1133

STEAM GENERATOR SUBSYSTEM REQUIREMENTS SPECIFICATION

FOR

MOLTEN SALT STEAM GENERATOR SYSTEM SUBSYSTEM RESEARCH EXPERIMENT (PHASE I)

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1.0 GENERAL

1.1 Scope - This specification defines the necessary requirements to design the molten salt steam generator subsystem (SGS) for:

- a 100 MWe solar stand-alone power plant
- a 50 MWe solar component of a 100 MWe fossil-fueled plant 50% repowered by solar energy.

The specification establishes the basis for the detailed design of the SGS.

1.2 Subsystem Description - The SGS consists of the following major components:

a. Preheater;
b. Evaporator;
c. Steam drum;
d. Boiler water recirculating pumps, piping, and valves;
e. Superheater;
f. Reheater;
g. Main steam and startup attemperators;
h. Salt, feedwater, and steam piping and valves;
i. Salt drain sump;
j. Salt drain sump pumps;
k. Thermal insulation and trace heating;
l. Foundations, component structural supports, and berm;
m. Controls and instrumentation.

The Steam Generator Subsystem (SGS) uses molten salt (60% $NaNO_3$, 40% KNO_3 by weight) as a heat transfer fluid and storage medium. The SGS is a forced recirculation system employing a separate preheater, evaporator, superheater, reheater and steam drum. Separate superheater, reheater, and evaporator components are mandated by the recirculating system and by the specification of a reheat turbine. A separate preheater results in a more economic utilization of the total heat transfer surface. The heat exchangers are horizontally oriented with both salt and water nozzles arranged to facilitate venting and draining.

The SGS flow schematic is shown in Figure 1. On the salt side, hot salt at 566°C (1050°F) is pumped from the hot salt tank and through the superheater and reheater in parallel. After delivering energy to these units the two flows are mixed to give 448°C (838°F) salt which is passed through the evaporator where it is cooled to 336°C (637°F). The salt then flows through the preheater where it reaches its minimum temperature of 288°C (550°F) before being pumped back to the cold salt tank.

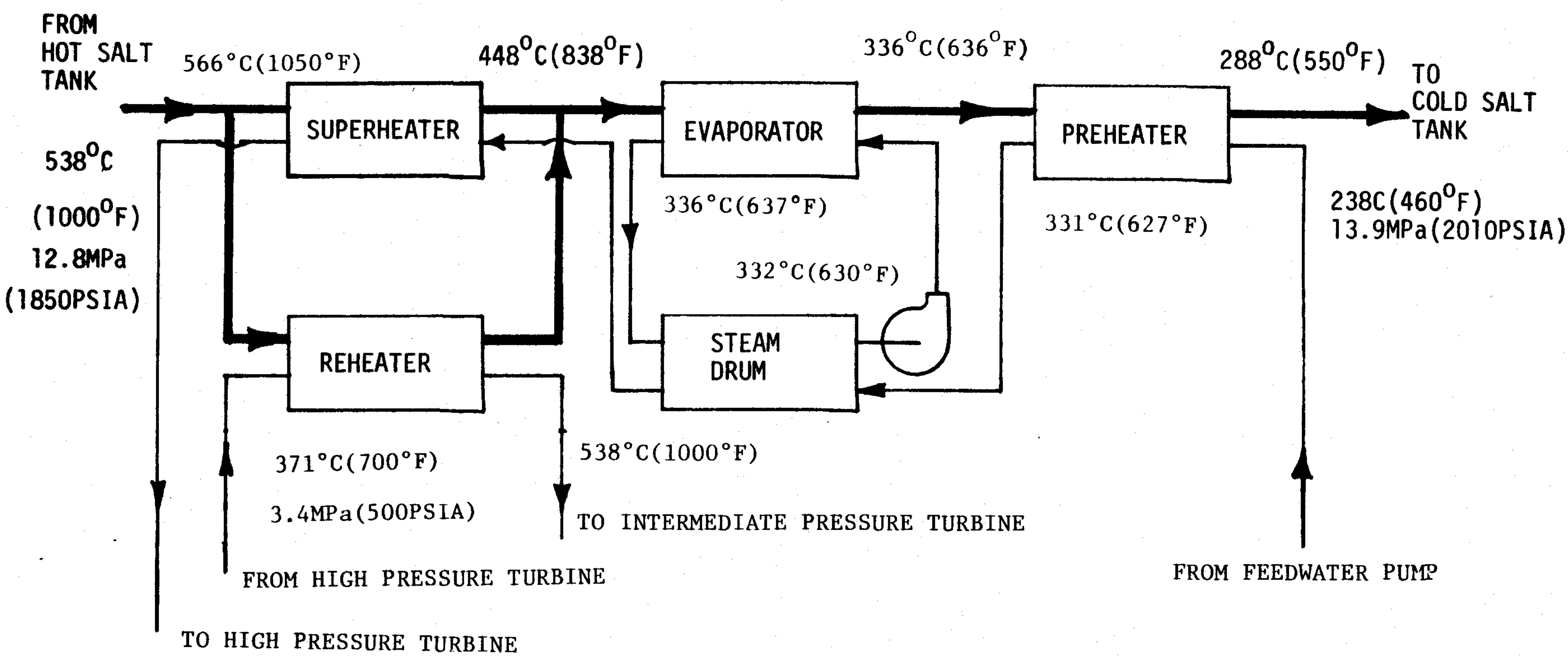


Figure 1 Steam Generator Subsystem Flow Schematic
(100 MWe Recirculating Cycle)

On the steam/water side, boiler quality steam at 538°C (1000°F) and 12.8 MPa (1850 psia) leaves the superheater and is expanded through the high pressure turbine to 3.4 MPa (500 psia) and 371°C (700°F). The steam then flows through the reheater where it is reheated to 538°C (1000°F) before passing through the intermediate pressure turbine, low pressure turbine, condenser, and feedwater pump of the Electrical Power Generation Subsystem (EPGS).

The water is then returned to the preheater to be heated from 238°C (460°F) to 331°C (627°F) before entering the steam drum. Water from the steam drum is forced through the evaporator by the recirculation pump. The evaporator produces a high-quality water/steam mixture at 336°C (636°F) that is fed back to the steam drum. Saturated steam is separated from the steam/water mixture in the drum. It then flows to the superheater completing the cycle.

1.3 Definition of Terms and Abbreviations

1.3.1 Definitions

Attemperator - Apparatus for reducing and controlling the temperature of a superheated vapor.

Code - ASME Code.

Cold Shutdown - State when the steam generator subsystem is at ambient temperature with the salt side drained.

Fouling - The process of forming an encrusting layer which may be permeable or imperemable on the tube walls due to precipation of dissolved and suspended solids from the fluids or due to the insitu chemical reaction of the tube wall material with that of the fluids.

Hot Standby - The SGS will be maintained in hot standby for diurnal shutdown for both stand-alone and repowering applications:

a. Repowered - The SGS maintained at or very near the throttle pressure at which the Electric Power Generation System is operating;

b. Standalone - A term to imply that the SGS is at any condition of pressure and temperature between those existing when the turbine is tripped to a minimum condition described by warm standby. It is determined only by time since trip and SGS heat losses until warm standby is reached.

Steam Reheat - Steam leaving the high pressure stage of a turbine is reheated in a separate reheat superheater and returned at higher temperature and enthalpy to the low pressure stage.

Turndown Ratio - The ratio of the total thermal power transmitted from the salt system to the steam water system at specified full load power to that transmitted at the lowest load at which the system operates under fully automatic control.

Warm Standby - Describes the minimum temperature and associated saturation pressure condition in which the SGS will be maintained in the event of an extended turbine outage. It will be essentially isothermal at a few degrees below cold salt temperature.

1.3.2 Abbreviations

CR - Circulation Ratio;

DNB - Departure from Nucleate Boiling;

NDE - Non-Destructive Examination;

SGS - Steam Generator Subsystem;

TBD - To Be Determined;

TES - Thermal Energy Storage.

2.0 APPLICABLE DOCUMENTS

2.1 General - In addition to this specification, the equipment, materials, design, and construction of the steam generator subsystem shall comply with all federal, state, local and user standards, regulations, codes, laws, and ordinances currently applicable at the power plant site. These shall include, but not be limited to, the government and non-government documents listed below. If there is an overlap in, or conflict between, the requirements of these documents and the applicable federal, state, county, or municipal codes, laws, or ordinances, the applicable requirement which is the most stringent shall take precedence.

2.2 Government Documents

a. Specifications
   - Regulations of the Occupational Safety and Health Administration (OSHA)
   - International System of Units, NASA SP-7012, 2nd Revision.

b. Standards
   - Applicable Human Engineering Design Criteria

2.3 Non-Government Documents

a. Standards and Codes

- Uniform Building Codes - 1979 Edition by International Conference of Building Officials
- ASME Boiler and Pressure Vessel Code
- Institute of Electrical and Electronic Engineers (IEEE) Standards as applicable
- National Fire Protection Association (NFPA) National Fire Design, Construction and Fabrication Standards
- Standards of ACI (American Concrete Institute)
- Standards of TEMA (Tubular Exchanger Association)
- Standards of ASTM (American Society of Testing Materials)
- Standards of NEMA (National Electrical Manufacturers Associaton)
- Standards of ICEA (Insulated Cable Engineers Association)
- Standards of AISC (American Institute of Steel Construction)
- ANSI B31.1 - Power Piping
- ANSI A58.1 - Building Code Requirements for Minimum Design Loads in Buildings and Other Structures
- ANSI B16.34 - Steel Valves, Flanged and Buttwelding Ends.

3.0 REQUIREMENTS

3.1 System Performance Requirements

3.1.1 Thermal Rating - The steam generator subsystem shall be designed for the following two (separate) applications:

a. 100 MWe - Recirculating Cycle, at 264.2 MWt overall thermal rating (Stand-alone);

b. 50 MWe - Recirculating Cycle, at 132.1 MWt overall thermal rating (Fossil-Fueled 50% repowered).

3.1.2 Operating Life - The SGS components shall be designed for a 30 year operating life and 95 percent availability.

3.1.3 Steam Conditions - The steam generator subsystem shall be capable of producing superheated steam at 538°C (1000°F) and 12,517 kPa (1,815 psia) and reheat steam at 538°C (1000°F) and 3,448 kPa (500 psia), with a feedwater preheat inlet temperature of 238°C (460°F).

3.1.4 Heat Transfer Fluid - The heat transfer fluid (heat source) shall be molten salt consisting of 60% $NaNO_3$ and 40% KNO_3 by weight, with thermophysical properties as shown in Table 1.

Table 1 Thermophysical Properties of Molten Salt (60% $NaNO_3$ - 40% KNO_3)

TEMP.	DENSITY	SPECIFIC HEAT	VISCOSITY X 10^3	THERMAL CONDUCTIVITY	COEFFICIENT OF THERMAL EXPANSION X10^4
$^oC(^oF)$	$\frac{kg}{m^3}$ $\frac{lb}{ft^3}$	$\frac{J}{kg-^oC}$ $\frac{BTU}{lb-^oF}$	Pa-sec $\frac{lb}{ft-hr}$	$\frac{W}{m^2-^oC}$ $\frac{BTU}{hr-ft-^oF}$	$\frac{1}{^oK}$
Solid					
38(100)	1922(119.8)	1553.3(0.371)		.363(.210)	
93(199)	1922(119.9)	1553.3(0.371)		.363(.210)	
	(Ref. 1)	(Ref. 1)		(Ref. 1)	
Liquid					
300(572)	1879(117.2)	1660.7(0.397)	3.22(7.79)	.500(.289)	3.4
350(662)	1848(115.4)	1628.2(0.389)	2.29(5.54)	.510(.295)	3.5
400(752)	1818(113.5)	1595.6(0.381)	1.80(4.35)	.519(.300)	3.5
450(842)	1787(111.5)	1563.0(0.374)	1.43(3.46)	.529(.306)	3.6
500(932)	1756(109.6)	1530.5(0.366)	1.21(2.93)	.539(.312)	3.6
550(1022)	1726(107.8)	1497.9(0.358)	1.05(2.54)	.548(.317)	3.7
600(1112)	1695(105.8)	1465 (0.350)	.93(2.25)	.558(.323)	3.7
	(Ref. 2)	(Ref. 2)	(Ref. 2)	(Ref. 2)	(Ref. 3)

Footnotes:

For melting/solidification properties see Figure 2.

Ref. 1 "Molten Nitrate Salt Technology Development Status Report" SAND 80-8052, March 1981.

Ref. 2 "Background for Preparation of Quotes Dealing With Molten Salt Steam Generator SRE".

Ref. 3 "Alternate Central Receiver Power System, Phase II", Final Report, Contract Sandia-18-6879C, May 1981.

3.1.5 Molten Salt Temperatures - The salt-side temperatures associated with the steam conditions specified under 3.1.3 are as follows:

a. Salt inlet to SGS: 565 ± 11°C (1050 ± 20°F);
b. Salt leaving SGS: 288 ± 11°C (550 ± 20°F).

3.1.6 Water Quality - Preliminary water quality standards are identified in table 2:

Table 2 Water Quality Standards

Item	Feedwater Recommended Values*	Item	Boiler Water Without Condensate Polishing
Oxygen	.007 ppm max.	Total Solids	15 ppm max.
Iron	.010 ppm max.	PO_4	3-10 ppm
		Na/PO_4 (mole ratio)	2.6
Copper	.005 ppm max.	OH	1.0 ppm max.
Hardness	0 ppm**	pH @ 25°C(77°F)	9.2-9.7
CO_2	0 ppm**	Silica	As determined by drum pressure
Organic	0 ppm**		
pH @ 25°C (77°F)	8.8-9.2 (Copper Alloy Preboiler System) 9.2-9.5 (Copper Free Preboiler System)		

*Measurement made at preheater inlet.
** Below Detectable Limits

3.1.7 Component Heat Exchanger Performance - The performance characteristics of the four heat exchangers comprising the SGS shall be consistent with the overall SGS requirements specified above, with thermal ratings, and temperature allocations approximately as shown in Table 3:

Table 3 Subsystem Performance Characteristics

100 MWe Recirculating Cycle

	Preheater	Evaporator	Superheater	Reheater
Thermal Rating MWt	48.1	107.8	76.3	32.0
Molten Salt				
Inlet Temp. ^{o}C (^{o}F)	336 (637)	448 (838)	566 (1050)	566 (1050)
Outlet Temp. ^{o}C (^{o}F)	288 (550)	336 (637)	448 (838)	448 (838)
Flow Rate $\frac{kg}{sec}$ $\frac{lb}{hr} x10^{-6}$	603 (4.78)	603 (4.78)	425 (3.37)	178 (1.41)
Steam/Water				
Inlet Temp. ^{o}C (^{o}F)	238 (460)	332 (630)	336 (636)	371 (700)
Outlet Temp. ^{o}C (^{o}F)	331 (627)	336 (636)	538 (1000)	538 (1000)
Outlet Press. MPa (Psia)	13.9 (2010)	13.9 (2010)	12.8 (1850)	3.4 (500)
Flow Rate $\frac{kg}{sec}$ $\frac{lb}{hr} x10^{-6}$	96.3 (0.764)	145 (1.146)	96.3 (0.764)	83.4 (0.662)

50 MWe Recirculating Cycle

	Preheater	Evaporator	Superheater	Reheater
Thermal Rating MWt	24.1	53.9	38.2	16.0
Molten Salt				
Inlet Temp. ^{o}C (^{o}F)	336 (637)	448 (838)	566 (1050)	566 (1050)
Outlet Temp. ^{o}C (^{o}F)	288 (550)	336 (637)	448 (838)	448 (838)
Flow Rate $\frac{kg}{sec}$ $\frac{lb}{hr} x10^{-6}$	301 (2.39)	301 (2.39)	212 (1.68)	90 (0.71)
Steam/Water				
Inlet Temp. ^{o}C (^{o}F)	238 (460)	332 (630)	336 (636)	371 (700)
Outlet Temp. ^{o}C (^{o}F)	331 (627)	336 (636)	538 (1000)	538 (1000)
Outlet Press, MPa(Psia)	13.9 (2010)	13.9 (2010)	12.8 (1850)	3.4 (500)
Flow Rate $\frac{kg}{sec}$ $\frac{lb}{hr} x10^{-6}$	48.2 (0.383)	72.3(0.574)	48.2 (0.383)	41.6(0.330)

3.1.8 Turndown Ratio - The steam generator subsystem shall be capable of operating in fully automatic control at part load conditions ranging from 30 to 110% of the rating specified under 3.1.1 during automatic control, and between 10 and 30% with manual control.

3.1.9 Operating Modes - The steam generator subsystem shall be capable of functioning in the following operating modes, within the constraints specified herein:

a. Cold Startup - This operation entails filling of the salt and water sides of the heat exchangers with the respective heat transfer fluids, and establishing flow through the salt side from and to the cold salt tank (Figure 1). Constraints:

- Freezing of salt, including the formation of dispersed solid particles shall be prevented by insuring that the salt side surfaces of the heat exchangers are at least 20°C (36°F) above the freezing point (238°C or 460°F) from start of salt fill throughout the operation;

- Entrapment of air pockets on the salt and water sides of the heat exchangers shall be prevented.

b. Warm Standby - The SGS temperature is maintained above the freezing point of the salt by recirculating salt from and to the cold salt tank, in combination with heat tracing and insulation, as required. Constraints:

- Heat loss from the salt to the environment and to the water/steam side of the SGS by the combined mechanisms of conduction, convection, and radiation shall be minimized, and shall not exceed TBD% of the rated capacity of the SGS.

c. Hot Standby - The SGS will be maintained in hot standby during diurnal shutdown for both stand-alone and repowering applications. For standalone operation, the SGS is at any condition of pressure and temperature between those existing when the turbine is tripped to a minimum condition described by warm standby. For repowering applications, the SGS is maintained at, or very near, the throttle pressure at which the Electric Power Generation System is operating.

d. Transient: Hot Standby to Normal Operation (# of events - 10,000) - This transient entails: (1) raising the water/steam side temperature and pressure of the evaporator to saturation levels; (2) raising the salt side temperatures of the evaporator, superheater, and reheater to water side saturation levels or above; (3) establishing water/steam flow; (4) establishing hot salt flow (from the hot tank); (5) establishing controlled operation at design setpoint conditions (with automatic control). Constraints:

- Salt temperatures in the evaporator and preheater shall not exceed the limits established to prevent material corrosion;
- Startup attemperators shall be included in the system to cool the superheated steam leaving the SGS to saturated steam during this transient, before it is routed to the condenser;
- It shall be a design objective to minimize the quantity of hot salt required to accomplish this transient.

e. Normal Operation - This mode includes all steady state operation at the conditions specified under 3.1.3 , 3.1.5, and 3.1.8. Normal operation shall be accomplished with either manual or automatic control.

f. Load Changes (# of events - 10,000) - The SGS shall be compatible with load changes of 10% of rated capacity per minute, between 30 and 110% of rating during automatic control and between 10 and 30% with manual control.

g. Transient: Normal Operation to Hot Standby - This operation requires the capability of controlled reduction of steam and salt flow from normal operating levels to zero, while maintaining steam drum temperatures and pressures at saturation levels. Constraints:

- Salt temperatures in the evaporator and preheater shall not exceed safe limits established to prevent material corrosion.

h. Long Term Shutdown - This operation requires the capability of isolation of the SGS flow paths from the other subsystems of the power plant, and complete drainability of both water/steam and salt sides.

3.1.10 Shutdown from Emergency or Upset Conditions - The steam generator subsystem shall be capable of safe, controlled shutdown resulting from upset and emergency conditions due to any of the following:

a. Turbine trip;
b. Loss of feedwater flow;
c. Loss of salt flow;
d. Break of any water/steam/salt pipe;
e. Indication of water-to-salt leak;
f. Loss of pneumatics;
g. Control system failure;
h. Loss of all station power (some emergency power required).

3.2 Compatibility with Molten Salt Operation

3.2.1 Drainability - The salt side of the SGS, including heat exchangers, interconnecting piping, valves and fittings, shall be completely drainable.

a. The heat exchangers (including interconnecting piping and valves) shall be designed such that the system will drain to the sump by gravity alone. The salt will be pumped from the sump to the cold or hot storage tanks as appropriate. If the salt is contaminated the system will be capable of gravity draining to a holding pond (earthen dikes);

b. The drain path shall be carefully layed out with due consideration to the boundary layer flow phase; drain lines shall have a minimum slope of 1 cm/m;

c. All salt valves shall be drainable valves;

d. The drain path shall be insulated, and provided with trace heating that is not adversely affected by a subsystem or station power failure;

e. Drain valves shall be equipped with manual override capability, so that they can be opened in case of power or control system failure;

f. Provisions shall be made for the detection and/or elimination of accumulation of frozen salt due to valve leakage downstream of the drain valves, so that the drain path may be kept free throughout the operation of the SGS.

3.2.2 Freeze and Thaw Considerations (refer to Phase Diagram on Figure 2)

a. The SGS shall be designed to handle salt in the liquid phase only.

b. The design and operation of the SGS shall be such as to prevent incipient or bulk freezing of the salt in any and all parts of the subsystem.

c. Local thawing shall not be relied on as a pratical means of correcting a freeze-up situation in the SGS components. The melting of the salt mixture results in a significant increase in salt specific volume, thus creating the potential for failure of closed containers.

d. Should salt freeze-up occur, heat tracing shall be provided to thaw the salt, with isolation valves open to permit thermal expansion.

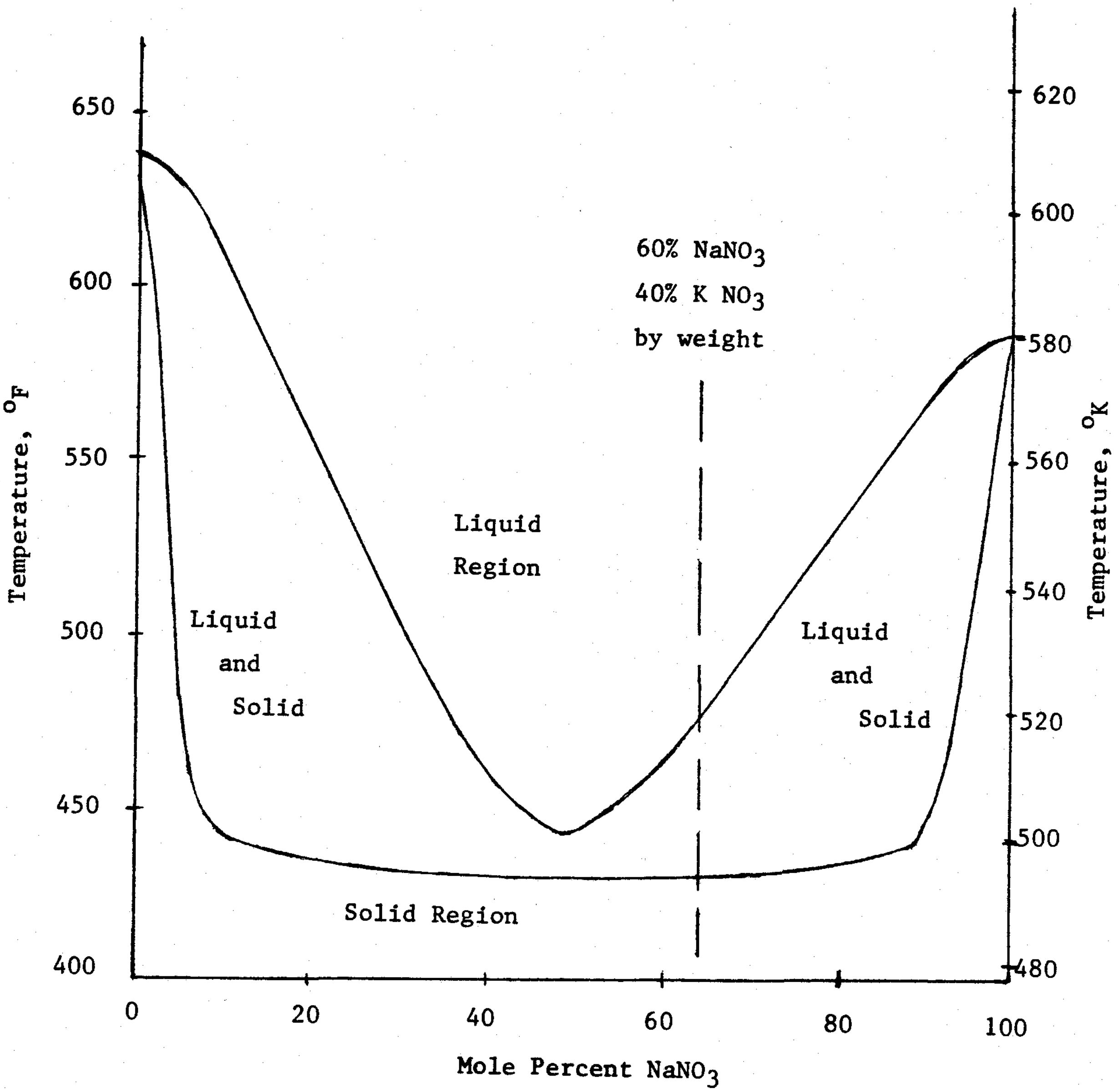
3.2.3 Heat Tracing - Heat tracing shall be provided to meet the requirements of Paragraphs 3.1 and 3.2.

a. The heat tracing subsystem may use steam, electric power, or a combination of the two, as an energy source.

b. The minimum pre-heat temperature for all trace heated surfaces of the SGS system which contact the molten salt is 277°C (530°F). The trace heating subsystem shall be designed to provide this minimum temperature prior to SGS system start-up.

c. Provisions shall be made to disconnect the power to electrical trace heaters when 1) this heating is no longer needed due to established molten salt flow or 2) the trace heating subsystem would experience temperatures above its maximum operating limit if left on.

d. Provisions shall be made to monitor the SGS component and piping metal temperatures adjacent to the trace heating subsystem heating elements.



I. Initial Melting - Initial melting of the original mixture begins at A where $NaNO_3$ is isothermally melted. Then the temperature of the mixture is raised to B where the KNO_3 is melted isothermally to form a completely liquid mixture.

II. Solidification - Solidification first occurs when the temperature of the mixture is lowered to C at the 60/40 by weight composition point. Solidification takes place while the temperature is lowered from C to D where the mixture is completely solid.

III. Subsequent Operational Melting - Melting first occurs at D and continues until the temperature is raised to C where the mixture is completely liquid.

Figure 2 Temperature - Composition Phase Diagram for $NaNO_3$-KNO_3

3.2.4 Molten Salt Component Design/Selection

a. Valves shall be of the drainable type, with laminated graphite packing or bellows-type seals to prevent leakage.

b. Pumps shall be of the open impeller, cantilever type.

c. Flanges shall be of the ring joint type where possible.

d. Electrical trace heaters shall use cabling with one-conductor Nichrome elements, 22 gage or larger (mineral insulated for high temperatures, Chemelex for low temperatures).

3.3 Steam Generator Components Design - This section of the specification identifies those requirements for the detailed design of the steam generator components.

3.3.1 Design Quality Assurance - The supplier shall establish and implement procedures required to assure that design, fabrication, inspection, and testing activities are planned and conducted in accordance with the requirements of applicable codes and this specification. Records shall be maintained in accordance with code requirements.

3.3.2 ASME Code Classification and Stamping - The steam generator subsystem components shall be designed and fabricated to Section VIII Division 1 of the ASME Code. Supplemental requirements for creep fatigue analysis will be developed as necessary.

3.3.3 General Requirements - The following requirements shall be met in designing the steam generator components:

- Heating surfaces must be oriented to promote efficient heat transfer and hydraulic stability of the heating fluid and steam/water mixture;

- Materials must be selected to provide adequate strength and corrosion/erosion resistance in the operating environment;

- Uniform distribution of flow to all heating surfaces must be assured;

- Sufficient flexibility must be provided for the U-tubes to preclude high stresses resulting from differential thermal expansion;

- Tube supports must be arranged to prevent potential damage resulting from flow-induced and machinery-induced vibration;

- Quality weld configurations and weld inspection standards must be provided to assure pressure boundary integrity;

- Access must be provided for inspection and corrective maintenance;

- The vessel must be capable of being fully drained and vented.

3.3.4 Design Conditions

Design Temperatures and Pressures

Table 4 lists the design temperatures and pressures for each SGS component for both water/steam and molten salt sides of each unit.

Table 4 Design Pressures and Temperatures

WATER/STEAM SIDE CONDITIONS	PRESSURE		TEMPERATURE	
	MPa	PSIA	°C	°F
Steam Drum	14.7	2125	343	650
Preheater	15.2	2200	371	700
Evaporator	15.2	2200	482	900
Superheater	14.7	2125	579	1075
Reheater	4.6	660	579	1075
MOLTEN SALT SIDE CONDITIONS				
Preheater	1.3	190	371	700
Evaporator	1.3	190	482	900
Superheater	1.3	190	579	1075
Reheater	1.3	190	579	1075

Seismic Loads - 0.1g in lateral direction (based on UBC zone 2).

Piping Loads - Maximum loads to be based on geometry at nozzle terminal.

3.3.5 Materials - Materials shall be selected for manufacture of the SGS components that meet the strength requirements of ASME Section VIII Division 1 as well as offering the corrosion resistance necessary in the operating environment. Materials selected for each component are identified in Table 5.

The materials identified in Table 5 were chosen after a review and evaluation of the available literature. However, data pertaining to the corrosion resistance of the selected alloys, particularly the low chromium alloys, in molten nitrate salt is very limited and often exhibits wide scatter. Thus, it will be necessary to reassess these choices based on the results of on-going and future test programs.

Table 5 Steam Generator Component Materials

COMPONENT	ENVIRONMENT	MAXIMUM OPERATING TEMPERATURE		MATERIALS
Preheater	Salt/Water	336°C	637°F	Carbon Steel
Evaporator	Salt/Water-Steam	448	838	2 1/4 Cr-1 Mo
Superheater	Salt/Steam	566	1050	304 Stainless Steel
Reheater	Salt/Steam	566	1050	304 Stainless Steel
Steam Drum	Water-Steam	336	636	Carbon Steel

Based on these material selections, the following allowances shall be made for corrosion (Table 6).

Table 6 Corrosion Allowances

	Carbon Steel		2 1/4 Cr - 1Mo		304 Stainless Steel	
Corrosion	mm	in	mm	in	mm	in
Salt Side	0.23	0.009	0.91	0.036	0.15	0.006
Water/Steam Side	0.28	0.011	0.41	0.016	0.10	0.004

3.3.6 Thermal/Hydraulic Design - The components in the SGS shall be designed to satisfy the following thermal/hydraulic requirments:

Fluid Velocities - The mass velocities of the water, water/steam, or steam shall be maximized, within pressure drop constraints, to develop efficient heat transfer and minimize surface requirements. Salt side velocities shall also be maximized within limits necessary to preclude tube vibration.

DNB - The evaporator circulation ratio shall be established sufficiently high to preclude departure from nucleate boiling (DNB).

Mixing - The heat exchanger components shall be designed to promote mixing of the molten salt and inhibit any tendency of the salt to stratify.

Subcooling in the Evaporator Downcomer - Sufficient subcooling will be provided in the downcomer to prevent flashing during transient operation.

Fouling - Component design shall consider the fouling on the salt side to be negligible. Water side fouling resistances are:

a. Preheater - 0.00002m-^{o}C/watt (.0001hr-^{o}F-ft^2/BTU);

b. Evaporator- 0.00002m-^{o}C/watt (.0001hr-^{o}F-ft^2/BTU);

c. Superheater- 0.000m-^{o}C/watt (.000hr-^{o}F-ft^2/BTU);

d. Reheater - 0.000m-^{o}C/watt (.000hr-^{o}F-ft^2/BTU).

Flow Induced Vibration - Flow induced vibration frequencies shall be safely below resonant frequencies at flow rates up to 110% of rated capacity.

3.3.7 Structural Design - The following structural design requirements shall apply.

Pressure Boundaries - Pressure boundaries will be designed to meet applicable codes.

Supports - Component supports and restraints shall be designed to account for deadweight and seismic loads.

Differential Expansion - Sufficient flexibility for differential thermal expansion shall be provided between tubes in the tube bundle so that the nominal stress in the tube bends will be in the elastic range.

Pressure Relief - Provisions shall be made for salt side pressure relief in the event of a heat exchanger tube leak.

Test Conditions - The SGS components shall be pressure tested as defined by the ASME Code on both salt and water/steam sides.

3.4 Control and Instrumentation Subsystem - The control and instrumentation subsystem shall provide the capability for manual or automatic control of the SGS and shall interface with the plant Master Control System (MCS) and Data Acquisition System (DAS), accepting commands from the MCS and providing data to the MCS and DAS. The control system shall provide the capability for manual or automatic start-up, normal operation, and shutdown of the steam generator subsystem. The control system will also issue emergency shutdown commands whenever critical process parameters exceed allowable operating limits.

3.4.1 Functional Requirements - The following capabilities shall be provided:

a. The control sysem shall automatically control the parameters listed below within the range indicated during normal operation.

Superheater outlet steam temperature	538°C ± TBD (1000°F ± TBD)
Reheater outlet steam temperautre	538°C ± TBD (1000°F ± TBD)
Steam supply pressure	12.5MPa ± TBD (1815 psi ± TBD)
Drum fluid level	66.7cm ± TBD (26.25 in ± TBD)
Evaporator salt supply temperature	Less than 482°C (900°F)
Preheater water supply temperature	238°C - TBD (460 °F - TBD)

Figure 3 is a flow diagram showing the control valves that are used to control the SGS. The function of and the method of controlling each control valve is described below:

1) The reheater salt-line valve is used to control the salt-flow through the heat exchanger. The control consists of a load-following, feedforward term plus a feedback term correcting any deviation in steam exit temperature;

2) The superheater salt-line valve controls 70% of the salt-flow to the evaporator and is therfore used to control the pressure of the supply steam with minimal interference to the reheater. As with the reheater, the control consists of a load-following, feedforward term plus a feedback term which here corrects any deviation in a supply pressure;

3) The steam attemperator valve controls the flow of saturated steam from the drum for mixing with the steam from the superheater. The purpose of this control is to maintain the temperature of the superheated steam using temperature feedback only;

4) The evaporator salt attemperator valve controls the flow of cold salt for mixing with the salt from the reheater and superheater. The temperature of the salt entering the evaporator is used as the feedback term to drive the valve such that the salt into the evaporator does not exceed 482°C (900°F);

5) The feedwater supply valve controls the flow of the water supply. A load-following feedforward term is used along with a feedback term correcting the fluid level in the drum;

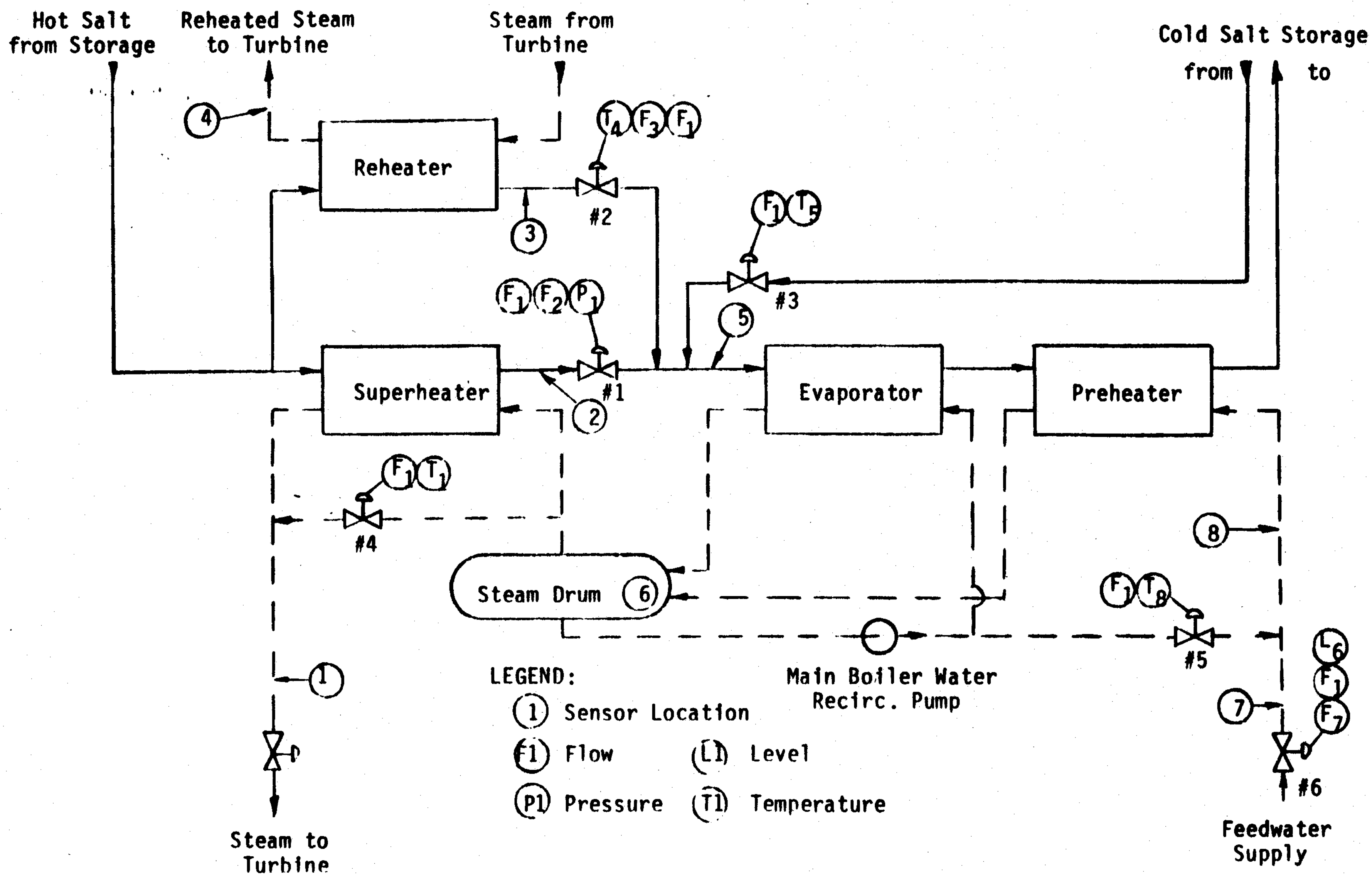


Figure 3 Steam Generator Control Schematic

6) The boiler water recirculation valve is used to ensure that the temperature of the preheater water supply does not fall below a specified value (TBD) high enough to limit local salt temperatures within the tube bundle to a safe minimum above the salt freezing point. As with the evaporator salt attemperator, temperature feedback of the water entering the preheater is used to generate the error signal.

b. The control system shall control the salt and steam systems in a safe and reliable condition under all modes of operation. Components/circuits shall have high reliability with redundancy incorporated where necessary to provide safe and reliable operation.

c. Manual control of the SGS will be possible during all operational modes. All control panel parameter displays and alarms will be easily read with all manual controls arranged for ease of operation. The following capabilities shall be available to the operator:

1. Capacity to change set points;
2. Display of system parameters and alarms;
3. Capability to accomplish start-stop and on-off functions.

d. Automatic control shall be possible during all operational modes except start-up and shut-down. The control system shall provide overall subsystem control and integration in the automatic mode.

e. During start-up, the SGS will be capable of a load increase of 2 to 3% of rated capacity per minute. When a preprogrammed sequence is followed, the control system will keep the operator apprised of the status of the start-up. The operator can interrupt the automated sequence at any point and complete the start-up manually. The system shall be capable of load changes between 30 to 110% of rated capacity automatically, and down to 10% with manual operation.

f. The control system shall monitor critical equipment parameters and operating conditions of the SGS. Upon detection of an abnormal condition which would compromise the safety of personnel or integrity of equipment, the control system will trigger an emergency shutdown of the system.

3.4.2 Major Components - The control and instrumentation subsystem consists of transducers, control valves and digital control equipment. The control system may be either a distributed or a centralized system.

A control console shall be provided for installation in the control room. Electronic control hardware shall be provided for installation in close proximity to the SGS to provide, as a minimium, the capability for transmitting data to and receiving commands from the control console in the control room. Communications between the control console in the control room and the equipment at the SGS shall be by high speed data highway.

The control system shall provide for ease of setting and changing control system gains, logic functions, set points, etc.

The control and instrumentation subsystem shall include transducers for the following measurements as a minimum.

Valve Being Controlled	Transducers
Superheater Salt-line	1) Turbine Steam Flow 2) Steam Throttle Pressure 3) Salt flow thru valve
Reheater Salt-line	1) Turbine Steam Flow 2) Steam exit Temperature 3) Salt flow thru valve
Feedwater Inlet Temperature Control	1) Preheater inlet temperature
Steam Attemperator	1) Steam temperature
Feedwater	1) Turbine Steam Flow 2) Feedwater Supply 3) Three independant drum levels 4) Optic transmission of water gauge to operator

3.5 Auxiliaries

3.5.1 Main Boiler Water Recirculation Pumps - The main boiler water recirculation pumps shall be vertical wet motor pumps designed specifically for boiler circulating water service. The pumps circulate water from the steam drum through the evaporator and back to the drum. Two half capacity pumps shall be provided each with a total developed head sized to overcome the piping and evaporator friction and static losses plus a suitable design margin. The pumps shall have a capacity of 409 m^3/hr (1800 gpm) for the 100 MW design and 204.5 m^3/hr (900 gpm) for the 50 MW design. Pump head shall be 18.3 m (60ft) for both designs.

3.5.2 Salt Piping, Valves, Trace Heaters and Insulation - Salt piping with design temperatures of 538 ^oC (1000 ^oF) and above shall be type 304 stainless steel. Salt piping with design temperatures between 427 ^oC (800 ^oF) and 538 ^oC (1000 ^oF) shall be ASTM A335 Grade P22 alloy steel.

Salt piping with design temperatures below 427 °C (800 °F) shall be ASTM A106 Gr B carbon steel. Pipe wall thickness shall be selected based on design pressure plus a suitable margin. Pipe size shall be selected based on providing reasonable fluid velocities and pressure loss.

Valves shall meet the code requirements of ANSI B16.34. Salt valves in piping with design temperatures of 538 °C (1000 °F) and above shall be stainless steel. Salt valves in piping with design temperatures between 427 °C (800 °F) and 538 °C (1000 °F) shall be alloy steel. Salt valves in piping with design temperatures below 427 °C (800 °F) shall be carbon steel.

Trace heaters shall be flexible type as manufactured by Chemelex or mineral insulated (MI) type depending on process temperature. Pipe insulation shall be calcium silicate with aluminum jacketing. Thickness of the pipe insulation shall be as indicated in Table 7.

3.5.3 Steam and Feedwater Piping, Valves and Insulation - High temperature steam piping above 371°C (700°F) shall be ASTM A335 Grade P22. Lower temperature steam piping and feedwater piping shall be ASTM A106 Grade B. Pipe wall thickness shall be selected based on design pressure plus a suitable margin. Pipe size shall be selected based on providing reasonable fluid velocities and pressure loss.

Valves shall meet the code requirements of ANSI B16.34. Steam valves in pipe with design temperatures above 371 °C (700 °F) shall be constructed of alloy steel. Valves in pipe with lower design temperatures shall be constructed of carbon steel.

Pipe insulation shall be calcium silicate with aluminim jacketing. Thickness of the pipe insulation shall be as indicated in Table 7:

TABLE 7 - Insulation Thickness

Operating Temperature	Pipe Size	Insulation Thickness
427°C (801°F) to 566°C (1050°F)	38 mm (1.5") and smaller	102 mm (4")
	51 mm (2") - 102 mm (4")	102 mm (4")
	127 mm (5") -203 mm (8")	127 mm (5")
	254 mm (10") and larger	152 mm (6")
261°C (501°F) to 427°C (800°F)	38 mm (1.5") and smaller	76 mm (3")
	51 mm (2") - 102 mm (4")	89 mm (3.5")
	127 mm (5") - 254 mm (10")	102 mm (4")
	305 mm (12") and larger	140 mm (5.5")
149°C (301°F) to 261°C (500°F)	51 mm (2") and smaller	76 mm (3")
	64 mm (2.5") and larger	89 mm (3.5")
66°C (150°F) to 148°C (300°F)	254 mm (10") and smaller	38 mm (1.5")
	305 mm (12") and larger	64 mm (2.5")

3.5.4 Structural Components - The structure in which the system components are located shall be designed in accordance with the AISC Manual of Steel Construction (Eighth Edition) and ACI Standard 318-77 (Building Code Requirements for Reinforced Concrete); this structure will be designed to make cost effective use of space, considering component size and weight, as well as potential seismic and wind loads. The berm for the salt drain sump shall be designed giving particular consideration to personnel safety during operation and maintenance.

4.0 INTERFACE DEFINITIONS

4.1 Turbine Generator

a.	Power	110 MWe (100 MWe net) or 55 MWe (50 MWe net)
b.	Throttle Temperature	538°C (1000°F)
c.	Throttle Pressure	12.5 MPa (1815 psia)
d.	Design Inlet Steam Flow Rate	96.3 kg/sec (764,000 lbs/hr) or 48.2 kg/sec (382,000 lbs/hr)
e.	Maximum Inlet Steam Flow Rate	105.9 kg/sec (840,000 lbs/hr) or 52.95 kg/sec (420,000 lbs/hr)
f.	Minimum Inlet Steam Flow Rate (30%)	28.9 kg/sec (229,000 lbs/hr) or 14.5 kg/sec (115,000 lbs/hr)
g.	Design Reheat Steam Flow Rate	83.3 kg/sec (661,000 lbs/hr) or 41.7 kg/sec (330,500 lbs/hr)
h.	Maximum Reheat Steam Flow Rate (110%)	91.6 kg/sec (727,000 lbs/hr) or 45.8 kg/sec (363,500 lbs/hr)
i.	Minimum Reheat Steam Flow Rate (30%)	25.0 kg/sec (198,000 lbs/hr) or 12.5 kg/sec (99,000 lbs/hr)
j.	Cold Reheat Steam Temperature	371°C (700°F)

k. Hot Reheat Steam Pressure — 3.5 MPa (500 psia)

l. Hot Reheat Steam Temperature — 538°C (1000°F)

m. Last Feedwater Heater Discharge Temperature — 238°C (460°F)

4.2 Hot Salt Supply

a. Flow vs. Head - Main Recirculation Pump:

100 MWe Size

Flow	Pressure
603 kg/sec (4.78 lb X 10^6/hr)	1.2 MPa (175 psi)

50 MWe Size

Flow	Pressure
301 k/sec (2.39 lb X 10^6/hr)	1.2 MPa (175 psi)

b. Salt Temperature: 565 ± 11°C (1050 ± 20°F)

4.3 Cold Salt Tank

a. Flow vs. Head - Recirculation Pump: (TBD)

b. Salt Temperature - 288 ± 11°C (550 ± 20°F)

4.4 Data Acquisition System - The SGS shall include transducers to provide signals to the plant Data Acquisition System (DAS). The DAS will provide the capability for data collection, storage, display, logging etc. for the whole plant. The required transducers are listed in Section 3.4. All of these signals shall be made available to the DAS. The signal interface between the SGS and the DAS is TBD.

4.5 Master Control System - The SGS control sytem shall provide the capability to accept commands from and transmit data to the plant Master Control System (MCS). The MCS will provide the capability for control of the total plant including emergency control. The commands and data to be transmitted between the MCS and the SGS and the signal interface are TBD.

5.0 ENVIRONMENTAL

5.1 General - The SGS shall be integrated into the design of a solar thermal central receiver power plant, and will be located near the turbine.

5.2 Operating Requirements - The system shall be capable of operating in and surviving appropriate combinations of the following environments:

a. Temperature - The plant shall be able to operate in the ambient air temperature range from -8 to 46^{o}C (17.6 to 114.8^{o}F). Performance requirements shall be met throughout and ambient air temperature range selected to be consistent with efficient plant operation.

b. Earthquake - Peak ground accelerations shall be as presented below per applicable UBC zone. Seismic design loads shall be calculated in accordance with the UBC 1979 conditions. The applicable UBC zone is 2.

Maximum Operational Ground Accelerations

UBC Zone	Peak Ground Acceleration(Average for Firm Soil Conditions)
2	0.07 g

5.3 Survival - The system shall be capable of surviving appropriate combinations of the environments specified below:

a. Wind - The plant shall survive winds with a maximum speed, including gusts of 40 m/s (90 mph), without damage.

b. Dust Devils - Dust devils with wind speeds up to 17 m/s (38 mph) shall be survived without damage to the plant.

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

d. Rain - The plant shall survive the following rainfall conditions:

Average Annual	-	340 mm (13.4 in.)
Maximum 24-hr rate	-	150 mm (6 in.)

e. Ice - The plant shall survive freezing rain and ice deposits in a layer 25 mm (1 in.) thick.

f. Earthquake - Peak ground accelerations shall be as presented below per applicable UBC zone. Seismic design loads shall be calculated in accordance with the UBC 1979 conditions. The applicable UBC zone is 2.

Maximum Survival Ground Accelerations

UBC Zone	Peak Ground Acceleration(Average for Firm Soil Conditions)
2	0.10 g

g. Sandstorm Environment - The plant shall survive after being exposed to flowing dust comparable to the conditions described by Method 510 of MIL-STD-810C.

5.4 Lightning Considerations - All electrical equipment enclosures, the energy storage tanks, horizontal piping and various points of the salt/steam heat exchanger subsystem shall be bonded to earth using ground straps and earth driven ground rods.

5.5 Water Quality Standards - The plant shall comply with the National Pollution Discharge Elimination Standards. The addition of the solar system should not affect that compliance.

6.0 PHYSICAL INTERFACES - Drawings to be provided.

7.0 FABRICATION REQUIREMENTS

7.1 Fabrication Quality Assurance - Quality Assurance for fabrication of the steam generator components shall be based on the requirements of the ASME Code.

7.2 Fabrication Process - The components of the steam generator subsystem shall be completely shop welded, assembled, stress relieved, pressure tested, and ASME Code stamped. Pressure testing may be performed as either a shop or field procedure but must precede Code stamping.

Heat Treatment - The need for heat treating after forming operations shall be evaluated and if necessary, temperatures, hold times, and heat up and cooldown rates in heat treatment procedures specified.

Surface Finish - The finish of surfaces subject to non-destructive examination shall be in accordance with Code requirements. Unless otherwise determined by the Supplier, all other surfaces shall be acceptable in the "as-formed" condition. Gross surface irregularities in pressure boundary material, such as dents or gouges, shall be ground to a smooth contour and shall not violate minimum wall thickness requirements.

Welding - Welding materials used for fabricating shall comply with the requirements of the ASME Code Section VIII, Section IX and applicable welding procedures.

7.3 Cleanliness - Care shall be taken to prevent unnecessary contamination of surfaces by dirt producing operations such as machining and grinding. Surfaces to be welded shall be clean and free of scale, rust, oil, grease, and other foreign material. Equipment shall be suitable for installation at the user's site without additional cleaning.

7.4 Spare Parts/Tooling - A list of spare parts for operation shall be developed. The list of spare parts to be stocked at the site shall include those parts and tools likely to be damaged or expended during delivery and/or operation.

7.5 Post-Fabrication Testing - Pressure vessels shall be hydrostatically tested in accordance with Code requirements.

7.6 Shipping and Handling - Shipping rigs and/or containers shall be provided to secure and protect components during shipment to the user's site. Open nozzles shall be sealed with temporary plugs or caps. Procedures for off-loading and lifting components shall be defined in the Operation and Maintenance Manual (see 9.2).

8.0 MAINTENANCE - Provisions shall be made for dry layup, cleaning, inservice inspection, and tube plugging for the components of the steam generator subsystem.

8.1 Layup - When steam generator components are shut down for short periods, adequate corrosion protection can usually be provided by blanketing the heat transfer surfaces with inert gas. For longer down periods, the components should be filled with treated water in addition to the inert cover gas. Procedures for wet and dry layup shall be defined in the Operation and Maintenance Manual (see 9.2).

8.2 Chemical Cleaning - Deposition on the water/steam side of steam generator components is generally produced by transport of corrosion products from the condensate and preboiler system. Depending on the quality of the user's water treatment practice, significant amounts of deposits may accumulate after several years of normal operation. This deposit build-up may contribute to corrosion of heat transfer surfaces and may eventually degrade the thermal-hydraulic performance of the equipment. Recommendations addressing cleaning solvents and procedures shall be provided in the Operation and Maintenance Manual (see 9.2).

8.3 Tube Plugging - Manway or handhole penetrations shall provide access to the water/steam side of tubesheets for plugging defective heat exchanger tubes. Plugged tubes shall be pierced to allow for draining salt, and the design and installation of plugs shall meet all Code pressure boundary requirements.

8.4 In-Service Inspection - Manways or handholes for visual inspection of components shall be provided in accordance with code requirements. Access shall be provided for in-service inspection of tubing (for example, by eddy current or ultrasonic examination techniques) if desired by the user. Procedures for tube inspection shall be defined in the Operation and Maintenance Manual (see 9.2).

9.0 SPECIAL REQUIREMENTS

9.1 Certification - Marking and certification of pressure vessels shall conform with Code requirements.

9.2 Operation and Maintenance Manual - An operation and maintenance manual shall be provided. This manual shall include instructions for:

a) Unloading and receipt inspecton;
b) Installation and post-installation inspection and check-out;
c) Testing, startup, and operation;
d) In-service inspection;
e) Preventive maintenance and trouble shooting;
f) Corrective maintenance and post-correction check-out;
g) Limits and precautions to be taken during filling, testing, startup, shutdown, and layup operations.

9.3 Safety - The steam generator subsystem shall be designed to minimize safety hazards to operating and service personnel, the public, and equipment. Electrical components shall be insulated and grounded. All components with elevated temperatures shall be insulated against contact with or exposure to personnel. Any moving elements shall be shielded to avoid entanglements, and safety override controls/interlocks shall be provided for servicing.