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Characteristics of Current Solar Central Receiver Projects

A. F. Baker, A. C. Skinrood

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CHARACTERISTICS OF CURRENT SOLAR CENTRAL RECEIVER PROJECTS

Alvin F. Baker
Alan C. Skinrood
Project Engineering Division III
Sandia National Laboratories Livermore

ABSTRACT

This report summarizes the characteristics and status of six experimental solar central receiver projects. These are Eurelios (located in Italy), CESA-I (Spain), International Energy Agency Small Solar Power Systems Project (Spain), Sunshine (Japan), Themis (France), and Solar One (U. S.).

PREFACE

This report is a revision of a document with the same title originally published in 1983. To prepare this revision, we asked representatives of six international solar central receiver projects to supply more current information. These are Eurelios (Italy), CESA-I (Spain), International Energy Agency Small Solar Power Systems Project (Spain), Sunshine (Japan), Themis (France), and Solar One (U.S.). Photographs of these plants are included in this report. The planned test and evaluation program for nearly all of the experimental projects has been successfully completed. Studies are being done so that decisions can be made as to whether the facilities will be retained, used for other purposes, or dismantled. Further information on the status can be obtained by contacting representatives of individual projects.

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PHOTOGRAPHS OF SOLAR PLANTS

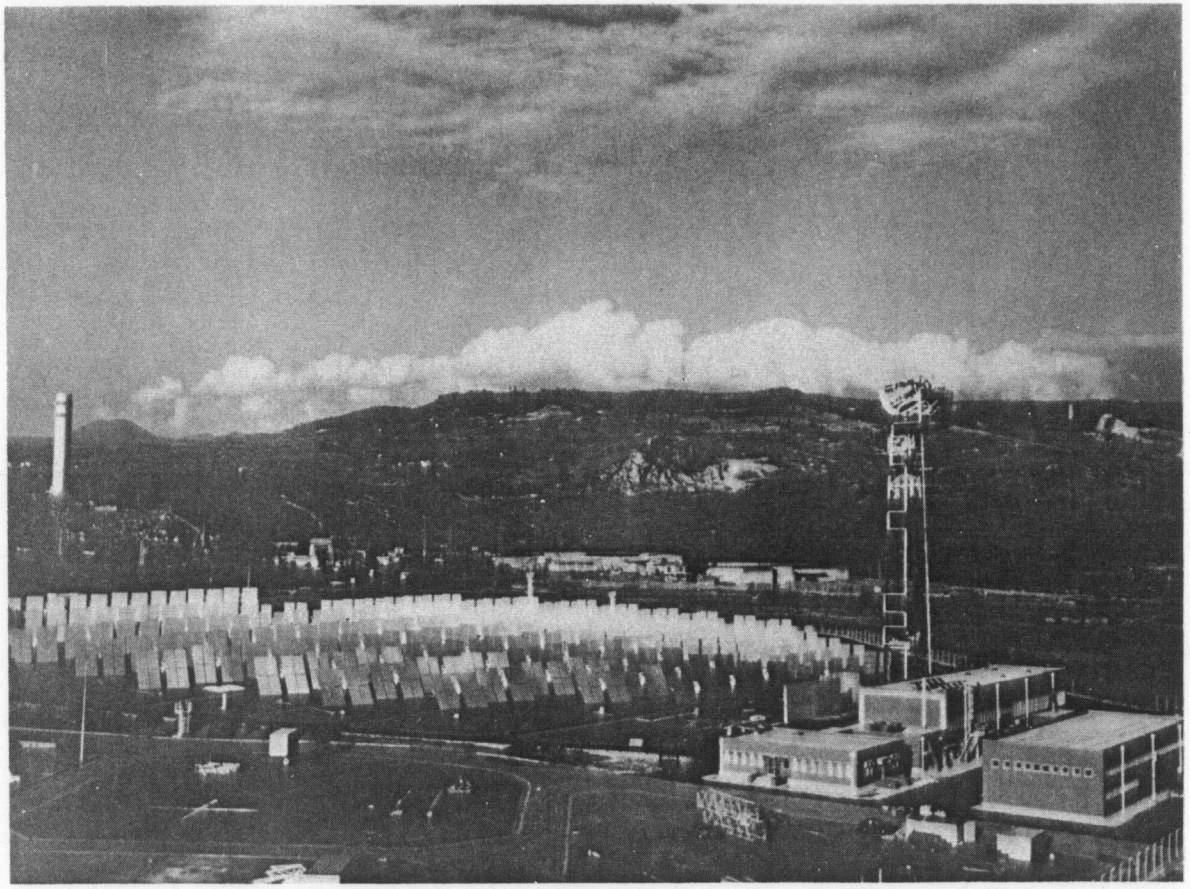

Figure 1. Eurelios, a 1 MW_e Experiment in Adrano, Italy, was sponsored by the Commission of European Communities and built by a consortium of European Industries.

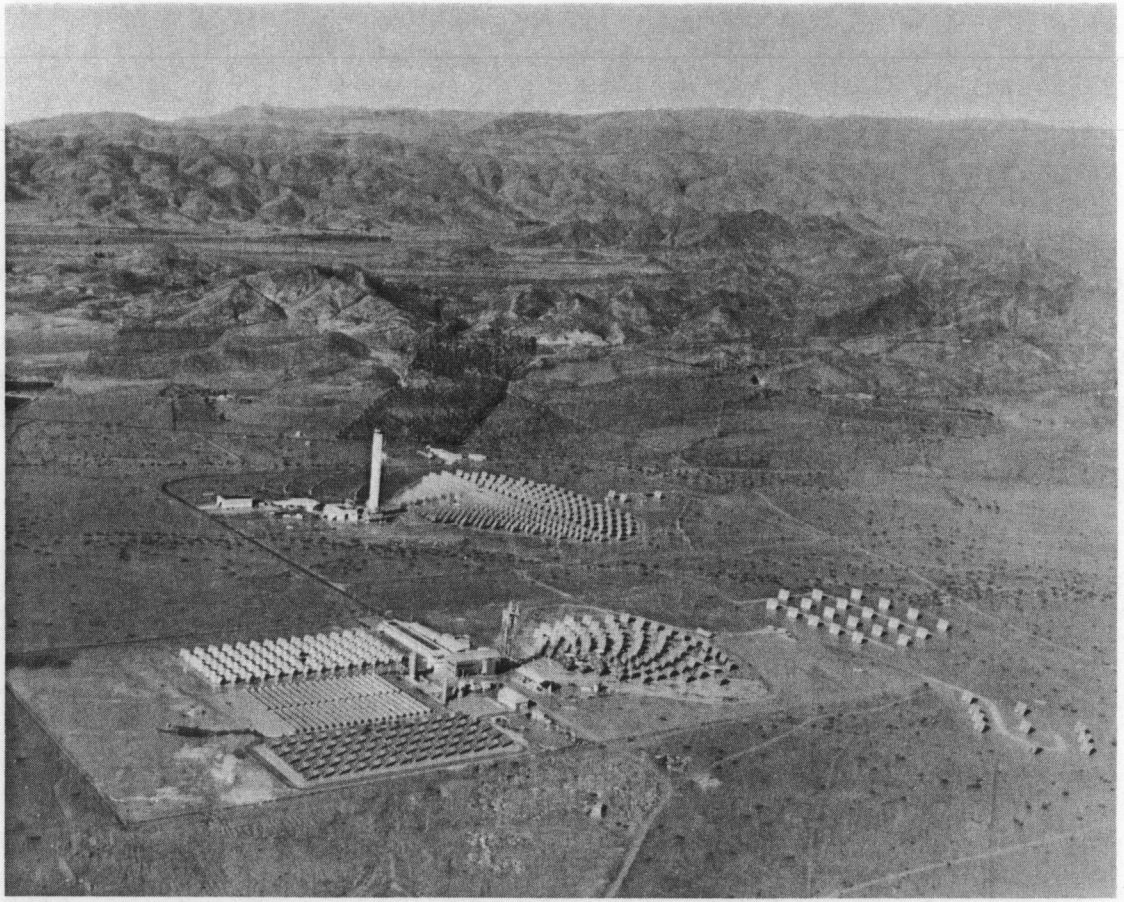

Figure 2. IEA/SSPS and CESA-I. The Plataforma Solar located near Almeria, Spain includes several solar experiments. The International Energy Agency 0.5 MW_e distributed collector facility is in the lower left and the 0.5 MW_e central receiver facility in the lower right. At the top is the 1.2 MW_e CESA-I project which was built by the Spanish government and continues to operate.

Figure 3. Project Sunshine, a 1 MW_e experiment located at Nio, Japan, on the north side of the island of Shikoku was built under the direction of Japan's Agency of Industrial Science and Technology.

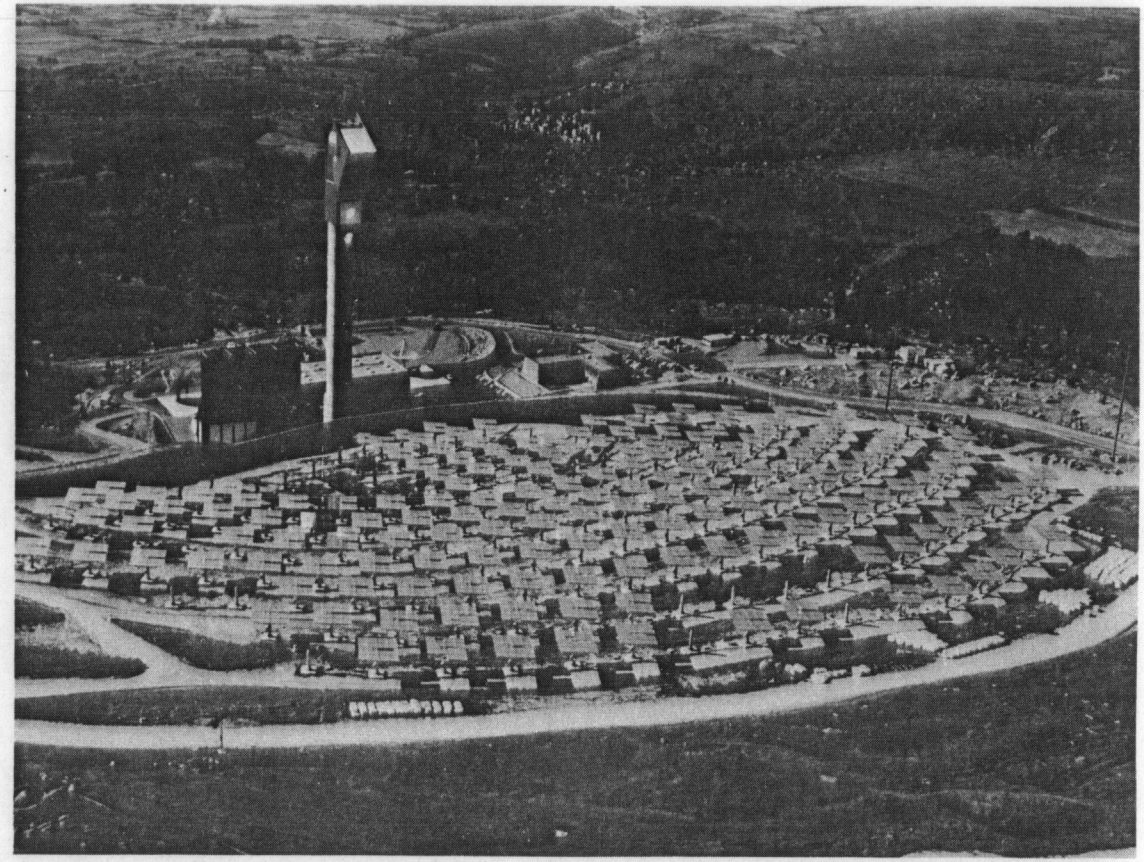

Figure 4. Themis, a 2.5 MW_e experiment, is located in the Pyrenees Orientales, near Targasonne, France. The plant was built under the direction of the French government agency A.F.M.E. and Electricite de France.

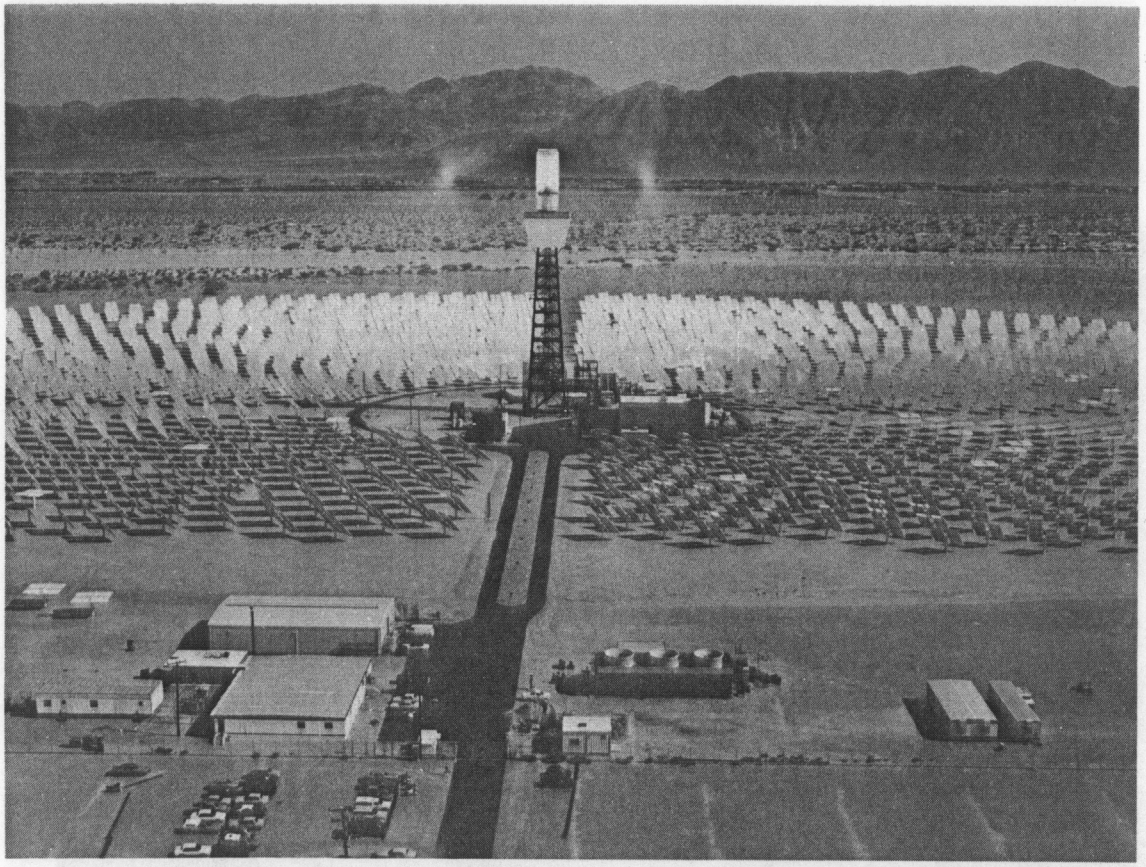

Figure 5. Solar One, a 10 MW_e experiment located near Barstow, California, was built under the direction of the U.S. Department of Energy and operated by a private utility, the Southern California Edison Company.

Table 1.
GENERAL PLANT INFORMATION

Plant Name	EURELIOS	Central Electrosolar de Almeria (CESA-1)	International Energy Agency Small Solar Power Systems (IEA/SSPS) Central Receiver System (CRS)	Sunshine Project Solar Thermal Power Generation System #1 Unit of Nio Solar Thermal Power Plant (SUNSHINE)	Centrale Solaire Thermis – 2.5MW (THEMIS)	10 MW_e Solar Thermal Central Receiver Pilot Plant (SOLAR ONE)
Plant Rated Output (MW_e	1.0	1.2	.5	1.0	2.0 – 2.5	10.0
Plant Location	Adrano, Sicily, Italy	Tabernas (Almeria, South Spain)	Tabernas (Almeria, South Spain)	43-1 Nio, Nio Town Kagawa Pref., Japan	Targasonne, Pyrenees Orientales, France	Daggett, California, United States
Plant Sponsor	Commission of the European Communities and the Governments of France, Italy, and Germany	Instituto de Energias Renovables JEN Ministerio de Industria y Energia	Nine IEA member countries of Austria, Belgium, Germany, Greece, Italy, Spain, Sweden, Switzerland, and United States	Agency of Industrial Science and Technology, Ministry of International Trade and Industry	Agence Francaise pour la Maitrise de l'Energie, (AFME) Electricite de France (EDF)	United States Department of Energy and Utility Associates (Southern California Edison, Los Angeles Dept. of Water and Power)
Plant Contact and Mailing Address	ENEL-CRTN 69 Vic. C. Battisi Pisa Italy	F. Sanchez Energia Solar Termica CIEMAT-IER	F. Sanchez Energia Solar Termica CIEMAT-IER		Centrale THEMIS Targasonne 66120 Font-Romeu Attn: B. Rivoire B. Bonduelle 68.30.03.86	DOE: M. Lopez SCE: C. W. Lopez Sandia: J. T. Holmes P.O. Box 366 Daggett, CA 92326

Table 1.
GENERAL PLANT INFORMATION (CONT)

	EUR.	CESA-1	IEA	SUNS.	THEMIS	SOLAR 1
Plant Objectives	Feasibility of operation of solar power plant directly linked to the grid. Obtain data for technical/economic evaluation.	Feasibility; system components and technology and development, plant operation, and evaluation in order to scale to commercial size.	Demonstration and Test Facility	Experiment	Demonstrate the technical feasibility of central receiver power plant experiment. This solar plant connected to the grid to obtain technical and and operational data.	Technical feasibility of a solar plant of the central receiver type to obtain sufficient development, production, and O&M data to indicate the potential for economic operation of commercial power plants of similar design.
Plant Designer	Industrial Consortium: Ansaldo Implianti and Enel, Italy; Cethel, France; MBB, Germany; Per L'Energia Elettrica (ENEL)	Group of Spanish Companies: Sener, Initec, CASA, EISA, Tecnicas Reunides	Interatom, Germany; Martin Marietta, U.S.A.; Sait, Belgium; Sevillana De Electricidad (Sevillana) MBB Germany	Mitsubishi Heavy Industries	Electricite de France (EDF); Centre National de la Recherche Scientifique (CNRS)	Martin Marietta; McDonnell Douglas; Construction Manager - Townsend and Bottum; Southern California Edison (SCE)
Plant Evaluator	ENEL/CEC	Instituto de Energias Renovables JEN	International Test and Evaluation Team (ITET)		EDF-CNRS-AFME	Sandia National Laboratories, Livermore, CA
Schedule and Status	Test program completed in July 1986. Future plans uncertain.	Test program continuing.	Test program continuing.	Test program completed, facility dismantled.	Test program completed July 1, 1986. Future plans uncertain.	Power Production Phase completed in July 1987. Future plans Operation will continue until Oct. 1988.

Table 2.
SITE DATA

	EUR.	CESA-1	IEA	SUNS.	THEMIS	SOLAR 1
GEOGRAPHICAL DATA						
Site Latitude (deg.)	37.5°N	37.1°N	37.1°N	34.18°N	42.48°N	34.87°N
Site Longitude (deg.)	15.25°E	2.4°W	2.38°W	133.63°E	2.12°E	116.83°W
Site Altitude (m)	2.15	500	500	5.9	1700	593
SITE DIRECT NORMAL INSOLATION AT NOON (W/m^2)						
March 21	820 (E)	900 (E)	920 (E)	800	1040	950
June 21	800 (E)	940 (E)	960 (E)	800	960	990
December 21	780 (E)	750 (E)	760 (E)	800	950	967
SITE ENVIRONMENTAL CONDITIONS						
Sunshine Hours Per Year	2250 at >250 W/m^2	3000 (E)	3000 (E)	2200	2400	3600 - 4000 (52% of daylight hours have zero skycover)
Temperature (°C)						
Average	18	17	17	12.8	7.2	19
Minimum	3	-3.5	-3.5	-6.3	-12	-12
Maximum	45	45	45	37.8	27	46
Wind						
Average Speed (km/h)	12	20	10	12.6	32	18.8
Average Direction (N, E, S, W)	NNW	W-E	—		NNW	W

Table 2.
SITE DATA (CONT)

	EUR.	CESA-1	IEA	SUNS.	THEMIS	SOLAR 1
Maximum Speed (km/h)	135	130	144	180	160	126
Rainfall						
Days Per Year		10	—	103	—	25
Average Daily Amount (mm)		2.9		2.7	2.45	9.4
Cloud Cover						
Days Per Year	222	36	145(E)	—	160	
Average Days of Continuous Cover		—	38(E)	—	40	

Table 3.
HARDWARE DEFINITION

	EUR.	CESA-1	IEA	SUNS.	THEMIS	SOLAR 1
HELIOSTATS						
Total Number	Cethel/MBB 70/112	300	MM/MBB 93/30	807	201	1818
Reflective Area Per Helio (m^2)	52/23	39.6	39.3/53.6	16	53.7	39.3
Total Plant Reflective Area (m^2)	6216	11,880	5262	12,912	10,740	71,447
Type of Glass Comm. Float	Float/Float	Float	Low Iron Float	Low Iron White	Sandwich	90% Low Iron Float 10%
Thickness of Glass (mm)	6/3	3	3	5	1.7 + 5	3
Clean Mirror Reflectivity (%)	77/85	87	91	92	90	91
Specific Weight (kg/m^2)	67/65	37.5	50 (E)	93	68.9	45.6
Number of Focal Lengths	4 cont.	4	4	4	5 (Mirrors) 25 (Heliostats)	1
Pointing Error Per Axis (mrad)	0.8	1.2	1.5	17	—	1.5
Beam Quality Error (mrad)	2.0	1.5	2.7	—	2.2	2.0
Aspect Ratio	1.2/1.0	1.02		—	1.2	1.0
Packing Density	.26/.23	.21		0.63	0.37	.25
Control Method	Open-Close Loop	Open Loop Digital	Open Loop Digital	Open-Close Loop	Open Loop Digital	Open Loop Digital
Tracking Motor Power Rating (watts)	—	CASA/Sener	—	—	—	—
Azimuth	—	130/35	169	140	40	1/6 H.P. D.C.
Elevation		130/100	169	140	40	

Table 3.
HARDWARE DEFINITION (CONT)

	EUR.	CESA-1	IEA	SUNS.	THEMIS	SOLAR 1
RECEIVER						
Type	Cavity	Cavity	Cavity/External	Cavity	Cavity	External
Cavity Aperture Shape	Circular	Square	Octagonal	Circular	Square	—
Cavity Aperture Size (m^2)	15.9	11.56	9.7	56.6	16	—
Cavity Aperture Inclination Angle (deg. from vertical)	23	21.8	0	90 Horizontal	30	—
External Receiver Shape	Conical	Flat Plate	Flat Plate	Temple Bell	Cubic	Cylindrical
External Receiver Size (m^2)	—	49 + 34 = 83	7.9	169	72	302 (226.5 boiler-superheater)
Receiver Fluid	Water/Steam	Water/Steam	Sodium	Water	Hitec Salt	Water/Steam
Receiver Fluid Inlet Temperature (°C)	37	200 (model)	270	115	250	104-175
Receiver Fluid Outlet Temperature (°C)	512	525	530	250	450	516
Receiver Fluid Outlet Pressure (bars)	62	108	2.7	40	1-2	105
Peak Heat Flux on the Absorber (MW/m^2)	.60	.56	.60/1.5	.13	.69	.35

Table 3.
HARDWARE DEFINITION (CONT)

	EUR.	CESA-1	IEA	SUNS.	THEMIS	SOLAR 1
STEAM GENERATOR						
Type	—	Evaporator and Reheater	Helical Coil Once Through	— —	Evaporator and Superheater	—
Working Fluid Inlet Temperature(°C)	—	150	190	—	203	—
Working Fluid Outlet Temperature(°C)	—	330	500	—	430	—
Heat Transfer Area (m2)	—	108 + 69 = 177	14.7	—	193	—
Tube Outside Diameter (mm)	—	18.75	25	—	14	—
Tube Inside Diameter (mm)		16.75	18.6	—	11	—
Tube Material		A-179	Ferritic Steel	—	15, 60, 205	
Working Fluid Flow Rate (kg/sec)	—	1.61	.86	—	3.3	—
DATA ACQUISITION SYSTEM						
Number of Channels	400 Analog 1280 Bilevel	384	240 Analog 1024 Bilevel	600	630 Analog 2300 Bilevel	>2000
Number and Type of Sensors	Temp - 150 Pres - 30 Flow - 9	Temp - 151 Press - 59 Flow - 9	180	Temp - 300 Press - 200 Flow - 60	Temp - 412 Press - 40 Flow - 10	Temp - 632 Press - 250 Flow - 60
PLANT SUPPORT SYSTEMS						
(Nonsolar subsystem characteristics)		Auxiliary Diesel Generator Auxiliary Boiler	156 kW Diesel 2 × 150 AM Battery	86 kW Diesel	625 kW Diesel Solar Subsystem for Auxiliary Pressurized water	

Table 3.
HARDWARE DEFINITION (CONT)

	EUR.	CESA-1	IEA	SUNS.	THEMIS	SOLAR 1
THERMAL ENERGY STORAGE						
Storage Description	Buffer	Two Tank Hot and Cold	Two Tank Hot and Cold	Five Tank Accumulators	Two Tank Hot and Cold	Oil/Rock Thermo cline
Storage Fluid	Molten Salt and Hot Water	Hitec Salt	Sodium	Pressurized Water	Hites Salt	Caloria HT-43
Storage Fluid High Temperature (°C)	430-Salt 410-Water	340	530	249	450	302
Storage Fluid Low Temperature (°C)	275-Salt 206/170-Water	220	275	197	250	218
Storage Capacity (MW_t-h)	.3 Water .06 Salt	18	5.5	17.9	40	165
Hours of Storage	.5	3.5	2	3	5	4
Storage Tank Size (m^3)	7	Two Tanks, Each 200	70	300 (5 x 60)	310	423
Tank Material	—	A-285 Gr.C	Austenitic Steel (Hot) Ferritic Steel (Cold)	Carbon Steel —	A 42 CP-15 CD 205	Ferritic Steel —
Insulation Material Thickness (mm)	Glasswool .1	Fiberglass 400	Mineral Wool 400/700	Mineral Wool 250	Rockwood 400	Fiberglass 356/630
Storage Thermal Fluid to Working Fluid Heat Exchanger Rating (MW_t)	.72	4.0			8.8	33.3
Control Method	Semi-automatic	Three Element		Pressure Change	Temperature	Digital

Table 3.
HARDWARE DEFINITION (CONT)

	EUR.	CESA-1	IEA	SUNS.	THEMIS	SOLAR 1
POWER CONVERSION SYSTEM						
Type of Conversion system	Turbine	Turbine	Motor	Turbine	Turbine	Turbine
Working Fluid	Steam	Steam	Steam	Steam	Steam	Steam
Working Fluid Temperature (°C) (from receiver)	510	520	—	250	—	515
Working Fluid Temperature (°C) (from storage)	410	330	500	187	430	274
Working Fluid Pressure from Receiver (bars)	62	98	—	40	—	100
Working Fluid Pressure from Storage (bars)	Upper/Lower 19/7	15	100	12	40	28
TURBINE GENERATOR STATISTICS	—	—	(Steam Motor) —	—	—	
Manufacturer	Ansaldo	Siemens	Spilling	Mitsubishi	ALSTROM	GE
Nameplate Rating (MW_e)	1.2	1.2	.617	1.0	2.5	12.5
Heat Rate (kW_{t/kw_e})	3.97 (4.82 net)	4.35	—	4.9	3.57	2.84 @1465 psia/950°F/2.5″ Hg
Cooling Tower Type (wet, dry)		Dry	Wet	Wet	Dry	Wet

Table 3.
HARDWARE DEFINITION (CONT)

	EUR.	CESA-1	IEA	SUNS.	THEMIS	SOLAR 1
Average Heat Flux on Absorber (MW/m^2)	.007	.14	.168/.320	.043	.134	.14
Receiver Weight (kg)	23,000	40,000	22,000/19,730	25,000	20,000	150,000
Maximum Thermal Power Rating of the Receiver (MW_t)	4.8	8	2.7/2.7	7.3	9	43.4
Control Method	Semi-automatic	Three Element System	Flow Control Outlet Temp.	Pressure Control	Outlet Temp. and Flux	Outlet Temp. Pressure
Absorber Tubing	Boiler/Evap. and Superheater	—	—	—	—	—
Inside Dia. (mm)	32.5/49	30	35/12	28.2	15	6.35
Outside Diameter(mm)	44.5/57	33.4	38/14	34	18	12.7
Material	Arsi 321	SA-106-B/X 20 Cr Mo V 121	Austenitic Steel	Carbon Shell	Stainless Steel 316	Incoloy 800
Coating	Pyromark		Pyromark	Okitsumo	Pyromark	Pyromark
Absorptance	.95	.95	.95	.97	.95	.97
Emittance	.90	.90	.95	.93	.8 – .94	.88
Maximum Surface Temperature (°C)	557	579	540	350	505	675

Table 4.
PLANT PERFORMANCE

	EUR.	CESA-1	IEA	SUNS.	THEMIS	SOLAR 1
Reference Day	March 21	Dec. 21	March 21	June 21	March 21	March 21
Reference Time	1200	1000	1200	1400	1200	Solar Noon
Reference Insolation (W/m^2)	1000	700	920	750	1040	950
Solar Multiple	1	1.93 (June 21)	1.11	1.13		1.25 (June 21)
Heliostat Field Efficiency	Cethel/MBB .74/.8	.72	.845	.83	.84	.70
Receiver Efficiency	.86 (without pyrex)	.91	.88/.92	.86	.95	.82
Storage Utilization Factor	.15	.05	1.0	1.0	0	.09
Power Conversion Systems Gross Efficiency	.18	.27	.272	.168	.28*	.345
Power Conversion Net Efficiency When Operating From Storage	.16	.21	.23	.168		.25
Overall Reference Day Plant Efficiency	.16	.13	.165	.085	.15*	0.174

*Project figures, TBD.

Table 5.
PLANT STAFFING AND SCHEDULE

	EUR.	CESA-1	IEA	SUNS.	THEMIS	SOLAR 1*
PLANT OPERATION						
Number of Days Per Week Plant Is Operated	5	7	7	7	7	7
Union/Nonunion		—	50 (DCS&CRS) Nonunion	Union	Union	Union
WORK SHIFTS PER DAY						
Winter	1	1	2	2	3	3
Spring	1	2	2	2	3	3
Summer	1	2	2	2	3	3
Fall	1	2	2	2	3	3
PEOPLE PER SHIFT						
Day (am)	16 (−1)	5	3.5	2	19	5
Day (pm)	16	5	3.5	2	19	5
Night		2	1/5 5.5 (nonshift)	0	3	3 Ex. Test Personnel

PEOPLE PER CATEGORY PER SHIFT	(am)	(pm)	night	(am)	(pm)	night	(am)	(pm)	night	(am)	(pm)	night	(am)	(pm)	night	(am)	(pm)	night	(am)	(pm)	night
Supervisors		1			4			1.5		1	1	0	2	2	0		1				
Secretaries	1	1	0		2			2.5		1	1	0	2	2	0		1				
Engineers	3	3	0		5			2.0		2	2	0	2	2	0		1				

Table 5.
PLANT STAFFING AND SCHEDULE (CONT.)

	EUR.			CESA-1			IEA			SUNS.			THEMIS			SOLAR 1*
	(am)	(pm)	night	(am)	(pm)	night	(am)	(pm)	night	(am)	(pm)	night	(am)	(pm)	night	(am) (pm) night
Operators	5	5	0	4		4	1.5	1.5	.5	4			3	3	3	Total: 4 Op. Foremen + 16 Operators
Maintenance	6	6	0	3		3	4.5			5			10	10	0	Total: 1 Main. Foreman 9 Main. People
Obervers	—	—	—	3		3	1.5	1.5	.5	0						Total: 0
Security	1	1	1	2		2	1			0			0	0	0	Total: 1 Day
SCHEDULE																
Start of Design	Nov. 1977			June 1977			June 1979			July 1979			Jan. 1976			1977
Start of Construction	Nov. 1978			Jan. 1980			Jan. 1981			Oct. 1979			Oct. 1979			Sept. 1979
Start of Operation	June 1981			June 1983			Sept. 1981			Sept. 1981			April 1983			April 1982
Duration of Operation	Open			3 years			4 years			2 years			3 years			5 years

*As of fall 1986.

DEFINITIONS OF TERMS AS THEY APPEAR ON THE QUESTIONNAIRE

General Plant Information

Plant Name: The name used to identify the specific solar plant.

Plant Rated Output: Nominal electric output provided to the grid under normal operating conditions.

Plant Location: The general geographical location where the plant is built.

Plant Sponsor: The name of the organizations that provided funding to design and build the plant.

Plant Designer: The names of the organizations that designed and built the plant.

Plant Operator: The name of the organization that is responsible for the routine operations of the plant.

Plant Evaluator: The name of the organization that is responsible for the evaluation of the plant's performance and the performance of the various systems comprising the plant.

Plant Contact: The name of the person who should be contacted for requests to visit the plant, for information concerning the plant's operation and performance, and for information exchange.

Site Latitude and Longitude: Measured in degrees North of the equator and West of Greenwich, England.

Site Altitude: Meters above sea level.

Site Direct Normal Insolation: The direct insolation measured on a surface perpendicular to the sun's rays. It is distinguished from the diffuse of the multidirectional component of solar radiation. "E" means the value is estimated.

Sunshine Hours per Year: Number of hours the sun would shine on the site if every day were clear. "E" means the value is estimated.

Temperature: Average, minimum, and maximum which occur at the site day or night.

Wind: Average wind speed at 3 m height. Average wind direction is the direction from which the wind is blowing, i.e., North, South, East, West, North-Northeast, etc.

Cloud Cover: Days when the sun is blocked by clouds so that the plant cannot collect useful solar energy.

Hardware Definitions

Heliostats: A combination of mirrors, support structure, drive mechanism, and mounting foundation that tracks in two axes of motion to continuously reflect the sun's rays onto a fixed receiver.

Heliostat Specific Weight: Weight of the heliostat, excluding pedestal and foundation, divided by the reflective area.

Pointing Error Per Axis: The one standard deviation (RMS) for each axis of the difference between the desired aimpoint and the beam centroid location. This error is in the heliostat reflected ray coordinate system and has units of milliradians.

Beam Quality Error: One standard deviation (RMS) of the difference between the isoflux contour that contains 90% of the heliostat total power for a perfect heliostat (i.e., no canting or mirror waviness errors) and the desired focal length, and the actual isoflux contour containing 90% of the heliostat total power. This error is in the heliostat reflected ray coordinate system and has units of milliradians.

Aspect Ratio: The overall width of the heliostat divided by the overall height.

Packing Density: The ratio of the total heliostat field reflective surface area to the total land area used by the heliostat field.

Receiver: That element of a solar central receiver system to which solar radiation is directed by the heliostats and where it is absorbed and converted to thermal energy.

Type: Cavity—receiver in the form of a cavity in which the solar radiation enters through one or more openings (apertures) and is absorbed on the internal heat exchanger surface. External—receiver in which the solar radiation is absorbed on the external surfaces.

Cavity Aperture Shape: Square, circular, octagonal, etc.

External Receiver Shape: Flat plate, cylindrical, etc.

Absorber Surface Area: The total area of that part of the receiver where radiant energy is absorbed by the receiver fluid.

Receiver Fluid: The fluid that is circulated through the receiver to absorb the solar radiation as thermal energy.

Receiver Weight: The weight of the entire receiver which is supported by the receiver tower.

Maximum Thermal Power Rating of the Receiver: The maximum thermal power at the base of the tower that the receiver will deliver sometime during the year.

Thermal Energy Storage: Any rechargeable unit capable of storing thermal energy for later use by the plant to generate electricity.

Storage Description: Examples include two tank hot-and-cold, single tank thermocline-oil, single tank thermocline-oil/rock, multiple tank pressurized water, etc.

Storage Fluid: The fluid which flows through the storage system and is used to store thermal energy.

Storage Fluid High and Low Temperature: The high temperature is the storage fluid temperature as it is put into the storage system from the receiver system. The low temperature is the storage fluid temperature as it is put into the system after its thermal energy has been extended to be used to generate electricity.

Storage Capacity: The amount of net thermal energy which can be delivered from a fully charged storage system and be used as a source of energy to generate electricity.

Hours of Storage: The number of hours a plant can produce electricity at a stated output level, normally at full rated system load, when operating exclusively from an initially fully-charged storage system.

Power Conversion System: That portion of the plant where thermal energy is converted to mechanical energy and the mechanical energy is used to generate electricity.

Type of Conversion System: The device which converts thermal to mechanical energy, e.g., turbine, motor, etc.

Working Fluid: The fluid that performs work and that is utilized in the end-use system e.g., the steam on a steam turbine generating system.

Working Fluid Temperature and Pressure: (a) If the plant uses the same fluid as both the receiver and working fluid, enter temperature and pressure under "from receiver"; (b) if the plant also has storage, enter the working fluid temperature and pressure achieved from the operating plant solely from storage under "from storage."

Generator Nameplate Rating: The full-load continuous rating of the electric generator under specified conditions as designated by the manufacturer.

Storage Thermal Fluid to Working Fluid Heat Exchanger Rating: The full-load continuous rating of the thermal to working fluid heat exchanger under specified conditions as determined by the manufacturer.

Plant Performance (Ref): All plant performance values should be on the reference day, time, and insolation.

Reference Day: If possible, use March 21 (equinox) as the reference day; state day used.

Reference Time: If possible, use noon solar time as the reference time; state time used.

Reference Insolation: If possible, use 950 W/m^2 as the reference insolation; state insolation used.

Solar Multiple: The ratio of the thermal power absorbed by the receiver fluid and delivered to the base of the tower on the reference day, time, and insolation to the thermal power required to operate the power conversion system at the generator nameplate rating.

Heliostat Field Efficiency: The ratio of the solar radiant power into the receiver cavity aperture or on an external receiver on the reference day, time, and insolation to the product of the insolation times the total heliostat field reflective area.

Receiver Efficiency: The ratio of the thermal power absorbed by the receiver fluid and delivered to the base of the tower to the solar radiant power into the receiver cavity aperture or on an external receiver on the reference day, time, and insolation.

Storage Utilization Factor: The ratio of the thermal power delivered to the storage system on the reference day, time, and insolation to the thermal power absorbed in the receiver fluid and delivered to the base of the tower with the power conversion system operating at the generator nameplate rating.

Power Conversion System Gross Efficiency: The ratio of the electric power delivered from the electric generator when operating at its nameplate rating to the thermal power delivered to the power conversion system on the reference day, time, and insolation.

Power Conversion System Net Efficiency: The ratio of the electric power delivered to the grid when the electric generator is operating at its nameplate rating to the thermal power delivered to the power conversion system on the reference day, time, and insolation.

Power Conversion System Net Efficiency when Operating From Storage: The ratio of the electric power delivered to the grid when the electric generator is operating at its maximum continuous rating for operations from storage to the thermal power delivered to the power conversion system from storage.

Overall Reference Day Plant Net Efficiency: The ratio of the total electric power delivered to the grid to the product of the total insolation times the total heliostat field reflective area. Assume the reference day is a clear day.

Number of Work Shifts Per Day: A work shift is an 8-hour period that an assigned group of people work to operate the plant.

Number of People Per Shift: This includes people for the operation and maintenance necessary for plant operations and for surveillance during the day and night.

Number of People Per Category Per Shift: If different for different seasons of the year, provide data for the summer. The total should be the same as the total number of people per shift for daytime summer periods.

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Energy Division
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IRC - CEC
ISPRA Establishment
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Italy
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