1291

FOSTER WHEELER SOLAR DEVELOPMENT CORPORATION

VOLUME 2

PHASE 1--FINAL REPORT
(APPENDICES A THROUGH F)

MOLTEN SALT STEAM GENERATOR SUBSYSTEM RESEARCH EXPERIMENT

Sandia Contract 20-9909B

Prepared for

Sandia National Laboratories
Livermore, California

September 1982

FWSDC No. 9-71-9202

FOSTER WHEELER SOLAR DEVELOPMENT CORPORATION
12 Peach Tree Hill Road, Livingston, New Jersey 07039

APPENDIX A: PREHEATER/EVAPORATOR PINCH-POINT TEMPERATURE DIFFERENCE

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Appendix A

PREHEATER/EVAPORATOR PINCH-POINT TEMPERATURE DIFFERENCE

A performance parameter that significantly affects the thermal sizing of the preheater and evaporator, as well as the ability of these units to meet part-load performance is the pinch-point temperature difference. The pinch-point temperature difference is defined as the difference between the saturation temperature at which boiling takes place and the salt temperature at the location where saturated water is obtained. Figure 1, which illustrates the full-load variation in salt and steam/water temperature through the SGS, indicates the preheater feedwater outlet and the evaporator salt outlet at the location where the pinch point occurs.

With the main and reheat steam inlet and outlet conditions defined (Sierra Pacific Power Fort Churchill Unit 1, a 5-percent overpressure turbine cycle balance), the parameters determining the pinch-point temperature difference are the drum saturation temperature and the salt inlet and outlet temperatures, which dictate the quantity of salt that must pass through the SGS to meet the required thermal duty. The nominal molten salt temperatures entering and leaving the SGS are respectively 566°C (1050°F) and 288°C (550°F). To compensate for the piping heat losses (hot storage tank to SGS) salt and to also provide a design margin, the fixed salt temperature entering the SGS used for performance calculations is 563°C (1045°F).

Using the nominal salt exit temperature of 288°C (550°F) and a drum pressure of 13.79 MPa absolute (2000 lb/in^{2}a), which has a saturation temperature of 335.4°C

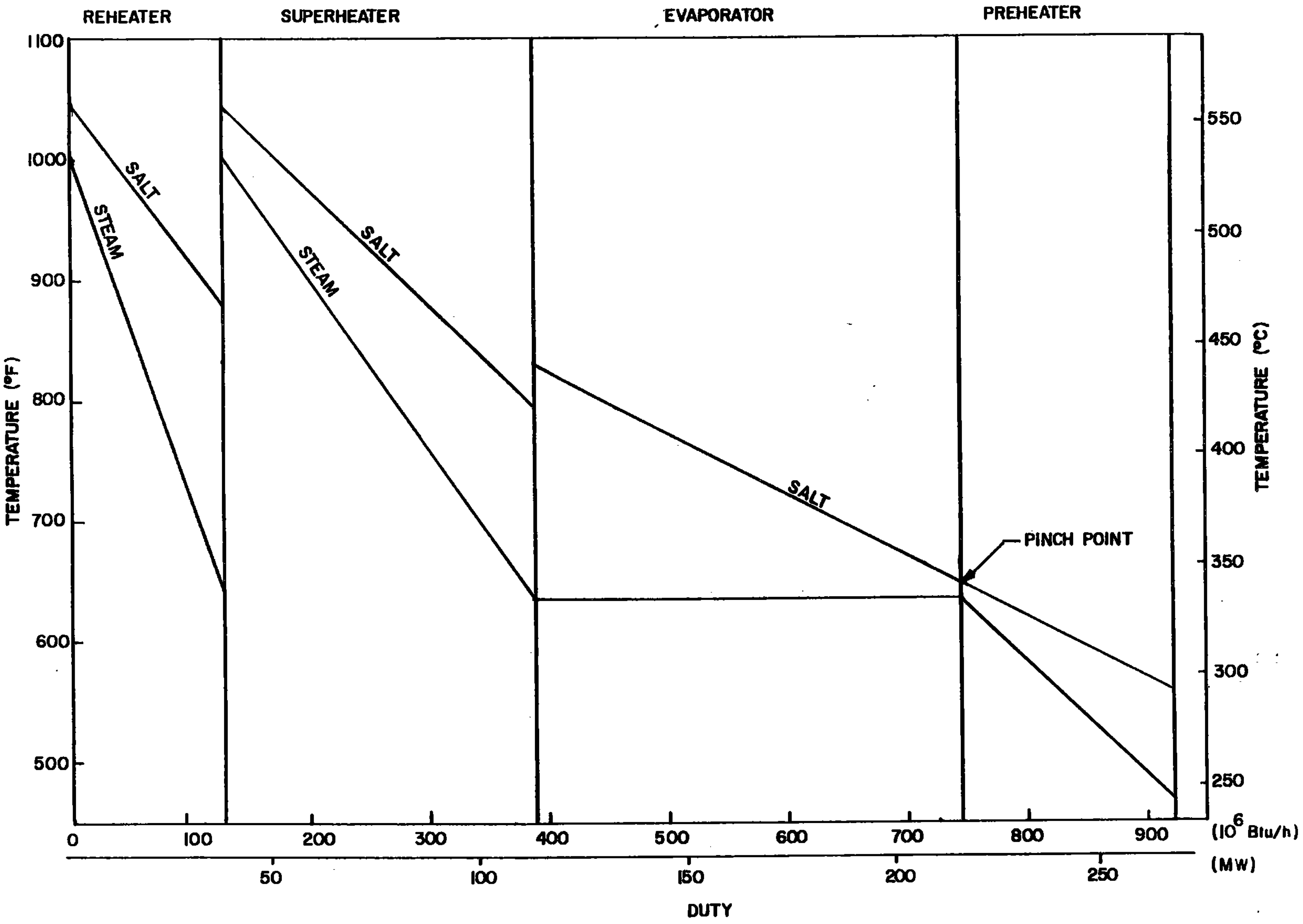

Figure 1 Design-Point Temperature Profile--100 MWe Solar Stand-Alone SGS

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(635.8°F), the pinch-point temperature difference is only 2.6°C (4.6°F). Based on Foster Wheeler heat exchanger design experience, the acceptable pinch-point temperature difference range is 5.6°C (10°F) to 8.3°C (15°F). Consequently, the salt exit temperature must be increased for the pinch point to fall within the acceptable range.

Figure 2 illustrates the variation in pinch-point temperature difference as a function of the salt exit temperature. Also illustrated is the variation in total salt flow rate and the fraction of preheater and evaporator heat-transfer surface required, relative to that required with a salt exit temperature of 288°C (550°F). The change in heat-transfer surface results from the change in log-mean-temperature difference (LMTD).

To obtain a pinch point between 5.6°C (10°F) and 8.3°C (15°F), the salt temperature leaving the preheater must be between 291.3°C (556.4°F) and 294.7°F (562.4°F). Consequently, a salt exit temperature of 293.3°C (560°F) was selected for the final SGS design. The resultant pinch-point temperature difference is 7.3°C (13.1°F), and the salt flow increase is 2.2 percent. In changing the salt exit temperature from 288°C (550°F) to 293.3°C (560°F), the preheater and evaporator heat-transfer surface is reduced 32 and 24 percent respectively.

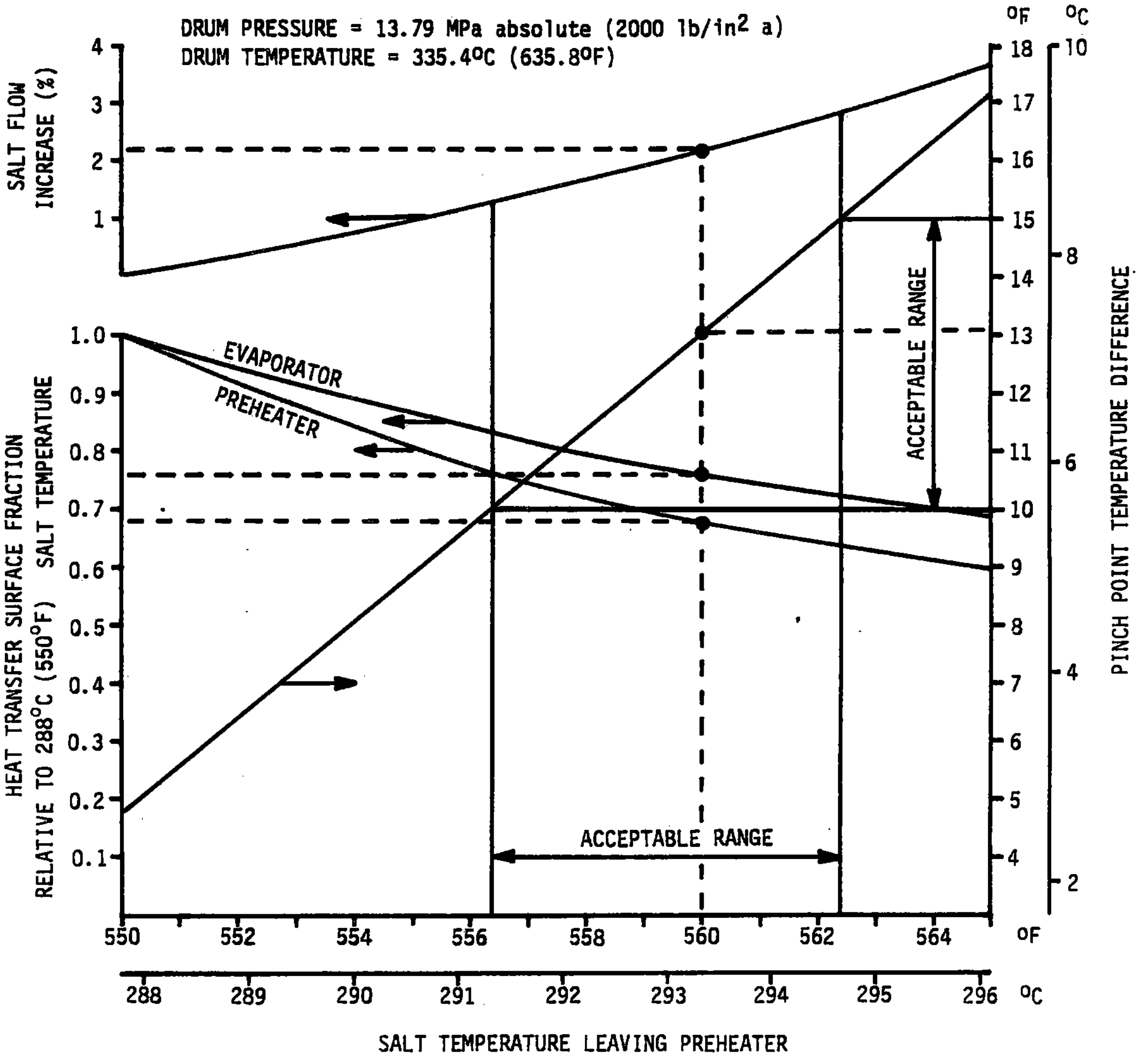

Figure 2 Effect of Salt Temperature Leaving Preheater on Pinch-Point Temperature Difference

APPENDIX B: STEAM GENERATOR SUBSYSTEM REQUIREMENTS AND SPECIFICATION

MOLTEN SALT STEAM GENERATOR SUBSYSTEM RESEARCH EXPERIMENT

Sandia Contract 20-9909B

Prepared for

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Section 1

SCOPE

This specification defines the requirements for and operating characteristics of a molten salt steam generator subsystem (SGS) for the following applications:

- Nominal 100-MWe net solar central receiver electric generating plant (100-MWe solar stand-alone)
- Nominal 100-MWe net fossil-fueled electric power generating plant that is 50 percent repowered by a solar central receiver system (50-MWe hybrid).

Both SGS designs will be capable of supplying main and reheat steam at 538°C (1000°F) and at a rated pressure of 13.12 MPa gage (1903 $\text{lb/in}^2\text{g}$) to a nominal 100-MWe turbine-generator.

The SGSs defined in this specification shall be designed to be site independent to the greatest extent possible. However, to quantify site-dependent design parameters, Yerington, Nevada, was selected as the site location.

Components within the SGS and interface terminal points are defined in Section 3.1.

Section 2

REFERENCES

The following documents of the issue in effect on the date of the contract award form a part of this specification to the extent stated herein.

2.1 STANDARDS AND CODES

- Uniform Building Code - 1976 Edition by International Conference of Building Officials
- OSHA Regulations:
  - OSHA Title 29, Part 1910 - Occupational Safety and Health Standards
  - OSHA Title 29, Part 1926 - Safety and Health Regulations for Construction
- ASME Boiler and Pressure Vessel Code:
  - Section I - Power Boilers, including: ANSI B31.1-1977 Power Piping
  - Section II - Materials Specifications
  - Section VIII - Unfired Pressure Vessels
- NRC Regulatory Guide 1.60
- NRC Regulatory Guide 1.61
- Institute of Electrical and Electronic Engineers (IEEE) Codes, as applicable
- National Fire Protection Association (NFPA) National Fire Codes - 1975
- Human Engineering Design Criteria (MIL-STD-1472)
- SAN 0501-01 "Pattern of Health and Safety Responsibility" - 21 April 1976
- SAN 0499-6 "Summary Safety Plan (RADL 2-24)" - July 1979

- Design, Construction, and Fabrication Standards:
  - Standard of AISC (American Institute of Steel Construction)
  - Standards of ACI (American Concrete Institute)
  - Standards of TEMA (Tubular Exchanger Manufacturers' Association)
  - Standards 650 of API (American Petroleum Institute) - Welded Steel Tanks for Oil Storage

2.2 REQUIRED PERMITS

- Construction order - Public Service Commission
- Offset, operating permit - Division of Environmental Protection
- Environmental Assessment and CRR - Bureau of Land Management
- Cultural Resource Clearance - SHPO
- Aviation Hazard Permit - Federal Aviation Authority

2.3 APPLICABLE LAWS AND REGULATIONS

- Construction Order - Utility Environmental Protection Act Rule 25
- Offset, Operating Permit - Clean Air Act Amendments 1977:
  - Title I--Section 127 Prevention of Significant Deterioration
    - -- Section 128 Visability Protection
    - -- Section 129 Nonattainment Areas
  - Code of Federal Regulations
  - Title 40 Part 51, Appendix S - Emission Offset
- Environmental Assessment and Cultural Resource Report:
  - CFR Title 40, Part 6 - Environmental Assessment
  - Historic Preservation Act 1966 - Public Law 89-665-80, Statute 915
- Cultural Resource Clearance - Historic Preservation Act 1966 - Public Law 89-665-80, Statute 915 (Duplicate copy of CRC is sent to State Historic Preservation Officer)
- Aviation Hazard Permit - Federal Aviation Regulations, Part 77, Subchapter 1

Section 3

TECHNICAL REQUIREMENTS

3.1 STEAM GENERATOR SUBSYSTEM (SGS)

The SGS is schematically illustrated in Figure 3.1. The subsystem shall be a natural-circulation steam generator comprising four shell-and-tube heat exchangers (preheater, evaporator, superheater, reheater) described in Section 3.2; auxiliary equipment defined in Section 3.3; and the associated support structures, foundations, and dikes described in Section 3.4. Components within the 100-MWe solar stand-alone and the 50-MWe hybrid systems shall be essentially the same, except as noted in Sections 3.2, 3.3, and 3.4.

Each SGS shall be designed to generate the following:

	100-MWe Solar Stand-Alone kg/s (lb/h)	50-MWe Hybrid kg/s (lb/h)
Superheated Steam [541°C (1005°F) and 13.48 MPa gage (1955 lb/in²g)]	96.1 (762,900)	48.1 (381,400)
Reheat Steam [541°C (1005°F) and 2.86 MPa gage (415 lb/in²g)]	83.2 (660,300)	41.6 (330,150)

Hot molten salt will enter the system at 563°C (1045°F), flow in parallel through the superheater and reheater, combine, and pass in series through the evaporator and preheater; cold salt will leave the preheater at 293°C (560°F). All heat exchangers will be oriented vertically with all heated steam/water

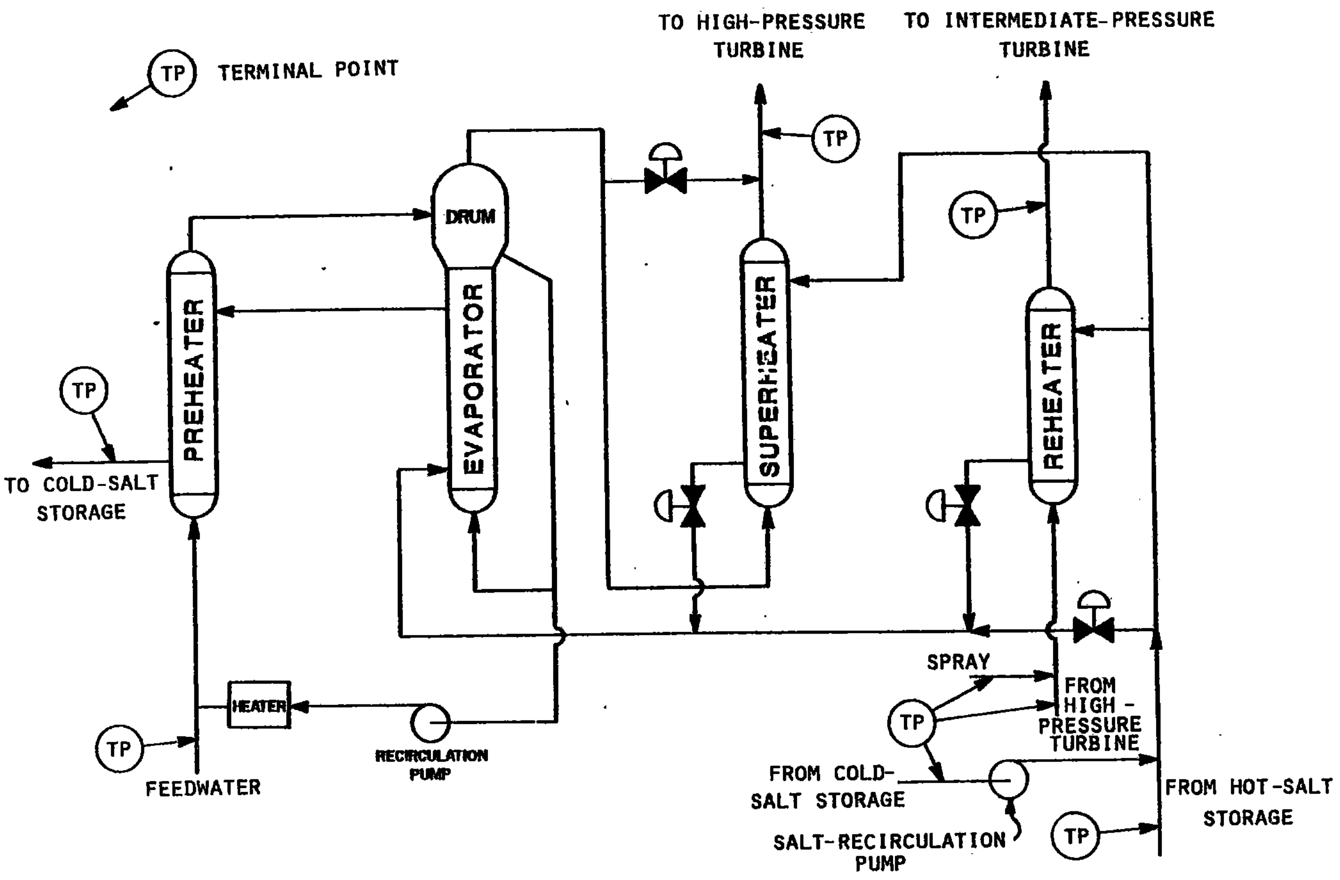

Figure 3.1 Steam Generator Subsystem Schematic

flowing upward. The preheater, superheater, and reheater will be counterflow; the evaporator will be parallel flow to improve natural circulation. A vertical steam drum will be mounted atop the evaporator, and a drum water recirculation pump will maintain the feedwater at a temperature above the salt freezing point [221°C (430°F)] during start-up and part-load operation. A cold-salt recirculation pump will provide salt at temperatures required for unit start-up and shutdown.

Terminal points defining components within the SGS are:

- Salt Side (at boundary of SGS support structure)
    - Hot salt line from thermal storage
    - Cold salt line to thermal storage
- Steam/Water Side (at boundary of SGS support structure)
    - Feedwater line
    - Main steam line to high-pressure turbine
    - Cold reheat line from high-pressure turbine
    - Hot reheat line to intermediate-pressure turbine.

3.2 HEAT EXCHANGERS

3.2.1 General

The heat exchangers (preheater, evaporator, superheater, and reheater) shall be single-pass shell-and-tube exchangers and shall include the following design features:

- Inlet and outlet nozzles for salt and steam/water.
- Safety valves at the superheater outlet, reheater inlet, reheater outlet, and preheater outlet.

- An inlet shroud to protect the tubes against direct impingement of the inlet salt and a flow distribution plate to distribute salt equally into the tube bundle.

- Tube supports/baffles designed and spaced to prevent tube vibration, tube wear, and excessive tube deflection. The support baffles will produce sufficient flow mixing to minimize temperature imbalance between the tubes.

- A heat exchanger support and snubber arrangement to hold the units in positon for all design seismic loads.

- Shell-and-tube design to accommodate the differential thermal expansion between tubes and shell for all design operating conditions.

Other general heat exchanger design requirements shall include the following:

- Integrity. All salt and steam/water boundaries shall be designed to minimize potential leaks. Welded construction will be used for all pressure boundaries.

- Inspection Capability. The heat exchanger design shall permit periodic in-service inspection, maintenance, tube plugging, and weld repair. Particular attention will be paid to tubewalls, tube-to-tubesheet junctions, tubesheet-to-shell junctions, and shell walls.

- Maintenance and Tube Plugging. Provisions shall be made for welded in-place tube plugging and salt removal to facilitate maintenance. The heat exchangers shall be designed so that single tubes can be plugged or tube joints sealed without removal of the tube bundle.

- Safety and Control Instrumentation. All safety and control instrumentation shall be designed for ease of inspection, maintenance, repair, and replacement during a normal shutdown interval.

- Unit Cleanup. Provisions for cleaning excessively fouled heat-transfer surfaces resulting from contaminated feedwater or salt shall be included in the design.

- Venting and Draining. Each heat exchanger shall provide for complete draining of the salt and water from the unit by gravity. Pockets, crevices, and other areas where salt or cleaning reagents might be trapped shall be kept to a minimum. Salt-side vents shall be provided to remove trapped gas during the salt fill.

- Preheat. The heat exchangers shall be designed to permit heat-up before salt fill, from ambient temperature to 249°C (480°F), at a rate that will not create a temperature difference between the tubesheet and shell greater than 93°C (200°F). The heat-up may be performed with a combination of electrical trace heating and feedwater heating.

- Design Service Life. The heat exchangers shall be designed for a total service life of 30 years.

- Transportation. The heat exchangers shall be designed and constructed so that they can be safely shipped by reasonable means to an inland site with railroad and all-weather highway access.

- Environmental Conditions. See Section 4.

3.2.2 Thermal/Hydraulics

The heat exchanger designs shall satisfy the following thermal/hydraulic performance requirements:

- Stable and predictable operation throughout the load range and the transients as defined in Section 3.6.

- Adequacy of the flow distribution profile on both the tube and shell sides for all specified flow rates; pressure and temperature conditions to prevent hot or cold spots, minimize thermal gradients, and thermal transient loadings.

- Provision for elimination or control of thermal stratification, internal recirculation of salt, and reverse flow of water or steam over the operating load range.

- Ensurance that the hydraulic characteristics are consistent with drainage requirements as provided.

- Provisions for adequacy with respect to thermal transients and cycling caused by chugging, flooding, or other phenomena under the specified operating conditions.

- Provision for thermally stable behavior and static and dynamic stability in the tube bundle.

Other thermal/hydraulic heat exchanger design requirements shall include the following:

- Thermal Performance The heat exchangers shall meet the turbine generator temperature, pressure, and flow requirements as defined in Section 3.5.
- Internal Circulation The design shall ensure that internal recirculation of salt and reverse flow of steam/water will not occur under the specified service conditions.
- Heat-Transfer Surface Allowances. The heat-transfer surface shall include allowances for tube plugging, design uncertainties, fouling, and any other factor that may reduce the effective thermal duty during the heat exchanger service life to provide a high level of confidence that full power can be maintained for the life of the unit. The rated thermal duty shall be maintained with 3 percent of the tubes plugged.
- Fouling. Fouling resistance on the salt side and the steam/water side for the design analysis are as follows:

	Fouling Resistance $m^2\cdot{}^\circ C/MW$ ($h\cdot ft^2\cdot{}^\circ F/Btu$)	
Component	Salt	Steam/Water
Preheater	90 (5×10^{-4})	21 (1.5×10^{-4})
Evaporator	90 (5×10^{-4})	54 (3×10^{-4})
Superheater	90 (5×10^{-4})	21 (1.5×10^{-4})
Reheater	90 (5×10^{-4})	21 (1.5×10^{-4})

- Flow Bypass. Flow bypass shall be kept to a minimum. Effects of flow bypass on the required heat-transfer surface area and the possible resultant effects on the temperature distribution shall be accounted for in the design.
- Thermal Transients. An analysis shall be performed to evaluate the response of the heat exchangers to water and salt inlet flow and temperature transients.

- Pressure Drop. The total salt pressure drop through the SGS shall not exceed 1.03 kPa (150 lb/in²). The reheater pressure drop shall not exceed 0.21 kPa (30 lb/in²). Steam/water pressure drop through the preheater, evaporator, and superheater shall be sufficient to ensure stable flow over the operating load range without using excessive pumping power.

- Orifices. Orifices shall be used as deemed necessary for stable flow.

3.2.3 Structural

The structural design of the heat exchanger shall be in accordance with the applicable codes as defined in Section 2. The heat exchangers shall be capable of withstanding the combined effects of seismic loads, dead loads, and thermally induced loads. Other structural requirements shall include the following:

- Corrosion Allowance

		Corrosion Allowance (mil)	
Component	Tube Material	Tube Side	Shell Side*
Preheater	CS	5†	---
Evaporator	1-1/4%Cr-1/2%Mo	5†	---
Superheater	Type 304SS	---	---
Reheater	Type 304SS	---	---

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*Values listed are preliminary and are subject to change as more salt corrosion data becomes available.

†To allow for acid cleaning.

- Structural Design Conditions. The heat exchangers shall be designed structurally according to the following conditions:

	Design Pressure MPa gage (lb/in n^{2}g)		Design Temperature °C (°F)	
	Tube Side	Shell Side	Tube Side	Shell Side
Preheater	15.51 (2250)	2.07 (300)	371 (700)	371 (700)
Evaporator	15.34 (2225)	2.07 (300)	371 (700)	468 (875)
Superheater	15.34 (2225)	2.07 (300)	566 (1050)	566 (1050)
Reheater	3.96 (575)	2.07 (300)	566 (1050)	566 (1050)

- Thermal Stresses. The heat exchangers shall accommodate differential expansion between individual tubes (including up to seven adjacent plugged tubes), tubes and shells, and any connected parts of the steam generator without exceeding allowable Code stresses. Regions of discontinuities such as nozzles, tubesheet-to-shell areas, tube-to-tubesheet joints, and thick sections such as tubesheets shall be recognized as those with potentially higher thermal stresses, and baffling shall be provided if needed.

- Vibration. The steam generator, including all internals, shall be designed to preclude damage or malfunction caused by internally generated vibrations. Baffles and tube support plates, tie-rods,impingement plates, and other internals shall be provided so that the natural frequencies of all unsupported spans are at least 50 percent higher than hydrodynamically generated frequencies in the flow range from 0 to 100 percent. The heat exchangers shall be designed to avoid damage from shock and vibration during shipping. The vibration analyses shall show that the maximum amplitude of tube vibration does not exceed 25 percent of the nominal distance between the outer surfaces of adjacent tubes and that the applicable Code case requirements for stress limit are satisfied.

3.2.4 Salt and Boiler Feedwater

3.2.4.1 Salt. The molten salt shall be a mixture of 60 wt% sodium nitrate and 40 wt% potassium nitrate. The salt shall be maintained at a high purity level by means of a salt purification loop, which is not within the scope of the solar SGS. The salt shall have the following thermophysical properties:

Temperature (°C)	Specific Heat (cal/g•°C)	Absolute Viscosity (Pa•s) x 10^3	Density (g/cm^3)	Conductivity (W/m•°C)
300	0.357	3.22	1.899	0.500
350	0.359	2.29	1.867	0.510
400	0.361	1.80	1.836	0.519
450	0.363	1.43	1.804	0.529
500	0.366	1.21	1.772	0.539
550	0.368	1.05	1.740	0.548
600	0.370	0.93	1.708	0.558

3.2.4.2 Boiler Feedwater. The boiler feedwater shall be maintained at the following purity level by a feedwater treatment facility, which is not within the scope of the solar SGS:

Total hardness - $CaCO_3$ (ppm)	0
Organics (ppm)	0
pH	8.5 to 9.2 nonferrous tubes 9.2 to 9.6 steel tubes
Oxygen (ppm)	0.007
Silica (ppm)	0.02
Iron (ppm)	0.01
Copper (ppm)	0.005
Hydrazine	0.02

Water and steam properties shall be obtained from the ASME Steam Tables, 1967 Edition.

3.2.5 Connections, Accesses, and Appurtenances

Connections, accesses, and appurtenances shall meet the following requirements:

- Accessibility for Inspection. Access to the tube side of the units shall be through the steam/water piping nozzles or channel by removing a bolted manway connection or with minimum cutting of the pipes welded to the nozzles. Access for inspection of the shell side shall be through 152-mm (6-in.) inspection nozzles below the upper tubesheet.
- Insulation Supports. Supports shall be provided on the exterior of the heat exchangers for the application of insulation. Insulation supports shall be welded to the exterior before installing the insulation in the field.
- Identification Plates. Identification plates and support brackets shall be furnished, and the plates will be mounted so that they are visible after installation of the thermal insulation. The plates shall be in conformance with the Code.
- Lifting and Handling. Lifting lugs or other appropriate lifting devices shall be provided to permit safe handling during shipment, installation, operation, and maintenance for the life of the unit. Special lifting and handling equipment, exclusive of chains, slings, and tackle, shall be supplied to permit lifting and handling of the empty heat exchanger components using standard construction lifting equipment.
- Foundation and Support Structures. The heat exchangers shall include the necessary supports to match the purchaser's foundations or support structure, to be specified later.
- Piping Connections. All piping connections shall be covered with suitable plugs to prevent water and other contaminants from leaking in during shipment, storage at the construction site, and erection.
- Threaded Elements and Bolts. Threaded connections shall conform to the following requirements:
  - All screw threads shall be in accordance with ANSI B1.1.
  - Protectors and/or lubrication shall be applied to all threaded parts to prevent damage and degradation.

3.2.6 Materials of Construction

The heat exchanger materials of construction shall be as follows:

	Preheater (CS)	Evaporator (1-1/4%Cr-1/2%Mo)	Drum (CS)	Super-heater (304SS)	Reheater (304SS)
Forgings	SA-266 Gr 4	SA-182-F-11	SA-266 Gr 4	SA-182	SA-182
Heads	SA-515 Gr 65	SA-387 Gr 11 Cl 1	SA-515 Gr 65	SA-240	SA-240
Plates	SA-515 Gr 65	SA-387 Gr 11 Cl 1	SA-515 Gr 65	SA-240	SA-240
Nozzles	SA-266 Gr 4	SA-182-F-11	SA-266 Gr 4	SA-182	SA-182
Bellows	SA-376 (304SS)	SA-376 (304SS)	---	SA-376	SA-376
Tubing	SA-556 Gr B2	SA-213 T11	---	SA-213	SA-213
Pipe	---	SA-335 P11	SA-106 Gr B	---	---
Tie-rod Nuts	SA-194 Gr 7	SA-194-7	---	SA-194	SA-194
Tie-rod Spacers	SA-106 Gr B	SA-335 P11	---	SA-376	SA-376
Tie-rods	SA-193 Gr B7	SA-193 B7	---	SA-193	SA-194

Material properties shall be selected from the applicable codes defined in Section 2. The heat exchanger tubes shall be hydrotested and eddy-current tested. The hydrotesting fluid shall be subject to the purchaser's approval, in particular for stainless steel tubes, to avoid contamination. Tubes shall be shipped and packaged dry. Preservatives that leave a film are not permitted.

3.2.7 Fabrication

- Construction Codes
  - The heat exchanger components shall be constructed in accordance with the ASME Code, Section VIII-Division 1; TEMA Class "R"; and as specified herein. ASME certification is to be provided for each unit.
  - All personnel used in manufacturing shall be qualified to the extent required by the ASME Code.
  - A Manufacturing and Inspection Plan shall be compiled giving the major fabrication and inspection steps planned. It shall include the overall sequence for fabrication, cleaning, inspection, NDE, welding, heat treatments, assembly, testing, and handling. The procedures requiring approval and qualification shall be specified.

- <u>Welding</u>
  - The heat exchangers shall be of all welded construction except as approved by the customer. Welding procedures shall be qualified in accordance with Section IX of the ASME Code.
  - Weld repair can be performed if made in accordance with the requirements of the Code.
  - All tubes shall be welded to the tubesheet using a qualified and approved welding procedure. In addition, the tubes shall be suitably expanded to the tubesheets. Production tube-to-tubesheet welds shall be visually examined as well as penetrant tested.
  - The supplier shall develop and demonstrate a means of plugging tube holes in the event leaks develop during operation of the units.

- <u>Heat Treatment</u>. All heat treatment during manufacturing shall be in accordance with the Code. The heating cycle on the unit shall be recorded.

- <u>Fabrication Mockups</u>. The supplier shall demonstrate difficult, new, or unusual procedures with mockups.

- <u>Bending and Forming</u>. Bending and forming operations shall be in accordance with the Code. The wall thickness after forming shall not be less than the minimum design thickness.

- <u>Plating and Coatings</u>. Plating and coatings shall not be permitted on surfaces in contact with salt or steam/water.

- <u>Cleaning</u>
  - <u>Interior Surfaces</u>. The interior surfaces of carbon and low-alloy steels shall be shotblasted. These surfaces shall then be cleaned to remove loose mill scale, foreign matter, and debris. Stainless steel surfaces shall be wiped clean.
  - <u>Exterior Surfaces</u>. For carbon and low-alloy steels, exterior surfaces shall be cleaned for painting with one coat of red oxide shop primer. Stainless steel surfaces shall not be painted.

- <u>Hydrotesting and Inerting</u>
  - Hydrotesting shall be performed using clean water. An inhibitor which leaves no residue after drying can be used in the water for carbon and low-alloy steel units. For the stainless steel units, demineralized water with a chloride content of no more than 10 ppm shall be used.

  - After hydrotesting each side of the heat exchanger separately, the unit shall be dried by applying a vacuum. After drying is complete, the vacuum shall be relieved using dry nitrogen. The unit shall be sealed and a pressure of 69 kPa gage (10 lb/in²g) applied to the tubes and shell. Suitable gages shall be installed to indicate the pressure. In addition, refill valves shall be provided for recharging, if necessary.

- Preparation for Shipment
  - The units shall be skidded and fastened to the transport vehicle to prevent shifting or damage during shipment.
  - The stainless steel units shall be covered with tarpaulins to prevent contamination by salt or chemical spray during transport.

- Unloading and Handling at the Job Site. The supplier shall compile a procedure to be submitted to the purchaser before shipment, giving a recommended method of unloading, handling, and storing the units at the job site.
  - The supplier shall provide, if required, any special handling rig for handling (exclusive of chains, sling, or tackle).
  - The procedure shall outline precautions and method of unloading and handling for storage and installation.
  - A recommended program of preservation maintenance shall be outlined.

3.3 SGS AUXILIARY EQUIPMENT

3.3.1 Piping

Interconnecting piping within the SGS terminal points shall be provided to transport molten salt, boiler water, and steam. The applicable Code requirements defined in Section 2 and corrosion allowance criteria for the selected materials and service application shall be used in determining wall-thickness requirements. The piping shall be arranged with adequate flexibility to permit thermal expansion and to minimize loadings on heat exchanger nozzle connections; the piping shall also be completely drainable. Welded connections shall be used.

3.3.2 Salt Recirculation Pumps

Salt recirculation pumps shall be provided to blend cold molten salt from the cold thermal storage tank with hot salt from the hot thermal storage tank to meet the inlet salt temperature requirements during unit start-up and shutdown. The pump shall be sized for 15 percent of the full-load total salt flow rate. Two 100-percent-capacity pumps shall be provided.

3.3.3 Boiler Water Recirculation Pumps

Boiler water recirculation pumps shall be provided to circulate water from the steam drum to the preheater inlet to maintain the feedwater temperature above the salt freezing point [221°C (430°F)] during unit start-up, shutdown, and low-load operation. The pumps shall be sized for approximately 15 percent of the full-load feedwater flow rate. Two 100-percent-capacity glandless in-line centrifugal pumps shall be provided.

3.3.4 Insulation and Lagging

Insulation and lagging shall be provided for the heat exchangers, steam drum, interconnecting piping, valves, and all other SGS components that are potentially a significant heat-loss source to ambient and that require protection for personnel. The casing temperature shall not exceed 66°C (150°F).

3.3.5 Trace Heating

All SGS components containing molten salt shall be equipped with electrical trace heaters. The trace heaters shall be designed to preheat each component from ambient temperature to 249°C (480°F). The trace heaters will also be able to maintain each component at 249°C (480°F) with -18°C (0°F) ambient temperature on a calm day.

3.3.6 Salt Drainage System

A salt drainage tank shall have sufficient volume to store 5 min of salt flow at the full-load operating condition. Salt drain to the tank shall be by gravity feed. A salt pump shall be provided to circulate salt to the cold storage tank and to permit drainage of the heat exchangers and interconnecting SGS pipes in 120 min.

3.3.7 Instruments and Controls

Instruments and controls shall be provided to monitor and ensure safe, stable operation of the SGS. The following parameters shall be monitored and controlled:

- Feedwater flow rate
- Feedwater temperature
- Drum water level
- Drum steam pressure
- Drum blowdown rate
- Main steam flow rate
- Final main steam temperature
- Reheater flow rate*
- Heat exchanger shell temperature[†]
- Reheater outlet steam temperature
- Reheater inlet temperature[†]
- Spray flow rates
- Salt inlet temperature
- Salt outlet temperature[†]
- Total salt flow rate
- Bypass salt flow rate
- Heat tracing power input
- Drum head temperature[†]

Control valves shall be either pneumatically or electronically actuated.

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*Monitored for solar stand-alone only.
[†] Monitored, not controlled.

3.3.8 Steam Drum

A vertical steam drum shall be provided as an integral component of the evaporator to deliver dry, saturated steam to the superheater. Carry-over from the drum shall not exceed 1.0 ppm. The drum boiler water shall not exceed the following limits:

Total dissolved solids (ppm)	50
Suspended solids (ppm)	0
Total alkalinity (ppm)	0
pH	10.5
Phosphate (ppm)	10
Sulfite (ppm)	0

The steam drum shall be equipped with a feedwater distribution pipe; steam separators, chevron driers; a manway; and connections for blowdown lines, safety valves, drum level controls, chemical feed lines, downcomers, and the steam outlet.

3.3.9 Safety Valves and Shell Pressure-Relief Devices

Code requirements specify that safety valves shall be located at the reheater steam inlet, reheater steam outlet, superheater steam outlet, steam drum, and preheater outlet. Relief flow rates and settings shall be established in accordance with Code requirements. Shell pressure-relief devices shall be located in the inlet and outlet salt piping of each heat exchanger to prevent overpressurizing of the shell in the event of a tube rupture. Piping to a dump tank shall be provided. The dump tank shall be equipped with guide vanes to separate the gaseous products from the liquid. Gaseous products shall be vented to the atmosphere.

3.4 SUPPORT STRUCTURE, FOUNDATIONS, AND DIKES

A structure shall be provided to support and provide access to the heat exchangers, steam drum, interconnecting piping, and all other SGS components requiring support to conform with the environmental criteria as defined in Section 4. A foundation shall be provided for the support structure, pumps, and tanks that fall within the scope of the SGS. A soil-bearing load of 24.4 Mg/m^2 (5000 lb/ft^2) shall be used for foundation design. The foundation shall be designed with a dike to contain the salt content of the SGS in the event of a salt leak.

3.5 BALANCE OF PLANT INTERFACES

3.5.1 Thermal Storage Subsystem

Molten salt used by the SGS shall be supplied from a dual-tank thermal storage subsystem. The thermal storage subsystem shall have the following design characteristics:

	100-MWe Solar Stand-Alone		50-MWe Hybrid	
Storage capacity, MWh	1904		952	
Hot tank fluid temperature, °C (°F)	566	(1050)	566	(1050)
Cold tank fluid temperature, °C (°F)	293	(560)	293	(560)
Hot tank maximum discharge rate, kg/s (10^3 lb/h)	633.5	(5028)	316.8	(2514)
Cold tank maximum discharge rate,* kg/s (10^3 lb/h)	95.0	(754)	47.5	(377.0)
Cold tank maximum charge rate, kg/s (10^3 lb/h)	633.5	(5028)	316.8	(2514)
Hot salt pump type	Constant speed, centrifugal			

---

*Based on cold-salt recirculation rate to SGS.

3.5.2 Turbine-Generator

The SGS shall be designed to generate main and reheat steam for a nominal 100-MWe net steam turbine-generator. The steam turbine-generator for both the 100-MWe solar stand-alone and the 50-MWe hybrid design shall be identical. For the purpose of defining SGS performance requirements over the operating load range, the Sierra Pacific Power Fort Churchill Unit 1 turbine-generator shall be used.

The turbine is a General Electric tandem compound, reheat, double-flow, condensing, 3600 r/min unit designed for 12.5 MPa gage (1800 lb/in^2g), 538°C (1000°F) main steam, and 538°C (1000°F) reheat steam. There are five uncontrolled feedwater heater extraction points. The turbine has a maximum capability of 115 MW when operating at 5-percent throttle overpressure [13.1 MPa gage (1903 lb/in^2g)].

The generator is a hydrogen-cooled, 3-phase, 60-cycle, 13,800-V, 36,000-r/min unit, rated at 135.3 kVA at 0.85 power factor and 0.2 MPa gage (30 lb/in^2g) hydrogen pressure.

The turbine steam temperature, pressure, and flow requirements that the 100-MWe solar stand-alone SGS and the 50-MWe hybrid SGS must meet are listed in Tables 3.1 and 3.2 respectively. Part-load SGS performance is defined as the percentage of the design point main steam flow.

3.5.3 Feedwater Cycle

The feedwater cycle for the SGS shall provide boiler feedwater at temperatures, pressures, and flow rates as dictated by the selected nominal 100-MWe

Table 3.1 100-MWe Solar Stand-Alone Turbine Interface Requirements

Solar SGS Load, % Design Steam Flow	100*	75	50	25
Generator Load, % Design (approximate)	100	75	50	25
High-Pressure Feedwater Heater Outlet:				
Flow rate, kg/s (10^3 lbm/h)	96.85 (766.67)	72.70 (575.00)	48.40 (383.34)	25.09 (198.13)
Temperature, °C (°F)	237.80 (460.00)	222.50 (432.50)	210.30 (410.50)	201.70 (395.10)
Pressure, MPa absolute (lb/in^{2}a)	---	---	---	---
High-Pressure Turbine Inlet:				
Flow rate, kg/s (10^3 lbm/h)	96.12 (762.86)	72.09 (572.14)	48.06 (381.43)	24.03 (190.72)
Temperature, °C (°F)	537.80 (1000.0)	537.80 (1000.0)	537.80 (1000.0)	537.80 (1000.0)
Pressure, MPa absolute (lb/in^{2}a)	13.12 (1902.60)	13.12 (1902.60)	13.12 (1902.60)	13.12 (1902.60)
High-Pressure Turbine Outlet:				
Flow rate, kg/s (10^3 lbm/h)	83.19 (660.28)	62.97 (499.75)	42.38 (336.32)	21.25 (168.67)
Temperature, °C (°F)	342.00 (647.60)	324.60 (616.20)	309.10 (588.30)	298.70 (569.60)
Pressure, MPa absolute (lb/in^{2}a)	3.19 (463.20)	2.46 (356.50)	1.68 (243.50)	0.94 (136.50)
Intermediate-Pressure Turbine Inlet:				
Flow rate, kg/s (10^3 lbm/h)	83.19 (660.28)	62.97 (499.75)	42.36 (336.32)	21.25 (168.67)
Temperature, °C (°F)	537.80 (1000.0)	537.80 (1000.0)	537.80 (1000.0)	537.80 (1000.0)
Pressure, MPa absolute (lb/in^{2}a)	2.91 (421.90)	2.20 (319.20)	1.47 (213.60)	0.77 (112.10)

---

*Solar SGS design point.

Table 3.2 50-MWe Hybrid Turbine Interface Requirements

Solar SGS Load, % Design Steam Flow	50*	50	50	25	12.5	12.5
Fossil SG Load, % Design Steam Flow	50	25	0	0	87.5	25
Generator Load, % Design (approximate)	100	75	50	25	100	37.5
High-Pressure Feedwater Heater Outlet:						
Flow rate, kg/s (10^3 lbm/h)	48.54 (383.34)	48.54 (383.34)	48.54 (383.34)	25.09 (198.13)	12.20 (95.83)	12.20 (95.83)
Temperature, °C (°F)	239.60 (460.00)	218.50 (425.30)	207.40 (410.50)	201.70 (395.10)	238.20 (460.00)	193.30 (380.00)
Pressure, MPa absolute (lb/in^2 a)	---	---	---	---	---	---
High-Pressure Turbine Inlet:						
Flow rate, kg/s (10^3 lbm/h)	48.06 (381.43)	48.06 (381.43)	48.06 (381.43)	24.03 (190.72)	12.01 (95.36)	12.01 (95.36)
Temperature, °C (°F)	537.80 (1000.0)	537.80 (1000.0)	537.80 (1000.0)	537.80 (1000.0)	537.80 (1000.0)	537.80 (1000.0)
Pressure, MPa absolute (lb/in^2 a)	13.12 (1902.60)	13.12 (1902.60)	13.12 (1902.60)	13.12 (1902.60)	13.12 (1902.60)	13.12 (1902.60)
High-Pressure Turbine Outlet:						
Flow rate, kg/s (10^3 lbm/h)	41.59 (330.14)	41.97 (333.17)	42.38 (336.32)	21.23 (168.67)	10.38 (82.41)	10.66 (84.65)
Temperature, °C (°F)	342.22 (648.0)	318.70 (605.70)	302.70 (576.80)	298.70 (569.60)	341.60 (646.80)	284.70 (544.40)
Pressure, MPa absolute (lb/in^2 a)	3.19 (463.20)	2.46 (356.50)	1.68 (243.50)	0.94 (136.50)	3.15 (497.00)	1.29 (187.40)
Intermediate-Pressure Turbine Inlet:						
Flow rate, kg/s (10^3 lbm/h)	41.59 (330.14)	41.97 (333.17)	42.38 (336.32)	21.25 (168.67)	10.38 (82.41))	10.66 (84.65)
Temperature, °C (°F)	537.80 (1000.0)	537.80 (1000.0)	537.80 (1000.0)	537.80 (1000.0)	537.80 (1000.0)	537.80 (1000.0)
Pressure, MPa absolute (lb/in^2 a)	2.96 (430.0)	2.27 (328.60)	1.47 (213.60)	0.77 (112.10)	2.99 (433.0)	1.20 (173.40)

---

*Solar SGS design point.

turbine-generator. Consequently, the Sierra Pacific Power, Fort Churchill Unit 1 feedwater cycle shall be used to define feedwater requirements. The selected feedwater cycle includes the following:

- Condenser
- Condensate pump
- Low-pressure feedwater heaters
- Deaerator
- Boiler feed pump
- High-pressure feedwater heaters
- Feedwater treatment facility

SGS performance requirements as dictated by the selected feedwater cycle are described in Tables 3.1 and 3.2 for the 100-MWe solar stand-alone and the 50-MWe hybrid units.

3.5.4 Fossil-Fuel-Fired Steam Generator

The fossil-fuel-fired steam generator requirements apply to the 50-MWe hybrid SGS only. For the purpose of defining the 50-MWe hybrid SGS performance requirements over the operating load range, the Sierra Pacific Power, Fort Churchill Unit 1 fossil-fuel-fired steam generator will be used. The unit is a Babcock & Wilcox radiant-type reheat, pressurized furnace steam generator designed to generate a maximum guaranteed continuous capacity of 97 kg/s (770,000 lb/h) main steam at 13.6 MPa gage (1960 lb/in^{2}g), 540°C (1005°F), with 83 kg/s (658,000 lb/h) reheat steam at 540°C (1005°F) when supplied with feedwater at 235°C (456°F). The unit has a maximum 2-hour peak of 102 kg/s (810,000 lb/h) steam. Either oil or natural gas can be fired. Operating characteristics of the fossil-fuel-fired steam generator are shown in Figures 3.2 and 3.3.

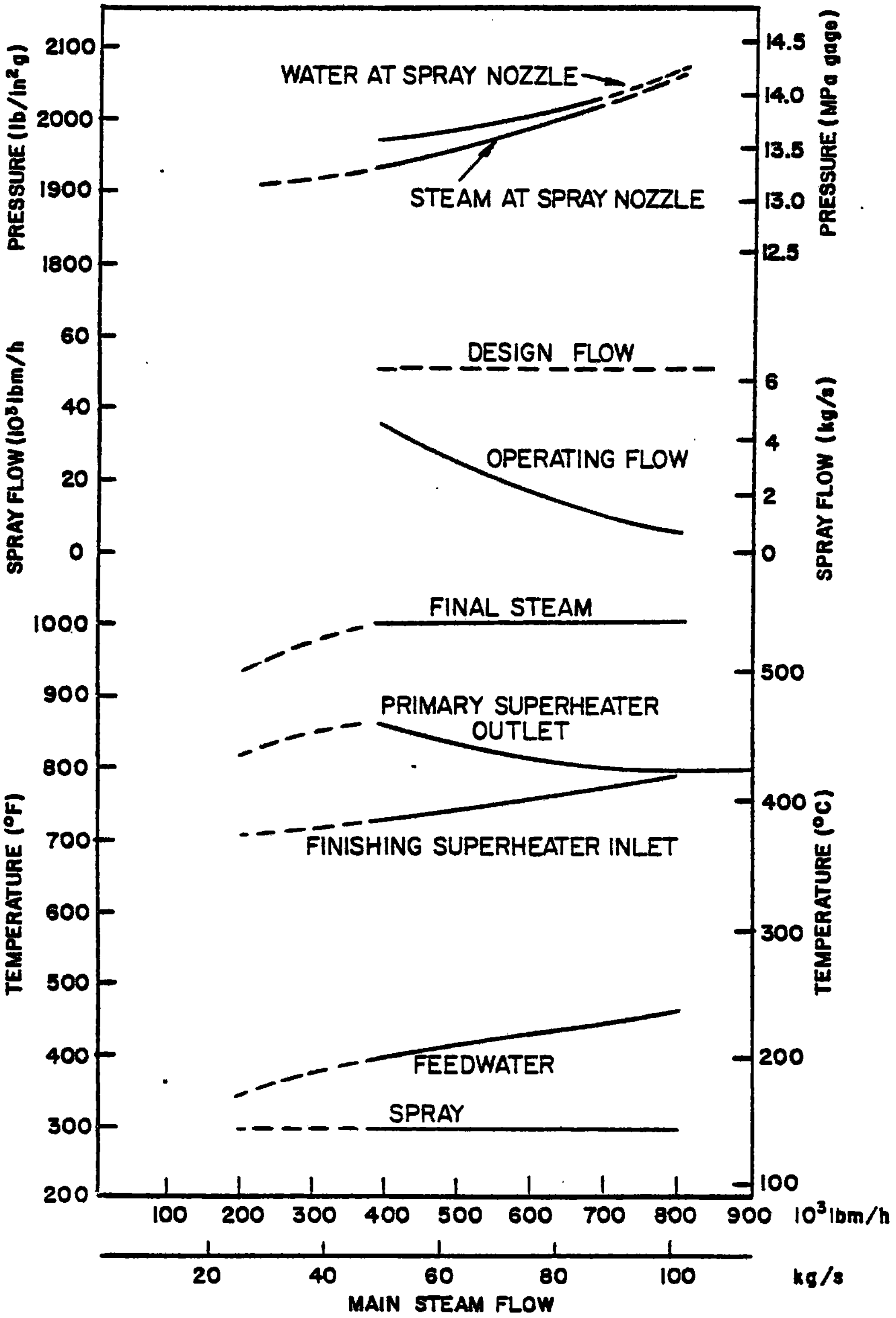

Figure 3.2 Fossil-Fuel-Fired Steam Generator Superheater Performance Characteristics

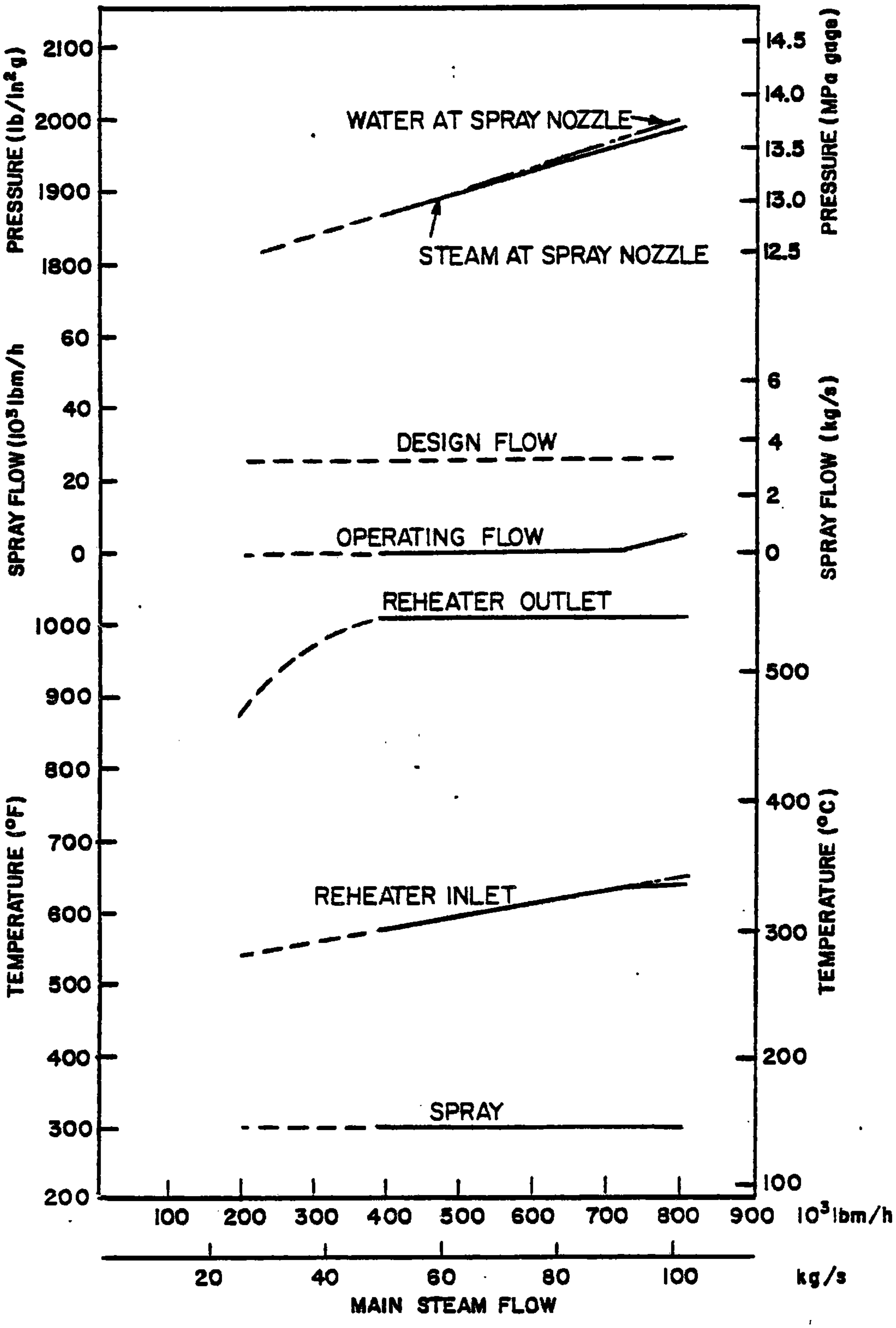

Figure 3.3 Fossil-Fuel-Fired Steam Generator Reheater Performance Characteristics

3.6 MODES OF OPERATION

3.6.1 General

Operating constraints to which the SGS units shall be designed are as follows:

- The minimum turbine load shall be approximately 25 percent.
- The minimum fossil-fuel-fired steam generator load shall be approximately 25 percent (for 50-MWe hybrid SGS only).
- The high-pressure steam turbine shall operate at constant pressure over the operating load range (i.e., at the 5-percent throttle overpressure condition).
- The maximum allowable rate of steam temperature change to the high-pressure turbine shall be 13.9°C/min (25°F/min).
- The maximum rate of load change on the turbine shall be 10 MWe of equivalent turbine generator output per minute.
- The normal SGS operating load range shall be from 25 to 100 percent. Below 25 percent load, the SGS will be in a start-up or shutdown mode, with steam production bypassing the turbine and sent directly to the condenser.

3.6.2 100-MWe Solar Stand-Alone/SGS

The 100-MWe solar stand-alone SGS shall follow the electric power generation load demands when ample hot salt is available from the thermal storage subsystem. With less than a 1-hour supply of hot salt, the solar SGS will be shut down.

The load distribution for the 100-MWe stand-alone SGS over its 30-year (263,000-hour) design life shall consist of 24 years (210,000 hours) at full-load, part-load, or hot-standby operation, with the remaining 6 years (53,000 hours) in shutdown or warm-standby modes. The following operating mode states and estimated times shall be used in the design:

Operating Mode	State	Operating Time (h)
100% load	1	80,000
75% load	2	20,000
50% load	3	20,000
25% load	4	20,000
Hot standby	5	77,000
Warm standby	6	20,000
Cold shutdown	7	26,000
TOTAL		263,000

The steam/water parameters (flow, pressure, and temperature) at the turbine for States 1 through 4 above are given in Table 3.1.

3.6.2.1 Start-Up From Cold, Dry Condition. The preheater, evaporator, superheater, and reheater modules and piping are assumed to be initially isothermal at 21°C (70°F) and filled with nitrogen on the shell side and the tube side. The feedwater pump is used to fill the preheater and evaporator modules with ambient water. At this point, a recirculating pump is used to circulate the water in the closed preheater-evaporator loop and the feedwater pump is isolated. An auxiliary boiler at the discharge of the recirculating pump is used to heat the water, and the electrical heat tracing on all four modules and associated piping is gradually activated. The rates of water and shell heating shall be such as to limit the difference in metal temperature between any two locations within any module to 100°F.

The auxiliary boiler and electrical trace heating continue until steam is produced at 4.68 MPa gage (681 lb/in^2g) and 260°C (500°F). At this point, 343°C (650°F) salt is admitted to the evaporator, blending hot and cold salts. The reheater-superheater bypass line is used for salt flow. The auxiliary boiler and trace heating on the preheater, evaporator, and associated piping are shut off. Through the letdown valve and sprays, 116°C (240°F) steam is admitted to the superheater and reheater to heat the tubes. The steam generator is raised to 260°C (500°F); the shells are heated by trace heating in a coordinated fashion. The 343°C (650°F) salt is then admitted to the reheater and superheater modules. Now a complete circuit on steam/water and salt sides is established, with the evaporator supplying saturated steam to the superheater and reheater, where it is slightly superheated. The superheated steam is bypassed around the turbine to the condenser. Some steam can be bled into the turbine for heating and initial rolling. Gradually the salt, feedwater flow, and temperature are increased to increase load. At 25-percent load, the superheater and reheater turbine bypasses are closed and the 25-percent load operating mode is established.

This event will occur 30 times during the SGS life.

3.6.2.2 Diurnal Start-Up. When the hot-salt storage tank has a 1-hour supply of hot salt, the daily start-up procedure begins. Salt at 443°C (830°F) is brought into the evaporator. When 4-percent steam is generated, salt at 563°C (1045°F) enters the reheater and evaporator. The generated steam flows to the condenser through the turbine bypass line. At 5-percent steam flow, the steam temperature is adjusted to match the first-stage turbine shell temperature by using a spray. Bypass lines are shut and steam is admitted to the turbine. From this condition steam/water and salt flows and temperatures shall be gradually increased to the desired values.

This event will occur 8000 times during the SGS life.

3.6.2.3 Diurnal (Overnight) Hot Standby. When the salt in the hot-salt storage tank drops to a 1-hour supply, the SGS will be brought to approximately 15-percent load by reducing the water and salt flows and temperatures at the rate of 3 percent/min. The steam generator is tripped and isolated by closing the valves.

The SGS will be in this mode of operation for 77,000 hours during its 30-year design life.

3.6.2.4 Sustained Warm Standby. This shutdown occurs when extended cloud cover prevents the solar receiver from supplying the required hot salt. The warm-standby mode is an extension of the hot-standby mode. The SGS system shall be bottled up by closing off all salt flow valves, closing superheater and reheater throttle valves, and bypassing the superheater steam to the reheater and then to the condenser. The trace heaters shall be activated if the shell temperature drops below 249°C (550°F). Any steam produced as a result of the stored energy shall be sent to the condenser.

The SGS will be in this mode of operation for 20,000 hours.

3.6.2.5 Shutdown to Cold, Dry Condition. This shutdown will be necessary when the whole system needs to be shut down for long periods or for maintenance. The SGS shall be brought to the warm-standby condition and salt and water shall be drained from the system. The trace heaters shall be kept on until all salt and water have been drained. The units shall then be filled with nitrogen on the shell side and on the tube side.

The SGS will be in this mode of operation for 26,000 hours during its 30-year design life.

3.6.2.6 Emergency Transient Conditions. The SGS shall be capable of safe, controlled shutdown resulting from all of the following events (the number of occurrences is typical for a 30-year lifetime):

- Turbine trip - 30 occurrences
- Loss of feedwater flow - 0 occurrences
- Loss of salt flow - 0 occurrences
- Break of any steam/water/salt pipe - 0 occurrences
- Break of a steam/water tube - 2 occurrences
- Loss of pneumatics - 5 occurrences
- Failure of control systems - 2 occurrences
- Loss of all station power - 30 occurrences.

3.6.3 50-MWe Hybrid SGS

The 50-MWe hybrid SGS operating modes shall be dictated by both the electric power generation load demands and the established procedure for coordinating fossil-fuel and solar steam generation to meet these load demands. The possible combinations of solar and fossil steam generator contributions to electric power generation are shown in Figure 3.4. Table 3.3 lists the normal operating modes and the constraints imposed on the hybrid plant by the solar SGS, the fossil-fuel steam generator, and the turbine.

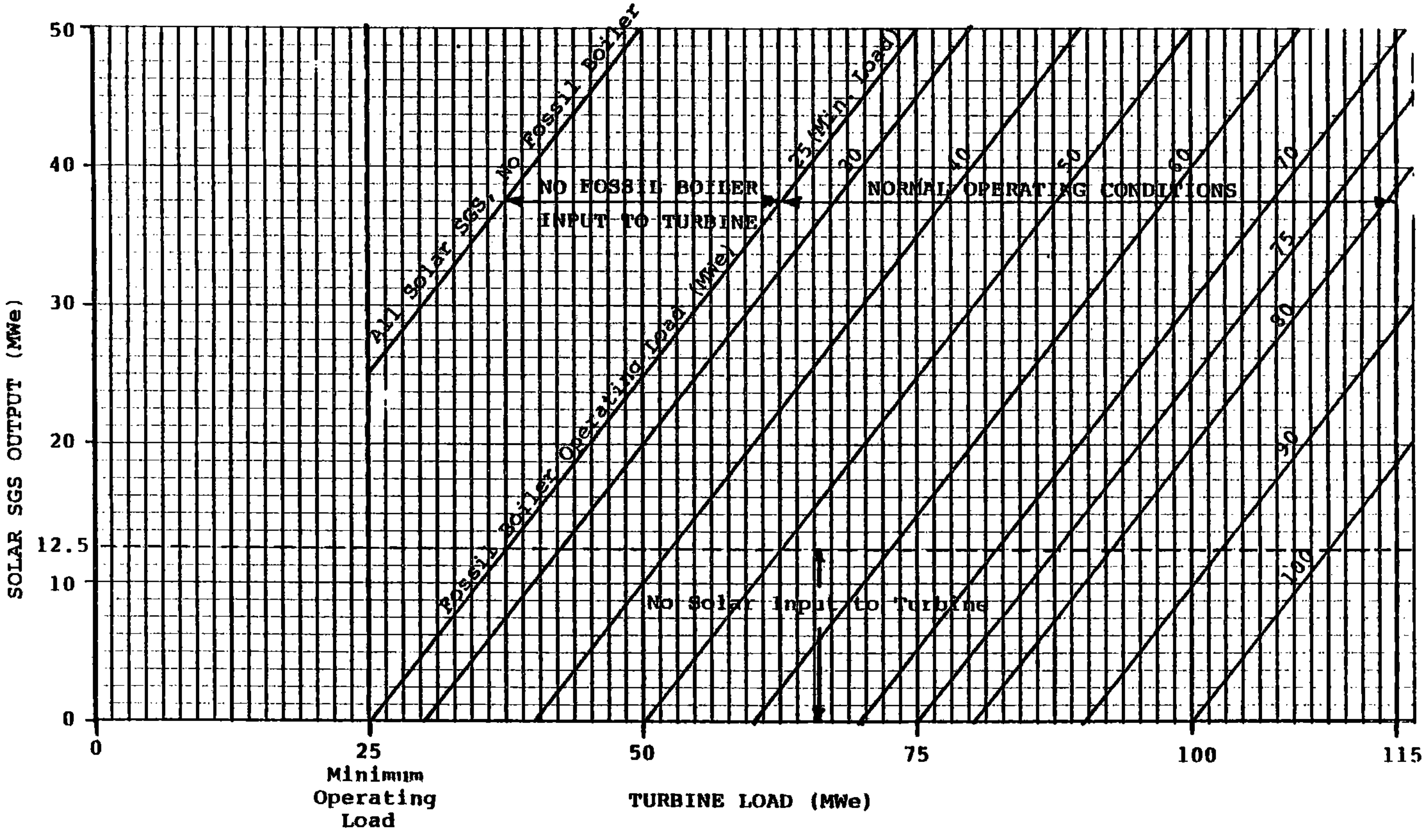

Figure 3.4 Solar SGS and Fossil Boiler Contributions to Electric Power Generation

Table 3.3 Hybrid Modes of Normal Operation

Mode of Operation	Power Plant Operating Range (MWe)	Operating Constraints Equipment	Minimum (MWe)	Maximum (MWe)
Solar SGS only	25 to 50	Turbine	25	---
		Solar SGS	---	50
Fossil Boiler only	25 to 115	Turbine	25	115
		Fossil Boiler	25	115
Combined Fossil and Solar:				
Minimum Fossil Boiler Loading	37.5 to 75	Fossil Boiler	25	---
		Solar SGS	12.5	50
Minimum Solar SGS Loading	37.5 to 115	Solar SGS	12.5	---
		Fossil Boiler	25	102.5
Maximum Solar SGS Loading	75 to 115	Solar SGS	---	50
		Fossil Boiler	25	65

The load distribution of the 50-MWe hybrid SGS over its 30-year (263,000-hour) design life shall consist of 24 years at full load or hot-standby operation, with the remaining 6 years (53,000 hours) in shutdown or warm-standby modes. The following operating mode states and estimated times shall be used in the design:

Operating Mode	State	Operating Time (h)
100% load	1	140,000
Hot standby	2	77,000
Warm standby	3	20,000
Cold shutdown	4	26,000

The steam/water parameters (flow, pressure, and temperature) at the turbine for State 1 above are given in Table 3.2.

3.6.3.1 Start-Up From Cold, Dry Condition. Start-up for the 50-MWe hybrid SGS is the same as that for the 100-MWe stand-alone SGS with the following exceptions:

- No steam is needed for turbine warm-up, rolling, and synchronizing.
- Once the necessary steam conditions are reached, the superheater steam shall be routed from the turbine bypass to the turbine, which is rotating to produce 50-MWe from the fossil-fueled boiler steam output.

This event will occur 30 times during the SGS life.

3.6.3.2 Diurnal Start-Up. This start-up is the same as that described for the 100-MWe solar stand-alone SGS except that:

- Hot feedwater is available.
- Steam produced by the SGS is routed to the condenser until 15-percent steam flow is achieved, matching steam flow from the fossil-fueled boiler.

This event will occur 8000 times during the SGS life.

3.6.3.3 Diurinal (Overnight) Hot Standby. The SGS shall be brought to approximately 15-percent load condition by reducing the water and salt flows and temperatures. At 15-percent load, the SGS shall be tripped and isolated by closing the appropriate valves.

The SGS will be in this mode of operation for 77,000 hours during its 30-year design life.

3.6.3.4 Sustained Warm Standby. This condition is the same as that defined in Section 3.6.2.4 for the 100-MWe stand-alone SGS.

The SGS will be in this mode of operation for 33,000 hours.

3.6.3.5 Shutdown to Cold, Dry Condition. This condition is the same as that defined in Section 3.6.2.5 for the 100-MWe stand-alone SGS.

The SGS will be in this mode of operation for 26,000 hours.

3.6.3.6 Emergency Transient Conditions. These conditions are the same as those defined in Section 3.6.2.6 for the 100-MWe stand-alone SGS.

Section 4

ENVIRONMENTAL CRITERIA

4.1 SGS ENVIRONMENTAL DESIGN REQUIREMENTS

4.1.1 Operating Environment

The SGS shall be capable of operating in and surviving appropriate combinations of the following environmental conditions:

- Temperature. The SGS equipment shall be able to operate in the ambient air temperature range from -9 to 50°C (16 to 122°F). Performance requirements shall be met throughout an ambient air temperature range of 0 to 50°C (32 to 122°F).

- Wind. The solar plant equipment shall be able to operate in winds up to 15.5 m/s (35 mi/h). Performance requirements shall be met for winds up to 15.5 m/s (35 mi/h) throughout the temperature range from 0 to 50°C (32 to 122°F). Wind analyses shall satisfy the requirements of ANSI A58.1-1972. The wind speeds are at a reference height of 10 m (32.8 ft). Wind speed at other heights is determined from $V/V_{10} = (Z/Z_{10})$ 0.15.

- Earthquake. Peak ground acceleration shall be 0.2 g horizontal and 0.05 g vertical (per UBC Zone 3). This peak ground acceleration is combined with the response spectrum given by NRC Regulatory Guide 1.60 and the damping values given for the operating bases earthquake in NRC Regulatory Guide 1.61. Zone 3 values shall be used for the design.

4.1.2 Survival

The system shall be capable of surviving appropriate combinations of the following environmental conditions:

- Wind. The SGS shall survive winds with a maximum speed, including gusts, of 40 m/s (90 mi/h) without damage. A local wind vector variation of +10 deg from the horizontal shall be assumed for the survival condition.

- Wind Rise Rate. A maximum wind rise rate of 0.01 m/s^2 (1.3 mi/h/min) shall be used in calculating wind loads. In addition, the plant should withstand, without catastrophic failure, a sudden wind of 22 m/s (50 mi/h) from any direction, such as might result from severe thunderstorm gust fronts.

- Dust Devils. Dust Devils with wind speeds up to 17 m/s (38 mi/h) shall not damage the plant.

- Snow. The plant shall survive a static snow load of 250 Pa (5 lb/ft^2) and a snowfall of 0.3 m (1 ft) in 24 hours.

- Rain. The plant shall survive the following rainfall:
  - Average annual - 135 mm (5.3 in.)
  - Maximum 24-hour rate - 52 mm (2.05 in.)

- Ice. The plant shall survive freezing rain and ice deposits in a layer 50 mm (2 in.) thick.

- Earthquake. The peak ground acceleration (UBC Zone 3 - Average or Firm Conditions: 0.2 g horizontal, 0.005 g vertical) is combined with the response spectrum given in NRC Regulatory Guide 1.60 and the damping values given for the operating bases earthquake in NRC Regulatory Guide 1.61. Zone 3 values should be used for the baseline design.

- Hail. The SGS shall survive hail impact up to the following limits:
  - Diameter: 25 mm (1 in.)
  - Specific Gravity: 0.9
  - Terminal Velocity: 23 m/s (75 ft/s)

- Sandstorm Environment. The SGS shall survive exposure to flowing dust comparable to the conditions described by Method 510 of MIL-STD-810C.

4.2 ENVIRONMENTAL STANDARDS

4.2.1 Air Quality Standards

The plant pollution emission requirements as dictated by state regulations are as follows:

SO_x:	1.86 kg/MWh_t (1.2 lb/10^6 Btu); 70-percent removal
NO_x:	0.78 kg/MWh_t (0.5 lb/10^6 Btu); 30-percent removal
Particulates:	0.05 kg/MWh_t (0.03 lb/10^6 Btu)
Visibility:	20-percent opacity.

4.2.2 Water Quality Standards

Not applicable.

APPENDIX C: DESIGN ANALYSIS PLAN

MOLTEN SALT STEAM GENERATOR SUBSYSTEM RESEARCH EXPERIMENT

Sandia Contract 20-9909B

Prepared for

Sandia National Laboratories
Livermore, California

October 9, 1981
(Revision 1)

FWSDC No. 9-71-9202

FOSTER WHEELER SOLAR DEVELOPMENT CORPORATION
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Section 1

INTRODUCTION

Task 4 of the Molten Salt Steam Generator Subsystem (SGS) Research Experiment requires preparation of a System and Component Design Analysis Plan. This Plan is to be reviewed and approved by Sandia National Laboratories (SNL) before the detailed analysis of the subsystem and components is begun. The purposes of the plan are to identify the various thermal/hydraulic and structural analyses and to show the sequence in which they will be performed and their interrelationships. Governing design criteria are also identified, along with computer codes and correlations to be used.

The Design Analysis Plan consists of four major subtasks:

- System Level Analysis
- Thermal/Hydraulic Analysis
- Structural Analysis
- Mechanical Design.

The subtasks are discussed in detail in the following sections. The flowchart shown in Figure 1 gives an overview of the design analysis process. The program schedule is shown in bar-chart form in Figure 2.

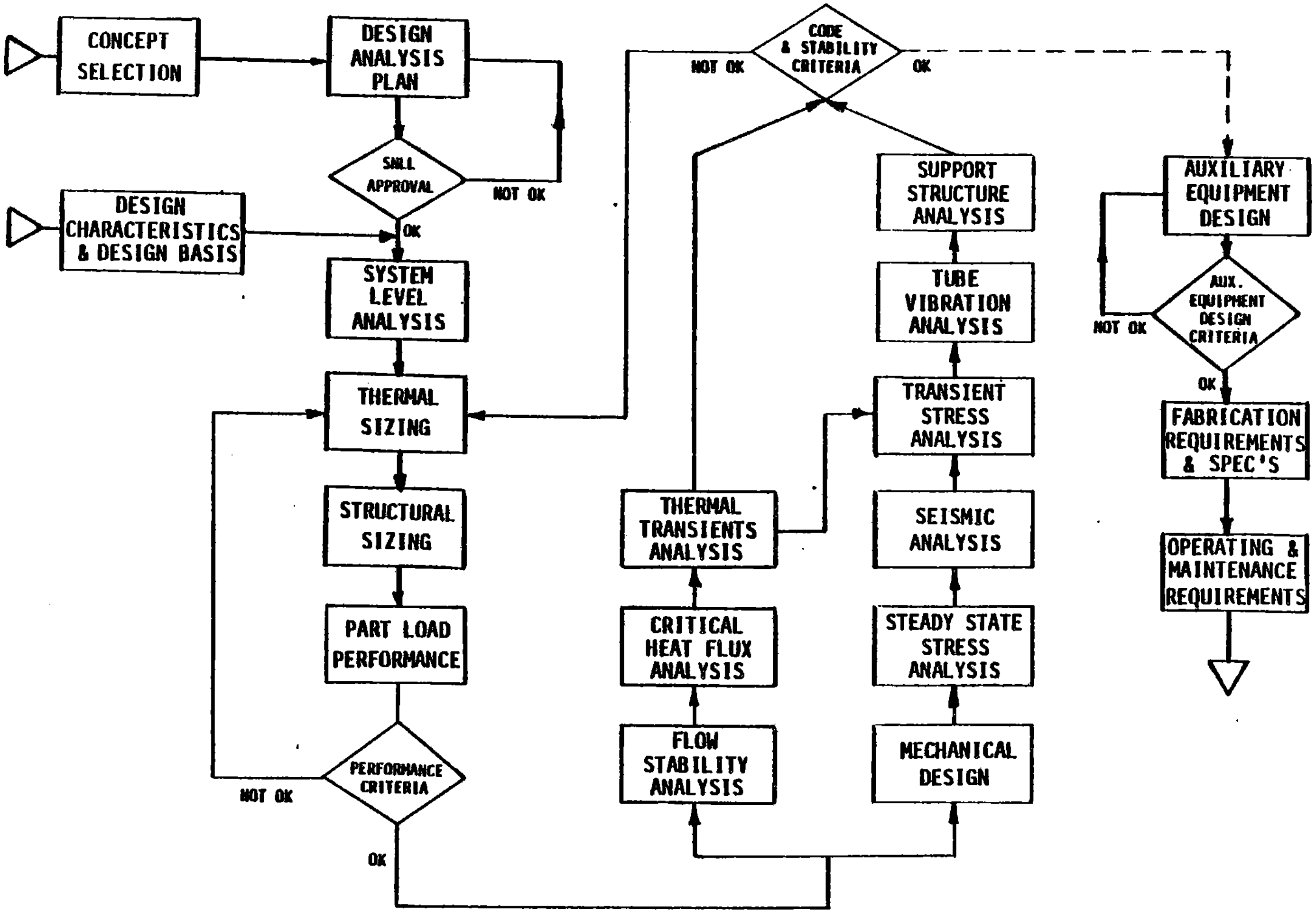

Figure 1 Flowchart--Design Analysis Process

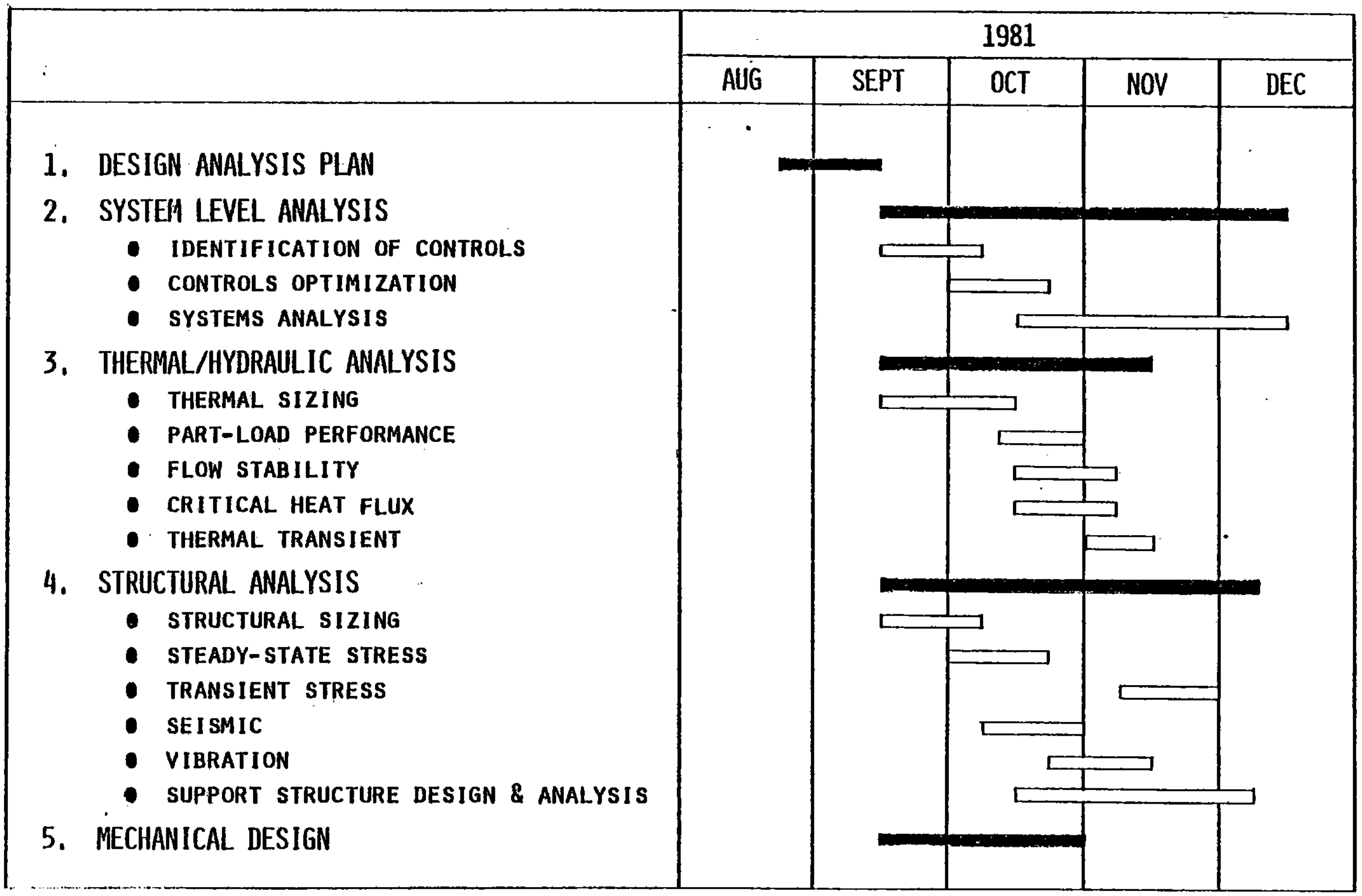

Figure 2 Program Schedule

Section 2

SYSTEM LEVEL ANALYSIS

This section defines the systems level analysis required to ensure a safe, stable, and optimally functional steam generator subsystem (SGS) under start-up, shutdown, steady-state, and system upset conditions. The analysis will consider all SGS components, piping, and controls and will include interface requirements with the balance of the plant. The plan described will consider both a 100-MWe stand-alone and a 50-MWe hybrid SGS.

The following steps describe the system level analysis of the SGS. A flowchart description of these activities is shown in Figure 3.

IDENTIFICATION OF CONTROLS

Literature will be reviewed to determine the state of the art for controlling molten-salt and sodium-heated steam generating systems. A review will also be made of the practice of controlling parameters of interest in fossil-fuel steam generators. Based on these reviews, primary control parameters for the steam generator system will be identified. Typical parameters that will be considered are:

- Superheat steam flow rate
- Superheat steam temperature
- Reheat steam temperature
- Drum level

One or more simple schemes will be identified to control the parameters of interest. Sensing and controlling elements will be determined. The following

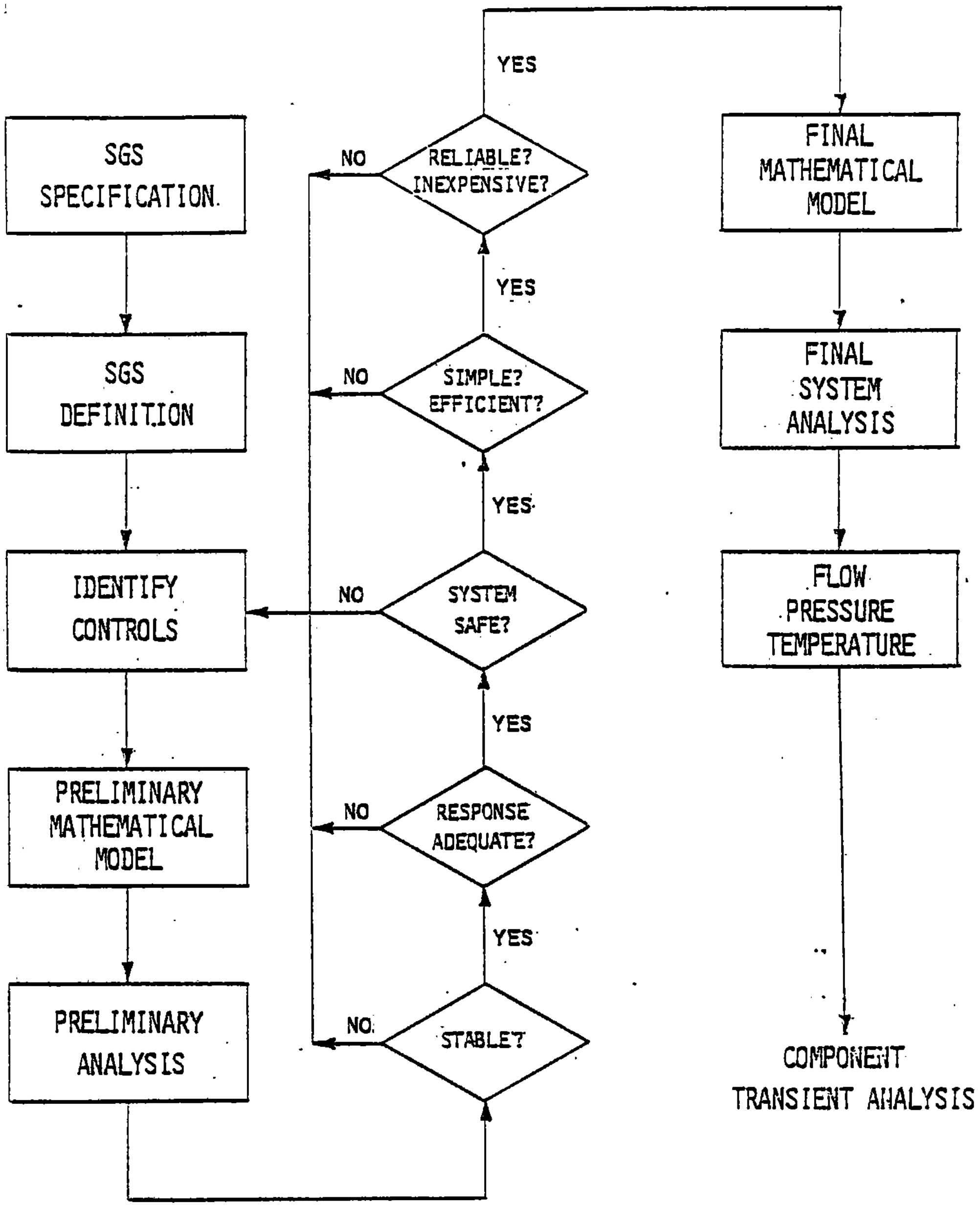

Figure 3 Flowchart--System Level Analysis

conditions will be considered in the analysis:

- Start-up from cold, dry condition
- Diurnal start-up
- Steady state at full and part loads
- Load changes
- Diurnal shutdown
- Diurnal (overnight) hot standby
- Sustained warm standby
- Shutdown to cold, dry condition

The control schemes identified will be used in SGS interfaces with the balance of plant.

CONTROLS OPTIMIZATION

To optimize the controls for the SGS, a preliminary mathematical model of the entire SGS and its interfaces with the balance of plant will be prepared. All components (preheater, evaporator, superheater, reheater, pumps, valves, etc.) and piping will be modeled to monitor system characteristics during start-up, shutdown, load change, and transient conditions. The following design criteria and associated analyses will be performed to evaluate the control schemes identified in Section 1:

- Stability--A Bode plot analysis of the preliminary control schemes will be performed to ensure stability for load changes.
- Response Time--The mathematical model will be analyzed to ensure that response times of controlled parameters are within the specified requirements for load changes.
- Safety--Salt and water/steam-side parameters (flow, pressure, temperature) will be monitored to ensure safety (i.e., the absolute and rates of change of these parameters will be kept below certain limits to avoid damage to any part of the SGS or the balance of plant).

- Efficiency--The impact of competing control schemes on overall system efficiency will be evaluated. For example, the desirability of using spray to control superheater or reheater steam exit temperatures will be weighed against the loss in system efficiency caused by the spray.

The outcome of this step of the analysis will be an optimized control scheme with associated sensing and controlling elements.

SYSTEM ANALYSIS

General

Using the optimized control scheme, we will describe the functioning of the control system under steady-state, full-load, and part-load operation; load changes; start-up; shutdown; and system transients. The mathematical model will be refined to include more details such as:

- Heat exchanger designs
- Piping lengths and configurations
- Pump and valve characteristics
- Interface variable characteristics.

The outcome of the analysis will be the time-dependent behavior of system parameters (flow, pressure, and temperature) at the entrance and exits of the system components and at interface points. These results can then be directly used to perform transient analyses of the SGS components.

Procedure

The overall steam generator model will be segregated into four specific control loops:

- Throttle-pressure loop
- Drum-level loop

- Superheater steam outlet temperature loop
- Reheater steam outlet temperature loop.

Although the four loops are intercoupled, valid transient and stability analyses can be performed separately on each loop. This approach permits first-order design parameters to be established and allows the analyst to "feel" his way through the loop performance. Use of a digital computer also permits the four loops to be intercoupled, and the ensuing results are more readily interpreted.

The technical tools used to perform the study include:

- The block-diagram concept using the Laplace Transform, which models the known physical and thermodynamic aspects of the steam generator. The same block-diagram concept is used to model the sensing elements and controllers, which then "close the loop" for the boiler.
- Bode-plot techniques for providing a sense of direction to the necessary system parameters and design iterations to permit acceptable transient response behavior.
- A computer program that solves the differential equations, which are an outgrowth of the Laplace Transform Block Diagram.

A schematic of the steam generator studied is shown in Figure 4. It is an unfired constant-pressure drum-type natural-circulation boiler. Feedwater is fed to the preheater through a feedwater control valve. From the preheater the feedwater is directed to the steam drum. The feedwater circulates through the downcomers and feeders before entering the evaporator. A steam/water mixture exits the evaporator and enters the steam drum, where steam and water separation takes place. The water is recirculated and the steam is sent to the superheater. The control valve at the superheater salt outlet controls the superheater outlet

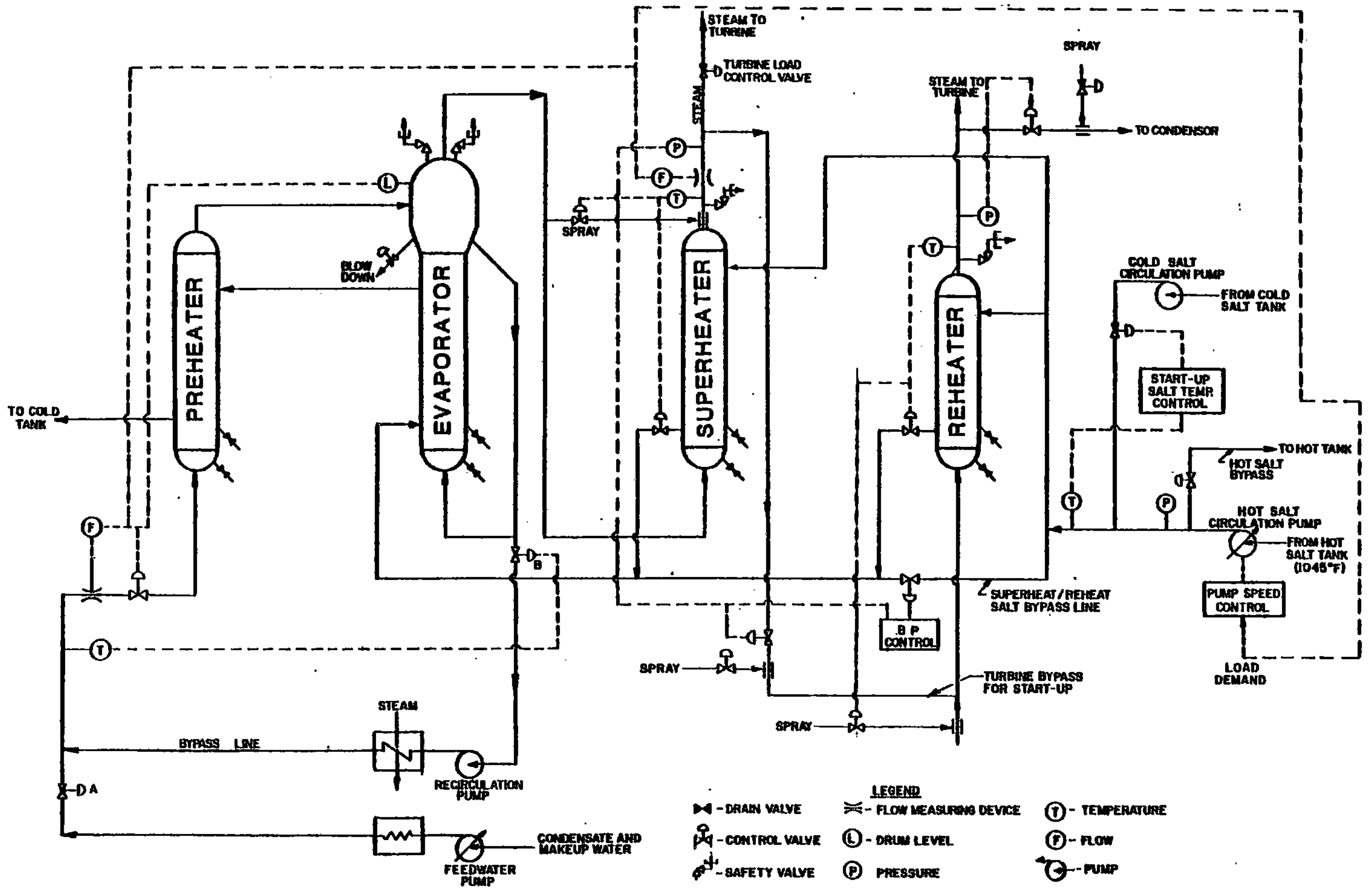

Figure 4 Natural-Circulation Control System

steam temperature by controlling the salt flow rate. Saturated steam from the steam drum is bypassed to the superheater steam outlet to control the steam outlet temperature in an emergency.

The reheater steam outlet temperature is similarly controlled by a valve at the reheater salt outlet. An emergency spray attemperator is provided at the inlet to the reheater, for rapidly bringing the reheater outlet temperature down to 541°C (1005°F) if needed.

The major control parameters in the SGS are the pressure and temperature upstream of the throttle valve, the drum level, and the reheater outlet temperature. The SGS load is characterized by the steam demand. The steam flow is increased or decreased by opening or closing the steam throttle valve. The transient condition followed by this action upsets the four major control parameters. Various controllers in the boiler control system will then restore the throttle pressure and temperature, drum level, and reheater temperature to their original values.

The most convenient and effective method of handling system dynamic problems is one in which all significant components of the system are represented by one or a combination of the three types of response characteristics shown in Figure 5. The boiler shown in Figure 4, along with its associated control system, will be represented in terms of these simple response types. The physical characteristics of each boiler component will be used to determine the numerical values of various model parameters.

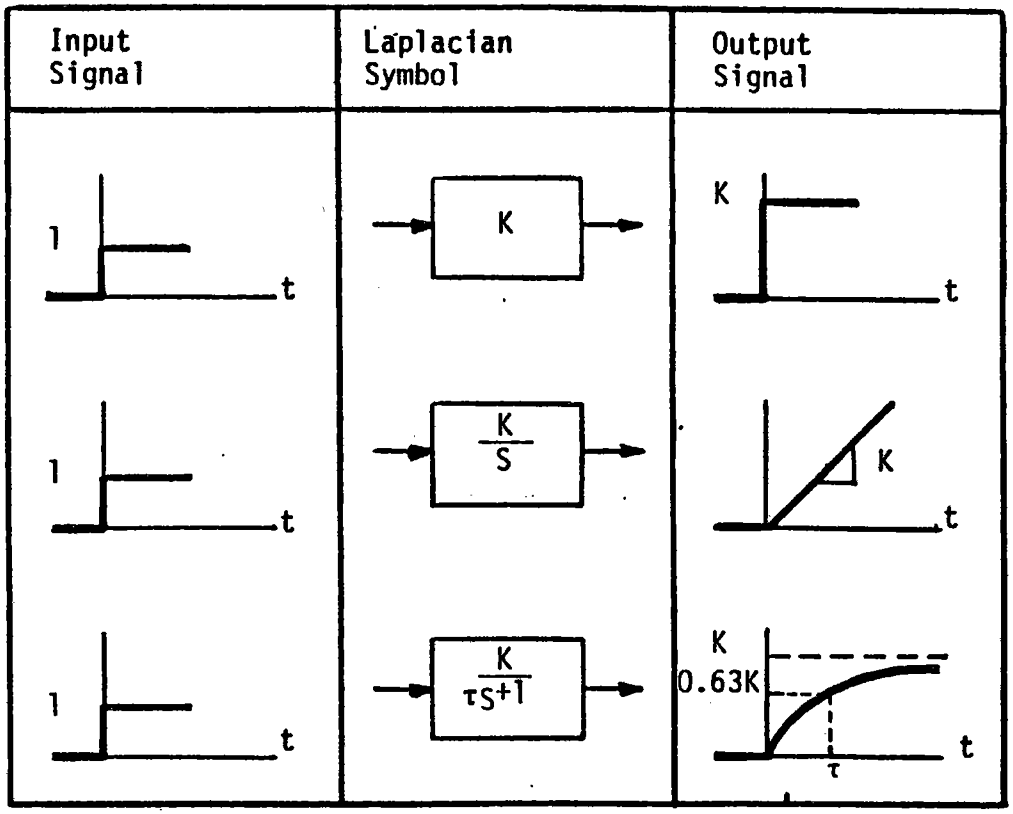

Figure 5 Laplacian Symbols

The dynamic model will represent the dynamic characteristics of various components in the boiler system, including the controllers, in terms of the Laplace Transform notation. An analytical solution of the equations resulting from this model will predict the response of throttle pressure, throttle temperature, reheater temperature, and drum level following a specific change in the steam flow rate.

Section 3

THERMAL/HYDRAULIC ANALYSIS

THERMAL/HYDRAULIC DESIGN AT FULL LOAD

The heat-transfer surface requirement of each heat exchanger will be determined at full-load conditions utilizing the in-house thermal sizing computer code MSSG. For computing heat-transfer coefficients, the MSSG code employs the following correlations:

Region	Correlation
Shell Side	Dittus-Boelter for Re >33,000[1]* Wong & Hochreiter for Re <33,000[2]
Tube Side:	
Subcooled Liquid	Dittus-Boelter
Subcooled Boiling	Thom, et al.[3]
Nucleate Boiling	Chen[4]
Critical Heat Flux	AI[5] or Westinghouse[6]
Film Boiling	Bishop, Sandberg, and Tong[7]
Superheated Steam	Bishop[8] or Heineman[9]

The MSSG code is a one-dimensional thermal sizing computer code that determines the required heat-transfer tube length. The conservation equations, governing the energy and momentum, form a system of 1st-order ordinary differential equations. With the outlet steam/water conditions and molten salt inlet temperature given, this system of coupled nonlinear equations is integrated using a 4th-order

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*Numbers indicate references in Section 6.

Runge-Kutta scheme. The integration terminates when the steam/water condition meets the specified outlet conditions, thus determining the required heat-transfer tube length.

Appropriate surface margins will be added to the heat-transfer area determined by the MSSG code to accommodate the uncertainties associated with heat-transfer coefficients, thermal conductivity of tube, fouling factors, and tube plugging. The surface margin will be determined statistically either by the simplified Root of Sum Square (RSS) method or by the SIMPAK[10] computer program.

The RSS method can be expressed by the following equation:

$$\Delta L = \sqrt{\Delta l_1^2 + \Delta l_2^2 + \ldots. + \Delta l_n^2}$$

where

ΔL = Total increment of length attributed to all variables

Δl_1 = Increment of length attributed to Variable 1

Δl_2 = Increment of length attributed to Variable 2.

SIMPAK is a package of subroutines which read data, draw random numbers, relate data to probability distributions, facilitate the Monte Carlo simulation, compute the mean and standard deviation of resultant probability distributions, and print out variable probability distribution details of interest. The required heat-transfer surface area can be determined according to the desired design confidence level (90 percent).

The configuration of baffle plates will be designed for proper shell-side flow distribution. Shell-side salt pressure loss will be computed by the Heat Transfer Research, Inc. (HTRI) computer program ST-4[11] for shell and tube heat exchangers. Tube-side steam/water pressure loss will be computed by the MSSG computer program, which utilizes the Moody[12] method for single-phase flow and the modified Martinelli-Nelson[13] method for two-phase flow.

A fouling resistance of 90 $m^2 \cdot {}^\circ C/MW$ ($5 \times 10^{-4} h \cdot ft^2 \cdot {}^\circ F/Btu$) will be used for salt, steam, and water as recommended by the Standards of the Tubular Exchanger Manufacturers Association (TEMA).

PART-LOAD PERFORMANCE

The thermal/hydraulic performance of each heat exchanger will be computed using the thermal performance version of the MSSG computer code for 25-, 50-, and 75-percent steam generator load, where load is defined as the fraction of the full-load SGS main steam flow.

STABILITY ANALYSIS

The possibility of static and dynamic instabilities of evaporators under operating conditions will be analyzed. The "Ledinegg"-type static instability analysis will be performed using the MSSG computer code, which calculates tube-side pressure drops at various loads.

Static instability is an amplification of steady-state disturbances which encompass tube-circuit configurations, heating imbalances, flow-rate perturbations. The static instability of primary importance in steam generators is the

"Ledinegg" excursive instability. A flow is subject to a static instability when the flow, changed by a small perturbation, will not return to original steady-state conditions. The significance of the static stability will be analyzed by plotting the pressure-drop flow characteristic. The operating point is stable if the derivative of the pressure-drop flow-rate curve is positive. It can be expressed as follows:

$$\delta \Delta p / \delta W > 0$$

where

W = Flow rate
ΔP = Pressure drop.

The NUFREQ[14] computer code will be utilized for the dynamic instability study. Dynamic instability is defined as sustained (or growing) oscillation of flow variables (such as pressure drop, flow rate, and fluid density) within a tube. In this analysis, a density-wave type of dynamic instability will be investigated, since it is the most common type of two-phase flow instability. Density-wave instability is caused by the feedback and interaction between the various pressure-drop components, specifically by the lag introduced through the density head term caused by the finite speed of propagation of density waves (i.e., density change in the direction of flow).

If either static or dynamic instability occurs, the evaporator design will have to be reevaluated. Inlet orifices may be required or the design may have to be changed to create the proper steam/water flow conditions required to eliminate the flow instability.

CRITICAL HEAT FLUX ANALYSIS

The critical heat flux analysis will identify if departure from nucleate boiling (DNB), dryout, or both occur within the evaporator tubes. DNB occurs in subcooled or low-steam-quality bubble-type flows when excessively high heat fluxes create a vapor blanket between the inner tubewall and the water/steam core. Dryout occurs at somewhat lower heat flux levels and higher steam qualities, when there is a transition from an annular flow regime to a dispersed (mist) flow regime. Water droplets in the flow core cannot maintain a wet tube surface because the heat flux level is such that the droplets vaporize before they reach the surface. When DNB or dryout occurs, the heat-transfer coefficient deteriorates sharply and the tube metal temperature increases sharply.

For the evaporator design considered in this study, the tube metal temperature cannot exceed the salt temperature. Consequently, tube burnout is not expected to be a problem. However, tube fatigue attributed to the tubewall thermal oscillation and dissolved solids deposition/corrosion at the critical heat flux point can be a potential problem.

To identify whether DNB or dryout will occur, the MSSG computer code will be used. Incorporated within the MSSG computer code are the AI[5] and Westinghouse[6] critical heat flux correlations. Should DNB or dryout occur, such design parameters as circulation ratio, tube diameter, or salt temperature/flow rate may have to be changed to eliminate the problem. If the problem cannot be eliminated because of system-imposed limitations on the variation of the aforementioned parameters, a tube-fatigue analysis, which is beyond the scope of this study, will be recommended for a more detailed design phase.

TRANSIENT ANALYSIS

The purpose of the thermal transient analysis is to provide the fluid temperatures, pressures, and heat-transfer coefficients required for the transient stress analyses of critical heat exchanger components, as identified in Section 4. Heat exchanger inlet and outlet salt and steam/water temperature and pressure changes as a function of time will be identified by the dynamic mathematical model described in Section 2. Based on these values, heat-transfer coefficients as a function of time will be determined.

The computed inlet and outlet time-dependent parameters will be applied to the critical component for the transient stress analysis. Parametric variations in the direction of flow will not be determined because the analysis is complex and is beyond the scope of this study. For example, in evaluating the transient stresses in the superheater upper tubesheet, the salt temperature and pressure entering the salt inlet nozzle will be assumed to be the same as on the salt side of the tubesheet. The temperature and pressure changes as the salt flows through the annular space between the shroud and shell, through the salt distribution slots, and along the tubesheet will not be determined.

Section 4

STRUCTURAL ANALYSIS

The objective of the stress analysis program is to ensure the structural integrity of the molten salt steam generator within the requirements of the Design Specification, Section VIII-Division 1 of the ASME Boiler and Pressure Vessel Code, Standards of the Tubular Exchanger Manufacturers Association (TEMA), the Uniform Building Code, and other applicable codes and standards. Criteria set forth in other sections of the ASME Boiler and Pressure Vessel Code will be used to the extent necessary to evaluate those failure modes that are not explicitly considered in Section VIII-Division 1.

The structural analysis effort will consist of the stress analysis, evaluation, documentation, and reporting of key components of the molten salt SGS. The major structural analyses tasks to be performed are:

- Structural sizing
- Steady-state stress
- Transient stress
- Seismic loads
- Vibration
- Support structure

STRUCTURAL SIZING

Preliminary structural sizing calculations will be performed to establish the mechanical requirements for thermal/hydraulic performance. Using the requirements of the ASME Code, Section VIII-Division 1, and the TEMA standards, preliminary values for the following parameters will be established:

- Tubewall thickness
- Tubesheet thickness
- Tube-to-shell clearance
- Tube pitch

- Nozzle size
- Number of tie-rods
- Tube-to-baffle clearance
- Interconnecting pipe size

With these parameters established, full- and part-load salt and steam/water pressure drop through the subsystem can be determined. Final values for these parameters will be determined during the Mechanical Design subtask, defined in Section 5.

STEADY-STATE STRESS ANALYSIS

Temperature distribution and thermal and pressure stress distributions in all critical elements of the heat exchangers will be determined at steady-state operating conditions. The critical elements will include the shell, tubesheets, tubes, nozzles, and shell heads. The stresses will be calculated using simplified methods given in design handbooks. For tubesheets, tubes, and shells, the finite element programs ANSYS[15] and NONAX[16,17] will be used.

ANSYS is a multipurpose finite-element program widely used in the nuclear power industry. It is capable of transient and steady-state heat-transfer analyses as well as static and dynamic stress analyses. Elastic, elastic-plastic, and creep analyses can be done using this program. ANSYS contains many element types, such as beam, plane stress, axisymmetric solid, axisymmetric shell, general shell and three-dimensional solid.

NONAX is a special-purpose program developed by Foster Wheeler Development Corporation to perform thermal and stress analyses on thick-walled cylinders made of homogeneous and isotropic material. The loading may be axisymmetric or nonaxisymmetric. It may consist of an arbitrary combination of internal and external tractions, axial load, axial bending, and an arbitrary temperature distribution. Elastic, elastic-plastic, and creep analyses under varying load cycles and hold times can be done using this program. NONAX is considerably less expensive to run than a multipurpose finite-element program.

TRANSIENT STRESS ANALYSIS

Because the tubesheet is the most critical element in a steam generator, transient analysis of the tubesheet will be done to determine the metal temperatures and stresses caused by start-up and shutdown. The finite-element program ANSYS will be used in this analysis. The results of the thermal/hydraulic transient analysis (i.e., the fluid temperatures, heat-transfer coefficients, and pressures as functions of time) will be the input in the transient stress analyses. The stresses will be evaluated using the fatigue curves of ASME Code Section VIII-Division 2 (for subcreep temperatures) and Code Case N-47 (for elevated temperatures).

SEISMIC ANALYSIS

The steam generator and support structure will be designed to withstand seismic loads corresponding to Zone 3 of the Uniform Building Code. Simplified calculations will be used to determine the first and second mode frequencies. These will be combined with the response spectra given in NRC Regulatory Guide 1.60 and the damping factors given in NRC Regulatory Guide 1.61 to determine the seismic loads. These loads will be compared with the loads determined by the UBC requirements. The more conservative value will be used in the design.

In the support structure, the stresses caused by earthquakes will be limited to the yield strength of the material. For the pressure boundary, the criteria of the ASME Code Section VIII-Division 2 will be used.

VIBRATION ANALYSIS

The severity of flow-induced vibration will be determined by using the primary and secondary check procedures described in the Heat Transfer Research, Inc. (HTRI) report.[18] The data required for the check procedures will be generated by using the HTRI ST-4 computer program. The data include ratio of span length to the maximum allowable by TEMA standards, leak stream velocities, and critical velocities for fluid elastic whirling, as well as the parallel and crossflow velocities, the crossflow Reynolds number, and the ratio of vortex shedding and turbulent buffeting frequencies to acoustic and natural frequencies. The inlet, central, and outlet regions of the heat exchanger units will be analyzed, and regions where the flow-induced vibration could be a problem will be identified. Suitable design modifications will be made to minimize flow-induced vibration.

SUPPORT STRUCTURE ANALYSIS

The support structure will be designed to withstand all dead and live loads and loads caused by earthquake, wind, and snow. Seismic stresses will be determined by an equivalent static-g analysis. The support structure design will satisfy the requirements of the Uniform Building Code and the AISC Manual for the design of steel structures.

Section 5

MECHANICAL DESIGN

In this subtask we will prepare layout drawings and specifications for the heat exchangers--preheaters, evaporators, superheater, and reheater--in sufficient detail to allow preparation of a fabrication plan and estimation of the SGS fabrication, shipping, erection, operation, and maintenance costs. All pressure parts--shells, tubes, shell heads, nozzles, reinforcements, etc.--will be sized according to Section VIII of the ASME Code, using nominal design pressures and temperatures. TEMA standards will be followed when sizing tubesheets.

Tubesheet hole pattern and pitch will be determined using the in-house computer program TUBELAY. TUBELAY determines the radius of the enclosing circle for any given number of tubes arranged in a triangular (equilateral) or square pitch pattern. It provides a row-by-row tube count and calculates the maximum radius to the center of the outermost tube in each row. An approximate plot of a typical quadrant of the tube pattern is also provided to assist in the selection of the final design configuration. The program assumes complete filling of the tube pattern, which originates from a central tube and extends outward until the input requirement for the total number of tubes has been filled.

Section 6

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APPENDIX D: SHOP/FIELD FABRICATION/ ERECTION PLAN

Molten Salt Steam Generator Subsystem Research Experiment

Sandia Contract 20-9909B

Prepared for

Sandia National Laboratories
Livermore, California

September 1982
(Revision 1)

FWSDC No. 9-71-9202

FOSTER WHEELER SOLAR DEVELOPMENT CORPORATION

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CONTENTS

ILLUSTRATIONS

Section 1

INTRODUCTION

The molten salt heat exchangers and steam drum, which is designed as an integral component of the evaporator, are shop-fabricated units that will be individually shipped to the job site and erected in a field-fabricated support structure. Identified in this appendix are the shop fabrication and field fabrication/erection plans for both the 100-MWe solar stand-alone SGS and the 50-MWe hybrid SGS.

The shop fabrication plans describe a step-by-step fabrication sequence, including all significant fabrication and inspection operations. Taken into consideration are the tools, jigs, fixtures, equipment, floor space, and special supplies required. Welding procedures, weld qualification requirements, and nondestructive examination and inspection requirements are identified. Also included are shop fabrication schedules showing fabrication of such subassemblies as shells, tubesheets, and tube bundles and final assembly of the heat exchanger components. Schedules for tool design and fabrication, welding development, and mock-ups are also included.

The field fabrication/erection plans include a schedule that identifies the interrelationship between and time periods required for preparing the site; pouring foundations; assembling structural supporting steel; installing the heat exchangers, piping, heat tracing, pumps, drain tanks, instrumentation and controls; and applying insulation.

Section 2

SHOP FABRICATION PLANS

2.1 100-MWe SOLAR STAND-ALONE SGS

2.1.1 Preheater

Tubesheets (2):

1. Receive and inspect forged and machined tubesheets (w/o edge preps)
   - Check dimensions
   - Inspect material certifications
2. Set up and machine for cladding
3. Clad low carbon steel and weld guides to lower tubesheet O.D.
4. Stress relieve
5. Shot blast all sealed surfaces
6. Machine clad
7. Ultrasonic test clad in "X" pattern
8. Set up and gun drill tube holes
9. Deburr tubeholes; drill and tap as required
10. Machine edge preps
11. Hold for next assembly.

Nozzle Forgings

1. Receive and inspect semifinished forgings
   - Check dimensions
   - Review material certifications
2. Machine nozzle
3. Hold for next assembly.

Upper (Outlet) End Head (1) and Lower (Inlet) End Heads (2):

1. Receive and inspect hemi-head
   - Check dimensions
   - Review material certifications
2. Lay out, cut, and machine nozzle openings
3. Set up and weld nozzles and attachments
4. Inspect back gouge of weld
5. Machine edge prep at tubesheet end
6. Set up and weld pipe extension at lower (inlet) end and inner head nozzle
7. Inspect back gouge of weld
8. Stress relieve head assemblies
9. Shot blast all surfaces
10. X-ray butt welds greater than 31.8 mm (1.25 in.) thick only
11. Hold for next assembly.

Expansion Joint

1. Receive and inspect expansion joint subassembly
   - Check dimensions
   - Inspect material certifications and ASME Code, Section VIII certifications by vendor
2. Weld end ring to expansion joint and weld drain nozzle to joint
3. Hold for next assembly.

Pressure Boundary Shell Sections and Support Shell

1. Lay out and cut courses to size
2. Machine edge preps
3. Crimp edges for rolling

4. Roll plate courses
5. Fit up longitudinal seams for welding
6. Weld longitudinal seams
7. Inspect back gouge
8. Spot x-ray seams
9. Re-round shell sections
10. Shot blast all surfaces
11. Hold for next assembly.

Conical Sections of Shell

1. Lay out and cut cone segments and prep "L" seam edges
2. Form cone segments--three pieces per circumference
3. Set up and weld "L" seams and inspection nozzle weld
4. Inspect back gouge of butt-welded seams
5. Round up cone assembly
6. Shot blast all surfaces
7. Machine circumferential weld preps
8. Hold for next assembly.

Seismic Ring and Upper Support Ring Fabrication

1. Receive and inspect material and material certifications
2. Lay out and cut material to size
3. Prep edges for welding
4. Crimp and roll ring
5. Set up and weld "L" seam
6. Inspect back gouge and final weld surface

7. Stress relieve ring
8. X-ray "L" seam
9. Re-round shell
10. Shot blast all surfaces
11. Set up and machine ring and "C" seam edge preps (2)
12. Hold for further assembly.

Shell Inlet Baffle

1. Receive and inspect material and material certifications
2. Lay out and cut shell size and prep weld edges
3. Perforate shroud as required--lay out and drill
4. Crimp and roll shroud section
5. Set up and weld "L" seam
6. Back gouge "L" seam
7. Re-round shroud
8. Shot blast all surfaces
9. Hold for next assembly.

Miscellaneous Parts--Spacers, Guides, Etc.

1. Receive and inspect material and material certifications
2. Lay out and cut
3. Machine and drill
4. Hold for assembly.

Tube Support Plates

1. Receive and inspect material and material certifications
2. Lay out and cut circles

3. Shot blast plates
4. Stack plates for drilling
5. Gun drill stacks
6. Dismantle stacks
7. Make cutouts and contour O.D.
8. Round sharp edges
9. Drill tie-rod holes and chamfer
10. Degrease and clean
11. Hold for further assembly.

Tie-Rods and Spacers

1. Receive and inspect materials and material certifications
2. Cut rods and spacers
3. Thread rods and deburr all parts
4. Degrease and clean
5. Hold for further assembly.

Shell Inlet End Subassembly

1. Set up and weld two conical sections and support ring to cylindrical section
2. Inspect back gouge of butt welds
3. Spot x-ray all seam welds
4. Machine circle seam edge preps at two ends
5. Set up and weld one course of small end shell
6. Inspect back gouge of butt welds
7. Spot x-ray all seam welds on small end shell
8. Lay out and cut inlet nozzle openings and edge preps

9. Set up and weld inlet nozzle and inspection nozzle
10. Inspect back gouge of weld
11. Set up and weld perforated shroud at I.D.
12. Set up and weld hydroclosure to shell inlet nozzle and inspection nozzles
13. Set up and weld shell supports
14. Hold for next assembly.

Shell Outlet End Subassembly

1. Set up and weld cylindrical courses and conical section at outlet end
2. Inspect back gouge of weld
3. Spot x-ray all seam welds
4. Hold for further assembly.

Shell Assembly

1. Set up and weld tubesheet to upper shell subassembly
2. Inspect back gouge of weld
3. Spot x-ray weld
4. Set up and weld vent connection to tubesheet lip
5. Set up and weld lower shell subassembly to upper shell tubesheet assembly
6. Inspect back gouge of weld
7. Spot x-ray weld
8. Hold for next assembly.

Tube Bundle Assembly

1. Receive and inspect tubes and material certifications
2. Set up upper end tubesheet/shell with shell assembly horizontally to prepare for tubing the unit
3. Set up tube bundle cage (tie-rods, spacers, and tube support plates) in I.D. of shell
    - Assure alignment of tube holes in support plates with tubesheet holes
    - Maintain cleanliness during tube assembly
4. Assemble all tubes
    - Push all tubes 305 mm (12 in.) past true position
    - Maintain cleaniness of tubes and tube holes and tube weld area
5. Position lower end tubesheet
    - Align with tubes/cage
    - Support lower tubesheet securely
6. Push tubes back through lower tubesheet and position tube ends in upper tubesheet for welding
7. Weld tubes to upper tubesheet (WP-1-1-B16) and visually inspect all welds
8. Cut tubes at lower end tubesheet to maintain required protrusion for welding and maintain cleanliness
9. Weld tubes to lower end tubesheet (WP-1-1-B16) and visually inspect all welds
10. DETNAFORM® expand tubes to tubesheets--both ends
11. Penetrant test all tube-to-tubesheet welds to meet acceptance criteria of ASME Code, Section VIII - Division 1.

Final Assembly--Test and Ship

1. Set up and weld channel hemi-head assemblies (both ends) to tubesheets and insert type weld
2. 5X-magnification-inspect root pass

3. 100-percent x-ray channel-to-tubesheet welds
4. Locally stress relieve head circle seams (2)
5. Assemble and weld seismic ring to conical end of shell and weld snubber lugs to seismic ring O.D.
6. 5X-magnification inspect root pass--ring to shell
7. 100-percent x-ray weld
8. Attach shell (outer) hemi-head assembly to seismic ring
9. 5X-magnification inspect root pass
10. 100 percent x-ray weld
11. Weld expansion-joint end plate to nozzle
12. 5X-magnification inspect root pass
13. Set up and weld hydroclosure cap to outer hemi-head nozzle
14. Weld on lifting lugs (3) for lifting unit and add nameplate brackets
15. Hydrotest shell side
    - ASME certification required
    - Drain completely
16. Weld closures to tube-side channel nozzles (2)
17. Hydrotest tube side
    - ASME certification required
    - Drain completely
18. Vacuum dry assembly and blanket with dry nitrogen
19. Remove hydroclosures (tube side only)
20. Remachine nozzle weld edge preps
21. Apply shipping closures and seal-weld
22. Apply 69 kPa gage (10 lb/in^2g) nitrogen and add pressure gages and refill valves

23. Paint carbon steel surfaces with one coat red oxide primer
24. Clear unit with Quality Control and complete ASME certification
25. Load and brace for shipment
26. Release shipment.

2.1.2 Evaporator

Tubesheets (2)

1. Receive and inspect forged and machined tubesheets (w/o edge preps)
   - Check dimensions
   - Inspect material certifications
2. Set up and gun drill tube holes
3. Deburr tube holes
4. Drill and tap tie-rod holes in upper tubesheet
5. Machine edge preps
6. Locate and weld spacer guides to lower tubesheet O.D.
7. Hold for next assembly.

Nozzle Forgings

1. Receive and inspect semifinished forgings
   - Check dimensions
   - Review material certifications
2. Machine nozzle
3. Hold for next assembly

Lower (Inlet) End Heads (2)

1. Receive and inspect hemi-heads
   - Check dimensions
   - Review material certifications

2. Lay out, cut, and machine nozzle openings
3. Set up and weld nozzles
4. Inspect back gouge
5. Stress relieve heads
6. Machine edge prep at tubesheet end
7. Shot blast
8. Inspect back gouge
9. 100-percent x-ray butt welds
10. Hold for next assembly.

<u>Expansion Joint</u>

1. Receive and inspect expansion joint subassembly
    - Check dimensions
    - Inspect material certifications and ASME VIII certifications by vendor
2. Set up and weld end ring and drain connections
3. Hold for next assembly
4. Machine weld preps on pipe extension
5. Weld pipe extension to inner head nozzle
6. Stress relieve
7. Shot blast
8. Inspect back gouge
9. 100-percent x-ray butt weld
10. Machine weld prep
11. Hold for end assembly.

Pressure Boundary Shell Sections and Support Shell

1. Inspect dimensions and material certifications
2. Lay out and cut courses to size
3. Machine edge preps
4. Crimp edges for rolling
5. Roll plate courses
6. Fit up longitudinal seams for welding
7. Weld longitudinal seams
8. Inspect back gouge
9. Re-round shell sections
10. 100-percent x-ray "L" seams
11. Shot blast all surfaces
12. Hold for next assembly.

Conical Sections of Shell

1. Lay out and cut cone segments and prep "L" seam edges
2. Form cone segments--three pieces per circumference
3. Set up and weld "L" seams and inspect nozzle weld
4. Back gouge butt seams
5. Inspect back gouge of butt-welded seams
6. Round up cone assembly
7. 100-percent x-ray butt welds
8. Shot blast all surfaces
9. Machine circumferential weld preps
10. Hold for next assembly.

Seismic Ring Fabrication

1. Receive and inspect material and material certifications
2. Lay out and cut material to size
3. Prep edges for welding
4. Crimp and roll ring
5. Set up and weld "L" seam
6. Inspect back gouge
7. 100-percent x-ray "L" seam
8. Re-round shell
9. Machine O.D.
10. Weld seismic snubbers
11. Stress relieve ring
12. Shot blast all surfaces
13. Set up and machine ring and "C" seam edge preps (2)
14. Hold for further assembly.

Shell Inlet Baffle

1. Receive and inspect material and material certifications
2. Lay out and cut shell size and prep weld edges
3. Perforate plate as required--lay out and drill
4. Crimp and roll shroud section
5. Set up and weld "L" seam
6. Back gouge "L" seam
7. Re-round shroud
8. Shot blast all surfaces
9. Hold for next assembly.

Miscellaneous Parts - Spacers, Guides, Etc.

1. Receive and inspect material and material certifications
2. Lay out and cut
3. Machine and drill
4. Hold for assembly.

Tube Support Plates

1. Receive and inspect material and material certifications
2. Lay out and cut circles
3. Shot blast plates
4. Stack plates for drilling
5. Gun drill stacks
6. Dismantle stacks
7. Deburr all tube holes
8. Make cutouts and contour O.D.
9. Round sharp edges
10. Drill tie-rod holes and chamfer
11. Degrease and clean
12. Hold for further assembly.

Tie-Rods and Spacers

1. Receive and inspect materials and material certifications
2. Cut rods and spacers
3. Thread rods and deburr all parts
4. Degrease and clean
5. Hold for further assembly.

Shell Inlet End Subassembly

1. Set up and weld two conical sections to cylindrical section
2. Back gouge weld
3. Inspect back gouge of weld
4. 100-percent x-ray all seam welding
5. Machine "C" seam edge preps at two ends
6. Set up and weld one course of small end shell
7. Back gouge weld
8. Inspect back gouge of weld
9. 100-percent x-ray all seam welds on small end shell
10. Lay out and cut inlet nozzle openings and edge preps
11. Set up and weld inlet nozzles
12. Inspect back gouge of weld
13. Set up and weld perforated shroud at I.D.
14. Set up and weld hydroclosure to shell inlet nozzle
15. Hold for next assembly.

Shell Outlet End Subassembly

1. Set up and weld cylindrical courses and conical section at outlet end
2. Inspect back gouge
3. 100-percent x-ray all seam welds
4. Hold for further assembly.

Steam Drum Lower Head Subassembly

1. Receive and inspect hemi-heads
    - Check dimensions
    - Review material certifications
2. Lay out and cut and machine nozzle openings
3. Set up and weld nozzles
4. 5X-magnification inspect gouge at nozzle welds
5. Set up and weld internal support ring and internal attachments
6. Stress relieve and sand blast
7. Machine "C" seam edge preps
8. Hold for next assembly.

Shell Assembly

1. Set up and weld tubesheet to shell inlet-end subassembly
2. Inspect back gouge
3. 100-percent x-ray weld
4. Set up and weld steam drum lower head subassembly to upper tubesheet
5. Inspect weld back gouge
6. Set up and weld lower shell subassembly to upper shell/tubesheet assembly
7. Inspect weld back gouge
8. 100-percent x-ray welds
9. Weld vent connection to tubesheet lip and apply hydroclosure
10. Hold for next assembly.

Lower Water Inlet Flanged Assembly

1. Receive and inspect materials
   - Check dimensions
   - Review material certifications
2. Lay out and cut nozzle openings (12)
3. Machine edge prep on flange side of main body
4. Set up and weld end flange and connections with hydroclosure to the blind flange
5. Set up and weld nozzles
6. 100-percent x-ray butt welds
7. Stress relieve assembly and flange (in process stress relief)
8. Machine edge preps and gasket faces
9. Hold for further assembly.

Tube Bundle Assembly

1. Receive and inspect tubes and material certifications
2. Set up upper end tubesheet/shell with shell assembly horizontally to prepare for tubing the unit
3. Set up tube bundle cage (tie-rods, spacers, and tube support plates) in I.D. of shell
   - Assure alignment of tube holes in support plate with tubesheet holes
   - Maintain cleanliness during tube assembly
4. Assemble all tubes
   - Push all tubes 305 mm (12 in.) past true position
   - Maintain cleanliness of tubes and tube holes and tube weld area
5. Position lower end tubesheet
   - Align with tubes/cage
   - Support lower tubesheet securely

6. Push tubes back through lower tubesheet and position tube ends in upper tubesheet for welding
7. Weld tubes to upper tubesheet and visually inspect all welds
8. Cut tubes at lower end tubesheet to maintain required protrusion for welding and maintain cleanliness
9. Weld tubes to lower end tubesheet and visually inspect all welds
10. DETNAFORM® expand tubes to tubesheets--both ends
11. Penetrant test all tube-to-tubesheet welds to meet acceptance criteria of ASME Code, Section VIII-Division 1.

Final Assembly of Shell

1. Set up and weld lower inner hemi-head assembly to lower tubesheet and insert type weld
2. 5X-magnification inspect root pass
3. 100-percent x-ray head-to-tubesheet weld
4. Assemble and weld seismic ring to conical end of shell
5. 5X-magnification inspect root pass (ring to shell)
6. 100-percent x-ray weld
7. Attach shell (outer) hemi-head assembly to seismic ring
8. 5X-magnification inspect root pass
9. 100-percent x-ray weld
10. Weld expansion joint end plate to nozzle
11. 5X-magnification inspect root pass
12. Set up and weld lower flange assembly to lower channel nozzle
13. 100-percent x-ray weld
14. Set up and weld downcomer and feed tubes to drum nozzles and lower flanged assembly

15. 100-percent x-ray welds

16. Set up and weld hydroclosure caps to outer hemi-head nozzle

17. Set up and weld lifting lugs (3) for lifting unit and add nameplate brackets

18. Stress relieve entire shell assembly and purge with nitrogen internally

19. Hydrotest shell side
    - ASME certification required
    - Drain completely

20. Shot blast or power brush to remove loose scale

21. Hold for final assembly.

Drum Shell Assembly

1. Receive and inspect shell plate halves (2)
    - Check dimensions
    - Review material certifications

2. Lay out for hot forming

3. Heat

4. Form half shells (2)

5. Flame cut circumference

6. Machine "L" seam edge preps

7. Set up and slag weld "L" seams (2)

8. Normalize

9. Shot blast

10. Machine "C" seam edge preps (2) and transition at ends

11. Flame cut nozzle openings

12. Set up and weld nozzles--internal and external

13. 5X-magnification inspect back gouge of nozzle weld

14. Set up and weld spray header

15. Set up and weld chemical spray pipe

16. Set up and weld lugs to I.D.

17. Stress relieve shell

18. Sand blast

19. Hold for next assembly.

Fabricating Complete Internal Structure and Shot Blasting and Welding Assembly to Hemi-Head Adapter Support Ring

Note: The adapter head should be welded to the tubesheet before the internal structure is assembled to it.

Final Assembly--Test and Ship

1. Attach shell open ends (2) to lower steam drum head
    - Weld internal structure lugs in place and apply bolts
    - Weld "C" seam weld from outside only (insert weld)
2. 100-percent x-ray weld
3. Set up and weld steam outlet hemi-head subassembly to shell, welding from outside only (insert weld)
4. 100-percent x-ray weld
5. Locally stress relieve "C" seams (2) and apply nitrogen purge to inside of steam drum
6. Apply closures to drum openings
    - Weld on two 305-mm (12-in.) and two 406-mm (16-in.) caps
    - Bolt on cover plates (2)
    - Weld on one 25.4-mm (1-in.) cap

7. Hydrotest tube side
   - ASME certification required
   - Drain completely
8. Vacuum dry shell side and tube side
9. Blanket with dry nitrogen
10. Remove hydroclosures (tube side)
11. Remachine nozzle edge preps (4) (tube side)
12. Apply shipping closures to tube-side nozzles and seal-weld
13. Paint exterior surfaces with one coat red oxide primer
14. Apply 69 kPa gage (10 lb/in^2g) nitrogen internally and add pressure gages and refill valves
15. Clear unit with Quality Control and complete ASME certification
16. Load and brace for shipment
17. Release shipment.

2.1.3 Superheater and Reheater

Tubesheets (2)

1. Receive and inspect forged and machined tubesheets (w/o edge preps)
   - Check dimensions
   - Inspect material certifications
2. Set up and gun drill tube holes
3. Deburr tube holes; drill and tap as required
4. Machine edge preps
5. Locate and weld guides to lower tubesheet (O.D.)
6. Hold for next assembly.

Nozzle Forgings

1. Receive and inspect semifinished forgings
   - Check dimensions
   - Review material certifications
2. Machine nozzles
3. Hold for next assembly.

Upper (Outlet) End Head (1) and Lower (Inlet) End Heads (2)

1. Receive and inspect hemi-head
   - Check dimensions
   - Review material certifications
2. Lay out, cut, and machine nozzle openings
3. Set up and weld nozzles and attachments
4. Penetrant test:
   - Back gouge of weld
   - Final surfaces of welds in material greater than 19.1 mm (0.75 in.) thick
5. Machine edge prep at tubesheet end
6. Set up and weld pipe extension at lower (inlet) end and inner head nozzle
7. Penetrant test:
   - Back gouge of weld
   - Final surfaces of welds in material greater than 19.1 mm (0.75 in.) thick
8. X-ray butt welds greater than 38.1 mm (1.5 in.) thick only
9. Hold for next assembly.

Expansion Joint

1. Receive and inspect expansion joint subassembly
    - Check dimensions
    - Inspect material certifications and ASME Code, Section VIII certifications by vendor
2. Set up and weld end ring and drain nozzle
3. Hold for next assembly.

Pressure Boundary Shell Sections and Support Shell

1. Lay out and cut courses to size
2. Machine edge preps
3. Crimp plate for rolling
4. Roll plate courses
5. Fit up longitudinal seams for welding
6. Weld longitudinal seams
7. Penetrant test back gouge
8. Re-round shell sections
9. Hold for next assembly.

Conical Sections of Shell

1. Lay out and cut cone segments and prep "L" seam edges
2. Form cone segments--three pieces per circumference
3. Set up and weld "L" seams
4. Back gouge butt seams
5. Penetrant test back gouge of welded seams
6. Round up cone assembly

7. Machine circumferential weld preps
8. Hold for next assembly.

Seismic Ring Fabrication

1. Receive and inspect material and material certifications
2. Lay out and cut material to size
3. Prep edges for welding
4. Crimp and roll ring
5. Set up and weld "L" seam
6. Penetrant Test back gouge and final weld surface
7. X-ray "L" seams
8. Re-round shell
9. Set up and machine ring and "C" seam edge preps (2)
10. Hold for further assembly.

Shell Inlet Baffle

1. Receive and inspect material and material certifications
2. Lay out and cut shell size and prep weld edges
3. Perforate shroud as required--lay out and drill
4. Crimp and roll shroud section
5. Set up and weld "L" seam
6. Back gouge "L" seam
7. Re-round shroud
8. Hold for next assembly.

Support Ring Subassembly

1. Receive and inspect rolled ring and material certifications
2. Set up and weld rolled ring
3. Set up and machine I.D. and O.D.
4. Set up and weld support shell to ring
5. Lay out for machining
6. Set up and machine ring mounting face
7. Hold for next assembly.

Miscellaneous Parts--Spacers, Guides, Etc.

1. Receive and inspect material and material certifications
2. Lay out and cut
3. Machine and drill
4. Hold for next assembly.

Tube Support Plates

1. Receive and inspect material and material certifications
2. Lay out and cut circles
3. Stack plates for drilling
4. Gun drill stacks
5. Dismantle stacks
6. Deburr all tube holes
7. Make cutouts and contour O.D.
8. Round sharp edges
9. Drill tie-rod holes and chamfer

10. Degrease and clean
11. Hold for further assembly.

Tie-Rods and Spacers

1. Receive and inspect materials and material certifications
2. Cut rods and spacers
3. Thread rods and deburr all parts
4. Degrease and clean
5. Hold for further assembly.

Shell Inlet End Subassembly

1. Set up and weld two conical sections to cylindrical sections
2. Back gouge weld
3. Penetrant test back gouge of weld
4. Spot x-ray all seam welds
5. Machine "C" seam edge preps at two ends
6. Set up and weld one course of small end shell
7. Back gouge weld
8. Penetrant test back gouge of weld
9. Spot x-ray all seam welds on small end shell
10. Lay out and cut inlet nozzle opening and edge prep
11. Set up and weld inlet nozzle
12. Penetrant test back gouge of weld
13. Set up and weld perforated shroud at I.D.
14. Set up and weld hydroclosure to shell inlet nozzle
15. Hold for next assembly.

Shell Outlet End Subassembly

1. Set up and weld cylindrical courses and conical section at outlet end
2. Penetrant test back gouge of weld
3. Spot x-ray all seam welds
4. Hold for further assembly.

Shell Assembly

1. Set up and weld tubesheet to upper shell subassembly
2. Penetrant test back gouge of weld
3. Spot x-ray weld
4. Set up and weld support cone to shell cone
5. Penetrant test back gouge of weld
6. Set up and machine support cone open-end edge prep
7. Set up and weld lower shell subassembly to upper shell/tubesheet assembly
8. Penetrant test back gouge of weld
9. Spot x-ray weld
10. Hold for next assembly.

Tube Bundle Assembly

1. Receive and inspect tubes and material certifications
2. Set up upper end tubesheet/shell with shell assembly horizontally to prepare for tubing the unit
3. Set up tube bundle cage (tie-rods, spacers, and tube support plates) in I.D. of shell
    - Assure alignment of tube holes in support plates with tubesheet holes
    - Maintain cleanliness during tube assembly

4. Assemble all tubes
   - Push all tubes 203 mm (8 in.) past true position
   - Maintain cleanliness of tubes and tube holes and tube weld area
5. Position lower end tubesheet
   - Align with tubes/cage
   - Support lower tubesheet securely
6. Push tubes back through lower tubesheet and position tube ends in upper tubesheet for welding
7. Weld tubes to upper tubesheet and visually inspect all welds
8. Cut tubes at lower end tubesheet to maintain required protrusion for welding and maintain cleanliness
9. Weld tubes to lower end tubesheet and visually inspect all welds
10. DETNAFORM® expand tubes to tubesheets--both ends
11. Penetrant test all tube-to-tubesheet welds to meet acceptance criteria of ASME Code, Section VIII-Division I

Final Assembly--Test and Ship

1. Set up and weld steam hemi-head assemblies (both ends) to tubesheets and insert type weld
2. Penetrant test:
   - Root pass
   - Final O.D. surface on material greater than 19.1 mm (0.75 in.) thick
3. 100-percent x-ray steam head-to-tubesheet welds
4. Assemble and weld seismic ring to conical end of shell and weld snubber lugs to seismic ring O.D.
5. Penetrant test root pass--ring to shell
6. 100-percent x-ray weld

7. Attach shell (outer) hemi-head assembly to seismic ring
8. Penetrant test root pass
9. 100-percent x-ray weld
10. Weld expansion joint end plate to nozzle
11. Penetrant test root pass and final weld
12. Set up and weld hydroclosure cap to outer hemi-head nozzle
13. Weld on lifting lugs for lifting entire unit and add nameplate brackets
14. Hydrotest shell side
    - Use demineralized water
    - ASME certification required
    - Drain completely
    - Vacuum dry
15. Weld closures to tube-side channel nozzles (2)
16. Hydrotest tube side
    - Use demineralized water
    - ASME certification required
    - Drain completely
17. Vacuum dry assemmbly and blanket with dry nitrogen
18. Remove hydroclosures
19. Remachine nozzle weld edge preps
20. Set up and weld support barrel and flange to conical extension on upper end shell
21. Penetrant test back gouge of weld
22. Apply shipping closures and seal-weld
23. Apply 69 kPa gage (10 lb/in^2g) nitrogen and add pressure gages and refill valves

24. Clear unit with Quality Control and complete ASME certification
25. Load and brace for shipment and cover with tarpaulins
26. Release shipment.

2.1.4 Shop Schedule

The shop fabrication schedule for the 100-MWe solar stand-alone SGS heat exchangers and steam drum is illustrated in Figure 2.1. Identified are the interrelationships between and time periods required to fabricate such subassemblies as shells, tubesheets, and tube bundles and final assembly and testing of the heat exchanger components. Also identified is the time period required for tool design and fabrication, as well as weld qualification and mock-ups. The period identified relates to the start of heat exchanger fabrication.

2.2 50-MWe HYBRID SGS

2.2.1 Preheater

Tubesheets (2). See Section 2.1.1.

Nozzle Forgings. See Section 2.1.1.

Upper (Outlet) End Head and Lower (Inlet) End Head

1. Receive and inspect hemi-head
   - Check dimensions
   - Review material certifications
2. Lay out, cut, and machine nozzle openings
3. Set up and weld nozzles and attachments
4. Inspect back gouge of weld

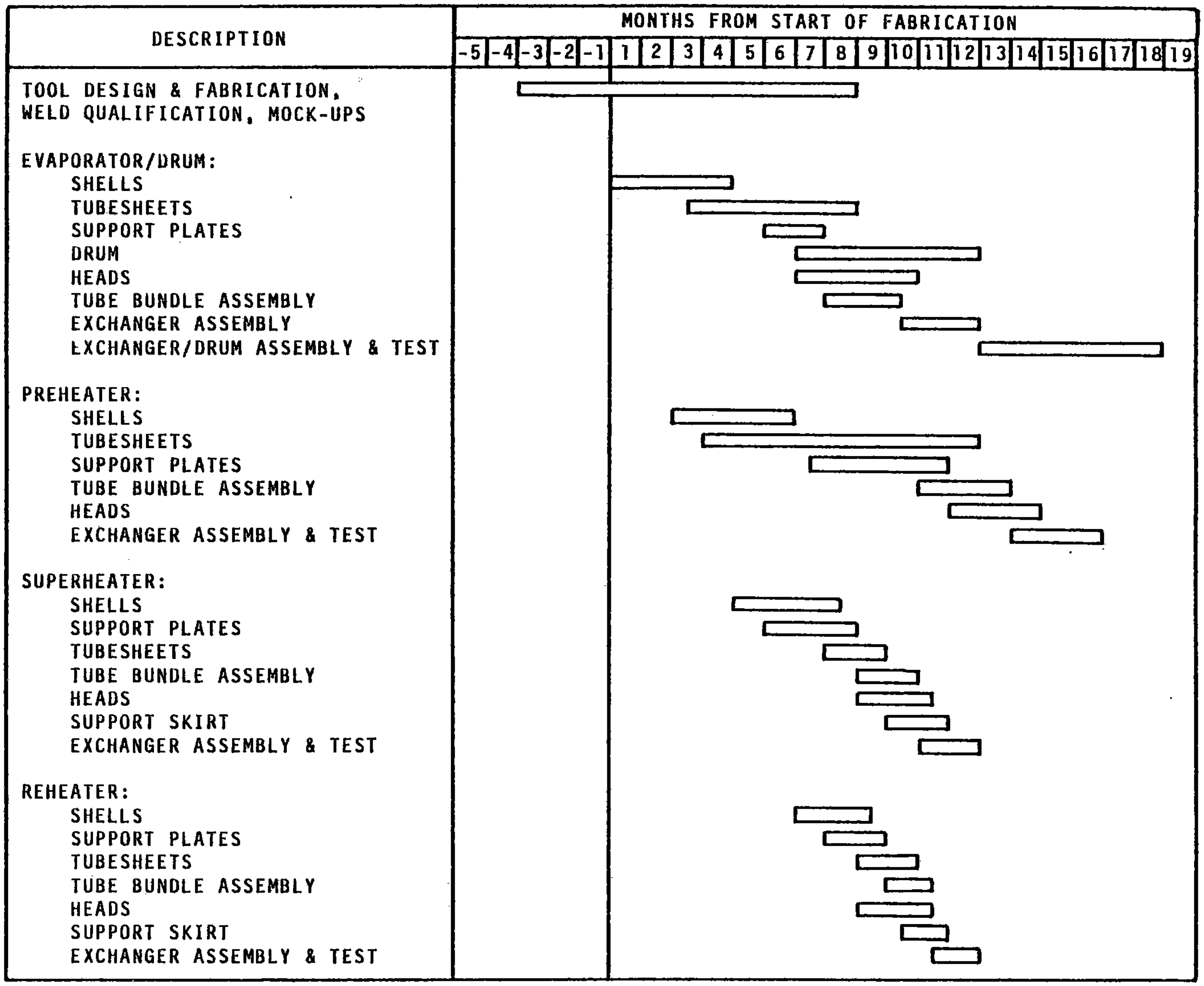

Figure 2.1 Shop Schedule--100-MWe Solar Stand-Alone Heat Exchangers

5. Stress relieve head assembly
6. Machine edge prep at tubesheets
7. Shot blast all surfaces
8. Hold for next assembly.

Expansion Joint

1. Receive and inspect expansion joint subassembly
   - Check dimensions
   - Inspect material certifications and ASME Code, Section VIII certifications by vendor
2. Hold for next assembly.

Pressure Boundary Shell Sections and Support Shell

1. Lay out and cut courses to size
2. Machine edge preps
3. Crimp edges for rolling
4. Roll plate courses
5. Fit up longitudinal seams for welding
6. Weld longitudinal seams
7. Inspect back gouge of weld
8. Spot x-ray seams
9. Re-round shell sections
10. Shot blast all surfaces
11. Hold for next assembly.

Conical Sections of Shell

1. Lay out and cut cone segments and prep "L" seam edges
2. Form cone segments--three pieces per circumference

3. Set up and weld "L" seams and inspection nozzle weld
4. Inspect back gouge of butt-welded seams
5. Round up cone assembly
6. Shot blast all surfaces
7. Machine circumferential weld preps
8. Hold for next assembly.

Shell Inlet Baffle. See Section 2.1.1.

Miscellaneous Parts--Spacers, Rings, Lugs, Etc. See Section 2.1.1.

Tube Support Plates. See Section 2.1.1.

Tie-Rods and Spacers. See Section 2.1.1.

Shell Inlet End Subassembly With Nozzle

1. Set up and weld two conical sections to cylindrical section
2. Inspect back gouge of weld
3. Spot x-ray all seam welds
4. Lay out and cut inlet nozzle opening and edge preps
5. Set up and weld inlet nozzle
6. Inspect back gouge of weld
7. Set up and weld perforated shroud at I.D.
8. Set up and weld hydroclosure to shell inlet nozzle
9. Machine circle seam edge prep at shell end square to axis
10. Set up and weld one course of small end shell
11. Inspect back gouge of weld

12. Spot x-ray all seam welds on small end shell
13. Machine both ends of shell square with axis and machine edge preps
14. Hold for next assembly.

Fabrication of Small-Diameter Lower Portion of Shell

1. Set up and weld cylindrical courses
2. Inspect back gouge of weld
3. Spot x-ray all seam welds
4. Set up and weld spacer rings and expansion joint end ring to shell
5. Machine edge prep end of shell square to axis
6. Hold for next assembly.

Shell Outlet End Subassembly With Nozzle

1. Set up and weld conical section to cylindrical section
2. Inspect back gouge of weld
3. Spot x-ray all seam welds
4. Lay out and cut nozzle opening and edge prep
5. Set up and weld inlet nozzle and inspection nozzles
6. Inspect back gouge of weld
7. Machine edge preps at both ends square with axis
8. Set up and weld expansion joint to shell
9. Inspect back gouge of weld
10. Spot x-ray all seam welds
11. Hold for next assembly.

Shell Assembly

1. Set up and weld upper tubesheet to inlet end shell subassembly
2. Inspect back gouge of weld
3. Spot x-ray weld
4. Set up and weld smaller-diameter lower portion of shell
5. Inspect back gouge of weld
6. Spot x-ray weld
7. Set up and weld outlet end subassembly with nozzle to expansion joint end ring and temporarily tie expansion joint
8. Hold for next assembly.

Tube Bundle Assembly

1. Receive and inspect tubes and material certifications
2. Set up upper end tubesheet/shell with shell assembly horizontally to prepare for tubing the unit
3. Set up tube bundle cage (tie-rods, spacers, and tube support plates) in I.D. of shell
   - Assure alignment of tube holes in support plates with tubesheet holes
   - Maintain cleanliness during tube assembly
4. Assemble all tubes
   - Push all tubes 305 mm (12 in.) past true position
   - Maintain cleanliness of tubes and tube holes and tube weld area
5. Position lower end tubesheet
   - Align tubes and tubesheet holes
   - Support lower end tubesheet securely
   - Retract sufficient tubes to hold tubesheet in alignment and finalize fit of shell at tubesheet lip
   - Apply tie strap across joint to hold firm

6. Set up and weld tubes
   - Retract remainder of tubes
   - Position tubes in upper tubesheet for welding
   - Weld tubes to upper tubesheet
7. Visually inspect all welds
8. Cut tubes at lower end tubesheet to maintain required protrusion for welding and maintain cleanliness
9. Weld tubes to lower tubesheet
10. Visually inspect all welds
11. Set up and weld tubesheet lip to shell and insert type weld
12. X-ray closure seam
13. Apply hydroclosures to all shell-side nozzles and maintain inside cleanliness
14. Soap and air test tube-to-tubesheet welds
   - Apply 172 kPa gage (25 $\mathrm{lb/in^2g}$) to shell side
   - Apply soapy water to each tube weld
15. DETNAFORM® expand tubes to tubesheets--both ends
16. Penetrant test all tube-to-tubesheet welds to meet acceptance criteria of ASME Code, Section VIII-Division 1
17. Hold for further assembly.

Final Assembly--Test and Ship

1. Set up and weld channel hemi-head assemblies (both ends) to tubesheets and insert type weld
2. 5X-magnification inspect root pass
3. 100-percent x-ray channel-to-tubesheet welds
4. Weld on lifting lugs, support lugs, seismic lugs, nameplate brackets, and all attachments

5. Locally stress relieve head to channel welds (2) and purge with nitrogen during stress relief
6. Clean channel side
7. Hydrotest shell side
   - Use potable water or equivalent
   - ASME certification required
   - Drain completely
8. Weld closures to tube-side channel nozzles (2)
9. Hydrotest tube side
   - Use potable water or equivalent
   - ASME certification required
   - Drain completely
10. Vacuum dry assembly and blanket with dry nitrogen
11. Remove hydroclosures (tube side only)
12. Remachine nozzle weld edge preps
13. Apply shipping closures and seal-weld
14. Apply 69 kPa gage (10 lb/in^2g) nitrogen and add pressure gages and refill valves to both shell and tube side
15. Paint carbon steel surfaces--one coat red oxide primer
16. Clear unit with Quality Control and complete ASME certification
17. Load and brace for shipment
18. Release shipment.

2.2.2 Evaporator. See Section 2.1.2.

2.2.3 Superheater and Reheater

Tubesheets (2). See Section 2.1.3.

Nozzle Forgings. See Section 2.1.3.

Upper (Outlet) End Head (1) and Lower (Inlet) End Heads (2). See Section 2.1.3.

Expansion Joint. See Section 2.1.3.

Pressure Boundary Shell Sections and Support Shell. See Section 2.1.3.

Conical Sections of Shell. See Section 2.1.3. Delete step 4.

Shell Inlet Baffle. See Section 2.1.3.

Support Ring Subassembly. See Section 2.1.3.

Miscellaneous Parts--Spacers, Guides, Etc. See Section 2.1.3.

Tube Support Plates. See Section 2.1.3.

Tie-Rods and Spacers. See Section 2.1.3.

Shell Inlet End Subassembly With Nozzle

1. Set up and weld two conical sections to cylindrical sections
2. Penetrant test back gouge of weld
3. Spot x-ray all seam welds
4. Lay out and cut inlet nozzle opening and edge prep
5. Set up and weld inlet nozzle
6. Penetrant test back gouge of weld
7. Set up and weld perforated shroud at I.D.

8. Set up and weld hydroclosure to shell inlet nozzle
9. Machine circle seam edge prep at shell end square to axis
10. Set up and weld one course of small end shell
11. Penetrant test back gouge of weld
12. Spot x-ray all seam welds on small end shell
13. Machine both ends of shell square with axis and machine edge preps
14. Hold for next assembly.

Fabrication of Small-Diameter Lower Portion of Shell

1. Set up and weld cylindrical courses
2. Penetrant test back gouge of weld
3. Spot x-ray all seam welds
4. Set up and weld spacer rings and expansion joint end ring to shell
5. Machine edge prep end of shell square to axis
6. Hold for next assembly.

Shell Outlet End Subassembly With Nozzle

1. Set up and weld conical section to cylindrical section
2. Penetrant test back gouge of circle seam
3. Spot x-ray all seam welds
4. Lay out and cut nozzle opening and edge prep
5. Set up and weld inlet nozzle and inspection nozzle
6. Penetrant test back gouge of weld
7. Machine edge preps at both ends square with axis
8. Set up and weld expansion joint to shell

9. Penetrant test back gouge of weld
10. Spot x-ray all seam welds
11. Hold for next assembly.

Shell Assembly

1. Set up and weld upper tubesheet to inlet end shell subassembly
2. Penetrant test back gouge of weld
3. Spot x-ray weld
4. Set up and weld support cone to shell cone
5. Penetrant test back gouge of weld
6. Set up and machine support cone open-end edge prep
7. Set up and weld smaller-diameter lower portion of shell
8. Penetrant test back gouge of weld
9. Spot x-ray weld
10. Set up and weld outlet end shell subassembly with nozzle to expansion joint end ring and temporarily tie expansion joint
11. Hold for next assembly.

Tube Bundle Assembly

1. Receive and inspect tubes and material certifications
2. Set up upper end tubesheet/shell with shell assembly horizontally to prepare for tubing the unit
3. Set up tube bundle cage (tie-rods, spacers, and tube support plates) in I.D. of shell
    - Assure alignment of tube holes in support plates with tubesheet holes
    - Maintain cleanliness during assembly

4. Assemble all tubes
    - Push all tubes 203 mm (8 in.) past true position
    - Maintain cleanliness of tubes and tube holes and tube weld area
5. Position lower end tubesheet
    - Align tubes and tubesheet holes
    - Support lower end tubesheet securely
    - Retract sufficient tubes to hold tubesheet in alignment and finalize fit of shell at tubesheet lip
    - Apply tie straps across joint to hold firm
6. Set up and weld tubes
    - Retract remainder of tubes
    - Position tubes in upper tubesheet for welding
    - Weld tubes to upper tubesheet
7. Visually inspect all welds
8. Cut tubes at lower end tubesheet to maintain required protrusion for welding and maintain cleanliness
9. Weld tubes to lower tubesheet (WP-8-8-B16)
10. Visually inspect all welds
11. Set up and weld tubesheet lip to shell
    - Insert type weld
    - Inspect root pass
12. X-ray closure seam
13. Apply hydroclosurs to all shell-side nozzles and maintain inside cleanliness
14. Soap and air test tube-to-tubesheet welds
    - Apply 172 kPa gage (25 lb/in^{2}g) to shell side
    - Apply soapy water to each tube weld
15. DETNAFORM® expand tubes to tubesheet--both ends
16. Penetrant test all tube-to-tubesheet welds to meet acceptance criteria of ASME Code, Section VIII-Division 1

17. Hold for further assembly.

Final Assembly--Test and Ship

1. Set up and weld channel hemi-head assemblies (both ends) to tubesheets and insert type weld
2. Penetrant test:
    - Root pass
    - Final O.D. surface on stainless steel material greater than 19.1 mm (0.75 in.) thick
3. 100-percent x-ray channel-to-tubesheet welds
4. Clean channel side
5. Weld on lifting lugs and seismic lugs and add nameplate brackets and all attachments
6. Hydrotest shell side
    - Use demineralized water
    - ASME certification required
    - Drain completely
    - Vacuum dry
7. Weld closures to tube-side channel nozzles (2)
8. Hydrotest tube side
    - Use demineralized water
    - ASME certification required
    - Drain completely
9. Vacuum dry assembly and blanket with dry nitrogen
10. Remove hydroclosures
11. Remachine nozzle weld edge preps
12. Apply shipping closures and seal-weld
13. Apply 69 kPa gage (10 lb/in^2) nitrogen and add pressure gages and refill valves

14. Set up and weld support barrel and flange to conical extension on upper end shell
15. Penetrant test back gouge of weld
16. Clear unit with Quality Control and complete ASME certification
17. Load and brace for shipment and cover with tarpaulins
18. Release shipment.

2.2.4 Shop Schedule

The shop fabrication schedule for the 50-MWe hybrid SGS heat exchangers and steam drum is illustrated in Figure 2.2. Identified are the interrelationships between and time periods required to fabricate such subassemblies as shells, tubesheets, and tube bundles and final assembly and testing of the heat exchanger components. Also identified is the time period required for tool design and fabrication, as well as weld qualification and mock-ups. The period identified relates to the start of heat exchanger fabrication.

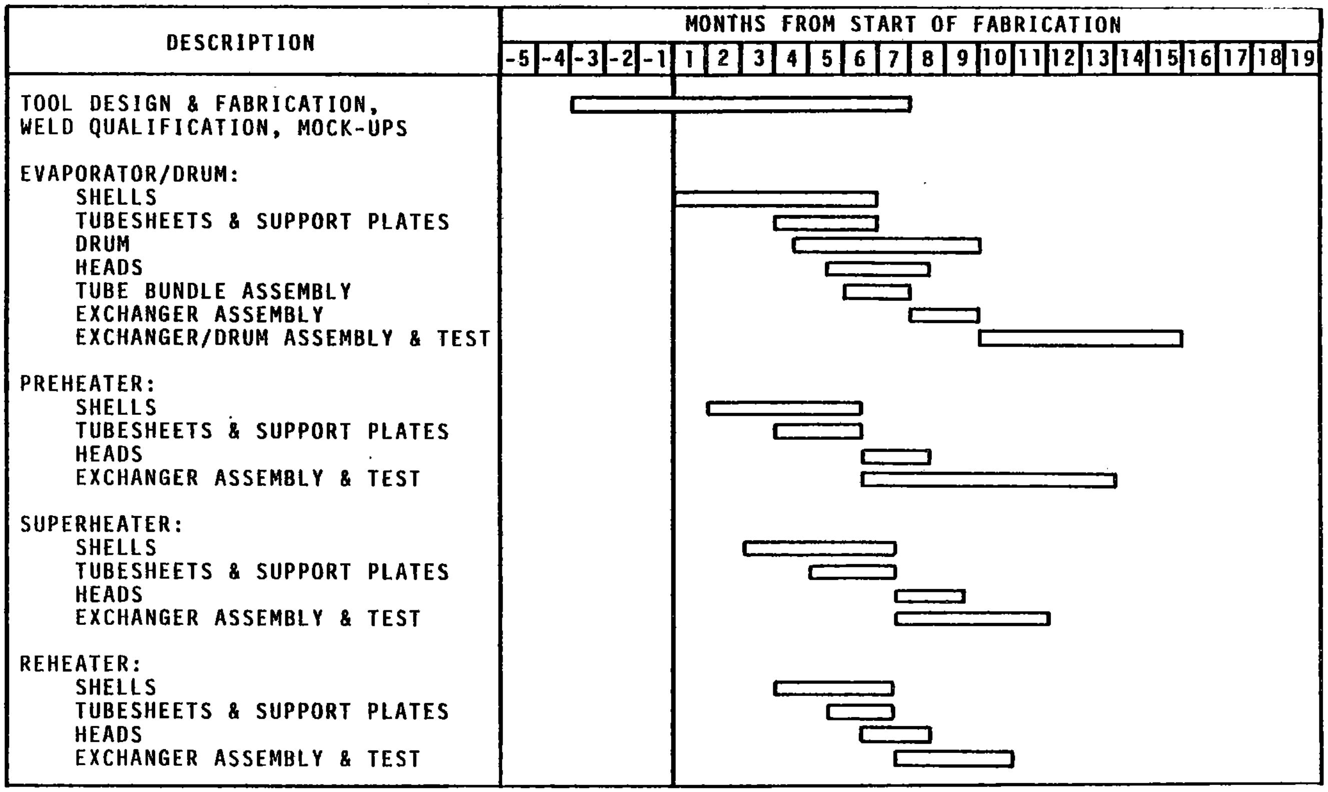

Figure 2.2 Shop Schedule--50-MWe Hybrid Heat Exchangers

Section 3

FIELD FABRICATION/ERECTION PLAN

3.1 100-MWe Solar Stand-Alone SGS

The shop-fabricated molten salt heat exchangers and steam drum, which is designed as an integral component of the evaporator, will be shipped to the job site as individual components and erected in a field-fabricated support structure. The schedule for field fabrication and erection of the molten salt SGS is shown in Figure 3.1. The time period from start of field activities to completion is estimated to be 27 weeks, with an additional week allowed for hydrostatic testing prior to checkout and start-up. The period identified begins with the arrival of the heat exchangers at the job site.

The schedule is essentially divided into three main areas: site preparation and foundations, erection of structural steel, and placement of the heat exchangers. These events are followed by the installation of piping, instrumentation, electrical, and other supporting systems.

Before the heat exchangers arrive at the job site, it is prepared and all foundations, footings, and concrete work--including a pit for the molten salt drain tank--are installed. Then follow the erection of steel and the placement of the heat exchangers upon their arrival. Because of their weight and size, the exchangers are placed in the structure and supported by an exterior system (e.g., crane or A-frame) while the rest of the steel is placed. Then the required cross bracing, stairway, guardrails, and floor grating are placed. The start-up feedwater heater, located outside of the boundaries of the SGS structure, is also placed during this phase.

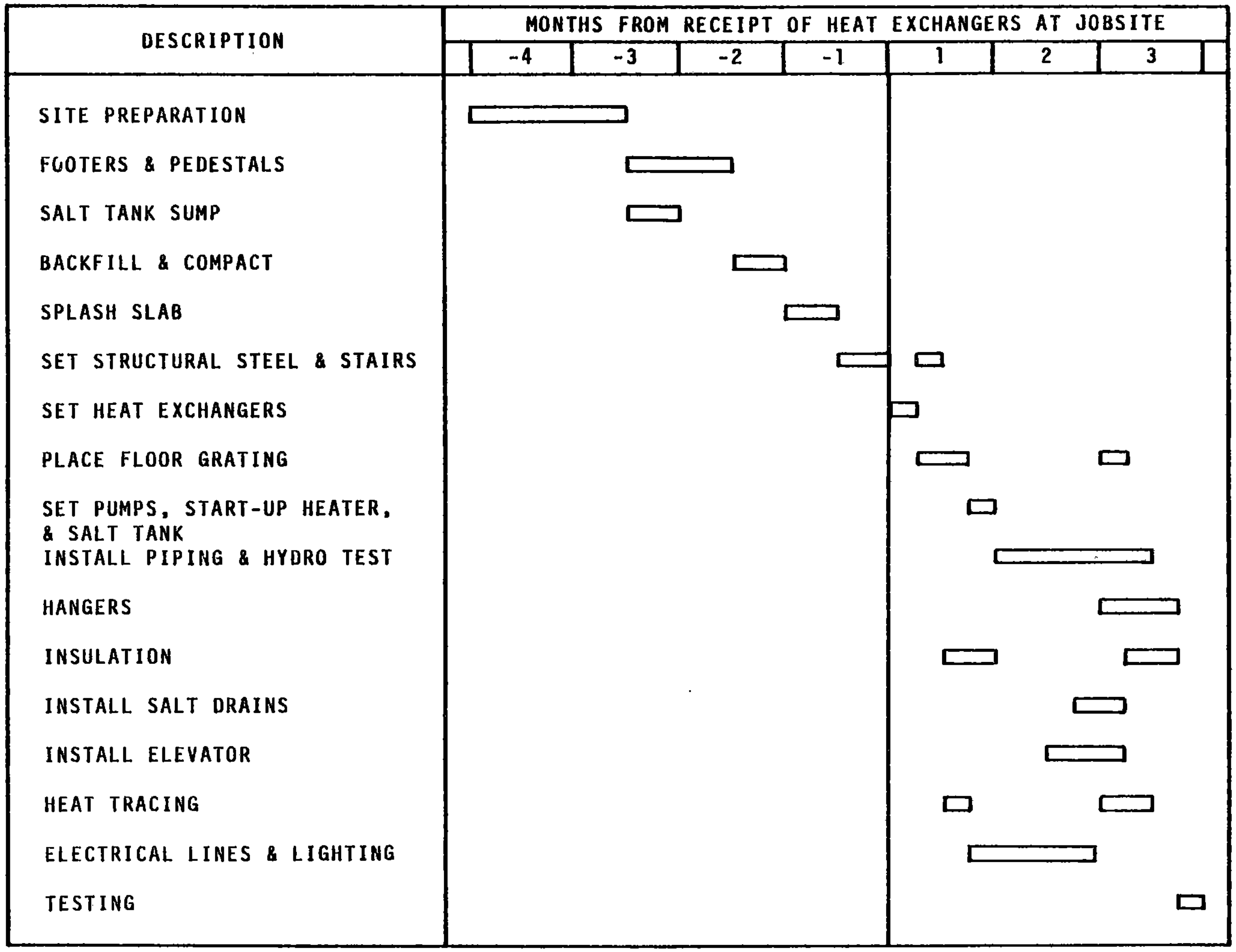

Figure 3.1 Field Fabrication/Erection Schedule

The next phase is the installation of pumps, piping, electric heat tracing, insulation and lagging, and 200 instruments and controls. Some of the subtasks will overlap. The valving, electric heat tracing, and some controls will be placed before the insulation and lagging are installed. Likewise, all of the grating cannot be installed before the installation of the piping and insulation has been completed.

The molten salt SGS is one of the many subsystems that comprise the overall solar stand-alone power station. Construction of the SGS will probably coincide with construction of other subsystems, such as thermal storage, the receiver, and the heliostat field. Therefore, the SGS field fabrication and erection plan may be modified as required by the overall system construction schedule to maximize the utilization of space, construction personnel, and equipment.

3.2 50-MWe HYBRID SGS

The field fabrication and erection plan for the 50-MWe hybrid SGS is essentially identical to that for the 100-MWe solar stand-alone SGS except that the 50-MWe unit has no auxiliary start-up feedwater heater. The schedule shown in Figure 3.1 for the 100-MWe unit also applies to the 50-MWe unit; elimination of the start-up feedwater heater has no impact on the schedule.

As with the 100-MWe unit, construction of the 50-MWe hybrid SGS will probably coincide with construction of other subsystems within the solar portion of the repowered power station. Therefore, the SGS field fabrication and erection plan may be modified as required by the overall system construction schedule to maximize utilization of space, construction personnel, and equipment.

APPENDIX E: TECHNICAL PROPOSAL
(ABRIDGED)

MOLTEN SALT STEAM GENERATOR
SUBSYSTEM RESEARCH EXPERIMENT

Sandia Contract 20-9909B

Prepared for

Sandia National Laboratories
Livermore, California

January 15, 1982

Abridged Version: September 1982

FWSDC No. 9-71-9202

FOSTER WHEELER SOLAR DEVELOPMENT CORPORATION
12 Peach Tree Hill Road, Livingston, New Jersey 07039

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ILLUSTRATIONS

ILLUSTRATIONS (Cont)

TABLES

SECTION 1
PROPOSAL SUMMARY

Section 1

PROPOSAL SUMMARY

1.1 INTRODUCTION

To develop a cost-effective molten salt steam generator subsystem (SGS) for solar thermal plants, DOE [through Sandia National Laboratories, Livermore (SNLL)] began a two-phase SGS development project, the first phase of which began in June 1981 and will be completed in April 1982. This project includes:

- Phase 1--Preliminary design of a molten salt SGS for a solar central receiver facility
- Phase 2--Design, construction, testing, and evaluation of a Subsystem Research Experiment (SRE) of sufficient scale to ensure successful operation of the full-size subsystem designed in Phase 1.

This document is the Foster Wheeler Solar Development Corporation (FWSDC) proposal for the Phase 2 effort generated as part of our Phase 1 work and based on the SRE requirements determined in Phase 1.

1.2 SRE OBJECTIVES

The program we propose meets the primary objectives of the SRE specified by SNLL, which are as follows:

- Demonstrate the ability to design, construct, and operate a molten salt steam generator for generating high-pressure [13.48 MPa gage (1955 lb/in²g)], high-temperature [541°C (1005°F)] steam for power generation
- Resolve all critical design fabricating, performance, operating, and cost-estimating uncertainties associated with the full-scale SGS designs developed during Phase 1
- Provide a molten salt steam generator that can be utilized for a future full-system experiment (FSE).

As directed by SNLL, our proposed field tests are compatible with the CRTF equipment and are limited to the thermal capacity of the thermal storage SRE.

Specific areas that will be investigated in the SRE to meet the aforementioned objectives are:

- Demonstrate the performance of the various heat exchangers and correlate it with analytical predictions. This will include:
  - Thermal duty
  - Pressure drop

  - Shell-side heat-transfer coefficient
  - Steam/water-side flow distribution
  - Evaporator circulation
  - Tube-side flow stability
  - Absence of departure from nucleate boiling (DNB)
- Demonstrate the behavior of the SRE control system and correlate it with the computer predictions obtained from the control system dynamic computer model
- Verify procedures established to start up and shut down the SGS during normal and emergency operating conditions
- Demonstrate the ability to design against tube vibration
- Demonstrate the absence of gross structural deformations
- Demonstrate the compatibility of materials of construction with the molten salt.

1.3 PROPOSED AND ALTERNATIVE SREs

Although a molten salt SGS for a high-temperature, high-pressure reheat power cycle has never been designed, fabricated, and operated, it is our assessment (based on our design, fabrication, and testing of similar heat exchangers in the past) that there are no critical design or fabrication uncertainties that must be resolved. However, since the proposed operating procedures have never been demonstrated, we believe that an SRE is needed primarily to demonstrate the ability to operate a molten salt steam generator designed for high-temperature, high-pressure applications. Therefore, our proposed SRE is oriented toward a complete subsystem rather than individual components and contains all essential features of the full-size subsystem.

To meet the objectives of the Phase 2 program, we propose an SRE and a simpler, less-expensive alternative SRE. Both will be designed to be compatible with an FSE and with other necessary equipment at the CRTF.

1.3.1 Proposed SRE

The proposed SRE SGS, like the full-scale 100- and 50-MWe subsystems, has four heat exchangers--preheater, natural-circulation evaporator, superheater, and reheater. All heat exchangers are oriented vertically with all heated steam/water flowing upward. The preheater, superheater, and reheater are counterflow; the evaporator is parallel flow to improve natural circulation. The proposed SRE SGS is designed to generate 1.57 kg/s (12,500 lb/h) superheated steam at 541°C (1005°F) and 13.5 MPa gage (1955 lb/in^{2}g), and 0.68 kg/s (5413 lb/h) simulated reheat steam at 541°C (1005°F) and 2.9 MPa gage (425 lb/in^{2}g).

The proposed SRE includes 11 test series to demonstrate subsystem-level as well as component-level features of the full-scale SGS. Subsystem-level aspects of the SRE involve demonstration of all operating modes of the full-scale system to show that the individual components can be operated as an integrated system in a safe and stable manner. Component-level aspects of the SRE involve monitoring each heat exchanger for specific data that will verify the ability of developed analytical methods to predict heat exchanger performance characteristics.

Subsystem-level testing will include demonstration of the following operating modes:

- Cold start-up
- Full- and part-load steady-state operation
- Load changes
- Diurnal shutdown
- Diurnal start-up
- Shutdown to warm standby
- Warm standby
- Start-up from warm standby
- Shutdown to cold conditions
- Emergency shutdown

While demonstrating the SRE SGS operating modes, data will also be obtained to evaluate component-level considerations such as the following:

- Salt-side film coefficients
- Dynamic flow stability of evaporator
- Absence of DNB/dryout in the evaporator
- Superheater flow stability
- Fouling
- Ambient heat losses
- Absence of tube vibration
- Absence of gross structural deformation
- Tubesheet temperature response to load change.

1.3.2 Alternative SRE

The alternative SRE reduces the SRE cost 21 percent, shortens the SRE schedule from 24 months to 21 months, and still includes 9 of the 11 test series planned for the proposed SRE.

The alternative SRE SGS includes only the evaporator and superheater; the preheater and reheater are eliminated. The superheater is identical to the superheater in the proposed SRE. The evaporator is also essentially the same as the proposed SRE evaporator except for increased pressure-part thickness.

Elimination of the superheater and reheater means that the following full-scale SGS features cannot be demonstrated:

- Evaporator drum-water recirculation to preheater inlet
- Use of main steam to preheat reheater
- Establishing main steam flow to reheater before admission of salt to reheater on start-up
- Control response of superheater/reheater bypass combination
- Demonstration of emergency shutdown procedures for complete subsystem.

We do not believe that these omissions pose serious development risks, as discussed in detail in Section 3.3.

1.4 STATEMENT OF WORK

FWSDC will perform the proposed work in accordance with the Statement of Work furnished by SNLL in the document "Molten Salt Steam Generator Subsystem Research Experiment--Evaluation Criteria and Preliminary Supporting Documents" dated November 16, 1981. We will accomplish the work in nine tasks and anticipate no difficulties in doing so. Figure 1.1 is our Work Breakdown Structure for the Phase 2 project.

1.5 PROJECT ORGANIZATION

To perform the Phase 2 SRE, we have assembled a team of our affiliated companies with complementary backgrounds in the design and shop fabrication of heat exchangers of all types and the design and field construction of complete process systems. The team consists of our affiliated companies--Foster Wheeler Energy Corporation (FWEC); FW Energy Applications, Inc. (FWEA); and Foster Wheeler Special Projects Engineering and Construction, Inc. (FWSPEC).

FWSDC, the prime contractor for this proposed project, is a separate operating entity within Foster Wheeler Development Corporation, the research and development arm of the parent holding company, Foster Wheeler Corporation. FWSDC personnel have done preliminary design, thermal/hydraulic analysis, and structural analysis on a wide variety of solar receivers and heat exchangers using steam/water, molten salt, and sodium as heat-exchange media. In addition, FWSDC personnel have participated in the design of many steam generators and heat exchangers for nuclear plants.

FWEC has designed and fabricated many steam generators and heat exchangers in accordance with ASME Codes as well as to more exacting nuclear standards. The heat exchangers proposed here will be fabricated in their plant in Mountaintop, Pennsylvania.

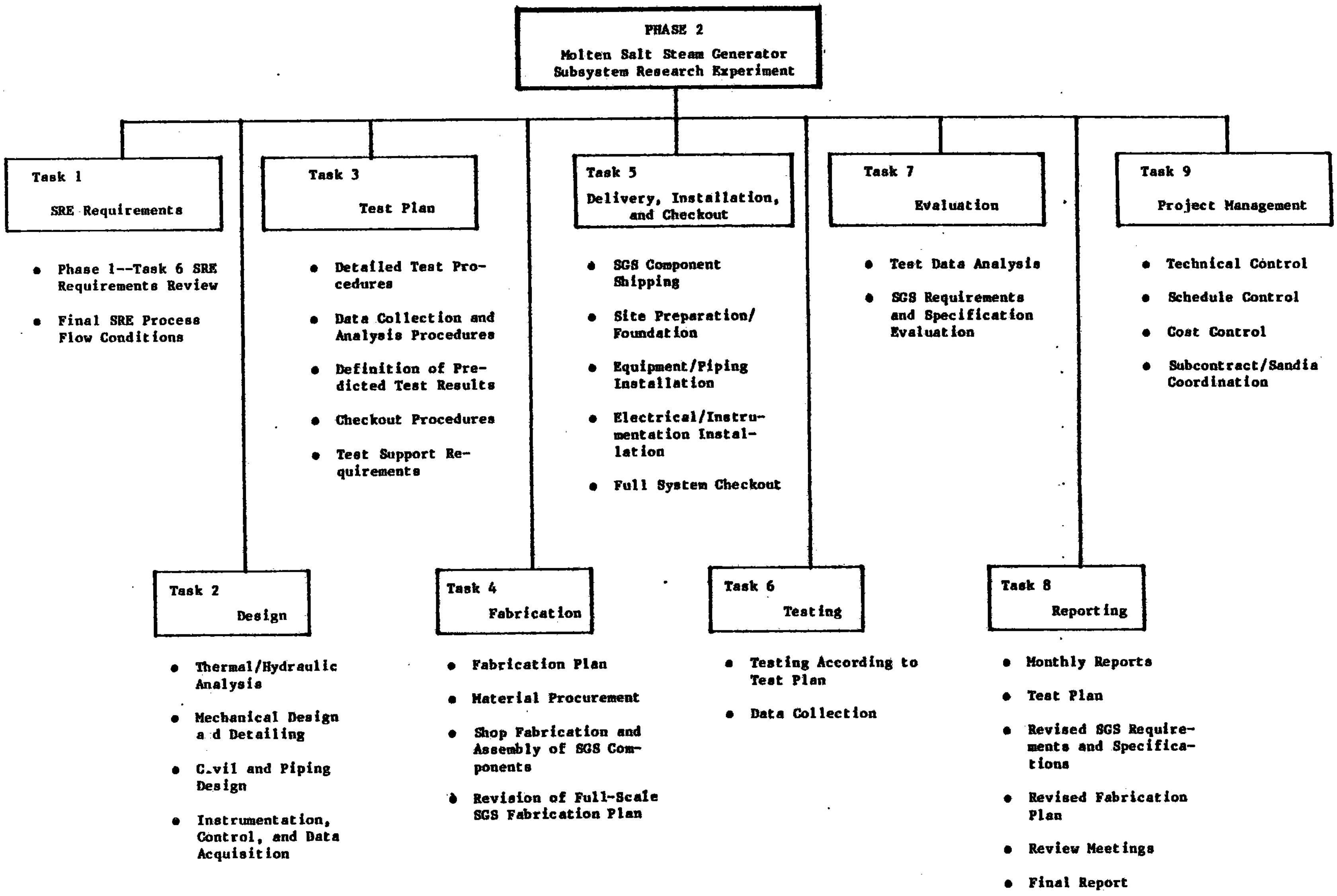


Figure 1.1 Work Breakdown Structure

FWEA has an extensive background in detailed thermal/hydraulic and structural analyses as well as in the detailed design of sodium steam generators and heat exchangers for nuclear service.

FWSPEC's strength lies in design of piping systems, foundations, and supporting structures; the specification and procurement of pumps, valves, controls, and similar components; and the construction of complete process plants.

To the greatest extent possible, key personnel who have been involved in the Phase 1 effort have been given responsible assignments in Phase 2.

SECTION 2

REVIEW OF PHASE 1 PROGRAM

Section 2

REVIEW OF PHASE 1 PROGRAM

2.1 OVERVIEW

To develop a cost-effective molten salt steam generator subsystem (SGS) for solar thermal plants, DOE through Sandia National Laboratories, Livermore (SNLL), began a two-phase SGS development project, the first phase of which started in June 1981 and will be completed in April 1982. The work to be accomplished in the two phases is:

- Phase 1--Preliminary design of a molten salt SGS for a solar central receiver facility
- Phase 2--Design, construction, testing, and evaluation of a Subsystem Research Experiment (SRE) of sufficient scale to ensure successful operation of the full-size subsystem designed in Phase 1.

The primary goals of the project are:

- Reduction of uncertainty in SGS capital, operating, and maintenance costs
- Demonstration of high-temperature high-pressure steam generation with molten salt.

The Phase 1 study presently being conducted by FWSDC incorporates the following major tasks:

Task 1--Review of SGS Definition and Interface Requirements
Task 2--Definition of SGS Requirements
Task 3--SGS Concept Selection
Task 4--SGS Design
Task 5--SGS Cost and Fabrication/Erection Plan
Task 6--SGS SRE and Development Plan
Task 7--Phase 2 Plan and Proposal
Task 8--Project Management.

This document is the Phase 2 proposal generated for Task 7 and is based on the SRE requirements determined in Task 6.

2.2 REVIEW OF FULL-SIZE SGS DESIGN

Pages 2-2 through 2-19 from the original proposal have been deleted. For details on the full-size SGS design, refer to Phase 1--Final Report, Volume 1, Section 5.

2.3 ASSESSMENT OF FULL-SIZE SGS DESIGN AND NEED FOR SRE

The selection of the vertical, straight-tube heat exchanger configuration was based on Foster Wheeler's past experience in the design and fabrication of sodium-cooled heat exchangers as well as conventional shell-and-tube heat exchangers for the power and process industries. From a manufacturing point of view, straight-tube designs are the simplest to fabricate. The expansion bellows incorporated in the design can accommodate the differential expansion between the tube bundle and shell resulting from the high-temperature molten salt and steam environment that will be encountered. A listing of references that contain discussions of similar heat exchanger designs is given in Table 2.3.

The materials selected for the heat exchangers are:

Preheater	- Carbon steel
Evaporator	- 1-1/4%Cr-1/2%Mo
Superheater	- Type 304SS
Reheater	- Type 304SS

The selection of these materials was based on a review of industry practices in heat exchanger design and a study of available data on material compatibility with molten salt. Our study concluded that the oxidation mechanism for corrosion in a high-temperature molten salt environment is similar to that observed on boiler tubing that was subjected to steam/water environments and that 2-1/4%Cr-1/2%Mo would be satisfactory for the superheater and reheater. However, because industrial experience in molten salt is mostly at a low temperature and the high-temperature experimental data are limited, Type 304 stainless steel was selected as a conservative approach. Foster Wheeler's opinion is that the selected materials are satisfactory for the molten salt environment that will be encountered. A larger, long-term data base for molten salt material compatibility is desirable to verify this conclusion and permit more cost-effective designs. Long-term laboratory corrosion testing should continue as an extension of previous SNLL-sponsored tests and is not recommended as part of the short-term field tests proposed in this document.

The heat exchanger heat-transfer surface requirements were determined by an in-house computer program, MSSG. The program utilizes well-established correlations for both shell- and tube-side film coefficients. The data base for steam and water is extensive. However, the data for molten salt are limited. Recent molten salt receiver tests conducted at the CRTF by Martin Marietta indicate that incorporating the fluid properties of molten salt into standard correlations gives good results. Although data are limited, Foster Wheeler has confidence in the selected correlations for molten salt. The proposed SRE will verify their accuracy.

Structural design and fabrication of the SGS heat exchangers are done according to Section VIII of the ASME Code. The Code design procedures are well

Table 2.3 References Containing Examples of Straight-Tube Heat Exchanger Designs

1. R. H. Sawyer, S. M. Cho, and D. H. Pai, "Intermediate Heat Exchanger Development for Clinch River Breeder Reactor Plant," ASME Paper 77-WA/NE-10, 1977.

2. B. E. Dawson, "Conceptual Design of an Intermediate Heat Exchanger for Conceptual Design Study Plant," Foster Wheeler Energy Corporation Report ND/80/37, September 1980.

3. B. E. Dawson, "Conceptual Design of an Intermediate Heat Exchanger for Large Pool LMFBR Plant," Foster Wheeler Energy Corporation Report ND/78/37, November 1978.

4. C. R. Adkins, D. J. Bongaards, and P. G. Smith, "Double Wall Tube Steam Generator for Breeder Nuclear Plants," ASME Paper 81-JPGC-NE-2, 1981.

5. J. Y. Hwang, et al., "Thermal Hydraulic Design and Performance of an LMFBR Double Wall Tube Seven-Tube Steam Generator Model," ASME 81-WA/NE-7, 1981.

established. Critical areas of the heat exchangers are tubesheets, nozzles, and bellows. Foster Wheeler has designed many of each of these components. Design approaches for the bellows were verified when we analyzed and tested four prototypical bellows in our laboratory as part of the Clinch River Breeder Reactor program. We are confident that the methods used in the SGS design are the best available and that they will receive the Code stamp of approval. Based on similar design, fabrication, and testing done in the past, it is Foster Wheeler's assessment that there are no material, design, or fabrication issues that must be resolved in the molten salt steam generator system.

A molten salt steam generator system for a high-temperature high-pressure reheat power cycle has never been designed, fabricated, and operated. The proposed procedures for unit operation have never been demonstrated. Consequently, Foster Wheeler believes that an SRE is needed primarily to demonstrate the ability to operate a molten salt steam generator for high-temperature high-pressure applications rather than to resolve any questionable design or fabrication feature of the proposed design. The proposed SRE is oriented toward a subsystem test rather than a component test; thus it includes all the essential features of the full-size subsystem.

SECTION 3
TECHNICAL DISCUSSION

Section 3

TECHNICAL DISCUSSION

3.1 SRE OBJECTIVES

The primary objectives of the SRE, specified by SNLL, are as follows:

- Demonstrate the ability to design, construct, and operate a molten salt steam generator for generating high-pressure [13.48 MPa gage (1955 lb/in^2g)], high-temperature [541°C (1005°F)] steam for power generation
- Resolve all critical design, fabricating, performance, operating, and cost-estimating uncertainties associated with the full-scale SGS designs developed during Phase 1
- Provide a molten salt steam generator that can be utilized for a future full-system experiment (FSE).

As directed by SNLL, our proposed field tests are compatible with the CRTF equipment and are limited to the thermal capacity of the thermal storage SRE.

Specific areas that will be investigated in the SRE to meet the aforementioned objectives are.

- Demonstrate the performance of the various heat exchangers and correlate it with analytical predictions. This will include:
  - Thermal duty
  - Pressure drop
  - Shell-side heat-transfer coefficient
  - Steam/water-side flow distribution
  - Evaporator circulation
  - Tube-side flow stability
  - Absence of departure from nucleate boiling (DNB).
- Demonstrate the behavior of the SRE control system and correlate it with the computer predictions obtained from the control system dynamic computer model.
- Verify procedures established to start up and shut down the SGS during normal and emergency operating conditions.
- Demonstrate the ability to design against tube vibration.
- Demonstrate the absence of gross structural deformations.
- Demonstrate the compatibility of materials of construction with the molten salt.

The scaling factors for the proposed SRE are approximately 60:1 and 30:1 in scaling down from the full-scale 100-MWe solar stand-alone and 50 MWe-hybrid SGS designs. With such large scaling factors, it is not possible to duplicate all the design features of the full-scale systems. For example:

- The mass of material in a scaled-down unit is much less than in a full-size unit; thus the temperature response and the thermally induced stresses are much different.
- Structural and fabrication considerations limit reduction in tube size; therefore, a scaled-down unit has fewer tubes than a full-size unit. Consequently, tube-side flow distribution and shell-side crossflow patterns will be different. In addition, tie-rods required for baffle-plate support occupy a more significant fraction of the exchanger volume and can affect the thermal performance of the unit by creating uncooled regions.
- Physical requirements such as tubesheet accessibility call for a different mechanical design in the smaller units. In the larger units, a person can gain access to the lower tubesheet through the steam/water inlet pipe. In a scaled-down unit, this is not possible, and expansion bellows must be located in the exchanger shell.

Since design considerations for scaled-down units differ somewhat from those for full-size units, the SRE heat exchanger components were sized to meet the subsystem-level performance requirements without duplicating all the component internal functional characteristics (i.e., shell-side crossflow pattern, bypass flow, etc.). Although the component internal functional characteristics for the SRE will be somewhat different from those for the full-size SGS, the SRE will permit evaluation of the analytical techniques used to estimate performance for both large and small subsystems.

3.2 PROPOSED SRE DESCRIPTION

3.2.1 SGS Description

The proposed SRE SGS is schematically illustrated in Figure 3.1. The subsystem is essentially a scaled-down version of the Phase 1 100-MWe solar stand-alone SGS design except for the following:

- The reheater is designed for 50 percent of the scaled-down steam capacity.
- The cold-salt recirculating pump required for salt temperature control during unit start-up and shutdown is not required because the existing CRTF cold-salt pump (thermal storage SRE) can be utilized for this purpose.
- A separate, vertical steam drum, rather than one designed as an integral component of the evaporator, is used to deliver dry, saturated steam to the superheater.

The proposed SRE SGS comprises four heat exchangers designed to generate 1.57 kg/s (12,500 lb/h) of superheated steam at 541°C (1005°F) and 13.5 MPa gage (1955 lb/in^2g) and to generate 0.68 kg/s (5413 lb/h) of simulated reheat steam at 541°C (1005°F), 2.9 MPa gage (425 lb/in^2g). Feedwater heated to the required test conditions is supplied by the existing CRTF steam/water heat-rejection system. Hot molten salt from the hot-salt storage tank in the existing CRTF thermal storage SRE enters the system at 566°C (1050°F), flows in parallel through the superheater and reheater, combines, and passes in series through the evaporator and preheater. Cold salt leaves the preheater at 288°C (550°F) and is directed back to the cold-salt storage tank in the thermal storage SRE. All heat exchangers are oriented vertically with all heated steam/water flowing upward. The preheater, superheater, and reheater are counterflow; the evaporator is parallel flow to improve natural circulation. The steam/water mixture leaving the evaporator discharges into a separate vertical steam drum which provides dry, saturated steam to the superheater.

The final main steam temperature is regulated by a valve at the superheater outlet that controls the salt flow rate through the superheater. Saturated steam from the steam drum is bypassed to the superheater outlet for emergency control. Reheat steam temperature is regulated by a valve at the reheater outlet which controls the salt flow rate through the reheater. A spray attemperator is located at the reheater steam inlet for emergency control. The quantity of steam generated is governed by the flow rate and temperature of the salt entering the evaporator. A salt line which bypasses hot salt around the superheater and reheater to the evaporator is provided for this purpose. A drum-water recirculation pump maintains the feedwater at a temperature above the salt freezing point of 221°C (430°F) during unit start-up when steam is not available to preheat the feedwater passing through the high-pressure feedwater heater. For cold unit start-up, an auxiliary propane-fired heater supplements

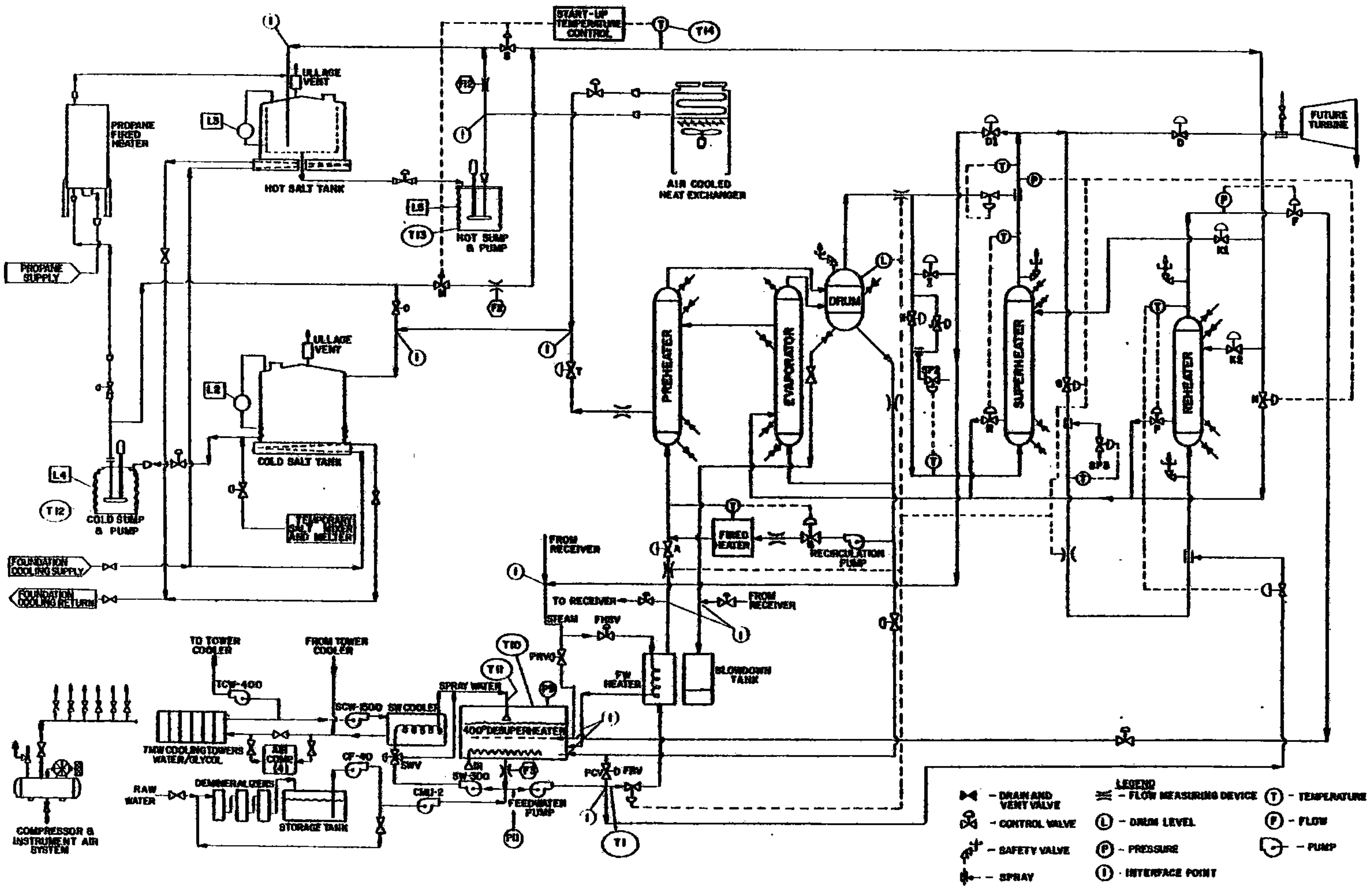


Figure 3.1 Schematic of Proposed SRE

the steam/water heat-rejection system (HRS) feedwater heating capability, which is limited to 204°C (400°F), until steam is generated and admitted to the high-pressure feedwater heater.

Approximately 38 percent of the main steam discharged from the superheater is passed through a bypass line to the reheater steam inlet. The flow is throttled and cooled by spray water extracted from the feedwater pump discharge to simulate reheat steam flow that would come from the high-pressure discharge of a full-sized reheat turbine. The heated steam leaving the reheater is recycled to the deaerator-desuperheater. The steam bypass line to the reheater, also used to simulate the bypass line in the full-sized system, is used for unit start-up.

The remaining steam discharged from the superheater outlet is used for feedwater heating. A fraction of the steam is throttled and passed through the high-pressure feedwater heater and then is sent to the deaerator-desuperheater. The remaining steam is sent directly to the deaerator-desuperheater. Excess heat not required for feedwater heating is dissipated to the atmosphere by the closed-loop dry-cooling towers incorporated in the CRTF steam/water HRS.

3.2.2 Interface Requirements

Steam/Water HRS. Chemically controlled feedwater is supplied to the SRE SGS by the existing CRTF steam/water HRS. The steam/water HRS, shown schematically in Figure 3.1, can supply boiler-quality feedwater at a maximum rate of 4.7 liter/s (75 gal/min) and a minimum temperature and pressure of 204°C (400°F) and 15.5 MPa (2250 lb/in^2). The feedwater temperature can be increased to 288°C (550°F) by using the high-pressure feedwater heater, if superheated steam is available. The steam/water HRS can also supply 25.2 liter/s (400 gal/min) of a 40-percent ethylene glycol/water solution to the experiment locations. The steam HRS can accommodate 2.5 kg/s (20,000 lb/h) of 518°C (965°F) and 13.8 MPa (2000 lb/in^2) steam.

The feedwater system starts at the CRTF raw water supply. Water is passed through cation, anion, and mixed demineralizer beds and stored in a 75,700-liter (20,000-gal) tank. The water is pumped from the tank into a low-pressure [1.6 MPa (233 lb/in^2)], spray-water loop that contains a deaerator-desuperheater and a heat exchanger. Hydrazine is added in this spray-water loop for dissolved-oxygen control. Feedwater is pumped into a high-pressure pipe running up the tower to the receiver experiment area. High-pressure steam/water piping from the receiver experiment area runs down the tower back to the deaerator-desuperheater to complete the cycle.

Water chemistry is monitored at five sample points in the feedwater system. On-line analyzers can measure:

- Cation conductivity
- Specific conductivity
- pH
- Dissolved oxygen
- Sodium
- Hydrazine
- Silica
- Copper
- Iron

A closed-loop dry-cooling-tower system dissipates energy returned in the feedwater steam. The cooling-tower loop uses a 40-percent ethylene glycol/water solution for coolant, passing it through the shell side of the heat exchanger in the spray-water loop. Coolant at 94.6 liter/s (1500 gal/min) is supplied to the heat exchanger. A second 94.6-liter/s (400-gal/min) pump taps coolant from the cooling-tower loop, pumps it up the tower to the working receiver equipment shed-heat exchanger, and provides coolant at each test level. The cooling-tower system also provides coolant to the air compressors that supply the air HRS.

A receiver blowdown line is routed down the tower and into an underground, blowdown holding chamber. Two chemical-feed mixing tanks and metering pumps are provided for the feedwater pH and O_2 control chemicals. A glycol/water mixing tank holds glycol/water makeup in the dry-cooling-tower loop. A 15,000-liter (4000-gal) industrial wastewater collection tank handles system waste.

The SRE SGS will interface with the steam/water HRS at the following locations:

- Feedwater pump discharge
- High-pressure feedwater heater feedwater outlet
- High-pressure feedwater heater steam inlet
- Deaerator-desuperheater steam/water inlet
- Blowdown tank inlet.

The location of these terminal points is identified on the SRE flow schematic (Figure 3.1).

Thermal Storage SRE. Hot molten salt at 566°C (1050°F) is supplied to the SRE SGS by the existing CRTF thermal storage SRE schematically illustrated in Figure 3.1.

Cold molten salt at 288.8°C (550°F) is stored in the 3.7-m (12-ft)-high 3.7-m (12-ft)-dia, carbon-steel cold-salt storage tank. Cold salt is drained into the sump of the cold-salt pump, which is designed to deliver 6.9 liter/s (110 gal/min) salt at a head of 1.2 MPa (174 lb/in^2). The cold salt is pumped through a 3-MWe propane-fired heater and is heated to 566°C (1050°F). The hot salt discharged from the heater is directed into the hot-salt storage tank. The I.D. and height of the tank are 3.06 m (10.04 ft) and 5.64 m (18.5 ft) respectively, giving it a thermal capacity of 7 MWh. The tank has a carbon-steel outer shell with internal insulation and a waffled, Incoloy 800 liner. Hot salt is drained from the hot-salt tank into the sump of the hot-salt pump, which is designed to deliver 6.6 liter/s (106 gal/min) salt at a head of 0.4 MPa (51 lb/in^2). The hot salt is pumped through a 5-MWt fan-driven air cooler and is cooled to 566°C (550°F) before it is returned to the cold-salt tank to complete the cycle.

The hot- and cold-salt tank foundations are water-cooled. Electric trace heaters are provided on all salt piping, pump sumps, and the lower section of the hot-salt tank shell. Both salt pumps are vertical, centrifugal, cantilever-type pumps. Discharge rates from the storage tanks are based on the pump capacities and the system resistance.

The SRE SGS will interface with the CRTF thermal storage SRE at the following locations:

- Hot-salt pump outlet
- Hot-salt tank inlet
- Cold-salt pump outlet
- Cold-salt tank inlet.

The location of these terminal points is identified on the SRE flow schematic (Figure 3.1).

Data Acquisition. During the SRE test, 166 transducers must be monitored. They are of the following types:

Thermocouples	122
Pressure Transducers	22
Flow Transducers	19
Level Monitors	5
	168

These transducers are listed in Section 3.2.4.

Requirements. The data acquisition system should be capable of performing the following functions:

- Collecting data from 168 transducers every 7 seconds
- Converting the data to engineering units
- Scanning and checking all data for alarms and out-of-limit conditions and printing or displaying these conditions
- Providing continuous display of selected transducers on demand
- Storing the converted data on magnetic tape for off-line data processing or archival purposes.

Ideally, the data acquisition system should have sufficient computer power for on-line performance evaluation and calculations and graphic capabilities so that calculated values or other data can be displayed for better understanding of the SGS. The Acurex Autodata 10/10 data acquisition system presently available in the HRS has no computer power for on-line data processing, performance evaluation, and graphic display. Because of these limitations, we are proposing the following system:

Proposed System. This system is a minicomputer-based data acquisition and data reduction (DARP) system, which incorporates the data logger as a front end to the minicomputer. It is controlled by a computer and requires little or no human supervision. Figure 3.2 shows the Foster Wheeler DARP system. The minicomputer is a multitasking real-time system. In this system data acquisition, reduction, and performance analyses are run as separate tasks. All tasks are written in FORTRAN and are in an interactive mode of operation. All commands to the computer for data reduction, acquisition, and analysis are in conversational English.

- System Hardware. The system hardware consists of a control unit, a data logger, and peripheral equipment. The control unit is a mini/microcomputer that accepts data in digital form only. It is programmed to take the data from the data logger into its memory. The data are reduced to engineering units; stored temporarily on disk; and at regular intervals, transmitted to magnetic tape, if needed.

  The data logger consists of the Analog Multiplexor (MUX) and Analog to Digital Converter (A/D). By means of solid-state switches, the MUX connects the many analog inputs to the A/D, which converts the analog input signals to a digital code. The data logger normally comprises one main frame with 100 input points and satellite units, as necessary, of 200 input points each. It includes the following:

  - Analog input
  - Two or four alarm setpoints per analog input

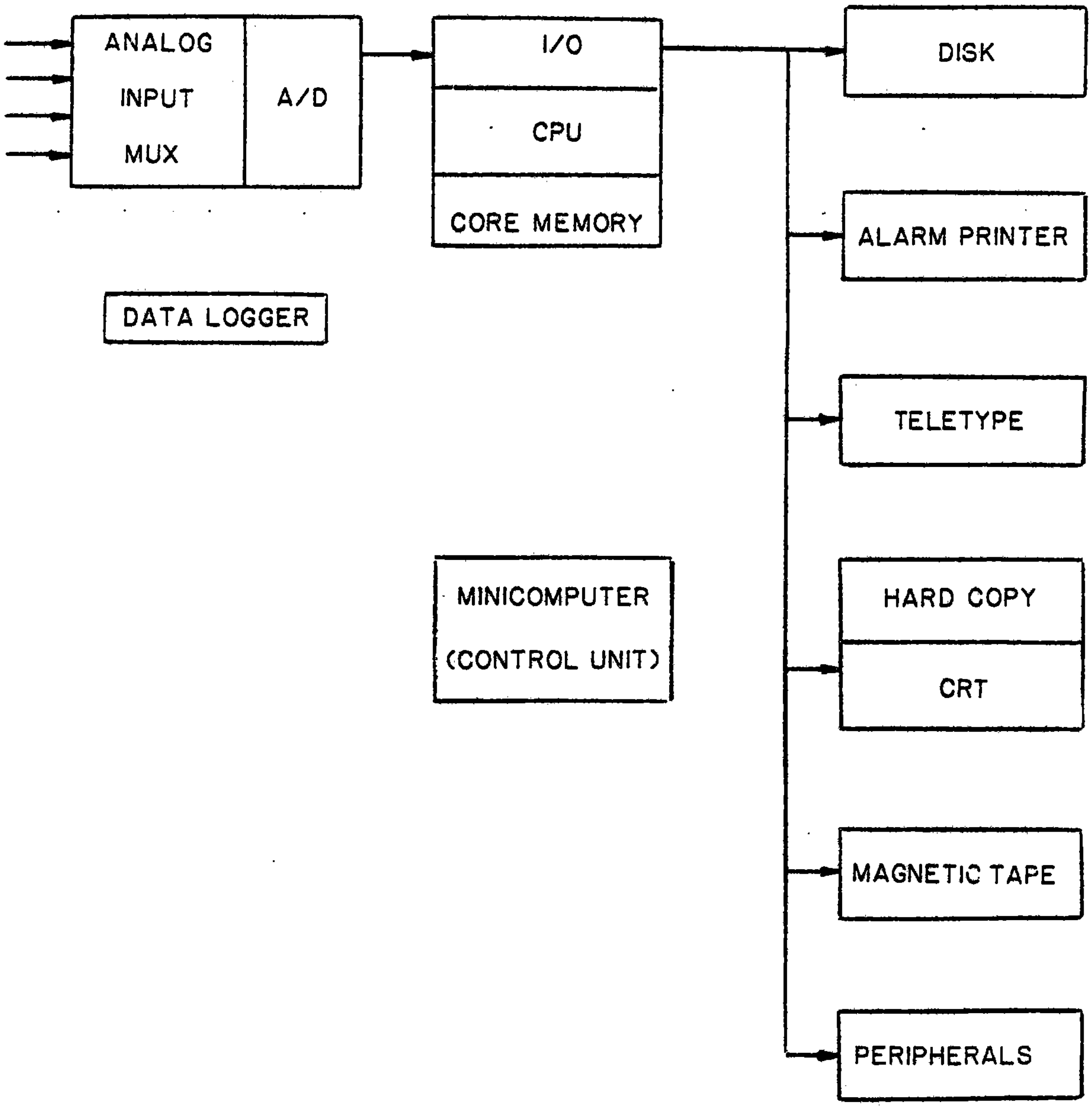


Figure 3.2 Foster Wheeler DARP System

- Point and data display
- Internal strip printer for alarm printout
- Thermocouple reference junction
- Terminal and computer interface

and has the following features:

- It can be programmed and controlled through the minicomputer.
- Commands to the data logger can be edited and listed without interrupting the scan sequence.
- It can operate as a "stand-alone" unit with front panel control after initialization.
- With the data logger system operating in scan sequence, individual points within the scan can be selected and logged without interrupting the scan sequence.

The peripherals consist of line printers, cathode ray tube (CRT) screens, disks, a hard-copy unit, magnetic tapes, and a teletype keyboard. When on-screen data are presented, the hard-copy units can make a copy of the information on 8-1/2 by 11-in. paper.

- System Software. All data acquisition, reduction, and analysis programs are written in FORTRAN in the interactive mode of operation. All commands to the computer regarding data acquisition changes or analysis are in conversational English. This mode of operation greatly reduces operator training time.

  Programs are run on the real-time multitasking concept. The software comprises the data acquisition program MAIN, consisting of a program called INIT and six tasks. The tasks are separate programs running in parallel, thereby efficiently utilizing the system resources. INIT assigns the priority to the tasks. The tasks gain control of the required resources on the basis of the predetermined priority assigned by INIT. A maximum of six tasks can be run at any given time. The tasks follow in order of their priority.

  - Task 1--Initiates and sets up the data logger system. All function, alarm, and set-point-limit assignments are covered by this task.
  - Task 2--Issues random access commands to provide access to all record data points.
  - Task 3--Decodes the record data points from Task 2 for storage in the Disc subsystem. All data are initially stored on disk. Data are stored on disk in a circular file and are available for real-time analysis.

- Task 4--Permits the operator to change alarm set-point limits, assignments, and scan delays and to interrogate the data logger system to determine its status; allows the operator access to any one test point for display; and is used for orderly shutdown.
- Task 5--Plots all the record data points either on command or at a fixed time of day.
- Task 6--Performs analytical calculations that use the collected input data.

Some of the highlights of the DARP system are:

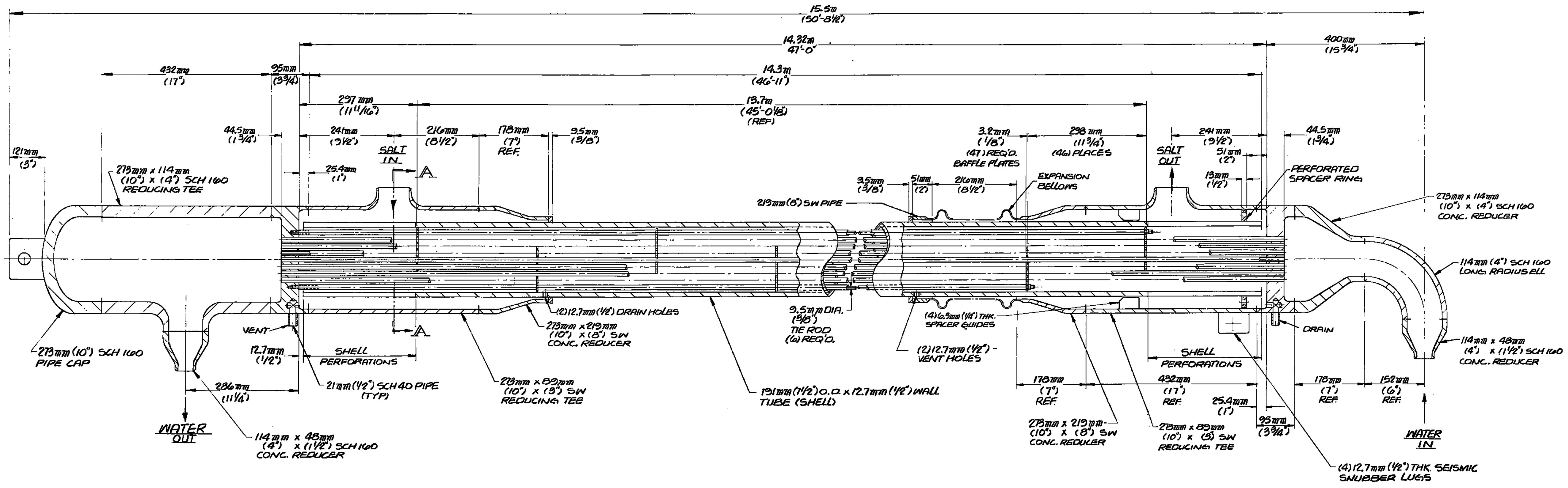
- Much data can be gathered over an arbitrarily long time period.
- All the information that is being collected is in computer-compatible form and can be evaluated and analyzed very rapidly.
- The results of data evaluation and analysis can be used as feedback for manual- or computer-controlled adjustments on experimental parameters.
- Once the system is installed, relatively little effort and investment are required to collect additional useful data.
- Graphic capabilities are built into the system.
- The data logger, as a stand-alone unit, can be programmed to log and monitor the alarm requirements even when the computer system is down. Therefore, no elaborate back-up system is required.
- Because data loggers are relatively inexpensive, the use of a data logger as a front end makes the system very economical.
- The interactive mode of operation greatly reduces the time and effort needed to train operators.
- This system is a general rather than a dedicated system. It can accept a wide range of inputs and be programmed to deliver a wide range of outputs.

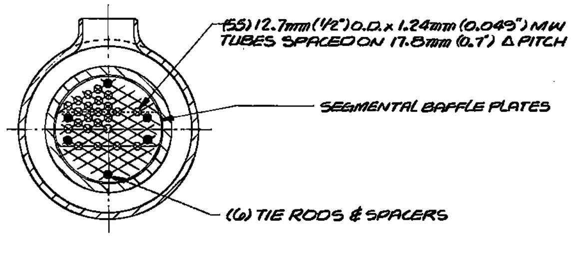
3.2.3 Heat Exchanger Description

The SRE SGS heat exchangers are straight-tube, single-pass shell-and-tube exchangers--each with segmental baffles and an expansion bellows located in the shell to permit differential expansion between the tube bundle and shell. The significant physical characteristics of the preheater, evaporator, superheater, and reheater are summarized in Table 3.1. Figures 3.3 through 3.6 illustrate them.

Table 3.1 Heat Exchanger Design Summary--Proposed SRE

Description	Preheater	Evaporator	Superheater	Reheater
Shell I.D., mm (in.)	165.1 (6.50)	236.5 (9.31)	115.8 (4.56)	97.3 (3.83)
Tube Length, m (ft)	14.3 (47.0)	12.8 (42.0)	16.5 (54.0)	7.9 (26.0)
Tube O.D., mm (in.)	12.7 (0.50)	25.4 (1.0)	15.9 (0.63)	12.7 (0.50)
Number of Tubes	55	31	15	15
Tube Material	CS	1-1/4%Cr- 1/2%Mo	304SS	304SS





SECTION A-A

NOTES:

1- VESSEL DESIGNED AS PER ASME BOILER & PRESSURE VESSEL CODE SECT VIII, DIV 1 1980 EDITION W/1980 WINTER ADDENDUM EXCEPT THE SHELL WHICH IS ASTM A-519 TYP 4130

2- DESIGN TEMP:
TUBE SIDE - 371°C (700°F)
SHELL SIDE - 371°C (700°F)

DESIGN PRESSURE:
TUBE SIDE - 15,512 KPAG (2,250 PSIG)
SHELL SIDE - 2,068 KPAG (300 PSIG)

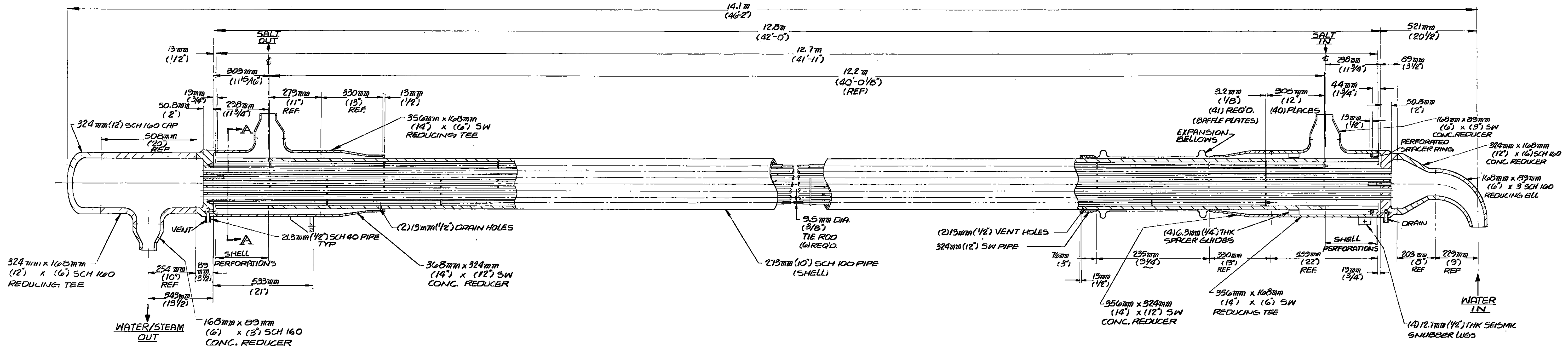
3- MATERIAL SPEC - CARBON ST'L.

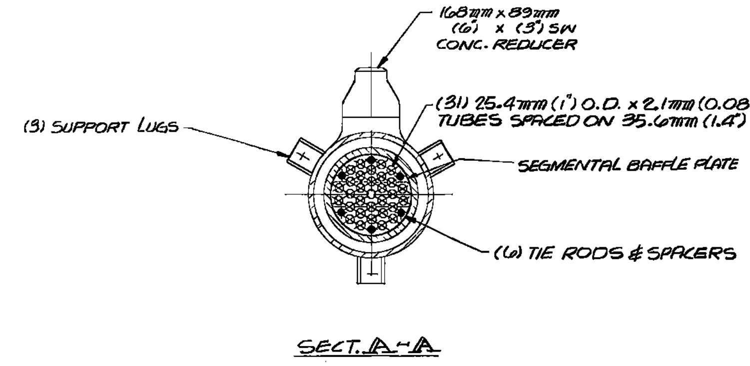
MAJOR PARTS	ASME SPEC
FORGINGS	SA-266-GR4
FITTINGS	SA-105
PLATES	SA-515-GR65
TUBING	SA-210-GRC
PIPE	SA-106-GRB
TIE RODS	SA-193-GRB7
TIE ROD NUTS	SA-194-GR7
TIE ROD SPACERS	SA-106-GRB
BELLOWS	SA-376 TY 304 SS

4- WEIGHTS:

DRY (NO INSUL.) - 1,460KG (3,220LBS) APPROX.
OPERATING WEIGHT, NO INSUL, WITH MOLTEN SALT @ 248°C (480°F) & WATER @ 287°C (516°F) - 1,970KG (4,343LBS.) APPROX.

Figure 3.3 Preheater--Proposed SRE





NOTES:

1- VESSEL DESIGNED AS PER ASME BOILER & PRESSURE VESSEL CODE SECT VIII, DIV. 1 1980 EDITION, W/1980 WINTER ADDENDUM

2- DESIGN TEMP:
TUBE SIDE – 371°C (700°F)
SHELL SIDE – 468°C (875°F)

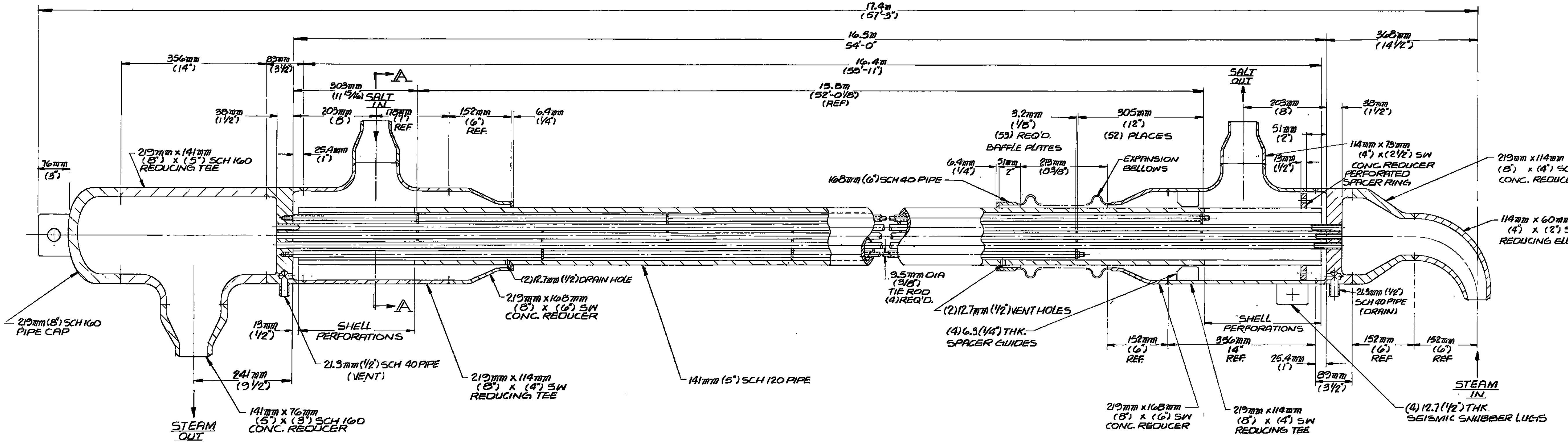
DESIGN PRESSURE:
TUBE SIDE – 15,340 K PAG (2225 PSIG)
SHELL SIDE – 2,068 K PAG (300 PSIG)

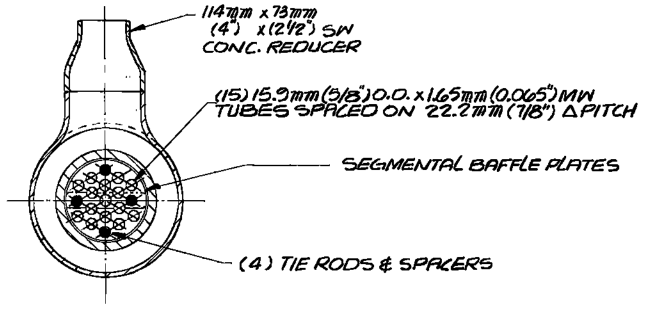
3- MATERIAL SPEC – 1 1/4 % CR, 1/2 % MO

MAJOR PARTS	ASME SPEC.
FORGINGS	SA-182-F11
FITTINGS	SA-182-F11
PLATES	SA-387 GR11-CL1
TUBING	SA-213-T11
PIPE	SA-335-P11
TIE RODS	SA-193-B7
TIE ROD NUTS	SA-194-7
TIE ROD SPACERS	SA-335-P11
BELLOWS	SA-376 TY 304 SS

4- WEIGHTS:
DRY (NO INSUL.) – 2,948 KG (6,500 LBS.) APPROX.
OPERATING WEIGHT, NO INSUL, WITH MOLTEN SALT @ 248°C (480°F) & WATER @ 578°C (636°F) – 4,649 KG (8,000 LBS) APPROX.

Figure 3.4 Evaporator--Proposed SRE





SECTION A-A

NOTES:

1- VESSEL DESIGNED AS PER ASME BOILER & PRESSURE VESSEL CODE SECT VIII, DIV 1 1980 EDITION W/1980 WINTER ADDENDUM

2- DESIGN TEMP:
TUBE SIDE – 565.6°C (1050°F)
SHELL SIDE – 565.6°C (1050°F)

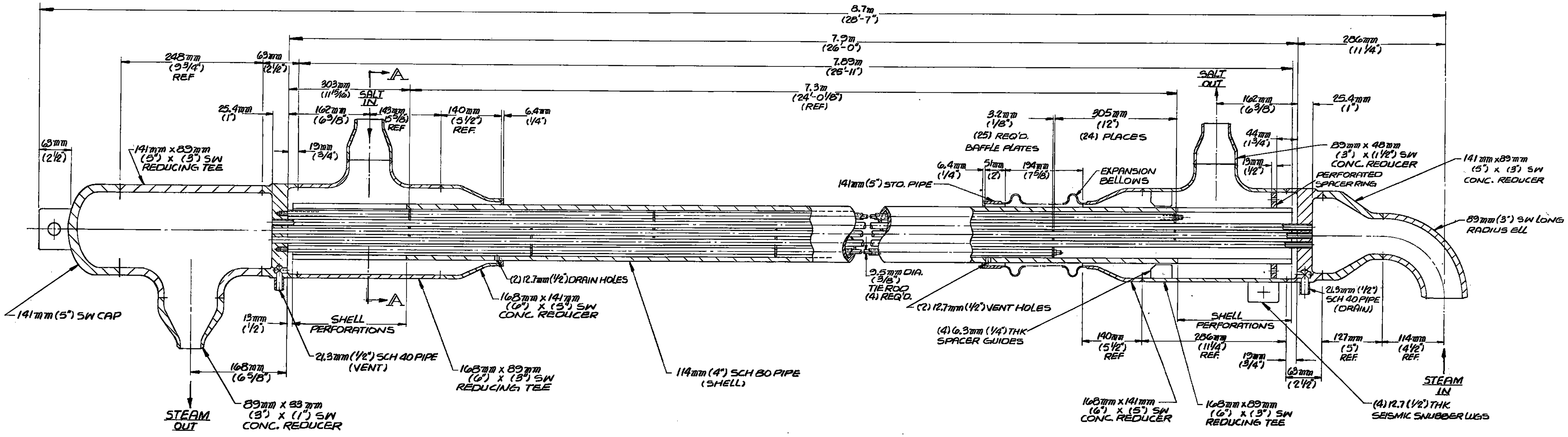
DESIGN PRESSURE
TUBE SIDE – 15,340 KPAG (2,225 PSIG)
SHELL SIDE – 2,068 KPAG (300 PSIG)

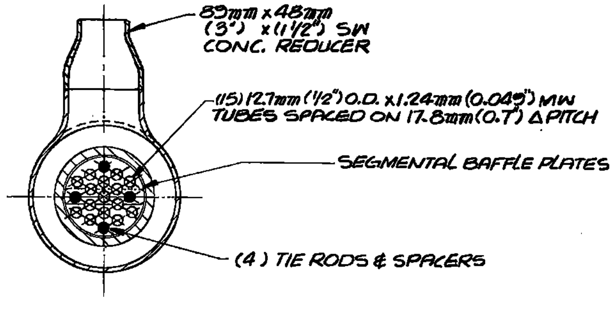
3- MATERIAL SPEC. – TYPE 304 SS

MAJOR PARTS	ASME SPEC
FORGINGS	SA-182
FITTINGS	SA-182
PLATES	SA-240
TUBING	SA-213
PIPE	SA-376
TIE RODS	SA-193
TIE ROD NUTS	SA-194
TIE RODSPACERS	SA-376
BELLOWS	SA-376

4- WEIGHTS:
DRY (NO INSUL.) – 1,077 KG (2,375 LBS) APPROX.
OPERATING WEIGHT, NO INSUL. WITH MOLTEN SALT @ 248°C (480°F) – 1,332 KG (2,936 LBS) APPROX.

Figure 3.5 Superheater--Proposed SRE





SECTION A-A

NOTES:

1- VESSEL DESIGNED AS PER ASME BOILER & PRESSURE VESSEL CODE SECT VIII, DIV 1 1980 EDITION W/1980 WINTER ADDENDUM

2- DESIGN TEMP:
TUBE SIDE - 565.6°C (1050°F)
SHELL SIDE - 565.6°C (1050°F)

DESIGN PRESSURE
TUBE SIDE - 3,964 K PAG (575 PSIG)
SHELL SIDE - 2,068 K PAG (300 PSIG)

3- MATERIAL SPEC. - TYPE 304SS

MAJOR PARTS	ASME SPEC.
FORGINGS	SA-182
FITTINGS	SA-182
PLATES	SA-240
TUBING	SA-213
PIPE	SA-376
TIE RODS	SA-193
TIE ROD NUTS	SA-194
TIE ROD SPACERS	SA-376
BELLOWS	SA-376

4- WEIGHTS:
DRY (NO INSUL.) - 329 KG (725 LBS.) APPROX.
OPERATING WEIGHT, NO INSUL, WITH MOLTEN SALT @ 248°C (480°F) - 367 KG (810 LBS) APPROX.

Figure 3.6 Reheater--Proposed SRE

Design features of special note include the following:

- Each exchanger is designed to be hung vertically. The preheater, superheater, and reheater have a single support lug on the top head; the evaporator has side lugs welded to the upper portion of the shell. Seismic snubber lugs on the bottom of each unit prevent lateral movement from seismic loading while permitting thermal expansion of the unit.
- Steam, water, or both flow upward through each exchanger. Salt flows downward through each exchanger, except the evaporator. The preheater, superheater, and reheater are counterflow; the evaporator is parallel flow to improve natural circulation, minimize the potential for departure from nucleate boiling (DNB) and dryout, and keep interconnecting piping to a minimum.
- The exchanger shells and heads are fabricated from standard pipe and fittings.
- Standard reducing tees or elbows are used for all nozzle connections, simplifying the design by eliminating the need for welding nozzles to the shells.
- The expansion bellows is placed in the shell to provide access to the lower tubesheet for possible tube plugging.
- Guide lugs and a guide ring between inner and outer shells at the lower salt nozzle location transfer bending loads from the lower tube-side nozzle to the shell. Without this arrangement, the bending load would be transferred directly to the tubes because of the flexibility of the expansion bellows.
- Vents and drain nozzles located in the tubesheet permit complete venting or draining of each exchanger. Inside annular spaces are vented or drained directly from the outer shell to the inner shell through holes that penetrate only the nonpressure-boundary inner shell.
- Heat-transfer tubes are welded to the face of the tubesheet using fillet-type welding techniques.
- Tie-rods attached to the upper tubesheet support the segmental baffles that function as tube support plates to suppress vibration and buckling.

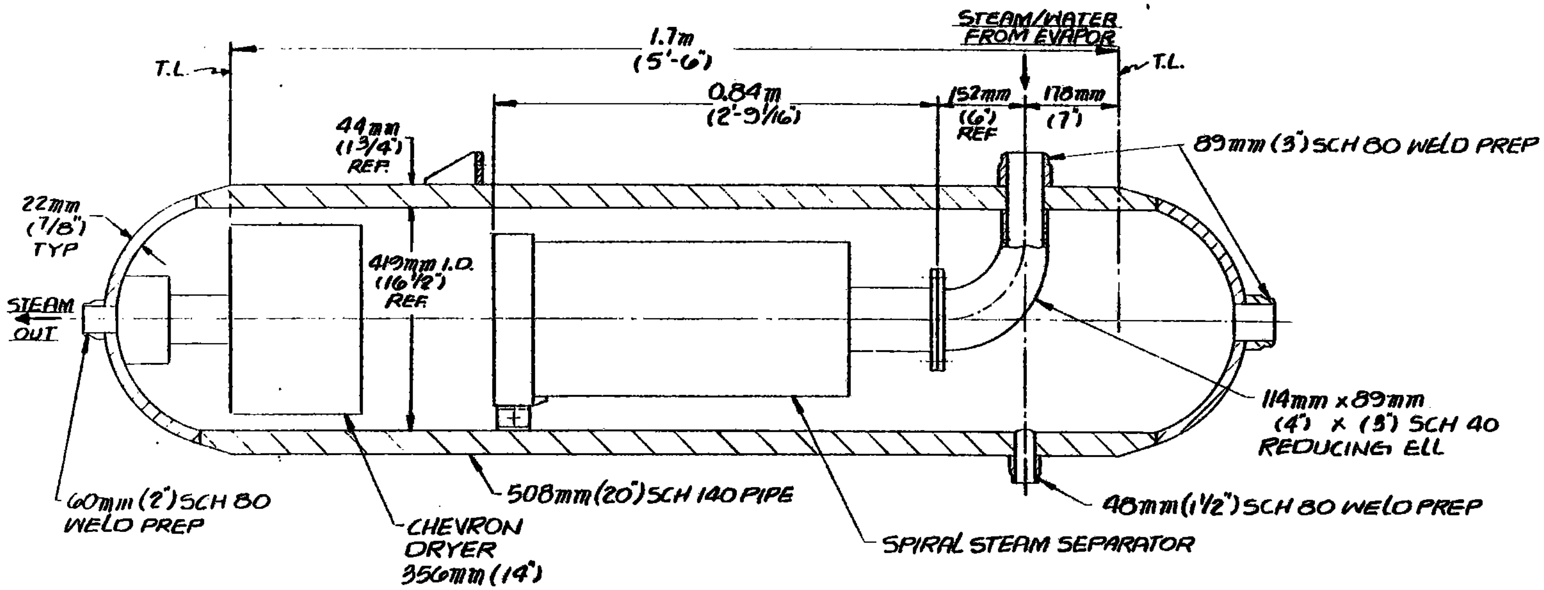
Physically, the exchangers are not identical, scaled-down duplicates of the full-size system. Because of the 60:1 scaling factor from the 100-MWe solar stand-alone SGS, we could not possibly simulate all the design features of the proposed straight-tube design. The following comments relate to the differences and their significance:

- The expansion bellows is located in the shell rather than being welded to the steam/water inlet nozzle and the lower shell head at the bottom of each unit. In the full-size system, the shell diameter is large enough so that the steam/water inlet nozzle can be sized to permit a man to gain access to the lower tubesheet for tube plugging. In the scaled-down SRE, such access is not possible without adding considerable design complexity. Because of the limited funds for Phase 2, we decided to keep the design as simple as possible. The ability of the expansion bellows to accommodate the differential growth between the tube bundle and shell is not a concern in either the full-size system or the SRE.

- Segmental rather than double-segmental baffles were used in the SRE design. In scaling down, it is desirable to maintain approximately the same shell-side and tube-side fluid velocities to provide sufficient pressure drop for flow stability and high enough film coefficients to minimize heat-transfer surface. In addition, tube sizes less than 12.7 mm (0.5 in.) O.D. are not recommended. Consequently, the unit length stays about the same and the number of tubes and the shell diameter are reduced. With the minimal number of tubes and a small shell I.D., we cannot possibly simulate the shell-side flow characteristics of the full-size system (i.e., cross flow path, bypass flow through gaps between baffle and shell, baffle and tube, etc.) Thus we decided to simplify the SRE design with segmental baffles. From the test results, we will be able to check our analytical technique for predicting unit performance by using the correlations for segmental baffles along with the thermal properties of molten salt.
- The vertical steam drum of the SRE is not designed as an integral component of the evaporator. The small diameter of the SRE evaporator makes it very difficult to mount the steam drum atop the evaporator and provide access to the upper tubesheet for plugging. Since the integral vertical steam drum is a conventional design with proven performance, we decided not to increase the SRE design complexity in an area that does not require testing. Consequently, the vertical drum was designed as a separate component as defined in Section 3.2.4.

3.2.4 Auxiliary Equipment

Steam Drum. A separate vertical steam drum delivers dry, saturated steam to the superheater. Figure 3.7 schematically illustrates the arrangement. The steam/water mixture discharged from the evaporator passes through a set of six spiral separator arms. The centrifugal action separates the steam from the water, the water drains to the bottom of the vessel, and the steam rises through a primary and secondary set of chevron driers. Moisture entrained in the steam adheres to these chevrons and drains to the bottom of the drum. A perforated plate acts as a vortex eliminator. A blowdown line to the CRTF blowdown tank maintains satisfactory drum-water purity levels. The steam/water inlet riser,



NOTES:

1- VESSEL DESIGNED AS PER ASME BOILER & PRESSURE VESSEL CODE SECT VIII, DIV 1 1980 EDITION W/1980 WINTER ADDENDUM

2- DESIGN TEMP - 371°C (700°F)
DESIGN PRESSURE - 15,340 KPAG (2225 LB/IN^{2}G)

3- MATERIAL SPECS: CARBON ST'L.
FORGINGS - SA-266 GR 4
HEADS - SA-515 GR 65
PLATES - SA-515 GR 65
NOZZLES - SA-266 GR 4
PIPE - SA-106 GR B

4- WEIGHTS:
DRY (NO INSUL.) - 1429 KG (3150 LBS) APPROX.
OPERATING WEIGHT, NO INSUL. - 1497 KG (3300 LBS) APPROX.

Figure 3.7 Steam Drum--Proposed SRE

downcomer, steam outlet pipe, blowdown line, and chemical feed lines are all single pipes connected to the drum. The drum shell is constructed from standard-size pipe.

The functional capability of the full-size system steam drum is not a concern, and its testing is not an objective of the SRE. Thus, the aforementioned design is not a duplicate scaled-down version. The SRE steam drum internals are duplicates of an experimental steam drum recently tested by Foster Wheeler and are sufficient for the steaming capacity of the SRE.

Insulation/Lagging. Asbestos-free, hydrous calcium silicate insulation (Johns Manville Thermo-12 or equivalent) and aluminum lagging are provided on all SGS SRE system components that require protection for personnel and are a potential source of significant heat loss to ambient.

Trace Heating. All SRE SGS components containing molten salt are equipped with flexible, stainless steel electric trace heaters (Thermon SSK Cable or equivalent). The trace heaters are sized to preheat each component from ambient temperature to 249°C (480°F). They are also capable of maintaining each component at 249°C (480°F) in the warm standby mode by compensating for ambient heat losses.

SGS Module. The SRE SGS components (heat exchangers, steam drum, etc.) will be assembled, shipped, erected, and supported in a shop-fabricated module that will be delivered to the job-site as a single unit and anchored to a concrete foundation. Figures 3.8 and 3.9 illustrate the SGS module.

The module includes the columns, platform framing, grating, horizontal and vertical cross-bracing, handrails, ladder, and cage required for support and access to the heat exchangers and steam drum. The structure is designed to withstand all the dynamic and static loadings it will encounter from handling, shipping, erection, wind, and seismic conditions.

When assembled, the module includes four heat exchangers, steam drum, interconnecting pipe, valves, insulation/lagging, trace heating, and electrical outlets. The assembled weight of the structure is approximately 22.7 Mg (50 x 10^3 lb).

Foundation/Dike. The SGS module will be anchored to a reinforced-concrete foundation that is 0.6 m (2.0 ft) high with a 6.7 m (22.0 ft) square base. The periphery of the foundation pad has a 0.76-m (2.5-ft)-high lip that acts as a dike to contain the salt from the heat exchangers and interconnecting pipe in case of a salt leak. The foundation includes four concrete piers on which to mount the SGS module. The center of the foundation will be located 30.2 m (99.0 ft) south and 15.8 m (51.8 ft) west of the CRTF tower centerline, as shown in Figure 3.10.

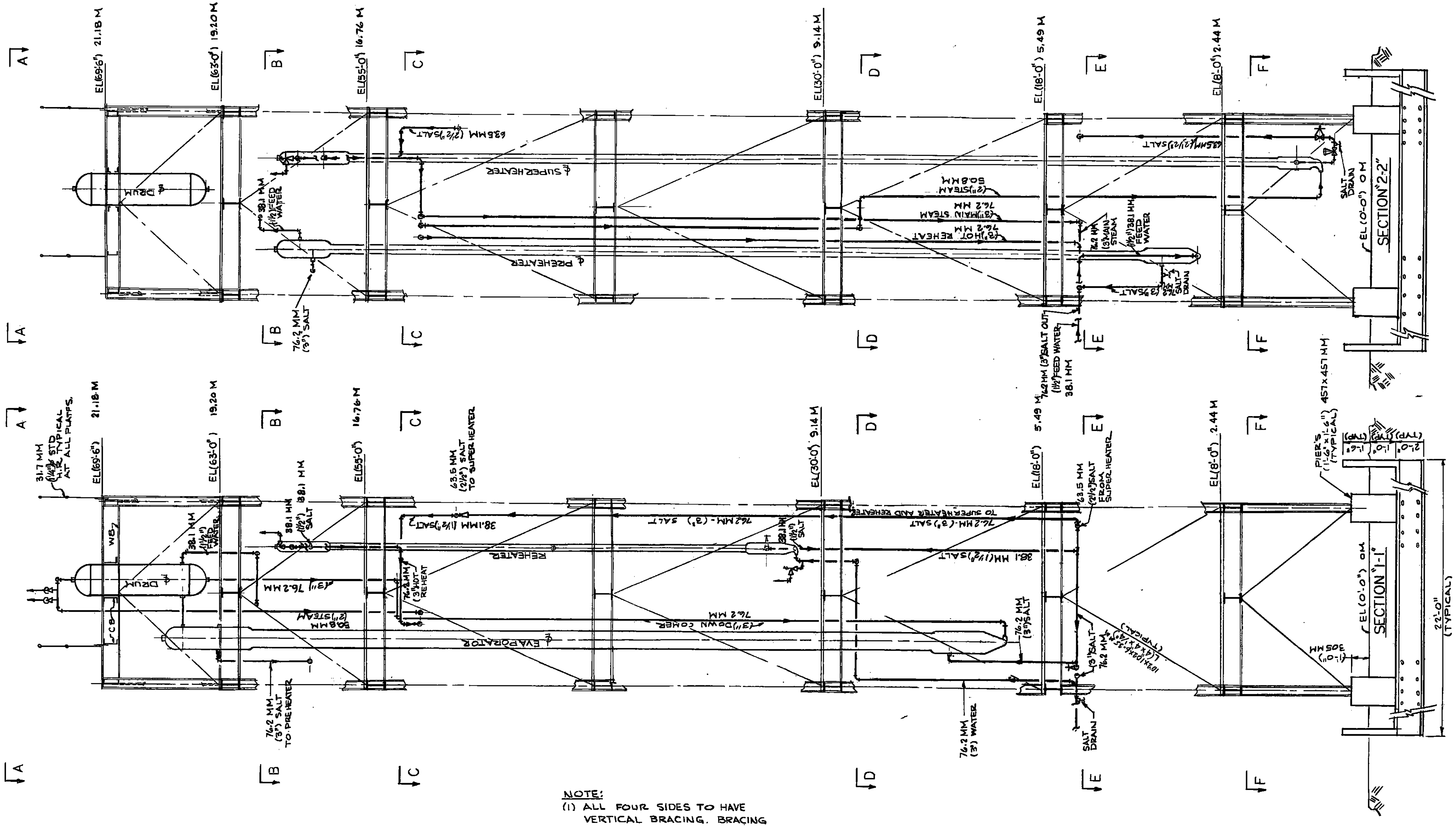
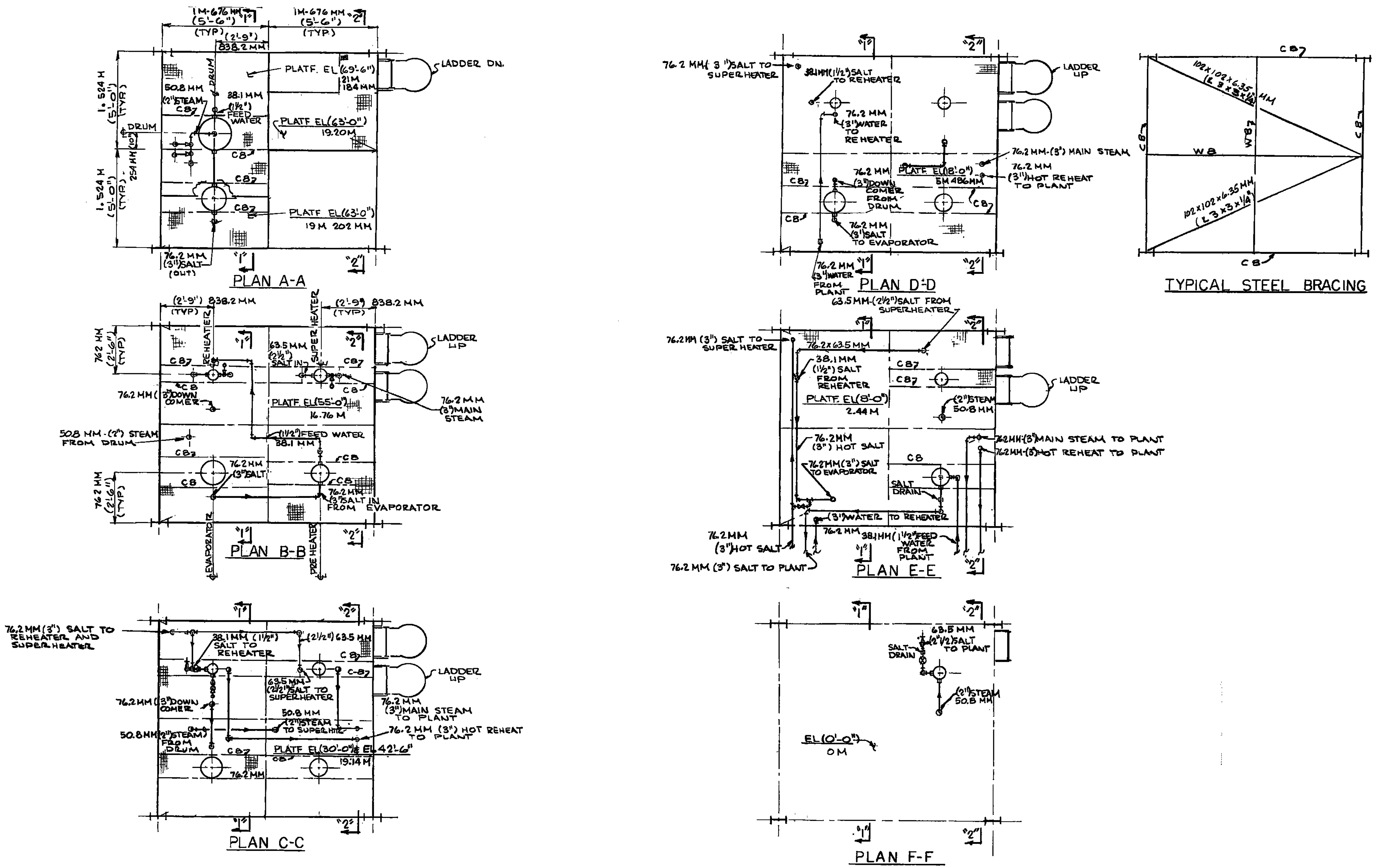


Figure 3.8 SGS Module (Side Elevation)--Proposed SRE



NOTE
"1" DENOTES SECTION "1-1" ON FIGURE 3.8
"2" DENOTES SECTION "2-2" ON FIGURE 3.8

Figure 3.9 SGS Module (Plan View)--
Proposed SRE

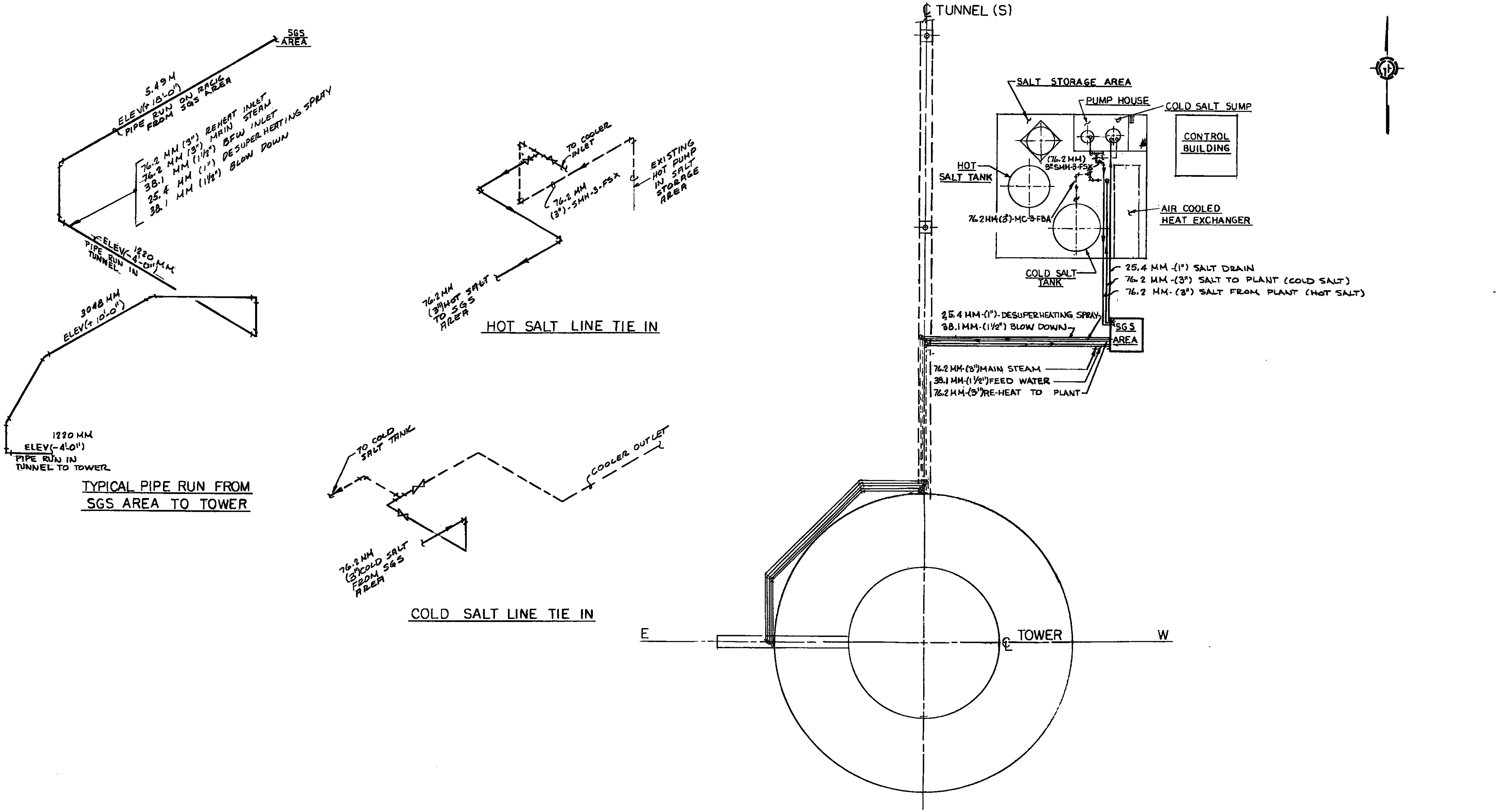


Figure 3.10 Location of SRE SGS

Drum-Water Recirculation Pump. A centrifugal pump recirculates drum water from the evaporator, through a propane-fired feedwater heater, to the preheater inlet. The pump provides positive circulation through the preheater and evaporator for cold start-up preheating and also maintains the feedwater temperature above the salt freezing point [221°C (430°F)].

Propane-Fired Feedwater Heater. A 0.3 MW (10^6 Btu/h) propane-fired heater is located in the drum-water recirculation loop between the drum-water recirculation pump and the preheater feedwater inlet. The heater preheats the recirculated drum water from 204 to 238°C (400 to 460°F) during the preheat phase of cold start-up to ensure that the temperature of the water in the preheater and evaporator is above the salt freezing point before salt is admitted to these units.

An electric-resistance heater can be used instead of a propane-fired heater. Cost trade-offs during the contract phase will dictate which type of heater is used.

Interface Piping. To interface the SRE SGS with the existing CRTF steam/water HRS and the thermal storage SRE, the steam/water and salt piping identified in Table 3.2 is required. The lengths listed are approximate and are based on the pipe routings shown in Figures 3.10 and 3.11. Exact interface locations and pipe routings to the steam/water HRS are not identified because detailed pipe drawings were not available. For cost-estimating, the pipe routings shown in Figures 3.10 and 3.11 are sufficient.

All piping will be arranged so that it will drain completely. The piping will be designed with adequate flexibility to permit thermal expansion and minimize loadings on interface connections. Insulation and lagging will be provided on all piping, and all salt piping will have trace heating, as discussed earlier. Interface connections will be welded.

Safety Valves/Rupture Discs. According to ASME Code requirements, we have located safety valves at the reheat steam inlet, reheat steam outlet, superheat steam outlet, and steam drum. Relief flow rates and settings conform to Code requirements. Rupture discs on each heat exchanger prevent overpressuring of the shell in the event of a tube rupture. Discharge from the rupture discs is directed to a lined dump pit located a safe distance from the thermal storage and SGS SREs.

Attemperators. Attemperators at the superheater steam outlet and the reheater steam inlet provide for emergency temperature control. The main steam attemperator uses saturated steam from the steam drum. The reheat steam

Table 3.2 SGS Piping--Proposed SRE

Description	Nominal Size mm (in.)	Schedule	Material	Approximate Length, m (ft)		
				In SGS Module	SGS Module to	In Tower
Steam/Water:					**Tower:**	
Blowdown	38.1 (1.5)	80	CS	15.2 (50)	73.1 (240)	9.1 (30)
Spray Water	25.4 (1.0)	80	CS	6.1 (20)	68.6 (225)	9.1 (30)
Feedwater	38.1 (1.5)	80	CS	3.0 (10)	71.6 (235)	9.1 (30)
Main Steam	76.2 (3.0)	160	2-1/4%Cr- 1%Mo	18.3 (60)	71.6 (235)	9.1 (30)
Hot Reheat	76.2 (3.0)	40	2-1/4%Cr- 1%Mo	21.3 (70)	71.6 (235)	9.1 (30)
Preheater to Drum	38.1 (1.5)	80	CS	6.1 (20)	---	---
Drum to Superheater	50.8 (2.0)	80	CS	24.4 (80)	---	---
Bypass to Reheater	76.2 (3.0)	160	2-1/4%Cr- 1%Mo	6.1 (20)	---	---
Reheater Inlet	76.2 (3.0)	40	2-1/4%Cr- 1%Mo	4.6 (15)	---	---
Downcomer	76.2 (3.0)	80	CS	15.2 (50)	---	---
Riser	76.2 (3.0)	80	CS	1.5 (5)	---	---
Salt:					**Thermal Storage:**	
Preheater to Salt Tank	76.2 (3.0)	40	CS	9.1 (30)	18.2 (60)	---
Hot Salt Pump to SGS Module	76.2 (3.0)	20	304SS	13.7 (45)	22.9 (75)	---
Reheater Inlet	38.1 (1.5)	20	304SS	4.6 (15)	---	---
Superheater Inlet	63.5 (2.5)	20	304SS	3.0 (10)	---	---
Reheater Outlet	38.1 (1.5)	20	304SS	3.0 (10)	---	---
Superheater Outlet	63.5 (2.5)	20	304SS	7.6 (25)	---	---
Bypass	38.1 (1.5)	20	304SS	1.5 (5)	---	---
Evaporator Inlet	76.2 (3.0)	20	304SS	4.6 (15)	---	---
Evaporator Outlet	76.2 (3.0)	40	CS	6.1 (20)	---	---
Drain	25.4 (1.0)	40	CS	---	24.4 (80)	---
					Dump Pit:	
Rupture Disc	25.4 (1.0)	40	CS	---	24.4 (120)	---

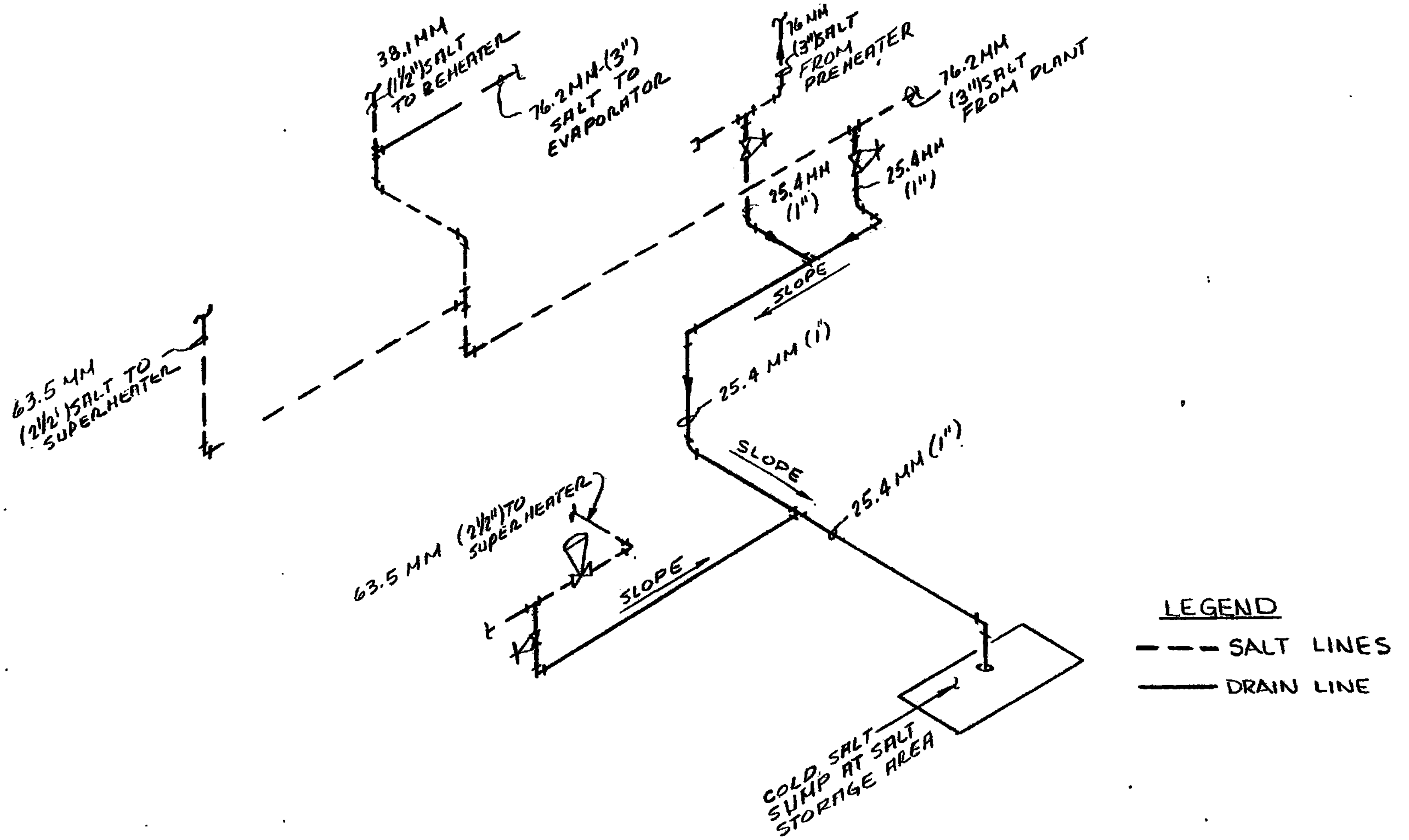


Figure 3.11 Salt Drain Piping--Proposed SRE

attemperator uses subcooled water discharged from the boiler feedwater pump outlet. An attemperator is located in the low-flow bypass steam line between the steam drum and the superheater inlet. This attemperator controls the temperature of steam entering the superheater during cold start-up. The steam line from the superheater discharge to the reheater inlet also includes an attemperator for reheat inlet temperature control.

Instruments and Control. The SRE SGS has the instruments and controls necessary for reliable and safe performance during tests.

Instruments. Transducers will monitor steam generator performance during the tests. Figures 3.12 and 3.1 shows these transducers and their locations. Thermocouples are identified by "T", pressure transducers by "P", flow measurement by "F", and level indicators by "L". Table 3.3 identifies the measurements taken by the instruments and their locations. Existing transducers are also identified. To monitor the steam generator during the test, 122 thermocouples, 22 pressure transducers, 19 flow meters, and 5 level indicators will be used. A summary of their functions is presented in the following paragraphs:

- Temperature Indicators. The thermocouples (all of the "T" type) will be located on the inlet and outlet sides as well as the shell wall of each heat exchanger. They will monitor water, steam, and salt temperatures during operation. Output signals from the thermocouples will be coupled to a data-acquisition system. There are some temperature measurements that are used for control purposes. These have been noted in Figure 3.12 and are discussed in the section on control, which follows. Some data (desuperheater, feedwater, and cold- and hot-salt tank temperatures) will be required from the heat-rejection and feedwater systems for verification of the energy balance.
- Pressure Measurements. The pressure measurements in the SRE SGS will be sensed by pressure to electrical signal transducers. The one exception is that the drum pressure will also be monitored by a pressure gauge. This gauge can be observed by a TV monitor at any time during testing. All the pressure transducers are connected to the data logger; some of them are used for controls.
- Flow Meters. Flow will be measured in feedwater lines; cold- and hot-salt lines; preheater, evaporator, superheater, and reheater steam/water lines; and salt lines. Flow will also be measured in the attemperators (sprays) and downcomer to determine circulation. Feedwater, salt, and steam flows will be measured by orifice plates. The attemperator (sprays) and

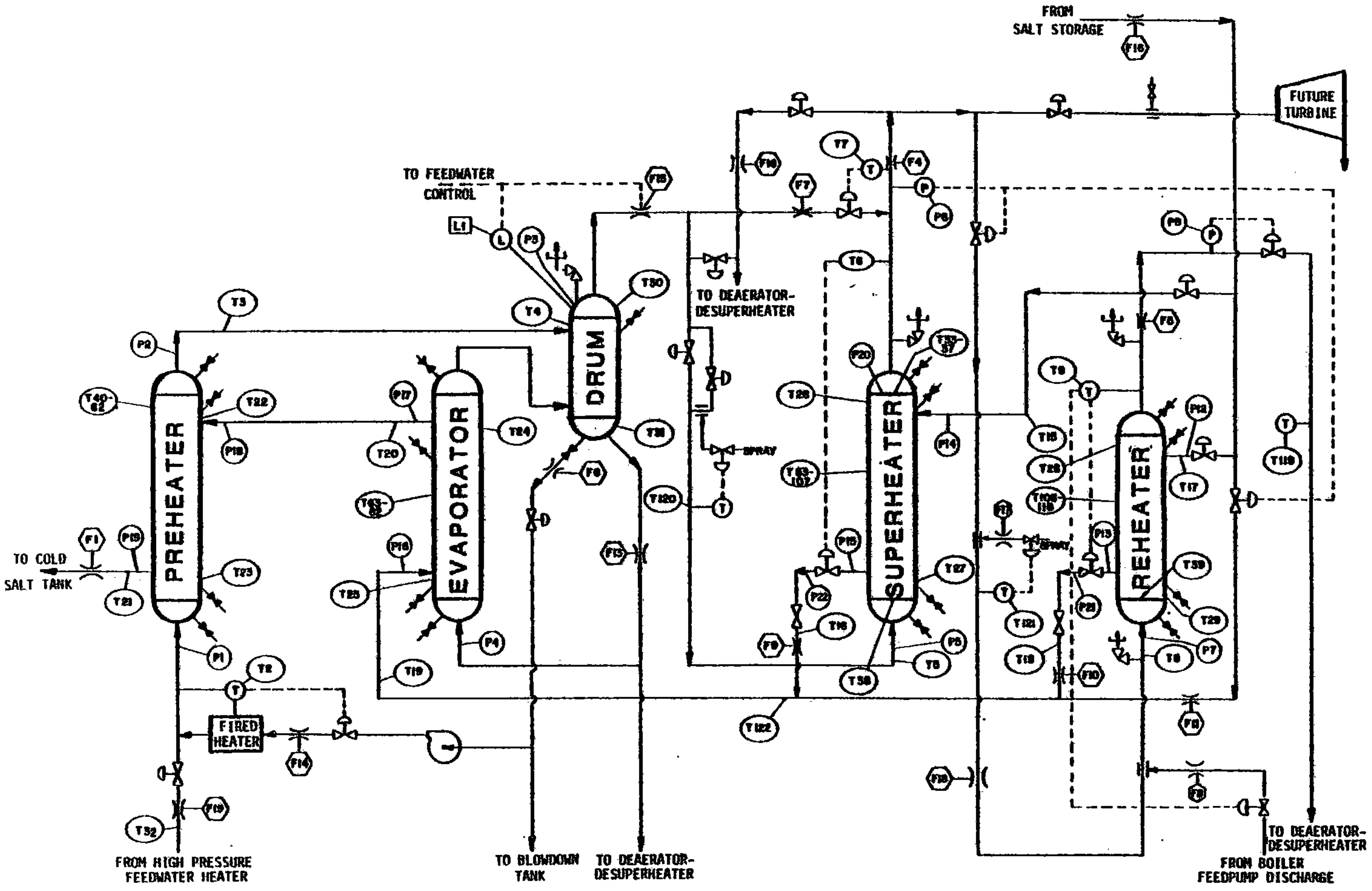


Figure 3.12 Instrument Diagram--Proposed SRE

Table 3.3 Instrument List

Measurement Identification	Location
Temperature:	
Feedwater (T1)	Downstream of high-pressure feedwater pump (Existing)
Feedwater (T2)	Downstream of high-pressure feedwater heater upstream of preheater
Water (T3)	Preheater outlet
Drum water (T4)	Steam drum
Superheater steam inlet (T5)	Inlet to superheater
Superheater steam outlet (T6)	Superheater outlet
Superheater steam outlet (T7)	Downstream of spray station
Reheater steam inlet (T8)	Inlet to reheater
Reheater steam outlet (T9)	Outlet of reheater
Deaerator/Desuperheater (T10)	(Existing)
Spraywater to Deaerator/Desuperheater (T11)	(Existing)
Salt in cold pump sump (T12)	(Existing)
Salt in hot pump sump (T13)	(Existing)
Blended salt (T14)	Main salt line
Salt superheater inlet (T15)	Inlet to superheater
Salt superheater outlet (T16)	Outlet of superheater
Salt reheater inlet (T17)	Inlet to reheater
Salt reheater outlet (T18)	Outlet of reheater
Salt evaporator inlet (T19)	Inlet to evaporator
Salt evaporator outlet (T20)	Outlet of evaporator
Salt preheater outlet (T21)	Outlet of preheater
Preheater upper shell (T22)	Preheater upper tubesheet
Preheater lower shell (T23)	Preheater lower tubesheet
Evaporator upper shell (T24)	Evaporator upper tubesheet
Evaporator lower shell (T25)	Evaporator lower tubesheet
Superheater upper shell (T26)	Superheater upper tubesheet
Superheater lower shell (T27)	Superheater lower tubesheet

Table 3.3 Instrument List--Proposed SRE (Cont)

Measurement Identification	Location
Temperature: (Cont)	
Reheater upper shell (T28)	Reheater upper tubesheet
Reheater lower shell (T29)	Reheater lower tubesheet
Drum (T30)	Top of drum
Drum (T31)	Bottom of drum
Feedwater (T32)	Downstream of high-pressure heater, upstream of recirculation pump connection
Steam leaving superheater tubes (T33-T37)	Upper end of superheater tubes
Tubesheet (T38)	Superheater lower tubesheet
Tubesheet (T39)	Reheater lower tubesheet
Preheater shell (T40-T62)	Adjacent to baffle window opening of every second baffle
Evaporator shell (T63-T82)	Adjacent to baffle window opening of every second baffle
Superheater shell (T83-T107)	Adjacent to baffle window opening of every second baffle
Reheater shell (T108-T118)	Adjacent to baffle window opening of every second baffle
Steam (T119)	Downstream of reheater on desuperheater bypass line
Steam (T120)	Downstream of evaporator steam line
Steam (T121)	Downstream of reheater bypass line
Salt (T122)	Junction of superheater salt outlet and bypass line
Pressure:	
Preheater-water inlet (P1)	Inlet to preheater
Preheater-water outlet (P2)	Outlet of preheater
Drum (P3)	Top of drum
Evaporator water inlet (P4)	Inlet to evaporator downstream of downcomer
Superheater steam inlet (P5)	Inlet to superheater
Superheater steam outlet (P6)	Outlet of superheater
Reheater steam inlet (P7)	Inlet to reheater
Reheater steam outlet (P8)	Outlet of reheater
Deaerator/desuperheater (P9)	(Existing)

Table 3.3 Instrument List--Proposed SRE (Cont)

Measurement Identification	Location
Pressure: (Cont)	
Boiler feed pump discharge (P10)	(Existing)
Feedwater (P11)	Upstream of feedwater pump (Existing)
Reheater salt inlet (P12)	Salt inlet to reheater
Reheater salt outlet (P13)	Salt outlet of reheater
Superheater salt inlet (P14)	Salt inlet to superheater
Superheater salt outlet (P15)	Salt outlet of superheater
Evaporator salt inlet (P16)	Salt inlet to evaporator
Evaporator salt outlet (P17)	Salt outlet of evaporator
Preheater salt inlet (P18)	Salt inlet to preheater
Preheater salt outlet (P19)	Salt outlet of preheater
Superheater tube exit (P20)	Top of superheater periphery tube
Reheater salt outlet (P21)	Outlet of reheater downstream of control valve
Superheater salt outlet (P22)	Outlet of superheater downstream of control valve
Flow:	
Salt leaving preheater (F1)	Outlet of preheater
Cold salt (F2)	Downstream of cold salt pump
Feedwater (F3)	Downstream of desuperheater (Existing)
Steam leaving superheater (F4)	Outlet of superheater
Steam leaving reheater (F5)	Outlet of reheater
Blowdown (F6)	Blowdown line of drum
Mainsteam spray (F7)	Steam line downstream of evaporator
Reheat water spray (F8)	Inlet to reheater
Salt leaving superheater (F9)	Salt outlet of superheater
Salt leaving reheater (F10)	Salt outlet of reheater
Salt bypass (F11)	Downstream of salt bypass valves
Hot salt (F12)	Downstream of hot salt pump
Downcomer water (F13)	Downstream of downcomer

Table 3.3 Instrument List--Proposed SRE (Cont)

Measurement Identification	Location
Flow: (Cont)	
Drum water recirculation (F14)	Downstream of recirculation pump
Steam (F15)	Downstream of evaporator
Steam (F16)	Feedwater bypass line
Steam (F17)	Spray reheater bypass line
Steam (F18)	Reheater bypass line
Feedwater (F19)	Feedwater line downstream of feedwater heater
Level:	
Drum (L1)	Steam drum
Cold-salt tank (L2)	Cold-salt tank (Existing)
Hot-salt tank (L3)	Hot-salt tank (Existing)
Cold-salt pump sump (L4)	Cold-salt pump (Existing)
Hot-salt pump sump (L5)	Hot-salt pump (Existing)

downcomer flows will be determined by venturi-type flow nozzles. All flow meters are connected to the data-acquisition system. The feedwater flow and exit steam flow are used to control the steam generator.

- Level Indicators The SRE SGS has five level indicators; four of these are in the heat-rejection facility. These will be monitored during start-up and shutdown operation. The drum-water level is also monitored and used for feedwater control. As a back-up, a sight glass that can be monitored by TV is installed on the drum. All level indicators are connected to the data-acquisition system.

  Strip-chart recorders will continuously monitor the superheater pressure and temperature; the superheater, reheater, and bypass salt flow; feedwater flow and temperature; and drum pressure and water level.

Control System. The control system for the SRE SGS (shown in Figure 3.1) uses interlocking controls to ensure safe and stable performance of the unit during experimental testing. System flow is regulated through a series of closed loops, which actuate control valves at designated locations. The control valves are identified in Table 3.4.

A summary of the control philosophies for the proposed tests follows:

- Drum-Water-Level Loop. The flow of feedwater to the heat exchanger drum will be under three-element control. The loop utilizes measurements of feedwater flow, steam flow, and drum-water level and feeds these parameters to a Program and Logic Controller (PLC). The output from this controller regulates the position of the feedwater control valve.
- Superheater Outlet Temperature Loop. A temperature indicator located on the outlet side of the superheater senses the outlet temperature. The signal is interfaced with the PLC to determine the proper analog setting for the superheater salt flow-control valve. Regulation of the salt flow controls outlet temperature over a specified range. Beyond this range, the PLC activates the saturated steam spray mechanism, which further reduces any excess temperature.
- Reheater Outlet Temperature Loop. The reheater outlet temperature loop and the superheater control loop are similarly controlled; that is, the temperature indicator on the outlet side of the reheater sends signals to the PLC which, in turn, positions the reheater salt flow-control valve. However, the spray

Table 3.4 Valve List--Proposed SRE

Identification	Function	Description
A	Shutoff	Feedwater
B	Control	Drum water recirculation
D	Shutoff	Main steam to future turbine
D_1	Control	Main steam to deaerator-desuperheater
F	Control	Reheat steam to deaerator-desuperheater
G	Control	Main steam to reheater
H	Shutoff	Drum steam to superheater inlet
I	Shutoff	Drum steam to deaerator-desuperheater
J	Control	Low-flow drum steam bypass
K_1	Shutoff	Superheater salt inlet
K_2	Shutoff	Reheater salt inlet
M	Control	Cold salt
N	Control	Salt bypass to evaporator
P	Control	Reheater salt flow
R	Control	Superheater salt flow
S	Control	Hot salt
T	Shutoff	Preheater salt outlet
FRV	Control	Feedwater (Existing)

control mechanism injects spray water on the inlet side of the reheater in contrast to injecting it on the outlet side of the superheater.

- Superheater Pressure Loop. Steam pressure is regulated by controlling the salt flow through the bypass valve. A transducer located on the outlet side of the superheater monitors superheater pressure for controlling the bypass valve. A pressure drop causes the salt bypass valve to open and admit more salt and hence more heat to the evaporator. The result is increased steam generation and the required pressure rise.
- Trace Heater Loop. Trace heaters utilizing single-element control are used on all heat exchangers and salt lines to maintain a 260°C (500°F) temperature during cold start-up.
- Recirculation Pump. A drum-water recirculation pump maintains the feedwater at a temperature above the salt freezing point [238°C (460°F)] during part-load operation.
- Feedwater Pump. A bypass line maintains minimum flow through the feedwater pump during periods of low-load demand.
- Reheat Steam Flow. The reheat steam flow is regulated by the valve on the superheater/reheater steam line. A signal from the drum-steam flow controls this valve.
- Pressure-Reducing and Spray Station. Located in the steam line between the superheater and reheater, this station ensures that the steam entering the reheater is at proper pressure and temperature, simulating the turbine reheat steam.
- Start-Up Salt Temperature Control Loop. Proper salt temperature during start-up is ensured by manipulating the valves at the exit of the hot- and cold-salt storage tanks.

3.2.5 Performance

Design-Point Performance. Estimated design-point performance for the proposed SRE is listed in Table 3.5. The same analytical techniques described in Section 2.2.4 for the full-scale systems were used to predict SRE performance. Foster Wheeler's computer code MSSG was used for thermal sizing. Shell-side film coefficients for the segmental baffle arrangement were determined by the HTRI Computer Program ST-4. Appropriate surface margins were added to the heat-transfer area determined by MSSG to accommodate the uncertainties with heat-transfer coefficients, thermal conductivity of the tubes, and fouling factors. An allowance for tube plugging was not included because of the small number of tubes in each each exchanger. Table 3.6 lists the heat-transfer margins applied to the SRE heat exchangers.

Table 3.5 Performance--Proposed and Alternative SRE

Performance Parameters	Proposed SRE		Alternative SRE	
	SRE	FSE	SRE	FSE
Temperature, °C (°F)				
Steam/Water:				
Feedwater	237.8 (460)	204.4 (400)	287.8 (550)	287.8 (550)
Superheater Inlet	335.6 (636)	335.6 (636)	335.6 (636)	335.6 (636)
Final Steam	540.6 (1005)	540.6 (1005)	540.6 (1005)	540.6 (1005)
Reheater Inlet	342.2 (648)	— —	— —	— —
Reheater Outlet	540.6 (1005)	— —	— —	— —
Salt:				
Superheater Inlet	565.6 (1050)	565.6 (1050)	565.6 (1050)	565.6 (1050)
Superheater Outlet	445.0 (833)	445.6 (834)	445.0 (833)	452.2 (846)
Reheater Inlet	565.6 (1050)	— —	— —	— —
Reheater Outlet	487.8 (910)	— —	— —	— —
Evaporator Inlet	456.1 (853)	476.7 (890)	480.0 (896)	482.2 (900)
Evaporator Outlet	342.2 (648)	340.0 (644)	344.4 (652)	346.1 (655)
Preheater Inlet	342.2 (648)	340.0 (644)	— —	— —
Preheater Outlet	287.8 (550)	287.8 (550)	— —	— —
Flow, kg/s (10^3 lb/h)				
Steam/Water:				
Feedwater	1.57 (12.50)	1.56 (12.42)	1.57 (12.50)	1.85 (14.71)
Blowdown	— —	— —	— —	— —
Main Steam	1.57 (12.50)	1.56 (12.42)	1.57 (12.50)	1.85 (14.71)
Reheater	0.68 (5.41)	— —	— —	— —
Recirculation	— —	— —	— —	— —
Salt:				
Preheater	9.35 (74.21)	9.14 (72.51)	— —	— —
Evaporator	9.35 (74.21)	9.14 (72.51)	9.95 (79.00)	11.87 (94.18)
Superheater	6.74 (53.52)	6.68 (53.0)	6.74 (53.52)	8.46 (67.18)
Reheater	2.61 (20.69)	— —	— —	— —
Bypass	— —	2.46 (19.51)	3.08 (24.48)	3.40 (27.00)
Pressure, MPa gage (lb/in²g)				
Steam/Water:				
Feedwater	13.89 (2015)	13.89 (2015)	13.69 (1985)	13.69 (1985)
Drum	13.69 (1985)	13.69 (1985)	13.69 (1985)	13.69 (1985)
Final Steam	13.48 (1955)	13.48 (1955)	13.48 (1955)	13.48 (1955)
Reheater Inlet	3.03 (440)	— —	— —	— —
Reheater Outlet	2.86 (415)	— —	— —	— —
Salt:				
Superheater Inlet	0.25 (36.8)	0.25 (36.6)	0.26 (37.1)	0.36 (52.5)
Reheater Inlet	0.25 (36.8)	— —	— —	— —
Preheater Outlet	0.23 (32.9)	0.23 (33.3)	— —	— —

Table 3.6 Heat-Transfer Surface Margins--Proposed SRE

Description	Preheater	Evaporator	Superheater	Reheater
Tube O.D., mm (in.)	38.1 (0.505)	25.4 (1.0)	15.9 (0.625)	38.1 (0.50)
Tubewall Thickness, mm (in.) -0%/+20%	1.24 (0.049)	2.11 (0.083)	1.65 (0.065)	1.24 (0.049)
Tube Material	CS	1-1/4%Cr-1/2%Mo	304SS	304SS
Pitch-to-Tube Diameter Ratio	1.40	1.40	1.40	1.40
Design Length*				
Basic Length, m (ft)	12.57 (41.24)	10.90 (35.76)	14.90 (48.88)	7.09 (23.25)
Uncertainties, 90% confidence level (h_i, h_o, h_w, δ_w, RSS method), m (ft)	13.94 (45.73)	12.54 (41.15)	16.00 (52.49)	7.65 (25.09)
Partially Inactive Region of Support Plates, m (ft)	14.01 (45.97)	12.61 (41.36)	16.08 (52.77)	7.69 (25.22)
Partially Inactive Length in Inlet/Outlet Bundle Area, m (ft)	14.21 (46.62)	12.80 (42.00)	16.29 (53.43)	7.89 (25.88)
Tube Plugging Allowance, tubes	0	0	0	0
Total Number of Tubes	55	31	15	15
Design Margin, %	13.05	17.45	9.31	11.32

---

*Length shown is accumulated length resulting from all preceding effects.

For the hot-salt flow required by the SRE [9.35 kg/s (7.42 x 10^4 lb/h), the existing hot-salt pump can develop a head of approximately 414 kPa (60 lb/in^2). Consequently, 310 kPa (45 lb/in^2) was allocated for the heat exchanger components, with the remainder left for inconnecting pipe, valves, flow-measuring devices, and any gravitational head difference resulting from the change in salt temperature as it passes through the system. The heat exchangers and piping were then sized on this basis. After completing the design, salt static pressures through the system were checked. The salt static pressure must stay above atmospheric pressure to prevent dissolved gases from coming out of solution and forming a gas pocket within the heat exchangers. The result of the static-pressure check was that the salt pump head must be approximately 600 kPa (87 lb/in^2) to keep the evaporator salt outlet static pressure above atmospheric conditions. This head requirement is beyond the capacity of the existing pump. During the Phase 2 contract, the heat exchanger frictional pressure drops and elevations will be optimized to be within the capacity of the existing hot-salt pump.

As a result of including a 50-percent capacity reheater, the SGS design-point duty was reduced by 7 percent. Advantages of this reduction are as follows:

- The salt flow requirement through the SGS was reduced by 7 percent, increasing the available head from the hot-salt pump by 34.5 kPa (5 lb/in^2).
- The reduction in salt flow and hot-end duty increased the pinch-point temperature difference from 3.0 to 6.8°C (5.4 to 12.3°F), allowing the inlet and outlet salt temperatures to be held at 566 and 288°C (1050 and 550°F) respectively.
- The continuous thermal output of the propane-fired heater is 3 MWt. With the reduction in SRE design-point duty, the SGS can be operated continuously at 73-percent load.

Performance Evaluation. The accuracy of the predicted steady-state, full- and part-load steam generator performance will be checked by evaluating the data obtained from the instrumentation defined in Section 3.2.4. Performance areas to be evaluated include the following:

- Thermal Duty. The thermal duty of the preheater, superheater, and reheater will be determined by measurement of the inlet and outlet steam/water temperatures, pressures, and flow rates. The thermal duty of the evaporator can be computed by difference or by the measured salt inlet and outlet temperatures and flow rates, taking into account ambient heat losses determined from cool-down tests.

- Pressure Drop. The total pressure drops of salt and steam/water through each heat exchanger will be determined by the aforementioned inlet and outlet static-pressure measurements. The frictional pressure drop will be determined by subtracting the acceleration and gravitational contributions to the measured total pressure drop.

- Shell-Side Heat-Transfer Coefficient. Thermocouples will be mounted on each heat exchanger shell on the outer surface at locations adjacent to every second baffle window opening. If there is a negligible heat loss to ambient through insulation, the thermocouple readings will be essentially the same as the molten salt temperature profile along the length of the unit. If the ambient heat loss is significant, the thermocouples will read temperatures lower than the salt temperature but will still provide correct shapes of the axial temperature profile.

  With the measured inlet and outlet salt temperatures known, the temperature profile can be shifted so that the end points of the curve coincide with the measured inlet and outlet temperatures, thereby establishing the salt temperature profile along the length of each unit. Having determined the salt temperature profile and knowing the tubeside steam/water inlet and outlet temperatures, we can use local heat balances along the tube length to construct the tube-side temperature profile as well as heat-flux and overall heat-transfer coefficient profiles. An example of the type of profiles generated is illustrated in Figure 3.13. The example is a sodium-heated evaporator that exhibits departure from nucleate boiling (DNB). (Note that the high-temperature primary fluid enters at the steam/water discharge end in this heat exchanger rather than at the steam/water inlet end as in our evaporator.)

  The thermal conductivity of the heat exchanger tube materials is well-documented with a high confidence level. Tubeside heat-transfer correlations, especially for subcooled water, are much more certain than correlations for salt flowing over the tube bundle. Therefore, if there is a discrepancy between the overall heat-transfer coefficient computed from measured data and the predicted overall heat-transfer coefficient, the discrepancy can be attributed to the uncertainty of the shell-side salt film coefficient.

- Departure From Nucleate Boiling. DNB is associated with the transition from the nucleate boiling regime to the film boiling regime. Nucleate boiling is characterized by a high heat-transfer coefficient from the water to the wall; film boiling exhibits a low heat-transfer coefficient. Therefore, if a heat flux-profile is constructed along the unit, the existence of an inflection point will denote DNB. The location in the tube at which the DNB occurs can fluctuate with time and can cause temperature cycling of the tubewall. This fluctuation in tubewall I.D. temperature is of principal concern in the evaporator. If the amplitude of the temperature oscillation is sufficiently

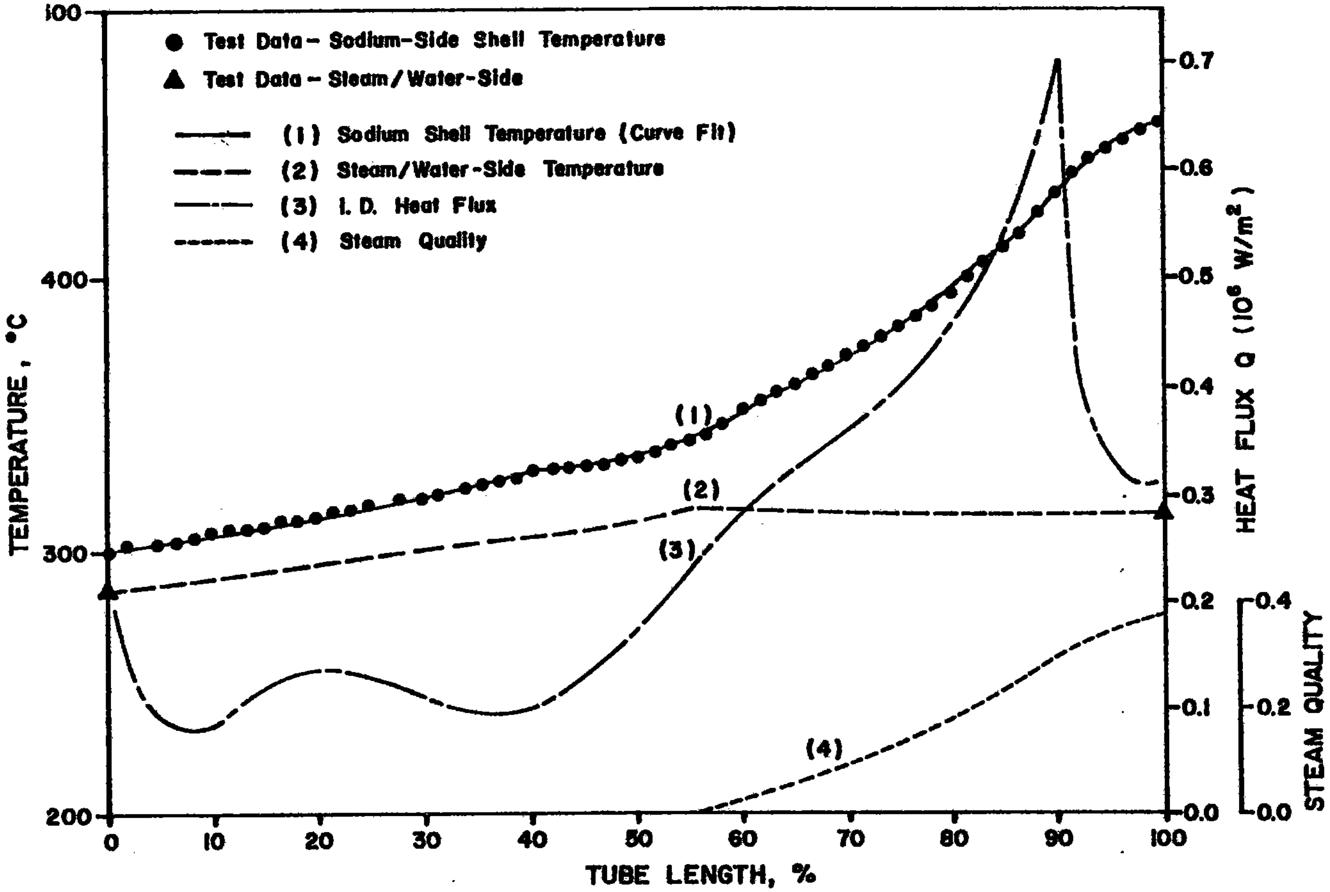


Figure 3.13 Typical Experimental Heat Exchanger Temperature Profile

large, prolonged temperature cycling can cause tubewall fatigue. The SRE evaporator is designed to be free of DNB, which can be confirmed by plotting the heat-flux profile along the unit using the method discussed in the preceding subsection (See Figure 3.13). The existence of the peak heat flux is also an indication of DNB in the evaporator.

- Tubeside Dynamic Flow Instability. Dynamic flow instability is defined as sustained (or growing) oscillation of flow variables (such as pressure drop, flow rate, and fluid density) within a tube. Therefore, to check dynamic instability, an instrument that can measure the oscillation of tube-side pressure or temperature would be utilized. For the evaporator, with constant saturated water temperature, the dynamic instability can be investigated using a static pressure tap mounted perpendicularly to the tube near the exit end. For easy access the instrumented tube will be the outermost tube of the evaporator.

  For the superheater, five thermocouples will be installed at the exit ends of five tubes to detect any temperature oscillations. The test and evaluation will confirm that the designs are dynamically stable.

- Effect of Shell-Side Flow Distribution. If significant shell-side flow maldistribution exists, its effects will be felt on the tube-side fluid. Any thermal imbalance caused by shell-side flow can easily be detected by thermocouples placed at the exit end of five selected tubes in the superheater and reheater.

- Heat Loss to Ambient Surroundings. Heat loss from the heat exchanger to ambient surroundings through the insulation can be determined by the cool-down curve of each heat exchanger. At first, a heat exchanger must be maintained at a constant shell temperature (e.g., by stopping tube-side flow circulation); then it should be allowed to cool down. A heat exchanger in a standby mode will cool down when both molten salt and steam/water circulations are stopped. The thermocouples mounted on the shell O.D. will then register the temperature drop as a function of time while the heat exchanger is cooling. The slope of the cool-down temperature curve will be used to calculate the heat loss through insulation from the heat exchanger to ambient surroundings.

- Circulation Ratio of Evaporator. A flow meter will be located inside the downcomer to measure the flow rate of recirculated, saturated water from the steam drum to the evaporator inlet. With the flow rate of feedwater measured at the feed line, the circulation ratio of the evaporator can be calculated and will be compared with the design condition.

- Fouling. Products of corrosion, dirt, or other foreign materials that deposit on heat-transfer surfaces increase the overall thermal resistance and lower the overall heat-transfer coefficient of the heat exchanger. At the beginning of the test, the unit is expected to be clean and thus will have the best thermal performance. Later on, any marked increase in pressure drop and reduction in performance may be attributed to fouling. We will compare the thermal performance data taken at the beginning with that taken during the test program to determine the magnitude of fouling, which will be compared with the design value. There is greater uncertainty associated with molten salt fouling on the shell side than on the steam/water side. The test results may reduce the uncertainty of fouling caused by molten salt for future designs. The calculation method will be based on the overall heat balance. The test may also indicate the intervals allowed between cleaning of the unit (if fouling is serious).

Post-Test Inspection. The unit will be inspected after the test to ensure the integrity of the heat exchangers. One or more sample tubes can be removed and examined metallographically. Visual inspection of the samples will indicate corrosion, erosion, geometric distortion, or dimensional change. The tubes will also be examined for fretting and wear at the tube supports and for possible thermal buckling attributed to thermal imbalance on the shell side. The tube/tubesheet welds will inspected for any defect or leak.

The integrity of the entire tube bundle will be assessed by eddy-current testing of the tubes before operation to obtain the baseline signature of each tube. Post-test inspection by the same equipment will reliably detect, identify, and quantify any tube damage that may have occurred.

3.2.6 Compatibility of SRE SGS With Future Full-System Experiment

SNLL has requested that the proposed SRE SGS design meet all the SRE objectives as well as be compatible with a future full-system experiment (FSE). Requirements for the FSE as defined by SNLL are as follows:

- Molten salt enters the SGS at 566°C (1050°F)
- Molten salt leaves the SGS at 288°C (550°F)
- Available thermal input 5-MWt from receiver, 3-MWt from propane heater, and 7-MWt from storage
- Condenser operates at 52°C (125°F) and 13.1 kPa absolute (1.9 lb/in^{2}a)
- Main steam flow of 1.26 kg/s (10,000 lb/h) at turbine throttle conditions of 510°C (950°F) and 10 MPa absolute (1450 lb/in^{2}a).

Based on the preliminary FSE flow schematic defined by SNLL, we prepared the flow schematic shown in Figure 3.14. Feedwater at 204°C (400°F) and 14 MPa absolute (2030 lb/in^{2}a) is supplied to the SGS by a feedwater system not within the scope of the SGS. The feedwater system includes a condenser, condensate pump, low-pressure feedwater heater, and boiler feed pump. Boiler drum water

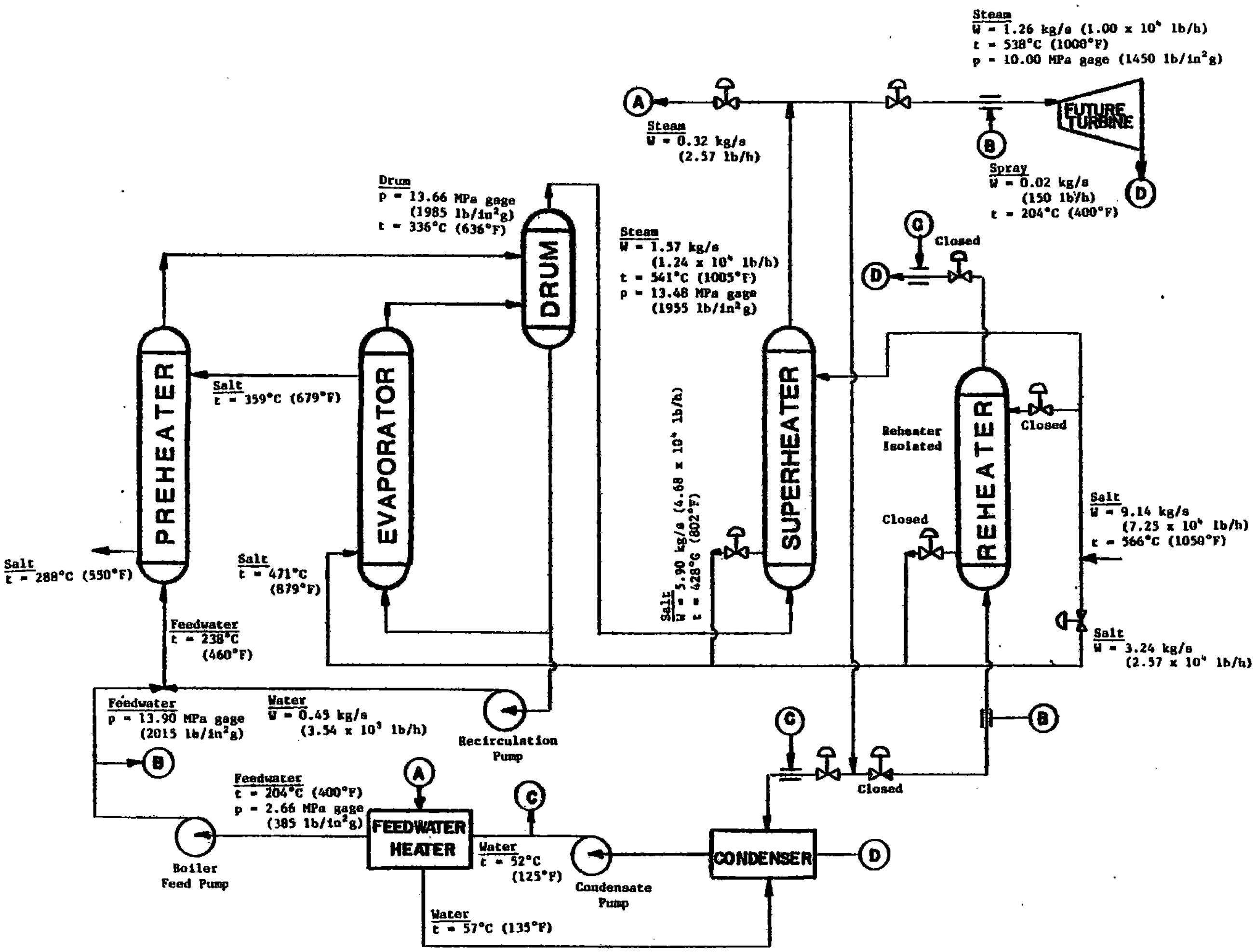


Figure 3.14 Preliminary FSE Requirements

is recirculated and blended with the feedwater so that the temperature of feedwater entering the preheater is above the salt freezing point. To meet the turbine flow requirement of 1.26 kg/s (10,000 lb/h) at 510°C (950°F) and 10 MPa absolute (1450 lb/in^{2}a), the SGS must be capable of generating approximately 1.58 kg/s (12,500 lb/h) superheated steam at 541°C (1005°F) and 13.58 MPa absolute (1970 lb/in^{2}a). Steam in excess of that required by the turbine is throttled and directed to the low-pressure feedwater heater, which operates at approximately 1.81 MPa absolute (262 lb/in^{2}a). Steam directed to the turbine is also throttled and cooled by spray water taken from the boiler feedwater pump discharge to meet the aforementioned turbine temperature and pressure requirements. The thermal duty of this arrangement is 4 MWt, which is well within the combined thermal rating of the receiver and propane heater at 8 MWt.

The 1.58 kg/s (12,500 lb/h) main steam generating requirement for the FSE was used as the basis for sizing the SRE SGS. A reheater was incorporated in the SRE design to permit evaluation of the reheater start-up procedures and the salt flow control arrangement. The reheater was designed for only 50 percent of the scaled-down thermal capacity to reduce system cost and to increase the available hot-salt pump head by reducing the salt-flow requirement. With the SGS hardware designed to meet the SRE performance requirements, performance for the FSE was evaluated. The results are shown in Table 3.5. As can be seen, the hardware designed to meet SRE requirements is also compatible with those of the FSE.

Incorporating the SGS of the SRE into a future FSE will involve connecting the main steam line leaving the superheater to the turbine and isolating the reheater. The main steam line will require a throttle and spray station to meet the turbine throttle steam pressure and temperature.

3.2.7 Test Description

General. The SRE includes tests to demonstrate subsystem-level as well as component-level features of the full-scale SGS. Subsystem-level aspects of the SRE involve demonstration of all operating modes of the full-scale system to show that the individual components can be operated as an integrated system in a safe and stable manner. Component-level aspects of the SRE involve monitoring each heat exchanger for specific data that will verify the ability of developed analytical methods to predict heat exchanger performance characteristics.

Subsystem-level testing will include demonstration of the following operating modes:

- Cold start-up
- Full- and part-load steady-state operation
- Load changes
- Diurnal shutdown
- Diurnal start-up
- Shutdown to warm standby
- Warm standby
- Start-up from warm standby
- Shutdown to cold conditions
- Emergency shutdown

Demonstration of these operating modes will include the following:

- Salt/water fill procedure
- Trapped gas venting
- Coordinated preheat of tube bundle and shell
- Drum-water recirculation for preheating the preheater and evaporator tube bundles
- Auxiliary feedwater heater operation for cold start-up feedwater heating
- Use of drum steam to preheat superheater
- Use of main steam to preheat reheater
- Main steam flow to reheater established before reheater salt admission on start-up
- Hot/cold salt blending for start-up
- Steam generator load response
- Superheater outlet temperature/pressure load response
- Salt mixing tee temperature response
- Drum-water recirculation to preheater for superheater inlet temperature control
- Control response of superheater/reheater/bypass combination
- Salt flow/attemperator main steam temperature control
- Salt flow/attemperator reheat temperature control.

Time-dependent salt/water/steam temperature, pressure, and flow measurements obtained during operational mode testing will be compared with the subsystem response predicted by the control system dynamic computer model briefly described in Section 2.2.4 and 3.2.5.

While demonstrating the SRE SGS operating modes, data will also be obtained to evaluate component-level considerations such as the following:

- Salt-side film coefficients
- Dynamic flow stability of evaporator
- Absence of DNB/dryout in evaporator
- Superheater flow stability
- Fouling
- Ambient heat losses

- Absence of tube vibration
- Absence of gross structural deformation
- Tubesheet temperature response to load change.

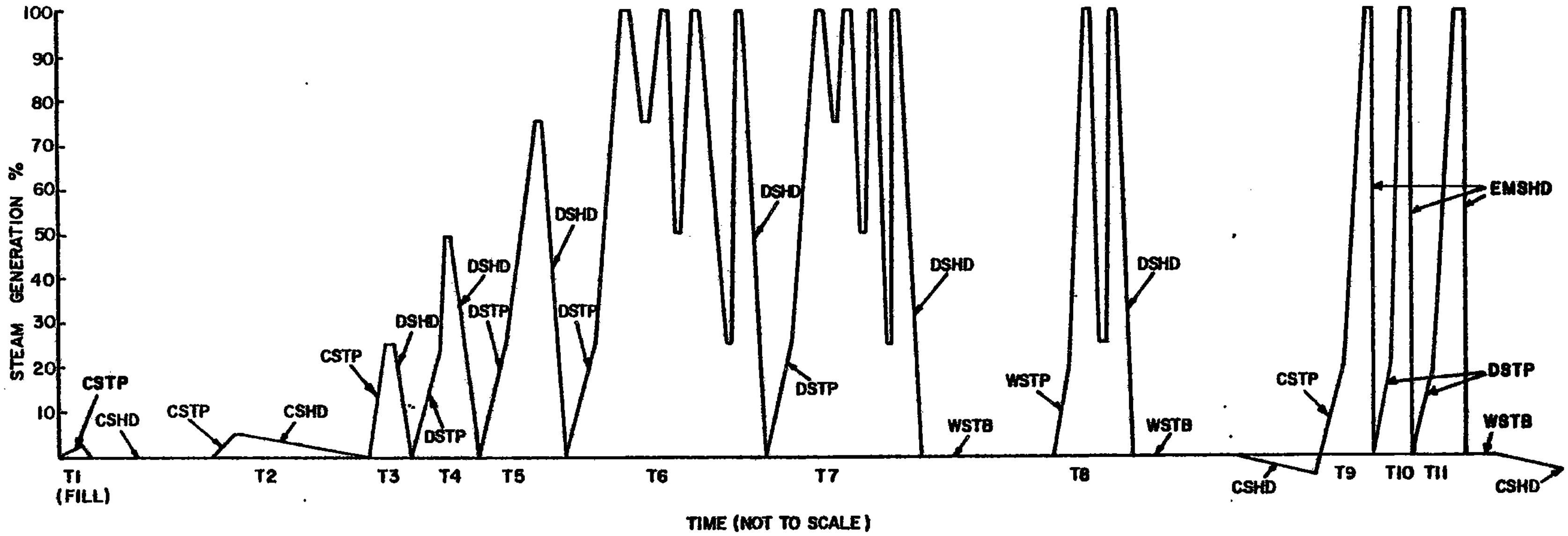
The data collected will be compared with the thermal/hydraulic correlations included in the computer codes described in Sections 2.2.4 and 3.2.5

Checkout. Before conducting formal test operations, verification checkout tests will be conducted without flow or heat input to the subsystem. The checkout tests will be performed before and after SGS module erection. The purpose of the checkout tests will be to verify that all instrumentation and control components are installed correctly and functioning properly and to make any necessary adjustments. Each valve and piece of mechanical equipment will be functionally operated after erection. Instrumentation will be checked completely to verify that there are no open or damaged circuits and to verify that the instrumentation and data acquisition systems are as programmed. In addition, system control functions will be checked out where possible.

Test Operations. After the checkout tests are completed, the formal test program will begin. The tests will progressively increase in complexity to allow personnel to become gradually familiar with the operating characteristics of the system. Initial test operations will also provide preliminary operating information and indicate the corrective actions to be taken in the event of unanticipated operating problems.

We will conduct 11 test series. Figure 3.15 illustrates the load conditions for each test series. (Load variations above 25-percent load that are not labeled "start-up" or "shutdown" are load-change operating modes.) The type of operating modes included in the test series and the number of times each will be tested are as follows:

Operating Mode		Number of Times Tested
Cold start-up		4
Cold shutdown		4
Diurnal start-up		6
Diurnal shutdown		6
Warm standby		3
Start-up from warm standby		1
Steady state:	25% load	4
	50% load	3
	75% load	3
	100% load	12
Load change		22
Emergency shutdown		3



CSTP	COLD STARTUP FROM COLD SHUTDOWN MODE
CSHD	COLD SHUTDOWN AND DRAIN TO COLD SHUTDOWN MODE
DSTP	DIURNAL STARTUP FROM HOT STANDBY MODE
DSHD	DIURNAL SHUTDOWN TO HOT STANDBY MODE
WSTP	WARM STARTUP FROM WARM STANDBY MODE
WSTB	WARM STANDBY
EMSHD	EMERGENCY SHUTDOWN
T_N	Nth TEST

Figure 3.15 Test Description--Proposed SRE

A brief description of the sequence of events occurring during each test series is included below. Steam/water/salt lines, valves, etc., mentioned are referenced in Figure 3.1 The operating modes, subsystem-level features, and component-level features addressed in each test series are identified in Table 3.7.

Test Series 1. In this test series, the steam/water HRS feedwater pump is used to fill the preheater and evaporator with water at ambient temperature. The water in the steam drum is maintained at its normal level. As water fills the vessels, displaced nitrogen is expelled through the vent valves. The drum-water recirculation pump circulates water through the preheater and evaporator. The recirculated water is heated by the propane heater. As the water temperature rises, the electric trace heaters on the preheater and evaporator are turned on so that the temperature difference between the tube bundle and shell does not exceed 56°C (100°F). Pressure is raised to 4.68 MPa gage (681 lb/in^{2}g), which corresponds to a saturation temperature of 238°C (460°F). This temperature and pressure are maintained for a half hour, after which the trace heaters, recirculation pump, and propane heater are turned off. The unit is then allowed to cool down. When near ambient conditions, the water is drained and the unit is filled with nitrogen.

Test Series 2. Test Series 2, in which 5 percent of the full-load steam flow is generated, is an extension of Test Series 1. The procedure followed in Test Series 1 is used to bring the water pressure and temperature up to 4.68 MPa gage (681 lb/in^{2}g) and 238°C (460°F). Salt from the hot- and cold-salt storage tanks is blended to 343°C (650°F) and admitted to the evaporator through the bypass line. Displaced nitrogen is vented from the evaporator and preheater. The electric trace heaters on the superheater and reheater are turned on. Steam discharged from the steam drum is throttled, cooled to 104°C (220°F) and 0.14 MPa gage (20 lb/in^{2}g), and passed through the superheater and the bypass to the reheater. The trace heaters are controlled so that the temperature difference between the tube bundle and shell does not exceed 56°C (100°F). Salt flow to the evaporator is increased to 5 percent of the full-load amount. The temperature of the steam entering the superheater is slowly increased to 260°C (500°F) by controlling the spray. After establishing salt flow through the superheater and reheater, the salt temperature is increased at a rate of 66°C (150°F)/hour until steam leaves the superheater and reheater at 399°C (750°F). These conditions are maintained for a half hour, after which the load is reduced at 2 percent/min. The unit is allowed to cool and then is drained.

Test Series 3. Test Series 2 procedures are repeated to bring the SGS up to 5-percent steam flow at 399°C (750°F). Using the start-up salt temperature control, the temperature of the salt entering the subsystem is raised to 566°C (1050°F). As the salt temperature increases, the steam temperature leaving the superheater and reheater is increased to 541°C (1005°F). The salt flow is increased until 25 percent of the full-load steam flow is established.

Table 3.7 Test Series Features--Proposed SRE

Test Series	Operating Mode	Subsystem Feature	Component Feature
1	1,9	1-5	—
2	1,9	1-9, 13-16	2,4,7,8
3	1,2,4	1-9, 13-16	1-9
4	2-5	8-16	1-9
5	2-5	8-16	1-9
6	2-5	8-16	1-9
7	2,3,5-7	8-16	1-9
8	2-4,6,7,9	8-16	1-9
9	1-3,10	1-16	1-9
10	2,3,5,10	8-16	1-9
11	2,3,5,7,9,10	8-16	1-9

OPERATING MODES

1. Cold start-up
2. Full- and part-load steady-state operation
3. Load changes
4. Diurnal shutdown
5. Diurnal start-up
6. Shutdown to warm standby
7. Warm standby
8. Start-up from warm standby
9. Shutdown to cold conditions
10. Emergency shutdown

COMPONENT FEATURES

1. Salt-side film coefficients
2. Evaporator dynamic flow stability
3. Absence of departure from nucleate boiling/dryout in evaporator
4. Superheater flow stability
5. Fouling
6. Ambient heat losses
7. Absence of tube vibration
8. Absence of gross structural deformation
9. Tubesheet temperature response to load change

SUBSYSTEM FEATURES

1. Salt/water fill procedure
2. Trapped gas venting
3. Coordinated preheat of tube bundle and shell
4. Drum-water recirculation for preheating the preheater and evaporator tube bundles
5. Auxiliary feedwater heater operation for cold start feedwater heating
6. Use of drum steam to preheat superheater
7. Use of main steam to preheat reheater
8. Main steam flow to reheater established before reheater salt admission on start-up
9. Hot/cold salt blending for start-up
10. Steam generation load response
11. Superheater outlet temperature/pressure load response
12. Salt mixing tee temperature response
13. Drum-water recirculation to preheater for preheater inlet temperature control
14. Control response of superheater/reheater/bypass combination
15. Salt flow/attemperator main steam temperature control
16. Salt flow/attemperator reheater temperature control

Steam pressure is raised to 13.48 MPa gage (1955 lb/in^{2}g). The SGS is maintained at this condition for a half hour, after which load is reduced by reducing the salt flow at 3 percent/min until 5-percent salt flow is obtained. The salt pump and SGS are then tripped and the unit is "bottled-up" for overnight hot standby. The steam bypass lines to the reheater and to the deaerator-desuperheater are set on automatic to vent steam generated as the salt in the evaporator cools to the water saturation temperature.

Test Series 4. In this test the SGS is brought up to 50 percent of the full-load steam flow from the hot standby mode. Salt from the hot- and cold-salt storage tanks is blended to 387°C (730°F) and passed through the salt bypass to the evaporator. Steam generated is bypassed around the superheater and sent directly to the deaerator-desuperheater. To maintain drum-water level, feedwater is admitted. Drum water is recirculated to the preheater to maintain the temperature of feedwater entering the preheater at 238°C (460°F). When approximately 4 percent of the full-load steam flow is generated, superheater steam bypass Valve I and salt bypass Valve N are closed as Valve H is opened, admitting steam to the superheater. Cold-salt flow is stopped by closing Valve M, and the cold-salt pump is turned off. Hot salt at 566°C (1050°F) is then passed through the superheater and reheater while the steam is passed through the reheater to the deaerator-desuperheater by opening Valves G and F. Salt flow is increased to 5 percent of the full-load value. By adjusting spray flows, the superheater and reheater outlet steam temperatures are controlled to 496°C (925°F). The 5-percent steam load condition is held for 15 minutes, after which steam flow and temperature are linearly increased to 25 percent and 541°C (1005°F) by increasing the salt flow at 3 percent/min. The 25-percent steam load is held for 15 minutes and then increased to 50 percent at the rate of 3 percent/min. The 50-percent steam load is held for a half hour, after which the SGS is brought down to the hot standby mode.

Test Series 5. This test is similar to Test Series 4 except that the SGS is brought up to 75 percent of the full-load steam flow. The SGS is maintained at 75-percent steam flow for a half hour and is then ramped down at 3 percent/min to the hot standby mode.

Test Series 6. Using the diurnal start-up procedure, the SGS is brought up to full load. It is held at this level for a half hour and ramped down at 3 percent/min to 75-percent load, where it is held for a half hour and then ramped up to full load. This load change operation is repeated for 50- and 25-percent loads. Finally, from the full-load condition, the SGS is ramped down to the hot standby mode.

Test Series 7. To obtain additional full- and part-load data, Test Series 6 is repeated. However, in this test the SGS is first brought to the hot standby mode and then allowed to cool further to simulate the warm standby mode. Shell temperature variations are monitored during this period to evaluate the ambient heat losses.

Test Series 8. In this test series, the SGS is brought to full load from the warm standby condition and is held at this level for a half hour. It is then ramped down to 25-percent load, held at this level for a half hour, and ramped up to full load. From full load it is ramped down to the hot standby mode using the diurnal shutdown procedure. It is allowed to cool further to simulate the warm standby mode. In this mode the SGS is maintained uniformly at 288°C (530°F) by using the electric trace heaters on the salt piping and the heat exchanger vessels.

From the warm standby mode, the SGS is brought to the long-term cold shutdown mode. In this procedure the electric trace heaters are turned off. Salt is drained to the cold-salt sump and pumped into the cold-salt storage tank. The salt side of the heat exchangers is then purged with nitrogen and bottled up.

Valve G in the steam bypass line to the reheater, Valve F in the steam line to the deaerator-desuperheater, and all vent valves are opened to reduce the water-side pressure to atmospheric conditions. Water is drained by opening all valves. Valve F is then closed and the system is purged with nitrogen. After the purge, the drain and vent valves are closed, isolating the system.

Test Series 9. Using the procedures established in earlier tests, the SGS is brought up to full load from cold shutdown. At full load the salt pumps are tripped to simulate emergency shutdown. The SGS is then maintained in the hot standby condition.

Test Series 10. The SGS is brought up to full load from hot standby. At full load the feedwater pump is tripped to simulate emergency shutdown. The SGS is then maintained in the hot standby condition.

Test Series 11. The SGS is brought to full load from hot standby. At full load the steam flow from the superheater is stopped to simulate a turbine trip. The automatic control system brings the SGS to warm standby, after which it is brought to the long-term cold shutdown mode.

3.3 ALTERNATIVE SRE

3.3.1 Description

The proposed SRE SGS described in Section 3.2 includes the essential features of a full-scale SGS and is also compatible with the requirements for a full-system experiment (FSE). The alternative SRE SGS (Figure 3.16) reduces the SRE cost 21 percent, shortens the SRE schedule from 24 to 21 months, includes 9 of the 11 originally proposed SRE tests, and is compatible with the FSE.

The alternative SRE SGS includes an evaporator, separate vertical steam drum, and a superheater. The superheater and steam drum are identical to the proposed SRE SGS designs described in Section 3.2. The evaporator is essentially the same as in the proposed SRE SGS design described in Section 3.2 except for a 14-percent material thickness increase resulting from the design temperature change from 468 to 496°C (875 to 925°F). Significant features of the alternative arrangement are as follows:

- At the 100-percent load test point, the SRE SGS generates the same main steam conditions as the alternative SRE SGS [i.e., 1.58 kg/s (12,500 lb/h) superheated steam at 541°C (1005°F) and 13.58 MPa absolute (1970 lb/in^{2}a)].
- Feedwater from the CRTF steam/water HRS enters the steam drum at 288°C (550°F). Superheated steam discharged from the superheater outlet is used to heat the feedwater in the steam/water HRS deaerator-desuperheater and the high-pressure feedwater system. Excess heat is removed by the closed-loop dry cooling towers incorporated in the steam/water HRS.
- With 288°C (550°F) subcooled feedwater entering the drum, excess steam must be generated in the evaporator to heat the feedwater to saturation. As a result, the evaporator duty is 27 percent greater than that required for the proposed SRE SGS. Since the heat-transfer area is the same as for the proposed SRE SGS, the salt inlet and outlet temperatures as well as the flow rate were increased to increase the log mean temperature difference and the salt-side film coefficient to generate the required amount of steam. Because of the increased steam generation rate, the downcomer and riser pipes were increased from 76.2 to 127.0 mm (3 to 5 in.) to 127.0 mm (5 in.) nominal size to maintain a 4:1 circulation ratio. The salt-side pressure drop increased from 27.6 to 31.3 kPa (4.0 to 4.5 lb/in^2).
- Salt leaves the evaporator at 344°C (652°F). Because the preheater is eliminated in the alternative SRE SGS, the salt must be passed through the air-cooled heat exchanger included in the CRTF thermal storage SRE and cooled to 288°C (550°F) before it can be put into the cold salt storage tank. As a result, approximately 0.93 MWt is lost to ambient.

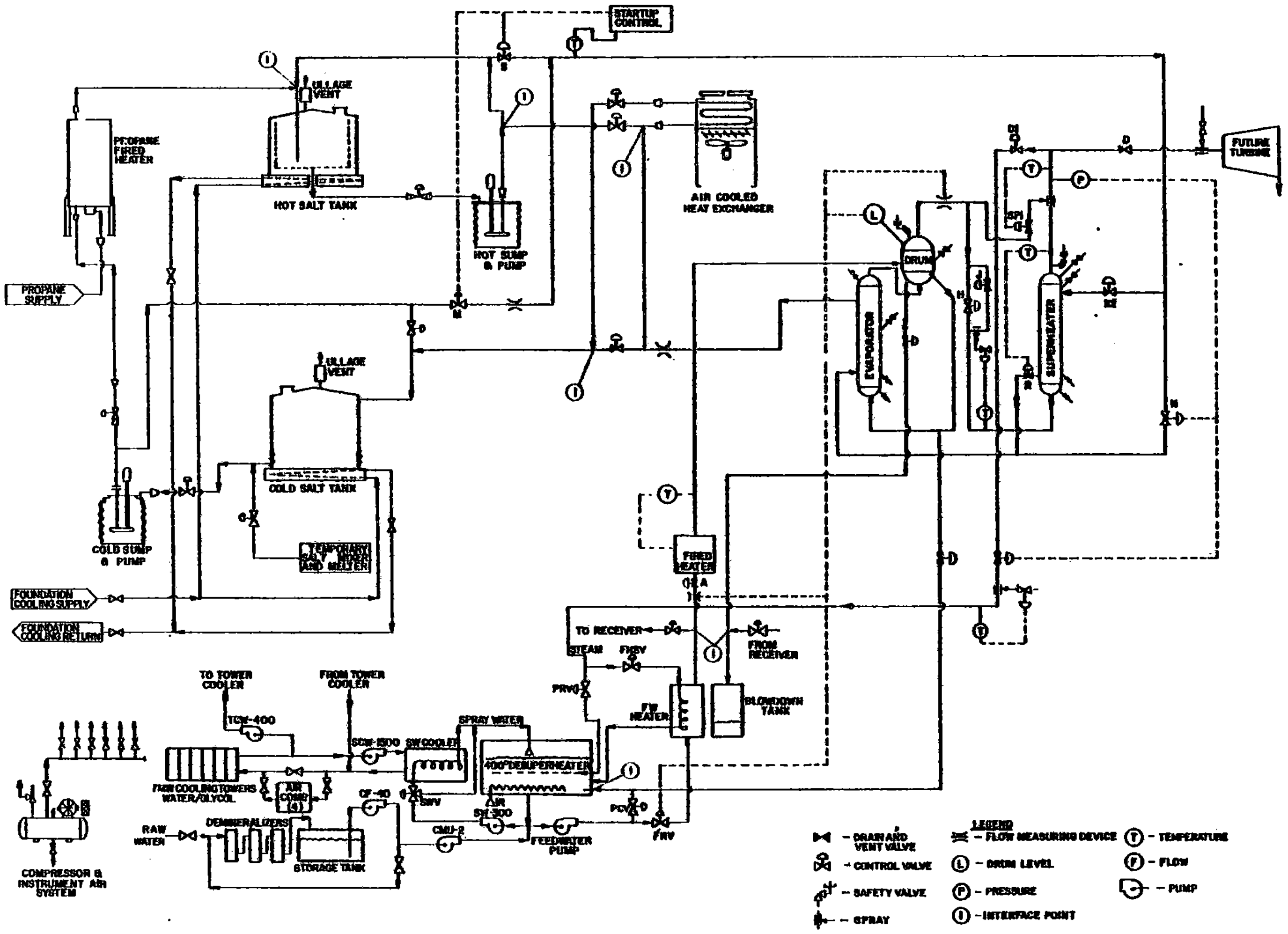


Figure 3.16 Schematic of Alternative SRE

Sufficient hot salt pump head is not available to pass the salt discharged from the evaporator directly through the propane-fired salt heater and into the hot-salt tank to avoid the aforementioned heat loss to ambient.

- For cold start-up a propane-fired heater is provided to preheat the feedwater from 204 to 238°C (400 to 460°F) to prevent salt from freezing in the evaporator.

With elimination of the preheater, reheater, and drum-water recirculation pump, the alternative SRE does not include all the subsystem-level features required to evaluate all operating modes. Consequently, the test program will be abbreviated to include Test Series 1 through 6 and 9 through 11 identified in Section 3.2.7 and modified to compensate for elimination of the aforementioned components.

Alternative Data Acquisition System. The alternative system utilizes the existing data logger in the HRS, which consists of an Acurex Autodata 10/10 Data Logger with 460 input channels. This system is capable of accepting 4 to 20 mA or 0 to 10 V analog inputs. However, 310 channels are currently being used by the HRS, leaving only 150 channels for the SRE test. The alternative SRE requires 110 transducers compared with the 168 required by the proposed SRE.

The system has six alarms/channels. Annunciators are connected to this data acquisition system to announce any alarms. The Acurex data logger is capable of accepting both seven- or nine-track Kennedy incremental tape recordings so that data can be stored for archival or off-line processing.

The present data acquisition system has no computer power for on-line data processing and real-time performance evaluations. All evaluation and processing must be done off-line. The system also has no graphic capability.

A Kennedy nine-track tape recorder would be attached to the data logger for data storage. All data processing and performance evaluation would be done off-line, using either the Foster Wheeler computer at Livingston or Sandia's computer at the CRTF. As mentioned, this system has no real-time data processing and evaluation capability, nor does it have any graphic display capability.

3.3.2 Compatibility With FSE

As described in Section 3.2.6, the FSE steam turbine requires 1.26 kg/s (10,000 lb/h) superheated steam at 510°C (950°F), 10 MPa absolute (1450 lb/in^{2}a).

In addition, the SGS must be capable of generating enough steam for feedwater heating. With elimination of the preheater in the alternative SRE SGS, it is desirable to heat the feedwater as much as possible with the existing steam/water HRS. The design limitation for the existing high pressure feedwater heater is 288°C (550°F). Raising the feedwater temperature to 288°C (550°F) will require approximately 0.62 kg/s (4900 lb/h) superheated steam, bringing the FSE SGS steam-generating requirement up to 1.85 kg/s (14,700 lb/h). This steam generating requirement is 49 percent and 18 percent above the design duty of the specified evaporator and superheater. This performance can be obtained by increasing the salt flow through the units as described for the proposed SRE. Table 3.5 lists performance for the alternative SRE to meet the FSE requirements. The computed total salt flow of 11.84 kg/s (94,000 lb/h) is approximately 2 percent above the cold-salt pump design flow rate. With the surface margins included in the heat exchanger design, the actual operating salt flow rate should be within the capability of the existing cold-salt pump.

Salt leaves the evaporator at of 346°C (655°F) and must be passed through the air-cooled heat exchanger to cool it to 288°C (550°F) to meet the receiver inlet salt temperature requirement. Consequently, 1.14 MWt is lost to ambient.

As with the proposed SRE SGS, implementing the alternative SRE SGS into a future FSE will involve connecting the main steam line leaving the superheater to the turbine. The main steam line will require a throttle and spray station to meet the turbine throttle steam pressure and temperature conditions.

3.3.3 Comparison Between Proposed and Alternative SREs

The proposed SRE described in Section 3.2 is essentially a scaled-down version of the full size SGS, which includes all the significant components required to simulate all the operating modes of the full-size SGS as requested by SNLL. In addition to simulating all aspects of the full-scale SGS operation, the proposed SRE permits verification of individual component performance (i.e., shell-side film coefficients, ambient heat losses, evaporator dynamic flow stability, evaporator DNB/dryout, superheater flow stability, and fouling). The proposed SRE also satisfies the requirements for a future full-system experiment (FSE).

The alternative SRE provides a less-expensive arrangement for meeting the primary objective of the SRE (i.e., to demonstrate the ability to generate high-pressure, high-temperature steam using molten salt). It also permits component performance verification tests and satisfies the requirements for a future FSE. However, it does not permit demonstration of all full-scale subsystem operating modes as requested by SNLL. SGS features that can and cannot be tested by the alternative SRE are listed in Table 3.8 as well as advantages and disadvantages of the alternative SRE.

Table 3.8 Alternative SRE Features

SGS Features That Can Be Tested by Alternative SRE

1. Salt/water fill procedure
2. Trapped gas venting
3. Coordinated preheat of tube bundle and shell
4. Use of drum steam to preheat superheater
5. Hot/cold salt blending for start-up
6. Steam generation load response
7. Superheater outlet temperature/pressure load response
8. Salt mixing tee temperature response
9. Salt flow/attemperator main steam temperature control
10. Salt-side film coefficients
11. Evaporator dynamic flow stability
12. Absence of DNB/dryout in evaporator
13. Superheater flow stability
14. Fouling
15. Ambient heat losses
16. Absence of tube vibration
17. Absence of gross structural deformation
18. Tubesheet temperature response to load change

SGS Features That Cannot Be Tested by Alternative SRE

1. Drum-water recirculation to preheater for preheat inlet temperature control and preheating purposes
2. Use of main steam to preheat reheater
3. Main steam flow to reheater established before reheater salt admission on start-up
4. Control response of superheater/reheater/bypass combination
5. Demonstration of emergency shutdown procedures for complete subsystem

Advantages

1. Low SRE cost
2. Shortened SRE schedule
3. Demonstration of ability to generate high-pressure high-temperature steam
4. Permits testing of the SGS features listed above

Disadvantages

1. Elimination of preheater requires cooling of salt before return to cold tank, resulting in heat loss to ambient
2. Larger salt flow rates required for comparable duties
3. Does not permit testing of the SGS features listed above

Elimination of the preheater in the alternative SRE precludes demonstration of the procedure for preheating the preheater and evaporator and for controlling the temperature of feedwater entering the preheater by recirculating drum water. The primary concern in the preheat procedure is the coordination of the tube-bundle/shell temperature increase rates. The tube bundle temperature is dictated by the water temperature; the shell temperature, by the trace heater heat input rate. In the alternative SRE, coordination of the tube bundle/shell preheat can be demonstrated in the evaporator with the boiler feed pump acting as the recirculating pump by draining evaporator water back to the deaerator-desuperheater. Feedwater temperature control by recirculating drum water to the preheater inlet is a simple control loop whose elimination in the alternative SRE is not critical to demonstration of operating procedures unique to the SGS.

In the proposed SRE, the primary component for verifying shell-side film coefficients is the preheater (see Section 3.2.5). Since tube-side water film coefficients are well-established and temperature measurements are more accurate at lower temperatures, the preheater should give best results. By eliminating the preheater in the alternative SRE, shell-side film coefficients will have to be verified by measurements in the evaporator and superheater. Although there is more room for error in nucleate boiling and steam film coefficients as well as high-temperature measurements compared with water film coefficients and low-temperature measurements, the difference should not be significant.

The reheater in the proposed SRE was included primarily for demonstration of SGS control and reheater-related operating procedures. A control system dynamic computer model developed by Foster Wheeler has shown that the full-scale SGS control system can operate in a safe and stable manner. The proposed SRE will permit verification of the model by including all significant SGS components. Elimination of the reheater in the alternative SRE simplifies the control system. Although the alternative SRE will not be able to demonstrate all the features of the full-scale SGS control system, the dynamic model can be modified to simulate the simplified arrangement. The ability of the modified model to predict system response can be verified by the alternative SRE to give confidence that the theory incorporated in the model reflects actual operating conditions. Design and operating features of the reheater, other than those mentioned above, are adequately demonstrated in the superheater.

Although the complete procedures followed by the automatic control system in shutting down the SGS in the event of loss of salt flow, loss of feedwater flow, or the sudden halt of steam flow caused by turbine trip cannot be demonstrated if the preheater and reheater are eliminated, successful emergency shutdown of the evaporator and superheater will establish that a control system can be properly designed for this purpose. The extension of the control system design to include automatic shutdown of the preheater and reheater does not entail significant risk. Inherently, the system is a highly safe one.

The effect of the fast shutdown transients on the heat exchangers can be adequately demonstrated on the evaporator and superheater. However, because of the small size and low thermal capacitance of the SRE heat exchangers compared with the full-scale SGS, the results may not be significant. In any event, the number of fast emergency shutdown transients expected in a full-size plant is very low, and the effect on the structural integrity of the heat exchangers will be minimal because of the low number of thermal stress cycles.

3.4 STATEMENT OF WORK

We do not take any exceptions to the Statement of Work presented by SNLL, nor do we anticipate any barriers to the successful completion of the project.

Task 1--SRE Requirements

Foster Wheeler will review the SGS SRE requirements identified in Task 6 of the Molten Salt Steam Generator Phase 1 contract along with the SRE interface requirements defined by SNLL to determine finally the experimental requirements that will satisfy the program objectives.

Discussion:

Most of this work was done during the preparation of our Phase 2 proposal. The work is thus primarily a review of the data already generated. The review will include:

- An evaluation of the SRE's ability to demonstrate the adequacy of the commercial-scale (100-MWe solar stand-alone and 50-MWe hybrid) molten salt SGS designs developed during the Phase 1 contract
- The SRE's ability to resolve any design, fabrication, operating, performance, or costing issues
- The SRE's compatibility with a future full-system experiment (FSE).

Process flow diagrams for both the SRE and FSE will be reviewed and revised, if necessary. All flow streams entering and leaving the SGS will be identified. The design-point temperatures of salt and steam/water entering and leaving each subsystem component will be determined by heat balances. Anticipated design-point salt and steam/water pressure losses through the SGS will be identified and used as the starting point for equipment design. Design-point pressure losses through the existing steam/water heat rejection system (HRS) and the thermal storage SRE will be reevaluated to ensure that anticipated pump-head requirements are within the capability of the existing pumps. The heating and heat-rejection capabilities of the steam/water HRS and thermal storage SRE equipment will also be checked relative to the requirements of the SRE.

Task 2--Design

Foster Wheeler will design the SRE based on the requirements defined in Task 1. The design effort will be divided into the following parts:

- Thermal/Hydraulic Analysis
- Mechanical Design
- Civil and Piping Design
- Control, Instrumentation, and Data Acquisition.

Discussion:

Thermal/Hydraulic Analysis. Based on the design-point process flow diagram conditions developed in Task 1, we will check the SRE components designed for Task 6 of the Phase 1 project to determine whether they meet the required performance. If the preliminary designs do not meet the SRE performance requirements, the components will be redesigned. Number, length, diameter, and spacing of tubes will be determined and tube materials will be selected. An appropriate surface margin will be defined for each component to cover the uncertainties in thermal/hydraulic parameters such as heat-transfer coefficients, thermal conductivity of the tubes, fouling factors, and tube plugging.

After completion of component sizing, full- and part-load performance characteristics will be evaluated. Pressure drops through all components will be calculated, and the drops across the SGS as a whole will be summarized. For the natural-circulation evaporator, steam/water flow characteristics will be evaluated to ensure that appropriate circulation criteria are satisfied.

Both tube- and shell-side flow distributions will be checked. Their effects on flow stability, tubewall temperature, and variations in tube outlet temperature (or outlet steam quality for the evaporator) will be estimated.

Mechanical Design and Detailing. Based on the thermal sizing requirements identified during thermal/hydraulic analysis, we will prepare general arrangement drawings for each heat exchanger and the steam drum. All pressure parts--shells, tubes, shell heads, nozzles, and reinforcements, etc.--will be sized according to Section VIII of the ASME Code, using nominal design pressure and temperature conditions. Tubular Exchanger Manufacturers Association (TEMA) standards will be followed when sizing tubesheets.

A general arrangement drawing of the SGS module will also be prepared. The module will be designed for shop fabrication so that the heat exchangers, drum, interconnecting piping, insulation/lagging, trace heating, electrical outlets, etc., can be shipped as a single unit. The SGS module will include the columns, platform framing, grating, horizontal and vertical cross bracing, handrails, ladder, and cage, etc., required for support and access to the heat exchanger components.

Detailed shop drawings will be prepared for the heat exchangers, steam drum, and SGS module to permit fabrication and assembly of all components into a single shippable unit.

Civil and Piping Design. We will complete detailed designs of all foundation, structural support, and piping layouts compatible with the site facilities at

The work will result in the following drawings or specifications:

- General arrangement drawing
- Heat exchanger assembly foundation drawing
- Piping asembly, details, and supports
- Circulating pumps and motors
- Circuit and pipeline schedules.

Foster Wheeler engineering standards and specifications, together with applicable local, State, and Federal codes and standards, will be used in these designs.

Control, Instrumentation, and Data Acquisition. We will prepare detailed designs of the instrumentation, control system, and data acquisition system consistent with the design and operating philosophies of the SRE SGS. The task will result in a final design package that will include:

- Instrumentation and control details and control logic diagram
- Control valve diagrams and data
- Engineering and process flow diagram
- Piping and instrumentation diagram
- Electrical diagram
- Safety and relief valves and safety procedures
- Data analysis system package specification
- Start-up, operation, and shutdown procedures
- Spare parts list
- Analytical predictions of steam generator system response under differing modes of SRE operation.

The work will be performed using Foster Wheeler engineering standards and applicable industry, local, State, and Federal codes and standards.

Task 3--Test Plan

Foster Wheeler will prepare a Test Plan that defines each test and contains the detailed test procedures necessary to satisfy the objectives of the SRE defined in Task 1. The plan will be submitted to SNLL for approval.

Discussion:

The Test Plan will address the areas of safety, instrumentation, codes and standards, operation, and maintenance of the test unit; expected performance; and methods for processing the collected data. Tests will be those described in Section 3.2.7. The Test Plan will include a test schedule as well as test support requirements such as feedwater treatment, salt purity maintenance, electrical power consumption, and propane fuel consumption.

Task 4--Fabrication

Foster Wheeler will prepare a shop fabrication plan for the SRE heat exchangers, steam drum, and SGS module and for the assembly of these components into a single shippable unit and will submit the plan to SNLL for approval. Foster Wheeler will fabricate the SRE heat exchanger equipment and assemble it according to the approved Plan and the ASME Boiler and Pressure Vessel Code Section VIII--Division I. They will be code stamped.

Discussion:

Fabrication Plan. A step-by-step fabrication sequence will be devised, including all significant fabrication and inspection operations. In doing this, consideration will be given to the tools, jigs, fixtures, equipment, floor space, and special supplies required. Special welding procedures, welding qualification requirements, and nondestructive examination and inspection requirements will be identified. Shop fabrication schedules will be prepared showing fabrication of subassemblies such as shells, tubesheets, tube bundles, and final assembly of the heat exchanger components. The schedule will also identify the period of performance for tool design and fabrication, welding development, mockups, and assembly of all components into the SGS module. Appendix B is a preliminary fabrication plan for the SRE heat exchangers and steam drum.

Fabrication of the SRE Heat Exchangers. Prototypical manufacturing techniques and procedures will be used to fabricate unit internals (i.e., drilling of the tubesheets, drilling and deburring of the tube-support plates, and welding and expanding of the tubes into the tubesheets). The tube-support plates will be supported by tie-rods prototypical of those in the actual units. All of these items, with the exception of the tube-to-tubesheet weld and kinetic expansion of the tubes into tubesheets, are standard procedures and do not require any development. The tube-to-tubesheet weld and the kinetic expansion procedures will be qualified for their specific geometries, but since they fall within the range of parameters previously used by Foster Wheeler, these qualifications are considered routine.

The shell sections and steam/water inlet and outlet channels will be fabricated from standard pipe and pipe fittings. A commercially available expansion bellows will be used.

Fabrication of the Steam Drum. A separate steam drum (Figure 3.7), will be fabricated from standard pipe and pipe caps. The spiral steam separator has prototypical arms and, in construction, is very similar to the in-line steam/water separators used in Foster Wheeler once-through steam generators. Construction of this unit does not require development of any new procedures.

Steam Generator Assembly. To minimize the cost of field assembly, all steam generator components will be shop-assembled within a module suitable for transportation and testing, as shown in Figures 3.8 and 3.9. The steam generator assembly will contain all required piping, control valves, safety valves, instrumentation, heat tracing, and insulation. The module will contain a number of platforms at various elevations to facilitate observation and maintenance during operation. The unit will be shipped horizontally. The 3.0-m (10-ft) width will permit shipment to the test site with no need for special routing. Suitable lifting lugs will be provided for turning the assembly upright and positioning it on the foundation.

The internals of the heat exchangers and the drum will be pressurized with nitrogen for shipment and storage at the site.

Long-Lead Items. The long-lead items for heat exchanger fabrication are the pipe fittings and tubing. The presently quoted deliveries are 16 to 18 weeks. The pipe fittings, which form the salt nozzle connections in the shell, are required at the beginning of the fabrication portion of the project and will have to be ordered at the beginning of the contract. Tubing is required in the later stages of fabrication and should not impact the overall schedule.

Full-Scale SGS Fabrication Plan. During fabrication of the SRE components, full-scale SGS fabrication techniques will be used where applicable. Possible improvements to these techniques will be noted. The full-scale SGS Fabrication Plan will be revised to incorporate the improvements.

Task 5--Delivery, Installation, and Checkout

Foster Wheeler will prepare field fabrication/erection plans showing the major steps involved in building dikes; pouring foundations; erecting the SGS module; installing piping, heat tracing, pumps, drain tanks, instrumentation, and controls; and applying insulation. Any inspection and testing activities required by the Code will also be included. Foster Wheeler will deliver, install, and check out the SRE SGS at the CRTF facility.

Discussion:

The SRE preheater, evaporator, superheater, reheater steam drum will be shop-assembled inside a module and shipped to the site as a single 3.4- x 3.7- x 21.3-m (11- x 12- x 70-ft) unit. To the extent possible, the interconnecting pipes, trace heaters, insulation, and instruments will be included within the SGS module. The size of the module will permit shipping without the need for any special routing.

The installation of the SRE involves the following steps:

- Excavation
- Foundation
- Structural work
- Piping installation
- Module assembly, erection, and tie-in
- Hydrotesting
- Electrical and instrumentation connection
- Insulation and painting

The preassembled SGS module will weigh approximately 25 tons. The assembly will be trucked alongside the foundation so that the top portion of the module is nearest to the foundation. The module will be lifted from the trailer by two cranes [30 tons x 45.7 m (150 ft) and 30 tons x 15.2 m (50 ft)] with a special spreader bar on the larger crane. The larger crane will be positioned so that it can swing over the foundation. The module will be lifted approximately 6.1 m (20 ft) and held in a horizontal position while the trailer is driven away. The module will then be turned vertically, lowered onto the piers, leveled, and checked out for alignment. The anchor bolts will be torqued to a preset value. The interconnecting piping, instrumentation, electrical connections, etc., will be field-fitted, and all utility connections will then be made.

The checkout procedure will involve the hydrostatic tests required by the ASME Boiler and Pressure Vessel Code and the tests to verify operation that are described in Subsection 3.2.7.

Task 6--Testing

Foster Wheeler will conduct 11 tests.

Discussion:

We will conduct the test described in Section 3.2.7 according to the SNLL-approved plan developed in Task 3. We anticipate the test series will run for 4 months using a two-shift operation. During this time Foster Wheeler will have a test engineer and a technician stationed at the site. Most of the test data will be reduced at the site utilizing the data analysis computer system developed and installed there. More detailed analyses will be done in Livingston.

Task 7--Evaluation

Foster Wheeler will evaluate the experimental data collected during the Task 6 tests.

Discussion:

The raw data collected will be reduced to a format for evaluation (i.e., curves and tables). Wherever possible, measured parameters will be checked by redundant measurements which permit checks by heat balance or by difference. The reduced data will be used to verify the accuracy of the subsystem control dynamic computer model and the correlations included in the thermal/hydraulic sizing and performance computer codes. Performance parameters to be evaluated are described in Section 3.2.5.

The impact of the test results on the full-scale SGS designs prepared in Phase 1 will be evaluated and documented. The SGS Requirements Specification for the full-scale SGS designs will be revised accordingly.

Task 8--Reporting

The Foster Wheeler team will provide the required reports and data for the duration of the project. The reports will be clear, concise, and comprehensive accounts of the various activities during the reporting period.

Discussion:

The Foster Wheeler team will prepare the following:

- Monthly Reports
- Final Report
- Test Plan
- Molten Salt SGS Subsystem Requirements Specification (Revised)
- Steam Generator Fabrication Plan (Revised)
- Agendas for Oral Reviews

The Foster Wheeler team will attend and prepare informative presentations for the following meetings:

- Kickoff
- Quarterly Reviews
- Final Review
- DOE Semiannual or Annual.

The products of this task will be in the format and detail specified by SNLL. A complete schedule of the deliverable items and meetings is shown in Section 4.3. In addition, periodic meetings will be held among members of the project team.

Task 9--Project Management

Foster Wheeler will provide the project and technical management (including planning, scheduling, organizing, staffing, directing, coordinating, reviewing, budgeting, and controlling) required to satisfactorily complete all tasks in Phase 2 of this proposed project according to the Project Plan. Project direction, review, and quality control will be exercised to achieve the project goals on a timely basis.

Management and technical progress reports provided to SNLL on a monthly basis, will highlight the progress for that reporting period and provide an overview for the subsequent report.

Manpower and financial reports will be provided to SNLL on a monthly basis. SNLL Forms 533 through 536 and the appropriate forms required for hardware and equipment to be provided during Phase 2 will be considered a deliverable item.

Discussion:

The project will be managed according to the Project Plan (Section 4.2). In the Plan, measurable engineering tasks are defined for the overall project, assigned a responsible task leader, checked by the manpower estimate, and keyed to the Project Schedule (Figure 4.3) to ensure continual control of the project.

During the project, the project manager will have complete control of all project activities. He will be given full authority and all the resources required to successfully perform the workscope and coordinate all project activities.

The project manager will establish budgets and define in detail all activities to be performed, when tasks are to be completed, and the individual responsible for performance. He will review all staff assignments and approve all project-related subcontract agreements, manufacturing orders, equipment and material purchases, travel, and other requests. This procedure is simple but effective in monitoring and assisting in the control of the contract effort and expenditures.

The project manager will work closely with the project administrator on all matters relating to contractual obligations. The project administrator will monitor contract activity, milestones, and task progress and will prepare the contract-required financial management reports. He will be reponsible for preparing, negotiating, and issuing all subcontracts; handling all contractual and business-related matters; and ensuring that the work is performed according to the terms and conditions of the prime contract. He will monitor the project from a contractual viewpoint to ensure satisfactory and timely fulfillment of all contractual obligations.

The procedure for monitoring and controlling costs will be weekly and monthly computer printouts. The printouts list man-hours charged by Foster Wheeler personnel and--on a monthly basis--the actual costs for labor, overhead, purchases, and travel of all personnel associated with this project. Project costs and activities, including subcontractor billings, will be reported by task according to the Work Breakdown Structure. These work packages are small enough to allow close monitoring by project management and to enable a realistic evaluation of actual progress and costs during the performance of the tasks. The size of these work packages provides a realistic gauge of progress without placing too great a burden on the project manager. Appropriate task sizes allow the project manager to compare, at any time, actual progress against planned progress and actual costs against budget and to obtain a clear overview of the status of the entire project without excessive bookkeeping.

Foster Wheeler has chosen a project review board to provide design consultation and to ensure that the project objectives are met. The members of this board are senior technical people drawn from the Foster Wheeler family of affiliates. The board will function independently of the project manager and will meet regularly to review the progress of the work and recommend any corrective action required. The corrective action will be initiated and implemented by the project manager, with the results reported to Foster Wheeler management. This will ensure that the full resources of our team will be applied to the successful completion of the project.

Technical progress within each task will be monitored by the project manager and the task leaders through frequent formal and informal design and performance reviews with Foster Wheeler and subcontractor project personnel. Deviations from the plan will be evaluated and corrective action taken.

The project manager will work closely with Sandia's program manager to ensure a clear transmission of key analytical data, basic design data, and program control documents. This close working relationship will provide for quick and efficient resolution of any problems and will permit constant monitoring of project performance.

SECTION 4

SUPPORTING DATA

Section 4

SUPPORTING DATA

4.1 ORGANIZATION

Foster Wheeler Solar Development Corporation (FWSDC), recognizing the need for competence as well as suitability to the proposed project, has assembled a team of highly qualified and knowledgeable individuals capable of meeting the Phase 2 objectives of this project. Through the combined efforts of our affiliated companies--Foster Wheeler Energy Corporation (FWEC), Foster Wheeler Special Projects Engineering and Construction, Inc. (FWSPEC), and FW Energy Applications, Inc. (FWEA)--a design of a molten salt steam generating subsystem pilot plant for the Central Receiver Test Facility (CRTF) will be prepared and fabrication will be completed to ensure proper interfacing with the existing system. Subsystem testing will resolve all critical uncertainties associated with full-system scale-up.

FWSDC, the proposed prime contractor, is a separate operating entity within Foster Wheeler Development Corporation (FWDC)--the research and development arm of the parent holding company, Foster Wheeler Corporation. FWDC fills virtually all of the research and development needs of Foster Wheeler's operating divisions and domestic affiliates, conducts research and development, and provides project management and administrative services for other companies and Government agencies. Foster Wheeler is a world leader in the design, fabrication, and erection of pressure vessels, boilers, and steam generators for nuclear and nonnuclear power plants; of process plants for the chemical industry; and of refineries for the petroleum industry. The position of FWSDC and the other Foster Wheeler affiliated companies in the overall corporate organization is shown in Figure 4.1.

FWSDC will have overall responsibility for the steam generator subsystem design, fabrication, and testing. A task-oriented project team (Figure 4.2) will be established to control all activities. During Phase 2 of the project, that team will consist of a project manager, who will coordinate and direct the total project; a project administrator, who will be responsible for cost, schedule, contract compliance, and performance status; and functional task leaders. The project manager will be given full authority and all the necessary resources to successfully perform the workscope and coordinate all project activities.

Working through a line organization, the project manager will control the activities of the other Foster Wheeler affiliated companies to ensure a coordinated effort. A project review board will provide consultation and review the work to ensure the successful completion of the project in a timely and efficient manner.

The resumes of key personnel follow Figure 4.2.

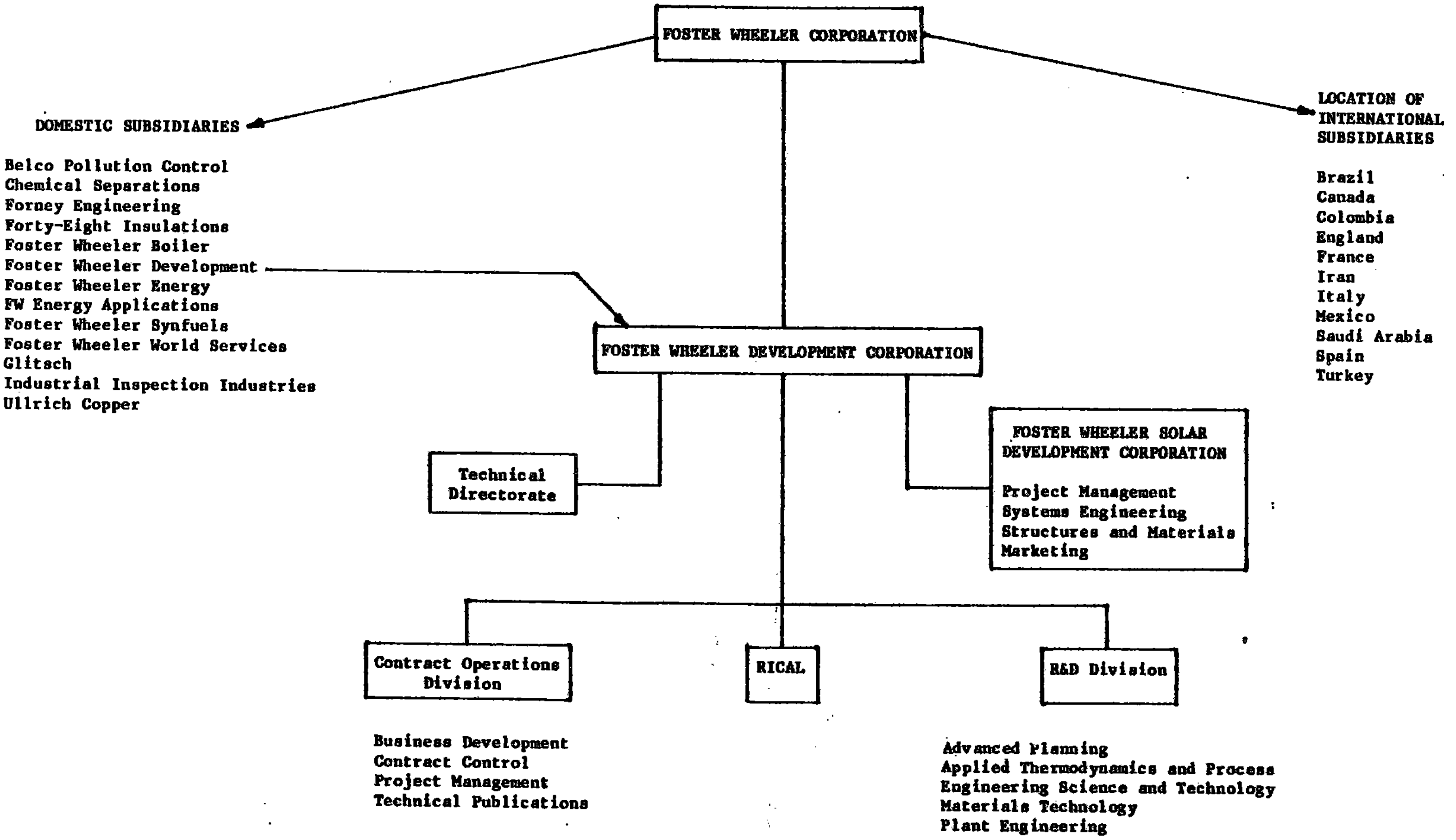


Figure 4.1 Corporate Organization Chart

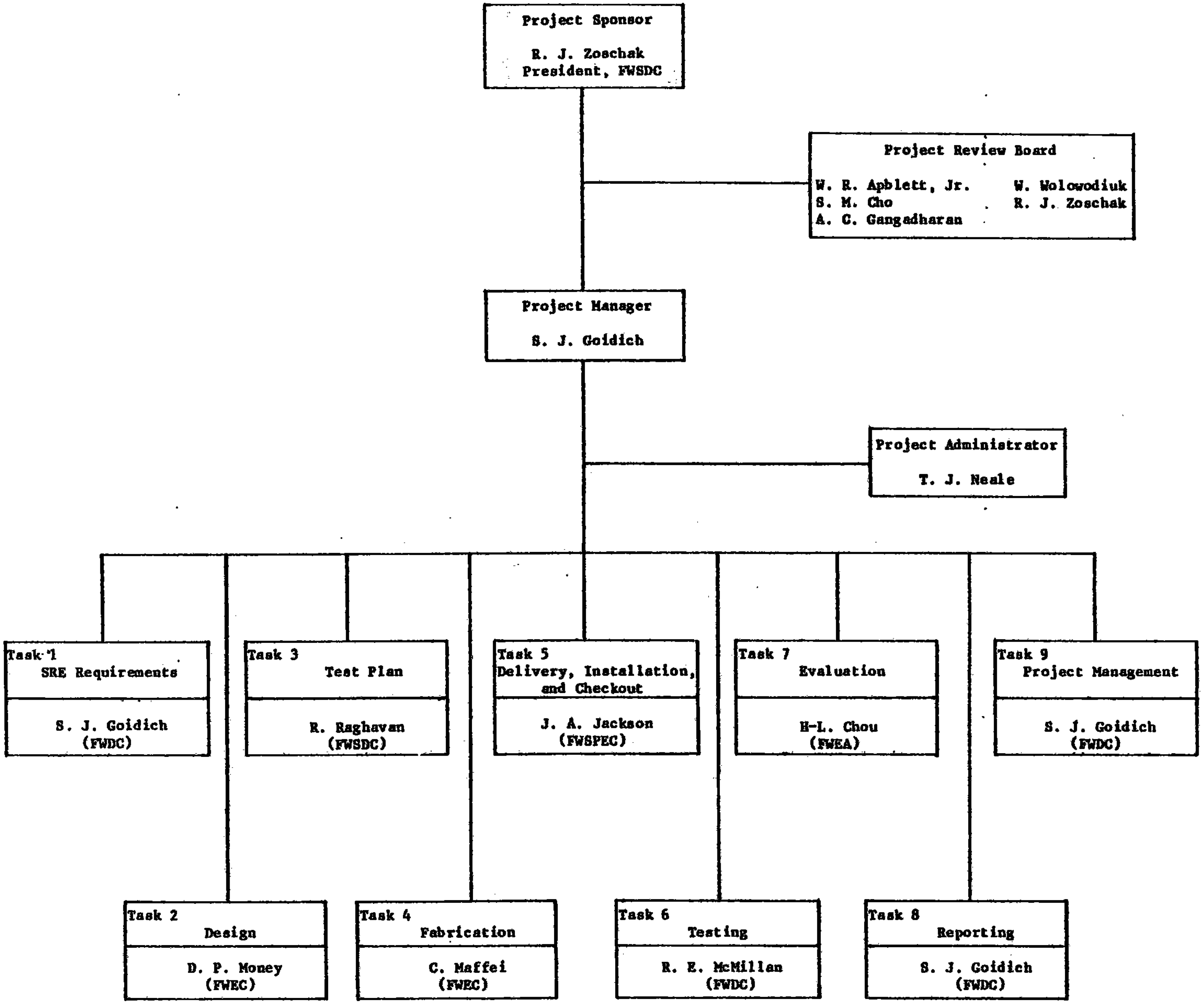


Figure 4.2 Project Organization

Robert J. Zoschak

President, Foster Wheeler Solar Development Corporation

Technical Director, Applied Thermodynamics Research
Foster Wheeler Development Corporation

Education

B.S. in M.E.	New Jersey Institute of Technology (formerly Newark College of Engineering) - 1948
M.S. in M.E.	Stevens Institute of Technology - 1958

Experience

1977 -	Responsible for directing Foster Wheeler activities in solar energy, other renewable energy fields, and conservation.
1976 -	Technical Director, Applied Thermodynamics Research. Responsible for technical direction on all corporate projects involving heat transfer, fluid flow, and combustion. Provides engineering consultation to various subsidiary companies and affiliates of Foster Wheeler Corporation.
1964 - 1976	Manager, Applied Thermodynamics Department, Research Division. Supervised research and development work in heat transfer, fluid flow, and combustion, covering such specific areas as experimental heat-transfer and fluid-flow investigations, air-pollution control methods and processes, fluidized bed combustion, gasification, corrosion and deposits from combustion gases, flow model studies, conceptual design of steam generators and heat exchangers for gas-cooled reactor and liquid-metal fast-breeder reactor plants and central receiver solar thermal power systems. Served as Program Manager on Receiver Subsystem for Central Receiver Solar Thermal Power System, Phase I.
1960 - 1964	Senior Research Engineer, Research Division. Responsibilities substantially the same as above.
1952 - 1960	Development Engineer, Research Division. Engaged in work related to steam generation: design of test rig for studies of oil ash corrosion and deposits in supercharged steam generators, functional design of naval supercharged steam generator for 20,000 shp, conceptual design of supercharged steam generators for utility application and of other advanced power cycle components and special heat-transfer apparatus, and experimental heat-transfer investigations related to steam generator design.

Robert J. Zoschak (Cont)

1948 - 1952 Field Service Engineer, Equipment Division. Supervised initial operation of large coal-, oil- and gas-fired central station steam-generating units and special tests and investigations.

Other

Published ten papers on design of steam generators, fluidized bed combustion and gasification, and solar thermal power plants. Holds eight patents. Member, ASME; serves on the ASME Task Force on Energy Conversion Research. Tau Beta Pi Association.

Stephen J. Goidich
Senior Engineer
Applied Thermodynamics and Process Department
Foster Wheeler Development Corporation

Education

B.S.	Mechanical Engineering, Rutgers University - 1972
M.E.	Mechanical Engineering, Rensselaer Polytechnic Institute - 1974

Experience

1980 -	Responsible for thermal hydraulic circuitry calculations for atmospheric fluid bed (AFB) steam generator proposals. Designed, supervised construction of, and tested a 2 ft 6 in. x 5 ft 0 in. cold flow model of the Georgetown AFB steam generator. Responsible for conducting experimental and analytical studies relative to the thermal and hydraulic aspects of power generating systems. Program manager for rifled tube friction factor tests, and the conceptual design of a molten salt solar receiver, steam generator, and thermal storage system for utility application.
1974 - 1979	Foster Wheeler Energy Corporation. Design/Performance Engineer, Equipment Division. Project engineer for the conceptual design of a 570-MW once-through AFB utility steam generator. Developed a damper design for wide range flow control of the Rivesville AFB steam generator. Performed engineering studies on proposed modifications to existing steam generators and auxiliary equipment, as well as special studies requiring thermal and hydraulic analyses.
1972 - 1973	Naval Air Engineering Center. Technical Writer, Weapons Division. Prepared technical manuals for handling, storing, and loading air-launched weapons aboard aircraft carriers.

Other

Associate Member, ASME. Licensed Professional Engineer, New Jersey. Holds one patent.

Ramjee Raghavan
Head, System Engineering Section
Engineering Science and Technology Department
Foster Wheeler Development Corporation

Education

B.S.	Jadavpur University - 1964
M.S.	Structural Engineering, Indian Institute of Technology - 1967
Ph.D.	Virginia Polytechnic Institute and State University - 1973

Experience

1980 -	Current projects include (1) dynamic simulation of a pulverized coal-fired utility boiler and (2) effect of coal quality on boiler capital and operating cost. Completed projects include (1) project management and system evaluation of refuse as fuel for Minnesota Environment Quality Board, (2) development of a real-time performance analysis system for Dow Chemical Solar Industrial process heat plant, and (3) project management of the Solar Thermal Retrofit System for Provident Energy Company's Fuel Refinery and the design. Also responsible for technical proposals, negotiations, and project management.
1973 - 1980	Head, Computer Instrumentation and Control Section, Engineering Science and Technology Department. Responsible for the evaluation and development of major computer programs and computerized design procedures and the creation and maintenance of a user-oriented documented library of structural computer codes for Corporate use. Completed projects include (1) design and operation of the real-time performance analysis and data-logging system for the Chemically Active Fluid Bed (CAFB) project and (2) real-time flow and vibration analysis for the Clinch River Breeder Reactor Intermediate Heat Exchanger Test Program.
1970 - 1973	Virginia Polytechnic Institute and State University. Graduate Research Assistant and Instructor, Engineering Science and Mechanics Department. Work involved analysis of moving loads on beams, plates, and shells.
1968 - 1970	Tata Ebasco, Consulting Engineers, Bombay. Senior Engineer. Involved in the computer-aided design of complex steel frames for industrial and power-plant structures; the design of flare stacks, catenary bins, pressure vessel structures, and pipe racks; the planning and layout of the material-handling system for a large fertilizer complex; and maintaining liaison with pressure vessel vendors and steel fabricators.

Ramjee Raghavan (Cont)

1967 - 1968	R. S. Steel Work, Barielly. Engineer. Involved in the design of 88-, 110-, and 220-kV transmission towers for various state electricity boards and the design of microwave towers up to 100 m for the Post and Telegraph Department. Work involved sales promotion and tender preparations.
1965 - 1967	Indian Institute of Technology. Research Associate.
1964 - 1965	Imperial Chemical Industries, Calcutta. Engineer Trainee. Involved in the design of concrete buildings for an explosive factory. Supervised the construction of a rubber chemical plant Phase 2 extension.

Other

Coauthor of 10 publications. Member, Sigma Xi, Society of Engineering Science, ASME (member, Executive Committee of ASME Computer Division; Chairman, Computer System Hardware/Software Committee of Computer Division; Committee on Computer Technology of Pressure Vessel and Piping Division; and member, Working Group on Axisymmetrical Shells of Boiler and Pressure Vessel Code). Reviewer, Applied Mechanics Reviews. Associate Editor, Journal of Pressure Vessel Technology and Computer Engineering Journal.

Joseph A. Jackson
Project Manager
Foster Wheeler Energy Corporation

Education

Polytechnic Institute of Brooklyn - Undergraduate studies in Chemical Engineering

Experience

1980 -	Completely responsible for all phases of contract execution, including engineering, detailed design, project control, procurement, and construction of Process Plants projects. Directs all management activities for the successful on-time and on-budget completion of the project. Specifically involved in the management of a solar thermal enhanced oil recovery project for Exxon Corporation (Phase 1).
1974 - 1980	Project Manager/Project Engineer. Responsible for the performance of all project and specialty engineering and design drafting activities on assigned projects, proposals, and studies. This includes the development of plot plans, equipment lists, engineering flow diagrams, and job specifications and requisitions for equipment, material, and subcontracts. Worked on the following projects/proposals: • Solar project for Dow Chemical Company (Phases 2 and 3) • Project coordinator for flexicracking and light ends project for Exxon Corporation • Project coordination for solar energy production of industrial process steam for Dow Chemical Company/DOE and the Provident Energy Company (Phase 1) • Engineering manager for LNG-3 plant for Sonatrach in Algeria • Plant facilities other than process for COALCON project for Union Carbide Corporation liquefaction plant • Process plants for various ammonia, methanol, and nitric acid plants • Proposal manager for LNG plant for IMPRESA in Chile.
1972 - 1974	Marketing Representative. Items included equipment sales vessels, structural steel, flare gas systems, SNG and refinery, sound-suppression systems, and expansion joints.

Joseph A. Jackson (Cont)

1967 - 1972	Account Manager, Sales Department. Responsible for business in Mexico and Canada as well as specialized clients in the United States. Reported to the Vice President of Sales.
1967	Manager, Paris office. Responsible for staffing, policy, and procedures, including plant start-up, as well as for sales to Eastern European countries utilizing French financing.
1966	Sales Engineer, London office. Handled sales associated with French financing.
1954 - 1966	Project Engineer. Worked on the following projects: • Pure hydrogen plant for Bocuze in France • Ammonia plant for Pemex of Mexico • Fertilizer project involving nitric acid, ammonium nitrate, and nitrochalk for Carolina Nitrogen Company • Hydrogen project for Linde Division of Union Carbide Corporation liquid hydrogen plant for NASA in Los Angeles • Ammonia plant expansion for Valley Nitrogen Company in southern California • Methanol plant for British Hydrocarbon Ltd. in Scotland • Front-end of 300-lb/in^{2}g ammonia plant involving reforming acetylene off-gas and natural gas for Aquitainechimie in France • Monomethylstyrene plant for American Cyanimid Company, Fortier, Louisiana • Nitric acid plant for CIL at Beloeil, Canada • Ammonia plant for Escambia Bay Chemical Corporation, Milton, Florida • Ammonia plant for Mississippi Chemical Corporation.
1953 - 1954	Research Engineer. Involved in metals recovery (cobalt, nickel, and copper) pilot plant at Linden, New Jersey.

Hsi-Lou Chou, P.E.
Senior Thermal/Hydraulic Engineer
FW Energy Applications, Inc.

Education

B.S. in M.E.	National Taiwan University - 1968
M.S. in M.E.	Stevens Institute of Technology - 1971
M.B.A.	Fairleigh Dickinson University - 1981

Experience

1981 -	Designed central solar receivers and system simulation for Texas Tech University. Prepared circulation calculations and stability study for Ashland waste heat boiler. Performed a Conceptual Design Study of the Intermediate Heat Exchanger for Clinch River. Performed design analyses of intermediate heat exchangers, reformers, and direct-contact evaporators/condensers for High-Temperature Gas Reactor process heat applications and of heat-exchange equipment for Sandia's Molten Salt Steam Generator Subsystem.
1974 - 1981	Foster Wheeler Energy Corporation. Senior Thermal/Hydraulic Engineer, Thermal/Hydraulic Task Leader. Designed steam supply system for soybean processing plant of Farmland Industries, including reboiler, drain tank, desuperheater, piping, and all other control devices. Designed supercritical, once-through steam generator start-up system and desuperheater for Molten Salt Breeder Reactor Plant. Responsible for the designs of the intermediate heat exchanger, reactor auxiliary cooling system, and steam generator for the commercial-size Liquid Metal Fast Breeder Reactor (LMFBR) plants. Designed central solar receivers for McDonnell Douglas and for Spanish solar programs. Designed thermal accumulator for Guilford Mills. Resident Engineer at Argonne National Laboratories to develop flow-distribution analysis code (COMMIX-IHX). Designed pool-type intermediate heat exchangers for LMFBR.
1973 - 1974	Public Service Electric & Gas Company. Power System Engineer. Performed thermal cycle analyses and developed computer programs in FORTRAN and BASIC language that simulate the thermal performance of nuclear and fossil power plant systems. Programs included performance calculations of steam turbines, condenser, feedwater heaters, steam generator (boiler), heat rate, and electrical output.

Hsi-Lou Chou, P.E. (Cont)

1970 - 1973 St. Mary's High School, Rutherford, New Jersey. Teacher of physics, chemistry, and physical science.

Other

Licensed Professional Engineer, New Jersey. Associate Member, ASME. Co-author of paper presented at Joint Power Generation Conference.

Dudley P. Money, P.E.
Manager, Condenser Projects
Contract Design Department
Foster Wheeler Energy Corporation

Education

Graduate of Institution of Mechanical Engineers, London - 1962

Experience

1978 -	Responsible for engineering, design, and drafting activities of stress analysis, computer applications, condenser, and feedwater heater groups.
1970 - 1978	Supervisor, Stress Analysis Group, Contract Design Department. Responsible for stress analysis of critical components of major steam generators, feedwater heaters, and condensers.
1966 - 1970	Senior Designer, Stress Analysis, Marine Boiler, and Vessel Groups. Responsible for designing marine boilers, process plants towers, vessels, and heat exchangers to ASME and TEMA codes including analysis of wind and seismic loadings. In stress analysis group responsible for analysis of major piping systems for thermal and dead-weight loadings, analysis of locally highly stressed components for thermal, weight, and pressure loadings using internal computer codes and external programs such as STRUDL, ANSYS, and NASTRAN.
1965 - 1966	M. W. Kellogg Corporation, New York. Vessel Designer. Responsible for mechanical design of process plants towers, tanks, and vessels to ASME codes and customer specifications. Work included design of high-pressure ammonia synthesis equipment.
1962 - 1965	E. I. Du Pont de Nemours, Dordrecht, Holland. Engineer, Field Purchasing Office. Responsible for engineering review of quotations for pumps, vessels, towers, and other mechanical equipment associated with artificial fibers plant. Conducted inspections of vendor's plant and engineering review of vendor's drawings.
1959 - 1962	Air Products, Incorporated, London. Group Leader, Vessel Group. Responsible for design of towers, heat exchangers, and regenerators for use in cryogenic air-separation equipment. Project Engineer, Project Group. Responsible for customer liaison and overall budget and progress control of high-tonnage liquid-oxygen installations.

Other

Licensed Professional Engineer, New Jersey.

Charles Maffei, P.E.
Manufacturing Engineer
Manufacturing Engineering Department, Equipment Division
Foster Wheeler Energy Corporation

Education

BSME	New Jersey Institute of Technology (formerly Newark College of Engineering) - 1947
Post Graduate	Metallurgy, Stevens Institute of Technology - 1952 through 1955.

Experience

1972 -	Responsible for nuclear and advanced technology power plant components, including primary sodium valves, heat exchangers, and others made to nuclear and commercial codes and standards. Reviews designs for manufacturing feasibility and ease; coordinates with Industrial Engineering, Quality Control, Production Engineering, Fabrication, and Laboratory concerning methods, tooling, and welding qualifications. Monitors compliance with projected manufacturing schedules, costs, and quality. Follows through on projects from proposal to delivery.
1967 - 1972	Supervisor of Mechanical/Structural Design. Involved with condenser products, including condensers, feedwater heaters, steam jet air ejectors, heat exchangers, pumps, and evaporators. Translated customer order and specification data into design calculations, fabrication drawings, bills of materials, and design specifications and procedures. Responsible for meeting schedule and budgeted costs.
1965 - 1967	Senior Designer/Group Leader. Responsible for design layout, detail drawings, checking, material requisitioning, and release to manufacture for condensate/circulating pump ejectors, heater exchanger.
1962 - 1965	Quality Control Engineer and Supervisor of Inspection. Involved with commercial power plant heat-exchanger products and pumps, nuclear submarine heat exchangers, and steam generators (Navship 200-1500). Responsible for planning quality control inspections and procedures for products and projects. Supervised plant inspectors to ensure compliance with preplanned acceptance criteria and coordinated with engineering functions and cognizant inspection agencies.

Charles Maffei, P.E. (Cont)

1960 - 1962	Methods Engineer. Investigated product design, equipment, fixtures, and methods concerning layout, machining, welding/allied processes, assembly, and finishing for possible cost reduction and improved quality, Made cost analyses; recommended and followed through on improvements.
1954 - 1960	L. O. Koven, Inc. Assistant Plant Superintendent. Involved in manufacturing, methods, production, plant and quality control engineering. Work encompassed plant layout, tool and fixture design and estimating, design calculations, process, methods, and quality control procedures. Consulted with management on metallurgical problems in fabrication. Conducted welding procedure qualifications. Worked with all shops and purchasing on trouble shooting and cost reduction. Shop processes involved layout, forming, stamping, welding/ allied processes, assembly, machining, heat treating, galvanizing, pickling, stone-lining, finishing, and painting. Responsible for development of stone-lining facility from engineering concept to full-scale production. Set up production schedules on special projects. Worked with product design on improvements.
1951 - 1954	Project Engineer. Coordinated engineering and manufacturing of fabrication project involving design, Government specifications, materials, tools and fixtures, process and quality requirement, schedules, and cost consideration for changes. Worked with plant functions, customers, vendors, and inspection agencies. Monitored costs and prepared data for termination of contract procedures.
1947 - 1951	S. Blickman, Inc. Engineer. Performed design engineering for fabricated products. Involved with calculations, material specifications, design layout, and field measurements. Worked with fabrication shops on job requirements.
1943 - 1944	Draftsman and Expediter. Made detail drawings and expedited material and production.

Other

Member, Tau Beta Pi Honorary society, ASME, Licensed Professional Engineer, New Jersey.

Richard E. McMillan

Senior Engineer, Applied Thermodynamics and Process Department
Foster Wheeler Development Corporation

Education

B.S.M.E.	University of Wisconsin - 1971

Experience

1977 -	Project Engineer responsible for on-site testing and multimedia assessment of the Chemically Active Fluid Bed (CAFB) demonstration plant. Responsible for the environmental assessment and various design aspects of the CAFB process.
1971 - 1977	Development Engineer, Applied Thermodynamics and Process Department, Research Division. Involved in air-pollution research. Supervised numerous field tests investigating nitrogen oxide, sulfur dioxide, carbon monoxide, and hydrocarbon emissions from stationary sources firing various fuels (including coal, oil, natural gas, and refinery pitch). Responsible for pollutant-emission analysis during a feasibility study for methyl fuel as a steam generator fuel. Participated in an EPA compliance test for a new stationary source and was responsible for particulate testing and analysis during these tests. Conducted tests to determine particulate emissions as a function of operation for a stoker-fired steam generator. Responsible for (1) particulate testing activities of the Research Division; (2) part of field trials and equipment operation of dry-injection process for SO_2 removal from combustion gases in large utility steam generators; and (3) part of field testing, system design, material procurement, and test program schedule of package boiler combustion modifications using flue-gas recirculation and staged firing for reducing nitric oxide emissions from combustion of natural gas, oil, and methyl fuels.
1971	Development Engineer, Research Division. Assistant to the Project Manager for Foster Wheeler's participation in the Fast Flux Test Facility Fast Breeder Reactor project. Responsibilities included attending all meetings and writing minutes of these meetings, assembling and distributing all progress reports connected with the project, and tabulating progress and requisitioning materials connected with various projects.

Richard E. McMillan (Cont)

1969	Engineering Aide, Research Division. Duties included drafting work, data reduction, and testing of a fluid flow model. Participated in early field trials of dry-injection process for SO_2 removal from combustion gases.

Other

Coauthor of two ASME papers on air pollution and three papers on the design and emission characteristics of the CAFB gasification process.

William R. Apblett, Jr.

Senior Vice President, Foster Wheeler Development Corporation

Technical Director, Materials Research Foster Wheeler Development Corporation

Chief Metallurgist, Foster Wheeler Energy Corporation

Education

B.S.	Metallurgical Engineering, University of Illinois - 1948

Experience

1976 -	Responsible for the technical direction of all research and development concerned with materials application, the development of working relations with FWEC divisions and FWC subsidiary companies to ensure that laboratory activity meets design needs, the establishment of guidelines for the initiation of Corporation-sponsored R&D programs on materials and processes, the solicitation of contracted R&D programs from Government agencies and industry, and the enhancement of technical capabilities required to meet the Corporation's present and future needs. As Chief Metallurgist of FWEC, responsible for the selection of materials to meet service requirements of temperature, stress, and corrosive environment, including evaluation and recommendations covering materials and processes used by foreign affiliates.
1955 - 1976	Manager, Materials Engineering Department, Research Division; Chief Metallurgist, Foster Wheeler Energy Corporation. Responsible for detailed planning and direction of all R&D work in materials engineering. Materials Engineering Department services all divisions of Corporation in the selection of materials to meet service requirements of temperature, stress, and corrosion environments and in the analyses of component failures involved in steam generators, process plant equipment, and fired heaters. Department personnel are assigned to operating divisions as needed.
1954 - 1955	Manager, Welding Development Laboratory, Research Division. Responsible for development of welding processes and procedures used in fabrication of steam generators and associated equipment. Responsible for the development of advanced tube-to-tube sheet welding techniques for use in nuclear steam generators and commercial heat exchangers.

William R. Apblett, Jr. (Cont)

1948 - 1954	Naval Research Laboratory. Head, Welding Section. Responsible for detailed planning and direction of all projects. Research broadly directed toward improvement of weldments in ferrous and nonferrous metals for application under severe conditions.
1944 - 1948	Naval Research Laboratory. Welding Metallurgist. Engaged in conducting research projects on welding of aluminum alloys for naval applications and stainless steel hot-cracking investigations. Developed unique techniques for weld heat-affected zone transformation studies.

Other

Author of 23 papers on welding, forming, fabrication, and selection of materials. Holds six patents. Member, American Welding Society, American Society of Metals, American Society for Testing and Materials, National Association of Corrosion Engineers (NACE). Chairman, Fabrication Division of PVRC and member of several committees of Welding Research Council. Member, Technical Advisory Committee, Metals Properties Council. Accredited Corrosion Specialist, NACE.

Soung M. Cho, P.E.
Deputy Director of Engineering
FW Energy Applications, Inc.

Education

B.S.M.E.	Seoul National University - 1960
M.S.M.E.	University of California, Berkeley - 1964
Ph.D.M.E.	University of California, Berkeley - 1967

Additional courses in Sodium Technology; Supervisory Management; ASME Boiler and Pressure Vessel Code, Section III and Code Cases 1592 to 1596; Hydraulic and Pneumatic Transport in Pipes; and Engineering Management.

Experience

1981 -	Deputy Director of Engineering.
1973 - 1980	Manager, Thermal/Hydraulic Engineering Section, Engineering Technology Department, Nuclear and Advanced Technology Operations, Equipment Division. Responsible for all of the following thermal/hydraulic analyses: GENERIC and contractual, thermal/hydraulic computer program development, and Thermal/Hydraulic and Nuclear Standards development. Components engineered include Fast Flux Test Facility Intermediate Heat Exchanger (FFTF IHX), Clinch River Breeder Reactor Plant (CRBRP) IHX, commercial Liquid Metal Fast Breeder Reactor (LMFBR) IHX, FFTF Closed-Loop System IHX and Pressure Surge Tank, FFTF check valves, CRBRP check valves, BWR/PWR-Moisture separators/reheaters, High-Temperature Gas Reactor (HTGR) steam generators, LMFBR steam generators, MSBR steam generators, shale oil plant ball heaters, flash tanks, Combined-Cycle Coal Gasification Plant System Analysis, commercial LMFBR Plant Cold Leg Check Valve (CLCV), commercial LMFBR (PLBR) steam generators, commercial LMFBR IHX, hydrogen storage systems, flow distribution analysis, steam drums, PWR steam generators, ocean thermal energy conversion heat exchangers, critical heat flux-induced thermal oscillation analysis, LMFBR pumps, reboilers, and solar boilers.
1969 - 1973	Liquid Metal Engineering Center (Division of Atomics International). Staff Consultant, Member of Technical Staff, Lead Engineer in Thermal/Hydraulic Engineering. Involved in the test and evaluation of a 30-MWt prototype sodium-to-sodium IHX and a 30-MWt prototype sodium-heated steam generator for the LMFBR Program. Participated in the FFTF Components Development Program. Performed thermal/hydraulic steady-state and transient system analyses for various test loops in the Center, as well as freeze-seal analyses. Conducted a steam generator boiling-flow instability study. Performed valve and orifice cavitation tests and evaluations.

Soung M. Cho, P.E. (Cont)

1967 - 1969	Garrett Corporation, AirResearch Division. Engineering Specialist, Preliminary Design Group/Advanced Propulsion Systems. Responsible for thermal aspect of the Hypersonic Research Engine Development Program (NASA project for the X-15 aircraft). Developed high-temperature instrumentation probes. Performed ablation heat transfer, hypersonic/supersonic flow analyses, shock interaction analyses, high-speed flow heat transfer, combustion chamber cooling, fuel-system analyses, and ground-engine performance tests. Developed various thermal-analysis computer codes.
1964 - 1967	University of California, Berkeley. Specialist. Worked on the Reactor Heat Transients Project (USAEC), in which transient boiling phenomena were studied both analytically and experimentally. Responsible for data reduction.
1962 - 1964	University of California, Berkeley. Research Assistant. Worked on various fluid-mechanics projects, including two-phase flow.
1960 - 1962	Atomic Energy Research Institute, Korean Atomic Energy Commission. Researcher, Reactor Division. Performed heat-transfer/fluid-flow studies for the first Korean experimental reactor (TRIGAR-MARK II).

Other

Author or coauthor of 25 papers. Member, ASME (member and Secretary, Nuclear Heat Exchanger Committee; and member, Nucleonics Heat Transfer Committee), American Nuclear Society, American Association for the Advancement of Science, National Society of Professional Engineers.

A. C. Gangadharan
Vice President, Engineering
Foster Wheeler Solar Development Corporation

Education

B.E.	Madras University, India - 1959
M.S.	Northwestern University - 1966
Ph.D.	Northwestern University - 1968

Experience

1980 -	Responsible for planning and execution of projects in solar energy, energy conservation, energy storage, and other renewable energy resources.
1976 - 1980	Manager, Engineering Science and Technology Department. Managed Corporate R&D programs in structural mechanics, reliability and safety, computer technology, mathematical modeling and systems analysis, and other advanced engineering disciplines. Program Manager of a project "Interim Structural Design Standard for Solar Energy Applications," funded by Sandia Laboratories. Supervised projects on solar thermal enhanced oil recovery, solar industrial process heat solar retrofit of an oil refinery.
1974 - 1976	Head, Analysis Section, Solid Mechanics Department, Research Division. Managed R&D projects in basic studies of plasticity, creep and fatigue, shell theory, structural reliability, and other solid-mechanics problems.
1973 - 1974	Head, Analysis Section, Solid Mechanics Department, Research Division. As Task Leader of the High-Temperature Gas-Cooled Reactor (HTGR) Methods Development Task, supervised engineers in experimental projects. Visiting Lecturer, Mechanical Engineering Department, Stevens Institute of Technology.
1971 - 1973	Head, Analysis Section, Solid Mechanics Department, Research Division. As Task Leader of the Fast Flux Test Facility-Intermediate Heat Exchanger (IHX), Inelastic Analysis, supervised engineers in analysis of IHX components. Performed basic studies in elastic-plastic-creep deformation of structures.
1969 - 1971	Development Engineer, Research Division. Developed elastic program for asymmetric loads.
1965 - 1969	Northwestern University. Civil Engineering Department. Research in engineering mechanics.

A. C. Gangadharan (Cont)

1961 - 1965	Indian Institute of Technology, Madras, India. Lecturer.
1959 - 1961	Government College of Technology, Coimbatore, India. Assistant Lecturer.

Other

Coauthor of 14 publications and 10 reports. Edited two symposium volumes on reliability and failure analysis. Member of the following ASME Committees: Computer Technology Committee, Policy Board Communications; Subcommittee on Constitutive Equations, Materials Division; Design and Analysis Committee, PVP Division; Working Group on Creep Analysis, Boiler and Pressure Vessel Code Committee. Vice Chairman, Research Committee on Reliability, Maintainability, and Failure Analysis.

Walter Wolowodiuk, P.E.
Vice President, Research and Development Division
Foster Wheeler Development Corporation

Education

B.S. (M.E.)	New Jersey Institute of Technology (formerly Newark College of Engineering) - 1953
M.S. (M.E.)	New York University - 1960

Experience

1980 -	Overall responsibility for research and development activities.
1976 - 1980	Manager, Applied Thermodynamics and Process Department. Supervised R&D work in the fields of combustion and fuel technology, thermal/hydraulic analysis and design, solar energy, and process development.
1973 - 1976	Chief Project Manager, Nuclear Components Section, Nuclear Department, Equipment Division. Overall responsibility for all Nuclear Components contracts.
1970 - 1973	Senior Research Associate, Research Division. Served as Project Manager with overall responsibility for the design, testing, and fabrication of the Intermediate Heat Exchangers for DOE's Fast Flux Test Facility (FFTF).
1965 - 1970	Research Associate, Applied Thermodynamics Department, Research Division. Responsible for independently planning and implementing analytical and experimental programs in the fields of heat transfer, fluid flow, and combustion, including conceptual design studies of advanced types of heat-exchanger equipment. Supervised design studies of helium-heated reheat steam generator for a 330-MW gas-cooled reactor plant. Project Manager for Liquid-Metal Fast Breeder Reactor (LMFBR) Intermediate Heat Exchanger (IHX) Research and Development, Program Definition Phase. Supervised conceptual design and experimental work on ESADA project sodium-heated steam generator. Project Manager for LMFBR Low Capacity IHX Conceptual Design Studies Supporting FFTF Development.
1955 - 1965	Senior Engineer, Research Division. Involved in conceptual designs of steam generators for breeder, gas-cooled, and light-water reactor power plants; design studies of supercharged boilers for naval and utility application; and design of a thermal cycling test facility for a 1/4-scale nuclear reactor vessel. Project Engineer on a number of experimental investigations involving convection and condensing heat-transfer and flow-model studies.

Walter Wolowodiuk, P.E. (Cont)

1953 - 1955	Curtiss Wright Corporation. Test Engineer. Performed experimental work connected with jet engine and engine components.

Other

Licensed Professional Engineer, New Jersey. Member, ASME. Holds 11 U.S. Patents. Author or coauthor of five technical papers. Part-time instructor at The City University of New York, Heat Transfer (1966-1968) and New Jersey Institute of Technology, Mechanical Engineering Laboratory (1965-1966).

Thomas J. Neale
Project Administrator
Contract Operations Division
Foster Wheeler Development Corporation

Education

AAS	Public Administration, County College of Morris - 1978
BBA	Management, Pan American University - 1980

Experience

1981 -

Responsible for negotiation and administration of Government and commercial contracts. Resolves numerous problems relating to contract administration, contract performance, and interpretation of contract documents. Responsible for review and coordination of corporate efforts relating to proposal preparation, including review of terms and conditions and preparation of quotations. Develops schedules, reviews costs, and monitors progress on contracts.

1978 - 1981

Emissions Monitoring Technician for the field operation of a 17-MW "Chemically Active Fluid Bed" demonstration unit in San Benito, Texas. Responsibilities for this project included:

- Coordination of computer/instrumentation interfacing for data acquisition system
- Wet chemistry and instrumentation analysis of process off-gases and solids sampling studies
- Particulate analysis and data reduction for monthly technical progress narratives and the Texas Air Control Board
- Mechanical inspection with debugging of all coal and limestone handling equipment
- Velocity traverses and boiler performance data incorporated into the CAFB operating parameters
- System modifications resulting from engineering design changes or equipment failure--welding and machining
- Detailed drawings and technical illustrations as required for reports.

1976 - 1978

Draftsman/Technical Illustrator for the Research Division of Foster Wheeler Energy Corporation. Responsibilities included design of various pilot plants and testing apparatus for chemical and energy R&D applications and drawing technical illustrations for R&D contract proposals and publications.

Thomas J. Neale (Cont)

1974 - 1976	Laboratory Mechanic for the Research Division of Foster Wheeler Energy Corporation. Primary responsibilities involved the layout, fabrication, and erection of hot and cold test models, with certification to weld.
1972 - 1974	Kenvil Newcrete Products, New Jersey. Foreman. Directly responsible for supervising skilled union labor during construction of prestressed and precast concrete products. Major projects included: New York Port Authority Bus Terminal, Newark International Airport, Garden State Parkway, New Jersey Turnpike, and Route 287.

Other

Holds two patents with one other pending. Member, Professional Business Association.

4.2 PROJECT PLAN

This section contains FWSDC's proposed Project Plan for Phase 2 of the Molten Salt Steam Generator Subsystem Research Experiment. For each of the nine tasks proposed, we have identified the responsible individual, the period of performance, the task end-product, travel required, subcontractors involved, and labor hours by classification/department for Foster Wheeler affiliated companies. At the end of this section, we have included summary charts showing direct labor hours by task for each participating company along with total labor hours by task and month (Tables 4.1 through 4.10).

If Sandia were to choose the Alternative SRE, this Project Plan would be substantially altered. Labor hours and costs would decrease significantly.

Task 1: SRE Requirements

Responsible Individual: S. Goidich will have ultimate responsibility, assisted by personnel from Foster Wheeler Special Projects Engineering and Construction, Inc., (FWSPEC) and FW Energy Applications, Inc. (FWEA).

Period of Performance: This task will be completed during Month 1.

End Product: Final SRE specification.

Travel: None required.

Subcontractors: FWSPEC, FWEA.

Labor Hours:

FWSDC/FWDC	
Technical Director	4
Senior Research Associate	4
Research Associate	4
Senior Engineer	80
Draftsman	8
Total	100

FWSPEC	
Engineering	15
Project Coordination	30
Total	45

FWEA	
Engineering Director	4
Senior Engineer	12
Total	16

Task 2: Design

Responsible Individual: FWSDC will have ultimate responsibility; however, D. P. Money of FWEC will take the lead. Support will be provided by FWSPEC and FWEA.

Period of Performance: The bulk of this effort will be completed during Months 1 through 7. Revisions anticipated will be made in Month 8.

End Product: Thermal/hydraulic analysis, mechanical design and detailing, civil and piping design, control, instrumentation, and data acquisition.

Travel: None required.

Subcontractors: FWEC, FWSPEC, FWEA.

Labor Hours:

FWSDC/FWDC	
Technical Director	40
Senior Research Associate	164
Research Associate	840
Senior Engineer	572
Development Engineer	1080
Total	2696

FWEC	
Design Supervisor	300
Design Leader	900
Senior Designer	1000
Designer	1300
Total	3500

FWSPEC	
Engineer	1360
Draftsman	2640
Total	4000

FWEA	
Engineering Director	80
Senior Engineer	240
Total	320

Task 3:	Test Plan
Responsible Individual:	R. Raghavan will have ultimate responsibility, assisted by personnel from FWEA.
Period of Performance:	The bulk of this effort will be completed during Months 1 and 2. Revisions anticipated will be made in Month 17.
End Product:	Safety procedures, detailed procedures for testing, schedule, analysis procedures, analytical prediction of test results, O&M procedures for the test unit, and test support requirements.
Travel:	None required.
Subcontractors:	FWEA.

Labor Hours:

FWSDC/FWDC	
Senior Research Associate	160
Research Associate	440
Senior Engineer	80
Total	680

FWEA	
Engineering Director	20
Senior Engineer	88
Total	108

Task 4: Fabrication

Responsible Individual: C. Maffei of FWEC will have primary responsibility; FWSDC will have ultimate responsibility.

Period of Performance: This task will be completed during Months 3 through 13.

End Product: Fabrication plan, SRE heat exchanger fabrication, steam drum fabrication, steam generator assembly, manufacturing and inspection plan, schedule, and procurement of materials.

Travel: Required.

Subcontractors: FWEC.

Labor Hours:

FWSDC/FWDC	
Research Associate	32
Senior Engineer	432
Project Administrator	16
Total	480

FWEC	
Manufacturing/Engineering	500
Estimator	400
Weld Development Engineer	50
Shop Labor	3400
Technical Direct	325
Total	4675

Task 5:	Delivery, Installation, and Checkout
Responsible Individual:	J. A. Jackson of FWSPEC will have primary responsibility, FWSDC will have ultimate responsibility.
Period of Performance:	This task will be completed during Months 12 through 16.
End Product:	Excavation, foundations, structural work, piping, SRE erection and tie-in, hydrotesting, electrical and instrumentation connections, and insulation and painting.
Travel:	Required.
Subcontractors:	FWSPEC.

Labor Hours:

FWSDC/FWDC		FWSPEC	
Research Associate	160	Project Coordinator	800
Senior Engineer	160	Draftsman	330
Technician	120	Field Labor	4500
Total	440	Total	5630

Task 6: Testing

Responsible Individual: R. McMillan of FWDC will have ultimate responsibility.

Period of Performance: This task will be completed during Months 18 through 21.

End Product: Tests conducted according to the SNLL-approved plan developed in Task 3.

Travel: Required.

Subcontractors: None required.

Labor Hours:

FWSDC/FWDC

Technical Director	32
Senior Engineer	1360
Technician	960
Total	2352

Task 7: Evaluation

Responsible Individual: S. Goidich will have ultimate responsibility, assisted by personnel from FWEA.

Period of Performance: This task will be completed during Months 20 and 21.

End Product: Data reduction for evaluation (i.e., curves and tables) that will be used to verify the accuracy of dynamic modeling correlations and performance parameters.

Travel: None required.

Subcontractors: FWEA.

Labor Hours:

FWSDC/FWDC	
Senior Research Associate	80
Research Associate	320
Senior Engineer	320
Total	720

FWEA	
Engineering Director	28
Senior Engineer	184
Total	212

Task 8:	Reporting
Responsible Individual:	S. Goidich will have ultimate responsibility, assisted by personnel from FWEA.
Period of Performance:	This task effort will be continuous throughout the project.
End Product:	Monthly reports, final report, test plan, revisions to requirements specification and fabrication plans, and agendas for oral reviews.
Travel:	Required.
Subcontractors:	FWEA.

Labor Hours:

FWSDC/FWDC	
Senior Engineer	860
Project Administrator	280
Draftsman	360
Total	1500

FWEA	
Engineering Director	32
Senior Engineer	112
Total	144

Task 9: Project Management

Responsible Individual: S. Goidich will have ultimate responsibility for this task, assisted by personnel from Foster Wheeler affiliates.

Period of Performance: This effort will be continuous throughout the project.

End Product: Successful completion of work on time and within budget.

Travel: Required.

Subcontractors: FWSPEC, FWEC.

Labor Hours:

FWSDC/FWDC	
Technical Director	96
Senior Research Associate	150
Senior Engineer	960
Project Administrator	368
Total	1574

FWSPEC	
Project Coordinator	520
Total	520

FWEC	
Contract Control	80
Contract Administration	80
Total	160

Table 4.1 Summary--Labor Hours by Month

MONTHS

		1	2	3	4	5	6	7	8	9	10	11	12	TOTAL
		13	14	15	16	17	18	19	20	21	22	23	24	
TECHNICAL DIRECTOR	(H)	16	16	4	8	8	8	12	4	4	4	4	4	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	4	4	4	4	4	12	12	12	12	4	4	4	172
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
SR. RESEARCH ASSOC.	(H)	56	134	10	26	50	54	46	6	6	6	6	6	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	6	6	6	6	6	6	6	6	46	46	6	6	558
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
RESEARCH ASSOCIATE	(H)	124	400	160	200	176	176	80	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	80	80	0	0	0	160	160	0	0	1796
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
SENIOR ENGINEER	(H)	256	280	160	204	216	152	176	80	80	80	80	80	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	136	56	56	56	216	396	396	396	556	216	280	220	4824
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
DEVELOPMENT ENGINEER	(H)	0	0	0	180	320	320	260	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	1080
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
PROJECT ADMIN.	(H)	80	52	20	20	28	28	20	20	20	20	20	20	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	20	20	20	20	20	20	20	20	20	20	20	96	664
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
DRAFTSMAN	(H)	8	0	0	40	0	0	40	0	0	40	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	40	0	0	40	0	0	40	0	0	40	0	80	368
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
TECHNICIAN	(H)	0	0	0	0	0	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	120	240	240	240	240	0	0	0	1080
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
ENGINEERING DIRECTOR	(H)	42	28	10	16	8	8	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	22	22	8	0	164
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.1 Summary--Labor Hours by Month (Cont)

SENIOR ENGINEER	(H)	128	116	24	40	24	24	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	124	124	32	0	636
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
CONTRACT CONTROL	(H)	12	8	8	8	8	4	4	4	4	4	4	4	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	8	0	0	0	0	0	0	0	0	0	0	0	80
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
CONTRACT ADMIN.	(H)	40	10	10	10	10	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	80
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
MANUFACT. ENGR.	(H)	100	100	100	100	100	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	500
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
ESTIMATING	(H)	0	0	80	160	160	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	400
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
WELD DEVEL. ENGR.	(H)	0	0	10	40	0	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	50
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
DESIGN SUPERVISOR	(H)	100	40	40	40	40	40	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	300
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
DESIGN LEADER	(H)	100	160	160	160	160	160	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	900
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
SENIOR DESIGNER	(H)	0	200	200	200	200	200	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	1000
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.1 Summary--Labor Hours by Month (Cont)

DESIGNER	(H)	0	100	400	400	300	100	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	1300
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
SHOP LABOR	(H)	0	0	0	0	300	400	400	400	400	400	400	400	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	300	0	0	0	0	0	0	0	0	0	0	0	3400
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
TECHNICAL DIRECT	(H)	0	0	0	0	45	35	35	35	35	35	35	35	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	35	0	0	0	0	0	0	0	0	0	0	0	325
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
PROJ. COORDINATOR	(H)	30	20	20	60	60	60	60	60	60	60	60	160	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	160	160	160	160	0	0	0	0	0	0	0	0	1350
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
ENGINEERING	(H)	15	0	0	80	240	240	240	160	160	160	24	24	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	32	0	0	0	0	0	0	0	0	0	0	0	1375
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
DRAFTING	(H)	0	0	0	480	480	480	660	180	180	180	0	40	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	40	40	40	40	130	0	0	0	0	0	0	0	2970
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
FIELD LABOR	(H)	0	0	0	0	0	0	0	0	0	0	0	400	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	1100	1100	1100	800	0	0	0	0	0	0	0	0	4500
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
LABOR TOTAL	(H)	1107	1664	1416	2472	2933	2489	2033	949	949	989	633	1173	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	1881	1386	1386	1206	576	674	714	674	1180	632	350	406	29872
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.2 Task 1—Labor Hours by Month

		MONTHS												
		1 13	2 14	3 15	4 16	5 17	6 18	7 19	8 20	9 21	10 22	11 23	12 24	TOTAL
TECHNICAL DIRECTOR	(H)	4	0	0	0	0	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	4
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
SR. RESEARCH ASSOC.	(H)	4	0	0	0	0	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	4
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
RESEARCH ASSOCIATE	(H)	4	0	0	0	0	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	4
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
SENIOR ENGINEER	(H)	80	0	0	0	0	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	80
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
DRAFTSMAN	(H)	8	0	0	0	0	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	8
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
ENGINEERING DIRECTOR	(H)	4	0	0	0	0	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	4
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
SENIOR ENGINEER	(H)	12	0	0	0	0	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	12
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
PROJ. COORDINATOR	(H)	30	0	0	0	0	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	30
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
ENGINEERING	(H)	15	0	0	0	0	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	15
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
LABOR TOTAL	(H)	161	0	0	0	0	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	161
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.3 Task 2--Labor Hours by Month

		MONTHS 1 13	2 14	3 15	4 16	5 17	6 18	7 19	8 20	9 21	10 22	11 23	12 24	TOTAL
TECHNICAL DIRECTOR	(H)	8	12	0	4	4	4	8	0	0	0	0	0	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	40
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0
SR. RESEARCH ASSOC.	(H)	0	8	4	20	44	48	40	0	0	0	0	0	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	164
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0
RESEARCH ASSOCIATE	(H)	0	80	160	200	160	160	80	0	0	0	0	0	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	840
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0
SENIOR ENGINEER	(H)	40	120	80	124	56	56	96	0	0	0	0	0	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	572
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0
DEVELOPMENT ENGINEER	(H)	0	0	0	180	320	320	260	0	0	0	0	0	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	1080
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0
ENGINEERING DIRECTOR	(H)	30	16	10	8	8	8	0	0	0	0	0	0	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	80
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0
SENIOR ENGINEER	(H)	80	64	24	24	24	24	0	0	0	0	0	0	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	240
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0
DESIGN SUPERVISOR	(H)	100	40	40	40	40	40	0	0	0	0	0	0	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	300
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0
DESIGN LEADER	(H)	100	160	160	160	160	160	0	0	0	0	0	0	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	900
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.3 Task 2--Labor Hours by Month (Cont)

SENIOR DESIGNER	(H)	0	200	200	200	200	200	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	1000
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
DESIGNER	(H)	0	100	400	400	300	100	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	1300
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
ENGINEERING	(H)	0	0	0	80	80	80	80	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	320
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
DRAFTING	(H)	0	0	0	480	480	480	480	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	1920
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
LABOR TOTAL	(H)	358	800	1078	1920	1876	1680	1044	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	8756
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.4 Task 3--Labor Hours by Month

MONTHS

		1 13	2 14	3 15	4 16	5 17	6 18	7 19	8 20	9 21	10 22	11 23	12 24	TOTAL
SR. RESEARCH ASSOC.	(H)	40	120	0	0	0	0	0	0	0	0	0	0	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	160
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0
RESEARCH ASSOCIATE	(H)	120	320	0	0	0	0	0	0	0	0	0	0	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	440
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0
SENIOR ENGINEER	(H)	40	40	0	0	0	0	0	0	0	0	0	0	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	80
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0
ENGINEERING DIRECTOR	(H)	8	12	0	0	0	0	0	0	0	0	0	0	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	20
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0
SENIOR ENGINEER	(H)	36	52	0	0	0	0	0	0	0	0	0	0	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	88
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0
LABOR TOTAL	(H)	244	544	0	0	0	0	0	0	0	0	0	0	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	788
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.5 Task 4--Labor Hours by Month

		MONTHS												
		1 13	2 14	3 15	4 16	5 17	6 18	7 19	8 20	9 21	10 22	11 23	12 24	TOTAL
RESEARCH ASSOCIATE	(H)	0	0	0	0	16	16	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	32
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
SENIOR ENGINEER	(H)	40	40	24	24	40	40	24	24	24	24	24	24	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	80	0	0	0	0	0	0	0	0	0	0	0	432
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
PROJECT ADMIN.	(H)	0	0	0	0	8	8	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	16
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
MANUFACT. ENGR.	(H)	100	100	100	100	100	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	500
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
ESTIMATING	(H)	0	0	80	160	160	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	400
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
WELD DEVEL. ENGR.	(H)	0	0	10	40	0	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	50
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
SHOP LABOR	(H)	0	0	0	0	300	400	400	400	400	400	400	400	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	300	0	0	0	0	0	0	0	0	0	0	0	3400
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.5 Task 4--Labor Hours by Month (Cont)

TECHNICAL DIRECT	(H)	0	0	0	0	45	35	35	35	35	35	35	35	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	35	0	0	0	0	0	0	0	0	0	0	0	325
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
ENGINEERING	(H)	0	0	0	0	160	160	160	160	160	160	24	24	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	32	0	0	0	0	0	0	0	0	0	0	0	1040
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
DRAFTING	(H)	0	0	0	0	0	0	180	180	180	180	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	720
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
LABOR TOTAL	(H)	140	140	214	324	829	659	799	799	799	799	483	483	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	447	0	0	0	0	0	0	0	0	0	0	0	6915
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.6 Task 5--Labor Hours by Month

		MONTHS												
		1	2	3	4	5	6	7	8	9	10	11	12	
		13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
RESEARCH ASSOCIATE	(H)	0	0	0	0	0	0	0	0	0	0	0	0	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	80	80	0	0	0	0	0	0	0	160
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0
SENIOR ENGINEER	(H)	0	0	0	0	0	0	0	0	0	0	0	0	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	160	0	0	0	0	0	0	0	160
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0
TECHNICIAN	(H)	0	0	0	0	0	0	0	0	0	0	0	0	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	120	0	0	0	0	0	0	0	120
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0
PROJ. COORDINATOR	(H)	0	0	0	0	0	0	0	0	0	0	0	160	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	160	160	160	160	0	0	0	0	0	0	0	0	800
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0
DRAFTING	(H)	0	0	0	0	0	0	0	0	0	0	0	40	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	40	40	40	40	130	0	0	0	0	0	0	0	330
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0
FIELD LABOR	(H)	0	0	0	0	0	0	0	0	0	0	0	400	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	1100	1100	1100	800	0	0	0	0	0	0	0	0	4500
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0
LABOR TOTAL	(H)	0	0	0	0	0	0	0	0	0	0	0	600	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	1300	1300	1300	1080	490	0	0	0	0	0	0	0	6070
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.7 Task 6--Labor Hours by Month

						MONTHS							
		1 13	2 14	3 15	4 16	5 17	6 18	7 19	8 20	9 21	10 22	11 23	12 24	TOTAL
TECHNICAL DIRECTOR	(H)	0	0	0	0	0	0	0	0	0	0	0	0	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	8	8	8	8	0	0	0	32
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0
SENIOR ENGINEER	(H)	0	0	0	0	0	0	0	0	0	0	0	0	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	340	340	340	340	0	0	0	1360
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0
TECHNICIAN	(H)	0	0	0	0	0	0	0	0	0	0	0	0	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	240	240	240	240	0	0	0	960
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0
LABOR TOTAL	(H)	0	0	0	0	0	0	0	0	0	0	0	0	
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	588	588	588	588	0	0	0	2352
	(S)	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.8 Task 7--Labor Hours by Month

		MONTHS												
		1 13	2 14	3 15	4 16	5 17	6 18	7 19	8 20	9 21	10 22	11 23	12 24	TOTAL
SR. RESEARCH ASSOC.	(H)	0	0	0	0	0	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	40	40	0	0	80
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
RESEARCH ASSOCIATE	(H)	0	0	0	0	0	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	160	160	0	0	320
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
SENIOR ENGINEER	(H)	0	0	0	0	0	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	160	160	0	0	320
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
ENGINEERING DIRECTOR	(H)	0	0	0	0	0	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	14	14	0	0	28
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
SENIOR ENGINEER	(H)	0	0	0	0	0	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	92	92	0	0	184
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
LABOR TOTAL	(H)	0	0	0	0	0	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	466	466	0	0	932
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.9 Task 8--Labor Hours by Month

						MONTHS							
		1	2	3	4	5	6	7	8	9	10	11	12	
		13	14	15	16	17	18	19	20	21	22	23	24	TOTAL
SENIOR ENGINEER	(H)	16	40	16	16	80	16	16	16	16	16	16	16	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	16	16	16	16	16	16	16	16	16	16	240	180	860
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
PROJECT ADMIN.	(H)	0	12	12	12	12	12	12	12	12	12	12	12	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	12	12	12	12	12	12	12	12	12	12	12	16	280
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
DRAFTSMAN	(H)	0	0	0	40	0	0	40	0	0	40	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	40	0	0	40	0	0	40	0	0	40	0	80	360
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
ENGINEERING DIRECTOR	(H)	0	0	0	8	0	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	8	8	8	0	32
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
SENIOR ENGINEER	(H)	0	0	0	16	0	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	32	32	32	0	112
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
LABOR TOTAL	(H)	16	52	28	92	92	28	68	28	28	68	28	28	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	68	28	28	68	28	28	68	28	68	108	292	276	1644
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.10 Task 9--Labor Hours by Month

		MONTHS												
		1 13	2 14	3 15	4 16	5 17	6 18	7 19	8 20	9 21	10 22	11 23	12 24	TOTAL
TECHNICAL DIRECTOR	(H)	4	4	4	4	4	4	4	4	4	4	4	4	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	4	4	4	4	4	4	4	4	4	4	4	4	96
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
SR. RESEARCH ASSOC.	(H)	12	6	6	6	6	6	6	6	6	6	6	6	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	6	6	6	6	6	6	6	6	6	6	6	6	150
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
SENIOR ENGINEER	(H)	40	40	40	40	40	40	40	40	40	40	40	40	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	40	40	40	40	40	40	40	40	40	40	40	40	960
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
PROJECT ADMIN.	(H)	80	40	8	8	8	8	8	8	8	8	8	8	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	8	8	8	8	8	8	8	8	8	8	8	80	368
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
CONTRACT CONTROL	(H)	12	8	8	8	8	4	4	4	4	4	4	4	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	8	0	0	0	0	0	0	0	0	0	0	0	80
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
CONTRACT ADMIN.	(H)	40	10	10	10	10	0	0	0	0	0	0	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	80
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
PROJ. COORDINATOR	(H)	0	20	20	60	60	60	60	60	60	60	60	0	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	0	0	0	0	0	0	0	0	0	0	0	0	520
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0
LABOR TOTAL	(H)	188	128	96	136	136	122	122	122	122	122	122	62	
	($)	0	0	0	0	0	0	0	0	0	0	0	0	
	(H)	66	58	58	58	58	58	58	58	58	58	58	130	2254
	($)	0	0	0	0	0	0	0	0	0	0	0	0	0

4.3 PROJECT SCHEDULE

Figure 4.3 is the Phase 2 Project Schedule. The schedule depicts a 24-month project along with deliverables and meetings. If Sandia chooses to fund the Alternative SRE discussed in Section 3.3, the duration of the program will be 21 months.

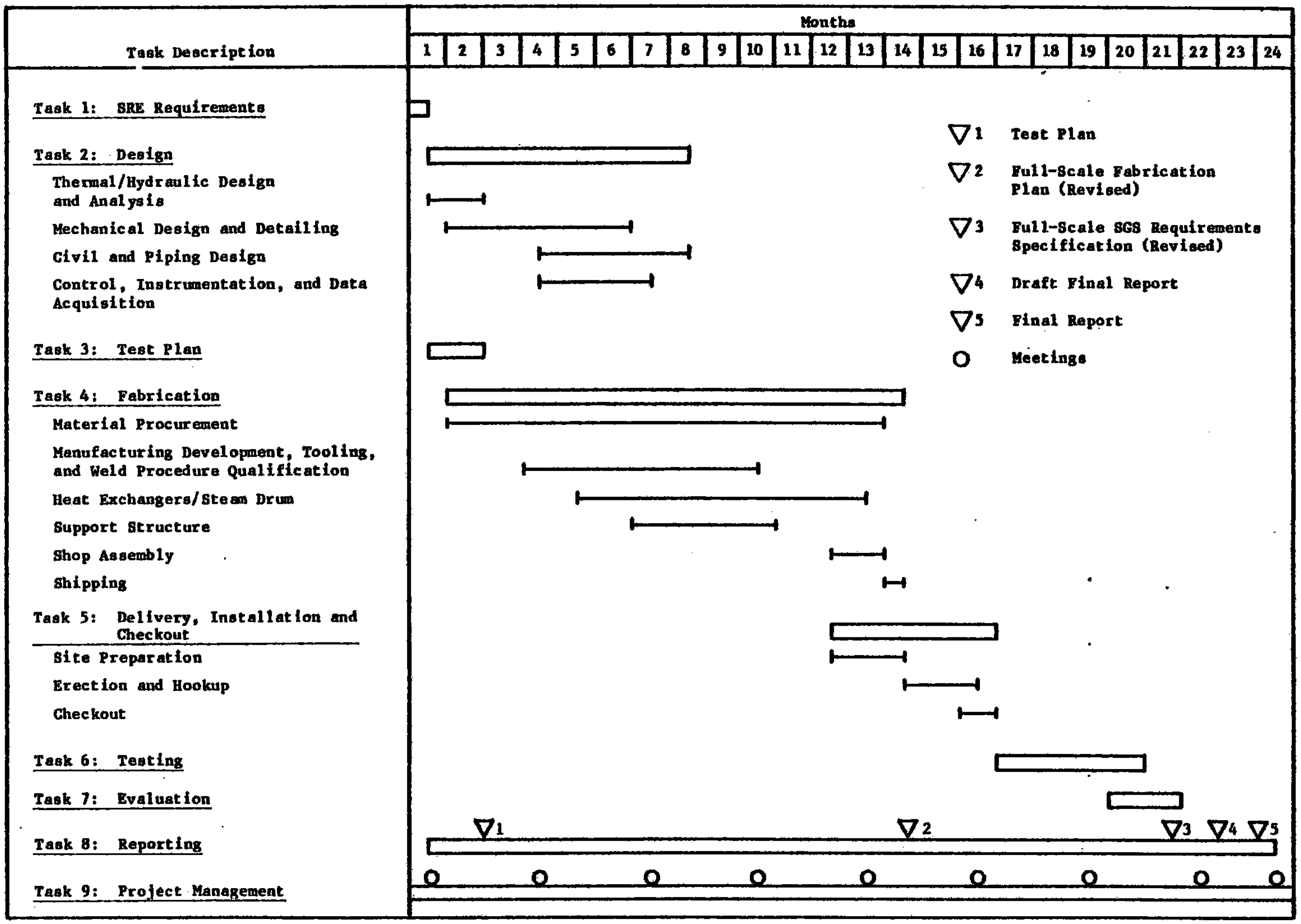


Figure 4.3 Phase 2 Project Schedule

4.4 MOUNTAINTOP MANUFACTURING FACILITY

Components for the SGS module will be fabricated in Foster Wheeler's Mountaintop plant in Pennsylvania. Situated on 104 acres, the long main building covers 80,000 ft^2, while side bays and a plate shop encompass another 75,200 ft^2. Adjacent service areas include stores, outside inspection, and a detached x-ray building.

The Mountaintop plant produces Foster Wheeler's largest pieces of equipment, including drums and headers for natural-circulation utility and marine steam generators, headers and piping for once-through designs, evaporators, flash tanks, and accumulators. A nuclear area provides for the assembly of critical, high-tolerance, extremely close-quality control components.

The fabrication of a cylindrical pressure vessel, such as a boiler drum, begins with the forming of its two halves. After heating in a furnace to approximately 1650°F, steel plate (up to 40 ft long and 8 in. thick) is formed by a huge 8000-ton-capacity hydraulic beam press. A bend planer prepares each of the halves by profiling the long seam edges.

Depending on the size of the vessel and its wall thickness, the halves may be joined either horizontally or vertically by submerged-arc or electroslag welding equipment. The shell ends are then cut to final length and machined for circle seam welding of the heads. Finally, submerged-arc welding procedures attach heads to the vessels.

During all phases of fabrication, various nondestructive test procedures are used to ensure that the vessel satisfies all requirements of the particular specifications to which it is built. A 2-million-volt x-ray machine in an adjacent building can detect faults to a maximum thickness of 12 in. Hydrostatic tests to pressures well beyond those anticipated in operation further certify the integrity of the vessel.

Conscious of the necessity to develop and apply new manufacturing methods, Mountaintop's engineers continuously direct their efforts toward achieving better techniques to ensure reliability. For example, Mountaintop's Welding Laboratory conducts experiments to improve manual and automatic welding. Over the years, this work has resulted in improved procedures and automated equipment for welds of all types.

Table 4.11 is an abbreviated list of available equipment at the Mountaintop facility.

Table 4.11 Summary of Mountaintop Equipment and Capabilities

Furnace Sizes

(1) 85 ft x 15 ft x 15 ft
(1) 55 ft x 11 ft x 15 ft
(1) 46 ft x 15 ft x 7 ft

Radiographic Capabilities

2,000,000 volts
300,000 volts
250,000 volts
Cobalt Sources
Iridium 192
Ytterbium

Equipment

8000-ton Press
(4) N.C. Lahr Tape Drilling Machines
(5) Special Radial Gun-Drills
144-in. VBM
3-AC Tape-Controlled Chucker Machine
Radial Drill Lone (4 drills)
Plasma Arc Cutting
Oxy Gas Cutting
HBM 6-in. Diameter Spindle, 136-in. Vertical, and 16-in. Horizontal
Plate Planer (28 ft-10 in.)

Welding Processes Used

Manual Stick Electrode
Manual TIG
Semiautomatic MIG
Automatic TIG
Automatic MIG
Single-Wire Submerged Arc
Twin-Wire Submerged Arc
Electroslag
Short-Arc MIG
Spray-Arc MIG
Pulse-Arc MIG
Vertical Submerged Arc
CO_2 Semiautomatic Flux-Cored
AC-DC Tandem Submergd-Arc Welding
Internal Bore Welding Single Fusion
Automatic TIG Fillet Welding
Orbital Automatic TIG
Innerbore Weld

Lifting Capabilities

Maximum Lift Capacity - 325 tons
Largest Crane - 150 tons

APPENDIX A

MOLTEN SALT SOLAR STAND-ALONE SGS OPERATING MODES

Appendix A

MOLTEN SALT SOLAR STAND-ALONE SGS OPERATING MODES

Appendix A from the original proposal has been deleted. For details on SGS operating modes, refer to Phase 1--Final Report, Volume 1, Section 5.6.

APPENDIX B

SRE FABRICATION PLAN

Appendix B

SRE FABRICATION PLAN

Preheater-Evaporator-Superheater-Reheater-Steam Drum

Receipt of Material

1. Receive and inspect material and material certifications
2. Review ASME Code Section VIII--Manufacturer's certifications for expansion joints
3. Identify parts and hold in protected storage

Shell Fabrication

1. Lay out and cut all parts
2. Sandblast internal surfaces to remove loose scale from material other than stainless steel
3. Set up and weld shell assembly
4. X-ray butt welds
5. Weld perforated flow distribution ring after all the welding is completed on open-ended shell
6. Apply temporary ties to expansion joints
7. Hold in protected storage for next assembly

Tubesheets

1. Machine tubesheets
2. Lay out for drillings
3. Drill and ream tubesheets
4. Lay out and drill tie-rod holes and drain/vent holes
5. Set up and weld drain/vent fittings
6. Machine edge preps
7. Inspect and hold for next assembly

Support Plates

1. Lay out and cut plates to contour
2. Shot blast plates other than stainless
3. Stack and brace plates for drilling
4. Drill tube holes through template
5. Deburr and remove sharp corners
6. Vapor degrease
7. Cover and hold in protected storage

Tie-Rods and Spacers

1. Cut to size
2. Thread ends as required
3. Deburr
4. Vapor degrease
5. Cover and hold in protected storage

Tube Bundle and Shell Assembly

1. Set up one tubesheet with support plates and tie-rod spacers
2. Ensure alignment of holes and cleanliness
3. Pull shell assembly over tube-support assembly
4. Set up and weld shell to tubesheet
5. Inspect root pass at 5X magnification
6. Spot X-ray butt weld
7. Tube-up unit; push tube 76mm (3 in.) past true position
8. Set up and weld second tubesheet to shell
9. Inspect root pass at 5X magnification
10. Spot X-ray butt weld
11. Push tubes back into second tubesheet
12. Weld tubes to first tubesheet
13. Cut tube ends at second end if necessary
14. Weld tubes to second tubesheet
15. Set up and weld reducers to second shell connections
16. Spot X-ray welds
17. Apply hydrotest covers to shell opening and vent and drain connections
18. Apply 345 kPa gage (50 lb/in^{2}g)(pneumatic) to shell side
19. Soap and air test tube-to-tubesheet welds
20. DETNAFORM® expand tubes into tubesheets
22. Clean unit
23. Hold for next assembly

Final Assembly, Testing, and Shipping

1. Set up and weld channel fittings to tubesheet weld preps
2. X-ray welds
3. Furnace stress-relieve entire evaporator only
    - Follow rules of ASME Code, Section VIII-Division 1
    - Purge internally with nitrogen
    - Remove temporary ties from expansion joints
4. Hydrotest shell side
    - Use demineralized water for superheater and reheater
    - Use hydrazine and water for evaporator and preheater
    - Drain thoroughly
5. Apply remaining fittings to channel--cap, elbow reducers, hydroclosures
6. X-ray welds
7. Locally stress-relieve evaporator welds--purge internally with nitrogen
8. Hydrotest channel (tube side)
    - Drain thoroughly after test
    - Use demineralized water for superheater and reheater
    - Use hydrazine and water for evaporator and preheater
9. Vacuum dry unit--shell side and tube side
10. Apply 69 kPa gage (10 lb/in^2g) nitrogen to each side of seal. Apply pressure-indicating gages for shipment
11. Clear unit with Quality Control--Certify to ASME Code, Section VIII-Division 1
12. Cover superheater and reheater with poly film for shipment; paint preheater and evaporator with one coat of red-oxide primer
13. Load and brace unit for shipment
14. Release shipment

Steam Drum

1. Fabricate drum using FWEC standard practice
2. Hydrotest drum; use water with hydrazine
3. Dry drum
4. Remove hydroclosures; apply shipping closures
5. Purge with nitrogen and apply 69 kPa gage (10 lb/in^2g); add pressure-indicating gages
6. Paint with one coat of red-oxide primer
7. Clear unit with Quality Control; certify to ASME Code, Section VIII-Division 1
8. Load and brace for shipment
9. Release shipment

APPENDIX F: PHASE 2--COST PROPOSAL
(ABRIDGED)

MOLTEN SALT STEAM GENERATOR SUBSYSTEM RESEARCH EXPERIMENT

Sandia Contract 20-9909B

Prepared for

Sandia National Laboratories
Livermore, California

January 15, 1982

Abridged Version: September 1982

FWSDC No. 9-71-9202

FOSTER WHEELER SOLAR DEVELOPMENT CORPORATION
12 Peach Tree Hill Road, Livingston, New Jersey 07039

CONTENTS

INTRODUCTION

This volume contains Foster Wheeler Solar Development Corporation's (FWSDC's) administrative and financial proposal for the Phase 2--Molten Salt Steam Generator SRE portion of the program, prepared under FWSDC's current contract with Sandia National Laboratories (20-9909B). Specifically, we have included Cost and Pricing Data including a Contract Pricing Summary with an Overall Project Cost Breakdown, Optional Form 60s for each participating organization with supporting schedules, Administrative and Supporting Information, a Cost-Sharing Proposal, and an Alternative SRE Cost Comparison.

Thomas J. Neale, Project Administrator of the Contract Operations Division, is authorized to represent FWSDC in contractual matters, including financial negotiations. He can be reached at (201) 533-4091.

COST AND PRICING DATA

REF.: 20-9909B
DATE: September 1982
(Abridged)

COST AND PRICING DATA

Pages 2 through 37 from the original proposal have been deleted. A summmary of the proposed SRE costs by major items and by task follows:

Cost Summary by Major Item

Item	Cost ($)
Heat Exchangers/Steam Drum	265,039
SGS Module	39,645
Instrumentation	81,950
Control Hardware	75,000
Auxiliary Equipment	40,000
Civil/Piping	104,200
Valves	63,844
Data System	65,500
Computer	11,000
Travel	57,559
Shipping	15,000
Installation	232,350
Home Office Labor	938,437
Miscellaneous	9,900
Total	1,999,424

Cost Summary by Task

Task	Cost ($)
1	7,562
2	492,956
3	40,103
4	358,593
5	746,722
6	107,824
7	48,268
8	71,208
9	126,188
Total	1,999,424

For a more detailed breakdown of SRE costs, refer to the original proposal.

ADMINISTRATIVE AND SUPPORTING INFORMATION

ADMINISTRATIVE AND SUPPORTING INFORMATION

PROPOSAL VALIDITY

This proposal is valid until April 30, 1982, as requested by Sandia.

CONTRACT TYPE/TERMS AND CONDITIONS

This proposal assumes that the Phase 2 work will be performed under a cost-reimbursable contract. This proposal is submitted subject to the understanding that any agreement with respect to Phase 2 will incorporate applicable provisions negotiated for Phase 1 (such as the Limitation of Liability Article) and additional provisions appropriate to the scope of work for Phase 2. We reserve the right to submit specific comments on any inquiry/contract documents Sandia proposes to furnish for Phase 2; or, if none are furnished, FWSDC will submit terms and conditions it proposes for Phase 2. Foster Wheeler agrees to accept an order for Phase 2 provided a mutual agreement on terms and conditions can be reached. Foster Wheeler will not assume any liabilities or be obligated to begin any work before mutual written agreement on terms and conditions is reached.

PERIOD OF PERFORMANCE

This proposal is based on a 24-month effort. All pricing information is presented on the basis of a "Month One" start of project activities, rather than a specific calendar month, to allow flexibility in the timing of any resultant contract modification. The Cost and Pricing data contain time-phased (monthly) estimated expenditures by cost element and task.

PRIMARY SUBCONTRACTORS

This proposal assumes that the following organizations will perform a portion of the project work as a subcontractor to Foster Wheeler Solar Development Corporation.

FW Energy Applications, Inc.
110 South Orange Avenue
Livingston, New Jersey 07039

Foster Wheeler Energy Corporation
110 South Orange Avenue
Livingston, New Jersey 07039

Foster Wheeler SPEC, Inc.
66 West Mt. Pleasant Avenue
Livingston, New Jersey 07039

Their efforts are described in the Subcontracts section that follows.

SUBCONTRACTS

FWSDC will utilize the services of its affiliated companies, FW Energy Applications, Inc.; Foster Wheeler Energy Corporation; and Foster Wheeler SPEC, Inc., for design, engineering, evaluation, procurement, fabrication and construction management services during performance of the Statement of Work. Foster Wheeler affiliates have been associated on a number of other projects and have ongoing good working relationships. Further, FWSDC/FWDC believes that this team is uniquely qualified to perform the work and that a single coordinated effort within our organization promotes efficiency and cost-effectiveness for the entire SGS project.

Foster Wheeler will procure all materials and related equipment competitively and will solicit bids for the prefabrication of subassemblies and the installation of the steam generating subsystem. It is the policy of Foster Wheeler Corporation and its subsidiary companies to encourage the participation of small and disadvantaged/minority-owned businesses in its programs and to subcontract to these business concerns the maximum amount of business consistent with the efficient performance of the work.

If this proposal is deemed acceptable, Foster Wheeler will submit a subcontracting plan for small business and disadvantaged/minority-owned business concerns.

COGNIZANT GOVERNMENT AUDITOR (for FWSDC/FWDC/FWEA/FWEC/FWSPEC)

Mr. Stephen L. Stronczer
Chief, Princeton Audit Operations Section
Department of Energy
Gibsen House - Forrestal Campus
P. O. Box 102
Princeton, New Jersey 08540
Telephone: (609) 452-1910

CAPABILITY/FINANCIAL CONDITION/CORPORATE PRIORITY

Foster Wheeler

The Foster Wheeler family of companies is highly regarded for its vast experience in the design, engineering, and construction of process plants for the chemical and petroleum industries as well as design, fabrication, and erection of components for utility power stations. Foster Wheeler's commitment to reduce America's dependence on fossil fuels, and its recognition that these fuels are finite, has led to a concentrated effort in the search for renewable energy sources. Toward this end, Foster Wheeler has been involved in solar programs for several years and has established FWSDC to concentrate in one organization the specific talents necessary to serve industrial and utility solar energy needs.

Foster Wheeler's efforts have led to more than 20 contracts in the field of solar energy. Our efforts have ranged from preliminary feasibility studies to the actual design, construction, and erection of a solar process steam system. A highlight of our experience is our recent completion of the construction of a solar process steam plant for Dow Chemical Company's latex manufacturing plant in Dalton, Georgia. This work was done under DOE funding in support of the Solar Production of Industrial Process Steam Program.

Foster Wheeler Corporation is a worldwide engineering, manufacturing, and construction organization providing process plants and steam generating equipment for the energy industries. It recorded earned billings of $1.56 billion in 1980 and has experienced significant growth in the last decade. It has contracted with military and civilian agencies of the Government for many years and its systems (e.g., accounting, procurement) have been reviewed by cognizant Government auditors.

Foster Wheeler is fully committed to meeting the objectives of this project. When our SGS design is installed, tested, and qualified, we will enthusiastically participate in the follow-on full-scale experiment and will offer our system to DOE at a competitive price.

MONTHLY COST STATUS REPORTS

FWSDC will prepare Sandia Forms 533 through 536 on a monthly basis and other forms that Sandia may require in this phase of the SGS project. The completed forms will be forwarded so as to be received by the SCR no later than the 20th of each month following the report period.

COST SHARING

(DELETED)

ALTERNATIVE SRE SYSTEM

ALTERNATIVE SRE SYSTEM

<u>Materials</u>		$199,300
Heat Exchangers (Including shop labor)	$ 85,237	
Piping, Insulation, Lagging, and Trace Heaters	13,401	
Valves (Control, manual, safety, etc.)	26,621	
Instrumentation	21,358	
Drum-Water Recirculation Pump	20,000	
Data Acquisition System	32,683	
Total	$199,300	
<u>Home Office Labor, Overhead, and G&A</u>		170,071
FWSDC/FWDC	$ 80,969	
FWEA	7,062	
FWEC	40,911	
FWSPEC	41,129	
Total	$170,071	
<u>Subcontracted Labor</u>		43,748
Field Labor/Craft	$43,748	
Total Cost Reduction		$413,119

Summary

*Baseline System Cost	$1,999,424
Alternative System Cost Reduction	(413,119)
*Total Alternative SRE Cost	$1,586,305

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*No fee proposed for either system.