CONTRACTOR REPORT

SAND84-8177
UC-62c
Unlimited Release

Molten Salt Steam Generator Subsystem Research Experiment — Executive Summary

Babcock & Wilcox

Prepared by Sandia National Laboratories, Albuquerque, New Mexico 87185 and Livermore, California 94550 for the United States Department of Energy under Contract DE-AC04-76DP00789.

Printed September 1984

Printed in the United States of America
Available from
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes
Printed copy: A02
Microfiche copy: A01

MOLTEN SALT STEAM GENERATOR SUBSYSTEM RESEARCH EXPERIMENT - EXECUTIVE SUMMARY

Phase I: Specification and Preliminary Design

FINAL REPORT

(SAND84-8177)

Prepared for: Sandia National Laboratories
Livermore, California

Prepared by: The Babcock & Wilcox Company

Nuclear Equipment Division
Barberton, Ohio

and

Contract Research Division
Alliance, Ohio

Sandia Contract No. 20-9909A

May, 1982

Abstract

This is the Executive Summary for a study in which steam generator subsystem and component designs were developed for central receiver solar power applications using molten nitrate salt as the primary heat transfer medium. Designs were established for a 100 MWe stand-alone plant and for a 100 MWe fossil-fueled plant which has been 50 percent repowered by solar energy. In the course of this progam, (1) an optimum steam system arrangement was selected for both the stand-alone and repowering applications; (2) cost-effective heat exchanger designs (preheater, evaporator, superheater, and reheater) were established based on conventional fabrication processes; (3) comprehensive subsystem and component specifications were prepared; (4) a control system was designed and characterized, and the system response to selected upset transients was simulated; (5) shop fabrication and field erection plans, schedules, and cost estimates were developed; and (6) development plans intended to resolve design uncertainties and assure user confidence and acceptance were prepared. The complete Phase I final report has been published as SAND82-8177.

EXECUTIVE SUMMARY

The Babcock & Wilcox Company, under contract to Sandia National Laboratories, has completed a study to develop steam generator subsystem and component designs for central receiver solar power applications using molten nitrate salt as the primary heat transfer medium. Subcontractor support was provided by Martin Marietta Corporation, Black & Veatch Consulting Engineers, and the Arizona Public Service Company.

The principal objectives of the program were:

(a) to select an optimum steam system arrangement for both stand-alone and repowering applications

(b) to establish cost-effective heat exchanger designs based on conventional fabrication processes

(c) to prepare comprehensive subsystem and component specifications

(d) to develop shop fabrication and field erection plans, schedules, and cost estimates

(e) to prepare development plans intended to resolve design uncertainties and assure user confidence and acceptance

The subsystem boundary conditions upon which the designs are based are summarized in Table 1.

STEAM GENERATOR CONCEPT SELECTION

A parametric evaluation of steam system arrangements and heat exchanger designs considered most appropriate for solar power service was completed. In the following paragraphs, the candidate designs are described, and the results of pertinent trade studies are presented.

> Steam System - Recirculation, once-through (or Bensen), and spill-over (or Sulzer) steam systems were considered. The principal selection criteria were overall cycle efficiency, total plant and component cost, operational requirements and control system complexity, and water chemistry and balance-of-plant material limitations. Based on this evaluation, the recirculation system was chosen as the preferred arrangement for both stand-alone and repowering applications. The recirculation steam system schematic is shown in Figure 1.

TABLE 1

Steam Generator Subsystem Boundary Conditions

	Stand-Alone (100MWe)	Repowering (50Mwe)
Thermal Rating - MWt	264.2	132.2
Salt Inlet Temp - ^oC (^oF)	566(1050)	566(1050)
Salt Outlet Temp - ^oC (^oF)	288(550)	288(550)
Salt Flow Rate - kg/sec (lb/hrx10^{-6})	603(4.78)	301(2.39)
Steam Throttle Temp - ^oC(^oF)	538(1000)	538(1000)
Steam Throttle Pres - MPa(psia)	12.5(1815)	12.5(1815)
Main Steam Flow Rate - kg/sec (lb/hr x 10^{-6})	96.3(.764)	48.2(.382)
Cold Reheat Stm Temp - ^oC(^oF)	371(700)	371(700)
Hot Reheat Stm Temp - ^oC(^oF)	538(1000)	538(1000)
Hot Reheat Stm Pres - MPa(psia)	3.4(500)	3.4(500)
Reheat Steam Flow Rate - kg/sec (lb/hr x10^{-6})	83.4(.661)	41.6(.330)
Saturation Pressure - MPa(psia)	13.8(2000)	13.8(2000)
Feedwater Temp - ^oC (^oF)	238(460)	238(460)

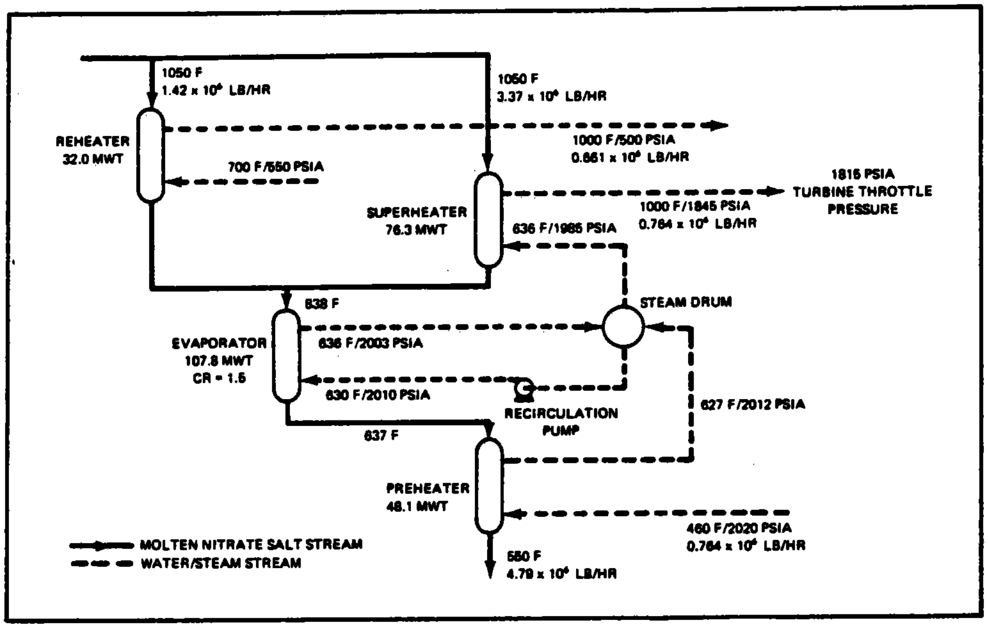


FIG. 1 RECIRCULATION STEAM SYSTEM-PROCESS FLOW SCHEMATIC

The recirculation boiler system is familiar to most users. It is used throughout the power industry for peaking service and other applications where frequent startups and load swings must be accommodated. It is thus uniquely suited to the diurnal cyclic service required in solar power applications.

A once-through system requires high-purity feedwater to avoid deposition of contaminants on evaporator surfaces. Achievement of the necessary water quality at candidate repowering sites would be prohibitively expensive as it would require substantial outlays for new water treatment equipment and high-alloy feedwater heaters. This system is unattractive for both stand-alone and repowering applications, even should adequate condensate polishing equipment be in place, because considerable time would be required to return the feedwater to once-through quality prior to each daily startup.

Inherent in the Sulzer system are high blowdown rates leading to large unrecoverable heat losses. The resultant poor cycle efficiency leads to unacceptable collector and receiver subsystem cost increases.

Heat Exchangers - Numerous heat exchanger configurations, including U-tube, straight-tube, helical coil, and serpentine tube bundles were examined for application in the recirculation steam system. These candidate designs were compared on the basis of performance characteristics, structural integrity and capability for withstanding operational transients, component cost and fabricability, reliability, and maintainability.

Based on this investigation, a horizontal U-tube bundle housed in a straight shell was chosen for the preheater and evaporator, and a U-tube bundle housed in a U-shell for the superheater and reheater. The heat exchanger designs are shown in Figure 2.

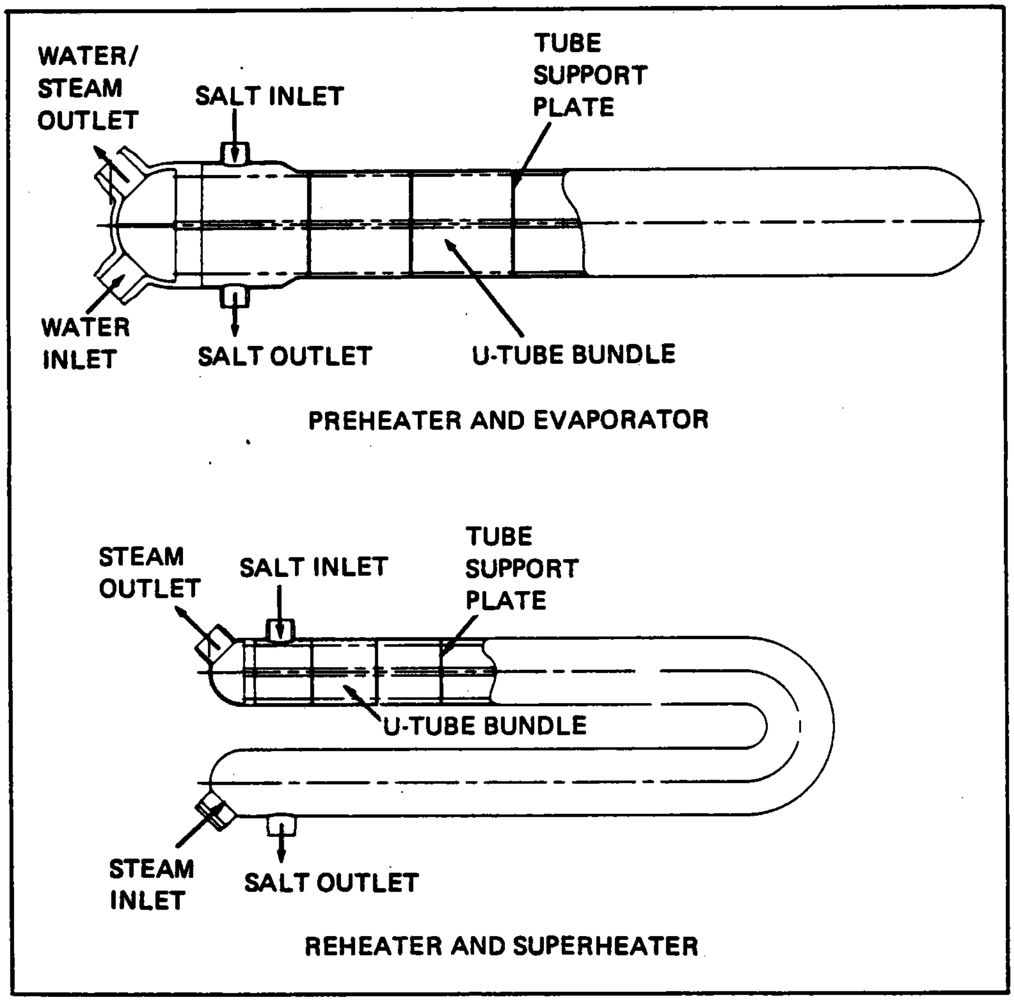


FIG. 2 STEAM GENERATOR COMPONENTS

Both arrangements offer compact tube bundles with efficient counterflow heat transfer. The inherent flexibility of the U-tubes readily accommodates the tube/shell and tube/tube differential thermal expansion characteristic of high-temperature, cyclic solar service. The straight shell configuration is a relatively low-cost assembly used reliably in many applications. However, it is not a suitable arrangement for the superheater and reheater in which the inlet-to-outlet tubeside terminal temperature difference is large, and in which unacceptable thermal stresses will be developed unless the tubesheets are independent. Thus, a U-shell assembly is preferred for these components, although it does present fabrication cost penalties associated with the complex shell closure weld in the bend region.

Straight-tube arrangements also offer compact tube bundles and efficient counterflow heat transfer. The cost of fabrication is typically low. However, when straight tubes are pinned between fixed tubesheets, thermal stresses produced by tube/shell and tube/tube differential thermal expansion are often unacceptable, particularly in high-temperature, cyclic service.

Use of an expansion bellows within the pressure boundary structure is one means of absorbing thermal motion. However, a bellows assembly is considered undesirable because it (a) requires rigorous analytical and/or experimental qualification, (b) requires lateral support, and (c) demands periodic in-service inspection and possibly replacement. It fails to alleviate thermal stresses produced by tube/tube differential expansion, which may occur in superheaters, reheaters, or heat exchangers having a significant amount of surface in subcooled heat transfer. Expansion bends within straight tubes, such as sine-wave bends, may also be used to absorb thermal motion. However, the complexity of the tubing process and tube support arrangement serves to substantially increase fabrication cost.

Helical coil and serpentine tube bundle configurations are superior technical designs, but not cost-effective for solar power service. Their major shortcomings are (a) high fabrication cost associated with the complex tube bundle and tube support assembly, and (b) a high material weight-to performance ratio for applications in which plant thermal ratings are small.

STEAM GENERATOR DESIGN

Hot molten salt, the primary heat source, is delivered to the steam generator from the high-temperature thermal storage tank. The stream is split and apportioned between the superheater and reheater, re-mixed, and delivered in sequence to the evaporator and preheater. The cold salt is then returned to the thermal storage subsystem.

Feedwater is preheated to near saturation temperature and delivered to the steam drum. In the drum, it is mixed with recirculated water and pumped to the evaporator, where a high-quality steam/water mixture is produced. This steam/water mixture is returned to the drum, and the steam and water phases are separated. The saturated steam is then superheated and sent to the high-pressure turbine. A portion of the high-pressure turbine exhaust steam is reheated for expansion in the intermediate and low-pressure stages of the turbine.

The principal geometric characteristics of the steam generator components for the stand-alone (100 MWe) and repowering (50 MWe) applications are summarized in Tables 2 and 3. Material selection and important aspects of the thermal-hydraulic and structural design are discussed in the following paragraphs.

> <u>Material Selection</u> - Component materials were selected to provide adequate strength and corrosion resistance in the operating environments. These materials are summarized below.

Component Materials

Component	Material	Maximum Operating Temperature ^{o}C(^{o}F) Salt-Side	Maximum Operating Temperature ^{o}C(^{o}F) Water-Side
Preheater	Carbon Steel	336(637)	330(627)
Evaporator	2 1/4 Cr-1 Mo	448(838)	336(636)
Superheater	304 Stainless Steel	566(1050)	538(1000)
Reheater	304 Stainless Steel	566(1050)	538(1000)
Steam Drum	Carbon Steel	-	336(636)

TABLE 2

Principal Geometric Characteristics

100 MWe Components

Component	Main Shell O.D. m(in.)	Total Length m(ft)	Tube Dimensions O.D. X Wall mm(in)	No. Of Tubes	Avg. Active Tube Length m(ft)	Primary Surface Area $m^2(ft^2)$
Preheater	1.422 (56.0)	10.448 (34.28)	12.700 X 1.473 (.500 X .058)	2461	18.288 (60.0)	1803 (19410)
Evaporator	1.588 (62.5)	15.225 (49.95)	22.225 X 3.759 (.875 X .148)	1236	27.218 (89.3)	2349 (25280)
Superheater	0.610 (24.0)	7.373 (24.19)	12.700 X 1.651 (.500 X .065)	774	13.868 (45.5)	428 (4610)
Reheater	0.762 (30.0)	8.251 (27.07)	15.875 X .889 (.625 X .035)	870	15.027 (49.3)	652 (7020)

TABLE 3

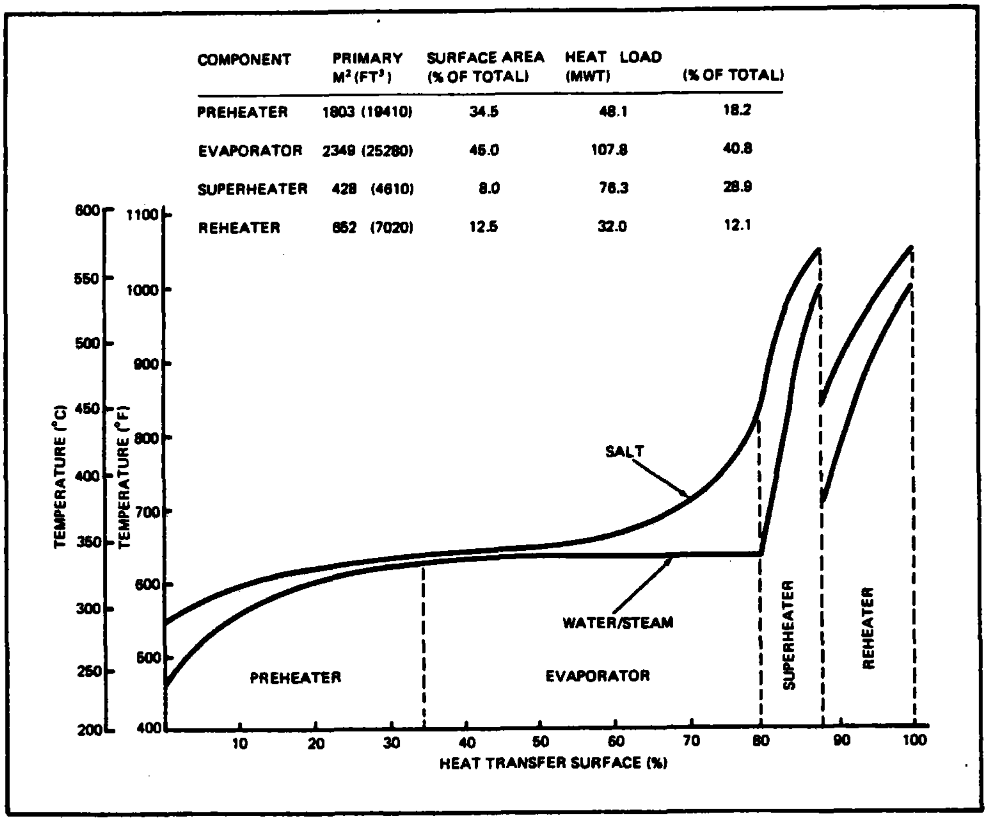
Principal Geometric Characteristics

50 MWe Components

Component	Main Shell O.D. m(in.)	Total Length m(ft)	Tube Dimensions O.D. X Wall mm(in)	No. Of Tubes	Avg. Active Tube Length m(ft)	Primary Surface Area $m^2(ft^2)$
Preheater	1.257 (49.5)	9.836 (32.27)	12.700 X 1.473 (.500 X .058)	1710	17.404 (57.1)	1187 (12780)
Evaporator	1.308 (51.5)	15.057 (49.40)	22.225 X 3.759 (.875 X .148)	775	27.157 (89.1)	1470 (15820)
Superheater	.457 (18.0)	7.705 (25.28)	12.700 X 1.651 (.500 X .065)	396	14.417 (47.3)	228 (2452)
Reheater	.560 (22.0)	8.019 (26.3)	15.875 X .889 (.625 X .035)	442	15.301 (50.2)	337 (3630)

Corrosion allowances were determined based on best available data. However, reported data pertaining to the corrosion resistance of the selected alloys, particularly the low-chromium alloys, in molten nitrate salt is very limited and often exhibits wide scatter. Thus, it will be prudent to re-assess these material choices based on the results of on-going and future test programs. The need for further corrosion testing to support design efforts is discussed later.

Thermal-Hydraulic Design - Predicted fluid temperature profiles throughout the steam generator subsystem, are shown in Figure 3. Design features intended to preclude DNB (departure from nucleate boiling) in the evaporator and assure proper flow distribution in all components are described in the following paragraphs.



COMPONENT	PRIMARY M^2 (FT^3)	SURFACE AREA (% OF TOTAL)	HEAT LOAD (MWT)	(% OF TOTAL)
PREHEATER	1803 (19410)	34.5	48.1	18.2
EVAPORATOR	2349 (25280)	45.0	107.8	40.8
SUPERHEATER	428 (4610)	8.0	76.3	28.9
REHEATER	652 (7020)	12.5	32.0	12.1

FIG. 3 FLUID TEMPERATURE PROFILES

- Ribbed tubing has been used for the final 32 feet of the upper, or steam/water outlet, leg of the evaporator. This represents the zone of highest heat flux and quality, and is consequently most susceptible to DNB and associated under-deposit corrosion which may occur when DNB exists in the presence of porous water-side deposits.

  The ribbed tube construction produces a swirling flow and centrifugal forces that keep the tube surface wetted and maintain nucleate boiling to a higher quality for a given pressure, heat flux, and mass flow rate than with a smooth-bore tube of the same general dimensions. Thus, nucleate boiling is maintained in all circuits without the high circulation rates that lead to increased pumping power requirements and reduced cycle efficiency.

- Since the thermal conductivity of the molten salt is relatively low, the overall resistance to heat transfer is dominated by the shell-side heat transfer resistance. Therefore, salt velocity has been maximized to promote efficient heat transfer, but within pressure drop constraints and within limits necessary to preclude tube vibration.

  Salt inlet flow distribution baffles control tube impingement velocities and limit excitation frequencies. Preferentially broached tube support plates promote crossflow to enhance heat transfer and inhibit salt stratification.

Structural Design - All component pressure boundaries were sized in accordance with Section VIII, Division 1, of the ASME code. As a supplement to this work, thermal-mechanical analyses, using Section VIII, Division 2, as a guide, and elevated temperature evaluations derived from Code Case N-47 were selectively made to assure the structural adequacy of the vessels at critical locations. The analytical work is summarized in Table 4. All calculated stresses were found to be within allowable limits.

TABLE 4

Structural Design Evaluation

Mechanical Stress

- Pressure boundary code calculations were made to establish vessel wall thicknesses.
- Pressure discontinuity analyses were made to assure acceptable tubesheet ligament and shell-tubesheet-head discontinuity stress levels.
- Dead weight and seismic loads were considered to design the vessel saddle supports.
- Allowable piping loads were determined.

Thermal Stress

- Finite element analyses were made to determine the response of the evaporator shell and tubes to imposed longitudinal thermal gradients. It was found that the shell deflections must be restrained to prevent interference with tube bundle growth.
- A finite element analysis of the preheater tubesheet was made to determine secondary stresses resulting from the divider lane temperature gradient.
- Discontinuity stresses resulting from longitudinal thermal gradients in the shell-tubesheet-head junctures of all components were determined.
- Fatigue analyses of the preheater tubesheet ligaments and evaporator shell-tubesheet juncture were made.

Elevated Temperature Effects

- Creep-ratcheting evaluations were made for the superheater and reheater steam-side heads, tubes, and salt-side shell (upper leg).
- Creep-fatigue interaction evaluations were made for the superheater and reheater tubesheet ligaments and head-tubesheet-shell juncture (upper leg).
- Creep-buckling evaluations were made for the superheater and reheater U-bend support region (upper leg).

OPERATION AND CONTROL

The controls for the steam generator subsystem are based on conventional boiler operating practice and provide the following functions required of any well-designed boiler control system:

(a) The superheater steam outlet pressure is controlled by adjustment of molten salt flow rate (analogous to fuel input in conventional practice).

(b) The supply of feedwater is controlled on average to match steam flow and also regulated to maintain a pre-determined steam drum water level.

(c) Final steam temperature is maintained within prescribed limits through attemperation with saturated steam.

(d) Flexibility of operation is provided by including operator automatic-manual transfer stations at appropriate points in the various control loops.

(e) Protection against equipment damage is provided by activation of functional operations which limit temperatures when an established criteria is reached.

A computer simulation was completed to examine the dynamic response of the system to selected normal and upset transients. The events which were analyzed are summarized in Table 5.

TABLE 5

Normal and Transient Events

100-80-100% Load Swing
100-60-100% Load Swing
100-30-100% Load Swing
Turbine Trip
One Recirculation Pump Tripped
Both Recirculaton Pumps Tripped
Feedwater Valve Failed Open
Feedwater Valve Failed Closed
Two Relief Valves Failed Open
One Relief Valve Failed Open
Superheater Salt Valve Closure
Hot Salt Pump Trip
Feedwater Pump Trip
Reheater Salt Valve Closure

The results of the analyses were used to assess the proposed control system, to refine control gain settings, and to provide corroboration of previously predicted steady-state plant performance. In no case were unacceptable thermal loads imposed on the components.

BALANCE OF SUBSYSTEM

The physical arrangement of the major components in the stand-alone (100 MWe) plant is shown in Figure 4. The heat exchangers and steam drum are incorporated into a typical turbine cycle feedwater heater bay that would be associated with a new plant design. The bay is an open space frame structure providing support for the equipment, piping, and platforms. The equipment has been arranged on four levels to accommodate cascade draining of the salt through the heat exchangers into the sump which is located below grade.

The most economical arrangement for the repowering (50 MWe) plant was found to be an outdoor, slab-mounted design with all components except the steam drum located on a concrete pad at grade level. The drum need be elevated only high enough to provide adequate net positive suction head for the recirculation pumps. The salt sump is located adjacent to the slab and below grade to facilitate draining the salt from the heat exchangers and piping. It is clear that the ability to physically lay out the components at grade level is dependent on the choice of forced circulation as the basic operating mode.

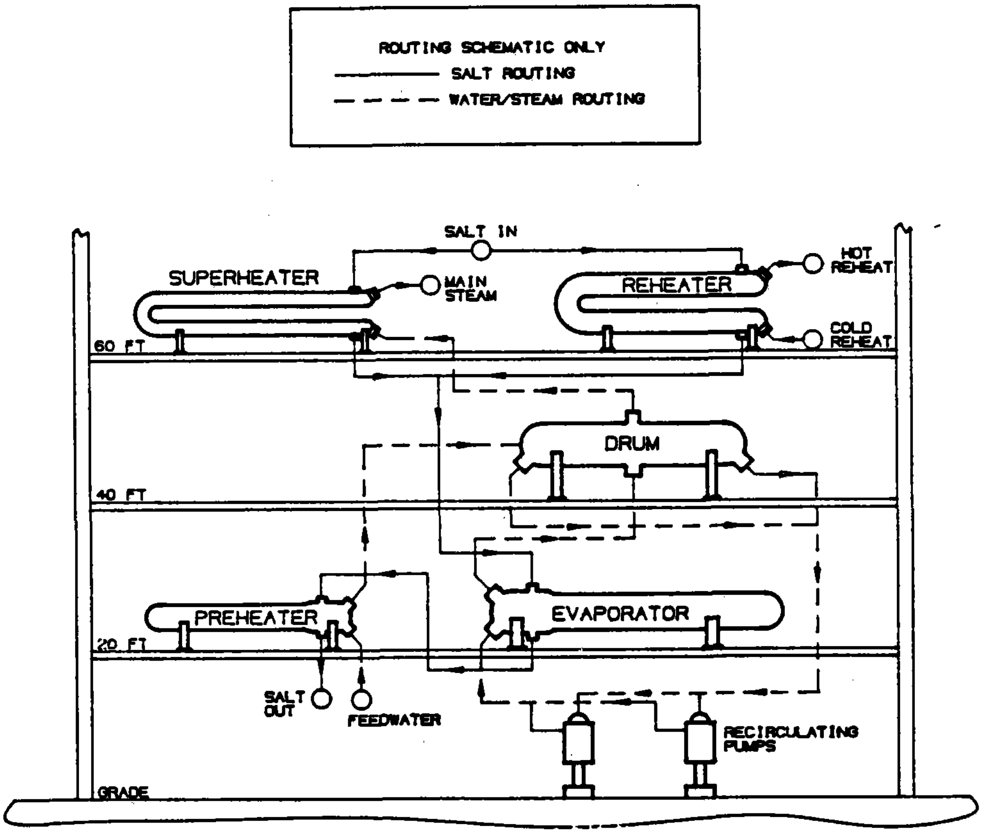


FIG. 4 LAYOUT OF STEAM GENERATOR COMPONENTS IN TURBINE BUILDING

FABRICATION AND FIELD ERECTION PLAN AND COST ESTIMATE

Plans, schedules, and cost estimates were developed for shop fabrication and field erection of the steam generator subsystem. Both a 100 MWe stand-alone plant and a 50 MWe repowered plant were considered.

The proposed construction methods are based on proven, qualified techniques and present no unusual risks or uncertainties. An integrated design, shop fabrication, and field erection schedule, applicable to both the 100 MWe and 50 MWe plants, is shown in Figure 5. Cost estimates are presented in Tables 6 and 7 and have been prepared using standards data, actual costs escalated from previous contracts, material vendor quotations, and catalog prices. Costs are expressed in current dollars (May, 1982).

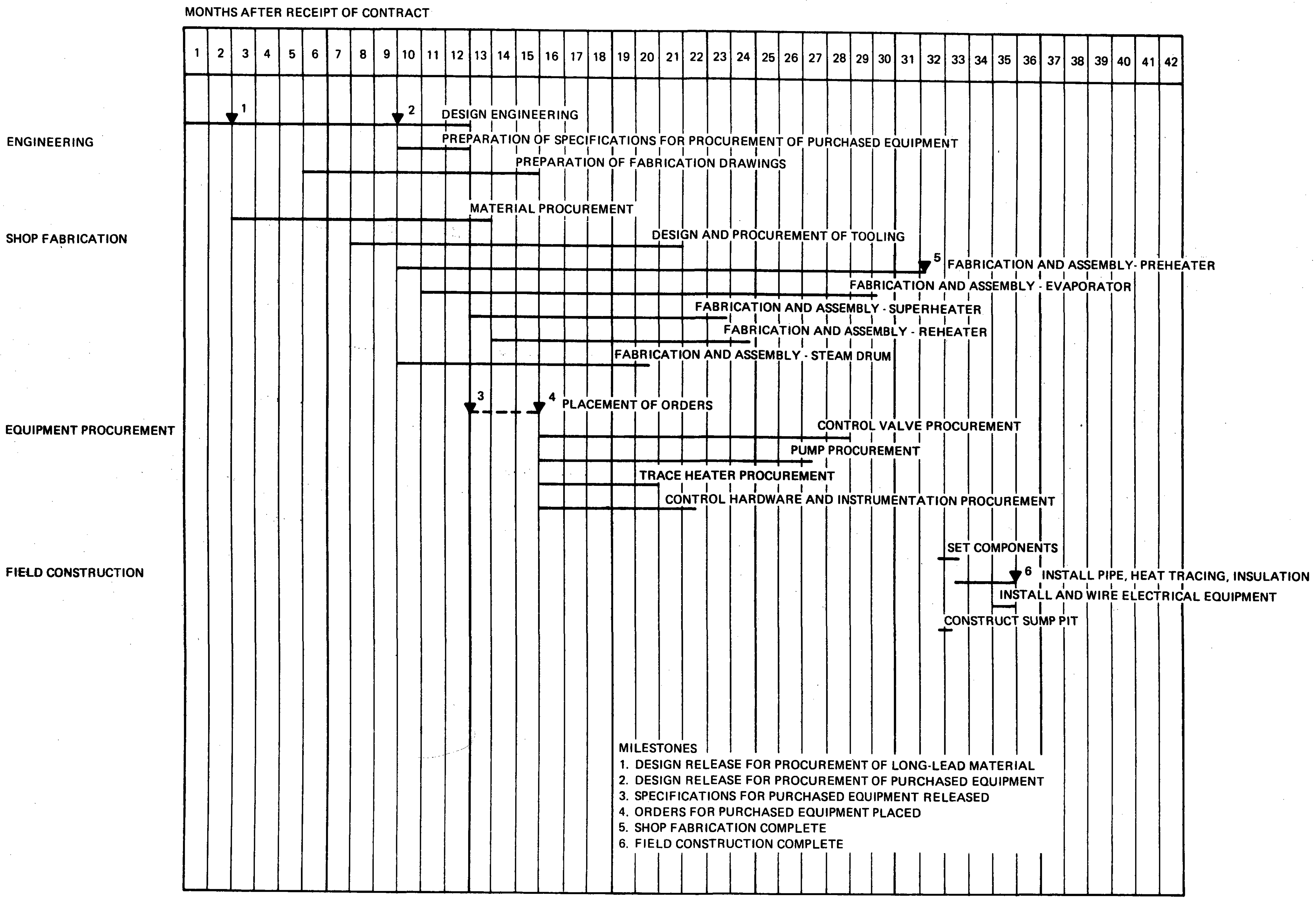
DEVELOPMENT PLAN

A development program has been proposed with the principal objectives of (a) demonstrating to potential users, through subscale modeling (SRE), the design adequacy and operational capability of the steam generator subsystem, and (b) resolving, through SRE and laboratory testing, design and performance uncertainties associated with the full-scale system. The development goals are summarized in the following paragraphs.

Performance Tests - Performance tests have been proposed to verify the analytical predictions upon which the heat exchanger designs are based. Specifically, the accuracy of the salt-side heat transfer correlations would be assessed and the specific heat of the molten nitrate salt would be determined from appropriate flow and temperature distribution measurements and heat balances. The data would then be compared with the assumptions used in the design analyses.

DNB Tests - DNB tests have been proposed to verify that the circulation ratio selected is sufficiently high to maintain nucleate boiling throughout the evaporator. Based on our review of available data, it is believed that the circulation ratio has been chosen conservatively. Accepting that this will be confirmed, the design margin would then be re-assessed to determine if the circulation rate can be reduced. Reduction of the circulation rate would result in some corresponding reducton in heat transfer surface and savings in pump costs.

Corrosion Tests - Corrosion tests have been proposed to better define the salt-side corrosion allowances to be applied to the heat exchanger tubing. If the test data compare favorably with analytical assumptions, no design adjustments would be required. If the data deviate significantly from the analytical assumptions, it would be necessary to re-size the tube bundles of the affected components. Assuming that the original assumptions were conservative, re-sizing would involve a reduction of heat transfer surface.



MILESTONES
1. DESIGN RELEASE FOR PROCUREMENT OF LONG-LEAD MATERIAL
2. DESIGN RELEASE FOR PROCUREMENT OF PURCHASED EQUIPMENT
3. SPECIFICATIONS FOR PURCHASED EQUIPMENT RELEASED
4. ORDERS FOR PURCHASED EQUIPMENT PLACED
5. SHOP FABRICATION COMPLETE
6. FIELD CONSTRUCTION COMPLETE

FIG. 5 DESIGN, FABRICATION AND FIELD ERECTION SCHEDULE

TABLE 6

Cost Estimate for 100 MWe Steam Generator Subsystem

Steam Generator		
Engineering		$ 689,000
Shop Fabrication		
Preheater		1,393,000
Evaporator		1,504,000
Superheater		756,000
Reheater		786,000
Steam Drum		412,000
	Sub-Total	$ 5,540,000
Controls and Instrumentation		$ 415,000
Balance of Subsystem		
Piping		$ 693,000
Valves		577,000
Pumps		317,000
Heat Exchanger and Steam Drum Erection		510,000
Electrical Equipment		254,000
Building/Structure		395,000
Other (insulation, spring hangers, yard pipe supports, and sump)		255,000
	Sub-Total	$ 3,001,000
Construction and Procurement		$ 1,611,000
(field costs, engineering and procurement, and construction services and management)		
	Grand Total	$ 10,567,000

TABLE 7

Cost Estimate for 50 MWe Steam Generator Subsystem

Steam Generator		
Engineering		$ 689,000
Shop Fabrication		
Preheater		1,045,000
Evaporator		1,046,000
Superheater		502,000
Reheater		597,000
Steam Drum		280,000
	Sub-Total	$ 4,159,000
Controls and Instrumentation		$ 415,000
Balance of Subsystem		
Piping		$ 293,000
Valves		427,000
Pumps		293,000
Heat Exchanger and Steam Drum Erection		365,000
Electrical Equipment		242,000
Building/Structure		118,000
Other (insulation, spring hangers, yard pipe supports, and sump)		171,000
	Sub-Total	$ 1,909,000
Construction and Procurement		$ 1,123,000
(field costs, engineering and procurement, and construction services and management)		
	Grand Total	$ 7,606,000

UNLIMITED RELEASE
INITIAL DISTRIBUTION

U.S. Department of Energy (4)
Forrestal Building, Room 5H021
Code CE-314
1000 Independence Avenue, S.W.
Washington, D.C. 20585
Attn: C. Carwile
H. Coleman
F. Morse
M. Scheve

U. S. Department of Energy (2)
P.O. Box 5400
Albuquerque, NM 87115
Attn: D. Graves
J. Weisiger

U.S. Department of Energy
Solar One Field Office
P.O. Box 366
Daggett, CA 92327

U.S. Department of Energy (4)
1333 Broadway
Oakland, CA 94612
Attn: T. Heenan
R. Hughey
G. Katz
W. Lambert

University of California
Environmental Science and Engineering
Los Angeles, CA 90024
Attn: R. G. Lindberg

University of Houston
Solar Energy Laboratory
4800 Calhoun
Houston, TX 77704
Attn: A. F. Hildebrandt

AMFAC
P.O. Box 3230
Honolulu, HI 96801
Attn: G. E. St. John

ARCO Power Systems
7061 S. University, Suite 300
Littleton, CO 80122
Attn: F. A. Blake

ARCO Power Systems
302 Nichols Drive
Hutchins, TX 75141
Attn: R. L. Henry

Arizona Public Service Company
P.O. Box 21666
Phoenix, AZ 85036
Attn: E. Weber

Babcock and Wilcox (3)
91 Stirling Avenue
Barberton, OH 44203
Attn: G. Grant
M. Seale
D. C. Smith

Badger Energy, Inc.
One Broadway
Cambridge, MA 02142
Attn: C. A. Bolthrunis

Bechtel Group, Inc.
P.O. Box 3965
San Francisco, CA 94119
Attn: G. W. Braun

Black & Veatch Consulting Engineers (3)
P.O. Box 8405
Kansas City, MO 64114
Attn: J. C. Grosskreutz
J. E. Harder
S. L. Levy

Boeing Engineering and Construction Company
P.O. Box 3707
Seattle, WA 98124
Attn: R. L. Campbell

California Energy Commission
1516 Ninth St., M/S 40
Sacramento, CA 95814
Attn: A. Jenkins

Combustion Engineering, Inc.
1000 Prospect Hill Road
Winsor, CT 06095
Attn: C. R. Buzzuto

El Paso Electric Company
P.O. Box 982
El Paso, TX 79946
Attn: J. E. Brown

Electric Power Research Institute (2)
P.O. Box 10412
Palo Alto, CA 94303
Attn: J. Bigger
E. DeMeo

Exxon Enterprises, Inc.
P.O. Box 592
Florham Park, NJ 07932
Attn: T. L. Guckes

Foster Wheeler Development Co. (2)
12 Peach Tree Hill Road
Livingston, NJ 07039
Attn: S. F. Wu
R. J. Zoschak

Georgia Institute of Technology
Atlanta, GA 30332
Attn: C. T. Brown

Gibbs and Hill, Inc.
393 Seventh Avenue
New York, NY 10001
Attn: J. J. Jimenez

Institute of Gas Technology
Suite 218
1825 K. Street, N. W.
Washington, D. C. 20036
Attn: D. Glenn

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91103
Attn: M. Alpert

Los Angeles Department of Water and Power
Alternate Energy Systems
P.O. Box 111
111 North Hope St.
Los Angeles, CA 90051
Attn: D. Chu

Martin Marietta Aerospace
P.O. Box 179, MS L0450
Denver, CO 80201
Attn: H. Wroton

McDonnell Douglas Astronautics Company (3)
5301 Bolsa Avenue
Huntington Beach, CA 92647
Attn: R. L. Gervais
H. H. Dixon
C. M. Finch

Meridian Corporation
5113 Leesburg Pike
Falls Church, VA 22041
Attn: R. King

Olin Chemicals Group
120 Long Ridge Road
Stamford, CT 06904
Attn: F. N. Christopher
L. C. Fiorucci

Pacific Gas and Electric Company
77 Beale Street
San Francisco, CA 94105
Attn: R. Molano
R. E. Price

Pacific Gas and Electric Company
3400 Crow Canyon Road
San Ramon, CA 94526
Attn: C. Weinberg

Pioneer Mill Company (AMFAC)
P.O. Box 727
Lahaina, HI 96761
Attn: R. K. MacMillan

Rockwell International
Energy Systems Group
8900 De Soto Avenue
Canoga Park, CA 91304
Attn: T. Springer

Rockwell International
Rocketdyne Division
6633 Canoga Avenue
Canoga Park, CA 91304
Attn: J. M. Friefeld

Solar Energy Industries Association
1140 19th St. N.W.
Suite 600
Washington, D.C. 20036
Attn: C. LaPorta

Solar Energy Research Institute (2)
1617 Cole Boulevard
Golden, CO 80401
Attn: B. Gupta
R. Hulstram

Southern California Edison
P.O. Box 325
Daggett, CA 92327
Attn: C. Lopez

Southern California Edison
P.O. Box 800
Rosemead, CA 92807
Attn: J. N. Reeves
P. Skvarna

Stearns-Roger
P.O. Box 5888
Denver, CO 80217
Attn: W. R. Lang

Stone and Webster Engineering Corporation
P.O. Box 1214
Boston, MA 02107
Attn: R. W. Kuhr

Westinghouse Electric Corporation
Advanced Energy Systems Division
P.O. Box 10864
Pittsbugh, PA 15236
Attn: J. R. Maxwell

E. H. Beckner, 6000; Attn: V. Dugan, 6200
D. G. Schueler, 6220
J. V. Otts, 6222
R. S. Claassen, 8000; Attn: D. M. Olson, 8100
A. N. Blackwell, 8200
D. L. Hartley, 8300
C. S. Selvage, 8000A
C. Hartwig, 8244
M. E. John, 8245
R. C. Wayne, 8400; Attn: L. D. Bertholf, 8430
H. Hanser, 8440
R. L. Rinne, 8470
J. B. Wright, 8450
A. C. Skinrood, 8452
J. C. Swearengen, 8453
J. B. Wright, 8454 (Actg.)

Publications Division 8265, for TIC (27)
Publications Division 8265/Technical Library Processes Division, 3141
Technical Library Processes Division, 3141 (3)
M. A. Pound, 8024, for Central Technical Files (3)