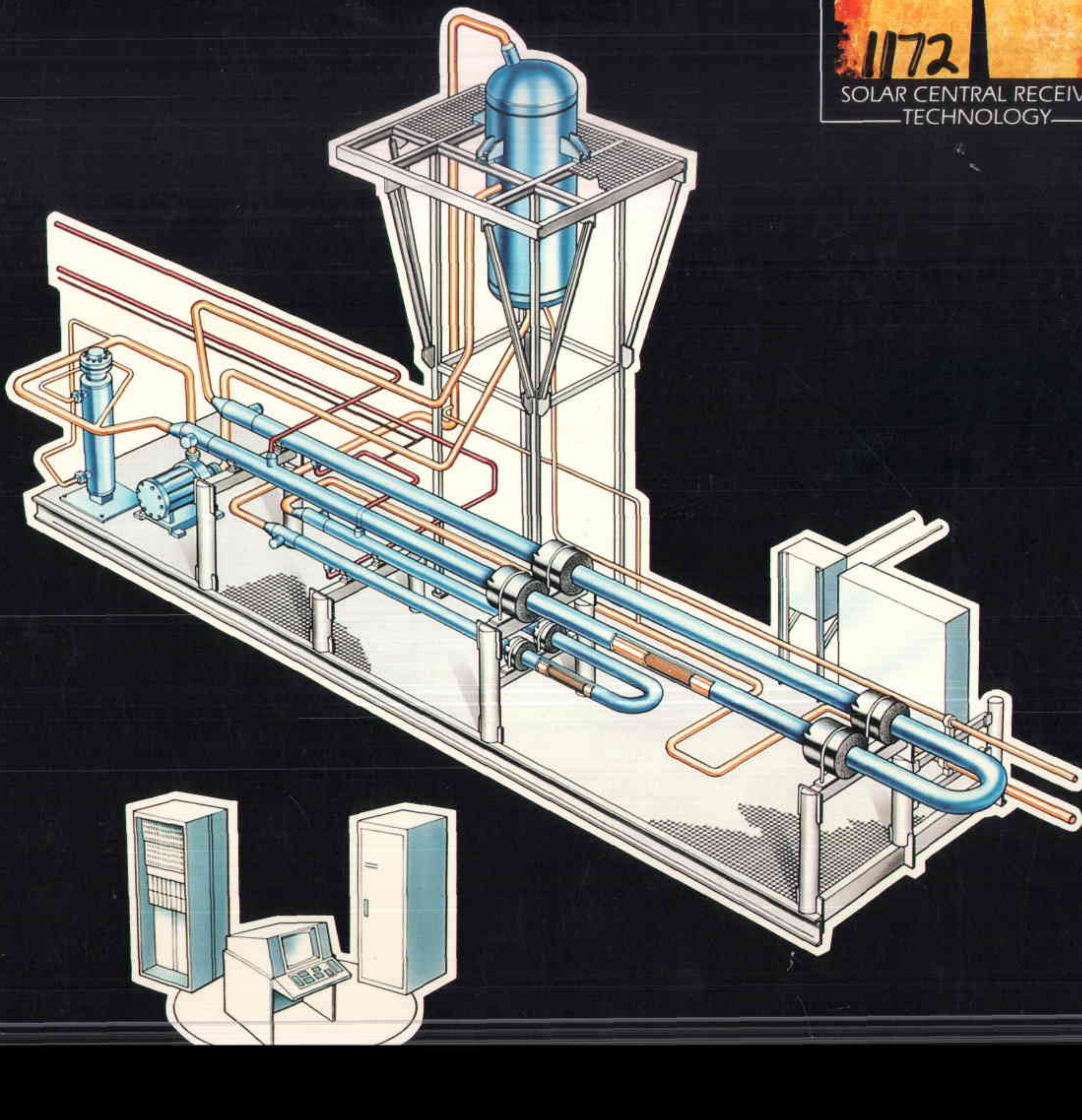
Molten Salt Electric Experiment
Steam Generating Subsystem



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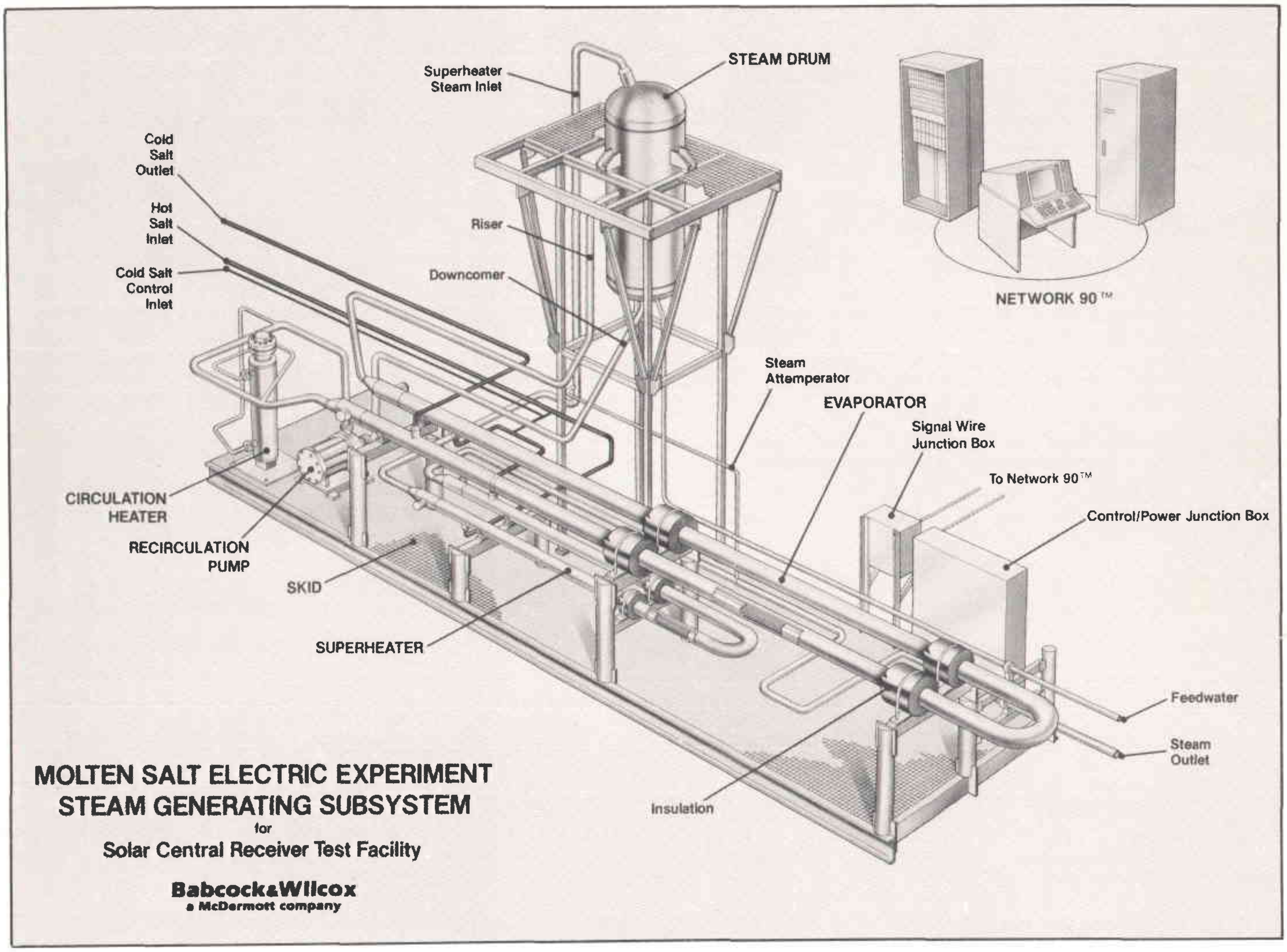
SOLAR CENTRAL RECEIVER
TECHNOLOGY



The steam generating system depicted above was supplied by Babcock & Wilcox for use in the Molten Salt Electric Experiment (MSEE). The background to the MSEE and B&W's involvement in the program is explained in this paper.

Molten Salt Electric Experiment Steam Generating Subsystem

Program Overview and B&W Involvement

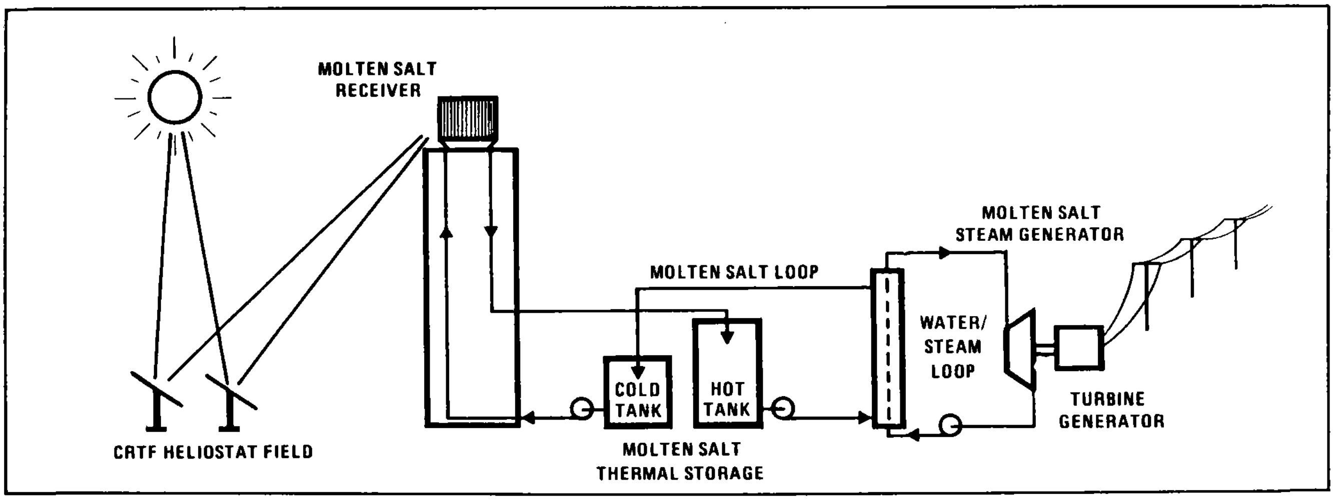
MOLTEN SALT ELECTRIC EXPERIMENT (MSEE)

The MSEE, constructed at Sandia National Laboratories' Central Receiver Test Facility (CRTF) in Albuquerque, New Mexico, integrates the major components of a Molten Salt Solar Thermal Central Receiver (STCR) power generation system. These include the collector field, receiver, thermal storage units, steam generator, turbine-generator, and integrated control system.

The MSEE is the second STCR system to be constructed in the United States, and the first U.S. system to use a non-phase-change working fluid (Solar One, the first STCR system to operate in the U.S., uses water/steam as the working fluid).

The MSEE produces electrical power which is dispatched into the Kirtland Air Force Base electric grid. An illustration of the system concept is shown in Figure 1.0.

Figure 1.0 - Molten Salt Electric Experiment (MSEE) System Concept



It is expected that the MSEE program, begun in late 1981, will demonstrate that a molten salt based STCR system is efficient and workable. Hopefully the demonstration will stimulate more intense interest in the technology, showing that molten salt STCR systems represent a credible alternative to oil-fired power generation.

The program is expected to formally terminate in mid-1984, after which the CRTF may be used for alternate working fluid experiments or for extended development of molten salt technology. Organizations involved in the MSEE program include those listed in Table 1.0.

Table 1.0 - Project Participants

Arizona Solar Energy Commission	Martin Marietta
Arizona Public Service Company	McDonnell Douglas
Babcock & Wilcox	Olin
Black & Veatch	Pacific Gas & Electric Company
Department of Energy (U.S.)	Sandia National Laboratories
Electric Power Research Institute	Southern California Edison Co.
Foster Wheeler	Stearns-Roger

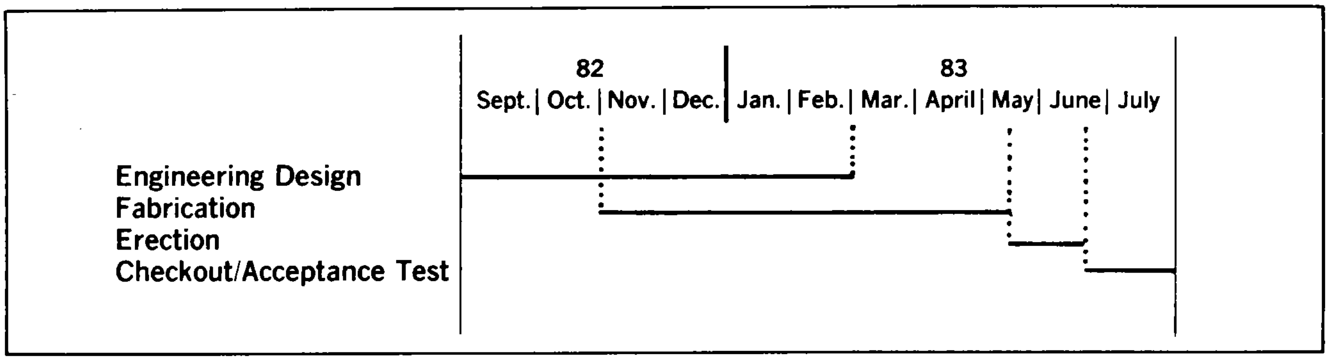
MSEE STEAM GENERATING SUBSYSTEM (SGS)

The MSEE steam generating subsystem, which is depicted on the front cover, represents a pioneering application in the use of molten nitrate salts for the production of electric power. Babcock & Wilcox designed, fabricated, and erected the complete subsystem including the components listed in Table 2.0. As shown in Table 3.0, B&W contracted for the skid-mounted SGS unit in September, 1982, and delivered the system to the site on May 16, 1983. The unit was checked out and ready to operate in late August, 1983.

Table 2.0 - Major MSEE SGS Components

° Evaporator	° Insulation/Lagging
° Superheater	° Salt-Side Heat Tracing
° Steam Drum	° Instrumentation
° Boiler Water Recirculation Pump	° Control System
° Circulation Heater	° Electrical System
° Salt-Side Piping/Valves	° Water-Side Piping/Valves
	° Skid

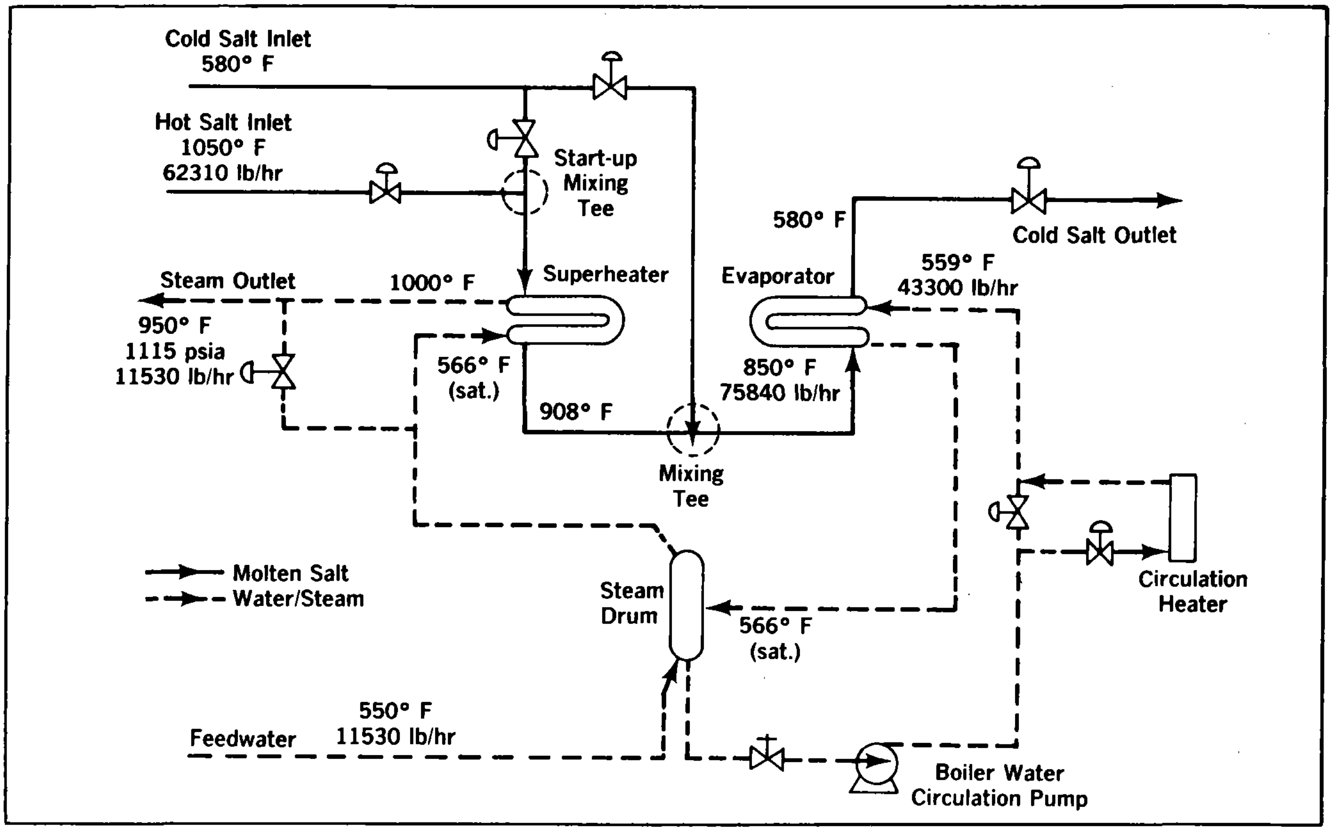
Table 3.0 - MSEE SGS Project Schedule



The MSEE SGS schematic is shown in Figure 2.0. A mixture of molten salts ($NaNO_3$ and KNO_3) enters the system at 1050°F with a mass flow rate of 62,310 pounds/hour. The salt is attemperated with cooler salt at 580°F to achieve proper input conditions for both the superheater and evaporator. Feedwater is heated in the system to form steam, which is transported to the turbine generator at 950°F, 1,115 psia, with a mass flow rate of 11,530 pounds/hour. The cooler salt is piped back into the thermal storage subsystem. The SGS is designed for complete control by a Bailey Controls Company Network 90 system.

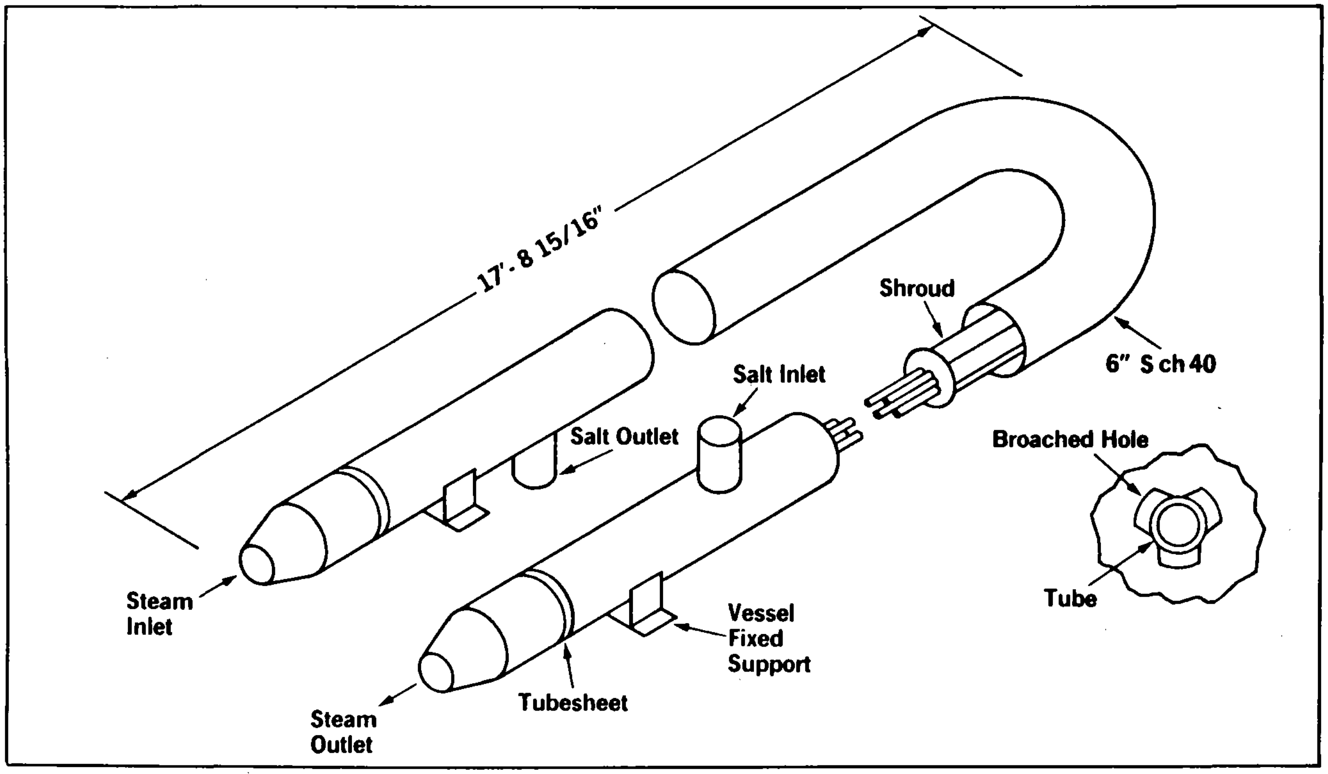
Forced recirculation of boiler water, together with using ribbed-tube evaporator construction ensures that departure from nucleate boiling (DNB), and resultant tube dryout does not occur.

Figure 2.0 - MSEE SGS Schematic



An illustration of the SGS superheater appears in Figure 3.0. Major features shown are typical of the evaporator construction. Both units are designed according to the requirements of ASME Code Section VIII, Division I. Design Characteristics and benefits of the design are summarized in Table 4.0.

Figure 3.0 - MSEE SGS Superheater



Design of the more critical SGS components was based on the full size component concepts developed by B&W in an earlier contract from Sandia National Laboratories. Prototypicality was a major design objective of the MSEE SGS program. Both heat exchangers, for instance, use the U-shell, U-tube configuration, typical of the units designed by B&W for both the APS Saguaro Repowering plant and SCE's Solar 100 plant.

Table 4.0 - MSEE SGS Evaporator/Superheater

Design Characteristics and Benefits

- o U-Tube, U-shell design
  - Tube-to-tube and shell-to-shell flexibility
  - Separate inlet and outlet tubesheets
  - Separate water/steam side inlet and outlet plenums
- o Long flow, countercurrent flow design
  - Efficient heat transfer
  - Good salt side pressure drop characteristics
- o Multi-lead ribbed tubing
  - Maintains nucleate boiling at a higher steam quality than smooth tubing for a given pressure, heat flux, and mass flux
  - Absence of DNB minimizes the potential for under-deposit corrosion
  - Permits lower circulation rate which results in less pumping power and therefore better cycle efficiency
- o Shroud and support plate design
  - Shroud provides uniform salt flow and uniform heat transfer to all tubes
  - Support plate pressure drop promotes good salt flow distribution in tube bundle
  - Shroud/support plates reduce salt stratification potential
- o Shroud by-pass restrictors
  - Limits salt by-pass of tube bundle
- o Tubesheet thermal baffles
  - Reduces thermal gradients at the tubesheet-shell juncture
- o Drainability and ventability
  - Gravity drain through system piping

Babcock & Wilcox hopes to gain important design and operating experience with the MSEE SGS. Combined with the insight we will gain from building and operating other planned CRTF experimental hardware, this experience will become part of the foundation for our involvement in planned future full size STCR power plants.

B&W has received sixteen Solar Thermal technology contracts since 1975. Solar Thermal work is primarily carried out in B&W's Nuclear Equipment Division. Located in Barberton, Ohio, the Nuclear Equipment Division's 2,500 employees are also engaged in designing and building equipment for use in Naval Nuclear propulsion systems, Ballistic Missile defense systems, commercial Nuclear Steam systems, Liquid Metal Fast Breeder Reactor systems, and fossil-fueled power generation systems.

Babcock & Wilcox Solar Thermal Central Receiver Contract List . . .

Project No.	Working Fluid	Component	Span	Customer	Application
Description: Develop baseline design for 55 MWt Plant. Develop conceptual and detail materials, fabricate, instrument, and erect on-site solar subassemblies.					
1	W/S	Receiver	1975/1977	Honeywell	All
Description: Engineering trade-off studies and analyses to select and define a subsystem design.					
2	Na	Heater	1978/1979	Rockwell	Hybrid
Description: Review of preliminary specifications, parametric analyses, selection of commercial configuration, interface requirements, assessment of 100 MWe commercial scale advanced water/steam system, and development of plan.					
3	W/S	Receiver	1979	Sandia	All
Description: Conceptual design of 33 MWe Receiver.					
4	W/S	Receiver	1979/1980	Black & Veatch	Repower
Description: Prepare & deliver a cost and schedule for the design and construction of a 60 MWe sodium heated steam generating system.					
5	Na	Steam Gen.	1980	General Electric	Repower
Description: Complete studies of existing or planned thermal energy storage systems with objectives being cost and performance improvement. Conceptual design of a commercial scale system using preferred concept.					
6	—	Storage	1980	Sandia	All
Description: Develop conceptual design and provide cost and performance data for system & subsystem tradeoff studies. Estimate performance of receiver and fossil fired steam generator.					
7	W/S	Receiver	1980	Black & Veatch	Cogeneration
Description: Specification and preliminary design for 100 MWe salt steam generating system, and recommendation of subsystem experiment program.					
8	Salt	Steam Gen.	1981/1982	Sandia	All
Description: Develop specifications, select steam cycle & component configurations, & prepare 100 MWe					
9	Salt	Receiver	1981/1982	Sandia	All
Description: Develop systems & components level specification, evaluate configuration improvements, select preliminary design.					
10	Salt	Steam Gen. & Receiver	1981/1982	Martin-Marietta	Repower
Description: Develop systems & components level specification, evaluate configuration improvements, select preliminary design.					
11	W/S	Receiver	1981/1982	Stone & Webster	Repower

Babcock & Wilcox Solar Thermal Central Receiver Contract List . . .

Project No.	Working Fluid	Component	Span	Customer	Application
		Description Prepare preliminary design of a receiver and steam generator subsystem for use in a pilot plant in Saudi Arabia.			
12	Salt	Receiver & Steam Generator	1982	Martin-Marietta	Desalination
		Description Design, build, and erect a 3.1 MWt steam generating (SGS) subsystem for use in a Molten Salt Electric Experiment. Provide a complete SGS control system.			
13	Salt	Steam Generator	1982/1983	Sandia	All
		Description Prepare preliminary design of a 41 MWe receiver.			
14	W/S	Receiver	1982/1983	Stone & Webster	Repower
		Description Prepare preliminary design of a 60 MWe receiver and steam generating system.			
15	Salt	Receiver Steam Generator	1982/1983	Martin-Marietta	Repower
		Description Provide site support to a Molten Salt Electric Experiment.			
16	Salt	—	1983	Sandia	All
		Description Prepare conceptual design of an experimental process to use solar thermal energy to destroy hazardous waste.			
17	—	System	1983/1984	U.S. DOE	PCB Destruction
		Description Conceptual design and cost estimate for a 20MWe steam generator and receiver system.			
18	Salt	Receiver & Steam Generator	1983/1984	Cambrian Engineering	Stand Alone Power
		Description Design, build, and erect a 5MWe model receiver and design and perform pump and valve loop experiments.			
19	Salt	Receiver & Pumps & Valves	1984/1986	Sandia	Repower
		Description System design study for the production and regeneration of activated carbon.			
20	Salt	System	1984/1985	Sandia	Fuels & chemicals

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