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Midtemperature Solar Systems Test Facility Test Results: Effects of Severe Hailstorm on August 9, 1978

Thomas D. Harrison

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MIDTEMPERATURE SOLAR SYSTEMS TEST FACILITY TEST RESULTS: EFFECTS OF SEVERE HAILSTORM ON AUGUST 9, 1978

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ABSTRACT

This report discusses the effects of a severe hailstorm August 9, 1978, over an area encompassing the DOE/Sandia MSSTF in Albuquerque, NM. At the time of the hailstorm the MSSTF contained line and point-focusing collectors for converting solar energy to thermal energy, as well as the fluid loops and thermal storage facilities necessary for an STE system and the CMTF. The MSSTF also contains a variety of photovoltaic devices for converting solar energy directly to electrical energy. The effects of the hail on the equipment in each subsystem are described.

ACKNOWLEDGMENT

I gratefully acknowledge the assistance of members of the Sandia Laboratories and EG&G, Inc. staffs of the MSSTF project (particularly L. E. Torkelson and R. M. Workhoven) and the Sandia staff of the PASTF project in gathering the data and photographs that comprise this report.

CONTENTS

ILLUSTRATIONS

A GLOSSARY OF ABBREVIATIONS AND ACRONYMS

cw	clockwise
CMTF	Collector Module Test Facility
CPC	Compound Parabolic Concentrator
DCPC	Dielectric-Filled Compound Parabolic Collector
DOE	The U.S. Department of Energy
FFMC	Faceted Fixed-Mirror Collector
FMSC	Fixed-Mirror Solar Collector
GE	General Electric
MDT	Mountain Daylight Time
MSSTF	Midtemperature Solar Systems Test Facility
OCLI	Optical Coating Laboratory, Inc.
PASTF	Photovoltaic Advanced Systems Test Facility
SLATS	Solar Linear Array Thermal System
STE	Solar Total Energy
STF	System Test Facility
T-66	Therminol 66 heat-transfer oil

Directions

E-W	East-west
NNW	North-northwest
N-S	North-south
SSW	South-southwest
WNW	West-northwest

MIDTEMPERATURE SOLAR SYSTEMS TEST FACILITY TEST RESULTS: EFFECTS OF SEVERE HAILSTORM ON AUGUST 9, 1978

Introduction

This report documents the effects of a severe hailstorm on components and subsystems in the DOE/Sandia MSSTF. The hailstorm, the worst observed at the MSSTF since it became operational in 1975 and also the most severe in Albuquerque, NM, within the last 5 years, occurred the night of August 9, 1978. In 1973, a hailstorm of similar intensity struck ~ 6 km northwest of the MSSTF site.

The MSSTF at Sandia Laboratories in Albuquerque, NM, was constructed in support of the DOE's national Small Solar Thermal Power Systems Program. Its objective is to develop technology for applying solar energy onsite to electrical power generation and other higher temperature applications such as solar irrigation and industrial process heat. At 32 kWe, the MSSTF is the largest solar electric power plant in the United States and also represents the world's first application of the solar total-energy concept to an actual load, an 1100-m^2 office building. The MSSTF tests major components such as concentrating solar collectors, thermal storage systems, and organic Rankine-cycle turbine/generators and develops practical system-level strategies based on operating experience. Results of this testing are disseminated to people and companies in the U.S. and to several government agencies and research facilities outside the U.S.

The MSSTF (Figure 1) consists of two separate facilities, the CMTF and the STF. In addition, area occupied by the MSSTF is shared by the PASTF.

The CMTF (Figure 2) is designed to obtain thermal and optical performance data for prototype collectors of up to ~ 45 m^2 in aperture. This facility presently incorporates three separately controlled fluid loops capable of testing three different collectors simultaneously. The three test stations use T-66 heat-transfer oil to 315°C, high pressure water to 330° C and 18.3 MPa, and low-pressure water to 110° C and 0.51 MPa. This latter loop is being modified to provide additional capability to test with heat-transfer oils to 425° C.

The STF consists of solar collector fields, high- and low-temperature thermal storage facilities, an electrical power generation subsystem, a lithium-bromide absorption air conditioner, an instrumentation and control system, a weather station, and a cooling tower. The STF can produce 32 kWe and about 200 kWth. It is configured so that individual components can be evaluated alone or interacting with other items of equipment to supply electrical and thermal energy to a nearby 1100-m^2 office building.

Figure 1. DOE/Sandia MSSTF: Aerial View from West, September 1978

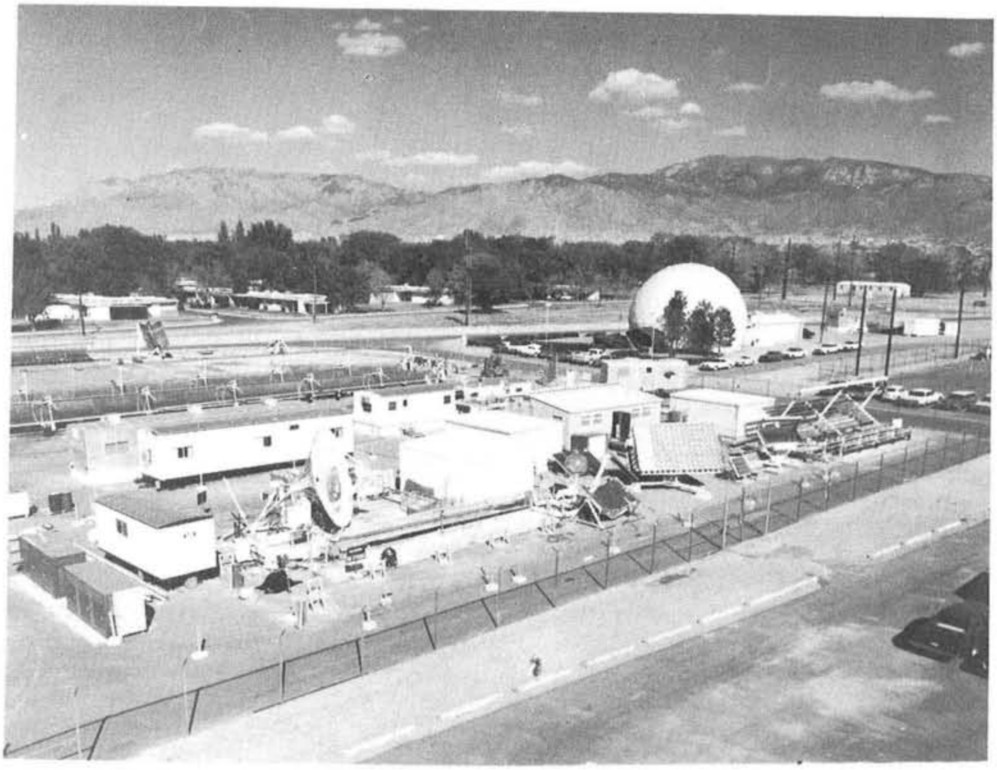

Figure 2. CMTF: Aerial View from South, February 1978

Description of Hailstorm

Between 8:30 and 9 p.m. on August 9, 1978, an intense, highly localized hailstorm struck the area of the MSSTF. The time of the storm was fixed by eyewitness accounts from the security force and by records from the meteorological station in the MSSTF. Dents in thin aluminum covers protecting insulated pipelines indicate that the diameter of the hailstones varied from 12 to 19 mm. Based on these dents and on a record of wind velocities (Figure 3), it was also determined that most of the hail came from the west and south. That there was a large quantity of hail was evidenced by drifts up to 20 cm deep at 8 a.m. the next morning even though recorded temperatures were never less than 18° C.

This hailstorm was the most severe observed at the MSSTF since its inception in 1975. However, according to the U.S. Weather Service, a hailstorm of similar intensity occurred in an area ~ 6 km WNW of the MSSTF in 1973. The Weather Service also stated that the probability of a second and similar hailstorm in the same area as the first is very low.

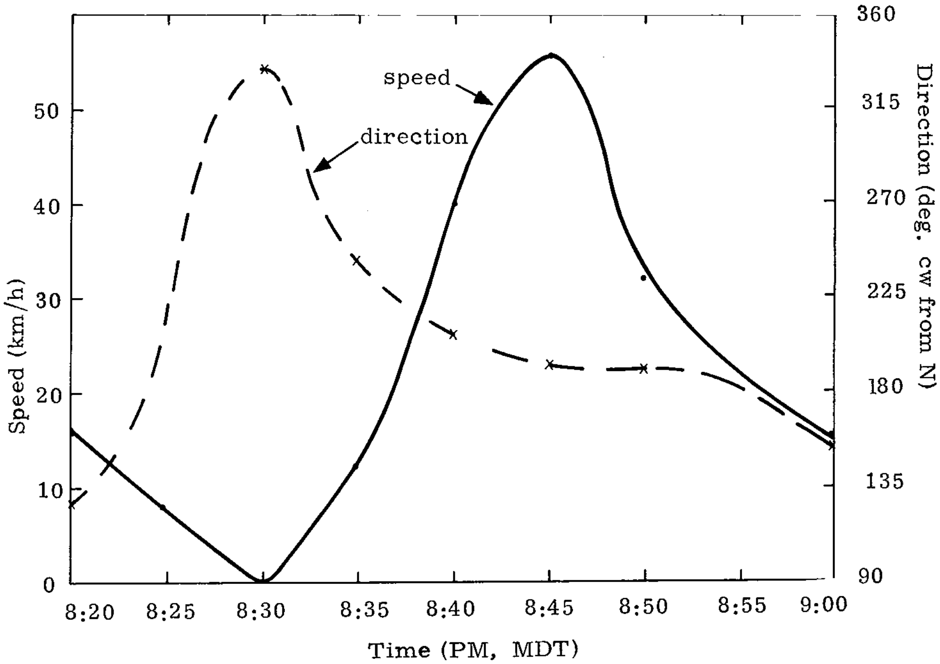

Figure 3. Wind Velocity During Hailstorm

The most intense part of the hailstorm appears to have been about 1 km NNW of the MSSTF. In that area, drifts were much deeper than at the MSSTF. This heavy concentration in one area is consistent with statements from a meteorologist in the Sandia Laboratories weather station that the heaviest concentration of hail tends to fall from a quadrant of the storm, usually the northeast quadrant.

Components and Subsystems Exposed to the Hailstorm

Solar equipment susceptible to hail damage on the MSSTF at the time of the storm consisted of the following:

CMTF

- Solar Kinetics Parabolic Trough
- GE/Scientific Atlanta 5-m Parabolic Dish
- Del Parabolic Trough
- Suntec SLATS 35-m^2 Collector
- FMC Fresnel Belt
- Scientific Atlanta FFMC
- Sandia Prototype Parabolic Trough
- Insulated Piping
- Meteorological Instruments

PASTF

- Argonne CPC
- Argonne DCPC
- RCA 300-W Array
- Spectrolab Reflective Trough
- Sandia 1000-W Array
- Suntec Array

STF

- Sandia 200-m^2 E-W Parabolic Trough
- Suntec 260-m^2 SLATS
- General Atomic 260-m^2 FMSC
- Raytheon 35-m^2 Parabolic Dish (~ 50% of mirrors installed)
- Insulated Piping
- Insulated Tanks
- Display of Reflector Test Samples
- Meteorological Instruments

Summary of Effects of Hail on Components and Subsystems

1. The only immediate functional damage from the hail was to the fixed-mirror collectors. The 260-m^2 General Atomic FMSC lost up to 5% of the mirror surface. The Scientific Atlanta FFMC had ~ 10% of its mirrors broken. Potential long-term damage occurred to the E-W parabolic-trough collectors in the small dents on the reflective surface. If a break in the Teflon occurs as a result of these dents, experience shows that delamination and loss of reflectivity around the break follow.

2. There were three thicknesses of glass reflectors in the MSSTF--3 mm (0.125 in.), 2.3 mm (0.090 in.), and 1.5 mm (0.060 in.). With one exception, only the 1.5-mm glass was damaged.

3. Polymer-type insulation materials that had been exposed to weather for 2 yr or longer suffered more severe damage than did those exposed for shorter periods.

4. Steel surfaces that supported film-type reflective surfaces suffered no damage, whereas similar surfaces of aluminum were dented.

5. There was no damage to glass components of the receivers. They were protected either by the stowed configuration of the collector or by construction of the receiver.

6. There is no indication of any advance warning of the storm on the records of windspeed and direction from the weather station in the MSSTF. However, the U. S. Weather Service detected the formation of the storm about 4 km west of the MSSTF on their radar ~12 min before it hit the MSSTF.

Detailed Description of the Effect of Hail on Components and Subsystems

Effect on Equipment in the CMTF

Solar Kinetic Parabolic Trough -- One row of the Solar Kinetics parabolic trough (Figure 4) remained installed after testing was completed. It is an aluminum monocoque with 18-gauge heat-treated aluminum-sheet skin front and back. The aperture is 1 x 12.2 m. The reflective surface is FEK 244 acrylic film. It was stowed facing south with the plane of the aperture down at an angle of about 20° to the vertical. When the wind was from the south, the angle of fall of the hail was estimated to be 20 to 30° from the vertical.

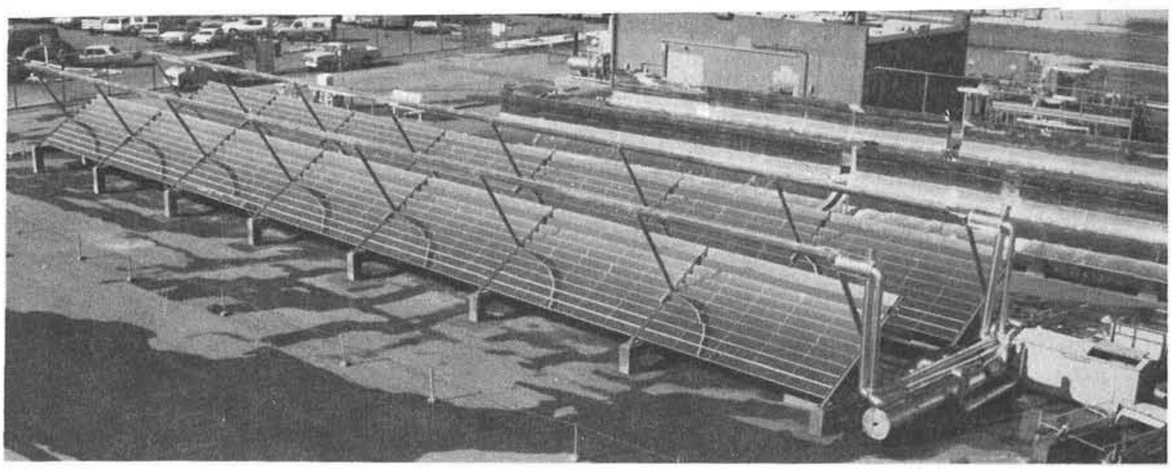

Figure 4. Solar Kinetics Parabolic Trough

GE/Scientific Atlanta 5-m Parabolic Dish -- This dish (Figure 5) is formed by twenty-four 2.3-mm-thick aluminum "petals" covered with FEK 244 acrylic film. It was stowed facing SSW. The face was covered with its heavy rubberized tarpaulin; no part of the dish including the exposed back side of the petals showed any damage.

Del Parabolic Trough -- This 11.5-m^2 array (Figure 6) has 128 pieces of 3.22-mm-thick sagged double-strength glass. There is partial rim support for the glass along stringers and sheet-metal ribs. The troughs were stowed facing down so that the backs of the mirrors were exposed between the structural members. No damage to the glass or structure was noted.

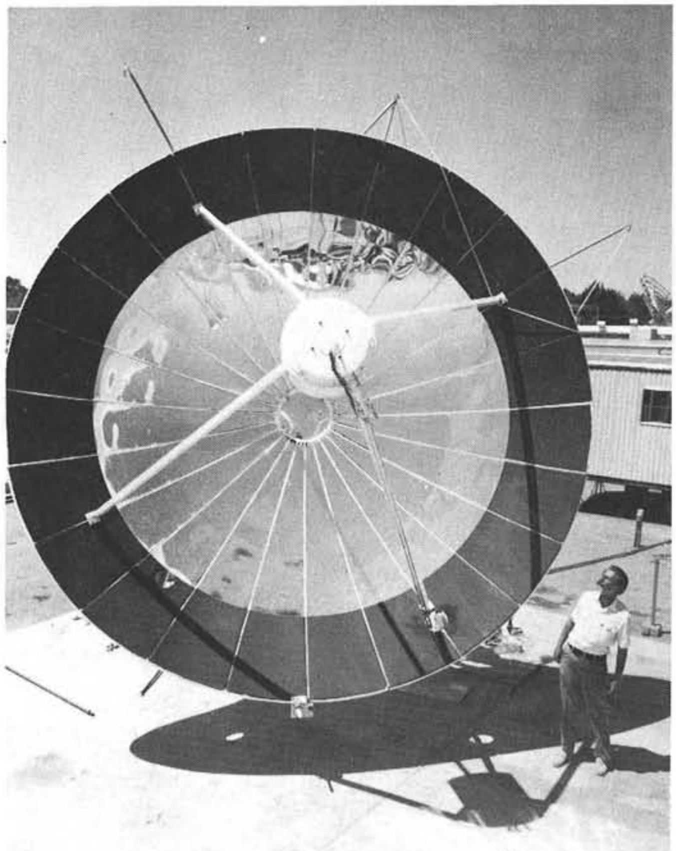

Figure 5.
GE/Scientific Atlanta Parabolic Dish

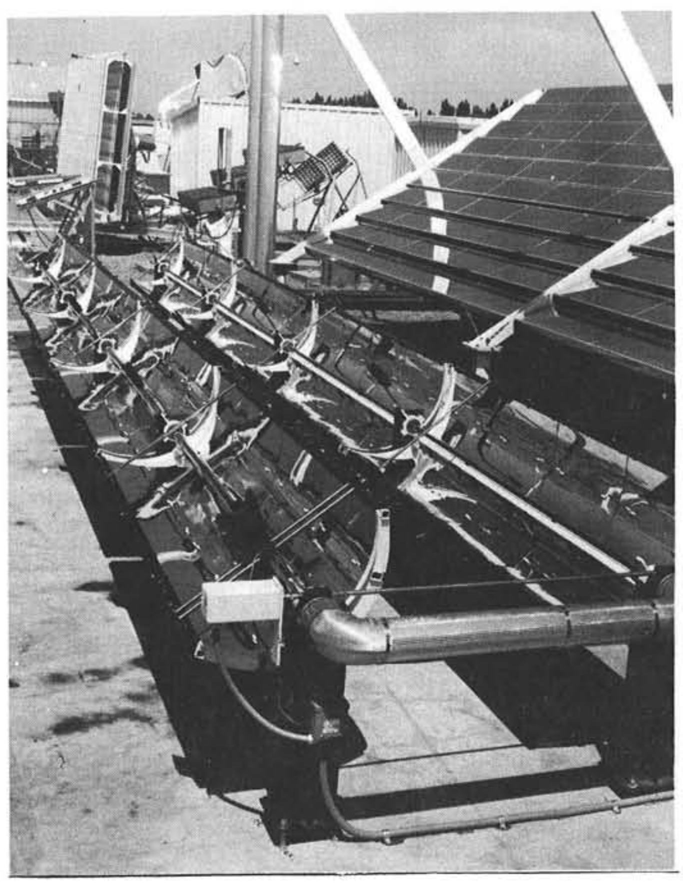

Figure 6.
Del Parabolic Trough

Suntec SLATS -- This collector (Figure 7) consists of two sections, each with 10 reflectors 0.3 x 6 m. The reflectors are 1.5-mm 0317 fusion glass bent to a radius of 6.6 m and fastened to marine plywood with polyester. The plywood is mounted on a half-cylinder of 28-gauge galvanized sheet. The reflectors were stored facing south and down at an angle of about 20° to the vertical. There was no damage.

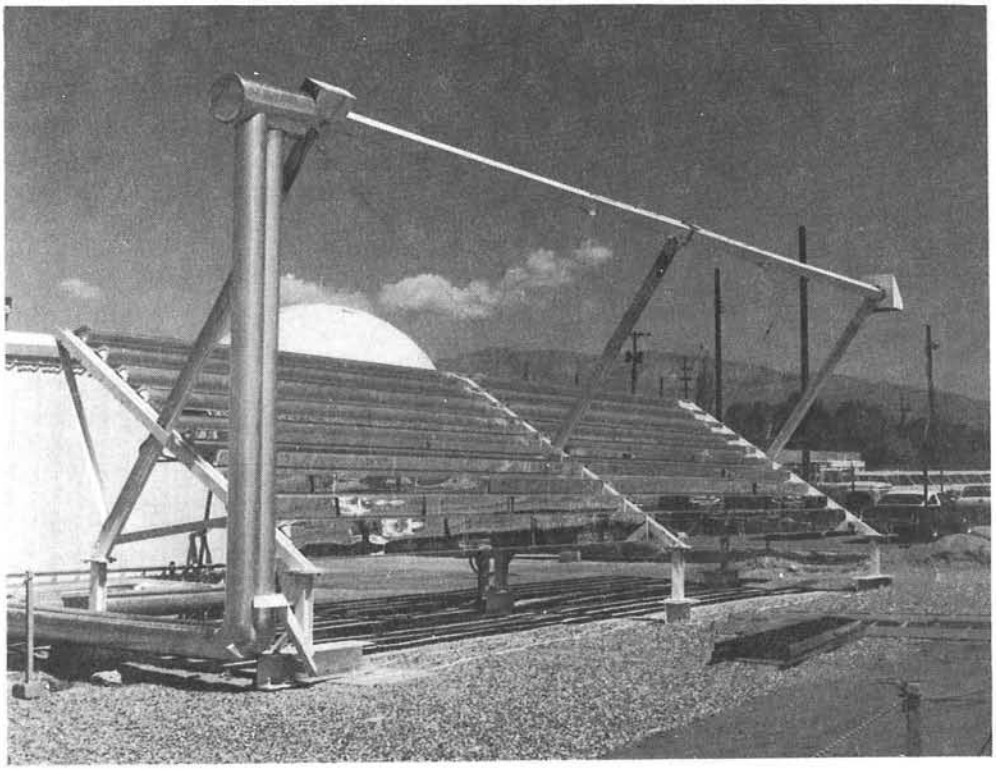

Figure 7. Suntec SLATS 35-m^2 Collector

FMC Fresnel Belt -- This fixed-receiver module (Figure 8) has 12-mm-wide, 1.5-mm-thick, front surface, silvered glass facets bonded with a pliable adhesive to a stainless-steel belt 0.8 mm thick backed by a rigid surface. The 4-m^2 aperture was tilted south at an angle of ~75° from vertical. Approximately 18 of the 552 mirror facets were broken or cracked by the hail.

Scientific Atlanta FFMC -- This collector (Figure 9) was stored in a display area facing south. The 2.5-mm-thick, 76-mm-wide, 1.5-mm-thick mirrors were loosely supported along their long edges only. Approximately 30 of the 327 mirror strips were broken by the hail.

Sandia Prototype Parabolic Trough -- This 2.7 x 3.6-m trough (Figure 10) is oriented N-S and tilted south about 45° to the vertical. The trough is formed by 19-mm plywood and the lower half has two reflective surfaces, an 0.6-mm ALZAK® reflector and two sections of 3.2-mm sagged glass. There was moderate dimpling of the ALZAK®. The adjacent two sections of 3.2-mm sagged glass were not damaged.

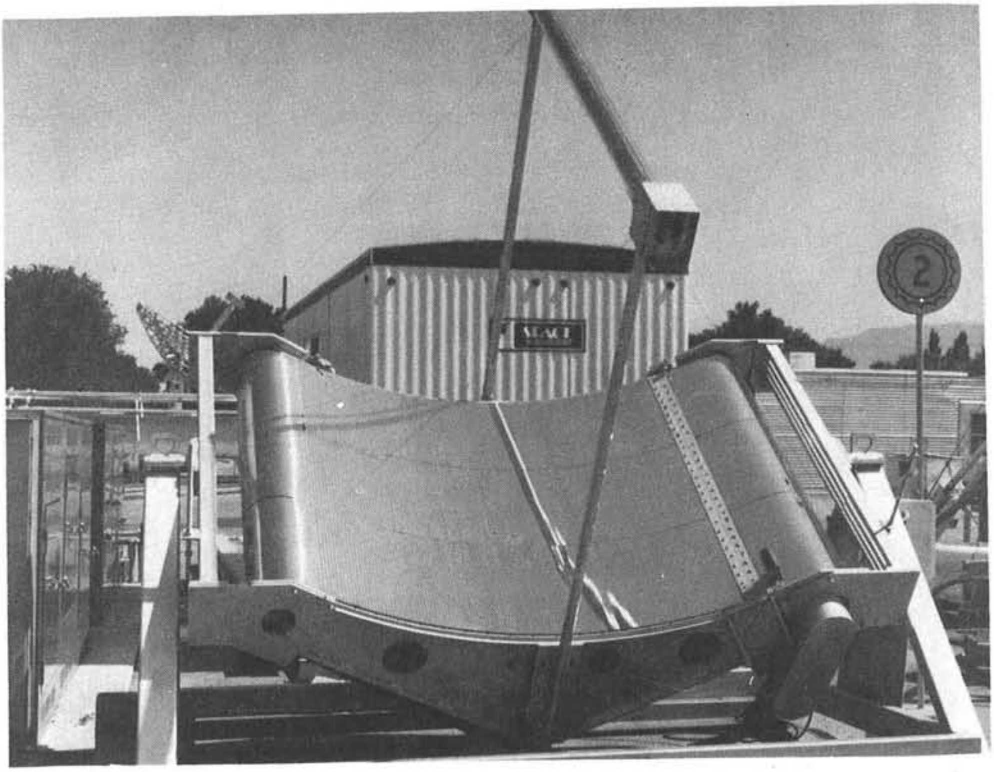

Figure 8. FMC Fresnel Belt

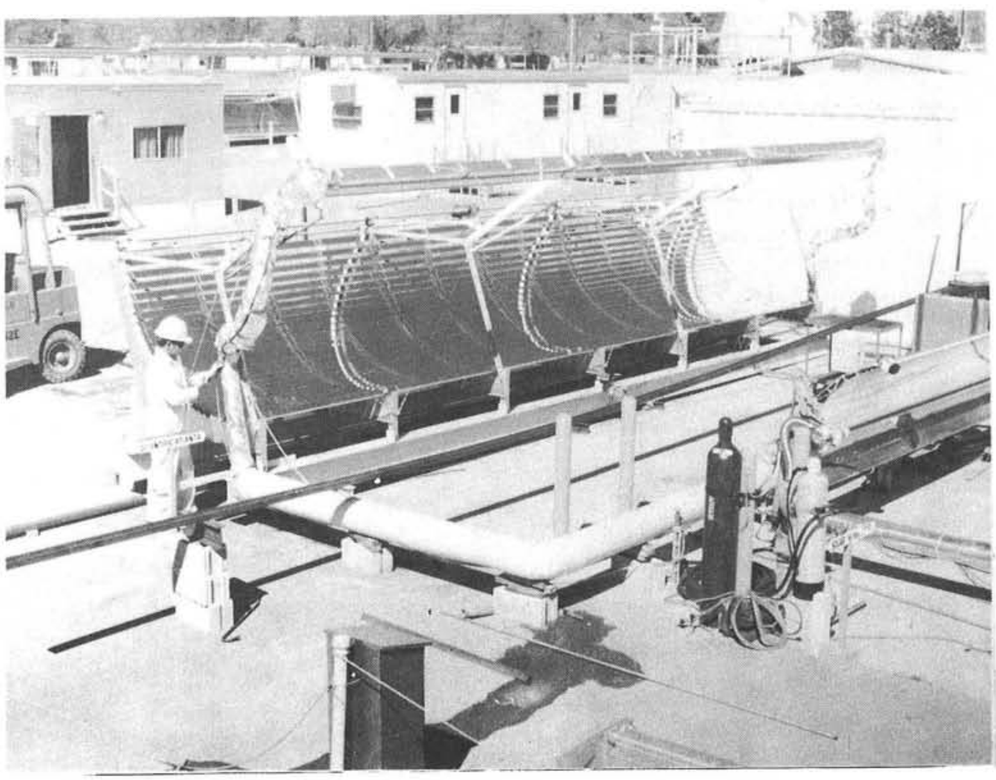

Figure 9. Scientific Atlanta FFMC

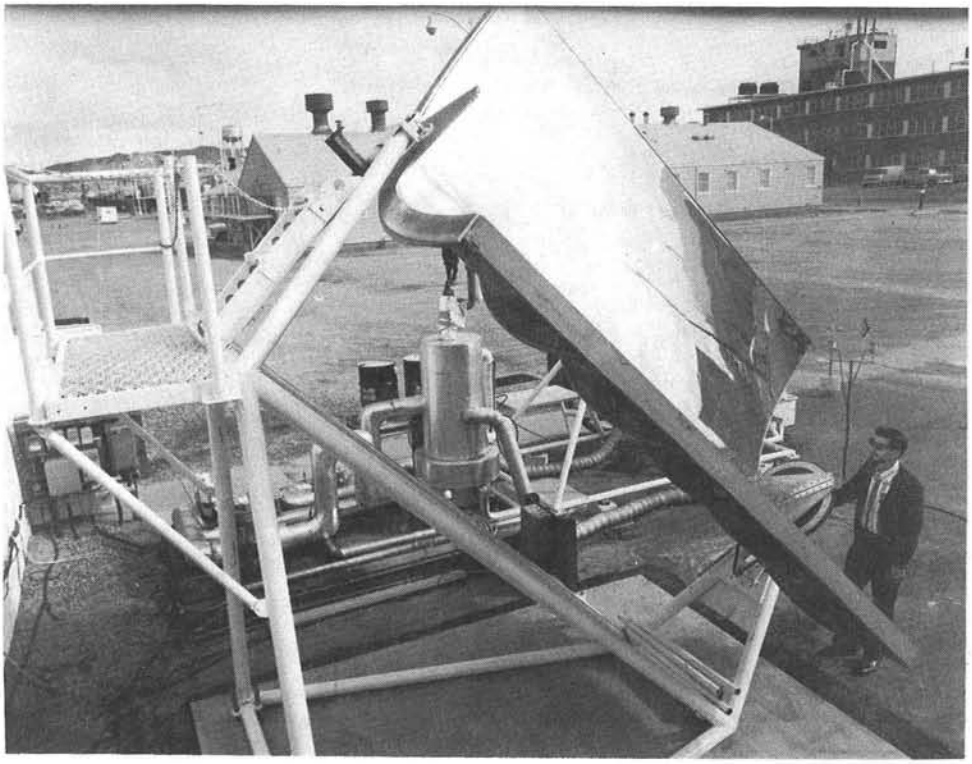

Figure 10. Sandia Prototype Parabolic Trough

Weather Station -- The CMTF has facilities for measuring wind direction, windspeed, and solar radiation. The plastic cups on the anemometer were completely destroyed.

Insulation --

- Aluminum-Covered: Moderate dimpling of the aluminum (Figure 11)
- Plastic-Covered: Newer plastic undamaged but older plastic (Figure 12) generally pulverized
- Heavy Foil-Backed Paper: Penetration and tearing of the top surfaces

Effect on Items in the PASTF

Even though the PASTF (Figure 13) is not part of the CMTF, it occupies part of the same land. The effects of the hail on equipment in the PASTF are included because they are of interest.

Argonne CPC -- In this device the active elements are protected by a sheet of acrylic. At the time of the hail the sheet was facing south at an angle ~20° to the horizontal. In this position, when the wind was from the south at maximum speed, impact was almost normal to the acrylic sheet. There was no damage.

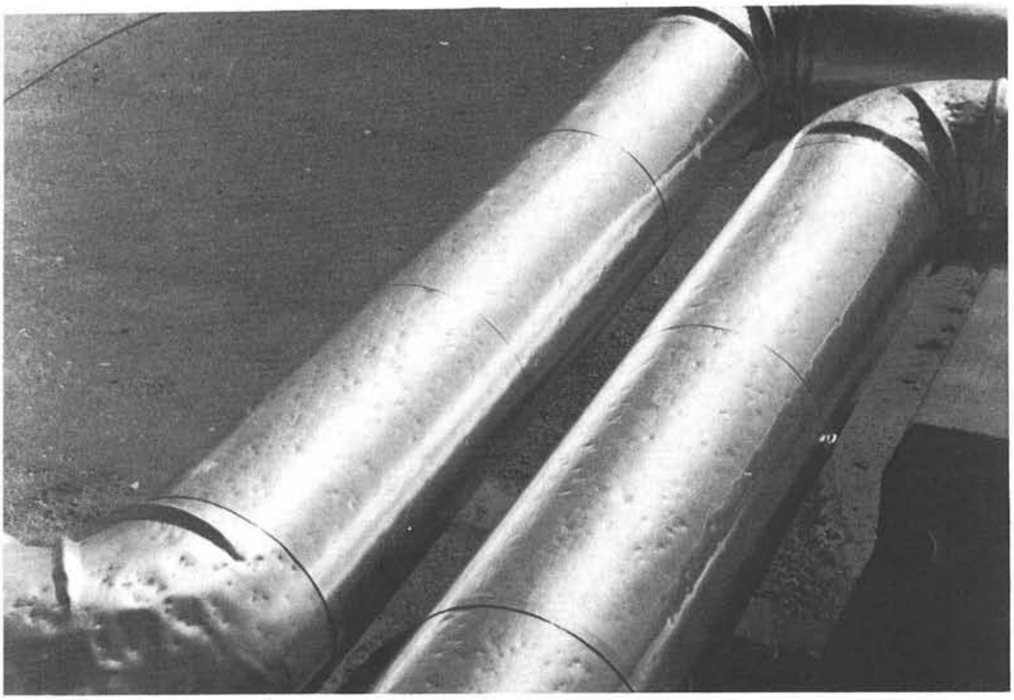

Figure 11. Effect of Hail on Aluminum-Covered Insulation

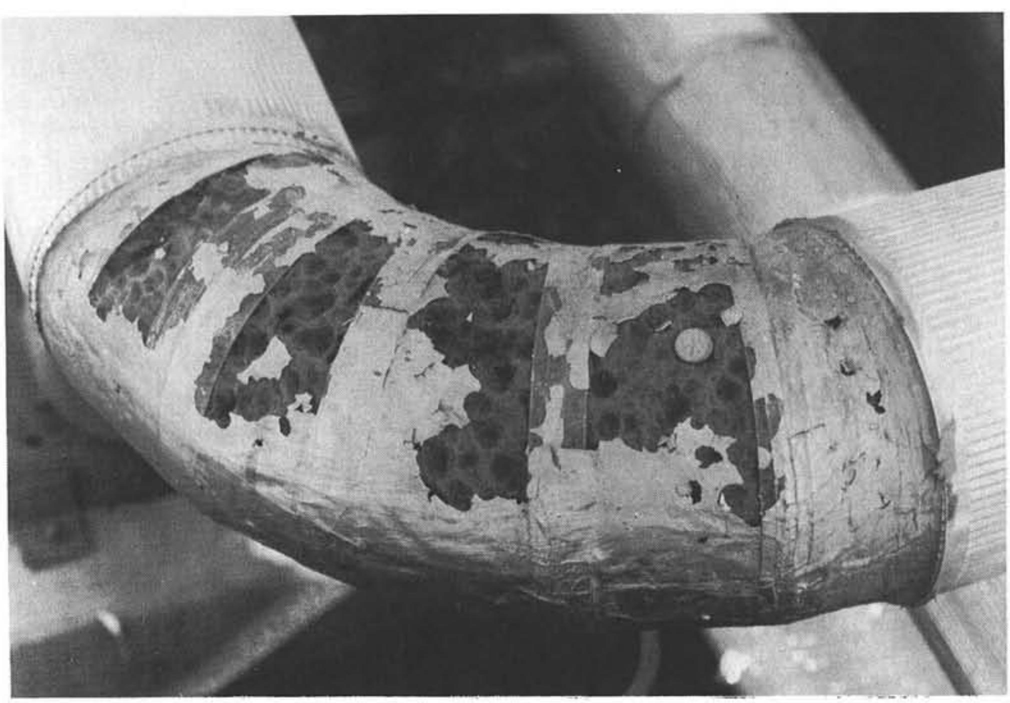

Figure 12. Effect of Hail on 2-Yr-Old Plastic-Covered Insulation

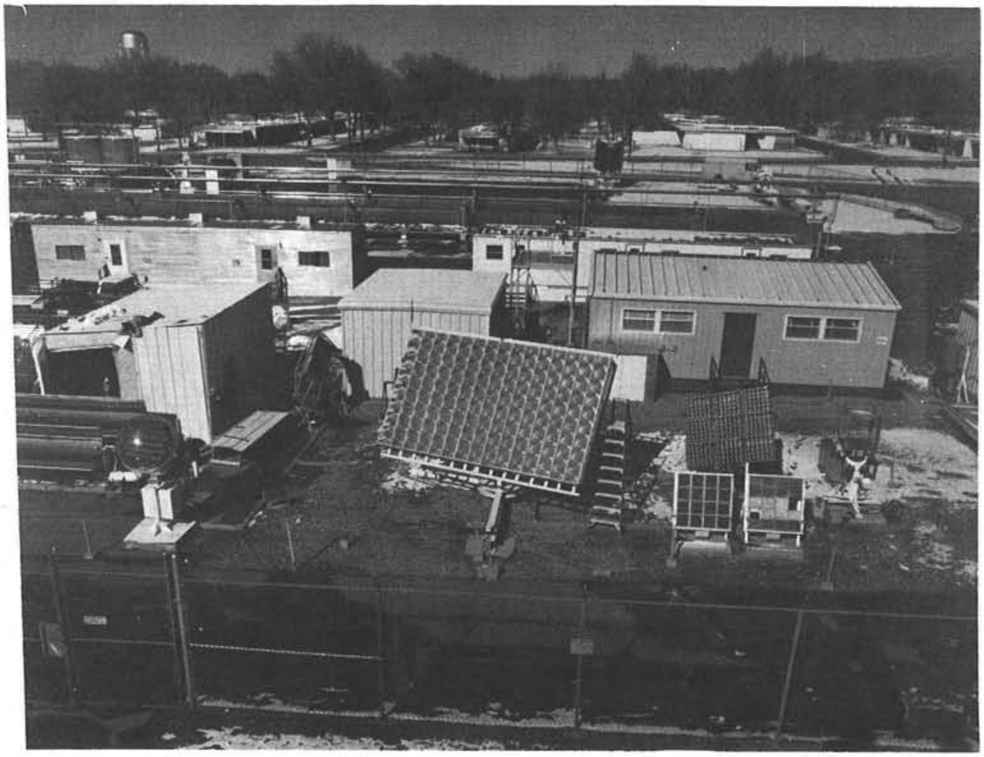

Figure 13. The PASTF

Argonne DCPC -- The active elements are encased in acrylic lens facing south at an angle to the horizontal of about 20°. There was no damage.

RCA 300-W Array -- The active elements are covered with Fresnel lenses made of acrylic. The device was tracking with the plane of the back side facing west at an angle of about 45° to the horizontal. There was no damage.

Spectrolab Reflective Trough -- This is a two-axis tracking device. The concentrator has an FEK 244 acrylic film reflector with steel backing. It was stowed with the aperture of the concentrator horizontal. There was no damage to the concentrator or the active elements; however, the sun tracker was destroyed.

Sandia 1000-W Array -- This item comprises 135 active elements, each covered by an acrylic Fresnel lens 30 cm on a side. It was stowed with the plane of the aperture vertical, facing south. There was no damage.

Suntrac Array -- The active elements and the concentrators are protected by an acrylic bubble. There was no damage.

Effect on Items in the STF

E-W Parabolic Trough Collector Field Subsystem -- This subsystem (Figure 14) comprises four strings, each 18.3 cm long. Two strings are south of the other two. The reflectors were stowed facing south with the aperture vertical. All surfaces on the bottom half contain shallow dents about 6 mm (1/4 in.) in diameter. The reflector surface is a sandwich of Mylar and aluminized Teflon on an aluminum sheet backing 0.6 mm (0.025 in.) thick. Two days of testing after the storm indicated that the short-term effects were negligible. However, long-term effects are possible if the hail caused microscopic breaks in the Teflon. By the end of August 1978, breaks in the Teflon were beginning to show. Peak efficiency tests conducted through October in the 2-1/2 mo after the hailstorm showed no degradation in efficiency attributable to the hail.

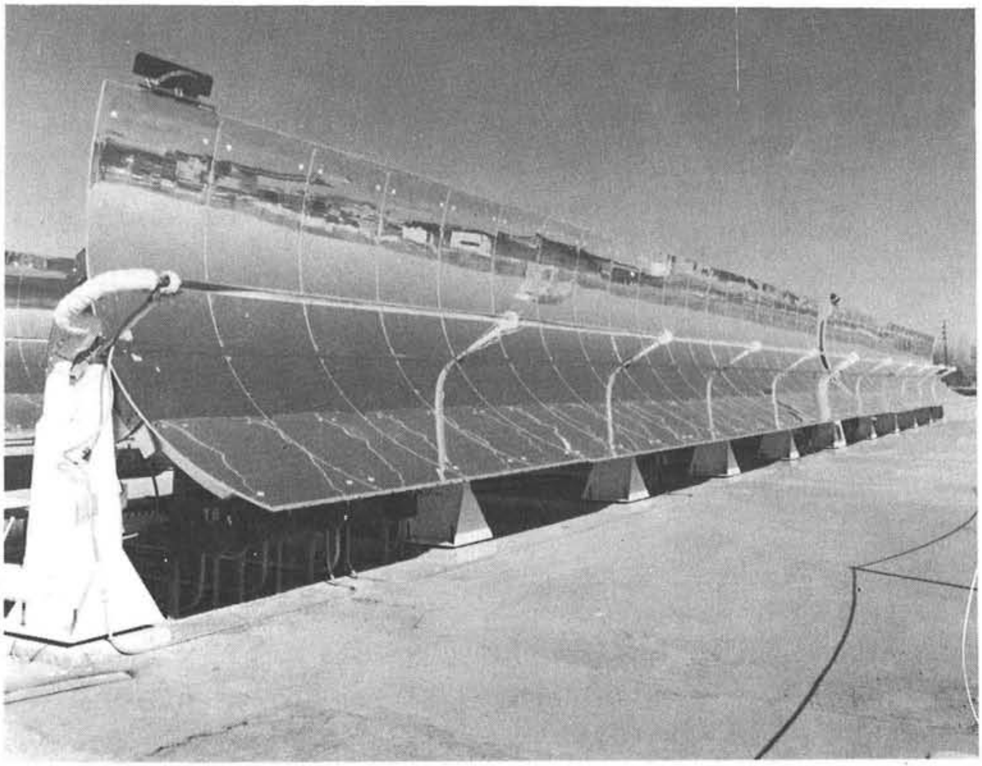

Figure 14. E-W Parabolic Trough Collector Field Subsystem

Suntec SLATS Collector Field Subsystem -- This 260-m^2 subsystem (Figure 15) comprises two rows, each consisting of seven modules like those installed in the CMTF. Construction of the reflectors is the same as those in the CMTF. The SLATS reflectors were stowed with the glass reflectors facing south and down at about an angle of 20° to the vertical. No damage was visible.

Figure 15. Suntec SLATS Collector Field Subsystem

General Atomic FMSC Field Subsystem -- This subsystem (Figure 16) comprises two rows, each 61 m long by 2.1 m wide. One row is south of the other. The FMSC concentrator consists of a series of fixed concrete troughs 3.8 m long by 2.1 m wide. The troughs have 5-cm-wide flat facets molded into them that run the length of the troughs. The flat facets have 5 x 127-cm flat-glass mirrors bonded to them with double-sided adhesive strips. The glass mirrors are Corning 0317 fusion glass 1.5 mm thick. Twenty-five percent of the glass mirrors were cracked or chipped in at least one place by the hail (Figure 17). This is expected to have a measurable effect on collector efficiency. The damage was concentrated at or near the tangent slat (center facet). The facets in this area underwent the most damage during construction and therefore provide the poorest support to the glass. A close examination of the cracked areas showed that there was indeed poor support for the glass at these points. The damage to the south row was greater than that to the north row, leading to the speculation that the south row provided some protection for the north row when the wind was from the south at maximum speed.

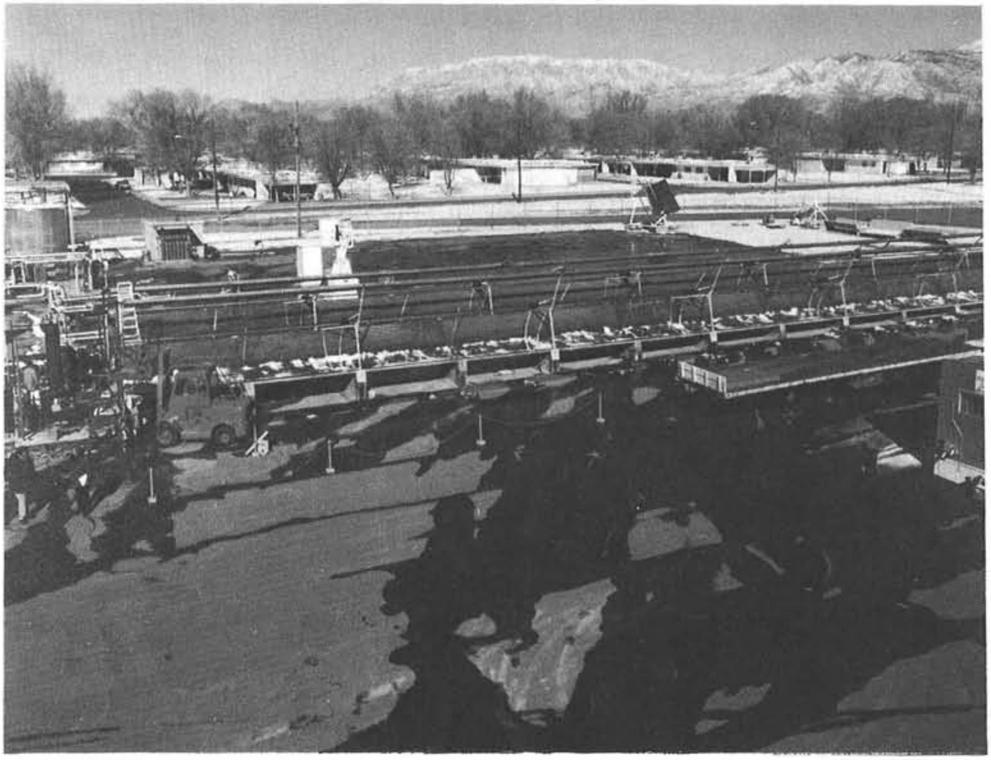

Figure 16. General Atomic FMSC Field Subsystem

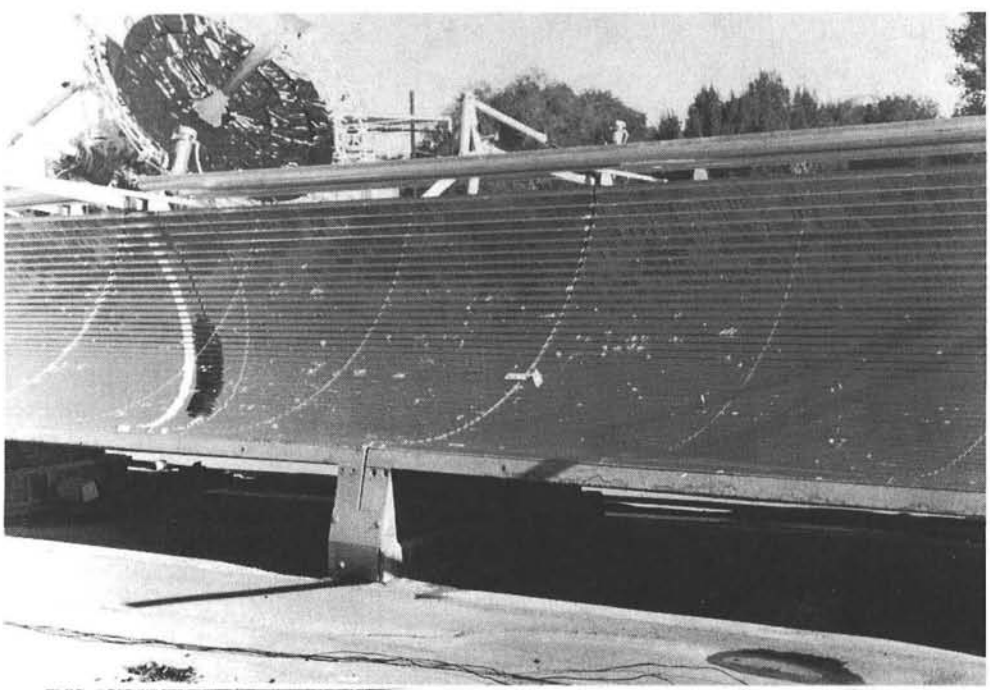

Figure 17. Hail Damage to FMSC

Raytheon Dish Collector -- The Raytheon collector (Figure 18) had 117 of its 228 glass-mirror segments mounted on its parabolic dish. The collector was stowed with the dish facing upward to the sky. The mirror segments are a maximum of 45.7 cm (18 in.) on a side and 0.3-cm (0.125-in.) thick, supported at four points by rubber grommets and bolts. The collector sustained no damage. There is a temptation to speculate that the high wind and shape of the dish may have given the glass some protection. However, evidence gathered from around the low-temperature thermal storage tanks indicates that some of the hail fell vertically, probably when there was little or no wind (see Figure 3 for wind velocity).

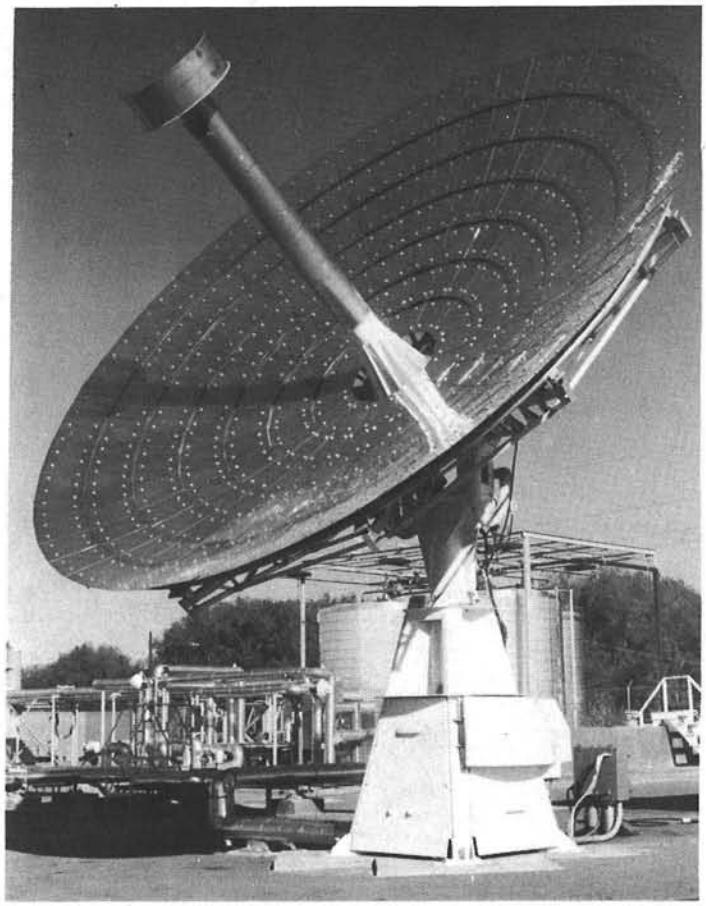

Figure 18. Raytheon Dish Collector

Fluid Loop -- With few exceptions, the insulation on the pipelines for all collector systems was covered by 0.15-mm (0.006-in.)-thick rolled-aluminum sheet. The aluminum is dented noticeably on the west side of the pipelines but was not damaged to the point that repair was necessary or that performance of the insulation is expected to change. In the exceptions where foam insulation was not covered with aluminum, the foam was damaged heavily. The damaged insulation had in all cases been exposed to the weather for more than 2 yr (see Figures 11 and 12).

Thermal Storage Subsystems -- There was no visible damage to either the thermocline thermal-storage subsystem (Figure 19) or the multitank thermal-storage subsystem (Figure 20). Both are protected by metal covers with one exception -- the top of the multitank thermal storage subsystem is insulated with polyurethane foam that has been exposed to the weather for less than 1 yr. The two low-temperature thermal-storage tanks (Figure 21) are insulated top and sides. with 10-cm polyurethane foam covered with 0.5-mm Diathon protective coating. Both tanks are exposed to the west and one is also exposed to the south. The insulation, which is less than 2 yr old, showed no damage. Some of the aluminum-covered pipe around these tanks is protected from all directions except vertical. From dents in the aluminum, it can be concluded that some of the hail fell vertically.

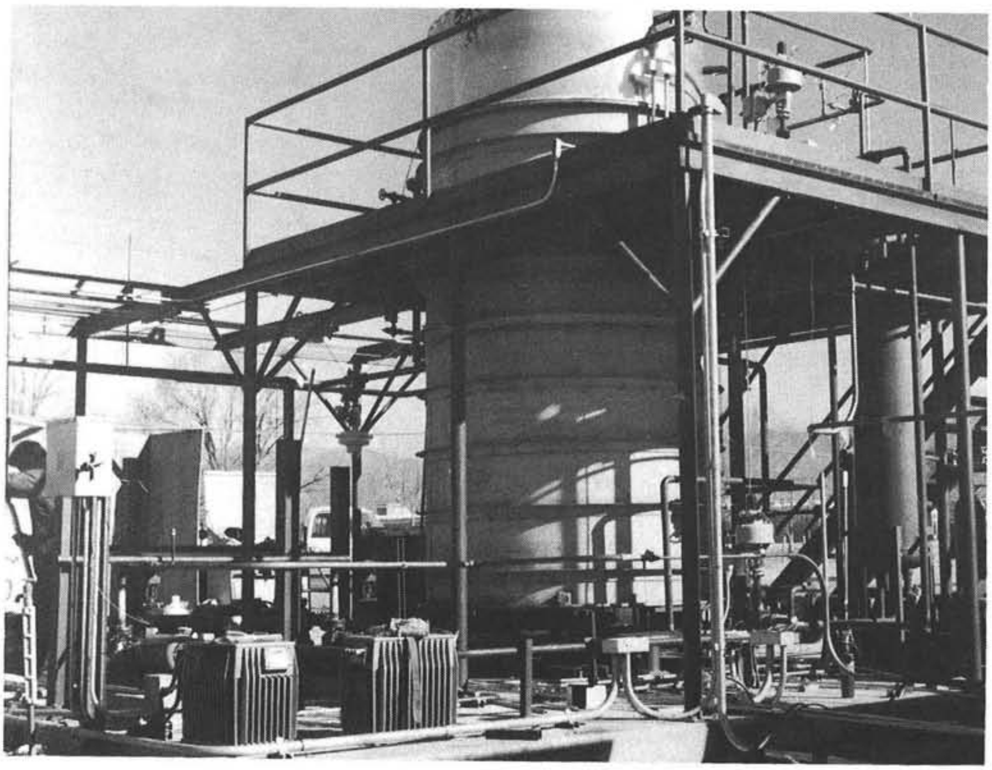

Figure 19. High-Temperature Thermocline Thermal Storage Subsystem

Weather Station -- There was no damage to the weather station; all parts are metal.

Figure 20. High-Temperature Multitank Thermal Storage Subsystem

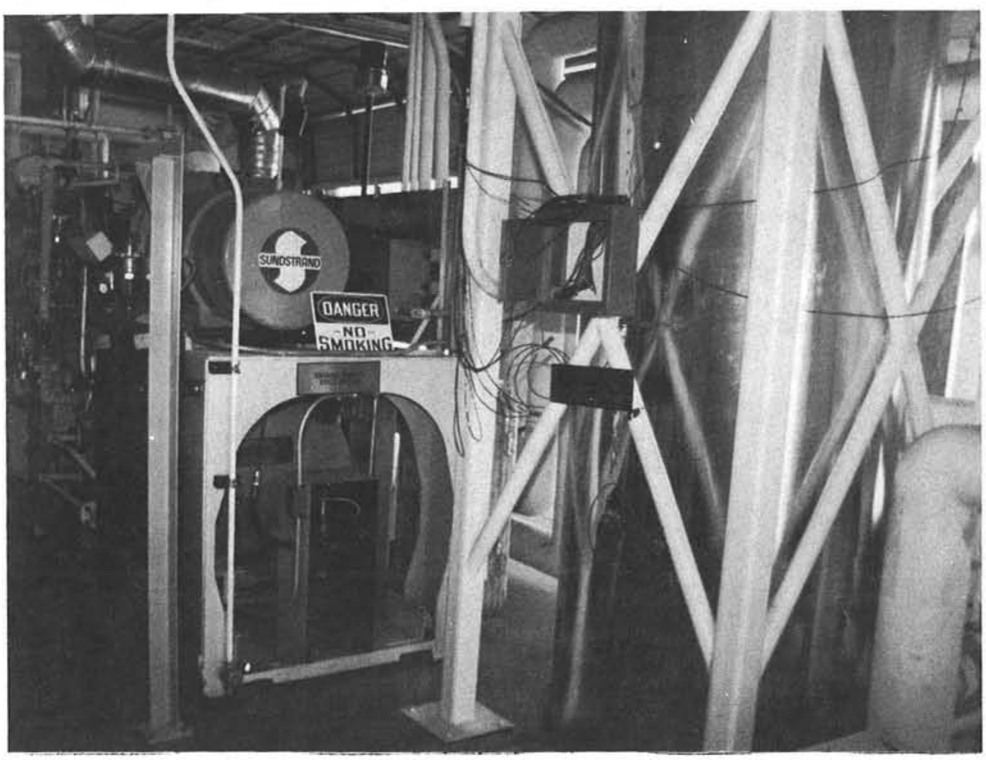

Figure 21. Low-Temperature Thermal Storage Subsystem

Reflector Sample Test Display -- In the STF there is a sample test display tilted to the south at an angle of about 10° to the horizontal on which various reflector surfaces are exposed to the elements. The effect of the hail on these samples is described below.

- There were five samples 10 cm on a side of the Sheldahl second-surface Teflon reflectors exposed since June 29, 1977. These are aluminized Teflon 0.03-mm (0.001-in.) thick with the aluminized surface sandwiched between the Teflon and Mylar and then bonded to aluminum sheet 0.6-mm (0.025-in.) thick. The hail did no damage.
- There were three samples 20 mm on a side of OCLI front-surface aluminum on ALZAK®. The aluminum is protected by an OCLI proprietary coating. The hail did no damage. These samples were installed June 14, 1977.
- There was an 0.6 x 0.9-m recently installed sample of Brookhaven National Laboratory reflector surface. It comprised a proprietary protective coating over front-surface aluminized Mylar atop a base of phenolic laminate supported by structural grade Styrofoam. The back surface is protected from the elements by a thick sheet of aluminum 0.25-mm (0.01-in.) thick. The hail did no damage.
- A piece of Schott water-white crystal sagged glass 0.5 x 0.5 x 3 m (20 x 20 x 0.125 in.) was damaged. It was mounted convex; i.e., back surface up. Four straps at the corners at an angle of 45° to the edge fastened the glass to the display surface. Immediately after the hail, one corner of the glass was observed to be broken between the corner and the strap. Later a crack was seen that started at the original break and proceeded almost diagonally to the opposite edge. It is possible that the strap was initially too tight and prestressed the glass.

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