPEN. MAINTAINED IN AUTO & CLOSE. PULL TO UNLOCK

* SEE THIS DWG



ITEM SW-12

NOT TO BE USED FOR CONSTRUCTION

DATE OF ISSUE 5-14-76

LOGIC DIAGRAM LD-1004-15

DATE	REVISIONS AND RECORD OF ISSUE	NO.	BY	CK	APP

DEPT HEAD / DES ENGR / CHECKED / DRAWN

I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY REGISTERED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF

SIGNED ____ DATE ____ REG. NO. ____

BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT 7021

ERDA – 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENTS
THERMAL STORAGE SYSTEMS
DE-ICER STEAM SHUTOFF VALVE

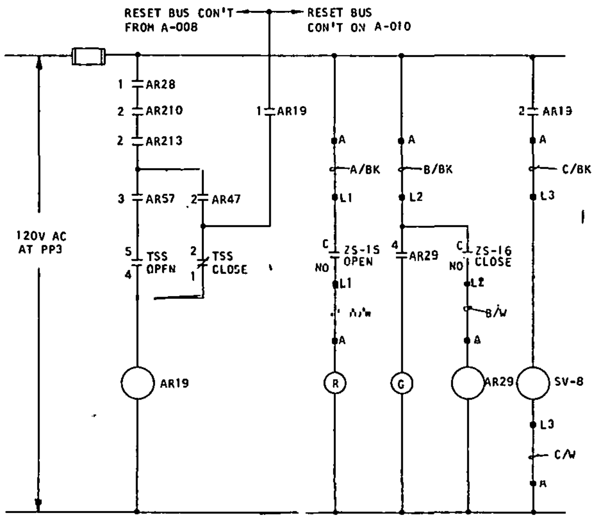
B & V DWG NO. A-008

40454

A167

A168

40454



SV-8-SOLENOID LOCATED ON VALVE M1004-9. ENERGIZE TO OPEN.

ZS-15-VALVE M1004-9 OPEN LIMIT SWITCH.

ZS-16-VALVE M1004-9 CLOSE LIMIT SWITCH.

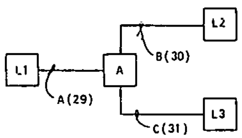
AR-57-MANUAL MODE SELECTION RELAY. SEE DWG A-007

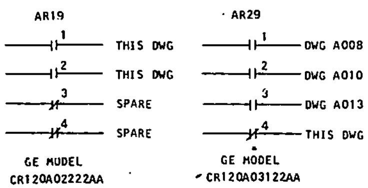
AR47-THAW MODE SELECTION RELAY. SEE DWG A-007.

AR28-CONTACT CLOSES WHEN VALVE M1004-7 IS FULLY CLOSED. SEE DWG A-008.

AR210-CONTACT CLOSES WHEN VALVE M1004-19 IS FULLY CLOSED. SEE DWG A-010.

AR213-CONTACT CLOSES WHEN VALVE M1004-23 IS FULLY CLOSED. SEE DWG A-013.



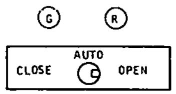


TSS(2TL1-50K)

CONTACTS	POSITION			REFERENCE DRAWING
	CLOSE	AUTO	OPEN	
2-1		X	X	☆
2-3	X			
5-4			X	☆
5-6	X	X		

MICROSWITCH TYPE TL. SPRING RETURN TO AUTO FROM OPEN. MAINTAINED IN AUTO & CLOSE. PULL TO UNLOCK.

☆ SEE THIS DWG



ITEM SW-13

LOGIC DIAGRAM LD1004-16

NOT TO BE USED FOR CONSTRUCTION

DATE OF ISSUE 5-14-76

DATE	REVISIONS AND RECORD OF ISSUE	NO.	BY	CK	APP

DEPT HEAD / DES ENGR / CHECKED / DRAWN

I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY REGISTERED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF

SIGNED ____ DATE ____ REG. NO. ____

BLACK & VEATCH CONSULTING ENGINEERS

PROJECT 7021

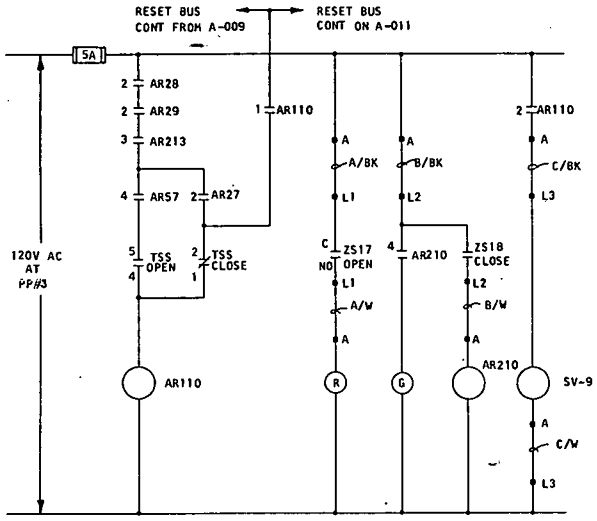
ERDA—10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENTS

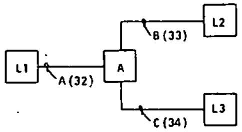
THERMAL STORAGE SYSTEMS
THAW SYSTEM SHUTOFF VALVE

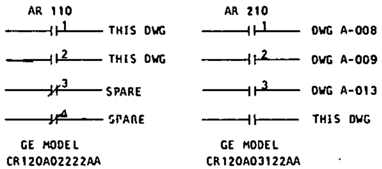
B & V DWG NO. A-009

40454

A169





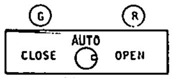


TSS(2TI1-50K)

CONTACTS	POSITION CLOSE	AUTO	OPEN	REFERENCE DRAWING
2-1		X	X	☆
2-3	X			
5-4			X	☆
5-6	X	X		

MICROSWITCH TYPE TL SPRING RETURN TO AUTO FROM OPEN. MAINTAINED IN AUTO & CLOSE. PULL TO UNLOCK

☆ SEE THIS DWG



ITEM SW-14

SV-9	SOLENOID LOCATED ON VALVES M1004-... ENERGIZE TO OPEN
ZS17	VALVE M1004-19 OPEN LIMIT SWITCH
ZS18	VALVE M1004-19 CLOSE LIMIT SWITCH
AR57	MANUAL MODE SELECTION RELAY SEE DWG A007
AR27	CHARGE MODE SELECTION RELAY SEE DWG A007
AR28	CONTACT CLOSES WHEN VALVE M1004-7 IS FULLY CLOSED SEE DWG A-008
AR29	CONTACT CLOSES WHEN VALVE M1004-9 IS FULLY CLOSED SEE DWG A-009
AR213	CONTACT CLOSES WHEN VALVE M1004-23 IS FULLY CLOSED SEE DWG A-013

LOGIC DIAGRAM LD-1004-17

NOT TO BE USED FOR CONSTRUCTION

DATE OF ISSUE 5-14-76

DATE | REVISIONS AND RECORD OF ISSUE | NO. | BY | CK | APP

DEPT HEAD / DES ENGR / CHECKED / DRAWN

I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY REGISTERED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF

SIGNED ______ DATE ______ REG. NO. ______

BLACK & VEATCH CONSULTING ENGINEERS

PROJECT 7021

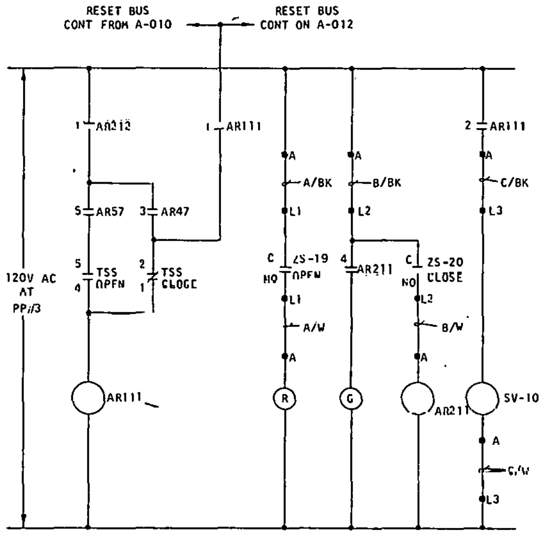
ERDA—10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENTS

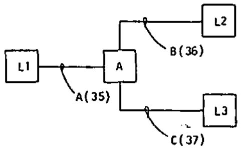
THERMAL STORAGE SYSTEMS
CHARGE STEAM SHUTOFF VALVE

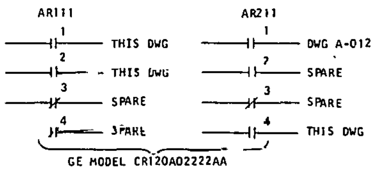
B&V DWG NO. A-010

A170

40454





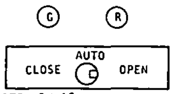


TSS (2TL1-50K)

CONTACTS	POSITION			REFERENCE DRAWING
	CLOSE	AUTO	OPEN	
2-1		X	X	*
2-3	X			
5-4			X	*
5-6	X	X		

MICROSWITCH TYPE TL SPRING RETURN TO AUTO FROM OPEN MAINTAINED IN AUTO & CLOSE PULL TO UNLOCK

* SEE THIS DWG



ITEM SW-15

SV-10	SOLENOID LOCATED ON VALVES M1004-20. ENERGIZE TO OPEN.
ZS-19	VALVE M1004-20 OPEN LIMIT SWITCH.
ZS-20	VALVE M1004-20 CLOSE LIMIT SWITCH.
AR-57	MANUAL MODE SELECTION RELAY. SEE DWG A-007.
AR-47	THAW MODE SELECTION RELAY. SEE DWG A-007.
AR-212	CONTACT CLOSES WHEN VALVE M1004-21 IS FULLY CLOSED. SEE DWG A-012.

NOT TO BE USED FOR CONSTRUCTION

DATE OF ISSUE 5-14-76

LOGIC DIAGRAM LD-1004-18

DATE | REVISIONS AND RECORD OF ISSUE | NO. | BY | CK | APP

DEPT HEAD / DES ENGR / CHECKED / DRAWN

I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY REGISTERED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF

SIGNED ____ DATE ____ REG. NO. ____

BLACK & VEATCH CONSULTING ENGINEERS

PROJECT 7021

ERDA – 10MWe SOLAR PILOT PLANT

SUBSYSTEM RESEARCH EXPERIMENTS

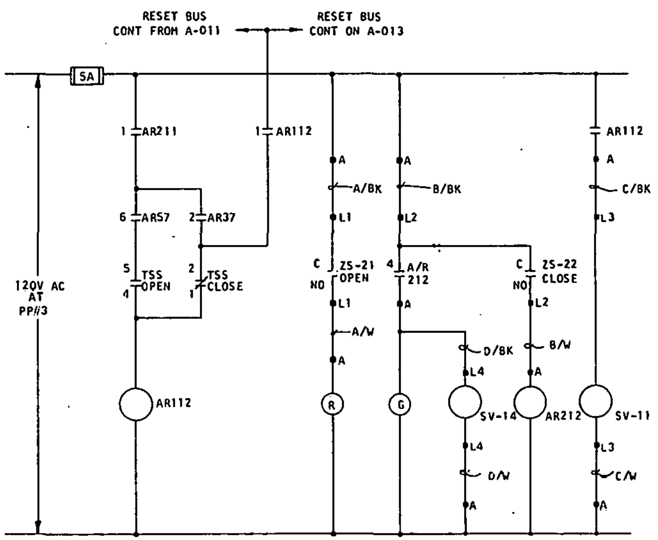
THERMAL STORAGE SYSTEMS

THAW STEAM DISCHARGE VALVE

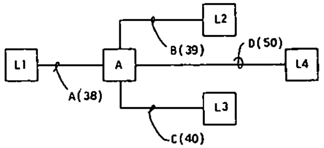
B & V DWG NO. A-011

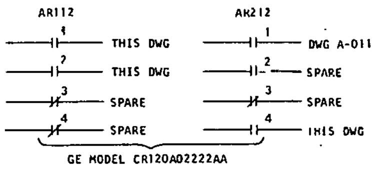
40454

A171



SV-11	SOLENOID LOCATED ON VALVES M1004-21. ENERGIZE TO OPEN.
ZS-21	VALVE M1004-21 OPEN LIMIT SWITCH.
ZS-22	VALVE M1004-21 CLOSE LIMIT SWITCH.
AR-57	MANUAL MODE SELECTION RELAY. SEE DWG A-007.
AR-37	DISCHARGE MODE SELECTION RELAY. SEE DWG A-007.
AR-211	CONTACT CLOSES WHEN VALVE M1004-20 IS FULLY CLOSED. SEE DWG A-011.
SV-14	SOLENOID LOCATED ON VALVE M1004-10 ENERGIZE TO PERMIT MODULATION



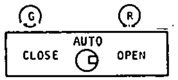


TSS(2TL1-50K)

CONTACTS	POSITION			REFERENCE DRAWING
	CLOSE	AUTO	OPEN	
2-1		X	X	*
2-3	X			
5-4			X	*
5-6	X	X		

MICROSWITCH TYPE TL SPRING RETURN TO AUTO FROM OPEN. MAINTAINED IN AUTO & CLOSE. PULL TO UNLOCK.

* SEE THIS DWG



ITEM SW-16

LOGIC DIAGRAM-1004-7 & 19

NOT TO BE USED FOR CONSTRUCTION

DATE OF ISSUE

DATE	REVISIONS AND RECORD OF ISSUE	NO.	BY	CK	APP

DEPT HEAD / DES ENGR / CHECKED / DRAWN

I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY REGISTERED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF.
SIGNED
DATE REG. NO.

BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT 7021

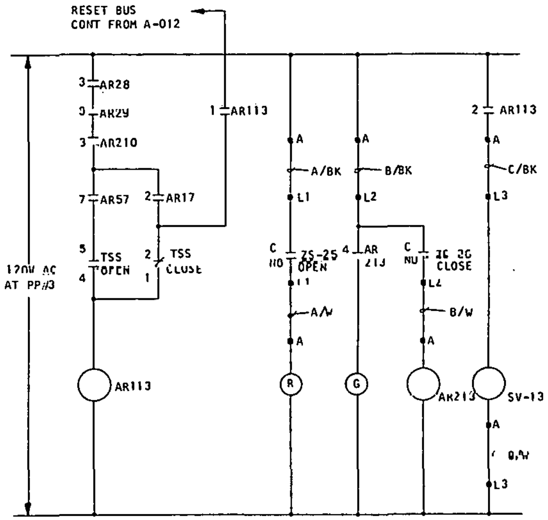
ERDA—10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENTS

THERMAL STORAGE SYSTEMS
DISCHARGE MODE SHUTOFF VALVE

B & V DWG NO. A-012

A172

40454



SV-13-SOLENOID LOCATED ON VALVE M1004-23 ENERGIZE TO OPEN

ZS-25-VALVE M1004-23 OPEN LIMIT SWITCH

ZS-26-VALVE M1004-23 CLOSE LIMIT SWITCH

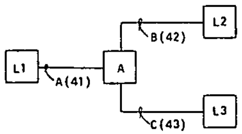
AR-57-MANUAL MODE SELECTION RELAY SEE DWG A007

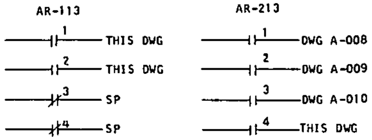
AR-17-PREWARMING MODE SELECTION RELAY. SEE DWG A-007.

AR-28-CONTACT CLOSES WHEN VALVE M1004-7 IS FULLY CLOSED
SEE DWG A-008

AR-29-CONTACT CLOSES WHEN VALVE M1004-9 IS FULLY CLOSED SEE DWG A-009

AR 210 CONTACT CLOSES WHEN VALVE M1004-19 IS FULLY CLOSED SEE DWG A-010





GE MODEL
CR120A02222AB

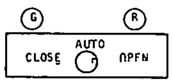
GE MODEL
CR120A00122AA

TSS(2TL1-50K)

CONTACTS	POSITION			REFERENCE DRAWING
	CLOSE	AUTO	OPEN	
2 1		X	X	*
2-3	X			
5-4			X	*
5-6	X	X		

MICROSWITCH TYPE JL. SPRING RETURN TO AUTO FROM OPEN. MAINTAINED IN AUTO & CLOSE. PULL TO UNLOCK.

* SEE THIS DWG



ITEM SW-19

LOGIC DIAGRAM LD-1004-21

NOT TO BE USED FOR CONSTRUCTION

DATE OF ISSUE

DATE	REVISIONS AND RECORD OF ISSUE	NO.	BY	CK	APP

DEPT HEAD
DES ENGR
CHECKED
DRAWN

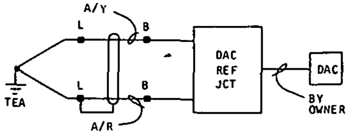
I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY REGISTERED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF

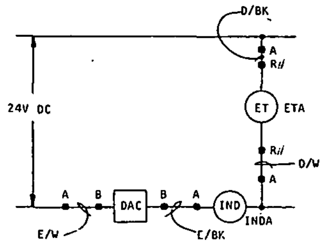
SIGNED
DATE REG. NO.

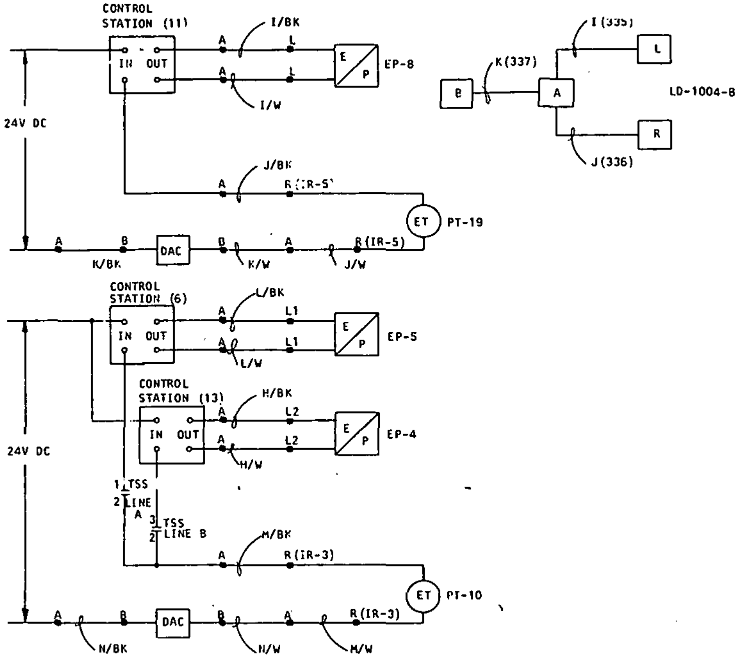
BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT
7021

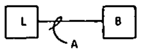
ERDA — 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENTS
THERMAL STORAGE SYSTEMS
DRUM PREWARMING SHUT OFF VALVE

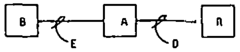
B & V DWG NO. A-013





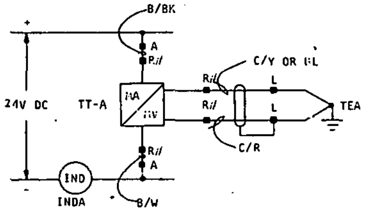


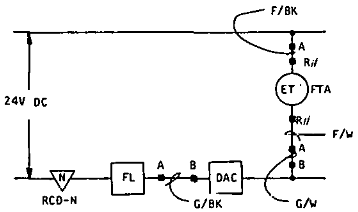


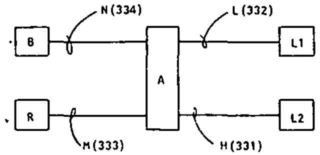


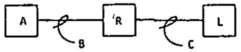
TEA	CABLE A	LOGIC
TE-9	301	LD1004-2
TE-7	302	LD1004-4
TE-8	303	LD1004-7
TE-12	304	LD1004-9
TE-13	305	LD1004-10
TE-11	306	LD1004-11

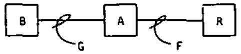
ETA	R//	INDA	CABLE D	CABLE E	LOGIC
PT-6	IR-5	IND-13	317	318	LD1004-2
PT-7	IR-3	IND-16	319	320	LD1004-4
PT-9	IR-4	NONE	321	322	LD1004-7
PT-13	IR-4	IND-8	323	324	LD1004-10
PT-5	IR-4	NONE	325	326	LD1004-11











TSS (2TL1-30)

CONTACTS	POSITION LINE A	POSITION LINE B	REFERENCE DRAWING
2-1	X		THIS DWG
2-3		X	THIS DWG
5-4	X		
5-6		X	

MICROSWITCH TYPE TL. MAINTAINED IN BOTH POSITIONS. PULL TO UNLOCK

ITEM SW-21

TEA	TTA	R//	INDA	CABLE B	CABLE C	LOGIC
TE-35	TT-35	IR-2	IND-5	307	308	LD1004-7
TE-14	TT-14	IR-2	IND-10	309	310	LD1004-10
TE-37	TT-37	IR-2	IND-11	311	312	LD1004-11
TE-34	TT-34	IR-5	IND-3	313	314	LD1004-2
TE-33	TT-33	IR-5	IND-4	315	316	LD1004-4

FTA	R//	RCD-N	CABLE F	CABLE C	LOGIC
FT-18	IR-4	RCD-2	327	328	LD1004-4
FT-9	IR-5	RCD-5	329	330	LD1004-9

NOT TO BE USED FOR CONSTRUCTION

5-14-76

DATE | REVISIONS AND RECORD OF ISSUE | NO. | BY | CK | APP

DEPT HEAD
DES ENGR
CHECKED
DRAWN

I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY REGISTERED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF.
SIGNED
DATE REG. NO.

BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT 7021

ERDA — 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENTS

THERMAL STORAGE INSTRUMENTATION

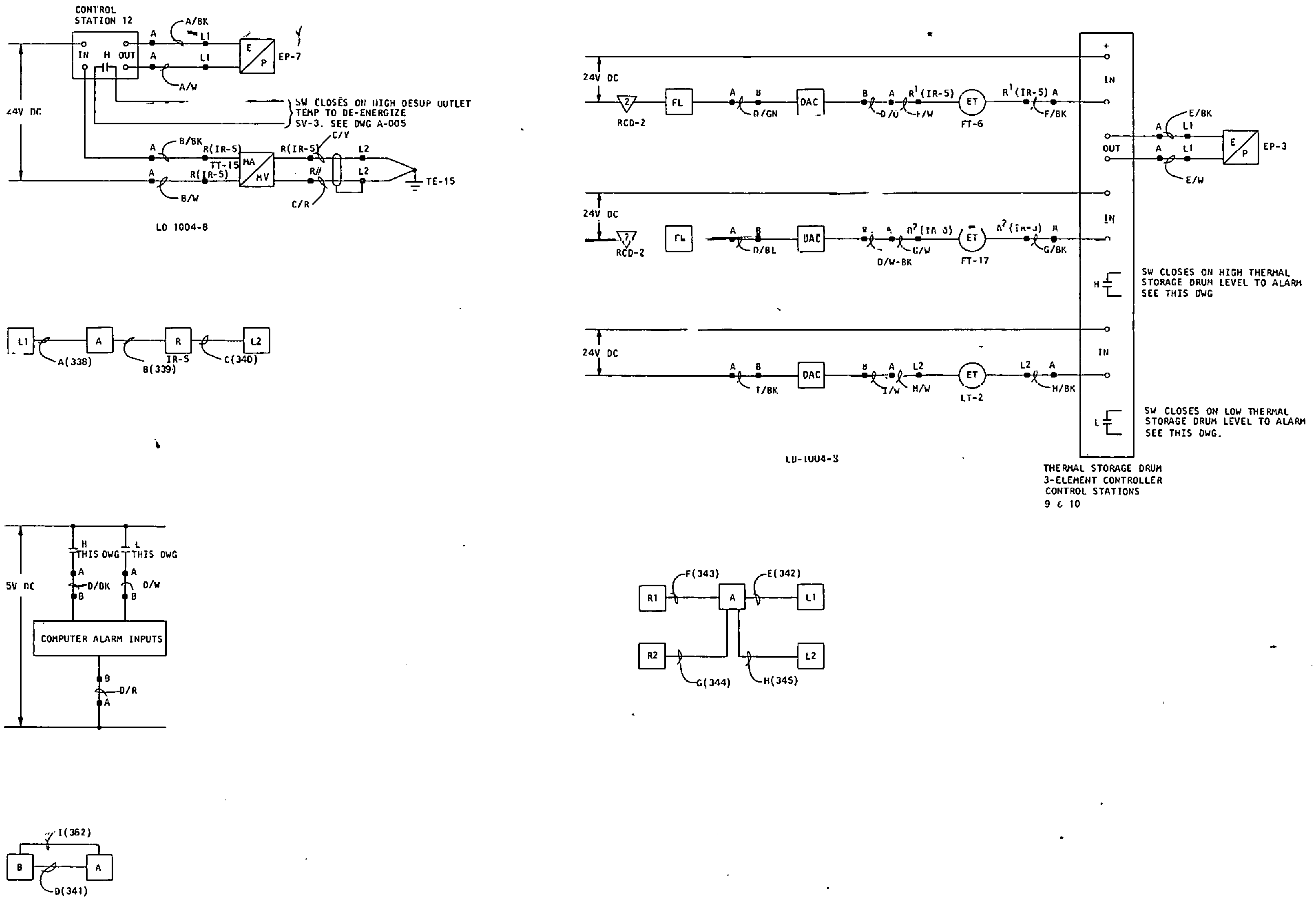
B & V DWG NO. A-300

40454

A173

A174

40454



NOT TO BE USED FOR CONSTRUCTION

DATE OF ISSUE 5-14-76

DATE	REVISIONS AND RECORD OF ISSUE	NO.	BY	CK	APP

DEPT HEAD / DES ENGR / CHECKED / DRAWN

I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY REGISTERED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF.

SIGNED ____ DATE ____ REG. NO. ____

BLACK & VEATCH CONSULTING ENGINEERS

PROJECT 7021

ERDA — 10MWe SOLAR PILOT PLANT

SUBSYSTEM RESEARCH EXPERIMENTS

THERMAL STORAGE INSTRUMENTATION

B & V DWG NO. A-301

40454

A175

V.	CIRCUITS CARRIED	EST LENGTH	SIZE	RACEWAY NUMBER
	3,4,5	40'	1"	R-1
	P-19	160'	1 1/2	R-2
	102	10'	3/4"	R-3
	114,115	5'	3/4"	R-4
	114,115	20'	3/4"	R-5
	208,217	15'	3/4"	R-6
	102,103,111,207,217,2,	35'	1 1/2"	R-7
	51	35'	3/4"	R-8
	1,65	20'	1"	R-9
	P-17	5'	1"	R-10
	P-16	15'	1"	R-11
	P-16,P-17	60'	1 1/2"	R-12
	401,403	15'	1"	R-13
	203	10'	1/2"	R-14
	206	10'	1/2"	R-15
	203,206	35'	3/4"	R-16
	P-29	125'	1 1/2"	R-17
	105,106,212,214	30'	1"	R-18
	216,	20'	1/2"	R-19
	7,8,9	20'	1"	R-20
	202,205,210,215	25'	1"	R-21
	20,	20'	3/4	R-22
	15,16,17	15'	1"	R-23
	335,338	15'	3/4"	R-24
	304,340	10'	3/4"	R-25
	P-18,P-23	150'	3"	R-26
	P-18	5'	2"	R-27
	P-23	5'	2 1/2"	R-28
	P-13	120'	1"	R-29
	P-20	20'	1 1/2"	R-30
	P-24	15'	2 1/2"	R-31
	23,24,25	10'	1"	R-32
	313,314,315,316,317,329,336,339,340,343,22,	5'	1 1/2"	R-33
	401	25'	3/4"	R-34
	301,314	10'	3/4"	R-35
		20'		R-36
	331,	30'	3/4"	R-37
	302,316,	5'	3/4"	R-38
	307,309,311,319,321,323,325,327,333,342,344,345,18,19,26,THRU 34,41,42,43,346,347,348,349,350,351,352,11,39,36	1'	4"	R-39
	108,109,113,303,305,306,332,12,13,35,37,38,40,44 THRU 50,353 THRU 361	1'	4"	R-40
	342,	10'	3/4"	R-41
	11,	15'	3/4"	R-42

REV	CIRCUITS CARRIED	EST LENGTH	SIZE	RACEWAY NUMBER
	345,	20'	1/2"	R-43
	26,27,28	20'	1 1/2"	R-44
	29,30,31	20'	1 1/2"	R-45
	32,33,34	20'	1 1/2"	R-46
	41,42,43	20'	1 1/2"	R-47
	303,308	25'	3/4"	R-48
	306,312	25'	3/4"	R-49
	332,50	15'	3/4"	R-50
	50	5'	3/4"	R-51
	332	10'	3/4"	R-52
	305,310,	15'	3/4"	R-53
	44,45,46	20,	1"	R-54
	35,36,37	20'	1 1/2"	R-55
	38,39,40	20'	1 1/2"	R-56
	47,48,49	20'	1"	R-57
	P-26	15'	2"	R-58
	P-25	5'	2"	R-59
	P-11	5'	1"	R-60
	P-25,P-11	10'	2"	R-61
	P-30	10'	2"	R-62
	P-32	10'	2"	R-63
	P-12	25'	1 1/2	R-64
	P-35	40'	3/4	R-65
	P-10	5'	1 1/2"	R-66
	P-15	50'	1"	R-67
	P-36	25'	3/4"	R-68
	108,109,113,321,323,325,327	40'	1 1/2"	R-69
	P-28	35'	1 1/2"	R-70
	307,308,309,310,311,312,333,344,18,19	55'	1 1/2"	R-71
	P-20,P-22	5'	2 1/2"	R-72
	P-22	25'	1 1/2"	R-73
	P-34	60'	3/4	R-74
	12,13	5'	1"	R-75
	P-31	10'	2"	R-96
	53,54	100'	3/4"	R-202
	55,56	250'	3/4"	R-203
	401,108,109,113,301,302,303,305,306,307,309,311,314,316,319, 321,323,325,307,331,332,333,342,344,345,11,12,13,18,19, 346 THRU 361	20'	6"x12"	T-1

NOT TO BE USED FOR CONSTRUCTION

DATE OF ISSUE 5-14-76

DATE	REVISIONS AND RECORD OF ISSUE	NO.	BY	CK	APP

DEPT HEAD / DES ENGR / CHECKED / DRAWN

I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY REGISTERED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF. SIGNED ____ DATE ____ REG. NO. ____

BLACK & VEATCH CONSULTING ENGINEERS — PROJECT 7021

ERDA – 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENTS
RACEWAY LIST

B & V DWG NO. R-1

A176

REV	CIRCUITS CARRIED	EST LENGTH	SIZE	RACEWAY NUMBER
	401,105,106,108,109,113,202,205,210,212,214,215,301,302,303,304,305,306,307,309,311,313,314,315,316,317,319,321,323,325 327,329,331,332,333,335,336,338,339,340,342,343,344,345,7,8,9,11,12,13,15,16,17,18,19,20,22,23,24,25,346 THRU 361	75'	6"x12"	T-2
	401,403,105,106,108,109,113,202,205,210,212,214,215,301,302,303,304,305,306,307,309,311,313,315,317,319,321,323,325,327,329,331,332,333,335,336,338,339,342,343,344,345,7,8,9,11,12,13,15,16,17,18,19,20,22,23,24,25,346 THRU 361	25'	6"x12"	T-3
	101,102,103,104,107,110,111,112,115,116,117,118,201,207,209,211,213,301,302,303,304,305,306,318,320,322,324,326,328,330,334,337,341,1,2,3,4,5,6,10,14,21,75 THRU 80,335 THRU 361	5'	6"x12"	T-4
	101,104,107,110,112,114,115,118,201,209,211,213,217,301,302,303,304,305,306,318,320,322,326,328,330,334,337,341,1,3,4,5,6,10,14,21,75,81 THRU 103,353, THRU 361	10'	4"x12"	T-5
	403,101-118,201,202,205,207,209-215,307,309,311,313,315,317-339,341-345,1-25,75 THRU 80,346 THRU 352	20'	6"x12"	T-6
	[illegible],[illegible],111,116,117,207,217,2,76 THRU 103	5'	6"x12"	T-7
	P-6	10'	4"x12"	T-8
	P-7	15'	4"x12"	T-9
	P-8	30'	4"x12"	T-10
	P-9	12'	4"x12"	T-11
	52	5'	3/4"	R-97
	74	55'	3/4"	R 98
	73	50'	3/4"	R-99
	72	20'	3/4"	R-100
	71	6'	3/4"	R-101
	61,62,63,64	7'	1 1/2"	W-1
	346 THRU 361	35'	4"	R-102

REV	CIRCUITS CARRIED	EST LENGTH	SIZE	RACEWAY NUMBER

40454

NOT TO BE USED FOR CONSTRUCTION

DATE OF ISSUE 5-14-76

DATE	REVISIONS AND RECORD OF ISSUE	NO.	BY	CK	APP

DEPT HEAD
DES ENGR
CHECKED
DRAWN

I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY REGISTERED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF

SIGNED
DATE REG. NO.

BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT 7021

ERDA — 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENTS
RACEWAY LIST

B & V DWG NO. R-2

REV	FROM	TO	REMARKS	EST LENGTH	NUMBER OF CONDUCTORS	SIZE OF WIRE	INSULATION	ROUTING	CIRCUIT NUMBER
	'A'	MS-2		65'	7	#14	TYPE D	T-6,T-4,T-5-R-9	1
	'A'	PS-1		85'	2	#14	TYPE D	R-7,T-7,T-4,T-6	2
	'A'	ZS-3		90'	2	#14	TYPE D	R-1,T-5,T-4,T-6	3
	'A'	ZS-4		90'	2	#14	TYPE D	R-1,T-5,T-4,T-6	4
	'A'	SV-5		90'	2	#14	TYPE D	R-1,T-5,T-4,T-6	5
	'A'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	6
	'A'	SV-7		125'	2	#14	TYPE D	R-20,T-2,T-3,T-6	7
	'A'	ZS-5		125'	2	#14	TYPE D	R-20,T-2,T-3,T-6	8
	'A'	ZS-6		125'	2	#14	TYPE D	R-20,T-2,T-3,T-6	9
	'A'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	10
	'A'	LS-3		195'	2	#14	TYPE D	R-42,R-40,T-1,T-2,T-3,T-6	11
	'A'	MS-1		175'	7	#14	TYPE D	R-75,R-40,T-1,T-2,T-3,T-6	12
	'A'	MS-1		175'	2	#14	TYPE D	R-75,R-40,T-1,T-2,T-3,T-6	13
	'A'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	14
	'A'	ZS-1		125'	2	#14	TYPE D	R-23,T-2,T-3,T-6	15
	'A'	ZS-2		125'	2	#14	TYPE D	R-23,T-2,T-3,T-6	16
	'A'	SV-3		125'	2	#14	TYPE D	R-23,T-2,T-3,T-6	17
	'A'	PS-6		240'	4	#14	TYPE D	R-71,R-39,T-1,T-2,T-3,T-6	18
	'A'	PS-2		240'	4	#14	TYPE D	R-71,R-39,T-1,T-2,T-3,T-6	19
	'A'	PS-5		125'	4	#14	TYPE D	R-22,T-2,T-3,T-6	20
	'A'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	21
	'A'	PS-3		150'	2	#14	TYPE D	R-33,T-2,T-3,T-6	22
	'A'	ZS-7		140'	2	#14	TYPE D	R-32,T-2,T-3,T-6	23
	'A'	ZS-8		140'	2	#14	TYPE D	R-32,T-2,T-3,T-6	24
	'A'	SV-2		140'	2	#14	TYPE D	R-32,T-2,T-3,T-6	25
	'A'	ZS-11		220'	2	#14	TYPE D	R-44,R-39,T-1,T-2,T-3,T-6	26
	'A'	ZS-12		220'	4	#14	TYPE D	R-44,R-39,T-1,T-2,T-3,T-6	27
	'A'	SV-1		220'	2	#14	TYPE D	R-44,R-39,T-1,T-2,T-3,T-6	28
	'A'	ZS-15		220'	2	#14	TYPE D	R-45,R-39,T-1,T-2,T-3,T-6	29
	'A'	ZS-16		220'	4	#14	TYPE D	R-45,R-39,T-1,T-2,T-3,T-6	30
	'A'	SV-8		220'	2	#14	TYPE D	R-45,R-39,T-1,T-2,T-3,T-6	31
	'A'	ZS-17		220'	2	#14	TYPE D	R-46,R-39,T-1,T-2,T-3,T-6	32
	'A'	ZS-18		220'	4	#14	TYPE D	R-46,R-39,T-1,T-2,T-3,T-6	33
	'A'	SV-9		220'	2	#14	TYPE D	R-46,R-39,T-1,T-2,T-3,T-6	34
	'A'	ZS-19		220'	2	#14	TYPE D	R-55,R-40,T-1,T-2,T-3,T-6	35
	'A'	ZS-20		220'	4	#14	TYPE D	R-55,R-40,T-1,T-2,T-3,T-6	36
	'A'	SV-10		220'	2	#14	TYPE D	R-55,R-40,T-1,T-2,T-3,T-6	37
	'A'	ZS-21		220'	2	#14	TYPE D	R-56,R-40,T-1,T-2,T-3,T-6	38
	'A'	ZS-22		220'	4	#14	TYPE D	R-56,R-40,T-1,T-2,T-3,T-6	39
	'A'	SV-11		220'	2	#14	TYPE D	R-56,R-40,T-1,T-2,T-3,T-6	40
	'A'	ZS-25		220'	2	#14	TYPE D	R-47,R-39,T-1,T-2,T-3,T-6	41

NOT TO BE USED FOR CONSTRUCTION DATE OF ISSUE 5-14-76

DATE	REVISIONS AND RECORD OF ISSUE	NO.	BY	CK	APP

DEPT HEAD
DES ENGR
CHECKED
DRAWN

I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY REGISTERED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF.
SIGNED______
DATE______ REG. NO.______

BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT 7021

ERDA — 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENTS
CIRCUIT LIST

B & V DWG NO. C-1

40454

A177

A178

40454

REV	FROM	TO	REMARKS	EST LENGTH	NUMBER OF CONDUCTORS	SIZE OF WIRE	INSULATION	ROUTING	CIRCUIT NUMBER
	'A'	ZS-26		220'	4	#14	TYPE D	R-47,R-39,T-1,T-2,T-3,T-6	42
	'A'	SV-13		220'	2	#14	TYPE D	R-47,R-39,T-1,T-2,T-3,T-6	43
	'A'	ZS-13		220'	2	#14	TYPE D	R-54,R-40,T-1,T-2,T-3,T-6	44
	'A'	ZS-14		220'	2	#14	TYPE D	R-54,R-40,T-1,T-2,T-3,T-6	45
	'A'	SV-6		220'	2	#14	TYPE D	R-54,R-40,T-1,T-2,T-3,T-6	46
	'A'	ZS-23		220'	2	#14	TYPE D	R-57,R-40,T-1,T-2,T-3,T-6	47
	'A'	ZS-24		220'	2	#14	TYPE D	R-57,R-40,T-1,T-2,T-3,T-6	48
	'A'	SV-12		220'	2	#14	TYPE D	R-57,R-40,T-1,T-2,T-3,T-6	49
	'A'	SV-14		220'	2	#14	TYPE D	R-51,R-50,R-40,T-1,T-2,T-3,T-6	50
	'A'	'H'		100'	2	#14	TYPE D	R-8,T-3,T-4,T-6	51
	'A'	LOAD BREAK SWITCH		85'	2	#14	TYPE D	R-97,T-2,T-3,T-6	52
	'A'	NSP BRKR 86A		350'	2	#14	TYPE D	R-202,T-2,T-3,T-6	53
	NSP BRKR 96A	NSP BRKR 96B		350'	2	#14	TYPE D	R-202,T-2,T-3,T-6	54
	'A' (SW-)	13.8KV OCB		400'	2	#14	TYPE D	R-203,T-2,T-3,T-6	55
	'A' (SW-)	13.8KV OCB		400'	2	#14	TYPE D	R-203,T-2,T-3,T-6	56
	'A'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	57
	'A'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	58
	'A'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	59
	'H'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	60
	'A'	'F' ZONE 1		15'	2	#14	TYPE D	W-1	61
	'A'	'F' ZONE 2		15'	2	#14	TYPE D	W-1	62
	'A'	'F' ZONE 3		15'	2	#14	TYPE D	W-1	63
	'A'	'F' ZONE 4		15'	2	#14	TYPE D	W-1	64
	'A'	MS-2		85'	2	#14	TYPE D	R-9,T-5,T-4,T-6	65
	'A'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	66
	'A'	'B'		50'	2	#14	TYPE D	T-6,T-4,T'5	67
	'A'	'B'		50'	2	#14	TYPE D	T-6,T-4,T-5	68
	'A'	'B'		50'	2	#14	TYPE D	T-6,T-4,T-5	69
	'A'	'B'		50'	2	#14	TYPE D	T-6,T-4,T-5	70
	'A'	'G' ZONE 1		55'	2	#14	TYPE D	R-101,T-3,T-6	71
	'A'	'G' ZONE 2		75'	2	#14	TYPE D	R-100,T-3,T-6	72
	'A'	'G' ZONE 3		105'	2	#14	TYPE D	R-99,T-3,T-6	73
	'A'	'G' ZONE 4		110'	2	#14	TYPE D	R-98,T-3,T-6	74
	'H'	'B'	HONEYWELL SUPPLIED: MULTI-CONDUCTOR, PLUG CONNECTOR CABLE	50'				T-6,T-4,T-5	75
	'A'	'C'	5 CABLES 10 TWISTED PR. #20 AWG	50'	20	#20	TYPE I	T-6,T-4,T-7	76 THRU 20
	'B'	'C'	23 CABLES 10 TWISTED PR. #20 AWG	25'	20	#20	TYPE I	T-5,T-7	81 THRU 103

NOT TO BE USED FOR CONSTRUCTION

DATE OF ISSUE 5-14-76

DATE	REVISIONS AND RECORD OF ISSUE	NO.	BY	CK	APP

DEPT HEAD / DES ENGR / CHECKED / DRAWN CAH

I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY REGISTERED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF.

SIGNED________

DATE________ REG. NO.________

BLACK & VEATCH
CONSULTING ENGINEERS

PROJECT 7021

ERDA – 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENTS

CIRCUIT LIST

B & V DWG NO. C-2

REV	FROM	TO	REMARKS	EST LENGTH	NUMBER OF CONDUCTORS	SIZE OF WIRE	INSULATION	ROUTING	CIRCUIT NUMBER
	'A'	'B'		50'	2	#16	TYPE [illegible]	T-6,T-4,T-5	101
	'A'	EP-11		85'	2	#14	TYPE D	R-7,T-7,T-4,T-6	102
	'A'	PT-1		85'	2	#16	TYPE H	R-7,T-7,T-4,T-6	103
	'A'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	104
	'A'	EP-14		160'	2	#14	TYPE D	R-18,T-2,T-3,T-6	105
	'A'	PT-2		160'	2	#16	TYPE H	R-18,T-2,T-3,T-6	106
	'A'	'B'		50'	2	#16	TYPE D	T-6,T-4,T-5	107
	'A'	EP-1		210'	2	#14	TYPE D	R-69,R-40,T-1,T-2,T-3,T-6	108
	'A'	PT-3		210'	2	#16	TYPE H	R-69,R-40,T-1,T-2,T-3,T-6	109
	'A'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	110
	'A'	FT-1		85'	2	#16	TYPE H	[illegible],[illegible],T-4,T-6	111
	'A'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	112
	'A'	FT-3		210'	2	#16	TYPE H	R-69,R-40,T-1,T-2,T-3,T-6	113
	'B'	TE-19		45'	2	#16	TYPE F	R-4,R-5,T-5	114
	'A'	TE-1		85'	2	#16	TYPE G	R-4,R-5,T-5,T-4,T-6	115
	'A'	'C'		55'	2	#14	TYPE D	T-6,T-4,T-7	116
	'A'	'C'		55'	2	#16	TYPE H	T-6,T-4,T-7	117
	'A'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	118

NOT TO BE USED FOR CONSTRUCTION

DATE OF ISSUE 5-14-76

DATE	REVISIONS AND RECORD OF ISSUE	NO.	BY	CK	APP

DEPT HEAD / DES ENGR / CHECKED / DRAWN

I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY REGISTERED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF

SIGNED ____ DATE ____ REG. NO. ____

BLACK & VEATCH CONSULTING ENGINEERS

PROJECT 7021

ERDA – 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENTS

CIRCUIT LIST

B & V DWG NO. C-3

40454

A179

A180

40454

REV	FROM	TO	REMARKS	EST LENGTH	NUMBER OF CONDUCTORS	SIZE OF WIRE	INSULATION	ROUTING	CIRCUIT NUMBER
	'A'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	201
	'A'	TT-16		155'	2	#16	TYPE H	R-21,T-2,T-3,T-6	202
	TT-16	TE-16		60'	2	#16	TYPE G	R-14,R-16	203
	'A'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	204
	'A'	TT-23		155'	2	#16	TYPE H	R-21,T-2,T-3,T-6	205
	TT-23	TE-23		60'	2	#16	TYPE G	R-15,R-16	206
	'A'	TT-25		85'	2	#16	TYPE H	R-7,T-7,T-4,T-6	207
	TT-25	TE-25		20'	2	#16	TYPE G	R-6	208
	'A'	'B'		50'	4	#14	TYPE D	T-6,T-4,T-5	209
	'A'	FT-13		155'	2	#16	TYPE H	R-21,T-2,T-3,T-6	210
	'A'	'B'		50'	2	#16	TYPE H	T-6, 4,T-5	211
	'A'	PT-16		165'	2	#16	TYPE H	R-18,T-2,T-3,T-6	212
	'A'	'B'		50'	7	#14	TYPE D	T-6,T-4,T-5	213
	'A'	PS-7		165'	2	#16	TYPE H	R-18,T-2,T-3,T-6	214
	'A'	TT-22		155'	2	#16	TYPE H	R-21,T-2,T-3,T-6	215
	TT-22	TE-22		35'	2	#16	TYPE G	R-19	216
	'B'	TE-24		85'	2	#16	TYPE F	R-6,R-7,T-7,T-5	217

NOT TO BE USED FOR CONSTRUCTION

DATE OF ISSUE [illegible]

DATE	REVISIONS AND RECORD OF ISSUE	NO.	BY	CK	APP

DEPT HEAD / DES ENGR / CHECKED / DRAWN

I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY REGISTERED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF.

SIGNED________

DATE________ REG. NO.________

BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT 7021

ERDA — 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENTS
CIRCUIT LIST

B & V DWG NO. C-4

REV	FROM	TO	REMARKS	EST LENGTH	NUMBER OF CONDUCTORS	SIZE OF WIRE	INSULATION	ROUTING	CIRCUIT NUMBER
	'B'	TE-9		165'	2	#16	TYPE F	R-35,T-1,T-2,T-3,T-4,T-5	301
	'B'	TE-7		165'	2	#16	TYPE F	R-38,T-1,T-2,T-3,T-4,T-5	302
	'B'	TE-8		190'	2	#16	TYPE F	R-48,R-40,T-1,T-2,T-3,T-4,T-5	303
	'B'	TE-12		125'	2	#16	TYPE F	R-25,T-2,T-3,T-4,T-5	304
	'B'	TE-13		180'	2	#16	TYPE F	R-53,R-40,T-1,T-2,T-3,T-4	305
	'B'	TE-11		190'	2	#16	TYPE F	R-49,R-40,T-1,T-2,T-3,T-4,T-5	306
	'A'	TT-35		240'	2	#16	TYPE H	R-71,R-39,T-1,T-2,T-3,T-6	307
	TT-35	TE-35		100'	2	#16	TYPE G	R-48,R-71	308
	'A'	TT-14		240'	2	#16	TYPE H	R-71,R-39,T-1,T-2,T-3,T-6	309
	TT-14	TE-14		90'	2	#16	TYPE F	R-53,R-71	310
	'A'	TT-37		240'	2	#16	TYPE H	R-71,R-39,T-1,T-2,T-3,T-6	311
	TT-37	TE-37		110'	2	#16	TYPE F	R-49,R-71	312
	'A'	TT-34		150'	2	#16	TYPE H	R-33,T-2,T-3,T-6	313
	TT-34	TE-34		50'	2	#16	TYPE G	R-35,T-1,T-2,R-33	314
	'A'	TT-33		150'	2	#16	TYPE H	R-33,T-2,T-3,T-6	315
	TT-33	TE-33		60'	2	#16	TYPE G	R-38,T-1,T-2,R-33	316
	'A'	PT-6		150'	2	#16	TYPE H	R-33,T-2,T-3,T-6	317
	'A'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	318
	'A'	PT-7		235'	2	#16	TYPE H	R-69,R-39,T-1,T-2,T-3,T-6	319
	'A'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	320
	'A'	PT-9		235'	2	#16	TYPE H	R-69,R-39,T-1,T-2,T-3,T-6	321
	'A'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	322
	'A'	PT-13		235'	2	#16	TYPE H	R-69,R-39,T-1,T-2,T-3,T-6	323
	'A'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	324
	'A'	PT-5		235'	2	#16	TYPE H	R-69,R-39,T-1,T-2,T-3,T-6	325
	'A'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	326
	'A'	FT-18		235'	2	#16	TYPE H	R-69,R-39,T-1,T-2,T-3,T-6	327
	'A'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	328
	'A'	FT-9		150'	2	#16	TYPE H	R-33,T-2,T-3,T-6	329
	'A'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	330
	'A'	EP-4		190'	2	#14	TYPE D	R-37,T-1,T-2,T-3,T-6	331
	'A'	EP-5		195'	2	#14	TYPE D	R-52,R-50,R-40,T-1,T-2,T-3,T-6	332
	'A'	PT-10		240'	2	#16	TYPE H	R-71,R-39,T-1,T-2,T-3,T-6	333
	'A'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	334
	'A'	EP-8		165'	2	#16	TYPE D	R-24,T-2,T-3,T-6	335
	'A'	PT-19		150'	2	#16	TYPE H	R-33,T-2,T-3,T-6	336
	'A'	'B'		50'	2	#16	TYPE H	T-6,T-4,T-5	337
	'A'	EP-7		165'	2	#14	TYPE D	R-24,T-2,T-3,T-6	338
	'A'	TT-15		150'	2	#16	TYPE H	R-33,T-2,T-3,T-6	339

NOT TO BE USED FOR CONSTRUCTION

DATE OF ISSUE 5-14-76

DATE	REVISIONS AND RECORD OF ISSUE	NO.	BY	CK	APP

DEPT HEAD
DES ENGR
CHECKED
DRAWN

I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY REGISTERED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF
SIGNED
DATE REG. NO.

BLACK & VEATCH CONSULTING ENGINEERS
PROJECT 7021

ERDA – 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENTS
CIRCUIT LIST

B & V DWG NO. C-5

40454

A181

A182

40454

REV	FROM	TO	REMARKS	EST LENGTH	NUMBER OF CONDUCTORS	SIZE OF WIRE	INSULATION	ROUTING	CIRCUIT NUMBER
	TT-15	TE-15		55'	2	#16	TYPE F	R-25.T-2.R-33	340
	'A'	'B'		50'	4	#14	TYPE D	T-6.T-4.T-5	341
	'A'	EP-3		220'	2	14	TYPE D	R-41.R-39.T-1.T-2.T-3.T-6	342
	'A'	FT-6		150'	2	16	TYPE H	R-33.T-2.T-3.T-6	343
	'A'	FT-17		240'	7	#16	TYPE H	R-71.R-39.T-1.T-2.T-3.T-6	344
	'A'	LT-2		220'	2	16	TYPE H	R-43.R-39.T-1.T-2.T-3.T-6	345
	'A'	THERMAL STORAGE UNIT CONTROL CABINET		240'	4	14	TYPE D	R-102.R-39.T-1.T-2.T-3.T-6	346 THRU 349
	'A'	THERMAL STORAGE UNIT CONTROL CABINET		240'	2	16	TYPE H	R-102.R-39.T-1.T-2.T-3.T-6	350
	'A'	THERMAL STORAGE UNIT CONTROL CABINET		240'	20	20	TYPE I	R-102.R-39.T-1.T-2.T-3.T-6	351 THRU 352
	'B'	THERMAL STORAGE UNIT CONTROL CABINET		245'	48	16	TYPE F-1	R-102.R-40.T-1.T-2.T-3.T-4.T-5	353 THRU 356
	'B'	THERMAL STORAGE UNIT CONTROL CABINET		245'	20	20	TYPE I	R-102.R-40.T-1.T-2.T-3.T-4.T-5	357 THRU 361
	S-1	H-1		5'	2	#16	TYPE H	FIELD	400
	H-1	H-2		150'	7	VARIED	TYPE K	R-34,T-1,T-2,T-3,R-13	401
	H-2	S-2			2	#16	TYPE H	FIELD	402
	H-2	H-3		70'	7	VARIED	TYPE K	R-13,T-3,T-6	403
	H-3	LINE BALANCING ASSEMBLY		5'	7	VARIED	TYPE K	FIELD	404
	H-3	S-3		10'	2	#16	TYPE H	FIELD	405
	H-3	PP-3		20'	2	#14	TYPE D	FIELD	406
	BELL TELEPHONE	EXISTING BELL SYSTEM						FIELD	407
								NOT USED	408
	H-4	EXISTING NSP PLANT COMMUNICATIONS						FIELD	409

NOT TO BE USED FOR CONSTRUCTION

DATE OF ISSUE 5-14-76

DATE	REVISIONS AND RECORD OF ISSUE	NO.	BY	CK	APP		

DEPT HEAD
DES ENGR
CHECKED
DRAWN

I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY REGISTERED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF

SIGNED

DATE ________ REG. NO. ________

BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT 7021

ERDA – 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENTS

CIRCUIT LIST

B & V DWG NO. C-6

FROM	TO	REMARKS	EST LENGTH	NUMBER OF CONDUCTORS	SIZE OF WIRE	INSULATION	ROUTING	
13.8	LOAD INTERRUPT SWITCH CNTR	BY NSP		3-(1/C/Ø)	500MCM	TYPE A	BY OTHERS	P-1
LOAD INTERRUPT SWITCH CNTR	'G' ZONE 1	BY NSP		3-(1/C/Ø)	500MCM	TYPE A	BY OTHERS	P-2
LOAD INTERRUPT SWITCH CNTR	'G' ZONE 2	BY NSP		3-(1/C/Ø)	500MCM	TYPE A	BY OTHERS	P-3
LOAD INTERRUPT SWITCH CNTR	'G' ZONE 3	BY NSP		3-(1/C/Ø)	500MCM	TYPE A	BY OTHERS	P-4
LOAD INTERRUPT SWITCH CNTR	'G' ZONE 4	BY NSP		3-(1/C/Ø)	500MCM	TYPE A	BY OTHERS	P-5
'G' ZONE 1	'F' ZONE 1		10'	12-(4/C/Ø)	500MCM	TYPE A	T-8	P-6
'G' ZONE 2	'F' ZONE 2		15'	12-(4/C/Ø)	500MCM	TYPE A	T-9	P-7
'G' ZONE 3	'F' ZONE 3		30'	12-(4/C/Ø)	500MCM	TYPE A	T-10	P-8
'G' ZONE 4	'F' ZONE 4		20'	12-(4/C/Ø)	500MCM	TYPE	T-11	P-9
PP-1	SW-1		10'	3-(1/C/Ø)	#12	TYPE A	R-66	P-10
SW-1	SW-2		15'	3-(1/C/Ø)	#12	TYPE A	R-61,R-60	P11
SW-2	SH-2		30'	3-(1/C/Ø)	#12	TYPE A	R-64	P-12
PP-2	'F'		125'	2	#12	TYPE A	R-29	P-13
VF-1	SW-4	NOT SHOWN IN DRAWING	15'	2	#12	TYPE A	FIELD ROUTE	P-14
SW-4	PP-2		50'	2	#12	TYPE A	R-67	P-15
PP-3	'B'		85'	2	#12	TYPE A	R-12,R-11	P-16
PP-3	'C'		75'	2	#12	TYPE A	R-12,R-10	P-17
480V BRKR L2	METER SOCKET 1		155'	3-(1/C/Ø)	1/0	TYPE A	R-26,R-27	P-18
METER SOCKET 1	MS-2		160'	3-(1/C/Ø)	#2	TYPE A	R-2	P-19
METER SOCKET 1	MS-1		25'	3-(1/C/Ø	#6	TYPE A	R-30,R-72	P-20
MS-2	STAM GEN RECIRC PUMP	BY OTHERS					BY OTHERS	P-21
MS-1	THER STOR. RECIRC. PUMP		30'	3-(1/C/Ø)	6	TYPE A	R-72,R-73	P-22
480V BRKR K2	METER SOCKETS 2		155'	3-(1/C/Ø)	3/10	TYPE A	R-26,R-28	P-23
METER SOCKET 2	PP-1		[illegible]	3-(1/C/Ø)	3/0	TYPE A	R-31	P-24
SW-1	SW-3		10'	3-(1/C/Ø	#4	TYPE A	R-59,R-61	P-25
SW-3	AR-1		[illegible]	3-(1/C/Ø)	4	TYPE A	R-58	P-26
AP-1	PH-1		35'	3-(1/C/Ø	#4	TYPE A	FIELD	P-27
SH-1	PP-1		35'	3-(1/C/Ø)	#8	TYPE A	R-70	P-28
PP-1	TX-2		125'	2	#6	TYPE A	R-17	P-29
PP-1	TX-1		10'	2	#8	TYPE A	R-62	P-30
TX-2	PP-3		10'	2	3/0	TYPE A	R-96	P-31
TX-1	PP-2		10'	2	1/0	TYPE A	R-63	P-32
DM-1	AR-2		30'	2	#12	TYPE A		P-33
'F' ZONE 1	'E' ZONE 1	BY OTHERS				TYPE A	BY OTHERS	P-101
'F' ZONE 2	'E' ZONE 2	BY OTHERS				TYPE A	BY OTHERS	P-102
'F' ZONE 3	'E' ZONE 3	BY OTHERS				TYPE A	BY OTHERS	P-103
'F' ZONE 4	'E' ZONE 4	BY OTHERS				TYPE A	BY OTHERS	P-104
SH-1	TH-1		65'	2	#14	TYPE A	R-74	P-34
SH-2	TH-2		40'	2	#14	TYPE A	R-65	P-35
PP-2	THERMAL STORAGE UNIT CONTROL CABINET		10'	2	#14	TYPE A	R-68	P-36

NOT TO BE USED FOR CONSTRUCTION

DATE OF ISSUE [illegible]

NO.	BY	CK	APP	DATE	REVISIONS AND RECORD OF ISSUE

DEPT HEAD
DES ENGR
CHECKED
DRAWN

I HEREBY CERTIFY THAT THIS PLAN WAS PREPARED BY ME OR UNDER MY DIRECT SUPERVISION AND THAT I AM A DULY REGISTERED PROFESSIONAL ENGINEER UNDER THE LAWS OF THE STATE OF
SIGNED
DATE REG. NO.

BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT 7021

ERDA—10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENTS
CIRCUIT LIST

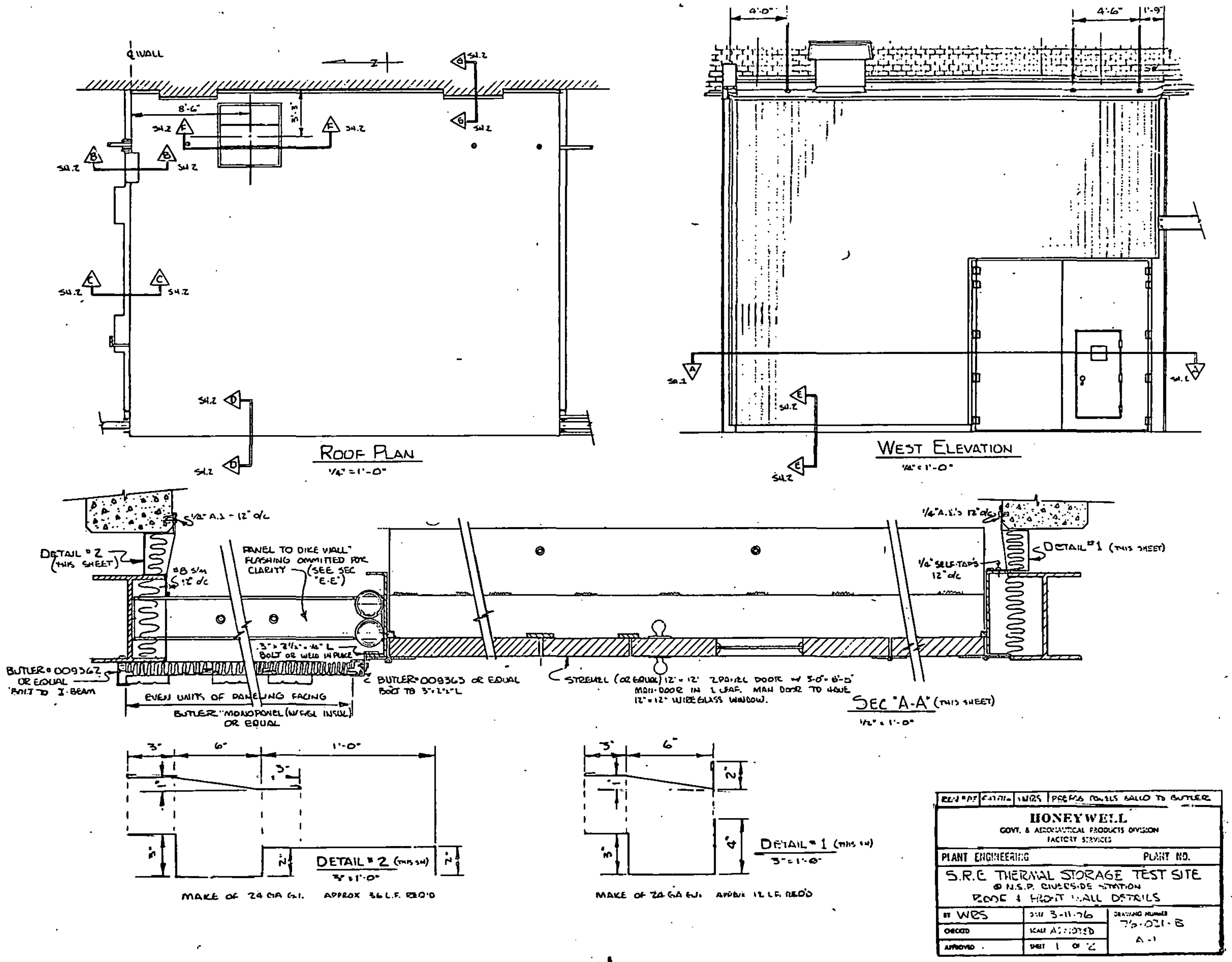
B & V DWG NO. P-1

40454

A183

Drawings (Contd)

DRAWING NO.	PAGES	TITLE	ORGANIZATION
		SFE Thermal Storage Test Side at NSP Riverside Station	
76-021-B A1	1	Roof and Front Wall Details	Honeywell
76-021-B A2	1	Architectural Sections & Details	"
76-021-B S1	1	Roof Framing	"
76-021-B S2	1	Front Wall Framing	"
76-021-B S3	1	Structural Sections & Details	"
76-021-B S4	1	Structural Sections & Details	"
76-021-B S5	1	Monorail Installation and Details	"



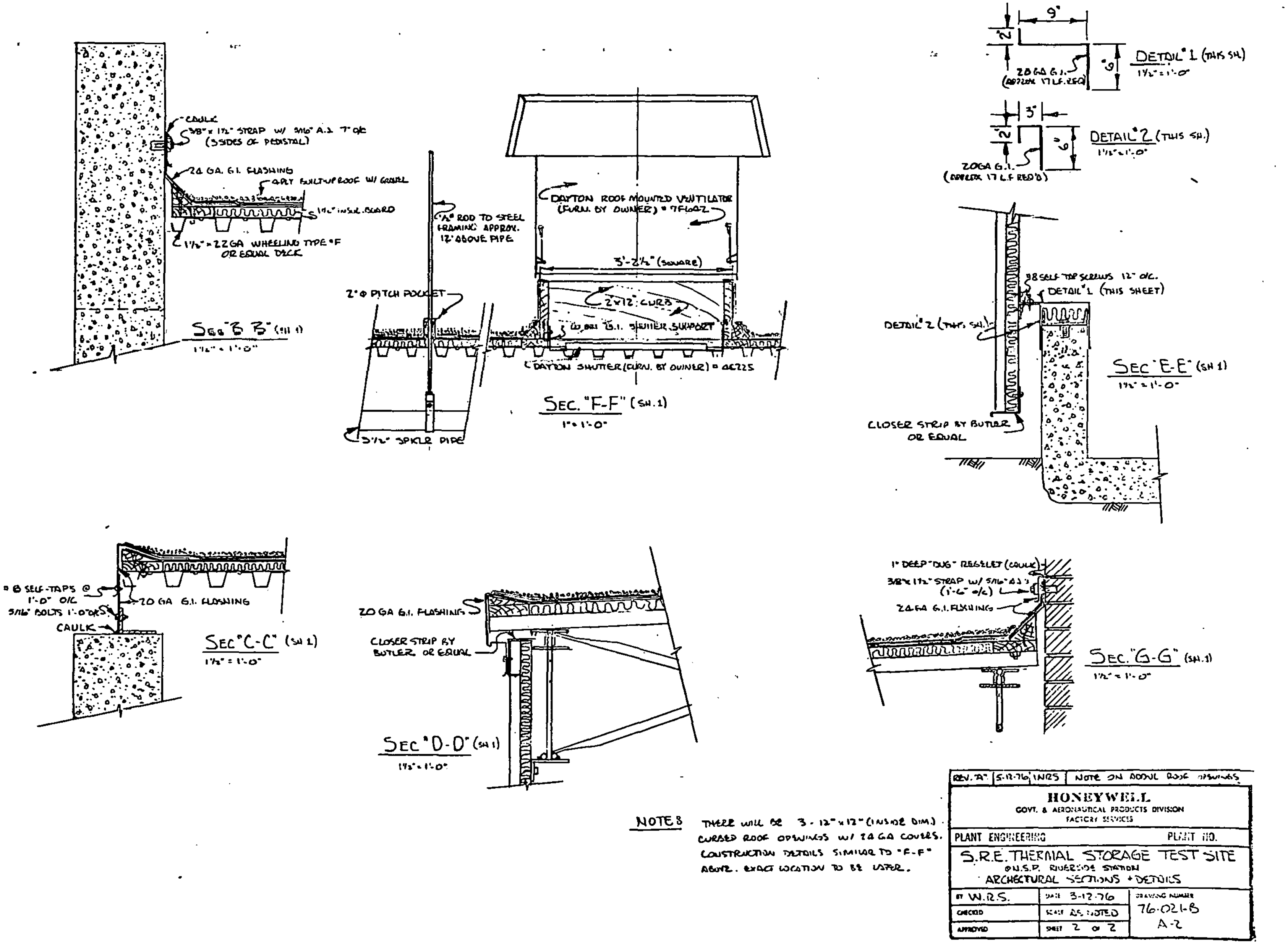
Roof and Front Wall Details

40454

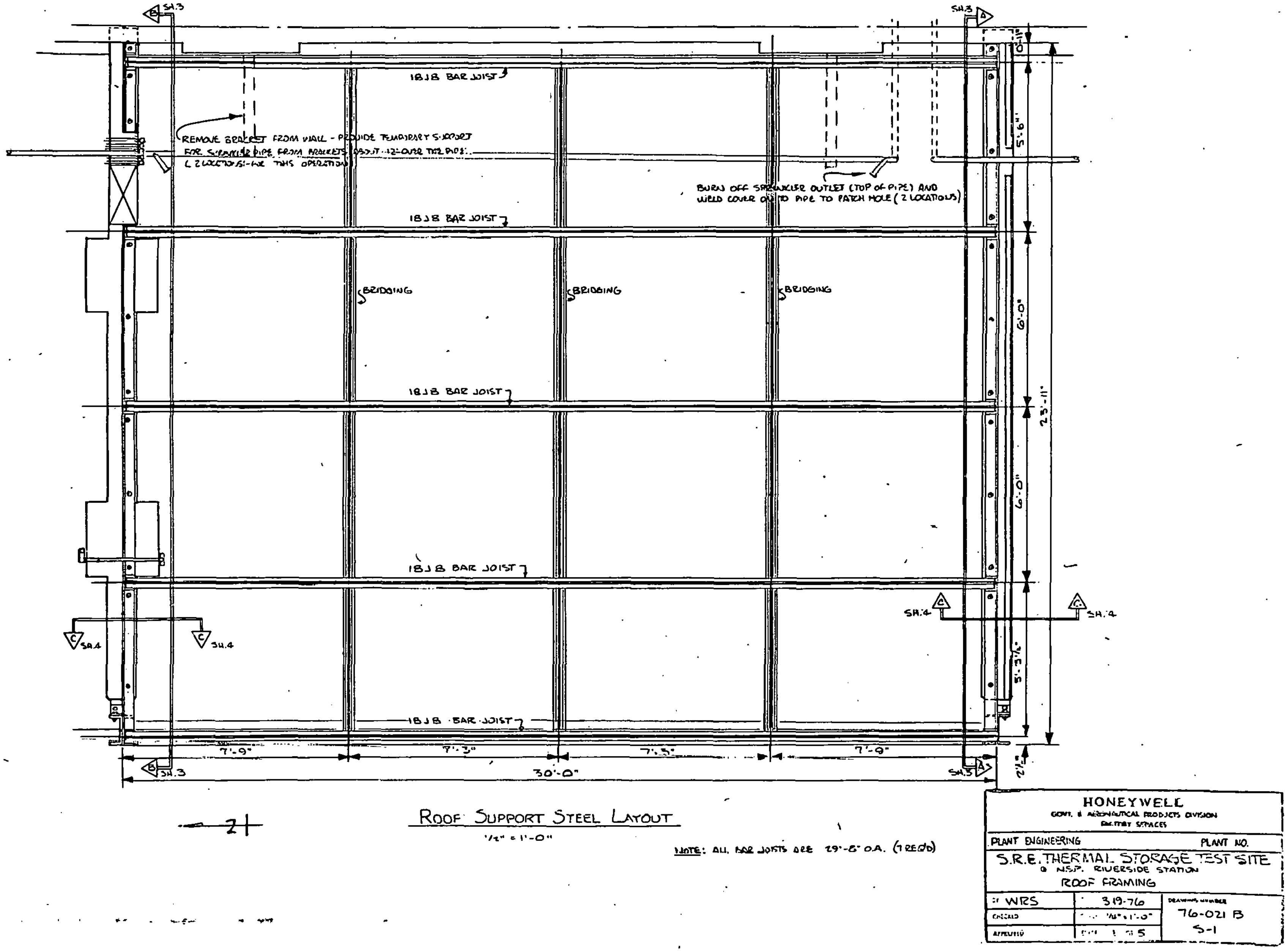
A185

A186

40454



Architectural Sections and Details

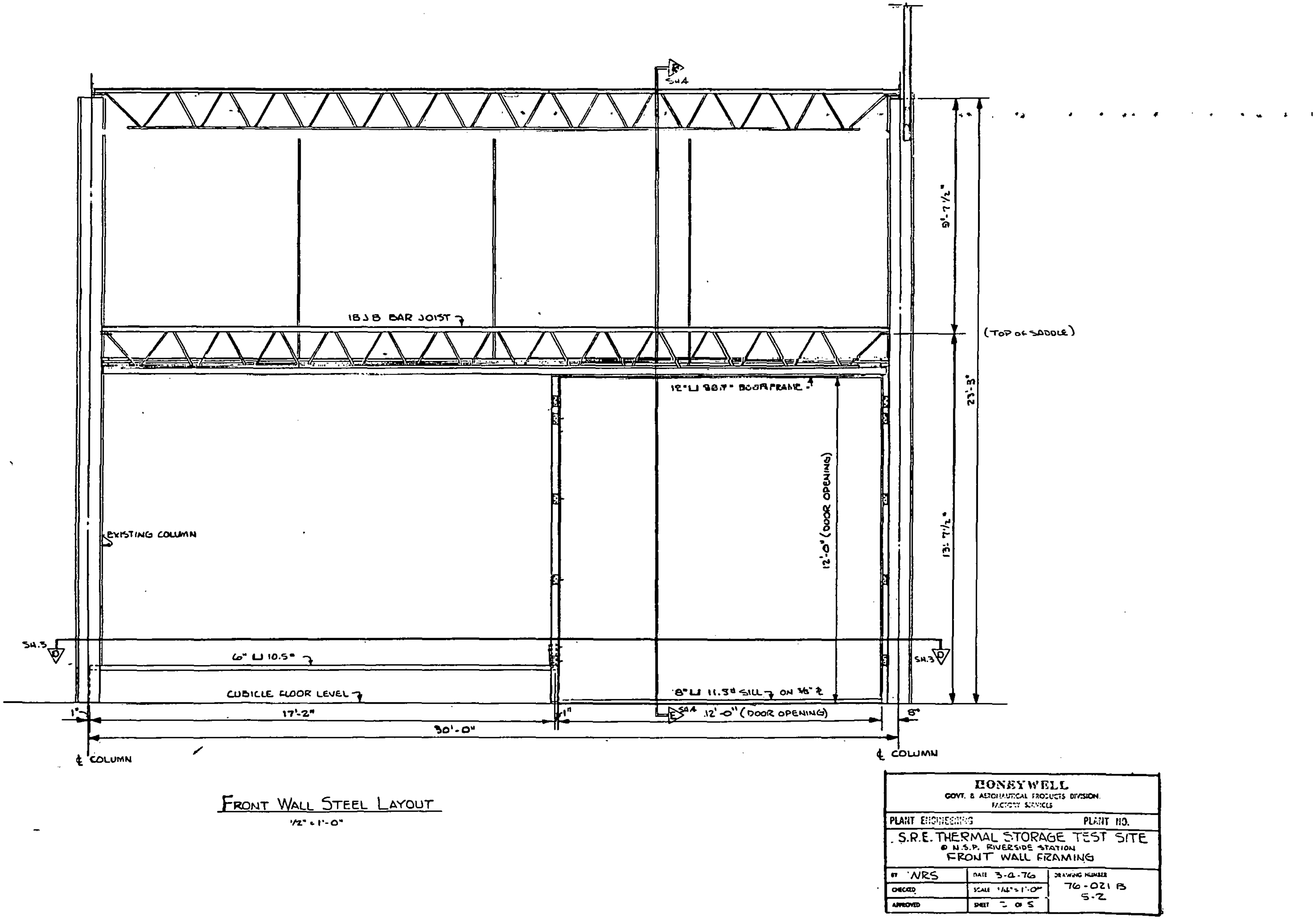


Roof Framing

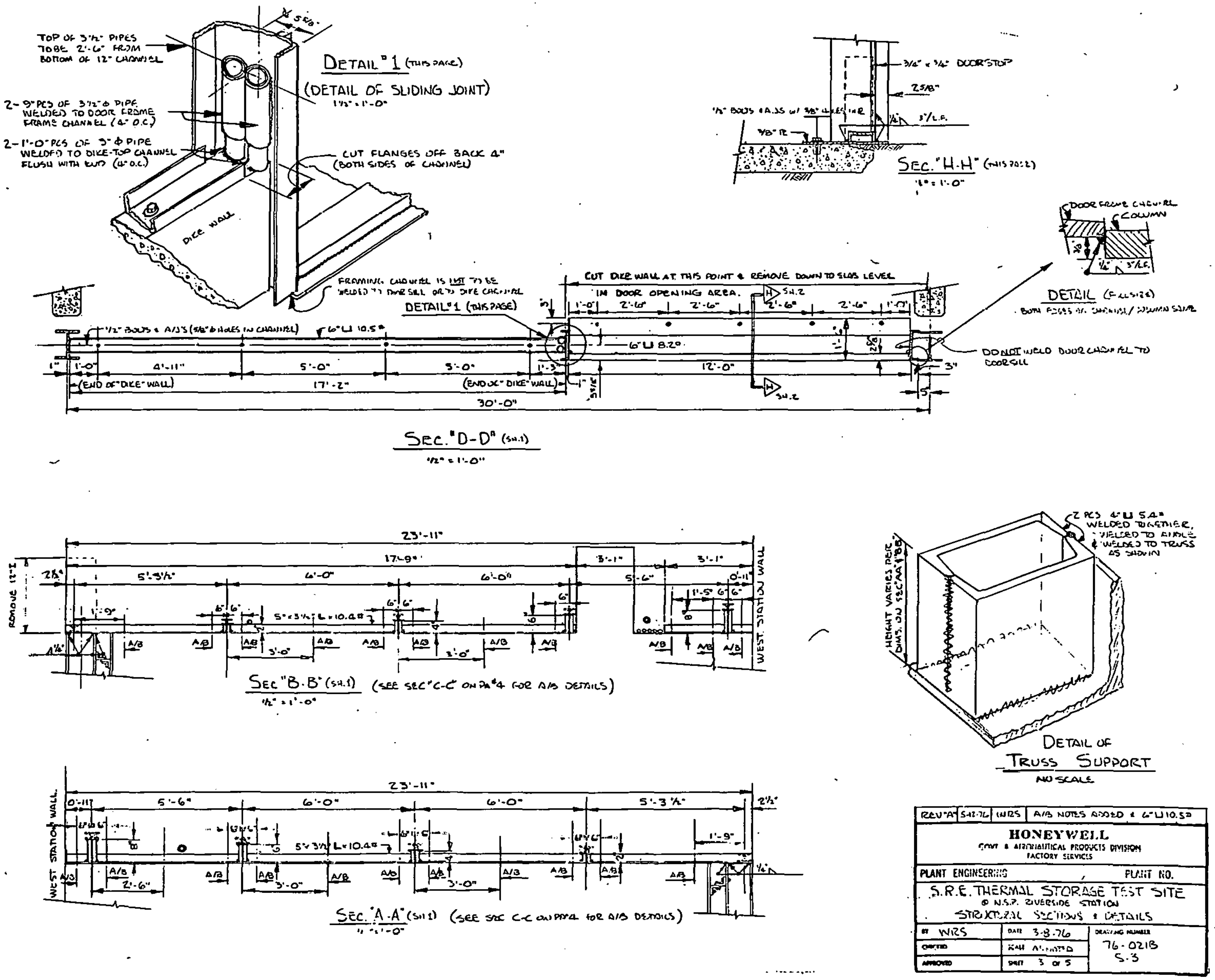
40454

A188

40454



Front Wall Framing



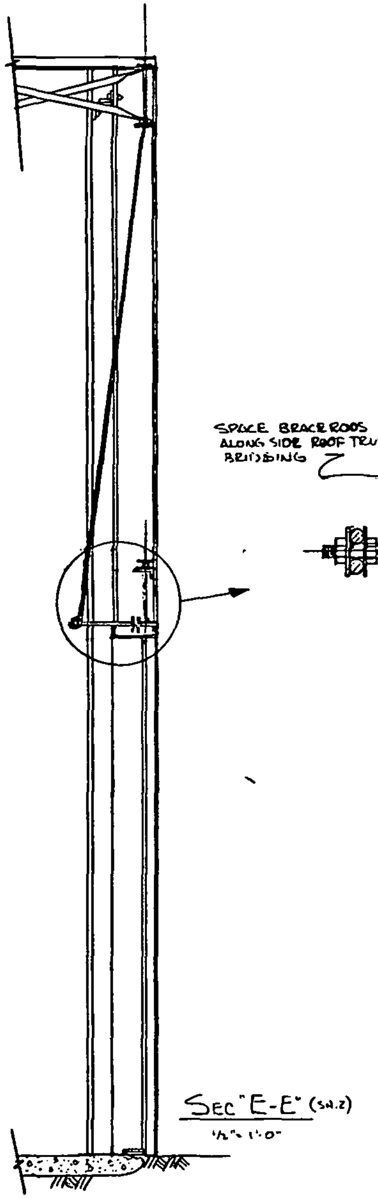
Structural Sections and Details

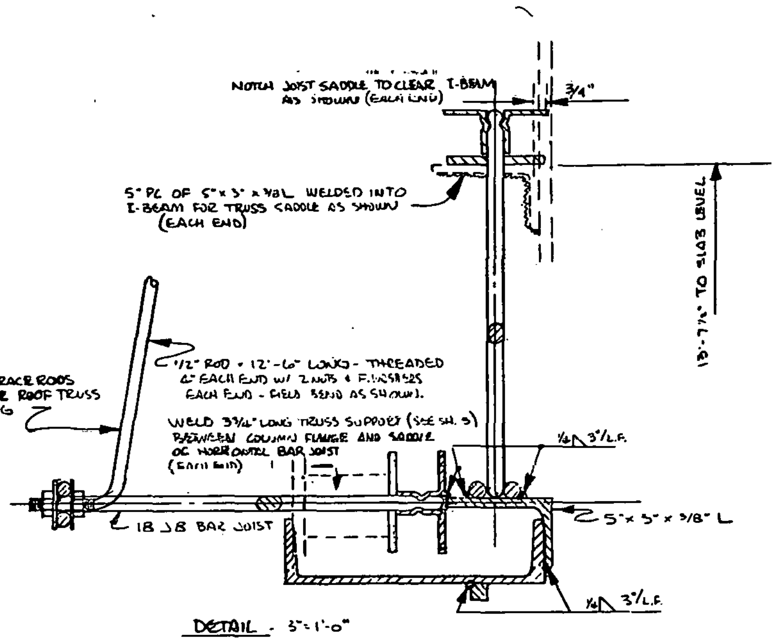
40454

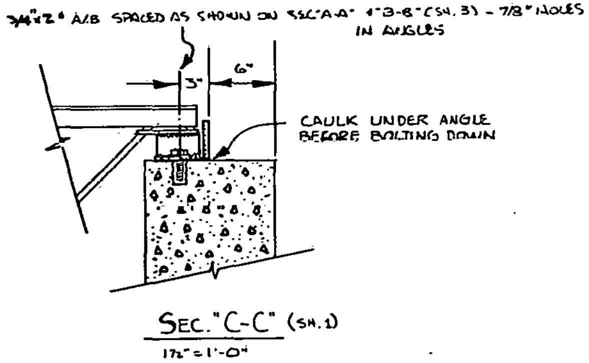
A189

A190

40454







REV. "A"	5-12-76	WRS	A/B NOTES ADDED

HONEYWELL
GOVT. & AERONAUTICAL PRODUCTS DIVISION
FACTORY SERVICES

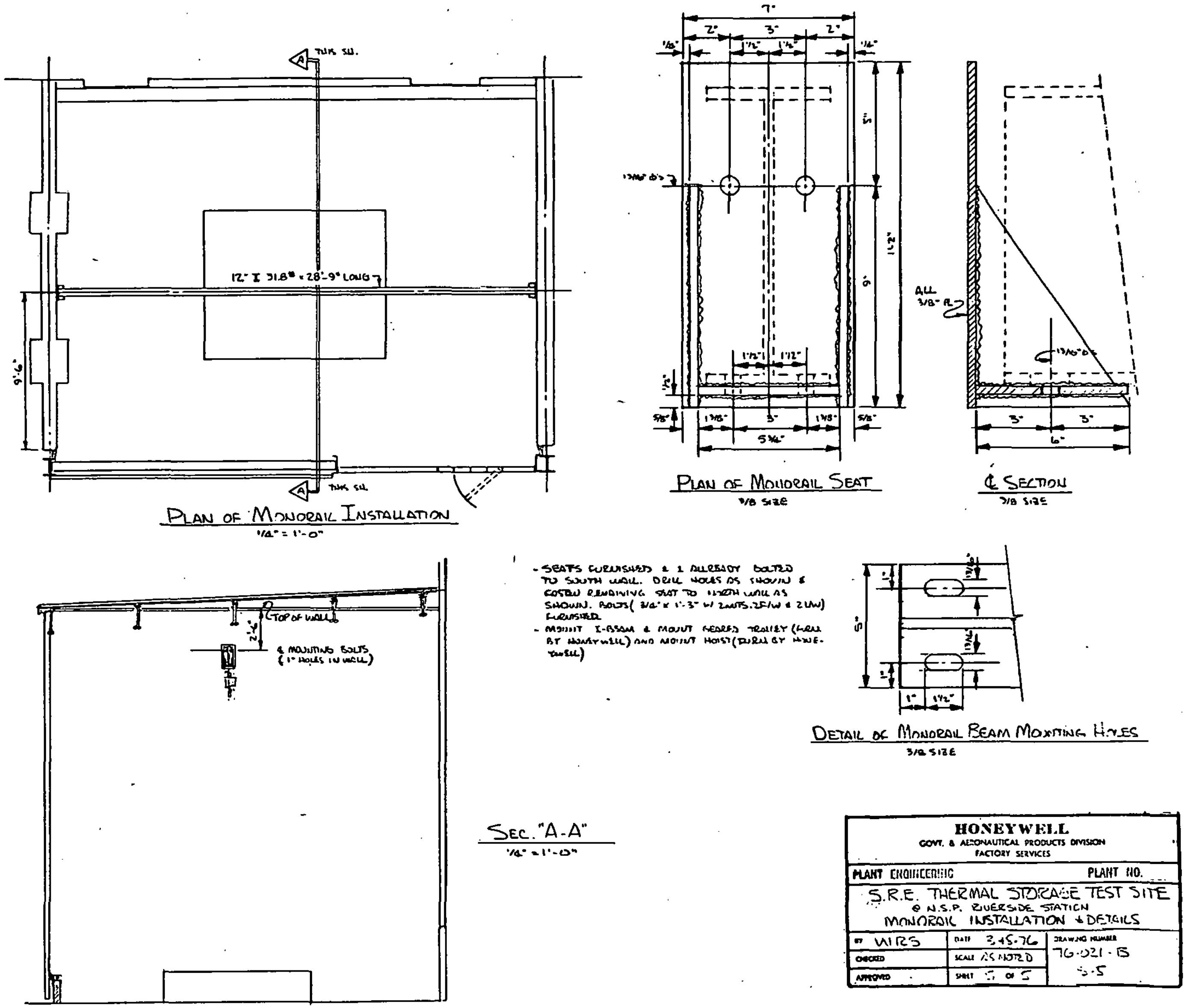
PLANT ENGINEERING — PLANT NO.

S.R.E THERMAL STORAGE TEST SITE
@ N.S.P. RIVERSIDE STATION
STRUCTURAL SECTIONS & DETAILS

BY WRS	DATE 3-19-76	DRAWING NUMBER 76-021 B S-4
CHECKED	SCALE AS NOTED	
APPROVED	SHEET 1 OF 5	

Structural Sections and Details

40454

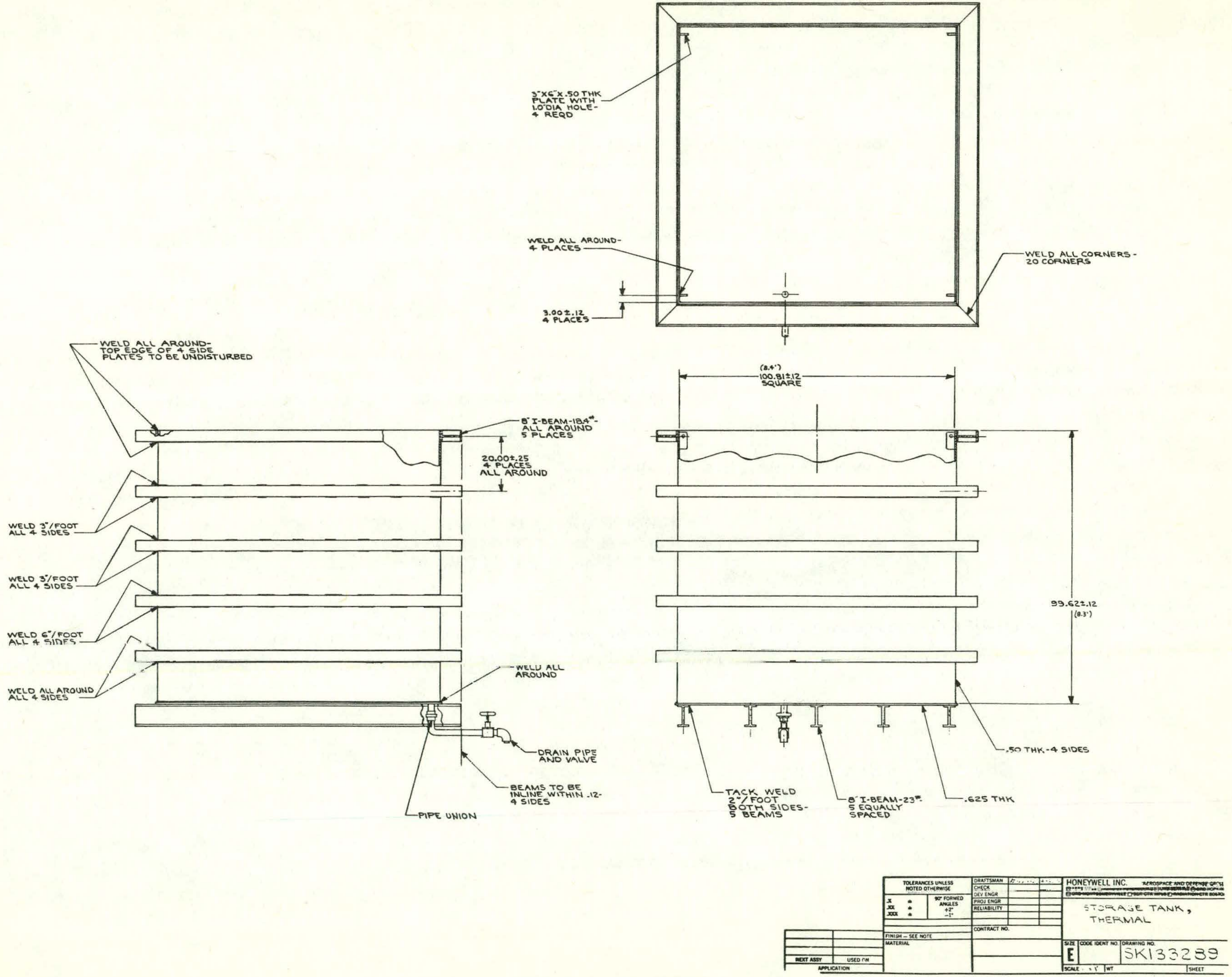


Monorail Installation and Details

Drawings

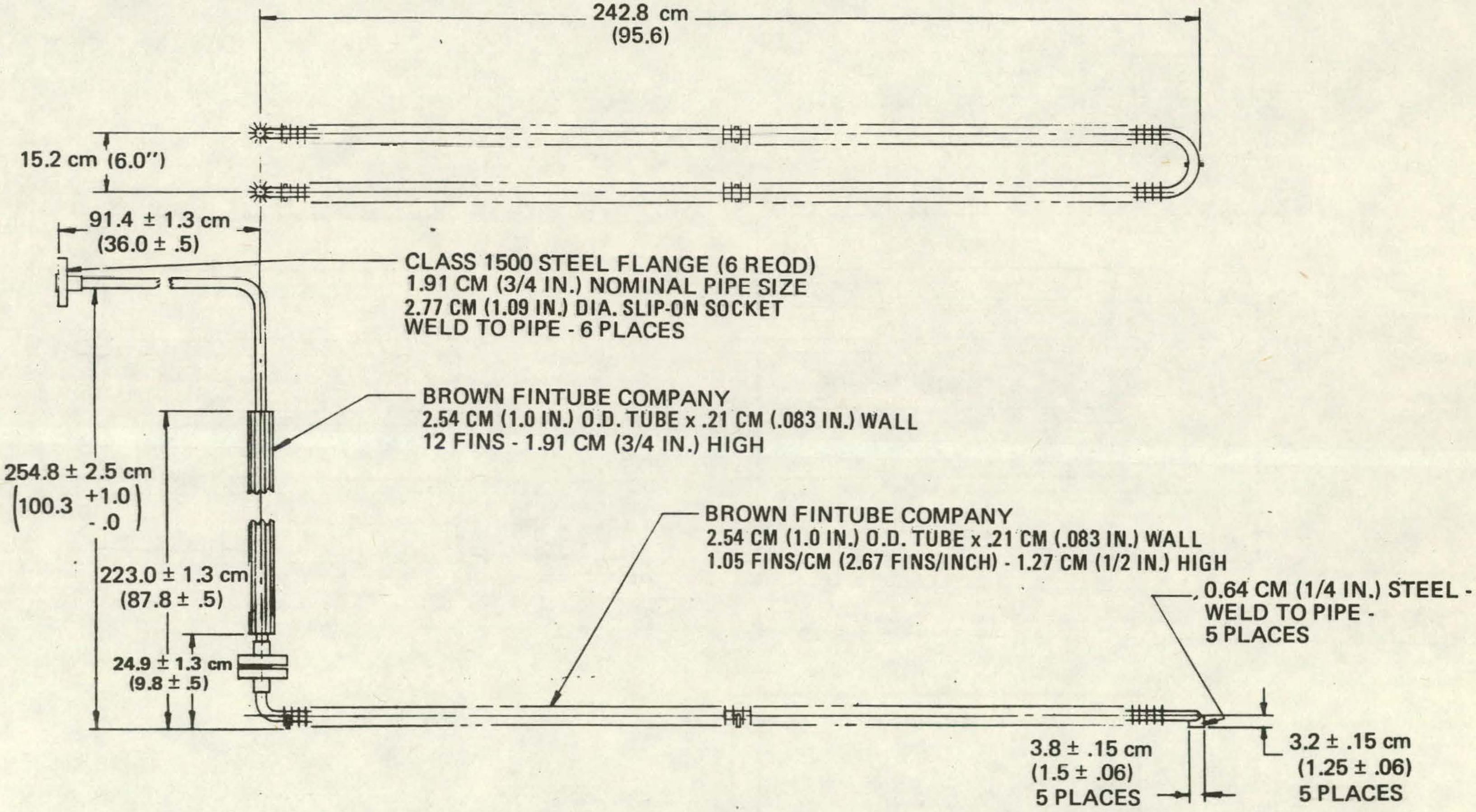
DRAWING NO.	PAGES	TITLE	ORGANIZATION
SK 133289	1	Thermal Storage Tank	Honeywell
SK 140009	1	Salt Pre-melt	"
SK 133500	1	Condenser	"
SK 133291	1	Vaporizer	"
SK 133292	2	Insulation and Heater Panels, Thermal Storage Tank	"
SK 140008	1	Final Assembly - Thermal Storage Tank	"
SK 140015	1	Valve Control Panel	"
SK 140016	1	Mode Selector Panel	"
SK 140017	1	Indication & Controller	"
SK 140018	1	Scraper Motor Control and Torque Readout	"
SK 140019	1	Control Console - Thermal Storage System	

40454



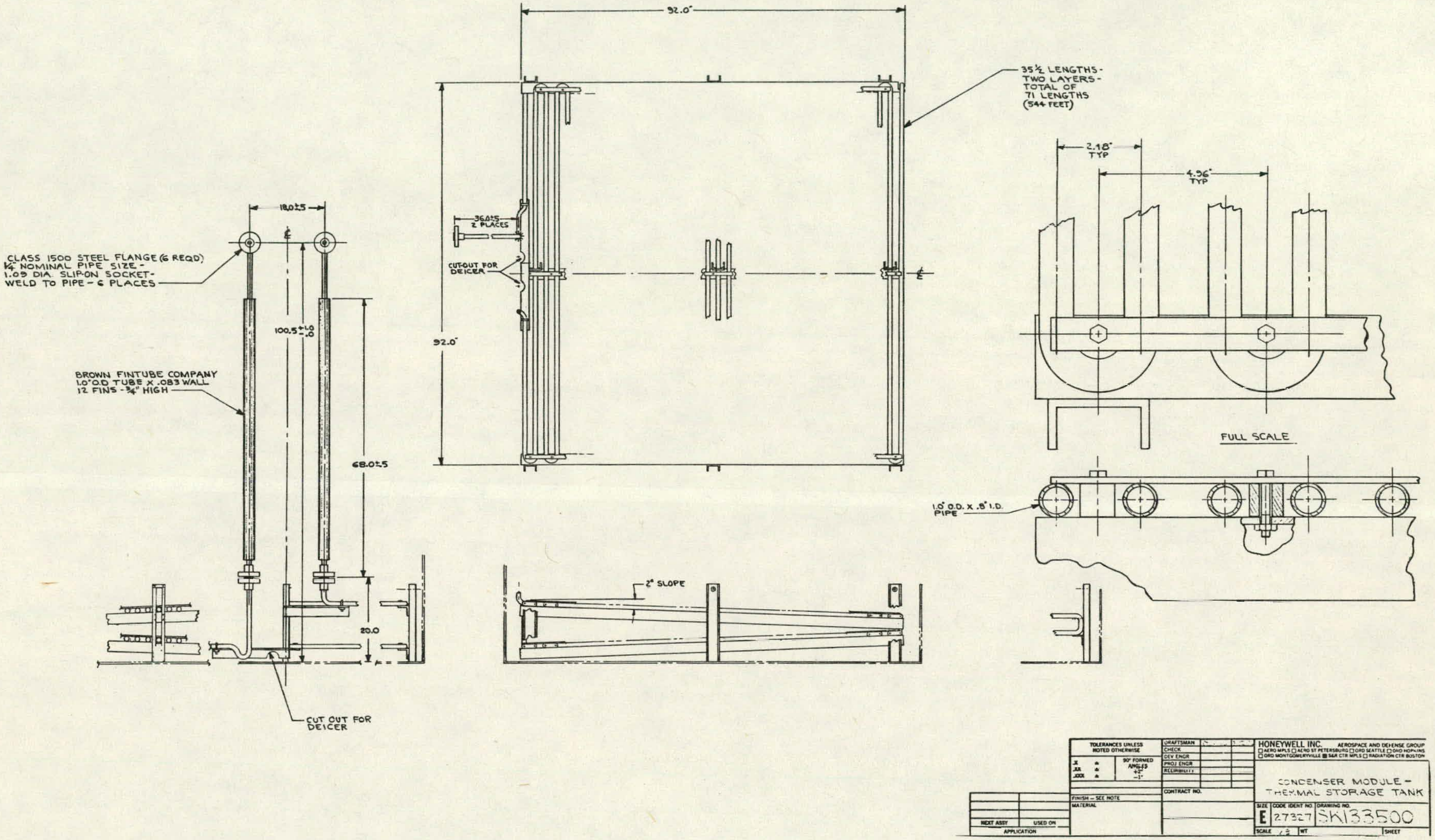
A193

Thermal Storage Tank



Salt Premelt - Storage Tank

40454



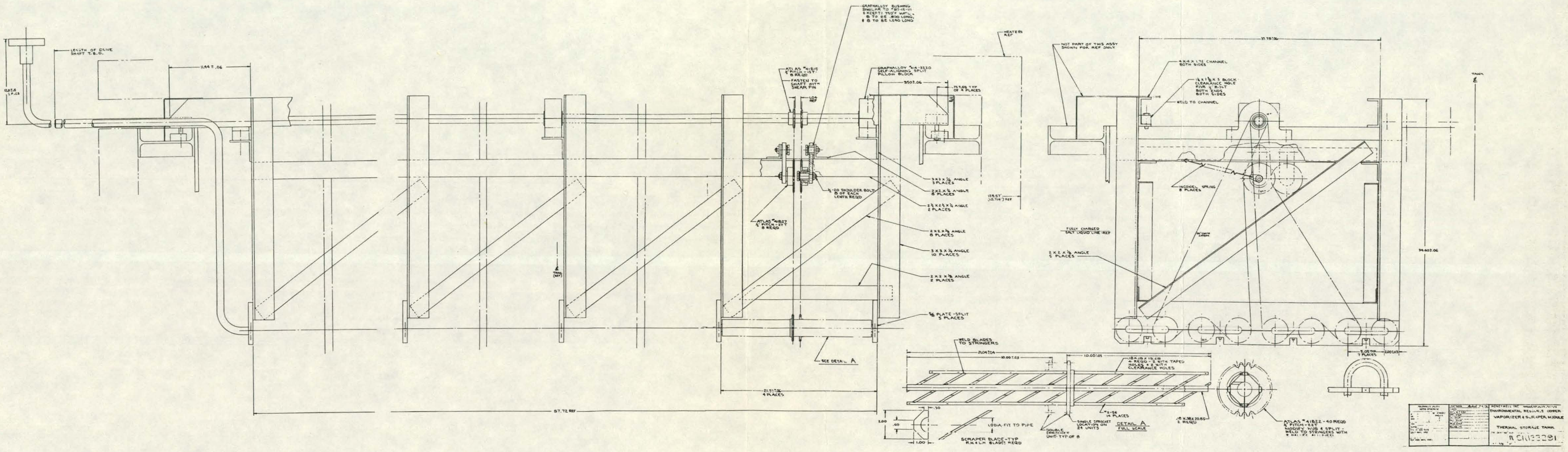
Condenser

40454

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

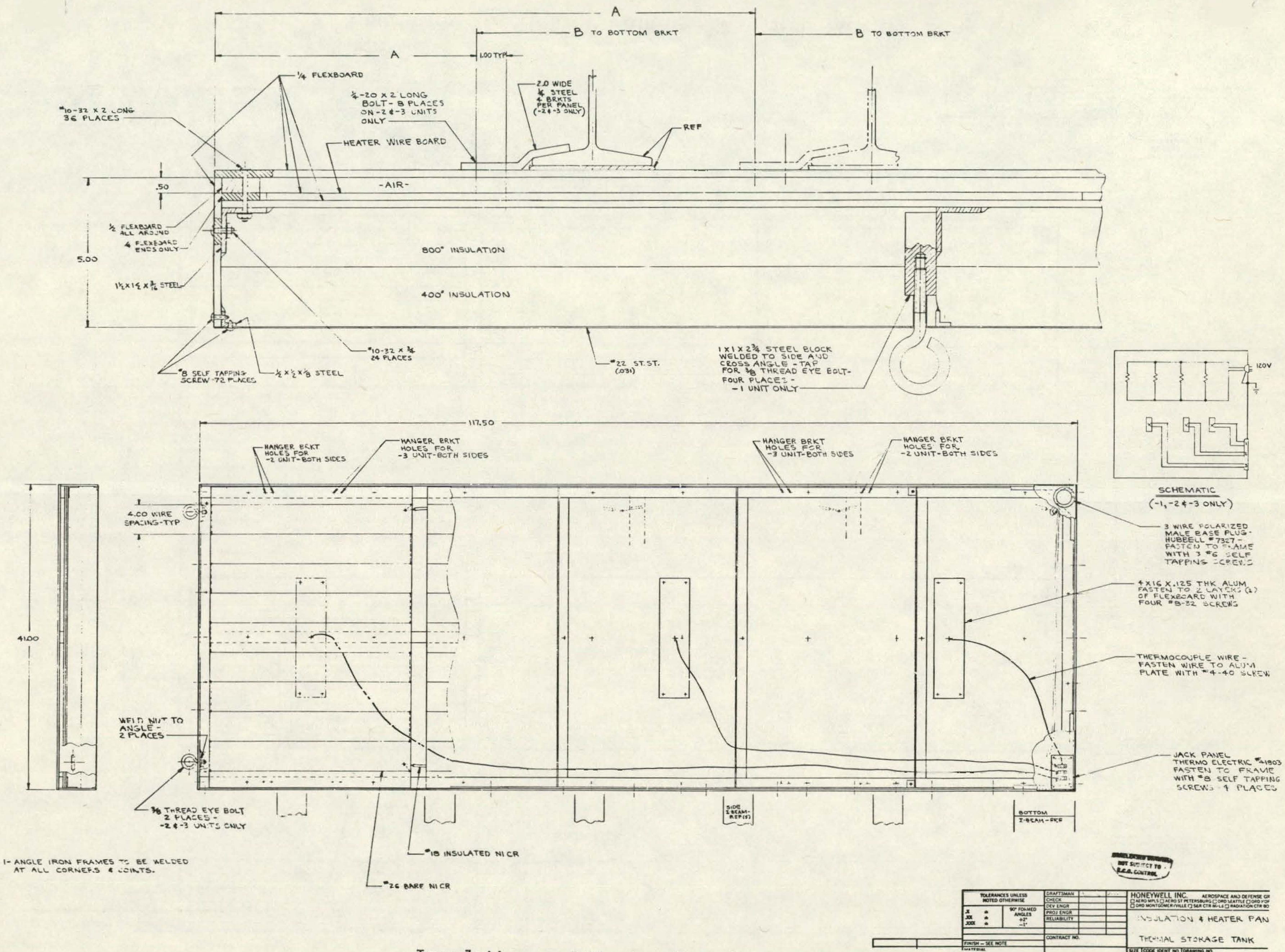


Vaporizer

THIS PAGE

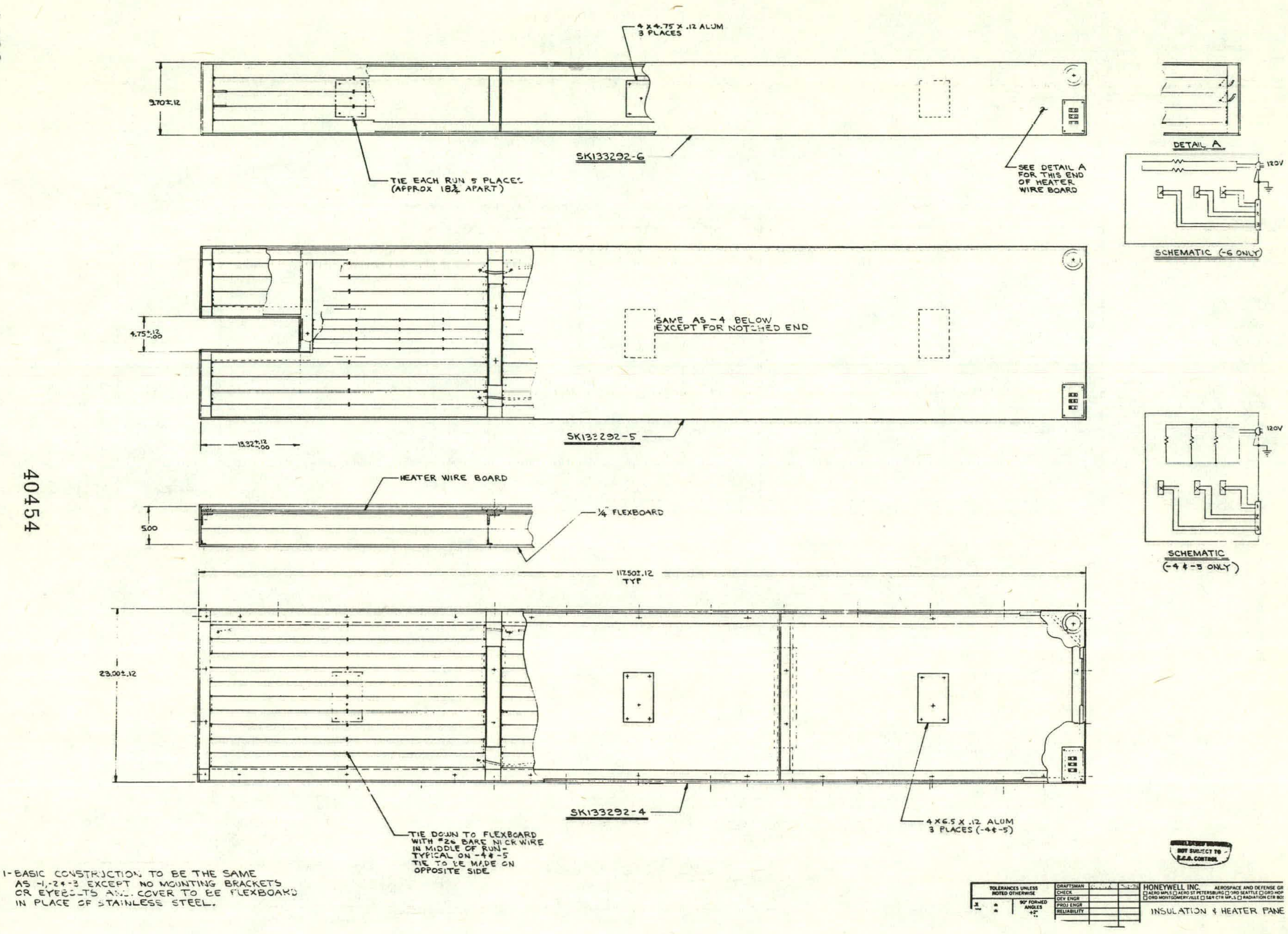
WAS INTENTIONALLY

LEFT BLANK



Insulation and Heater Panels

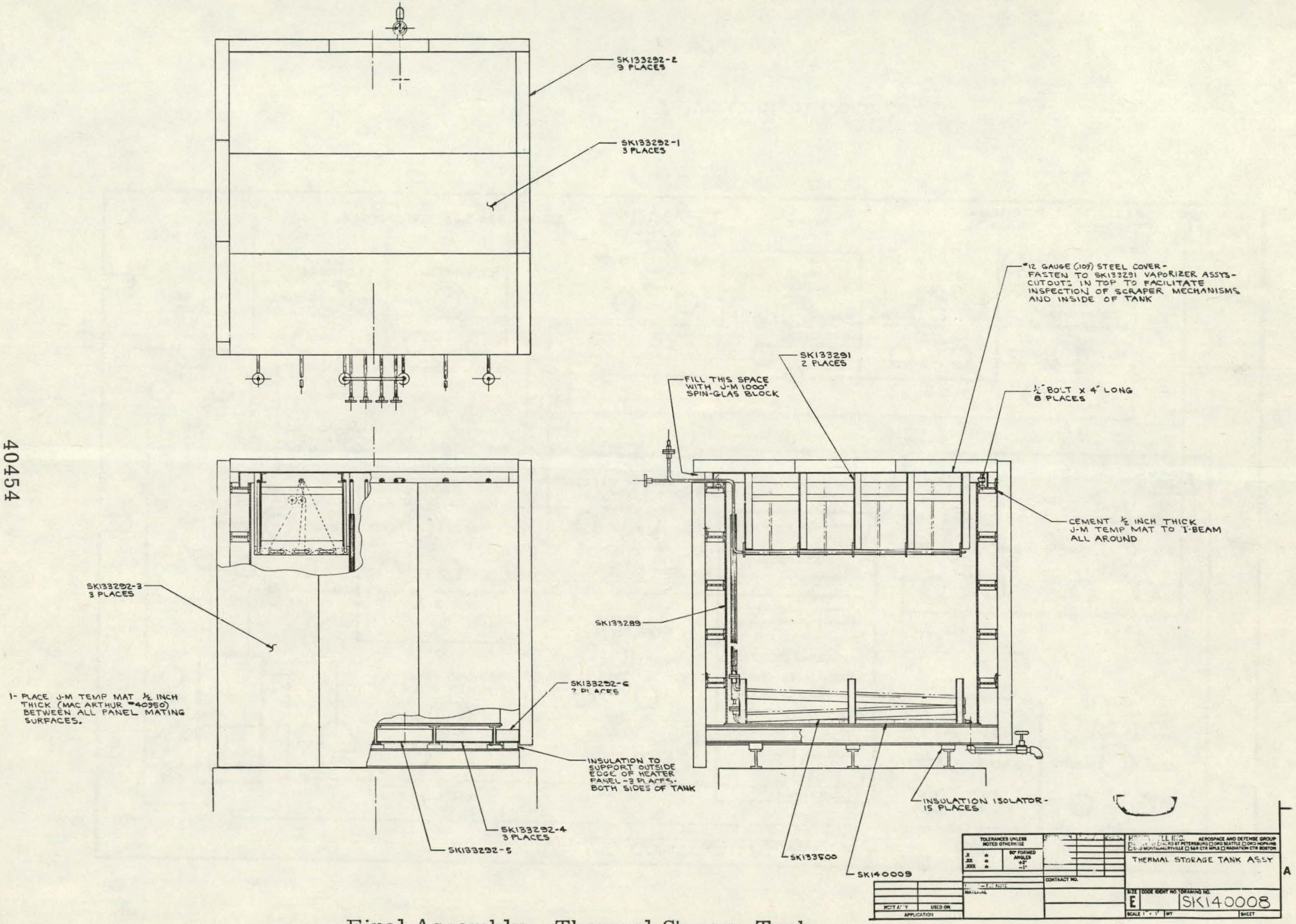
40454 1



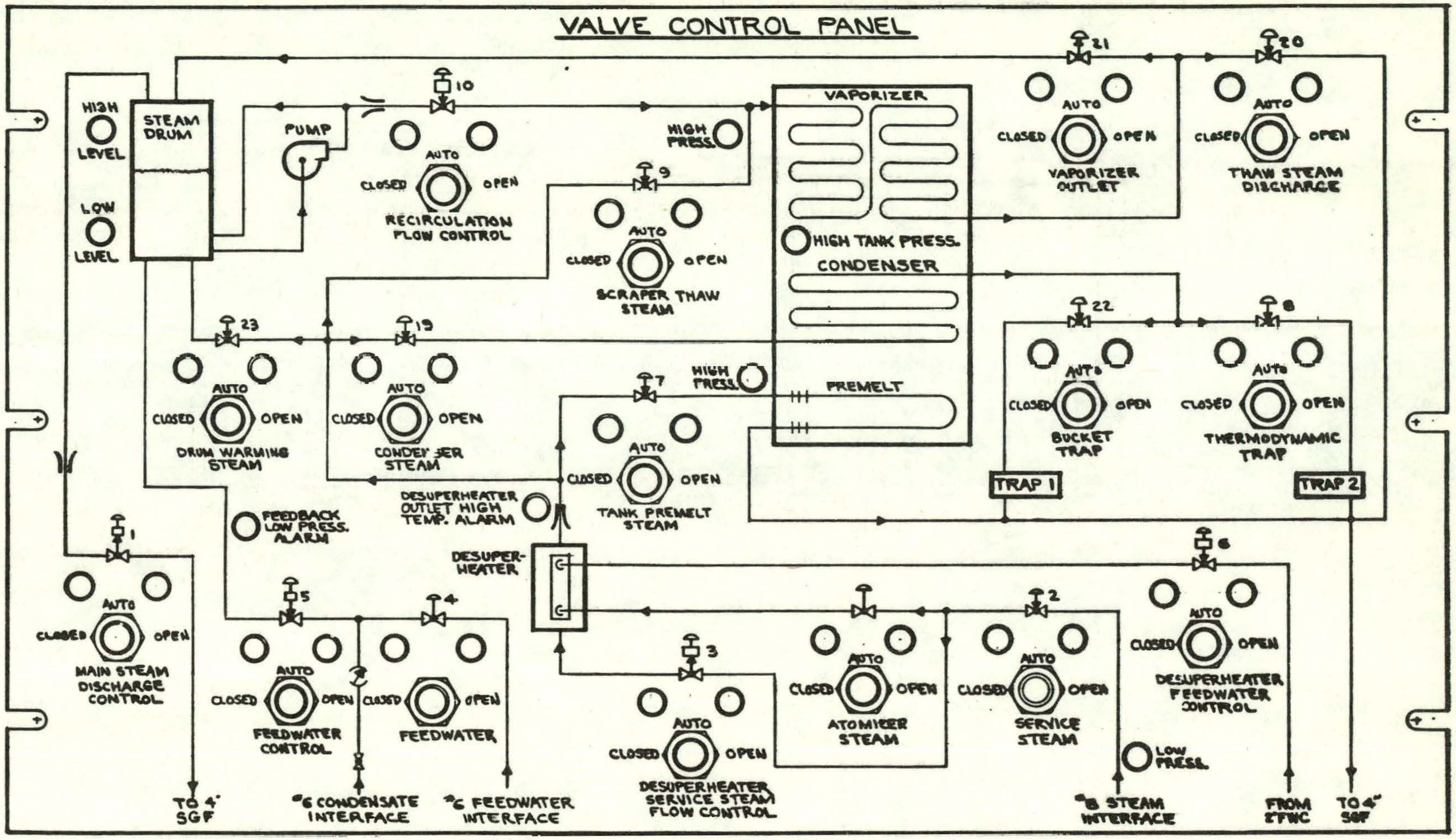
Insulation and Heater Panels - Thermal Storage Tank

40454

A 201

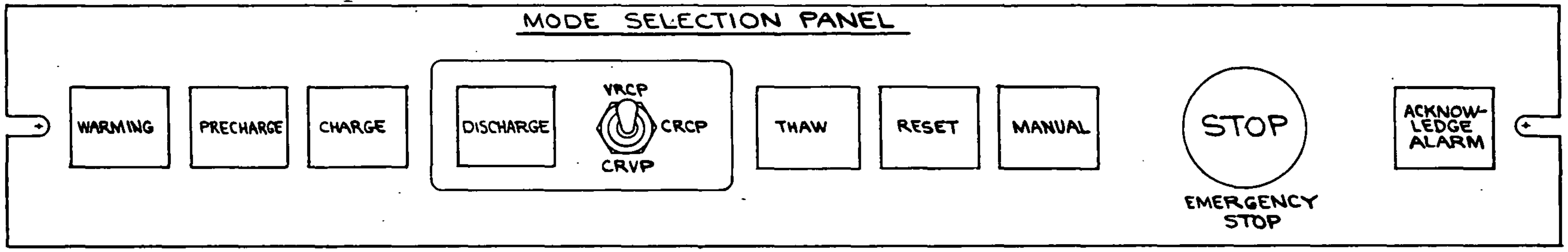


Final Assembly - Thermal Storage Tank



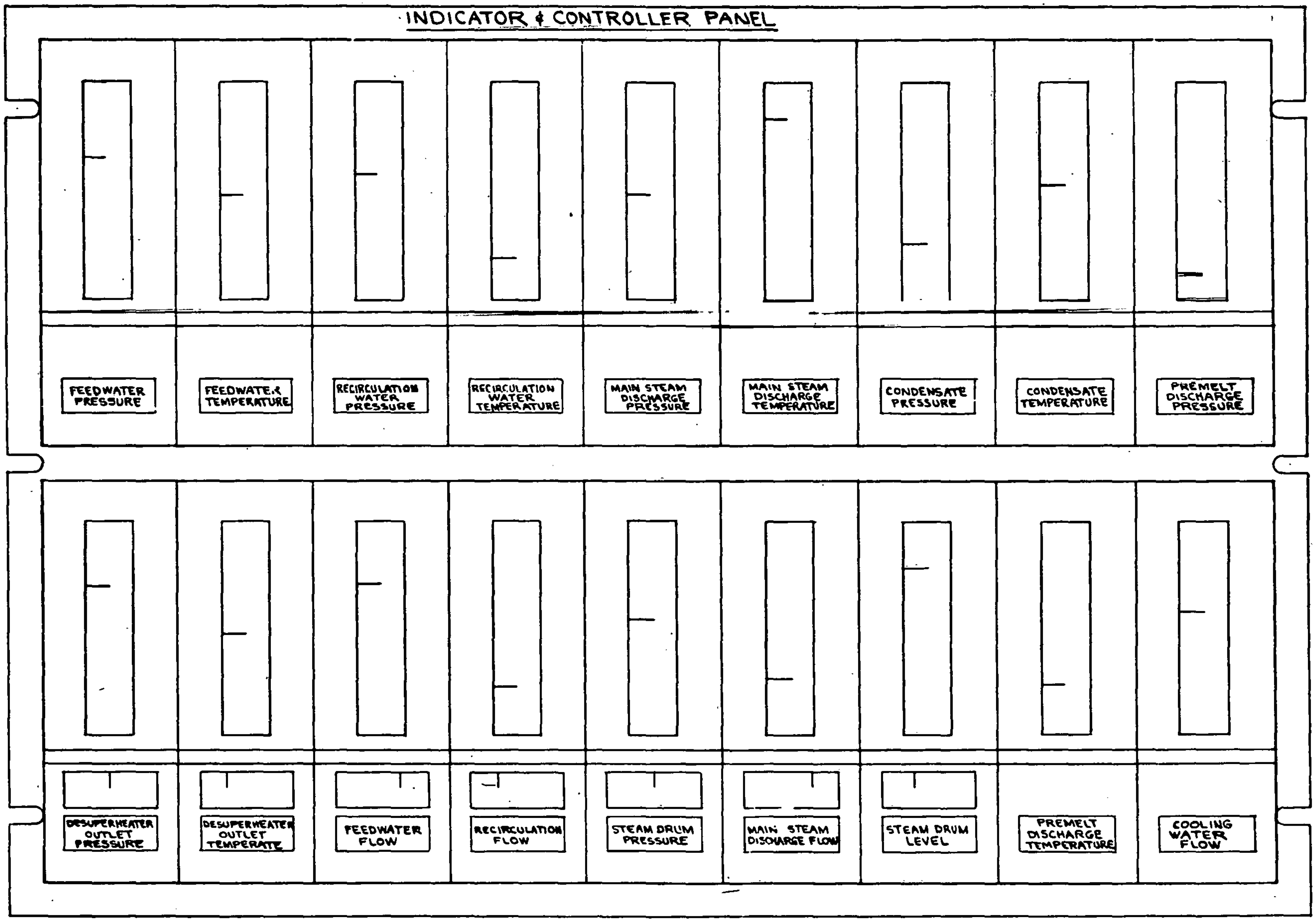
Valve Control Console

40454



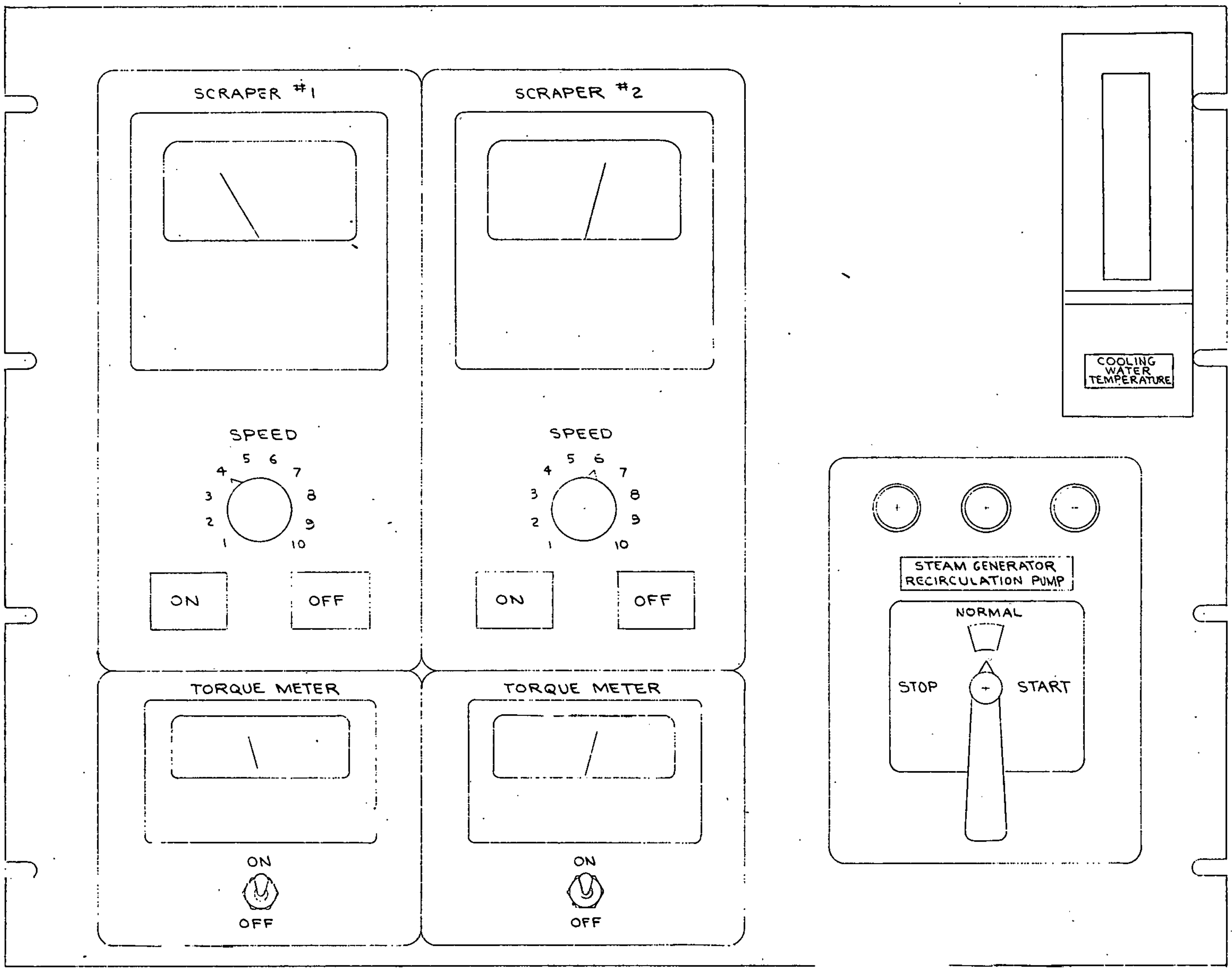
Mode Selector Control Panel

40454



Indicator and Controller Panel

40454



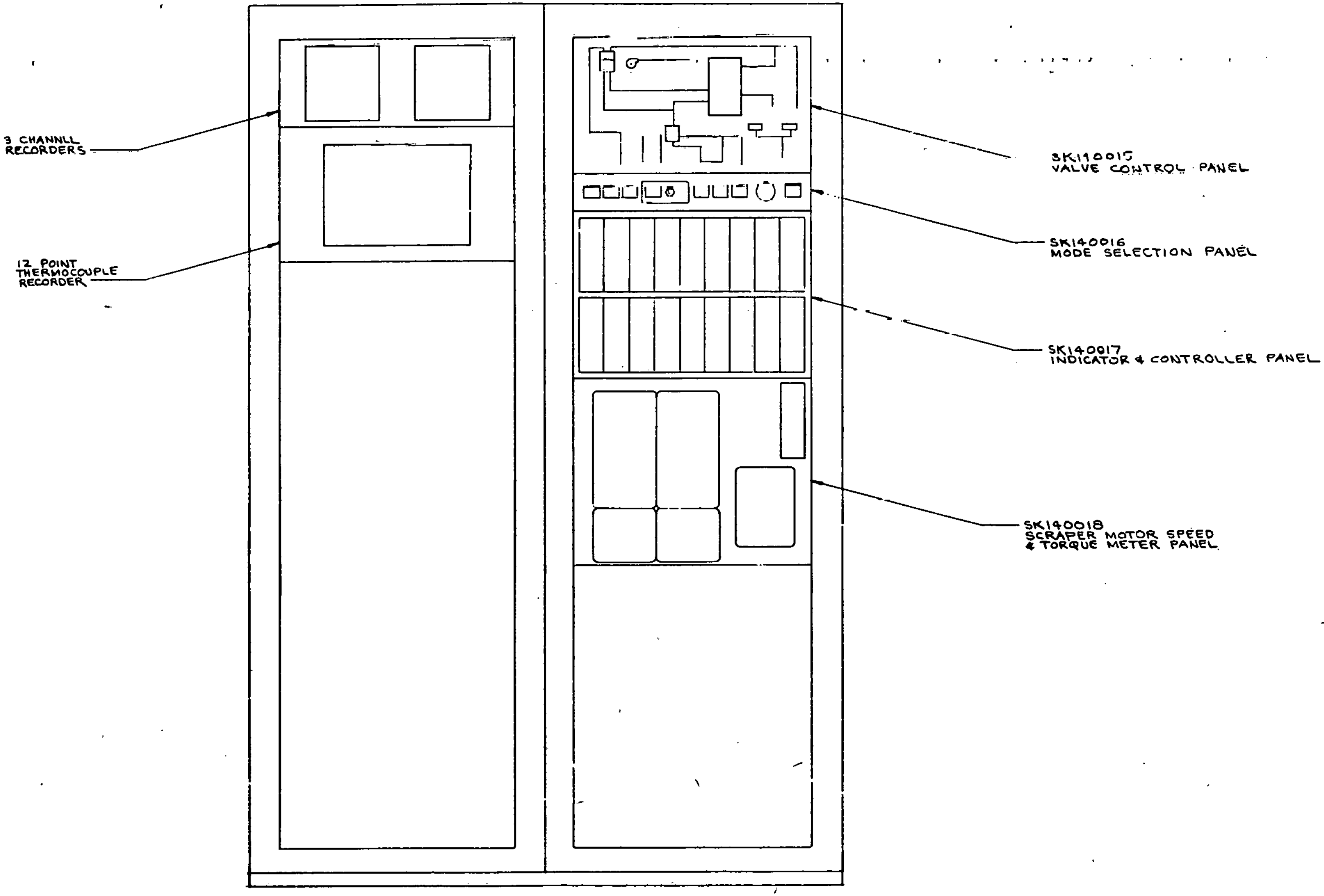
A205

Scraper Motor Control and Torque Readout

HONEYWELL INC.	SYSTEMS AND RESEARCH CENTER MINNEAPOLIS, MINN. 55413
SCRAPER MOTOR SPEED & TORQUE METER PANEL	
SIZE D / CODE IDENT NO. 27327	DRAWING NO. SK140018
SCALE 1/1	SHEET 1 OF

A206

40454



Control Console - Thermal Storage System

APPENDIX B

APPENDIX B
PRESSURE DROP CALCULATIONS

PART I

VAPORIZER PRESSURE DROP CALCULATIONS AND RECIRCULATION PUMP REQUIREMENTS

ABSTRACT

For the TSS/RE (thermal storage subsystem research experiment) steam generation system pressure drop is estimated using the method of Thom. The general equations are derived first and pressure drops are calculated for different flow rates, steam drum pressures and exit steam qualities. Using the vaporizer performance model, described in Appendix I, the expected pressure drops at design and off-design conditions are calculated. Based on these calculations, the requirements of a recirculation pump are presented.

VAPORIZER PRESSURE DROP CALCULATIONS

"The Thom method is most accurate and convenient for adiabatic and non-adiabatic systems involving water, or other fluids less viscous than water. Mass velocities should be greater than 0.5×10^6 lb/hr-ft^2 as all the data used to establish the correlation were taken at mass velocities above this. For systems involving water above a pressure of 250 psia, this method gives the highest precision." (Ref. Handbook of Heat Transfer, Rohsenow and Hartnett, pg. 14-2.)

Method of Thom

Used for, $G > 0.5 \cdot 10^6$ lb/hr-ft^2

$P > 250$ psia

$0.2 \text{ in.} < D_i < 2 \text{ in.}$

(Accuracy = ± 20%)

The total pressure drop,

$$\Delta P = \underset{\text{(friction)}}{\Delta P_f} + \underset{\text{(gravitational)}}{\Delta P_g} + \underset{\text{(momentum)}}{\Delta P_m} \quad \text{(B1)}$$

$$\Delta P_f = 4 \cdot f \cdot \left(\frac{L}{D}\right) \cdot \frac{G^2 \hat{V}_f}{2 g_o} \cdot r_{fh} \quad \text{(B2)}$$

$$\Delta P_g = \rho_f \cdot \frac{g}{g_o} \cdot L \cdot (\sin \theta) \cdot r_{gh} \quad \text{(B3)}$$

$$\Delta P_m = \frac{G^2}{g_o} \cdot (\hat{V}_2 - \hat{V}_1) \quad \text{(B4)}$$

$$\hat{V} = \hat{V}_f + \hat{V}_{fg}$$

ΔP_f = friction pressure drop

ΔP_g = gravity pressure drop

ΔP_m = momentum pressure drop

$\hat{V}$ = specific volume, ft^3/lb

$\hat{V}_f$ = specific volume of liquid, ft^3/lb

$\hat{V}_{fg}$ = $\hat{V}_g - \hat{V}_f$

$\hat{V}_g$ = specific volume of vapor, ft^3/lb

r_{fh} = multiplier for two-phase pressure drop

f = fanning friction factor

G = mass velocity, $lb/hr\text{-}ft^2$

Friction Pressure Drop, ΔP_f

The TSS/RE vaporizer and recirculation pump flow schematic is presented in Figure B1. Friction pressure drop in two-phase flow for straight pipe is calculated from

$$\left(\frac{\Delta P}{L}\right)_{tpf} = \left(\frac{\Delta P}{L}\right)_{lo} \cdot r_{fh} \qquad \text{(B5)}$$

tpf = two-phase flow

lo = liquid only

r_{fh} = multiplier for heated tubes given in Figure B2

For purposes of computation, with a computer the curves in Figure B2 when approximated by the relationship $r_{fh} = 1+9000\ X_e P^{-0.981}$.

For fittings and valves, two-phase pressure drop is calculated from

$$\left(\frac{\Delta P}{L}\right)_{tpf} = \left(\frac{\Delta P}{L}\right)_{lo} \left(1+C \cdot \frac{\hat{V}_{fg}}{\hat{V}_f} \cdot X\right) \qquad \text{(B6)}$$

$\hat{V}_{fg}$ and $\hat{V}_f$ are specific volumes

X = exit steam quality

C = dimensionless coefficient given in Table B1

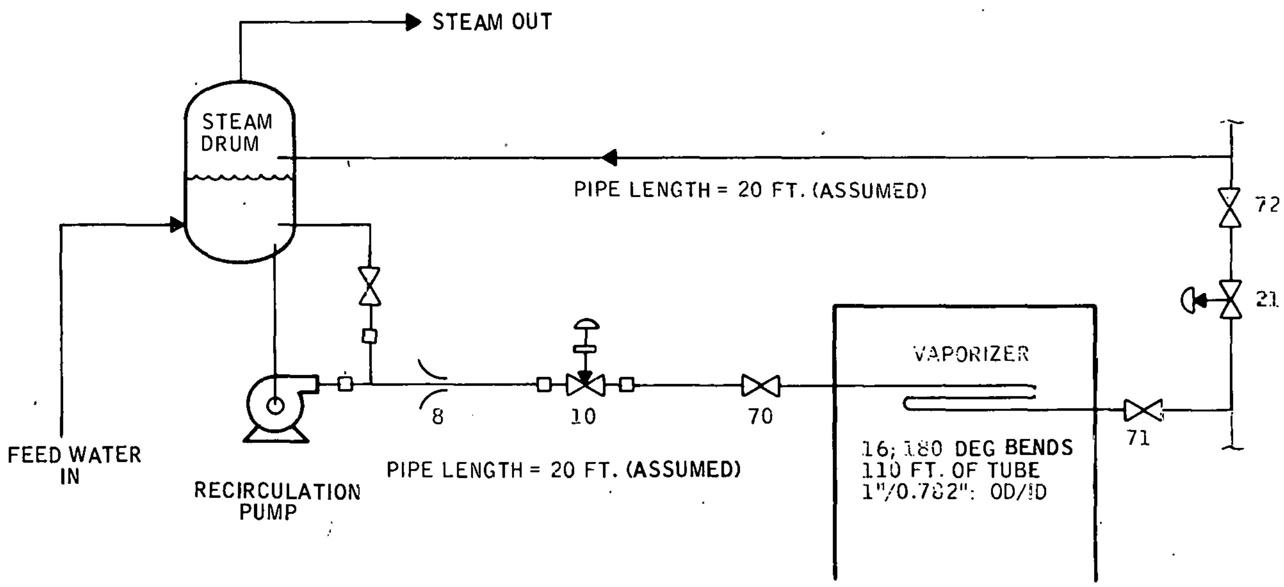


Figure B1. Vaporizer Flow Schematic for the Thermal Storage SRE

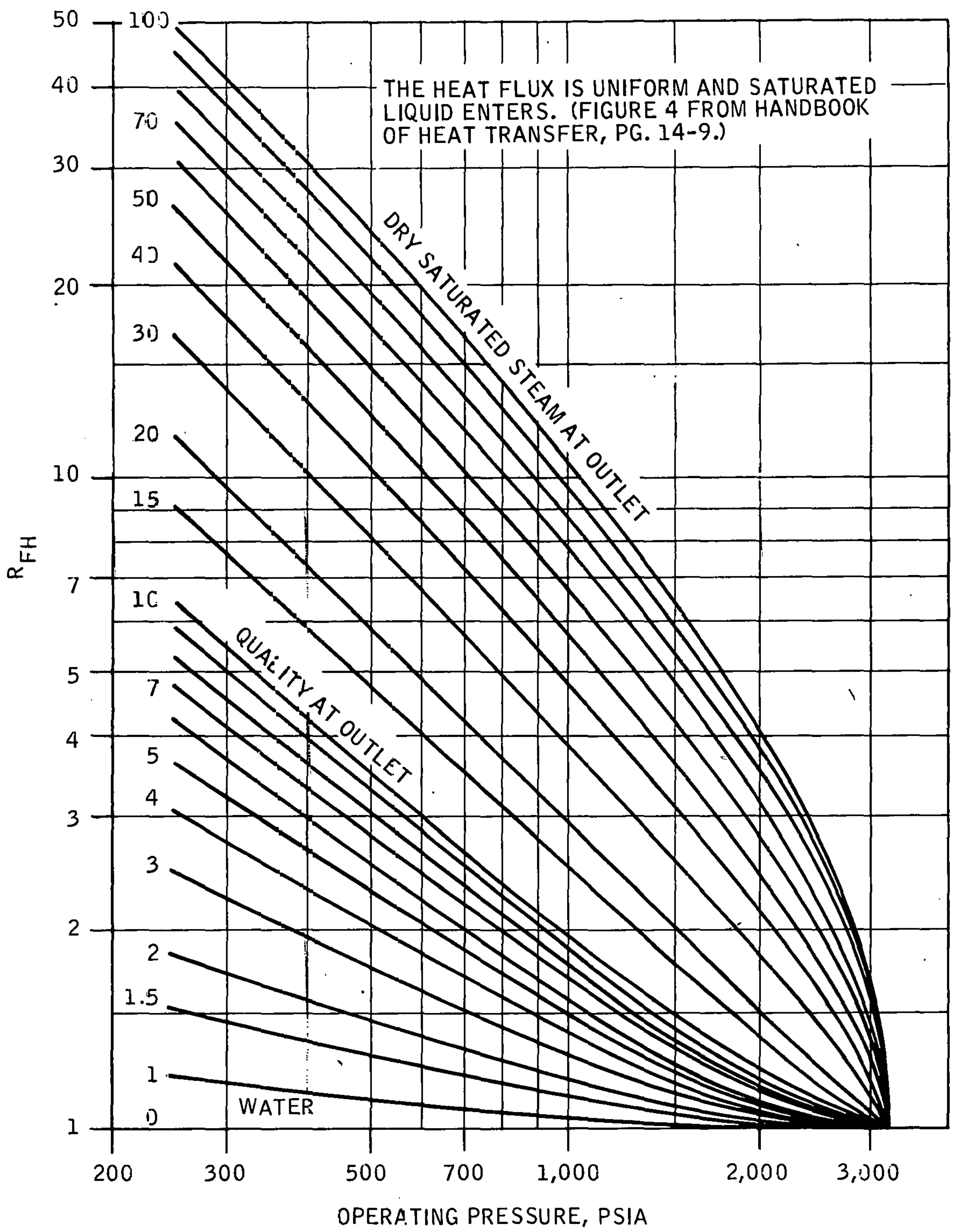


Figure B2. Friction Multiplier, r_{Fh}, for Heated Tubes. The Heat Flux is Uniform, and Saturated Liquid Enters. (Figure 4 from Handbook of Heat Transfer, p. 14-9).

Table B1. Coefficient for Pressure Drop in Fittings

Fitting	Phase tpf	Phase lo	K_c	$C^{\#}$	Valve Nos. (Ref. Figure B1)
Valves and Fittings					
Gate valve, open	2	1	0.17	1.5	21, 71, 70
Globe valve, 1/2 open	---	1	9.5	---	10
90 deg. bends	5	5	0.75	1.5	assumed
180 deg. bends	16	---	1.5	1.1**	vaporizer serpentine
Check valve (swing)	1	---	2.0	1.0	72
Expansions	2	2	0.4	1.1	assumed
Contractions	2	2	0.4	1.0	assumed
Straight Pipe					
Heat exchanger length	110 ft	---		---	
Plant piping (ft)	20	20	---	---	assumed

Ref: Handbook of Heat Transfer, page 14-11.

* J. H. Perry Handbook, page 5-20.

** The 180-deg bends are in vaporizer tubes. Since X changes from 0 to X_e, C value given in reference was integrated.

The total friction pressure drop, ΔP_f, is given by

$$\Delta P_f = \left(\frac{\Delta P}{L}\right)_{lo} \cdot \underbrace{\left[L_{tpf}\, r_{fh} + C_1 L_{e,lo} + L_{lo}\right]}_{L_{e,total}} \qquad \text{(B7)}$$

where

L_{tpf} = length of pipe with two-phase flow

L_{lo} = length of pipe with liquid only

L_e = equivalent length of fitting (calculated from K_c values) (Ref. Table B1)

$$C_1 = 1+C \cdot \frac{\hat{V}_{fg}}{\hat{V}_f} \cdot X$$

Calculation of L_{total}

Length of straight pipe with two-phase flow, L_{tpf} = 130 ft

Length of straight pipe with liquid only flow, L_{lo} = 20 ft

Equivalent length of fittings in tpf and lo flow is calculated from K_c and C values given in Table B1. The number and type of fittings being used in TSS/RE vaporizer is also given. K_c is the equivalent number of velocity heads.

Equivalent length of fittings depends on the Reynolds number and is calculated from

$$L_e = K_c \cdot \frac{D_i}{4f}$$

where f is function of Reynolds number. The friction factor, f, is obtained from the Moody diagram (Ref. J.H. Perry, 4th ed. pg. 5-20).

For $V \geq 5$ ft/sec, $Re \geq 2 \times 10^5$ and $f = 0.006$.
For $V < 5$ ft/sec, $Re < 2 \times 10^5$ and $f \sim 0.0065$.

The equivalent length of fittings (in ft or straight pipe) is

$$L_e = K_c \cdot \frac{0.782/12}{4 \cdot 0.006} = 2.72\, K_c,\ \text{ft}$$

The sum of velocity heads is obtained from

$$(\Sigma K_c)_{lo} = \Sigma\ (\text{No. of fittings in lo flow}) \cdot K_c$$

$$(\Sigma K_c)_{tpf} = \Sigma\ (\text{No. of fittings in tpf}) \cdot K_c \cdot \left(1 + C \cdot \frac{\hat{V}_{fg}}{\hat{V}_f} \cdot X_e\right)$$

Using the values given in Table 1, we get

$$(\Sigma K_c)_{lo} = 1.50$$

$$(\Sigma K_c)_{tpf} = 30.9 + 38.8 \cdot \frac{\hat{V}_{fg}}{\hat{V}_f} \cdot X_e$$

The equivalent length of fittings is

$$L_{e,lo} = (15) \cdot (2.72) = 40 \text{ ft}$$

$$L_{e,tpf} = \left(30.9 + 38.8 \frac{\hat{V}_{fg}}{\hat{V}_f} \cdot X_e\right)(2.72)$$

$$= 84 + 105.5 \cdot \frac{\hat{V}_{fg}}{\hat{V}_f} \cdot X_e$$

Therefore, the total equivalent length of pipe in TSS/RE vaporizer is

$$L_{e,total} = \text{Length of st. pipe} + \text{equivalent length of fittings}$$

$$L_{e,total} = \underbrace{130\, r_{fh} + 84 + 105.5 \frac{\hat{V}_{fg}}{\hat{V}_f} \cdot X_e}_{tpf} + \underbrace{20 + 40.8}_{lo}$$

$$\boxed{L_{e,total} = 130\, r_{fh} + 105.5 \frac{\hat{V}_{fg}}{\hat{V}_f} X_e + 144} \qquad \text{(B8)}$$

Pressure Drop

Calculation of the several components and the total pressure drop follows.

Friction Pressure Drop -- Using Fanning equation for friction pressure drop,

$$\left(\frac{\Delta P}{L}\right)_{lo} = 4 \cdot \frac{f}{D} \cdot \frac{V^2}{2g_c \cdot \hat{V}_f}$$

with, $f = 0.006$, $D = 0.782/12$, ft,

$$\left(\frac{\Delta P}{L}\right)_{lo} = 4 \cdot 10^{-5} V^2; \quad [\text{psi/ft}]$$

where, V is in ft/sec.

Now,

$$V\ (\text{ft/sec}) = \frac{Q\ [\text{gpm}]}{\pi D^2/4} \cdot (\text{conv. factors})$$

$$V = \frac{1}{7.48 \cdot 60} \cdot \frac{1}{0.0033} \cdot Q$$

$$V = 0.6685\ Q$$

or 1.5 gpm = 1 ft/sec

Therefore,

$$\boxed{\left(\frac{\Delta P}{L}\right)_{lo} = 1.787 \cdot 10^{-5} \frac{Q^2}{\hat{V}_f}} \qquad \text{(B9)}$$

Q is flow rate in [gpm]

V_f is specific volume of liquid, [ft^3/lb]

$$\Delta P_f = \left(\frac{\Delta P}{L}\right)_{lo} \cdot L_{e,\,total}$$

<u>Momentum Pressure Drop, ΔP_m</u> --

$$\Delta P_m = \frac{G^2}{g_o} \cdot (\hat{V}_2 - \hat{V}_1)$$

$$\hat{V}_2 = X_e \cdot \hat{V}_{fg} + \hat{V}_f$$

$$\hat{V}_1 = V_f$$

$$\Delta P_m = \frac{G^2}{g_o} \cdot X_e \cdot \hat{V}_{fg}$$

$$\boxed{\Delta P_m = 0.00142\ X_e,\ [\text{psi}]} \quad \text{(negligible)}$$

X_e = exit quality of steam

Gravitional Pressure Drop, ΔP_g --

ΔP_g = 0 (horizontal tube)

Total Pressure Drop negligible 0

$$\Delta P = \Delta P_{fh} + \Delta P_m + \Delta P_g$$

Therefore, the total pressure drop, ΔP, is calculated from Equations B8 and B9.

$$\boxed{\Delta P = 1.787 \cdot 10^{-5} \cdot \frac{Q^2}{\hat{V}_f} \cdot \left[130\ r_{fh} + 105.5 \frac{\hat{V}_{fg}}{\hat{V}_f} \cdot X_e + 144\right]},\ [\text{psi}] \quad \text{(B10a)}$$

and

$$\boxed{H_{fs} = \Delta P \cdot \hat{V}_f = 2.573 \cdot 10^{-3} \cdot Q^2 \cdot \left[130\ r_{fh} + 105.5 \frac{\hat{V}_{fg}}{\hat{V}_f} \cdot X_e + 144\right]},\ \text{ft-lb}_f/\text{lb} \quad \text{(B10b)}$$

where $r_{fh} = 1 + 9000\ X_e\ P^{-0.981}$.

Pressure Drop at Off-Design Pressures

(i) At pressure, P = 1000 psia; $\hat{V}_f = 0.02159\ \text{ft}^3/\text{lb}$

$$\boxed{\Delta P = 8.277 \cdot 10^{-4} \cdot Q^2 \cdot [130\ r_{fh} + 2073 X_e + 144]} \quad \text{(B11)}$$

(ii) At P = 800 psia

$$\hat{V}_f = 0.02087,\ V_g = 0.5691,\ ft^3/lb$$

$$\hat{V}_{fg} = 0.54823$$

The total length from Equation B8 is

$$L_{e,total} = \underbrace{130.r_{fh} + 84 + 2771X_e}_{tpf} + \underbrace{20 + 40}_{lo}$$

and from Equation B9

$$\left(\frac{\Delta P}{L}\right)_{lo} = 8.465 \cdot 10^{-4} \cdot Q^2 \text{ psi/ft}$$

$$\boxed{\Delta P = 8.563 \cdot 10^{-4} \cdot Q^2\ 130\ r_{fh} + 2771X_e + 144} \qquad (B12)$$

(iii) At P = 1100 psia

$$\hat{V}_f = 0.02195,\ V_g = 0.4005,\ [ft^3/lb]$$

$$\hat{V}_{fg} = 0.37855$$

Then,

$$L_{e,total} = 130\ r_{fh} + 84 + 1819X_e + 144$$

and

$$\left(\frac{\Delta P}{L}\right)_{lo} = 8.049 \cdot 10^{-4} \cdot Q^2$$

$$\boxed{\Delta P = 8.141 \cdot 10^{-4} \cdot Q^2 \cdot [130\ r_{fh} + 1819X_e + 144]} \qquad (B13)$$

The pressure drop at different exit qualities and flow rates and at drum pressures of 800, 1000 and 1100 psia is calculated assuming same tube length and fittings and the numerical values are given in Table B2 and Figure B3.

Table B2. Pressure Drop Table

(Accuracy: ± 20%)

*Flow Rate [gpm]	Drum Pressure [Psia]	EXIT STEAM QUALITY, X_e								ΔT [F°] $T_{salt}-T_{steam}$
		0	0.05	0.1	0.2	0.4	0.6	0.8	1.0	
4	800	3.8	6.9	10.0	16.16	28.0	40.0	51.6	66	50
	1000	3.6	5.8	8.8	12.56	21.3	30.4	39.4	48.3	31
	1100	3.57	5.4	7.1	8.6	18.1	25.4	32.8	40.8	10
8	800	15.2	27.6	40	64.6	112	162.4	206.4	264	T_{salt} = 568°F
	1000	14.4	23.4	35.2	50.2	85.2	121.6	157.6	193.2	
	1100	14.28	21.7	28.4	35.4	72.4	101.6	131.2	163.2	Assumptions
12	800	34.2	62.1	90.0	145.3	252.0	365.4	464.4	594	1. Exchanger Tube Length = 110 ft.
	1000	32.4	52.7	79.2	113.0	191.7	273.6	354.6	437.7	
	1100	32.1	48.8	63.9	77.6	162.6	228.6	295.2	367.2	2. Steam Properties taken at drum press. assumed to be same throughout the system.
16	800	60.8	110.4	160	258.4	448	649.6	825.6	1056	
	1000	57.8	93.6	140.8	200.8	340.8	486.4	630.4	772.8	
	1100	57.1	86.8	113.6	138	289.6	406.4	524.8	652.8	

* 1 gpm ≈ 370 lb/hr @ 1000 psia

40454

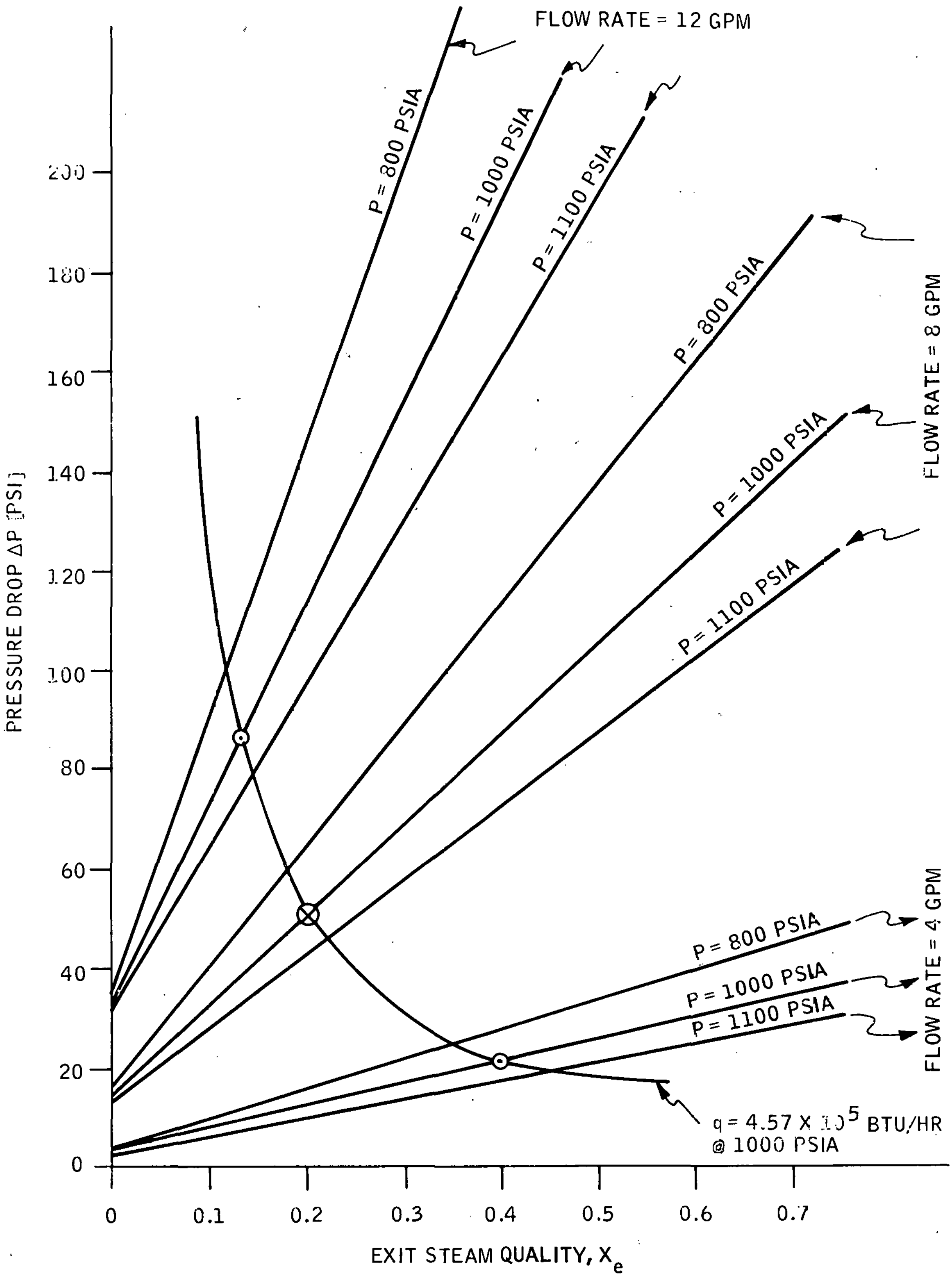


Figure B3. Pressure Drop versus Exit Steam Quality for Several Flow Rates and Pressures. Refer to Table B2.

EXPECTED PRESSURE DROP AND PUMP HEAD REQUIREMENT AT OFF-DESIGN CONDITION IN TSS/RE

The exit steam quality and heat rate is calculated from

$$q = U_\infty A_o \Delta T = m_R \cdot X_e \cdot (H_{sat} - H_{FW})$$

where

A_o = tube surface area = 29.32 ft^2

$\Delta T = T_{salt} - T_{sat}$

T_{salt} = 568°F

T_{sat} = saturation steam temperature at pressure P

U_∞ = overall-overall coefficient, (Btu/hr-ft^2-F°)

$$U_\infty = \frac{\int^L U_c \, dL}{\int_o^L dL}$$

The pressure drop and head loss is calculated from Equation (B10a) and (B10b) and presented in Table B3. Figure B4 shows the head versus capacity curves with steam drum pressure P as parameter.

TSS/RE RECIRCULATION PUMP REQUIREMENTS

The parameters used for designing the TSS/RE were

Pipe O.D./I.D. = - in/0.782 in; L = 112 ft

P = 948 psia, $T_{water,}$ in = 537°F

T_{salt} = 568°F and ΔT = 31F°

Table B3. Required Pump Head versus Flow Rate as a Function of Steam Drum Pressure and Associated Steam Conditions

FLOW RATE= 4.GPM SCRAPER SPEED= 120.(RPM)

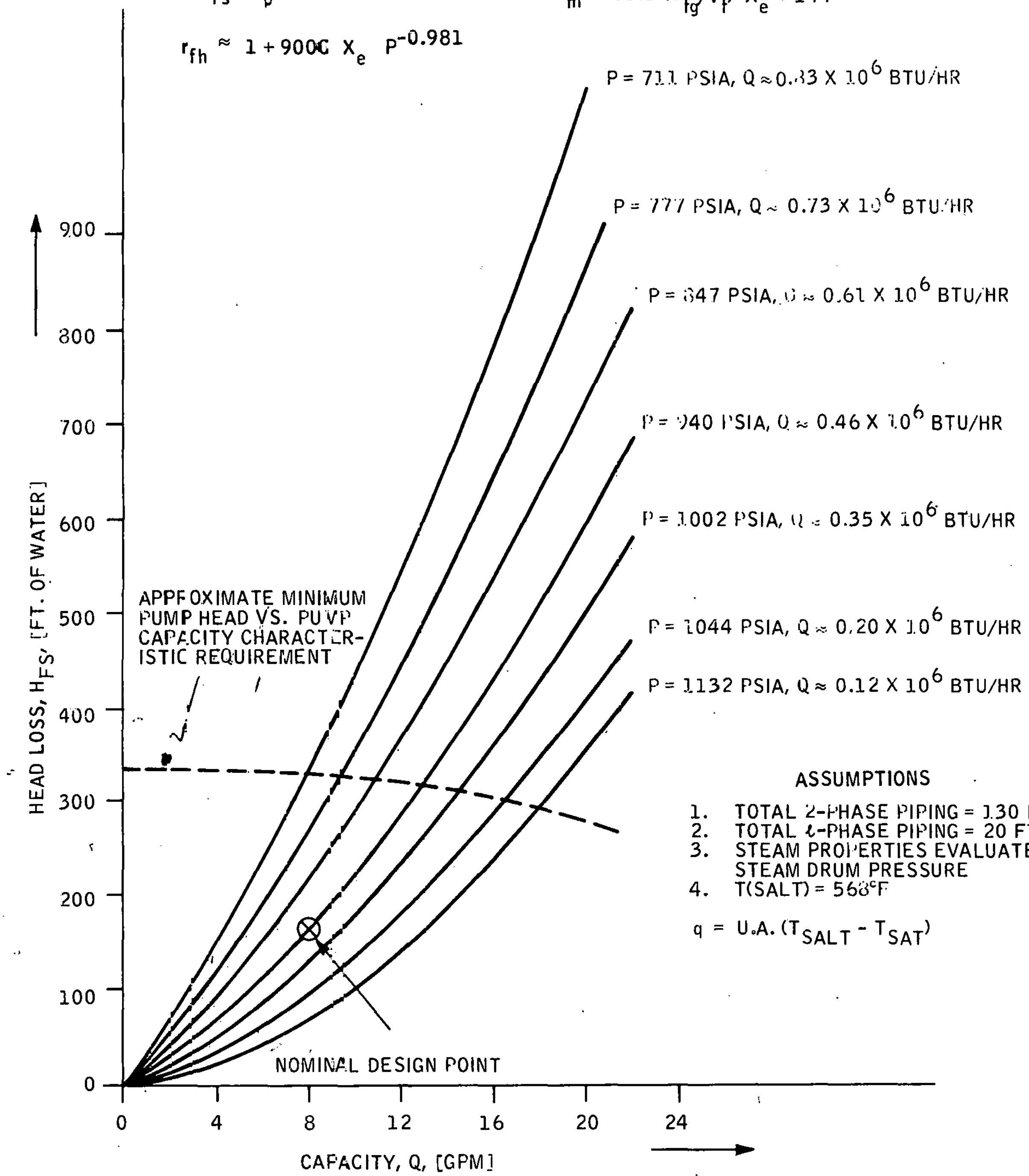
DRUM PRESSURE PSIA	TEMP. DIFF. F.	O-OVERALL COEFFICIENT BTU/HR-FT2-F	EXIT QUALITY	STEAM RATE LB/HR	HEAT RATE BTU/HR	PRESSURE DROP PSI	HEAD FT. OF WATER
711.	63.0	437.3	0.687	1030.8	0.807E 06	49.4	146.3
777.	53.0	450.0	0.597	895.3	0.698E 06	38.9	116.5
847.	43.0	463.9	0.501	750.9	0.584E 06	30.8	93.3
922.	33.0	477.2	0.397	594.8	0.461E 06	23.4	71.7
940.	31.0	480.1	0.375	562.6	0.436E 06	22.2	68.2
1002.	23.0	487.5	0.283	425.1	0.328E 06	16.6	51.7
1044.	13.0	487.5	0.161	240.2	0.186E 06	10.7	33.6
1132.	8.0	469.9	0.096	143.5	0.110E 06	7.6	24.2

FLOW RATE= 8.GPM SCRAPER SPEED= 120.(RPM)

DRUM PRESSURE PSIA	TEMP. DIFF. F.	O-OVERALL COEFFICIENT BTU/HR-FT2-F	EXIT QUALITY	STEAM RATE LB/HR	HEAT RATE BTU/HR	PRESSURE DROP PSI	HEAD FT. OF WATER
711.	53.0	451.4	0.355	1064.1	0.833E 06	108.9	322.2
777.	53.0	466.6	0.309	928.3	0.724E 06	87.5	262.1
847.	43.0	483.7	0.261	763.0	0.604E 06	71.1	215.3
922.	33.0	501.9	0.209	625.5	0.485E 06	56.0	172.0
940.	31.0	505.9	0.198	592.8	0.459E 06	53.6	165.0
1002.	23.0	519.3	0.151	453.3	0.350E 06	42.3	131.7
1044.	13.0	534.1	0.088	263.8	0.203E 06	30.2	94.7
1132.	8.0	530.1	0.054	161.9	0.124E 06	23.7	75.4

FLOW RATE= 16.GPM SCRAPER SPEED= 120.(RPM)

DRUM PRESSURE PSIA	TEMP. DIFF. F.	O-OVERALL COEFFICIENT BTU/HR-FT2-F	EXIT QUALITY	STEAM RATE LB/HR	HEAT RATE BTU/HR	PRESSURE DROP PSI	HEAD FT. OF WATER
711.	63.0	461.5	0.181	1088.0	0.851E 06	250.0	739.8
777.	53.0	478.9	0.159	958.8	0.743E 06	207.3	620.7
847.	43.0	498.9	0.135	807.6	0.628E 06	174.4	528.5
922.	33.0	521.5	0.108	649.9	0.504E 06	144.4	443.0
940.	31.0	526.5	0.103	616.9	0.478E 06	139.6	429.5
1002.	23.0	546.6	0.079	476.6	0.369E 06	117.0	368.8
1044.	13.0	573.7	0.047	283.4	0.218E 06	92.4	289.4
1132.	8.0	583.3	0.030	178.1	0.137E 06	79.8	252.0



$$H_{fs} = \frac{\Delta P}{\rho} = 2.573 \times 10^{-3} \; Q^2 \quad 130\, r_{fh} + 105.5\, (\hat{V}_{fg}/\hat{V}_f)\, X_e + 144$$

$$r_{fh} \approx 1 + 9000\, X_e \; P^{-0.981}$$

ASSUMPTIONS

1. TOTAL 2-PHASE PIPING = 130 FT.
2. TOTAL ℓ-PHASE PIPING = 20 FT.
3. STEAM PROPERTIES EVALUATED AT STEAM DRUM PRESSURE
4. T(SALT) = 568°F

$$q = U.A. (T_{SALT} - T_{SAT})$$

Figure B4. Head versus Capacity for TSS/RE Steam Generation System

40454

U_o = 505 Btu/hr-ft^2-F°

$\dot{m}$ = 3000 lb/hr, (8 gpm)

Steam quality = 0.2

q = 4.57 x 10^5 Btu/hr

For the above conditions the head loss was calculated to be 155 ft (± 20%). These conditions were considered to be conservative in designing the vaporizer module. Our calculations show that increasing the heat rate or quality, increases the pressure drop. Therefore, the worst conditions for sizing the pump would be the best we would expect from the vaporizer. Our best estimate of the best case for vaporizer would be to assume the following:

T_{salt} = 578°F; ΔT = 41 F°

U_o = 630 Btu/hr-ft^2-F° (25% above the design)

Therefore

q = 7.57 · 10^5 Btu/hr.

And with $\dot{m}$ = 3000 lb/hr (8 gpm)

exit quality will be, X_e = 0.33.

The pressure drop corresponding to 8 gpm and 0.33 quality extrapolated from Table B2 is, ΔP = 74 psi, h_{fs}, = 230 ft, (± 20%)

Therefore, the design point for pump is 8 gpm capacity at operating conditions and pump head of at least (230 · 1.2 =) 280 ft.

However, the TSS/RE is required to meet the off-design conditions which include varying the water flow rate up to 16 gpm, steam drum pressures in the range of 700-1200 psia, scraper speed, etc. The pressure drop increases with flow rate and quality. Increasing the drum pressure decreases the ΔT and heat rate and, therefore, exit quality and pressure drop. Therefore the pressure drop in the TSS/RE module can be adjusted to meet the pump head. Figure B4 shows the head loss versus capacity curve (dotted lines). must meet conditions below the dotted curves. Thus at 16 gpm and a drum pressure of 1100 psia, the head loss is 250 ft. To offset the ±20 percent uncertainty in the calculations, this becomes 1.2 x 250 = 300. Figure B4 is based on calculations which result by approximating the friction multiplier in Figure B2 by the relationship $r_{fh} = 1 + 9000 \cdot X_e \cdot P^{-0.981}$.

PART II

SRE CONDENSER PRESSURE DROP CALCULATIONS

For the thermal storage SRE condenser, the pressure drop is calculated using the Thom method.

The liquid-only pressure drop,

$$\left(\frac{\Delta P}{L}\right)_{LO} = 4 \frac{f}{D} \quad \frac{G^2 \hat{V}_f}{2\ gc}$$

where

f = friction factor = 0.0065

D = inside pipe diameter = 0.762/12 ft

G = mass velocity = 79.64 lb/sec-ft^2
($\dot{m}$ = 908 lb/hr)

gc = gravitational const. = $32.17 \frac{lb_m}{lb_f} \cdot \frac{ft}{sec^2}$

Steam properties at 1800 psia,

$\hat{V}_f$ = 0.02472 ft^3/lb

V_g = 0.2183 ft^3/lb

Substituting in the above equation,

$$\left(\frac{\Delta P}{L}\right)_{LO} = 0.997 \text{ lb/ft}^2\text{/ft}$$

$$= 0.00693 \text{ psi/ft}$$

The two-phase flow pressure drop for straight pipe and fittings is calculated from the following equation:

Straight pipe:

$$(\Delta P)_{tpf} = \left(\frac{\Delta P}{L}\right)_{LO} \cdot (L_{pipe}) \cdot r_f$$

Fittings:

$$(\Delta P)_{tpf} = \left(\frac{\Delta P}{L}\right)_{LO} \cdot (L_e) \cdot \left(1 + C \frac{V_{fg}}{V_f} X\right)$$

where,

L_{pipe} = length of straight pipe

r_f = multiplier for unheated tubes obtained from Figure B1 Handbook of Heat Transfer, Rohsenow - Hartnett

C = constant for fittings (ref. Handbook of H. T., pg. 14-11)

X = steam quality

L_e = equivalent length of fittings

For the SRE condenser, the following is assumed:

L_{pipe} = 540 ft

No. of 180 deg bends = 70

The value of X changes from 1.0 at condenser inlet to 0 at condenser outlet. r_f changes with quality. An equation for r_f has been derived to fit the curves in Figure B4.

At 1800 psia:

$$r_f = 0.97\,(1+X)^{7.15} \qquad 0 \le X < 0.2$$

$$r_f = 1.88\,(1+X)^{2.67} \qquad 0.2 \le X < 1.0$$

The above equations approximately fit the curves, but are more convenient to use.

To calculate the total equivalent tube length, a uniform condensation rate is assumed. Then,

$$L_{total} = L_{tube} \frac{\int_0^1 r_{fg}\, dX}{\int_0^1 dX} + L_e \frac{\int_0^1 \left(1 + C \frac{V_{fg}}{V_f} X\right) dX}{\int_0^1 dX}$$

$C = 1.1,\ V_{fg}/V_f = 7.83$

Substituting the above equations

$$L_{total} = L_{tube} \left[\int_0^{0.2} 0.97\,(1+X)^{7.15}\, dX + \int_{0.2}^{1.0} 1.88\,(1+X)^{2.67}\, dX \right]$$

$$+ L_e \int_0^{1.0} (1 + 8.61\, X)\, dX$$

Integrating we get

$$L_{total} = L_{tube}\,(5.927) + L_e\,(5.3)$$

L_e for 180 deg bends = 4 ft/bend

Number of bends = 70

$$\therefore \quad L_{total} = 540 \cdot 5 \cdot 927 + 70 \cdot 4 \cdot 5 \cdot 3$$
$$= 4684 \text{ ft}$$

$$(\Delta P)_{tpf} = \left(\frac{\Delta P}{L}\right)_{LO} L_{total}$$
$$= 0.00693 \cdot 4684 \text{ psi}$$
$$= 32 \cdot 4 \text{ psi}$$

The momentum and gravitational pressure drops are neglected. The total pressure drop is

$$\Delta P = 32 \cdot 4 \text{ psi} \pm 20 \text{ percent}$$

APPENDIX C

APPENDIX C

MATERIALS STUDIES FOR THERMAL ENERGY STORAGE

APPENDIX C
MATERIALS STUDIES FOR THERMAL ENERGY STORAGE

The differential scanning calorimetric studies on $NaNO_3$ containing 0.5 percent (by weight) of NaOH show that the thermal spectrum (Figure C1) has one major endothermic peak around 581°F, a small peak around 523.4°F and another small peak around 500°F after correction has been made for the high scanning rate. The major peak around 581°F is attributed to the fusion of $NaNO_3$, the one at 523.4°F to the solid-solid transition of $NaNO_3$ and the small peak around 500°F to the congruently melting solid solution of $NaNO_3$ and NaOH. The thermal spectrum of $NaNO_3$ containing 1 percent (by weight) of NaOH shows four endothermic peaks. There is a major peak around 577.4°F; there are two small peaks, one around 523.4°F and the other around 500°F. In addition, there is a very small peak around 464°F (Figure C2). The major peak around 577.4°F can be attributed to the fusion of $NaNO_3$; the peak around 523.4°F is due to the solid-solid transition of $NaNO_3$; the peak around 500°F is due to the congruently melting solid-solution of $NaNO_3$ and NaOH and the peak around 464°F is due to the fusion of the eutectic mixture of $NaNO_3$ and NaOH. The endothermic peaks, particularly those around 464°F and 500°F, become more pronounced in the thermal spectrum of $NaNO_3$ containing 2 percent (by weight) of NaOH (Figure C3).

The differential scanning calorimetric curves obtained for the ternary mixture of $NaNO_3$NaCl-Na_2SO_4 (99.06-0.57-0.37)mole percent show two endothermic peaks; the one around 548.6°F is due to the ternary eutectic accounting for about 6 percent of the total mixture and the major peak around 581°F is due to the pure $NaNO_3$ (Figure C4). The above mixture was contained in closed mild steel tubes and cycled thermally 190 times between 212-662°F, holding the mixture around 662°F for about one hour. The material from one container tube was examined by differential scanning calorimetry and it was found that there are two peaks, a small one around 548.6°F due to the ternary eutectic accounting for about 6 percent of the total mixture and the major peak around 581°F due to the pure $NaNO_3$ (Figure C5). The second cycled tube was sectioned into four parts and the mixture from each part was analyzed by differential scanning calorimetry. It was found, as expected, in all these four parts that there are two endothermic peaks, the small one corresponding to the eutectic mixture around 548.6°F accounting for about 5 percent of the total mixture and the major peak corresponding to pure $NaNO_3$ melting around 581°F (Figures C6 and C7). It appears from these results and those of chemical analyses that there is no phase separation of the mixture during thermal cycling. The cooling curves obtained for 99 percent $NaNO_3$ with 0.5 percent, 1.0 percent and 2.0 percent NaOH (by weight) show that in all these cases there is no significant super cooling and the cooling behavior of the mixture is similar to that of industrial grade material (Figure C8).

Sodium nitrate, both reagent grade and industrial grade, has a heat of fusion of 3.54 Kcals/mole, whereas, sodium nitrate containing 1 percent (by weight) of sodium hydroxide has 3.2 Kcals/mole (68 Btu/lb). This is due to the formation of eutectic and congruently melting solid solutions which melt at much lower temperatures compared to that of sodium nitrate. Therefore, it was thought that sodium nitrate, containing small amounts of sodium compounds like NaF, Na_2SO_4, NaCl and Na_2CO_3 which do not form complex phase diagrams giving low melting eutectics, should lower the melting point of sodium nitrate and not substantially change the heat of fusion value of pure sodium nitrate. Several exploratory experiments were carried out adding small percentages of sodium salts to $NaNO_3$. On adding 1 percent to 4 percent by weight of NaF to $NaNO_3$, the melting point was depressed from 581°F to 566.6°F, whereas, the heat of fusion shows a slight increase at 1 percent and 2 percent and no appreciable change at 4 percent (Table C1). In the case of Na_2SO_4, the addition of 1 percent by weight shows a depression of the melting point from 581°F to 570.2°F and a slight increase in the heat of fusion, whereas, with a 2 percent, 3 percent and 4 percent addition of Na_2SO_4, the depression in the melting point is much less and the heat of fusion associated with the main peak is not appreciably changed (Table C1). The addition of 1 percent (by weight) of NaCl to $NaNO_3$ gives rise to two endothermic peaks appearing at 560.3 and 578.3°F with a slight increase in the heat of fusion value. At 2 percent (by weight), the two peaks persist, whereas, at 3 percent and 4 percent, they merge into one peak appearing at 563.9°F with a heat of fusion value of about 5.6 Kcals/mole (Table C1). The addition of 2 percent, 3 percent, and 4 percent (by weight) of Na_2CO_3 depresses the melting point of $NaNO_3$ from 581°F to 576.5, 575.6, and 573.8°F, respectively. There is no appreciable change in the value of the heat of fusion (Table C1). The results of these studies indicate that the addition of a small amount of these compounds to $NaNO_3$ depresses the melting point of $NaNO_3$ with no adverse effect on the heat of fusion value unlike the addition of NaOH.

It is known that sodium nitrate melts without decomposition to a liquid which is stable in air at least to 932°F and begins to decompose slowly at 1112°F.* The decomposition reaction is $NaNO_3 \rightarrow NaNO_2 + \frac{1}{2} O_2$. It has also been shown by differential scanning calorimetry that even under drastic conditions, namely, $NaNO_3$ containing 30 mole percent of NaOH, the mixture is stable up to 752°F. The same mixture, when subjected to thermal cycling between 302°F and 662°F for 140 times and analyzed by differential scanning calorimetry, shows good thermal stability. Therefore, it is reasonable to assume that the stability of $NaNO_3$ containing 1 percent (by weight) of NaOH will approach the stability of pure $NaNO_3$. The corrosion studies which used a more corrosive mixture of $NaNO_3$-NaOH (70-30 mole percent) on mild steel and stainless steel and were carried out by thermogravimetry, electrochemical current potential curves and Auger electron spectroscopy show that the above mixture is not highly corrosive. The corrosion rate on mild steel is high initially and levels off with time (Figure C9), whereas, in the case of stainless steel the initial rate, though not very high, also levels off with time (Figure C10). The corrosion rate is about 1.5 mils/year for mild steel and is about 0.28 mil/year for stainless steel. It is also known from literature that pure $NaNO_3$ is not very

*Bartos, Henry R. and Margrave, John L., "The Thermal Decomposition of $NaNO_3$," The Journal of Physical Chemistry, Volume 60, 1956, pg. 256.

corrosive because it forms a passive layer on metals and alloys. Therefore, the mixture with 99 percent $NaNO_3$ and 1 percent (by weight) of NaOH should have corrosivity approaching that of pure $NaNO_3$.

The accelerated electrochemical corrosion studies carried out in $NaNO_3$ containing 1 percent (by weight) of NaOH with a mild steel working electrode and a Ag/AgCl reference electrode show that in the cathodic mode there is a gradual decrease in current with decreasing potential followed by a sharp decrease, and finally, the potential moves toward the anodic range (Figure C11). On the anodic side, there is also a decrease in current with potential.

From this current-potential curve, the corrosion current density comes out to be very small indicating low rate of corrosion for mild steel in this molten salt mixture.

Auger electron spectroscopic studies have been done on the mild steel surface of the cylinder containing the ternary eutectic ($NaNO_3$-NaCl-Na_2SO_4) thermally cycled for 140 times (Figure C12). The analysis of the surface films that are thicker than the Auger electron escape depth is accomplished by controlled in-situ ion etching of the specimen surface. The results of this study show that there is corrosion to mild steel (#1020)(Figure C13). Corrosion experiments carried out with annealed mild steel immersed in the ternary eutectic at about 10°C above the melting point for about 96 hours show that the corrosion products is much less compared to the unannealed specimen (Figure C14). The mild steel (#1020) surface of the cylinder containing the binary eutectic $NaNO_3$-NaOH thermally cycled 140 times and examined by Auger electron spectroscopy with controlled in-situ ion etching shows some corrosion (Figure C15). The corrosion experiments carried out with annealed mild steel immersed in the binary eutectic at about 10°C above the melting point for about 72 hours show that the corrosion is much less pronounced and the depth of penetration of the corrosion products is small (Figure C16). It seems that annealing relieves stress in the material and increases particle size, thereby increasing the overpotential for the cathodic reactions of the galvanic cell action.

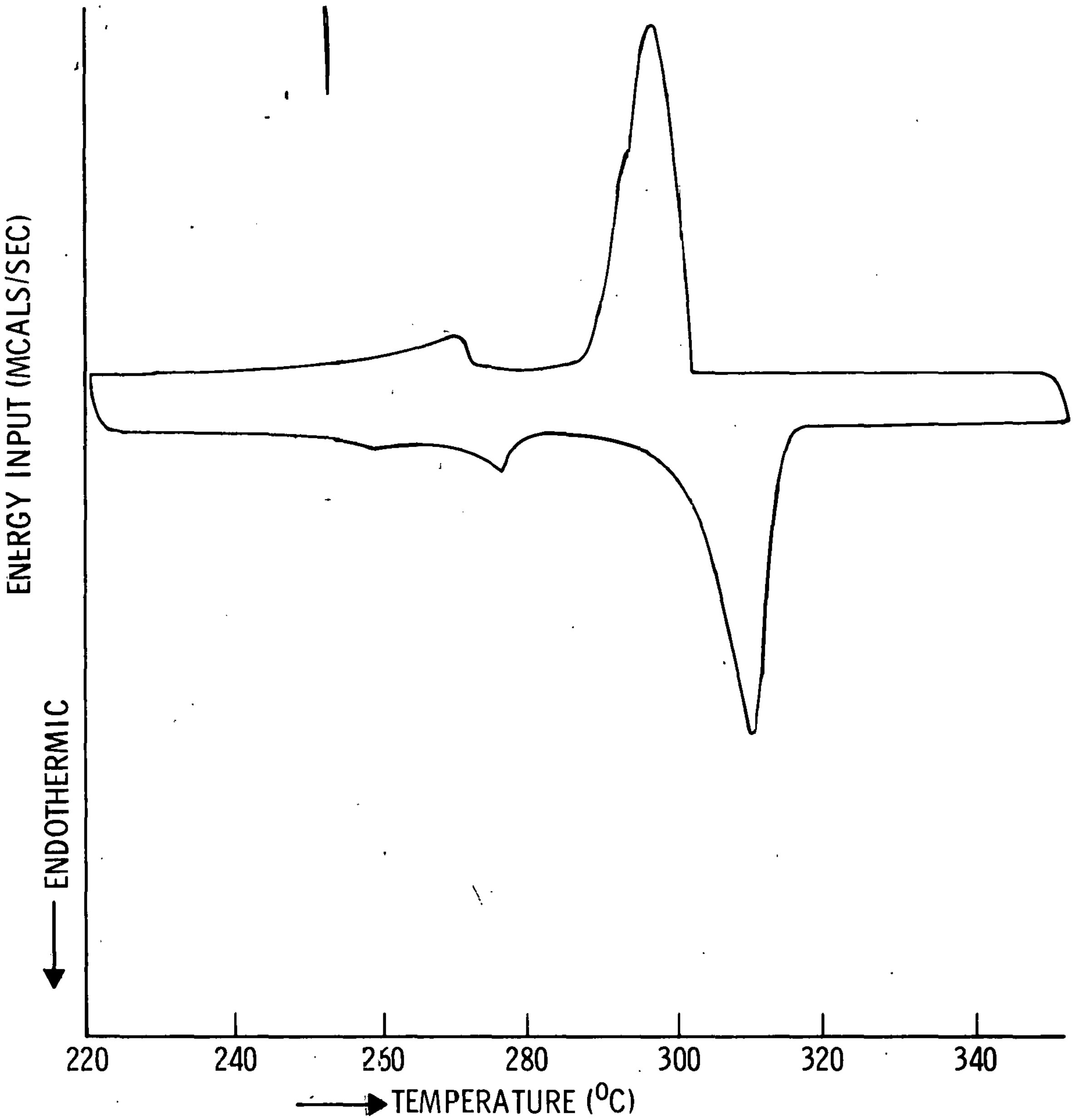


Figure C1. $NaNO_3$ + NaOH (0.5% by Weight)

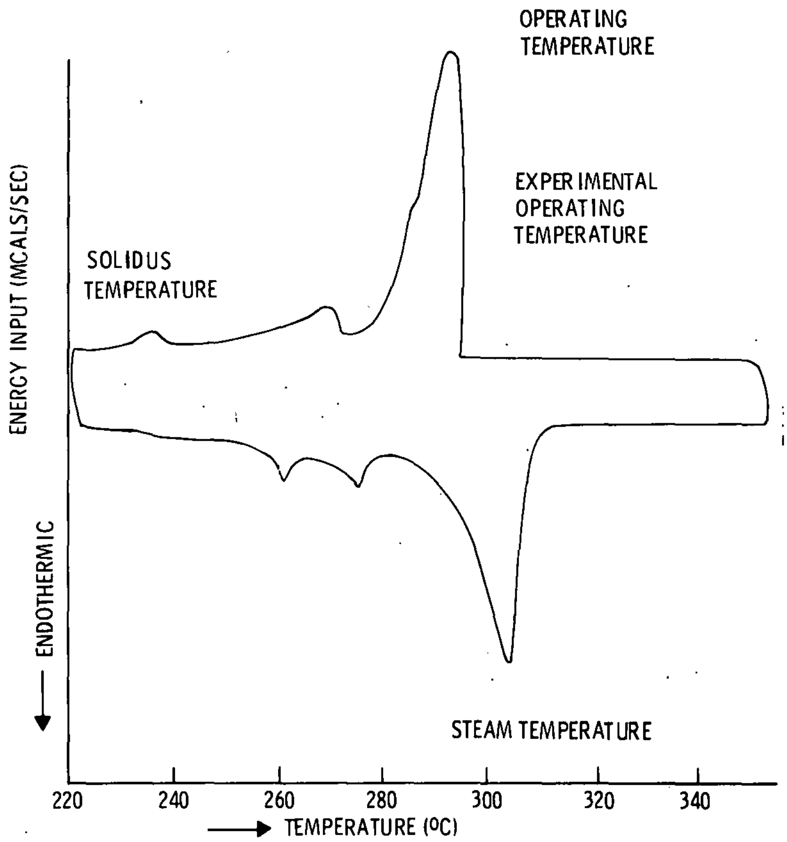


Figure C2. $NaNO_3$ + NaOH (1% by Weight)

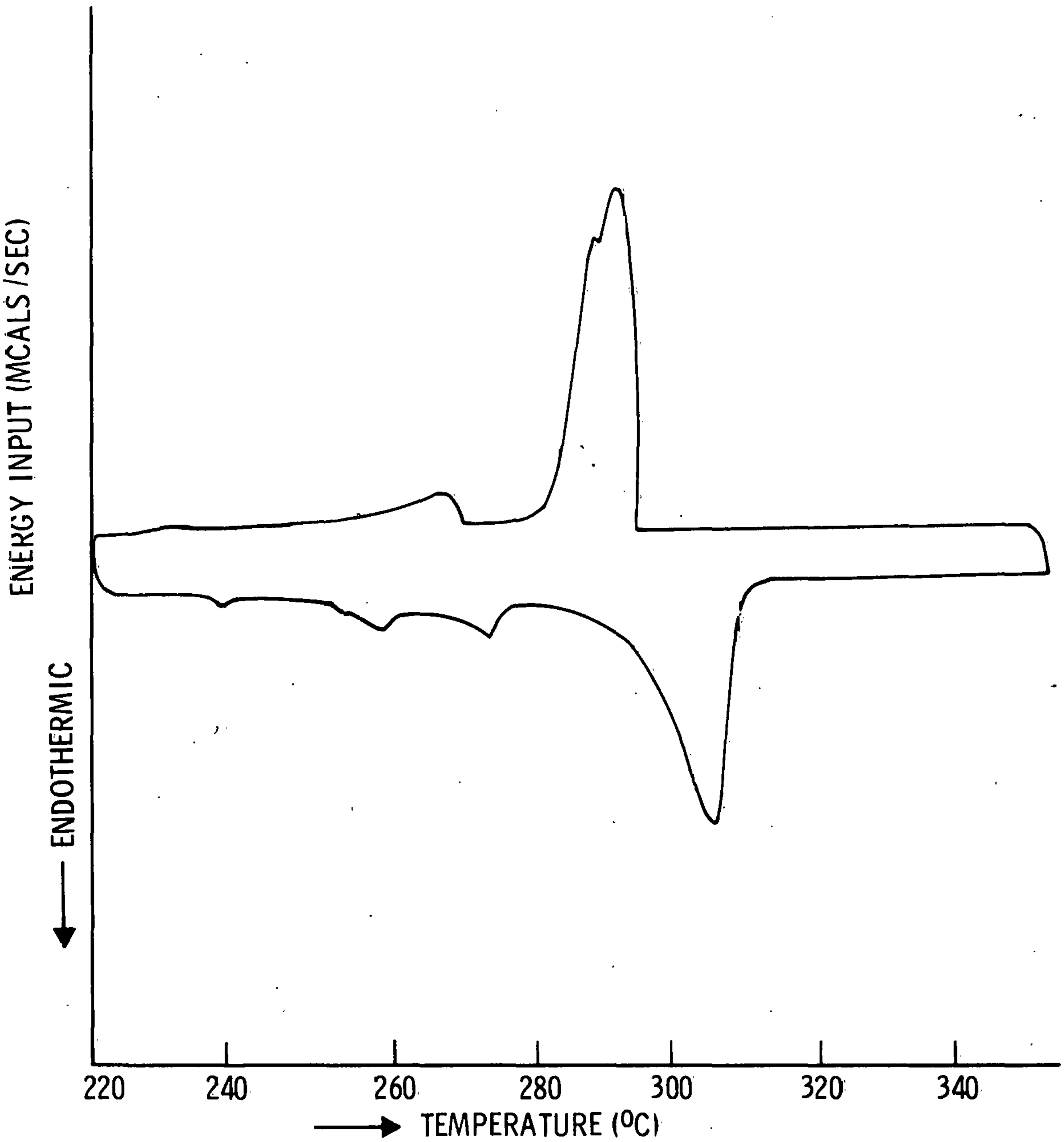


Figure C3. $NaNO_3$ + NaOH (2% by Weight)

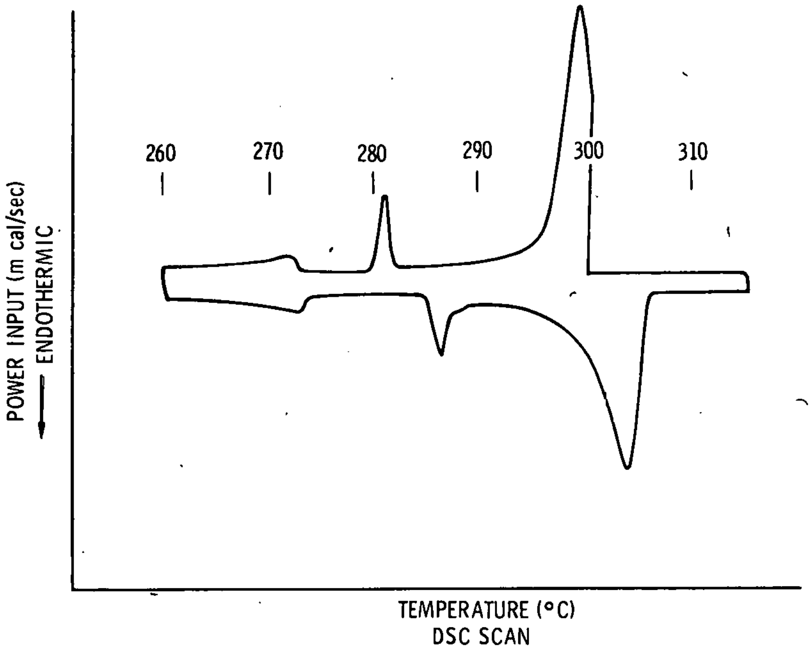


Figure C4. $NaNO_3$ (99%) Not Cycled

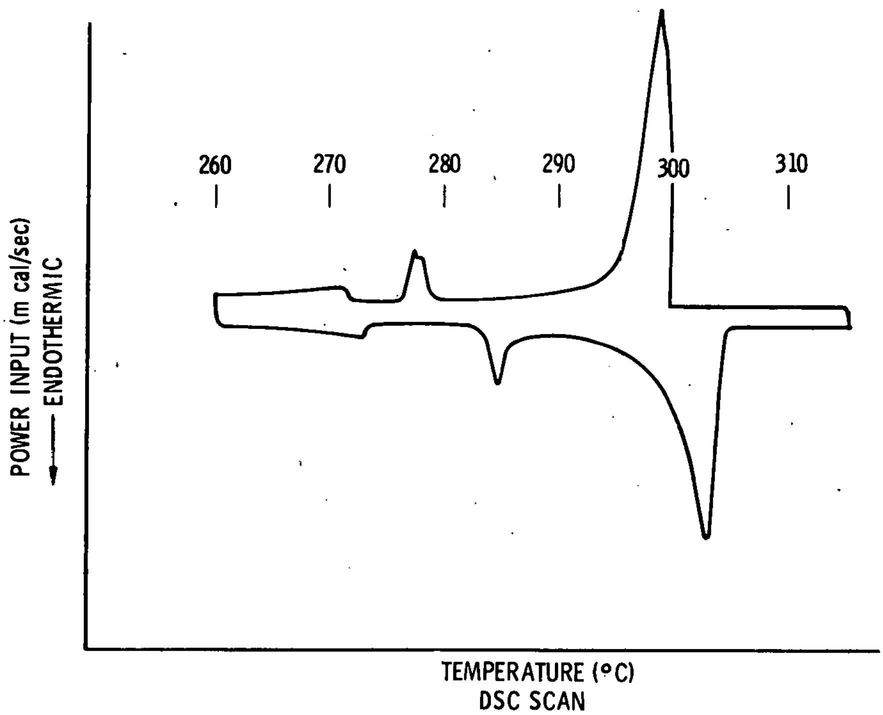


Figure C5. $NaNO_3$ (99%) Cycled

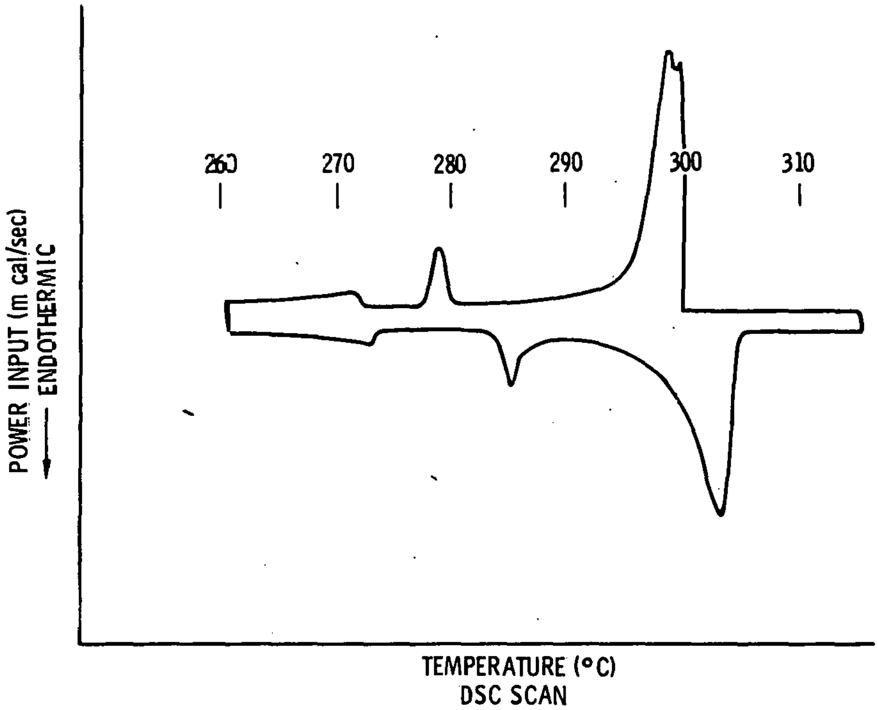


Figure C6. $NaNO_3$ (99%) Cycled-Top Portion

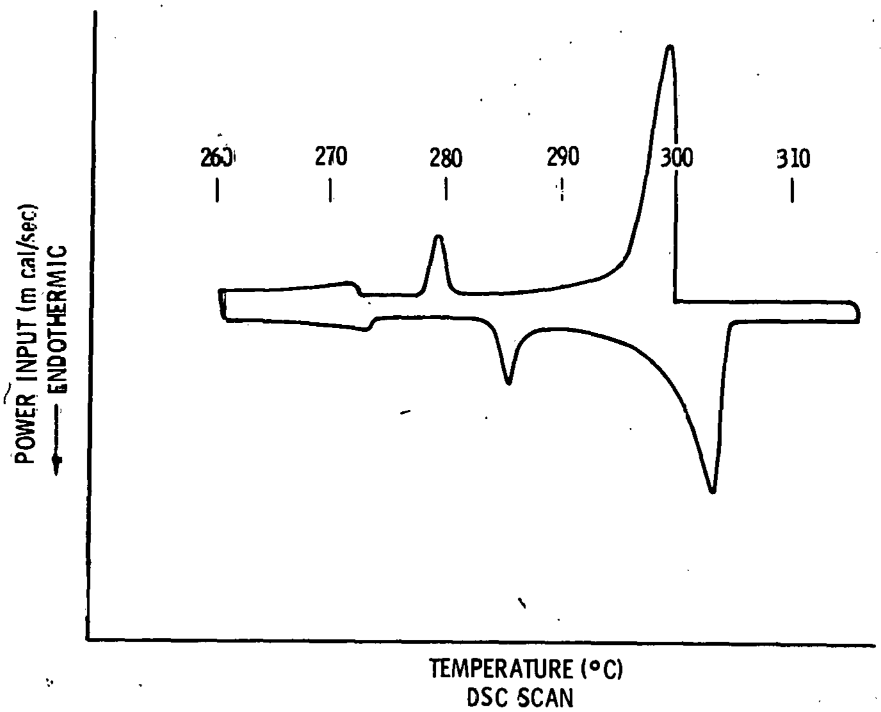


Figure C7. $NaNO_3$ (99%) Cycled-Bottom Portion

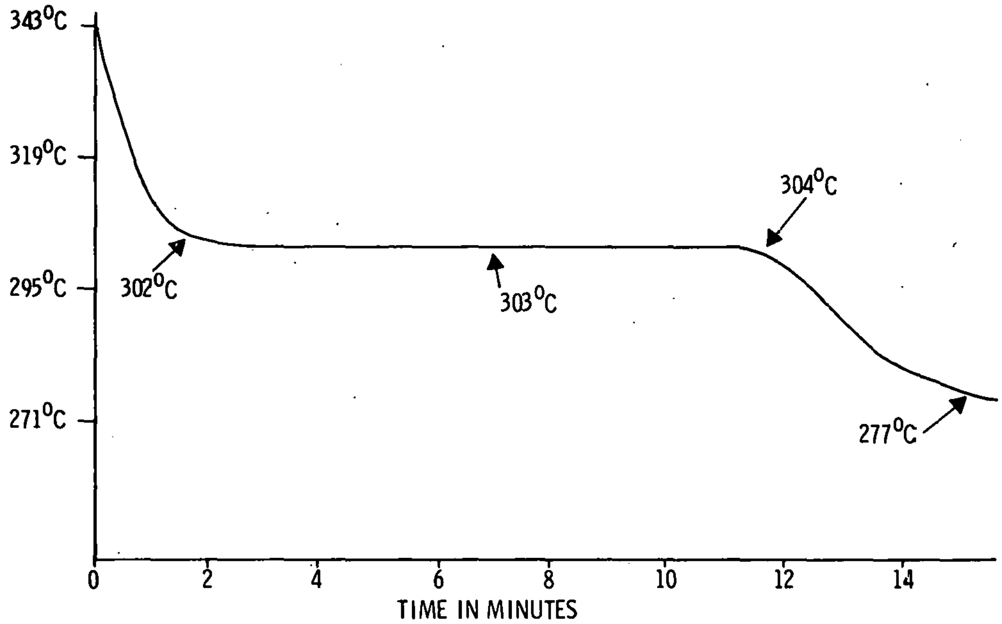


Figure C8. Cooling Curve 99% $NaNO_3$ % 1% (By Weight)

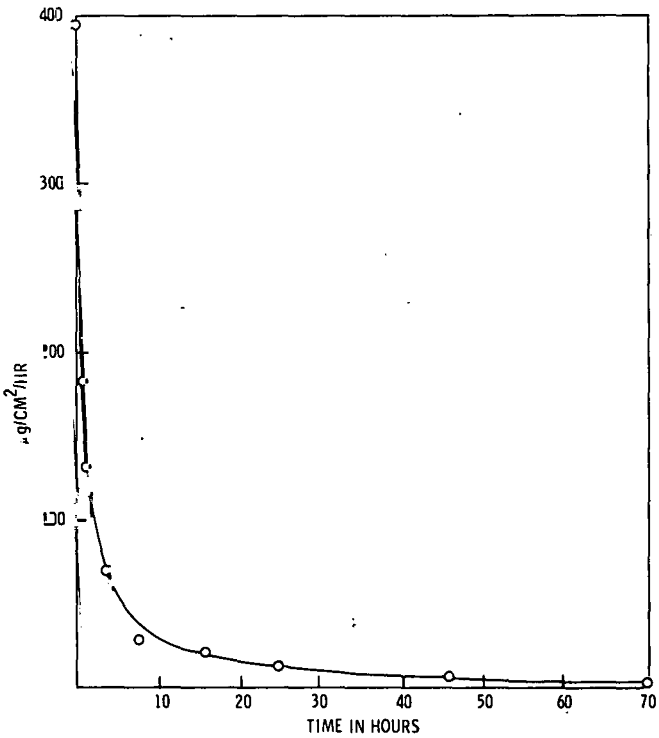


Figure C9. $NaNO_3$ - NaOH at 250°C
Mild Steel

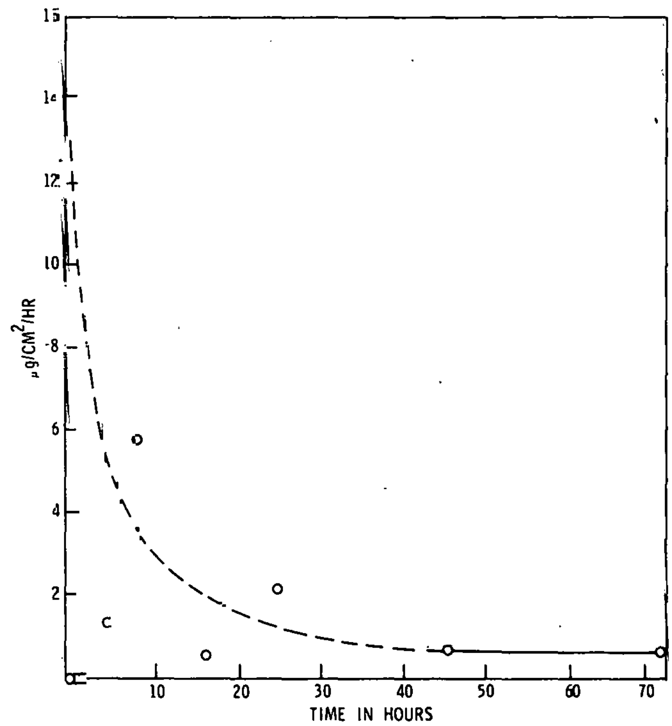


Figure C10. $NaNO_3$ - NaOH at 250° S. S.

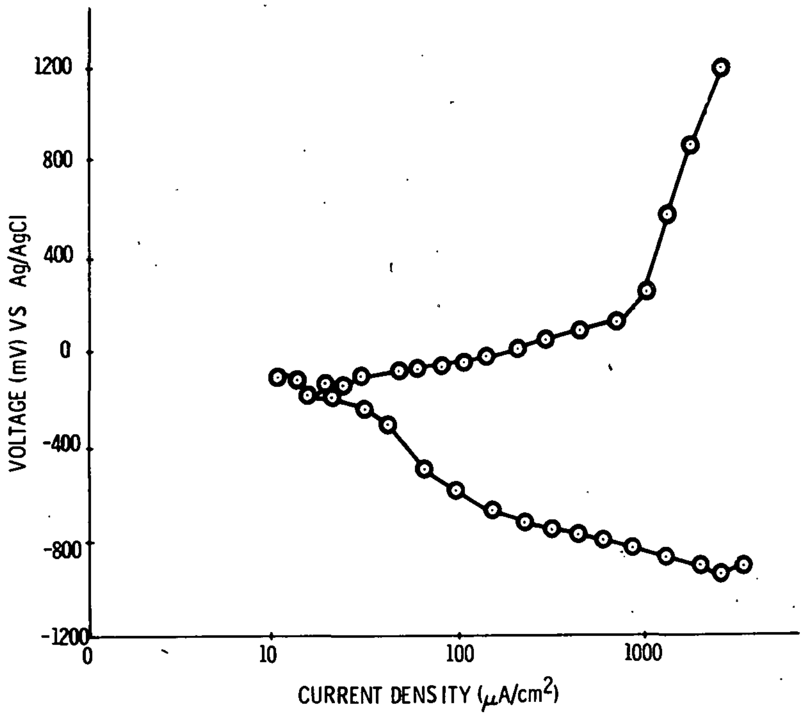


Figure C11. $NaNO_3$ + 1% NaOH Mild Steel W. E.

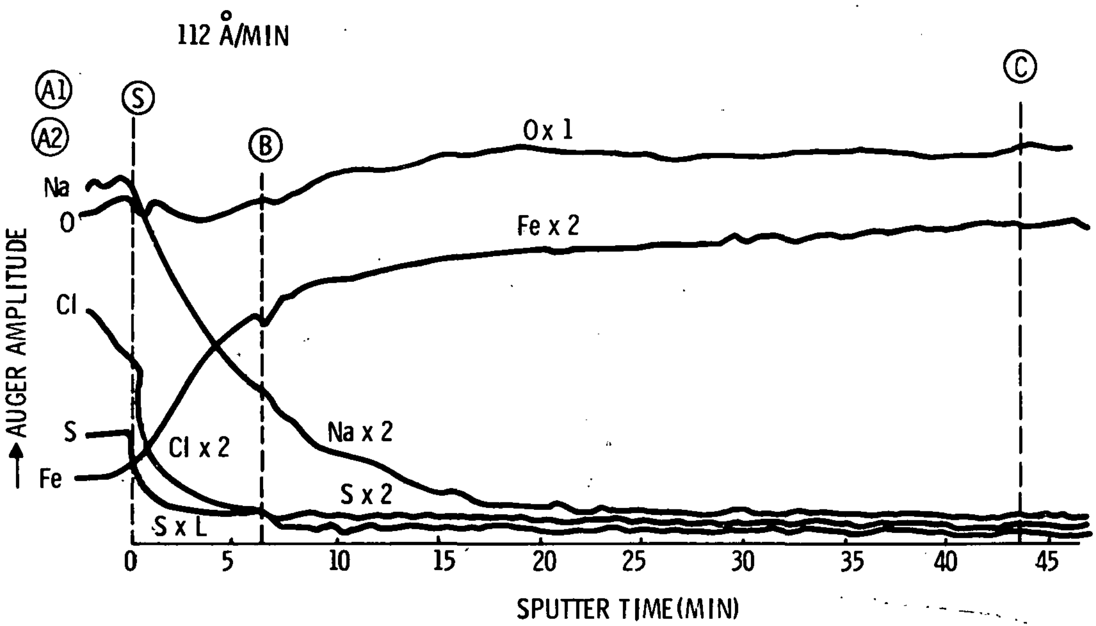


Figure C12. Mild Steel - $NaCl$-$NaNO_3$-Na_2SO_4 140x

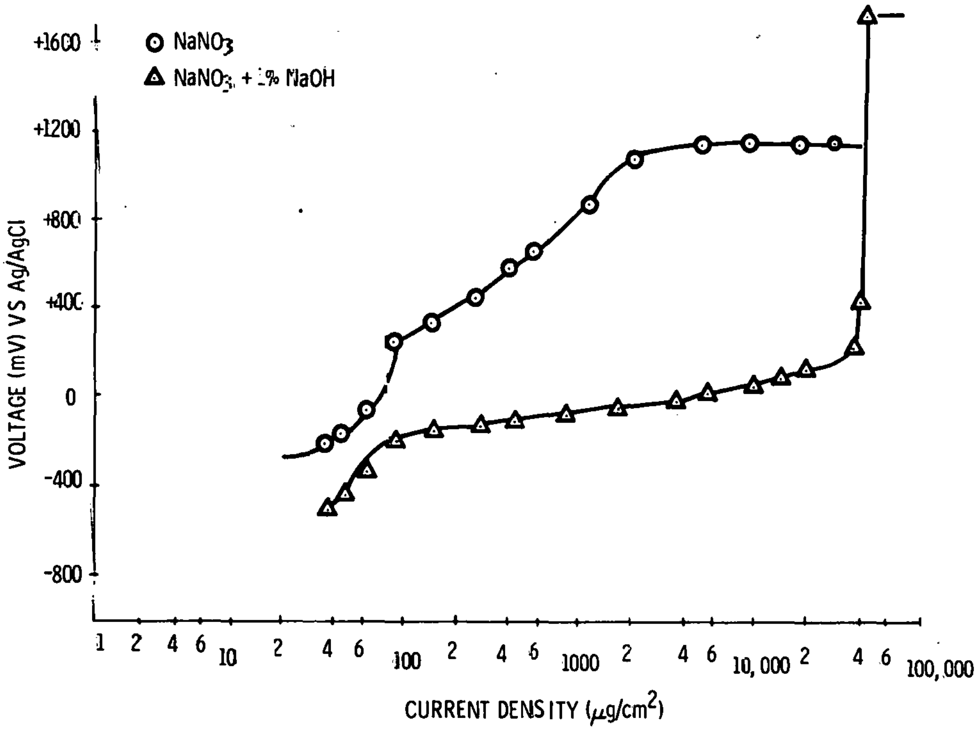


Figure C13. $NaNO_3$ and $NaNO_3$ + 1% NaOH - Mild Steel (No. 1020) at 324°C

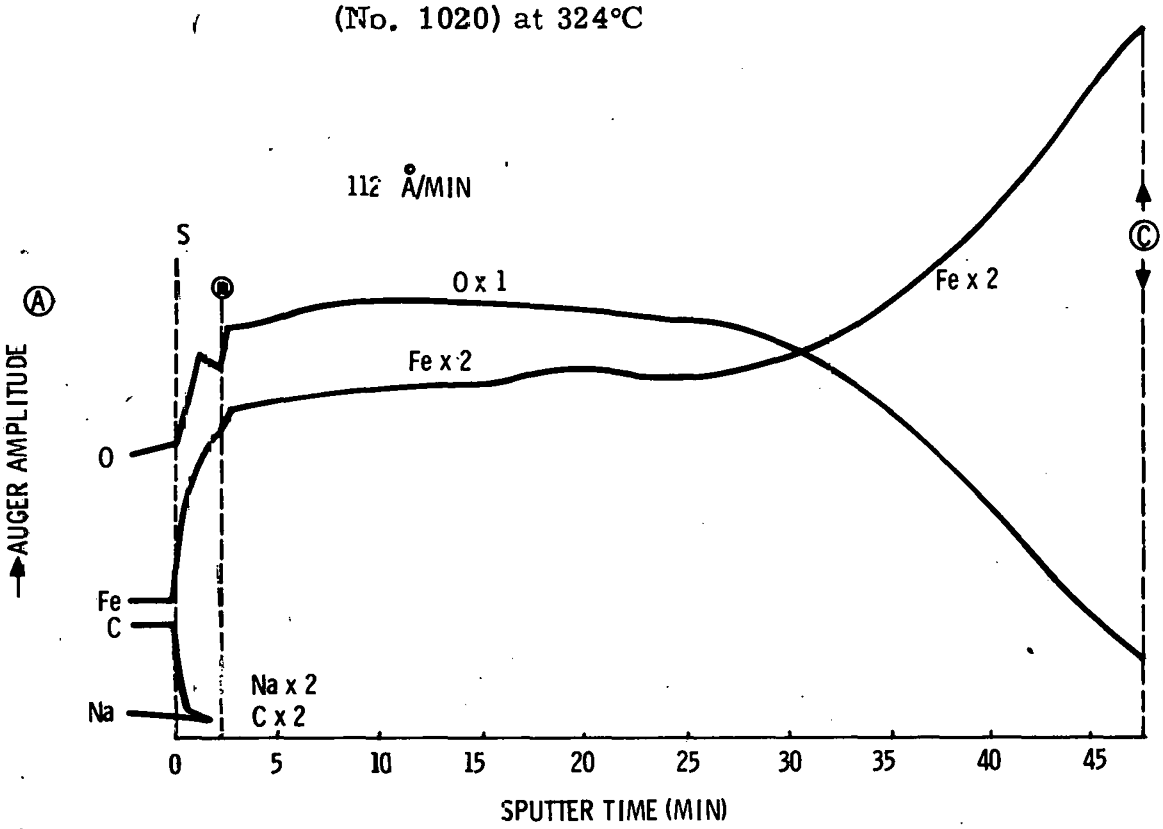


Figure C14. Mild Steel Annealed - 3 Salts - 96 Hrs

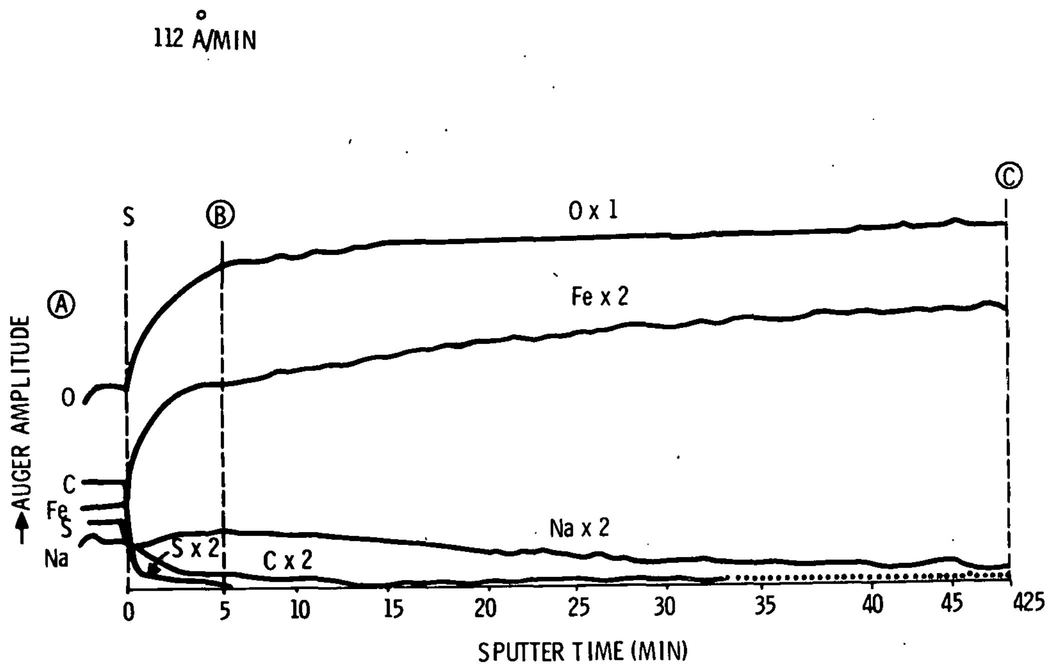


Figure C15. Mild Steel - $NaNO_3$ - NaOH - 140x

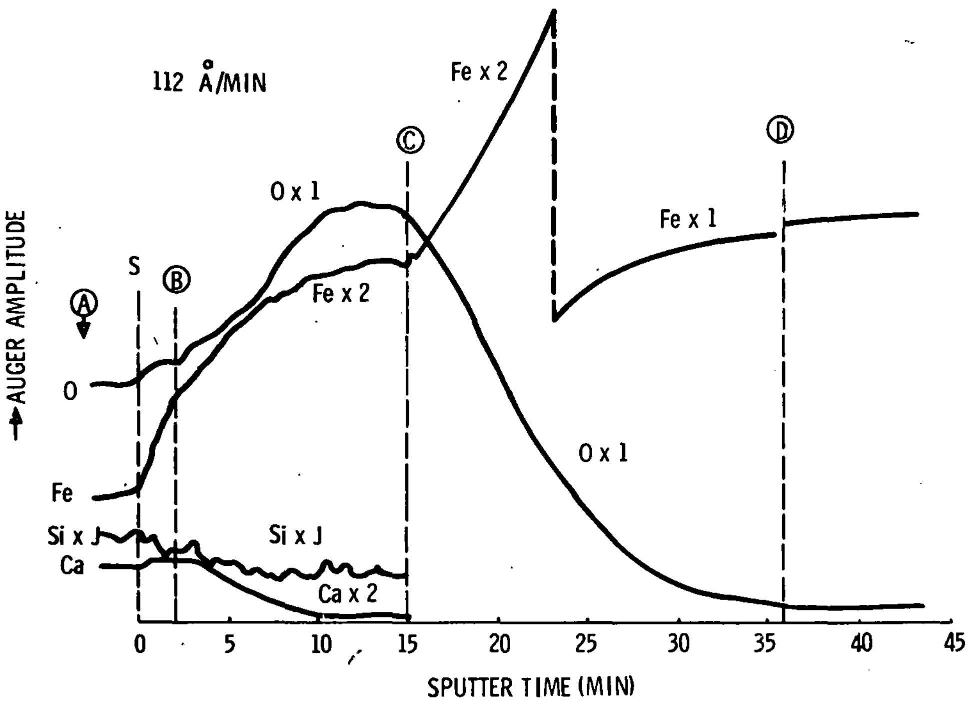


Figure C16. Annealed Miled Steel - $NaNO_3$ - NaOH - 3 Days

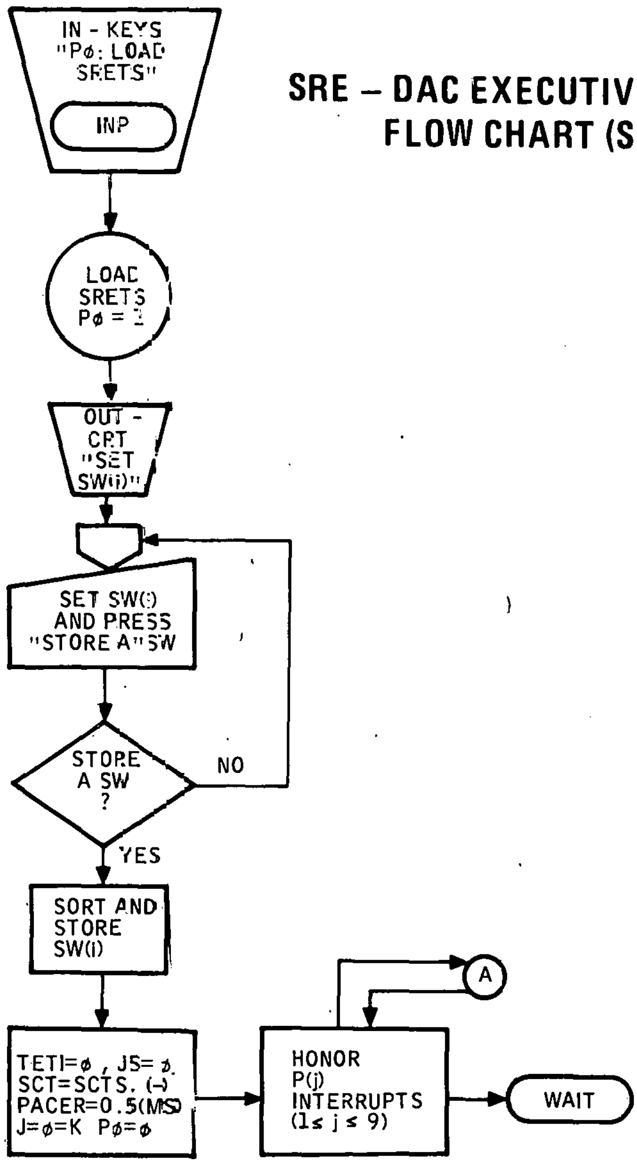
Table C1. Melting Points and Heats of Fusion of $NaNO_3$ - Based Mixtures

MIXTURE	M_P (°F)	(°C)	H_f EXPTAL KCALS/MOLE
$NaNO_3$ (IND. GRADE)	581	305	3.52
$NaNO_3$ + 1% (BY WT.) NaOH	577.4	303	3.20
$NaNO_3$ + 2% (BY WT.) NaOH	572.9	300.5	3.0
$NaNO_3$ + 1% (BY WT.) NaF	566.6	297	3.79
$NaNO_3$ 2% (BY WT.) NaF	566.6	297	3.61
$NaNO_3$ 4% (BY WT.) NaF	565.7	296.5	3.42
$NaNO_3$ + 1% (BY WT.) Na_2SO_4	570.2	299.5	3.66
$NaNO_3$ + 2% (BY WT.) Na_2SO_4	573.8	301	3.66
$NaNO_3$ + 3% (BY WT.) Na_2SO_4	577.4	303	3.58
$NaNO_3$ + 4% (BY WT.) Na_2SO_4	577.4	303	3.59
$NaNO_3$ + 1% (BY WT.) NaCl	560.3; 578.3	293.5; 303.5	3.73
$NaNO_3$ + 2% (BY WT.) NaCl	560.3; 570.2	293.5; 299	3.55
$NaNO_3$ + 3% (BY WT.) NaCl	563.9	295.5	3.60
$NaNO_3$ + 4% (BY WT.) NaCl	563.9	295.5	3.58
$NaNO_3$ + 2% (BY WT.) Na_2CO_3	576.5	302.5	3.62
$NaNO_3$ + 4% (BY WT.) Na_2CO_3	575.6	302.0	3.54
$NaNO_3$ + 6% (BY WT.) Na_2CO_3	573.8	301.0	3.49

APPENDIX D

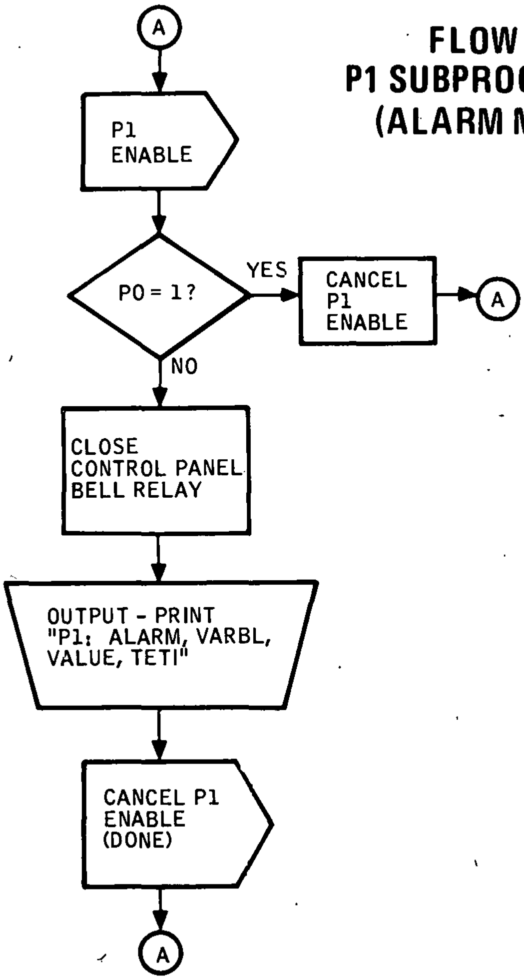
APPENDIX D
DAC FLOW CHARTS

SRE – DAC EXECUTIVE PROGRAM FLOW CHART (SRETS)

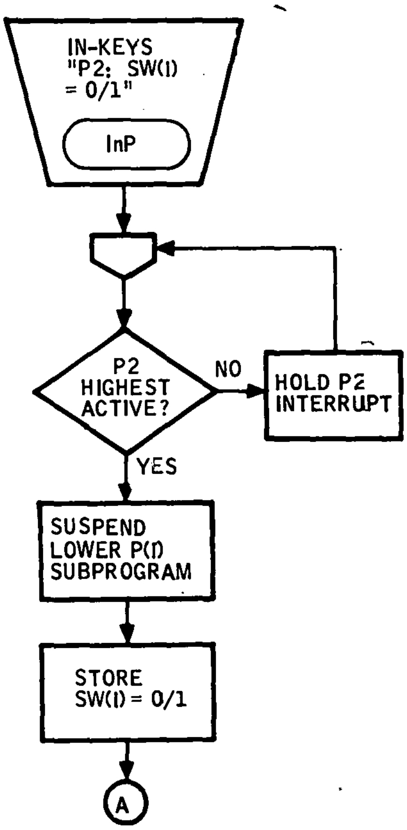


40454

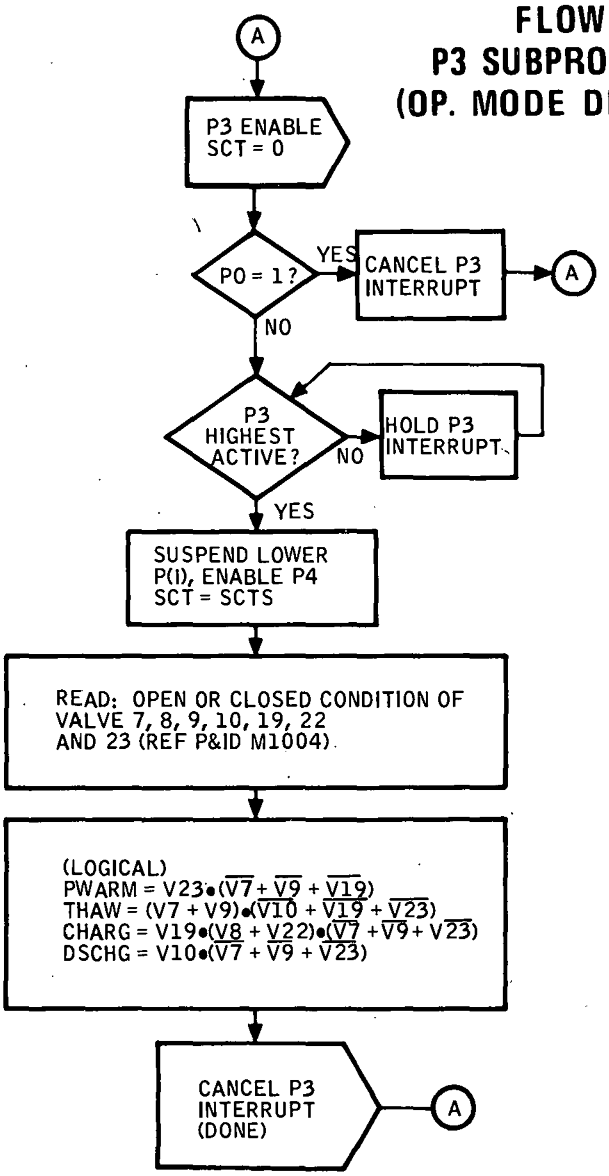
FLOW CHART
P1 SUBPROGRAM SRETS
(ALARM MESSAGES)



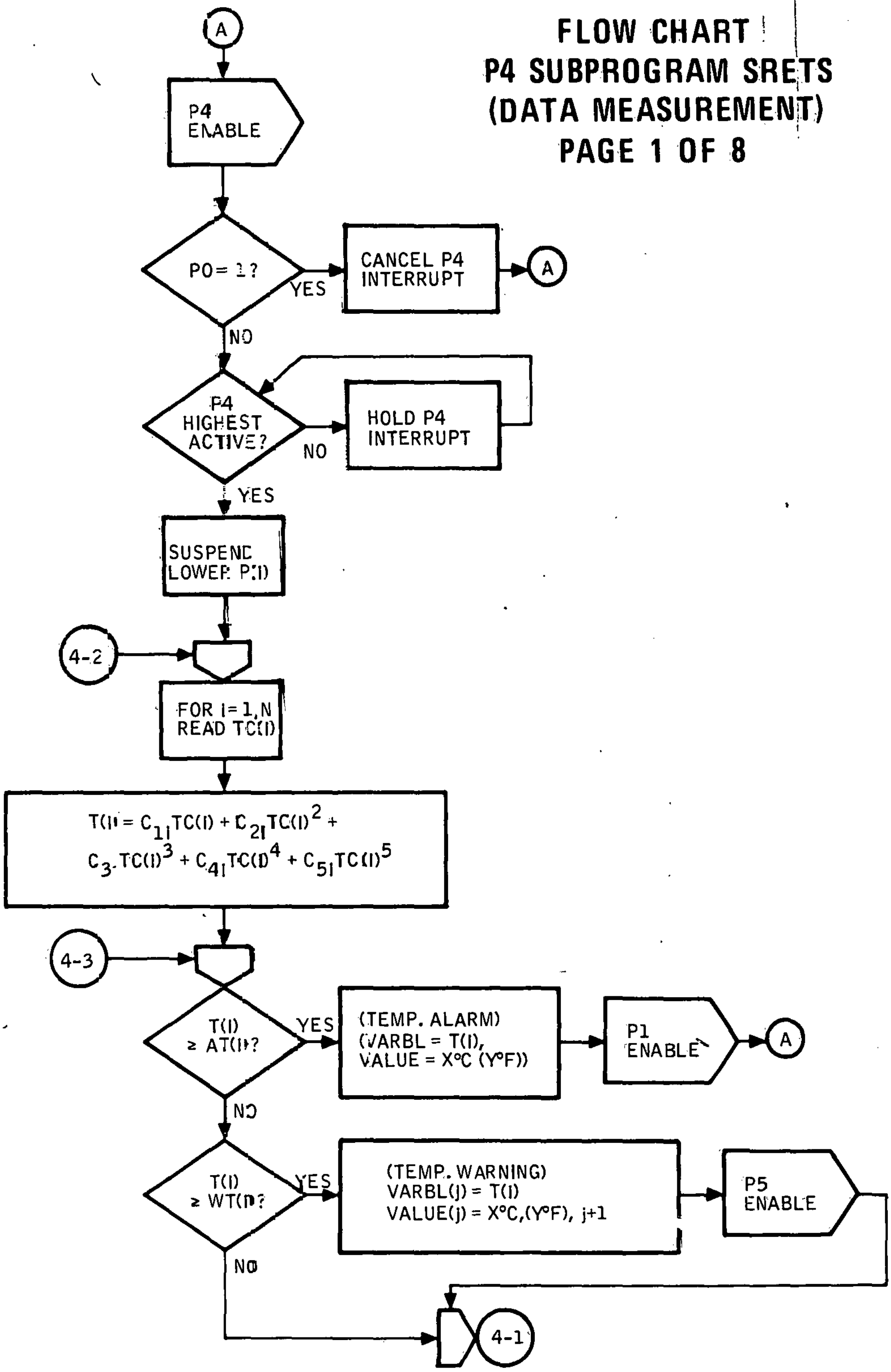
FLOW CHART
P2 SUBPROGRAM SRERC/SRETC
(CHANGE PROGRAM VARIABLES)

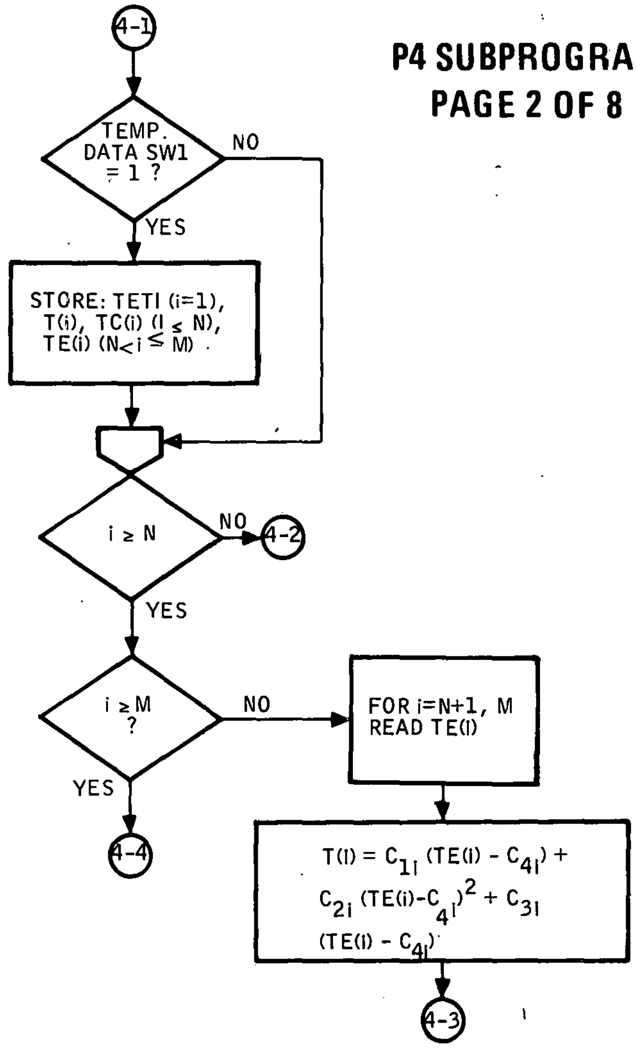


FLOW CHART
P3 SUBPROGRAM SRETS
(OP. MODE DETERMINATION)

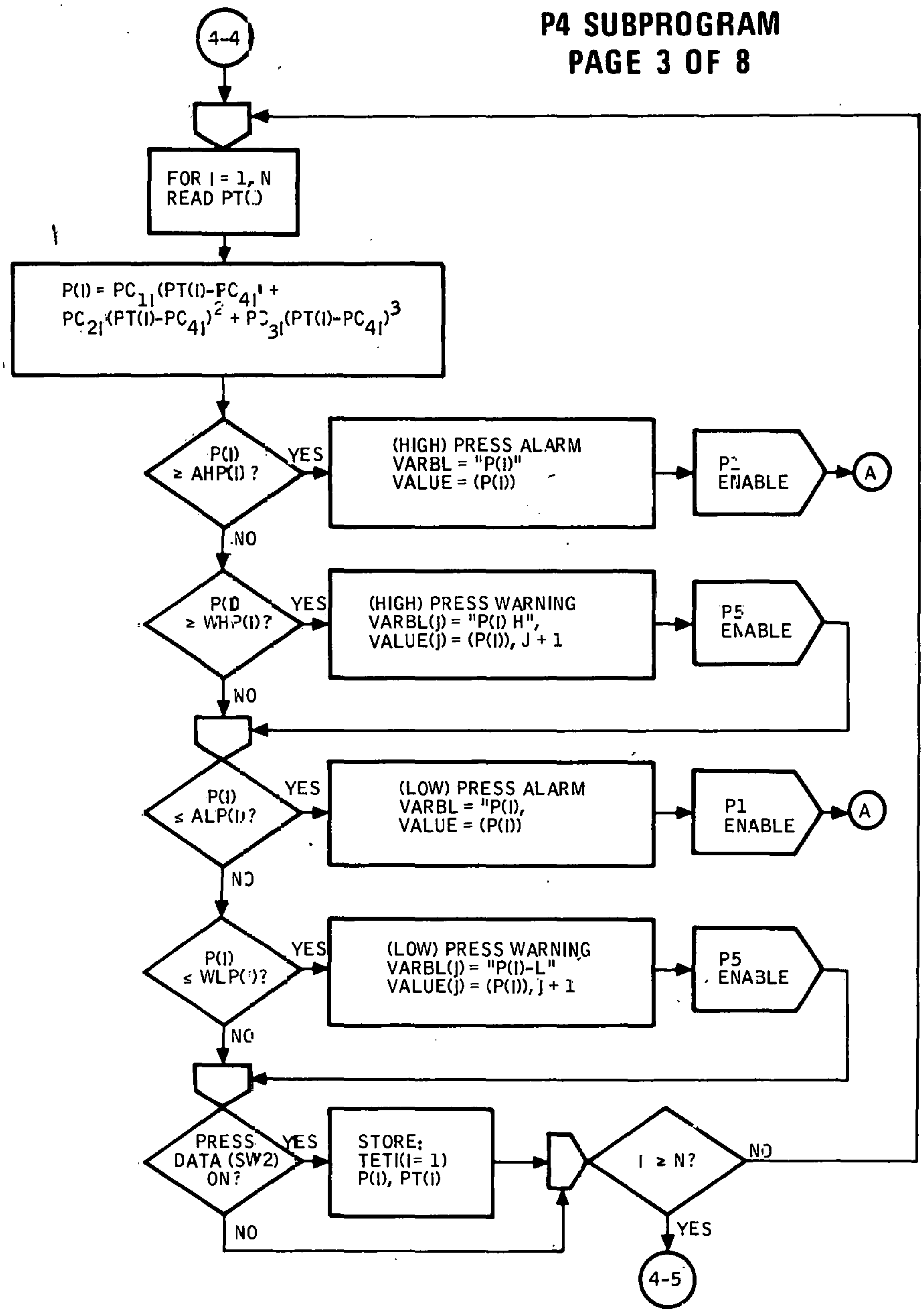


FLOW CHART
P4 SUBPROGRAM SRETS
(DATA MEASUREMENT)
PAGE 1 OF 8

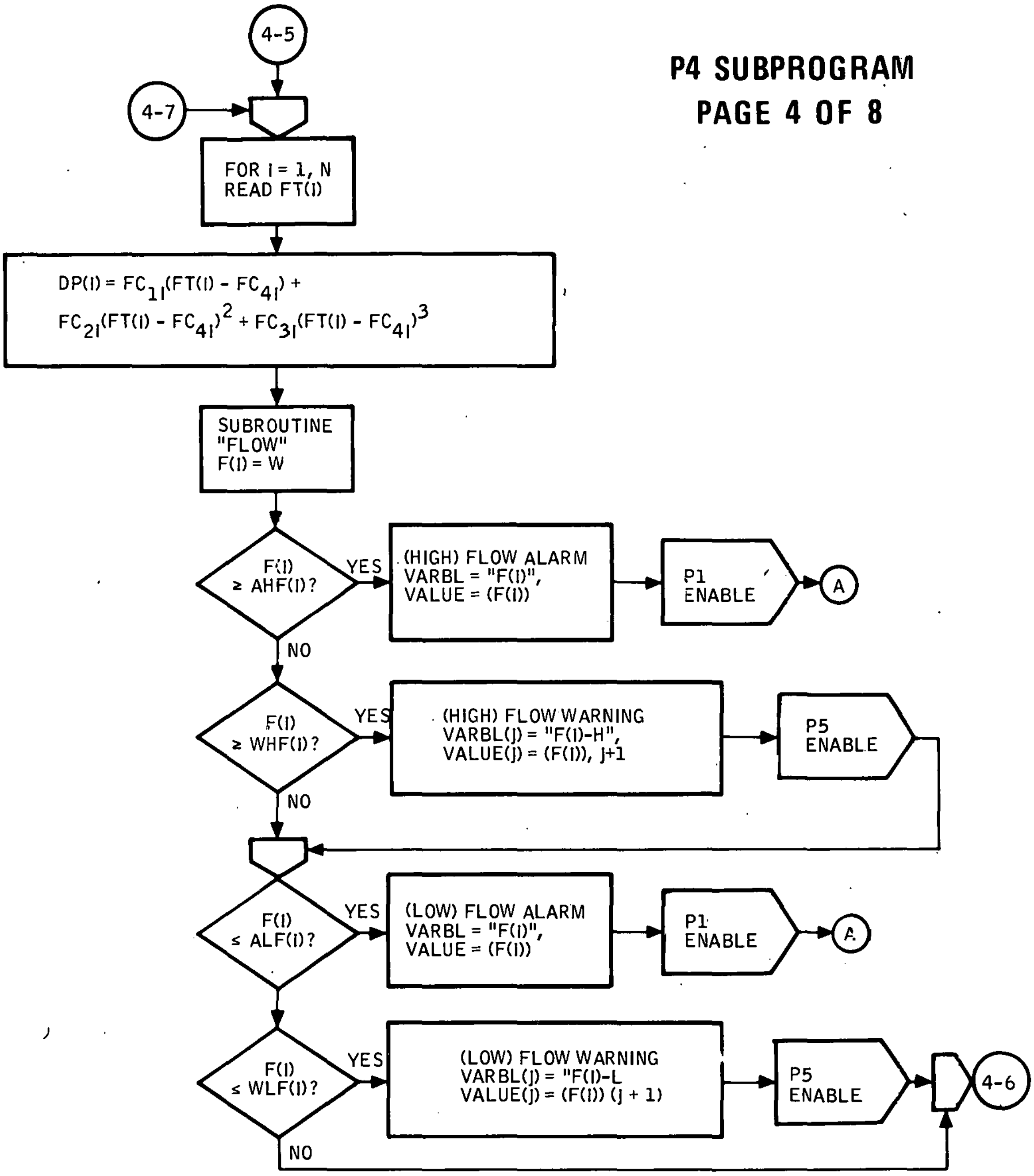




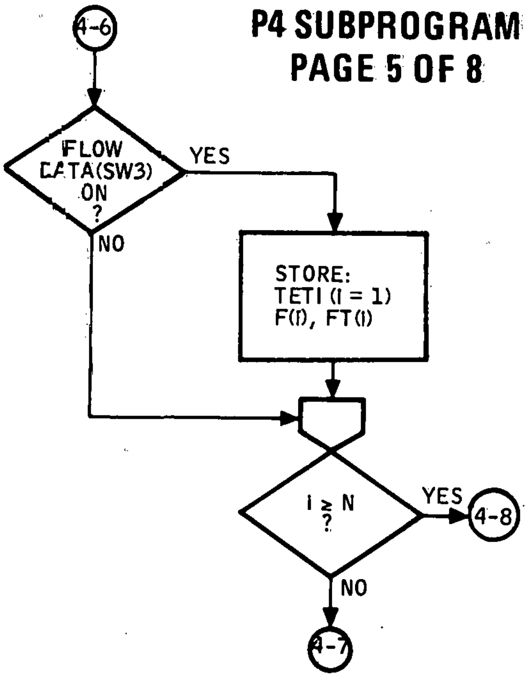
P4 SUBPROGRAM
PAGE 2 OF 8


4-4
FOR I = 1, N
READ PT(I)
P(I) = PC1I (PT(I)-PC4I) +
PC2I (PT(I)-PC4I)^2 + PC3I (PT(I)-PC4I)^3
P(I) ≥ AHP(I) ?
YES
NO
(HIGH) PRESS ALARM
VARBL = "P(I)"
VALUE = (P(I))
P1
ENABLE
A
P(I) ≥ WHP(I)?
YES
NO
(HIGH) PRESS WARNING
VARBL(J) = "P(I) H",
VALUE(J) = (P(I)), J + 1
P5
ENABLE
P(I) ≤ ALP(I)?
YES
NO
(LOW) PRESS ALARM
VARBL = "P(I),
VALUE = (P(I))
P1
ENABLE
A
P(I) ≤ WLP(I)?
YES
NO
(LOW) PRESS WARNING
VARBL(J) = "P(I)-L"
VALUE(J) = (P(I)), J + 1
P5
ENABLE
PRESS DATA (SW2) ON?
YES
NO
STORE:
TETI(I= 1)
P(I), PT(I)
I ≥ N?
NO
YES
4-5

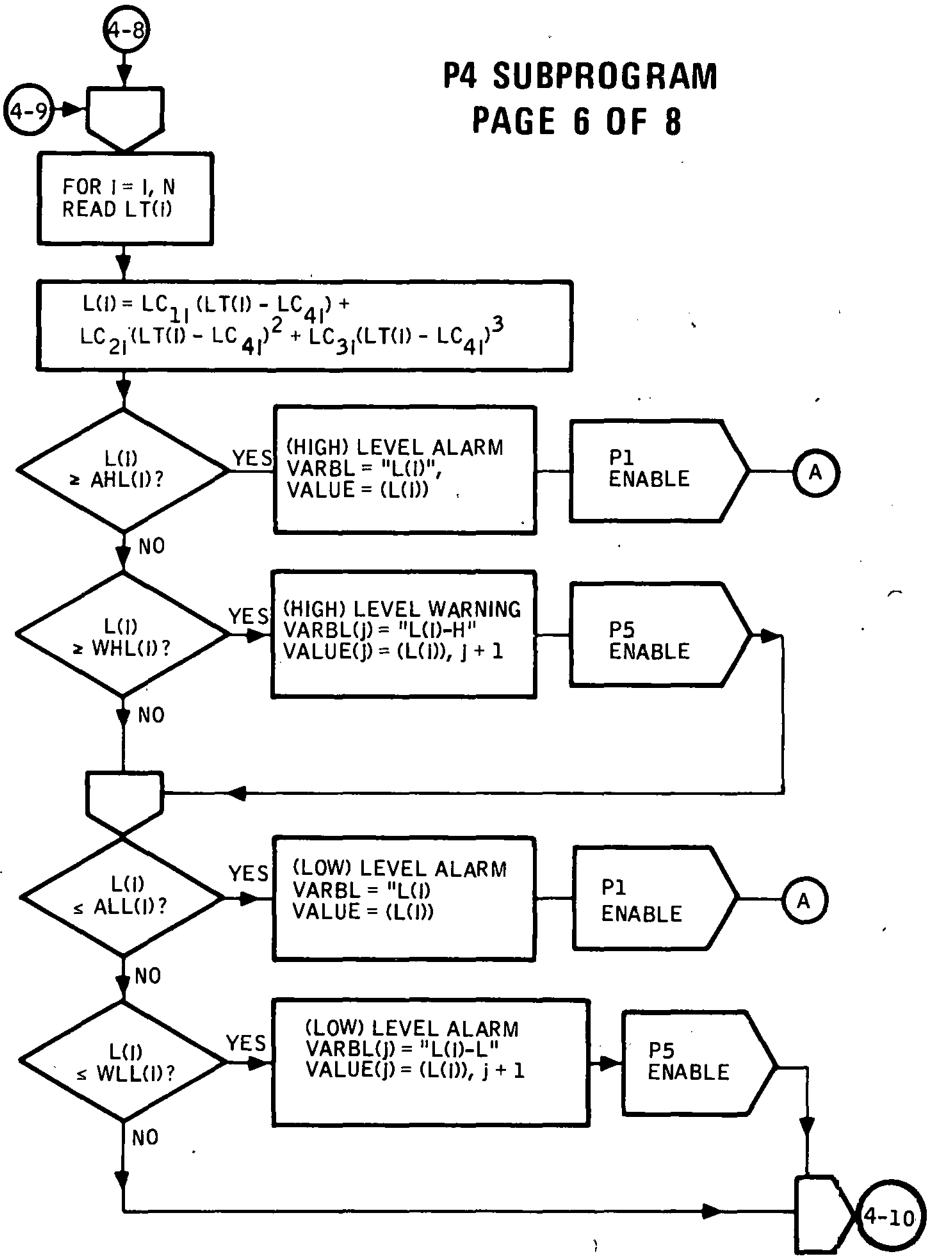
P4 SUBPROGRAM
PAGE 4 OF 8



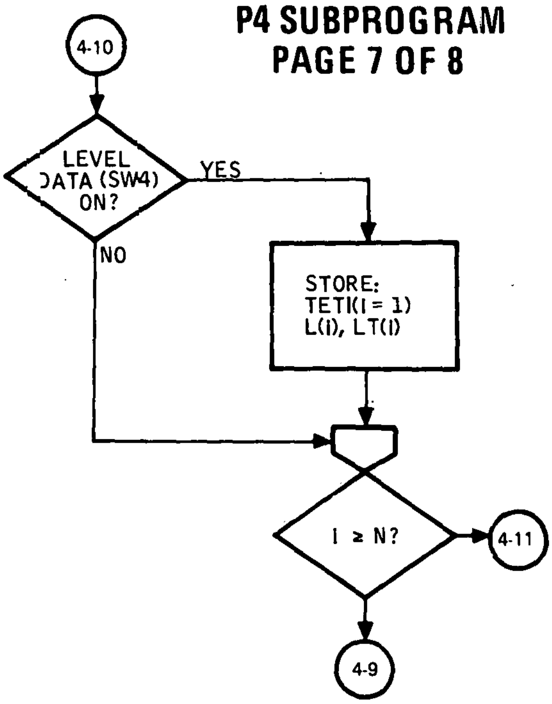
P4 SUBPROGRAM
PAGE 5 OF 8



P4 SUBPROGRAM
PAGE 6 OF 8

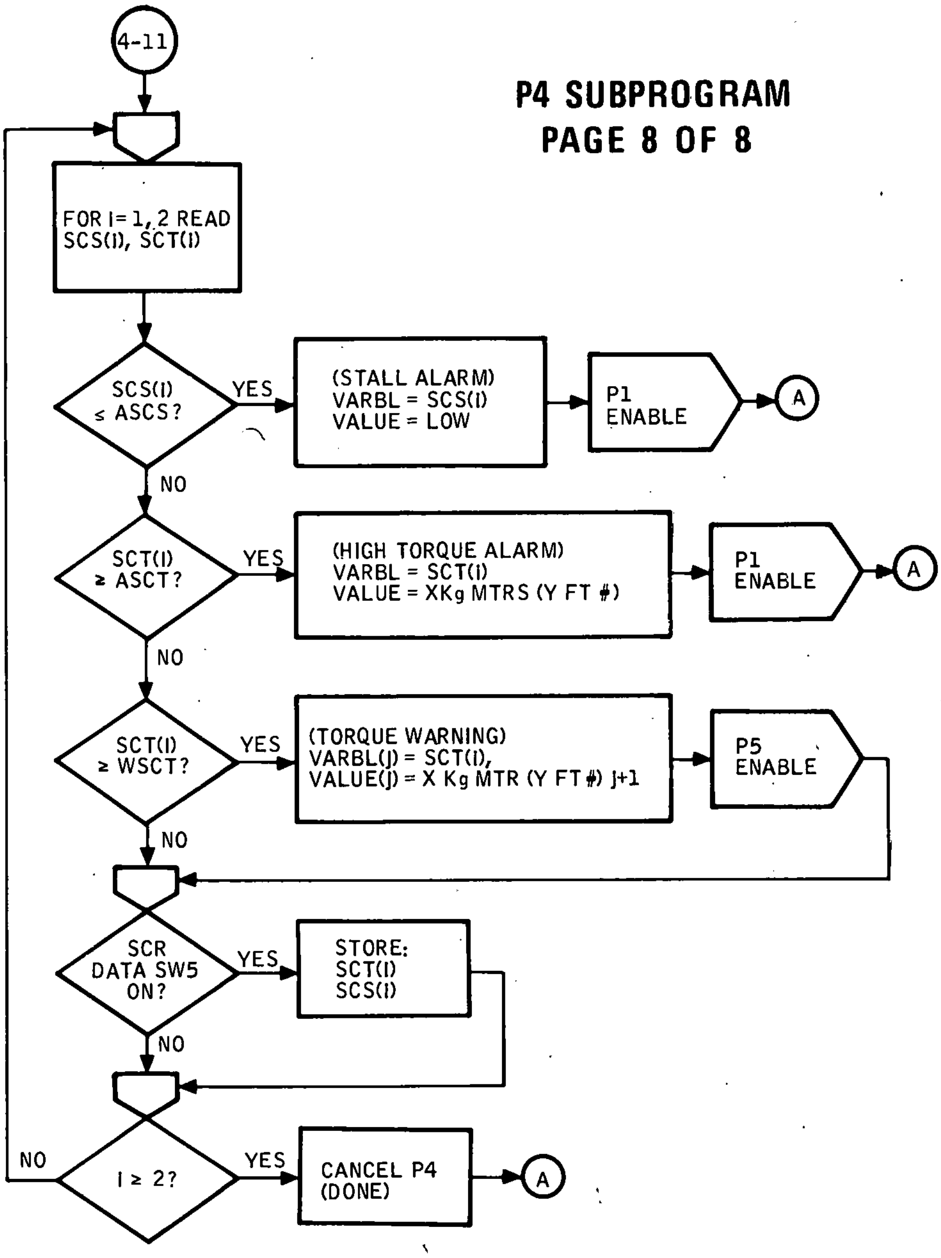


40454


P4 SUBPROGRAM
PAGE 7 OF 8
4-10
LEVEL DATA (SW4) ON?
YES
NO
STORE:
TETI(I = 1)
L(I), LT(I)
I ≥ N?
4-11
4-9

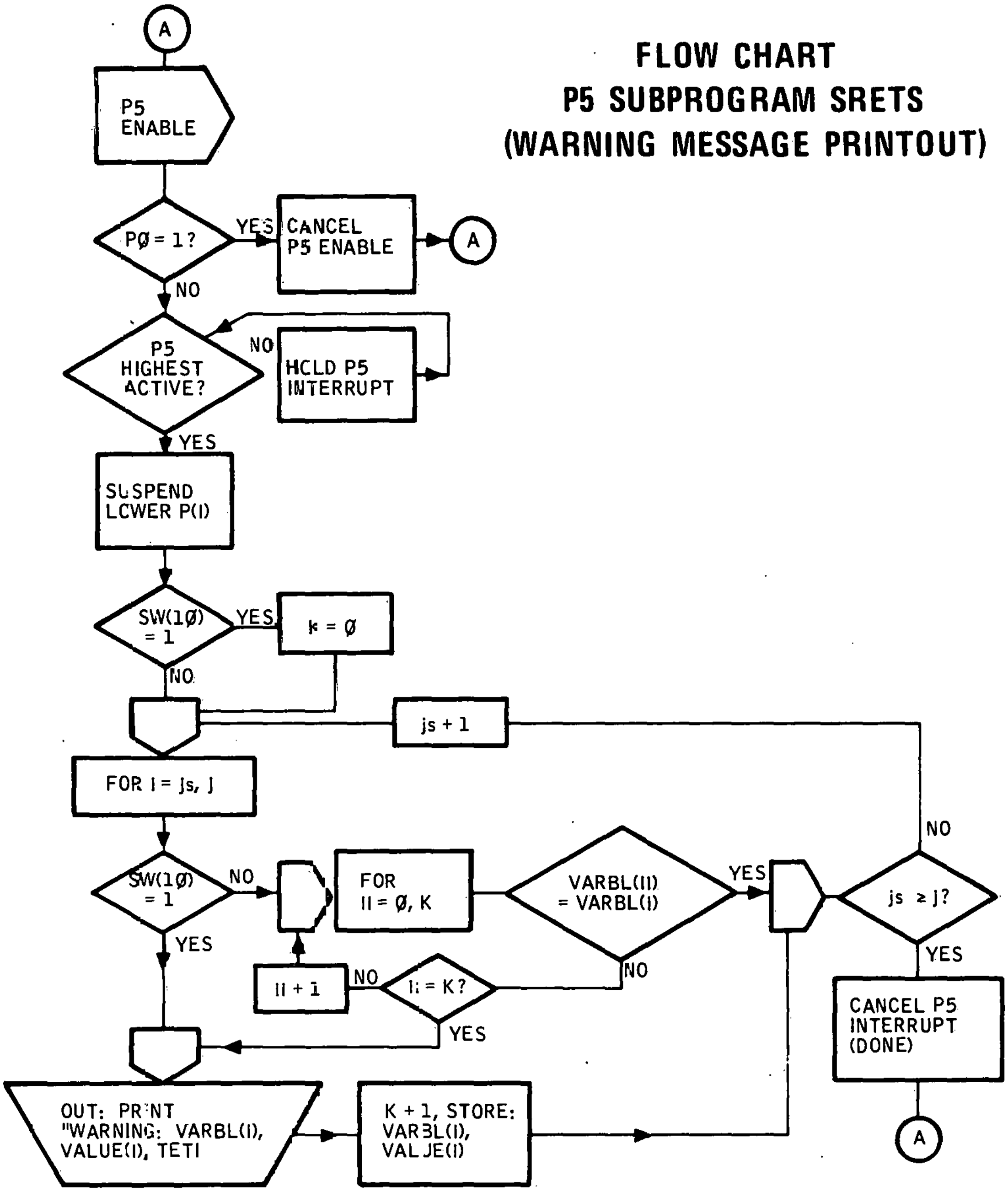
40454

P4 SUBPROGRAM
PAGE 8 OF 8



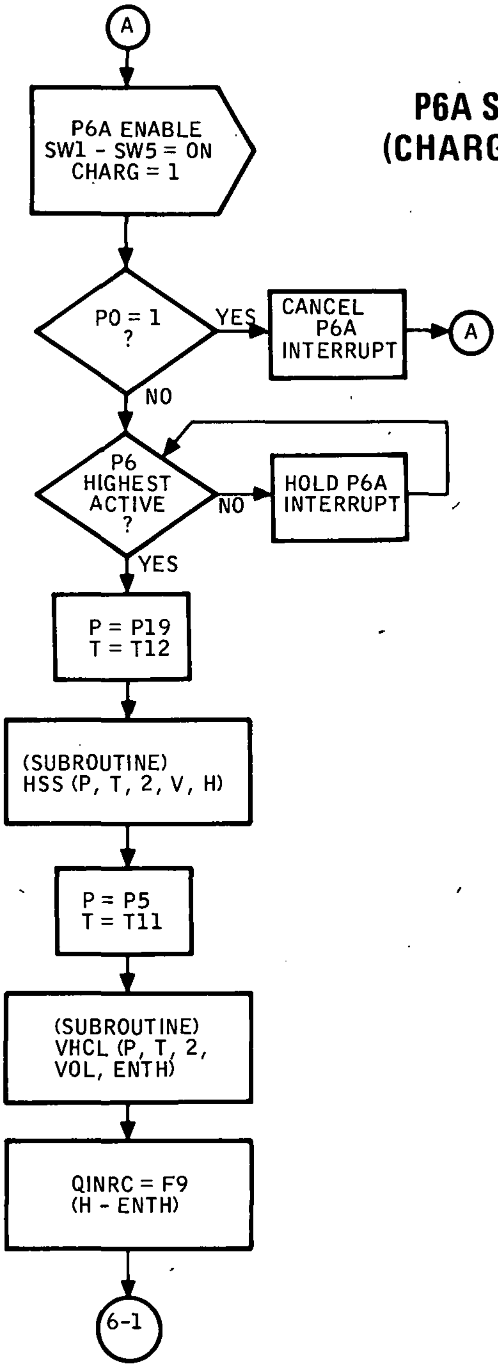
40454

FLOW CHART
P5 SUBPROGRAM SRETS
(WARNING MESSAGE PRINTOUT)



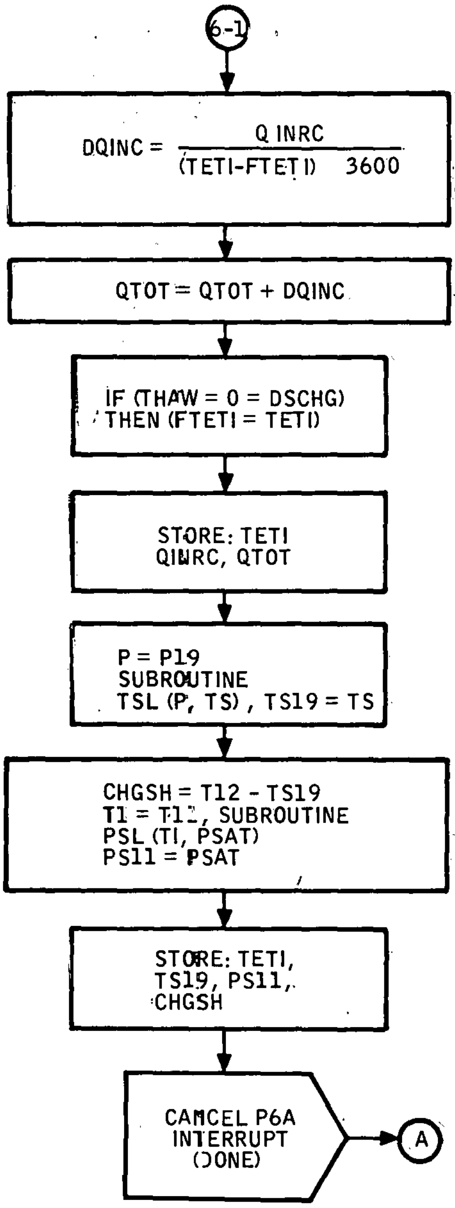
40454

FLOW CHART
P6A SUBPROGRAM SRETS
(CHARGE DATA REDUCTION)
PAGE 1 OF 2



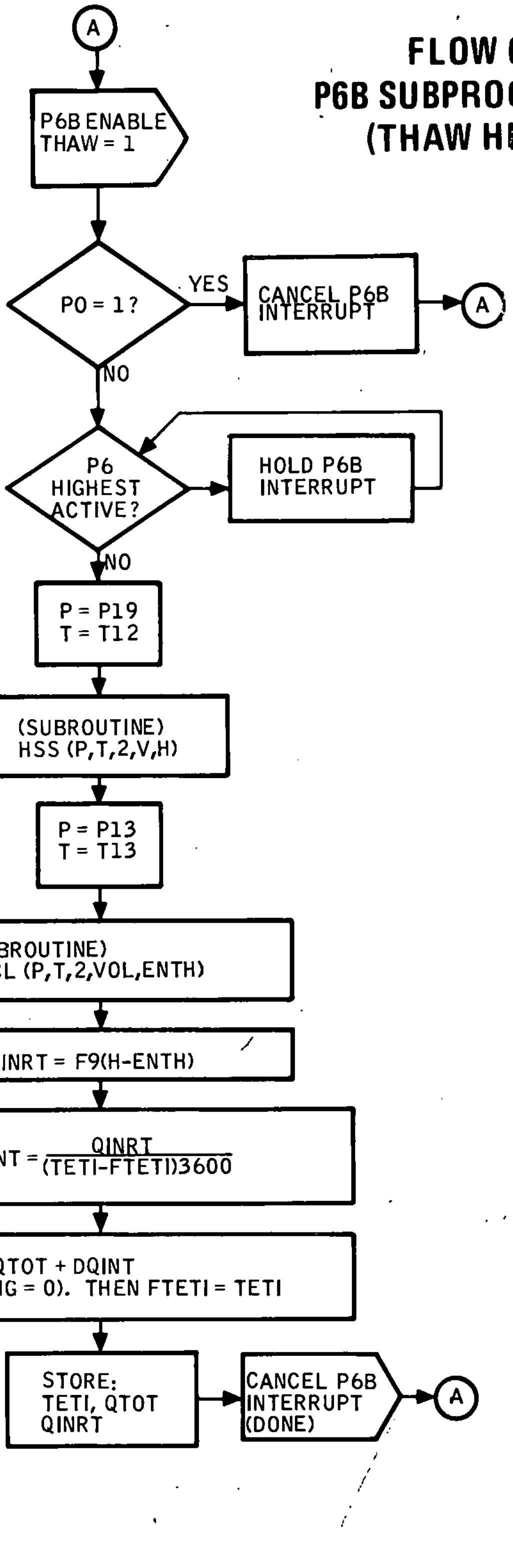
40454

P6A SUBPROGRAM
PAGE 2 OF 2



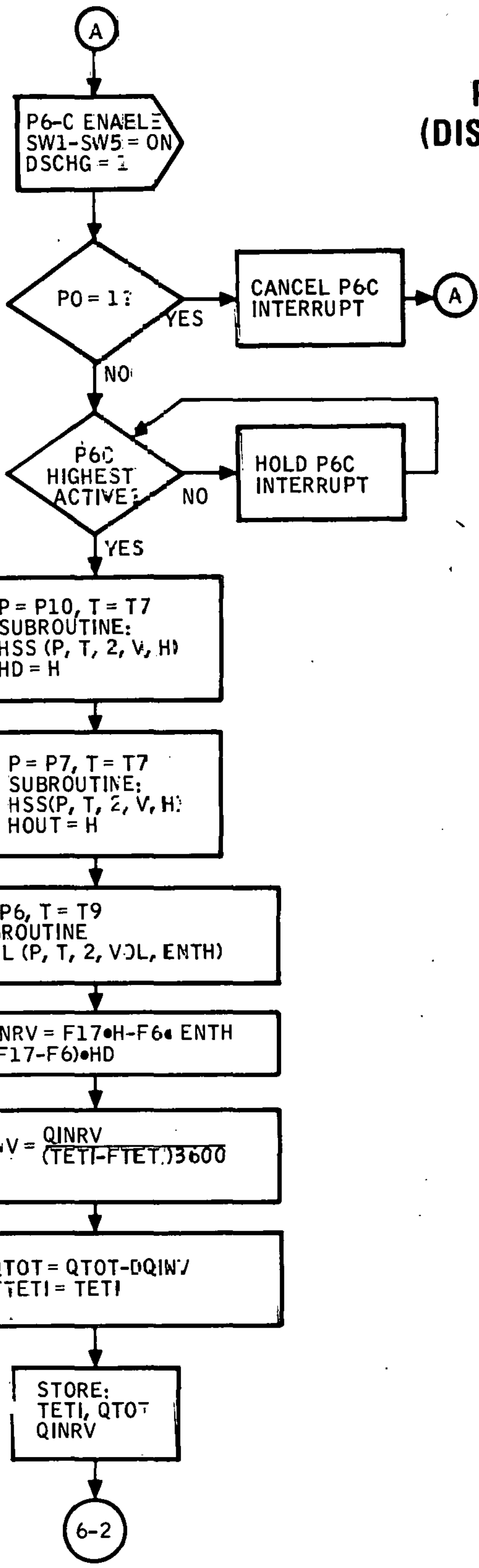
40454

FLOW CHART
P6B SUBPROGRAM SRETS
(THAW HEAT BAL.)



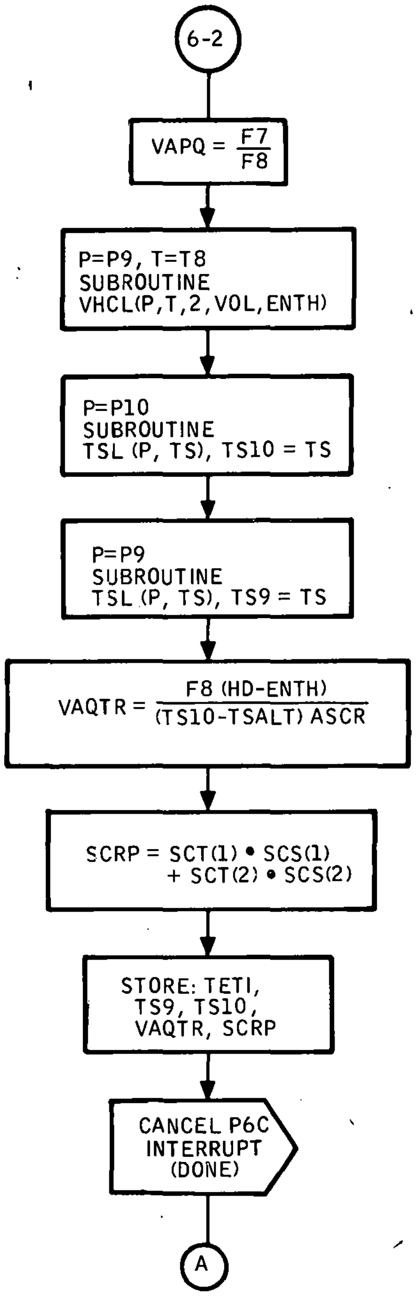
40454

**FLOW CHART
P6C SUBPROGRAM SRETS
(DISCHARGE DATA REDUCTION)
PAGE 1 OF 2**



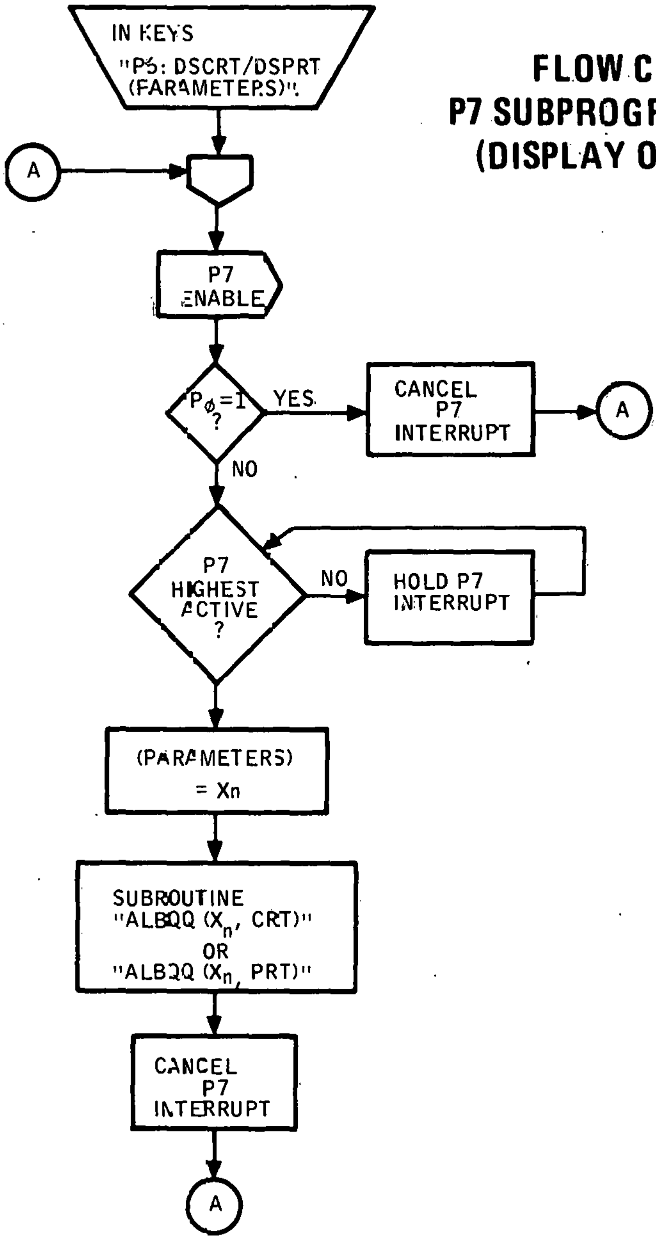
40454

P6C SUBPROGRAM
PAGE 2 OF 2



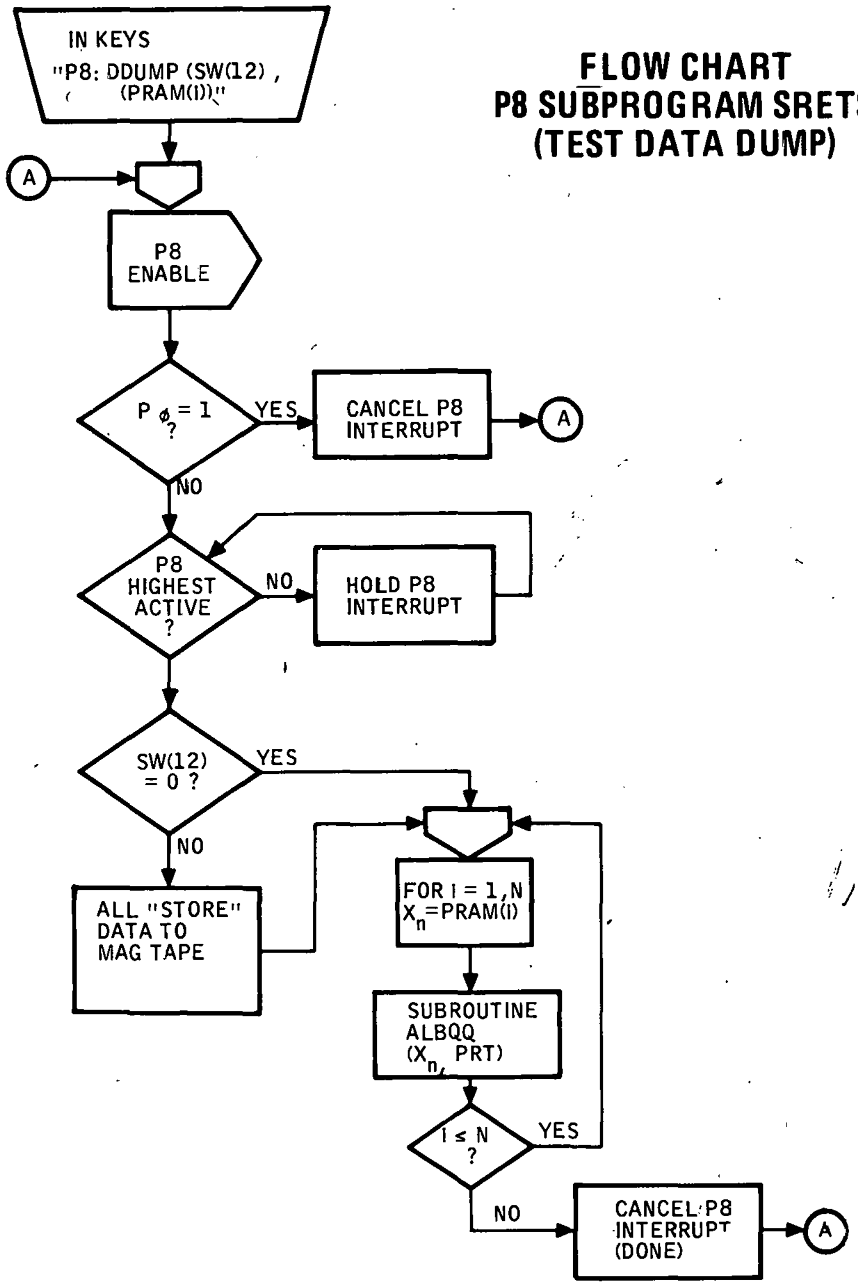
40454

FLOW CHART
P7 SUBPROGRAM SRETS
(DISPLAY OUTPUTS)



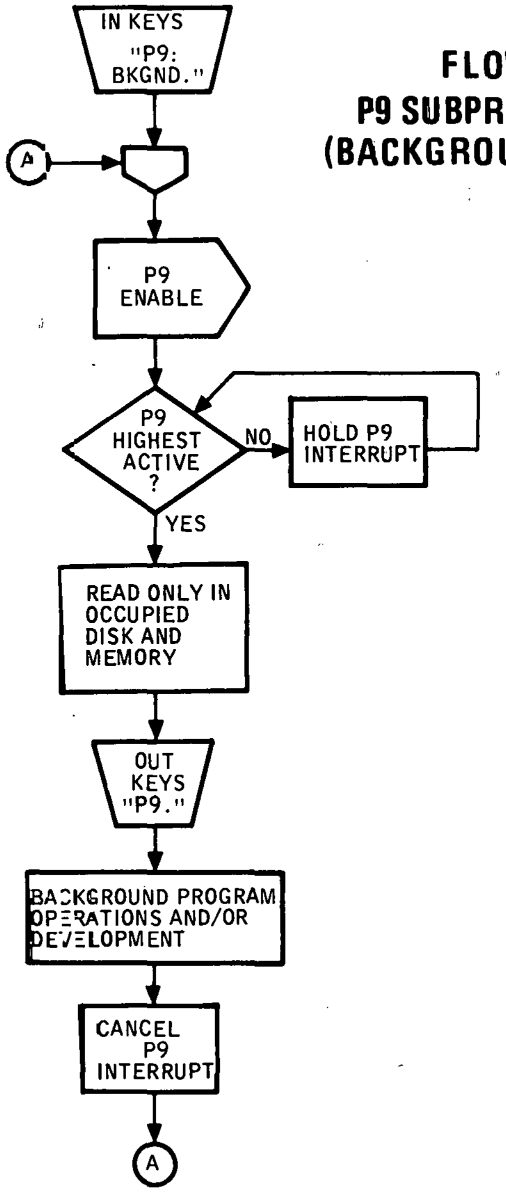
40454

FLOW CHART
P8 SUBPROGRAM SRETS
(TEST DATA DUMP)



40454

FLOW CHART
P9 SUBPROGRAM SRETS
(BACKGROUND PROGRAMS)



40454

APPENDIX E

APPENDIX E
SRE CONDENSER DETAIL DESIGN CALCULATION

40454

APPENDIX E

SRE CONDENSER DETAIL DESIGN CALCULATIONS

PIPE WALL THICKNESS CALCULATIONS

The equation recommended for minimum wall thickness is

$$t_m = \frac{PD_o}{2(SE + PY)} + C$$

where

P = design pressure

D_o = outside pipe diameter

S = allowable stress

Y = coefficient for steel

E = weld joint factor

t_m = minimum wall required

C = sum of allowances; corrosion, etc.

Now,

P = (1 · 1) working pressure = 13.5 MPA (1962 psi)

S = 73.7 MPA @ 400°C 10,700 psi @ 750°F)

Y = 0.4, E = 1

D_o = 2.54 cm (1.00 in.)

C = 0.0762 cm (0.03 in.)

$$t_m = \frac{13.5 \times 2.54}{2(73.8 + 13.5 \times 0.4)} + 0.0762$$

t_m = 0.293 cm (0.115 in.)

Because the metal gets thinner at the bends, its thickness must be increased.

$$t_o = t_1 \left[1 + \frac{D_o}{4R}\right] = 0.115 \left[1 + \frac{1.0}{4(1.25)}\right]$$

$$t_o = 0.138 \text{ in.}$$

$$9 \text{ gauge} = 0.148 \text{ in.}$$

A 2.54 cm O.D. by 1.79 cm I.D. (9 gauge, 1 in.) tubing is recommended.

CONDENSATION OF SUPERHEATED VAPOR

Computer calculations are done to predict the performance of SRE condenser under off-design conditions. Figure E-1 illustrates the flow chart for the calculations.

If the temperature of the wall is above the saturation temperature at the prevailing pressure, there will be no condensation and the case is that of cooling of gas. If the temperature of the wall is below the saturation temperature, condensation at the wall will occur even though the bulk of vapor is not yet at saturation, i.e., a process of simultaneous condensation and vapor desuperheating occurs. The sensible heat travels across the gas film, and the total heat (Sensible + Latent) travels across the condensate film. The procedure for estimating the coefficients for simultaneous desuperheating and condensation in accordance with the above mechanism is as follows: (Ref. Chemical Engineers Handbook, 4th Ed., J. H. Perry, pg 10-20).

$$\frac{q_g}{h_g} + \frac{q_T}{h_c} = A\Delta T_o \qquad (1)$$

$$\frac{q_T}{A\Delta T_o} = h_{cg} \qquad (2)$$

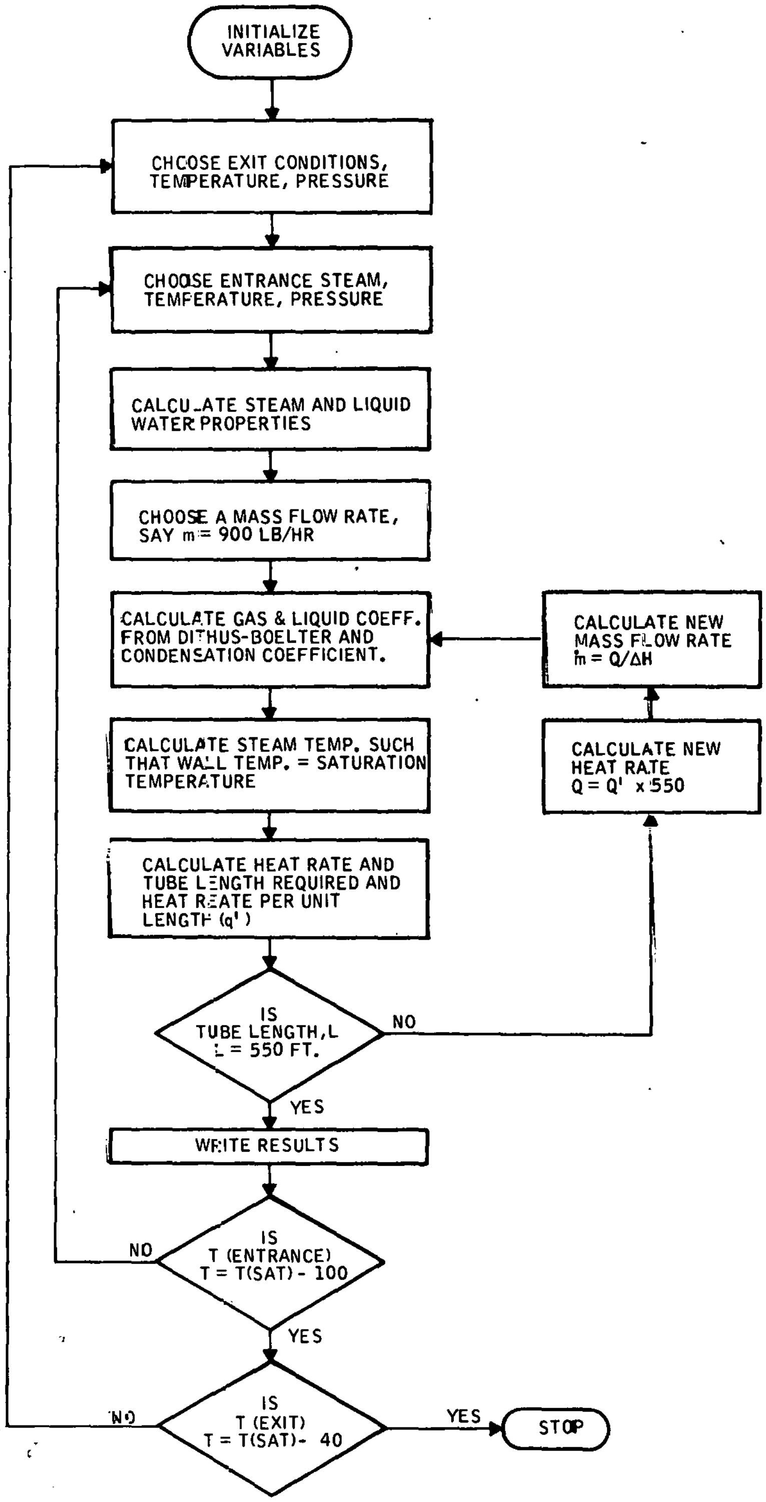


Figure E-1. Condenser Performance Flow Chart

Substituting (1) in (2) we get,

$$h_{cg} = \frac{1}{\frac{q_g}{q_T} \cdot \frac{1}{h_g} + \frac{1}{h_c}}$$

where,

$$q_T = q_g + q_c$$

q_g = Sensible heat or superheat

q_c = Latent heat

q_T = Total heat

h_g = Gas coefficient (Dittus-Boelter)

h_c = Condensation Coefficient

h_{cg} = Coefficient for simultaneous desuperheating and condensation, (inside coefficient).

The heat rate is calculated from the energy equation:

$$q = \dot{m} \left[\underbrace{C_{pg} \left(t_{in} - t_{sat} \right)}_{\text{Superheat}} + \underbrace{H_{fg}}_{\text{Latent heat}} + \underbrace{C_{pl} \left(t_{sat} - t_{o} \right)}_{\text{Sub cool}} \right] \quad (4)$$

and

$$q = U_g A_g (\Delta T_g)_{LN} + U_{cg} A_{cg} (\Delta T_{cg})_{LN} + U_L A_L (\Delta T_L)_{LN} \quad (5)$$

where

$$(\Delta T_g)_{LN} = \frac{t_{in} - t_{stm}}{\ln \left[(t_{in} - t_{salt}) / (t_{stm} - t_{salt}) \right]}$$

$$(\Delta T_{cg})_{LN} = \frac{t_{stm} - t_{sat}}{\ln\left[(t_{stm} - t_{salt})/(t_{sat} - t_{salt})\right]}$$

t_{stm} = Steam temperature at which wall temperature . t wall $\leq t_{sat}$; $t_{in} \leq t_{stm} \leq t_{sat}$

(when $t_{stm} = t_{sat}$, $(\Delta T_{cg})_{LN} = t_{sat} - t_{salt}$

and when $t_{stm} = t_{in}$, $(\Delta T_{g})_{LN} = 0$)

$$(\Delta T_{L})_{LN} = \frac{t_{sat} - t_{out}}{\ln\ (t_{sat} - t_{salt})/t_{out} - t_{salt})}$$

t_{in} = Entrance steam temperature

t_{sat} = Saturation steam temperature

t_{out} = Exit steam/water temperature

$\dot{m}$ = Steam flow rate at entrance to condenser

C_{pg} = heat capacity of superheated steam

C_{pl} = heat capacity of liquid water

H_{fg} = Latent heat or heat condensation

$U_{g} = \left(\frac{1}{h_{g}} + \frac{1}{U_{oT}}\right)^{-1}$ (used when $t_{in} > t_{stm}$)

$U_{cg} = \left(\frac{1}{h_{cg}} + \frac{1}{U_{oT}}\right)^{-1}$ (for $t_{stm} = t_{sat}$, $h_{cg} = h_{c}$ and $U_{cg} = U_{c}$)

$$U_L = \left(\frac{1}{h_L} + \frac{1}{U_{oT}}\right)^{-1}$$

$$U_{oT} = \left(\frac{1}{h_{outside}} + \frac{1}{h_{tube}} + \frac{1}{h_{dirt}}\right)^{-1}$$

h_g = $C_g \ (\dot{m})^{0.8}$ (Dittus-Boelter)

h_L = $C_L \ (\dot{m})^{0.8}$ (Dittus-Boelter)

A_g = Tube surface area for cooling of gas to t_{stm}.

A_{cg} = Tube area for condensation and desuperheating

A_L = Tube area for sub cooling of condensate

C_g = Constant for given fluid

h_o = Outside coefficient (salt side)

U_{oT} = Outside and tube coefficient

The first term in equation 5 is the heat rate for vapor desuperheating when the tube wall temperature is above the saturation. The second term is the heat rate for simultaneous vapor desuperheating and condensation and the last term is heat rate for subcooling of condensate (if any). Trial and error calculations were done to obtain the steam temperature at which the wall temperature equals the saturation temperature.

The following assumptions were made :

1. The outside salt coefficient is constant at h_o = 91.4 Btu/hr-ft^2 -F

2. The condensation coefficient is constant at h_c = 2350 Btu/hr-ft^2 -F

3. Fouling coefficient, h_{dirt} = 1000 Btu/hr-ft^2-F

4. Salt temperature, T (salt) = 578°F

5. Design tube length, L = 550 ft

6. Feedwater temperature = 440°F

The design tube length is based on condensation of saturated steam to give a heat rate of 4.59×10^5 Btu/hr.

Results

Figures E-2(a) and (b) show the effect of superheat on heat rate and heat rate per unit length at design coefficient and tube length. The heat rate or heat flux increases with increase in steam temperature. Figure E-3 is a plot of heat rate versus steam mass flow rate at different entering steam conditions. The conditions at condenser exit, assuming 550 ft of 0.762 in. I. D. tubing, is plotted in dotted lines. Figure E-4, same as Figure E-3, shows the condenser performance starting with same mass flow rate of superheated steam at 800°F and desuperheated to different degrees of superheat using 620°F feedwater. Figure E-5 and E-6 show the effect of outside and tube wall coefficient on heat rate and steam temperature. When the inside coefficient controls heat rate decreases with superheat and then increases.

Note: With steam trap in the condensation system, the chances of high subcooling of condensate are low because the capacity of the trap is almost five times the condensation rate and water will be forced out of the tube at a high velocity. Besides we do not see any steam vapor coming out since neither traps would pass any appreciable steam. We would, therefore, see essentially saturated water coming out from the system. In the former case the controller action would be to force more steam into the condenser while in the latter it acts to shut off the steam inlet valve and causing it to develop a pressure level to eventually condense steam.

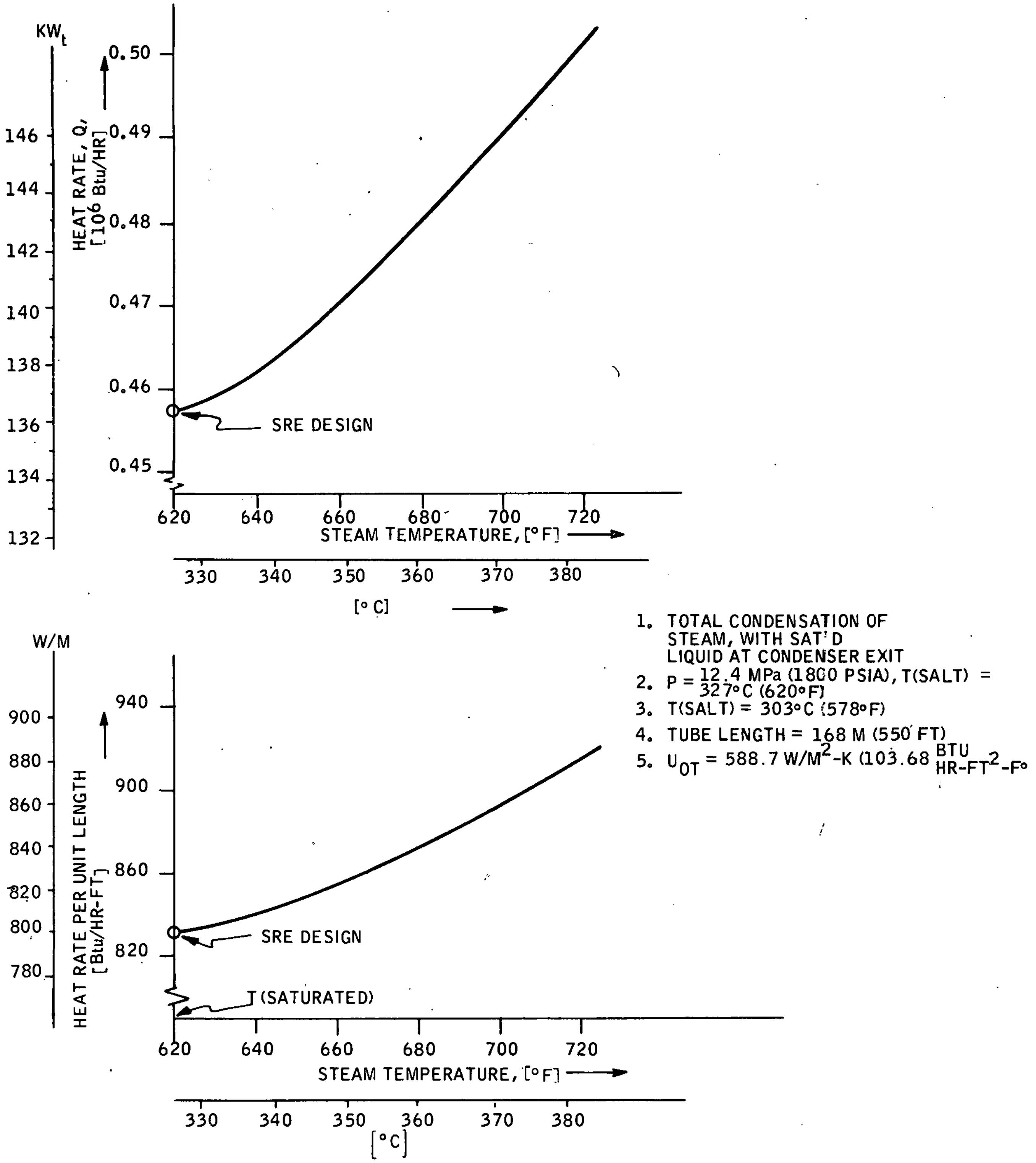


Figure E-2. SRE Condenser Heat Rate versus Steam Temperature

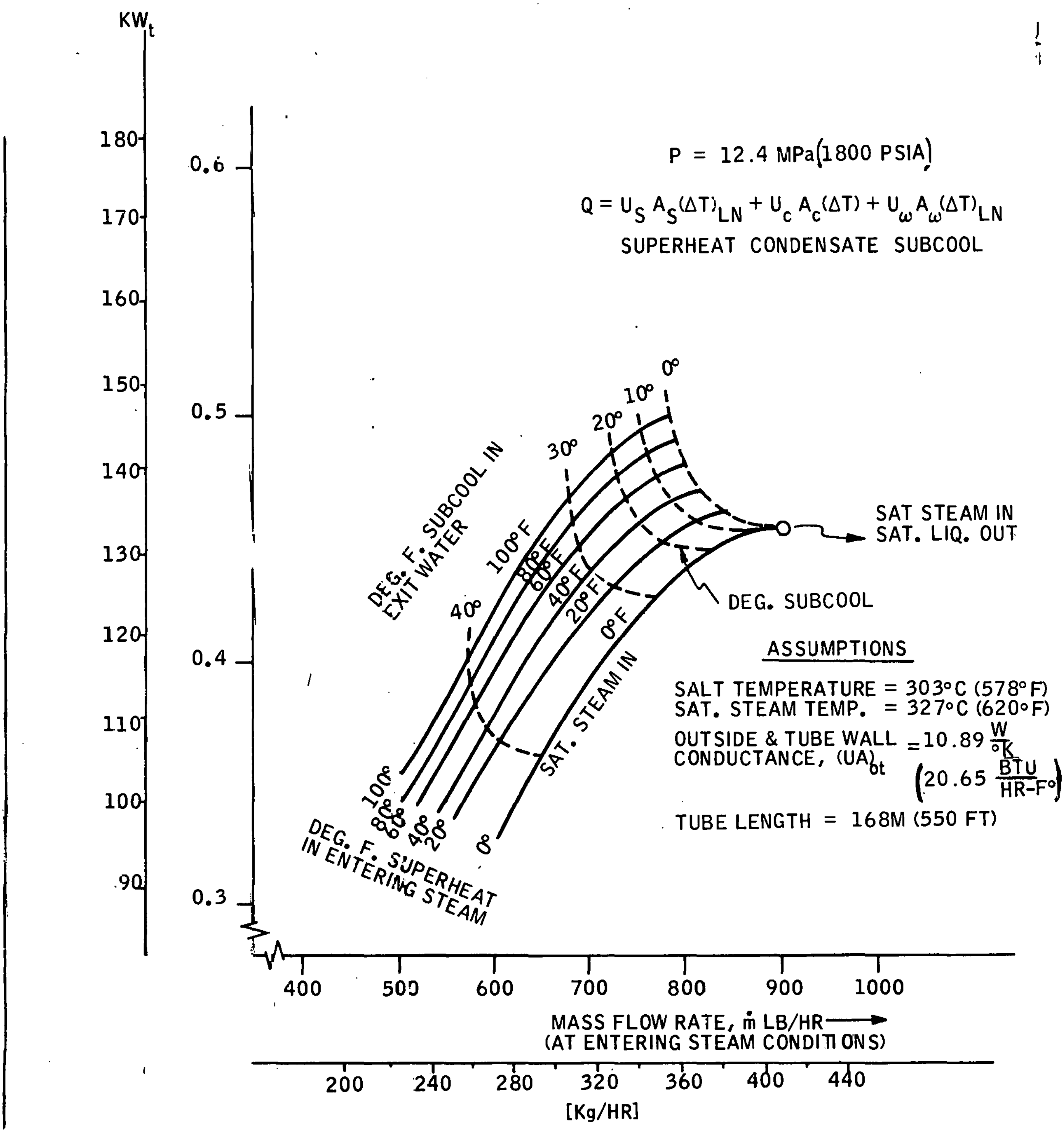


Figure E-3. SRE Condenser Performance Heat Rate versus Steam Flow Rate

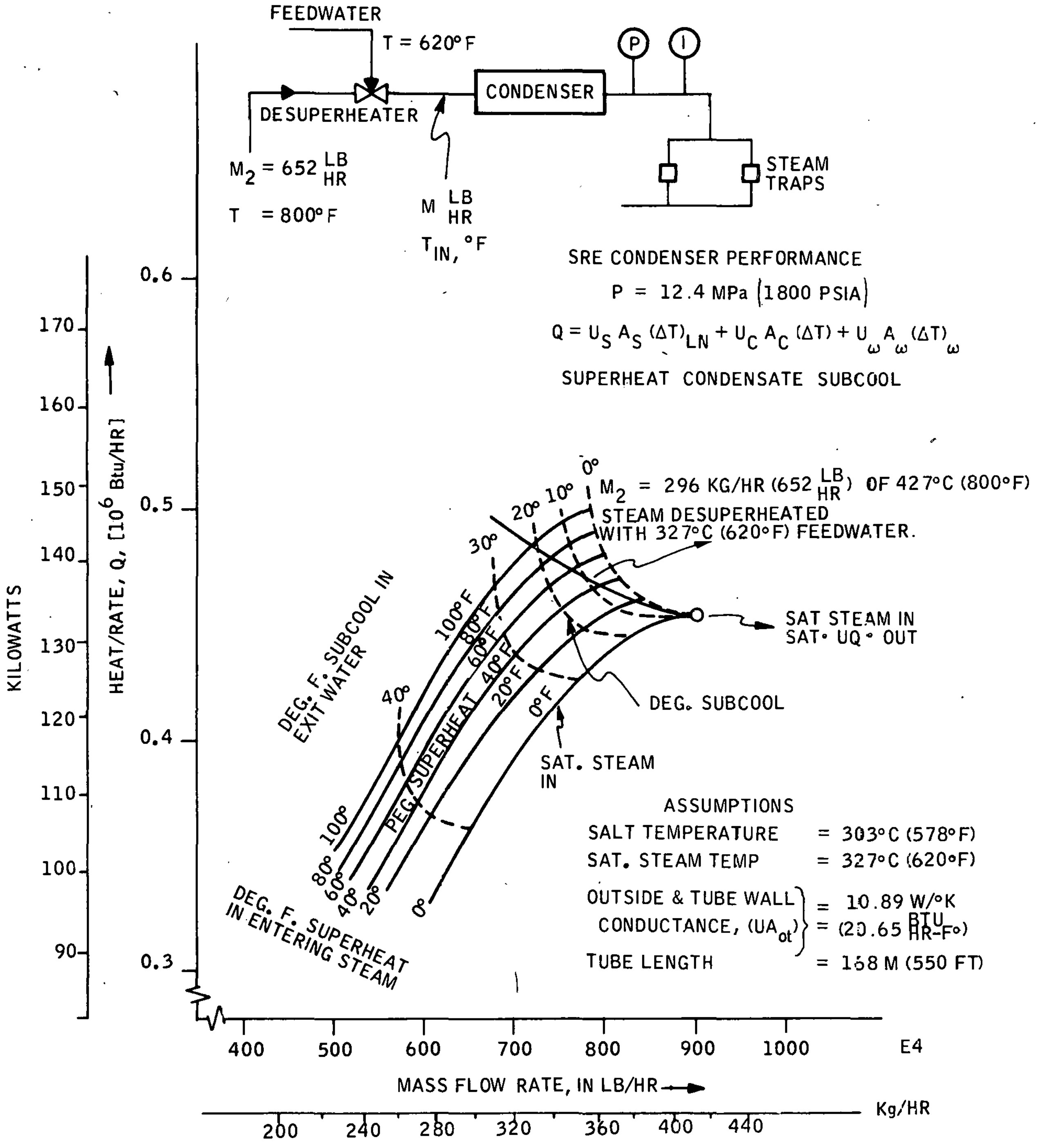


Figure E-4. SRE Condenser Performance, q versus m

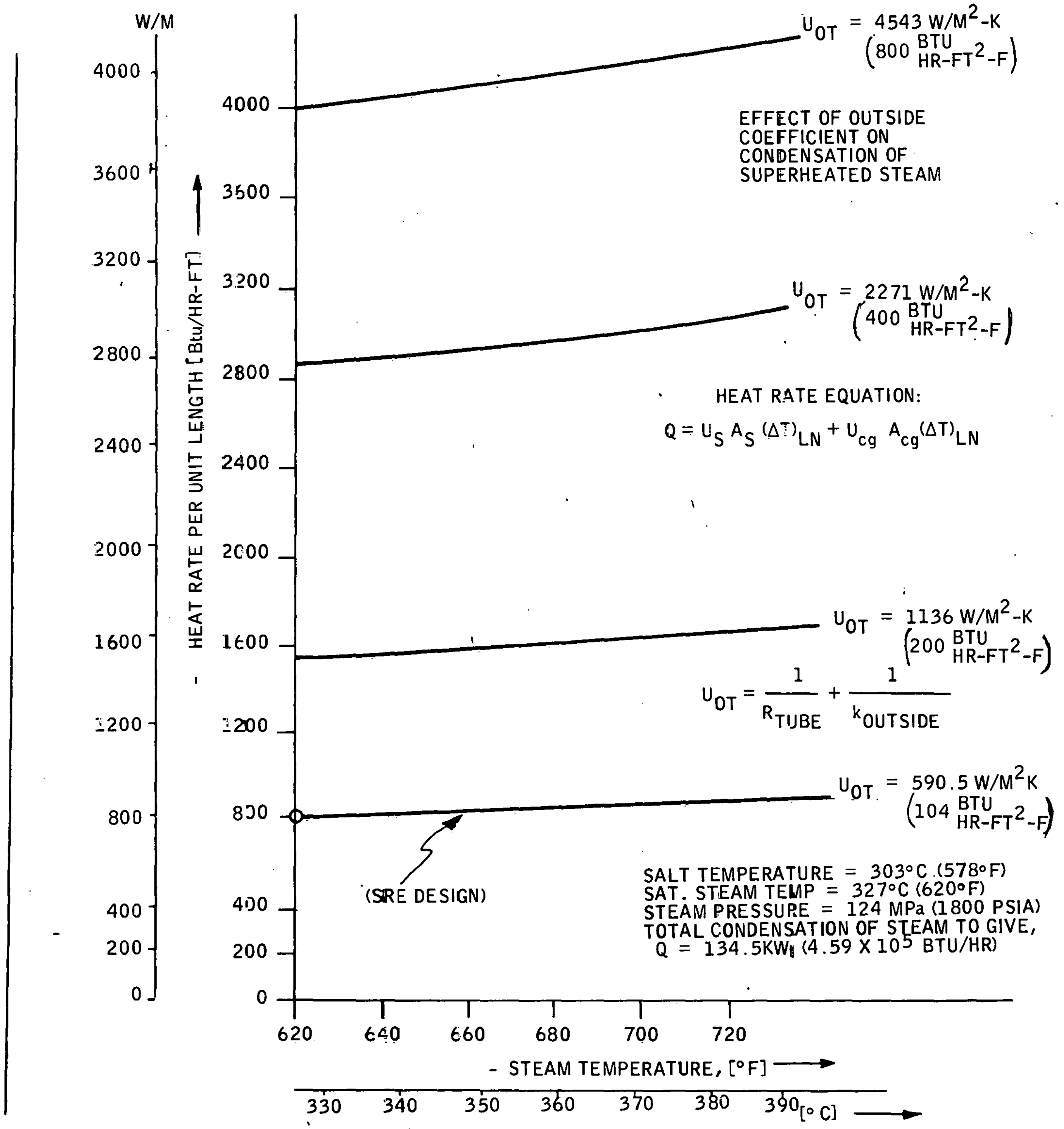


Figure E-5. Effect of Outside Coefficient on Condensation of Superheated Steam

40454

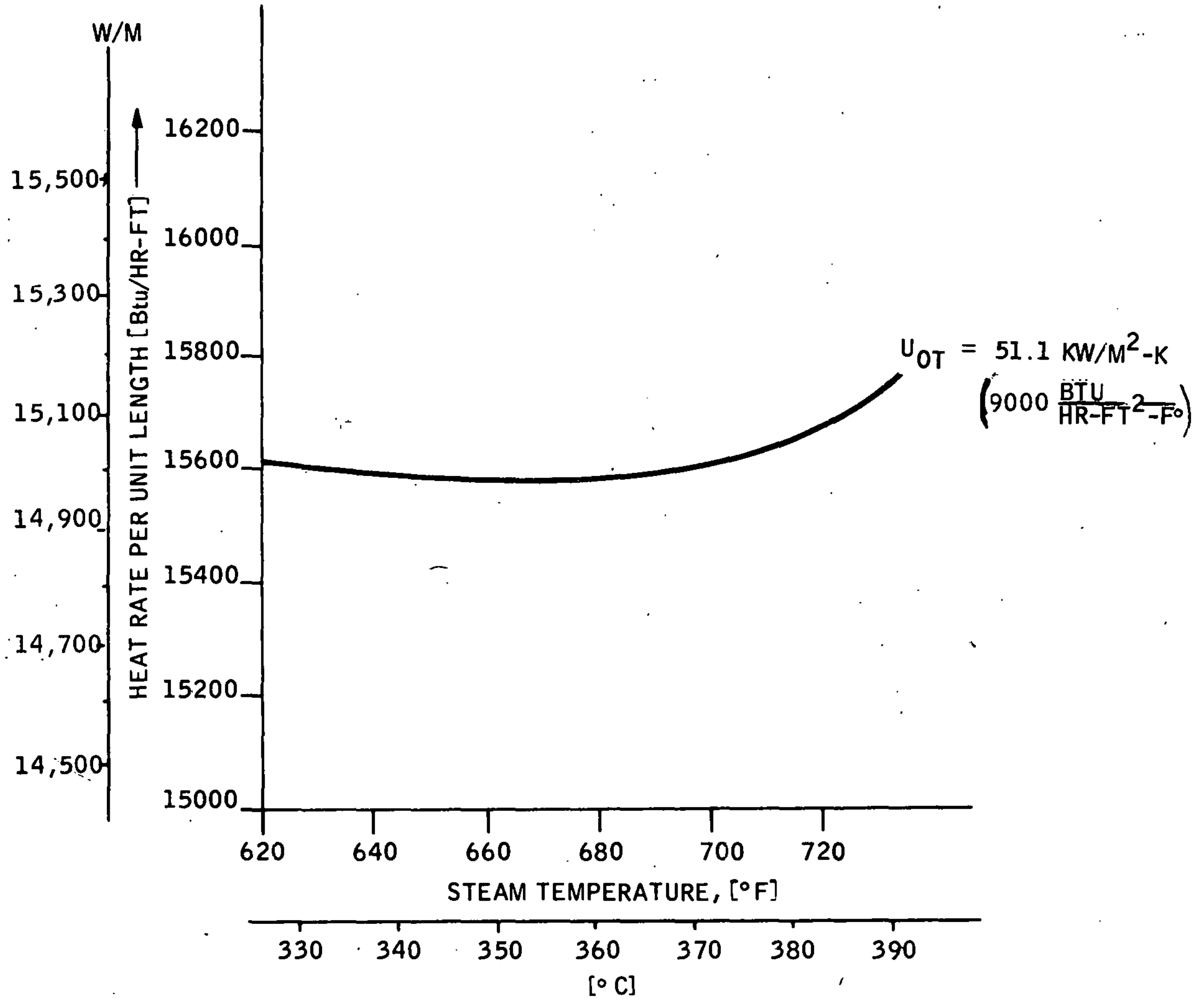


Figure E-6. Effect of Outside and Tube Wall Coefficient on Heat Rate and Steam Temperature

APPENDIX F

APPENDIX F
INSTRUMENTATION ERROR ANALYSIS

40454

APPENDIX F

INSTRUMENTATION ERROR ANALYSIS

Preliminary calculations have been made which demonstrate that the SRE/TS instrumentation will permit an accurate heat balance to be made.

To perform heat flow and heat storage calculations, four types of information must be known: pressure, temperature, mass flow rate and quality. The heat is all transported, neglecting heat loss terms, across system boundaries by water or steam flow, thus steady-state energy balances are made by summing fluid enthalpy fluxes.

Measurement error analysis starts with consideration of the inaccuracies in the primary sensors. Table F-1 lists the basic instrument types and their accuracies. In most cases the data acquisition system contributes as much to the overall error in a reading as does the basic sensor.

Steam quality will not be measured in this experiment, but will be calculated where necessary. The steam drum supplier guarantees a discharge steam quality of better than 99.5 percent, which is greater than can be measured with most instruments. The vaporizer discharge line steam quality can be calculated by performing an energy balance around the steam drum.

In mass flow measurements three errors must be included in the measurement error: calibration error of the venturi, pressure transducer error, and data acquisition system error. Determination of the fluid density error should also be included, particularly where vapor flow is being measured. To get a better view of the effect the total instrumentation error has on enthalpy determination, four design state points were chosen and the error envelopes plotted on steam charts.

The steam charts plot lines of constant pressure and constant temperature as functions of specific volume and enthalpy. Figure F-1 shows the region of uncertainty in enthalpy determination for the feedwater at the design point. For the feedwater, the temperature measurement uncertainly accounts for most of the uncertainty in enthalpy since enthalpy is not a strong function of pressure for a liquid.

Figure F-2 shows the discharge steam enthalpy determination around the design point. To better show the small region interest, an enlargement was made (Figure F-3). Because the lines of constant pressure and temperature intersect at oblique angles, it would not be intuitively obvious without the diagram which points constitute the extreme maximum and minimum values of uncertainty in enthalpy determination. This particular point is interesting in that three properties are required to define the enthalpy range. Figure F-4 shows the design point conditions for the condenser inlet. Due to the inherent requirement for a few degrees of superheat in the desuperheater discharge, the saturation vapor line is used as the lower limit for the enthalpy range.

The condenser outlet enthalpy range is shown in Figure F-5 . If the steam traps are working properly, the discharge condensate should be very nearly all saturated water with little live steam lost. The fluid is compressed liquid; like the feedwater, its enthalpy is largely a function of temperature with little dependence upon pressure.

Table F-2summarizes the graphical results. To calculate an enthalpy flux, the enthalpy of each fluid stream must be multiplied by the fluid flow rate which has its own error in measurement. The errors in flow measurement add to the errors in enthalpy determination to give the maximum range of error in enthalpy flux or heat flux determination.

Table F-3 gives the range of errors that the heat flux determination may take on when operating at the design conditions. The lower block lists the largest error that is expected in determination of energy flux to or from storage. These error intervals represent the sum of errors resulting from several independent measurements of pressure temperature and flow rate. It is highly unlikely that all of the errors will add in the same direction to produce the maximum errors calculated in Table F-3.

Table F-1. Discharge Steam Enthalpy Summary

INSTRUMENT	RANGE	OUTPUT SIGNAL	ERROR
PRESSURE TRANSDUCER	0-1500 PSI	4-20 MA	MAX ± 0.2% OF SPAN TYPICAL ± 0.1% OF SPAN
PRESSURE TRANSDUCER	P > 1500	4-20 MA	MAX ± 0.5% OF SPAN TYPICAL ± 0.35% OF SPAN
DIFFERENTIAL PRESSURE		4-20 MA	MAX ± 0.35% OF SPAN TYPICAL 0.25% OF SPAN
VENTURI TUBES			± 0.5% OF F/S
THERMOCOUPLES ANSI TYPE K PREMIUM GRADE	0-2300°F	MILLIVOLTS	± 0.38% OF READING
DATA ACQUISITION SYSTEM HP-9611	± 10 MV ± 20 MV ± 20 MA		± 0.33% OF F/S ± 0.28% OF F/S ± 0.39% OF F/S

40454

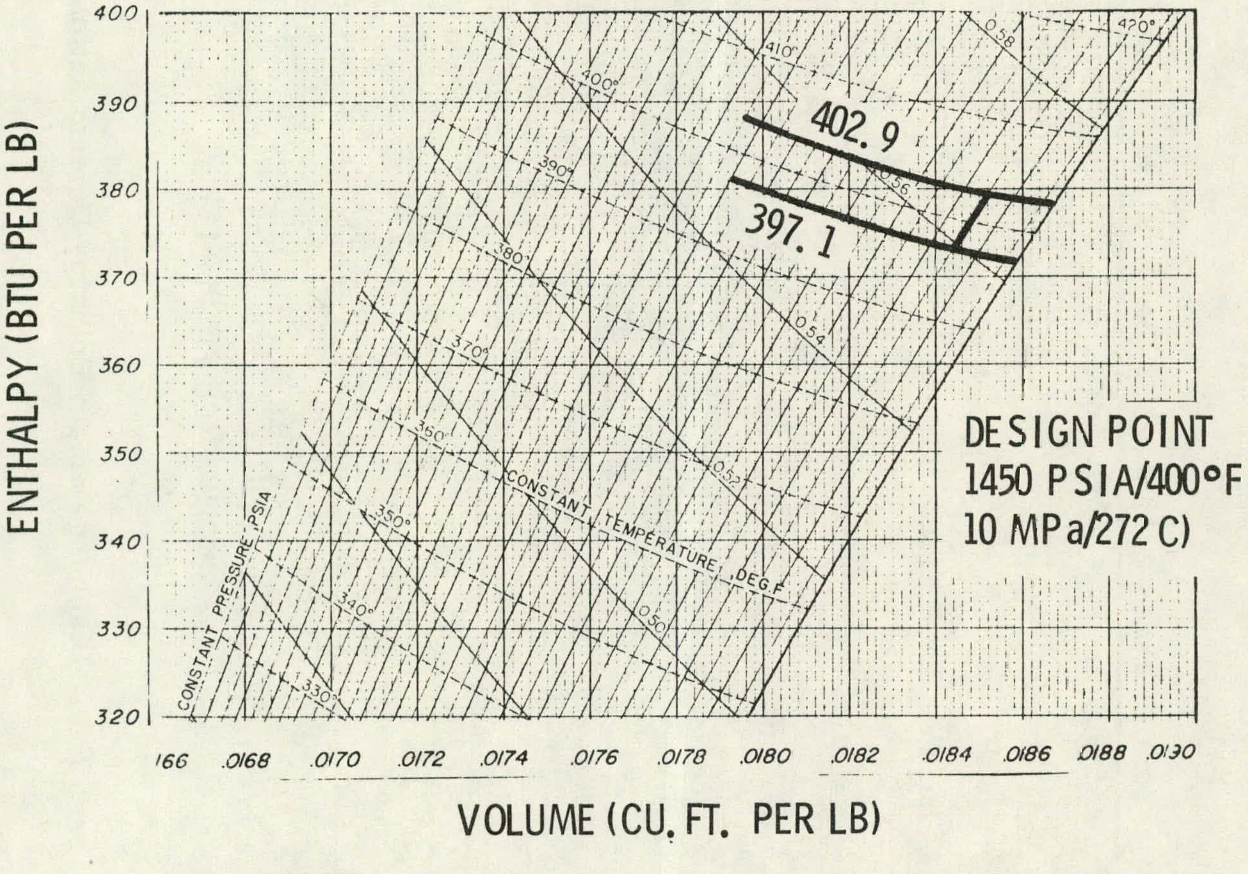


Figure F-1. Feedwater Enthalpy Determination

40454

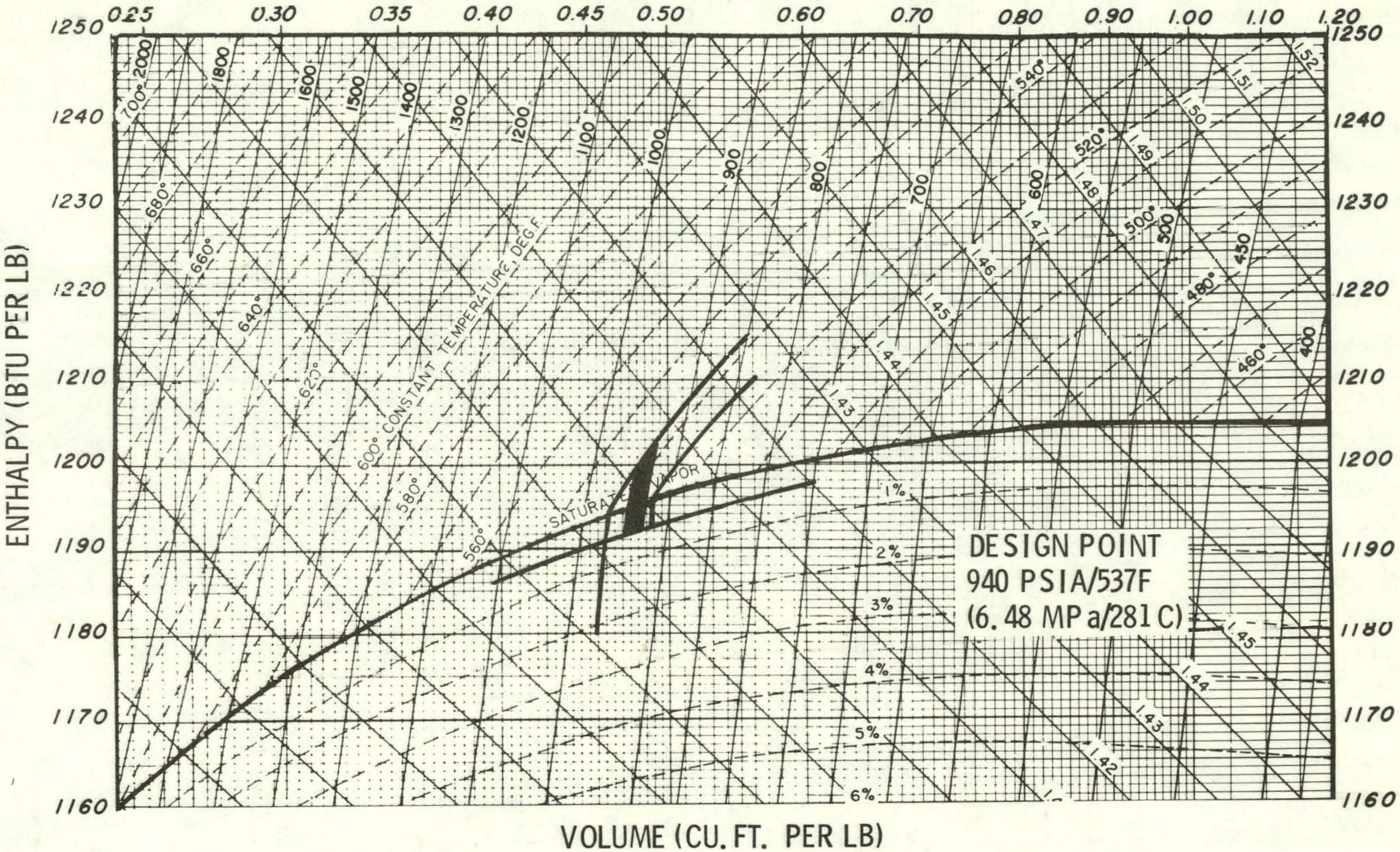


Figure F-2. Discharge Steam Enthalpy Determination

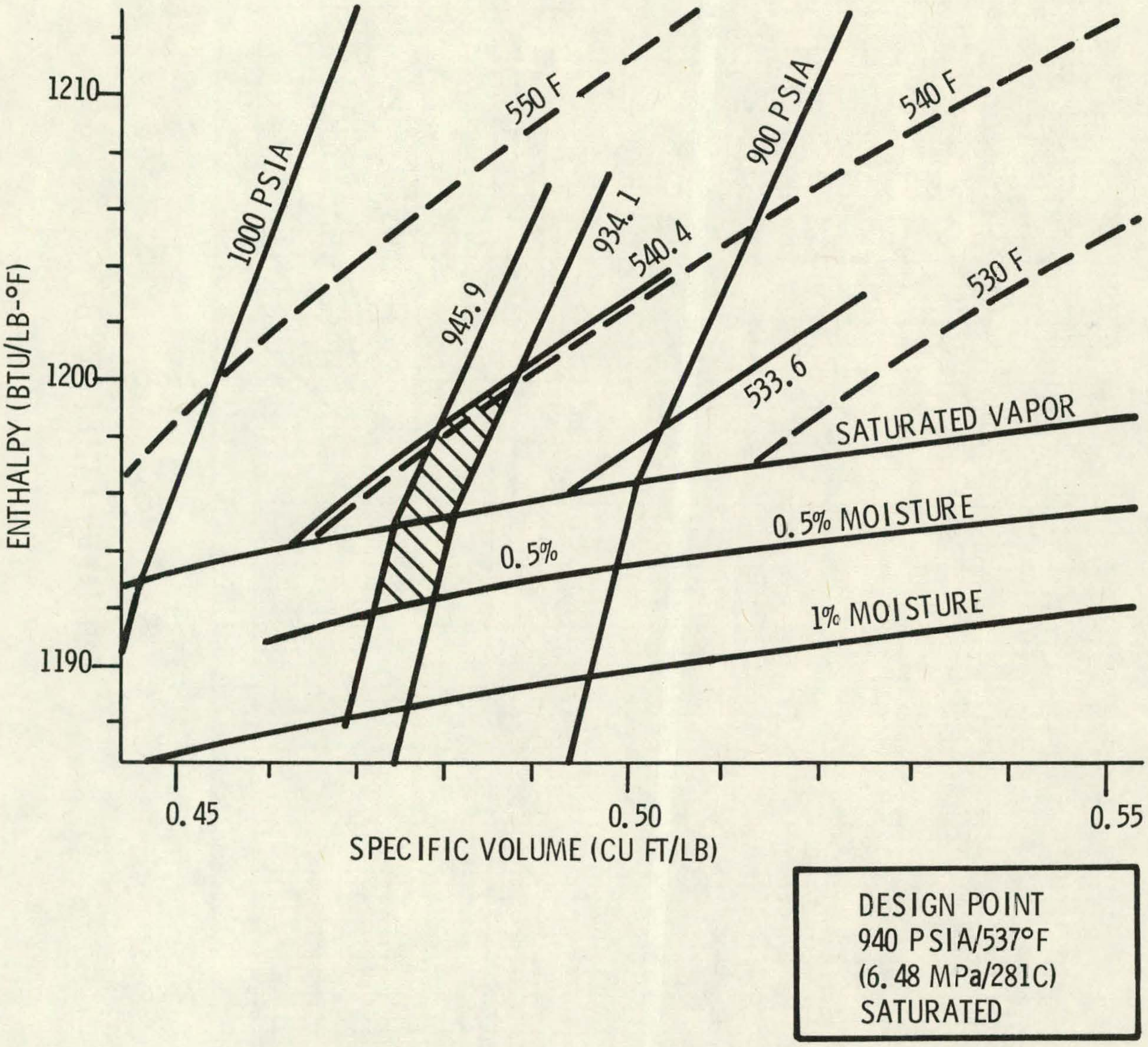


Figure F-3. Discharge Steam Enthalpy Determination

40454

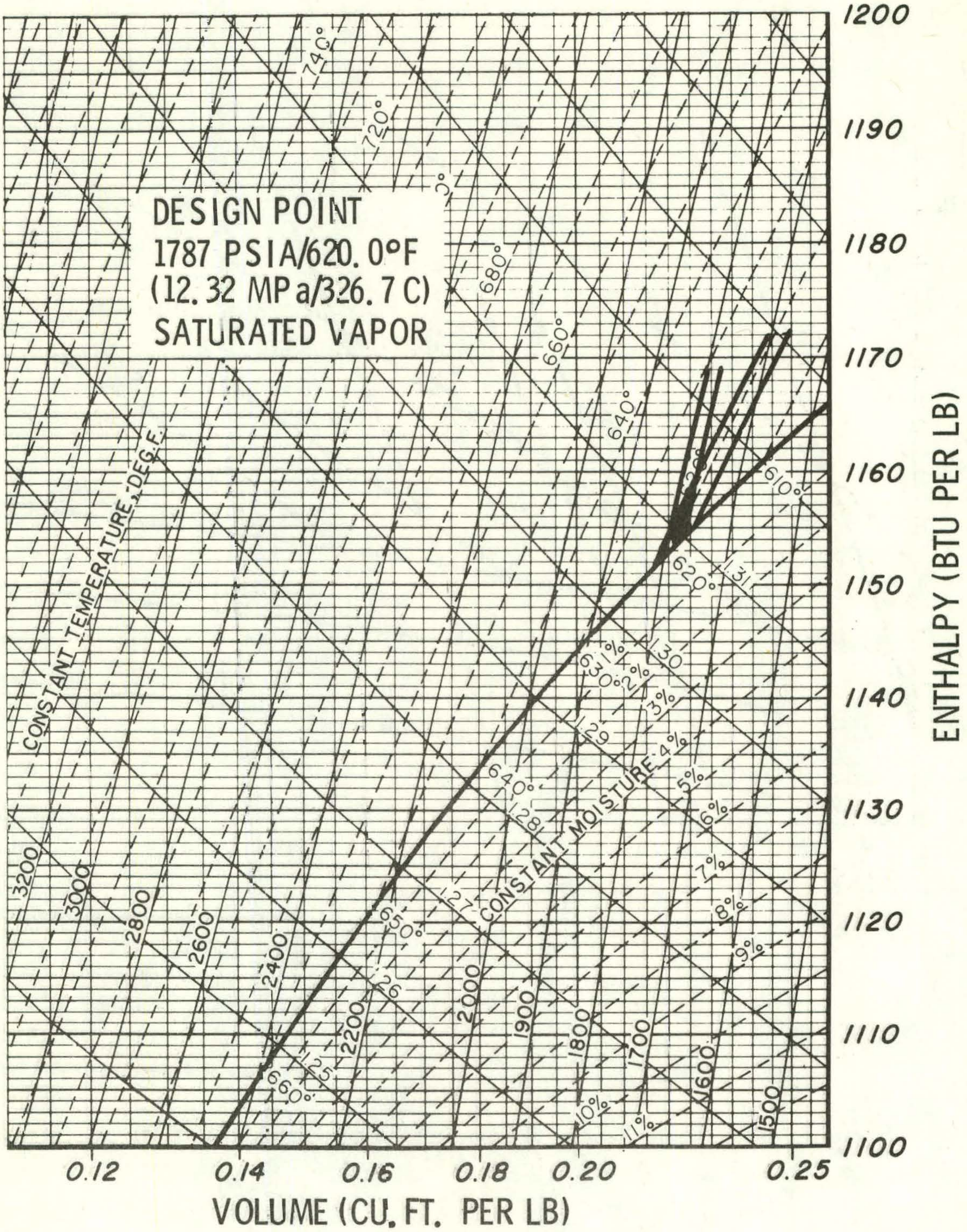


Figure F-4. Condenser Inlet Enthalpy Determination

40454

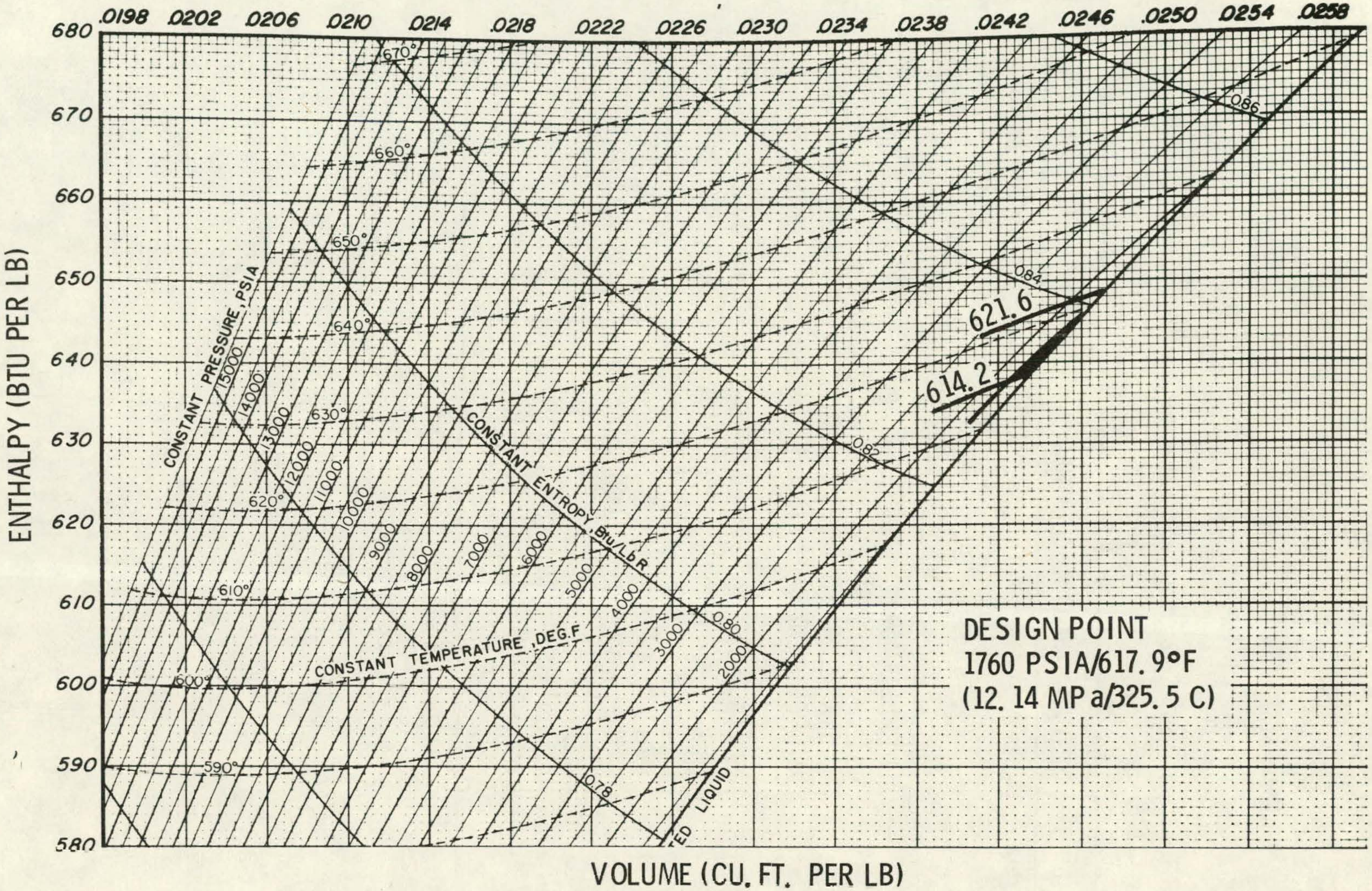


Figure F-5. Condenser Outlet Enthalpy Determination

Table F-2. Enthalpy Determination

SYSTEM LOCATION	DESIGN CONDITIONS	ENTHALPY	INDETERMINANT RANGE
DISCHARGE STEAM	6.48 MPa/281C (940 PSIA/537F)	2779.1 kJ/KG (1194.8 BTU/LB)	2773 TO 2796 kJ/KG (1192 TO 1202 BTU/LB)
FEEDWATER	10.0 MPa/204°C (1450 PSIA/400°F)	876 kJ/KG (376.5 BTU/LB)	869 TO 883 kJ/KG (373.5 TO 379.7 BTU/LB)
CONDENSER INLET	12.32 MPa/326.7°C (1787 PSIA/620°F)	2682 kJ/KG (1153.2 BTU/LB)	2681 TO 2697 kJ/KG (1152.5 TO 1159.5 BTU/LB)
CONDENSATE OUTLET	12.14 MPa/325.5°C (1760 PSIA/617.9°F)	1497 kJ/KG (643.7 BTU/LB)	1483 TO 1500 kJ/KG (637.6 TO 645.0 BTU/LB)
VAPORIZER INLET	6.86 MPa/284.4°C (995 PSIA/502.4°F)	1141.6 kJ/KG (490.8 BTU/LB)	1132.5 TO 1150.7 kJ/KG (486.9 TO 494.7 BTU/LB)
VAPORIZER OUTLET	6.53 MPa/281°C (946.9 PSIA/538°F)	CALCULATED FROM ENERGY BALANCE	

40454

Table F-3. Enthalpy Changes Across the Thermal Storage System

SYSTEM	NOMINAL H	MIN H	MAX H	PERCENTAGE ERROR
VAPORIZER	1903 kJ/KG 818.3 BTU/LB	1889 kJ/KG 812.3 BTU/LB	1927 kJ/KG 828.5 BTU/LB	-0.7% TO + 1.2%
CONDENSER	1185 kJ/KG 509.5 BTU/LB	1180.4 kJ/KG 507.5 BTU/LB	1214 kJ/KG 521.9 BTU/LB	-0.4% TO + 2.4%

MASS FLOW RATE

DISCHARGE STEAM	272 ± 5.6 KG/HR = ± 2.1% 600 ± 12.3 LB/HR
CONDENSATE	412 ± 7.3 KG/HR = ± 1.8% 908 ± 16 LB/HR

TOTAL HEAT FLUX DETERMINATION ERROR

VAPORIZER	-2.8% TO + 3.3%
CONDENSER	-2.2% TO + 4.2%

40454

APPENDIX G

APPENDIX G
LOGIC DIAGRAMS FOR CONTROL OF THE THERMAL STORAGE SUBSYSTEM RESEARCH EXPERIMENT

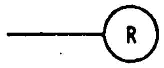
40454

ABBREVIATION	MEANING
CP	CONTROL PANEL
EP	ELECTRONIC/PNEUMATIC POSITIONER
EE	ELECTRICAL TRANSDUCER
FT	FLOW TRANSMITTER
LT	LEVEL TRANSMITTER
PT	PRESSURE TRANSMITTER
TE	TEMPERATURE ELEMENT
CS	CONTROL SWITCH
IND	INDICATOR
LS	LEVEL SWITCH
PS	PRESSURE SWITCH
RCD	RECORDER
SV	SOLENOID VALVE
DA	DATA ACQUISITION
TT	TEMPERATURE TRANSMITTER
PB	PUSH BUTTON SWITCH
TSS	TOGGLE SELECTOR SWITCH
OL	MOTOR OVERLOAD SWITCH
ZS	POSITION SWITCH

				DATE	REVISION OR ISSUE	NO.	BY

BLACK & VEATCH CONSULTING ENGINEERS PROJECT 7021	ERDA - 10MWe SOLAR PILOT PLANT SUBSYSTEM RESEARCH EXPERIMENT	LD1001-1
	SYSTEM CODES	

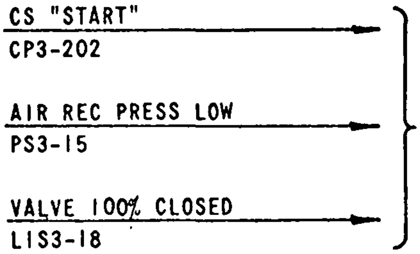
EXAMPLE	MEANING



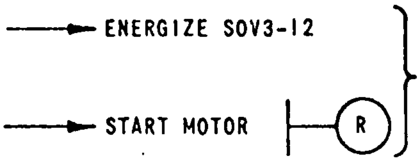
LIGHT COLOR INDICATED BY LETTER (PREFIX D - DIM)

WINDOW ANNUNCIATOR

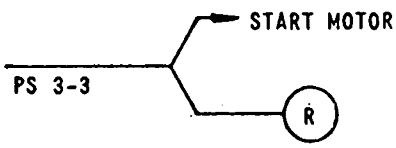
RECORDING ANNUNCIATOR



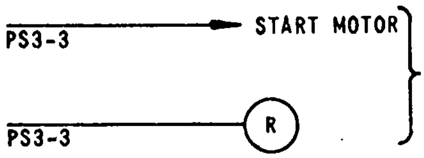
INPUT CONDITION IS STATED ON TOP OF LINE AND SOURCE OF INPUT IS INDICATED BELOW THE LINE



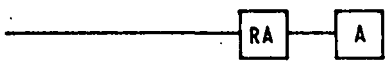
ARROW INDICATES A CONSEQUENTIAL ACTION.
VERTICAL LINE INDICATES A LOGIC SIGNAL ORIGINATING WITH A STARTER OR BREAKER AUXILIARY CONTACT.



BOTH MOTOR AND LIGHT ARE ACTUATED BY ONE CONTACT IN PS3-3 THROUGH AN AUXILIARY RELAY



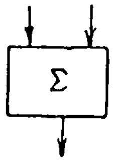
MOTOR AND LIGHT ARE ACTUATED BY TWO ELECTRICALLY SEPARATE CONTACTS IN PS3-3



SIGNAL TO RECORDING ANNUNCIATOR ALSO ACTUATES WINDOW ANNUNCIATOR

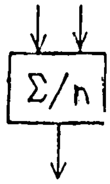
BLACK & VEATCH CONSULTING ENGINEERS PROJECT 7021	ERDA - 10 MWe SOLAR PILOT PLANT SUBSYSTEM RESEARCH EXPERIMENTS	DATE
	LOGIC DIAGRAM CONVENTIONS	SHEET LD1001-2

1.
SUMMING TWO SIGNALS



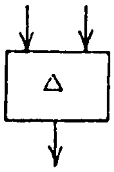
MORE THAN TWO SIGNALS CAN BE SUMMED IF REQUIRED

2
AVERAGING TWO SIGNALS

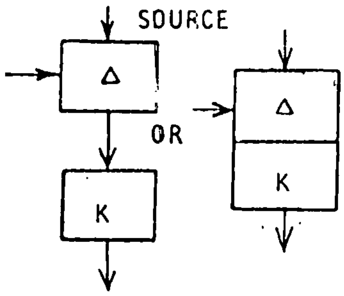


MORE THAN TWO SIGNALS CAN BE AVERAGED IF DESIRED.

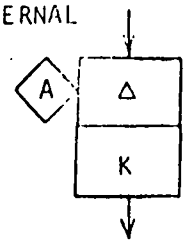
3
DIFFERENCE OF TWO SIGNALS



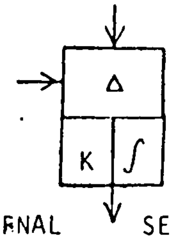
4
PROPORTIONAL CONTROL WITH SET POINT FROM EXTERNAL SOURCE



5
PROPORTIONAL CONTROL WITH INTERNAL SET POINT

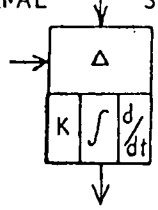


6 PROPORTIONAL PLUS INTEGRAL CONTROL WITH SET POINT FROM EXTERNAL SOURCE.



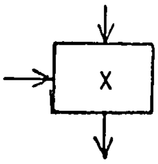
INTERNAL SET POINT TO BE DIAGRAMMED AS IN EXAMPLE 5

7 PROPORTIONAL PLUS INTEGRAL PLUS DERIVATIVE CONTROL WITH SET POINT FROM EXTERNAL SOURCE

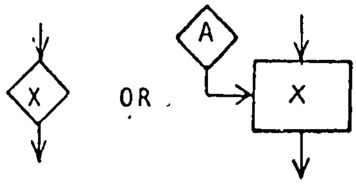


INTERNAL SET POINT TO BE DIAGRAMMED AS IN EXAMPLE 5

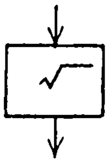
8
MULTIPLYING ONE SIGNAL BY ANOTHER.



9
MULTIPLYING ONE SIGNAL BY A MANUALLY ADJUSTED MULTIPLIER.

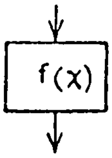


10
ROOT EXTRACTING

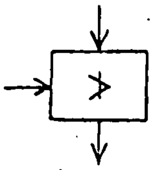


ROOT MAY BE ADDED FOR CLARITY SUCH AS $\sqrt[2]{\ }$ $\sqrt[3]{\ }$

11
NON-LINEAR OR UNSPECIFIED FUNCTION PERFORMED ON A SIGNAL

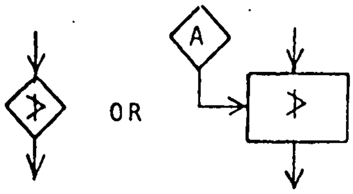


12
HIGH LIMITING OF ONE SIGNAL BY ANOTHER

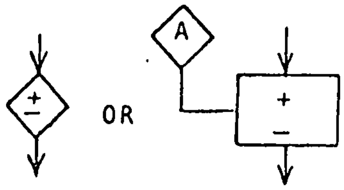


LD1001-3

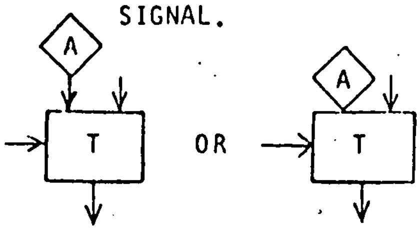
13 HIGH LIMITING OF A SIGNAL BY A MANUAL ADJUSTMENT



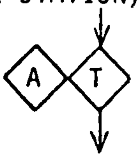
14 BIASING OF A SIGNAL BY A MANUAL ADJUSTMENT



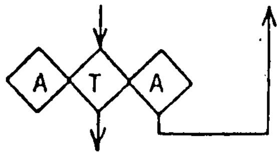
15 AUTOMATIC TRANSFER TO OR FROM A MANUALLY ADJUSTED SIGNAL.



16 MANUAL TRANSFER TO OR FROM A MANUALLY ADJUSTED SIGNAL. (MANUAL-AUTOMATIC CONTROL STATION)

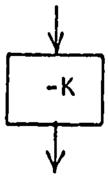


17 MANUAL TRANSFER TO OR FROM A MANUALLY ADJUSTED SIGNAL AND INCLUDED SET POINT.

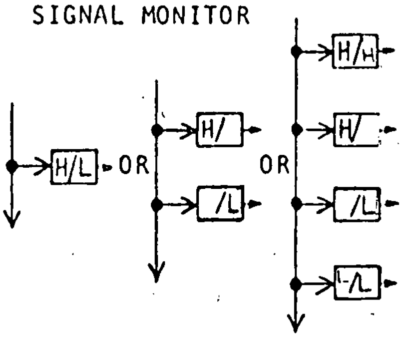


(MANUAL-AUTOMATIC CONTROL STATION WITH SET POINT)

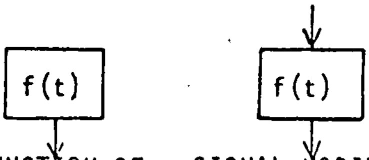
18 SIGNAL REVERSAL



19 SIGNAL MONITOR



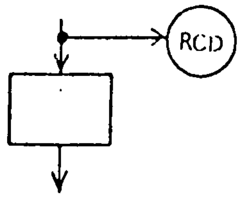
20 TIME FUNCTION



FUNCTION OF TIME ONLY. (PROGRAM CONTROLLER)

SIGNAL MODIFIED BY A FUNCTION OF TIME.

21 READOUT FUNCTION (RECORDER, INDICATION, INTEGRATOR)



22 FINAL CONTROLLING FUNCTION (CONTROL VALVE OR DRIVE)

WITH CHARACTERIZATION

WITH GAIN ADJUSTMENT

LD1001 -4

THERMAL STORAGE SYSTEMS - LOGIC DIAGRAMS

TABLE OF CONTENTS

				DATE	REVISION OR ISSUE	NO.	BY

BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT 7021

ERDA - 10 MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENTS

THERMAL STORAGE SYSTEMS - LOGIC DIAGRAMS
TABLE OF CONTENTS

LD1004-1

B&V DWG. NO.	TITLE
LD1004-17	CHARGE STEAM SHUTOFF VALVE
LD1004-18	THAW STEAM DISCH. VALVE
LD1004-19	DISCHARGE MODE SHUTOFF VALVE
LD1004-20	CHARGE STEAM DISCH. SHUTOFF VALVES TO TRAPS
LD1004-21	THERMAL STORAGE DRUM PREWARMING SHUTOFF VALVE

DATE	REVISION OR ISSUE	NO.	BY

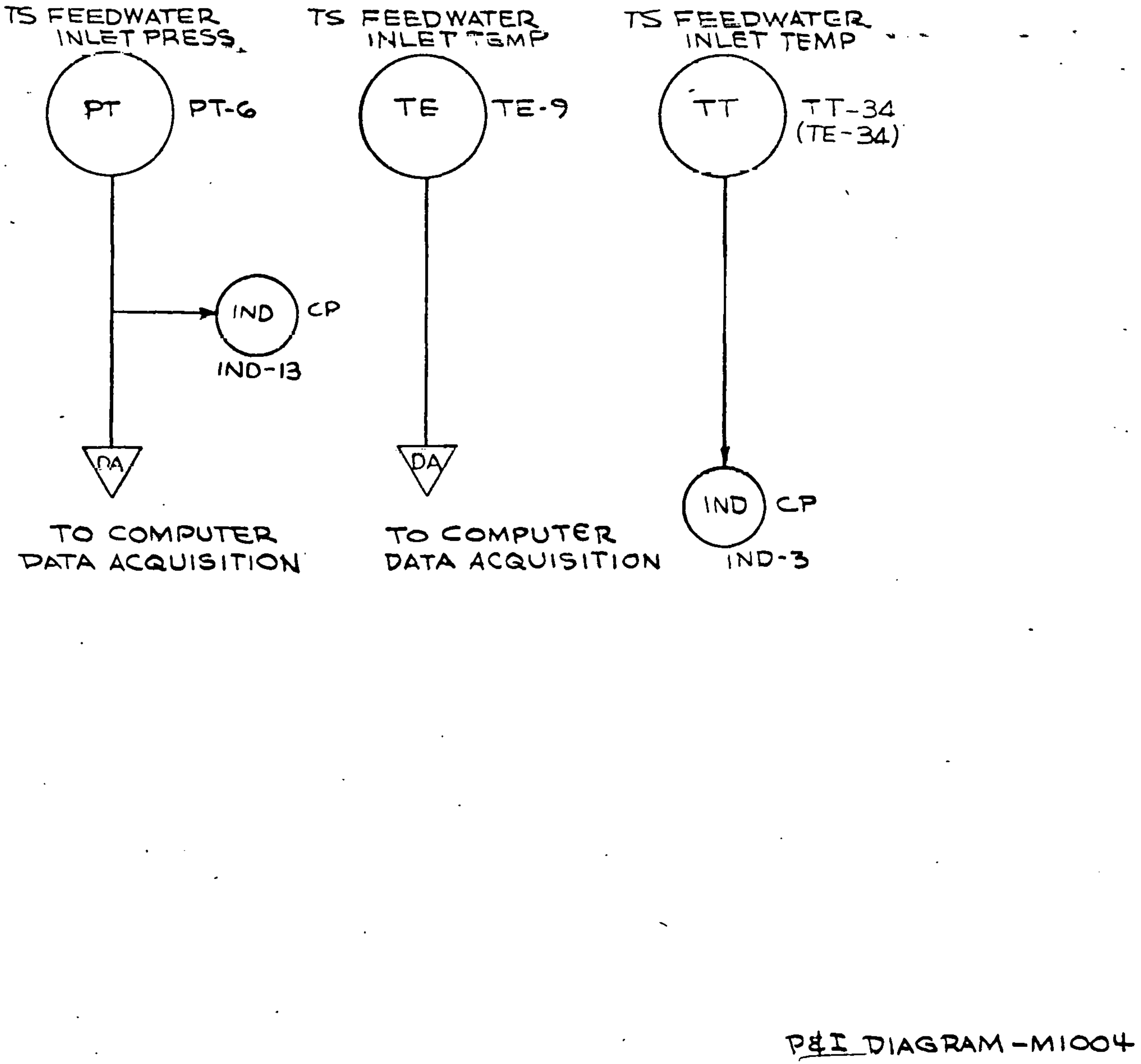
BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT
7021

ERDA - 10 MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENTS

THERMAL STORAGE SYSTEMS - LOGIC DIAGRAMS
TABLE OF CONTENTS

LD1004-1A

- G8 -



BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT 7021

ERDA - 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENT
THERMAL STORAGE SYSTEMS-LOGIC DIAGRAMS
THERMAL STORAGE DRUM INLET CONTROL ANALOG LOGIC

DATE	REVISION OR ISSUE	NO.	BY

LD 1004-2

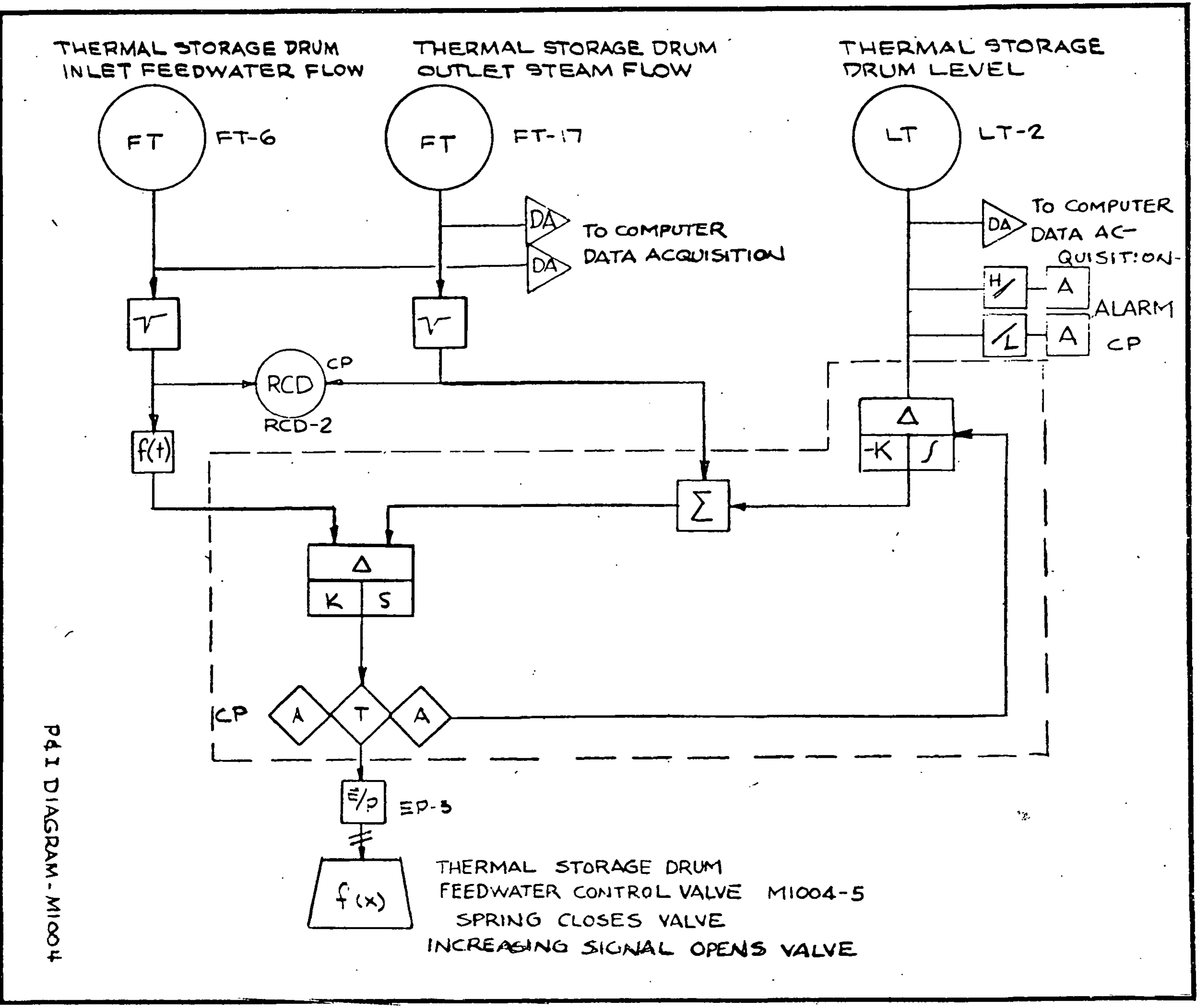
40454

BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT 7021

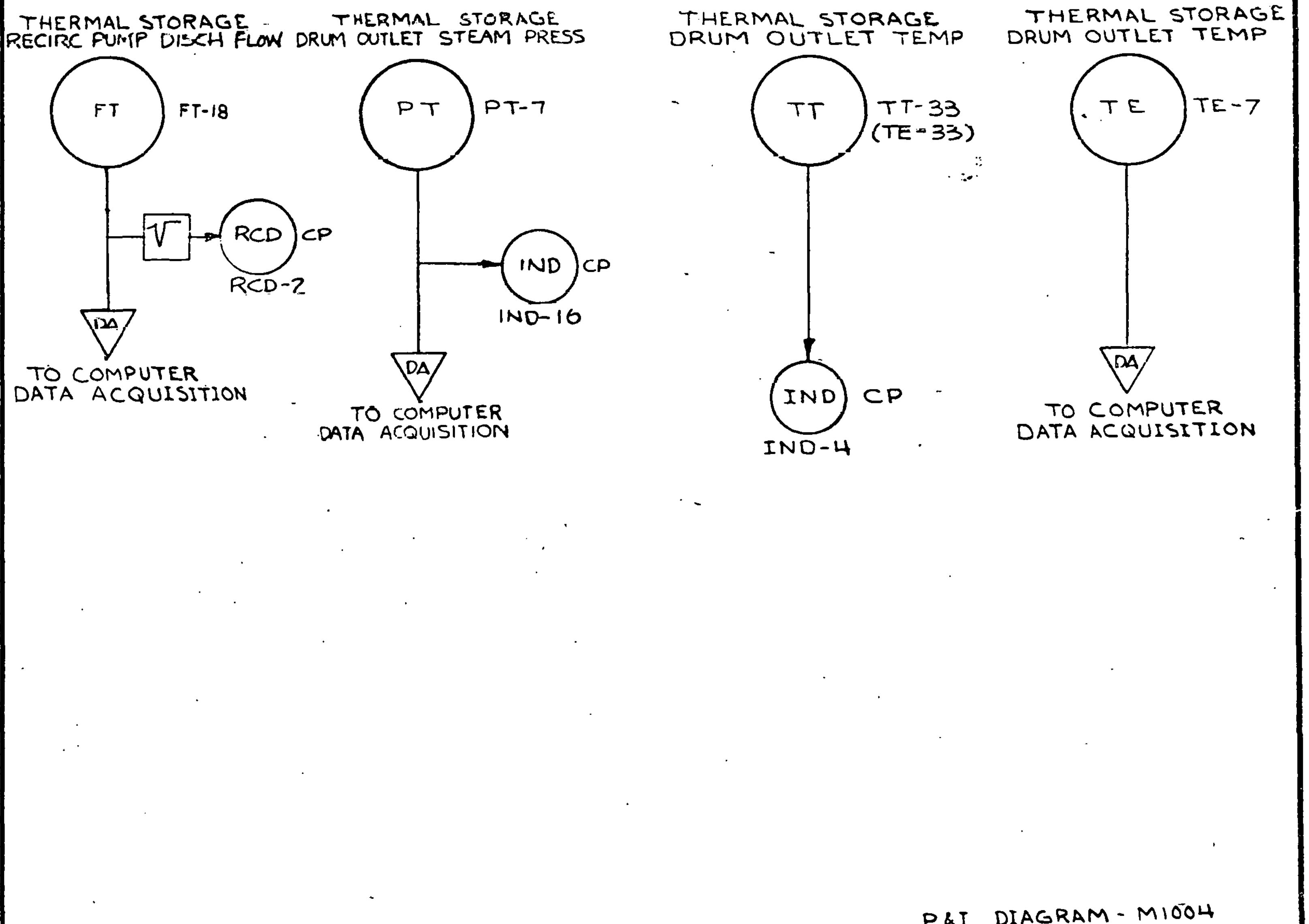
ERDA - 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENT
THERMAL STORAGE SYSTEMS - LOGIC DIAGRAMS
THERMAL STORAGE DRUM LEVEL CONTROL-ANALOG

NO.	BY	DATE	REVISION OR ISSUE

LD1004-3



40454



BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT
7021

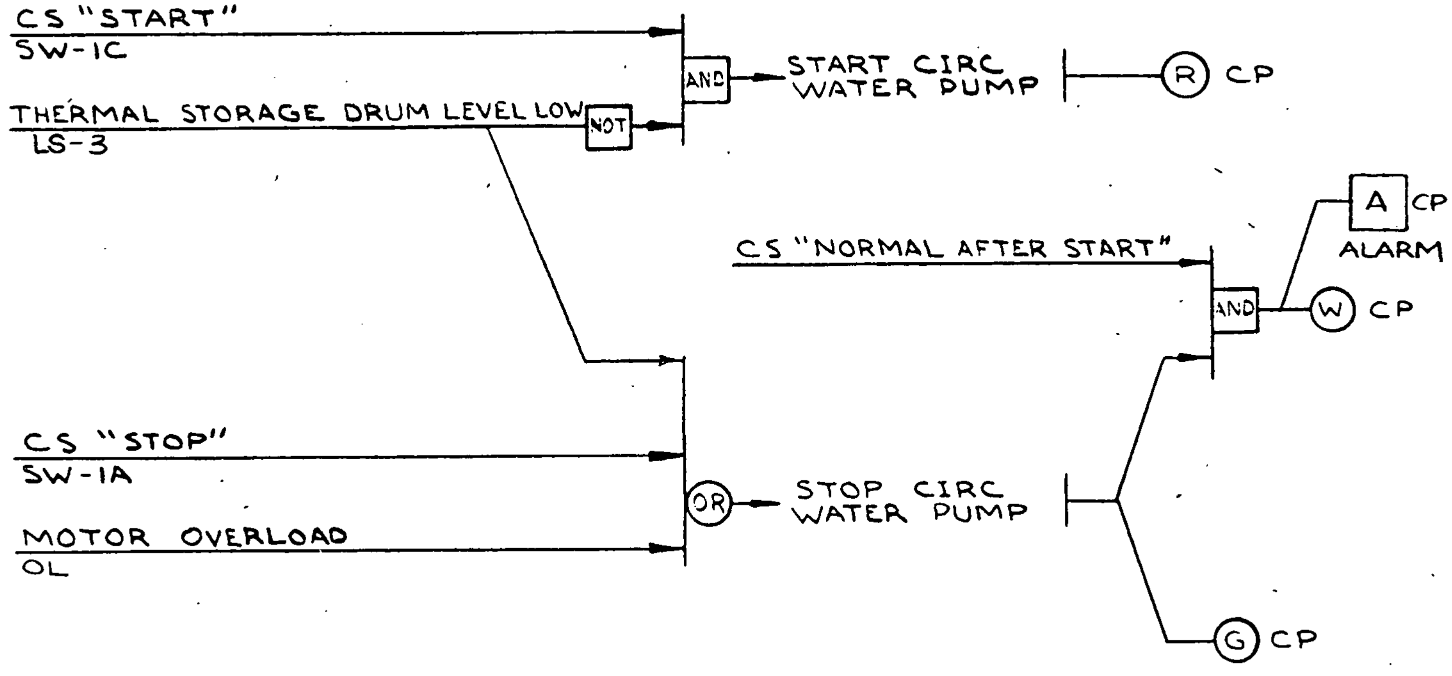
ERDA - 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENT

THERMAL STORAGE SYSTEMS-LOGIC DIAGRAMS
THERMAL STORAGE OUTPUT CONTROL - ANALOG LOGIC

LD1004-4

DATE	REVISION OR ISSUE	NO.	BY

40454



A - B - C
CS-GE-SB1 - "STOP-NORMAL-START" MOMENTARY CONTACTS, SPRING RETURN TO "NORMAL" FROM "STOP" OR "START", WITH TARGET, WITH GREEN, WHITE, & RED HONEYWELL TYPE PTW INDICATING LIGHTS.

PI DIAGRAM - M1004

BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT
7021

THERMAL STORAGE SYSTEMS-LOGIC DIAGRAMS
THERMAL STORAGE CIRCULATING WATER PUMP

LD1004-5

DATE	REVISION OR ISSUE	NO.	BY

40454

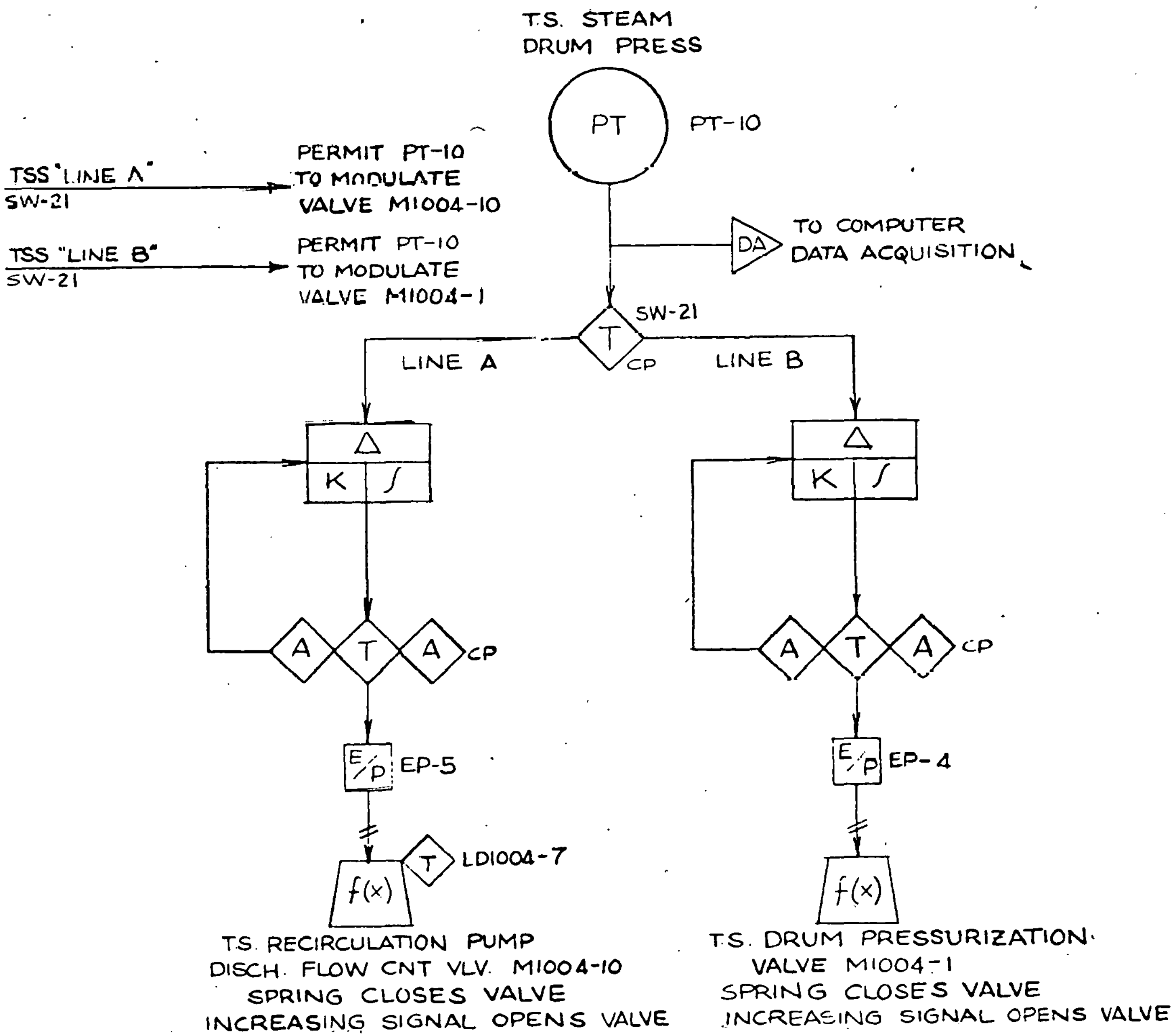
BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT
7021

THERMAL STORAGE SYSTEMS - LOGIC DIAGRAMS
T.S. DRUM PRESSURE CONTROL - ANALOG LOGIC

LD1004-6

NO.	BY	REV SION OR ISSUE	DATE

P&I DIAGRAM - M1004

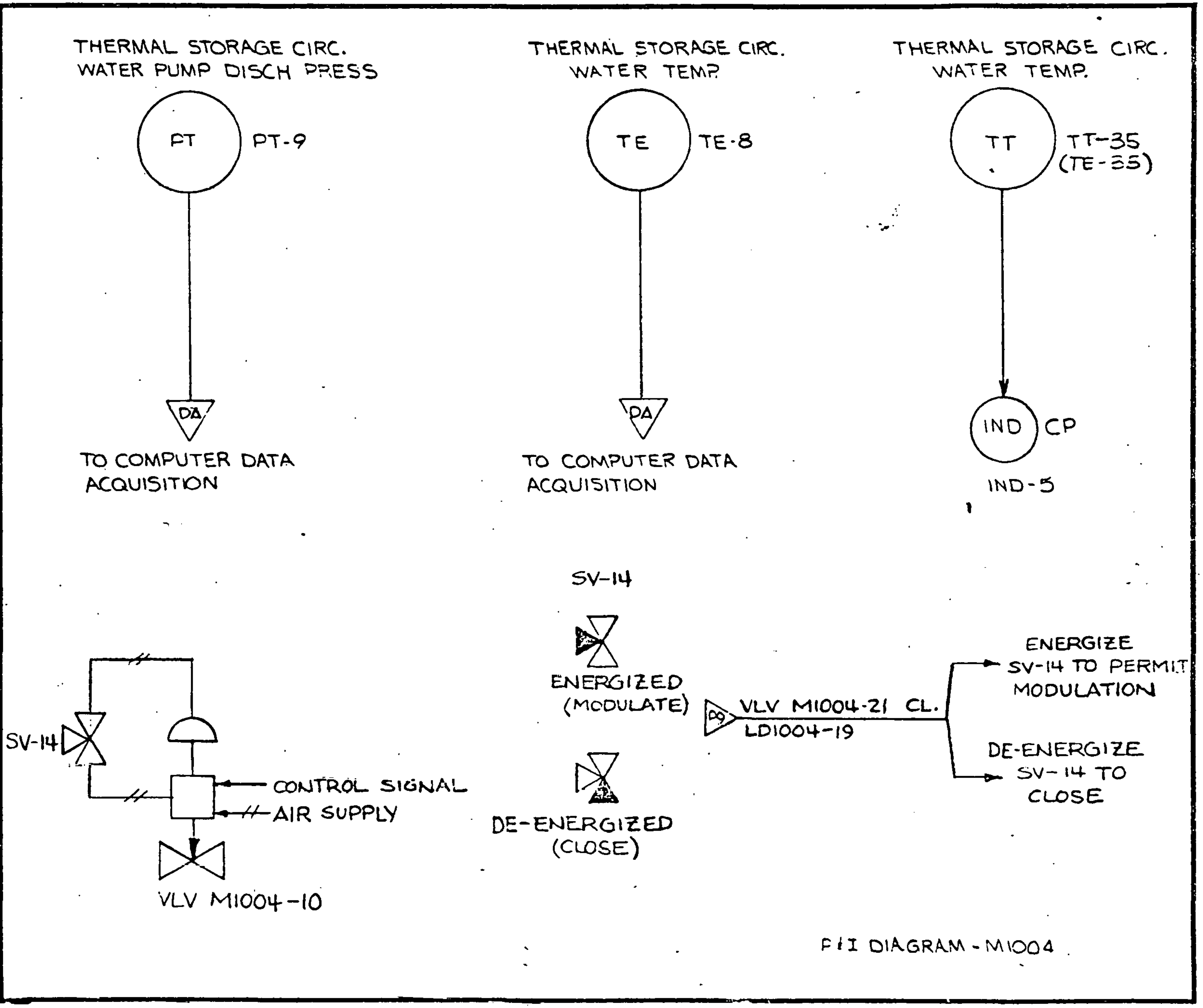


BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT 7021

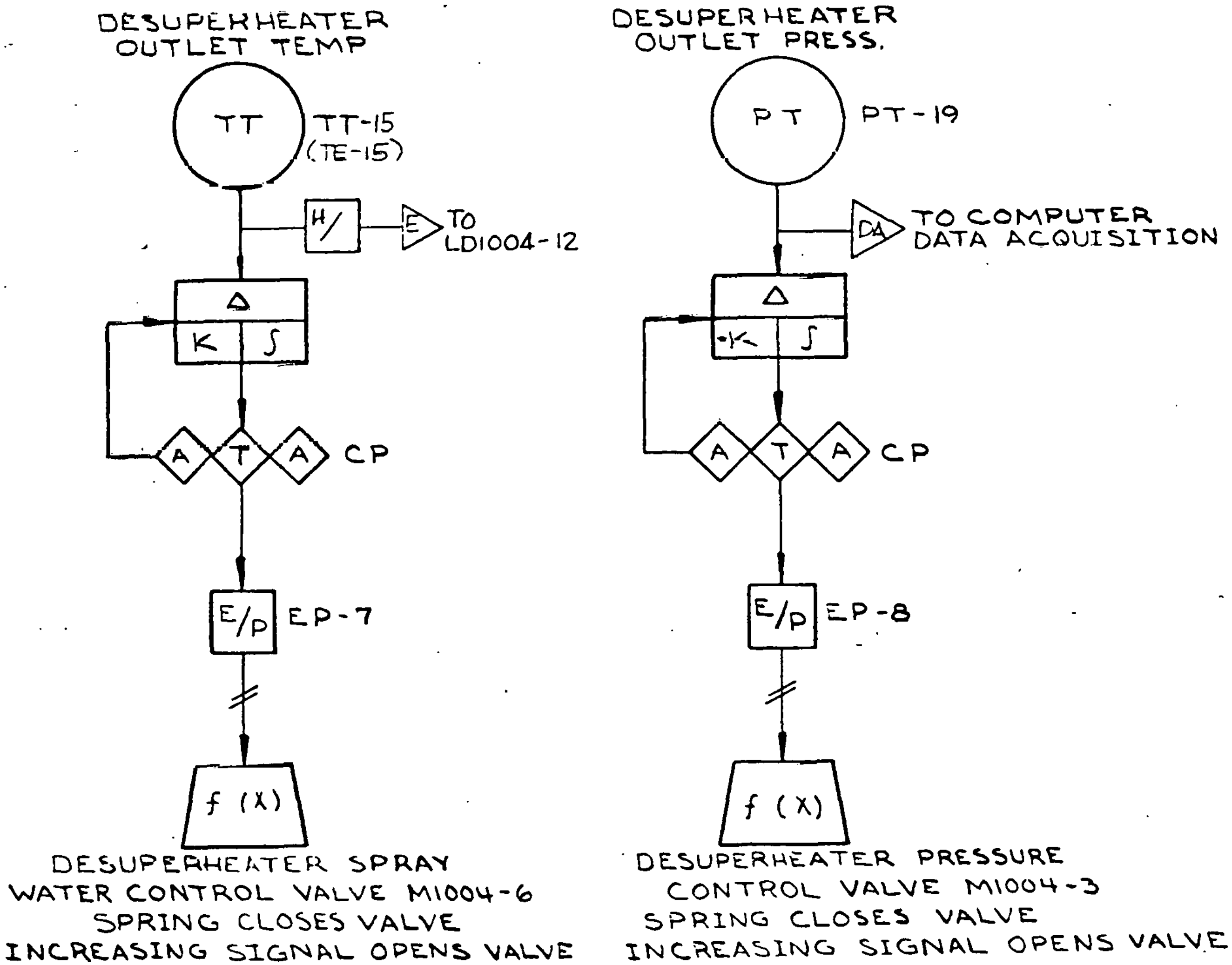
ERDA - 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENT
THERMNAL STORAGE SYSTEMS-LOGIC DIAGRAMS
THERMAL STORAGE DISCHARGE LOOP-ANALOG LOGIC

LD1004-7

DATE	REVISION OR ISSUE	NO.	BY



40454



P&I DIAGRAM - M1004

BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT 7021

ERDA - 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENT
THERMAL STORAGE SYSTEMS-LOGIC DIAGRAMS
THERMAL STORAGE CHARGE LOOP DESUPHTR
CONTROL - ANALOG LOGIC

LD1004-8

DATE	REVISION OR ISSUE	NO.	BY

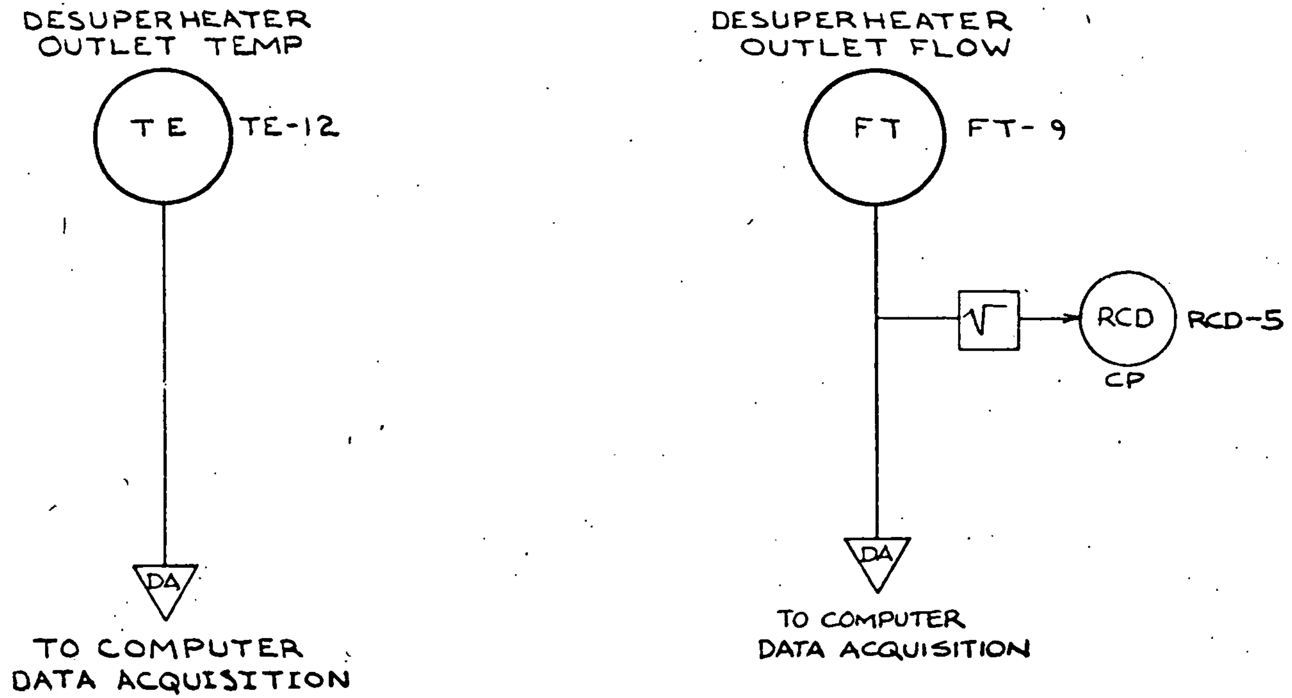
40454

BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT 7021

ERDA - 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENT
THERMAL STORAGE SYSTEMS-LOGIC DIAGRAMS
THERMAL STORAGE CHARGE LOOP-ANALOG LOGIC

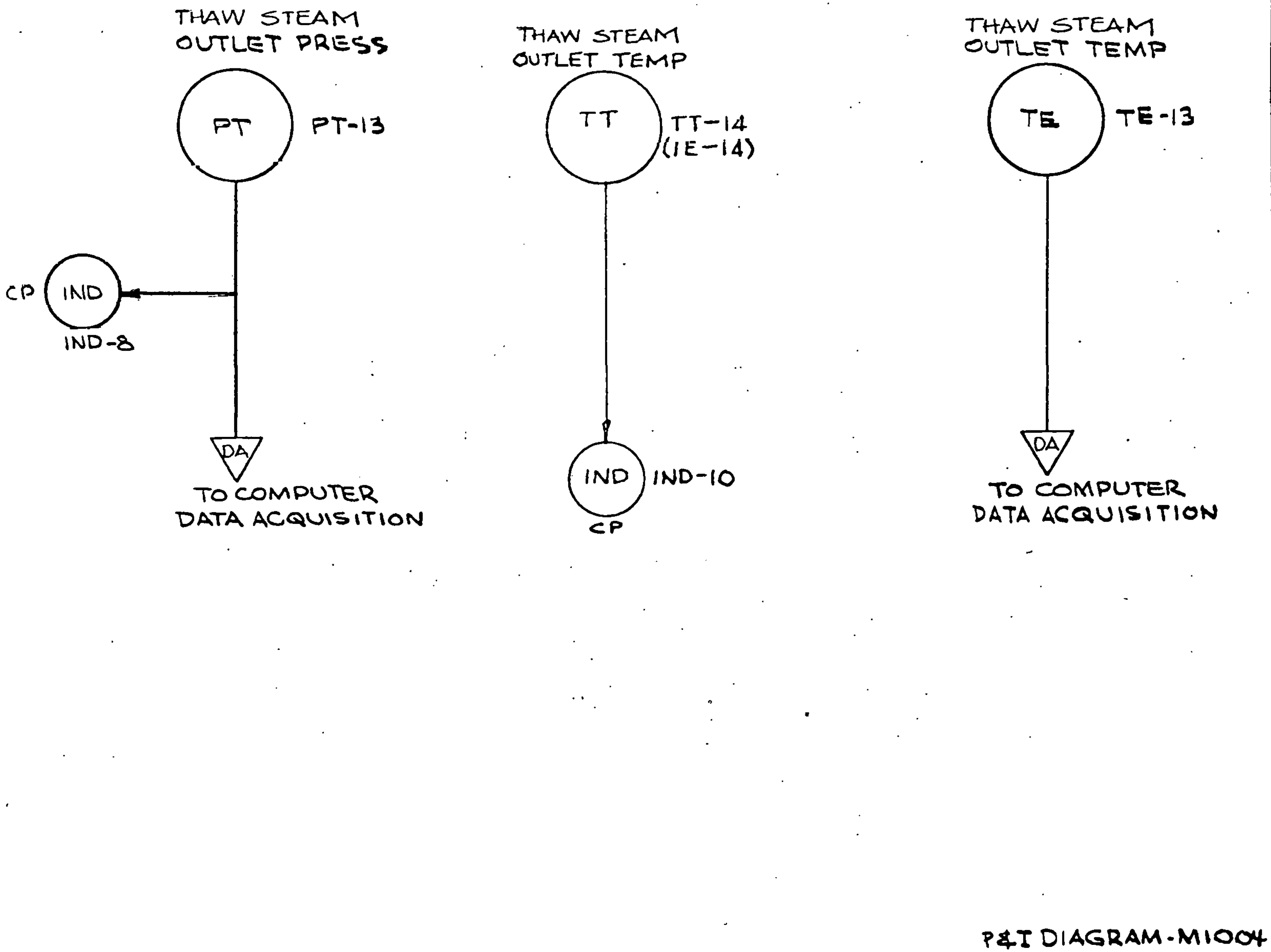
LD1004-9

DATE	REVISION OR ISSUE	NO.	BY



P & I DIAGRAM M1004

40454



BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT 7021

ERDA - 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENT

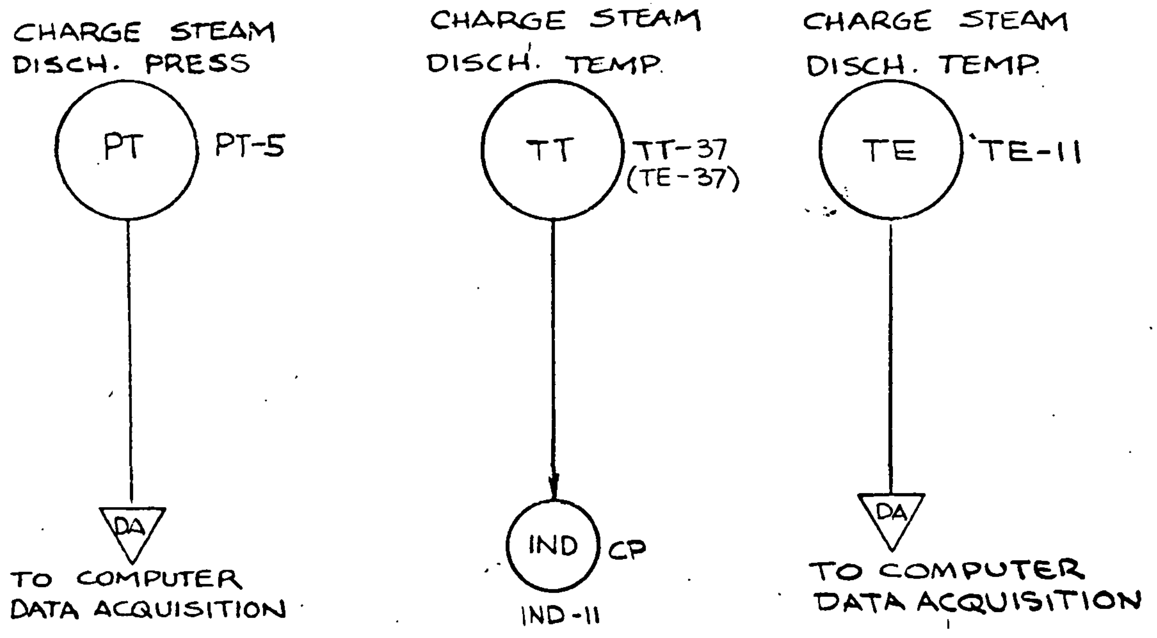
THERMAL STORAGE SYSTEMS-LOGIC DIAGRAMS
THAW STEAM OUTLET CONTROL-ANALOG LOGIC

LD1004-10

NO.	BY	DATE	REVISION OR ISSUE

- G16 -

40454



P& I DIAGRAM - M1004

BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT 7021

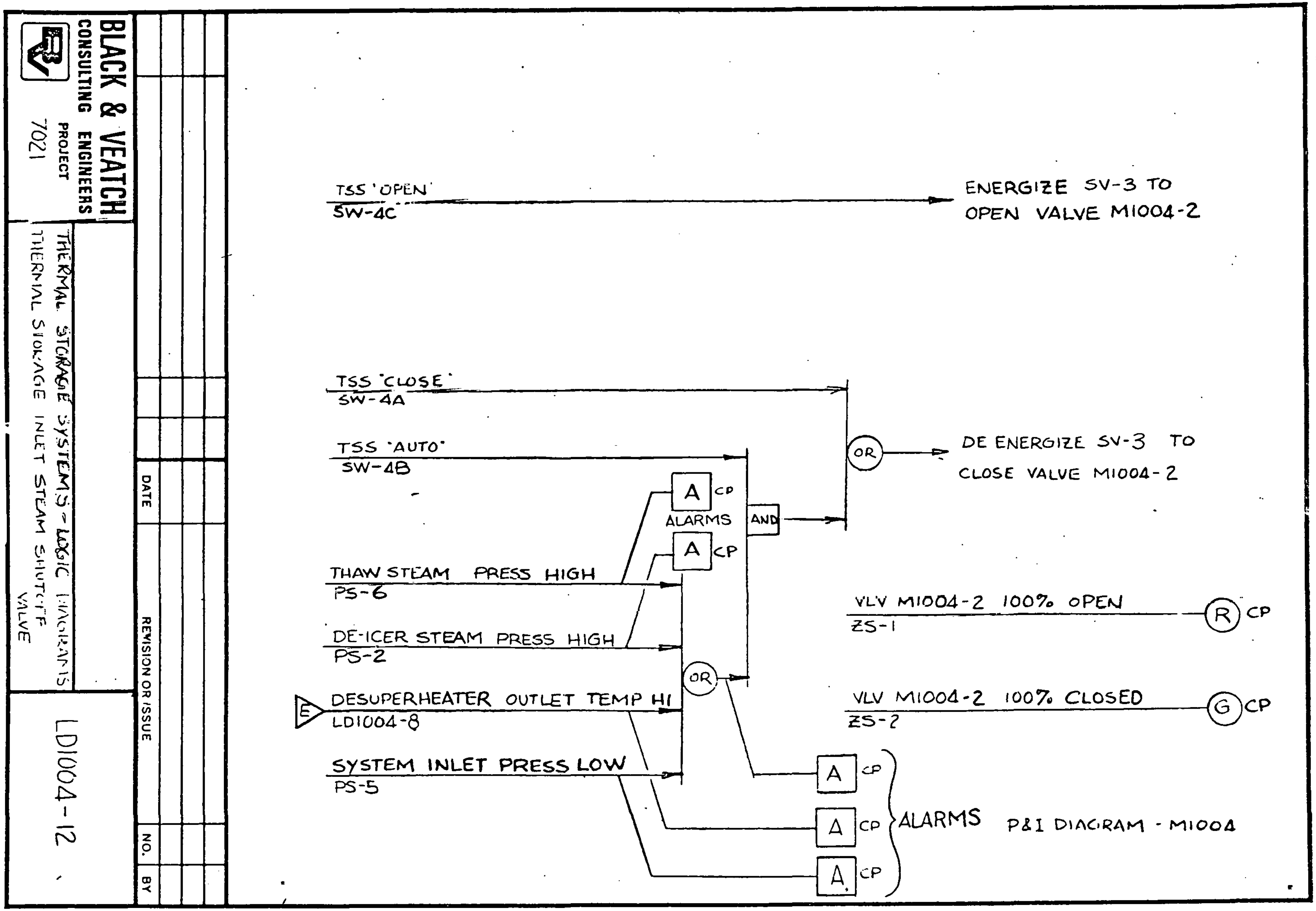
ERDA - 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENT
THERMAL STORAGE SYSTEMS-LOGIC DIAGRAMS
THERMAL STORAGE CHARGE STEAM-ANALOG LOGIC

LD1004-11

NO.	BY	DATE	REVISION OR ISSUE

40454

40454

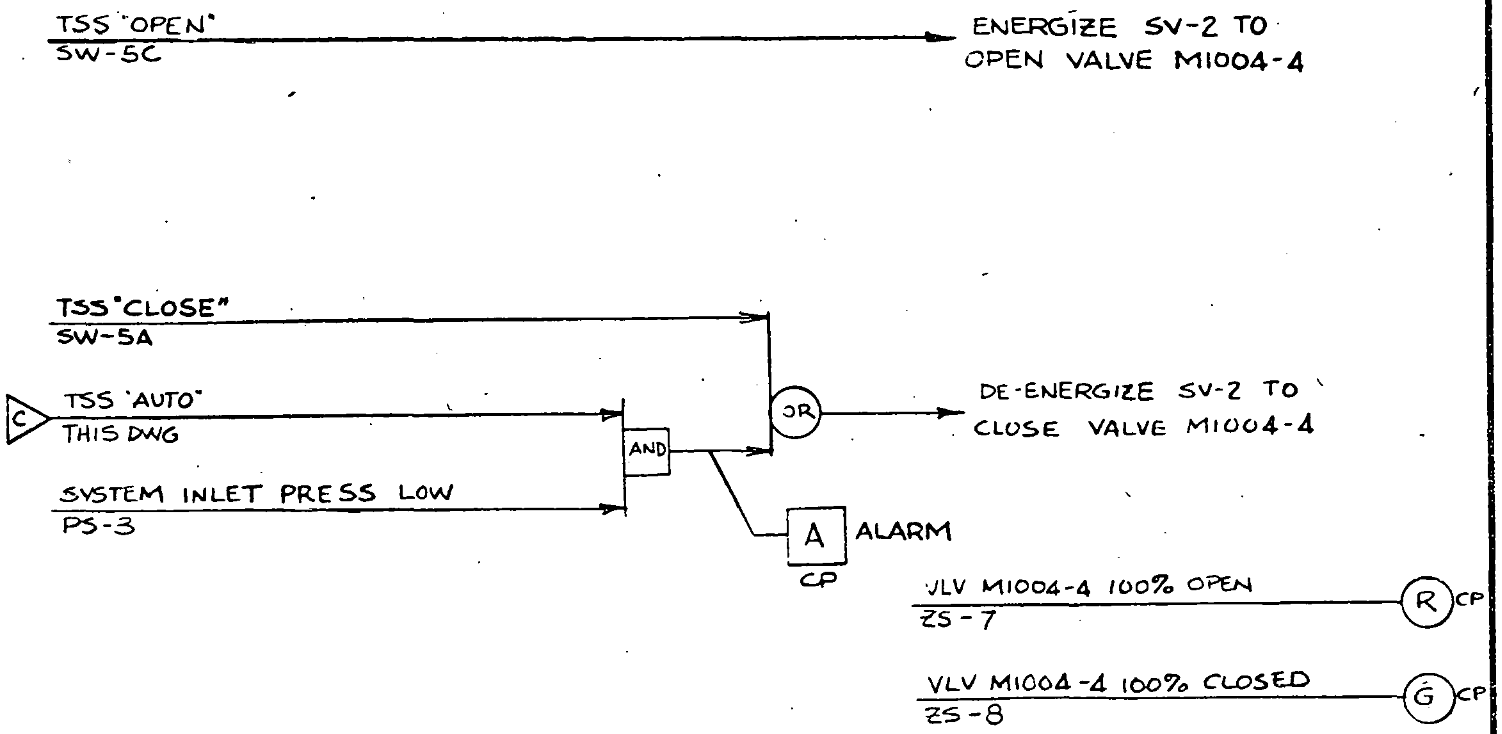

BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT 7021
THERMAL STORAGE SYSTEMS - LOGIC DIAGRAMS
THERMAL STORAGE INLET STEAM SHUTOFF VALVE
LD1004-12
DATE
REVISION OR ISSUE
NO.
BY
TSS 'OPEN'
SW-4C
ENERGIZE SV-3 TO OPEN VALVE M1004-2
TSS 'CLOSE'
SW-4A
TSS 'AUTO'
SW-4B
OR
DE ENERGIZE SV-3 TO CLOSE VALVE M1004-2
A CP
ALARMS
AND
A CP
THAW STEAM PRESS HIGH
PS-6
DE-ICER STEAM PRESS HIGH
PS-2
OR
E
DESUPERHEATER OUTLET TEMP HI
LD1004-8
SYSTEM INLET PRESS LOW
PS-5
VLV M1004-2 100% OPEN
ZS-1
R CP
VLV M1004-2 100% CLOSED
ZS-2
G CP
A CP
A CP
A CP
ALARMS
P&I DIAGRAM - M1004

BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT
7021

THERMAL STORAGE SYSTEMS - LOGIC DIAGRAMS
THERMAL STORAGE FEEDWATER SHUTOFF VALVE.

LD1004-13

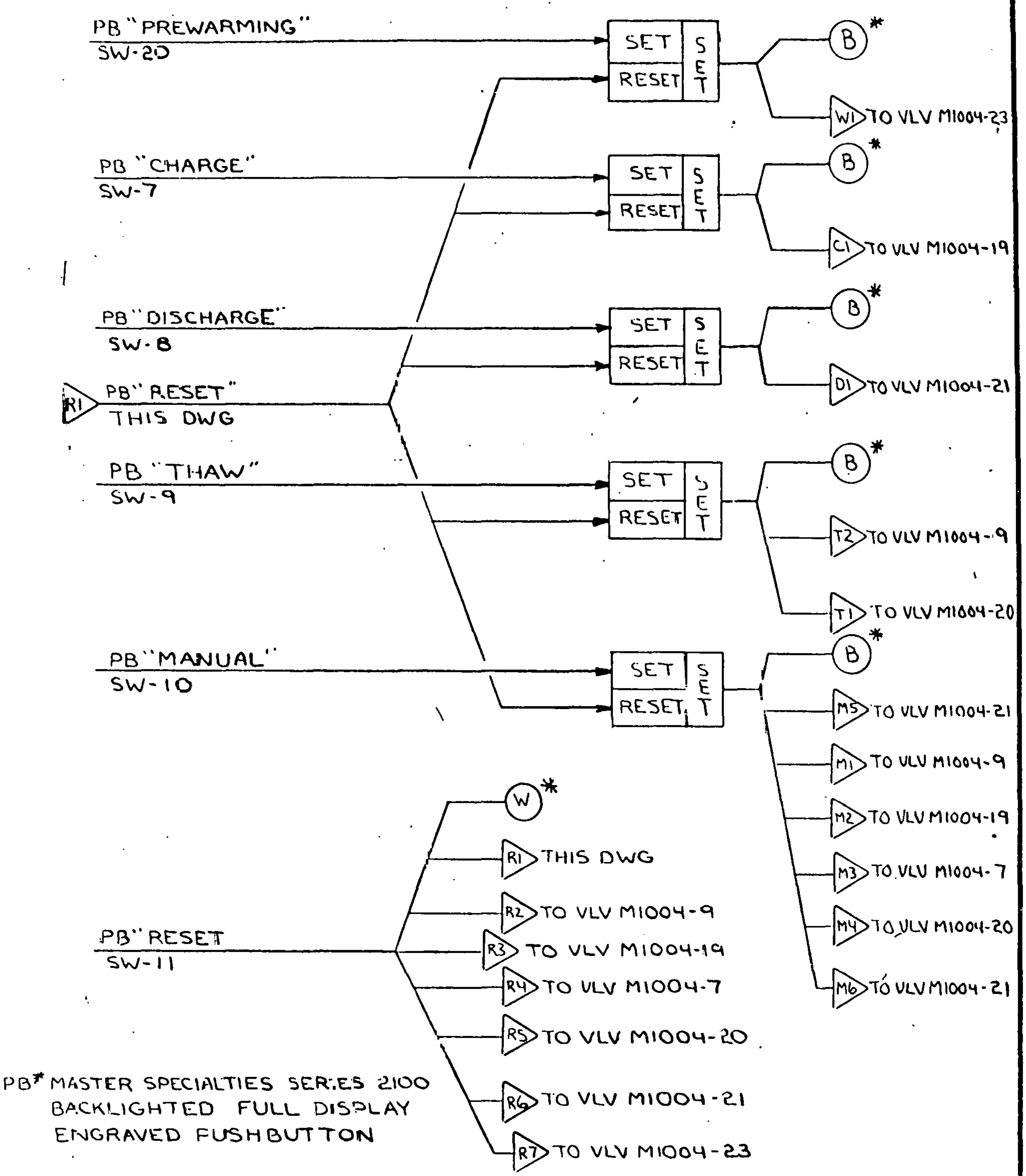
DATE	REVISION OR ISSUE	NO.	BY



TSS- MICROSWITCH TYPE TL "CLOSE, AUTO, OPEN", SPRING
RETURN TO "AUTO" FROM "OPEN", PULL TO UNLOCK,
WITH RED & GREEN INDICATING LIGHTS

P&I DIAGRAM - M1004

40454



DATE	REVISION OR ISSUE	NO.	BY

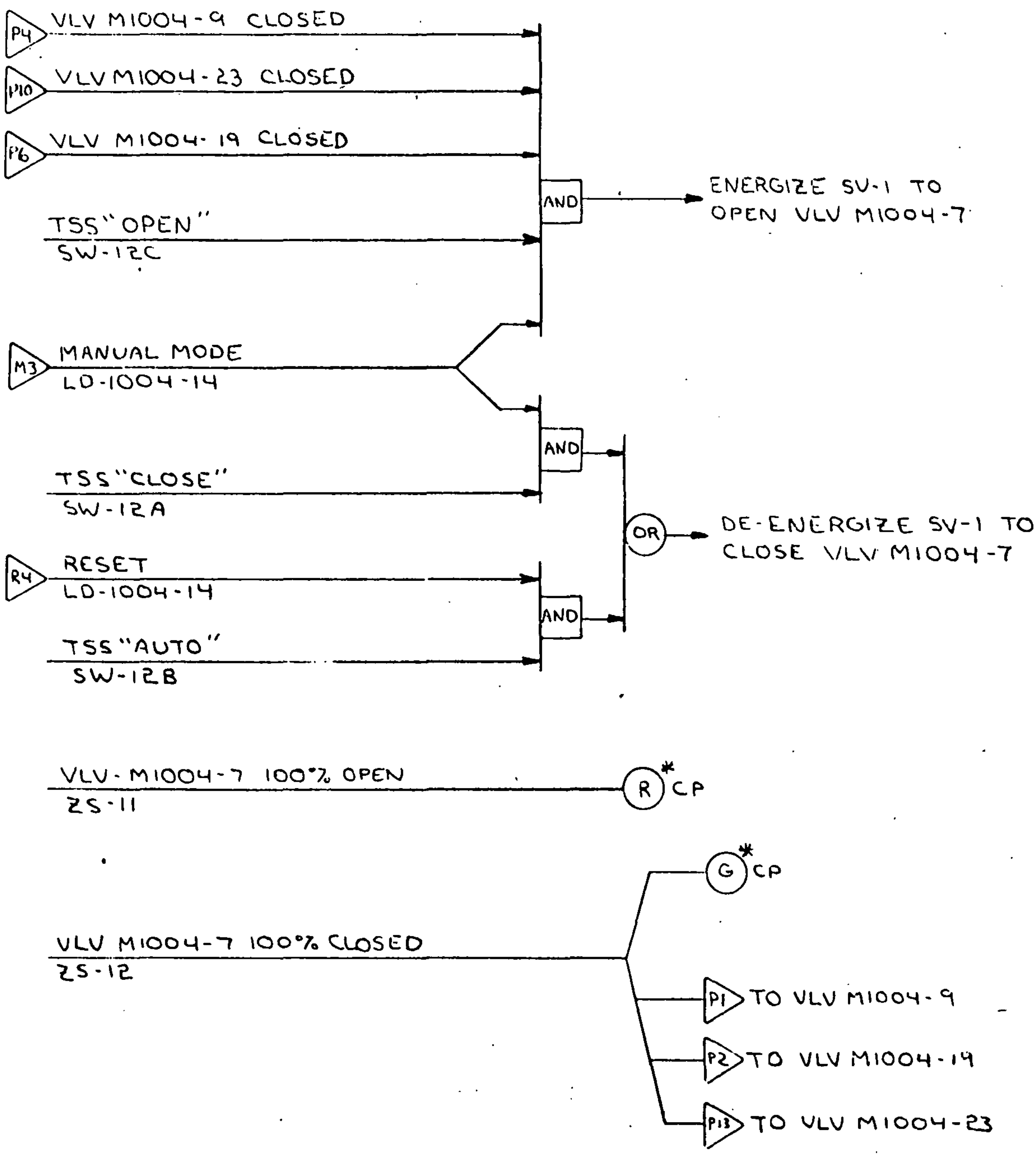
BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT
7021

ERDA - 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENT

THERMAL STORAGE SYSTEMS - LOGIC DIAGRAMS
MODE SELECTION

L-D-1004-14

40454



TSS - MICROSWITCH TYPE TL
* - PTW INDICATING LIGHT.

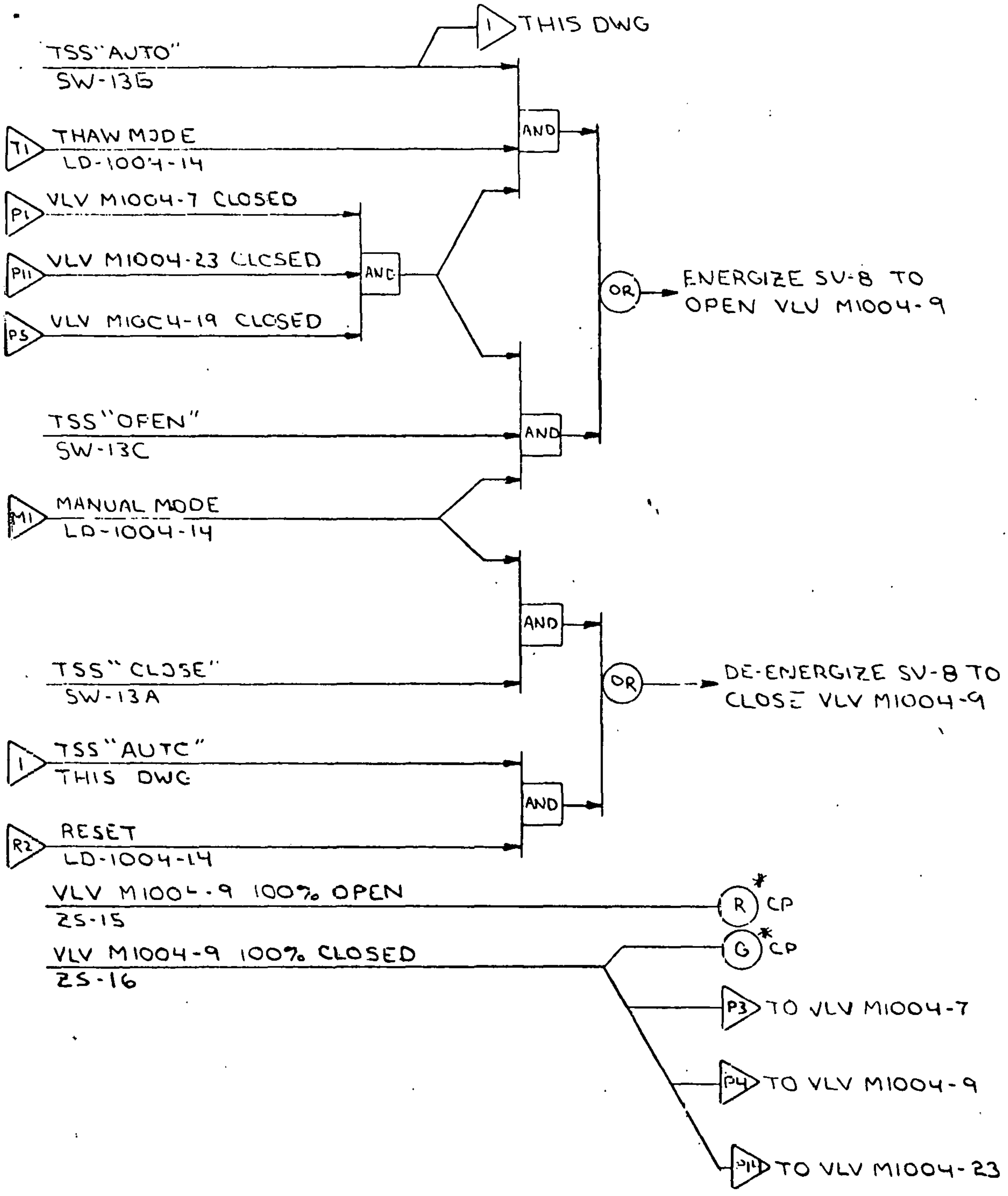
				DATE	REVISION OR ISSUE	NO.	BY

BLACK & VEATCH CONSULTING ENGINEERS
PROJECT 7021

ERDA - 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENT

THERMAL STORAGE SYSTEMS - LOGIC DIAGRAMS
DE-ICER STEAM SHUTOFF VALVE

LD-1004-15



TSS- MICROSWITCH TYPE TL
* - PTW INDICATING LIGHT

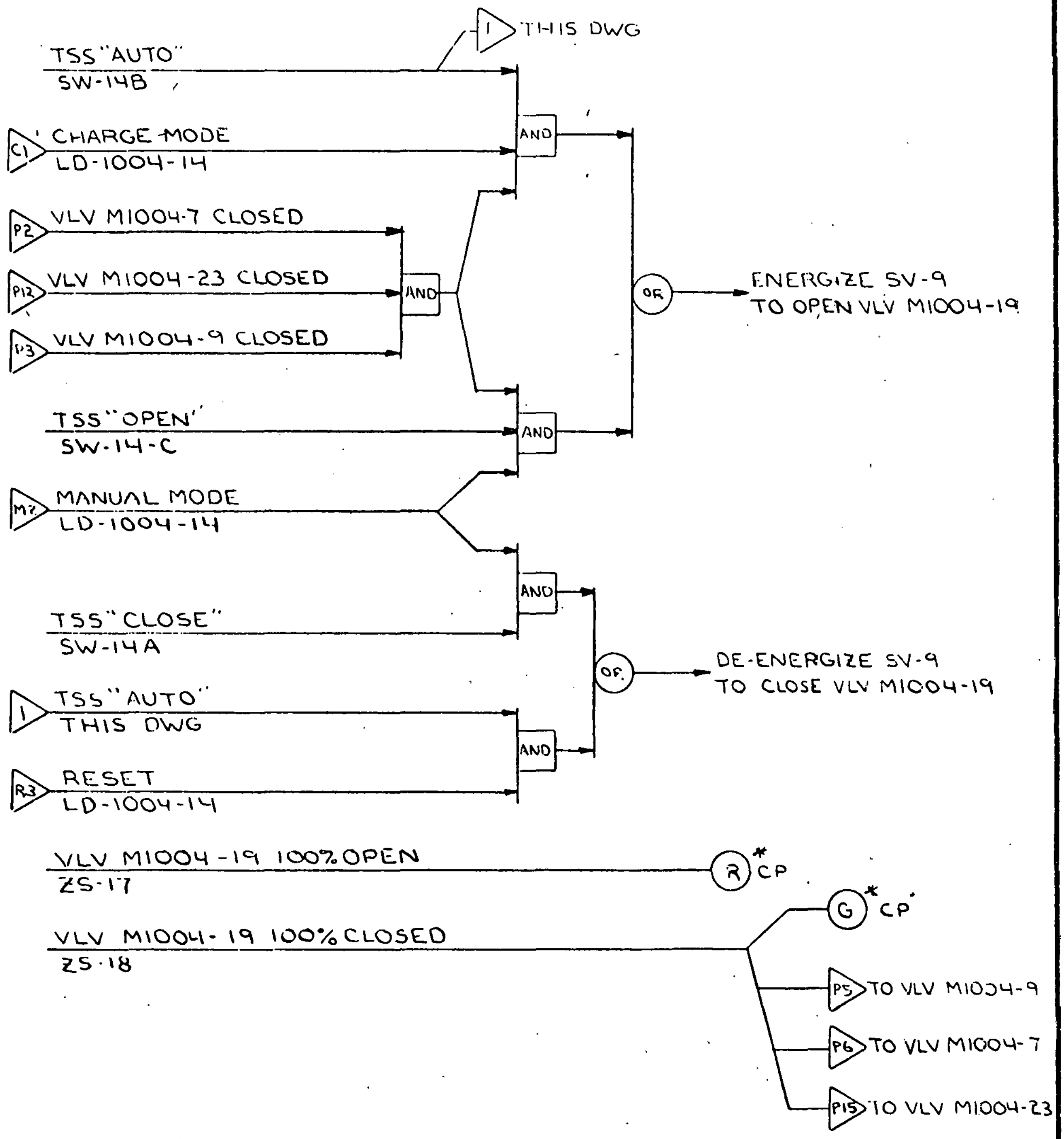
				DATE	REVISION OR ISSUE	NO.	BY

BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT 7021

ERDA - 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENT

THERMAL STORAGE SYSTEMS-LOGIC DIAGRAMS
THAW SYSTEMS SHUTOFF VALVES

LD-1004-16



TSS - MICRO SWITCH TYPE TL
* - PTW INDICATING LIGHT

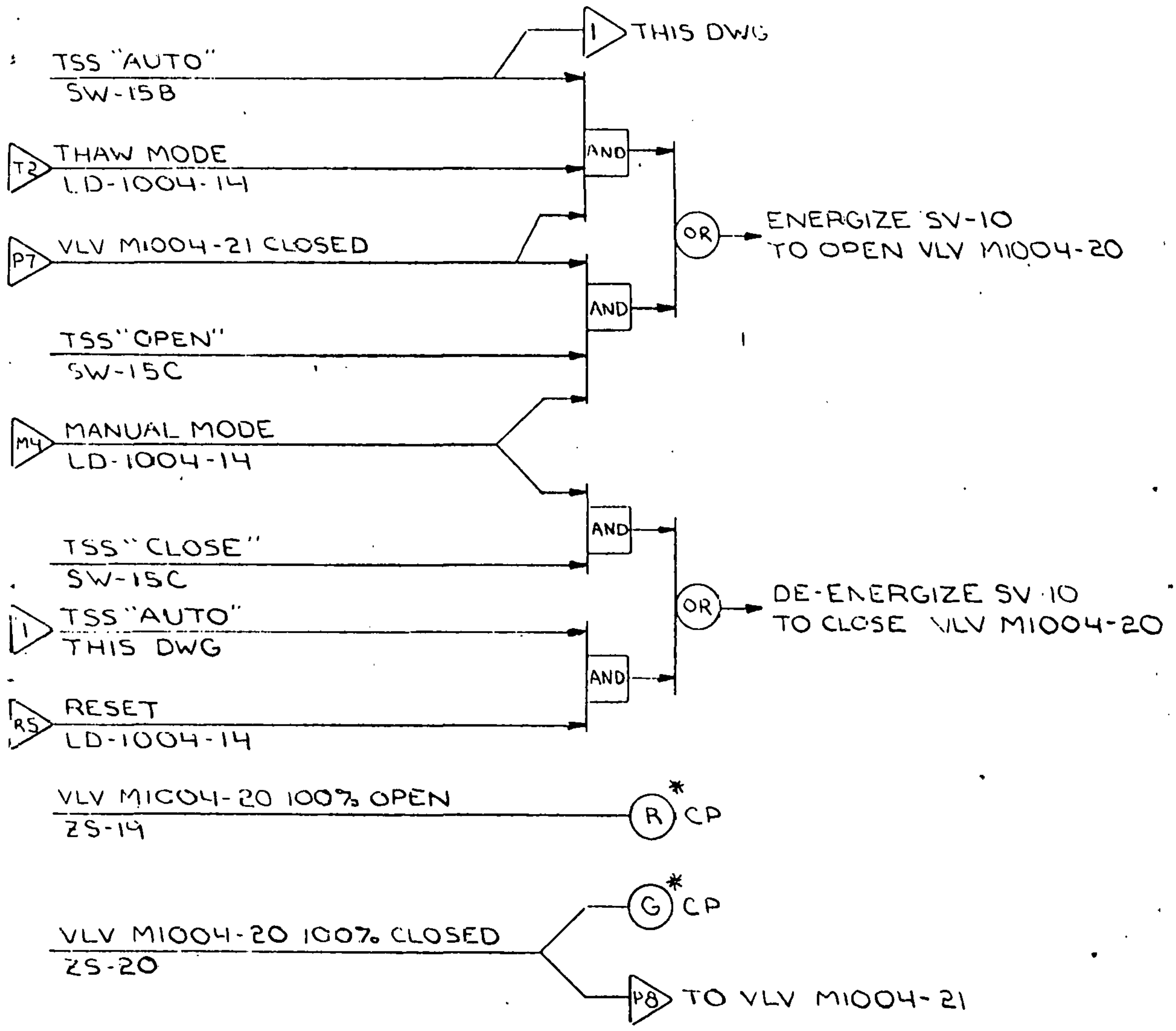
			DATE	REVISION OR ISSUE	NO.	BY

BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT 7021

ERDA - 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENT

THERMAL STORAGE SYSTEMS-LOGIC DIAGRAMS
CHARGE STEAM SHUTOFF VALVE

LD-1004-17



TSS - MICROSWITCH TYPE TL
* - PTW INDICATING LIGHT

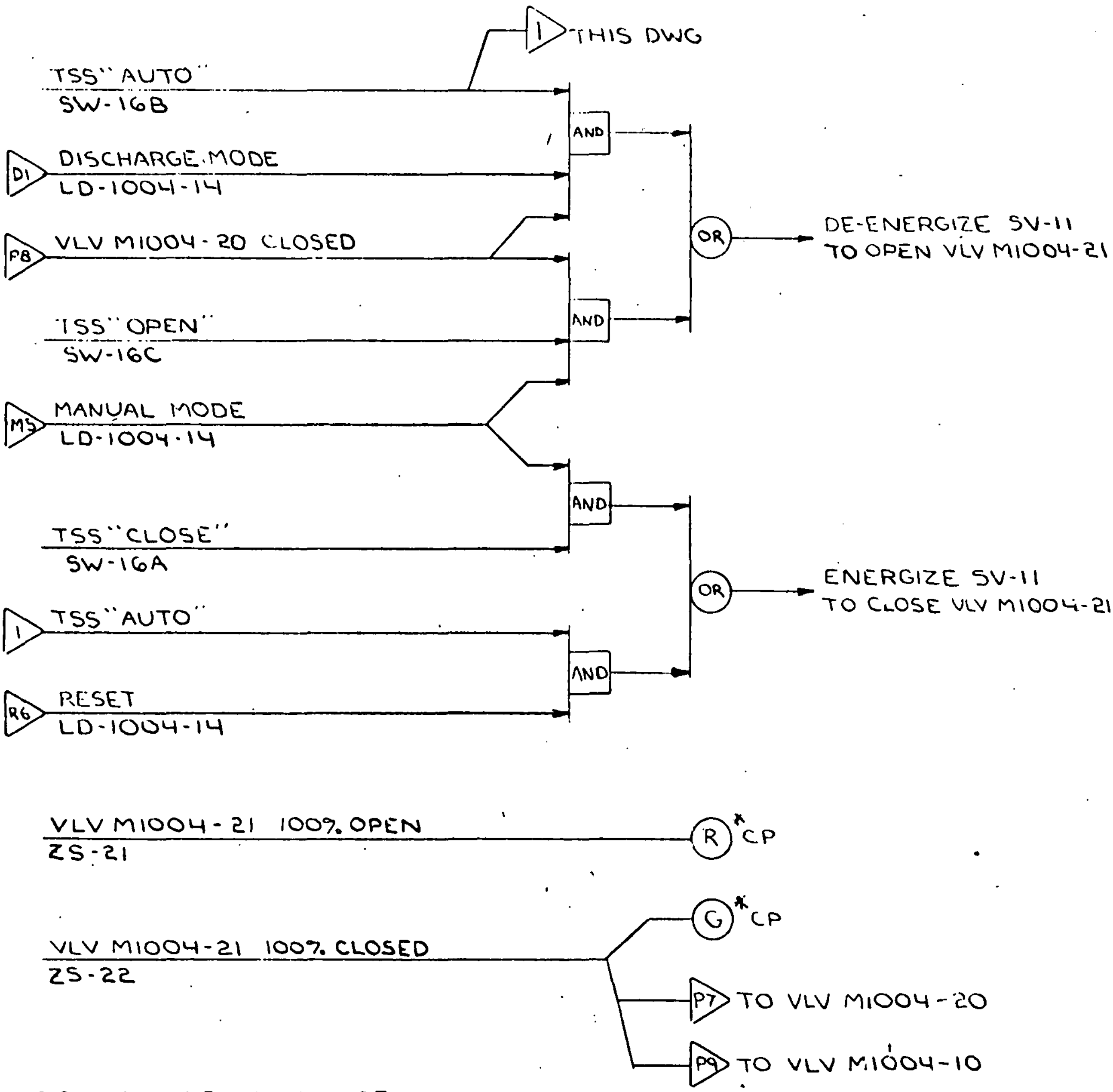
DATE	REVISION OR ISSUE	NO.	BY

BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT 7021

ERDA - 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENT

THERMAL STORAGE SYSTEMS - LOGIC DIAGRAMS
THAW STEAM DISCHARGE VALVE

LD-1004-18



TSS- MICROSWITCH TYPE TL
* - PTW INDICATING LIGHT

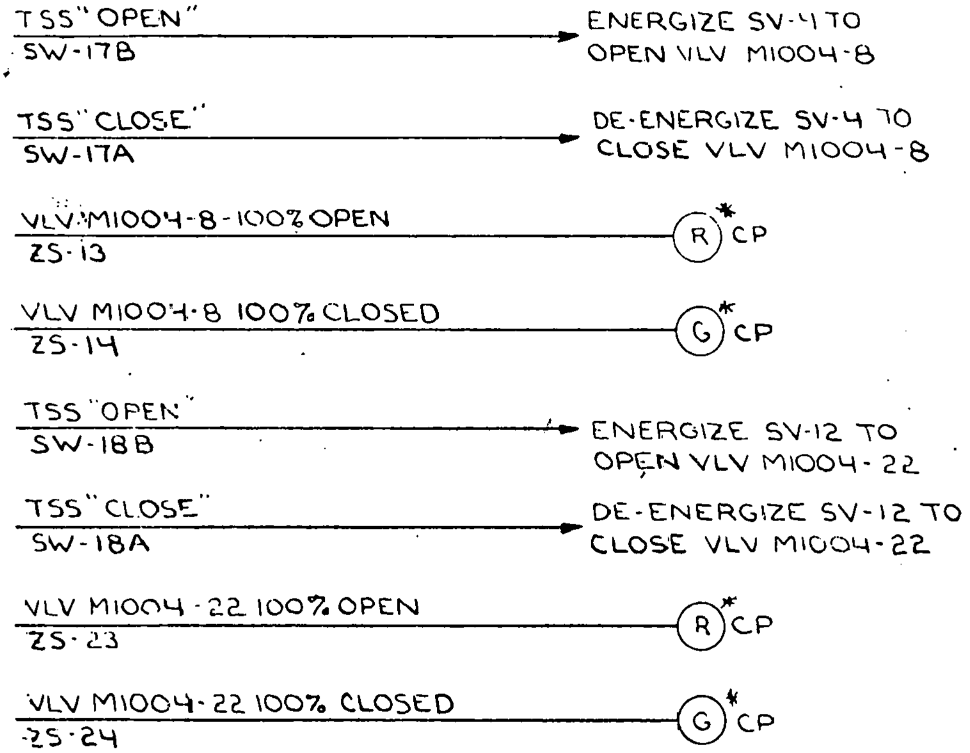
				DATE	REVISION OR ISSUE	NO.	BY

BLACK & VEATCH
CONSULTING ENGINEERS
PROJECT 7021

ERDA - 10MWe SOLAR PILOT PLANT
SUBSYSTEM RESEARCH EXPERIMENT

THERMAL STORAGE SYSTEMS - LOGIC DIAGRAMS
DISCHARGE MODE SHUTOFF VALVE

LD-1004-19

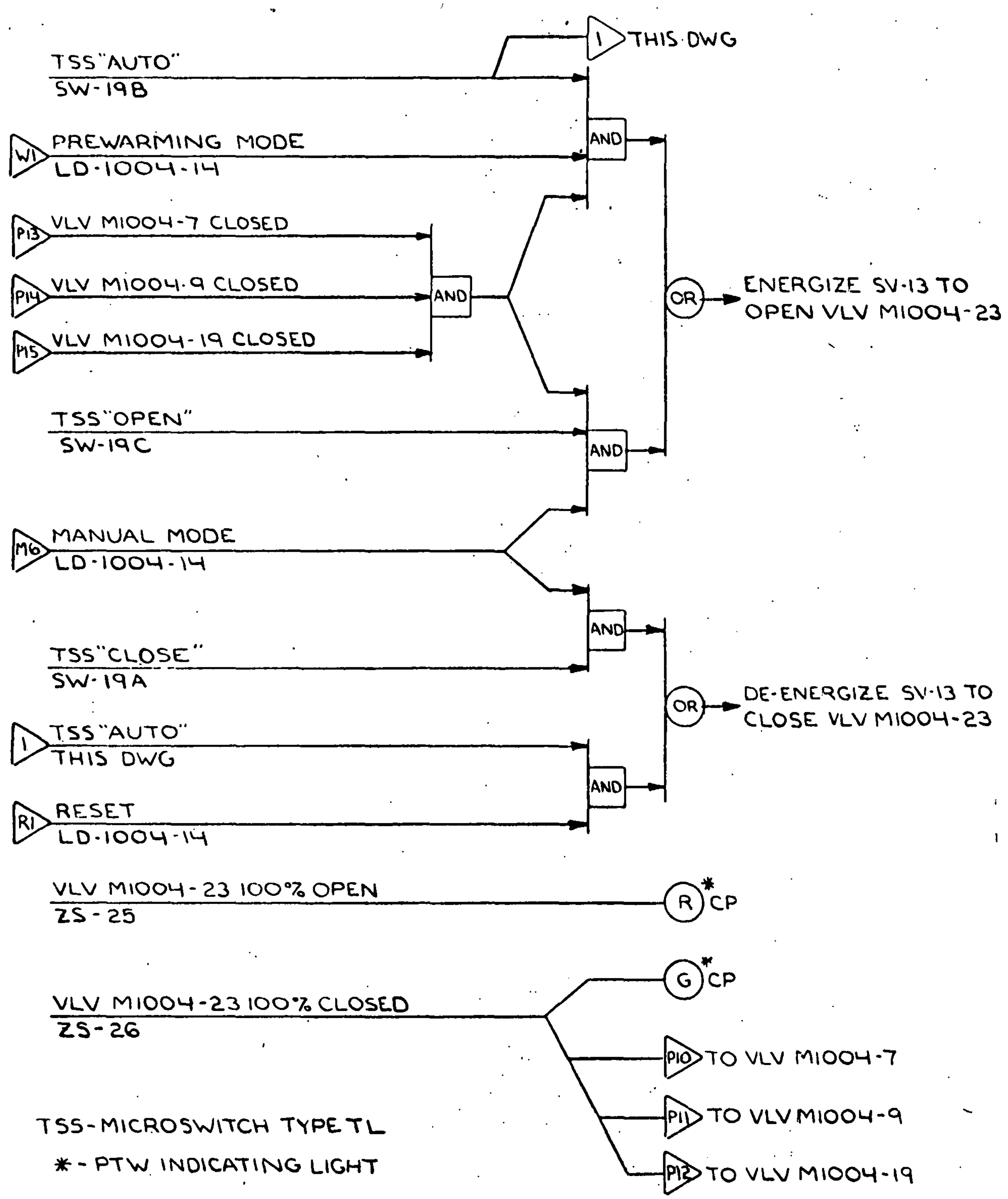


TSS - MICROSWITCH TYPE TL

* - PTW INDICATING LIGHT

				DATE	REVISION OR ISSUE	NO.	BY

BLACK & VEATCH CONSULTING ENGINEERS PROJECT 7021	ERDA - 10MWe SOLAR PILOT PLANT SUBSYSTEM RESEARCH EXPERIMENT	LD-1004-20
	THERMAL STORAGE SYSTEMS-LOGIC DIAGRAMS CHARGE STEAM DISCH SHUTOFF VLVS TO TRAPS	



TSS-MICROSWITCH TYPE TL

* - PTW INDICATING LIGHT

				DATE	REVISION OR ISSUE	NO.	BY

BLACK & VEATCH CONSULTING ENGINEERS PROJECT 7021	ERDA - 10MWe SOLAR PILOT PLANT SUBSYSTEM RESEARCH EXPERIMENT	LD-1004-21
	THERMAL STORAGE SYSTEMS-LOGIC DIAGRAMS DRUM PREWARMING SHUTOFF VALVE	

APPENDIX H

APPENDIX H

VAPORIZER SCRAPER MODEL USED TO EVALUATE THE OUTSIDE HEAT TRANSFER COEFFICIENT

APPENDIX H

VAPORIZER SCRAPER MODEL USED TO EVALUATE THE OUTSIDE HEAT TRANSFER COEFFICIENT

SUMMARY

This literature survey is to evaluate the qualitative and quantitative aspects of the two-phase forced convection heat transfer.

Chen's correlation is used to evaluate the inside heat transfer coefficients for qualities between 0.01 to dryout pt (~0.6). Rohsenow's relation is used for qualities below 0.01. The inside coefficient increases with quality.

Salt thickness as a function of time is evaluated using the energy conservation equation. Assuming a clearance between scraper blades and vaporizer tubes, outside heat transfer coefficients as a function of time are evaluated for clearances between 0 to 2.54×10^{-2} cm (0 to 10 mils). The overall coefficient is calculated as a function of both time and quality. Simpson's rule of integration is used to calculate the time-averaged coefficients. The outside coefficient is found to be controlling.

Trial and error calculations were done to estimate temperature drops and heat fluxes at different qualities and time. In thermal storage, boiler heat fluxes vary between 34.7 to 50.5 kW/m^2 (11,000 to 16,000 $Btu/hr\text{-}ft^2$).

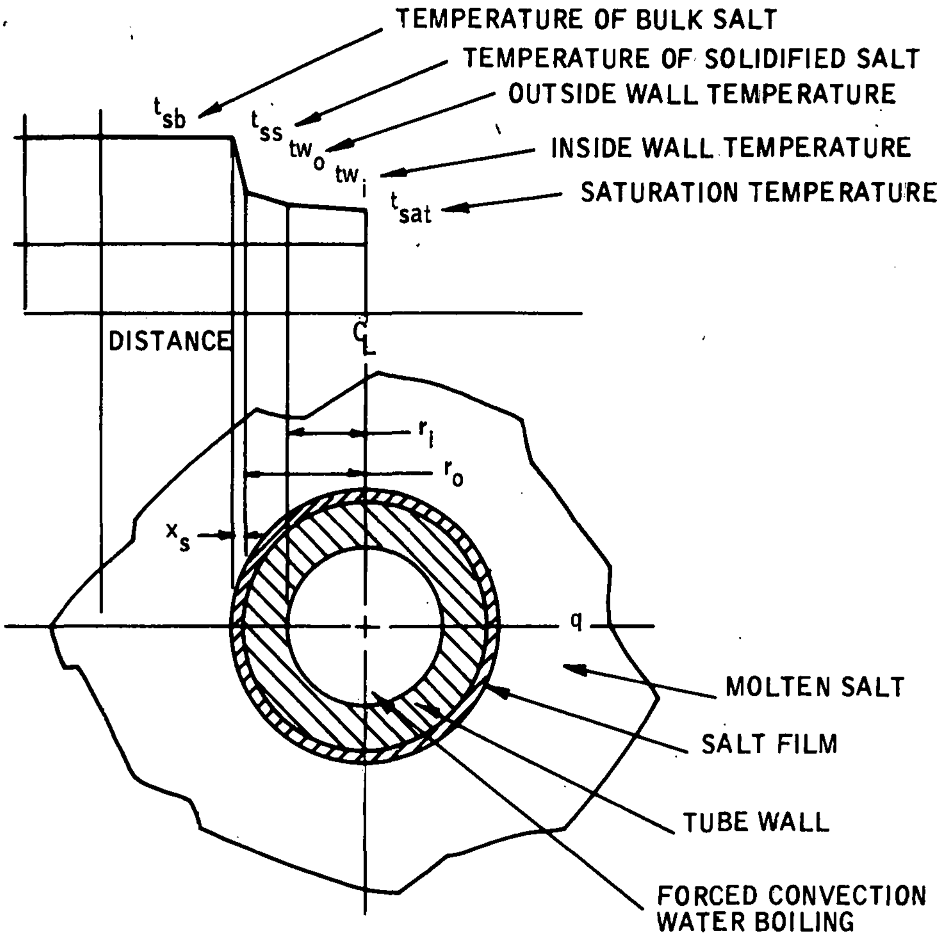
Macbeth's correlation for critical heat flux is used to determine the exit steam quality. For design, 20 percent quality at the vaporizer exit was chosen.

QUALITATIVE DESCRIPTION OF THE PROCESS:

In the vaporization of a liquid stream flowing through a closed channel, essentially three regimes of heat transfer can occur (see Figures H-1 and H-2):

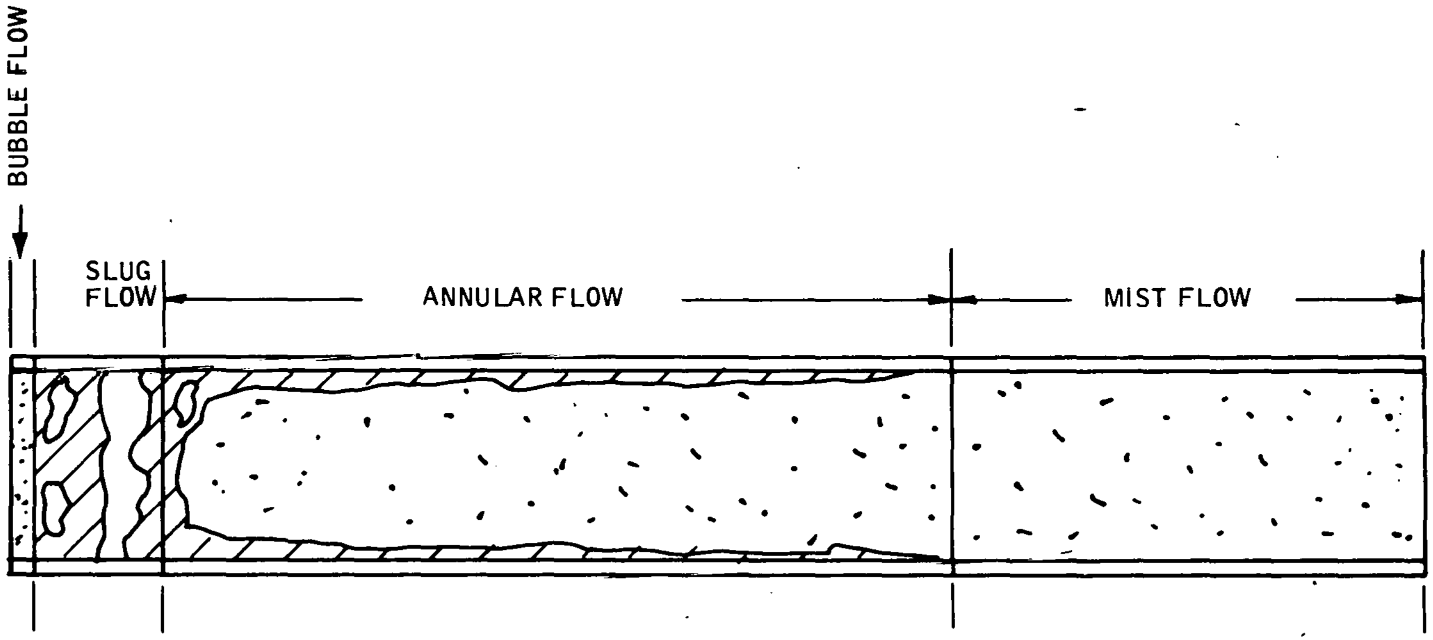
1) Nucleate boiling regime
2) Forced convection controlled heat transfer regime
3) Regime of liquid deficiency

The first regime is characterized by bubble growth and nucleation at the heat transfer surface, and the heat transfer coefficient is a function of heat flux. In the convection controlled regime, the heat transfer coefficient is independent of the heat flux and is given by a modified form of the Dittus-Boelter-type equation (Reference 2) as for single phase convection heat transfer. The



$$\frac{U_I A_I}{L} = \frac{1}{\dfrac{1}{h_I A_I} + \dfrac{\ln \frac{D_o}{D_I}}{2\pi k_s} + \dfrac{1}{h_o A_o}}$$

Figure H-1. Boiler Tube Heat Transfer



0.01	0.10	QUALITY (%)	0.60	0.90
0.01	0.11	DISTANCE ALONG PIPE, X/L	0.67	1.00
0.18	0.68	VOID FRACTION (%)	0.96	0.999

NOTE: CONSTANT HEAT FLUX MAKES QUALITY PROPORTIONAL TO PIPE LENGTH.

Figure H-2. Boiling Flow Regimes

40454

third regime is characterized by a liquid deficient condition at the wall and occurs at high vapor mass fractions. It is in this regime the heat transfer coefficient experience a sharp decrease. Experimental studies for each case were done by various authors and the heat transfer relations were correlated.

EMPIRICAL CORRELATION FOR TWO-PHASE COEFFICIENTS:

Table H-1 lists the authors and the correlating equations and Table H-2 gives the variables studied by investigators. Of the equations listed, Chen's correlation had received much of our attention. Contacts were made to specialists in the area of forced-convection two-phase boiling heat transfer. It was established that Chen's correlation ought to be satisfactory.

Chen's (Reference 1) correlation for heat transfer coefficients is based upon macroconvective and microconvective effects. The macroconvective term is the modified Dittus Boelter equation and the microconvective term is based on the Forster-Zuber (Reference 4) formulation for pool boiling. Table H-3 gives the variables and system conditions and the ranges for which Chen's correlation is applicable. The conditions fall within or close to the specified range. However, Chen's correlation is for vertical flow, but at the high velocities the correlation could satisfactorily be applied to horizontal boilers (Reference 2).

Besides Chen's correlation, other correlations considered were those of Rohsenow (Reference 3) for low-quality regimes, and of David and Davis for annular flow regime. The heat transfer coefficients calculated as a function of quality are shown in Figure H-3 for each of the correlations.

Chen's Correlation: (Ref. Table H-4 for definition of terms)

Quality range used $0.01 < X < 0.7$ (or dryout pt.)

$$h = h_{mic} + h_{mac}$$

$$h_{mac} = 0.023\, F\, (R_e)^{0.8}\, (Pr)^{0.4}\, \frac{k_L}{D}$$

$$h_{mic} = 0.00122 S\, K_C\, (\Delta T)^{0.24}\, (\Delta P)^{0.75}$$

where

$$R_e = \frac{G(1-x)D}{\mu}$$

$$F = F(\tilde{X}) \text{ and}$$

$$\tilde{X} = \left(\frac{X}{1-X}\right)^{0.9} \left(\frac{\rho_L}{\rho_g}\right)^{0.5} \left(\frac{\mu g}{\mu_L}\right)^{0.1}$$

Table H-1. Proposed Correlating Equations

Authors	Correlating Equations*
David, et al (Ref. 4)	$\frac{hD}{k_L} = 0.06C\left(\frac{P_L}{P_g}\right)^{0.28}\left(\frac{DG_tX}{\mu L}\right)^{0.87}\left(\frac{C_p}{k}\right)_L^{0.4}$
Bennett, et al. (Refs. 3, 13)	$\frac{h_{TP}}{h_L}\left(\frac{q}{A}\right)^{0.11} = 0.64\left(\frac{1}{X_u}\right)^{0.74}$
Chen (Ref. 1)	$h = h_{mac} + h_{mic}$
	$h_{mac} = 0.023\,(Re_L)^{0.8}\,(Pr_L)^{0.4}\,\frac{k_L}{D}\,F$
	$h_{mic} = 0.00122\,\frac{k_L^{0.79}C_{PL}^{0.45}\rho_L^{0.49}g_c^{0.25}}{\sigma^{0.5}\mu_L^{0.29}h_{fg}^{0.24}\rho_v^{0.24}}\,(\Delta t)^{0.24}\times(\Delta P)^{0.75}S$
	where F and S are empirically correlated factors. (S = 0 when nucleate boiling is totally suppressed)
Dengler (Ref. 5)	$\frac{h_{TP}}{h_L} = 3.5\left(\frac{1}{X_u}\right)^{0.5}$
Fikry (Ref. 6)	$\frac{hD}{k_g} = \left(\frac{D\rho_g U_c}{\mu g}\right)^{0.8}$
	where C = 0.84 0.4 x 0.5 C = 0.887 0.55 x 0.65 C = 0.904 0.70 x 0.80
Guerrieri and Talty (Ref. 7)	$\frac{h_{TP}}{h_L} = 3.4\left(\frac{1}{X_u}\right)^{0.45}$
Groothuis and Hendal (Ref. 8)	$\frac{hD}{k_L} = 0.029\left(\frac{P_L u_L D}{\mu_L} + \frac{\rho_g u_g D}{\mu g}\right)^{0.87}\left(\frac{C_p u}{\ }\right)^{0.33}\times\left(\frac{\mu b}{\mu w}\right)^{0.14}$

Table H-1. Proposed Correlating Equations (Concluded)

Authors	Correlating Equations*
Kvamme (Ref. 9)	$\frac{h_{TP}}{h_L} = 1.5 \left(\frac{1 - X}{1 - R_g} \right)^{0.8}$ where R_g = steam void fraction calculated from Martinelli-Lockhart correlation
Mumm (Ref. 10)	$\frac{hD}{K} = \left[4.3 + 5.0 \times 10^{-4} \left(\frac{V_{Lg}}{V_L} \right)^{1.64}_{0.464} X \right] X \left(\frac{q}{G\lambda} \right) \left(\frac{DG}{\mu L} \right)^{0.808}$ where V_{Lg} = specific volume increase upon vaporization
Shrock and Grossman (Ref. 11)	$\frac{hD}{k_L} = 170 \left[B_o + 1.5 \times 10^{-4} \left(\frac{1}{X_u} \right)^{2/3} \right] X \; R_e^{0.8} \; Pr^{1/3}$ where $B_o = \left(\frac{q}{A} \right) \left(\frac{1}{G\lambda} \right)$
Silvestri, et al. (Ref. 12)	Graphical correlation of $\frac{h}{\Delta\pi / \Delta T} \times \frac{\pi / T^{3/2}}{R_e 0.8}$ vs. $\frac{DG_t}{\mu TP}$ where $\mu TP = X_{\mu g} + (1 - x) \mu_L$

*These empirical equations were obtained under specific flow conditions and may not be applicable to other configurations and fluids. However, these typify the manner of analyzing and predicting the behavior of two-phase forced-convection systems.) Note, the correlating equations are in English units. See references for definition of terms.

Table H-2. Variables Studied by Investigators of Two-Phase Convection Heat Transfer

Investigator	System	Pressure, PSIA	Mass Flow Rate, lb/hr-sq ft x 10^{-3}	Vapor Mass Fraction	Heat Flux, Btu/hr-sq ft x 10^{-3}	Tube Dia., ft	Tube Orientation
Anderson, et al.	Steam-water	20-120	32.8-656	0.01-0.60	3.7-97.0	0.0387	Vertical
Bennett, et al.	Steam-water	15-35	51.5-217	0-0.546	63-138	0.0203 (equiv. diam.)	Vertical (annulus)
Davis	Steam-water	25-150	50-600	0.30-0.90	50-260	0.0324 (equivl diam.)	Horizontal (rectangular duct)
Dengler and Lee	Steam-water	7-40	44-1010	0.07-0.90	0-200	0.0833	Vertical
Fikry	Steam-water	15-25	41.4-74.7	0.02-0.82	6.0-30	0.0208	Horizontal
Groothuis and Hendal	Air-water	14.7	112-621	0-0.20	Not reported	0.0460	Vertical
Kvamme	Steam-water	18-87	52-182	0-1.00	9.4-50.2	0.0208	Horizontal
Mumm	Steam-water	45-200	252-1008	0-0.60	50-250	0.0387	Horizontal
Parker and Grosh	Steam-water	49-61	37-73	0.89-0.99	3.0-20.7	0.0833	Vertical
Silvestri, et al.	Steam-water	15-75	73.6-162 (steam) 51.5-332 (water)	0.25-1.00	0-1427	0.0164	Vertical

Table H-3. High-Quality, Forced-Convection Evaporation Correlations (Yadigaroglu and Bergles)*

AUTHOR	CHEN (97)
FLUID	WATER, METHANOL, CYCLOHEXANE, PENTANE, HEPTANE, BENZENE
DIRECTION OF FLOW	UP AND DOWN
CHANNEL GEOMETRY	CIRCULAR AND ANNULAR
DIAMETER, D (IN.)	LARGE RANGE
LENGTH, L (FT)	LARGE RANGE
PRESSURE LEVEL, p (psia)	8-505
MAX FLUX, $G/10^5$ ($LB/HR\text{-}FT^2$)	LARGE RANGE
HEAT FLUX, q" ($Btu/HR\text{-}FT^2$)	2000-760,000
QUALITY RANGE, x	0-0.71
RECOMMENDED CORRELATION	$h = h_{mic} + h_{mac}$ $= 0.00122 \dfrac{k_\ell^{0.79} c_\ell^{0.45} \rho_\ell^{0.49} g_c^{0.25}}{\sigma^{0.5} \mu_\ell^{0.29} h_{fg}^{0.24} \rho_v^{0.24}}$ $(\Delta T)^{0.24} (\Delta p)^{0.75} S + h_{LP} F$ WITH: $\Delta p = \dfrac{\Delta T h_{fg}}{T_{sat}\, v_{fg}}$ diff. in sat. vap. press. corr. TO $\Delta T = T_w - T_{sat}$ $g_c = 32.2(3600)^2$, S and F given in comp. vugraph
PROPERTIES EVALUATED AT	T_{sat}
NO. OF DATA POINTS/RUNS	DATA OF MANY INVESTIGATORS
ERROR IN CORRELATING DATA	85% WITHIN $\pm$ 15.1%
EQUATION	38

* REF. HANDBOOK OF HEAT TRANSFER, P 13-40

Table E-4. Properties of Saturated Liquid Water
P = 940 psia, T = 537 F

		English Units	SI Units
Density	ρ_L	46.8 lb/ft^3	749.6 kg/m^3
Heat Capacity	C_L	1.244 Btu/lb-F°	5208 Ws/kg-K
Viscosity	μ_L	0.2422 lb/hr-ft	0.36 kg/m-hr
Thermal Conductivity	k_L	0.335 $\frac{\text{Btu}}{\text{hr-ft-F°}}$	0.58 W/m-k
Prandt 1 No.	Pr	0.91	0.91
Heat of Vaporization	h_{fg}	650 Btu/lb	1.51 x 10^6 j/kg
Surface Tension*	σ	0.0296 lb/ft	13.39 $\frac{\text{dynes}}{\text{cm}}$
Properties of Saturated Steam			
Density		2.09 lb/ft^3	33.5 kg/m^3
Viscosity		0.05 lb/hr-ft	7.44 x 10^{-2} $\frac{\text{kg}}{\text{hr-m}}$

*Walden's Rule (Ref. J. H. Perry, 3-223, 4th ed.)

$\sigma = h_{fg} \cdot \rho_L / 364$

h_{fg} in cal/g-mole

ρ_L in g/cc

σ in dynes/cm

Walden's Rule used to estimate approximate value of surface tension.

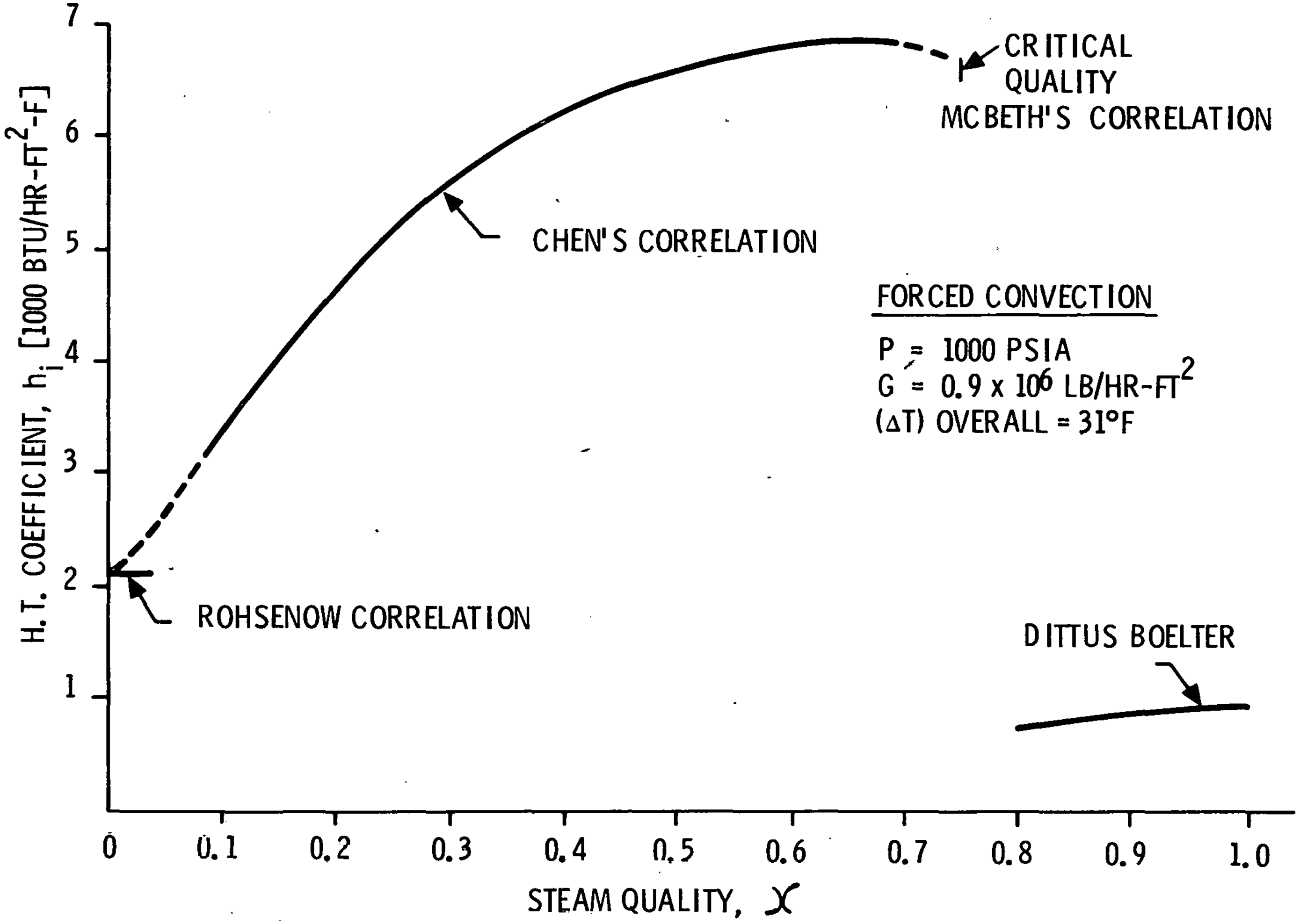


Figure H-3. Two-Phase Heat Transfer Correlation

40454

$$K_c = \frac{k_L^{0.79} C_L^{0.45} \rho_L^{0.49} g_0^{0.25}}{\sigma^{0.5} \mu_L^{0.29} h_{fg}^{0.24} \rho_g^{0.24}}$$

$S = S(y)$ and

$$y = R_e' F^{1.25} \times 10^{-5}$$

the functions for F and S used were,

$$\log F = 0.447 + 0.57 \log \tilde{X} + 0.1055 \log^2 \tilde{X} - 0.0176 \log^3 \tilde{X}$$

$$S = 0.0962 + 0.786\, e^{-0.9405y} - 0.9405y.$$

Using these relations with the fluid properties given in Table H-4, parameters F and S were calculated and plotted as shown in Figures H-4 and H-5, while Figure H-6 gives a plot of heat transfer coefficient versus quality. Chen's equation for the specified conditions is,

$$h_i = 0.0962(F)(R_e')^{0.8} + 782(S)(\Delta T)^{0.99}$$

Rohsenow's Relation:

Quality: $0 < x < 0.01$ (used)

$$h_i = (q/A)^{0.67} / (0.014) K_R$$

where

$$K_R = \frac{(h_{fg}\mu_L)^{0.67}}{k\rho} \left(\sqrt{\frac{(\sigma g_o)}{g(\rho_L - \rho_g)}} \right)^{0.33}$$

Substituting for $q/A = h_i \Delta t_i$

we get,

$$h_i = K(\Delta t_i)^2 \ (\text{Btu/hr-ft}^2\text{-F}^\circ)$$

where

$$\Delta t_i = t_{wi} - t_{sat} \ (F^\circ)$$

$$K = 3.64 \times 10^5 / K_R^3$$

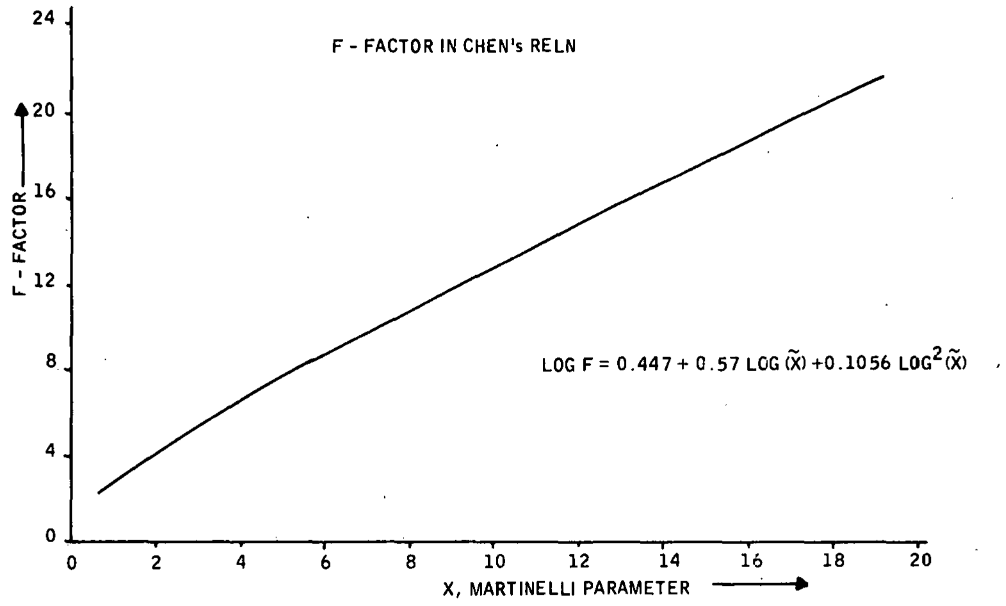


Figure H-4. F-Factor in Chen's Correlation

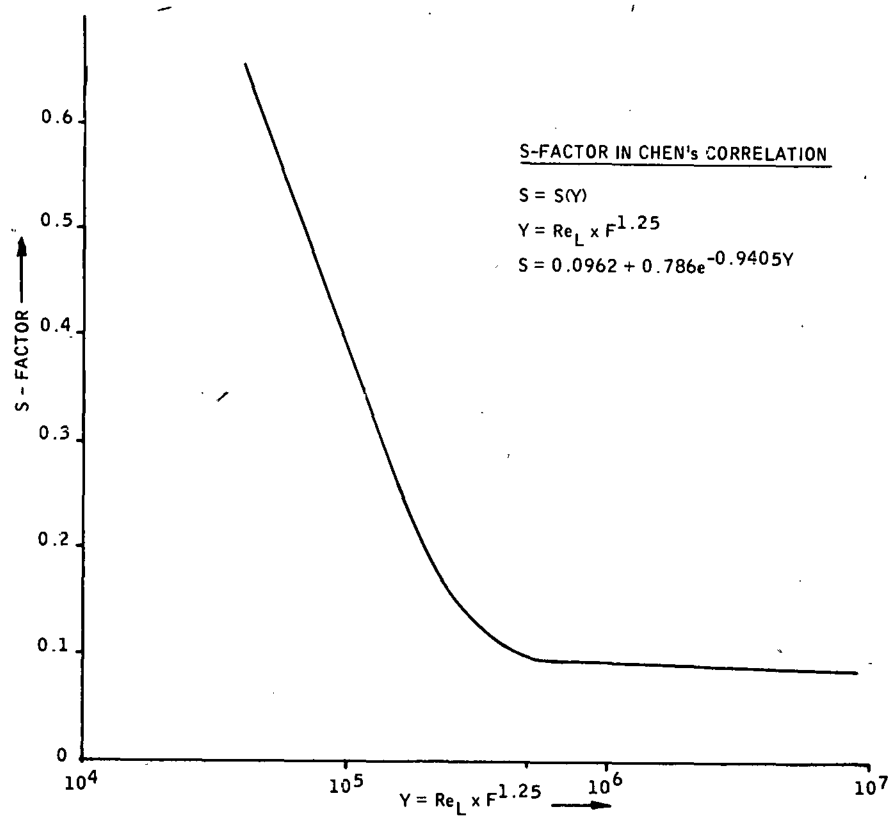
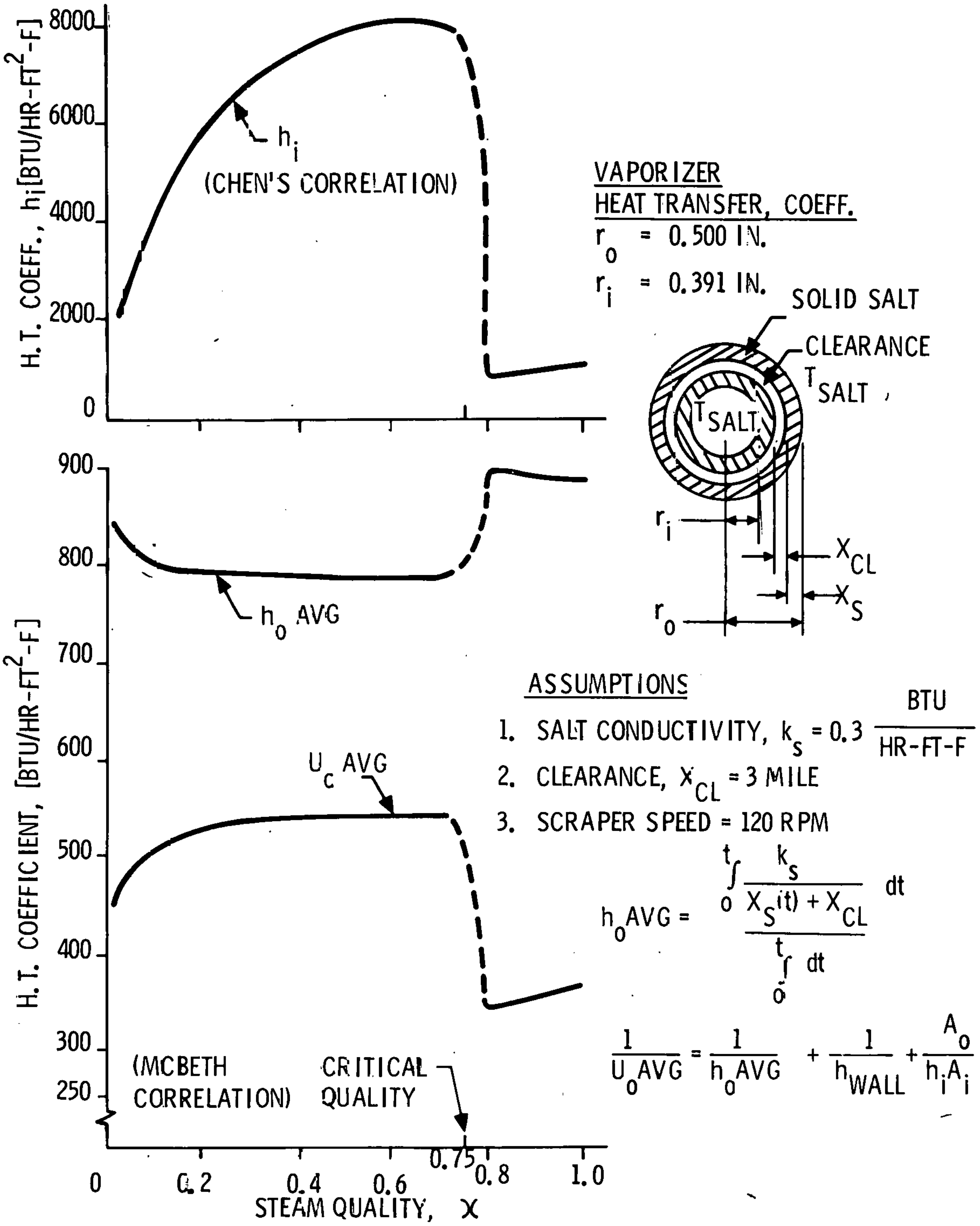


Figure H-5. S-Factor in Chen's Correlation



$$h_o AVG = \frac{\int_0^t \frac{k_s}{X_S(t) + X_{CL}}\, dt}{\int_0^t dt}$$

$$\frac{1}{U_o AVG} = \frac{1}{h_o AVG} + \frac{1}{h_{WALL}} + \frac{A_o}{h_i A_i}$$

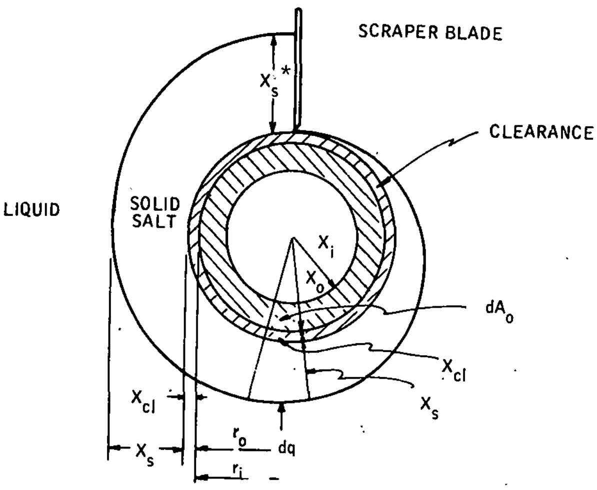
Figure H-6. Heat Transfer Coefficients versus Quality

In the high quality $(X > 0.1)$ the S factor in Chen's correlation is of the order of 0.01 and h_{mic} is relatively small compared to h_{mac}. However, for low qualities, heat transfer coefficient is a function of heat flux and, hence, Δt_i. To calculate h_i; Δt_i has to be estimated by trial and error for which outside coefficients are required.

OUTSIDE HEAT TRANSFER COEFFICIENTS:

Scraping Model

The solid salt thickness X_s is calculated as a function of time. The expression for X_s was obtained as follows: (see proposal).



Consider the elemental area dA_o; we have from energy conservation,

$$dq = U_o dA_o \cdot \Delta T = \rho_s H_{fs} dA_o \cdot \frac{dXs}{dt} \quad . \qquad \text{(H-1)}$$

Now,

$$\frac{1}{U_o} = \frac{r_o}{r_i h_i} + \frac{r_o \ln\left(\frac{ro}{ri}\right)}{k_t} + \frac{r_o \ln\left(\frac{r_o + X_{cl}}{ro}\right)}{k_f} + \frac{r_o \ln\left(\frac{r_o + X_{cl} + X_s}{r_o + X_{cl}}\right)}{k_s}$$

$$\begin{pmatrix}\text{overall}\\ \text{resistance}\end{pmatrix} = \begin{pmatrix}\text{Inside}\\ \text{Resistance}\end{pmatrix} + \begin{pmatrix}\text{Tube wall}\\ \text{Resistance}\end{pmatrix} + \underbrace{(\text{clearance}) + \begin{pmatrix}\text{outside}\\ \text{salt film}\end{pmatrix}}_{\text{outside resistance}}$$

For,

$$\frac{X}{r_o} << 1$$

$$\ln\left(\frac{r_o + X}{r_o}\right) = \ln\left(1 + \frac{X}{r_o}\right) \approx \frac{X}{r_o}$$

$$U_o = \frac{1}{\frac{ro}{r_i h_i} + \frac{r_o \ln\left(\frac{r_o}{r_i}\right)}{k_t} + \frac{X_{cl}}{k_s} + \frac{X_s}{k_s}}$$

where,

h_i = Inside coefficient, Btu/hr-ft^2-F°

k_t = Tube material thermal conductivity = 25 $\frac{\text{Btu}}{\text{hr-ft-F}^\circ}$

k_s = Salt thermal conductivity = 0.3 $\frac{\text{Btu}}{\text{hr-ft-F}^\circ}$

ΔT = $T_{sat'd} - T_{salt}$ = overall temperature difference

U_o = overall coefficient, $\frac{\text{Btu}}{\text{hr-ft}^2\text{-F}^\circ}$

ρ_s = salt density, lb/ft^3

H_{f_s} = salt heat of fusion, Btu/lb

X_{C_L} = clearance between scraper blade and tube, ft

X_s = salt thickness outside of clearance, ft

Substituting U_o in Equation (H-1) and integrating, we get

$$X_s(t) = k_s\left(-B + \sqrt{B^2 + \frac{2\,\Delta T\,t}{\rho_s H_{f_s} K_s}}\right) \qquad \text{(H-2)}$$

where,

$$B = \frac{r_o}{r_i h_i} + \frac{r_o \ln \frac{ro}{ri}}{k_t} + \frac{X_{cl}}{k_s}$$

B has the units of reciprocal heat transfer coefficient.

Let $h_{ieff} = \frac{1}{B}$

Defining a dimensionless variable,

$$\theta = \frac{h_{ieff}^2 \, \Delta T \cdot t}{\rho_s \, H_{f_s} \, k_s}$$

$$Bi = \frac{h_{ieff} X_s}{k_s}$$

Equation (H-2) can be written in dimensionless form as,

$$\boxed{Bi = -1 + \sqrt{1 + 2\theta}} \qquad \text{(H-3)}$$

The outside coefficient, h_o is calculated from,

$$h_o(t) = \frac{k_s}{X_s(t) + X_{cl}}$$

The average outside coefficient is obtained from

$$h_o \text{ avg} = \frac{\int_o^{t^*} h_o(t)\, dt}{\int_o^{t^*} dt}$$

$$t^* = \frac{1}{60N} \text{ (hrs)}$$

N = Scraping speed in (rpm)

Integrating we get,

$$h_{oavg} = \frac{1}{At^*}\left[\frac{X_s}{k_s} + \left(B - \frac{X_{cl}}{k_s}\right) \ln \left(1 + \frac{X_{s^*}}{X_{cl}}\right)\right] \qquad \text{(H-4)}$$

where

$$A = \frac{\Delta T}{\rho_s h_{fs} k_s}$$

$$X_s^* = X_s(t^*)$$

In dimensionless form, Equation (H-4) becomes

$$h_{oavg} = h_{eff} \left[\frac{Bi - (K-1) \ln (1 + \frac{Bi}{K})}{\theta} \right] \qquad \text{(H-5)}$$

where,

$$B_i = \frac{hi_{eff} \; X_s}{k_s} = -1 + \sqrt{1 + 2\theta}$$

$$K = \frac{hi_{eff} \; X_{cl}}{k_s}$$

The overall coefficient, U_o

$$U_o(t) = \frac{1}{B + \frac{X_s}{k_s}} = h_{eff} \left(\frac{1}{1 + Bi}\right)$$

$$U_{oavg} = \frac{\int_o^{t^*} U_o(t) \, dt}{\int_o^{t^*} dt}$$

Steps (i) through (iv) were repeated for steam qualities from 0.1 to 0.8. The critical steam quality as obtained from Macbeth's correlation is ~ 0.75 for the 1800 psia/950°F cycle and water velocity of 5 ft/sec. The above calculations were repeated for scraper clearances from 1 mil to 6 mils.

Substituting and integrating, we get

$$U_{oavg} = h_{eff} \frac{Bi}{\theta} \qquad \text{(H-6)}$$

Table H-5 gives typical values of X_s, h_{oavg}, U_{oavg}, h_i for a 3 mil clearance as a function of scraping speed. Figure H-6 is a plot of h_i, h_{eff}, h_{oavg}, and U_{oavg} as a function of steam quality for a scraper speed of 120 rpm and salt clearance of 3 mils. Figure H-7 is a plot of U_{oavg} as a function of h_{eff} for 100 rpm and 600 rpm scraper speed.

40454

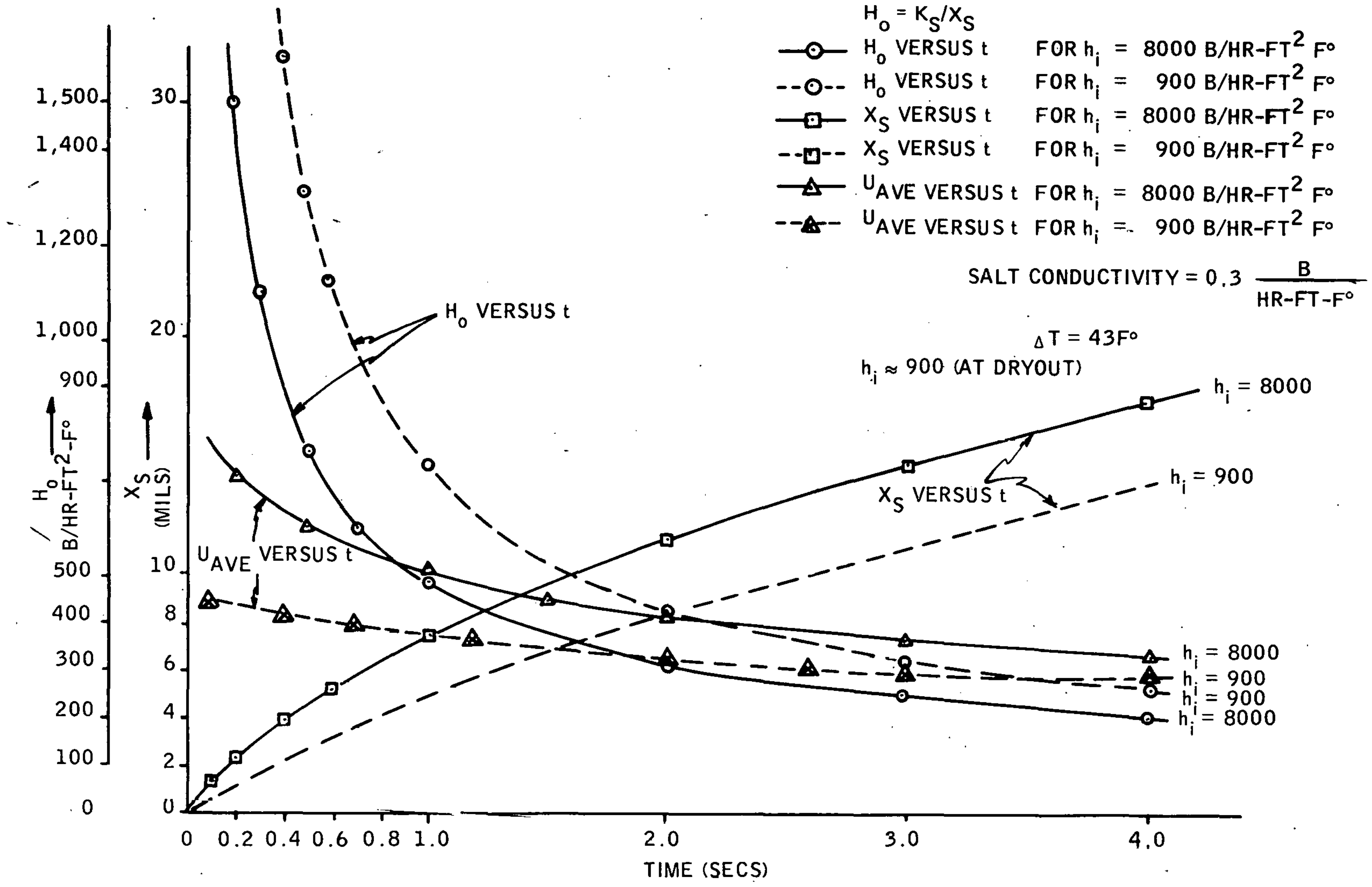


Figure H-7. Salt Thickness as a Function of Time

Table H-5. Typical Values for X_s, h_o, U_i versus 't' for a Clearance of 1.27 x 10^{-2}cm (5 mils)

QUALITY	REY NUMBER	HMAC OR HI	CMIC	MASS VELOCITY
0.100	2.1112453E 05	4.5804766E 03	3.8723689E-01	8.3339987E 05

CLEARANCE ,(INCHES)= 0.00300

SCR TIME SECS	RPM	S.THICKNESS (INCHES)	HOAVG	UOAVG	H(EFF)	BIOT	THETA
			BTU/HR-SQ.FT.-F				
0.10	600.	0.00380	1050.6	693.1	761.1	0.169	0.185
0.20	300.	0.00449	956.1	649.4	761.1	0.316	0.369
0.30	200.	0.00512	885.2	614.6	761.1	0.448	0.554
0.40	150.	0.00569	829.3	585.8	761.1	0.569	0.739
0.50	120.	0.00623	783.5	561.4	761.1	0.682	0.924
0.60	100.	0.00672	745.1	540.4	761.1	0.787	1.108
0.70	86.	0.00720	712.2	521.9	761.1	0.887	1.293
0.80	75.	0.00764	683.5	505.5	761.1	0.982	1.478
0.90	67.	0.00807	658.3	490.8	761.1	1.072	1.663
1.00	60.	0.00848	635.8	477.5	761.1	1.158	1.847
1.20	50.	0.00925	597.3	454.2	761.1	1.322	2.217
1.40	43.	0.00997	565.4	434.5	761.1	1.474	2.586
1.60	37.	0.01065	538.3	417.4	761.1	1.618	2.956
1.80	33.	0.01130	514.9	402.4	761.1	1.754	3.325
2.00	30.	0.01191	494.4	389.1	761.1	1.884	3.695
2.50	24.	0.01334	452.6	361.3	761.1	2.185	4.619
3.00	20.	0.01464	420.2	339.3	761.1	2.460	5.542
3.50	17.	0.01584	394.0	321.1	761.1	2.715	6.466
4.00	15.	0.01697	372.3	305.9	761.1	2.954	7.390

SCR Time = Scraping time

X_S = Salt thickness

H_o = Outside heat transfer coefficient at time 't'

G = Mass velocity = Vel x ρ

U_i = Overall coefficient based on inside area

$(H_o A_o)$ avg = (Outside coefficient x Area) averaged over the Scraping time

H_i = Inside heat transfer coefficient calculated from Chen's Equation

CRITICAL HEAT FLUX (MACBETH[16] CORRELATION)

To determine the critical heat flux (i. e., the point where the liquid disengages from the wall) or the dryout point, Macbeth's correlation for high flow regimes was used.

$$\left(\frac{q}{A}\right)_{crit} \times 10^{-6} = A - \frac{1}{4} \times CD(G \times 10^{-6})\, h_{fg}\, X_e,$$

where $A = y_0 D^{y1} (G \times 10^{-6})^{y_2}$

$C = y_3 D^{y4} (G \times 10^{-6})^{y_5}$

At 1000 psia the y values given are:

$y_0 = 1.06$ $\quad y_3 = 0.0085$

$y_1 = -0.470$ $\quad y_4 = -1.4$

$y_2 = -0.179$ $\quad y_5 = -0.555$

Now,

$G = 0.9 \times 10^6$ lb/hr-ft^2 (4.39×10^6 kg/hr-m^2)

$D = 0.782$ in (2.431 cm)

$h_{fg} = 650$ Btu/lb (420 WH/kg)

$A = 1.215$

$C = 0.0127$

$$\left(\frac{q}{A}\right)_{crit} \times 10^{-6} = 1.215 - 1.454\, X_e$$

Figure H-8 is a plot of $(q/A)_{crit}$ versus X_e, which shows that at qualities of about 45 percent and above, a small amount of heat flux would cause a dry wall.

The heat flux in the thermal storage vaporizer is in the range of 60 KW/m^2 (20,000 Btu/hr-ft^2). Thus, according to plot the dryout point will be at $X_e = 0.8$. However, the critical flux is not quite critical in our case, since we have a constant temperature environment. But since the heat transfer coefficient decreases sharply above this quality, economics dictate that the design point be chosen below the critical point.

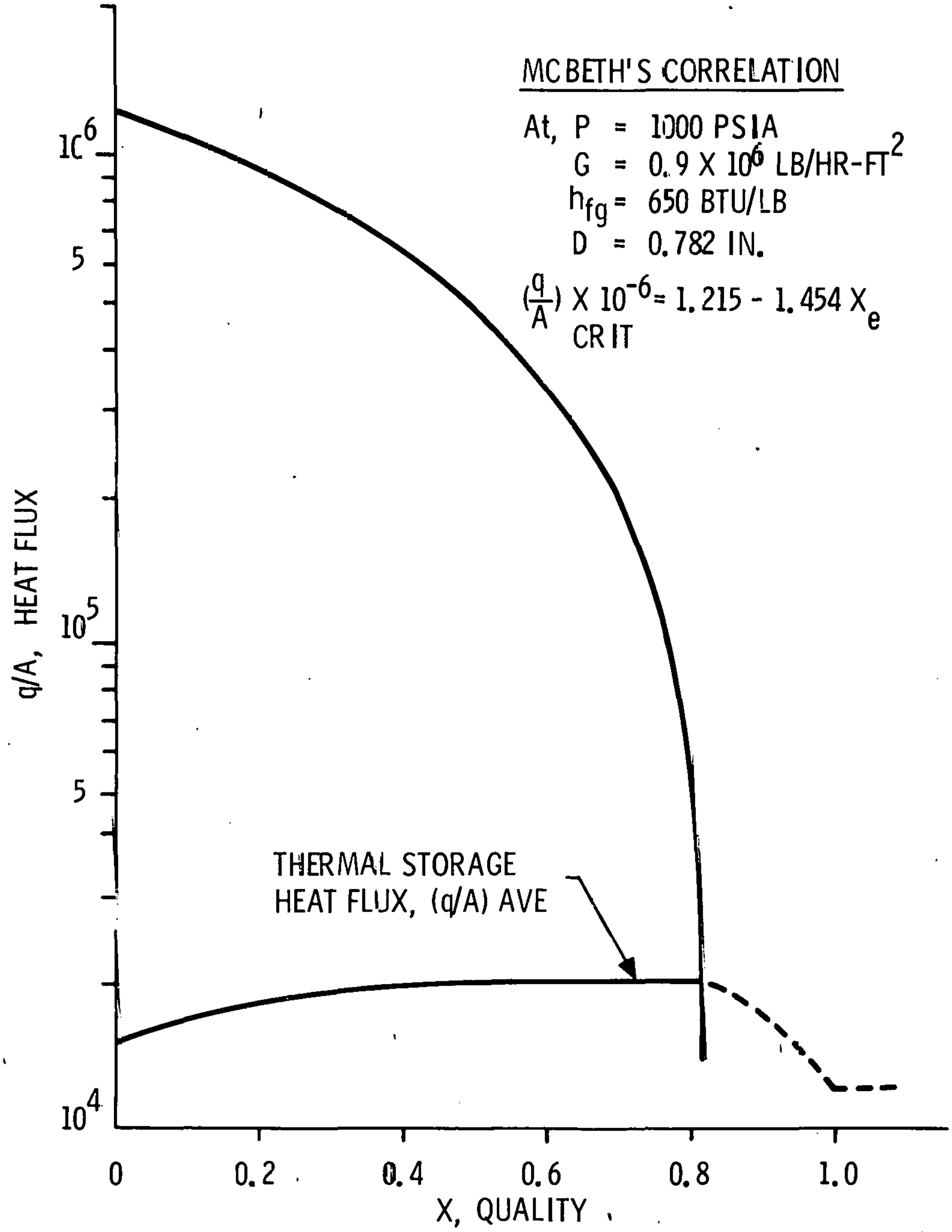


Figure H-8. Heat Flux versus Steam Quality

The design point chosen is 40 percent quality at the pipe exit: which means an operating recirculation ratio of 5 to 2.

BIBLIOGRAPHY:

1. Chen, J.C., "Correlation for Boiling Heat Transfer to Saturated Fluids in Convective Flow", A.S.M.E.-A.I. Ch.E. Heat Transfer Conference, Boston - 1963.

2. Art Bergles, Private Communication with Prof. E.M. Sparrow.

3. Handbook of Heat Transfer, Rohsenow W.M. and Martinett, J.P., pp 13-28.

4. David, E.J., Davis, M.M., "Two-phase Gas-Liquid Convection Heat Transfer," I and EC Fundamentals, Vo.. 3 (1964), pp 111-118.

5. Dengler, C.E., Addoms, J.N.; Chem. Eng. Prog. Symp., Ser., 52, 95 (1956).

6. Fikry, M.M., PhD. Thesis, Imperial College, London, 1953.

7. Guerrieri, S.A., and Talty, R.D., Chem. Eng. Progr. Symp. Ser., 52, 69, (1956).

8. Groothuis, H., Hendal, W.P., Chem. Eng. Sci., 11, 212, (1959)

9. Kvamme, A., M.S. Thesis, University of Minnesota, 1959.

10. Mumm, J.F., Argonne National Lab Report ANL-5276 (1954).

11. Shrock, V.E., Grossman, L.M., Nuclear Sci. Eng., 12, 474, (1962).

12. Silvestri, M., Finzi, S., Roseo, L., Schiavon, M., Zavattaralli, Z.; Proc. Second UN Intern. Conf. Peaceful Uses At. Energy 7, (1958).

13. Bennett, J.A.R., Collier, J.G., Pratt, H.R.C., Thornton, J.D., Trans. Inst. Chem. Engrs. (London) 39, 113 (1961).

14. Stone, R.A., and Berenson, B.J., "A Photographic Study of the Mechanisms of Forced Convection Vaporization," Ch. Eng. Prog. Symp. Ser., No. 57, p-213.

15. Forster, H.K., Zuber, N., A.I. Ch. E., J, 1, 531, (1955).

16. Handbook of Heat Transfer, Rohsenow and Martinett, pp. 13-57 (1974).

APPENDIX I

APPENDIX I
SRE VAPORIZER PERFORMANCE MODEL

APPENDIX I

SRE VAPORIZER PERFORMANCE MODEL

Computer calculations are done to predict the SRE vaporizer test results, using the mathematical model described in Appendix . The following equations were used:

1. Inside heat transfer coefficient --

   (i) Rohsenow's Correlation, $0 \le x < 0.05$

   (ii) Chen's Correlation, $0.05 \le x < x_{crit}$

   (iii) Dittus-Boelter equation, $x \ge x_{crit}$

2. Critical steam quality, x_{crit}, - McBeth's Correlation; (Appendix)

3. Outside heat transfer coefficient -- Scraping Model equations; (Appendix)

4. Two-phase pressure drop calculations -- Method of Thom; (Appendix)

The following assumptions were made:

a. Salt temperature, T(salt) = 298°C (568°F)

b. Scraper clearance, $X_{cl} = 7.62 \times 10^{-6}$m (3 mils)

c. Constant overall temperature difference, ΔT = T(salt) - T(sat steam)

d. Constant steam and salt properties at T(sat) and T(salt) respectively.

e. Feedwater temperature = 227°C (440°F)

Figure I-1 illustrates the flow chart of the calculations. The results are presented with recirculation flow, steam drum pressure and scraper speed as parameters. Recirculation flows are varied between 454 kg/hr (1000 lb/hr) to 3175 kg/hr (7000 lb/hr). Steam drum pressures are varied between 4.9 MPa (711 psia) to 7.8 MPa (1132 psia) at scraper speed of 120 rpm (See attached printout). Scraper speeds are varied between 30 rpm to 270 rpm at drum pressure of 940 psia (see attached printouts).

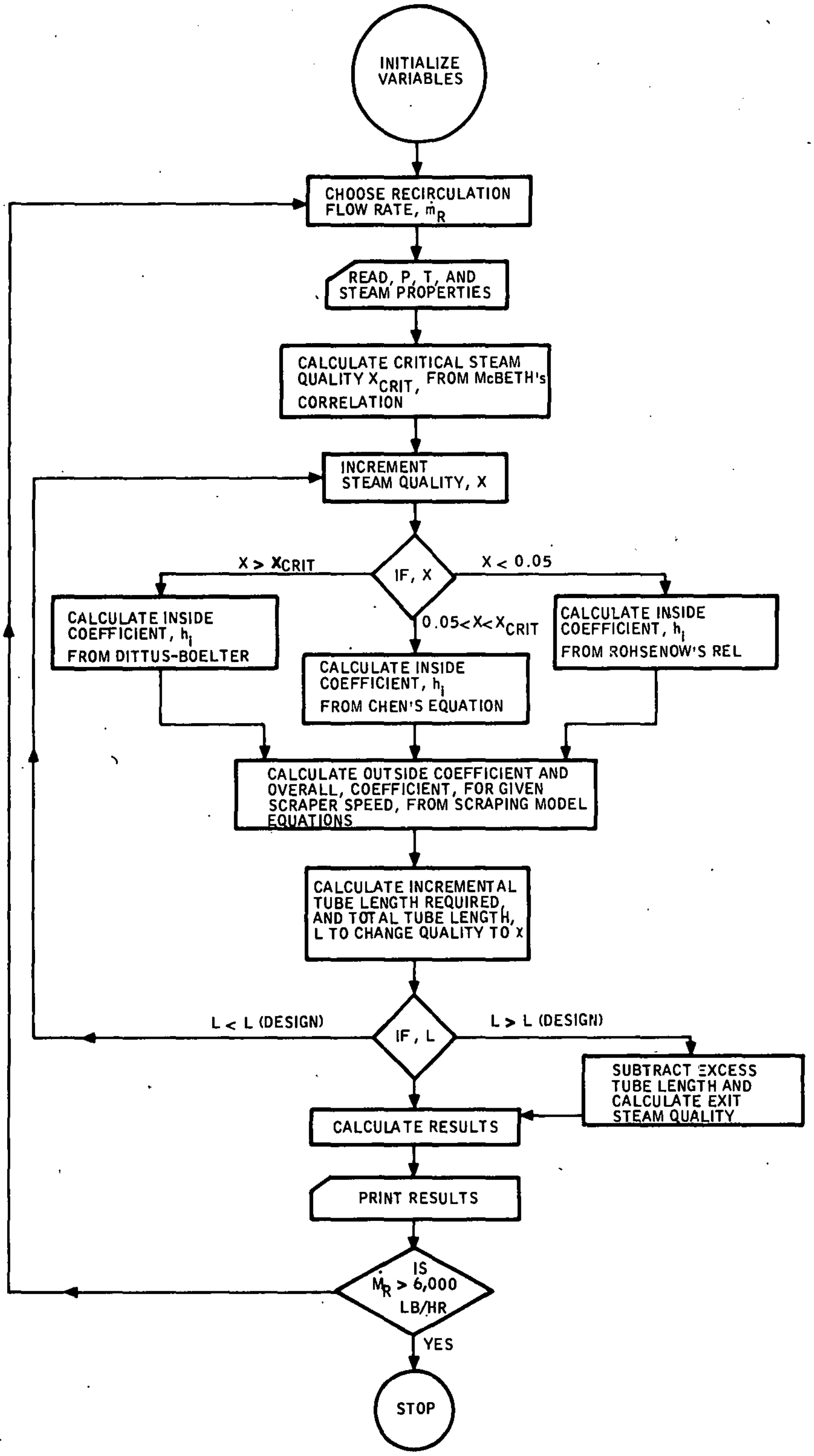


Figure I-1. SRE Vaporizer Performance Analysis - Flow Chart

DRUM PRESSURE = 940.PSIA SAT. TEMPERATURE= 537.F.
OVERALL DELTA T= 31.F. SCRAPER SPEED = 120.(RPM)

RECIRCULATION FLOW LB/HR	GPM	U-OVERALL COEFFICIENT BTU/HR-FT2-F	EXIT QUALITY	STEAM RATE LB/HR	HEAT RATE BTU/HR	PRESSURE DROP PSI	HEAD FT. OF WATER
500.	1.3	394.8	0.925	462.6	0.358E 06	5.5	16.9
1000.	2.7	461.5	0.541	540.7	0.419E 06	13.5	41.5
1500.	4.0	480.1	0.375	562.6	0.436E 06	22.2	69.2
2000.	5.3	491.6	0.288	576.0	0.446E 06	31.8	97.8
2500.	6.7	499.7	0.234	585.5	0.454E 06	42.3	130.1
3000.	8.0	505.9	0.198	592.8	0.459E 06	53.6	165.0
3500.	9.3	510.9	0.171	598.6	0.464E 06	65.8	202.6
4000.	10.7	515.0	0.151	603.4	0.467E 06	78.9	242.8
4500.	12.0	518.5	0.135	607.6	0.471E 06	92.8	285.6
5000.	13.3	521.5	0.122	611.1	0.473E 06	107.6	331.0
5500.	14.7	524.2	0.112	614.3	0.476E 06	123.2	379.0
6000.	16.0	526.5	0.103	616.9	0.478E 06	139.6	429.5
6500.	17.3	528.7	0.095	619.5	0.480E 06	156.8	482.6
7000.	18.6	530.7	0.089	621.8	0.482E 06	174.9	538.2
7500.	20.0	532.4	0.083	623.8	0.483E 06	193.8	596.4

DRUM PRESSURE = 711.PSIA SAT. TEMPERATURE= 505.F.
OVERALL DELTA T= 63.F. SCRAPER SPEED = 120.(RPM)

RECIRCULATION FLOW LB/HR	GPM	U-OVERALL COEFFICIENT BTU/HR-FT2-F	EXIT QUALITY	STEAM RATE LB/HR	HEAT RATE BTU/HR	PRESSURE DROP PSI	HEAD FT. OF WATER
500.	1.3	331.5	1.000	500.0	0.391E 06	7.8	23.1
1000.	2.6	403.0	0.950	950.0	0.743E 06	29.8	88.1
1500.	3.8	437.3	0.687	1030.8	0.807E 06	49.4	146.3
2000.	5.1	443.9	0.522	1046.4	0.819E 06	68.4	202.4
2500.	6.4	448.2	0.423	1056.6	0.827E 06	88.2	261.1
3000.	7.7	451.4	0.355	1064.1	0.833E 06	108.9	322.2
3500.	9.0	453.9	0.306	1070.0	0.837E 06	130.3	385.7
4000.	10.2	455.9	0.265	1074.8	0.841E 06	152.7	451.7
4500.	11.5	457.6	0.240	1078.9	0.844E 06	175.8	520.2
5000.	12.8	459.1	0.216	1082.3	0.847E 06	199.7	591.0
5500.	14.1	460.4	0.197	1085.3	0.849E 06	224.5	664.2
6000.	15.4	461.5	0.181	1088.0	0.851E 06	250.0	739.8
6500.	16.7	462.5	0.168	1090.4	0.853E 06	276.4	817.8
7000.	17.9	463.4	0.156	1092.5	0.855E 06	303.5	898.2
7500.	19.2	464.3	0.146	1094.5	0.856E 06	331.5	980.9

DRUM PRESSURE = 777.PSIA SAT. TEMPERATURE= 515.F.
OVERALL DELTA T= 53.F. SCRAPER SPEED = 120.(RPM)

RECIRCULATION FLOW LB/HR	GPM	U-OVERALL COEFFICIENT BTU/HR-FT2-F	EXIT QUALITY	STEAM RATE LB/HR	HEAT RATE BTU/HR	PRESSURE DROP PSI	HEAD FT. OF WATER
500.	1.3	337.3	1.000	500.0	0.390E 06	7.0	20.9
1000.	2.6	435.5	0.866	866.5	0.676E 06	24.4	73.1
1500.	3.9	450.0	0.597	895.3	0.698E 06	38.9	116.5
2000.	5.2	457.6	0.455	910.4	0.710E 06	54.3	162.5
2500.	6.5	462.7	0.368	920.6	0.718E 06	70.5	211.0
3000.	7.8	466.6	0.309	928.3	0.724E 06	87.5	262.1
3500.	9.1	469.6	0.267	934.3	0.729E 06	105.4	315.7
4000.	10.4	472.0	0.235	939.2	0.733E 06	124.2	371.8
4500.	11.7	474.1	0.210	943.2	0.736E 06	143.7	430.3
5000.	13.0	475.9	0.189	946.9	0.739E 06	164.1	491.3
5500.	14.3	477.5	0.173	950.0	0.741E 06	185.3	554.8
6000.	15.6	478.9	0.159	952.8	0.743E 06	207.3	620.7
6500.	16.9	480.1	0.147	955.2	0.745E 06	230.1	689.0
7000.	18.1	481.3	0.137	957.5	0.747E 06	253.8	759.7
7500.	19.4	482.2	0.128	959.5	0.748E 06	278.2	832.8

DRUM PRESSURE = 847.PSIA SAT. TEMPERATURE= 525.F.
OVERALL DELTA T= 43.F. SCRAPER SPEED = 120.(RPM)

RECIRCULATION FLOW LB/HR	GPM	U-OVERALL COEFFICIENT BTU/HR-FT2-F	EXIT QUALITY	STEAM RATE LB/HR	HEAT RATE BTU/HR	PRESSURE DROP PSI	HEAD FT. OF WATER
500.	1.3	344.6	1.000	500.0	0.389E 06	6.4	19.5
1000.	2.6	448.3	0.726	725.7	0.564E 06	19.1	57.9
1500.	3.9	463.9	0.501	750.9	0.584E 06	30.8	93.3
2000.	5.2	472.8	0.383	765.4	0.595E 06	43.3	131.3
2500.	6.6	479.0	0.310	775.4	0.603E 06	56.8	172.0
3000.	7.9	483.7	0.261	783.0	0.609E 06	71.1	215.3
3500.	9.2	487.4	0.225	788.9	0.614E 06	86.2	261.2
4000.	10.5	490.4	0.198	793.9	0.617E 06	102.2	309.6
4500.	11.8	493.0	0.177	798.0	0.621E 06	119.0	360.6
5000.	13.1	495.2	0.160	801.7	0.624E 06	136.7	414.1
5500.	14.4	497.2	0.146	804.8	0.626E 06	155.1	470.0
6000.	15.7	498.9	0.135	807.6	0.628E 06	174.4	528.5
6500.	17.0	500.4	0.125	810.1	0.630E 06	194.5	589.3
7000.	18.4	501.9	0.116	812.4	0.632E 06	215.5	652.9
7500.	19.7	503.1	0.109	814.5	0.633E 06	237.2	718.6

DRUM PRESSURE = 922.PSIA SAT. TEMPERATURE= 535.F.
OVERALL DELTA T= 33.F. SCRAPER SPEED = 120.(RPM)

RECIRCULATION FLOW LB/HR	GPM	Q-OVERALL COEFFICIENT BTU/HR-FT2-F	EXIT QUALITY	STEAM RATE LB/HR	HEAT RATE BTU/HR	PRESSURE DROP PSI	HEAD FT. OF WATER
500.	1.3	379.4	0.946	472.9	0.367E 06	5.6	17.3
1000.	2.7	459.3	0.572	572.3	0.444E 06	14.3	43.8
1500.	4.0	477.2	0.397	594.8	0.461E 06	23.4	71.7
2000.	5.3	488.2	0.304	608.5	0.472E 06	33.4	102.4
2500.	6.6	496.0	0.247	618.1	0.479E 06	44.3	135.9
3000.	8.0	501.9	0.209	625.5	0.485E 06	56.0	172.0
3500.	9.3	506.6	0.180	631.4	0.490E 06	68.7	210.7
4000.	10.6	510.5	0.159	636.3	0.493E 06	82.1	252.0
4500.	12.0	513.9	0.142	640.4	0.497E 06	96.4	295.9
5000.	13.3	516.7	0.129	644.0	0.499E 06	111.6	342.4
5500.	14.6	519.2	0.118	647.1	0.502E 06	127.6	391.5
6000.	15.9	521.5	0.108	649.9	0.504E 06	144.4	443.0
6500.	17.3	523.4	0.100	652.3	0.506E 06	162.0	497.1
7000.	18.6	525.3	0.094	654.7	0.508E 06	180.5	553.8
7500.	19.9	527.0	0.088	656.8	0.509E 06	199.8	613.0

DRUM PRESSURE = 1002.PSIA SAT. TEMPERATURE= 545.F.
OVERALL DELTA T= 23.F. SCRAPER SPEED = 120.(RPM)

RECIRCULATION FLOW LB/HR	GPM	Q-OVERALL COEFFICIENT BTU/HR-FT2-F	EXIT QUALITY	STEAM RATE LB/HR	HEAT RATE BTU/HR	PRESSURE DROP PSI	HEAD FT. OF WATER
500.	1.3	417.0	0.727	363.6	0.281E 06	4.1	12.8
1000.	2.7	465.0	0.406	405.5	0.313E 06	9.9	30.7
1500.	4.0	487.5	0.283	425.1	0.328E 06	16.6	51.7
2000.	5.4	501.7	0.219	437.5	0.338E 06	24.3	75.6
2500.	6.7	512.0	0.179	446.4	0.345E 06	32.9	102.3
3000.	8.1	519.8	0.151	453.3	0.350E 06	42.3	131.7
3500.	9.4	526.3	0.131	458.9	0.354E 06	52.7	163.8
4000.	10.8	531.6	0.116	463.6	0.358E 06	63.8	198.5
4500.	12.1	536.1	0.104	467.5	0.361E 06	75.8	235.9
5000.	13.5	540.1	0.094	471.0	0.364E 06	88.7	275.9
5500.	14.8	543.6	0.085	474.0	0.366E 06	102.4	318.6
6000.	16.2	546.6	0.079	476.6	0.368E 06	117.0	363.8
6500.	17.5	549.2	0.074	478.9	0.370E 06	132.3	411.6
7000.	18.8	551.9	0.069	481.3	0.372E 06	148.6	462.1
7500.	20.2	554.3	0.064	483.3	0.373E 06	165.6	515.2

\+++

DRUM PRESSURE = 1044.PSIA SAT. TEMPERATURE= 555.F.
OVERALL DELTA T= 13.F. SCRAPER SPEED = 120.(RPM)

RECIRCULATION FLOW LB/HR	GPM	U-OVERALL COEFFICIENT BTU/HR-FT2-F	EXIT QUALITY	STEAM RATE LB/HR	HEAT RATE BTU/HR	PRESSURE DROP PSI	HEAD FT. OF WATER
500.	1.4	399.5	0.395	197.3	0.152E 06	2.3	7.3
1000.	2.7	457.1	0.226	225.8	0.174E 06	6.0	18.9
1500.	4.1	487.5	0.161	240.8	0.186E 06	10.7	33.6
2000.	5.4	507.5	0.125	250.7	0.193E 06	16.3	51.2
2500.	6.8	522.3	0.103	258.0	0.199E 06	22.8	71.6
3000.	8.1	534.1	0.089	263.8	0.203E 06	30.2	94.7
3500.	9.5	543.3	0.077	268.4	0.207E 06	38.5	120.4
4000.	10.8	551.5	0.068	272.4	0.210E 06	47.6	149.0
4500.	12.2	558.4	0.061	275.8	0.213E 06	57.5	180.1
5000.	13.6	564.0	0.056	278.6	0.215E 06	68.3	213.9
5500.	14.9	568.8	0.051	281.0	0.217E 06	79.9	250.3
6000.	16.3	573.7	0.047	283.4	0.218E 06	92.4	289.4
6500.	17.6	578.3	0.044	285.6	0.220E 06	105.7	331.2
7000.	19.0	582.3	0.041	287.6	0.222E 06	119.9	375.5
7500.	20.3	585.8	0.039	289.4	0.223E 06	134.9	422.5

\+++
\+++

DRUM PRESSURE = 1132.PSIA SAT. TEMPERATURE= 560.F.
OVERALL DELTA T= 8.F. SCRAPER SPEED = 120.(RPM)

RECIRCULATION FLOW LB/HR	GPM	U-OVERALL COEFFICIENT BTU/HR-FT2-F	EXIT QUALITY	STEAM RATE LB/HR	HEAT RATE BTU/HR	PRESSURE DROP PSI	HEAD FT. OF WATER
500.	1.4	364.3	0.223	111.3	0.853E 05	1.4	4.5
1000.	2.8	432.1	0.132	132.0	0.101E 06	4.0	12.8
1500.	4.1	469.9	0.096	143.5	0.110E 06	7.6	24.2
2000.	5.5	495.3	0.076	151.3	0.116E 06	12.1	38.4
2500.	6.9	515.4	0.063	157.4	0.121E 06	17.5	55.6
3000.	8.3	530.1	0.054	161.9	0.124E 06	23.7	75.4
3500.	9.6	542.5	0.047	165.7	0.127E 06	30.8	98.0
4000.	11.0	553.9	0.042	169.2	0.130E 06	38.8	123.5
4500.	12.4	563.2	0.038	172.0	0.132E 06	47.7	151.6
5000.	13.8	571.0	0.035	174.4	0.134E 06	57.4	182.4
5500.	15.1	577.6	0.032	176.4	0.135E 06	67.9	215.9
6000.	16.5	583.3	0.030	178.1	0.137E 06	79.3	252.0
6500.	17.9	588.2	0.028	179.7	0.138E 06	91.5	290.8
7000.	19.3	592.6	0.026	181.0	0.139E 06	104.6	332.3
7500.	20.6	597.3	0.024	182.4	0.140E 06	118.5	376.6

STOP.

DRUM PRESSURE = 940.PSIA SAT. TEMPERATURE= 537.F.
OVERALL DELTA T= 31.F. SCRAPER SPEED = 30.(RPM)

RECIRCULATION FLOW LB/HR	GPM	U-OVERALL COEFFICIENT BTU/HR-FT2-F	EXIT QUALITY	STEAM RATE LB/HR	HEAT RATE BTU/HR	PRESSURE DROP PSI	HEAD FT. OF WATER
1000.	2.7	339.5	0.398	397.7	0.308E 06	9.6	29.5
2000.	5.3	354.3	0.208	415.2	0.322E 06	21.6	66.6
3000.	8.0	361.4	0.141	423.5	0.328E 06	35.6	109.4
4000.	10.7	366.0	0.107	428.8	0.332E 06	51.3	157.8
5000.	13.3	369.2	0.087	432.6	0.335E 06	68.8	211.6
6000.	16.0	371.6	0.073	435.4	0.337E 06	88.0	270.8
7000.	18.6	373.7	0.063	437.8	0.339E 06	109.0	335.4

DRUM PRESSURE = 940.PSIA SAT. TEMPERATURE= 537.F.
OVERALL DELTA T= 31.F. SCRAPER SPEED = 60.(RPM)

RECIRCULATION FLOW LB/HR	GPM	U-OVERALL COEFFICIENT BTU/HR-FT2-F	EXIT QUALITY	STEAM RATE LB/HR	HEAT RATE BTU/HR	PRESSURE DROP PSI	HEAD FT. OF WATER
1000.	2.7	404.7	0.474	474.2	0.367E 06	11.3	34.7
2000.	5.3	426.7	0.250	499.9	0.387E 06	25.4	78.0
3000.	8.0	437.1	0.171	512.2	0.397E 06	41.4	127.4
4000.	10.7	443.7	0.130	519.9	0.403E 06	59.3	182.4
5000.	13.3	448.5	0.105	525.5	0.407E 06	79.0	243.0
6000.	16.0	452.2	0.088	529.8	0.410E 06	100.4	309.1
7000.	18.6	455.0	0.076	533.1	0.413E 06	123.6	380.5

DRUM PRESSURE = 940.PSIA SAT. TEMPERATURE= 537.F.
OVERALL DELTA T= 31.F. SCRAPER SPEED = 90.(RPM)

RECIRCULATION FLOW LB/HR	GPM	0-OVERALL COEFFICIENT BTU/HR-FT2-F	EXIT QUALITY	STEAM RATE LB/HR	HEAT RATE BTU/HR	PRESSURE DROP PSI	HEAD FT. OF WATER
1000.	2.7	439.4	0.515	514.8	0.399E 06	12.2	37.4
2000.	5.3	466.1	0.273	546.1	0.423E 06	27.4	84.3
3000.	8.0	478.8	0.187	561.0	0.435E 06	44.6	137.3
4000.	10.7	486.8	0.143	570.4	0.442E 06	63.7	196.1
5000.	13.3	492.6	0.115	577.2	0.447E 06	84.6	260.5
6000.	16.0	497.0	0.097	582.3	0.451E 06	107.4	330.4
7000.	18.6	500.6	0.084	586.6	0.454E 06	131.9	405.8

DRUM PRESSURE = 940.PSIA SAT. TEMPERATURE= 537.F.
OVERALL DELTA T= 31.F. SCRAPER SPEED = 120.(RPM)

RECIRCULATION FLOW LB/HR	GPM	0-OVERALL COEFFICIENT BTU/HR-FT2-F	EXIT QUALITY	STEAM RATE LB/HR	HEAT RATE BTU/HR	PRESSURE DROP PSI	HEAD FT. OF WATER
1000.	2.7	461.5	0.541	540.7	0.419E 06	12.7	39.2
2000.	5.3	491.6	0.288	576.0	0.446E 06	28.7	88.3
3000.	8.0	505.9	0.198	592.8	0.459E 06	46.7	143.7
4000.	10.7	515.0	0.151	603.4	0.467E 06	66.6	205.0
5000.	13.3	521.5	0.122	611.1	0.473E 06	88.4	271.9
6000.	16.0	526.5	0.103	616.9	0.478E 06	111.9	344.4
7000.	18.6	530.7	0.089	621.8	0.482E 06	137.3	422.4

DRUM PRESSURE = 940.PSIA SAT. TEMPERATURE= 537.F.
OVERALL DELTA T= 31.F. SCRAPER SPEED = 150.(RPM)

RECIRCULATION FLOW LB/HR	GPM	0-OVERALL COEFFICIENT BTU/HR-FT2-F	EXIT QUALITY	STEAM RATE LB/HR	HEAT RATE BTU/HR	PRESSURE DROP PSI	HEAD FT. OF WATER
1000.	2.7	476.9	0.559	558.8	0.433E 06	13.1	40.4
2000.	5.3	509.7	0.299	597.2	0.463E 06	29.6	91.2
3000.	8.0	525.3	0.205	615.5	0.477E 06	48.2	148.3
4000.	10.7	535.2	0.157	627.1	0.486E 06	68.7	211.4
5000.	13.3	542.2	0.127	635.3	0.492E 06	91.0	280.1
6000.	16.0	547.8	0.107	641.8	0.497E 06	115.2	354.5
7000.	18.6	552.2	0.092	647.0	0.501E 06	141.1	434.3

DRUM PRESSURE = 940.PSIA SAT. TEMPERATURE= 537.F.
OVERALL DELTA T= 31.F. SCRAPER SPEED = 180.(RPM)

RECIRCULATION FLOW LB/HR	GPM	0-OVERALL COEFFICIENT BTU/HR-FT2-F	EXIT QUALITY	STEAM RATE LB/HR	HEAT RATE BTU/HR	PRESSURE DROP PSI	HEAD FT. OF WATER
1000.	2.7	488.4	0.572	572.2	0.443E 06	13.4	41.2
2000.	5.3	523.3	0.307	613.1	0.475E 06	30.3	93.3
3000.	8.0	539.8	0.211	632.5	0.490E 06	49.3	151.8
4000.	10.7	550.4	0.161	644.9	0.500E 06	70.3	216.2
5000.	13.3	557.9	0.131	653.7	0.506E 06	93.0	286.3
6000.	16.0	563.8	0.110	660.6	0.512E 06	117.7	362.1
7000.	18.6	568.5	0.095	666.1	0.516E 06	144.1	443.4

DRUM PRESSURE = 940.PSIA SAT. TEMPERATURE= 537.F.
OVERALL DELTA T= 31.F. SCRAPER SPEED = 210.(RPM)

RECIRCULATION FLOW LB/HR	GPM	0-OVERALL COEFFICIENT BTU/HR-FT2-F	EXIT QUALITY	STEAM RATE LB/HR	HEAT RATE BTU/HR	PRESSURE DROP PSI	HEAD FT. OF WATER
1000.	2.7	497.2	0.583	582.6	0.451E 06	13.6	42.0
2000.	5.3	533.8	0.313	625.5	0.485E 06	30.9	95.0
3000.	8.0	551.2	0.215	645.9	0.500E 06	50.2	154.5
4000.	10.7	562.3	0.165	658.8	0.510E 06	71.5	220.0
5000.	13.3	570.2	0.134	668.2	0.518E 06	94.6	291.2
6000.	16.0	576.4	0.113	675.4	0.523E 06	119.6	368.1
7000.	18.6	581.3	0.097	681.1	0.528E 06	146.4	450.5

DRUM PRESSURE = 940.PSIA SAT. TEMPERATURE= 537.F.
OVERALL DELTA T= 31.F. SCRAPER SPEED = 240.(RPM)

RECIRCULATION FLOW LB/HR	GPM	0-OVERALL COEFFICIENT BTU/HR-FT2-F	EXIT QUALITY	STEAM RATE LB/HR	HEAT RATE BTU/HR	PRESSURE DROP PSI	HEAD FT. OF WATER
1000.	2.7	504.3	0.591	590.9	0.458E 06	13.8	42.5
2000.	5.3	542.3	0.318	635.4	0.492E 06	31.3	96.3
3000.	8.0	560.4	0.219	656.6	0.509E 06	50.9	156.7
4000.	10.7	571.9	0.168	670.1	0.519E 06	72.5	223.0
5000.	13.3	580.2	0.136	679.8	0.527E 06	95.9	295.1
6000.	16.0	586.6	0.115	687.3	0.532E 06	121.2	372.9
7000.	18.6	591.6	0.099	693.2	0.537E 06	148.2	456.2

DRUM PRESSURE = 940.PSIA SAT. TEMPERATURE= 537.F.
OVERALL DELTA T= 31.F. SCRAPER SPEED = 270.(RPM)

RECIRCULATION FLOW LB/HR	GPM	A-OVERALL COEFFICIENT BTU/HR-FT2-F	EXIT QUALITY	STEAM RATE LB/HR	HEAT RATE BTU/HR	PRESSURE DROP PSI	HEAD FT. OF WATER
1000.	2.7	510.0	0.598	597.6	0.463E 06	14.0	43.0
2000.	5.3	549.3	0.322	643.6	0.499E 06	31.7	97.5
3000.	8.0	567.9	0.222	665.4	0.515E 06	51.5	158.5
4000.	10.7	579.8	0.170	679.3	0.526E 06	73.3	225.5
5000.	13.3	588.4	0.138	689.4	0.534E 06	97.0	298.4
6000.	16.0	595.0	0.116	697.1	0.540E 06	122.5	376.9
7000.	18.6	600.1	0.100	703.2	0.545E 06	149.8	460.9