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# The Shenandoah Solar Total Energy Project

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# The Shenandoah Solar Total Energy Project

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## Abstract

The design and construction of the world's first solar total energy plant in the private sector has been completed and checkout is underway. The project, a major element of the Department of Energy's Solar Thermal Program, is the Solar Total Energy Project at Shenandoah, Georgia. During its operational phase, the solar plant will furnish electrical power, process steam, and other thermal energy to a nearby knitwear factory.

The solar system consists of a collector field containing 114 parabolic dish collectors which supply thermal energy at 400° C to drive a 400 kW multi-stage Rankine cycle turbine generator. Some steam is extracted from the turbine and supplied to the knitwear manufacturing processes. The system will be grid-connected, and the Georgia Power Company, through a cooperative agreement with DOE, is a participant in the project.

The report contains: (1) a description of the system and components being installed; (2) a summary of performance testing of the extraction turbine and of four prototype parabolic dish collectors; and (3) a discussion of design considerations and insights which have general applicability to solar thermal system designs.

# FOREWORD

The material in this report was presented at the 1981 International Solar Energy Conference, "Solar Rising," and has been published in their proceedings. This publication is intended to widen the distribution to include other interested persons within the solar community; particularly with regard to thermal dish technology and solar total energy (cogeneration) applications.

A comprehensive set of Shenandoah project reports dealing with system performance modeling, summaries of fabrication and construction phase experiences, actual costs, checkout and startup experiences, as-built system descriptions, and operational phase test and evaluation plans will be published and distributed during 1983.

## Contents

## System Description

The Solar Total Energy Project at Shenandoah, Georgia, (Figure 1), is a prototype of a cascaded energy system using solar energy. Through system operation, definitive performance, cost, and operational and maintenance data will be obtained and an industrial solar total energy capability evaluated.

Shenandoah, about 35 miles south of Atlanta, is an industrial-residential planned community. Sun right easements have been obtained on the land bounding the STES site to prevent future shading of the collector field.

The system has the flexiblity to operate in either a stand-alone or peak-shaving mode while providing the electrical, steam, and heating and cooling needs of the nearby Bleyle Knitwear Plant.

The STES consists of three major loops: solar collection and storage, power conversion, and thermal utilization, Figure 2.

One hundred and fourteen parabolic dish solar collectors, each seven meters in diameter, connected in parallel branches, form the collector field with a peak energy delivery rate of 2.7 MWt (MMBtu/hr). Energy is either transported to storage or supplied to a steam generator by a high-temperature silicone heat-transfer fluid. The temperature range of the solar collector field is 260°C (500°F) inlet, 400°C (750°F) outlet. To permit operation during transient weather conditions, a thermal storage capacity of 3 MWh (10 MMBtu) has been incorporated in the system. The solar collector is a 7-meter diameter paraboloid with a cavity receiver with 45 cm (18 in.) aperture. Reflected solar energy is focused onto a coil of blackened stainless steel tubing within the receiver. The total field temperature rise of 140°C (250°F) occurs in each receiver.

The power conversion loop employs a high efficiency, high speed (42,500 rpm) 4-stage steam, Rankine-cycle turbine, capable of providing 400 kWe. Process steam for the knitwear plant is extracted at an intermediate turbine stage. In a later phase, thermal energy from the turbine exhaust will be transferred to a thermal utilization loop for cooling of the Bleyle plant. An absorption air conditioner, operating on 110°C (230°F) steam will provide chilled cooling water. The solar plant will be connected to the Georgia Power Company grid so that electrical power production in excess of or less than the Bleyle plant demand can be accommodated for optimum solar economics. As a control system experiment, the plant can also be operated at any set-point output, in a load-following mode, or in a peak-shaving mode. Table 1 lists the energy capabilities of the STES.

TABLE 1

STES Energy Output Capacity

| | |
|---|---|
| Electrical: | 400 kWe |
| Cooling: | 900 kWt (257 tons) |
| Process Steam: | 630 kg/hr (1380 lbs/hr, 114 psia, 347°F) |

High-temperature storage is provided in an ASME code carbon steel tank. The tank is 3.0 meters (10 feet) in diameter and 5.5 meters (18 feet) high with a capacity of 42 cubic meters (11,000 gallons). Thermal energy storage is provided in 400°C (750°F) heat transfer fluid in a thermocline mode. Approximately 1 hour equivalent of collector energy output is provided in storage for solar transient conditions. Storage for extended operation is not intended.

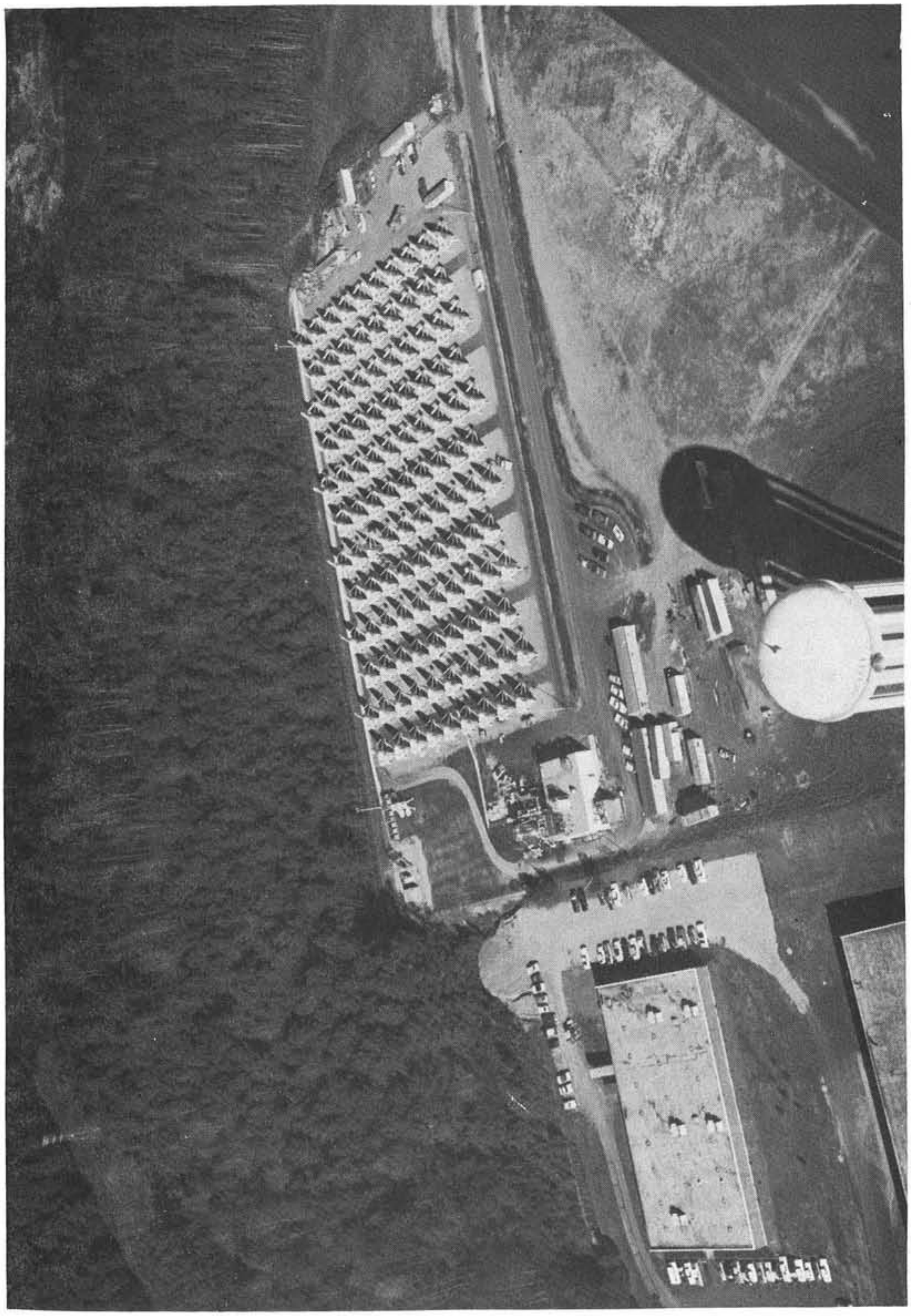

Figure 1

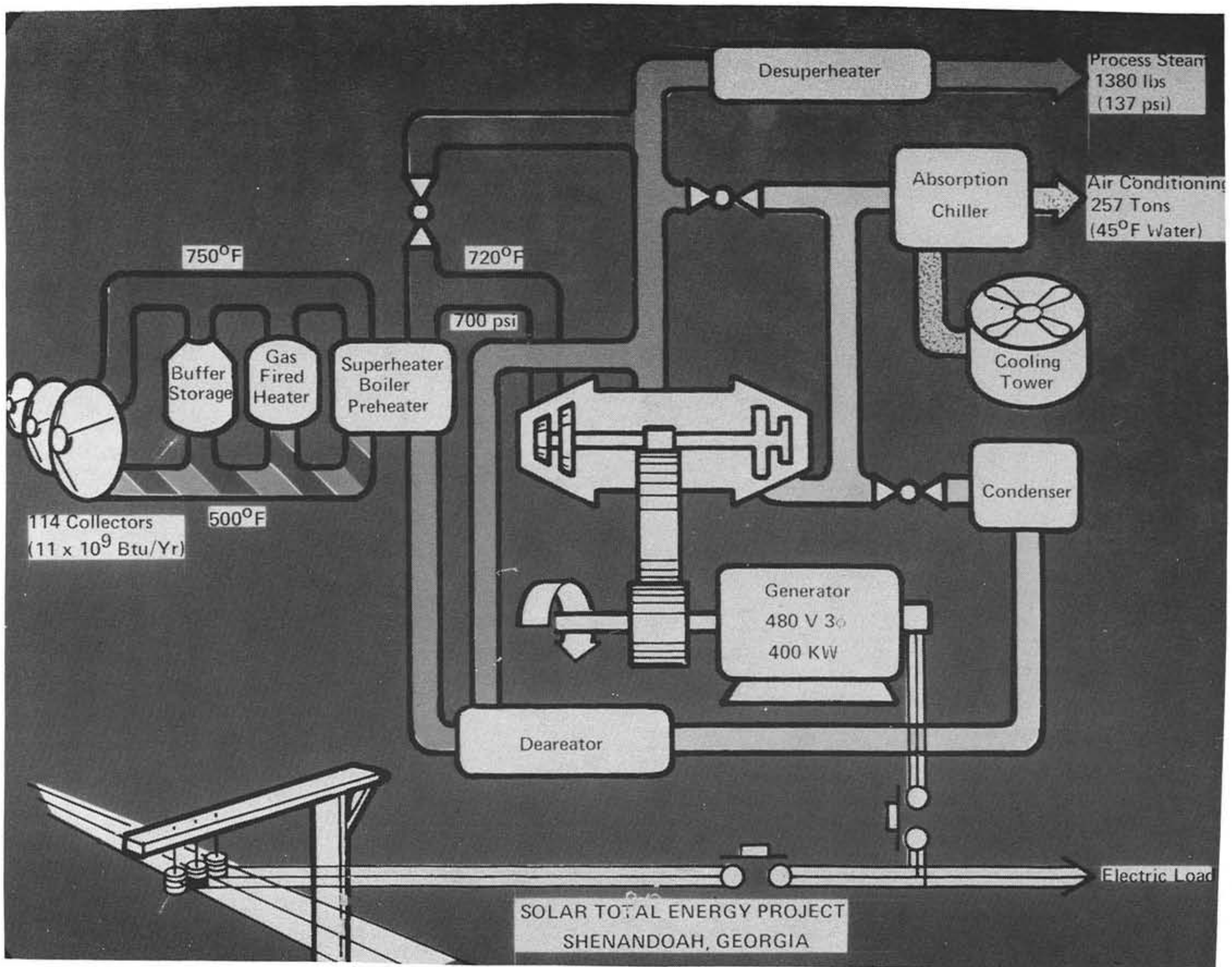
Desuperheater
Process Steam
1380 lbs
(137 psi)
Absorption
Chiller
Air Conditioning
257 Tons
(45°F Water)
750°F
720°F
700 psi
Cooling
Tower
Buffer
Storage
Gas
Fired
Heater
Superheater
Boiler
Preheater
Condenser
114 Collectors
(11 x 10⁹ Btu/Yr)
500°F
Generator
480 V 3ϕ
400 KW
Deareator
Electric Load
SOLAR TOTAL ENERGY PROJECT
SHENANDOAH, GEORGIA

Figure 2

The Control and Instrumentation Subsystem initiates, regulates, and terminates collector tracking, energy storage, power generation, and thermal utilization for heating and cooling of the Bleyle plant. When operating in the peak-shaving mode, the CAIS will monitor and regulate the generation of power to satisfy steam requirements.

The CAIS consists of a central control console, a central minicomputer, and two remote microprocessor control units. The control system has the flexibility to be operated in a manual or automatic mode, and permits the operator to monitor or control the system functions from the control panel. Color graphic cathode ray tubes are employed for data display. Data archiving is performed with magnetic storage tapes and in hard copy form on a computer line printer. The remote microprocessors are programmable from the central minicomputer to allow a high degree of system control and versatility.

## Qualification Test Summary

### Parabolic Dish Collectors

A prototype collector array, simulating a portion of the STEP, was installed and tested at Sandia National Laboratories in Albuquerque. The facility has four 7-meter diameter collectors and a heat transfer loop. Pumps, valves, tubing/piping, insulation, controls and other components specified for the STEP were included.

The facility provided installation experience, design, and operation data and verification of design. Some of the major results are:

- Mechanical and structural designs were evaluated, modified, where necessary, and retested in several instances, and the collectors qualified.
- Receiver aperture plate and optical sensors overheated during normal operation and were redesigned using quartz cloth thermal protection.
- The original reflector surface (RTV) proved unsatisfactory and a change to FEK 244 was developed and tested.
- The receiver design was switched from a circuit of two parallel tubes to a single tube design to improve flow characteristics.
- The heat transfer fluid, Syltherm 800, proved satisfactory at 750°F operating temperature.
- The hybrid computer and optical tracking system was validated.
- Stagnation testing, simulating loss of tracking power while in track, was performed and damage assessed.

Peak overall efficiency approached 62 percent for the collector with the FEK 244 reflector. Total aperture area of the collector is 38.5 $m^2$ (414 $ft^2$). Weight per aperture area (less concrete counterweight—2650 lbs) is 52 $kg/m^2$ (10.6 $lbs/ft^2$).

### Turbine/Generator

The turbine/generator was specifically designed and developed for the Shenandoah project by Mechanical Technologies, Inc. of Albany, New York, under contract to Sandia National Laboratories (SNL) after it was determined that commercially available small-size turbine generators could attain thermal to electric efficiencies of only 7 to 11 percent at the system operating condition of 382°C and 4.8 MPa (720°F, 700 psia). The MTI turbine provides thermal to electric efficiencies up to 15 percent. The turbine/generator acceptance testing has been completed. Daily startup and operating tests were run prior to shipment to the site.

## System Design Considerations and Insights

### Foundations

Initial designs of the foundations for the solar collector specified piers of up to 28 inches diameter with 21 feet embedded length using initially provided soils data.

Tests were performed at the Site to evaluate the soils characteristics by actual test of piers. The governing criteria of failure was .64 cm (.25 inch) deflection at the ground level with 2727 kg (600 lbs) applied horizontal load at (4 feet, 9 inches) above ground and 8182 kg (18,000 lbs) uplift capacity. Test piers were 46 cm (18 inches) in diameter with embedded lengths of 1.83 m (6 feet), 2.74 m (9 feet), and 3.65 m (12 feet). The test data show a 45.7 m (18 inches) diameter pier, adequately reinforced with an embedded depth of (6 feet) is capable of withstanding the load. To account for varying soil conditions for the 20 $km^2$ (5 acre) field, and construction factors, the caissons were built to 20 inches diameter and 10 feet embedded length. The design provides a factor of safety of 2 based on test data.

- Foundation tests on Site are highly recommended where large numbers of foundations are required.
- Sufficient engineering effort should be provided to minimize the labor effort by well designed tools and fixtures.

### Reflective Structure and Surfaces

As part of the development effort, the reflector materials, selected from a large matrix of candidate materials, were tested in a collector configuration. Materials tested were:

- Aluminum chemically brightened with RTV coating.
- Aluminum chemically brightened with clear anodize.
- Aluminum laminated with FEK 244 aluminized film.

The RTV surface exhibited a strong affinity for dust and cleaning was difficult requiring detergent wash, scrubbing, and a Freon cleaning agent to remove water spots.

The anodized aluminum initially had reflectance values comparable with the RTV coated reflector. The FEK 244 reflector showed a dramatic increase in collector efficiency. This experience showed that:

- Laboratory-size test samples are not necessarily indicative of full-scale performances in an actual environment. Results may be misleading.
- Reflector surface cleaning should be translated from small samples to large areas with care.

### Piping System

It is essential and cost-effective to devote more design effort and capital investment to the piping system of a solar thermal plant than has traditionally been invested in conventional thermal transport piping systems. This is true primarily because of the high value of thermal quality in a solar system. Whereas little penalty is associated with operation of a flame-fired heater at higher temperatures than necessary, a solar collector field's efficiency is reduced as operating temperature is increased. Other facts affecting this philosophy are the diurnal operating condition of solar collector systems and the relatively high value of solar collected energy. The latter point will increasingly influence the designs of conventional systems as well.

The following comments typify the application of such insights and the means by which they have been implemented in the Shenandoah design:

- o Daily thermal cycling and low viscosity oils can cause leaks to appear sooner than in systems with steady-state temperatures.
- o Welding and compression fittings provide much more reliable leak-tight joints than do screwed joints.
- o Leaking joints can cause soaked insulation, greatly increased thermal conductivity, fire hazards, and an unsightly appearance.
- o Penetrations in pipeline insulation for valves, supports, instrumentation, fittings, and maintenance should be minimized to reduce thermal losses.
- o Piping, valves, pumps, and fittings must be of an energy conservative design and must be well insulated.
- o Ease and speed of maintenance access is less important for a solar system than for a "round-the-clock" plant because maintenance can be performed when the sun is not shining.
- o The Shenandoah design has eliminated literally hundreds of insolation valves and other "convenience" fittings in favor of reduced capital cost and thermal losses.
- o The Shenandoah design has incorporated welded rather than flanged fittings at most valves.
- o Low thermal density insulation is cost effective by providing more usable energy off the field.
- o Nesting piping in a common insulation is thermally more efficient than individually insulated pipes.

## Summary

A solar total energy system that uses parabolic dish collectors is being constructed that will have the capability to provide various energy forms, electrical and thermal, to a contemporary industrial facility with 25,000 square feet of floor space. Collector tests have demonstrated that existing fabrication techniques could produce an efficient parabolic dish solar collector. Performance measurements on the 7-meter dish have shown that the specified fabrication tolerances and performance of the full-scale unit can be realized in hardware.

Acknowledgement

The information presented is the results of efforts by the U.S. Department of Energy. Georgia Power Company, through Cooperative Agreement with DOE, participates in the project by providing the Site and cost-shared services. General Electric, under DOE contract, provided the collector and initial system design. Sandia National Laboratories provides technical and management support to the DOE.

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